Alaska Statewide Digital Mapping Initiative

Control Requirements Report

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LIST OF ACRONYMS AND ABBREVIATIONS

AGDC	Alaska Geographic Data Committee
AHAP	Alaska High-Altitude Aerial Photography Program
ANCSA	Alaska Native Claims Settlement Act
ADNR	Alaska Department of Natural Resources
AGPS	Airborne Global Positioning Systems
ASPRS	American Society for Photogrammetry and Remote Sensing
BLM	Bureau of Land Management
CBJ	City & Borough of Juneau
CIR	Color Infra-Red (imagery)
COE	Corps of Engineers (US Army)
CORS	Continuously Operating Reference Stations
COTS	Commercial Off The Shelf (in reference to software)
DCCED	(Alaska) Department of Commerce, Community and Economic Development
DEC	(Alaska) Department of Environmental Conservation
DEM	Digital Elevation Model
DF&G	(Alaska) Department of Fish and Game
DGGS	(Alaska) ADNR-Division of Geological and Geophysical Surveys
DGPS	Differential Global Positioning System
DOC	U.S. Department of Commerce
DMVA	Alaska Division of Military and Veterans Affairs
DOD	U.S. Department of Defense
DML&W	(Alaska) ADNR-Division of Mining Land and Water
DOG	(Alaska) ADNR-Division of Oil and Gas
DOT&PF	(Alaska) Department of Transportation and Public Facilities.

DRG	Digital Raster Graph is a scanned image of a USGS topographic map
DSM	Digital Surface Model (not bare earth)
DTED	Digital Terrain Elevation Data
DTM	Digital Terrain Model (of the bare earth)
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FNSB	Fairbanks North Star Borough
GCP	Ground Control Point
GINA	Geographic Information Network of Alaska, part of UAF
GIS	Geographic Information System
GPS	Global Positioning System
GRS	ground receiving station, used to collect satellite data
GSA	General Services Administration
IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organization
IFTN	Imagery for the Nation, a pending federal initiative for ortho-imagery
KPB	Kenai Peninsula Borough
KGB	Ketchikan Gateway Borough
MOA	Municipality of Anchorage
MS	Multi-Spectral imagery
NAIP	National Agriculture Imagery Program
NDGPS	Nationwide Differential Global Positioning System
NED	National Elevation Dataset
NGA	National Geospatial-Intelligence Agency
NMAS	National Mapping Accuracy Standards
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service

NRI	Natural Resource Inventory
NRCS	Natural Resources Conservation Service
NSB	North Slope Borough
NSGIC	National States Geographic Information Council
NSSDA	National Standard for Spatial Data Accuracy
NTSB	National Transportation Safety Board
NWI	National Wetlands Inventory of USFWS
OHMP	(Alaska) Office of Habitat Management and Permitting
PAN	Panchromatic (black & white) imagery
PSM	Pan-Sharpened Multi-spectral imagery
RFP	Request For Proposal
RMSE	Root Mean Squared Error
ROM	Rough Order of Magnitude
RSS	Root Sum Squared
SDMI	Statewide Digital Mapping Initiative
TIN	Triangular irregular network: elevation points networked for elevation surface creation
UAF	University of Alaska, Fairbanks
URISA	Urban Regional Information & Systems Association
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VFR	Visual Flight Rules
WAAS	Wide-Area Augmentation System
WRST	Wrangell-St. Elias National Park

EXECUTIVE SUMMARY

The objective of this report is to summarize control requirements for horizontal and vertical control necessary to meet the target of National Map Accuracy Standards at 1:24,000; and provide alternative methodologies for meeting the specification. Alaska poses a major challenge in terms of ortho-controlling regional coverages of imagery and elevation data. The extremes of terrain from sea level to 6,000 meter plus mountain peaks make a consistent ortho control model difficult. Logistics involved with ground control are also a formidable challenge. This report summarizes the issues associated with control of Alaska imagery and elevation data; provides a report on methods currently used by mapping agencies and firms; and proposes methods for control standards, and serving up ground control from a common repository.

Ground control is an important, if not critical, factor contributing to the accuracy of a basemap. At urban area level scales, ground control typically is survey controlled and requires establishment of a control network. At SDMI type rmapping scales, ground control is not as demanding, particulary when it comes to satellite imagery. Ground control is typically expensive and logistically challenging in Alaska. Ground control points (GCP) are currently being collected in varying densities throughout Alaska for project level and regional acquisitions. For very high resolution mapping in urban areas and development projects densely distributed ground control is essential, but for a statewide, moderate resolution map, ground control can be much less of a requirement. Therefore, determining the amount of ground control points (GCP) is essential to a cost effective statewide mapping program. Control requirements for regional mapping using imagery have evolved in recent years such that there is a consistent methodology used amongst vendors collecting imagery and elevation data in Alaska. Section 7 of this report describes these methods.

There is a substantial amount of existing good quality ground control in Alaska, consisting of ground control points and image chips. Mapping projects particularly since 2000 have used modern control methods and technologies with good results. Also, the collection of control since that time has accumulated such that an extensive network exists statewide (see Figure 8). Our analysis reveals that this control is extensive, and could provide a statewide level of control for SDMI mapping needs. In Alaska, a number of key regional mapping projects collecting 1-meter to moderate resolution mapping data has been underway since 2003, and have helped evolve and mature feasible control methodologies and requirements (see summary in Section 8, Table 3). Higher resolution imagery and elevation projects require more ground control, as expressed in interviews with key mapping and surveying firms (see Section 7). Costs for ground control as collected in major Alaska projects is provided, along with estimates for control for a statewide digital basemap. We recommend a repository of statewide ground control be established for SDMI mapping purposes that could be used by agencies and industry alike.

Technology improvements in the area of inertial systems have greatly improved in the past five years, and coupled with improvements in the continuously operating (CORS) enable imagery providers to

collect and control imagery more quickly and accurately. Traditional or conventional survey control methods may not be as much of a requirement in times of improved CORS networks, GPS, and related technology. Additionally, with the realization that many of the monuments once thought stable are now realized to be in geotectonic flux, a more real world control network based on CORS and related technologies makes more sense. Terrain, however, is a serious consideration in Alaska. Although most of the state is actually of moderate gradient, there are the extremes of the mountain ranges such as the Alaska and Broos Ranges. For example, airborne GPS and IMU offer tremendous potential as accurate, low cost, and easy means of getting control, but fall short in certain terrain types. The advent of GPS-based control and advances in our understanding of the earth's geoid model argue for basing control on a continuously operating reference stations (CORS) network and GPS/IMU methods, rather than on traditional reference to in-situ ground control. Alaska's dynamically changing terrain also makes static in-ground control uncertain. A CORS network provides for a consistent GPS-based reference upon which to control mapping. Except for a few notable gaps in interior Alaska, CORS coverage in Alaska is actually quite good (see Figure 7). High quality, accurate moderate resolution mapping can be achieved using CORS and DGPS/IMU with an evenly distributed, and widely spaced set of ground control points (orthoimage chips).

Finally, in this report, an error budgeting tool is provided wheby the factors determining mapping accuracy can be relatively assessed. For example, for an SDMI type scale of 1:24,000, this tool provides guidelines regarding how much ground control is needed given a certain type of imagery sensor, look angle, and terrain type. Mapping accuracy is contingent on a number of key control factors that influence ortho control of imagery and elevation.This applies to both satellite and aircraft platforms. These factors are:

- Image pixel resolution
- Sensor native accuracy or improved accuracy specifications
- Sensor off-nadir angle
- Terrain vertical accuracy
- Terrain horizontal accuracy and slope
- Quality of RPCs or on-board GPS/IMU
- Ground control point accuracy and distribution

1.0 INTRODUCTION

Horizontal and vertical Control is a major challenge in a statewide digital data acquisition of orthoimagery products. As experienced in numerous projects throughout Alaska, and through information collected in this analysis, horizontal and vertical control can be problematic due to lack of an extensive, consistently acquired control network; and still unresolved issues with geodetic models on a statewide basis. With regard to basemap data, control would benefit from a number of factors, and perhaps most from a regional network of accessible photo-observable ground control points (GCP) or image chips. Key projects in Alaska (see Table 3, page 31) have established working models for control acquisition as well as regional networks of control in remote areas that could collectively form a statewide control network for SDMI purposes.

We have focused our analysis of control requirements in large part on satellite imagery due to the fact that the advent of high resolution commercial imaging satellites in recent years makes regional acquisition of orthoimagery in remote areas more feasible and cost effective.

Section 3 of this report addresses control required for the various commercial satellite imaging options in Alaska. Control requirements are discussed for each satellite imaging option based on interviews with satellite vendor representatives and technicians. Table 2 summarizes the mix of control and DEM parameters by imaging sensor type.

Section 4 of this analysis addresses the issue of terrain and vertical control for a statewide imagery product. Please refer for more detailed coverage of digital elevation models to the SDMI DEM Whitepaper produced by Dewberry in July, 2008.

In Section 5.0 we describe methods in use by the major Alaska mapping firms and their assessment of control technologies for use in production of orthoimagery. Note, that many of these firms are mostly involved in urban level mapping projects, or community projects such as the Alaska Profiles, thus their experience is more limited and perhaps less informed when it comes to regional imagery acquisitions such as a statewide imagery program.

Section 6 addresses continuously operating reference systems (CORS), and their impact on control for statewide imagery acquisitions. As discussed in the NDOP Workshop in Anchorage in August, 2008, the Alaska CORS network has grown and is improving, and will play a major role in control. Section 7.0 describes models of how to serve and store control data to mapping agencies and vendors, and Section 8.0 provides a thorough compilation of control being acquired by Alaska agencies (see Table 3).

Section 9.0 includes the review and assessment of the factors involved in control to produce orthoimagery, tools for evaluating control with various satellite imagery sources, existing sources of control data, and various approaches and methodologies utilized by vendors as well as by local mapping agencies and companies. An error budget methodology is introduced which describes how control factors into the final resolution of the imagery product.

2.0 BACKGROUND

The stated goal of the SDMI project is to produce a statewide basemap at 1:24,000 scale NMAS. Currently, Alaska basemap needs are met mostly with USGS topographic mapping, and at 1:24,000 only in a few selected areas, mostly the major urban areas such as Anchorage and Fairbanks. Imagery and other related basemap data is being acquired in local projects at detailed scales for a large variety of local projects throughout the state, including small communities (e.g. the Alaska Village Profiles program), corridor projects (e.g. gas pipeline projects), and natural resource projects (e.g. Chugach National Forest, Pebble Copper-Gold Mine, etc.) Orthoimagery has been collected using conventional aerial photography in many areas, e.g. the Alaska Profiles, but increasingly satellite imagery is being used by a broad user group in Alaska from detail level preliminary engineering to regional studies. SDMI has established the goal of acquiring imagery base map data for Alaska with sufficient registration accuracy to meet the National Map Accuracy Standards (NMAS) at 1:24,000 statewide and at other scales for designated areas to meet the needs of a broad user group. For scale reference, Table 1 below shows various measures of registration accuracy and their map scale equivalencies.

TABLE 1 APPROXIMATE MAP SCALE EQUIVALENCIES BASED ON THE US NMAS

MAP SCALE	CE90	CE95	RMSE	1-Sigma
1:50,000	25.4 m	29.0 m	15 m	12 m
1:24,000	12.2 m	13.9	6 m	3 m
1:12,000	10.2 m	11.6 m	5 m	2 m
1:4,800	4.1 m	4.7 m	2 m	2 m
1:2,400	2 m	2.3 m	1 m	1 m

3.0 CONTROL REQUIREMENTS & SATELLITE ORTHOIMAGERY

The current primary sources of potential high resolution satellite base map imagery include IKONOS, QuickBird, Worldview, and SPOT sensors. Table 2 below lists, by sensor, the requirements to produce orthorectified imagery at the listed NMAS accuracies. These requirements include specifications regarding sensor look angle, DEM quality, and need/quality of ground control points (GCPs). In Table 2, the row indicating map scale accuracy of 1:24,000 (the SDMI target) is bolded for reference. Standard products are not offered at this scale by the vendors; therefore, the next higher target accuracy scale (1:12,000) is blue-highlighted for the purposes of discussion.

For future consideration, two new high-resolution sensors with very high native spatial accuracies include the recently launched WorldView-1 and GeoEye-1.

Image orthorectification is the process of creating an image that has the planimetric characteristics of a map. Production of ortho-imagery conventionally involves the use of a DEM to remove distortion due to terrain effects and sensor look angle, and ground control to tie the imagery to geographic coordinates. According to most vendors, the Alaska NED DEM has very poor accuracy and so is not useful at the 1:12,000 requirement level[1]. Use of the NED DEM also appears to increase the need for quantity and quality of ground control points.

3.1 REQUIREMENTS TO ORTHORECTIFY IKONOS IMAGERY TO 1:12,000 SCALE NMAS

Information on IKONOS was summarized from the *IKONOS Imagery Products Guide* and verified through discussion with Jeff Ferrara, Supervisor of Commercial Order Management at GeoEye. The key point to note is the following: to achieve orthorectification at 1:12,000 scale requires an accurate DEM but does not require the use of GCPs. Mr. Ferrara claims that using a high-quality DEM produced from IKONOS stereo-pairs or another source (e.g., Intermap IFSAR) would result in registration to the desired accuracy level without the need for GCPs. Moreover, the vendor's cost to task the satellite with acquisition of a second image (from which to produce a stereo-pair DEM) is significantly less than the vendor's cost to obtain ground control, in order to meet a standard product specification.

Gene Dial of GeoEye observes that stereo models block-adjust quite well, so multi-model stereo projects can achieve 1:12,000 without GCPs. However, Mr. Dial feels that using ground control is still very desirable, as control removes a large source of error from the project so the entire error budget can be available for residual errors, terrain extraction errors, and all the other little things that go wrong as the project moves through processing. So while it is possible to hit the desired accuracy without control, errors can approach the 1:12,000 specification. The use of GCPs removes all doubt about accuracy, and the results can be much better than 1:12000 (see Table 2).

[1] Gene Dial, GeoEye; Mark Syren, Aero-Metric.

Both Mr. Ferrara and Mr. Dial feel confident that the 1:24,000 accuracy standard can be achieved without the use of ground control. Further research may be required for verification. For example, the USDA NRCS in Alaska, as part of their National Resources Inventory (NRI) project, has a contract with GeoEye to produce 1:24,000 NMAS imagery. Ted Cox, NRCS NRI manager, notes that GeoEye has assumed responsibility for meeting this specification, apparently using high-resolution DEMs produced from IKONOS stereo-pairs with no ground control. An accuracy assessment could be conducted of selected NRI imagery to verify GeoEye's claims.

3.2 Requirements to Orthorectify QuickBird Imagery to 1:12,000 Scale NMAS

Orthorectification of QuickBird imagery to 1:12,000 scale requires both a good quality DEM and the use of GCPs, according to the *QuickBird Imagery Products* Guide and discussion with Andrew Canales of Digital Globe. Mr. Canales estimates a requirement of four GCPs per 100 square miles (some points could be re-used in overlapping segments). It is possible that the requirements for ground control to produce a 1:24,000 scale product with large geographic coverage would be less rigorous.

