Digital Elevation Model (DEM) Data for the

Alaska Statewide Digital Mapping Initiative (SDMI)

September 18, 2008

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Project Sponsors

This whitepaper is sponsored by the Alaska Geographic Data Committee (AGDC) including Alaska Mapped, the Bureau of Land Management (BLM), the Geographic Information Network of Alaska (GINA) and the University of Alaska Fairbanks (UAF). Alaska Mapped represents the Statewide Digital Mapping Initiative (SDMI).

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Purpose

This whitepaper is the report outcome of the Alaska DEM Workshop held in Anchorage on July 22-23, 2008 and follow-on meetings with project sponsors on July 24, 2008 and August 19-20, 2008. It identifies statewide requirements and alternative solutions for obtaining accurate and current digital elevation data for Alaska.

<u>The conclusions and recommendations in this report reflect consensus of the sponsors, as well as all attendees of the Alaska meeting of the National Digital Orthophoto Program (NDOP) and National Digital Elevation Program (NDEP)[1].</u>

Through the Alaska Statewide Digital Mapping Initiative (SDMI) and Alaska Geographic Data Committee (AGDC), the community evaluated different technical and cost options for elevation technologies that could satisfy these programmatic time constraints within three different cost ranges:

- <$15M
- $15-$30M
- >$30M

[1] NDOP/NDOP agencies include the Bureau of Land Management (BLM), Federal Emergency Management Agency (FEMA), National Aeronautics and Space Administration (NASA), National Geospatial-Intelligence Agency (NGA), National Oceanic and Atmospheric Administration (NOAA), Natural Resources Conservation Service (NRCS), National States Geographic Information Council (NSGIC), U.S. Army Corps of Engineers (USACE), U.S. Census Bureau (USCB), Farm Bureau Agency (FBA), U.S. Forest Service (USFS), U.S. Fish & Wildlife Service (USF&WS), and U.S. Geological Survey (USGS). The Alaska NDOP/NDEP meeting was held in Anchorage on August 18-21, 2008 during which this whitepaper was discussed in detail, receiving unanimous consensus of all attendees.

This whitepaper is also intended to assist those who will subsequently be writing statewide DEM specifications and/or a request for proposal (RFP) to acquire the data for the SDMI.

Alaska's DEMs in Comparison to the Rest of the Nation

The National Elevation Dataset (NED) is the primary elevation data product produced and distributed by the U.S. Geological Survey (USGS). Since its inception, the USGS has compiled and published topographic information in many forms, and the NED is the latest development in this long line of products that describe the land surface. The NED provides seamless raster elevation data of the conterminous United States, Alaska, Hawaii, and the island territories. The NED is derived from diverse source data sets that are processed to a specification with a consistent resolution, coordinate system, elevation units, and horizontal and vertical datums. The NED is the logical result of the maturation of the long-standing USGS elevation program, which for many years concentrated on production of map quadrangle-based digital elevation models (DEM). The NED serves as the elevation layer of *The National Map*, and it provides basic elevation information for earth science studies and mapping applications in the United States. Other than project-specific datasets of higher accuracy, the NED serves as the predominant elevation layer for Alaska geospatial data users.

The current NED for Alaska is both lower resolution and lower accuracy (both vertically and horizontally) than that for the contiguous lower-48 states. In addition to vertical inaccuracies of hundreds of meters, entire mountain ranges are known to be horizontally misplaced by as much as two nautical miles, making it extremely difficult to use the NED for the simplest task — orthorectification of imagery. The NED for Alaska was produced from 1:63,360-scale topographic quad maps of lesser accuracy than in other states, and the accuracy of many of these maps was never tested. The NED for most of the lower-48 states was produced from higher-accuracy 1:24,000-scale topographic quad maps that satisfies a broad base of user requirements. The current NED for Alaska does not satisfy Alaska user requirements and national priorities as identified during the user surveys and subsequent vetting/validation of requirements by the sponsors of this program. Like the lower-48 states, Alaska requires accurate and consistent elevation data, driven by user applications. Because the NED in Alaska is so different than the NED in the lower-48 states, and because Alaska has different user requirements, the existing NED cannot serve the same broad range of user applications as it can in the lower-48.

The NED is designed to address the requirement for large-area coverage of the "best available" elevation data. "Best available" refers to the highest resolution elevation data available to be incorporated into the NED database. These vary from area to area. As stated in the NED Release Notes, the source data for the NED are selected from the available DEMs according to the following ranking (highest priority listed first): high-resolution elevation data, 10-meter USGS DEMs, 30-meter Level 2 USGS DEMs, 30-meter Level 1 USGS DEMs, 2-arc-second USGS DEMs, 3-arc-second USGS DEMs. Note that the 2-arc-second DEMs are used only in Alaska, and the 3-arc-second DEMs are used only to fill in values over some large water bodies.

High resolution does not necessarily imply high accuracy. Comparing North Carolina and West Virginia, for example, shown in Figure 1, both are in red and are of the highest resolution 1/9-arc-second spacing. However, North Carolina's DEM has vertical accuracy equivalent to 2 foot contours, obtained from LiDAR acquired for the North Carolina Floodplain Mapping Program, whereas West Virginia's DEM has vertical accuracy equivalent to 20-foot contours, compiled photogrammetrically.

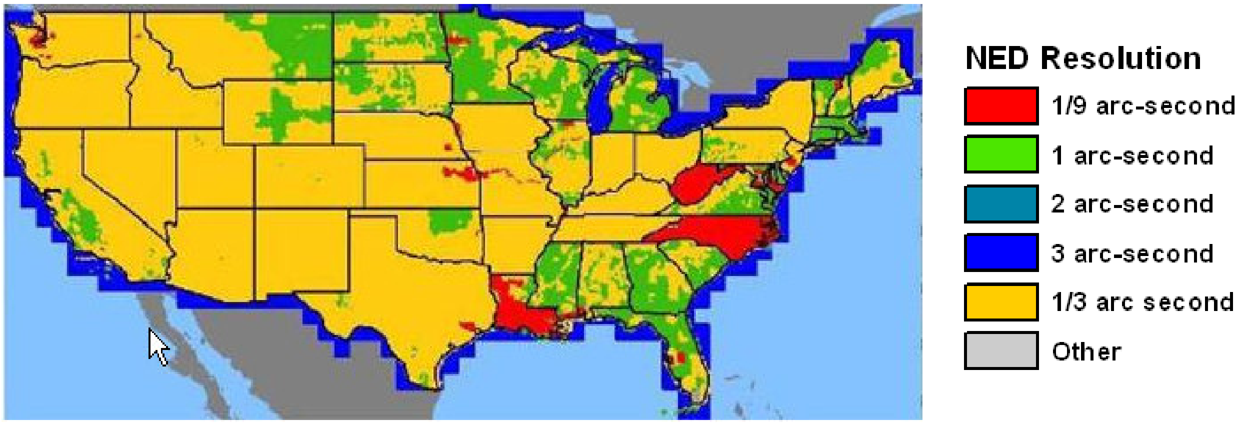

Figure 1. Resolution of NED source data.

In other states, depending on source materials available, the vertical accuracy at the 95 percent confidence level may be as good as 1 foot or as poor as 15 meters, depending on the original source data; but in Alaska vertical errors are hundreds of meters. Figure 2 shows the variable source data used as "best available" for the NED in the lower-48 states.

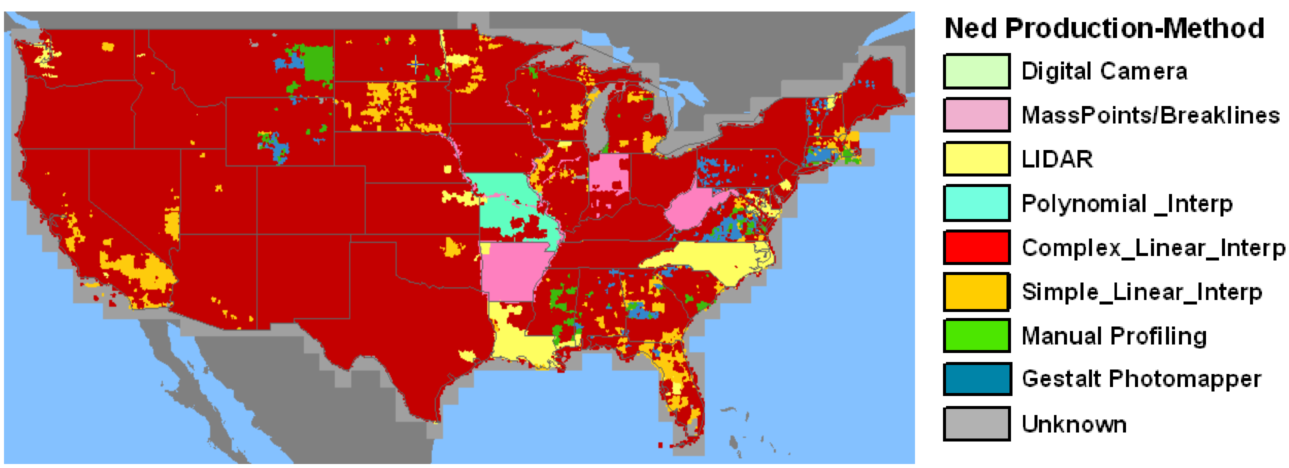

Figure 2. NED source data in the lower 48 states.

Answers to NED frequently asked questions can be found at http://seamless.usgs.gov/ffaq/ned_faq.php.

Definitions

Several definitions are key to the understanding of the terms DEM, DTM and DSM, the coordinate systems in which elevation points are mapped, and DEM enhancements to model the flow of water.

- **Cartesian Coordinates:** In coordinate geometry, horizontal positions are defined in terms of orthogonal X and Y coordinates relative to an origin point where X and Y coordinates are zero. In the surveying and mapping professions, X and Y coordinates are called Eastings and Northings, respectively, because positive X values increase in the easterly direction from the origin and positive Y values increase in the northerly direction from the origin. It is standard practice to establish the Cartesian coordinate system origin southwest of the entire project area in order to ensure that all X/Y coordinates are positive numbers. Cartesian coordinates are used in common coordinate systems such as the Alaska State Plane Coordinate System, the Alaska Albers Equal Area Projection, and the Universal Transverse Mercator (UTM) coordinate system.

- **Digital Elevation Models (DEMs):** As used in this paper, the term DEM is generally used to refer to a gridded elevation model, as opposed to irregularly-spaced elevation points. The term DEM is sometimes used in the generic sense to define digital elevation data in its myriad forms. Gridded DEMs (whether derived from DSMs or DTMs) are interpolated from irregularly-spaced elevation mass points, and the $\Delta x/\Delta y$ grid spacing can be defined either in terms of Cartesian coordinates (Northing/Easting) in meters or geographic coordinates (Latitude/Longitude) in arc-seconds.

- **Digital Terrain Models (DTMs):** As used in this paper, DTM refers to the bare-earth terrain beneath the trees. Normally, DTMs could include irregularly-spaced mass points and breaklines as used for generation of topographic contours; but in the context of this report, in determining whether DTMs or DSMs are needed, requirements for DTMs refer to gridded elevation models of the bare-earth ground surface.

- **Digital Surface Models (DSMs):** As used in this paper DSMs refer to the top reflective surface (e.g., treetops); in the context of this report, in determining whether DTMs or DSMs are needed, requirements for DSMs refer to gridded elevation models of the top reflective surface.

- **Ellipsoid Height:** The reference ellipsoid is shown at Figure 3 and the ellipsoid height is shown at Figure 4. The ellipsoid height is the height above or below the reference ellipsoid, i.e., the distance between a point on the Earth's surface and the ellipsoidal surface, as measured along the normal (perpendicular) to the ellipsoid at the point and taken positive upward from the ellipsoid. The ellipsoid height is defined as "h" in the geodetic equation: $h = H+N$. The North American Datum of 1983 (NAD83) is based on the Geodetic Reference System 1980 (GRS 80) ellipsoid which is nearly identical to the World Geodetic System 1984 (WGS84) ellipsoid. GPS surveys, on land or from the air, determine differences in ellipsoid heights above the WGS84 ellipsoid.

- **Geographic Coordinates:** Geographic coordinates comprise the traditional coordinate system based on latitude and longitude. Coordinates are measured using degrees, minutes, and seconds.

- **Geoid:** The geoid is that equipotential (level) surface of the Earth's gravity field which, on average, coincides with mean sea level in the open undisturbed ocean. In practical terms, the geoid is the imaginary surface where the oceans would seek mean sea level if allowed to continue into all land areas so as to encircle the Earth. As shown at Figure 3, the geoid undulates up and down with local variations in the mass and density of the earth. The local direction of gravity is always perpendicular to the geoid. The North American Vertical Datum of 1988 (NAVD88) is based on the geoid having the potential of gravity at the NAVD88 datum point, i.e., Father Point Rimouski, near the mouth of the St. Lawrence River in Canada.

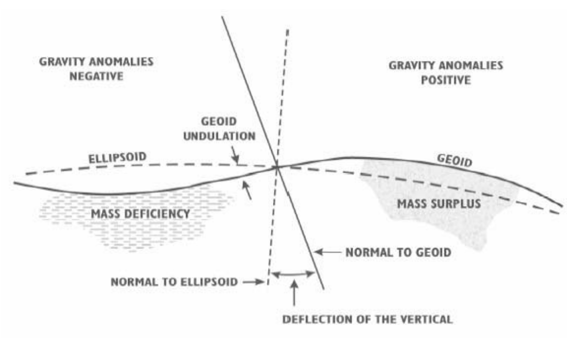

Figure 3. Ellipsoid, geoid, and geoid undulation (geoid height).

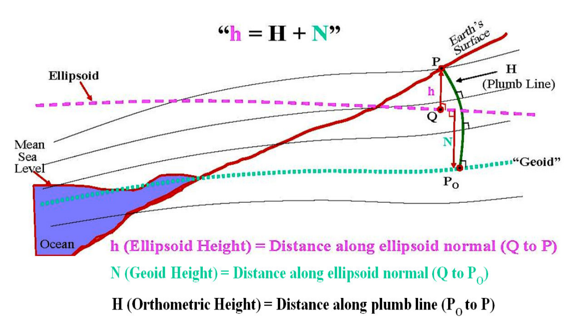

Figure 4. Geodetic formula for conversions between ellipsoid heights and orthometric heights.

- **Geoid Height :** The geoid height, also called the *geoid undulation*, is the difference between an ellipsoid height and an orthometric height. The geoid height is shown at Figure 4 and defined as "N" in the geodetic equation: N = h–H (or h = H+N). For most of the United States the value of N is a negative number because the geoid is below the GRS80 ellipsoid. NOAA's GRAV-D project is intended to provide accurate gravity data for an improved geoid height model so that ellipsoid heights can be accurately converted to orthometric heights (elevations).

- **Hydro-Conditioned:** Hydrologic conditioning is the processing of a DEM so that the flow of water is continuous across the entire terrain surface (not just water bodies), including the removal of all spurious sinks. Rather than draining sinks, automated hydrologic conditioning normally fills sinks by elevating them to levels so that water would flow out of them in a hydrologic model rather than form "puddles" surrounded by points of higher elevation.

- **Hydro-Enforced:** Hydrologic enforcement is the processing of a DEM so that lakes are level and streams flow downhill. Lakes are typically hydro-enforced by use of a polyline for the shore that has a constant z-value and then forcing all points within that polygon to have the same elevation. Numerous different methods are used to hydro-enforce streams, some including the manual digitizing of 3-D breaklines for shorelines that decrease in elevation as the stream moves downhill; other methods are more automated and include hydro-conditioning of the entire area, including streams so that water anywhere on the surface (other than lakes) would have an outlet.

- **Orthometric Height (Elevation):** The orthometric height is the height above the geoid as measured along the plumbline between the geoid and a point on the Earth's surface, taken positive upward from the geoid. Shown at Figure 4 and defined as "H" in the geodetic equation: H = h-N (or h = H+N). Traditional differential leveling determines differences in orthometric heights or differences in elevation.

- **Terrain:** The Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO) use the term *terrain* in a slightly different context. Depending on the source of information, a terrain database may describe something between "bare earth" and "bare earth with cultural features and/or obstacles (canopy, buildings, etc.)". According to ICAO Document 9881, *terrain* is defined as "The surface of the Earth containing naturally occurring features such as mountains, hills, ridges, valleys, bodies of water, permanent ice and snow, excluding obstacles. In practical terms, this will represent the continuous surface that exists at the bare earth, the top of the vegetation canopy, or something in-between as presented in [Figure 5]".

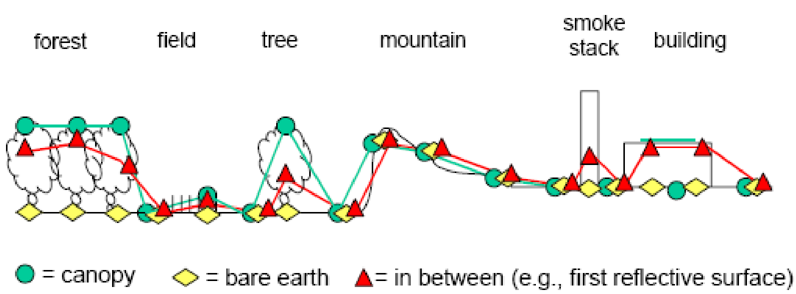

Figure 5 — In FAA and ICAO terminology, the term "terrain" could pertain to the tree canopy, bare earth, or something in between such as the first reflective surface. As used in this report, the term "DTM" refers to the bare earth elevation surface (yellow), and the term "DSM" refers to either the canopy (green) or the top (first) reflective surface (red).

Alaska Mapping and Geodesy Issues

The National Geodetic Survey (NGS) has identified the following issues that will impact the State's ability to accurately map elevation data in Alaska. As indicated below, numerous Alaska stakeholders agree with the issues described and steps proposed by NOAA to address these issues.

- Alaska is the only state that does not have digital imagery and elevation data at nationally accepted standards[2]. The sheer size and remoteness of the state has precluded this in the past. The underlying horizontal and vertical reference datums, NAD83 and NAVD88, form our nation's

[2] Some mountains are known to be mapped several miles away from their true locations, with elevations that are several hundred meters too low common throughout Alaska. Such horizontal and vertical errors are 1-2 orders of magnitude larger than allowed by the National Map Accuracy Standard.

National Spatial Reference System (NSRS). However, in Alaska, the reference system does not have the density of control points to support sub-meter level accuracies for mapping and positioning activities. In the case of the vertical datum, NAVD88 does not even provide coverage to the entire western half of the state. Today, almost all spatial mapping and data collection is GPS-based. It is essential for the NSRS to have the accuracy needed to support accurate GPS positioning activities in Alaska.

- Fundamental geodetic infrastructure is severely lacking throughout this region. Orthometric heights (elevations on maps and DEMs) in Alaska are in error by as much as 2 meters vertically, because of errors in the geoid height model, even for newly-surveyed GPS points on the ground or ground points mapped from the air or satellites.

- As shown at Figure 6, Continually Operating Reference Station (CORS) coverage necessary to provide efficient access to the National Spatial Reference System (NSRS) is sparse, especially in Western Alaska. CORS are required for accurate GPS surveys on the ground and for airborne GPS control of mapping aircraft. Accuracies of ellipsoid heights from airborne and ground GPS surveys decrease with distance from these CORS. Additional CORS stations are needed throughout the state. Similarly, of the over 100 tide stations in Alaska, only one is tied to the NSRS. Tying these stations to the NSRS is essential for monitoring of changes in sea-level, glacial rebound, and mitigating the effects of climate change in the region.

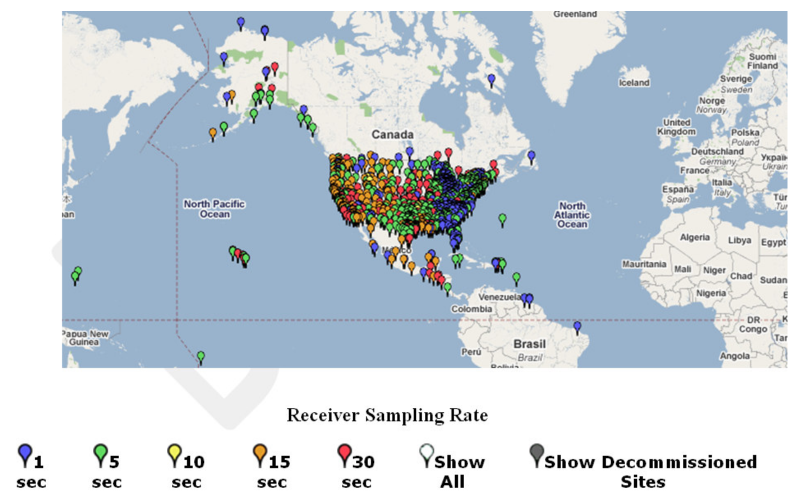

Figure 6. Density of CORS stations in Alaska, compared with other states.

- Coastal communities, in particular, require accurate land elevations and water depths to build flood protection infrastructure, harden roads, bridges and observing systems, ensure safe and efficient marine transportation, plan evacuation routes, model storm surge, and monitor sea-levels.

- Climate change also poses a complex set of challenges for the U.S. transportation industry. In particular Alaska and the Arctic are experiencing unprecedented impacts, with loss of sea ice and permafrost, rising sea levels and eroding coasts all occurring faster than forecast. This is causing thawing, slumping and erosion of roadways, impeding access to remote communities and commerce, and endangering coastal and native communities. There is also the very real potential for at least a seasonal, if not permanent, oceanic trade route across the Arctic that could cut existing oceanic transport by an estimated 5,000 nautical miles (one week of sailing time). These changes have implications for a host of activities such as shipping, oil/resource development, fishing, ecotourism, subsistence livelihoods, and scientific exploration — all in an ecologically fragile region lacking the security and safety infrastructure necessary to handle this rapid change effectively.

- The study of sea level variability in the Arctic Ocean is important in its own right, primarily because of its practical importance for people living and working in Arctic coastal regions. For them the current rates of local sea level rise are already causing severe problems. In addition, the variability of sea level in the Arctic Ocean can be used as an indicator of changes in ocean circulation, water, ice and sediment transport, coastal erosion, and many other processes.
- The State of Alaska understands and supports the requirements necessary to create a high resolution map of the state for which various NOAA programs provide the fundamental geodetic infrastructure. The lead state agencies supporting this initiative are the University of Alaska, the Department of Military and Veterans Affairs (DMVA), and the Department of Natural Resources (DNR). To foster the oversight, management and planning required to facilitate these initiatives these three agencies have developed the required concepts under the titled name of the Statewide Digital Mapping Initiative (SDMI). In order to secure formal cooperation and support the SDMI, the State of Alaska elected to request teaming partners and stakeholders to sign a Memorandum of Endorsement (MOE). This MOE was signed by NOAA's National Geodetic Survey and the leader for NOAA's Alaska Regional Team.
- The Alaska Climate Impact Assessment Commission recently assessed the effects of climate change as it would affect the citizens, resources, economy, and assets of Alaska. Commissioners worked on developing a comprehensive overview of the likely impacts of climate change affecting Alaska, and recommendations to mitigate that impact. It also considered impacts upon publicly-owned facilities and infrastructure, identify the financial implications of climate change, and assess impacts on local communities. The Commission's Report recommended that the state encourage NOAA to seek funding for gravity collection of Alaska's littoral (coastal) regions so that decisions affecting communities are clear as to the orthometric heights, risks of flooding, and rates of coastal erosion. As noted by the commission, this effort will also produce an accurate shoreline that can be monitored with GPS technology.
- NOAA's Arctic Regional Collaboration Team supports GRAV-D (described below) and wants to collaborate across NOAA line offices and external partners to co-locate CORS at existing or planned facilities to increase the accuracy of NSRS. The Team also stands ready to support and assist Alaska's SDMI and provide input to final data products.

- An Arctic Gravity Project was coordinated by the National Geospatial-Intelligence Agency (NGA) in 1998-2000. The National Geodetic Survey will partner with NGA to use data from this effort for areas of Alaska north of 64 degrees north latitude. The existence of existing NGA gravity data of northern Alaska is the reason why that area is priority 6 in NOAA's GRAV-D plan whereas remaining areas of Alaska are in priority areas 1 and 2.
- Programs in the NOAA Commerce and Transportation Goal Team are also partnering to address the complex challenges for the U.S. transportation industry in Alaska and the Arctic.

NOAA's GRAV-D Project

For DEM elevations to be accurate, we need to ensure that we have accurate procedures for measurement and mapping of ellipsoid heights, as well as an accurate geoid height model for conversion of ellipsoid heights to orthometric heights. Furthermore, accurate and consistent DEMs are integral to making a better geoid model.

In the past 20 years, the use of GPS technology for determining fast and accurate ellipsoid heights has created a pressing desire for a similarly fast and accurate determination of orthometric heights. Ellipsoid heights cannot be used to determine where water will flow, and therefore are not used in topographic or floodplain mapping. Orthometric heights are related to water flow and are more useful for many applications. In order to transform ellipsoid heights to orthometric heights, a model of the geoid heights must be computed, and geoid height modeling can only be done with measurements of the acceleration of gravity near the Earth's surface. Digital Elevation Models (DEMs) can be usefully defined in terms of ellipsoid heights for some applications such as aviation safety, for example; or DEMs can be defined in terms of orthometric heights for other applications where the flow of water is important, e.g., hydrologic and hydraulic modeling. It is also an option to preserve DEMs from aerial surveys in their native ellipsoid heights, subject to future computations of orthometric heights based on changing and ever-improving geoid models, e.g., GEOID03, GEOID06 and GEOID08. NGS's current GEOID-06 is believed to contain vertical errors as large as 2 meters. The geoid model for Alaska is depicted at Figure 7; this figure shows variations in gravity which differs from variations in elevations.

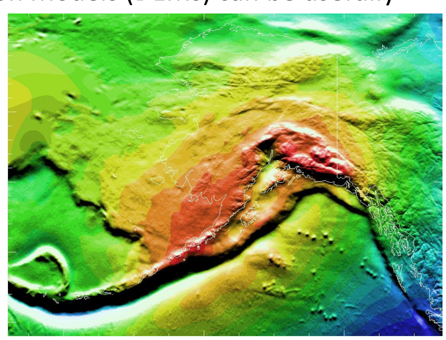

Figure 7. The geoid model of Alaska contains vertical errors as large as 2 meters, compared with a few centimeters in the lower 48 states.

With the use of GPS Continuously Operating Reference Stations (CORS), the National Geodetic Survey (NGS) has been tracking and predicting changes to the ellipsoid heights in the United States for some time. A similar tracking of orthometric heights would not only fulfill NOAA's mission, but would also allow users of heights (elevations) to know changes over time for coastal elevations and other critical applications that require tracking in a dynamic world.

NGS has done an excellent job collecting existing gravity information for the United States and computing geoid height models to determine orthometric heights from GPS. Unfortunately, these efforts are insufficient at the highest levels of accuracy due to the extremely disparate nature of the available data (with thousands of surveys, conducted by hundreds of sources, over dozens of years, and with no attempt to monitor changes in gravity over time in this data. Unfortunately, with no committed large-scale tracking of gravity changes over time being conducted by any agency in the United States, the situation will only worsen as crustal motion (from subsidence to glacial isostatic adjustments) continues to change the nature of the land. A new, self-consistent and temporally tracked measure of the gravity field in the only way to ensure fast, accurate, useful heights (elevations) at all times in the future.

NOAA's GRAV-D plan for addressing this issue nationwide is available at: www.ngs.noaa.gov/GRAV-D/.

NOAA's airborne gravity campaign is planned to proceed with Phase I testing for determination of optimal flight parameters and proof of operations, followed by Phase II operational data collection (currently unfunded) based on the following priorities: (1) Alaskan littoral (coastal) regions (shown in lavender at Figure 8), excluding the Aleutians, (2) southern Alaska (shown in dark blue at Figure 8), (3) CONUS littoral regions, (4) Hawaii, Pacific Island territories, and the Aleutian chain, (5) Inland CONUS, and (6) Northern Alaska (shown in dark green at Figure 8).

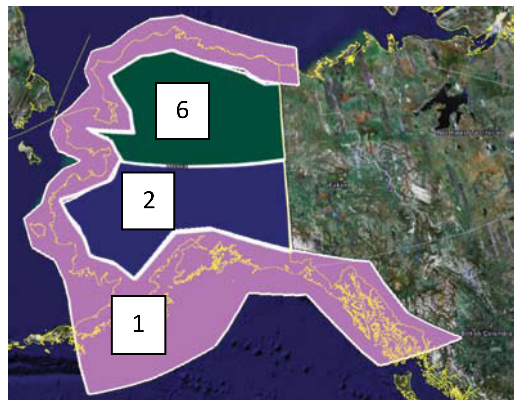

Figure 8. GRAV-D collection areas in Alaska

Unfortunately, GRAV-D currently has no dedicated funding. The funding for finishing Phase I will be fought for and would come out of NGS' base funds in FY09. Without dedicated extra funding, which NGS is seeking through the NOAA PPBES process, NGS will only be able to pursue Phase II at about 10% of the proposed speed, and that will require annual competition against other in-NGS annual projects for discretionary funds. Even with full funding, the completion date would be approximately 2018. With only discretionary funding, this initiative will take far more than one decade to complete. In addition to seeking all-NOAA funding, NGS is also seeking funding partnerships within the federal government with other agencies, and also looking for state/federal partnerships where individual states share costs for surveys over their lands. The estimated cost of the GRAV-D program in Alaska is about $6 million for all phases; the State of Alaska may want to consider a role in co-sponsoring this valuable survey.

Whereas there is strong support in Alaska for the GRAV-D program, Alaska may need to start work prior to completion of GRAV-D surveys by relying on ellipsoid heights and current geoid models initially, but there is a critical requirement for an accurate geoid model in the near future. In urgent situations at near-sea-level elevations, temporary, interim models may need to be developed.

Alaska Regional NOAA Integrated Services Plan

The NOAA Alaska Regional Collaboration Team (ARCTic) completed another milestone in the development of an Integrated Services Plan (ISP) for NOAA in Alaska with the completion of the second Integrated Services Assessment (ISA) meeting. The meeting, held in Anchorage, October 30-31, 2007, focused on the third goal of the ISP: Develop an approach for strategic product and service enhancements in concert with key partners and stakeholders. Participants included representatives from the Aircraft Owners & Pilots Association, Alaska DOT, University of Alaska Anchorage and Fairbanks, North Pacific Fishery Management Council, US Army Corps of Engineers, North Slope Science Initiative, Geographic Information Network of Alaska, Eskimo Walrus Commission, The Nature Conservancy, Alaska Ocean Observing System, Alaska Fisheries Development Foundation, Alaska Climate Impact Assessment Commission, US Arctic Research Commission, and representatives from all Line Offices. The outcome of the meeting was a revised set of vision papers describing shared NOAA-customer desired end-states in 2015 across eight strategic focus areas. These papers will be further polished by the NOAA team and incorporated into the ISP. NOAA-customer interactions will continue past this meeting through the ARCTic's focus area working groups.

The Integrated Services Plan is intended to solve the major issues described above by the year 2020. It's objective is: (1) to improve the current NSRS in Alaska to meet national mapping standards, (2) to increase the density of CORS stations in Alaska, especially in coastal regions, (3) to support NGS's GRAV-D Plan through planning and budgeting process as a means to improve NSRS in Alaska, and (4) to assist in the Alaska SDMI to ensure the products are available to all NOAA line offices whose work involves Alaska issues.

NOAA's role is to fully develop the horizontal and vertical datums in Alaska upon which all geospatial data is based and support the Alaska SDMI to provide digital imagery and elevation models that will be beneficial to a wide range of NOAA products and services.

Two main aspects of a National Spatial Reference System need to be addressed in Alaska. The first is the coverage and density of the CORS for which Alaska currently has about 30 sites as shown above in Figure 6. Increasing the number of sites through cooperation and collaboration with internal and external partners will increase the accuracy of GPS obtained positions and connect remote areas of the state with the NSRS. Second, in order to determine orthometric heights (elevations) above the geoid, the geoid height model needs to be improved significantly in order to correct geoid height model errors of 1-2 meters for Alaska. NOAA's GRAV-D plan is to conduct a nationwide gravity survey with the aim to develop a high resolution geoid height model, with highest priority to Alaska coastal areas and southern Alaska, as shown in Figure 8. This plan is fully supported by the Arctic Regional Collaboration Team.

A National Spatial Reference System that is able to support modern GPS surveying techniques and GIS is a fundamental step in providing accurate positioning for the future. With the importance of the Arctic and climate change in this region, the risk of not addressing this is significant. A well-defined and robust reference system is central to all spatial data collected and/or produced in Alaska.

Alaska SDMI User Survey Report.

During early 2008, HDR, Inc. conducted an Alaska User Survey on behalf of the SDMI. The following is quoted from the Executive Summary of the draft SDMI's User Survey Report, dated June 12, 2008 which addressed the need for statewide digital basemap data, both imagery and elevation data.

"The initial SDMI planning project task was to survey and interview users in order to clearly identify stakeholders, identify project needs, user preferences, and potential partnerships. These results were used to identify current and planned mapping projects and existing data that meet the goals of the SDMI program and to perform an initial inventory of existing digital data held by respondents.

"The task began with:

- Planning and stakeholder meetings to launch the project
- Identifying the SDMI stakeholder list for survey
- Developing the user survey and implementing it.

"Following the survey:

- Capturing area of interest through shapefile submission or input into an online map tool
- Developing use profiles and area of interest summaries
- Completing the documentation of an inventory of existing basemap data sources held by respondents.

"The user survey was distributed to 320 individuals gathered from mailing lists for the Alaska Geographic Data Committee, Anchorage Arc User Group, and Alaska Surveying and Mapping Conference registrants. 152 responses were collected, representing a cross-section of users of mapping data in Alaska. For comparison, the Imagery For The Nation (IFTN) survey, a national survey, collected an average of 38 responses per state. The following is a high level summary of the survey responses.

"Key survey observations and findings:

- Most respondents are technical users or a mix of technical and managerial, and use digital basemap data frequently for general mapping, remote sensing, and 3D visualization in that order.
- Respondents were from state agencies (35%), federal agencies (25%), the private sector (17%), local government (8%), academia (4%), utilities (3%), military (3%), not-for-profit (2%), not-for-profit Native corporations (1%), and other (2%).
- The user profiles fall into the following types (in this order): land management, environmental data collection and analysis (land cover, wetlands, other), GIS and mapping/surveying consulting, forestry, mining and earth sciences, and water resources.
- As one would expect from the demographic profile of the state, most respondents operate statewide at 42 percent, followed closely by south central Alaska at 34 percent, with interior, southeast, and north slope grouped at about 16 percent.

- Most respondents felt the most important improvement is to make digital least-cost basemap data easily available. When digital basemap data is not available, respondents use USGS maps and Google Earth as a substitute.
- There is a definite interest (23.5% said yes, 64% said maybe) in partnering with SDMI for digital data. Participation ranges from willingness to share data to providing financial support.
- When asked which data type would be used most frequently if available, imagery clearly is preferred over elevation data for decision support, but elevation is required to convert raw imagery to orthophotos and to support Aviation Safety and hydrologic applications, for example. The two basemaps themes (orthophotos and elevations) are tightly related.
- In terms of preferences, one question identified three important qualities respondents want in digital basemap data are spatial resolution, absolute accuracy, and metadata. [Note: digital orthophotos require accurate DEMs for accurate orthorectification.]
- Hydrographic features (river features, water bodies, and related – wetlands) are the most common features mapped by respondents with existing basemap data, followed by infrastructure – roads, buildings; and then land management boundaries.
- River corridors, highway and pipeline corridors, and populated places were the three specific area types desired for acquisition. South Central, Interior, and Southeast Alaska were the top three geographic regions.
- Most respondents (70%) want a minimum five year refresh rate on imagery; 46% favor refresh of three years or better. This is supported by the survey's finding of the top nine features being mapped by respondents are dynamic in nature.
- Most respondents prefer moderate resolution elevation data (1:24,000 scale equivalent – between 1/3 and 1/9 arc-second), with updates provided when changes occur or better resolution data become available. It is clear, however, that many respondents want a DEM coverage in order to properly control imagery and provide a base. More clarification of DEM needs is needed.
- Although moderate resolution imagery and elevation data are most commonly requested, more clarification is needed regarding priorities for imagery and elevation data acquisition.
- 78 imagery datasets identified in the inventory of existing datasets; and 36 digital elevation datasets identified. These are a mix of local government, National Park Service, BLM, and USFWS holdings.
- Most (72%) are willing to participate in SDMI activities and follow-up to the survey."

Alaska Land Ownership/Management Responsibilities

Appendix A of this report explains land management responsibilities of those who own/manage Alaska patented lands, and a map that shows the location of these land holdings statewide. Table 1 summarizes relevant statistics for upland land ownership. When taking Tide and Submerged Lands into account for imaging and monitoring, for offshore drilling for example, the scope of orthophoto coverage statewide totals approximately 1.8 million square kilometers.

Table 1 — Alaska Upland Land Ownership/Management Responsibilities

	Million acres	Km^2	% of total
State of Alaska	89.8	363,408	24.1
BLM	82.5	333,866	22.1
USF&WS	78.8	318,892	21.1
NPS	52.4	212,055	14.1
ANCSA	39.3	159,041	10.5
USFS	22.4	90,650	6.0
Other private	5.9	23,876	1.6
DoD	1.7	6,880	0.5
TOTALS	**372.8**	**1,508,668**	**100.0**

- The State of Alaska currently owns and manages 89.8 million acres (≈24.1 %); because BLM is in the process of surveying and conveying additional lands to the State, this percentage is expected to increase to approximately 28% in the near future, as explained at Appendix A. The State of Alaska owns and manages an additional 65 million acres of Tide and Submerged Lands that extend from mean high water to the three mile limit. The surface waters over these lands are within scope of imaging and monitoring requirements set by users, for example, mapping offshore drilling activities and sea ice monitoring.

- The Bureau of Land Management (BLM) currently owns/manages 82.5 million acres (≈22.1 %); this percentage is expected to decrease to approximately 18% in 2009, as explained at Appendix A, with the surveying and conveying of additional lands to the State.

- The U.S. Fish & Wildlife Service (USF&WS) owns/manages 78.8 million acres (≈21.1 %).

- The National Park Service (NPS) owns/manages 52.4 million acres (≈14.1 %).

- ANCSA Native Corporation (private) owns/manages 39.3 million acres (≈10.5 %).

- The U.S. Forest Service (USFS) owns/manages 22.4 million acres (≈6.0 %)

- Other private organization and local governments own/manage 5.9 million acres (≈1.6 %).

- The U.S. Department of Defense (DOD) owns/manages 1.7 million acres (≈0.5 %).

DEM User Interviews

In preparation for the Alaska DEM Workshop and preparation of this whitepaper, the University of Alaska Fairbanks provided Dewberry with names and contact information for a cross section of DEM users representative of users throughout the state who have been actively involved in acquisition and/or use of DEMs for Alaska. Because of cost and time constraints, it was not possible to identify and contact every potential DEM user group throughout the state. During the weeks of July 6 and July 13, 2008, Dewberry interviewed 11 of these user groups using the Alaska *DEM User Requirements Menu*, adapted from Table 13.1 of the 2nd edition of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published in 2007 by the American Society for Photogrammetry and Remote Sensing (ASPRS) and edited by Dr. David Maune of Dewberry. Dewberry also provided additional instructions for making user choices from this "menu" to help develop a consensus among potential DEM users in Alaska. The results of their choices were then used as a basis for discussion during the Alaska DEM Workshop on July 22-23, 2008. Three additional DEM user groups (NOAA, USGS, and DOD) provided their input after the DEM Workshop.

Following the Alaska DEM workshop, additional information was requested from the aviation safety user group, and their explanation of issues is documented at Appendix B, to include a sidebar of examples that show that mountain peaks and ridgelines are often in error vertically by hundreds of meters and horizontally by several nautical miles.

DEM User Applications

The following DEM user groups were interviewed, and their DEM user applications and requirements are documented at Appendix C to this whitepaper:

Aviation Safety: Steve Colligan, Lars Gleitsmann, Nick Mastrodicasa (plus George Sempeles of FAA who was interviewed later). Because of the remote terrain and sparse road network, Alaskans rely heavily on air transportation. Alaska has the highest aviation accident rate in the nation due to hazardous flying conditions where aircraft navigate through mountain passes rather than over the mountains as is common elsewhere. The aviation safety issues are so severe that Appendix B of this report documents the issues; it also provides maps of Alaska airfields, villages, and the location and severity of aircraft accidents throughout the State in recent years, recognizing that many aviation accidents are not caused by poor elevation data. Nevertheless, it is clear that aviation safety, and poor elevation data, are major issues in Alaska which relies heavily on air transportation under the most difficult flying conditions in the U.S.

The U.S. agreed in 2004 to comply with the International Civil Aviation Organization (ICAO) standards for terrain mapping and creation of an Area 1 compliant database for all of its territory by November of 2008 and "Area 2" compliant database for Instrument Flight Rule (IFR) airfield sites by November of 2010. Because the Shuttle Radar Topography Mission (SRTM) did not collect elevation data north of 60° north latitude, and because of the major known horizontal and vertical errors in the NED, as reported at Appendix B, the U.S. currently does not satisfy the relatively simple Area 1 standard in Alaska (equivalent to 200-ft contour accuracy). Neither is the U.S. prepared to satisfy the more-demanding Area 2 standard in Alaska (equivalent to 20-ft contour accuracy) which pertains to 148 IFR site terminal control areas, shown as circled areas at Figure 9 for which each circle has a radius of 45 Km. Whereas the total area of 148 such circles is more than half the total area of Alaska, this is somewhat misleading because many of the circles overlap and some of the circled areas are over water[3].

The Electronic Terrain and Obstacle Database (eTOD)[4] is an internationally agree-on standard to provide a safe terrain database for safe flying and navigation under Instrument Meteorological Conditions (IMC) when pilots cannot see the terrain at all due to night and clouds or other weather such as heavy rain and snowfall. When Visual Flight Rules (VFR) cannot be safely followed, and especially during emergency air evacuations at remote villages, aviators then operate under Instrument Flight Rules (IFR) designed to keep aircraft from unintentionally flying into obstacles due to navigation errors. The need for elevation data to create a reliable and compliant FAA eTOD for navigation in Alaska, during periods of limited visibility, has never been greater. IMC flying conditions have to be coped with in Alaska on a regular basis for airfields throughout the state, even for airfields that are not part of the FAA's 148 IFR sites. Accurate DEMs are vital for flight planning, terrain avoidance, transiting through mountain passes, and landing of float planes on rivers and other water bodies. DEMs are also used for pilot training and simulators.

[3] On August 5, 2008, Dewberry interviewed Mr. George P. Sempeles, FAA ATOR-R, Aeronautical Information Services, Cartographic Standards, who stated that there is a serious lack of reliable elevation data in Alaska and that he agreed with the concerns raised by the Alaska aviation community. He stated that the area of Alaska north of 60° north latitude does not comply with ICAO Area 1 standards and that elevation data equivalent to airborne IFSAR statewide would be needed to bring Alaska into conformance with Area 2 standards, stating that it makes no sense to have high accuracy elevation data within those circles and low accuracy elevation data elsewhere.

[4] See Aeronautical Information Services, 12th Edition, Annex 15, to the Convention on International Civil Aviation, ICAO, July 2004.

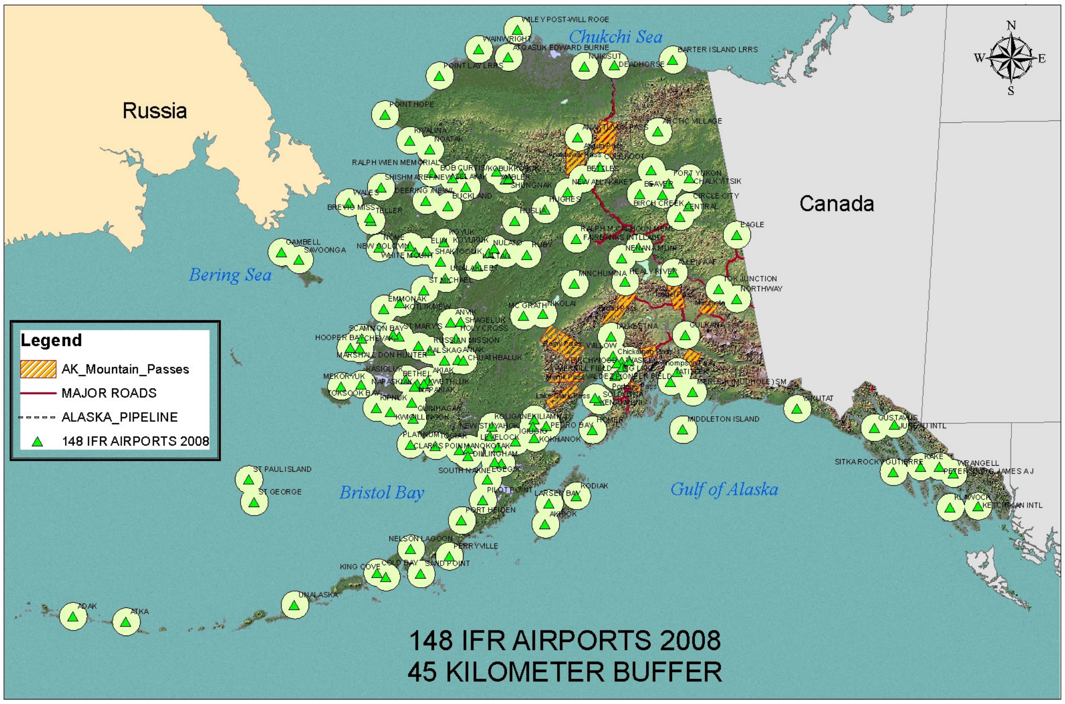

Figure 9. 148 FAA IFR airfield sites requiring DEMs with 20-ft contour accuracy

User applications focus on aviation safety consistent with ICAO Area 1 standards for the entire state and Area 2 standards for terminal control areas at IFR airfield sites located throughout the state; but as validated by Mr. Sempeles of FAA, it makes no sense to acquire higher accuracy elevation data within those circles and lower accuracy data elsewhere. As shown in Table 2 below, Area 1 standards could be satisfied by many low-cost options, whereas Area 2 standards are much more demanding and would require airborne IFSAR or a comparable technology. Satisfaction of Area 2 standards would bring Alaska on-par with the other 49 states where weather and light conditions are less severe, where flying conditions are less dangerous, and where emergency evacuations are routinely performed by ground ambulances rather than air ambulances as in Alaska.

Table 2. Comparison of ICAO Area 1 and Area 2 Standards

ICAO	Area 1 Standards	Area 2 Standards
Post Spacing	3-arc-seconds (≈90 meters)	1-arc-second (≈30 meters)
Vertical Accuracy (LE90)	30 meters	3 meters
Equivalent Contour Interval	60 meters (200 ft)	6 meters (20 ft)
Vertical Resolution	1 meter	0.1 meter
Horizontal Accuracy (CE90)	50 meters	5 meters
Confidence Level	90%	90%
Compliance Date	November 20, 2008	November 20, 2010

Note: Dewberry is not an authority on aviation safety and can make no professional decision or recommendation regarding the applicability of ICAO Area 2 requirements to the 148 FAA IFR sites at Figure 9. However, Dewberry did translate the ICAO Area 1 statewide standard, and Area 2 terminal control area standard, into the criteria at Table 2 so that aviation requirements could be compared with those of other DEM user groups.

