High-Resolution Satellite Image Processing in Interior Alaska:
The good, the bad, and the ugly

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Abstract: This presentation outlines operational problems, pitfalls, and solutions encountered in orthorectifying and classifying large amounts of high-resolution satellite imagery as part of a project concerning vegetation and community mapping of the Tanana Valley conducted cooperatively by the State of Alaska Division of Forestry and Tanana Chiefs Conference. Essentially a case study of an ongoing, evolving project, this presentation will focus on the limitations encountered and the processes employed to accomplish project goals.

Introduction

The Tanana Chiefs Conference Forestry Program and the State of Alaska Division of Forestry in Fairbanks are currently cooperatively engaged in a project focused on acquiring, processing, and utilizing high- and medium-resolution satellite imagery in the Tanana Valley of interior Alaska. This paper outlines some of the experiences we have had while completing this project, including some of the limitations and obstacles we have encountered.

The Organizations
- Tanana Chiefs Conference, Forestry Program (TCC) – Tanana Chiefs Conference is a regional non-profit Native corporation serving tribes and individual natives in interior Alaska through a variety of programs and services. The Forestry Program at TCC is a small staff charged with forest management responsibilities on trust lands (Native allotments) and also provides technical assistance to village corporations and other entities as needs and available funding sources allow. As part of the delivery of these services, TCC Forestry has been active in GIS technologies for about 15 years. Development of GIS capabilities has allowed TCC Forestry to provide spatial data services to other programs and functions at TCC as resources allow.
- State of Alaska Department of Natural Resources, Division of Forestry (DOF) – The northern regional office of the Division of Forestry located in Fairbanks provides spatial data support for the Tanana Valley State Forest and other forested State lands in the Tanana Valley.   In recent years, that work has involved

extensive use of remotely sensed data, and there has been substantial development in capacity for processing, classifying, and analyzing imagery by the agency.

The Need
In both our organizations we have recognized for some time the potential uses for remotely sensed imagery. At TCC in particular, there is recognition of the wide variety of uses such imagery could be put to, but there has been little opportunity to acquire or process such data. DOF has been involved in acquiring and processing imagery from several different sensors for some time, but has been frustrated in the inability to produce or acquire data that are spatially accurate enough to integrate with other GIS data. The lack of a good "base" layer of data in our region has proven to be a substantial impediment to past projects. In addition, the relatively recent availability of satellite imagery with previously unimaginably high spatial resolutions generated a desire to examine the suitability of these new data for purposes such as community mapping, infrastructure mapping, and land cover mapping. DOF was very interested in testing the feasibility of high-resolution imagery for wildland fuels mapping to complement their role as a wildland fire suppression and management agency. TCC was interested in similar land cover mapping uses, but was even more interested in general community mapping for a variety of planning and community needs.

The Grant
A funding opportunity appeared in June 2001 in the form of $3 million earmarked for Alaskan remote sensing projects. Through the efforts of Sen. Ted Stevens, funds were provided through NASA and administered by the Alaska Department of Natural Resources. A proposal was submitted cooperatively by DOF and TCC to acquire, orthorectify, and classify imagery around communities and other areas of the Tanana Valley. The grant was awarded, and the project ensued.

The Cooperators
Support from other organizations was enlisted as part of the proposal. One of the implications of the project was that data products produced by the project would be widely available, and there were a number of agencies and organizations that expressed interest in the project on that basis alone. As time progressed, budgetary limitations were encountered, and many of these organizations made contributions to ensure the success of the project. The cooperators were to be licensed to have full access to the data. The list of cooperators eventually consisted of the following:
- State of Alaska DNR
- State of Alaska DOT
- State of Alaska DCED
- Fairbanks North Star Borough
- Golden Valley Electric Association
- University of Alaska
- Tanana Chiefs Conference
- USDA Natural Resource Conservation Service

The Data

<u>Satellite Imagery</u>

The project as originally envisioned in the proposal was to focus on 2 types of imagery; high-resolution imagery to be acquired around all communities in the Tanana Valley except Fairbanks and North Pole (which were covered at the same time in a similar project run by DOF and funded by USDA Forest Service fire planning funds), and medium-resolution imagery in other areas of interest between communities. "High-resolution" for this project was determined to be something on the order of 1 meter (1m) spatial resolution, and "medium-resolution" was determined to be on the order of 5m spatial resolution. At the time of the writing of the proposal, IKONOS imagery by Space Imaging was the only commercial high-resolution data source, and the medium-resolution imagery to be used was Indian Remote Sensing (IRS) imagery, also licensed by Space Imaging. The IKONOS imagery comes in a 1m resolution panchromatic band and 4 4m multi-spectral bands, which were to be fused to produce high-resolution multi-spectral products. The IRS imagery, which comes in a 5m panchromatic band, was to be fused with available LandSat imagery to produce medium-resolution multi-spectral products.