3.3 Requirements to Orthorectify SPOT-5 Imagery to 1:12,000 Scale NMAS

SPOT Image provides specifications only to 1:50,000 scale accuracies, which are achievable through use of SPOT's Ref3D DEMs and GCPs derived from Ref3D ortho-imagery. No documentation has been provided describing requirements to produce imagery at higher accuracies; however, given the improved accuracy specifications for SPOT-5 imagery, and assuming the use of quality ground control and a DEM that exceeds Ref3D DEM accuracy standards, it could be possible to achieve NAS 1:24,000 scale map standards utilizing SPOT-5 imagery. This statement has been verified through the use of the satellite ortho-accuracy estimation worksheet produced for SDMI by i-cubed R&D Specialist, Yusuf Siddiqui (M.S. Civil Engineering, ASPRS CMS in Remote Sensing) and reviewed by industry expert Gene Dial. See Section 8 (Error Budget and Cost Analysis) for more details on how to verify this finding.

3.4 Requirements to Orthorectify Imagery to Higher Scales of Accuracy

Table 2 indicates that increased rigor in the quality of the DEMs and/or GCPs for all sensor-products would be required to achieve higher map accuracies, such as 1:4,800 scale NMAS. The Satellite Ortho Accuracy Estimation Worksheet (Appendix 11.2) can be utilized to determine horizontal and vertical control requirements to meet any mapping accuracy for any sensor product.

TABLE 2 SATELLITE IMAGERY PRODUCTS AND REQUIREMENTS FOR ORTHORECTIFICATION BY MAP SCALE

ACCURACY		IKONOS	IKONOS ORTHO	QUICKBIRD	QB ORTHO	SPOT-5	SPOT-5 ORTHO
MAP SCALE	CE90	PRODUCT	REQUIREMENT	PRODUCT	REQUIREMENT	PRODUCT	REQUIREMENT
1:100,000		"Standard Ortho"		"2A Standard"	Coarse DEM (non-ortho)	"SPOT Scene 1A, 1B, 2A"	N/A (non-ortho)
1:50,000	25.4 m	"Ref"	Look angle 0-30 deg.	"3A - Ortho"	Standard DEM; Look angle <26 deg.	"SPOTView 3"	Use of SPOT Ref3D DEM & GCPs from Ref3D orthoimagery (or similar products)
1:24,000	**12.2 m**	**Custom Product Available**	**GCPs probably not required, OR one GCP per 50 km along image strip**	**No Standard Product**		**No Standard Product**	Presumably higher quality DEM and GCPs than available from Ref3D orthoimagery
1:12,000	10.2 m	"Pro"	DEM from IKONOS stereo-pairs OR good quality DEM AND look angle <25 deg.; GCPs possibly not required OR one GCP/50 km along image strip	"3D - Ortho"	GCPs required; Good quality DEMs; Look angle <26 deg. (<16 deg. for high relief areas)	No Standard Product	Presumably higher quality DEM and GCPs than available from Ref3D orthoimagery
1:4,800	4.1 m	"Precision"	DEM from IKONOS stereo-pairs OR good quality DEM AND look angle <19 deg.; One GCP per 50 km along image strip	"3G - Ortho"	Good quality GCPs; High quality DEMs; Look angle <16 deg.	No Standard Product	
1:2400	2 m	"Precision+"	High precision GCPs; Precise DEMs; Look angle 0-15 deg.	NO PRODUCT	N/A	No Standard Product	

4.0 Digital Elevation Models & Control Requirements

Following is a brief summary of DEMs in the context of control requirements. For more comprehensive treatment of DEMs with regard to SDMI please refer to the SDMI DEM Whitepaper.

DEMs produced by the USGS are classified into three levels of increasing quality. Level 1 classification is generally reserved for data derived from scanning National High-Altitude Photography Program, National Aerial Photography Program, or equivalent photography. A vertical Root Mean Square Error (RMSE) of 7 meters is the targeted accuracy standard, and a RMSE of 15 meters is the maximum permitted. Level 2 classification is for elevation data sets that have been processed or smoothed for consistency and edited to remove identifiable systematic errors. A RMSE of one-half of the original map contour interval is the maximum permitted. There are no errors greater than one contour interval in magnitude. Level 3 classification DEMs are derived from Digital Line Graph (DLG) data by using selected elements from both hypsography (contours, spot elevations) and hydrography (lakes, shorelines, drainage). If necessary, ridge lines and major transportation features are also included in the derivation. A RMSE of one-third of the contour interval is the maximum permitted. There are no errors greater than two-thirds of the contour interval in magnitude. Most data produced within the last decade fall into the level 2 classification. The availability of level 3 DEMs is very limited.

The Spatial Resolution (otherwise known as Grid Posting) of a Digital Elevation Model highly depends upon two different factors: contour interval and the topographic map scale. The contour interval of a topographic map will vary depending on the lay of the land and the amount of detail that can be represented at any given Topographic Map scale. This chart shows some typical spatial resolutions from different Topographic Maps: (Note: Different cell sizes can be used for different scales of Topographic Maps, however this could result in a loss of accuracy.)

Map Scale	Contour Interval	Geographic	UTM
1:24,000	30 Feet	1/3 Arc Second	10 Meters
1:50,000	20 Meters	1 Arc Second	30 Meters
1:100,000	40 Meters	2 Arc Second	60 Meters
1:200,000	50 Meters	3 Arc Second	90 Meters
1:250,000	100 Meters	3 Arc Second	90 Meters

Control points are an important component of the DEM Quality Assurance check. Control points range from spot heights to points along index contours. Several different elevation values are used to spread the checked points evenly throughout the entire map. Several of the control points will be chosen near the edges and corners of the DEM to account for edge matching. Two RMSE tests and an average deviation test are performed to ensure the quality of the DEM. All three of the tests outcomes should be less than half the value of the contour interval of that specific map. DEM horizontal resolution and its ratio to vertical resolution can have a significant bearing on computed land surface parameters that involve differences in elevations. For example, slope is computed as the difference in elevation between two adjacent pixels divided by the distance between them.

Since DEM elevations are generally reported in full meters or feet, the computed slope can only take on a limited number of discrete values. For a 30 meter DEM with elevations reported in meters, a slope value between two pixels can be zero (no change in elevation), 0.033 (1 meter change in elevation), or a multiple thereof. Such increments may be adequate to represent slope values in mountainous terrain, but for flat areas, such as the Great Plains of the United States, a 1 meter vertical DEM resolution is insufficient to provide accurate local slope values. Thus, DEMs of low relief landscape and limited vertical resolution do not lend themselves well to an accurate determination of drainage slopes and precise location of channels and ridges.

The problems of DEM quality and resolution can generally not be overcome by smoothing or averaging the DEM. Such approaches simply cover up the problems without increasing the quality of the output. The easiest solution to overcome the described resolution problems is to custom produce a DEM with a pre-specified horizontal to vertical resolution ratio, or to use a high resolution DEM produced by more advanced methods. Other solutions include the use of DEM analysis methods that are designed to overcome problems associated with digital representations of low relief landscapes by DEMs of limited resolution.

4.1 Alaska Terrain Characteristics

Alaska is a state with variable terrain, ranging from near sea level plains to the highest peaks in North America. In summary, terrain can be summarized as follows (this is based on analysis using the USGS NED dataset):

- Alaska area: 585,000 square miles, (1,530,700 km^2)
- 67% of the state is less than 1,500 feet elevation, or 389,930 square miles
- Mean elevation is 1900 feet
- Slope > 20 degrees is 78,846 square miles

5.0 METHODOLOGIES FOR ESTABLISHING CONTROL IN ALASKA

In this section we describe methodologies used to currently establish ground control for mapping in Alaska, and the costs associated with these methods. Many of the firms cited below have had long, extensive experience either in mapping and/or surveying for mapping in Alaska. A common consensus among them is that in general control networks are lacking in the state, thus making control for any detailed mapping project difficult to develop. Even in the Anchorage area this has been a challenge as for example experienced in the 2006 orthoimagery project.

We have interviewed public and private sector mapping organizations and firms active in this area. Along with this we have compiled a summary of various existing control knowledge bases. These cover the spectrum from ortho-control of imagery at local scales to control for more regional acquisitions of satellite imagery, and regional DEMs. Ground control will be needed for statewide mapping and a strategy is needed for collecting control that will minimize costs to the SDMI over the course of the program. In this section we identify control alternatives that align with imagery and elevation options identified in Task 2, and Use Cases defined in the SDMI User Survey.

5.1 CONTROL PROVIDERS IN ALASKA---COMMENTS ON WHAT WORKS AND DOESN'T IN ALASKA

CompassData Inc.

A major reseller of ground control worldwide is CompassData Inc. They have collected control for various regional imagery collections in Alaska for ASRC, the Census Bureau, NRCS, and others.

CompassData both acquires new GCPs worldwide and actively maintains an archive of photo-identifiable and usable GCPs for re-sale. There are 290 existing points for Alaska collected by Compass. A degraded form of the archive is downloadable in shapefile format from the company website, along with documentation. In summer season 2008 Compass collected points for 25 villages. These typically consist of 4 points/village (see Alaska_Villages_Summer08.xls for list of villages).

Hayden Howard has generously provided the following information (dated August, 2008).

Archive: Sub-meter accuracy **$336 / GCP**

70 cm horizontal

1.25 m vertical

Archive: Deci-meter accuracy	**$420 / GCP**
sub-20-cm horizontal	
sub-20-cm vertical	
New collection	**$900 - $1000 / GCP**

Global Positioning Services, Inc. (GPI)

A major surveying firm based in Anchorage is involved in obtaining control for remote Alaska imagery, the best example being the DCCED Profiles project. This has involved the survey of 130 villages statewide. Typically, GPI collects 12 to 15 GCPs per village using RTK GPS supplemented by on ground panels. In addition, since 2001, the standard method has been to collect approximately four photo-identifiable GCPs per village, *after* the photography has been acquired, rather than set out panels prior to flight. This saves on logistics costs, and has proved to be an accurate method. The primary contact interviewed at GPI has been John Guffey.

AeroMetric Inc. (formerly Aeromap)

In-state, Aero-Metric is the oldest (since 1960), and largest commercial provider of aerial photography and LIDAR.

John Ellis states that most Aero-Metric photography since 2000 is controlled by airborne GPS or GPS/IMU surveys. The survey data are available for orthophoto production or mapping from the related photos, but not as independent archives. Ellis and his colleagues confirm that aside from horizontal control, vertical control in Alaska is often plagued by lack of good quality DEMs. Aero-Metric is also a registered land surveyor, and holds a large repository of orthorectified image chips and ground control statewide. Following are Aero-metric's (John Ellis, Paul Brooks) responses to our stock questions:

1. **What control do you use for orthophoto products?**

   Photo ID's, Pre and post-marked control targets, natural photo ID points depending on scale and accuracy required, ABGPS, ABGPS/IMU, controlled image chips

2. **What are your thoughts regarding photo identifiable control**

   Like lots of it. Used for QC of ground control and our airborne systems. Depending on scale we will use building corners, corners of sidewalks, poles, single trees, and other identifiable features. Used and proven method and ASPRS sanctioned. Photo ID control is the least invasive and most cost efficient. Need to plan well in advance to obtain permits for access to establish ground control.

3. What are your thoughts regarding airborne IMU?

Use it extensively, useless without GPS – need both. Reduces need for ground control points. IMU makes some flight plans feasible such as over water bodies or ice/snow covered terrain where other control methods are impractical or impossible.

4. What are the challenges of ad hoc DGPS for airborne operations, especially as it affects logistics costs and accuracy in remote areas?

Could be considered for low resolution projects, but caution is advised.

5. General thoughts on terrain correction?

Quality of the DEM is important for the accuracy of the Orthophoto

6. Is Lidar a suitable vertical data source for terrain correction?

Yes, it is a good source for producing Orthophotos. It is preferred especially on large remote, vegetated projects. Cost in sanitizing data might be an issue depending on accuracy required.

7. What vertical data sources do you typically use?

Stereo plotters, automated image correlation software such as Match T, and Lidar. USGS quads are not an acceptable source as they were not produced to comply with NMAS.

8. Do you maintain a current archive of control, and is there a repository of control that you are willing to share?

The control we establish in the field for projects is client owned and protected. However, some of the control will be in the public domain and available through the client, such as the USGS.

9. What are the lessons learned from recent orthorectification of satellite and other imagery projects that you think would be useful for SDMI?

Orthorectification of satellite imagery is particularly dependent on good quality pre-existing DEM's and ground control is imperative. Beware of optic axis offsets when performing pan-sharpening procedures.

Kodiak Mapping, Inc.

Operating since 1992, Kodiak Mapping is another Alaska firm with a history of aerial photography, photogrammetry, and some LIDAR acquisition.

Jim Woitel's firm Kodiak Mapping employs photogrammetric techniques using traditional ground survey control to establish high quality, accurate orthoimage products in urban and remote parts of Alaska. Kodiak Mapping has extensive experience throughout Alaska, with notable projects including the Pebble orthophotography project and Northern Rail Corridor aerial photography project. Mr. Woitel believes that Aerial Triangulation (AT) remains the most viable and proven way to establish ortho-control for orthophotography. Woitel is known for high quality photogrammetric-based products throughout the state. Acknowledging that IMU is an important control technology that continues to improve, Mr. Woitel maintains that obtaining on-the-ground control is essential to production of high-level ortho-imagery and DEMs. Most of Kodiak Mapping's ortho-photography production employs the AT method coupled with surveyed ground control. As with Aero-metric, further discussion is needed with Kodiak Mapping to investigate their control sources for various parts of Alaska.

Mr. Woitel's responses to a standard set of questions relating to ground control are listed below.

1. What control do you use for orthophoto products?

Control panels, photo IDs and ABGPS. Most importantly, Aerotriangulation (AT) to bring it all together.

2. What are your thoughts regarding photo identifiable control?

Photo ID points work well in urban areas where there is a multitude of paint line corners, definite sidewalk corners and other features that can be absolutely defined. If points such as these are used, very little degradation of the RMSE is induced into the AT solution as compared to photo panels. Utility poles are not especially liked by surveyors. In rural areas or out in the bush, we are sometimes reduced to using utility poles, single trees, building corners etc.. but due to the interpolation of these points, errors are inherent to photo ID usage as compared to photo panels. Sometimes schedules dictate that we must fly a project prior to pre-paneling the area and we have no choice but to use photo ID points out in the bush. It usually creates a lot of extra work for the photogrammetrist and degrades final accuracies.

3. What are your thoughts regarding airborne IMU?

Because the majority of our mapping and orthophoto projects are large scale (1" = 50' to 1" = 100' plot scale) and involve two foot contours, we do not buy into the IMU technology. IMU may work well for large orthophoto projects where vertical accuracy is not as critical as horizontal accuracy. The ABGPS data will usually suffice to meet horizontal specs if the ABGPS data is corrected for shift and drift. But no ground control!!!!!! Give me a break. IMU controls each stereo model independently and are not tied together as a block unless it is subjected to the AT process. I have seen mapping projects controlled with IMU/ABGPS with no ground control and it simply doesn't work. When I questioned the individuals that mapped the IMU controlled photography how they deal with the vertical datum shifts from stereo model to stereo model, they simply stated "we feather it in". It is no secret that photogrammetric mapping and ortho projects are expensive, so why not put ground control in up front and spend a little more money to assure mapping accuracy instead of relying on questionable IMU technology/accuracies.

4. What are the challenges of ad hoc DGPS for airborne operations, especially as it affects logistics costs and accuracy in remote areas?

For large projects in areas that are absolutely not accessible to surveyors or totally cost prohibitive, this could be considered. In 1993 the estimated error growth of 0.67 meters per 100km from the broadcast site was a generally accepted policy regarding DGPS. This could be a problem in Alaska and I am not so sure that the stated accuracy is correct. In my opinion, 3 meters per 100Km may be a more reasonable and accurate value to use.