Department of Commerce, Community, and Economic Development (DCCED): Keith Jost and George Plumley. DEM applications pertain to rural Alaska Community Maps, elevation data suitable for road and sanitation design, airport and other high-accuracy civil engineering applications. The elevation data are also used to display the flood of record. Because DCCED works at the infrastructure level, their requirements for elevation data (suitable for 2-foot contours) differ greatly from other statewide accuracy requirements. This is considered to be project-specific rather than a statewide requirement.

Division of Geological and Geophysical Survey (DGGS): De Anne Stevens, Kate Bull, Diana Solie, Jennifer Athey, and Rod Combellick. DGGS DEM applications requiring the highest accuracy (2-ft contour equivalent) include tsunami modeling and neotectonics/active faulting studies. DGGS DEM applications requiring mid accuracy (10-ft contour equivalent) include bedrock structural analysis, lahar modeling, and volumetric analysis. DGGS DEM applications requiring lower accuracy (50-ft contour equivalent) include DEM interpretation for geologic mapping, rectification of digital orthophotos, 3-D landscape drapes for visual analysis and display, slope/aspect analysis, generation of topographic base maps (contour lines), generation of topographic cross-section lines, and geophysical overlays for analysis. The higher accuracy requirements are considered to be project-specific whereas the lower accuracy requirements are statewide.

Department of Natural Resources (DNR): Rich McMahon, Marc Lee, Gordon Worum, Duncan Purvis, and Frank Wallis. The DNR Land Records Information Section (LRIS) builds and maintains the DNR on-line transaction processing systems in support of department business units. LRIS also provides decision support documents, typically in the form of maps, to policy makers and others. Interactive GIS is provided via Alaska Mapper and the Forestry Map Site access the full UAF GINA repository via the Web Mapping Services protocol (WMS). DNR is incorporating location based services to the transaction processing engines as part of the modernization effort. DNR LRIS primarily uses Alaska NED-derived DEMs for two purposes. First DNR uses the derived products of hillshade, contours, slope, and aspect as part of the decision support documents associated with permits, leases, sales, easements, etc. Decision support map scales typically span 1:24,000 to 1:2,500,000, and vertical accuracy requirements are equivalent to 40-foot contours. State status plats, a core LRIS product line depicting the disposition of state lands, range from 1:6,000 to 1:24,000 scale. Second, DNR uses best available DEMs, through contractors, to control imagery acquired from satellite vendors. The Alaska NED has been demonstrated to be unusable for many of its intended DNR applications.

Department of Transportation and Public Facilities (DOT or DOT&PF): Tim Sprout, Scott Sexton, Larry King. DOT uses DTMs for mapping roadway corridors and villages. DOT needs DTMs with 10-ft contour accuracy for general planning, and 4-ft contour accuracy for remote design purposes. DOT also uses DEMs to support hundreds of airfields statewide that need accurate DSMs for flight paths. Similar to the DCCED, DOT also works at the infrastructure level and requires elevation data of higher accuracy than those that map statewide for broad applications. These requirements are project-specific rather than statewide.

University of Alaska Fairbanks (UAF): Tom Heinrichs, David Atkinson, Hilmar Maier, Kevin Engle. DSMs and/or DTMs are used for orthorectification of digital images; arctic research; atmospheric sciences and weather forecasting; forestry and vegetation analyses; hydrology analyses; geology analyses; and diverse studies such as coastal erosion, rates of erosion, subsidence, and sea level change. Accuracy requirements vary, but are typically on the order of 10-foot contour accuracy for project work and 30- to 50-foot contour interval accuracy for broad scale work. Some coastal applications may require 2- or 4-foot contours, supplemented by improved vertical datum information and improve near-shore bathymetry. With the exception of digital orthorectification and landscape scale projects, remaining requirements are project-specific rather than statewide.

Bureau of Land Management (BLM): Garth Olson, Lynette Nakazawa, Chris Noyles. BLM mapping applications that require DEMs with 20 foot contour accuracies or better:

- Floodplain management; especially in coastal areas.
- Management of wetlands and other ecologically sensitive flat areas. This is significant along Alaska's North Slope, the Yukon – Kuskoquim Delta areas, and designated Wild and Scenic River areas.
- BLM as well as other agencies perform field operations in light aircraft and helicopters in steep, mountainous terrain where elevation accuracy is critical.
- Delineating rights of ways and easements, especially delineating ANCSA 17b easements, and delineation of hard rock and placer mining planning, operations, and reclamation.
- Base maps for wild land fire suppression
- Existing and potential oil and gas infrastructure areas, especially along proposed natural gas line routes, both intrastate and instate.
- Support to Cadastral Surveys in accurately delineating meander-lines for lakes, rivers and coastlines. BLM has the responsibility to survey and patent land selected under the Alaska Native Claims Settlement Act (ANCSA) and the Alaska Statehood Act. As of 5/29/2008 the status[5] of this workload was:
  - ANCSA (millions of acres)
    - Total Entitlement …45.6
    - Patented (survey complete/final title document issued)…24.4
    - Transferred by Interim Conveyance (before final survey)…14.1
    - Remaining Entitlement …7.1

[5] Source BLM Conveyance Report and Summary 3rd Quarter, 2008 dated 5/29/2008.

- State (millions of acres)
  - Total Entitlement…104.5
  - Patented (survey complete/final title document issued)…55
  - Transferred by Tentative Approval (before final survey)…42
  - Remaining Entitlement…7.5

The acreages requiring survey and remaining entitlement (ANCSA 21.1 million acres, and State 49.5 million acres) are the areas that require the most accurate digital elevation information. Meander-line data is photogrammetrically added to cadastral survey plats as explained below (see Figure 10).

> Accurate digital orthophotos are required by all Alaska user groups, including BLM.
>
> Orthophotos are produced by orthorectification of aerial imagery "draped" over a DTM or DSM. If the elevation data are inaccurate, the orthophotos are also inaccurate.
>
> The Alaska NED datasets are so inaccurate that mountain ranges are horizontally displaced by several miles, and elevations are in error by hundreds of meters, causing major discrepancies between orthophotos and elevation datasets. Orthophotos show rivers on mountainsides, at different locations than the lower DTM elevations where hydrographic features are naturally present.
>
> BLMs surveys are routinely based on stream meander lines. However, stream meander lines produced from inaccurate DEMs depict rivers climbing up and over mountains, and there is no accurate reference surface on which to resolve major discrepancies. This is ultimately why BLM needs accurate elevation data, both horizontally and vertically.

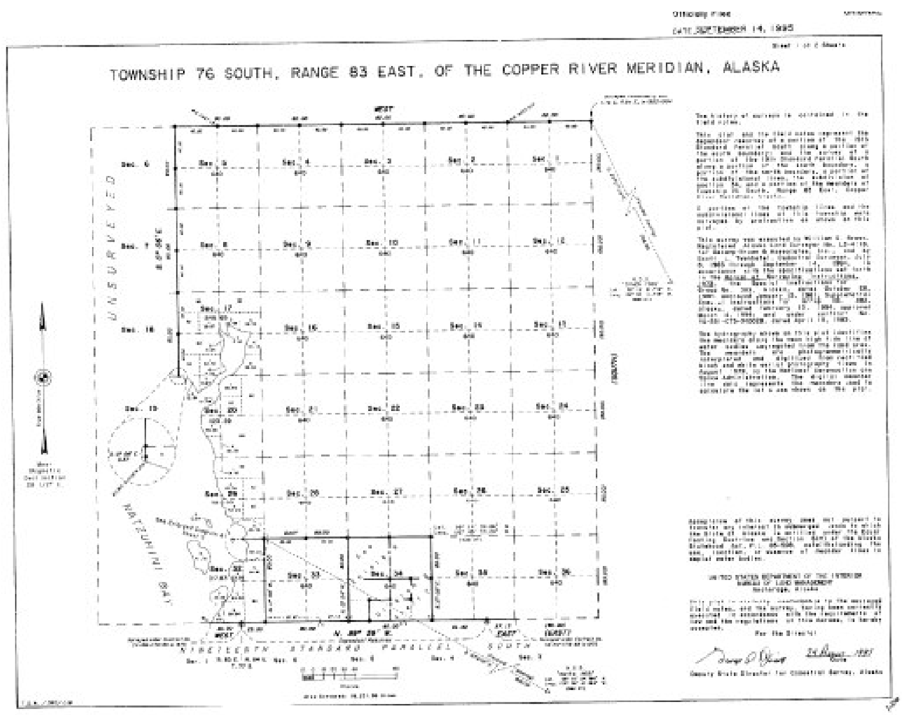

Figure 10. The example plat shown here is of a township that contains hydrography delineated photogrammetrically. The plat notes in the margin state the following:

"This plat and the field notes represent the dependent resurvey of the portion of the 19th Standard Parallel South along a portion of the south boundary; and the survey of a portion of the 19th Standard Parallel South along a portion of the south boundary, a portion of the north boundary, a portion of the subdivisional lines, the subdivision of section 34, and a portion of the meanders of Township 76 South, Range 83 East, Copper River Meridian, Alaska.

"A portion of the township lines and the subdivisional lines of this township were surveyed by protraction as shown on this plot. This survey was executed by …

"The hydrography shown on this plat identifies the meanders along the mean high tide line of water bodies segregated from the land area. The meanders are photogrammetrically interpreted and digitized from rectified black and white aerial photography flown in August 1979 by the National Aeronautics and Space Administration. The digital meander line data represents the meanders used to calculate the lot areas shown on the plat."

Department of Defense (DOD): John Gumpert, Mike Davis, Rob Beachler. The DOD in Alaska needs DTED 4 data (3-5 meter DEM, 20-foot contour accuracy) for military training throughout the state. This activity includes troop exercises within the 1.5 million acres of Army owned land, joint training within restricted airspace, and aerial activity within the 200,000 square miles of Military Operations Areas (MOAs). DTED 4 is especially important for UAV and rotary wing aircraft, which are playing an increasing role in the training activity in Alaska. Outside military airspace, 20-foot contour accuracy

DEMs are an essential tool for rotary wing operations performing search-and-rescue and medivac operations throughout the state.

National Geospatial-Intelligence Agency (NGA): Barry Heady. NGA would use the DEM (DTED 2) generated over Alaska to populate its global resolution elevation foundation layer above 60N latitude to compliment the SRTM-derived DTED 2 data that exists below 60N latitude. DTED 2 data is one of the foundation data layers necessary for DoD mission planning and a variety of terrain visualization applications. DTED 2 is also utilized to orthorectify standard NGA orthoimage products such as the 1m Controlled Image Base (CIB) product. The Alaska NED does not satisfy the DTED 2 accuracy requirements.

National Oceanographic and Atmospheric Administration (NOAA): Kirk Waters (NOAA CSC), Dave Zilkoski, Dan Roman and Mark Howard (NOAA NGS). NOAA's National Geodetic Survey (NGS) plays a vital role in implementing the Federal Aviation Administration's Advisory Circular 150/5300-18B: *General Guidance and Specifications for Submission of Aeronautical Surveys to NGS: Field Data Collection and Geographic Information System (GIS) Standards*; these standards implement the International Civil Aviation Organization (ICAO) standards, including those cited above for aviation safety. In addition to aviation safety, NGS indicated that it needed IFSAR elevation data statewide. Others at NGS indicated they had less-accurate needs that could be satisfied with data having 40-foot contour accuracy. NOAA's Coastal Services Center (CSC), on the other hand, indicated that it needed LiDAR elevation data with 2-foot contour accuracy in order to measure or predict small elevation changes (permafrost) in coastal areas from climate change, for example, and to monitor coastal erosion that may become more prevalent with longer open-water seasons. This is a higher-accuracy requirement that pertains to a major area of Alaska but only to coastal areas for which additional funding would be needed for LiDAR. The low relief coastal areas and steeper coastal areas threatened by tsunamis have a real need for more-accurate DEM data for monitoring and runup and surge modeling. Such high-accuracy elevation data of coastal areas is vital for NOAA's mission. NOAA estimates that it needs such data for an estimated 55,000 mi^2 (142,449 Km^2) area. Most of the flatter areas where high-accuracy DEMs are needed are on the Bearing Sea (north from Kuskokwim Bay) and on the north slope, near Barrow.

National Park Service (NPS): Parker Martyn, John Pinamont. NPS DEM user applications include general mapping, coastal mapping, production of topographic maps and digital orthophotos, wetland maps, forest maps, corridor (right-of-way) maps, shoreline delineation, climate change, sea level change, coastal management, coastal inundation modeling, water supply and quality, subsidence monitoring, disaster preparedness and response, fire propagation modeling, floodplain management, geological applications, and resource management. NPS requirements can be satisfied with elevation data equivalent to 40-foot contours but are not satisfied by the current Alaska NED.

Natural Resources Conservation Service (NRCS): Ted Cox. DEMs are used for orthorectification of digital imagery and for analyses of slope and aspect for the following applications:

soil surveys, landscape modeling of geomorphic land forms, natural resources inventories, and engineering applications such as emergency watershed analyses. NRCS requirements can be satisfied with elevation data equivalent to 50-foot contours.

U. S. Forest Service (USFS): Mark Riley, Jim Schramek, Joe Calderwood. DEMs are used for orthorectification of digital imagery, for hydrology, and for diverse forestry analyses to include slope and aspect, study of forest health (e.g., causes of yellow cedar decline), for determination of tree heights (DSM elevations minus DTM elevations), biomass and wildfire modeling. USFS requirements for DSMs and DTMs can be satisfied with elevation data from airborne IFSAR, i.e., equivalent to 20-foot contours.

U.S. Geological Survey (USGS): Carl Markon, Craig Seaver, George Lee, Dean Gesch, Karl Heidemann, Gayla Evans. DEMs form the elevation layer in The National Map and form the basis for two national datasets that comprise our National Spatial Data Infrastructure (NSDI): (1) National Elevation Dataset (NED) and (2) National Hydrologic Dataset (NHD). DSMs and/or DTMs are used for orthorectification of digital orthophoto quads and quarter-quads (DOQs and DOQQs) produced by USGS, for hydrologic analyses, watershed analyses, geological analyses, seismic monitoring, sea level change analyses, subsidence monitoring, floodplain modeling, wetland mapping, coastal erosion modeling, coastal inundation modeling, saltwater intrusion, landslide modeling, and many other applications. USGS is normally a provider of DEMs to others, rather than a data user, but USGS has long been underfunded for the production of accurate DEMs nationwide. USGS indicated that 10-foot contour accuracy would be "ideal," 20-foot contour accuracy would be "preferred," and 40-foot contour accuracy would be "acceptable."

U.S. Fish & Wildlife Service (USF&WS): Comments were solicited but no responses were received from this agency.

DEM User Requirements

In setting the goals for the Alaska DEM Workshop on July 22-23, 2008, Tom Heinrichs summarized the need to study requirements for an improved statewide Alaska DEM.

A requirement is a documented need of what a particular product or service should be or do. It is a statement that identifies a necessary attribute, capability, characteristic, or quality of a system in order for it to have value and utility to a user.[6]

DEM requirements are not: (1) a particular type of elevation data users have worked with in the past and are comfortable with, (2) what other colleagues were able to get to map his/her project site, municipality, or state, or (3) a "better" product that would be really nice to have.

[6] Young, Ralph R. *Effective Requirements Practices*. Boston: Addison-Wesley, 2001, through http://en.wikipedia.org/Wiki/Requirement

Indicating that "Alaska needs the same data as available in the rest of the U.S." is *user envy* that is often unfounded. Florida, Louisiana and North Carolina funded high-accuracy LiDAR mapping programs because of devastating hurricanes that impacted millions of people living near coastal areas, whereas West Virginia funded photogrammetric DEMs with accuracy equivalent to 20 foot contours. Many states have DEMs in the National Elevation Dataset (NED) produced by digitizing the contour lines from USGS topographic quad maps produced in the 1960s and 1970s and then converting those contours into gridded DEMs with 1-arc-second or 1/3-arc-second grid spacing. The vertical accuracy depends on the original contour interval, on USGS topographic quad maps, which depends on the ruggedness of the terrain. Topographic quad maps in mountainous areas typically have 50 foot contours, whereas flat areas may have 10 foot contours on these old USGS quad maps. Each state is different, largely depending on the ruggedness of the terrain, the dates and methods then used to produce the quad maps, techniques used to convert contours into DEMs, and state initiatives to provide funding to improve DEMs they considered to be inadequate.

Dewberry was tasked to differentiate, if possible, between statewide/broad-scale requirements and local/project requirements, recognizing there is no sharp dividing line and there will be no one-size-fits-all solution. Mapping the Chugach National Forest or the National Petroleum Reserve – Alaska has broad scale projects with statewide implications that differ from projects for local infrastructure, for example.

The Alaska Statewide Digital Mapping Initiative (SDMI), AGDC members, and other stakeholders need to analyze the variables of data accuracy, costs, data enhancements (e.g., hydro-enforcement), spatial extent of coverage, and licensing to optimize the impact and value of funds spent. "In deciding the specifications for an organization's acquisition of DEMs, it ultimately comes down to making choices. Some of these choices impact costs, whereas others do not."[7]

In asking 15 different user groups (6 State-level and 9 Federal-level) to document their DEM requirements from Dewberry's *DEM User Requirements Menu*, Dewberry was cognizant of the fact that some of the stated requirements were project-specific rather than statewide, and some of the stated requirements were possibly overstated. During the Alaska DEM Workshop, after review of user input by Dewberry, the individual user groups were all asked to resubmit their final *User Requirements Menus*, resulting in statewide requirements that converged within the range of 20- to 50-ft contour accuracy, plus higher accuracy (2-ft contour) for flat/coastal areas. Although there were other choices in which DEM user groups had differing requirements, none of the other differences had a significant impact on the overall cost of the SDMI.

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[7] Maune, David F., *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 2nd Edition, ASPRS, 2007

Elevation Surface

Of the 14 DEM user groups that responded, nine indicated that they needed a Digital Surface Model (DSM) of the top reflective surface (tree tops) and all 14 indicated they needed a Digital Terrain Model (DTM) of the bare-earth terrain. Nine user groups indicated that they needed both a DSM and DTM. For the elevation dataset to be included in the NED, a DTM needs to be produced. However, for non-forested areas of Alaska, the DTM and DSM are essentially the same, so some costs could possibly be avoided by delivering DSMs for such areas.

Elevation Type

Of the 14 DEM user groups that responded, seven indicated they needed ellipsoid heights and nine indicated they needed orthometric heights. Two user groups indicated they needed both ellipsoid heights and orthometric heights, depending on project requirements. Although the majority of user applications are actually for orthometric heights, many user groups indicated that they needed ellipsoid heights so they could always produce improved orthometric heights as the geoid model is improved. USGS indicated that it would consider ellipsoid heights in lieu of orthometric heights because ellipsoid heights are much more accurate in Alaska because of the poor geoid model which causes errors in orthometric heights on the order of two meters.

Data Model Types

All DEM user groups indicated that they needed gridded DSMs and DTMs. Several asked for raw elevation mass points (especially if LiDAR is collected); four asked for breaklines of selected features, primarily linear hydrographic features and ridgelines; two asked for contour lines; and three asked for concurrent imagery.

Ten of the user groups preferred their gridded DSMs and DTMs with geographic coordinates (latitude and longitude), but USGS stated a preference for a gridded DEM with 10-meter post spacing with the Alaska Albers Equal Area projection for QA/QC purposes, prior to USGS' conversion into geographic coordinates for the NED. When all user groups were asked what grid spacing they needed for geographic coordinates, one (DOD) replied that it needed 1/9-arc-second spacing, seven replied they needed 1/3-arc-second grid spacing, and four indicated they needed 1-arc-second grid spacing, consistent with specifications of the National Elevation Dataset (NED).

Two user groups (DCCED and DOT), working at the infrastructure level, need their elevation data in State Plane coordinates, whereas three DEM user groups (BLM, NRCS and USGS) indicated that they also use the Alaska Albers Equal Area projection, preferably with grid spacing of 10 meters in Northings and Eastings. Figures 11 and 12 compare geographic and Cartesian coordinates.

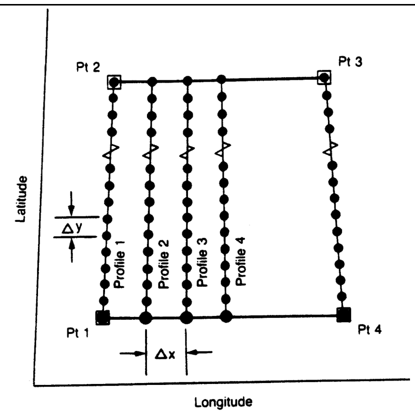

Figure 11. Geographic coordinates: Δx and Δy in latitude/longitude arc-seconds

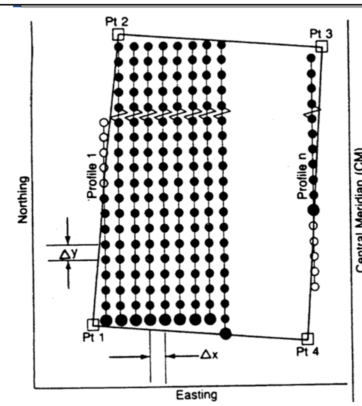

Figure 12. Cartesian coordinates: Δx and Δy in northing/easting meters

Vertical Accuracy

Vertical accuracy requirements vary greatly among the various DEM user groups. Dewberry separated the high-accuracy, mid-accuracy and low-accuracy requirements because they also tracked well with the different technologies under consideration. Table 3 summarizes the various accuracy requirements.

<u>High-Accuracy Requirements</u>. With the exception of NOAA's Coastal Services Center (CSC), all of the high-accuracy requirements are project-specific for small areas and are not statewide. However, requirements submitted by NOAA's CSC pertain to requirements for LiDAR data with 2' contour accuracy for all Alaska coastlines, especially flat coastal areas, such as shown in red at Figure 13. Covering an estimate area of 142,450 Km^2, this requirement is very expensive and would appear to require additional, specific-purpose funding that differs from funding requirements otherwise identified for the SDMI. Whereas NOAA requires the ability to measure or predict small elevation changes (permafrost) in coastal areas from climate change, or to measure coastal erosion expected to become more prevalent with longer open-water seasons, this requirement could be partially satisfied by airborne IFSAR. A unique characteristic of SAR is its ability to map small changes in elevation through time, exploiting a process of differential IFSAR. For example, ground subsidence rates on the order of 2 mm per year have been measured. IFSAR is also superior for mapping of littoral zones in detecting the land-water interface. Furthermore, numerous other DEM user groups indicated

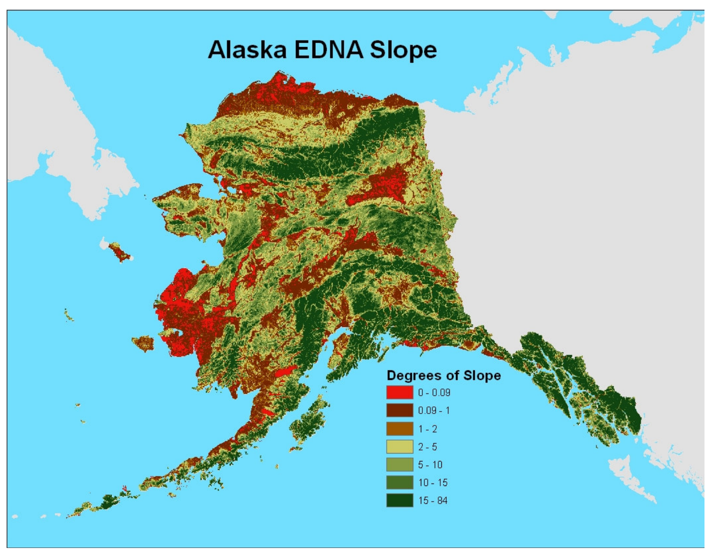

Figure 13. This map from USGS' Elevation Derivatives for National Applications (EDNA) shows flat areas in red where high accuracy elevation datasets are needed of coastal areas.

that they also need high-accuracy elevation data for areas of flat terrain and wetlands, such as shown in red at Figure 13.

Table 3 — Vertical Accuracy Requirements

DEM User Groups	High-accuracy 10' and better contour accuracy (Airborne LiDAR)	Mid-accuracy 20' to 30' contour accuracy (Airborne IFSAR)	Low-accuracy 40' and worse contour accuracy (Satellite Sensors)
Alaska Aviation		20' contour accuracy ICAO Area 2 standard	200' contour accuracy ICAO Area 1 standard
Alaska DCCED	2' contour accuracy		
Alaska DGGS	2' & 10' contour accuracy		50' & 100' contour accuracy
Alaska DNR			40' contour accuracy
Alaska DOT	4' & 10' contour accuracy		
Alaska University Users	2' & 10' contour accuracy	30' contour accuracy	50' contour accuracy
BLM		20' contour accuracy	
DOD		20' contour accuracy	
NGA			50' contour accuracy
NOAA[8]	2' contour accuracy	20' contour accuracy	40' contour accuracy
NPS			40' contour accuracy
NRCS			40' contour accuracy
USFS		20' contour accuracy	
USGS	10' contour accuracy ("ideal")	20' contour accuracy ("preferred")	40' contour accuracy ("acceptable")

Mid-Accuracy Requirements. The total area of Alaska is 1,508,668 Km^2, or 372.8 million acres. At least six DEM user groups in Alaska require elevation data equivalent to 20' contour accuracy for major portions (or all) of the State, and together they present a compelling argument for statewide elevation data that can most cost-effectively be provided by airborne IFSAR. These requirements for DEMs with 20-foot contour accuracy are summarized as follows:

- Aviation safety: Alaska has 148 FAA IFR airfield sites that require elevation data that satisfy ICAO Area 2 requirements for DSMs and DTMs equivalent to 20-foot contour accuracy for circles with a 45 Km radius around each of these airfields. The total area could by computed by the formula 148 x πr^2 = 941,535 Km^2, but because many of these circles (see map at Figure 9) overlap or are over water, the area requiring this accuracy is less than half that of the entire state. Nevertheless, it would be highly impractical (and ultimately more expensive) to map the areas outside these circles to a lesser accuracy standard than inside these circles.

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[8] Whereas NOAA's CSC requires LiDAR data with 2-ft contour accuracy of flat/coastal areas, airborne IFSAR data could partially satisfy CSC needs for coastal change detection and mapping of littoral regions.

- BLM: The Bureau of Land Management manages lands for 46% of the area of Alaska for which BLM and the State have land ownership/management responsibilities (see map at Appendix A). The acreages requiring survey and remaining entitlement (ANCSA 21.1 million acres, and State 49.5 million acres, total 70.6 million acres) are the areas that require the most accurate digital elevation data. This comprises approximately 19% of the total 372.8 million acres in Alaska. In addition to this 19%, BLM is one of the users that indicated that they needed higher accuracy elevation data in flat areas and wetlands.

- DOD: The DOD in Alaska needs DTED 4 (3-5 meter grid spacing, 20-foot equivalent contour accuracy) for military training and operations throughout Alaska, including troop exercises within Army owned land; joint training within restricted airspace; aerial activity within the 200,000 square miles of Military Operations Areas (MOAs); search-and-rescue and medivac operations throughout the state.

- NOAA: Whereas NOAA's National Geodetic Survey (NGS) otherwise requires IFSAR data statewide, the Coastal Services Center (CSC) requires LiDAR data with 2-foot contour accuracy for all Alaska coastlines, especially flat areas, estimated to comprise 142,450 Km^2 or about 9.4% of the total land area of Alaska. This would be extremely expensive, and this whitepaper assumes that project-specific funding would be required for this effort. To the degree that the CSC could instead accept IFSAR data (which has advantages for change detection and mapping of littoral areas) with 20-foot contour accuracy, the SDMI could at least partially address this legitimate CSC need.

- USFS: The U.S. Forest Service requires digital elevation data with 20-foot contour accuracy for the 6% of the area of Alaska (national forests) managed by the USFS. The USFS specifies that they need IFSAR data that maps both the DSM (top reflective surface of trees) and the DTM (bare-earth terrain beneath the trees) in order to determine tree heights, biomass, and changes over time to the forests that they manage. IFSAR is ideal for these applications, especially GeoSAR which uses X-band SAR to map the DSM and P-band SAR to map the DTM.

- USGS: Along with hydrographic data, orthoimagery, and geographic names, elevation data is an A-16 responsibility of the U.S. Geological Survey which indicates that they consider 10-foot contour accuracy to be ideal, but not expected statewide. Instead, USGS indicates a preference for 20-foot contour accuracy statewide, but with 40-foot contour accuracy as acceptable if higher-accuracy elevation data cannot be funded. This requirement pertains to the entire area of Alaska.

The estimated vertical accuracies of the two competing airborne IFSAR sensors are detailed in Table 4.

Table 4 — Vertical Accuracy of Airborne IFSAR Systems

Competing Airborne IFSAR Systems	Slope: 0° to 10° (Accuracy$_z$ at 95% confidence level)	Slope: 10° to 20° (Accuracy$_z$ at 95% confidence level)	Slope: 20° to 30° (Accuracy$_z$ at 95% confidence level)
Intermap's STAR-3/4/5/6			
Type III DSM	6 m ≈33-ft contour accuracy	9 m ≈50-ft contour accuracy	12 m ≈66-ft contour accuracy
Type II DSM	1.8 m ≈10-ft contour accuracy	3 m ≈17-ft contour accuracy	4 m ≈22-ft contour accuracy
Type II DTM (untested, assumed equal to DSM)	1.8 m ≈10-ft contour accuracy	3 m ≈17-ft contour accuracy	4 m ≈22-ft contour accuracy
	Flat Terrain Yahoo County, MS	**Moderate Terrain Southern California**	**Rolling Terrain Southeast Asia**
Fugro EarthData's GeoSAR X-band DSM	1.8 m ≈10-ft contour accuracy	1.86 m ≈10-ft contour accuracy	8.78 m ≈49-ft contour accuracy
P-band DTM	≈10-ft contour accuracy	≈10-ft contour accuracy	≈49-ft contour accuracy
	P-band foliage penetration (10-20m typical) is slope and foliage dependent		

Low-Accuracy Requirements. The remaining DEM user groups have DEM requirements that could be satisfied by DEMs of lower accuracy, i.e., 40-foot contour accuracy or poorer. These DEM user groups include the Alaska Department of Natural Resources (DNR), the National Geospatial-Intelligence Agency (NGA), the National Park Service (NPS), the Natural Resources Conservation Service (NRCS), and (projected) the U.S. Fish & Wildlife Service (USF&WS). Airborne IFSAR can definitely satisfy these accuracy requirements, but various optical and synthetic aperture radar (SAR) satellite options come close to satisfying these low-accuracy requirements.

As requested at the Alaska DEM Workshop, additional information was provided by SPOT, ASRC and MDA to reflect degradation in vertical accuracy of their satellite options based on terrain slope; the other satellite image providers did not provide information on how their DEM accuracies degraded as a function of terrain slope. Both Intermap Technologies and Fugro EarthData provided information regarding such degradation of their airborne IFSAR systems based on slope.

The estimated vertical accuracies of the competing satellite sensors are shown in Table 5. Several options are far from meeting the requirement for 40-ft contour accuracy, even with ground control points (GCPs).

Table 5 — Contour Interval (CI) Vertical Accuracy of Satellite Sensor Systems

Competing Satellite Sensor Systems with contour interval (CI) accuracy	Slope: 0° to 20° Accuracy$_z$ at 95% confidence level and equivalent CI	Slope: 20° to 40° Accuracy$_z$ at 95% confidence level and equivalent CI	Slope: >40° Accuracy$_z$ at 95% confidence level and equivalent CI
ASTER Global DEM	20m (110-ft CI)	Unavailable	Unavailable
GeoEye's IKONOS, 1-arc-sec w/o GCPs **0.2-arc-sec w/1 GCP per stereo model**	24 m (132-ft CI) 16.7 m (92-ft CI)	Unavailable	Unavailable
Digital Globe's WorldView-1, w/o GCPs	8 m (44 ft CI)	Unavailable	Unavailable
Spot Image Corp's SPOT-5, w/o GCPs	11.9 m (66-ft CI)	21.4 m (118-ft CI)	35.7 m (197-ft CI)
ASRC's Cartosat-1 w/9 GCPs/scene	6-9 m (33-50 ft CI)	10-20 m (55-110 ft CI)	Unavailable
MDA's Radarsat-2, w/minimal GCPs (see mode explanations below)	**Slope: 0° to 20°**	**Slope: 20° to 40°**	**Slope: >40°**
— Multi-Look Fine (MLF) beam mode	0-10°: 8m (44-ft CI) 11-20°: 12m (66-ft CI)	21-30°: 15m (83-ft CI) 31-40°:17m (94-ft CI)	20m (110-ft CI)
— Ultra Fine (UF) beam mode	0-10°: 6m (33-ft CI) 11-20°: 8m (44-ft CI)	21-30°: 11m (61-ft CI) 31-40°: 12m (66-ft CI)	15m (83-ft CI)

Digital Globe indicates that it achieves its vertical accuracy, without GCPs, by taking advantage of the native accuracy of the satellite sensor, augmented by tiepoints measured between overlapping scenes.

SPOT does not use GCPs in processing its Reference3D DEM products. The absolute accuracies achieved are the result of using the large block bundle space triangulation process that it employs. SPOT explained this process further in a supplemental paper provided with its answers to the 18 questions asked by Dewberry of all data providers.

MDA provided further differentiation and accuracy specifications for Table 5 above, taking into account slope dependency of errors by two different beam modes, illustrated in Figure 14 below:

- The Multi-Look Fine (MLF) beam mode can be used statewide; the standard operation is a combination of 1 ascending and 1 descending pair for each location.
- The Ultra-Fine (UF) beam mode (Note: The Spotlight mode could even be better but is more limited to specific smaller areas).
- Theoretically, MDA could improve statewide vertical accuracy of slopes between 0 and 20 degrees to a better number (~ 5 m LE95, equivalent to 28-ft contour accuracy) if MDA would blend in the ERS tandem IFSAR archive with the Radarsat-2 radargrammetry.

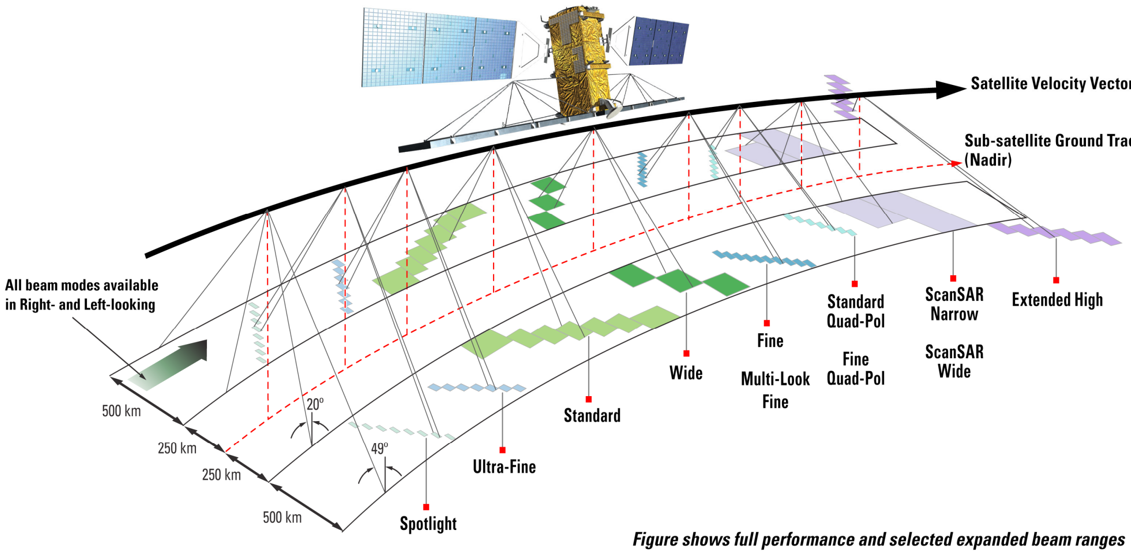


Figure 14 — Radarsat-2 Beam Modes and Features

Horizontal Accuracy

All DEM user groups were consistent in their stated needs for DEMs to have horizontal accuracy equivalent to 1:24,000-scale topographic quad maps, i.e., about 14 meter horizontal (radial) accuracy at the 95% confidence level, defined as $Accuracy_r$ by the FGDC.

Accuracy Reporting

Most DEM user groups were consistent in wanting some form of accuracy testing, at least spot testing, as opposed to the use of the "compiled to meet" accuracy statement used without testing.

Surface Treatment Requirements

Data Voids/Artifacts

Several of the DEM user groups expressed concern for data voids/artifacts that exist in SAR products as a result of layover and shadow, for example, explained in Appendix E, for which ancillary data could be required. If satellite or airborne SAR options are chosen, actions would need to be taken to minimize such artifacts and to fill unacceptable void areas by ancillary means, including optical satellite options.

Hydro-Enforcement

Ten of the 14 DEM user groups felt that they needed some form of hydro-enforcement of DTMs to ensure the lakes are flat and the streams flow downhill, as shown in Figures 15 and 16. Hydro-enforcement is performed on DTMs — not on DSMs.

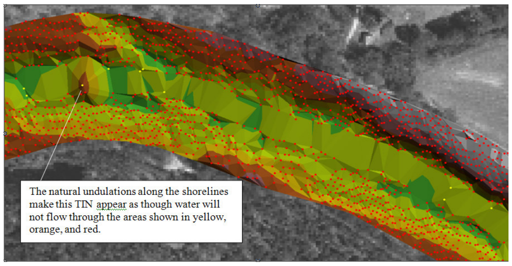


Figure 15. DTM prior to hydro-enforcement.

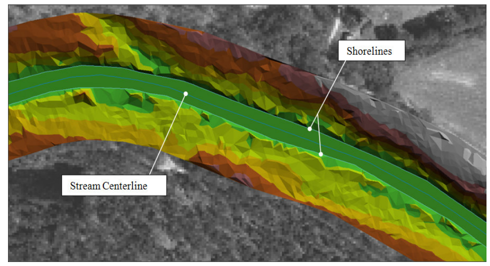


Figure 16. DTM after hydro-enforcement

- Aviation users need open lakes and streams to be identified so that float plane pilots are better prepared to land safely on water.
- USGS was specific in stating that the NED is based on a "bare-earth surface, hydrologically corrected such that streams flow downhill, wide (double-line) rivers are level bank-to-bank, and water bodies are flattened. Filling or leveling of incidental sinks is neither required nor encouraged."
- DNR, DOT, BLM, DOD, NPS, NRCS and USFS were not specific in stating their requirements for hydro-enforcement, but they all had needs for DEMs to depict downward flow of water, requiring additional processing of the elevation data.
- NGA was able to be more specific because the DTED Level 2 specification for water (3.5.3.1) has the following hydro-enforcement requirements:
  - "Flattened water bodies. Elevation values within a lake with a diameter equal to or greater than … 600 meters for DTED Level 2 must be identical.
  - "Double-line drains. Drains with a width equal to or greater than 183 meters shall be visible in the DTED area."

Hydro-enforcement of DEMs may be performed by the same firms producing the DEMs or by other specialty firms contracted to execute this task. Funding and contracting for hydro-enforcement could be separated from data acquisition and production, perhaps using local labor.

Warped Roads, Bridges and Buildings

As shown at Figure 17, DEMs are voxels (3-D pixels) for which a single elevation represents a 30-by-30 meter, 10-by-10 meter, or 5-by-5 meter grid cell, for example. Figures 18 through 21 show roads and buildings on digital orthophotos warped by draping imagery over such DEMs during the orthorectification process, regardless of whether DEMs are from optical imagery IFSAR, or LiDAR. Orthophotos can be warped with either large or small grid cell sizes; larger warps exist in steeper terrain where there is a larger offset between elevations in adjoining cells. In Figures 18 through 21, comparisons were made between 10-meter NED DEMs and 5-meter IFSAR DTMs that had been smoothed from the original DSMs.

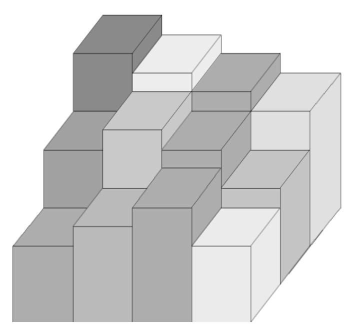


Figure 17. DEM cells are called "voxels" (3-D or volume pixels)

Figure 18. Orthophoto with warped roads in Orange County, CA when orthorectified w/10-meter NED DEM.

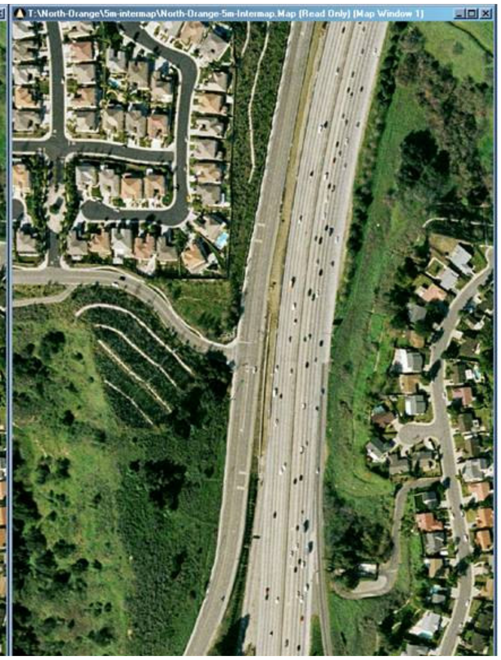


Figure 19. Orthophoto with smooth roads in Orange County, CA when orthorectified w/5-meter DTM from Intermap, smoothed from the original DSM.

Figure 20. Orthophoto with warped building in Orange County, CA when orthorectified w/10-meter NED DEM.

Figure 21. Orthophoto with normal building in Orange County, CA when orthorectified w/5-meter DTM from Intermap, smoothed from original DSM.

Although orthophotos are normally orthorectified by draping imagery over the DTM, as opposed to the DSM, bridges and overpasses are better represented when draped on the DSM that includes bridge deck elevations. Bridges may be warped into an hourglass shape when draped over a DTM. For this reason it is common to retain a bridge file, separate from the normal DTM, with elevation of the bridge decks. Figure 22 shows an "hourglass" bridge warped by a photogrammetric DTM which modeled the terrain in the gulley below the bridge deck. By orthorectification to the DSM, Figure 23 shows the same bridge unwarped. Whereas bridges are removed to a separate bridge file in order to perform hydro-enforcement, bridges are retained in the DSM for correct orthorectification of those bridges.

Figure 22. Orthophoto with warped bridge due to DTM orthorectification.

Figure 23. Orthophoto with correct bridge due to DSM orthorectification.

Figures 24 through 27 were provided by Marc Lee, Division of Forestry, Alaska DNR. Figures 24 and 25 show roads warped when QuickBird satellite images were orthorectified to a 10-meter IFSAR DEM; research indicates this was a DSM from a NASA data buy collected and processed in 1999 when Intermap delivered DSMs only and did not have a DTM option.

Figure 24. Orthophoto with warped road when image is orthorectified to 10-meter IFSAR DSM.

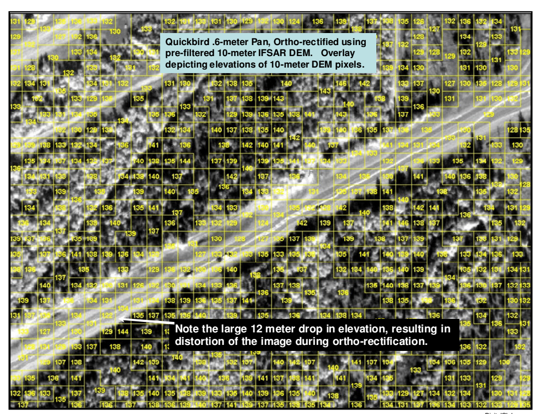


Figure 25. Grid elevations shows the road is warped due to variable elevations of grid cells on the road.

Figures 26 and 27 show that the roads are not warped on the orthophotos when images are orthorectified using the same IFSAR data that received additional filtering to smooth the roads.

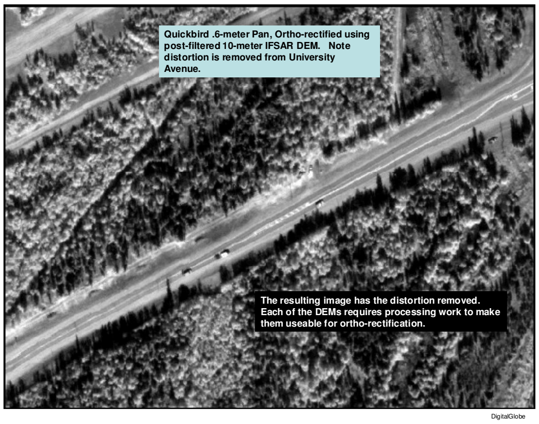


Figure 26. Orthophoto with straight road when image is orthorectified to 10-meter IFSAR that has been post-processed with a smoothing filter.

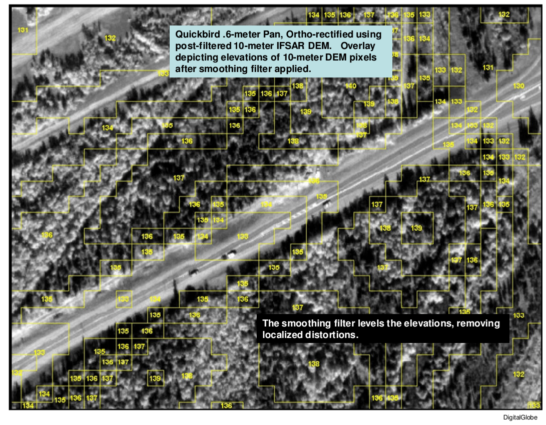


Figure 27. A smoothing filter leveled the elevations on the road, removing localized distortions.

Subsequently, Intermap developed DTM v1.0 (which flattened roads) and today's DTM v1.5 (which does not flatten roads). Intermap's Product Handbook (page 58) shows the evolution of DTM processing for different features and reasons for changes. Table 6 is taken from this Product Handbook.