5. General thoughts on terrain correction?

An orthophoto is only as accurate as the DTM it is rectified to.

6. Is Lidar a suitable vertical data source for terrain correction?

LiDAR is what it is. If it is used properly regarding application (orthos), it is a good vertical data source. When the capabilities of LiDAR are over stated, it is not a good thing. I have heard companies promise 6 centimeter accuracy!!! It is difficult to get that accuracy with kinematic GPS technology let alone from an aircraft flying along doing about 100 knots. As with IMU controlled photography having vertical issues due to the IMU technology itself, LiDAR has the same issues regarding vertical accuracy. It is commonly known that LiDAR is expensive. In my opinion, LiDAR should be able to compete on a cost basis to photogrammetry. I have seen many LiDAR projects go through the DOT at costs that are far beyond what a photogrammetric project would cost and the photogrammetric project would undoubtedly have higher accuracies and the client would receive planimetric data as well as an orthophoto.

7. What vertical data sources do you typically use?

KMI uses photogrammetric data via stereo plotters from aerial photography controlled by ground control, ABGPS and AT.

8. Do you maintain a current archive of control, and is there a repository of control that you are willing to share

No we don't have an "official" archive. We do have extensive control throughout the state acquired on a project by project basis. It would be necessary to contact the client on a project by project basis to see if they are willing to share the data.

9. What are the lessons learned from recent orthorectification of satellite and other imagery projects that you think would be useful for SDMI?

We do not use satellite imagery. The lesson we have learned regarding conventional images acquired with a camera is that good ground control survey data is essential.

KAPPA Mapping, Inc..

Kappa Mapping was subcontracted by Boutet Company to manage the acquisition and production of orthophotography for the Anchorage area. This orthoimagery was partly funded by USGS and is considered part of the USGS Urban Imagery program. Kappa president, Claire Kiedrowski, is a certified photogrammetrist, specializing in various techniques including aerial triangulation for orthophoto production. Kappa and Crazy Mountains Joint Venture (CMJV) jointly produced the 2006 Anchorage area orthophotography, utilizing image chips and RTK GPS GCPs. The Kappa/CMV team took an innovative, progressive approach to controlling orthoimagery in the Anchorage area. Faced with lack of a consistent survey control network and vertical control, they undertook to develop a suitable network to produce the Anchorage orthoimagery using a combination of their own RTK GPS-based survey data, LiDAR data, and USGS DEMs. Further investigation of Kappa/CMJV's control database is needed as this could be a valuable source of local control in this large area spanning about 450 square miles.

Ms. Kreidowski's responses to the standard set of questions relating to ground control are listed below.

1. What control do you use for orthophoto products?

We use targets, natural pick points, scaled control from USGS quads (or other data), AGPS, AGPS/IMU, depending on what accuracy level is required and what sources is available.

2. What are your thoughts regarding photo-identifiable control?

It depends on the project requirements. For an engineering-scale project (e.g.,1"=50' map scale with 1 foot contours), I am reluctant to use all natural features as ground control points, but sometimes we have no choice). Regarding use of road centerlines, these are ok to use, but not ideal. Any other sources of control must be photo-identifiable.

3. What are your thoughts regarding airborne IMU?

It's useful in images that have lots of tree cover or hydrologic cover, i.e., areas that are difficult to measure pass and tie points (because of the lack of identifiable features). IMU is also useful for when using software packages that are able to automatically select pass and tie points.

4. What are the challenges of ad hoc DGPS for airborne operations, especially as it affects logistics costs and accuracy in remote areas.?

A surveyor will need to address this question.

5. What are your general thoughts on terrain correction?

Orthophoto accuracy is dependent on the following: imagery and scan resolution, aero-triangulation (which is based on ground control, pass and tie points, and the ability to measure those features in stereo), and the Digital Terrain Model (DTM). The better the DTM/DEM, the better the resulting orthophoto.

6. Is LIDAR a suitable vertical data source for terrain correction?

Absolutely, but I require use of the end product, i.e., with all of the corrections applied, perhaps fitering applied, etc. Metadata would be helpful too.

7. What vertical data sources do you typically use?

LIDAR, and USGS DEMs (various postings).

8. Do you maintain a current archive of control, and is there a repository of control that you are willing to share?

Yes, we have archived information for all control points.

9. What are the lessons learned from recent orthorectification of satellite and other imagery projects that you think would be useful for SDMI?

Merging the various DEM datasets was challenging. It would have been useful to fly at a lower altitude for the Municipality area, and at higher altitudes for the more rural mountainous areas. Also, it was challenging to orthorectify images with ground elevations that range from sea level to mountainous terrain.

Crazy Mountains Joint-Venture (CMJV)

CMJV is a leading survey firm and leading provider of GPS technology in Alaska. CMJV was a leader in the effort to establish "Bowl 2000," a GPS-based standard for the Anchorage bowl area. CMJV also partnered with Kappa Mapping in the collection of the 2006 Anchorage area orthoimagery. This orthoimagery was partly funded by USGS and is considered part of the USGS Urban Imagery program. CMV was not interviewed for this report.

McClintock Land Surveying

An Alaska survey firm that provides control for aerial photography and LiDAR is McClintock Land Surveying. Bill McClintock provides ground control and other related services to engineering and photogrammetry firms statewide. They were not interviewed.

Bob Kean Associates

This firm has a long Alaska history, and provides survey control for various aerial photography projects throughout the state. Kean worked closely with Aero-metric and other mapping firms for many years. They were not interviewed.

F. Robert Bell and Associates

This firm has provided survey control for various aerial photography projects throughout the state. They were not interviewed.

5.2 Panel set-outs / Image identifiable points

To control orthoimagery photoID image chips are often used (see for example the DCCED Profiles project listed in Table 2 below). In the case of the Profiles project, Global Positioning Services uses the image chips, and then follows up with a minimum of four GCPs per community project. The GCPs are surveyed with RTK GPS (sometimes mapping grade GPS).

In general photographs can be controlled using three different methods:

- Ground control points that were surveyed on the ground using ordinary surveying techniques.
- Bridging control through aerial triangulation. Bridging is accomplished by measuring on the photographs common points that appear in three consecutive photographs or in two adjacent strips and computing their 3 D coordinate values.
- Aerial photography control through kinematic GPS technique in which the position and the attitude of the camera are computed without ground control.

In most photogrammetric projects, a combination of all or some of these methods are utilized.

Identifiable points on the ground (ground control points) are used to determine distances and geometric properties of the image, including camera height above the ground, degree of tilt at the time the photo was taken, and distance between photo centers, and to correct for distortions on the image. There are two types of distortion that commonly occur on aerial photographs: relief displacement and stereoscopic parallax. Relief displacement causes tall objects to appear to lean away from the center of the image, and parallax is the apparent shift of an object with respect to a point of reference (this can be seen in successive photographs, where there is a variation in ground elevation). In order to correct (or rectify) these distortions, overlapping photos and ground control points are integrated to produce a stereo model of the terrain, which forms the basis of photogrammetric mapping and orthophotography. Ground control, or accurate geodetic data, is essential for all photogrammetric operations.

In conjunction with low and middle altitude aerial photography, as applied to either single vertical exposures or stereo photogrammetric ground mapping, pre-marking of the ground to facilitate the photo mission and the interpretation of the photos subsequently is a commonly accepted practice.The ground control marks which are provided in the ground marking serve to assist the pilot in a more precise identification of the positions of control points on the ground, as viewed from the air, as well as assisting in recognizing these same points in the photograph for subsequent analysis. Ground pre-marking has been a long accepted practice in ground point identification.

Aerial panels used today for ground marking typically are shaped in across, a "VEE", a "TEE", or a "WYE". By far the most widely used configuration is a symmetrical cross, which in most cases is the easiest to distinguish amidst the various shapes and hues of the typical, vertical black-and-white ground photography. In Alaska panels are used still particularly for projects requiring 1 foot pixel resolution and engineering grade orthophotography (Ellis—Aero-metric, Woitel—Kodiak). The sizes of the ground marking panels are dependent upon flight altitude, which in turn depends on the mapping scale. Photogrammetrists differ in their preferences for the sizes of targets. The effective size of the ground marking panel also is largely dependent on anticipated shading conditions on the ground, namely contrast, being the most important element in visual point acquisition. Clearly, the sizes are proportional to the altitude in most cases.

At altitudes of less than 1,000 feet above ground level (AGL), panel sizes("section" or arm-length vs. width) may be as small as 12"×3",particularly when the panel is painted. Usually, white is used for black asphalt surfaces, or when a cross is applied to black cloth or felt paper.At the highest mapping altitudes, panel sections may reach 20'×2',or larger. At ultra-high altitudes, such as those used for aerial mosaic work, pre-marking is not possible. Control point identification in such high altitude situations normally is accomplished by identifying objects which clearly appear in the photography after the photo mission, such as street intersections, a building, or the corner of a cultivated field. This latter process, effected by identifying objects on the photo to provide marking points, is known as "photo identification"; and it also frequently is applied to high and middle altitude projects where the precision requirements have been somewhat relaxed.

Ground control can be classified as targeted and photo-identifiable (picked) control points, and can also be classified as horizontal control, vertical only control, or as 3-D control. Horizontal and vertical controls require different configurations to make them serve their intended purposes. The use of only ground control is now limited to small projects, such as bridge sites, borrow areas and where only one or two models are needed. Photo identifiable control points are rarely needed. The surveyor needs to know what type of control is called for when he or she attempts to pick or photo-identify the point. Accessibility for surveying is also a major consideration in Alaska.

5.2.1 Targeting Pick Points – Alaska Examples

Targeting operations are an essential part of photogrammetric mapping to be considered prior to establishing a control survey. Preflight targeting is performed to make ground locations of control points visible on the photographs. Easy identification and clear image of the control points on the photograph increases the accuracy and efficiency of the photogrammetric process. General guidelines for targeting are (Kappa Mapping): Symmetrical shape, Adequate size, Contrast, and Visibility.

Schedule is key to the operation, and vendors surveyed follow these guidelines:

- Target, then fly
- Survey before or after flight

Other targeting guidelines are listed in the Appendices.

FIGURE 1. EXAMPLE OF PICK POINT IN ANCHORAGE, AK. (COURTESY, KAPPA MAPPING)

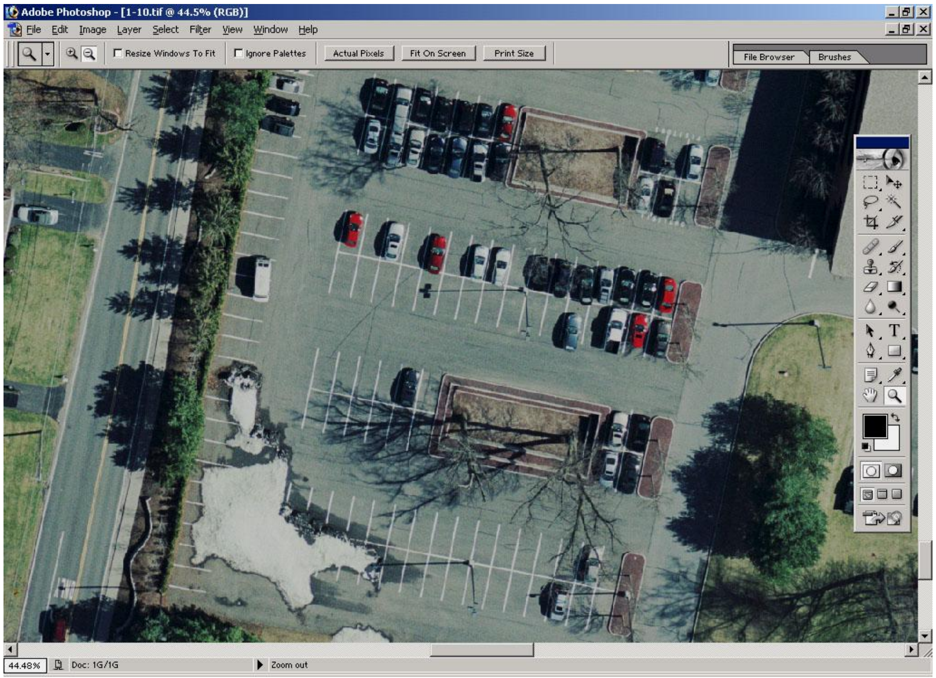


FIGURE 2. PICK POINT BEING SURVEYED, ANCHORAGE, AK. (COURTESY KAPPA MAPPING)

Kappa Mapping used Google Earth and GCPs to control urban orthoimagery for the Muncipality of Anchorage.

FIGURE 3. PHOTO ID GCP, ANCHORAGE, AK. (COURTESY KAPPA MAPPING)

FIGURE 4. PHOTO ID GCP, RURAL ALASKA (COURTESY AERO-METRIC AK)

5.3 Image Chips

An industry alternative to collecting GCPs from ground surveys is to extract GCPs from high-resolution orthoimagery, i.e. image chips, if the imagery has a map scale equivalent to, or larger than the target output map scale. For example, SPOT Image Corp. extracts ground control points from its Ref3D orthoimagery to orthorectify SPOT scenes to 1:50,000 scale accuracy.

In Alaska, several public-domain orthoimagery datasets could be accessed as sources of control, including USGS DOQs, which are produced at scales of 1:12,000 and 1:24,000. Well-controlled orthophotos of urban areas, such as Anchorage and Fairbanks could also be used as control sources. Another potential source of image-based control for Alaska includes Intermap ORIs (ortho-rectified radar images). The ORIs have resolutions of 2.5 m or 1.25 m, the latter with an excellent horizontal accuracy of 4.0 m CE95 (map scale accuracy of1:4,800).

Digital Globe's recently launched satellite, WorldView-1 and GeoEye's soon to be launched, GeoEye-1, have the potential to be utilized as control sources in remote, hard to reach locations within the state of Alaska. Both of these satellites have relatively high metric geolocation accuracy, which is often referred to as native accuracy. Digital Globe states WorldView-1 to have a geolocation accuracy specification of 6.5 m CE90 at nadir, with actual operational accuracies in the range of 4.0-5.5 m CE90 at nadir, excluding terrain and off-nadir effects. GeoEye states that GeoEye-1 will have a geolocation accuracy of 2 m CE90 and 3 m LE90 for stereo collection and 2.5 m CE90 for single scene collection.

Another commercial alternative is to produce orthorectified image chips from aerial photography. For example, Aero-Metric typically collects a 1:1000- 1:1500 scale stereo photo-pair using on-board GPS/IMU, flying an average of 9000 feet above terrain. Using standard photogrammetric techniques, an ortho-image is produced covering approximately a 3 square mile area. Any photo-identifiable feature within the image chip can then be used as a control point in orthorectifying satellite imagery. The accuracy of the image chip control points far exceeds that required to achieve 1:24,000 NMAS (which requires only mapping grade, 1-3 m accuracy GCPs). Aerometric states that they can collect these image chips in a cost-effective manner even over high terrain and they have a large aerial photography archive for which onboard GPS/IMU has been collected, but no orthophotos have been produced. This archive could be processed to produce image chips.

As another example, SPOT Image Corp. extracts ground control points from Ref3D orthoimagery to orthorectify SPOT scenes to 1:50,000 scale. USGS DOQs are produced at scales of 1:12,000 and 1:24,000, and can be used as a source of GCPs to generate new orthoimagery at these scales. DOQ coverage of Alaska is not complete, but where extant, DOQs could be used as a source of GCPs. However, most Alaskan DOQs are 1:63,360, and based on older (1950's—1960's) photogrammetry, thus likely not a good source for GCPs.

Aerial photography of urban areas, such as Anchorage and Fairbanks, was acquired using GCPs to produce orthophotos at map scales larger than 1:24,000. These aerial photos could be used as a source of GCPs to orthorectify more current satellite or aerial imagery. Another potential source of image-based GCPs for Alaska includes Intermap ORIs (ortho-rectified radar images) or CORIs (colorized ORIs). The ORIs/CORIs have resolutions of 2.5 m or 1.25 m, the latter with an excellent horizontal accuracy of 4.0 m CE95 (map scale accuracy 1:4,800). Another new option is Digital Globe's WorldView imagery.

Launched in Sept. 2007, the satellite collects a panchromatic band at 50 cm resolution. Advanced automated processing produces orthoimagery at 1:12,000 scale, from which GCPs could be extracted. A 15-km swath width coupled with high revisit times in northern latitudes means potentially rapid coverage of Alaska, although no on-spec acquisition is planned. Weather, however, is a large variable in Alaska data collection due to the short summer acquisition timeframe.

Steve Hamilton, CompassData, former photogrammetrist provided input regarding the use of orthoimagery as a control source: From his experience, in flat areas, existing 1:24,000 NMAS imagery can be used to extract GCPs to ortho new imagery to same scale – overallaccuracy would still fall within 1:24,000 NMAS.In mountainous areas, one would need 1:12,000 or 1:15,000 existing orthos to ortho rectify new collection to 1:24,000, as is airborne IMU.

Regarding Worldview-1 accuracy, Hamilton thought that accuracy claims are true; the imagery is almost orthorectified on its own, even for high terrain. The satellite tasking is currently booked up for NGA collection, mostly in foreign countries. For CompassData to get control on a mountain top is cost-prohibitive. WV-1 offers a great alternative for obtaining control for high/inaccessible terrain Regarding the use of control data from multiple sources/accuracies, Hamilton thought that the resulting ortho accuracy will be constrained by the worst-possible GPS accuracy in the control data set; e.g., if you had one GCP accurate to 30 feet, and multiple GCPs accurate to 1 foot– the 1 foot data would not be able to compensate for the 30-foot error.

Aero-Metric staff (Ellis, Syren, Cimiyotti) think that a substantial archive of public domain GCPs and image chips exist for Alaska, but stereo-pair IMU should selectively be done for the “void” areas where GCPs are lacking. They think this could be done at relatively low cost. Image chips also could be produced where needed from Aero-Metric’s large orthophoto repository. The major issue is lack of a consistent DEM suitable for use with GCPs.

5.4 Extraction of GCPs from LIDAR data

At least one agency in Alaska (USDA Forest Service) has used LIDAR points as GCPs. The details of this process were not provided, but presumably LIDAR points located at identifiable junctures (e.g., road intersections) in the LIDAR-derived DEM and/or intensity image were selected as GCPs. Ken Winterberger of USDA FS notes that the LIDAR data collection was very well controlled, with resulting high spatial accuracy and that the ortho-imagery produced using the LIDAR GCPs is of very good quality. Most Alaska LIDAR data is collected by Aero-Metric and is not restrictively-license

6.0 Inertial Systems, CORS, and Their Role in Control

In this section we focus on technologies involved in establishing control. Technologies such as diferential global position systems, CORS, all play a role. The goal of this section is to define strengths and weaknesses and dependencies on ground control for a given use case scenario. A background on DGPS and CORS is provided.

We have researched the options for ground control in Alaska by consulting with public and private sector mapping organizations. Key to this effort is documenting various existing control knowledge bases. These cover the spectrum from ortho-control of imagery at local scales to control for satellite imagery, and regional DEMs. Ground control will be needed for statewide mapping and a strategy is needed for collecting control that will minimize costs to Statewide Digital Mapping Initiative over the course of the program. Identify control alternatives that align with purchase contracts alternatives presented under forthcoming SDMI imagery RFP, and Use Cases defined in the SDMI User Survey.

6.1 Differential Global Positioning System (DGPS)

Differential Global Positioning System (DGPS) is an enhancement to Global Positioning System that uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions. These stations broadcast the difference between the measured satellite pseudoranges and actual (internally computed) pseudoranges, and receiver stations may correct their pseudoranges by the same amount.

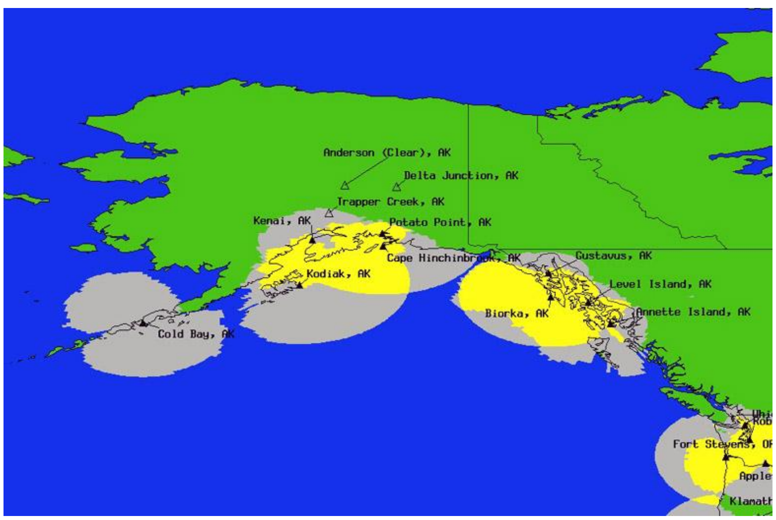
NDGPS provides real-time enhancement to GPS, including integrity monitoring and accuracy improvements to enable advanced highway, rail, and maritime applications. It uses a network of fixed ground based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions. These stations broadcast the difference between the measured satellite pseudoranges and actual (internally computed) pseudoranges, and receiver stations may correct their pseudoranges by the same quantity. Future enhancements to the NDGPS, is in final research and development stages, are aiming to provide sub-meter accuracy.

The goal of NDGPS is to provide dual terrestrial coverage over the continental U.S. and portions of Alaska to support a wide range of navigation and positioning requirements at the federal and state levels, as well as fulfilling the needs of current and future commercial applications. NDGPS currently provides single coverage service over 87% of the continental U.S., Alaska, Hawaii, and Puerto Rico, and dual coverage over approximately 55% of the same area. Dual coverage provides improved system availability, and will increase the availability of the system from the current 99.7% to 99.99%. NDGPS is built to an international standard (ITU-R-M.823). The DGPS System reached Full Operating Capability (FOC) on 15 March 1999. The U.S. Coast Guard (USCG) announced full operational capability of its Maritime Differential Global Positioning System (DGPS) Service on March 15, 1999. The U.S. DOT, in conjunction with the Federal Highway Administration, the Federal Railroad Administration and the

National Geodetic Survey appointed the Coast Guard as the maintaining agency for the US Nationwide DGPS network. The centralized Command and Control unit is USCG Navigation Center, based in Alexandria, VA. The USCG has carried over its NDGPS duties after the transition from the Department of Transportation to the Department of Homeland Security.The Coast Guard service provides coastal coverage of the continental United States, the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. Based on this established and proven system, DOT decided to expand the Coast Guard DGPS nationwide.

The investment to establish the NDGPS is estimated to be $36.9 million in capital expenses. Following establishment of the system, operation and maintenance of the NDGPS is estimated to be $6.9 million annually. The Federal Railroad Administration (FRA), as the program sponsor and holder of the federal requirement for the NDGPS, requests $10.4 million in the President's Budget for FY 2000.

FIGURE 5. DGPS COVERAGE IN ALASKA



A similar system that transmits range corrections from orbiting satellites instead of ground-based transmitters is called a Satellite Based Augmentation System. Different versions of this system include the Wide Area Augmentation System, European Geostationary Navigation Overlay Service, Japan's Multi-Functional Satellite Augmentation System, Canada's CDGPS and the commercial VERIPOS, StarFire and OmniSTAR.

6.2 Continuously Operating Reference Stations (CORS)

The continuously operating reference stations (CORS) program, managed by the National Geodetic Survey (NGS), comprises a nationwide network of permanently operating GPS receivers supporting non-navigation, post-processing applications by providing users with ties to the National Spatial Reference System for accurate, 3-dimensional positioning. The CORS system enables positioning accuracies that approach a few centimeters relative to the National Spatial Reference System, both horizontally and vertically.

Typical uses of CORS include land management, coastal monitoring, civil engineering, boundary determination, mapping, and geographical information systems, geophysical and infrastructure monitoring, as well as future improvements to weather prediction and climate monitoring. Surveyors, GIS/LIS professionals, engineers, scientists, and others can apply CORS data to position points at which GPS data have been collected.

The current realization of the North American Datum of 1983 (NAD 83), denoted by NAD 83 (CORS96), is derived from the original definition of NAD 83 (1986), established around 1986 through a combined adjustment of all classical geodetic observations supplemented with available Doppler observations and a few VLBI baselines measured at the time. As a result, the National Geodetic Survey (NGS) provided a consistent set of geodetic latitudes and longitudes for more than 200,000 points on a frame that replaced the outdated NAD 27 datum. Subsequently, NGS recognized the implications and promise of GPS technology since its early stages of development and embarked on the promotion and adaptation of GPS methods to improve the NAD 83 (1986). Consequently, progressing along with the constant improvements in our knowledge of terrestrial coordinate frames, NGS has devised and published several newer realizations of NAD 83, refining at each step the published coordinates.

Today, a proliferation CORS are being operated for a myriad of applications. Such is the case of the network maintained by NGS, comprised in February, 2003 of a set of 351 permanently monumented GPS antennas whose coordinates define the National Spatial Reference System (NSRS). NGS's National CORS network has become an effective tool for accurate 3D geodetic positioning in the United States, the corresponding GPS data are being used by a plethora of investigators interested in ionospheric research, crustal motion, water vapor studies, photogrammetric applications, etc.

The CORS system benefits from a multi-purpose cooperative endeavor involving many government, academic, commercial and private organizations. New sites are evaluated for inclusion according to established criteria. All national CORS data are available from NGS at their original sampling rate for 30 days. After that time, the data are decimated to a 30 second sampling rate. Cooperative CORS data are available from the participating organization that operates the respective site.

6.2.1 CORS Network Implications For SDMI Level Control

Our research has revealed two combined factors that impact the accuracy for Differential GPS:

i. Baseline distance of a remote receiver from a CORS base station

ii. Part Per Million (PPM) specification of the remote GPS receiver

An algorithm was established to calculate the amount of error being introduced by these two factors:

(GPSReceivers_PPM_Value /1,000,000)* Distance = Error Introduced

In the above formula the resulting Error units will be the same as the units utilized to express the Distance, which refers to the distance along baseline from the CORS

We conclude that inaccuracies are introduced, but would not affect mapping at an NMAS 1:24,000 scale specification. However, for designated areas, where larger scale mapping is desired, the effects of these two factors might need to be taken in to consideration during project planning and prior to control collection.

Because of the sparse CORS network, Aero-Metric staff noted that they do not rely on CORS for GPS correction. Rather, for a project they set up base stations to reference their DGPS/IMU, and they have a network of base stations to serve their project areas. Coupled with IMU, they are able to establish excellent horizontal control, on the order of 10 centimeters accuracy in most locations (Cimiyotti).

The two maps below depict the relative paucity of the CORS network in Alaska versus the conterminous United States, and the decline in effectiveness of the Alaska with distance.

FIGURE 6. COMPARISON OF THE DENSITY OF THE CORS NETWORK IN ALASKA & THE CONTERMINOUS UNITED STATES.

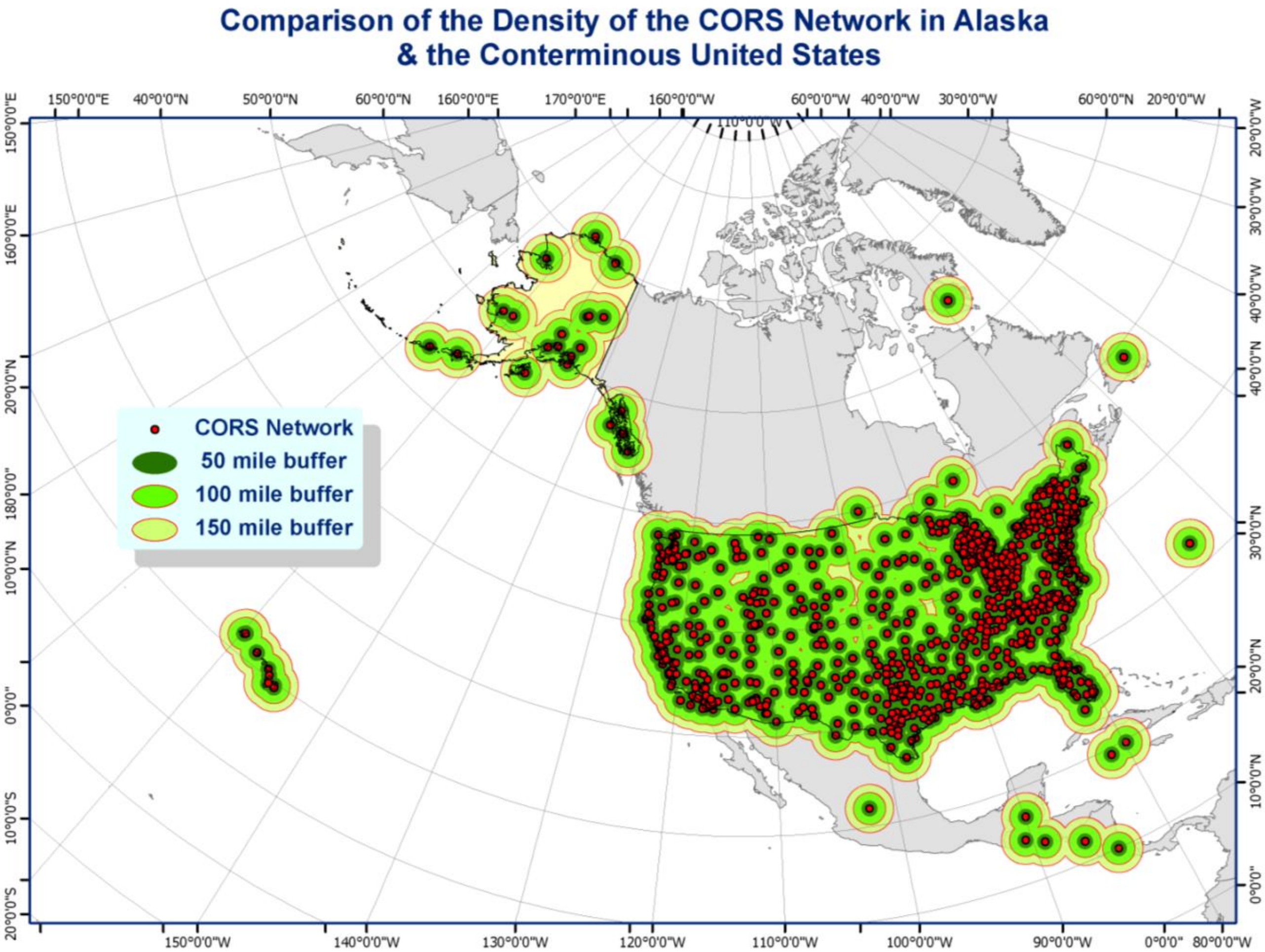
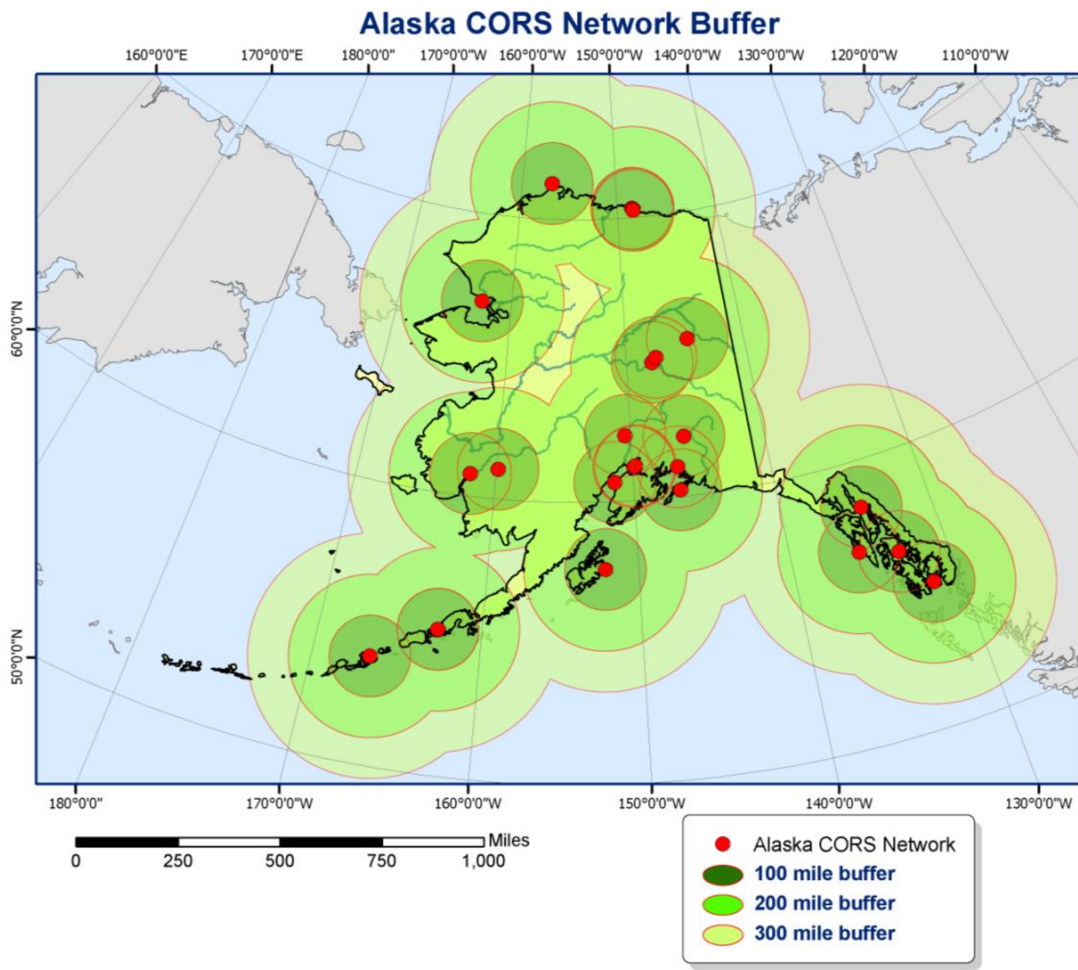