Table 6. Intermap's DTM processing procedures from Product Handbook

Feature	Description	DTM v1.0	DTM v1.5	Benefit
Streams	Single line drains	No interruption of monotonicity greater than 2 meters shall be present in single line drains	No interruption of monotonicity greater than 1 meter shall be present in single line drains	Further supports flood modeling applications
Buildings	All man-made dwellings	Built-up areas greater than 100 meters across are smoothed but will contain some remnant building elevations	Buildings are removed regardless of magnitude of built-up area using best technology and ability (see section 6.2.2 *FITS Editing Process*)	Further supports flood modeling and contour applications
Forests	All trees and groupings of tree canopy heights	Tree stands greater than 100 meters across remain in DTM	No magnitude criteria – all trees / forests are removed from the DTM	Further supports flood modeling, contour, forestry applications
Crops	All field crops detectable in the radar data greater than 1 meter in height	Crops are smoothed to bring their elevation closer to surrounding ground elevations	Crops are removed when detected within radar sensed data	Further supports agricultural applications such as precision farming and flood modeling applications
Major Roads and Railroads	Highways, major roads, and railroads	Highways, major roads, and railroads were flattened so as to be more aesthetically pleasing	Highways, major roads, and railroads are left as sensed by radar	Flattening major roads did not provide an appreciable benefit from an analytical perspective

Just because Intermap's standard process no longer flattens roads does not mean that this could not yet be done by Intermap, or others, to satisfy SDMI requirements. Fugro EarthData is expected to have a similar situation with the DTM produced from their P-band GeoSAR datasets.

The SDMI could or should specify geographic locations where roads and bridges will require special post-processing in order to avoid wavy road distortions discussed in this section of the whitepaper. There is no industry standard automated procedure for such smoothing of roads; normally, this involves some degree of human analysis/interpretation to define road centerlines that are buffered in order to smooth the elevation offsets between adjoining cells within the road buffers. Assuming that Marc Lee, Division of Forestry, has developed a viable process as used in the examples at Figures 26 and 27, perhaps this process could be performed in-state, separate from the commercial firm producing the DSMs or DTMs.

Datums and Geoid Model

All DEM user groups said they needed the NAD83 horizontal datum and NAVD88 vertical datum. Many deferred the question on geoid models to those who better understand the issues, and NGS informed Dewberry that the GEOID06 model should be used.

Coordinates and Units

As indicated above, many of the DEM user groups indicated that they preferred their DSMs and DTMs in geographic coordinates, consistent with requirements of the National Elevation Dataset (NED), with elevations in meters. Users using State Plane coordinates preferred their elevations in U.S. Survey Feet. Others preferred elevations in meters. The various DEM user groups were generally consistent in not wanting to deal with 10 different State Plane or 10 different UTM zones, but DCCED and DOT do prefer State Plane coordinates because they work at the infrastructure level and never deal with seam lines between adjoining State Plane zones. Several user groups preferred the Alaska Albers Equal Area Projection in order to have a single gridded DEM with 10-meter post spacing statewide.

File Size

Having the most experience with this subject, USGS recommended that the file sizes be between 150 Mb and 1 Gb per file.

Tile Size

USGS recommended that tile sizes should comply with some multiple of 7.5-minute topographic quad sheets. All DEM user groups indicated they would accept 1° x 1° tiles.

Licensing of Data

Whereas almost all DEM user groups showed a strong preference for DEMs to be available to all via the public domain, as with the current NED, they did indicate that they understood that some options would cost less with a government use license (federal, state and/or local government use only) or an enterprise user license agreement (that would restrict the use to specific parties).

Technology Options

At the Alaska DEM Workshop on July 22-23, 2008, seven commercial firms presented their credentials to address the 18 questions that had been asked of them in advance by Dewberry:

1. Sensor: What sensor do you propose to use for acquisition of source data to be used for DEM production?
2. Model: Are your DEMs produced from the Digital Surface Model (DSM) of the top reflective surface, or do you also produce DEMs from the Digital Terrain Model (DTM) of the bare-earth or near bare-earth -- or a combination or other process?
3. Native Z accuracy: With minimal ground control, what is the vertical accuracy ($Accuracy_z$) of your DSMs at the 95% confidence level? [Note: $Accuracy_z = RMSE_z \times 1.9600$.] If you also produce DTMs, what is the vertical accuracy ($Accuracy_z$) of your DTMs at the 95% confidence level?
4. Improved Z accuracy: For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?
5. R accuracy: What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: Accuracy r = $RMSE_r \times 1.7308$.]
6. Grid spacing: What DEM grid spacing(s) do you normally use or provide?
7. Deliverables: What is delivered with your product, e.g. DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc? Please distinguish between standard products and value-added products.
8. Archive: If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g. produced DEMs, validated data, raw data meeting cloud specs, etc?
9. Product: Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?
10. Processor: If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain software that works well? Do you have established processing partners? Is there an opportunity for local Alaska productions of DEMs?
11. Special Applications: Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.
12. Ground Control: What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you require more? If more control is required, what spacing or density of survey points would be needed?
13. Geodesy Issues: How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection? Do you have preferences for datums, projections, coordinate systems, and units?
14. License: What license options are available for your elevation data?

15. Production volume: How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.
16. Experience: Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.
17. Pricing: One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity, either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)
18. IDIQ Contracts: Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.

The following sections summarize the answers to these questions provided by the invited firms. Their detailed answers are at Appendix D.

ASTER Global DEM Project

No.	Question Topic	Response
1	Sensor	ASTER, which includes visible/near infrared (VNIR), short wave infrared (SWIR) and thermal infrared (TIR) radiometers
2	Model (DSM and/or DTM)	DSM generated using bands 3N (nadir-viewing) and 3B (backward-viewing) of an ASTER Level-1A image acquired by the VNIR sensor.
3	Native vertical accuracy	20m at 95% confidence level (110-ft contour accuracy)
4	Improved vertical accuracy	N/A
5	Horizontal accuracy	30m at 95% confidence level
6	DEM grid spacing	30m postings
7	Deliverables	30m DSM from ASTER stereo images
8	Alaska archive	Most of Alaska has been imaged
9	DEM produced in-house	All processing in Japan
10	Processor software	Information not available
11	Special applications	Although of lesser accuracy, could potentially be used to fill in void areas from SAR sensors
12	Ground control	Information not available
13	Geodesy issues	Uses EGM96 global gravity model
14	License	Unrestricted
15	Production volume	DEMs available starting in 2009
16	Comparable experience	This is a global DEM project
17	Pricing	No charge
18	IDIQ contracts	Not applicable

GeoEye (IKONOS)

No.	Question Topic	GeoEye Response
1	Sensor	ASTER w/Ikonos control
2	Model (DSM and/or DTM)	DSMs edited to a near bare-earth DTM
3	Native vertical accuracy	ASTER, 24m at 95% confidence level (132-ft contour accuracy); Ikonos 1-arc-second, 14m at 95% confidence level (77-ft contour accuracy)
4	Improved vertical accuracy	Ikonos 0.2-arc-second, 4m at 95% confidence level (22-ft contour accuracy) requires 1 ground control point per stereo model
5	Horizontal accuracy	29m (1-arc-sec) and 14m (0.2-arc-sec) at 95% confidence level
6	DEM grid spacing	30-m (1-arc-sec) and 5m (0.2-arc-sec)
7	Deliverables	Standard products: GeoReference, Precision Plus, Pro, and Stereo
8	Alaska archive	80,000 to 90,000 Km^2 of active archive
9	DEM produced in-house	In-house or provide stereo imagery to vendors
10	Processor software	Socet Set preferred
11	Special applications	No value-added applications are offered
12	Ground control	1-arc-sec, no GCPs needed; 0.2-arc-sec, 1 GCP per stereo pair
13	Geodesy issues	Orthometric heights produced using EGM96; can deliver ellipsoid heights
14	License	Customized to fit project needs
15	Production volume	10-20% per year
16	Comparable experience	DEM experience in Alaska, Canada, Greenland, Central Africa
17	Pricing	Negotiable
18	IDIQ contracts	USGS (Dewberry sub); NGA (sub to BAE, Technigraphics, Boeing, Harris)

Digital Globe (Worldview-1)

No.	Question Topic	Digital Globe Response
1	Sensor	Worldview-1
2	Model (DSM and/or DTM)	DSM is automatically extracted; DTM is manually edited for bare-earth
3	Native vertical accuracy	DSMs and DTMs, 8m at 95% confidence level (44-ft contour accuracy)
4	Improved vertical accuracy	No proposal for use of GCPs to improve accuracy
5	Horizontal accuracy	5m (for 10m DEM), 15m (for 30m DEM) at 95% confidence level
6	DEM grid spacing	Variable
7	Deliverables	DSM, DTM, contours, orthoimages, and orthoimage mosaics
8	Alaska archive	No significant stereo pair coverage of Alaska
9	DEM produced in-house	DigitalGlobe will partner with PCI Geomatics for creation of DEM products
10	Processor software	PCI Geomatics will provide
11	Special applications	Stereo imagery could be used for 3D feature extraction, land cover classification, modeling of drainage
12	Ground control	No GCPs required
13	Geodesy issues	No issues other than poor geoid which pertains equally to all
14	License	A Government Enterprise License will be offered
15	Production volume	10-12% of the state annually
16	Comparable experience	Canadian National Imagery Project, a contract from the Canadian Government to PCI
17	Pricing	Cannot provide without detailed scope
18	IDIQ contracts	USGS (Dewberry sub) plus numerous other federal and state contracts

SPOT Image Corp (SPOT-5)

No.	Question Topic	Spot Image Corp. Response
1	Sensor	SPOT-5, High Resolution Stereo (HRS) and High Resolution Ground (HRG)
2	Model (DSM and/or DTM)	DSMs only (commercial name Reference 3D); do not collect DTMs
3	Native vertical accuracy	11.9m LE95 (66-ft contour accuracy) for slopes of 0-20° 21.4m LE95 (118-ft contour accuracy) for slopes of 20-40°
4	Improved vertical accuracy	SPOT does not use GCPs to improve vertical accuracy
5	Horizontal accuracy	17.1m at 95% confidence level
6	DEM grid spacing	30x30 m post spacing, or 1-arc-sec (latitude) by 2-arc-sec (longitude)
7	Deliverables	DEM in DTED format, orthoimage mosaic, eight different masks
8	Alaska archive	76% of Alaska is already archived
9	DEM produced in-house	SPOT delivers the finished DEM (DSM)
10	Processor software	SPOT does not provide source imagery to others for DEM production
11	Special applications	Reference 3D DEMs have a large variety of applications
12	Ground control	GCPs not used for production; GCPs are used for accuracy validation
13	Geodesy issues	SPOT uses the EGM96 geoid model
14	License	Two options: Regional Business User and public release for the NED
15	Production volume	18 months after vast majority of state is covered by HRS source imagery
16	Comparable experience	Vast areas of northern Africa, Middle East, and Asia
17	Pricing	Reference 3D DEM: \$4.00/Km^2. DEM + orthoimages: \$10.95/Km^2
18	IDIQ contracts	USGS and NGA
19	Hydro Enforcement	For NGA, double-line drains are motonically stepped in 1-meter increments

IRS/ASRC (Cartosat-1)

No.	Question Topic	ASRC Response
1	Sensor	Cartosat-1
2	Model (DSM and/or DTM)	ASRC provides stereo pairs to value added companies for DSM/DTM production
3	Native vertical accuracy	6 -9m @ 95% confidence level (33-50 ft contour accuracy) in open terrain using 9 GCPs/scene; 10-20m @ 95% confidence level (55-110 ft contour accuracy) in hilly and vegetated regions w/9 GCPs/scene
4	Improved vertical accuracy	Improved accuracy with 25 GCPs per scene
5	Horizontal accuracy	5-7m @ 95% confidence level with 9 GCPs/scene
6	DEM grid spacing	20-meter grid is optimal; 10-meter grid is can be easily achieved
7	Deliverables	DSM, edited DEM, ortho imagery, breaklines if stereo edited
8	Alaska archive	1000 Pan A stereo pairs collected of Alaska; approximately 50% with clouds
9	DEM produced in-house	DSMs and DTMs are produced by value-added providers
10	Processor software	Leica Socet Set; PCI OrthoEngine; and Geomatica
11	Special applications	DSM, edited DEM, ortho imagery, and breaklines if stereo edited
12	Ground control	At least 9 GCPs/scene; 25 GCPs/scene for improved accuracy (note: no inventory of statewide GCPs exist for Alaska, the Cartosat option would require several thousand properly distributed GCPs to be collected)
13	Geodesy issues	Relies on value-added processors to resolve geodesy issues
14	License	"Open license"
15	Production volume	Will take 5-6 years, depending on acquisition of cloud-free imagery
16	Comparable experience	India and Europe
17	Pricing	With Satellite Receiving Ground Station in Alaska, images would cost about $3.26/Km^2, plus costs of value-added processing and the significant costs associated with collection of GCPs, especially in remote areas of the state.
18	IDIQ contracts	USDA; ASRC MS is a partner in the NJVD which manages contract with NGA

MacDonald, Dettwiler and Associates (Radarsat-2)

No.	Question Topic	MDA Response
1	Sensor	Radarsat-2
2	Model (DSM and/or DTM)	DSM only
3	Native vertical accuracy	8m LE95 (44-ft contour accuracy) Multi-Look Line Beam mode, 0-10° slope 6m LE95 (33-ft contour accuracy) Ultra Fine Beam mode, 0-10° slope 12m LE95 (66-ft contour accuracy) Multi-Look Line Beam mode, 11-20° slope 8m LE95 (44-ft contour accuracy) Ultra Fine Beam mode, 11-20° slope
4	Improved vertical accuracy	Could improve to 5m LE95 (28-ft contour accuracy) for slopes of 0-20° is MDA blends in the ERS tandem InSAR archive with the Radarsat-2 radargrammetry.
5	Horizontal accuracy	25m at 95% confidence level
6	DEM grid spacing	10 to 30 meters
7	Deliverables	DSM, ortho radar image, optional breaklines, features, waterbodies, rivers.
8	Alaska archive	No archive; but new Radarsat-2 can acquire MLF beam mode (50 Km swaths) for all of Alaska within 6-12 months.
9	DEM produced in-house	MDA produces all DEM products in-house
10	Processor software	MDA has a good relationship with the Alaska Satellite Facility (ASF) and could collaborate
11	Special applications	MDA could provide InSAR deformation monitoring. The radar data is also suitable for other types of change detection (urban, permafrost, etc.)
12	Ground control	No GCPs needed for production, but NGS control would be used to check horizontal accuracy and for vertical control/calibration.
13	Geodesy issues	No problems anticipated
14	License	Standard license to use (for State of Alaska, etc.). Some flexibility exists and negotiations are possible.
15	Production volume	Data acquisition within 1 year; DEM production completed in 1-2 years.
16	Comparable experience	DTED-2 from ERS InSAR DEMs for the Canadian Government, generating elevation data for 1:50,000 scale maps
17	Pricing	Pricing is likely to be in bin 1 (<$15M) or low bin 2 ($15-$30M)
18	IDIQ contracts	NGA IDIQ prime contractor; Dewberry subcontractor for USGS GPSC contract

Intermap Technologies (STAR-3, 4, 5, 6)

No.	Question Topic	Intermap Response		
1	Sensor	STAR-3 and STAR-5 are on Lear Jets, better suited for Alaska		
2	Model (DSM and/or DTM)	DSMs and edited DTMs		
3	Native vertical accuracy	Slope = 0-10°	Slope = 11-20°	Slope = 21-30°
	Type III DSM	6m LE95 (33-ft CI)	9m LE95 (50-ft CI)	12m LE95 (66-ft CI)
	Type II DSM	1.8m LE95 (10-ft CI)	3m LE95 (17-ft CI)	4m LE95 (22-ft CI)
	Type II DTM (untested)	1.8m LE95 (10-ft CI)	3m LE95 (17-ft CI)	4m LE95 (22-ft CI)
4	Improved vertical accuracy	Type II requires limited radar reflectors at corner tie points and near center of acquisition block. "Ultra Long Lines" of approximate 1,200 Km will be used. By surveying radar reflectors on the ends of tie lines, the vertical accuracy improves from Type III to Type II.		
5	Horizontal accuracy	3.46 meters at 95% confidence level		
6	DEM grid spacing	5 meter post spacing; can resample to 10 or 30 meter grid if desired		
7	Deliverables	DSM, DTM, ortho-rectified radar imagery (ORI), metadata		
8	Alaska archive	202,500 Km^2, mix of Type II and Type III DSM/DTM/ORI data		
9	DEM produced in-house	All products are produced in-house		
10	Processor software	N/A. Intermap provides final products, not source data		
11	Special applications	Numerous standard and special products, e.g., TerrainOnDemand; L-band PolInSAR; DInSAR for change detection; geology maps; lithology interpretation		
12	Ground control	No control for Type III; Type II requires radar reflectors placed at corner tie lines, and, optimally, a few in the center of an acquisition block		
13	Geodesy issues	Uses precise ephemeris solutions from the Natural Resources Canada Precise Point Positioning (NRC-PPP) service.		
14	License	Numerous options, including: (1) EULA which restricts use to specific parties, (2) All Government License, (3) Public Domain, or (4) other to be negotiated		
15	Production volume	Type III data collection in 1-2 flying seasons; additional 18 months to process and edit the data		
16	Comparable experience	NextMAP USA; NEXTMap Britain; NEXTMap Europe		
17	Pricing	Depends on product options chosen; can discuss under a non-disclosure agreement (NDA)		
18	IDIQ contracts	USGS GPSC and NOAA CGSC (subcontractor to Dewberry); NGA (subcontractor to Boeing)		

Fugro EarthData (GeoSAR)

No.	Question Topic	Fugro EarthData Response		
1	Sensor	GeoSAR Airborne IFSAR (X-band and P-band) single pass mapping system		
2	Model (DSM and/or DTM)			
3	Native vertical accuracy	Flat Terrain (Yahoo County MS)	Moderate Terrain (Southern California)	Rolling Terrain (Southeast Asia)
	X-band DSM	1.8m LE95 (10-ft CI)	1.86m LE95 (10-ft CI)	8.78m LE95 (49-ft CI)
	P-band DTM	2m LE95 (11-ft CI)	2m LE95 (11-ft CI)	9m LE95 (50-ft CI)
	Foliage penetration (10-20m typical) is slope and foliage dependent			
4	Improved vertical accuracy	Surveyed radar reflectors within the block to provide control and check points		
5	Horizontal accuracy	10.4m CE95 (X-band) and 17.3m CE95 (P-band)		
6	DEM grid spacing	3m X-band and 5m P-band		
7	Deliverables	X-band DSM and imagery depicts above-ground features. P-band DTM and imagery depicts ground features and structures hidden beneath foliage.		
8	Alaska archive	No Alaska archive to date		
9	DEM produced in-house	DSM/DTM and ORI imagery are all produced in-house		
10	Processor software	Interferometric processor (X-band and P-band) provided by NASA JPL. Fugro uses TerraScan and TerraModeler software to perform finishing in-house		
11	Special applications	Planimetric and topographic mapping; mapping of inundation under tree canopies; identification of crop types; surveying of forest characteristics (stem diameter, biomass, fuel loading, etc)		
12	Ground control	Little or no ground control needed. Sparse network of radar reflectors used for quality control and accuracy verification. Integrated Lidar profiler provides project-wide vertical control (decimeter accuracy)		
13	Geodesy issues	Uses precise ephemeris solutions from the Natural Resources Canada Precise Point Positioning (NRC-PPP) service.		
14	License	Fugro EarthData collects and processes data based on a fee-for-services business model; the data is wholly owned by the customer		
15	Production volume	Assuming a collection season of May 1 to September 30, the State of Alaska can be collected in 5 seasons using GeoSAR		
16	Comparable experience	Southern California, Colombia, Panama, Ecuador, and Southeast Asia		
17	Pricing	Costing is proprietary, but will answer questions in a non-public forum		
18	IDIQ contracts	Prime contractor for NOAA, NGA, USACE, Bureau of Reclamation; subcontractor to Dewberry for USGS GPSC contract; subcontractor to Titan for USF&WS Region 7 contract		

Advantages and Disadvantages of Competing Technologies

In order to compare the various technologies, the advantages and disadvantages of each are summarized in bullet form below.

Optical Imagery

- Softcopy photogrammetry uses optical imagery to produce orthophotos and elevation data.
- Optical image acquisition is <u>neither</u> day/night <u>nor</u> all-weather, making it extremely difficult to acquire cloud-free imagery in some areas of Alaska.
- DSMs produced by automated image correlation are relatively less expensive than DTMs produced by manual compilation.
- Whether automated or manual, it is very difficult to accurately maps glaciers and mountains with perpetual snow cover.
- Airborne imagery: With good base/height ratios, DTM vertical accuracy comparable to 1-foot to 20-foot contours can be achieved, but this is very expensive.
- Satellite imagery: Most options are DSMs only and not DTMs. With relatively poor base/height ratios, vertical accuracy comparable to 50-ft contours is very expensive, especially when ground control points (GCPs) are required. Vertical accuracy comparable to 200-ft contours is less expensive, without GCPs.

LIDAR

- LiDAR <u>is</u> day/night, but <u>not</u> all-weather; LiDAR requires cloud-free conditions.
- Because single laser pulses penetrate through or between trees, LiDAR is the most accurate option for DTMs in dense forests and vegetation.
- LiDAR provides the most accurate elevation differences between DSM and DTM for forestry applications.
- LiDAR is ideal for 1-foot to 2-foot contour accuracy requirements.
- As tested in Greenland, LiDAR can accurately map mountains with perpetual snow cover.
- Although LiDAR is required by NOAA Coastal Services Center for flat, coastal areas of Alaska, costs statewide would be hundreds of millions of dollars, i.e., an unaffordable option.

SAR/IFSAR

- SAR/IFSAR is <u>both</u> day/night <u>and</u> all-weather, making it ideal for Alaska's conditions.
- IFSAR delivers ortho-rectified radar images (ORI), plus DSMs and DTM, ideal for 10-foot to 20-foot contour accuracy.

- Intermap produces DTMs by editing of DSM; Fugro EarthData produces DTMs from P-band IFSAR.
- Intermap may have licensing issues; Fugro EarthData has no licensing issues.
- Airborne IFSAR is significantly less expensive than either airborne LiDAR or airborne imagery solutions.
- Radarsat-2 has the least expensive option, but the DSM combined accuracy is equivalent to 83-ft contours.
- IFSAR accurately maps glaciers and mountains with perpetual snow cover; also excellent for mapping littoral surfaces.
- Differential SAR is uniquely suited for change detection, to include the use of Radarsat-2 to monitor changes to DSMs from airborne IFSAR.

Quality Assurance/Quality Control

The SDMI sponsors agree that the delivered DEM products should receive professional QA/QC testing to include completeness, quantitative (accuracy) and qualitative testing:

- Completeness testing ensures that the files can be read on the hard drive or other media provided and that the following characteristics are correct: file organization, file names, conformance to index grid, format of gridded DEM, georeferencing, horizontal and vertical units, horizontal and vertical datums, coordinate system, and metadata.
- Quantitative (accuracy) testing ensures that the vertical accuracy specification is satisfied for slopes of 0° to 10° and that accuracies in higher slopes approximate the target values specified in the Scope of Work that defines the tasks to be performed and vertical accuracy acceptance criteria. Dewberry recommends that LiDAR profiles be flown across IFSAR or satellite tracks to test the vertical accuracy of the chosen option.
- Qualitative testing ensures that tiles are seamless and DEMs are free of significant artifacts that would jeopardize product usability for intended purposes. For geographic areas of higher priority, this includes visual checks of DEMs along roads and bridges to ensure orthoimages will not show these features as distorted.

Data Distribution

Through the SDMI user survey, a variety of formats and distribution methods were identified. To support the varied user requirements the Geographic Information Network of Alaska (GINA) will arrange for provision of data to the stakeholders and/or public in different formats, including Digital Surface Models (DSMs) and Digital Terrain Models (DTMs) in both ellipsoid heights and orthometric heights, so as to address data needs beyond those served by the NED.

Conclusions

The project sponsors' conclusions address three issues: (1) user requirements issues, (2) data provider issues, and (3) funding issues.

User Requirements Issues

The following tables summarize issues caused by differing requirements stated by various potential stakeholders:

Issue No. 1: Vertical Accuracy

A number of DEM users are confused by differences between references to equivalent contour interval, vertical root mean square error ($RMSE_z$), LE90 (vertical accuracy at the 90% confidence level, as used with the obsolete National Map Accuracy Standard -- NMAS), and $Accuracy_z$ (vertical accuracy at the 95% confidence level, as used with the current National Standard for Spatial Data Accuracy -- NSSDA). For ease of comparison, Table 7 is provided below, comparing these terms for the different equivalent contour intervals referenced in this whitepaper.

Table 7. Comparison of Contour Interval with other DEM vertical accuracy criteria[9]

Equivalent Contour Interval (CI)	NMAS LE90	$RMSE_z$	NSSDA $Accuracy_z$
2 ft	1.0 ft	0.6 ft	1.2 ft
5 ft	2.5 ft	1.5 ft	3.0 ft
10 ft	5.0 ft	3.0 ft	6.0 ft
20 ft ≈ 6m	10.0 ft ≈ 3m	6.0 ft	12.0 ft
40 ft	20.0 ft	12.0 ft	24.0 ft
50 ft	25.0 ft	15.0 ft	30.0 ft
100 ft	50.0 ft	30.0 ft	60.0 ft

Repeated from Table 3 above, Table 3R summarizes the vertical accuracy issue.

Conclusion 1: The high-accuracy DEM requirement (2' to 10' contour accuracy) can best be satisfied by airborne LiDAR; however, only the NOAA Coastal Services Center has such a need over a large area, i.e., all of the Alaska coastlines. This will require special funding beyond the SDMI funding which applies statewide.

[9] Because the ICAO Area 2 DEM standards are for 3 meters (9.84 ft) LE90, this is equivalent to 6-meter or approximately 20-ft contour accuracy. This table is extracted from "Digital Elevation Model Technologies and Applications: The DEM Users Manual," ASPRS, 2007, 2nd edition, edited by Dr. David Maune of Dewberry.

Conclusion 2: The mid-accuracy DEM requirement (20' to 30' contour accuracy) can best be satisfied by airborne IFSAR. This mid-accuracy is needed to satisfy FAA and DOT Area 2 requirements for Aviation Safety, as well as statewide requirements of BLM, DOD, NOAA, USFS and USGS. These mid-accuracy statewide requirements "drive" the overall DEM requirements of the SDMI because they essentially cover the entire state.

Conclusion 3: The low-accuracy DEM requirement (40' contour accuracy and above) could be satisfied by several satellite alternatives to address the less-demanding needs of DNR, NGA, NPS, NRCS and USF&WS. Although the satellite options would not satisfy the more-demanding needs of FAA, DOT, BLM, DOD, NOAA, USFS and USGS, they could potentially be used to fill any voids in the terrain surface that might occur from IFSAR data.

Conclusion 4: The vertical accuracy issue is the major issue with significant impacts on the overall cost of the SDMI.

Table 3R — Vertical Accuracy Requirements

DEM User Groups	High-accuracy 10' and below contour accuracy (Airborne LiDAR)	Mid-accuracy 20' to 30' contour accuracy (Airborne IFSAR)	Low-accuracy 40' and higher contour accuracy (Satellite Sensors)
Alaska Aviation		20' contour accuracy ICAO Area 2 standard	200' contour accuracy ICAO Area 1 standard
Alaska DCCED	2' contour accuracy		
Alaska DGGS	2' & 10' contour accuracy		50' & 100' contour accuracy
Alaska DNR			40' contour accuracy
Alaska DOT	4' & 10' contour accuracy		
Alaska University Users	2' & 10' contour accuracy	30' contour accuracy	50' contour accuracy
BLM		20' contour accuracy	
DOD		20' contour accuracy	
NGA			50' contour accuracy
NOAA[10]	2' contour accuracy	20' contour accuracy	40' contour accuracy
NPS			40' contour accuracy
NRCS			40' contour accuracy
USFS		20' contour accuracy	
USGS	10' contour accuracy ("ideal")	20' contour accuracy ("preferred")	40' contour accuracy ("acceptable")
USF&WS			40' accuracy presumed

[10] NOAA CSC's true need is for LiDAR data with 2-ft contour accuracy; this need would be only partially satisfied by IFSAR data with 20-ft contour accuracy

Issue No. 2: Data Types and Formats

Table 8 illustrates the user differences as to whether DSMs or DTMs are required, whether elevation data should be provided as ellipsoid heights or orthometric heights, whether geographic or Cartesian coordinates should be used, and what file formats are required. For comparison purposes, a row was added at the bottom of the table to show the data types/formats that are used for the NED. It is presumed that Geographic Information Network of Alaska (GINA) or other agency would provide a server for provision of additional datasets, especially DSMs and ellipsoid heights. Ellipsoid heights are more important in Alaska than elsewhere where the geoid height models are more accurate and yield accurate conversions from ellipsoid heights to orthometric heights; in Alaska, users have legitimate requirements for ellipsoid heights which will be known to greater accuracy than orthometric heights because of known limitations in the geoid height model for Alaska. Whether or not the State sees the need to provide data in State Plane or Alaska Albers, or in GeoTiff format, for example, these needs must be decided. It is interesting to note that State users appear to prefer GeoTiff whereas most Federal users prefer ESRI binary grid formats. Most of these choices have minimal impact on product costs.

Table 8. Differences in DEM User Group Data Type/Format

DEM User Group	DSM or DTM	Orthometric Height or Ellipsoid Ht	Geographic or X/Y Coordinates	File Format
Alaska Aviation	Both	Ellipsoid Ht only	Geographic & UTM	GeoTiff
Alaska DCCED	DTM only	Orthometric Ht only	State Plane	AutoCAD
Alaska DGGS	DTM only	Orthometric Ht only	Geographic	GeoTiff (.img)
Alaska DNR	Both	Ellipsoid Ht only	Geographic	GeoTiff
Alaska DOT	Both	Orthometric Ht only	State Plane	GeoTiff
Alaska University	DTM only	Orthometric Ht only	Geographic	GeoTiff (.img, ascii)
BLM	Both	Ellipsoid Ht only	Geo + AK Albers	GeoTiff
DOD	Both	Both	Geographic	GeoTiff; ESRI grid
NGA	DTM	Orthometric Ht only	Geographic	DTED 2
NOAA	DTM	Both	Geographic	ESRI grid
NPS	Both	Orthometric Ht only	Geographic	ESRI grid
NRCS	Both	Ellipsoid Ht only	Geographic	.img
USFS	Both	Ellipsoid Ht only	Flexible	ESRI grid, GeoTiff
USGS	Both	Orthometric Ht only	AK Albers	ESRI grid, .img
NED Formats	**DTM**	**Orthometric Height**	**Geographic**	**ESRI grid**

Conclusion 5: Largely because USGS cited a preference for DTM data to initially be provided in the Alaska Albers Equal Area Projection, and because ellipsoid heights may be more suitable than orthometric heights because of major errors in the geoid height model, the sponsors conclude that DTMs with ellipsoid heights in ESRI grid format should be provided to USGS for inclusion in the NED, assuming a license agreement can be negotiated with the data provider(s). USGS is expected to convert these Cartesian coordinates into geographic coordinates for inclusion in the NED. DSMs and/or DTMs in orthometric heights, other coordinate systems and file formats can be provided on state servers after careful consideration of stakeholder needs.

Issue No. 3: DEM Enhancements

Conclusion 6: Those agencies with differing requirements for DEM enhancements, as shown at Table 9, should preferably pay the additional costs necessary for their areas of responsibility, with funding separate from SDMI funding.

Conclusion 7: Those agencies with requirements for roads and bridges on orthophotos to be free from warps, as demonstrated in Figures 18 through 27 above, should identify geographic areas where additional post-processing should be performed to minimize such warps, and provide additional funding to cover the higher costs for such post-processing, unless performed in-house.

Table 9. Differences in DEM User Group Data Enhancement Requirements

DEM User Group	Breaklines	Contours	Hydro-Enforced	Imagery
Alaska Aviation	Hydro + ridges		Hydro-Enforced	
Alaska DCCED		2-ft		
Alaska DGGS		2-ft & 10-ft		
Alaska DNR	Hydro		Hydro-Enforced	
Alaska DOT			Hydro-Enforced	
Alaska University	Hydro			Yes
BLM	Hydro		Hydro-Enforced	
DOD			Hydro-Enforced	
NGA			Hydro-Enforced	
NOAA				
NPS			Hydro-Enforced	
NRCS			Hydro-Enforced	Yes
USFS			Hydro-Enforced	Multispectral
USGS			Hydro-Enforced	
USF&WS				

Data Provider Issues

Repeated from Table 4 above, Table 4R compares the airborne IFSAR technical alternatives from Intermap and Fugro that would satisfy all mid-accuracy (20-ft contour accuracy) and low-accuracy (40-ft contour accuracy) requirements statewide.

Table 4R — Vertical Accuracy of Airborne IFSAR Systems

Competing Airborne IFSAR Systems	Slope: 0° to 10° (Accuracy$_z$ at 95% confidence level)	Slope: 10° to 20° (Accuracy$_z$ at 95% confidence level)	Slope: 20° to 30° (Accuracy$_z$ at 95% confidence level)
Intermap's STAR-3/4/5/6			
Type III DSM	6 m ≈33-ft contour accuracy	9 m ≈50-ft contour accuracy	12 m ≈66-ft contour accuracy
Type II DSM	1.8 m ≈10-ft contour accuracy	3 m ≈17-ft contour accuracy	4 m ≈22-ft contour accuracy
Type II DTM (untested, assumed equal to DSM)	1.8 m ≈10-ft contour accuracy	3 m ≈17-ft contour accuracy	4 m ≈22-ft contour accuracy
	Flat Terrain Yahoo County, MS	**Moderate Terrain Southern California**	**Rolling Terrain Southeast Asia**
Fugro EarthData's GeoSAR X-band DSM	1.8 m ≈10-ft contour accuracy	1.86 m ≈10-ft contour accuracy	8.78 m ≈49-ft contour accuracy
P-band DTM	≈10-ft contour accuracy	≈10-ft contour accuracy	≈49-ft contour accuracy
	P-band foliage penetration (10-20m typical) is slope and foliage dependent		

In addition to satisfying all statewide requirements, because their aircraft fly at altitudes between 35,000 and 40,000 feet, IFSAR aircraft could potentially be fitted to accommodate the National Geodetic Survey's GRAV-D sensor and operator in order to simultaneously collect gravity data for improving the geoid height model so desperately needed in Alaska.

- Intermap Technologies appears to have a competitive advantage by having more flexibility with a larger fleet of aircraft, and it has proven experience for large, successful projects in production of NEXTMap USA, NEXTMap Britain, and NEXTMap Europe.
- Fugro EarthData appears to have a competitive advantage because of GeoSAR's X-band and P-band sensors that may be superior for accurate mapping of both the DSM and DTM in forested regions and images the terrain with about 4x redundancy from multiple look directions.

<u>Conclusion 8</u>: An IFSAR hybrid solution should be considered in order to benefit from the advantages of both Intermap and Fugro EarthData. Discriminating factors should include (a) comparative costs, (b) licensing, (c) technical advantages of X-band and P-band for different areas of Alaska, (d) plans to minimize and mitigate artifacts from layover and shadow, (e) past performance, and *possibly* (f) whether or not the IFSAR aircraft could simultaneously accommodate a NGS gravimeter and operator in order to also support the GRAV-D program by collecting gravity data along the same flight lines as the IFSAR data collection.

Repeated from above, Table 5R compares the technical alternatives from satellite optical and SAR technologies that would satisfy the low-accuracy (40-ft contour accuracy) requirements of DNR, NGA, NPS, NRCS and USF&WS, but without satisfying the mid-accuracy requirements of FAA and DOT for aviation safety Area 2 requirements for IFR sites throughout the state, as well as statewide requirements of BLM, DOD, NOAA, USFS, and USGS.

Table 5R — Contour Interval (CI) Vertical Accuracy of Satellite Sensor Systems

Competing Satellite Sensor Systems with contour interval (CI) accuracy	Slope: 0° to 20° Accuracy$_z$ at 95% confidence level and equivalent CI	Slope: 20° to 40° Accuracy$_z$ at 95% confidence level and equivalent CI	Slope: >40° Accuracy$_z$ at 95% confidence level and equivalent CI
ASTER Global DEM	20m (110-ft CI)	Unavailable	Unavailable
GeoEye's IKONOS, 1-arc-sec w/o GCPs 0.2-arc-sec w/1 GCP per stereo model	24 m (132-ft CI) 16.7 m (92-ft CI)	Unavailable	Unavailable
Digital Globe's WorldView-1, w/o GCPs	8 m (44 ft CI)	Unavailable	Unavailable
Spot Image Corp's SPOT-5, w/o GCPs	11.9 m (66-ft CI)	21.4 m (118-ft CI)	35.7 m (197-ft CI)
ASRC's Cartosat-1 w/9 GCPs/scene	6-9 m (33-50 ft CI)	10-20 m (55-110 ft CI)	Unavailable
MDA's Radarsat-2, w/minimal GCPs	**Slope: 0° to 20°**	**Slope: 20° to 40°**	**Slope: >40°**
— Multi-Look Fine (MLF) beam mode	0-10°: 8m (44-ft CI)	21-30°: 15m (83-ft CI)	20m (110-ft CI)
	11-20°: 12m (66-ft CI)	31-40°:17m (94-ft CI)	
— Ultra Fine (UF) beam mode	0-10°: 6m (33-ft CI)	21-30°: 11m (61-ft CI)	15m (83-ft CI)
	11-20°: 8m (44-ft CI)	31-40°: 12m (66-ft CI)	

Funding Issues

Conclusion 9: Several of the options at Table 5R could satisfy the "low-accuracy" requirements only for elevation data equivalent to 40-foot contours, without satisfying the "mid-accuracy" requirements for data equivalent to 20-foot contours. These options should not be pursued unless funding becomes the overriding argument. Whereas the Table 5R solutions do meet a primary SDMI goal of providing a DEM suitable for orthophoto generation, they do not meet the major goals of a DEM suitable for Aviation Safety or other high- to-mid-accuracy needs.

Conclusion 10: For "high-accuracy" requirements, other than the NOAA Coastal Services Center's requirements for LiDAR data with 2-foot contour accuracy of Alaska's flat, coastal areas, for which project-specific funding would be required, the remaining "high-accuracy" user requirements pertain to special projects of DCCED, DGGS, DOT, and university users for which project-specific funding would be required. Furthermore, NOAA should evaluate airborne IFSAR to see if it can succeed by "piggy backing" with AGDC members to benefit from SDMI mapping products should the airborne IFSAR option be funded.

Conclusion 11: For "mid-accuracy" requirements of FAA and DOT for the Aviation Safety Program, and BLM, DOD, NOAA, USFS, and USGS, while also satisfying the "low-accuracy" user requirements of DNR, NGA, NPS and NRCS, airborne IFSAR is "all-weather" and is significantly less expensive than other aerial mapping technologies. The cost for statewide IFSAR coverage is in bin 3 (>$30M)

Conclusion 12: For satisfying only the "low-accuracy" requirements of DNR, NGA, NPS, NRCS, and (projected) USF&WS (i.e., meeting the SDMI goal of a DEM suitable to control medium scale orthoimagery), various satellite options could be considered, having costs believed to be in bin 2 ($15M to $30M) or the upper end of bin 1 (<$15M).

Recommendations

Recommendation 1: Actions must be taken immediately to address the legitimate DEM needs of all major federal and state users in Alaska. The U.S. will be in noncompliance with ICAO Area 1 requirements by November of 2008 and Area 2 requirements by November of 2010; there is no time to waste. Alaska is truly America's Last Frontier and endures with DEMs that are unacceptable. The "mid-accuracy" DEM needs of FAA/DOT (aviation safety), BLM, DOD, NOAA, USFS and USGS are legitimate and need to be satisfied without further delay.

Recommendation 2: For delivery of mid-accuracy elevation data, airborne IFSAR is the strongest technology candidate and should be carefully considered because of its all-weather capability and significantly lower costs when compared with other airborne mapping alternatives capable of producing digital elevation data with 20' contour accuracy.

Consensus Points

At the Alaska meeting of the NDOP/NDEP on August 19, 2008, there was unanimous agreement of all attendees to the primary and secondary "consensus points" summarized in Tables 10 and 11.

Table 10. Primary Consensus Points agreed to by NDOP/NDEP Participants

We have no time to waste	We must remain true to Alaska's requirements	We must find a timely, cost-effective solution
• ICAO Area 1 Requirements: 11/20/2008 • ICAO Area 2 Requirements: 11/20/2010 • Other statewide DEM user requirements: Immediate for orthorectification of optical imagery • Alaska's mapping needs have been neglected for 50 years; unmet needs in Alaska are dire, especially aviation safety	• 20' contour accuracy or better • Both DSM and DTM, especially mountain peaks, ridgelines and hydrology • Technology that overcomes adverse weather conditions • Technology that maps snow-capped mountains & glaciers • Technology that is cost-effective	• Only airborne mapping options can satisfy AK's technical and accuracy requirements • Airborne IFSAR costs are significantly less than airborne LiDAR or photogrammetry • Multiple contracting options are available to obtain the most cost-effective solution for timely delivery of quality products • Need both federal and state funding

Table 11. Secondary Consensus Points agreed to by NDOP/NDEP Participants

We have time to reach consensus elsewhere	What other requirements should be satisfied? How? By Whom?	We must find cost-effective solutions
• Data acquisition and post-processing can proceed if we choose ellipsoid heights and Alaska Albers, for example, knowing that NED will be provided as geographic coordinates in ESRI grid format. • Other issues can be resolved while data are being acquired and processed.	• Will GINA serve multiple datasets to the public? • Will GINA provide orthometric heights that change with new geoid models? • Will GINA provide GeoTiff and/or other file formats ? • Who will perform hydro-enforcement of DTM? How? Who pays? • Who will filter DTM so roads are smooth on orthophotos? How? Who pays?	• Answers to these questions may depend on available funds and contract costs for data acquisition & processing. • If available funds are inadequate to pay for everything as part of major contract, get data acquired and DSM/DTM delivered ASAP; then determine if those responsible for land management pay for hydro-enforcement, etc. if needed for their areas of responsibility.

Funding

Both Intermap Technologies and Fugro EarthData are reluctant to provide cost estimates that could be used against them in a nose-to-nose competition; but both have told Dewberry that they would provide confidential technical and cost proposals when they receive a formal scope of work for acquisition, processing, and licensing.

In summary, there is broad consensus on the conclusions and recommendations in this whitepaper. Funding is the primary remaining issue to be resolved. The main unanswered questions are: How much will this cost, and who is going to pay for it?

Appendices

The four appendices provide additional information to supplement and clarify information in the main body of this report:

Appendix A provides the map of land ownership for patented lands and explains land management responsibilities of each land owner. BLM is in the process of surveying and conveying the remaining lands to the State. Ultimately, the State will own 105 million acres, i.e., 28% of the total acreage, an increase of 4% from their current 24%. After the transfer, the BLM will own 18% of the total acreage, a decrease of 4% from their current 22%.

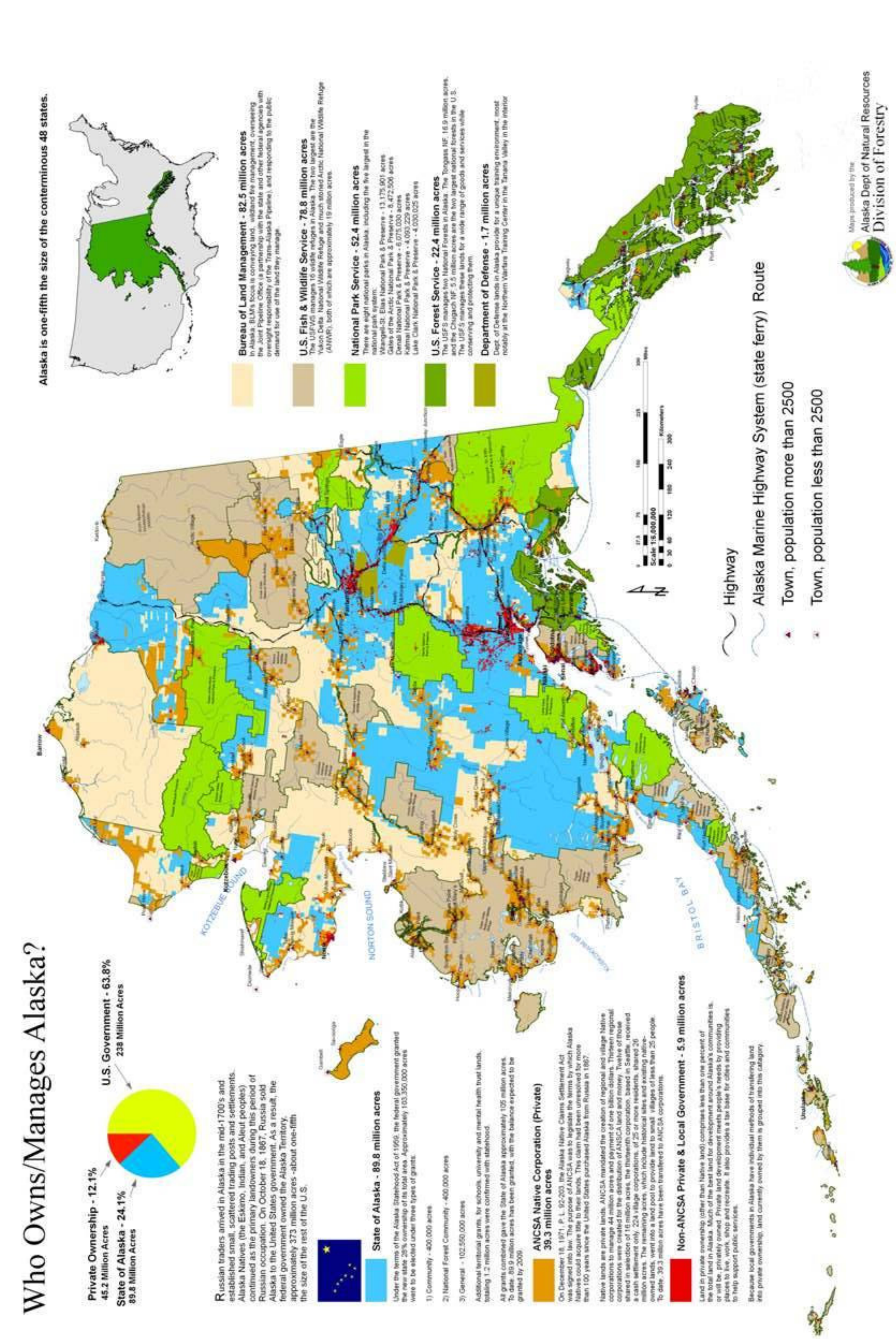
Appendix B provides a review of the severe aviation safety issues caused by the unacceptable deficiencies in the Alaska NED.

Appendix C provides the *DEM User Requirements Menu* as completed by each of the 14 DEM user groups interviewed.

Appendix D provides each of the data provider's answers to the 18 questions asked by Dewberry of each potential satellite and airborne mapping company considered for the SDMI.

Appendix E explains IFSAR artifacts and actions taken by Intermap Technologies and Fugro EarthData to minimize such artifacts.