FIGURE 7. ALASKA CORS NETWORK BUFFER



6.3 INERTIAL SYSTEMS

Today there are three generally accepted methods to geoposition airborne or remotely sensed images to a local or national mapping frame of reference. The conventional method is completely dependent on well-distributed photo-identifiable geodetic ground control points and aerotriangulation. The second method combines airborne integrated GPS/INS collected data and a lesser number of ground control points with assisted aerotriangulation. The latter method, which was chosen for this pilot study, is completely dependent on airborne GPS-aided inertial navigation systems to identify the location and orientation of each aerial image at the time of exposure. The purpose of this section is focused on mapping standards attainable with control provided through on-board satellite and airborne GPS/IMU systems.

An inertial measurement unit (IMU) is a small device that is directly mounted onto sensors such as LiDAR instruments and camera units. It is composed of accelerometers and gyros. The IMU records the orientation of the instrument in relation to true north and true vertical and outputs the accelerometer and gyro data as incremental velocities and angular rates. The orientation data provided by the IMU when combined with GPS data effectively eliminates the need for aerial triangulation in airborne photography and enables scanners to be used as mapping tools.

Inertial Measurement Units (IMUs) are used in precision navigation of airborne vehicles. IMU technology has been developed and advanced primarily for military applications (e.g., missile guidance) and the space program. This discussion, however, focuses on an important civilian application of IMUs: the direct georeferencing of airborne mapping data, such as aerial photography or airborne lidar data. An IMU uses three gyroscopes ("gyros") and three accelerometers, orthogonally-mounted on an airborne mapping sensor (e.g., camera or lidar system), to measure the current rotation and acceleration. These measurements are summed to determine the change from the initial position of the aircraft.

The problem with IMU, however, is that accumulating measurements leads to errors that grow with time. Because an IMU is continually adding detected changes to the current position, any error in the measurement is accumulated, leading to an ever-increasing error between what the IMU thinks the position is and the actual position. To solve this problem, global positioning system (GPS) technology is used to provide updates to the IMU.

A technique called "Kalman filtering" is used to combine the information from the GPS and IMU, to obtain statistically optimal estimates of the three-dimensional position and angular orientation of the airborne mapping sensor. Using these data and simple geometrical relationships, scientists can determine the coordinates of the remotely sensed data in the mapping coordinate frame. This process of directly relating the remotely sensed data to the Earth is referred to as "direct georeferencing."

6.4 Airborne GPS/IMU & Aerotriangulation

Airborne GPS (AGPS)

This is a new technology which has been used in practice for only four or five years, and is proven for the production of two foot contours, but only where great care is taken with the ground control layout. The aircraft carries a GPS receiver on board which receives satellite signals along with simultaneous reception by another GPS receiver on a nearby ground station, resulting in the calculation of the coordinates of the exact center of the camera lens being obtained at the instant of exposure of each photograph, to an accuracy of about 10 cm or 4 inches. Note that this gives a control point for every photograph which limits the systematic build-up described above, but also note that 4 inches of error is already a significant proportion or the allowable rms of 0.67 feet!

However, this technology requires the full understanding of the evaluation of what is called the 'geoidal model'. It is essential to measure the elevations of existing leveled benchmarks inside the mapped area with the GPS unit as well, to calculate the difference between the leveled and the GPS elevations, and use these to model the geoid in that particular area, so that all the air stations used in the final aerial triangulation can be adjusted accordingly. The differences between regional published geoidal models, e.g. GEOID96 published by NGS, and local geoidal effects, vary up to 30 feet in some parts of the country. Clearly, non-attention to this detail will result in non-compliance with the specifications. While it is true that only four ground control points are necessary when AGPS is used for planimetric mapping, if accurate contours are required, far more points must be surveyed by a competent geodesist who fully understands the issues.

A study done on a GIS mapping project in Georgia shows that using airborne GPS, adequate ground control and proper processing of the geoidal model, 2-foot contouring accuracy can be achieved from 1"=600' (1:7200) scale photography using about one bench mark per four or five square miles for the geoidal modeling. To the author's knowledge, no similar tests have ever been done using 1"=800' (1:9600) scale photography. An 'educated guess' of the extent of this error would be an RMS of 0.4 feet.

6.4.1 Aerial Triangulation

What is not well understood or practiced is the weighting of ground control points in AT, but that is a discussion outside the scope of this project. An 'educated guess' of the extent of this error would be an RMSE of 0.3 feet.

6.4.2 Challenges of ad hoc DGPS for airborne operations

As noted in above, Aero-Metric staff does not feel that DGPS is a limiting factor in Alaskan remote areas. The typical mode of operation for Aero-Metric is to use ad-hoc DGPS and airborne IMU, and then, in the case of Profile imagery, correct this data against GCPs mostly collected by Geopositioning Services, Inc.

7.0 Models for Serving control sets

In this section we present options and recommendations for gathering and serving existing control data. Many of the agencies and firms we have contacted have control, and are willing to contribute it to a control repository. There are number of good models for regional control databases. The following two are successfully operating repositories offering particularly good models for an SDMI repository.

7.1 Canadian Ground Control Database (GCDB)

This a collection of geo-corrected aerial photo images (or chips) developed for the GIS and remote sensing community. The purpose of the GCDB was initially developed to supplement processing and/or correction of LANDSAT and SPOT data for value added satellite imagery products. The database provides accurate and useful information obtained from corrected aerial photos. This database can be used by the end-user as a fundamental data source for correction and validation of satellite, vector and raster data, as well as for map correcting and updating, analysis, modeling, and image processing. The GCDB was initially developed to supplement processing and/or correction of LANDSAT and SPOT data for value added satellite imagery products. Now, through GeoGratis, online access to the GCDB is offered as an efficient and cost effective method of delivery to the end-user.

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E-mail: patrick.king@ccrs.nrcan.gc.ca

http://www.geogratis.ca/geogratis/en/collection/detail.do?id=28

7.2 USDA Aerial Photography Field Office

The US Department of Agriculture (USDA) Aerial Photography Field Office (APFO) has a system for archiving image control chips for inspecting NAIP and other imagery they manage (David Davis, USDA). This includes support photos of site, description, and basic requirements for ground control points for NAIP and attributes or info they have in their main NAIP ground control point database. Listed below are links to the reports about the first two absolute control states for NAIP. This year APFO is using ground control for the following states: Indiana, Minnesota, New Hampshire, North Carolina, Texas, Vermont, and Virginia.

APFO is open to storing ground control point sources for other state programs. For all of the states they have done using absolute control (tied to ground control points) rather than relative control (tied to prior orthoimagery) they have worked closely with state representatives as well as other agencies such as USGS, USFS, and NGS to acquire ground control for that state. Additionally, they have published standards for ground control requirements. The APFO plans to use the same standards and approach for all of the states that are flown for NAIP in the future.

http://www.fsa.usda.gov/FSA/apfoapp?area=contact&subject=landing&topic=landing

David Davis APFO: 801.844.2922 ext. 2933

8.0 ALASKA CONTROL DATA SOURCES

We inventoried sources of Alaska control including municipalities, boroughs, federal agencies, and private firms active in Alaska focused on activity since 2000. We also collected GCPs where vendors and/or agencies were willing to provide them. All of this data was used to create Figure 8 below. Key projects that took place since 2000 or that are still in progress to produce mapping at 1:12,000 and/or 1:24,000 scale are summarized below in Table 3. These projects are highlighted to illustrate regional projects, and the control requirements associated with them.[2]

Based on this inventory, our next objective was to produce an Alaska Existing Potential Sources of Control (or gap analysis) map (see Figure 8 on the following page). The datasets that are illustrated on the Figure 8 represent a "gap analysis" showing existing control sources that were all deemed to be "largely" photo identifiable points. On the map, most sources of control are themselves imagery. Control point datasets included on the map were determined to have photo identifiable descriptors associated with the points. Primary sources for these were Compass, GPI, and the USDA-USFS (David Davis, Mark Riley). Aerometric photo centers illustrate where image chips could be licensed for use as control. The map does not reflect all the records from the GCP inventory spreadsheet (see Appendices). Records from that spreadsheet that were deemed to be unsuitable were not included in the map.

We examined the existing GCP Inventory spreadsheet entries for viable existing control options, i.e., control that is current, accessible, accurate and photo-identifiable. We then contacted the owners or providers of control to request access to the data. Some contacts were able to provide the actual or degraded-quality GCPs. Other contacts were unable to provide actual data points (e.g., due to current propriety issues), but were able to provide GIS polygons representing geographic areas that could potentially be controlled in an image by the available GCPs. Orthoimagery datasets produced using

[2] The results of this inventory are provided in a spreadsheet, Appendices (Task4_Existing_GCP_Inventory_Methods_20080718.xls).

viable control, such as the 2006 Anchorage orthoimagery or USDA DOQQs, were considered themselves to be viable control sources. We obtained or digitized the orthoimagery footprints for display in the control inventory/gap analysis map.

The following notes provide additional details regarding the specific sources of control selected for inclusion in the control inventory/gap analysis map:

- Barrow Control Points are provided on the ANSCIA project website
- Chugach National Forest Control Points were provided by Randy Schrank, along with all supporting documentation.
- CompassData Control Points were provided by CompassData.
- Profiles Village Orthophotos & Control Points were provided by John Guffey of Global Positioning, Inc.
- Aero-Metric Photocenters 2005-2007 were provided in shapefile format by Aerometric. The photocenters represent aerial photographs for which GPS/IMU data are available to produce orthorectified image chips.
- NRCS Villages Planned 1:12,000 Imagery and Control Areas (QuickBird footprints, enlarged for visibility) were provided by Ted Cox.
- Kenai Peninsula Borough (KPB) Road Centerlines and other road survey data are provided on the KPB website. To make these barely visible on the statewide control inventory map, we digitized polygons around clusters of road centerlines.
- Urban Orthophotos & Control Areas are not well-visible on the map, but include Municipality of Anchorage (MOA) and Tanana Valley orthoimagery for which control was acquired.
- Kanuti NWR SPOT Imagery & Control Area.
- Tongass NF Orthoimagery & Control Areas: Mark Riley provided a .JPG map displaying the locations of existing GCPs against the Tongass NF area. He is unable to provide the actual GCPs at this time because the information is proprietary.
- Census Orthophotos & Control Areas were imported from AlaskaMapped.
- NRCS DOQQs & DNR Forestry Orthoimagery & Control Areas were provided by Ted Cox.
- Intermap ORIs/DEMs & Control Areas were provided by Intermap (as ORI/DEM footprints).

TABLE 3. KEY PROJECTS SINCE YEAR 2000 ACQUIRING REGIONAL ALASKA IMAGERY AND CONTROL DATA.

Agency or Organization sponsoring mapping	Description:	Scale/Spec	Control?	Notes: Status and results of project, contact
USDA-NRCS (1) 90 villages NRCS Villages 2004-2006.	Variable footprints.	1:12000	2006: Compass, photoID 2004: ?	2004 centerlines don't match DOT GIS. IKONOS (04), QuickBird (06). Ted Cox.
USDA-NRCS (1)—National Resources Inveotnry. Contracted to ASRC.	50 km 2 footprints for 1100 sites statewide.	1:24000	Control uncertain.	IKONOS. 360 in 2004; 854 in 2006. excluded southeast AK. Parks excluded. Ted Cox
USDA-NRCS (1) afognak, Kodiak (Aerometric, NW geomatics)	DOQQ footprints	1:24000	Onboard GPS/IMU.	Spec exceeded. Ted Cox.
USFS (7) Chugach National Forest	SPOT	2.5m	HRS Selective GCPs using RTK GPS and other.l	Scheduled for completion in 2009. Joe Calderwood.
USFWS: Yukon Delta (3)	IKONOS pan sharpened.	25m, 90CE	Post processed handheld GPS	2009 completion date. Phil Martin.
USFWS: Kanuti Refuge (3)	SPOT	2.5m, 90CE	Post processed handheld GPS	Lisa Saperstein, Mark Syren.
USFWS: Yukon Charley (3)	Orthophotography	1m	Airborne GPS/IMU	Mark Syren.
ADNR Minto –Nenana—Fairbanks—Delta.	SPOT	2.5m	Various control	Gordon Worum, Marc Lee, Rick Guritz
ADNR—NRCS: Delta Junction – Fairbanks area	Quickbird	~1m	Various control	Gordon Worum, Marc Lee, Rick Guritz
Census Bureau (1) contracted to Harris Corporation.	Selected communities/census areas statewide.	1 meter pixel (IKONOS, QB)	Compass photoID control	Ground work completed. Problems with alignment. Hydro features a problem. Compass contracted for control. Ted Cox, NRCS and Rick Campbell, Census Bureau—Juneau, AK.
DCCED (4)	Profiles mapping of	1-2 ft. pixel orthoimage	RTK GPS	150 communities acquired since 2000. Global Positioning Services

	villages satewide.	ry.	photoID	contracted for control. George Plumley.
Kenai Watershed Forum, USGS (2)	Non-mountainous areas Kenai Peninsula.	2ft west low, 5 ft. other	Base stations, GPS/IMU. GCPs.	Control being sent to UAF for consistency checks and QC. Western portion completed. Robert Ruffner.
(1) **BLM/USGS** NPRA	Intermap and Aerometric	2.5m posting.	Selective GCPs.	Greg Barrett.
MOA and USGS, 2006 (6)	Anchorage area	2 ft.pixel	LIDAR, USGS DEM, RTK GPS GCP.	2006. Note, the Anchorage DOQQ in 2002 used LIDAR for vertical control, and proprietary Aerometric horizontal control. AC Brown.