Appendix A — Alaska Land Ownership/Management



State of Alaska (89.8 million acres, shown as aqua blue on the adjoining map). Under the terms of the Alaska Statehood Act of 1959, the federal government granted the new state 25% ownership of the total area. Approximately 103,350,000 acres were to be elected under three types of grants: 1) Community – 400,000 acres, 2) National Forest Community - 400,000 acres, 3) General – 102,550 acres. Additional territorial grants for schools, university and mental health trust lands totaling 1.2 million acres were confirmed with statehood. All grants combined gave the State of Alaska approximately 105 million acres. To date, 89.9 million acres have been granted with the balance expected to be granted by 2009.

Bureau of Land Management (BLM) (82.5 million acres, shown as beige on the adjoining map). In Alaska, BLM's focus is conveying land, wildland fire management, overseeing the Joint Pipeline Office (a partnership with the state and other federal agencies with oversight responsibility of the Trans-Alaska Pipeline), and responsibility to the public demand for use of the land they manage.

U.S. Fish & Wildlife Service (USF&WS) (78.8 million acres, shown as taupe on the adjoining map). The USF&WS manages the wildlife refuges in Alaska. The two largest are the Yukon Delta National Wildlife Refuge and the much storied Arctic National Wildlife Refuge (ANWR), both of which are approximately 19 million acres.

National Park Service (NPS) (52.4 million acres, shown as light green on the adjoining map). NPS manages eight national parks in Alaska including the five largest in the national park system: 1) Wrangell-St. Elias National Park & Preserve (13,175,901 acres); 2) Gates of the Arctic National Park & Preserve (8,472,506 acres); 3) Denali National Park & Preserve (6,075,030 acres); 4) Kamal National Park & Preserve (4,093,229 acres); and 5) Lake Clark National Park & Preserve (4,030,025 acres).

ANCSA Native Corporation (Private) (39.3 million acres, shown as gold on the adjoining map). On December 16, 1971, P.L. 92-200, the Alaska Native Claims Settlement Act (ANCSA) was signed into law. The purpose of the ANCSA was to legislate the terms by which Alaska Natives could acquire title to their lands. This claim had been unresolved for more than 100 years since the United States purchased Alaska from Russia in 1867. Native lands are private lands. ANCSA mandated the creation of regional and village Native corporations to manage 44 million acres and payment of one billion dollars. Thirteen regional corporations were created for the distribution of ANSCA land and money. Twelve of those shared in selection of 16 million acres; the thirteenth corporation, based in Seattle, received a cash settlement only. 224 village corporations, of 25 or more residents, shared 26 million acres. The remaining acres, which include historical sites and existing Native-owned lands, went into a land pool to provide land to small villages of less than 25 people. To date, 39.3 million acres have been transferred to ANCSA corporations.

U.S. Forest Service (USFS) (22.4 million acres, shown as dark green on the adjoining map). The USFS manages two National Forests in Alaska. The Tongass National Forest (16.9 million acres) and the Chugach National Forest (5.5 million acres) are the two largest national forests in the U.S. The USFS manages these lands for a wide range of goods and services while conserving and protecting them.

Non-ANCSA Private and Local Governments (5.9 million acres, shown in red on the adjoining map). Land in private ownership (other than Native land) comprises less than one percent of the total land in Alaska. Much of the best land for development around Alaska's communities is, or will be, privately owned. Private land development meets people's needs by providing places to live, work, shop and recreate. It also provides a tax basis for cities and communities to help support public services.

U.S. Department of Defense (DoD) (1.7 million acres, shown as olive green on the adjoining map). DoD lands in Alaska provide for a unique training environment, most notably at the Northern Warfare Training Center in the Tanana Valley in the interior.

Appendix B — Aviation Safety

Standards for an Electronic Terrain and Obstacle Database (eTOD)

References: The requirements for an Electronic Terrain and Obstacle Database (eTOD), and the standards and guidelines for establishing an eTOD are documented in the following documents published by the International Civil Aviation Organization (ICAO) and endorsed by the Federal Aviation Administration (FAA).

- ICAO International Standards and Recommended Practices, Annex 15, *Aeronautical Information Services*, to the Convention on International Civil Aviation, 12th edition, July 2004.
- ICAO Doc 9881, Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information

Although uncommon in the U.S., the term "aerodrome" is defined as follows by the ICAO: "A defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft." As such, this term includes airfields in Alaska used for the arrival and departure of aircraft.

To satisfy identified user requirements for eTOD data, while taking into account cost-effectiveness, acquisition methods and data availability, the data are to be provided according to four basic coverage areas:

- Area 1 has a coverage over the whole territory of a state or country, including aerodromes/heliports.
- Area 2 covers the established terminal control areas, not exceeding a 45 km radius from the aerodrome reference point (ARP), to coincide with the existing specification for the provision of topographical information on the Aerodrome Obstacle Chart.
- Area 3 covers the area which is within the specified distances from the edges of a defined aerodrome or heliport surface movement area.
- Area 4 is restricted for use only for those runways where precision approach Category II or III operations have been established.

ICAO Doc 9881 provides the minimum user requirements applicable to the origination and publication of terrain data from creation through the entire life cycle of the data. It provides a minimum list of attributes associated with the terrain data and a description of associated errors that may need to be addressed. Any data processing must be accomplished in accordance with known and established quality processes and procedures.

According to Sections 10.3 and 10.4, Chapter 10, of Annex 15 referenced above:

- "A terrain database shall contain digital sets of data representing terrain surface in the form of continuous elevation values at all intersections (points) of a defined grid, referenced to a common datum. A terrain grid shall be angular or linear and shall be of regular or irregular shape. *Note — In regions of higher latitudes, latitude grid spacing may be adjusted to maintain a constant linear density of measurement points."*

- "Sets of electronic terrain data shall include spatial (position and elevation), thematic and temporal aspects for the surface of the Earth containing naturally occurring features such as mountains, hills, ridges, valleys, bodies of water, permanent ice and snow, and excluding obstacles. In practical terms, depending on the acquisition method used, this shall represent the continuous surface that exists at the bare Earth, the top of the canopy or something in-between, also known as "first reflective surface".

- "Terrain data shall be collected according to the areas specified in 10.2, terrain data collection surfaces and criteria specified in Appendix 8, Figure A8-1, and in accordance with the terrain data numerical requirements provided in Table A8-1 of Appendix 8. In terrain databases, only one feature type, i.e., terrain, shall be recorded. Feature attributes describing terrain shall be those listed in Appendix 8, Table A8-3. The terrain feature attributes listed in Table A8-3 represent the minimum set of terrain attributes, and those annotated as mandatory shall be recorded in the terrain database."

- "One obstacle database shall contain a digital set of obstacle data and shall include those features having vertical significance in relation to adjacent and surrounding features that are considered hazardous to air navigation. Obstacle data shall comprise the digital representation of the vertical and horizontal extent of man-made objects. Obstacles shall not be included in terrain databases. Obstacle data elements are features that shall be represented in the database by points, lines or polygons."

Figure B.1 provides an example of a DEM of fixed grid elevations when annotated with obstacle data. This whitepaper addresses only the terrain portion of the eTOD and not the obstacle portion.

Table B.1 specifies the terrain data quality requirements for Area 1 and Area 2.

Table B.2 presents the list of attributes defined to describe terrain data. Attributes that are designated "mandatory" must be recorded. ICAO recommends that "optional" attributes be recorded as well.

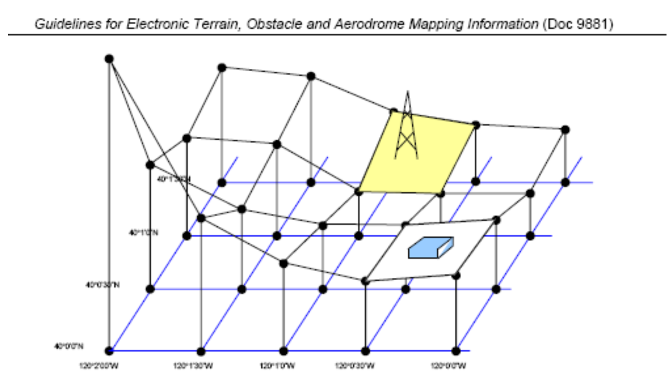


Figure B.1. Example of eTOD data

Table B.1. Comparison of ICAO Area 1 and Area 2 Requirements

ICAO	Area 1 Requirements	Area 2 Requirements
Post Spacing	3-arc-seconds (≈90 meters)	1-arc-second (≈30 meters)
Vertical Accuracy (LE90)	**30 meters**	**3 meters**
Equivalent Contour Interval	**60 meters (200 ft)**	**6 meters (20 ft)**
Vertical Resolution	1 meter	0.1 meter
Horizontal Accuracy (CE90)	50 meters	5 meters
Confidence Level	90%	90%
Compliance Date	November 20, 2008	November 20, 2010

Table B.2. Terrain Attributes

Attribute	Mandatory/Optional
Area of Coverage	Mandatory
Data Source Identifier	Mandatory
Acquisition Method	Mandatory
Post spacing	Mandatory
Horizontal Reference System	Mandatory
Horizontal Resolution	Mandatory
Horizontal Accuracy	Mandatory
Horizontal Confidence Level	Mandatory
Horizontal Position Data	Mandatory
Elevation	Mandatory
Database Units	Mandatory
Elevation Reference	Mandatory
Vertical Reference System	Mandatory
Vertical Resolution	Mandatory
Vertical Accuracy	Mandatory
Vertical Confidence Level	Mandatory
Surface Type	Mandatory
Recorded Surface	Mandatory
Penetration Level	Optional
Known Variations	Optional
Integrity	Mandatory
Date and Time Stamp	Mandatory

Detailed explanation of all terms in Table B.2 are provided in ICAO Doc 9881, section 2.1.

Area 2 requirements officially pertain to the 148 circles shown at Figure 9 in the main body of this report. Unofficially, they should pertain also to the 561 additional Alaska village circles added in Figure B.2 and the 295 state-controlled airfields in Figures B.3 and B.4 because, unlike the lower-48 states, air ambulances must access remote villages and airfields throughout Alaska during times of emergency, regardless of whether the airfield is rated for instrument flight rules (IFR) or visual flight rules (VFR). Road networks are not available for traditional ground evacuation of personnel to hospitals, for example.

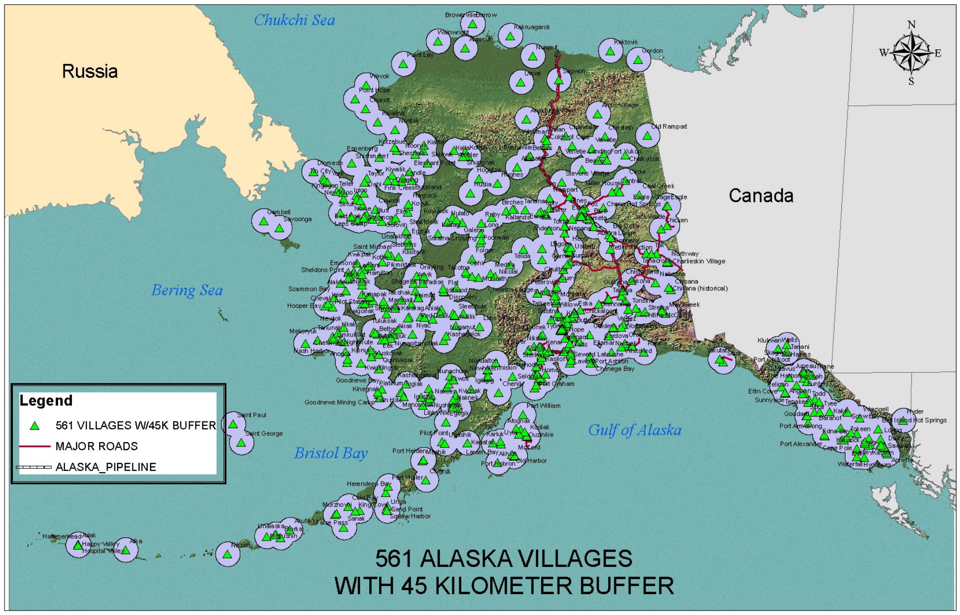


Figure B.2. 561 Alaska villages with 45 Km buffer

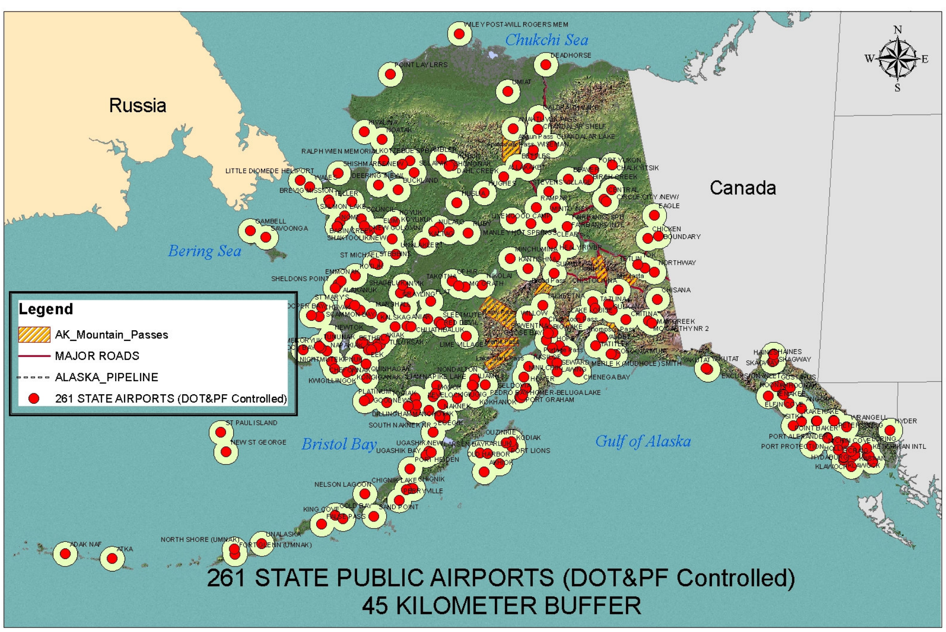


Figure B.3. 261 State public airports (DOT controlled) with 45 Km buffer

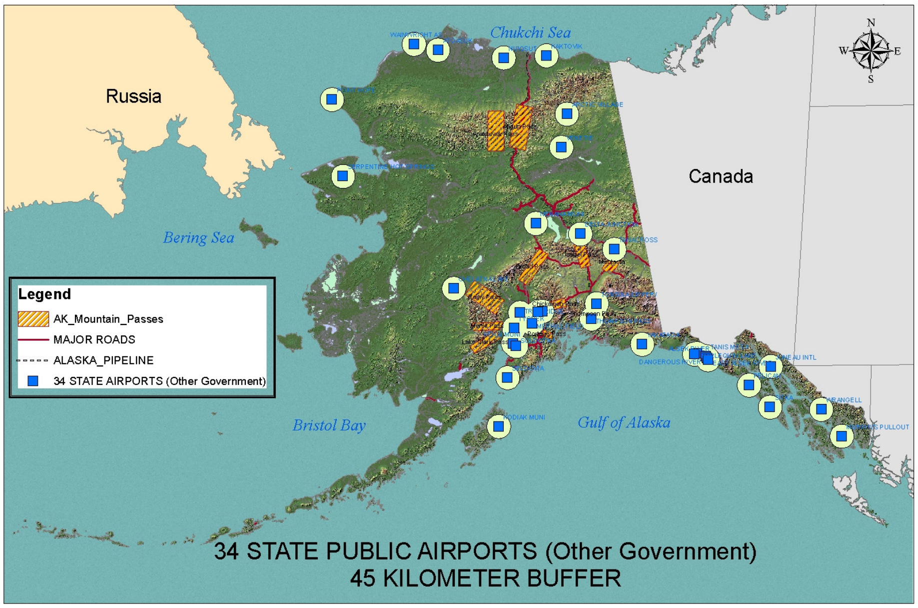


Figure B.4. 34 other State public airports

When these 561 Alaska village airstrips and 295 state public airports are merged with the 148 FAA IFR sites, the total (unofficial) requirements can be seen by the 1,004 circles in Figure B.5.

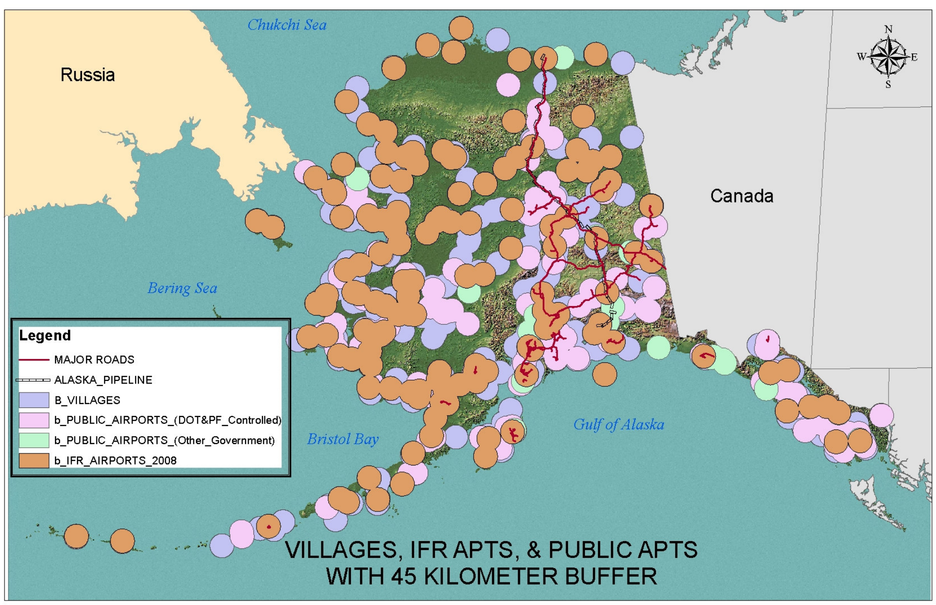


Figure B.5. Alaska villages, AK public airports and FAA IFR sites combined

Alaska's Unique DEM Accuracy Issues

The United States agreed in 2004 on the ICAO standards for terrain mapping and creating an Area 1 compliant database for all of its territory by the 20th of November, 2008 and an Area 2 compliant database for its territory by the 20th of November, 2010. By the end of 2008, the U.S. will fail to meet the Area 1 requirement north of 60° north latitude in Alaska, and the SDMI is the primary initiative to address both Area 1 and Area 2 requirements by 2008 and 2010, respectively.

On August 5, 2008, Dr. David Maune of Dewberry interviewed Mr. George Sempeles of FAA. He is responsible for Cartographic Standards, Aeronautical Information Services, at the Federal Aviation Administration. Mr. Sempeles stated that "there is a serious lack of reliable elevation data in Alaska" and he agreed with concerns raised by the Alaska aviation community. He stated that the area of Alaska north of 60° north latitude does not comply with ICAO Area 1 standards because the Shuttle Radar Topographic Mission (SRTM) did not extend north of the 60th parallel and NED datasets in Alaska are inadequate for basic Area 1 requirements, much less the Area 2 requirements that require DEM 10 times more accurate than for Area 1 requirements. He further indicated that elevation data equivalent to airborne IFSAR (or equivalent data) would be needed statewide to bring Alaska into conformance with Area 2 requirements. He agreed that it makes no sense to have high accuracy elevation data within the Area 2 circles and low accuracy elevation data elsewhere.

When the U.S. is in noncompliance with ICAO standards, the FAA can file a difference with ICAO and advertise such difference in Alaska's Aeronautical Information Plan. However, this would do nothing to address the serious and unique aviation safety issues that pertain only to Alaska.

Whereas most of Alaska has not even been surveyed to meet the Area 1 requirements, motions exist to upgrade the services situation in almost every other state except Alaska to meet Area 2 requirements because of a similar density of airfields. But in other states, they have roads and ground ambulances to reach remote sites during times of emergency; Alaska is never expected to have such a road network and must rely on air transport during times of emergency. This makes Alaska unique. Alaska's dangerous terrain and weather also make it unique. It is understandable that the Alaskan aviator (and even more so the people depending on aviation services) often feels shortchanged and emotional, especially when considering the very high rate of aviation accidents in Alaska.

Aviation is an absolutely essential mode of transportation only in Alaska, because it's the only mode of transportation for most of Alaska's villages. Even the state capitol, Juneau, is inaccessible by road from the remainder of the state. This fact is unique within the United States and must be taken into consideration in plans for the SDMI. This need for adequate and safe aviation is an inherent fact in Alaska's future and definitively not a thing of the past. With the lack of roads and extreme conditions, people depend on general aviation for emergencies, mail, and supplies. Some students even get to school by using General Aviation. With growing communities in remote locations, many of them 500 air miles (over wilderness) away from the next possible tie-in to Alaska's road system, there won't be any reduction in the need for aviation as an essential service. With regards to cost involved, roads to Alaska's remote communities are definitively not even an option in the future. Apart from costs, even small local road projects in Alaska are always troubled legally by land ownership rights (National Parks, State Parks, Native Lands, World Heritage sites, etc.) and even more so, by environmental concerns.

The map at Figure B.6 shows the high density of commercial and general aviation in Alaska for a single year. This flight density diagram illustrates how heavy the traffic is between points. For many years to come, aviation will remain the prime transportation mode in rural Alaska, with flying conditions the most dangerous in the nation.

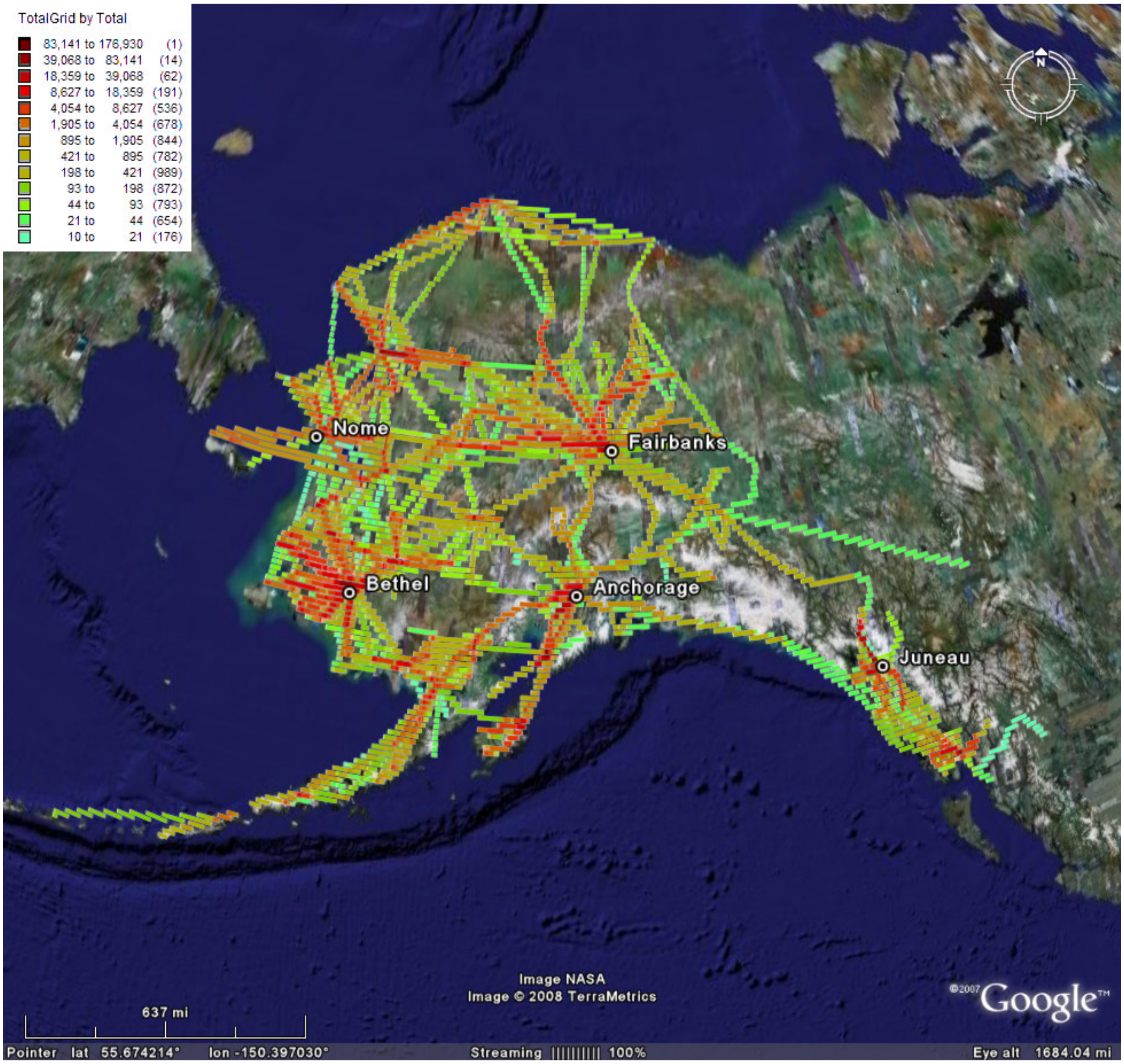


Figure B.6 — Flight density diagram for a single year

USGS mapping in the 1950s is the basis for the National Elevation Dataset (NED) in Alaska. This mapping was performed before the introduction of GPS technology, using World War II (analog) vertical aerial stereo-photogrammetry equipment that had problems with shadows of clouds and terrain, resulting in errors and blunders during stereoscopic work. With the technology available a half-century ago, the USGS Quadrangle maps of 1inch=1 mile were considered to be generally good under the circumstances, but for a variety of reasons the errors are larger in remote areas, far from any survey control. The more remote the area is, the bigger the errors in the positioning of objects and the larger the errors in elevation.

For areas in southern Alaska where Shuttle Radar Topography Mission (SRTM) DEMs exists for the same areas as DEMs from the NED, there are numerous instances where the NED data shows elevations to be between 60 and 140 meters lower than mapped by the SRTM in 2000. Unfortunately, NED data is all that exists for the majority of Alaska, and it is presumed that elevation errors of this magnitude exist throughout the State in remote regions.

The next important fact is the inherent prevailing flight conditions in Alaska. In the other 49 states, even small communities have large, paved runways. This is possible because in the contiguous United States the creation and maintenance of those facilities is cheap, when compared to the costs of them in Alaska. In Alaska the maintenance of paved runways is a financial nightmare due to permafrost and talik (localized areas of unfrozen ground within permafrost). With this fact and the remote locations, paved runways are definitely not an option in almost all locations in Alaska. The typical small unpaved gravel runway in Alaska in turn forces the use of certain types of aircraft, which can operate under such conditions. These are typically piston engine (which use the low lead-containing AVGAS, 100LL) unpressurized aircraft.

The common turbine powered pressurized aircraft (which uses the diesel-like Jetfuel, Jet A1) often seen as a feeder-airliner or executive aircraft in the central USA, cannot operate under the normal Alaskan conditions on an ongoing basis. Much higher landing and takeoff speeds force the use of bigger runways and throw gravel up from the tires at the plane's structure and cause widespread damage. Turbine engines cannot have effective air filters and ingest dust, sand and even gravel, which naturally seriously shortens their service life. Turboprop aircraft often still have inadequate propeller-to-ground clearance and gravel gets sucked into the propeller blades.

"During 2003-2006[11] there were 441 aviation "accidents" in Alaska and 40 fatal accidents. These mostly involved pilots flying under FAR Part 91 (353 accidents) but also included air taxi and commuter operations (79 accidents), larger commercial airlines (5), helicopters lifting external loads (3), and public use aircraft (1). There were 42 accidents that the NTSB determined involved controlled flight into terrain (CFIT). Of these, the majority involved Part 91 flights (31) and the rest were air taxi and commuter revenue generating flights (11). For all types of flying in Alaska, 26% (11/42) of the CFIT accidents resulted in fatalities, while only 7% (29/399) of the nonCFIT accidents were fatal. These data support previous NIOSH research that identified CFIT as the most fatal type of crash for Alaska air taxi and commuter operations. That research found that CFIT accidents were 12-times more likely to result

[11] The data used for the aviation accident summaries are from the National Transportation Safety Board, Aviation Accident Database, as downloaded 1 Jan 2008 by the Aviation Safety in Alaska Project Officer, National Institute for Occupational Safety and Health, CDC, 4230 University Drive, Suite 310, Anchorage, AK 99508. Data was included for 2003-2006 since the database doesn't have complete CFIT data for earlier years, and the final reports aren't in for many accidents in 2007.

On the track from Fairbanks to Kobuk, AK, there is a mountain that is more than 1000 feet higher than in the sectional aeronautical map, and it is depicted displaced by more than 2 nautical miles E-W.

Wolverine Mountain (149° 50' W, 65° 20' N), unnamed peak (at 151° 45 W, 65° 46'), and Angutikada Peak (155° 50 W, 66° 45' N) are "way off" in the sectionals.

Sample of NED database blunders:

Hill 3870, Seward Peninsula, an AlasCom repeater site, is mapped at 3870 ft; should be 4250 ft.

Kongarok Mountain, Seward Peninsula, south of Serpentine Hot Springs, is 600 feet higher than mapped in the NED.

A peak in Galbraith Camp Area, Brooks Range, near Head of Twin Glaciers, is mapped at 7700 ft; should be 8200 ft.

Where both NED and SRTM data are available for comparison, the NED is dangerously lower in peak elevations, per these examples from the Tongass National Forest:

135° 0' 37" W, 59° 4' 16" N, NED elevations for the ridgeline are between 60 and 140 meters lower than the SRTM.

134° 59' 49" W, 59° 7' 6" N, NED elevations for the ridgeline are approximately 100 meters lower than the SRTM, and the depressions are absent.

135° 0' 35" W, 59° 8' 47" N, the NED elevations around the mountain top are approximately 90 meters too low.

in a fatality than a nonCFIT accident, and that CFIT accidents are much more likely to occur in instrument meteorological conditions." Ref: National Institute for Occupational Safety and Health, CDC, 23rd Jan 2008. Figure B.7 shows the location of Alaska aviation accidents between 2001 and 2005. Those shown with red were fatal accidents, those in yellow were non-fatal.

The crashes that actually kill people are what matters, and the crashes that kill people are the CFIT (Controlled Flight into Terrain) crashes in IFR conditions; those are avoidable with today's technology, i.e., D-GPS, moving map, and an accurate eTOD terrain database. Inaccurate terrain data lures pilots into a false sense of security, causing CFIT. During 2003-2006, in only 3 years, there were 42 accidents that the NTSB determined involved controlled flight into terrain (CFIT).

Perfectly safe and legal marginal VFR and IFR procedures in the contiguous United States are legal but inherently unsafe in Alaska due to the old inaccurate Terrain data. Yet in Alaska those procedures are the only possible way there is to serve the remote Communities, and those procedures are the only possible way in Alaska to fly back to any airport in the event of emergency-return-to-base-navigation when the weather turns too bad to fly to the original destination.

The typical piston-powered-not-pressurized Alaskan aircraft can deal with the short gravel runways, but has the drawback of the impracticality of high altitude flights and steep climb-outs over the mountains. The need to fly low through mountain passes or in altitudes where there are peaks present is thus an inherent part of aviation in Alaska. This in turn, makes the urgent need for a decent eTOD (Electronic Terrain *and* Obstacle Database) in Alaska so serious. In Alaska it is common for the pilot to encounter vast differences between sectional aeronautical maps and the reality of the terrain beneath. **See examples in adjoining sidebar.**

Such blunders would not be acceptable in the contiguous United States, and it does not exist in other states since the SRTM mission that resolved such DEM issues south of 60° north latitude. Most likely such vast blunders did get corrected elsewhere even long before the SRTM data was available. Pilots' complaints are answered with "yes, there was suspicion about it, but there is no money to do anything about it". Naturally no aircraft flies into a mountain in good weather, but mountain obscuration and bad weather and IFR conditions are the nature of Alaska, much more than they are the nature in the contiguous United States. Because Alaska has more mountains and higher mountains, mountain ranges and passes are the nature of flight-routes in Alaska. The long winters' darkness is unique within the United States too; no other state has to cope with that.

Alaska's high rate of aviation accidents has persisted for decades. According to FAA documents at http://www.faa.gov/about/office_org/headquarters_offices/arc/programs/capstone, "Alaska has approximately 10% of the nation's air carriers or commercial operators. Historically, this 10% generates approximately 35% of the nation's air carrier / commercial operator accidents. During the three year period from 1994 to 1996, there were 112 (accidents) involving Alaska's air carrier /commercial operator's - a study of those accidents indicated that 38% might have been avoided by availability of information in the cockpit of the type provided by modern equipment" … such as terrain information for safe operation in areas where no IFR procedures exist. A decade later, the accident rate is similar; Figure B.7 plots the location and severity of aviation accidents in Alaska between 2001 and 2005.

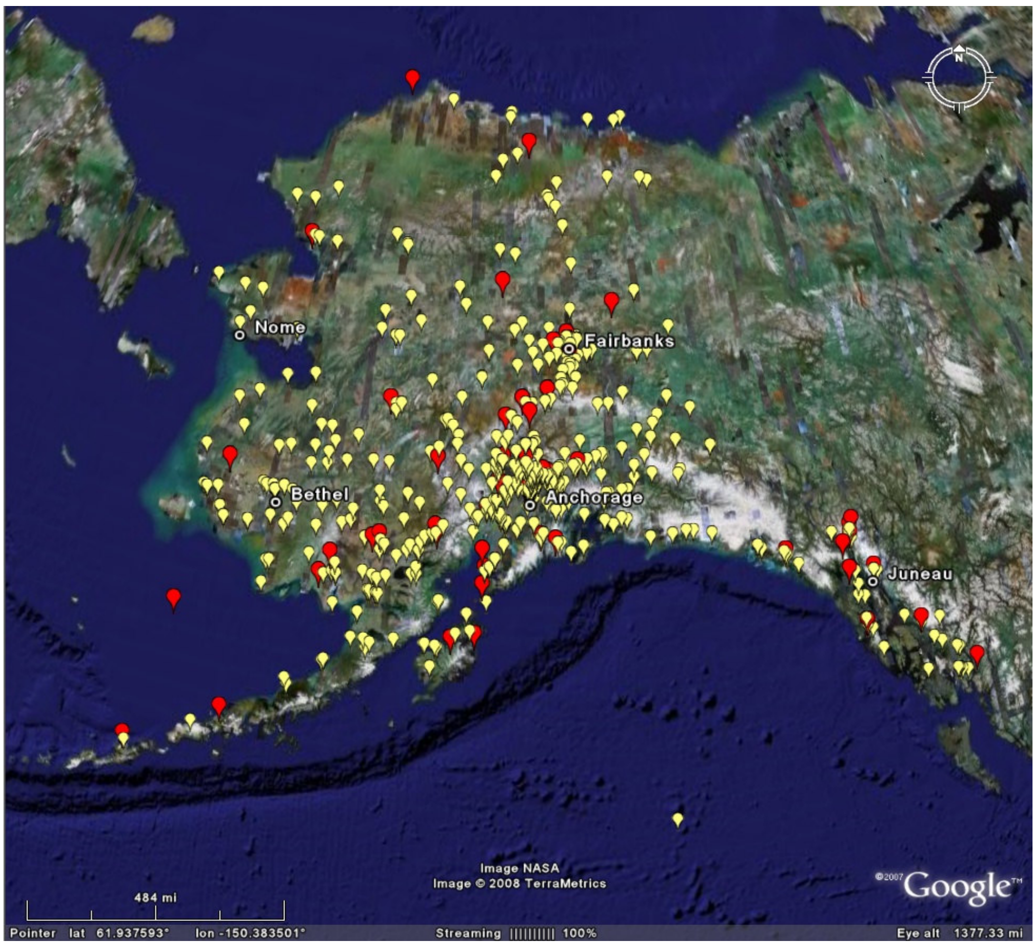


Figure B.7 — Location of fatal (red) and non-fatal (yellow) aviation accidents, 2001 to 2005

Figure B.8 shows a Visual Flight Rule (VFR) Terminal Area Chart for which mid-accuracy elevation data (equivalent to 20-ft contour accuracy) would be required within a Terminal Control Area or within the 45 Km radius airfield circle, whichever is smaller, when landing under Instrument Flight Rule (IFR) conditions. For most airfields in Alaska, the 45 Km circles will apply. Under emergency conditions, e.g., medical air evacuation, Alaska pilots regularly land at airfields in Alaska that are not official FAA IFR sites, adding 856 other airfields (for practical, humanitarian purposes) to the 148 FAA IFR sites for which accurate eTOD data are needed so that the real total is 1,004 such airfields throughout Alaska.

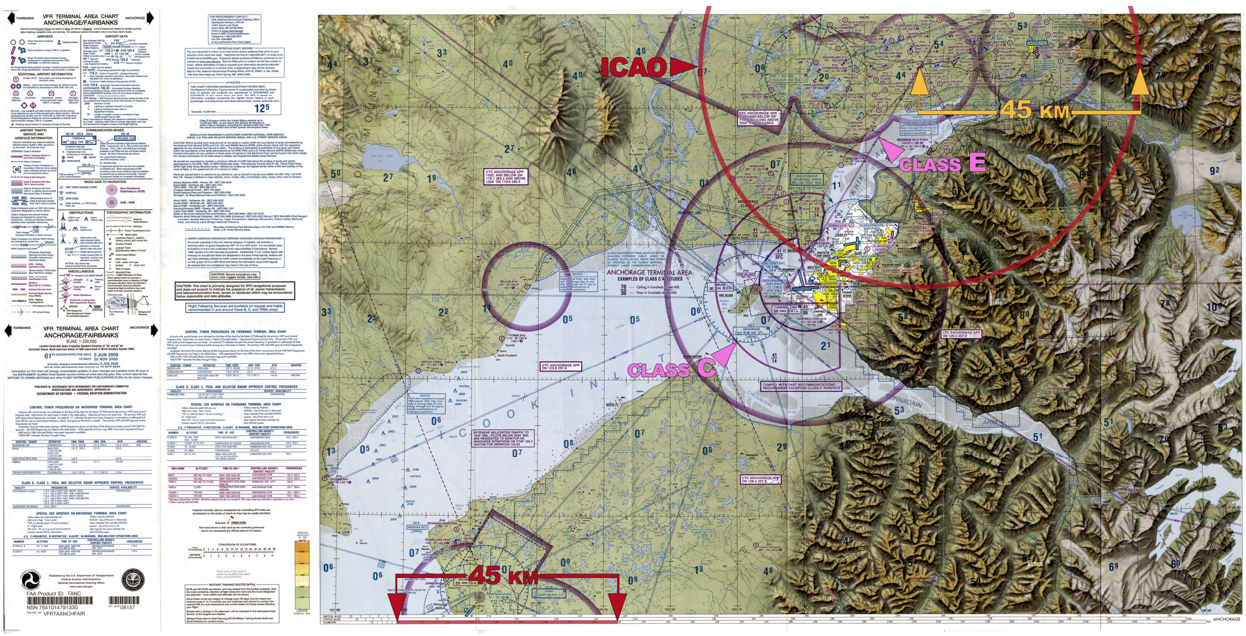


Figure B.8. VFR Terminal Area Chart showing red circle within which elevation data with 20-ft contour accuracy would be required when landing under IFR conditions at the Wasilla, Alaska airport.

Appendix C —DEM User Requirements Menu Choices

The following pages show the choices as finalized by the various DEM user groups interviewed by Dewberry. Approximately half of these requirements were changed after participation in the Alaska DEM workshop where user requirements were "scrubbed" to convert "wish lists" into true requirements. Some of these choices are project-specific and not statewide.

Requirements from two federal agencies (USGS and NOAA) were received after the Alaska DEM workshop and were not discussed during that workshop. Both introduce interesting perspectives on statewide requirements.

- The USGS indicates that elevation data with 10-ft contour accuracy and 10-meter post spacing would be ideal. This would be consistent with desires to have the entire country mapped with the best available elevation data with 1/3-arc-second spacing, i.e., approximately 10 meters at the equator. [As a rule-of-thumb, 10-ft contour accuracy is appropriate for 10-meter post spacing.] However, recognizing that LiDAR data for all of Alaska would not be affordable, USGS indicates that its next preference would be for 20-ft equivalent contour accuracy from IFSAR data, if licensing issues can be resolved. [Airborne IFSAR can achieve 10-ft contour accuracy in flat areas, but lesser accuracies with steeper slopes.] USGS indicated that it preferred the data to be delivered in Alaska Albers Equal Area projection, a surprise choice when considering that USGS converts data to geographic coordinates when placed in the NED. Whereas orthometric heights are normally preferred elsewhere, USGS recognized that ellipsoid heights might be preferred as a special case in Alaska where geoid models cannot produce reliable orthometric heights.

- NOAA's Coastal Services Center indicates that it needs LiDAR data, with 2-ft equivalent contour accuracy, for flat/coastal areas of Alaska (estimated at 142,450 Km^2) because of climate change, coastal erosion, and other issues that impact NOAA's ability to serve the citizens of Alaska. This would be a tremendous undertaking that would appear to be a special project requiring special project-specific funding.

User Group 1: Alaska Aviation — DEM User Requirements Menu

Project Area **STATEWIDE** Identify selected area of interest if not statewide: / **International**

General Surface Description

Elevation Surface (choose one or more)
- ☒ Digital surface model (DSM) top reflective surface
- ☒ Digital terrain model (DTM) bare earth terrain
- ☐ Other ________________

Elevation Type (choose one or more)
- ☐ Orthometric height
- ☒ Ellipsoid height
- ☐ Other ________________

Data Model Types (choose one or more) * Designate either feet or meters
- ☐ Mass Points
- ☒ Grid (post spacing = _10 M__ feet/meters) *
- ☐ Contour Lines
- ☒ Breaklines
- ☐ Grid (post spacing = ___ arc-seconds)
- ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
- ☒ Optical
- ☒ IFSAR
- ☒ Lidar

Vertical Accuracy at 95% Confidence Level
- ☐ Other (including metric options)
- ☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
- ☒ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
- ☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
- ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
- ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
- ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
- ☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
- ☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
- ☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
- ☒ Other 1:12,000 and better as per FAA Regs for facilities, approaches and obstacles

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
- ☒ Tested 5.96ft (meters/ft) vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
- ☒ Tested 45.6ft (meters/ft) horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
- ☒ Hydro-enforcement
- ☒ Hydro-conditioning
- ☒ Vegetation
- ☒ No data areas (Voids)

Horizontal Datum (choose one)
- ☒ NAD 83 (default)
- ☐ NAD 27 (obsolete)

Vertical Datum (choose one)
- ☒ NAVD 88 (default)
- ☐ NGVD 29 (obsolete)

Geoid Model (choose one)
- ☐ GEOID03
- ☒ GEOID06

Coordinate System (choose one)
- ☒ UTM zone
- ☐ State Plane
- ☒ Geographic
- ☐ Albers Equal Area
- ☐ Other _____

USGS / FAA STANDARDS

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
- ☐ Elevations to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
- ☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
- ☐ Decimal degrees to ___ decimal places or ☐ DDDMMSS to ___ decimal places

USGS / FAA STANDARDS

DEM File Format(s)
- ☐ ASCII Float Grid
- ☐ ESRI Binary Float Grid
- ☐ Other
- ☒ GeoTiff
- ☐ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) ______ Mb Other __________

USGS / FAA STANDARDS

Tile Size

Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☐ Other

USGS / FAA STANDARDS

Data Licensing Aviation minimum expectation is to have source data available and derived products freely distributed for simulation, embedded navigation aids etc .
Vendor Specific Solutions Multiple Vendors may be able to meet given specifications, several vendor may be able to produce higher end value added products for aviation industry, avionics, facilities and infrastructure management.

User Group 2: Alaska DCCED — DEM User Requirements Menu

Project Area and Applications Rural Alaska Community Maps, suitable for road and sanitation design, airport, and other civil engineering. Maps also display flood of record.

General Surface Description

Elevation Surface (choose one or more)
☐ Digital surface model (DSM) top reflective surface
☒ Digital terrain model (DTM) bare earth terrain
☐ Other ________________

Elevation Type (choose one or more)
☒ Orthometric height
☐ Ellipsoid height
☐ Other ________________

Data Model Types (choose one or more) * Designate either feet or meters
☒ Mass Points ☐ Grid (post spacing = ___ feet/meters) * ☒ Contour Lines
☐ Breaklines ☐ Grid (post spacing = ___ arc-seconds) ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
☒ Optical, Airborne ☐ IFSAR ☐ Lidar

Vertical Accuracy at 95% Confidence Level ☒ Other (2 foot contour accuracy)
☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft) ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft) ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft) ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
☐ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products) ☒ Other (3 foot)

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
☒ Tested 2 ft vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
☒ Tested 3 ft horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors **not applicable**
☐ Hydro-enforcement ☐ Hydro-conditioning ☐ Vegetation
☐ No data areas (Voids)

Horizontal Datum (choose one) **Vertical Datum** (choose one) **Geoid Model** (choose one)
GEOID96 and GEOID03 have been used
☒ NAD 83 (default) ☒ NAVD 88 (default) ☒ GEOID03
☐ NAD 27 (obsolete) ☐ NGVD 29 (obsolete) ☐ GEOID06

Coordinate System (choose one) ☐ UTM zone ☒ State Plane
☐ Geographic ☐ Albers Equal Area ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
☐ Elevations to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
☒ Northings/Eastings to 2 decimal places ☒ U.S. Survey Feet ☐ Meters
☐ Decimal degrees to ___ decimal places or ☐ DDDMMSS to ___ decimal places

DEM File Format(s)
☐ ASCII Float Grid ☐ ESRI Binary Float Grid ☒ Other AutoCAD
☐ GeoTiff ☐ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) 500 Mb Other __________

Tile Size
Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☒ Other 10,000' x 15,000'

User Group 3: Alaska DGGS — DEM User Requirements Menu

Project Area Statewide NOTE: Requirements are color-coded, red for 2' contour accuracy, green for 10' contour accuracy, black for 100' contour accuracy

User applications for this data

Interpretation for geologic mapping
Generate orthophotos using digital aerial photographs
3-D landscape drapes for visual analysis and display
Slope/aspect analysis
Neotectonics/active faulting studies
Bedrock structural analysis
Generate topographic base maps (contour lines)
Generate topographic cross-section lines
Lahar modeling
Tsunami modeling
Volumetric analysis
Geophysical overlays for analysis

General Surface Description

Elevation Surface (choose one or more)
☐ Digital surface model (DSM) top reflective surface
☒ Digital terrain model (DTM) bare earth terrain
☐ Other ______________

Elevation Type (choose one or more)
☒ Orthometric height
☐ Ellipsoid height
☐ Other ______________

Data Model Types (choose one or more) * Designate either feet or meters
☐ Mass Points ☒ Grid (post spacing = ≤30 meters) * ☒ Contour Lines
☐ Breaklines ☐ Grid (post spacing = ___ arc-seconds) ☒ Concurrent imagery (Multispectral, stereo overlap preferred)

Preferred Source (choose one and explain reason for preference) **No preference, all have pros/cons**
☐ Optical ☐ IFSAR ☐ Lidar

Vertical Accuracy at 95% Confidence Level
☒ 2' contour equivalent
☒ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
☒ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
☒ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
☒ $Accuracy_r$ = 20 ft or 7 m

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
☒ Tested 5 (2) meters vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
☒ Tested 10 (5) meters horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
☐ Hydro-enforcement ☐ Hydro-conditioning ☐ Vegetation
☐ No data areas (Voids)

Horizontal Datum (choose one)
☒ NAD 83 (default)
☐ NAD 27 (obsolete)

Vertical Datum (choose one)
☒ NAVD 88 (default)
☐ NGVD 29 (obsolete)

Geoid Model (choose one)
☐ GEOID03
☒ GEOID06 (if improvement over GEOID03)

Coordinate System (choose one)	☐ UTM zone	☐ State Plane	
☒ Geographic	☐ Albers Equal Area	☐ Other _____	
Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ			
☒ Elevations to 2 decimal places	☐ U.S. Survey Feet	☒ Meters	
☐ Northings/Eastings to ___ decimal places	☐ U.S. Survey Feet	☐ Meters	
☒ Decimal degrees to 5 (6) decimal places or	☐ DDDMMSS to ___ decimal places		
DEM File Format(s)			
☐ ASCII Float Grid	☐ ESRI Binary Float Grid	☐ Other	
☒ GeoTiff	☒ .IMG (ERDAS Imagine)		
File Size	(Maximum file size, if applicable) ______ Mb	Other _________	
Tile Size			
Tile Size, if applicable	☐ _____ ft x _____ ft	☐ _____ meters x _____ meters	☐ Other

User Group 4: Alaska DNR — DEM User Requirements Menu

Project Area Identify selected area of interest if not statewide: Statewide 7/28 Update

General Surface Description

Elevation Surface (choose one or more)
- ☒ Digital surface model (DSM) top reflective surface
- ☐ Digital terrain model (DTM) bare earth terrain
- ☐ Other ________________

Elevation Type (choose one or more)
- ☐ Orthometric height
- ☒ Ellipsoid height
- ☐ Other ________________

Data Model Types (choose one or more) * Designate either feet or meters
- ☐ Mass Points
- ☒ Grid (post spacing = _20-30m__ meters) *
- ☐ Contour Lines
- ☐ Breaklines
- ☐ Grid (post spacing = ___ arc-seconds)
- ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
- ☒ Optical
- ☐ IFSAR
- ☐ Lidar

Optical is lowest cost for statewide solution to meet requirements of controlling imagery at 1:24,000 NMAS IFSAR and LIDAR both needed and used for project specific applications. Statewide IFSAR estimates run ~$60-$70 MM. Contours can be derived on a project specific basis following delivery of the new DEM.