FIGURE 8: EXISTING POTENTIAL SOURCES OF ALASKA CONTROL

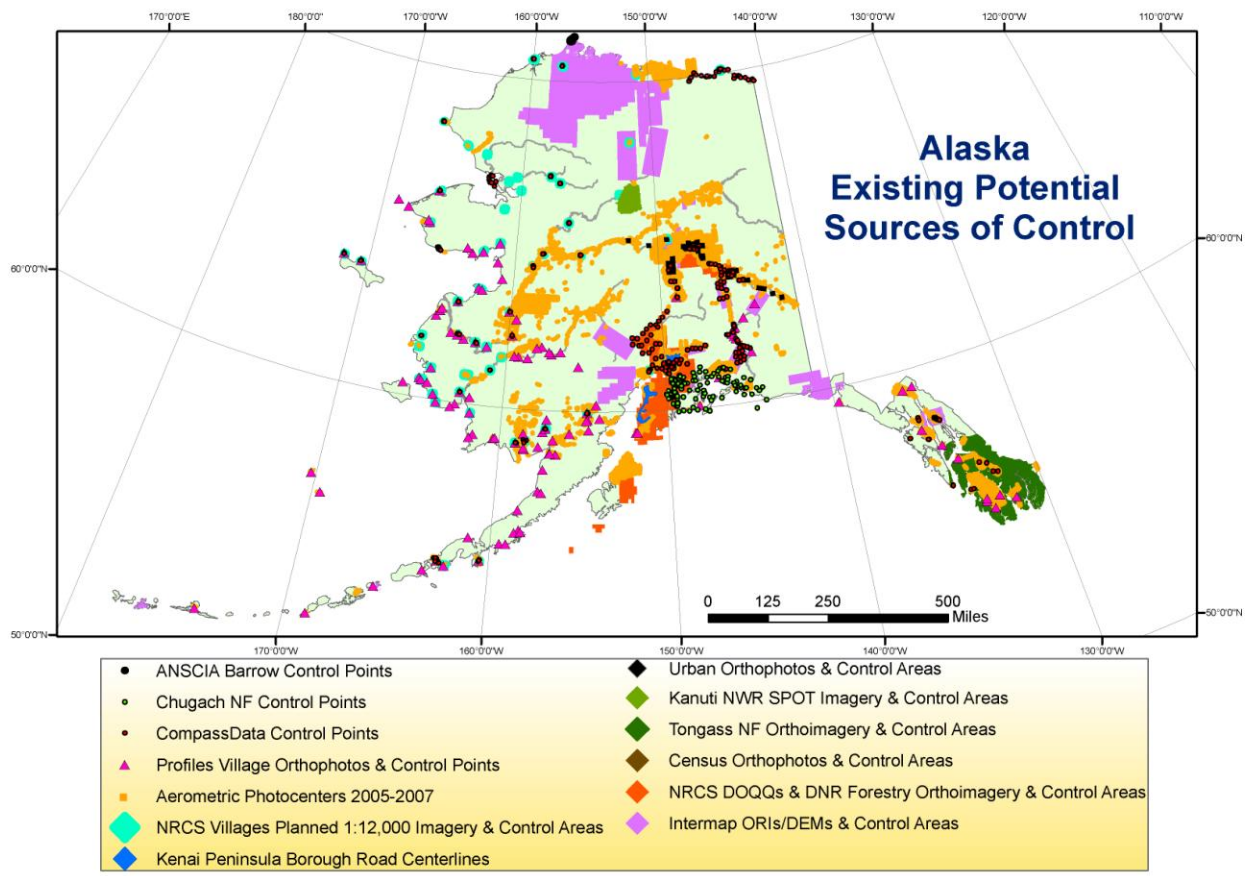
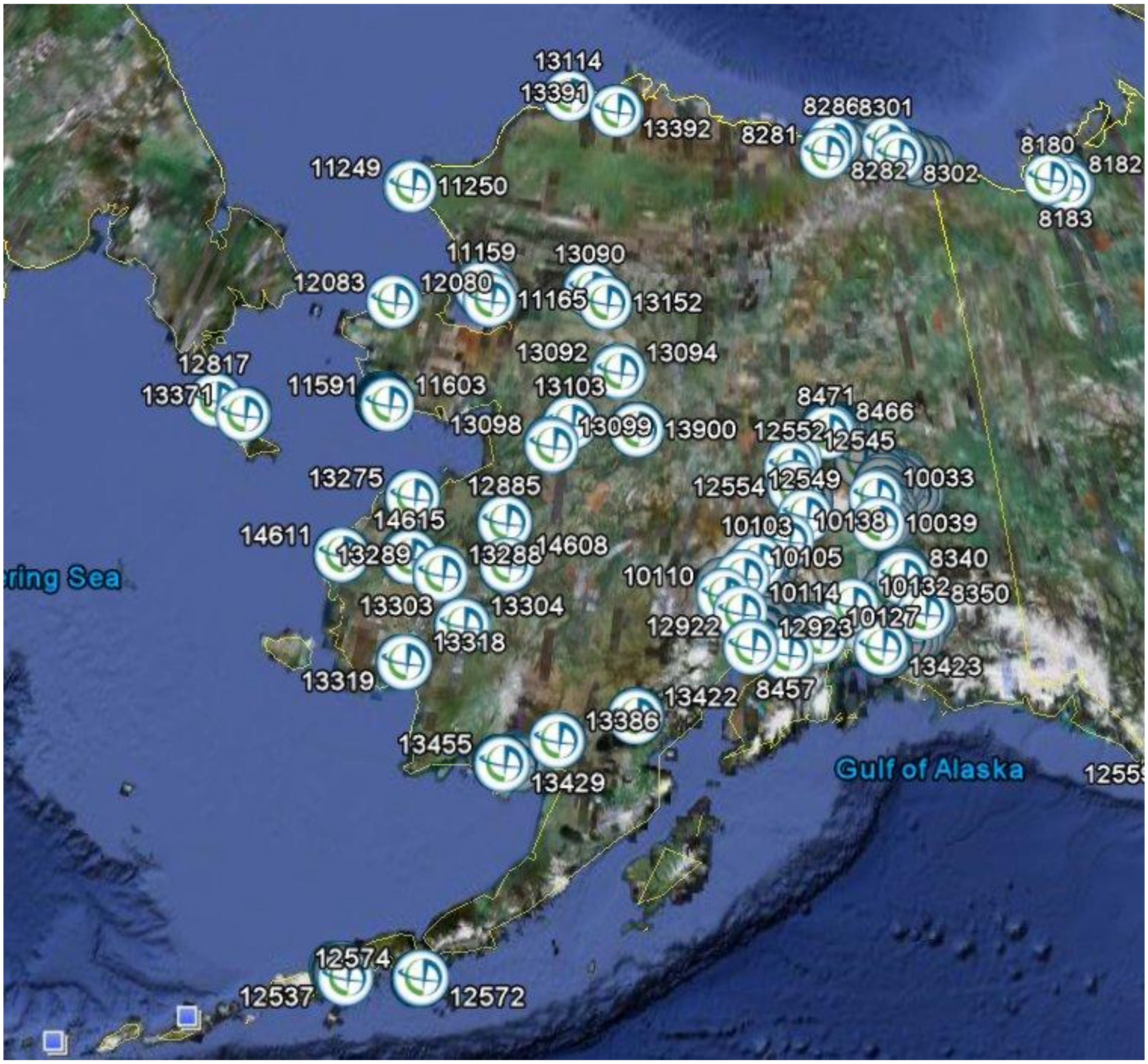


FIGURE 9. COMPASS, INC. CONTROL POINTS (AS OF 2008). SEE ALSO PUBLISHED CONTROL POINTS DATA (SHP FILE AND EXCEL)



9.0 ERROR BUDGETING

Error budgeting is a method for evaluating factors that introduce error into an image orthorectification project. The factors considered include:

- Sensor native accuracy or improved accuracy specifications
- Image pixel resolution
- Sensor off-nadir angle
- Terrain vertical accuracy
- Terrain horizontal accuracy and slope
- Quality of RPCs or on-board GPS/IMU
- Ground control point accuracy and distribution

This section explores the relative impact of each potential source of error and provides an error budgeting tool by which the expected orthoimage accuracy can be calculated for any project.

9.1 ERROR BUDGET WORKSHEET

The sections below graphically illustrate the impacts of variable Sensor/Source Image accuracy, Terrain accuracy, and Control accuracy on introduction of error into a final orthorectified image product.

In support of SDMI objectives, i-cubed has developed a Satellite Ortho-accuracy Estimation Worksheet (See SatAccuracy.xls). This interactive worksheet helps to identify the major components of an error budget for any orthorectification project involving satellite imagery, based on user inputs. The worksheet is supported by a detailed primer that documents each field in the spreadsheet, presents mathematical calculations, and explains the scientific basis behind each calculation. [3]

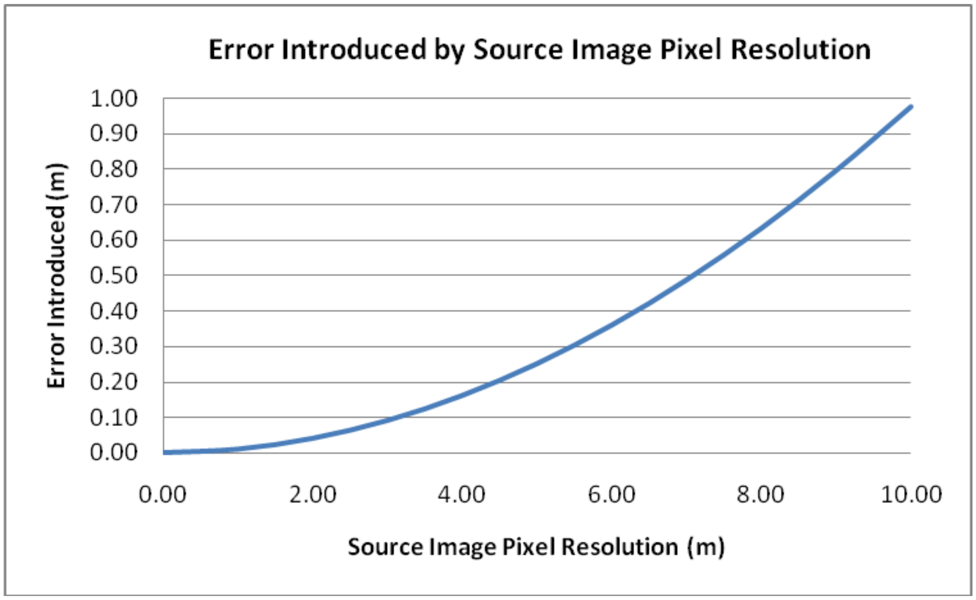
PIXEL RESOLUTION

The Ground Sampling Distance (GSD) or Pixel Resolution of a satellite has an impact on the level of detail that will be available from an image source. However, it has a relatively small impact on the overall orthopositional error.

The following graph illustrates the relatively low introduction of orthopositional error due to actual pixel resolution of the source imagery, assuming that the native accuracies of the satellites are the same:

[3] (Appendices- Satellite_Accuracy_Spreadseet_Details.pdf). Examples of the kind of analysis that can be rendered from utilizing the error budget worksheet are provided in Appendices- Error_Budget_Charts.docx.

FIGURE 10: ERROR INTRODUCED BY SOURCE IMAGE PIXEL RESOLUTION



Satellite Native Accuracy

A much stronger determinate of error introduction is the native accuracy of the satellite. This is the error inherent in the satellite model using the best method available when ground control is *not* used. Typically, this would be a model that uses rational polynomial coefficients, or RPCs. Most vendors provide RPCs with their non-orthorectified imagery, and they often will quote a number that represents the accuracy you can expect using RPCs without ground control points (GCPs). This is often referred to as the geolocation accuracy of the satellite.

Utilization of ground control eliminates the influence of the satellite's native accuracy on the orthopostional error that is introduced. Instead the satellite's improved accuracy is utilized.

The following table lists vendor stated native and improved accuracies for various satellites:

Name of Satellite	Native Horizontal Accuracy (m) CE90	Improved Horizontal Accuracy (m) CE90
GeoEye-1 [to-be-launched]	planned 2 -2.5	not yet provided by vendor
WorldView-1	6.5-13	2
QuickBird	23	~6 not officially provided by vendor
IKONOS	15	4
SPOT 5	39	10

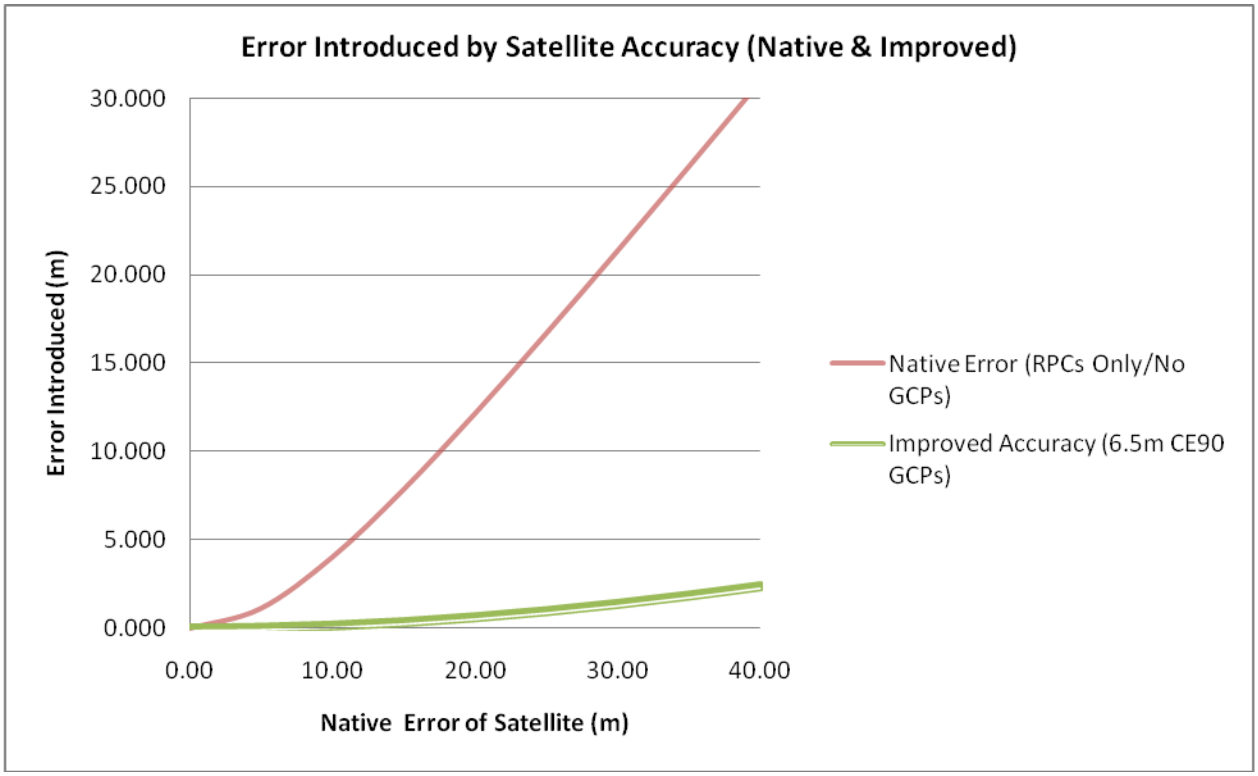
[to-be-launched] Scheduled launched date for GeoEye-1 is September 4th, 2008

The red line of the following graph illustrates error introduced as a result of the native accuracy of the satellite model, without the use of horizontal controls (GCPs).