Vertical Accuracy at 95% Confidence Level
- ☐ Other (including metric options)
- ☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
- ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
- ☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
- ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
- ☒ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
- ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

DNR generates and responds to projects throughout the state; medium resolution scales are needed for project planning and permitting. Detailed engineering level data (eg.LIDAR) may be required, and are provided to DNR at the expense of the project applicant. Some projects will require higher level detail.

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
- ☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
- ☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
- ☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
- ☐ Other

SDMI broad objective is to create an ortho-photo basemap that can meet or exceed 1:24,000 NMAS. If rule of thumb is DEM can be 2x less resolution than imagery for adequate control, the 95' product line may meet statewide objective. Reference: *"Error Propagation in Ortho-rectified Imagery Using the Co-linearity Condition,"* Kari Craun, USGS, Reston, VA.

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
- ☐ Tested ___ (meters/ft) vertical accuracy or ☒ Compiled to meet ~10 (meter) vertical accuracy
- ☐ Tested ___ (meters/ft) horizontal accuracy or ☒ Compiled to meet ~20 meters horizontal accuracy

We can perform testing independent of the contractor at a lower total cost, we would receive the compiled product from the vendor.

Surface Treatment Factors (optional – explain with separate text)
- ☒ Hydro-enforcement
- ☐ Hydro-conditioning
- ☐ Vegetation
- ☐ No data areas (Voids)

DNR-Land Records Information Section (LRIS) is a frequent source of decision support map products for senior managers. The project model must be logically consistent with the policy maker's view of the environment. Therefore proper treatment of hydrography is important when including elevation data as part of the decision support document. For general mapping purposes (e.g. display the alternative gas line routes for the Governor to present), the present Alaska NED is adequate.

Horizontal Datum (choose one)
- ☒ NAD 83 (default)
- ☐ NAD 27 (obsolete)

Vertical Datum (choose one)
- ☒ NAVD 88 (default)
- ☐ NGVD 29 (obsolete)

Geoid Model (choose one)
- ☐ GEOID03
- ☐ GEOID06

Not sure which geoid model NGS uses for AK, we do know the geoid model is particularly sparse for the state and our opportunities to generate orthometric heights via GPS technologies are limited.

Coordinate System (choose one) ☐ UTM zone ☐ State Plane
☒ Geographic ☐ Albers Equal Area ☐ Other _____
Geographic is the preference, double precision coordinates. 10 UTM Zones in Ak and 12 State Plane Zone in AK make handling data in these coordinate systems cumbersome. Albers is 'Alaska Albers', a variation of standard Albers and has been registered with EPSG.

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
☒ Elevations to _0__ decimal places ☒ U.S. Survey Feet ☐ Meters
☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
☒ Decimal degrees to _5_ decimal places or ☐ DDDMMSS to ___ decimal places

DEM File Format(s)
☐ ASCII Float Grid ☐ ESRI Binary Float Grid ☐ Other
☒ GeoTiff ☐ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) ______ Mb Other _________

Tile Size
Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☐ Other

The DNR Land Records Information Section (LRIS) builds and maintains the DNR on-line transaction processing systems in support of department business units. LRIS also provides decision support documents, typically in the form of maps, to policy makers and others. The section maintains the centralized DNR databases, including the Oracle Spatial database of state land ownership and use. Interactive GIS is provided via Alaska Mapper which accesses the full UAF GINA repository via the Web Mapping Services protocol (WMS). LRIS also provides central IT services to a staff of 880. DNR is incorporating location based services to the transaction processing engines as part of the modernization effort.

DNR LRIS primarily uses Alaska NED-derived DEMs for two purposes. First LRIS uses the derived products of hillshade, contours, slope, and aspect as part of the decision support documents associated with permits, leases, sales, easements, etc. Decision support map scales typically span 1:24,000 to 1:2,500,000, and vertical accuracy requirements are equivalent to 40-foot contours. State status plats, a core LRIS product line depicting the disposition of state lands, range from 1:6,000 to 1:24,000 scale. Second, LRIS uses best available DEMs, through contractors, to control imagery acquired from satellite vendors. Most recently LRIS acquired Ortho-imagery of Chugach State Park (east of Anchorage) from Quickbird via the local vendor eTerra.

On-line customers frequently use the USGS raster images as a backdrop to their queries, for example, the display of state and federal mining claims against USGS basemaps; or the NOAA nautical charts for coastal applications. The Alaska NED has been demonstrated to be unusable for many of its intended DNR applications.

Richard McMahon, Section Chief, 907.269.8836 Frank Wallis, GIS Manager, 907.269.8847

User Group 5: Alaska DOT — DEM User Requirements Menu

Project Area and Applications Roadway corridors and villages. DOT needs 10-ft contour accuracy for general planning, and 4-ft contour accuracy for remote design purposes. DOT also supports hundreds of airfields statewide that need accurate DSMs for flight paths.

General Surface Description

Elevation Surface (choose one or more)
☒ Digital surface model (DSM) top reflective surface
☒ Digital terrain model (DTM) bare earth terrain
☐ Other _______________

Elevation Type (choose one or more)
☒ Orthometric height
☐ Ellipsoid height
☐ Other _______________

Data Model Types (choose one or more) * Designate either feet or meters
☒ Mass Points ☒ Grid (post spacing = 30 feet/meters) * ☐ Contour Lines
☐ Breaklines ☐ Grid (post spacing = ___ arc-seconds) ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
☒ Optical ☐ IFSAR ☐ Lidar Accuracy

Vertical Accuracy at 95% Confidence Level
☒ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
☒ Other (4' contour equivalent for remote design)
☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
☐ Other

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
☐ Tested ___ (meters/ft) vertical accuracy or ☒ Compiled to meet __6_ (meters/ft) vertical accuracy
☐ Tested ___ (meters/ft) horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
☒ Hydro-enforcement ☐ Hydro-conditioning ☐ Vegetation
☐ No data areas (Voids)

Horizontal Datum (choose one)
☒ NAD 83 (default)
☐ NAD 27 (obsolete)

Vertical Datum (choose one)
☒ NAVD 88 (default)
☐ NGVD 29 (obsolete)

Geoid Model (choose one)
☐ GEOID03
☒ GEOID06

Coordinate System (choose one) ☐ UTM zone ☒ State Plane
☐ Geographic ☒ Alaska Albers Equal Area ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
☐ Elevations to 2 decimal places ☒ U.S. Survey Feet ☐ Meters
☐ Northings/Eastings to 2 decimal places ☒ U.S. Survey Feet ☐ Meters
☐ Decimal degrees to __ decimal places or ☒ DDDMMSS to 3 decimal places

DEM File Format(s)
☐ ASCII Float Grid ☐ ESRI Binary Float Grid ☐ Other
☒ GeoTiff ☐ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) 100 Mb Other _________

Tile Size
Tile Size, if applicable ☒ 50 ft x 50 ft ☐ _____ meters x _____ meters ☐ Other

User Group 6: Alaska University — DEM User Requirements Menu

Project Area and Applications DSMs and/or DTMs are used for orthorectification of digital images; arctic research; atmospheric sciences and weather forecasting; forestry and vegetation analyses; hydrology analyses; geology analyses; and diverse studies such as coastal erosion, rates of erosion, subsidence, and sea level change. Requirements below generally pertain to selected project areas, and not statewide.

General Surface Description

Elevation Surface (choose one or more)
- ☐ Digital surface model (DSM) top reflective surface
- ☒ Digital terrain model (DTM) bare earth terrain
- ☐ Other ______________

Elevation Type (choose one or more)
- ☒ Orthometric height
- ☐ Ellipsoid height
- ☐ Other ______________

Data Model Types (choose one or more) * Designate either feet or meters
- ☒ Mass Points ☐ Grid (post spacing = ___ feet/meters) * ☐ Contour Lines
- ☒ Breaklines ☐ Grid (post spacing = ___ arc-seconds) ☒ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
- ☐ Optical ☐ IFSAR ☐ Lidar

Vertical Accuracy at 95% Confidence Level ☒ Other 2', 4', 10' 30', 50' for different application
- ☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft) ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
- ☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft) ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
- ☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft) ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
- ☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
- ☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
- ☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
- ☐ Other

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
- ☐ Tested ___ (meters/ft) vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
- ☐ Tested ___ (meters/ft) horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
- ☐ Hydro-enforcement ☐ Hydro-conditioning ☐ Vegetation
- ☐ No data areas (Voids)

Horizontal Datum (choose one)
- ☒ NAD 83 (default)
- ☐ NAD 27 (obsolete)

Vertical Datum (choose one)
- ☒ NAVD 88 (default)
- ☐ NGVD 29 (obsolete)

Geoid Model (choose one)
- ☐ GEOID03
- ☐ GEOID06

Coordinate System (choose one) ☐ UTM zone ☐ State Plane
- ☒ Geographic ☐ Albers Equal Area ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
- ☐ Elevations to ___ decimal places ☐ U.S. Survey Feet ☒ Meters
- ☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
- ☒ Decimal degrees to ___ decimal places or ☐ DDDMMSS to ___ decimal places

DEM File Format(s)
- ☒ ASCII Float Grid ☐ ESRI Binary Float Grid ☐ Other
- ☒ GeoTiff ☒ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) ______ Mb Other __________

Tile Size

Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☐ Other

User Group 7: BLM Alaska — DEM User Requirements Menu

Project Area **STATEWIDE** Identify selected area of interest if not statewide: ____________

General Surface Description

Elevation Surface (choose one or more)
- ☒ Digital surface model (DSM) top reflective surface
- ☒ Digital terrain model (DTM) bare earth terrain
- ☐ Other ______________

Elevation Type (choose one or more)
- ☐ Orthometric height
- ☒ Ellipsoid height
- ☐ Other ______________

Data Model Types (choose one or more) * Designate either feet or meters
- ☐ Mass Points
- ☒ Breaklines
- ☒ Grid (post spacing = _10 M__ feet/meters) *
- ☐ Grid (post spacing = ___ arc-seconds)
- ☐ Contour Lines
- ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
- ☐ Optical
- ☒ IFSAR
- ☐ Lidar

Vertical Accuracy at 95% Confidence Level
- ☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
- ☒ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
- ☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
- ☐ Other (including metric options)
- ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
- ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
- ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
- ☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
- ☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
- ☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
- ☐ Other

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
- ☒ Tested 11.9ft (meters/ft) vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
- ☒ Tested 45.6ft (meters/ft) horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
- ☒ Hydro-enforcement
- ☐ Hydro-conditioning
- ☐ Vegetation
- ☒ No data areas (Voids)

Horizontal Datum (choose one)
- ☒ NAD 83 (default)
- ☐ NAD 27 (obsolete)

Vertical Datum (choose one)
- ☒ NAVD 88 (default)
- ☐ NGVD 29 (obsolete)

Geoid Model (choose one)
- ☐ GEOID03
- ☒ GEOID06

Coordinate System (choose one)
- ☒ Geographic
- ☐ UTM zone
- ☒ Albers Equal Area
- ☐ State Plane
- ☐ Other _____

DEFER TO USGS STANDARD

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
- ☐ Elevations to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
- ☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
- ☐ Decimal degrees to ___ decimal places or ☐ DDDMMSS to ___ decimal places

DEFER TO USGS STANDARD

DEM File Format(s)
- ☐ ASCII Float Grid
- ☒ GeoTiff
- ☐ ESRI Binary Float Grid
- ☐ .IMG (ERDAS Imagine)
- ☐ Other

File Size (Maximum file size, if applicable) ______ Mb Other _________

DEFER TO USGS STANDARD

Tile Size

Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☐ Other

DEFER TO USGS STANDARD

Data Licensing BLM's preference is for public domain licensing of any and all data acquired in this effort.
Vendor Specific Solutions We acknowledge that multiple vendors may have solutions in this effort.

BLM Mapping applications that require 20 foot contour vertical accuracies:

- Floodplain management; especially in coastal areas.
- Management of wetlands and other ecologically sensitive flat areas. This is significant along Alaska's North Slope and the Yukon – Kuskoquim Delta areas, and designated Wild and Scenic River areas.
- Existing and potential oil and gas infrastructure areas, especially along proposed natural gas line routes, both intrastate and instate.
- Support to Cadastral Surveys in accurately delineating meander-lines for lakes, rivers and coastlines. BLM has the responsibility to survey and patent land selected under the Alaska Native Claims Settlement Act (ANCSA) and the Alaska Statehood Act. As of 5/29/2008 the status[12] of this workload was:
    - ANCSA (millions of acres)
        - Total Entitlement 45.6
        - Patented (survey complete/final title document issued) 24.4
        - Transferred by Interim Conveyance (before final survey) 14.1
        - Remaining Entitlement 7.1
    - State (millions of acres)
        - Total Entitlement 104.5
        - Patented (survey complete/final title document issued) 55
        - Transferred by Tentative Approval (before final survey).......... 42
        - Remaining Entitlement 7.5

  The acreages requiring survey and remaining entitlement (ANCSA 21.2 million acres and State 49.5 acres) are the areas that require accurate digital terrain model information. Meander-line data is photogrammetically added to cadastral survey plats. Elevation accuracy is critical to this process.
- Contour accuracy in areas of steep terrain. BLM as well as other agencies perform field operations in light aircraft and helicopters in steep, mountainous terrain.
- Delineating rights of ways and easements, especially accurately delineating ANCSA 17b easements
- Delineation of hard rock and placer mining planning, operations, and reclamation.
- Base maps for wild land fire suppression

[12] Source BLM Conveyance Report and Summary 3rd Quarter, 2008 dated 5/29/2008.

User Group 8: DOD — DEM User Requirements Menu

Project Area and Applications DOD in Alaska needs DTED 4 (3-5 meter DEM, 20-ft contour accuracy) for military training throughout the state. This activity includes troop exercises within the 1.5 million acres of Army owned land, joint training within restricted airspace, and aerial activity within the 200,000 square miles of Military Operations Areas (MOAs). DTED 4 is especially important for UAV and rotary wing aircraft which are playing an increasing role in the training activity in Alaska. Outside military airspace, 20-ft contour accuracy DEMs are an essential tool for rotary wing operators performing search-and-rescue and medivac operations throughout the state.

General Surface Description

Elevation Surface (choose one or more)
☒ Digital surface model (DSM) top reflective surface
☒ Digital terrain model (DTM) bare earth terrain

Elevation Type (choose one or more)
☒ Orthometric height
☒ Ellipsoid height

Data Model Types (choose one or more) * Designate either feet or meters
☒ Mass Points ☒ Grid (post spacing = 3 meters) * ☐ Contour Lines
☐ Breaklines ☐ Grid (post spacing = 1 arc-seconds) ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
☐ Optical ☒ IFSAR ☐ Lidar

Vertical Accuracy at 95% Confidence Level ☐ $Accuracy_z$ = 10 meters, based on 5m RMSE
☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft) ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
☒ 20' contour equivalent ($Accuracy_z$ = 11.9 ft) ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft) ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
☐ Other

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
☒ Tested ___ (meters/ft) vertical accuracy or ☐ Compiled to meet 15 meters vertical accuracy
☐ Tested ___ (meters/ft) horizontal accuracy or ☐ Compiled to meet 29 meters horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
☒ Hydro-enforcement ☐ Hydro-conditioning ☒ Vegetation
☐ No data areas (Voids)

Horizontal Datum (choose one)
☒ NAD 83 (default)
☐ NAD 27 (obsolete)

Vertical Datum (choose one)
☒ NAVD 88 (default)
☐ NGVD 29 (obsolete)

Geoid Model (choose one)
☐ GEOID03
☒ GEOID06

Coordinate System (choose one) ☐ UTM zone ☐ State Plane
☒ Geographic ☐ Albers Equal Area ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
☒ Elevations to 2 decimal places ☐ U.S. Survey Feet ☒ Meters
☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters

DEM File Format(s)
☐ ASCII Float Grid ☒ ESRI Grid ☐ Other (DTED 2)
☒ GeoTiff ☐ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) ______ Mb Other __________

Tile Size
Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☒ Other 1x1 deg

User Group 9: NGA — DEM User Requirements Menu

Project Area and Applications NGA would use the DTED 2 generated over Alaska to populate our global resolution elevation foundation layer above 60N latitude to compliment the SRTM derived DTED 2 data that exists below 60N latitude. DTED 2 data is one of the foundation data layers necessary for DoD mission planning and a variety of terrain visualization applications. DTED 2 is also utilized to orthorectify standard NGA orthoimage products such as the 1m Controlled Image Base (CIB) product.

General Surface Description

Elevation Surface (choose one or more)
- ☐ Digital surface model (DSM) top reflective surface
- ☒ Digital terrain model (DTM) bare earth terrain
- ☐ Other ________________

Elevation Type (choose one or more)
- ☒ Orthometric height
- ☐ Ellipsoid height
- ☐ Other _________________

Data Model Types (choose one or more) * Designate either feet or meters
- ☐ Mass Points
- ☐ Grid (post spacing = ___ feet/meters) *
- ☐ Contour Lines
- ☐ Breaklines
- ☒ Grid (post spacing = 1 arc-seconds)
- ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
- ☐ Optical
- ☒ IFSAR
- ☐ Lidar

Vertical Accuracy at 95% Confidence Level
- ☒ $Accuracy_z$ = 10 meters, based on 5m RMSE
- ☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
- ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
- ☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
- ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
- ☐ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
- ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r$ x 1.7308
- ☐ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
- ☒ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
- ☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
- ☐ Other

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
- ☐ Tested ___ (meters/ft) vertical accuracy or ☒ Compiled to meet 15 meters vertical accuracy
- ☐ Tested ___ (meters/ft) horizontal accuracy or ☒ Compiled to meet 29 meters horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
- ☐ Hydro-enforcement
- ☒ Hydro-conditioning
- ☐ Vegetation
- ☐ No data areas (Voids)

Horizontal Datum (choose one)
- ☒ NAD 83 (default)
- ☐ NAD 27 (obsolete)

Vertical Datum (choose one)
- ☒ NAVD 88 (default)
- ☐ NGVD 29 (obsolete)

Geoid Model (choose one)
- ☐ GEOID03
- ☒ GEOID06

Coordinate System (choose one)
- ☐ UTM zone
- ☐ State Plane
- ☒ Geographic
- ☐ Albers Equal Area
- ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
- ☒ Elevations to integer meters ☐ U.S. Survey Feet ☒ Meters
- ☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
- ☐ Decimal degrees to ___ decimal places or ☐ DDDMMSS to ___ decimal places

DEM File Format(s)
- ☐ ASCII Float Grid
- ☐ ESRI Binary Float Grid
- ☒ Other (DTED 2)
- ☐ GeoTiff
- ☐ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) ______ Mb Other __________

Tile Size

Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☒ Other 1x1 deg

User Group 10: NOAA — DEM User Requirements Menu

Project Area Identify selected area of interest if not statewide: Coastal Areas

General Surface Description

Elevation Surface (choose one or more)
- ☐ Digital surface model (DSM) top reflective surface
- ☒ Digital terrain model (DTM) bare earth terrain
- ☒ Other _____Bathymetry______

Elevation Type (choose one or more)
- ☒ Orthometric height (NGS)
- ☒ Ellipsoid height (CSC)
- ☐ Other ________________

Data Model Types (choose one or more) * Designate either feet or meters
- ☒ LiDAR Mass Points
- ☐ Grid (post spacing = ___ feet/meters) *
- ☐ Contour Lines
- ☐ Breaklines
- ☐ Grid (post spacing = ___ arc-seconds)
- ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
- ☐ Optical
- ☒ IFSAR (NGS)
- ☒ LiDAR (CSC)

Vertical Accuracy at 95% Confidence Level
- ☐ 10' contour equiv. ($Accuracy_z$ = 5.96 ft)
- ☒ 20' contour equiv. ($Accuracy_z$ = 11.9 ft)(FAA)
- ☒ 40' contour equiv. ($Accuracy_z$ = 23.8 ft)(NGS)
- ☒ 2' contour accuracy in coastal areas only (CSC)
- ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
- ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
- ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r$ x 1.7308
- ☐ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
- ☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
- ☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
- ☒ Other* Coastal data may require significantly more accuracy than inland areas of the state. Ability to measure or predict small elevation changes (permafrost) in coastal areas from climate change is one example. Coastal erosion may also become more prevalent with longer open-water seasons.

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
- ☒ Tested _0.3 (meters) vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
- ☒ Tested __1 (meters) horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
- ☐ Hydro-enforcement
- ☐ Hydro-conditioning
- ☒ Vegetation
- ☒ No data areas (Voids)

Horizontal Datum (choose one)
- ☒ NAD 83 (default)
- ☐ NAD 27 (obsolete)

Vertical Datum (choose one)
- ☐ NAVD 88 (default)
- ☐ NGVD 29 (obsolete)

Geoid Model (choose one)
- ☐ GEOID03
- ☐ GEOID06

Coordinate System (choose one)
- ☐ UTM zone
- ☐ State Plane
- ☒ Geographic
- ☐ Albers Equal Area
- ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
- ☒ Elevations to __3_ decimal places ☐ U.S. Survey Feet ☒ Meters
- ☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
- ☒ Decimal degrees to _7_ decimal places or ☐ DDDMMSS to ___ decimal places

DEM File Format(s)
- ☐ ASCII Float Grid
- ☒ ESRI Binary Float Grid
- ☐ Other
- ☐ GeoTiff
- ☐ .IMG (ERDAS Imagine)

File Size (Maximum file size, if applicable) __500__ Mb Other __________

Tile Size

Tile Size, if applicable ☐ _____ ft x _____ ft ☒ ___5000__ meters x _5000___ meters ☐ Other

User Group 11: NPS Alaska — DEM User Requirements Menu

Project Area Identify selected area of interest if not statewide, and applications:

ALL NPS LANDS IN AK

- General Mapping Applications
- Coastal Mapping Applications
- Planimetric Maps
- Topographic Maps
- Digital Orthophotos
- Wetland Maps
- Forest Maps
- Corridor or Right-of-Way Maps
- NED Layer in The National Map
- Shoreline Delineation
- Climate Change
- Sea Level Rise
- Coastal Management
- Coastal Inundation Modeling
- Water Supply and Quality
- Subsidence Monitoring
- Disaster Preparedness and Response
- Fire Propagation Modeling
- Floodplain Management
- Geological Applications
- Resource Management

General Surface Description

Elevation Surface (choose one or more)
☒ Digital surface model (DSM) top reflective surface
☒ Digital terrain model (DTM) bare earth terrain
☐ Other ________________

Elevation Type (choose one or more)
☒ Orthometric height
☐ Ellipsoid height
☐ Other ________________

Data Model Types (choose one or more) * Designate either feet or meters
☐ Mass Points ☒ Grid (post spacing = _10__ feet/meters) * ☐ Contour Lines
☐ Breaklines ☐ Grid (post spacing = _1/3__ arc-seconds) ☐ Concurrent imagery

Preferred Source (choose one and explain reason for preference)
☒ Optical ☒ IFSAR ☐ Lidar

Vertical Accuracy at 95% Confidence Level
☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
☒ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
☐ Other (including metric options)
☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
☐ Other

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
☐ Tested ___ (meters/ft) vertical accuracy or ☒ Compiled to meet _23.8__ (meters/**ft**) vertical accuracy

☐ Tested ___ (meters/ft) horizontal accuracy or ☒ Compiled to meet _45.6__ (meters/**ft**) horizontal accuracy
Surface Treatment Factors (optional – explain with separate text) ☒ Hydro-enforcement ☐ Hydro-conditioning ☐ Vegetation ☒ No data areas (Voids)
Horizontal Datum (choose one) **Vertical Datum** (choose one) **Geoid Model** (choose one) ☒ NAD 83 (default) ☒ NAVD 88 (default) ☐ GEOID03 ☐ NAD 27 (obsolete) ☐ NGVD 29 (obsolete) ☒ GEOID06
Coordinate System (choose one) ☐ UTM zone ☐ State Plane ☒ Geographic ☐ Albers Equal Area ☐ Other _____
Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ ☐ Elevations to ___ decimal places ☐ U.S. Survey Feet ☐ Meters ☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters ☐ Decimal degrees to ___ decimal places or ☒ DDDMMSS to ___ decimal places
DEM File Format(s) ☐ ASCII Float Grid ☒ ESRI Binary Float Grid ☐ Other ☐ GeoTiff ☐ .IMG (ERDAS Imagine)
File Size (Maximum file size, if applicable) ______ Mb Other _________
Tile Size Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☒ Other (1 degree)

User Group 12: NRCS – DEM User Requirements Menu

Project Area **NRCS Soil Survey Areas and Areas of primary interest within Roaded Corridors would be very useful to have DTM with a 5-10 meter posting. Remainder of State – a 20 meter DSM suitable for ortho-rectification to NMAS 24k.**

General Surface Description

Elevation Surface (choose one or more)
- ☒ Digital surface model (DSM) top reflective surface
- ☒ Digital terrain model (DTM) bare earth terrain
- ☐ Other - DTM needed for Soil Survey Areas

Elevation Type (choose one or more)
- ☐ Orthometric height
- ☒ Ellipsoid height
- ☐ Other ________________

Data Model Types (choose one or more) * Designate either feet or meters
- ☐ Mass Points
- ☐ Breaklines
- ☒ Grid (post spacing = _10-20 meters) *
- ☐ Grid (post spacing = ___ arc-seconds)
- ☐ Contour Lines
- ☒ Concurrent imagery

Concurrent Imagery desirable within NRCS AOI's in Roaded Network

Preferred Source (choose one and explain reason for preference) **Best solution for Statewide acquisition**
- ☐ Optical ☐ IFSAR ☐ Lidar **No preference expressed**

Vertical Accuracy at 95% Confidence Level
- ☐ 10' contour equivalent ($Accuracy_z$ = 5.96 ft)
- ☐ 20' contour equivalent ($Accuracy_z$ = 11.9 ft)
- ☒ 40' contour equivalent ($Accuracy_z$ = 23.8 ft)
- ☐ Other (including metric options)
- ☐ 50' contour equivalent ($Accuracy_z$ = 29.8 ft)
- ☐ 80' contour equivalent ($Accuracy_z$ = 47.7 ft)
- ☐ 100' contour equivalent ($Accuracy_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level $Accuracy_r = RMSE_r \times 1.7308$
- ☒ $Accuracy_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products)
- ☐ $Accuracy_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
- ☐ $Accuracy_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products) ☐ Other

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
- ☒ Tested __10 (meters) vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
- ☐ Tested ___ (meters/ft) horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

Surface Treatment Factors (optional – explain with separate text)
- ☒ Hydro-enforcement
- ☐ Hydro-conditioning
- ☐ Vegetation
- ☐ No data areas (Voids)

Horizontal Datum (choose one)
- ☒ NAD 83 (default)
- ☐ NAD 27 (obsolete)

Vertical Datum (choose one)
- ☒ NAVD 88 (default)
- ☐ NGVD 29 (obsolete)

Geoid Model (choose one)
- ☐ GEOID03
- ☒ GEOID06

Coordinate System (choose one)
- ☐ UTM zone
- ☐ State Plane
- ☒ Geographic
- ☐ Albers Equal Area
- ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
- ☐ Elevations to **2** decimal places ☐ U.S. Survey Feet ☒ Meters
- ☐ Northings/Eastings to _**4** decimal places ☐ U.S. Survey Feet ☒ Meters
- ☐ Decimal degrees to _**8** decimal places or ☐ DDDMMSS to ___ decimal places

DEM File Format(s)
- ☐ ASCII Float Grid
- ☐ GeoTiff
- ☐ ESRI Binary Float Grid
- ☒ .IMG (ERDAS Imagine)
- ☐ Other

File Size (Maximum file size, if applicable) 4000 Mb Other _________

Tile Size

Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☐ Other

User Group 13: USFS — DEM User Requirements Menu

Project Area and Applications Statewide + smaller project areas, typically 20,000-100,000 acres. SE Alaska alone has 6M acres total. Applications include hydrology and forestry; study forest health; slope, aspect, orthorectification. SPOT Image Corp. now acquiring 7M acres for USFS.

General Surface Description

Elevation Surface (choose one or more)
☒ Digital surface model (DSM) top reflective surface
☒ Digital terrain model (DTM) bare earth terrain
☒ **Determine tree heights from DSM minus DTM**

Elevation Type (choose one or more)
☐ Orthometric height
☒ Ellipsoid height
☒ **Need DEM consistency w/GPS surveys**

Data Model Types (choose one or more) * Designate either feet or meters
☐ Mass Points ☒ Grid (post spacing = 10/meters ☐ Contour Lines
☐ Breaklines ☒ Grid (post spacing = 1/3 arc-seconds ☒ Spectral imagery (not mandatory)

Preferred Source (choose one and explain reason for preference)
☐ Optical ☒ IFSAR overall ☒ Lidar (small areas only for special projects)

Vertical Accuracy at 95% Confidence Level ☒ Accept vertical accuracy from IFSAR DSMs/DTMs
☐ 10' contour equivalent (Accuracy$_z$ = 5.96 ft) ☐ 50' contour equivalent (Accuracy$_z$ = 29.8 ft)
☐ 20' contour equivalent (Accuracy$_z$ = 11.9 ft) ☐ 80' contour equivalent (Accuracy$_z$ = 47.7 ft)
☐ 40' contour equivalent (Accuracy$_z$ = 23.8 ft) ☐ 100' contour equivalent (Accuracy$_z$ = 59.6 ft)

Horizontal Accuracy at 95% Confidence Level Accuracy$_r$ = RMSE$_r$ x 1.7308
☐ Accuracy$_r$ = 45.6 ft or 13.9 m (typical for 1:24,000 scale products) **Not really good enough**
☐ Accuracy$_r$ = 95.0 ft or 29.0 m (typical for 1:50,000 scale products)
☐ Accuracy$_r$ = 120.4 ft or 36.7 m (typical for 1:63,360 scale products)
☒ Other. **Prefer horizontal accuracy on the order of 20 ft at 95% confidence level**

Accuracy Reporting (choose one vertical and one horizontal at the 95 percent confidence level)
☐ Tested ___ (meters/ft) vertical accuracy or ☒ Compiled to meet ___ (meters/ft) vertical accuracy
☐ Tested ___ (meters/ft) horizontal accuracy or ☒ Compiled to meet ___ (meters/ft) horizontal accuracy
Use "Compiled to meet" but with spot testing

Surface Treatment Factors (optional – explain with separate text)
☒ Hydro-enforcement (wish, but not need) ☐ Hydro-conditioning ☐ Vegetation
☐ No data areas (Voids)

Horizontal Datum (choose one)
☒ NAD 83 (default)
☐ NAD 27 (obsolete)

Vertical Datum (choose one)
☒ NAVD 88 (default)
☐ NGVD 29 (obsolete)

Geoid Model (choose one)
☐ GEOID03
☐ GEOID06

Coordinate System (choose one) ☐ UTM zone ☐ State Plane
☐ Geographic ☐ Albers Equal Area ☐ Other _____

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
☒ Elevations to 1 decimal place ☐ U.S. Survey Feet ☒ Meters (State law)
☒ Northings/Eastings to no decimal places ☐ U.S. Survey Feet ☒ Meters (State law)
☐ Decimal degrees to ___ decimal places or ☒ DDDMMSS to 1/3-arc-seconds

DEM File Format(s)
☒ ESRI Integer Grid (currently maintain integer elevations in feet, but convert to integer meters if needed)
☒ ESRI Binary Float Grid (acceptable, but don't want coordinate precision to exceed accuracy)
☐ GeoTiff ☐ .IMG (ERDAS Imagine) ☐ ASCII Float Grid

File Size (Maximum file size, if applicable) ______ Mb Other __________

Tile Size
Tile Size, if applicable ☐ __ ft x ___ ft ☐ __ meters x __ meters ☒ Other 1° x 1° cells

User Group 14: USGS — DEM User Requirements Menu

Data Licensing -- USGS policy is to acquire data that will go into the public domain but recognizes this may not always be the case. Agreements for data that are licensed or that otherwise cannot be placed into the public domain are an option, e.g. view only with sunset clause. Alaska is a special case which may dictate USGS review its current policy in order to attain State-wide coverage in the interests of all parties, private and public.

Vendor Specific Solutions – USGS is open to discuss all solutions in efforts to attain Statewide coverage in the most expedient and cost-effective way(s) within reason.

Project Area – With very few exceptions, Alaska is a State which USGS has poor elevation data coverage. Project area considerations are determined by a number of criteria but basically fall under the following area definitions.

1. Urban Areas – per NGA requirements. Cities and towns with significant populations; areas of important infrastructure, e.g. pipelines, shipyards, harbors; military installations
2. Areas of scientific significance – per USGS science disciple requirements. Oil and natural gas field exploration; natural hazards – earthquakes, floods, shoreline inundations,
3. Partnership areas – Areas defined primarily by other Federal, State of Alaska or regional or local requirements

General Surface description

1. Elevation surface
    a. Digital surface model – If derived from lidar; prefer complete classified lidar point clouds
    b. Digital terrain model – YES, as raster
    c. Other – possible as an option; dependent on project requirements
2. Elevation type
    a. orthometric height -- YES, preferred
    b. ellipsoid height – Discouraged, though recognized to be preferable in special cases where geoid models cannot produce reliable orthometric heights.

Data Model Types - model types are project specific but a general policy of USGS is to gather as much data as can be afforded. If projects are run through the GPSC contract, there are default requirements regardless of the project specifics for elevation data. At the very least, aside from the projects elevation model, raw data mass points are to be collected

1. Mass points classified lidar points are preferred
2. Breaklines are preferred, at a minimum: to enforce downhill hydrologic flow, level wide rivers bank-to-bank, and flatten water bodies
3. Grid post spacing

If projected coordinates	**If geographic coordinates**
30 meters	1 arc-second (in decimal degrees, ~0.00028)
10 meters	**1/3 arc-second** (in decimal degrees, ~0.00009)
3 meters	1/9 arc-second (in decimal degrees, ~0.00003)

Preferred Source

1. Optical – acceptable, but least preferred
2. IFSAR – acceptable, but with reservations due to licensing issues
3. Lidar – preferred, primarily due to public domain data requirement

Lidar is preferred for its proven ability to provide accurate bare-earth surface models, as well as numerous other data products.

The USGS mission to provide data for public domain use makes any licensed data product less desirable. Although not absolute, most IFSAR and Optical products are licensed, most lidar products are not. See opening statement on "Data Licensing".

Vertical Accuracy at 95% Confidence Level - contours equivalents and vertical accuracy's will likely vary by topography and locations as well as acquisition source and project requirement

1. 10' contour equivalent ($Accuracy_z$ = 5.96 ft) Ideal, not expected for Alaska state-wide
2. 20' contour equivalent ($Accuracy_z$ = 11.9 ft) Preferred
3. 40' contour equivalent ($Accuracy_z$ = 23.8 ft) Acceptable
4. 50' contour equivalent ($Accuracy_z$ = 29.8 ft)) – not likely
5. 80' contour equivalent ($Accuracy_z$ = 47.7 ft)) – not likely
6. 100' contour equivalent ($Accuracy_z$ = 59.6 ft) – not likely
7. Other (including metric options)
   a. 2' contour – Urban areas and shorelines
   b. 5' contour – Urban areas, shorelines, other areas of low relief

Horizontal Accuracy at 95% Confidence Level - some projects may be acquired for use for 1:12,000 scale products or larger. The USGS horizontal accuracy requirement is for 1:24K products.

1. $Accuracy_r$ = **45.6 ft or 13.9 m (typical for 1:24,000 scale products)**
2. Other

Accuracy Reporting - Horizontal and vertical reporting will be **reported as "Tested"** at various accuracies dependent on project requirements

Surface Treatment Factors - Surface treatment will be dependent on nature of project, i.e., National Map vs other USGS discipline requirements (mapping vs science). The NED is based on the "best available" **bare-earth surface**. "Hydrologic enforcement" is preferred, but not required. In general, the surface preferred for inclusion in the NED is a bare-earth surface, **hydrologically corrected** such that streams flow downhill, wide (double-line) rivers are level bank-to-bank, and water bodies are flattened. Filling or leveling of incidental sinks is neither required nor encouraged.

Horizontal Datum - **NAD 83 (default)**

Vertical Datum **-NAVD 88 (default)**

Geoid Model **- GEOID06**

Coordinate System - Requirements vary or may be more than one if partners request differing needs.

1. UTM zone	Discouraged
2. State Plane	Discouraged
3. Geographic	Acceptable
4. Albers Equal Area	**Preferred (Meters, NAD83)**
5. Other	

Units Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ - (List USGS preferences)

Elevations to **2** decimal places		~~U.S. Survey Feet~~	or	**Meters**
Northings/Eastings to **2** decimal places		~~U.S. Survey Feet~~	or	**Meters**
Decimal degrees to **8** decimal places	or	~~DDDMMSS to ___ decimal places~~		

We have, on occasion, received data that uses the arc-second as the unit of measure. This is discouraged.

DEM File Format(s) – (Pick one or more)

1. ~~ASCII Float Grid~~
2. ~~ESRI Binary Float Grid~~
3. ~~GeoTiff~~
4. **.IMG (ERDAS Imagine)**
5. **Other: ESRI GRID**

File Size (Pick a USGS preference(S) or state whether it is immaterial) **150 MB → 1 GB per file**

Tile Size (Pick a USGS preference(S) or state whether it is immaterial) **7-1/2 Minute Quad sheets**, or standard multiple thereof. Smaller (i.e., Quarter-Quads) or larger (i.e., 1-degree tile) as necessary to maintain reasonable file size and total number of files.

Appendix D — DEM Technical Alternatives

Optical Sensors

ASTER Global DEM

Responded to request for answers to 18 questions by stating it should not be compared with commercial sources of DEM data. Some answers were provided in PowerPoint presentation made at the Alaska DEM Workshop on July 23, 2008.

GeoEye (IKONOS)

Question 1: Sensor. What sensor do you propose to use for acquisition of source data to be used for your DEM production?

We have the ability to produce DEMs using: ASTER w/ Ikonos control for improved accuracy); Ikonos; and GeoEye-1 (pending a successful launch 22AUG08.)

Question 2: Model. Are your DEMs produced from the digital surface model (DSM) of the top reflective surface, or do you also produce DEMs from the digital terrain model (DTM) of the bare-earth or near bare-earth—or a combination or other process?

DEM's are typically generated as DSMs, then edited to a DTM or near bare-earth.

Question 3: Native Z accuracy. With minimal ground control, what is the vertical accuracy ($Accuracy_z$) of your DSMs at the 95% confidence level? Note: $Accuracy_z = RMSE_z \times 1.9600$.

DTM ($Accuracy_z$): With no ground control, ASTER 1arcsecond DEM: 24m at 95% confidence level; and Ikonos 1arcsecond DEM: 14m at 95% confidence level.

Question 4: Improved Z accuracy. For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?

Ikonos .2 arcsecond DEM 4m at 95% confidence level (requires 1gcp per stereo model)

Question 5: <u>Radial accuracy</u>. **What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: $Accuracy_r = RMSE_r \times 1.7308$.]**

Ikonos 1 arcsecond: 29m at 95% confidence level; Ikonos .2 arcsecond: 14m at 95% confidence level

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Question 6: <u>Grid spacing</u>. **What DEM grid spacing do you normally use or provide?**

1 by 1 arc second or 30m posting; and .2 by .2 arc second or 5m posting

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Question 7: <u>Deliverables</u>. **What is delivered with your product, e.g., DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc.? Please distinguish between standard products and value-added products.**

Standard products: GeoReference, Precision Plus, Pro, and Stereo. The standard DEM product can be produced in the following formats: USGS DEM, DTED, GeoTIFF, etc.

Question 8: <u>Archive</u>. **If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g., produced DEMs, validated data, raw data meeting cloud specs, etc?**

We have 80,000-90,000km^2 of archive DEM. Our useable stereo imagery (meeting cloud specs) is approximately the same 80,000-90,000km^2.

Question 9: <u>Products</u>. **Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?**

We can produce the DEMs, or provide stereo imagery for alternate vendors to produces.

Question 10: <u>Processor</u>. **If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain software that works well? Do you have established processing partners? Is there an opportunity for local Alaska productions of DEMs?**

Ikonos stereo pairs with RPC's are needed for DEM creation. I prefer SocetSet on the commercial off the shelf product for DEM extractions/editing. We have local Alaska partners: Aero-Metric, and ETerra. We also work with I-Cubed in Fort Collins, CO.

Question 11: **<u>Special Applications</u>. Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.**

For DEMs, we do not offer value added applications such as: vertical change detection, or volumetric data.

Question 12: **<u>Ground control</u>. What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you require more? If more control is required, what spacing or density of survey points would be needed?**

Our requirements for ground control: we prefer professionally surveyed ground control. However, other legitimate control sources could be utilized.

- 1arc DEMs, no ground control necessary with multi-image block adjustment.
- .2arc DEMs, 1 gcp per stereo pair is needed

Question 13: **<u>Geodesy issues</u>. How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection? Do you have preference for datums, projections, coordinate systems, units?**

All using WGS84/ITRF through JPL. Our standard DEM product is produced using geoid EGM96. Non-standard DEMs can be produced in Ellipsoid.

Question 14: **<u>License</u>. What license options are available for your elevation data? Whereas the State would prefer to have licenses such that the data can be inserted into the National Elevation Dataset (NED), this could change if alternative licensing turns out to be more advantageous for other reasons.**

Licensing would most likely need to be customized to fit the needs of this project.

Question 15: **<u>Production volume</u>. How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.**

We have the potential to produce between10-20% per year, this will likely increase when GeoEye-1 becomes operational.

Question 16: <u>Experience</u>. Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.

We have experience producing DEMs in Alaska (80,000+km^2), Greenland (25,000km^2), Canada, Central Africa and other regions around the world.

Question 17: <u>Pricing</u>. One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity, either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)

A negotiable pricing scheme would be likely for a project of this size. (I know this is not the desired answer; perhaps this will be clarified with the RFP formal request)

Question 18: <u>IDIQ Contracts</u>. Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.

Prime: USGS IDIQ Contract 08CRCN0011

Subcontractor: USGS GPSC Contract, subcontractor to Dewberry.

Subcontractor: NGA IDIQ Global Geospatial Intelligence Contract; subcontractor to:

- BAE
- Technigraphics, Inc.
- Boeing, Inc.
- Harris Corp.

Digital Globe (WorldView-1)

Question 1: **Sensor. What sensor do you propose to use for acquisition of source data to be used for your DEM production?**

WorldView-1 will be used for all source data acquisition.

Question 2: **Model. Are your DEMs produced from the digital surface model (DSM) of the top reflective surface, or do you also produce DEMs from the digital terrain model (DTM) of the bare-earth or near bare-earth—or a combination or other process?**

We use both DSM and DTM using the maximum level of automation. First the original, automatically-extracted DEM represents the top reflective surface. Second manual editing is performed to create a Digital Terrain Model in regions where the bare earth can be located.

Question 3: **Native Z accuracy. With minimal ground control, what is the vertical accuracy ($Accuracy_z$) of your DSMs at the 95% confidence level? Note: $Accuracy_z = RMSE_z \times 1.9600$.**

The vertical accuracy of the DSMs is 6-8 meters at the 95% confidence level. The vertical accuracy of DTMs is approximately 8 meters at the 95% confidence level. It is significant to note that this accuracy is achieved with no ground control points. It will be achieved by taking advantage of the native accuracy of the satellite sensor, augmented by tiepoints measured between overlapping scenes.

Question 4: **Improved Z accuracy. For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?**

There is no plan to establish an improved control network; in fact, the "Improved Z accuracy" and "Native Z accuracy" categories are virtually identical for WorldView-1, as this satellite has very high accuracy with no ground control. After bundle adjustment with tiepoints, there is little benefit to be derived from the use of ground control points; the DEM accuracy is mostly determined by stereo geometry and the accuracy of the image matching process.

Question 5: **Radial accuracy. What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: $Accuracy_r = RMSE_r \times 1.7308$.]**

It depends on the spacing of the DEM. Assuming that we generate WV-1 DEM at 1m spacing, the horizontal accuracy is within 2m RMS (R accuracy of 3.4m). After bundle adjustment, the stereo imagery will be accurate at the 2 meter (95%) level; the DEM has the same accuracy but due to its coarser post spacing, its perceived accuracy may be up to 5 meters for the 10m product (95%) or 15 m for the 30 m product.

Question 6: **Grid spacing. What DEM grid spacing do you normally use or provide?**

We normally generate at 2 times the original spacing of the image. However, we can generate downsampled epipolar images to generate lower resolution DEMs. Actual spacing is something that we determine with the client based upon detailed contract specifications.

Question 7: **Deliverables. What is delivered with your product, e.g., DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc.? Please distinguish between standard products and value-added products.**

We generate DSM, DTM, contours and orthoimages as standard products. As value-added products, we could generate orthoimage mosaics.