When GCPs are utilized the error introduced is based on the stated improved accuracy of the satellite and the horizontal accuracy of GCPs utilized. The green line represents error introduced when GCPs of 6.5 m. CE90 accuracy are utilized (equivalent to utilizing WorldView-1 imagery for control).

For the purpose of this graph, Improved Error of Satellite can be represented by 1/5 of the Native Accuracy represented along the X –axis.

FIGURE 11: ERROR INTRODUCED BY SATELLITE ACCURACY (NATIVE & IMPROVED)



The fixed parameters for generation of the above graph are as follows: Source image pixel size 1 m.; Error in satellite model DEM vertical error (LE90) 20 m.; DEM horizontal error (CE90) 30 m.; 95th percentile of slope: 37.98%; Photo-identifiable precision of ground control: 0.5 input pixel.

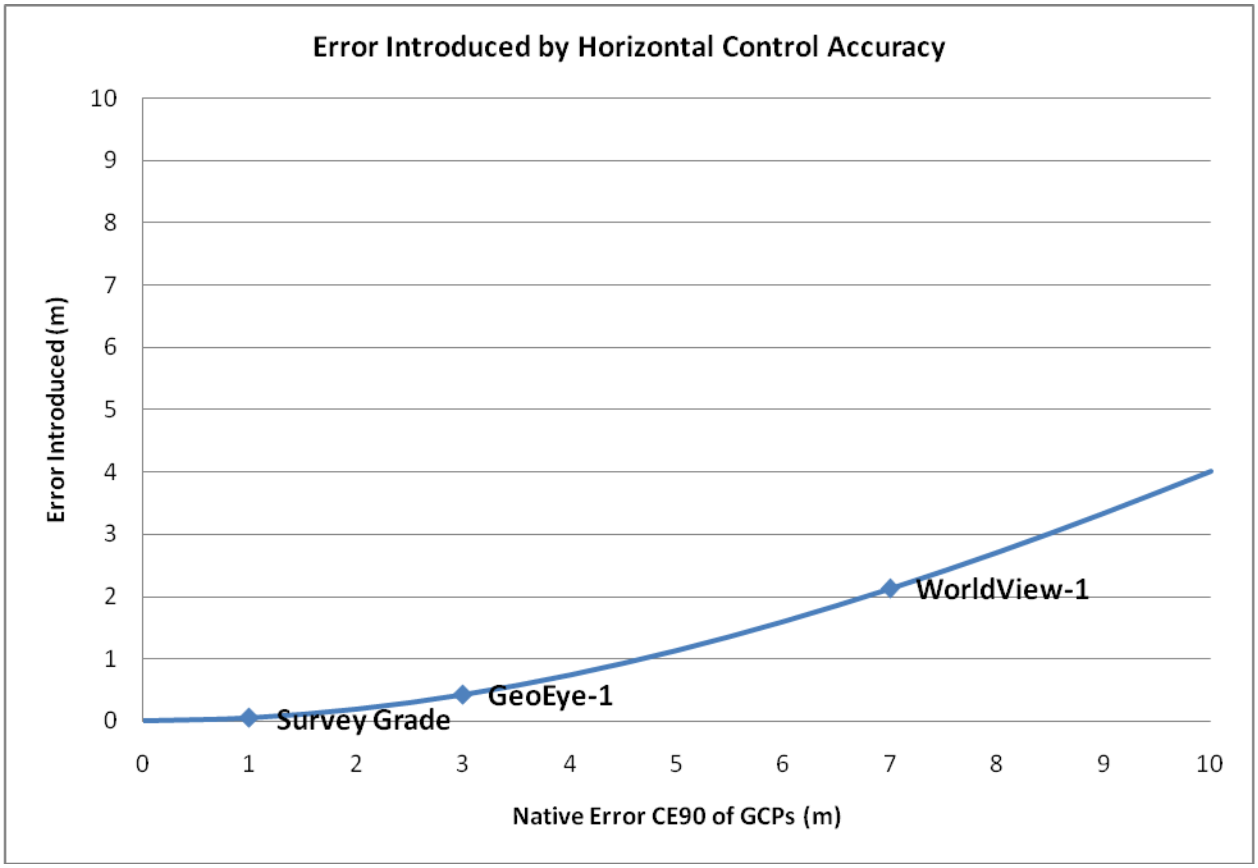
Accuracy of Horizontal Controls

When horizontal controls are utilized the provider of the control should be able to provide a stated accuracy for that control. The following table illustrates some options for horizontal control and their stated CE90 accuracies:

Ground Control Source	Horizontal Error (m) CE90
WorldView-1	6.5
GeoEye-1	2
CompassData	0.5

The following graph illustrates error introduced by increases in the native error of the horizontal controls utilized:

FIGURE 12:ERROR INTRODUCED BY HORIZONTAL CONTROL ACCURACY



The fixed parameters for generation of the above graph are as follows: Source image pixel size 1 m.; Incident Angle 24 degree. Error in satellite model (rigorous model) with gcps: 2 m.; DEM vertical error (LE90) 20 m.; DEM horizontal error (CE90) 30 m.; 95th percentile of slope: 37.98%; Photo-identifiable precision of ground control: 0.5 input pixel.

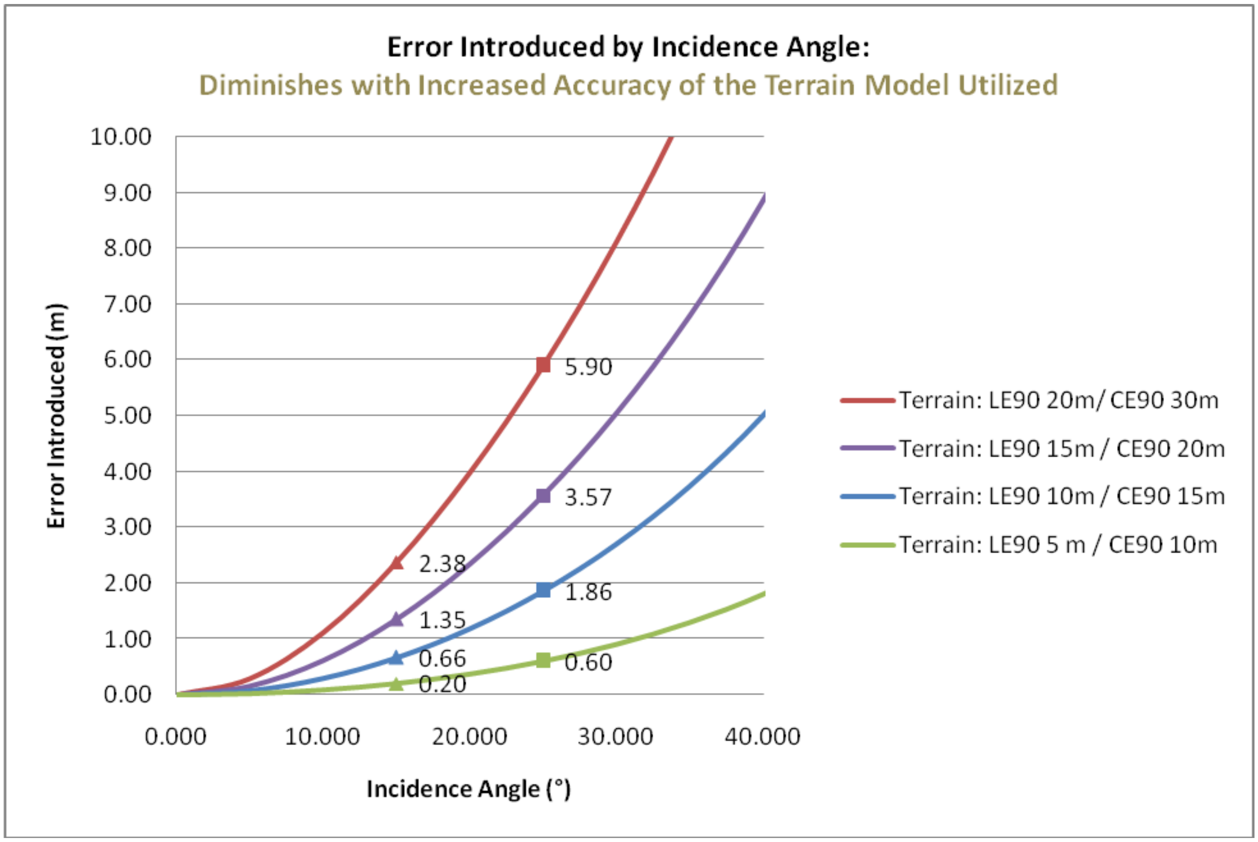
INCIDENCE ANGLE

Imagery collected is done so at a specific incidence angle. This is a value that relates to the off-nadir look angle of the imaging sensor. For a multiple scene project, the incidence angle may vary among source scenes collected. If this is the case, the maximum incidence angle should be utilized for error budget analysis.

In the following graph the different colored lines represent error introduced by increases in incidence angle, utilizing terrain sources of varying vertical (LE90) and horizontal (CE90) error. The graph illustrates the following relationships:

- An increase in incidence angle of source imagery collected, increases the contribution to overall orthopositional error
- The error introduced by incidence angle can be reduced by utilizing a more accurate terrain model

FIGURE 13: ERROR INTRODUCED BY INCIDENCE ANGLE.



The fixed parameters for generation of the above graph are as follows: Source pixel size: 1 m; Error inherent in satellite model (CE90) with rigorous model using GCPs: 2 m.; 95th percentile of slope: 37.98%; Circular accuracy (CE90) of ground control: 6.5m; Photo-identifiable precision of ground control: 0.5 input pixel

Data points on the above graph highlight error introduced at incidence angles of 15° compared to 24°. These values are highlighted as vendor recommended cutoffs for products that should be able to meet NMAS 1:24,000 scale accuracies and better.

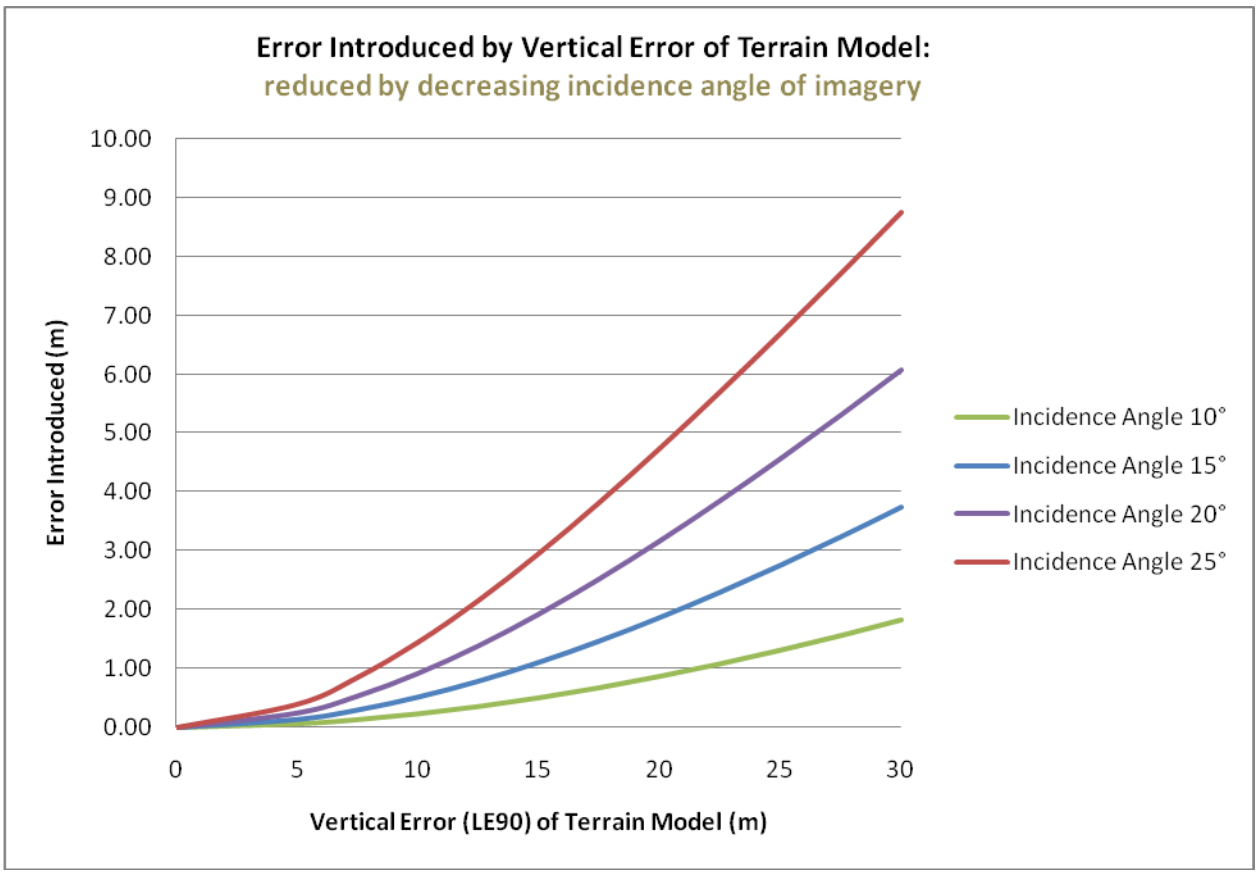
VERTICAL ERROR OF TERRAIN MODEL

The vertical accuracy, of the terrain model utilized, is a significant contributor to orthopositional error. Providers of Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) should be able to provide a vertical error for each unique dataset. Vertical error is expressed in meters as linear error (LE) at a certain value (i.e. 90 or 95).

The influence of the vertical accuracy of the terrain model can be mitigated by decreasing the incidence angle at which the source imagery is collected.

The following graph illustrates how an increase in the vertical error of the terrain model increases the positional error introduced. This relationship is illustrated with the use of four different incidence angles of source imagery, to illustrate how the error introduced can be minimized by decreasing the incidence angle.

FIGURE 14: ERROR INTRODUCED BY VERTICAL ERROR OF TERRAIN MODEL



The fixed parameters for generation of the above graph are as follows: Source pixel size: 1 m; Error inherent in satellite model (CE90) with rigorous model using GCPs: 2 m.; No horizontal error in the terrain; Circular accuracy (CE90) of ground control: 6.5m; Photo-identifiable precision of ground control: 0.5 input pixel

HORIZONTAL ERROR OF TERRAIN MODEL

The horizontal accuracy, of the terrain model utilized, can also be a significant contributor to orthopositional error. Providers of Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) should be able to provide a horizontal error associated with their terrain product.