Question 8: **Archive. If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g., produced DEMs, validated data, raw data meeting cloud specs, etc?**

We do not have any significant stereo pair coverage for the State of Alaska at this time

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Question 9: **Products. Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?**

DigitalGlobe will partner with PCI Geomatics for creation of the DEM product.

Question 10: **Processor. If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain software that works well? Do you have established processing partners? Is there an opportunity for local Alaska productions of DEMs?**

DigitalGlobe will partner with PCI Geomatics for creation of the DEM product.

Question 11: <u>Special Applications</u>. Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.

The stereo imagery could be used for 3D feature extraction (e.g., lakes and roads). The improved DEM could be used for more precise hydrological computations. Slope and aspect characteristics derived from the DEM can be used to assist in land cover classification and for better modeling of drainage/runoff patterns. The DEM can be used for better analysis of air routes through some of Alaska's mountain passes, and for line-of-sight assessment for planning of communications network upgrades.

Question 12: <u>Ground control</u>. What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you require more? If more control is required, what spacing or density of survey points would be needed?

We do not require any ground control points for acquisition or production. For horizontal/vertical accuracy testing, we can rely on bundle adjustment statistics and on comparison of DEMs created from overlapping stereo pairs.

NGS control would also be suitable for vertical accuracy testing, if it is valid to assume that each NGS control point is within 1 meter or so of the ground surface. It would not be suitable for horizontal accuracy testing, because we cannot in general see this type of control point (usually a brass plug inserted in a rock or a concrete pillar) in WorldView-1 data.

Question 13: <u>Geodesy issues</u>. How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection? Do you have preference for datums, projections, coordinate systems, units?

CORS network and solar activity will not have an impact on the EM production. Geoid limitations can be circumvented (on our end) by producing elevation data referenced to the ellipsoid. If the state of Alaska wishes to use a custom geoid, it can then be applied as a post processing step for conversion to mean sea level. We can generate DEM in almost any projection, we have no particular preference for datums, projections, coordinate systems, or units.

Question 14: <u>License</u>. What license options are available for your elevation data? Whereas the State would prefer to have licenses such that the data can be inserted into the National Elevation Dataset (NED), this could change if alternative licensing turns out to be more advantageous for other reasons.

A Government Enterprise License will be offered that allows for usage at any level of Government as well as viewing access to the general public.

Question 15: Production volume. How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.

Utilizing WorldView I DigitalGlobe can capture approximately 10 – 12% of the State on an annual basis. When WorldView II becomes available the rate will more than double. PCI Geomatics is capable of producing DEMs from as much imagery as can be made available.

Question 16: Experience. Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.

The Canadian National Imagery Project, a contract from the Canadian Government to PCI through a partner is an example of production of large volumes of data in remote, poorly controlled areas. We use a high degree of automation in our activities that allow scaling to meet extremely high volume challenges. Many of the areas covered in this project fall within regions of poorly ground controlled areas.

Question 17: Pricing. One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity, either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)

Firm pricing cannot be provided until we have a better idea of the scope of our involvement.

Question 18: IDIQ Contracts. Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.

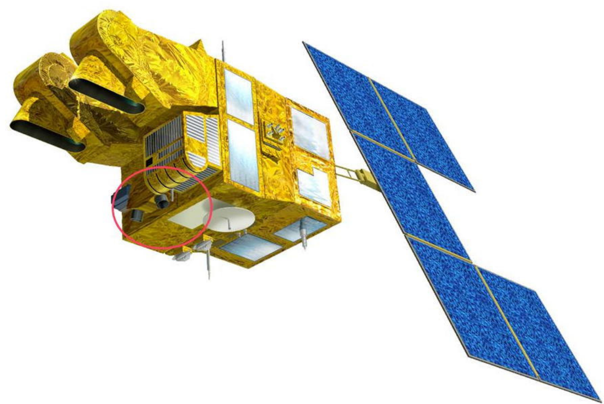
DigitalGlobe has a number of both Federal and State level contracts that may be suitable as a contract vehicle.

Subcontractor to Dewberry for USGS GPSC contract.

Spot Image Corp. (SPOT-5)

Question 1: **<u>Sensor</u>. What sensor do you propose to use for acquisition of source data to be used for your DEM production?**

We will use data from the High Resolution Stereo (HRS) sensor. This is a fore-and-aft dedicated stereo sensor that is a secondary payload on the SPOT 5 satellite. This sensor collects stereo data strips measuring 120 KM wide by 600 KM long. The forward camera looks 20 degrees forward of nadir, and the aft camera looks 20 degrees aft of nadir (base to height of 0.8). The stereo strips are collected on the same pass, within about 90 seconds of each other, so radiometric and geometric characteristics of the stereo pair match very closely. The images are collected in a panchromatic mode, with a ground sampling distance of 5 meters across track and 10 meters along track. The electro-optical energy collected is in the bandwidth from 0.49 microns to 0.69 microns.



SPOT 5 satellite, red circle shows HRS secondary payload.

In addition, for areas of high terrain, the two primary High Resolution Ground (HRG) instruments are used to collect 5 meter panchromatic data at nadir, to supplement the HRS data collected at the same time. This supplemental HRG data permits elevation extraction in extreme mountainous terrain where shadowing would be a problem using just the HRS data.

Question 2: **<u>Model</u>. Are your DEMs produced from the digital surface model (DSM) of the top reflective surface, or do you also produce DEMs from the digital terrain model (DTM) of the bare-earth or near bare-earth—or a combination or other process?**

The SPOT DEM, which has the commercial name Reference3D, is a Digital Surface Model. We do not collect data to produce a Digital Terrain Model.

Question 3: **<u>Native Z accuracy</u>. With minimal ground control, what is the vertical accuracy ($Accuracy_z$) of your DSMs at the 95% confidence level? Note: $Accuracy_z = RMSE_z \times 1.9600$.**

The published absolute elevation accuracy specifications are—

●Terrain slope 0 to 20 degrees 11.91 M LE95 or better

●Terrain slope 20 to 40 degrees 21.44 M LE95 or better

●Terrain slope greater than 40 degrees 35.74 M LE95 or better

In actual practice, much better absolute vertical accuracies are normally achieved. Here are the results from a 2006 cross comparison done by a US government organization over 12 geocells at various locations around the world.

Cell ID	(Relief Type) (%High-Med-Low)	Vertical (Z) (DEM-GCP) Difference			
		Mean	90% error	Mean	90%error
N30E33	(0-35-65)	0.59	5.40	-2.33	7.13
N30E32	(0-30-70)	3.44	3.50	2.71	2.28
N30E49	(0-15-85)	2.09	6.05	2.86	5.75
N29E48	(0-0-100)	0.84	4.34	6.33	6.16
N32E39	(0-40-60)	2.77	3.53	4.65	3.86
N33E35	(45-25-30)	-0.17	6.58	1.83	6.35
N30E47	(0-0-100)	-0.48	3.38	4.34	3.85
N30E48	(0-0-100)	0.70	4.05	5.88	3.99
N36E43	(25-25-50)	1.85	5.12	7.99	6.06
N32E48	(30-35-35)	-0.69	5.26	6.61	7.21
N36E44	(90-0-10)	-0.67	6.13	6.76	6.90
		SRTM		Ref3D/SPOT 5	

Question 4: **<u>Improved Z accuracy</u>. For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?**

SPOT does not use GCPs in processing its Reference3D DEM products. The absolute accuracies we achieve are the result of using the large block bundle space triangulation process that we employ. We explain this process further, in a supplemental paper provided with this document.

Question 5: **<u>Radial accuracy</u>. What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: $Accuracy_r = RMSE_r \times 1.7308$.]**

The published absolute horizontal accuracy is 17.11 M CE95 or better. In actual practice accuracies are usually better than the published specification. Here is an example a project over northern Africa that we recently finished. We performed an accuracy evaluation using a comparison with common points selected from the SRTM DTED1 public release data set and the Ref3D of the same location; and the result was a difference of 10.05 M CE95.

Question 6: **Grid spacing. What DEM grid spacing do you normally use or provide?**

The SPOT Referenc3D product conforms completely to the US National Geospatial-Intelligence Agency's Digital Terrain Elevation Data (DTED) specification, with a Level 2 data density. This DTED Level 2 posting specification results in a grid of about 30 by 30 meter elevation postings. The exact specification is

- 0 degrees to 50 degrees north or south latitude—Elevation postings are one arc second of latitude by one arc second of longitude
- 50 degrees to 70 degrees north or south latitude—One arc second of latitude by 2 arc seconds of longitude
- 70 to 75 degrees north or south latitude--One arc second of latitude by 3 arc seconds of longitude
- 75 to 80 degrees of north or south latitude-- One arc second of latitude by 4 arc seconds of longitude
- 80 to 90 degrees of north or south latitude-- One arc second of latitude by 6 arc seconds of longitude

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Question 7: **Deliverables. What is delivered with your product, e.g., DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc.? Please distinguish between standard products and value-added products.**

Here are the components of the SPOT Reference3D DEM—

- The DEM itself, in DTED format, to a Level 2 data density of one arc second.

Optional components (at an additional cost) include--

- Ortho-image. A mosaic of HRS imagery, covering the entire geocell. The image is resampled to 1/6th arc second, which equates to about a 5 meter pixel size.

●Correlation Mask (MCo): The MCo is created in the initial part of the production process, when the block bundle calculation is complete. It is a measure of the quality of the alignment of the various stereo image strips that make up the block bundle. The other masks are generated much later in the process, after exogenous data is added (if required) and after areas are manually interpolated, etc. The MCo reflects possible correlation "problems" early in the production process. Any problem areas from the MCo mask are contained in the MQu mask, which is part of the overall MVa mask.

●MCl Cloud/snow MaskMCl): Generated manually, based on a operator assessment of clouds or snow present in the HRS strips.

●Exogenous Mask (MEx): This mask shows areas of the DEM calculated using external (non-HRS data). It is created manually.

●Regulation Mask (MRe): This mask delineates areas corrected without external data; meaning an interpolation method was used. It is generated automatically.

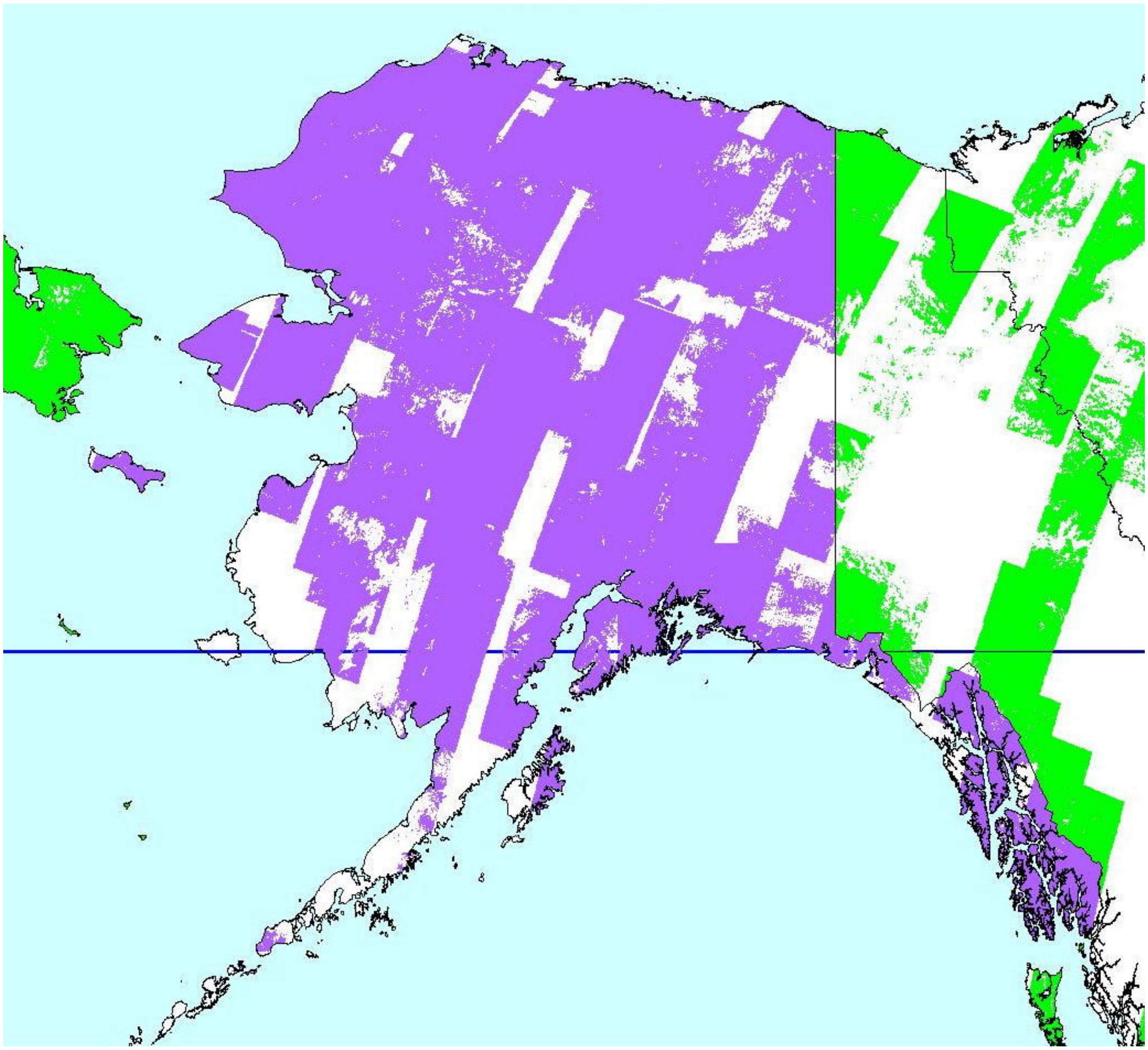
●Quality Mask (MQu): This is the primary quality mask. It is generated manually by an operator looking at the finished DEM (displayed both as a shaded image and contour lines) the HRS ortho-image, the MCo mask, and SRTM/HRS difference (where available). Also, if absolutely necessary, a stereo view check is performed. The entire DEM is visually scanned on a CRT screen at a scale of about 1:35,000..

●Water Mask (MWa): An operator uses the HRS ortho-image to identify water bodies greater than 600 meters across. The water mask is first captured in a vector form and then later converted into a raster-based file. There is no intent to capture information about water flow direction. The water body is contained within a boundary and an elevation for the water body is determined from the Ref3D DEM data and this elevation is made standard across the entire water body feature. Other specifications also apply.

●Merge Mask (MMe): This mask shows areas derived from a single HRS stereo pair strip, with no overlap from adjoining strips. In cases where two or more strips overlap, the actual elevation value presented is an average of values from the various strips. Thus, this mask shows the areas where the elevation value was from a single source strip, and averaging was not done.

● (MVa): The MVa mask is the sum of masks; MVa = MQu + MRe + MCl + MEx. The MVa mask is the worst case scenario for assessing aggregate possible data anomalies.

Question 8: **Archive. If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g., produced DEMs, validated data, raw data meeting cloud specs, etc?**



Validated HRS stereo pair coverage of Alaska (purple color), as of June 30, 2008, 76% of the state's 1.478 M KM2 territory is now covered.

SPOT has had an ongoing HRS collection program running over Alaska for each of the past three collection seasons. We generally begin collection over the southern part of the state in April, and the northern area in May. We typically stop all collection in October. One of our main requirements is to collect data only when the sun angle is above 30 degrees, for adequate illumination. We do also collect data over areas that are perennially snowy, as we can achieve good results extracting data over snow covered terrain.

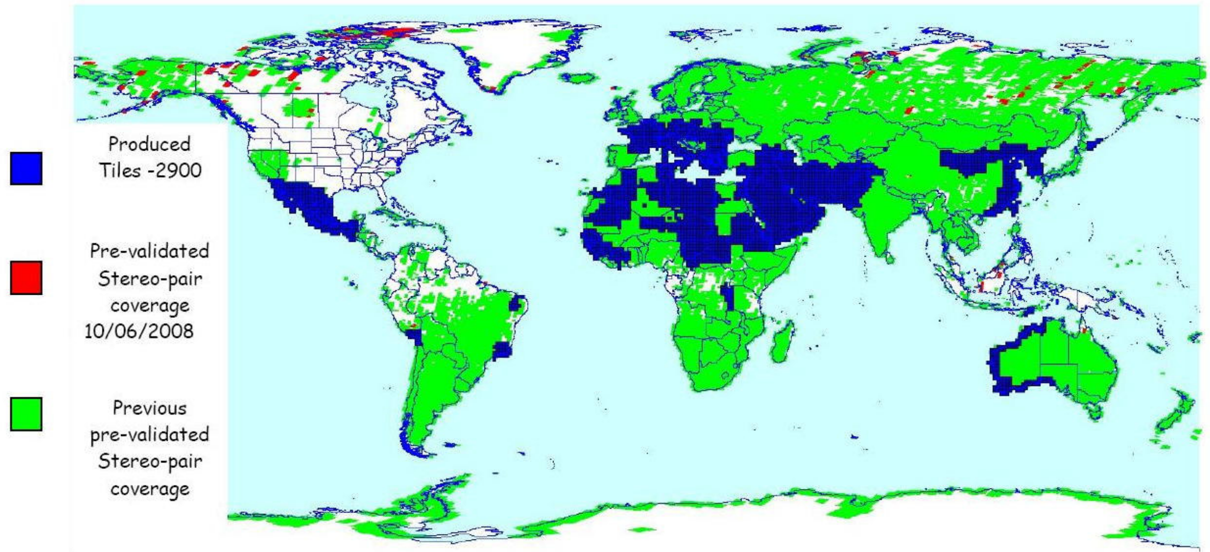
Validated coverage is defined as stereo pairs that have gone through a quality control process that we call "Zorro." In this process a 1 in 10 subsample of pixels are processed to ensure good radiometric quality for elevation correlation. Only data that passes a certain threshold of correlation percentage is then placed in the archive. When we get one or more validated data sets over an area, we then close out that area for collection and focus efforts elsewhere.

Question 9: <u>Products</u>. Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?

We deliver only a finished DEM product and optional quality layers and orthomosaic.

Question 10: <u>Processor</u>. If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain software that works well? Do you have established processing partners? Is there an opportunity for local Alaska productions of DEMs?

As a policy, SPOT does not provide the source HRS and HRG data to other organizations to do the elevation extraction and DEM finishing. In cooperation with the Institut Geographique National Espace (IGN Espace) we have set up a dedicated production facility in Toulouse, France. Our investment in this facility is many millions of dollars and the staff of about 50 employees are dedicated full-time to producing the Reference3D DEMs. We have had a large-scale production program in place since 2002, and a version two five-year plan is being implemented this year to run through at least 2013. To date 2900 one degree geocells of data have been processed and delivered to customers worldwide. See the graphic below:



This graphic shows Reference3D product status as of June 30, 2008. 2,900 one degree geocells (blue tile area) have been produced. The green and red areas show validated HRS stereo pair coverage, over 122 M KM2 globally.

We have chosen to not encourage third party production for two reasons. First, we wanted to control the production process to ensure a high level of DEM product uniformity and quality. Second, we have had some experience with providing technical expertise to third parties attempting to establish a production chain of their own. This is a difficult and very expensive process, at best, and success only comes to those willing to invest a considerable amount of resources over a term of many years.

Question 11: **<u>Special Applications</u>. Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.**

The Reference3D DEMs are used for a myriad of purposes, familiar to cartographic and GIS professionals. We do provide the eight quality masks for those customers requiring an auditable record of how the DEM was produced, the sources of data, and the accuracy by sectors. The optional orthomosaic which is coregistered to the DEM, is very handy when trying to locate tie points on other imagery (such as imagery to be orthorectified using the DEM). Some customers actually use small image plus DEM chips of the data as GCPs for use in referencing other GIS data to an absolute grid.

Question 12: Ground control. What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you require more? If more control is required, what spacing or density of survey points would be needed?

We would not use the GCPs for production. However, we would very much appreciate having GCPs for additional post-processing accuracy validation. See the paper, included with this Q&A sheet, explaining our production process without using GCPs.

Question 13: Geodesy issues. How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection? Do you have preference for datums, projections, coordinate systems, units?

Like all products built to the DTED specification, the Reference3D DEMs are horizontally referenced to WGS84, elevations are provided in meters referenced to the WGS84 EGM96 ellipsoid (height above mean sea level). We can convert the data to other horizontal or vertical references, if a customer so specifies. We process our data to the NGA's DTED grid specification, as mentioned in answer #6. We can also process the DEM data into other formats, such as GeoTIFF.

From supplemental conversations, we believe that the issues of the CORS network, and solar activity will have no impact on our product over Alaska. As to the issue of the EGM96 geoid, we do not know enough to venture an assessment on that issue.

Question 14: License. What license options are available for your elevation data? Whereas the State would prefer to have licenses such that the data can be inserted into the National Elevation Dataset (NED), this could change if alternative licensing turns out to be more advantageous for other reasons.

We have offered the SMDI consortium two license options.

> Option One—Regional Business User—This would include all US federal government, Alaska state government, and local government users. This would also include contractors, when working on projects for the above government entities.
>
> Option Two—Inclusion in the National Elevation Data (NED) data holdings. We also call this, "Public Release."

Both these options represent a one-time fee for perpetual use. There is no annual subscription involved.

Question 15: Production volume. How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.

We estimate that we can complete the production and processing of state-wide coverage in from 12 to 18 months, from project start. Note that the project would start when we have the vast majority of the state is covered with validated HRS source imagery.

Question 16: Experience. Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.

See the graphic provided for answer #10. We have produced thousands of finished geocells in northern Africa, the Middle East, and Asia. All this production is done unobtrusively from data collected only by satellite, with no need for aerial overflight, and no need for GCPs.

Question 17: Pricing. One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity, either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)

Our public "list" price for the Reference3D DEM itself is $4.00 per KM2. The list price for the DEM plus orthoimage plus quality layers is $10.95 per KM2. For Alaska state-wide coverage we are probably best placed into Bin #2, above.

Question 18: IDIQ Contracts. Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.

Yes, we have several IDIQ contracts.

1. NGA Master Contract. We are in the third year of a five year contract.

2. USGS Contract via the centralized Denver contracting facility

3. USGS Contract via USGS HQ, Reston, Virginia

We would be happy to provide further contract details to interested Alaska government representatives.

Question 19: Supplemental question added by SPOT. Do you produce finished DEM data that has been edited with hydrologic enforcement?

Yes, for our project with the NGA, we have obtained the technical capability to process full geocells to an NGA standard that they call double line drain (DLD) treatment. This standard requires streams wider than 183 meters to have the stream flow motonically stepped down in on meter increments, and the stream sides are elevated by one meter, to contain the stream boundary. Also, water bodies larger than 600 meters in any horizontal dimension must have the boundaries elevated by one meter to contain the lake. There are other details to this specification. We developed a series of algorithms to do most of this DLD treatment. Final steps in this process include operator examination of the output to ensure quality. We also use NGA-supplied software to review our work. This software is a series of ERDAS extensions that permit the rapid visualization of water bodies, stream stair steps, and boundary areas.

SPOT will be happy to work with the state of Alaska to develop a suitable specification for editing DEMs to include hydrologic enforcement.

IRS/ASRC (Cartosat-1)

Question 1: Sensor. What sensor do you propose to use for acquisition of source data to be used for your DEM production?

ASRC Management Services, a subsidiary of Arctic Slope Regional Corporation, established in 1971, is the Exclusive provider of RESOURCESAT and CARTOSAT data for the United States.

CARTOSAT –1 was launched on 5th May 2005. The CARTOSAT-1 sensor offers an across-track resolution of 2.5 m in panchromatic mode. The satellite flies along a Sun-synchronous orbit at a mean altitude of 618 km, with an inclination of 97.87 degrees and a mean revolution period equal to 97.12 minutes. In addition the optical sensor is configured with two push broom cameras which are mounted such that one camera is looking at +26° (band F) and the other at -5° (band A) along the track. These two cameras provide stereoscopic image pairs in the same pass. CARTOSAT – 2a was successfully launched and images received in May of 2008. The sensor has been utilized for DEM development globally.

Question 2: Model. Are your DEMs produced from the digital surface model (DSM) of the top reflective surface, or do you also produce DEMs from the digital terrain model (DTM) of the bare-earth or near bare-earth—or a combination or other process?

ASRC provides the Stereo Pairs to value added companies who generate DEMs from the Digital Surface Model:

PCI Geomatics has achieved complete certification for its flagship software, Geomatica® to be used for processing data from the CARTOSAT-1 satellite.

Most value added processors use PCI-OrthoEngine software to orient the stereo pair with an approach based on "generic rigorous model". The tested version of this software implements the well-known Toutin's rigorous model. It is well known that a rigorous model should describe the physical properties of the sensor and its image acquisition mode. It is an approach mainly photogrammetric (collinearity equations) accounting for the satellite position, the sensor attitude and characteristics, and an eventual final cartographic transformation.

For the CARTOSAT-1 rigorous model, a minimum of six GCPs per scene are required. More GCPs may be needed depending on the accuracy of the GCPs and the final accuracy requirement of the project. After the block adjustment, it is possible to analyze the results of the stereo images orientation in terms of residuals both on GCPs and TPs. For best accuracy, it is useful to have 5 or more GCPs per scene. There is also a possibility to be able to meet the Alaska accuracy requirement with a just a couple of good GCPs per scene as demonstrated in several projects in Europe by Euromap.

In addition you can perform triangulation on a strip by strip basis (i.e., all scenes collected on the same orbital pass) rather than a scene by scene basis, which would reduce the ground control requirements substantially.

It is possible to measure tiepoints between adjacent scenes however; the use of tiepoints cannot completely remove ground control requirements. Utilize scenes which are no farther than one scene from ground control. This will equate to 3 GCPs per every 4 scenes (assuming a 2x2 grid with control, and tiepoints measured to obtain the data between strips).

A Digital Surface Model (DSM) can be extracted from stereo CARTOSAT-1 imagery using PCI's DEM extraction module. The procedure involves the computation of a model, creation of an epipolar pair and then the extraction of a DSM. [Epipolar images are stereo pairs that have been reprojected so that the two images have a common orientation. DEMs can be extracted from the overlap between epipolar pairs].

The generated DSM may contain pixels and/or areas of 'failed' or incorrect values. Such errors in the DSM can be edited to smooth the irregularities and create a more pleasing and accurate output.

A DEM can also be generated from the DSM by editing the above ground points in stereo or by using filters.

Question 3: Native Z accuracy. With minimal ground control, what is the vertical accuracy (Accuracy$_z$) of your DSMs at the 95% confidence level? Note: Accuracy$_z$ = RMSE$_z$ x 1.9600.

It is recommended to use at least one control point every 25sqkm, which provides a uniform spread of 9 GCP's per CARTOSAT scene even though the minimum software requirement is 6 GCP's per scene. If the control points are surveyed DGPS points with high accuracy, the accuracy expectation of DSM in the urban and open zones will be in the range of 6.0 m – 9.0 m. However this can be in the range of 10 – 20m in the hilly and vegetated regions.

GCP's could be derived from accurate maps if available for the regions or even by using a handheld GPS.

With a couple of GCPs per scene, the vertical DSM accuracy is probably going to be about 15 meters at 95%, based on the numbers in Table 1.

Using the Aerial strip mechanism less ground control will be needed and accuracy will be maintained similar to the results in the table below.

Table 1. CARTOSAT -1 accuracy with offset-only correction

Scene	Avg. dLon [m]	Avg. dLat [m]	Avg. dHt [m]	Std. dLon [m]	Std. dLat [m]	Std. dHt [m]	CE90 Hz [m]	LE90 V [m]
J	0.49	0.18	-0.88	3.95	1.74	8.26	6.57	13.62
D	0.04	0.19	0.03	2.00	1.49	4.75	3.79	7.82
R	0.84	0.47	0.50	3.39	1.40	5.42	5.65	8.93
A	-0.01	0.47	2.58	2.34	1.81	4.55	4.51	7.91
P	0.45	0.05	0.31	2.00	2.45	3.80	4.83	6.26
C	0.60	-0.41	1.49	1.37	1.66	6.32	3.35	10.50

Question 4: **Improved Z accuracy. For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?**

An improved control network is necessary. If the number of GCP's is increased to 25 per scene or one in every 9 sqkm, accuracy of DEM in Urban and Open zones could be in the range of 2.5m – 5m.

The onboard GPS/IMU solution is not accurate enough to do DEM extraction (see Table 2). The figure quoted in question 3 assumed that a better control network is available.

Using the Aerial strip mechanism less ground control will be needed and accuracy will be maintained similar to the results in the table below.

Table 2. CARTOSAT-1 uncontrolled accuracy

Scene	Avg. dLon [m]	Avg. dLat [m]	Avg. dHt [m]	Std. dLon [m]	Std. dLat [m]	Std. dHt [m]	CE90 Hz [m]	LE90 V [m]
J	156.7	360.7	15.7	3.7	1.8	8.2	393.3	20.7
D	79.7	111.0	-116.0	3.2	1.3	4.7	136.8	116.2
R	10.2	114.6	-50.6	3.7	1.4	5.4	115.2	51.4
A	-66.6	61.3	-139.7	3.2	1.8	4.5	90.7	139.9
P	-206.1	268.9	-168.8	3.2	2.4	4.3	338.8	168.9
C	-66.9	353.9	-98.9	1.6	1.5	6.4	360.2	99.5

Question 5: **Radial accuracy. What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: $Accuracy_r = RMSE_r \times 1.7308$.]**

Horizontal accuracy of the DEM will be in the range of 5m – 7m for 9 GCP's per scene and 3m – 5m for 25 GCP's per scene.

Horizontal accuracy should be better than 10 meters at 95% with a couple of GCPs per scene.

Question 6: **Grid spacing. What DEM grid spacing do you normally use or provide?**

A 20m regular grid generated from epipolar pairs is considered to be optimum and 10 meters has also been easily achieved.

Question 7: **Deliverables. What is delivered with your product, e.g., DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc.? Please distinguish between standard products and value-added products.**

ASRC provides stereo pairs and thus these products would be completed by a value added provider which provide:

a) DSM
b) Edited DEM
c) Ortho imagery
d) Breaklines if stereo editing is desired.

Question 8: **Archive. If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g., produced DEMs, validated data, raw data meeting cloud specs, etc?**

ASRC Management Services relies upon value added processors for DEM production and will work closely with our current value added processors in order to assist Alaskan value added firms and universities to achieve program milestones utilizing CARTOSAT stereo images to build DEMs.

The CARTOSAT-1 imagery archive has approximately 1000 Pan A Stereo Pairs of imagery (imagery that DEMs may be developed from) of Alaska available. This imagery was collected between June 2005 through April 2008. Coverage is scattered throughout Alaska because a collection plan/strategy has not been implemented to date; of those stereo pairs approximately 50% are available due to cloud cover. GDA Corp. has developed a Cloud Cover Extraction Tool which improves the percentage of usable data by 25%.

Question 9: **Products. Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?**

ASRC Management Services provides CARTOSAT-1 Panchromatic 2.5 meter stereo imagery pairs to be used for generation of DEMs by value added processors.

Question 10: **Processor. If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain**

software that works well? Do you have established processing partners? Is there an opportunity for local Alaska productions of DEMs?

ASRC Management Services works with numerous value added processing partners. PCI and Genesys are being demonstrated at the workshop due to their recent experience.

Most value added processors use Leica, SOCET Set, or PCI-OrthoEngine software to orient the stereo pair with an approach based on "generic rigorous model". The tested version of this software implements Toutin's rigorous model. It is well known that a rigorous model should describe the physical properties of the sensor and its image acquisition mode. It is an approach mainly photogrammetric (collinearity equations) accounting for the satellite position, the sensor attitude and characteristics, and an eventual final cartographic transformation.

Additionally, PCI Geomatics has achieved complete certification for its flagship software, Geomatica® to be used for processing data from the CARTOSAT-1 satellite. This software has become the standard processing tool for CARTOSAT imagery data.

ASRC Management Services as a subsidiary of Arctic Slope Regional Corporation not only encourages the use of Alaskan labor in the creation of DEMs for the State, but is currently involved in the recent development and support of GIS Programs in coordination with several North Slope Borough District High Schools for students to obtain GIS Certification to enter college with credit. Programs are underway with Ilisagvik College and the University of Alaska.

Question 11: Special Applications. Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.

ASRC Management Services value added processors provide the following standard mapping products:

- DSM
- Edited DEM
- Ortho imagery
- Breaklines if stereo editing is desired

Our value added processors provide unique value applications such as 3-D fly through from digital terrain models generated with panchromatic CARTOSAT-1 stereo imagery as well as colorization of said imagery so that the 3-D experience is more realistic. Change detection and environmental monitoring services are also available.

Question 12: Ground control. What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you

require more? If more control is required, what spacing or density of survey points would be needed?

It is recommended to use at least one control point every 25 sqkm, which provides a uniform spread of 9 GCP's per CARTOSAT scene even though the minimum software requirement is 6 GCP's per scene. If the control points are surveyed DGPS points with high accuracy, the accuracy expectation of DSM in the urban and open zones will be in the range of 6.0 meters – 9.0 meters. However this can be in the range of 10 – 20meters in the hilly and vegetated regions.

With an improved control network such as the number of GCP's is being increased to 25 per scene or one in every 9 sqkm, accuracy of DEM in Urban and Open zones could be in the range of 2.5 meters – 5 meters.

Horizontal accuracy of the DEM will be in the range of 5 meters – 7 meters for 9 GCP's per scene and 3 meters – 5 meters for 25 GCP's per scene.

Horizontal accuracy should be better than 10 meters at 95% with a couple of GCPs per scene.

A 20 meters regular grid generated from epipolar pairs is considered to be optimum and 10 meters has also been easily achieved. <u>In addition you can perform triangulation on a strip by strip basis (i.e., all scenes collected on the same orbital pass) rather than a scene by scene basis, which would reduce the ground control requirements substantially.</u>

<u>It is possible to measure tiepoints between adjacent scenes however, the use of tiepoints cannot completely remove ground control requirements. Utilize scenes which are no farther than one scene from ground control. This will equate to 3 GCPs per every 4 scenes (assuming a 2x2 grid with control, and tiepoints measured to obtain the data between strips).</u>

Question 13: <u>Geodesy issues</u>. How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection? Do you have preference for datums, projections, coordinate systems, units?

ASRC Management Services will utilize the technical knowledge and expertise of our value added processors to determine how sparse CORS network, geoid limitations, and solar activity (k-index) on airborne and ground GPS data collection can and will effect the generation of mapping products from CARTOSAT-1 stereo imagery. It appears from the I-Cubed study of survey control in Alaska that there are more control points available than were originally assumed making CARTOSAT a viable option for a large part of the state.

Our value added providers do not have a preference for datums, projections, coordinate systems and units. All major industry standard datums, projections, coordinate systems and units are supported and requirements for the project will be determined upon close consultation with the State and other relevant parties.

Question 14: License. What license options are available for your elevation data? Whereas the State would prefer to have licenses such that the data can be inserted into the National Elevation Dataset (NED), this could change if alternative licensing turns out to be more advantageous for other reasons.

ASRC Management Services is currently working with the Alaska SDMI on an "open license".

However, derived products from CARTOSAT-1 imagery such as DEMs currently may not be placed out on the internet free of charge for all i.e. in the National Elevation Database (NED).

Question 15: Production volume. How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.

ASRC Management Services has estimated that cloud free CARTOSAT-1 imagery collection for the entire State of Alaska will require a minimum of -24-36 months.

As cloud free stereo pair imagery is critical in the development of DEMs, the acquisition the imagery must be factored into the development time-frame. Assuming that DEM development runs parallel with the imagery acquisition effort and weather related issues are favorable to the effort i.e. clouds are not pervasive and the State chooses to break the effort into a more highly accurate DEM in populated regions with less focus in the "wilderness", the DEM production of the entire state would require approximately 5-6 years. This equates to roughly 250,000 km/year.

Question 16: Experience. Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.

The horizontal and vertical accuracy of the datasets above and beyond that which can be produced from imagery off of the satellite is in effect proportional to the amount, location and quality of ground control. NED and SRTM could be utilized with CARTOSAT to produce DEMs.

ASRC Management Services reliance upon value added processors included such firms as Genesys and PCI. Genesys has been engaged in utilizing CARTOSAT-1 stereo pair imagery since launch to generate DEMs of the nations of India. In the course of this massive project large volumes of data have been produced in areas of minimal or no control. Similar projects are also underway by Euromap for the end user.

Question 17: Pricing. One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity, either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)

ASRC Management Services believes that under certain circumstances such as the existence of as a "Satellite Receiving Ground Station" in Alaska that is capable of down linking CARTOSAT-1 and other imagery i.e. RESOURCESAT an expenditure of between $900,000 and $1,000,000 per year for five years will be necessary for the CARTOSAT-1 imagery alone.

Under that assumption imagery costs are 20% of that total project cost and under the scenario above, it will require an investment based on the Value Added Community charges for DEMs.

Keep in mind, the costs of "Acquiring CARTOSAT-1 Data in Alaska" is approximately $3.26/per sqkm vs. $8.60 per sqkm if CARTOSAT-1 Data is purchased from the recorder.

Question 18: IDIQ Contracts. Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.

ASRC Management Services is The Prime Contractor and subcontractor on numerous IDIQ type contracts.

ASRC Management Services manages the US Department of Agriculture Prime Vendor Contract. This contract provides access to numerous types of satellite imagery providers and other unique capabilities such as Cloud and haze removal and digital watermarking of imagery.

ASRC MS is also a partner in the NJVC which manages a multimillion dollar IDIQ for NGA in St. Louis providing numerous Geospatial Services.

Synthetic Aperture Radar (SAR) Sensors

MDA (Radarsat-2)

Question 1: **Sensor. What sensor do you propose to use for acquisition of source data to be used for your DEM production?**

RADARSAT-2

Question 2: **Model. Are your DEMs produced from the digital surface model (DSM) of the top reflective surface, or do you also produce DEMs from the digital terrain model (DTM) of the bare-earth or near bare-earth—or a combination or other process?**

Digital Surface Model (DSM)

Question 3: **Native Z accuracy. With minimal ground control, what is the vertical accuracy ($Accuracy_z$) of your DSMs at the 95% confidence level? Note: $Accuracy_z = RMSE_z$ x 1.9600.**

Error Slope Dependency	Statewide 20-30 m postings Multi-Look Fine Beam Modes $Accuracy_z$ (LE95)	Local/Regional 10-30 m postings Ultra Fine Beam Modes $Accuracy_z$ (LE95)
All slopes combined	15 m (83-ft contour accuracy)	11 m (61-ft contour accuracy)
0° to 10° slopes	8 m (44-ft contour accuracy	6 m (33-ft contour accuracy)
11° to 20° slopes	12 m (66-ft contour accuracy)	8 m (44-ft contour accuracy)
21° to 30° slopes	15 m (83-ft contour accuracy)	11 m (61-ft contour accuracy)
31° to 40° slopes	17 m (94-ft contour accuracy)	12 m (66-ft contour accuracy)
>40° slopes	20 m (110-ft contour accuracy)	15 m (83-ft contour accuracy)

Question 4: **Improved Z accuracy. For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?**

Theoretically we can improve statewide vertical accuracy of slopes between 0 and 20 degrees to a better number (~5 m) if we would blend in the ERS tandem InSAR archive with the Radarsat-2 radargrammetry. This would then be equivalent to 27.5-ft contour accuracy, improved from the 44-ft to 66-ft contour accuracy cited in the table above.

Question 5: **<u>Radial accuracy</u>. What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: $Accuracy_r = RMSE_r \times 1.7308$.]**

Approximately 25 m CE95

Question 6: **<u>Grid spacing</u>. What DEM grid spacing do you normally use or provide?**

10-30 m

Question 7: **<u>Deliverables</u>. What is delivered with your product, e.g., DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc.? Please distinguish between standard products and value-added products.**

DSM, ortho radar image (optional breaklines, features, waterbodies, rivers etc)

Question 8: **<u>Archive</u>. If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g., produced DEMs, validated data, raw data meeting cloud specs, etc?**

We have currently little or no DEM coverage (Radarsat. However we have a capacity for relatively quickly acquiring Alaska with the MLF beam mode (50 km swaths). The advantage of satellite radar is the reliability of acquiring good data. Radarsat-2 has a great capacity for acquiring large volumes of data. We might be able to acquire the coverage for Alaska within ~6 months, certainly within 1 year.

Question 9: **<u>Products</u>. Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?**

We deliver DEM products.

Question 10: **Processor. If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain software that works well? Do you have established processing partners? Is there an opportunity for local Alaska productions of DEMs?**

We have a good relationship with ASF. We might be able to find an arrangement for collaboration.

Question 11: **Special Applications. Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.**

We operationally provide InSAR Deformation services for oil and gas and mining industries. We could possibly include deformation monitoring applications into this program if this is of interest. This could be applied to specific areas of interest to Alaska (e.g. for oil fields or other sites of interest). The radar data is also suitable for other types of change detection (urban, permafrost etc).

Question 12: **Ground control. What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you require more? If more control is required, what spacing or density of survey points would be needed?**

In principle we are able to provide horizontal accuracy based on orbit alone of 15 m CE90 or better. The NGS control would likely be sufficient to check horizontal quality (adjust if necessary) and for vertical control/calibration.

Question 13: **Geodesy issues. How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection? Do you have preference for datums, projections, coordinate systems, units?**

We do not expect to have significant problems. We are flexible as to the needs of the customer.

Question 14: **License. What license options are available for your elevation data? Whereas the State would prefer to have licenses such that the data can be inserted into the National Elevation Dataset (NED), this could change if alternative licensing turns out to be more advantageous for other reasons.**

Our standard license is a license to use (for State of Alaska etc.). Some flexibility exists and negotiations are possible.

Question 15: <u>Production volume</u>. How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.

Our current estimate is that we could acquire all data required for DEM generation with Multi-Look Fine for the state of Alaska within 1 year. The production would start in parallel and could be completed within 1 to 2 years depending on budgets and requirements.

Question 16: <u>Experience</u>. Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.

DTED-2 from ERS InSAR DEMs for the Canadian Government, CTI (Center for Topographic Mapping) (Baffin Island). We used Canadian Digital Database (similar to NGS) for control. The purpose was the generation of elevation data for 1:50,000 maps. The data was fully finished (waterbody flattening, drainage patterns etc.) using vectors that were provided by the client. Several 100 mapsheets were provides and were integrated in maps and also provided as DEMs to users.

MDA-GSI has ample mapping experience in many areas of the world (photogrammetry).

The use of ERS InSAR in combination with the Radarsat-2 Radargrammetry might be an option if of interest to the users.

Question 17: <u>Pricing</u>. One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity, either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)

We have no publicly posted pricing. Our pricing is likely in bin 1 or low bin 2.

Question 18: <u>IDIQ Contracts</u>. Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.

Subcontractor for Dewberry's USGS GPSC contract.

Intermap Technologies (STAR 3, 4, 5, 6)

Question 1: **Sensor. What sensor do you propose to use for acquisition of source data to be used for your DEM production?**

Intermap proposes their fleet of airborne IFSAR sensors to use for acquisition of source data to be used for DEM production. IFSAR (Interferometric Synthetic Aperture Radar) is a radar-based remote sensing technique that provides X, Y, and Z coordinates of a location imaged by a radar beam at high accuracy. Our fleet is made of IFSAR sensors onboard two Lear jets (STAR-3 and STAR-5) and two King Air airborne platforms (STAR-4 and STAR-6). Any one of these sensors is capable of collecting 4000 km^2 per hour.

Intermap's IFSAR systems use two antennas separated by an interferometric baseline (B) to image the earth's surface by transmitting radar pulses toward the terrain. The reflected energy, represented by the lines from the two antennas to the terrain below, is recorded by both antennas, simultaneously providing the system with two SAR images containing amplitude and phase of the same point on the ground, separated only by the phase difference created by the space between the two antennas. In addition, as the aircraft passes over the terrain, global positioning system (GPS) data from both aircraft- and ground-based GPS devices and navigation data from an Inertial Measurement Unit (IMU) onboard the aircraft are collected. The phase difference between the antennas for each image point — along with range, baseline, GPS, and navigation data — is used to infer the precise topographic height of the terrain being imaged. This enables us to create an interferogram (depicting the phase difference) from which we derive our digital terrain models (DSMs) and orthorectified radar images (ORIs). Through additional processing, we generate our digital Terrain Model (DTM) and colorized orthorectified radar image (CORI) products.

Question 2: **Model. Are your DEMs produced from the digital surface model (DSM) of the top reflective surface, or do you also produce DEMs from the digital terrain model (DTM) of the bare-earth or near bare-earth—or a combination or other process?**

- Intermap creates first surface digital surface models (DSM's) as well as fully edited digital terrain models (DTM's).
- Both products are edited within a three dimensional environment using our proprietary editing system (called IES – Interferometric Editing System). This is an ISO compliant editing and quality controlled process. A combination of tools within IES provides the ability to create bald-earth DTM's from the source IFSAR - DSM, as well as incorporating best available ancillary data in areas of ground obstruction. All DSM and DTM are fed through our quality system and 10% of all data are independently verified and validated.
- See section 6.2.2 (page 50) of Product Handbook version 4.2 for more detail on Intermap's Fully Integrated Terrain Solution (FITS) Editing Process.
- Additional information about these products is available in questions below.

Question 3: **<u>Native Z accuracy</u>. With minimal ground control, what is the vertical accuracy ($Accuracy_z$) of your DSMs at the 95% confidence level? Note: $Accuracy_z = RMSE_z \times 1.9600$.**

The State of Alaska is seeking statewide solutions to acquire DEMs with postings between 30 and 10 meters (1-arc-second and 1/3-arc-second). The vertical errors in the elevation data should not exceed 10-20 meters at the 95% confidence level. Intermap can meet the requirements of a 10-20 meter 95% confidence level.

Slopes less than 10 degrees:

- Type III DSM/DTM has a 6 meter or better vertical accuracy at 95% confidence level, for open areas of slope less than 10 degrees.
- Type II DSM/DTM has a 2 meter or better vertical accuracy at 95% confidence level, for open areas of slope less than 10 degrees.
    - Most often in flat terrain, the RMSE is approximately 70 cm; and thus 1.4 meters at 95% confidence level, for open areas of slope less than 10 degrees.

	Measures of Vertical Accuracy			
	Specifications		Nominal	
Product	**$RMSE_z$**	**$Accuracy_z$**	**Mean**	**Std. Dev**
DSM Type I	0.5 m	1.0 m	0.3 m	0.3 m
DSM Type II	1.0 m	2.0 m	0.7 m	0.7 m
DSM Type III	3.0 m	6.0 m	2.0 m	2.0 m
DTM Type I	0.7 m	1.0 m	0.5 m	0.5 m
DTM Type II	1.0 m	2.0 m	0.7 m	0.7 m

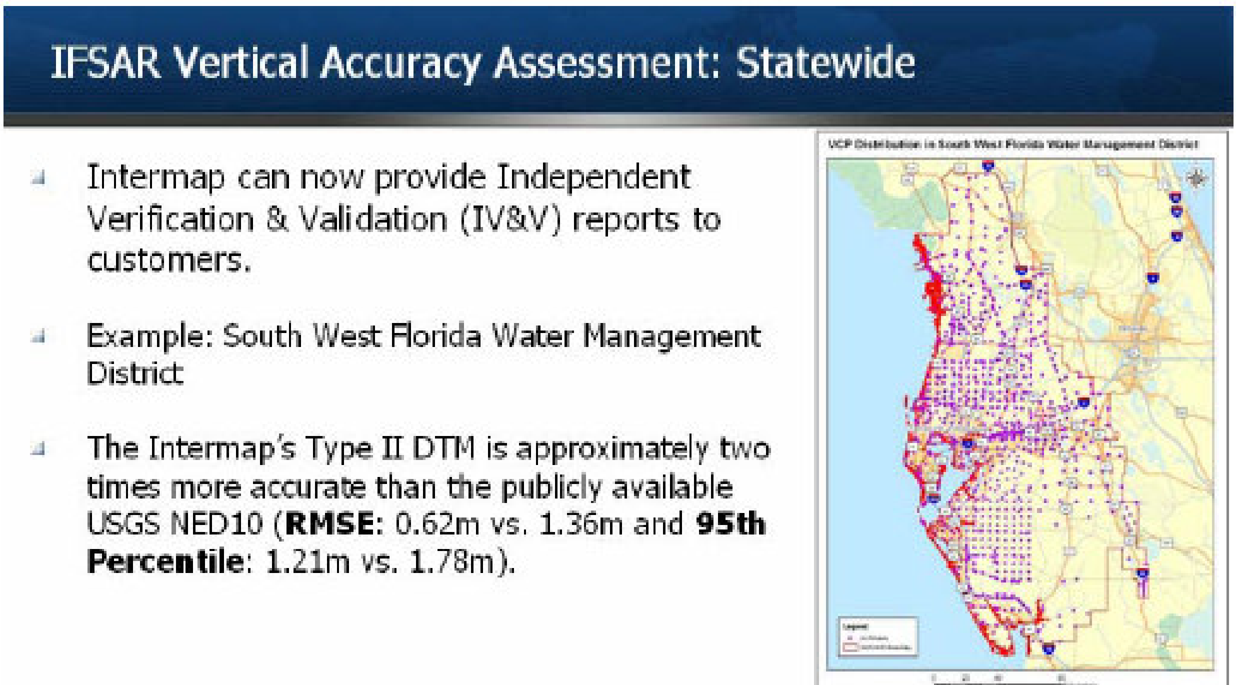
Slope effects: Slopes greater than 10 degrees cause reduced accuracy. Slope may be terrain slope or it may also be localized slopes caused by first surface features. The impact depends on the magnitude of the slope, whether the slope is positive or negative, aspect angle and where it lies in the radar swath (look angle). As a general rule, the RMSE will increase in areas with slopes above 10 degrees. In areas with slopes of 20-30 degrees, the RMSE is estimated to double, and it will continue to increase as the slope increases.

Slopes 20-30 degrees:

- Type III DSM/DTM has a 12 meter or better vertical accuracy at 95% confidence level, for open areas of slope between 20-30 degrees.
- Type II DSM/DTM has a 4 meter or better vertical accuracy at 95% confidence level, for open areas of slope between 20-30 degrees.

Intermap can provide Independent Verification & Validation (IV&V) reports for large project areas previously collected in Alaska.

An example of an independent verification and validation report is presented below.



	DSM	DTM	NED30m*	NED10m**
Total VCPs	1442	1442	1442	1442
STDEV	0.63	0.61	1.38	1.34
RMSE	0.64	0.62	1.41	1.36
95 Percentile	1.26	1.21	1.95	1.78

*NED 30m purchased from Global Mapper 2004
**NED 10m downloaded from USGS seamless database Feb-06 (http://seamless.usgs.gov/)

Question 4: **Improved Z accuracy. For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?**

- Intermap uses military grade GPS/IMU parameters for Type III DSM/DTM collection, in addition to STRNAV, Intermap's proprietary navigational software, to post process differentially GPS data collected by our survey team within the project area.
- The sparse CORS network is not a concern as Intermap uses a PPP (precise point positioning) technique for the GPS processing prior to the GPS/INS integration of the navigation data. This

PPP technique relies on precise ephemeris data computed by the International GNSS Service (IGS). The CORS stations (i.e. DGPS) are used as backup in the case of a poor PPP solution, with baseline lengths of up to 300km (Type III data) suitable for obtaining our specified vertical accuracies.

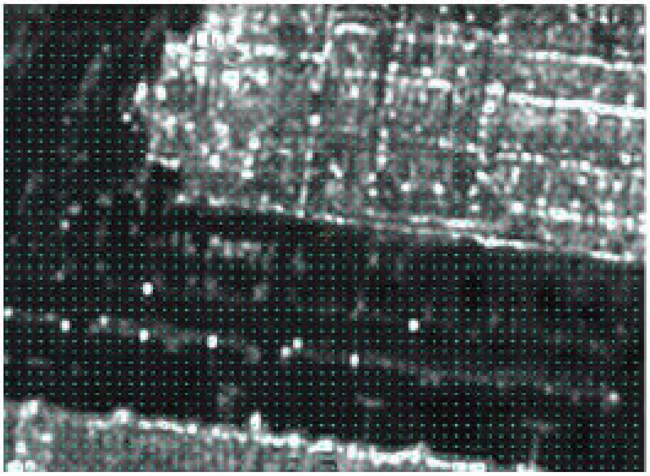
- Type II DSM/DTM requires some limited ground control (radar reflectors) at corner tie points, and, optimally, additional limited control near the center of a given acquisition block. In Alaska we would be flying “Ultra Long Lines” of approx. 1,200 km in length, per acquisition block.
- By surveying radar reflectors on the ends of tie lines, the vertical accuracy would improve from a Type III to a Type II product. If no reflectors are surveyed in the field a Type III vertical accuracy would be the best expected.

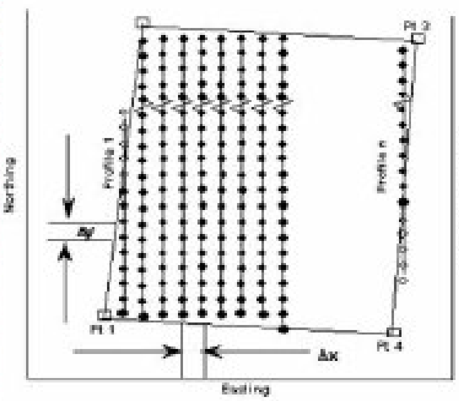
Question 5: **Radial accuracy. What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: $Accuracy_r = RMSE_r \times 1.7308$.]**

- Type II DSM/DTM has a 2 meter RMSE * 1.7308 yields a 3.46 meter horizontal accuracy at 95% confidence level.
- Type III DSM/DTM has a 2 meter RMSE * 1.7308 yields a 3.46 meter horizontal accuracy at 95% confidence level.

Question 6: **Grid spacing. What DEM grid spacing do you normally use or provide?**

- Type II & Type III DSM/DTM contains a rectangular grid of elevation values with a post spacing 5m in each direction of the grid.
- For Example: 7.5-minute quadrangle (140 km2) ~4.8 m elevation values. The illustration below depicts an orthorectified radar image, with our DTM elevation data represented as a 5 meter posted grid.





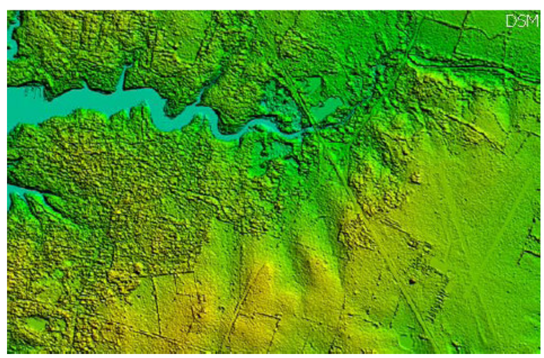
Intermap is able to resample the data to a coarser posting such as 10 or 30 meters, if so desired by the client.

Question 7: **<u>Deliverables</u>. What is delivered with your product, e.g., DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc.? Please distinguish between standard products and value-added products.**

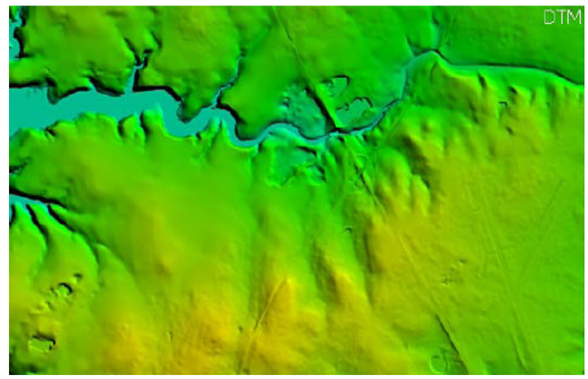
Standard Products: ORI, DSM, DTM. Metadata

Orthorectified Radar Image (ORI): The ORI is a grayscale image of the earth's surface that has been corrected to remove geometrical distortions that are a normal part of the imaging process. This product appears similar to a black-and-white aerial photograph. What differentiates an ORI from a photograph is that an ORI uses radar signals, not visible light, to produce images. As the radar waves strike the ground and return to the antennas, they also provide distance and intensity measurement data. The key feature of this product is that it provides a means of viewing the earth's surface in a way that accentuates features far more than is possible with aerial photography. The radar pulses are transmitted at an angle from the side of the aircraft, which casts "shadows" that enable the user to visually perceive the elevation information in the image, which appears similar to a shaded relief. The ORI has many applications in value-added products. For example, it can be used to extract cultural features, such as road networks and buildings, and it lends itself readily to terrain, land cover, and geological analyses. The illustration at right represents an example of an ORI.

Digital Surface Model (DSM): The DSM is a topographic model of the earth's surface that can be manipulated using a computer. It is comprised of elevation measurements that are laid out on a grid. These measurements are derived from the return signals received by two radar antennas mounted on Intermap's aircraft. The signals bounce off the first surface they strike, making the DSM a representation of any object large enough to be resolved. This includes buildings and roads, as well as vegetation and other natural terrain features. The key feature of this product is that it provides a geometrically correct reference frame over which other data layers can be draped. For example, the DSM can be used to enhance a pilot's situational awareness, create 3D fly-throughs, support location-based services applications, augment simulated environments, and conduct viewshed2 analyses. It can also be used as a comparatively inexpensive means to ensure that cartographic products, such as topographic line maps or even road maps, have a much higher degree of accuracy than would otherwise be possible. The illustration at right represents an example of a DSM.



Digital Terrain Model (DTM): Intermap has two versions of the DTM, based on when the data was collected and how it was processed. The differences between the two versions, DTM v1.0 and DTM v1.5, are described in Section *6.2 Product Characteristics*. When the DTM is mentioned in this product handbook and no version is mentioned, the implication is that the data being referred to is DTM v1.5. If you have specific questions about Intermap's DTM data and which DTM is best for your particular applications, please contact an Intermap sales representative. The DTM is a topographic model of the bare earth that can be manipulated using a computer. The DTM has had vegetation, buildings, and other cultural features digitally removed, leaving just the underlying terrain. This is achieved using our proprietary software, which derives terrain elevations based on measurements of bare ground contained in the original radar data as well as manually reviewing and editing every tile. The key feature of the DTM is that it infers the terrain characteristics that may be hidden in the DSM. The illustration below represents an example of a DTM. See how the buildings and trees that were evident in the previous figures are no longer visible. See Section *6.2 Product Characteristics* for a sample list of applications that can use the DTM v1.0 and DTM v1.5 data.



File Metadata: Standard formats for metadata files are supported; they include

HTML, XML, and flat ASCII. These formats can be generated so they comply with a number of widely recognized standards, including those set by the Federal Geographic Data Committee (FGDC). The following is a list of core product attributes that Intermap stores in the database:

- Intermap project number
- Project manager
- Country
- Task order number
- Project area
- Version (issue identification)
- Product level
- Product level accuracy (meter RMSE)
- Acquisition start date (YYYYMMDD)
- Acquisition end date (YYYYMMDD)
- Publication / process date (YYYYMMDD)
- Horizontal accuracy (meters (1 sigma))
- DSM vertical accuracy (meters (1 sigma))
- DTM vertical accuracy (meters (1 sigma))
- Flight height
- Primary look

- Secondary look
- Mission number(s)
- Phase unwrapper
- Look (primary or secondary)
- Horizontal datum
- Vertical datum
- Projection
- Ellipsoid
- Spheroid
- Alternative / forced zone
- EULA

Metadata files are created separately for each data layer. The metadata file naming convention is the same as the corresponding data file, but with an extension designating the format of the metadata file. These extensions are listed in the table below.

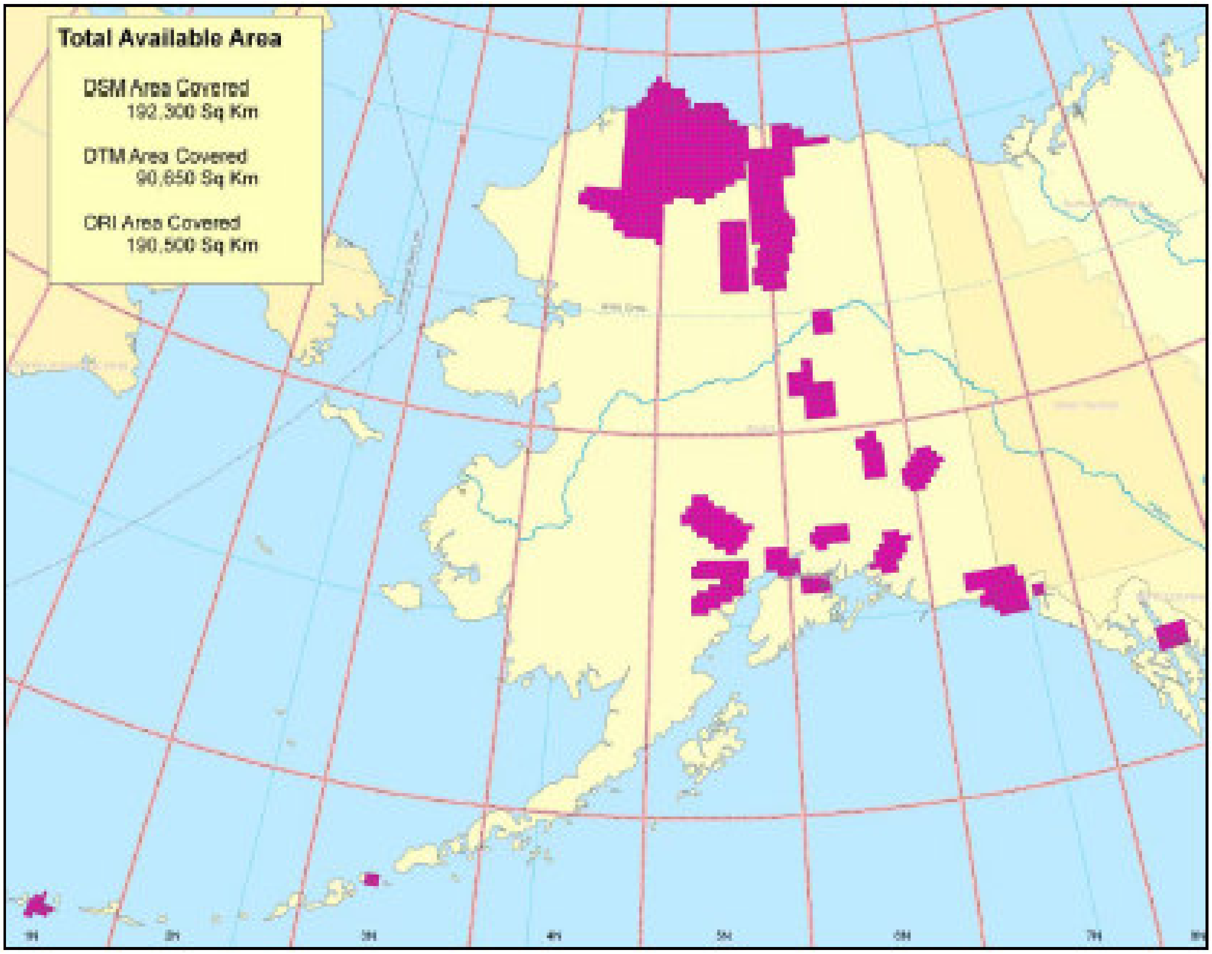
Extension	Contents
*.BIL	DSM or DTM data in 32-bit floating point binary grid format
*.TIF	ORI in 8-bit grayscale unsigned GeoTIFF format
*.JP2	CORI in 24-bit color JPEG2000 format at 1:30 compression ratio
*.html	Metadata in Hypertext Markup Language (HTML) format — FGDC-compliant standard
*.xml	Metadata in eXtensible Markup Language (XML) format — FGDC-compliant standard
*.txt	Metadata in ASCII text

Value Added Products:

Intermap offers a wide range of value added products. Intermap has a department, called professional services, dedicated to creating value added products. Examples include: canopy height models, land cover maps, orthorectified data, contours, Interferometric coherence data, Type IV TerraSAR X elevation data, topographic maps, geological maps and others. Examples of such value added products are available upon request.

Question 8: **Archive. If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g., produced DEMs, validated data, raw data meeting cloud specs, etc?**

Approximately 202,500 sq km of data, which is a mix of Type II & Type III DSM/DTM/ORI data. Some is multi-pass, most is single pass. Where present, DEM's generated from multi-pass data, ORI created from primary pass only. We can provide additional information about this should you require it.



Question 9: **Products. Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?**

Intermap delivers final mapping products, created through rigorous ISO compliant editing procedures. We do not deliver data that can be made into DEMs by others.

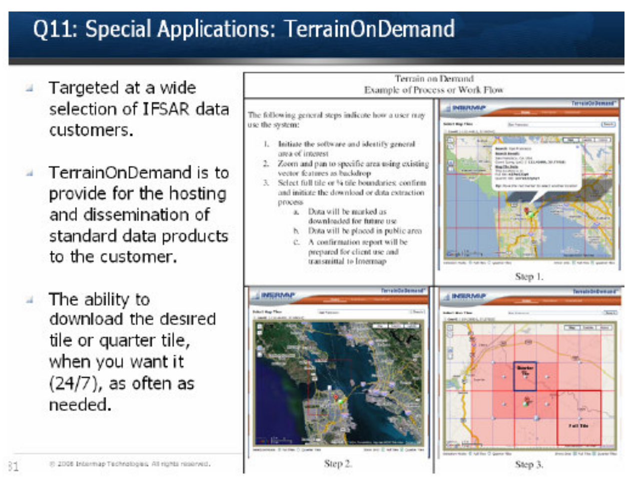
Question 10: **Processor. If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain software that works well? Do you have established processing partners? Is there an opportunity for local Alaska productions of DEMs?**

Not Applicable, as we provide final products, not source data.

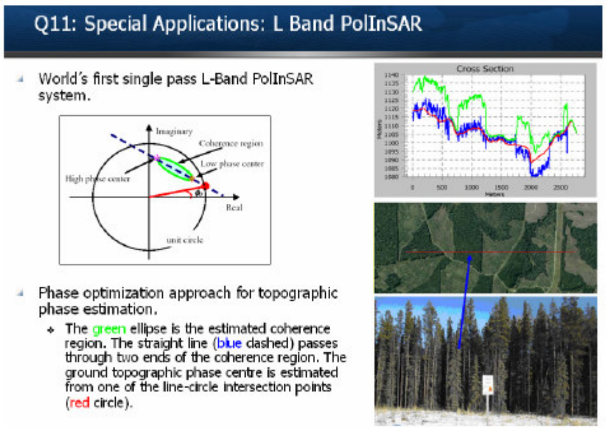
Question 11: Special Applications. Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.

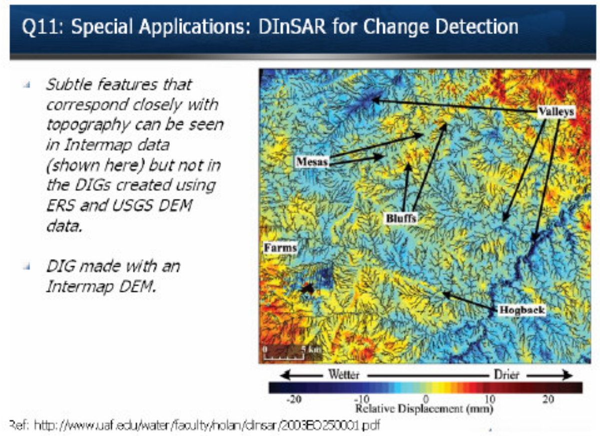
- Traditional Applications
  - Base Mapping
  - Topographic Mapping
  - Vegetation Mapping
  - Urban Mapping
  - Landuse Classification
  - Contour Maps
  - Data orthorectification
  - Land Slip Risk Assessment
  - Biomass Study
  - Geology applications
  - Flood analysis
  - Hydrology
  - Seismic Hazards
  - 3D Visualization
  - Automotive Safety, Energy Savings, Mapping Convenience
  - Infrastructure Design
  - Environmental Planning
  - Engineering Planning
  - Telecommunications
  - Off-road Recreational (PDA)

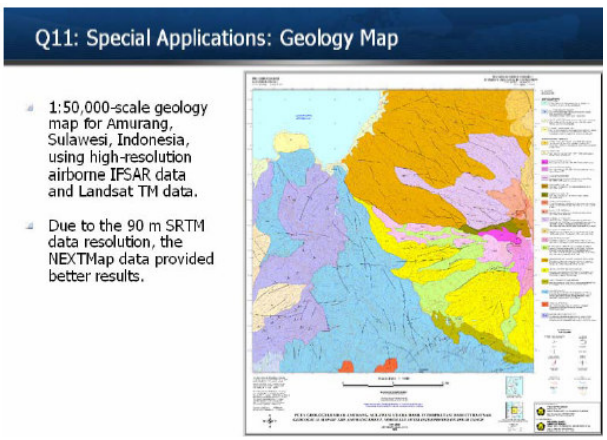
- Examples:
  - 3D Road Vector
  - 1:20,000 Base Mapping
  - Geologic Structure Mapping
  - Lithology
  - Data Fusion (multiple sources)
  - DInSAR for subsidence, vertical displacement, costal monitoring
  - World's first L-Band PolInSAR
  - Training
  - TerrainOnDemad
  - Type IV – TerraSAR X Elevation Data

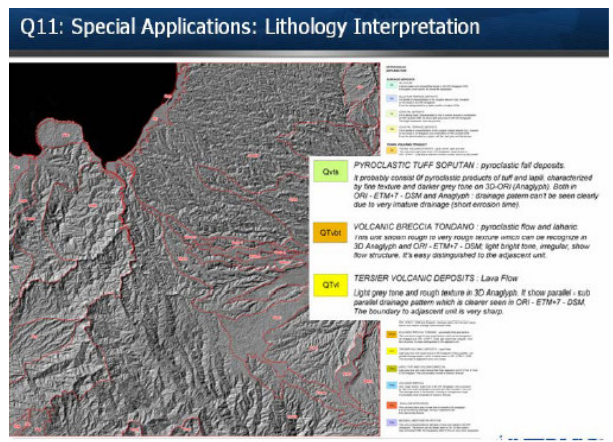


Intermap has three departments devoted to special applications. The first is the research and development department, which is currently working on polarimetric interferometric SAR (known as PolInSAR) to derive bare earth elevations using l-band radar sensing. The second is the professional services group which is responsible for the producing elevation data using TerraSAR X and radargrammetric principals as well as void fills for the SRTM data and topographic and geological maps. The third is the Solutions group who are working on: deriving a canopy height model from our X-band sensors; creating a terrain on demand solution to allow for easy access to our data 24/7; biomass and land and fire applications, and using our elevation data in conjunction with spaceborne SAR data and differential InSAR methods to monitor subsidence, coastal erosion, as well as other changes in elevation. A few examples are provided here.









Question 12: **<u>Ground control</u>. What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you require more? If more control is required, what spacing or density of survey points would be needed?**

- Type III DSM/DTM does not require ground control points
- Existing NGS GCPs would be usable if visible in the data
- Type II DSM/DTM requires radar reflectors placed at corner tie lines, and, optimally, a few in the center of an acquisition block

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Question 13: **Geodesy issues. How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection? Do you have preference for datums, projections, coordinate systems, units?**

Intermap is very experienced in data collection in Alaska, and we have successfully addressed all challenges stated in past Alaska projects, as well as other extremely remote and rugged areas are the globe. The sparse CORS network will not be a concern as Intermap uses a PPP (precise point positioning) technique for the GPS processing prior to the GPS/INS integration of the navigation data. This PPP technique relies on precise ephemeris data computed by the International GNSS Service (IGS). The CORS stations (i.e. DGPS) are used as backup in the case of a poor PPP solution, with baseline lengths of up to 300km suitable for obtaining our specified vertical accuracies. Intermap's stringent QC on the navigation solution would ensure that any lines/flights where the GPS data is impacted by high solar activity that would make it unsuitable for achieving our published accuracies would be re-flown.

We store all our data in ellipsoidal heights but usually deliver in orthometric heights because this is typically what is requested by the end user.

- Core product spec: Geographic Coordinate System, lat/long, meters (NAD83, NAVD88 in AK). However we can provide whatever the client wishes.

Question 14: **License. What license options are available for your elevation data? Whereas the State would prefer to have licenses such that the data can be inserted into the National Elevation Dataset (NED), this could change if alternative licensing turns out to be more advantageous for other reasons.**

Intermap is willing to negotiate a license agreement that will suit the uses requirements, below are a few (not all) options:

- Standard Intermap EULA which restricts use to specific parties, or
- All Government License: Federal, State, Local Govt. We will work with SDMI team to include entities that must be included. Non-commercial. Intermap will retain the right to re-sell the data to Oil & Gas companies and other commercial entities.
- Or Public Domain

Question 15: **Production volume. How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.**

- Type III data collection could be complete in two flying seasons, possibly one. We are open to discuss this further.

- An additional 18 months to fully process and edit the data (DSM/DTM/ORI)
    - Example edits are to remove spikes and wells, water bodies leveled, drainages enforced to be monotonic
    - We have 480 editors in two production facilities to work on the data. We work within a three-dimensional environment using a set semi-automated process. Human eyes look at every 7.5" tile for, at the least, 9 hours.

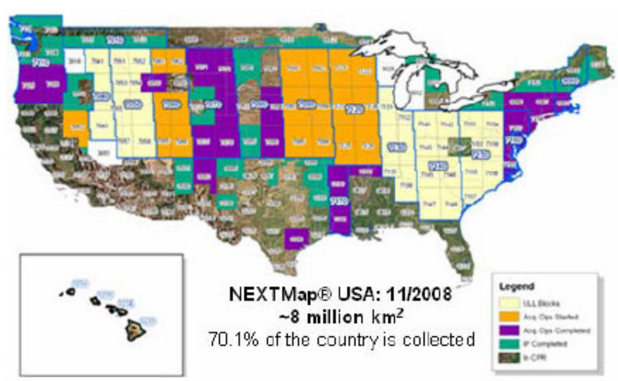
DSM and DTM Feature Content

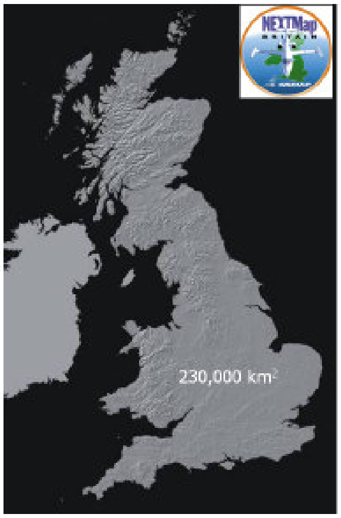
Fully populated raster files represent the elevation models. If the target could not be resolved by the sensor, the values in that area are set to -10,000, otherwise known as the NULL data value. Where the sensor was targeted at the ground but no return signal was received, the elevation is interpolated from the surrounding terrain. The location of these areas of interpolation is identifiable in a correlation file, which is available as a value-added product. Due to the nature of radar, certain features must be edited in the DSM and the corresponding DTM. To ensure our products are consistent, well-defined rules have been established and are abridged in Table 6-8 below. These correspond to the manner in which the DTM v1.5 data is edited. The abridged version of the edit rules below does not include all exceptions and is provided only as a guide. In some cases, ancillary data is required to aid in feature identification. The comprehensive edit rules indicate where and how ancillary data is used to support the elevation model editing. The complete list of edit rules is available for existing Intermap clients and business partners upon request.

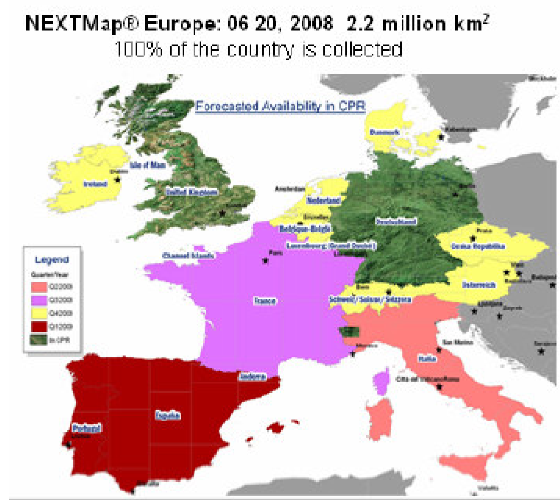
Tables of DSM and DTM feature content are available upon request.

Question 16: <u>Experience</u>. Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.

Intermap has a vast amount of data collection experience. We have collected 2 million km^2 of standard products data in the most rugged terrain across the globe (Solomon Islands; Vanuatu; Kalimantan; Sulawesi, and other areas). To date we have collected approximately 13 million km^2 across the globe. In Alaska, we have collected and delivered standard products for 202,500 km^2. Examples of large area data collection are provided below for NEXTMap USA, NEXTMap Britain and NEXTMap Europe.







Question 17: **Pricing. One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity, either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)**

Pricing will be discussed under a non-disclosure agreement (NDA). Pricing is based on a number of parameters such as (but not limited to):

- **NEXTMap data or Customer Collect Data Offering (both of which offer competitive pricing).**
- **Many product types: Types I-IV DTM/DSM/ORI – Blended solution.**
- **Depends on requirements, license/public domain.**
- **Depends on the end-users (type, volume, applications).**
- **Whether we incorporate archived data.**

Question 18: **IDIQ Contracts. Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.**

Prime contractor under: USGS, NGA, IDIQs

Subcontractor under Dewberry USGS (GPSC) and NOAA (CGSC)

Subcontractor under Boeing

Fugro EarthData (GeoSAR)

Question 1: Sensor. What sensor do you propose to use for acquisition of source data to be used for your DEM production?

Fugro EarthData proposes to use GeoSAR radar mapping to produce the Alaska statewide DEM; our lidar and digital camera capabilities also can be used for areas where higher resolution and accuracy may be required. GeoSAR is a dual-sided, dual-frequency, interferometric synthetic aperture radar (IFSAR) mapping system. Highlights of GeoSAR follow:

PLATFORM:	GeoSAR is integrated onto a Gulfstream-II jet
ACQUISITION:	The system typically operates from 40,000 ft and at an airspeed speed of over 400 kts to yield a net collection rate of over 280 sq km per minute
RADAR FREQUENCY:	The SAR operates at two frequencies simultaneously: – X-Band operates with a center frequency of 9,700 MHz – P-Band operates with a center frequency of 350 MHZ
STANDARD PRODUCTS:	The system produces accurate DEMs through the process of radar interferometry, as well as SAR orthophoto mosaics

Additionally, GeoSAR incorporates a profiling lidar system for in-air ground control. This capability provides an accurate measure of surface height and can serve as an excellent substitute to sending surveyors into difficult or dangerous areas for collection of ground control points. The lidar profiler also helps to define canopy structure of the foliage and can be used to aid P-band data interpretation. Characteristics of the on-board lidar profiler follow:

– Variable pulse rate, 0 to 45 kHz (10,000 Hz at 10,000 meters AGL)
– 1,064 nanometer wavelength
– 4-Watt laser transmitter, 0.15 mj max/pulse
– 8.5 nanosecond pulse width
– 3 ranges (first, second, true last) with 3 intensities (first, second, third)
– 3 m spot size at 10,000 meters AGL
– 2 cm post spacing at 180 m/s velocity

Question 2: Model. Are your DEMs produced from the digital surface model (DSM) of the top reflective surface, or do you also produce DEMs from the digital terrain model (DTM) of the bare-earth or near bare-earth—or a combination or other process?

The X-band produces a DSM; the 3 cm center wavelength signal will tend to reflect off the tops of trees; the P-band signal, with an 85 cm center wavelength, will penetrate deep into the forest canopy, often producing, through post-processing, a true DTM.

Question 3: Native Z accuracy. With minimal ground control, what is the vertical accuracy ($Accuracy_z$) of your DSMs at the 95% confidence level? Note: $Accuracy_z = RMSE_z \times 1.9600$.

The Z-accuracy for a DSM produced from the GeoSAR sensor data can be estimated in three ways:

1. The residual $RMSE_z$ resulting from the least squares adjustment of the tie and control points used to tie swaths together into a block
2. A comparison between the elevation values from the DSM with the points derived from the lidar profiler data
3. A comparison between the DSM and external surveyed check points

Examples of each method follow:

- **Method 1:** the residual $RMSE_z$ resulting from the least squares adjustment of the tie and control points used to tie swaths together into a block.

  Yazoo County, Mississippi

  - Very flat terrain
  - 32 swaths
  - 132,000 tie points
  - $RMSE_z$ = 0.93 m
  - LE_{95} = 1.82 m

  SE Asia, Block 8

  - Rolling Terrain
  - 120 swaths in solution
  - 2,300,000 tie points
  - $RMSE_z$ = 2.70 meters
  - LE_{95} = 5.92 meters

  SE Asia, Block 2

  - Extreme terrain (sea level to +4000 m)
  - 48 swaths in solution
  - 66,000 tie points
  - $RMSE_z$ = 3.72 m
  - LE_{95} = 7.29 m

- **Method 2:** a comparison between the elevation values from the DSM with the points derived from the lidar profiler data.

  Yazoo County, Mississippi

  - 695 lidar points in open terrain
  - $RMSE_z$ = 0.92 m
  - LE_{95} = 1.80 m

  SE Asia, Block 8

  - 159 lidar points in open terrain
  - $RMSE_z$ = 4.48 m
  - LE_{95} = 8.78 m

– **Method 3:** a comparison between the DSM and external surveyed or photogrammetric check points.

  NOAA Southern California Project

  – Moderate terrain
  – 10 surveyed control points
  – $RMSE_z$ = 0.95 m
  – LE_{95} = 1.86 m

As a conclusion, the Z-accuracy for the GeoSAR-derived DEM will vary with terrain roughness, but will be better than the 10-20 m LE_{95} requirement that was stated in the background information provided to us.

Question 4: Improved Z accuracy. For producing digital topographic data of Alaska, would you plan to rely upon satellite or GPS/IMU parameters for accuracy, or would you plan to establish an improved control network? What improved vertical accuracy would you then hope to achieve for your DSMs or DTMs with improved ground control?

GeoSAR relies on military-grade encapsulated GPS/IMU (EGI) positioning. Depending on the logistics of the project, it also relies on one of the following for precise position of the aircraft:

– dGPS from local position set-up in project area
– CORS net stations
– Precise ephemeris solutions from the Natural Resources Canada Precise Point Positioning (NRC-PPP) service

Fugro EarthData would also install a surveyed array of radar reflectors within the block to provide control and check points. Any additional control points will mainly be used to validate the GeoSAR results, and not to significantly improve the vertical accuracy.

Question 5: Radial accuracy. What is the (radial) horizontal accuracy ($Accuracy_r$) of your DSMs or DTMs at the 95% confidence level? [Note: $Accuracy_r$ = $RMSE_r$ x 1.7308.]

The typical radial accuracy for GeoSAR products is better than 2 pixels, in line with the ASPRS accuracy standards:

– $Accuracy_r$: X-band 3 m pixel = 6 * 1.7308 = 10.4 m
– $Accuracy_r$: P-band 5 m pixel = 10 * 1.7308 = 17.3 m

The residual $RMSE_{xyz}$ resulting from the least squares adjustment of the tie and control points used to tie swaths together into a block is generally 2-3 m.

Question 6: Grid spacing. What DEM grid spacing do you normally use or provide?

Standard GeoSAR DEM spacing is 3 m for X-band, 5 m for P-band, significantly higher than the 10-30 m requirement as stated in the project background documents. Fugro EarthData could consider a variable resolution solution for AK to include:

- Higher resolution in flat areas such as the North Slope
- Lower resolution in mountain ranges

Lower resolution (as stated above) would allow an averaging of several height estimates into every point, greatly improving the relative accuracy.

Question 7: Deliverables. What is delivered with your product, e.g., DEM, DSM, breaklines, contours, orthoimage, ortho radar image, backscatter intensity, etc.? Please distinguish between standard products and value-added products.

Standard GeoSAR deliverables include:

- **Orthorectified radar imagery**
  - P-band imagery: 5 m pixel resolution data depicting ground features and structures hidden beneath foliage and very dry soils
  - X-band imagery: 3-5 m pixel resolution data depicting above ground features
- **Digital elevation models**
  - P-band DEM: 5 m post-spacing
  - X-band DEM: 2.5-3 m post-spacing
- **Relative error maps for X- and P-band datasets**

Value-added GeoSAR deliverables include:

- **Image Products:** $Sigma_0$ image product which normalizes the backscatter return per unit area, useful in land-cover extraction and similar tasks; false-color images that are a combination of X- and P-band image data; stereo pairs created from SAR imagery and elevation models
- **Digital Terrain Model (DTM):** produced by a combination of the X-band DEM (for open terrain) and the P-band DEM for forested terrain, requiring some editing and filtering to produce bare-earth model
- **Topographic/Thematic Mapping:** includes the ability to extract specific data types, such as breaklines, contours, drainage, and road networks

Question 8: **Archive. If you have created DEMs for previous projects or acquired data that can be used to produce DEMs, how much coverage do you have for Alaska? To what specification? What is the status of the data coverage, e.g., produced DEMs, validated data, raw data meeting cloud specs, etc?**

Fugro EarthData currently has no GeoSAR holdings of digital elevation data for Alaska.

Question 9: **Products. Do you deliver a DEM product or do you deliver data that can be made into DEMs by others?**

The basic products of the GeoSAR system are orthorectified image mosaic and DEMs.

Question 10: **Processor. If you provide data to generate DEMs, rather than a finished product, what is required to produce DEMs from your data? Have you found certain software that works well?**

N/A. Fugro EarthData uses Terrasolid's TerraScan and TerraModeler software packages to perform product finishing.

Do you have established processing partners?

Yes, Fugro EarthData has a well established network of out-source resources for DEM production and finishing

Is there an opportunity for local Alaska productions of DEMs?

Yes, Fugro EarthData can work with qualified local Alaska companies to provide DEM production and finishing services

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Question 11: Special Applications. Please identify special applications for planimetric and topographic mapping, and unique value-added applications such as vertical change detection, for example.

As discussed previously, GeoSAR data can support most aspects of planimetric and topographic mapping. Additionally, Fugro EarthData has ongoing R&D projects in several areas:

- Identification of inundation under tree canopies, in cooperation with NGA
- Identification of crop types using GeoSAR data, in cooperation with USDA
- Surveying of forest characteristics (stem diameter, biomass, fuel loading etc.), in cooperation with the Virginia Tech Forestry Department

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Question 12: Ground control. What are your requirements for ground control points for acquisition, production, and/or horizontal/vertical accuracy testing? What accuracy would you require both horizontally and vertically for such ground control? Would the existing NGS control be suitable for your needs, or would you require more? If more control is required, what spacing or density of survey points would be needed?

GeoSAR can achieve the previously reported accuracy levels with little or no ground control. We propose installing a sparse network of radar reflectors that are precisely positioned to be used for quality control and accuracy verification.

Question 13: Geodesy issues. How do you propose to address geodesy issues such as sparse CORS network, geoid limitations, and the impact of solar activity (k-index) on airborne and ground GPS data collection?

Fugro EarthData has found that it can overcome sparse CORS network through the use of precise ephemeris solutions from the Natural Resources Canada Precise Point Positioning (NRC-PPP) service. The basic output of the processing system is ellipsoid heights; GeoSAR (and all data providers) will be dependent on the published NGS models, and will probably not amount to a discriminating factor between providers. We are currently at a solar minimum, but at high latitudes minor solar events can affect GPS accuracies; Fugro EarthData will monitor the solar environment through NOAA services, and make decisions in the field.

Do you have preference for datums, projections, coordinate systems, units?

Fugro EarthData can accommodate customer preferences in these areas.

Question 14: License. What license options are available for your elevation data? Whereas the State would prefer to have licenses such that the data can be inserted into the National Elevation Dataset (NED), this could change if alternative licensing turns out to be more advantageous for other reasons.

Fugro EarthData collects and processes data based on a fee-for-services business model; in other words, the data is wholly owned by the customer.

Question 15: Production volume. How much area could you produce each year over Alaska? Incorporate factors such as clouds, sun angle, and available duty cycle.

Assuming a collection season of May 1 to September 30, the State of Alaska (1,717,855 km^2) can be collected in 5 seasons using GeoSAR.

Question 16: Experience. Please provide examples if you produced large volumes of data in remote, poorly ground controlled areas in the past.

Project Location	Area (sq. km)	Longest Flight Line (km)	Duration of Collection (days)
California	45,000	<220	Collected in 3 separate phases
Colombia/Panama	94,000	200	110
Colombia	50,000	200	36
Colombia	52,000	445	41
SE Asia	Phase I: 321,000 Phase III: 62,438	753	127
Colombia	62,499	535	39
Colombia/Ecuador	30,610		
Colombia	70,755	361	24

Question 17: Pricing. One goal of the workshop is to bin solutions by cost. A potential binning is <$10M, $10-30M, >$30M. We recognize that pricing is often proprietary, but if you have publicly posted pricing and general discount plans for large volumes, please provide. This information will go into public documents. There will be opportunity,

either through a future RFP or discussions under NDA, to discuss pricing with potential buyers. Costs should approximate all expenses (tasking, collection, production, licensing to include annual subscription fees, etc.)

Fugro EarthData treats all project estimates and costing data as proprietary information; we are happy to answer this question, however, we would prefer to address this in a non-public forum.

Question 18: IDIQ Contracts. Are you a prime contractor and/or subcontractor on existing government IDIQ contracts? If so please list the contract(s) as well as name(s) of prime contractor(s) for which you serve as subcontractor.

- **NOAA, Costal Services Center**
  Architect and Engineering Services (Non-Construction), Coastal Geospatial Services
  Contract Number: EA133C-05-CQ-1051
  Fugro Prime Contract
- **National Geospatial-Intelligence Agency**
  Global Geospatial Intelligence (GGI) Contract
  Contract Number: HM157404D0002
  Fugro Prime Contract
- **U.S. Army Corps of Engineers, St. Louis District**
  Indefinite Delivery AE contract for Photogrammetric Mapping and Aerial Photography
  Contract Number: WP12P9-06-D-0510
  Fugro Prime Contract
- **Bureau of Reclamation**
  Contract for Aerial Photography and Mapping, Bureau-wide
  Contract Number: 03-CA-40-8025 (recently re-awarded 8/7/08)
  Fugro Prime Contract
- **U.S. Geological Survey**
  Geospatial Products and Services Contract (GPSC)
  Contract Number: 07CRCN0004
  Subcontractor to the Dewberry
- **U.S. Fish and Wildlife Service – Region 7**
  IDIQ contract for Aerial Imagery and Mapping Services within the State of Alaska
  Contract Number: (recently awarded on 6/1/08)
  Subcontract to L3 Communications - Titan group

All of these represent current U.S. government contract vehicles available that could be used to help support mapping work in Alaska.

Appendix E — IFSAR Geometry Artifacts

The first section below is quoted verbatim from a report provided to Dewberry on 8/19/08 by Dr. Kirk Waters of NOAA's Coastal Services Center.

NOAA Review of NEXTMap USA IFSAR Data

Introduction

"The National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center partners with private-sector companies to provide geospatial data to the coastal resource management community. With a demonstrated need for updated digital elevation models (DEM) by the community, the Center has acquired Interferometric Synthetic Aperture Radar (IfSAR) data. IfSAR data can provide an accurate and detailed synoptic elevation model at a reasonable cost.

"As with any data set, the user needs to be aware of its limitations. IfSAR's performance is best in sparsely vegetated areas with relatively low slopes and away from dense urban areas. Also, analysis using an IfSAR elevation model is more appropriate for a watershed-scale analysis and is probably not appropriate for a detailed analysis of a small region (e.g., determining the height of a specific tree). If available, ancillary information, such as land cover maps or the IfSAR correlation mask[13], can be very helpful in indicating areas where the elevation model is likely to be less accurate. As with any project, the data limitations need to be considered within the context of the application.

"This document provides initial guidance on the use of Intermap's NEXTMap USA IfSAR product; however, most of the cautions apply to any IfSAR data set. The intent is to provide potential users with information on the limitations of the technology and avoid inappropriate application of the data. While most of the cautions expressed in this document can also be found in Intermap's *Product Handbook and Quick Start Guide*[14] (version 3.3, hereafter referred to as *handbook*), some considerations were only discovered during further discussions with Intermap. In these notes, we, the NOAA Coastal Services Center and its staff, have selected the issues we consider most relevant to our partners. The primary focus is on the identification of areas that may not meet the fundamental accuracy[15] specification. It should be noted that the products from the IfSAR vendors we have worked with do meet their specifications for accuracy, but their specifications need to be clearly understood. Additional information on applications and editing rules can be found in the product *handbook*.

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[13] A correlation mask can show where the IfSAR system was unable to determine the elevation with sufficient confidence and, thus, where interpolation was required.

[14] *www.intermap.com/products/ProductHandbookVer3.3.pdf*

[15] Fundamental accuracy is determined from checkpoints located only in open terrain. See the National Digital Elevation Program's *Guidelines for Digital Elevation Data* for more information (*www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf*)

Ground Truth and Accuracy Verification

"IfSAR data have a reported fundamental accuracy that is based on comparisons with surveyed ground checkpoints. The reported accuracy is only valid for the areas suitable for these checkpoints and cannot be considered to represent the entire data set. For instance, data in forested areas cannot be considered to have the same accuracy as data in open terrain areas, unless it was also tested and validated. Note that different technologies will have different vertical checkpoint criteria (e.g., a LiDAR, or light detection and ranging, checkpoint can be closer to the trees than an IfSAR checkpoint). Several references in this document and in the *handbook* refer to appropriate locations for vertical checkpoints to test the accuracy of the data. Again, only areas suitable for checkpoints are used in the calculation of fundamental accuracy. If a location is not suitable for a checkpoint, the fundamental accuracy statement does not represent that area and the data in that location may have an unknown accuracy. These data may be accurate, but without verification of representative areas (e.g., checkpoints near steep slopes or near obstructions), there is no way for the user to know. This is an important issue because users of other digital elevation model (DEM) data sources would likely assume these areas of unknown accuracy in IfSAR were covered by the fundamental accuracy because they were suitable checkpoint locations for other technologies.