Horizontal error is expressed in meters as circular error (CE) at a certain value (i.e. 90 or 95).

The error introduced by the horizontal error of the terrain model is increased as the slope of the project area increases.

The following graph illustrates how an increase in the horizontal error of the terrain model increases the positional error introduced. This relationship is illustrated with the use of four different slope percentages, to illustrate how the error introduced by horizontal error of the terrain model is magnified by increases in the slope

The fixed parameters for generation of the above graph are as follows: Source pixel size: 1 m; Incidence Angle 24°; Error inherent in satellite model (CE90) with rigorous model using GCPs: 2 m.; Vertical accuracy of terrain (CE90) 20 m.; Circular accuracy (CE90) of ground control: 6.5m; Photo-identifiable precision of ground control: 0.5 input pixel

10.0 Control Costs

We are currently in the process of researching and documenting the native and GCP-improved accuracies from all potential providers of imagery, terrain, and control data. The draft deliverable (See Appendices: Accuracy.xls) is a spreadsheet containing specific satellite, terrain and control values necessary to run a multitude of scenarios through the Error Budget worksheet (See Appendices).

A sample cost analysis relating to procurement of ground control data for a statewide orthoimagery project is provided here. (The additional costs of obtaining suitable DEM and satellite imagery are not addressed.)

Example: The IKONOS GCP density requirement is one GCP spaced every 50 km or less along an 11-km-wide image strip. Estimating a 1-km overlap between adjacent image strips, we imagine the GCP distribution to be along a grid with 10 km x 50 km spacing.

Approximate GCP density: 1 GCP per 500 sq km

Alaska land area: 1,530,700 sq km

Total # of GCP required = $\frac{\text{1,530,700 sq km}}{\text{500 sq km}}$ = 3061 pts

Cost of statewide GCP new acquisition @ $1000/pt = $3,061,000

11.0 CONCLUSIONS & RECOMMENDATIONS

Control requirements for development of a moderate resolution specification statewide basemap meeting user specifications must take into account a number of factors including availability of CORS, ground control points, terrain, sensor variations, etc. There are a number of alternatives for horizontal and vertical control that are necessary to meet the goal of National Map Accuracy Standards at the target 1:24,000 statewide mapping use cases identified through the SDMI User Survey. In this report we recommend a control strategy that is most economical and supports quality control for both elevation and ortho-imagery.

Alaska geospatial data users have identified the need for more accurate and higher resolution statewide DEMs as a key priority. Horizontal and vertical accuracy of the datasets beyond what can be produced from imagery off of the satellite is in effect proportional to the amount, location and quality of ground control. Most of the vendors interviewed in this study agree that DGPS/IMU is a valid technique for establishing good quality moderate, if not high resolution, imagery products anywhere in Alaska despite the lack of complete CORS coverage.

Ground control distribution and density requirements are becoming less stringent as improvements in DGPS, IMU, CORS, airborne digital acquisition and satellite technology occur. What is clear from interviews with vendors and experts in the area of control is that a consistently distributed network of GCPs (in the form of a combination of GCPs and/or orthoimage chips) would be very valuable in the production of an acceptable statewide digital basemap at moderate resolution. As shown the error budgeting analysis provided in Section 9.0 ground control even at a less dense coverage can significantly enhance base mapping accuracy. Cost estimates for a statewide GCP network vary, but based on vendors collecting such a control network in remote Alaska could vary from three to 15 million dollars.

Key recommendations regarding control for development of an SDMI basemap are as follows:

1. Via FGDC/AGDC endorse a an accepted standard or approach for control for statewide or large regional orthoimagery acquisitions. We recommend a standard based on real work experience by firms such as Compass or Global Positioning Services in the Alaska Profiles orthoimagery project, USFS Chugach National Forest project, Census Bureau (Compass) project, Aero-metric, and Kappa Mapping. Photo-idenfiable image chips coupled with limited GPS-surveyed GCPs over a distributed network in the state at a density recommended by Digital Globe and others (e.g. 1 GCP per 1,000 square kilometers) would provide a suitable network of ground control assuming adequate terrain model.

2. A control repository or database is recommended for SDMI. Ground control for this repository could come from various sources, e.g.:

    - Collected pro-bono by field workers on other projects, and donated to a statewide database

- Existing unlicensed GCP archives
- Extracted from unlicensed aerial photography or DOQs
- Selectively purchased control from qualified vendors.

We recommend building an SDMI Control Repsitory or Database similar to models like the Canadian Ground Control Database through community cooperation. With the sponsorship of an entity such as the University of Alaska, a community donor GCP data base could be established, whereby field crews conducting biological or other natural surveys for other projects, are asked to collect photo-identifiable ground control as the opportunity arises and submit the points and supporting data to the database. Additionally, vendor archives such as held by Aero-metric could serve to supplement the agency contributed GCPs. As shown in Table 3 above, a number of Alaska agency projects are collecting GCPs that are public domain, and could form the basis for this database. The state of Alaska Profiles mapping program is acquiring a large archive of GCPs statewide in their program to map remote communities. They are open to releasing this GCP archive to the public, and this could be part of a larger community donor database.

Costs to acquire a new control network would range from three to 15 million dollars, but this could be mitigated by using a methods listed above.

Orthoimagery production to NMAS accuracies of 1:24,000 or better requires at least a DTED-2 DEM-level terrain model as shown by the error budgeting worksheet, which means better quality DEMs than currently available. Given funding constraints, SDMI may need to give priority to purchase of better quality DEMs, over GCPs. In either case, as shown by the error budgeting tool, a balance of adequate DEM, ground control, and good quality imagery is necessary to produce an SDMI basemap.

12.0 REFERENCES

KEY DOCUMENTS

NGS, 2003, U.S. National CORS network consult the web address: http://www.ngs.noaa.gov/CORS/.

USGS, National Mapping Program, Technical Instructions, Standards for Digital Elevation Models

SDMI DEM Whitepaper, David Maune, Dewberry, July, 2008

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Rick Campbell, Census Bureau
Andrew Canales, Digital Globe
Dean Cimiyotti, Aero-metric
Steve Colligan, eTerra LLC
Ted Cox, NRCS
David Davis, USDA Aerial Photo Office
Gene Dial, Geoeye
John Ellis, Aero-metric
Anthony Follett, Aero-metric
John Guffey, Surveyor, Global Positioning Services, Inc.
Rick Guritz, UAF
Steve Hamilton, CompassData
Hayden Howard, Compass
Claire Keldrowski, Kappa Mapping (see also powerpoint, document provided by Claire)
Marc Lee, ADNR-Forestry
David Maune, Dewberry
Mark Riley, USFS
Bob Schweitzer, Aero-metric
Mark Syren, Aero-metric
Ken Winterberger, USFS
Jim Woitel, Kodiak Mapping
Gordon Worum, ADNR-Forestry

13.0 APPENDICES

Appendices 3-7 are provided as separate attachments in zip file published on alaskamapped.org website

1. TARGETING GUIDELINES[4]

The table below shows the minimum dimensions that are necessary for the targets to be seen on aerial photographs.

PHOTO SCALE (PS)	LEG WIDTH **(PS/500)**	**Leg Length (PS/100)**
1”=200’	0.4’	2.0’
1”=250’	0.5’	2.5’
1”=300’	0.6’	3.0’
1”=500’	1.0’	5.0’
1”=600’	1.2’	6.0’
1”=800’	1.6’	8.0’
1”=1000’	2.0’	10.0’
1”=2000’	4.0’	20.0’
1”=3000’	6.0’	30.0’

Accuracy Requirements

The horizontal and vertical accuracy requirements for the ground control are listed below based upon the final map scale that is required for traditional-type photogrammetric mapping.

[4] KAPPA Mapping, Inc.

MAP SCALE	HORIZONTAL ACCURACY	**Vertical Accuracy**
1”=50’	0.25’	0.05’
1”=100’	0.50’	0.10’
1”=200’	1.0’	0.20’
1”=400’	2.0’	0.40’
1”=500’	2.5’	0.5’
1”=1000’	5.0’	1.0’
1”=2000’	10.0’	2.0’

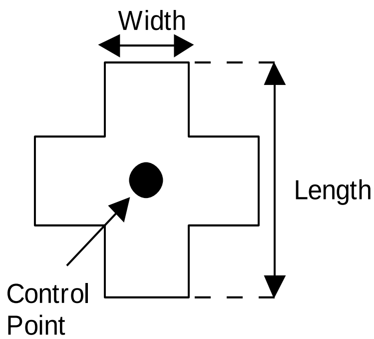
Delivery Materials from Surveyor

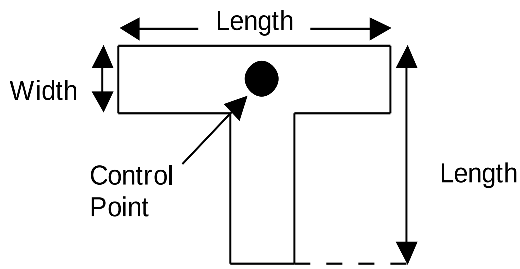
Upon completion of the ground survey, the surveyor shall deliver:

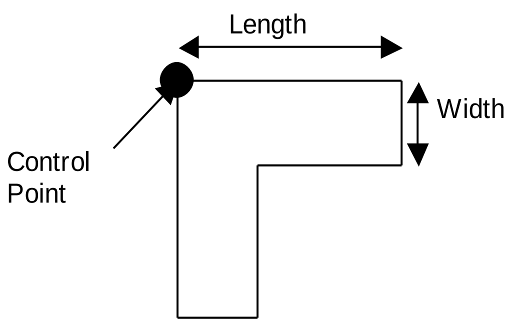
1. The original annotated copies of the aerial photos
2. A hard copy and electronic copy of the X, Y, Z or N, E, Elev of the requested points. The surveyor must specify the basis of the coordinates: coordinate system (SPCS zone, UTM zone, assumed, etc.), horizontal and vertical datums, and units.
3. Copies of field sketches for each requested point.

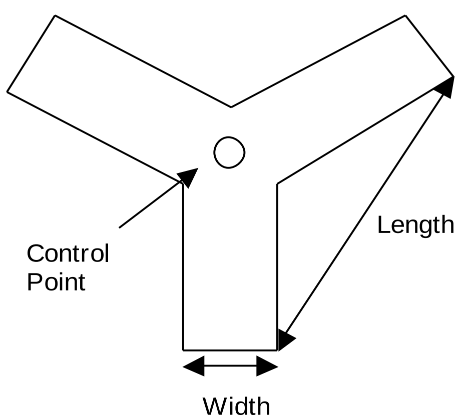
Shape

The shape of individual targets can be in the shape of an “X”, a “T”, a “^”, or a “propeller”. The sketches below show the location of the control point in relationship to each target configuration.


Width
Length
Control
Point


Length
Width
Control
Point
Length


Length
Width
Control
Point


Control
Point
Length
Width

2. NATURAL PICTURE POINT GUIDELINES[5]

Typically the vendor will provide contact prints and a picture point selection map. The map will indicate nominal picture point locations. Note that nominal locations are selected such that a control point will be imaged on as many photos as possible. This increases redundancy in the aerotriangulation solution.

In general:

1. Any point must be imaged on two adjacent photos in the same flight line.
2. Corner points will be imaged on only two photos.
3. Points common to two flight lines will be imaged on four, five, or six photos. The more the better. Number 1 is always applicable.
4. Edge points will be imaged on three photos except for cases 2 & 3 above.
5. Any picture point should be at least 0.5" from any inner camera frame edge. The frame is typically black on a contact print. Don't push the edge unless you are in a really bad pinch. The more an edge is pushed, the better the chance that the point will not be usable. This could mean a return to the field to find a suitable point.

Some guidelines for picture point selection for engineering grade -foot contour mapping:

- Point should be horizontally well defined in each photo in which it is imaged.
- Point should be on a flat or gently sloping surface.
- Flat points on hard surfaces are preferred.
- Avoid tree lean, pole lean, any kind of lean over a point.
- Do not select points in shadows.
- Do not use poles, sign legs, or the like unless you are in a really bad pinch.
- Point should be directly occupy-able with survey-grade GPS equipment.
- Verify each selected point with field stereoscopes.

[5] Kappa Mapping

- Pin-prick each point in ONE photo on EACH flight line in which it appears. Be certain to pin-prick the image of the point that you survey. Do not pin-prick it on every photo. We need to be able to see what you picked.

- Put a triangle around the pin-prick, and number the point on the front of the photo. Describe and/or sketch the point on the back of the photo, and include the point number. Note that targets do not need to pin-tricked.

Regarding the pin-holes: When we hold the photo up to the light, we want to see light through a fine pin-hole, not through a crater made with a nail. A safety pin works great. It has a fine point, it is easy to grip, and it clips nicely to a shirt pocket.

When using T, +, L, or V shapes, place the nail as follows:

1. T, at the intersection and center of both stripe widths.
2. +, at the intersection and center of both stripe widths.
3. L, at the outer corner of the L. Describe it as such in your sketch.
4. V, at the outer point of the V. Describe it as such in your sketch.
5. Exceptions MAY be OK, but must be clearly documented.

Example of Bad Point Selection

A paint stripe at the foot of a curb is no good because it is not flat, and the top of the curb may obscure the foot of the curb. **A picture point must always be unobstructed when viewed from the exposure center of each photo on which it is imaged.**

Examples of Good Point Selection

Center of round Manhole (MH) is good if it is flush with the pavement. Corner of square Catchbasin (CB) is good if it is flush with the pavement, *but not if it is at the foot of a curb*. The CB must be described and sketched so that we are certain which corner was used. ***Recessed MHs and CBs are not acceptable.***

In general, flat and flush are good. Contrast is good too.

Select points that are close to the indicated nominal point locations. Find points that are imaged on as many photos as possible without pushing any photo edges.

Occasionally, it is helpful to take pictures of a picture point, and its vicinity, and send them along with the coordinates, statistics, etc. However, this is not a substitute for properly marked control prints.

Please number the points as indicated on the plot if numbers are indicated.

Please mark the photos with ink that does not smear/smudge/run.

Please keep the photos dry. Otherwise, they will stick together, the emulsion will tear, and they will be useless where the emulsion is torn. Typically, this happens where a point must be selected.

Regarding the aerotriangulation solution for 1' mapping:

1. We expect horizontal residuals to be sub 0.35', and vertical residuals to be sub 0.10'. Therefore we must know precisely which points have been controlled. We rely on your pin-pricks, sketches and descriptions to know where to measure the control points with the degree of accuracy required for a solution suitable for 1' contour mapping.

2. Please directly occupy each picture point, and build-in some sort of check (locate each one twice?). Please do not sideshoot picture points. Please provide GPS network adjustment results, and/or error statistics with the picture point coordinates. It helps with control point weighting and bundle adjustment analysis.

3. Existing GCP Inventory – "Existing_GCP_Inventory_20080815.xls"

See spreadsheet in zip file

4. Satellite Ortho Accuracy Estimation Worksheet – "SatAccuracy.xls"

See spreadsheet in zip file

5. Error Budget Worksheet Documentation

See document in zip file

6. Sample Output Derived from Error Budget Worksheet - "Error_Budget_Charts.docx"

See document in zip file

7. Cost Analysis Worksheet – "Accuracy.xls"

See spreadsheet in zip file