Obstructions

"The least restrictive guidance given for an area suitable for a checkpoint is an area clear of objects for at least 5 meters in all directions. Within this area the surface should be flat or uniform with a slope less than 10 degrees. The following bullets illustrate additional restrictions that accompany the 5-meter rule.

- "Areas with obstructions at about 30 degrees elevation or higher can cause problems in the radar observation of an area. While a single tree may not cause a problem, it could shadow any given point within a distance of approximately two times the tree's height and result in an erroneous return; therefore, checkpoints need to be placed at a distance from trees at least twice their height. Thus, areas with trees, even sparse trees, have the potential for error beyond specifications. Lamp posts, telephone poles, etc., can also cause problems in the same way. Thus, a typical residential area is very likely to have some problem areas even though much of the data are good.
    - Note that the 30 degree elevation is derived from the *handbook* recommendation for ground checkpoints to create "a buffer of width about twice the height of the building/woods (version 3.3, page 39)." However, Intermap's International Standards Organization (ISO) documentation[16] indicates that vertical checkpoints should have:
        - An unobscured view of the sky in all directions above 10 degrees elevation (this would be a buffer of width almost six times the height of a potentially shadowing object).
        - No Multi-path sources nearby (e.g., building, trees, etc.).

[16] This information regarding the contents of Intermap's ISO documents was provided by Intermap. The NOAA Coastal Services Center has not seen or reviewed the actual ISO documents.

    - No interference sources nearby (e.g., cell, microwave, and radio towers).
- "Terrain and the viewing angle of radar and the radar "look direction" are considerations when using any radar data. The viewing angle of radar is from 30 to 60 degrees. For example, the look direction for the Hawaiian Islands is approximately west. Therefore, vertical features will cause radar shadows on the west side of the feature. Very steep terrain facing east can result in areas of layover or saturated areas, preventing the estimation of elevation. While the look direction may not be known to the user in advance, it can generally be determined from the DEM and the radar imagery.
- "In addition to objects that present an intuitive shadow, such as trees, objects such as overhead phone and power lines also must be considered obstructions. Power lines that are perpendicular to the look direction of the radar sensor can cause errors beyond specification. This same situation may be true for wire fences. Since the user may not be aware of the look direction, these features should be viewed with caution in all cases.

Bright Objects and Low Correlation

- "Objects that are bright (i.e., high signal return) in the radar can cause errors in the elevations near the objects, especially if the other areas are dark in the radar image. For example, a guardrail on a road will cause a problem retrieving the road elevation because the guardrail is very bright and the road is typically dark. Street signs with the right orientation relative to the radar look direction can also return a very bright signal and cause errors in nearby elevations.
- "There are areas where the radar signal is not able to sufficiently retrieve a height (areas with low correlation). These areas are generally in high slope areas or areas with low radar return, such as pavement, and have been interpolated based upon surrounding areas. Interpolations in rapidly varying terrain can have very large errors. For example, vertical errors greater than 10 meters were found in interpolated areas in the Hawaiian Islands. A mask of low correlation areas can be provided to identify these areas.

Slopes

- "Slopes greater than 10 degrees can often result in a higher error. Note that it is not only the local slope within a few pixels that matters, but also the general slope of the area for several tens or hundreds of meters around. A flat area near a steep slope may be good, but it may also have added error because of the generalized slope.

General Data Applicability

Analysis Scale

- "The data are best suited for regional-scale analysis, although smaller scale analysis have been done. Using the data on a local scale may result in erroneous conclusions. For instance, the data are not suitable for determining water flow in a neighborhood, but they should be adequate for generalized flow for a whole watershed. As an example, stream edit rules used by Intermap are detailed in the *handbook* for both double line drainages (at least 20 meters wide for more than 400 meters) and single line drainages (less than 20 meters wide and longer than a kilometer). While the water should flow correctly within these drainage features, if you need water to flow correctly over the general landscape (e.g., through the forest, not around it), serious errors could arise where first-surface features, such as large tree stands, could not be removed. Even where first-surface features have been removed, it should be remembered that an interpolation has been done.

NEXTMap Data Editing

“The following edit rules from the *handbook* are used by Intermap when it creates its NextMap USA product and so are relevant to coastal resource managers. Other IfSAR providers will have their own edit rules that may have similar implications.

- “Bridge features and raised roads remain in both the digital surface model (DSM) and digital terrain model (DTM) products. This may have water flow implications by creating a “dam” feature where one does not exist; however, it does allow for more accurate terrestrial transportation networks.
- “Roads edits (smoothing of road surface): Only roads that have a TIGER line classification of A1, A2, or A3 have been smoothed. All other roads may display sharp undulating elevations or inconsistencies.
- “Stream and river edits (Hydro enforcing): double line drainages (at least 20 meters wide for more than 400 meters) and single line drainages (less than 20 meters wide and longer than a kilometer) are smoothed in a stepped fashion to enforce monotonic flow.
- “Road networks and rivers sometimes must be edited in interpolated areas by the image editor. In these cases, ancillary data are used to determine where the roads or rivers should be placed and can result in “cutting” through interpolated elevations, sometimes resulting in unrealistic canyons. There can be error in the placement of the river or road feature or in the interpolated terrain.

Digital Terrain Model (DTM)

- “The removal of first-surface features, such as trees and buildings, in the DTM product is contingent upon a couple of factors. First, according to the *handbook*, regions of trees greater than 50 meters in radius will not be removed. Additionally, a sufficient area of unobstructed regions surrounding the first-surface features is required for accurate interpolation. Consequently, regions in the DTM bordering the coastline are not considered dependable because of the lack of unobstructed land on one side for interpolation due to the ocean presence. Similar observations are also found in dense urban regions.

Additional Resources

American Society for Photogrammetry and Remote Sensing. 2001. *Digital Elevation Model Technologies and Applications: The DEM Users Manual*. 539 pages.

Federal Geographic Data Committee (FGDC). 1998. *Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy*. Federal Geographic Data Committee. This document is available on-line at *www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3*.

Intermap Product Handbook and Quick Start Guide. 2004. Version 3.3. This document is available on-line at *www.intermap.com/products/ProductHandbookVer3.3.pdf*.

National Digital Elevation Program. 2004. *Guidelines for Digital Elevation Data*. This document is available on-line at *www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf*.

These notes were produced by the NOAA Coastal Services Center. For further information, please contact Dr. Kirk Waters (Kirk.Waters@noaa.gov).

Intermap's Product Handbook & Quick Start Guide

NOAA's review, above, of NEXTMap USA IFSAR data is now several years old, when Intermap was using v3.3 of its handbook. Intermap's current *Product Handbook & Quick Start Guide*, Standard Edition, v4.2, provides detailed explanations for understanding IFSAR technology and IFSAR artifacts. Most of this section of Appendix E was extracted from pages 33 through 41 of this handbook. The follow-on section on Redundant Coverage was added by Fugro EarthData to demonstrate the advantages of GeoSAR for minimizing such artifacts.

"To ensure our products are of the highest possible quality, Intermap puts them through numerous quality assurance checks as part of our standard production process as well as an independent verification and validation process. This is not a completely intuitive task, because we do not interpret the world around us using ranging devices and signal processing. Our eyes operate in the visible portion of the EM spectrum, much like optical sensors, while IFSAR sensors operate in the microwave portion of the electromagnetic (EM) spectrum. It means that some of the attributes of radar are not as familiar as those associated with photography, for example, which uses many of the same principles of the human eye. Certain characteristics that exist in IFSAR data, therefore, require close attention to ensure the final products are not adversely affected.

"Table [E.1] identifies artifacts first by class and then by type. It describes many of the AFSAR artifacts we look for and explains how we address them. The goal is to produce the best possible data that meets our core product specifications.

Table E.1 Artifact classification and type

Artifact Class	Definition	Type
Geometry	Related to the viewing geometry of the IFSAR sensor	Layover
		Shadow
Sensor	IFSAR sensor parameters	Signal Saturation
		Decorrelation
		Motion Ripples
Processor	Related to the post processing of the IFSAR data	Missing Data
		Image Tone Brightness

"Geometry artifacts result from the viewing geometry of IFSAR sensors. Unlike some optical sensors which look directly below the imaging platform, radar and IFSAR sensors 'view' the ground according to a perspective beam that looks out to the side of the platform. See [Figure E.1] for an illustration of this principle. The beam shown in yellow in [Figure E.1] corresponds to the line between the radar antenna and the target on the ground points the radar beam out to one side of the aircraft, defining an incidence angle range. This configuration is an optimized viewing geometry for an IFSAR topographic mapping system. As the aircraft flies over the terrain, an image strip or swath is collected. This beam, called the slant range, is the distance as measured by the radar directly, in effect along each line perpendicular to the flight vector and directly with the radar and each scatter. The slant range is further defined by two terms: near range (NR) and far range (FR). A target located in the NR is closer to the antenna than a target positioned in the FR location. This viewing geometry creates distortions radiating out from the NR to the FR, rather than radiating out from nadir, as with aerial photography data collections. Two types of distortions are common: layover and shadow.

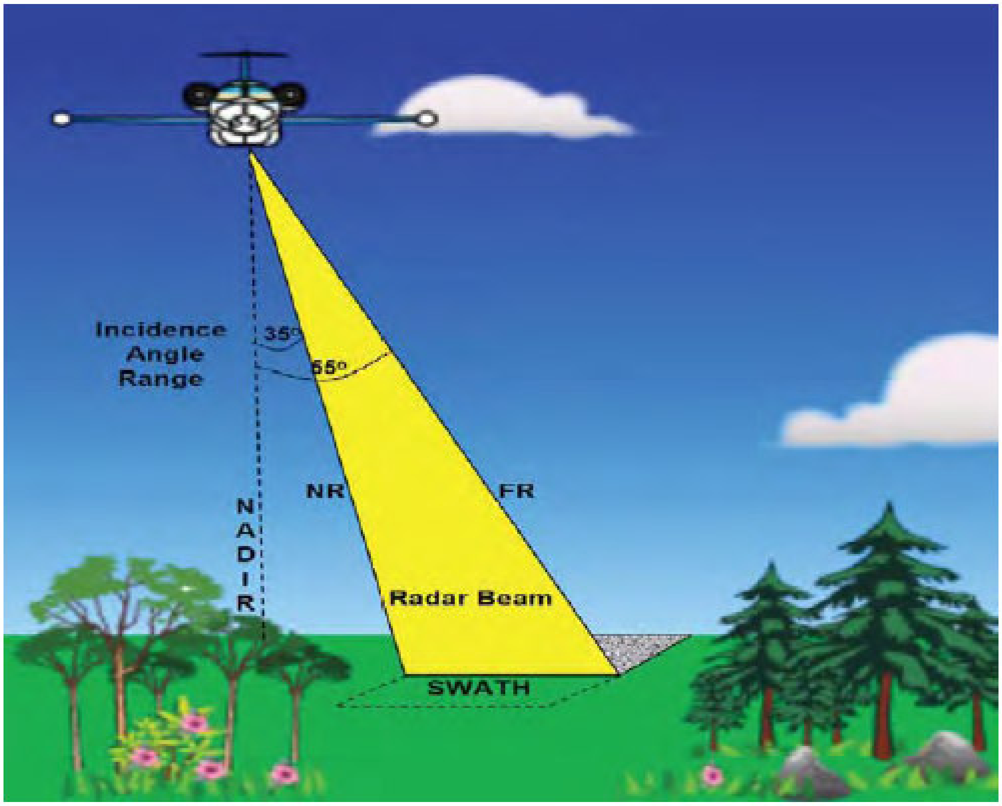

Figure E.1. Radar sensor geometry example of our system configuration in which the radar beam (in yellow) has an incidence angle range from 35° to 55°. The location of the near range (NR) and far range (FR) and swath width are also indicated. At a flying height of 10.4 km (34,000 feet), our swath width is approximately 11.5 km in width. A typical flight line can be as long as 1200 km

Layover

"Layover results from the side-looking nature of the radar with respect to the ground it is imaging. Geometric viewing of the sensor can cause objects to look shorter than in reality, because of the viewing angle of the observer. For example, a pencil tipped toward your eye appears shorter than when it is held upright. Layover, which occurs when the top of the object is recorded before the bottom of the object, takes place most frequently in the extreme near range, where the peaks of the mountains are nearer to the sensor than the bases. Therefore, the peak gets imaged first, and none or little of the information on the face of the mountain that looks toward the aircraft can be recovered. The effect of layover is most noticeable in mountainous areas and tends to make them appear to be closer to the radar antennas than they actually are.

“Figure [E.2] illustrates the geometric relationship that must exist between the ground and the radar for layover to occur. The strip along the top of the figure is the view of the scene looking down from above. The lower portion is a front view of the aircraft and the mountain it is imaging. The dotted yellow lines connect corresponding points in each representation. They are key to understanding layover because they show the time that the radar pulse takes to reach various parts of the mountain. Because the top of the mountain (B) is closest to the aircraft, it is imaged ahead of everything else(B’). The effect is to eclipse the view of the front of the mountain (in red).

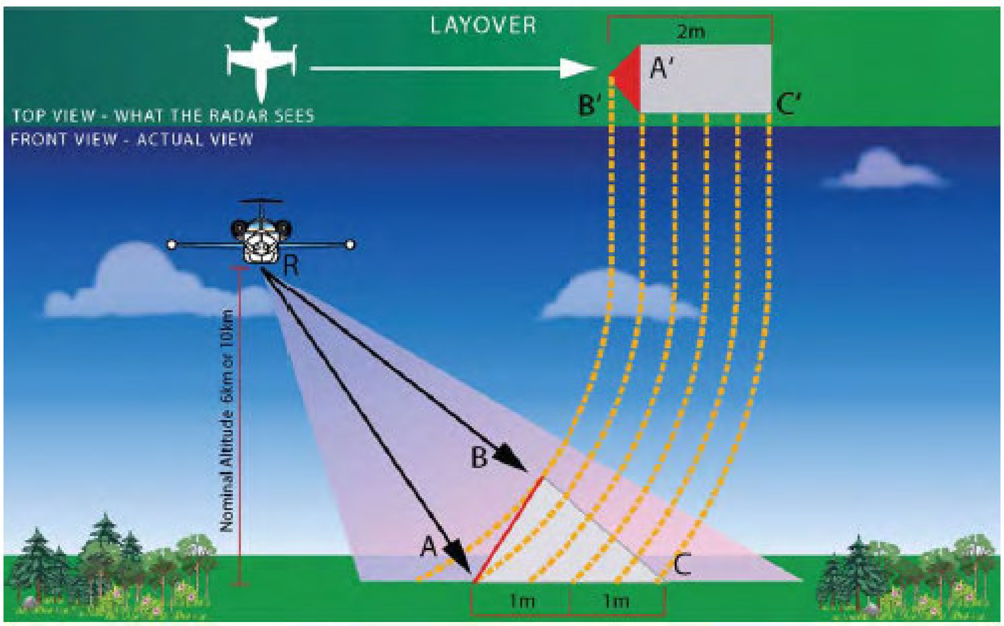

Figure E.2. The geometry of layover. The perceived effect is that the red area is smaller than it actually is. In the top view, it appears as less than ½ meter, but in the front view, you can see that the red area actually covers more than ½ meter.

“Through flight planning and data processing, we try to reduce the amount of layover that occurs in our data products. However, depending on the type of terrain type and where it is located within the swath, layover may still occur. As part of the production process, layover is corrected so that all image pixels can be used as a map output (orthorectified). Previously compressed regions are ‘stretched’ to cover the true terrain. This correction (stretching) is illustrated in [Figure E.3].

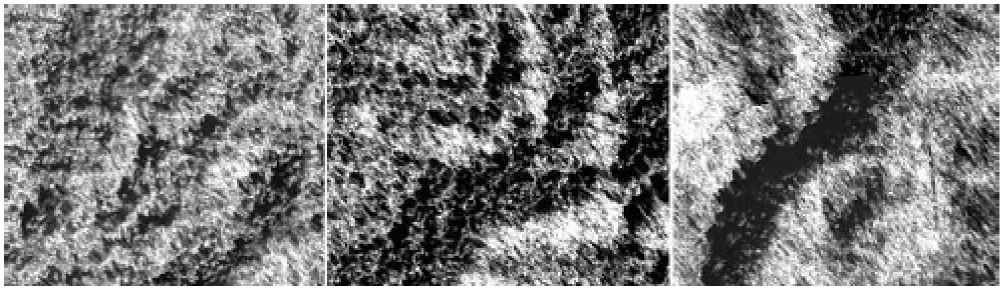

Figure E.3. Layover effect illustrated

"All three images in [Figure E.3] are of a jungle and mountainous terrain in northern Sulawesi, Indonesia. The left image represents a mid-swath data collection, in which little or no layover anomalies are present. This gives way to the homogenous tone and texture of the forest canopy. The middle and right images were collected in the NR, where the sides of the mountains appear to be leaning toward the radar illumination beam, thereby resulting in layover anomalies.

"The layover is manifested as blurred or stretched regions because the radar processor has tried to 'pull' or 'stretch' areas of higher terrain back to their correct position. In some cases, the layover portion may be represented as a white band, as illustrated in the ORI ([Figure E.4] left image) where the edge of the forest canopy is white in image tone due to a strong return from the edge of the forest canopy. Notice how the corresponding elevation data (DSM, middle image; DTM, right image) is not adversely affected in the region containing layover.

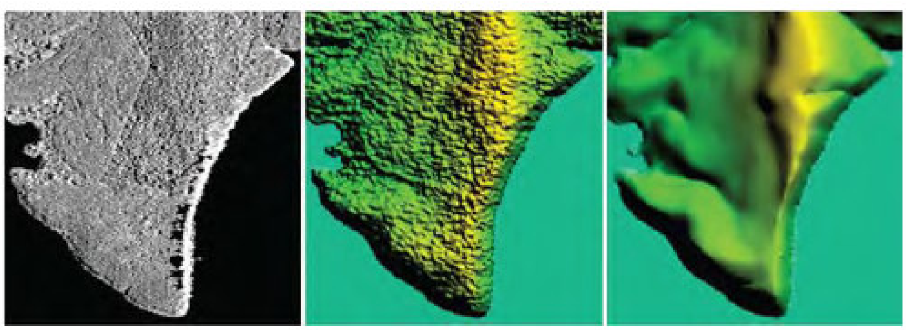

Figure E.4. Layover illustrated

"Layover causes mountains to resemble shark fins ([Figure E.5], red arrow), due to the visual compression of the near slopes. As part of the production process, the data is corrected. The previously compressed regions are effectively stretched to better represent the terrain. Thus, layover often appears as a blurred region, because the processor has tried to 'pull' areas of higher terrain back to their correct position. The DTM ([Figure E.5], right image) has valid elevation data in the region of layover due, in this case, to overlapping elevation data from an adjacent flight line. If overlapping data is not available, areas of layover would be filled in either through interpolation or using ancillary data."

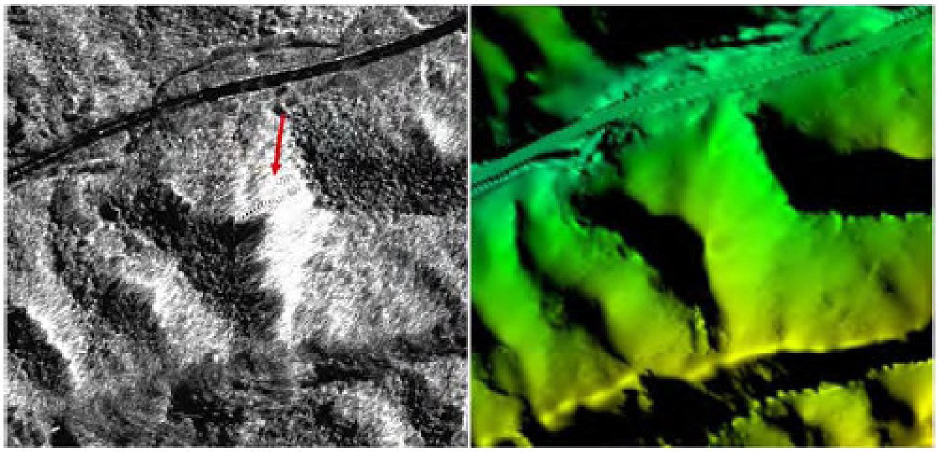

Figure E.5. Layover illustrated

Shadow

"Radar shadows represent an absence of data — regions from which no information was returned to the sensor. Such shadows are not the result of sunlight that is being blocked by higher objects, although they often appear that way. Instead, they are caused by the radar's side-looking signal being eclipsed by various terrain features — just as the flash on a camera creates shadows that are evident in the photograph of the subject. Therefore, if one thinks of the radar as a camera that images an area by illuminating it with a flash of radio waves, then shadows occur in regions where the flash cannot reach. SAR sensors, however, are active sensors continuously collecting snapshots of the terrain. Thus, the amount of shadow is generally less than what is presented in data collected by optical sensors. [Figure E.6] illustrates the geometric relationship that must exist between the terrain (for example, a mountain) and the radar sensor for a shadow to occur. The back slope of the mountain is facing away from the radar look direction, which will result in a region of shadow on the radar image.

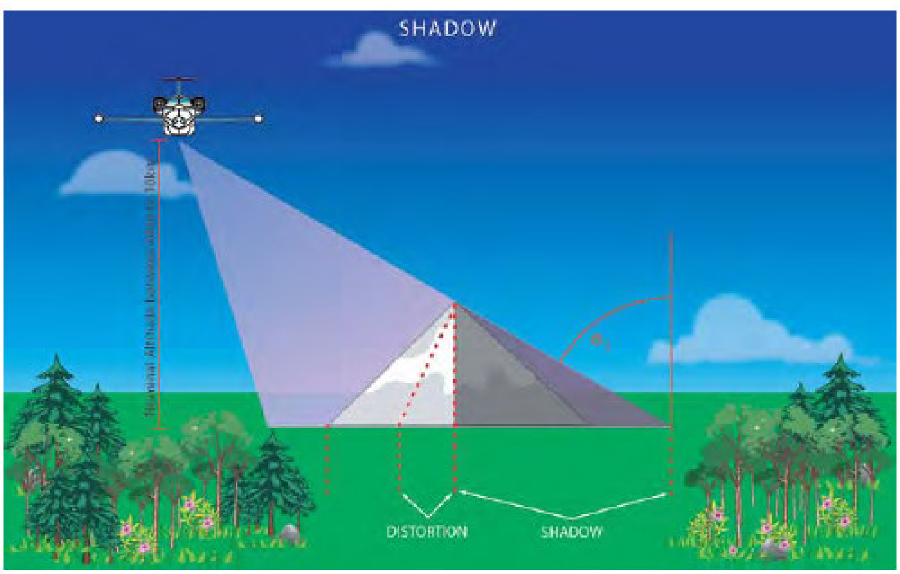

Figure E.6. Radar shadow illustrated.

“Shadow is a geometric artifact that cannot be eliminated. Through flight planning and data processing, however, it is possible to minimize this effect. For example, if an adjacent pass covers the shadow area, it is possible that the area will be filled with data during the merge. If a large part of the pass is affected by shadow, an additional sensor look may need to be acquired to fill these areas in the DEM. The additional look may come from an orthogonal tie line or a secondary look. In the case of the tie line, it would be positioned through the area where we would expect to have shadow; for example, in areas of steep terrain. As for a second look, it could come from a flight pass that is parallel to the original one, only looking in the opposite direction.

“[Figure E.7] illustrates tree shadows. In much the same way as we would see a tree cast a shadow as the sun goes down, shadows behind trees will be depicted as dark spots in the imagery and missing information in the elevation data. The amount of elevation data lost due to this type of shadow is minimal, and the affected areas can be filled in by interpolating elevation information from nearby areas. Note that the location of the shadow gives an obvious clue as to the look direction of the radar. In this case, the radar is looking from the right to the left. As a result, areas of shadow are on the left sides of the trees, denoted by the yellow arrows in the ORI. Conversely, the right side the radar return is strongest and appears brighter in the ORI. Notice that the shadows do not present a problem for the DSM (middle image) or DTM (right image).

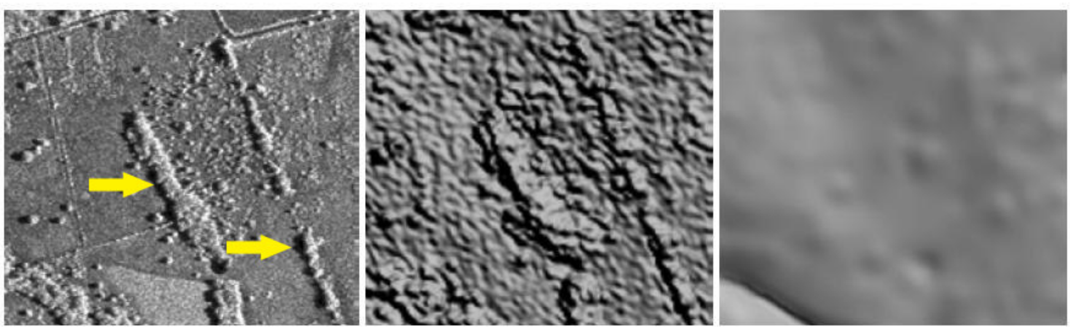

Figure E.7. Dark regions behind trees; ORI left image, DSM middle image, DTM right image

“While small shadows can accentuate terrain features and help form a better impression of the landscape — which can be helpful in confirming or eliminating certain characteristics of the data — large shadows may be problematic. Large shadows may require the re-acquisition of data from a better flight angle (recall, tie line or secondary look options). Large shadows are evident in [Figure E.8], located northeast of Pearl Harbor, Hawaii, USA.

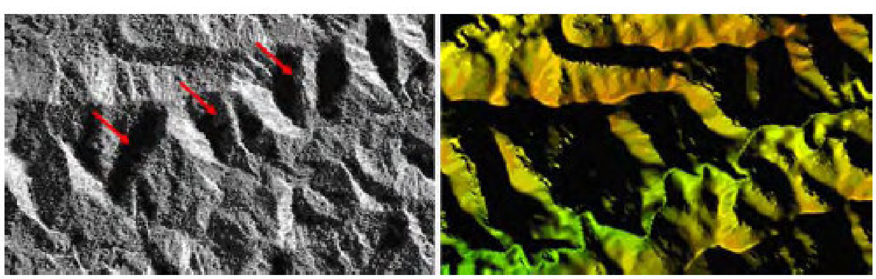

Figure E.8. Dark region (indicated by red arrows in the ORI, left image) are regions of shadow where the radar pulse was not able to reach. The corresponding elevation data is illustrated in the right image.

“A profile (yellow line and graph, [Figure E.9]) through the region of shadow areas reveals that there are elevation data in those areas[17]. In regions of shadow, elevation data can be retrieved from an overlapping flight line, a secondary flight line, ancillary data, or through interpolation. Intermap endeavors to have less than 5 percent of its elevation data derived through interpolation.”

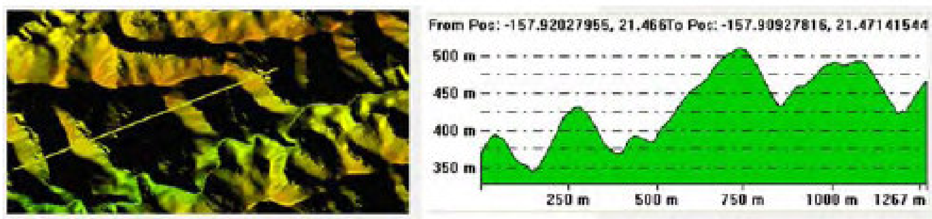

Figure E.9. A profile through the shadow regions, indicated by the yellow line in the DTM image on the left, is presented in the chart to the right to demonstrate that there is elevation data in areas of shadow regions.

GeoSAR’s Redundant Coverage

Whereas Intermap’s STAR-3/4/5/6 IFSAR systems image to one side of the aircraft, as shown in Figures E.1, E.2 and E.6 above, the dual-sided configuration of the antennas on the GeoSAR system (see Figure E.10) allows four or more independent looks for most points on the ground for each frequency band.

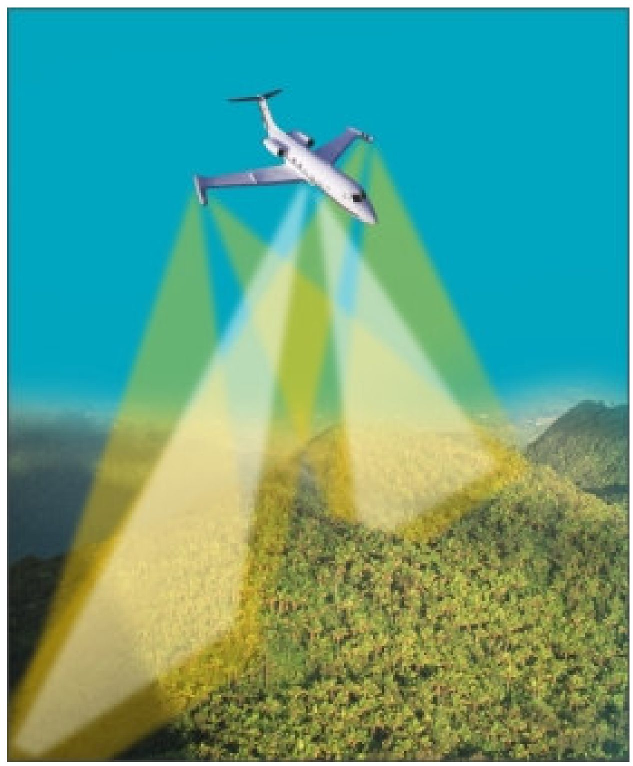

Figure E.10. Dual-sided configuration of the GeoSAR

Fugro EarthData’s flight plan for a GeoSAR mission depends on the required accuracy of the end products. For example, when the DEM must support contour extraction at 2m, the data would be collected at about 50% overlap, yielding an average 4:1 redundancy in the collection. Redundant area coverage is illustrated in Figure E.11, wherein the line spacing has been adjusted to cover the “nadir hole,” which results in each ground point (within the project area) being looked at twice from the left and twice from the right, at a steep and shallow angle. This helps to assure coverage of areas that might otherwise be obscured by radar shadow, specular reflection, and foreshortening. Fugro EarthData prefers to never interpolate ground points to fill in data gaps.

[17] Comment added by Dr. David Maune. Without such an auxiliary source of information, there would be no data in such areas of shadow because the image would not directly be receiving radar illumination.

Because the GeoSAR interferometric processor generates a height error estimate for each pixel in a swath, this redundant swath area coverage can be optimally combined in the mosaicer to generate a low noise composite DEM by weighting each swath data sample in a least mean squared sense. Fugro EarthData's paper on the GeoSAR indicates that DEM noise reduction, by averaging independent samples, is superior to the more traditional IFSAR technique of low pass filtering the DEM to reduce interferometric height noise.

The "bottom line" is that data gaps in extreme terrain can be minimized, but not totally eliminated.

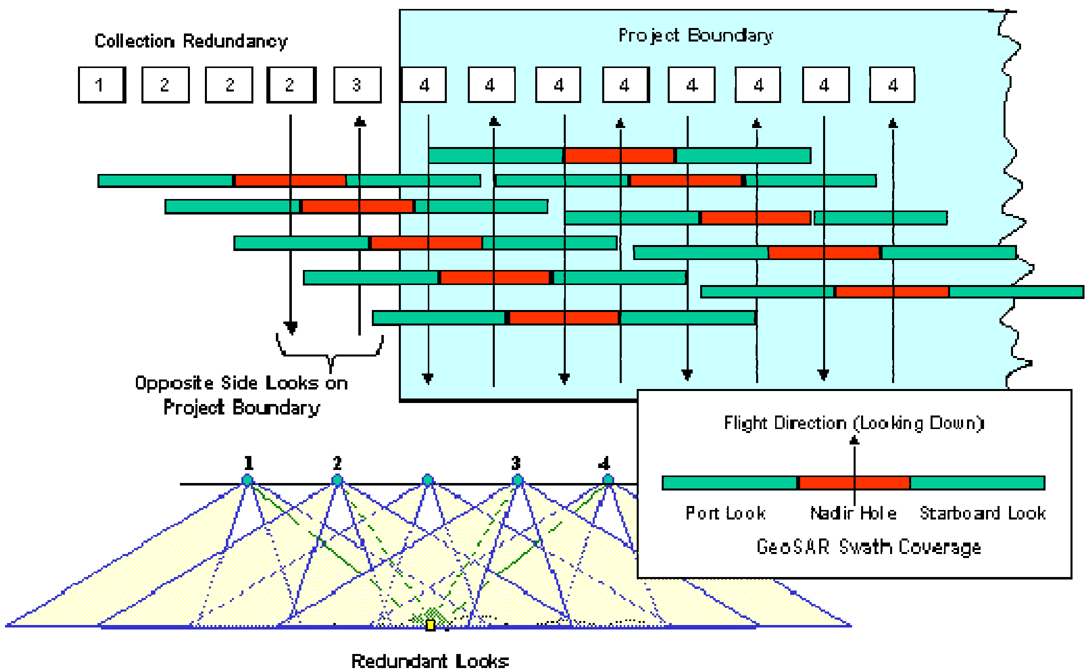

Figure E.11. Illustration of GeoSAR's Redundant Area Coverage

The dual sided, single-pass nature of GeoSAR minimizes layover and shadow and is ideal for mapping of Alaska's rugged terrain. With GeoSAR, for each line-km flown, twice as much data is acquired—one swath looking left, and one swath looking right—which is needed for filling shadows and resolving interferometric degeneracy.

Interferometric degeneracy is a special case of layover, where the incident angle between the IFSAR antenna and the slope of the terrain is very close to 90-deg; under this condition, an IFSAR DEM cannot be generated even though the radar returns are very bright. The only way this condition can be resolved is by collecting this slope at a different look angle, i.e., from a flight line that is closer or farther away for the offending degeneracy. GeoSAR is much more robust for these (frequent) terrain occurrences in glacier carved terrain because its dual sided architecture inherently images the terrain from two different incident angles.

A region of low return (e.g., a mud flat) will generate a DEM measurement, provided the SNR is sufficiently high; however, as the SNR falls, the DEM uncertainty rises—this is where multiple independent DEM measurements (ala GeoSAR) especially comes in handy, since the measurements are independent (and at different incident angles), the DEM uncertainty can be reduced by sqrt(number of measurements). This acquisition methodology is an important GeoSAR distinctive that has significant implications for reducing acquisition risk. Single sided (looking) systems simply do not have this capability without flying each line twice (one looking left and the other looking right).

Layover is generally not an issue so long as the incident angle of the terrain slope to the line of sight to the radar is not close to 90-degrees, which leads to interferometric degeneracy (it's very similar to attempting to generate a stereo model when the two "eye" locations are collinear with the viewing direction… the parallax disappears, hence no depth perception). Both interferometric degeneracy (a more appropriate term) and shadows (i,e,, lack of illumination) are *only* fixable by additional acquisition lines (similar to viewing the street level obscured on the back-side of a tall building). Single sided systems provide very little inherent redundancy in their acquisition, which is limited to how much side-lap they choose (can afford) to cover the terrain; but whatever the side-lap chosen, a two sided system flying the same number of line-km will always provide superior ground coverage, i.e., twice as much data. While this redundancy is not necessarily *essential* in relatively flat regions, it becomes increasingly important as the terrain becomes more convoluted, rugged, or tilted. A single-sided system must fly more lines to get the same coverage that a dual sided system provides inherently. It's not that a single sided system cannot achieve adequate coverage; it's just that to do so can greatly increase the acquisition cost and schedule. All things being equal, multiple measurements are *always* better than single measurements, since measurement redundancy allows one to *measure* the internal consistency of the generated products. Even with GeoSAR's standard acquisition redundancy (50% sidelap, dual-sided acquisition, yielding 4:1 redundancy over relatively flat terrain), some filler lines are still necessary in the most rugged terrain, especially around tall volcanic and uplifted structures.

IFSAR Bright Objects and Low Correlation

In response to the NOAA comments on bright objects and low correlation distorting elevation data, both Intermap and Fugro responded to Dewberry's request for actions they would take to minimize or mitigate such issues from their IFSAR data, in addition to explanations previously provided above.

Intermap's Response

Where there are a vast number of corner reflector type objects in an area, such as an urban core, Intermap would place a tie line through the city to yield two sets of data that cover the urban core. The tie line is perpendicular to the primary flight line and thus offers an additional look at the terrain. In NEXTMap USA (1 m vertical RMSE) tie lines are positioned across the primary flight paths every 75 kilometers. Therefore, the tie line and the primary flight line as well as over-lapping primary flight lines now provide a vast amount of phase data for use in generated a near fully populated elevation data set that requires minimum interpolation (less than 5%). The imagery, however is a product of the primary flight lines, in other words we do not process the tie line data to generate ORIs. Henceforth, dropout in the imagery ORI may not necessarily correspond to "interpolated" elevation data in the DEM because the elevation data set is populated with the tie line data as well.

In addition, the new editing methods have a different obstruction module to remove spikes (e.g. poles, towers, etc.) than what was used in version 3.3 of the product handbook.

Also, the tone of the radar image does not indicate "coherence of the two SAR antennae." For example, over roads (dark image tone) we get a very high coherence, meaning a strong correlation in phase received by both antennae. It is only when the road surface is very smooth (roughness less than 3 cm) does the coherence drop off.

Regarding NOAA's comments that there are areas where the radar signal is not able to sufficiently retrieve a height (areas with low correlation), Intermap replied that this is perhaps true for spaceborne platforms which typically are plagued with temporal decorrelation. Single pass systems are less so affected. To add, Intermap sets its coherence threshold very high (cannot publish the threshold value) because we have very stable platforms. It has taken Intergraph many years to be able to use such high thresholds. The higher the threshold is, the better the accuracy of the elevation data is. High thresholds mean strong coherence data is accepted, medium coherence data is rejected.

Intermap generates the coherence (correlation) image and it is mostly white, indicating high correlation between the two sensors. Intermap could make this available as a product as it is quite valuable for land cover classification. However, as with the imagery the coherence would represent one pass, and in steep terrain we would have many passes (overlapping primary flight lines and tie lines) and a coherence image for each pass would be required to determine low coherence over all. The Hawaii data was collected and edited under different specification to what we have today. In steep terrain, Intermap would have additional tie lines and greater overlap between flight lines to compensate for data dropout.

Fugro EarthData's Response

GeoSAR produces a height error layer at the swath and mosaic level. In addition to outputting the interferometric correlation layer, the GeoSAR's interferometric processor also calculates the expected relative *height error* at every output pixel which incorporates the interferometric correlation and the imaging geometry to provide a statistical estimate of height uncertainty in meters. This error excludes large area systematic effects such as swath tilt and phase screen terms. Figure E.12 shows a P-band example of the (single swath) DEM height error layer, color wrapped at 5m and thresholded at 2m for display. As expected, DEM height error increases for areas with very low returns The height error is a statistical expectation, i.e., an estimate of the DEM accuracy (at a given pixel)—it does not mean that the actual DEM values are incorrect (and they may well be), but that based on interferometric correlation and IFSAR processing theory, this is the confidence in the DEM value provided by the processor. For GeoSAR, one of the mosaicing modes is to error propagate multiple DME measurements for "optimal" LMS estimation. Note, single look systems do not have this measurement redundancy to exploit.

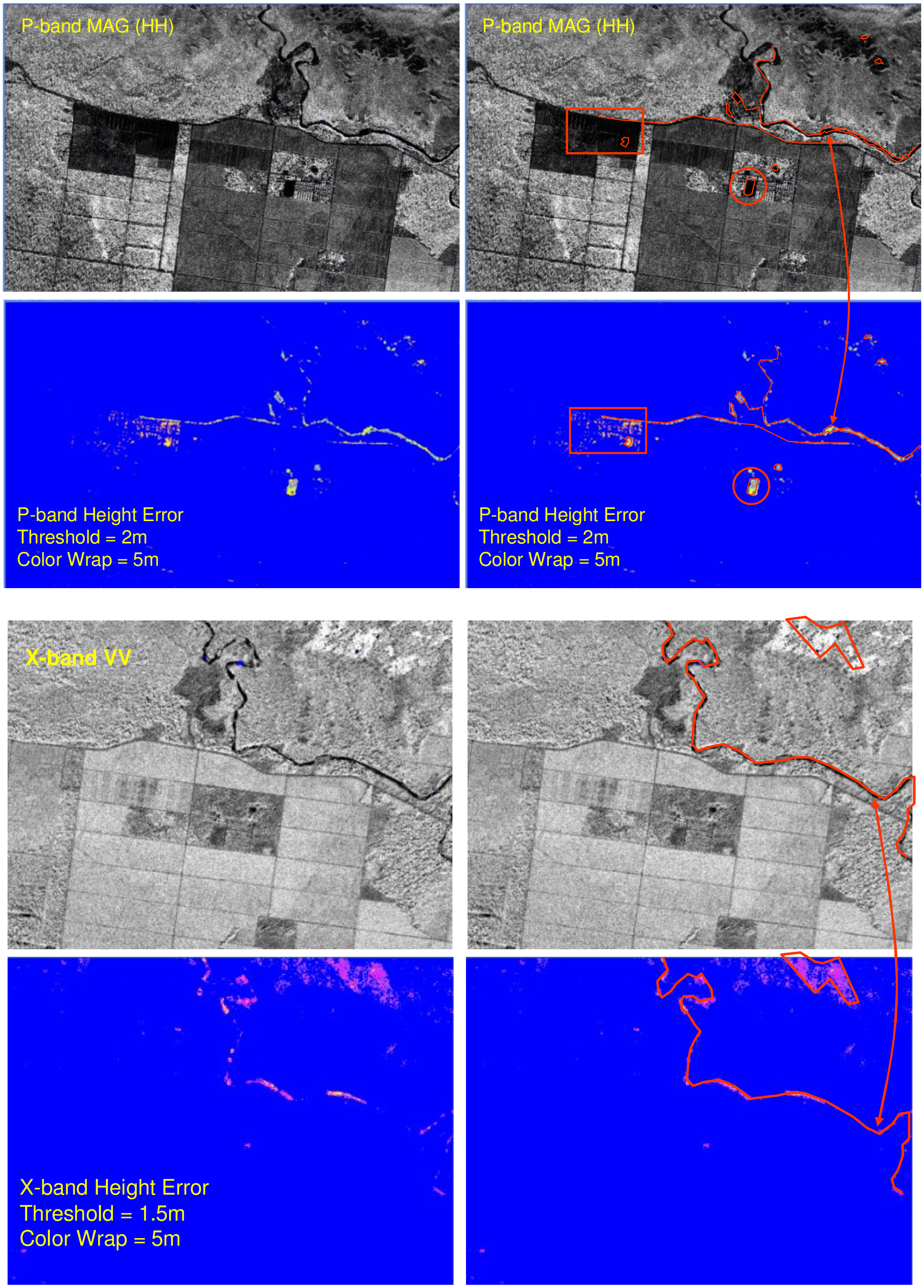

Figure E.12. Height Error Example Agricultural Field (P-band/X-band, 5m Post)

In P-band, fence lines, trenches, stone walls, power lines can become quite bright, especially when viewed broadside, or nearly so. P-band is much more efficient in detecting these kinds of surface features than is X-band (see Figure E.13)—this can be both a blessing and a curse, depending on the kind of information being extracted from the data. Multi-look DEM averaging and height error weighting helps in mitigating these features.

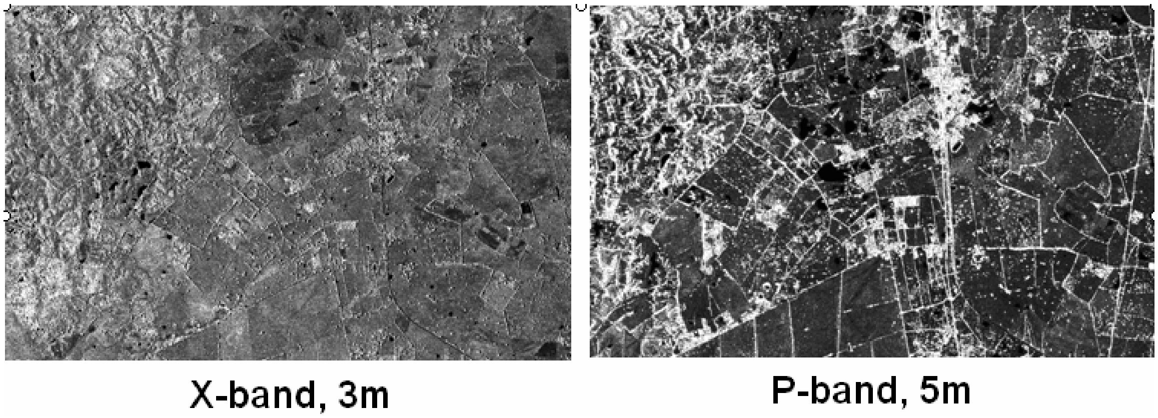

Figure E.13. Fence lines and powerlines in X and P-band. Compared to X-band, P-band has much greater sensitivity in detecting fences and power lines.]

DEM height error noise is a strong function of signal to noise ratio (SNR), which generally means that brighter returns have less system noise, and less noise means more accurate DEMs. More specifically, let:

- SNR = thermal noise, source ambiguity, quantization noise, and misregistration
- Baseline = geometric distortion
- Volumetric = volumetric decorrelation where the scattering volume (rather than just the surface) displays slightly different phase behaviors in the two antennas
- Residual = residual noise sources (e.g., RFI plus any other non-systematic source of phase noise)

Then:

$$\sigma_\phi^2 \approx \sigma_{SNR}^2 + \sigma_{Baseline}^2 + \sigma_{Volumetric}^2 + \sigma_{\mathrm{Re}sidual}^2 = T\text{otal System Phase Noise}$$

and[18],

$$\gamma = \frac{1}{\sqrt{2n\sigma_\phi^2 + 1}} = \text{ the interferometric correlation coefficient between the two antennas at a point.}$$

Given γ, the interferometric correlation coefficient, the height error, σ_h, is estimated from:

[18] From the JPL GeoSAR system design document, 1998.

$$\sigma_h = \frac{1}{\sqrt{2N}}\sqrt{\frac{1-\gamma^2}{\gamma^2}}, \text{ where } N = \text{effective number of looks (independent measurements)}$$

Therefore we have a relationship between total phase noise, interferometric correlation coefficient, and DEM height error. The more phase noise, the lower the interferometric correlation; the lower the interferometric correlation, the greater the DEM height error noise.

GeoSAR's interferometric processor calculates the height error, σ_h, for each output pixel. The above results apply to individual swaths. However, mosaicing multiple independent DEM measurements effectively multiplies N by the number of independent measurements, and further reduces the overall DEM uncertainty.