From the outset, 2 primary goals of the project were to produce orthorectified image products at as high a horizontal spatial accuracy as possible and to make that imagery as widely available as possible. Both goals proved to be problematic due to a combination of data requirements and licensing restrictions. To produce an accurate ortho product from satellite imagery requires several components:

1) Relatively raw unprocessed imagery
2) Associated orbital or ephemeris data from the vendor
3) Relatively low off-nadir satellite view angles
4) Accurate, well distributed ground control
5) Horizontally and vertically accurate digital elevation model data.

Each of these 5 components presented challenges, but the first 2 are controlled by licensing restrictions imposed by the satellite vendors. Making the imagery available to organizations outside of TCC and DOF required multi-agency licensing that stretched project budgets to unanticipated levels, and in the case of both IKONOS and IRS imagery, the vendor was unwilling to allow us to license either the raw imagery or the associated ephemeris data. The marketing model employed by the vendor didn't accommodate users that were willing to collect their own ground control and do their own orthorectification work, but instead attempted to retain that as a value-added service provided to their clients, although this was not apparent at the onset of negotiations. The solution to this dilemma appeared in the form of new vendors and products in the satellite game. The QuickBird satellite was launched by DigitalGlobe in October 2001; similar to the IKONOS products, but with a slightly higher resolution (60cm pan, 2.4m multi), QuickBird was offered in a "basic" image product that closely fit our needs. Similarly, Spot Image Corp. in France launched the Spot 5 satellite in May 2002, and was able to provide "medium-resolution" imagery (2.5m pan, 10m multi) in a licensing framework that fit our needs. Our problems with licensing and data availability may be less of an issue in the future; increased competition appears to be having the effect of producing

better pricing, product availability, and licensing options among the vendors, at least from the perspective of the image consumer.

Digital Elevation Models (DEMs)

Although we recognized from the outset the importance of having quality DEMs in producing accurate ortho products, we were not able to ensure that quality DEM datasets were going to be available. There was a naïve hope that something acceptable would be available to us, and we had reason to expect that some products would become available to us for this project. Most forseeable options involved producing DEMs from some sort of synthetic aperture radar (SAR) or inferometric synthetic aperture radar (IFSAR) product, either aircraft-based or satellite-based. The University of Alaska Geophysical Institute was involved with a couple projects that showed promise in terms of useful DEM products in portions of the Tanana Valley, one from aircraft-based SAR data and one from satellite-based SAR data. Neither one eventually panned out in terms of producing suitable DEM product in a timely manner. NASA's Jet Propulsion Laboratory (JPL) was able to provide some aircraft-based SAR DEM data for some areas, and IFSAR based DEM data from Intermap (acquired through a NASA data buy) were available for some areas, but this was mostly in the Fairbanks area; the Fairbanks project run concurrently by DOF was well serviced by this data, but the relatively remote areas covered by the Tanana Valley project were not covered. In addition, there were some problems with some of these data; the JPL data had some data gaps in it that had profound effects on orthorectification. The IFSAR data in particular are of remarkable quality, but can be quite expensive. The only remaining alternative for DEM coverage of the remainder of the Tanana Valley were various flavors of DEMs generated from USGS topographic quadrangles either through the Multi-Resolution Land Characteristics Consortium (MRLC) or the National Elevation Dataset (NED) maintained by USGS. While these datasets have the advantage of complete coverage of the entire State, they are relatively coarse spatially (about 44m horizontal spatial resolution for the NED) and there is often reason to suspect the accuracy of the elevation data itself. Experimentation with various DEMs in the Fairbanks area and conversations with professionals at DigitalGlobe have led us to the conclusion that the spatial resolution of the DEM used, while important, is not as critical as the vertical and horizontal accuracy of the DEM.

The effect of DEM accuracy on the accuracy of the resultant ortho product is complex, but there appears to be an important relationship between DEM accuracy and the off-nadir view angle of the satellite. View angles for the images ordered for this project were specified to be less than 15 degrees, but several times the images came in with view angles at the upper end of those specifications, and combined with relatively poor DEM data could potentially produce spatial accuracy problems in the ortho products. Elevations of GPS points collected for ground control sometimes varied from the DEM elevations by as much as 30m, with the biggest discrepancies in upland areas. Planimetric orthoimage accuracy is most critical in the developed areas in and around communities, most of which occur in lowland flat areas. Fortunately, as a result, poor horizontal accuracies as a result of poor DEMs tended to occur in the less critical undeveloped areas of the images.

If there are to be problems with the accuracy of the ortho products resulting from this project, it will be because of the lack of adequate DEM data. This project was never meant to produce those data, but for many places in Alaska, the lack of good digital elevation model data remains a problem.

Ground Control Data
Another component required for accurate ortho production is good ground control data, a factor we felt we could control. The plan as originally envisioned was to acquire the images, examine the images for appropriate features that we could identify on the image and on the ground, travel to the features on the ground and determine the coordinates of the ground control points (GCPs) with a resource-grade GPS receiver, and post-process the GPS data to achieve accuracies on the order of 1.5m or less. This happened pretty much as planned, with a few wrinkles.

We were told that 6 or 7 GCPs per image should be adequate for producing a good quality orthoimage, but we found that more GCPs, preferably 12 or more, were required per image to produce a product of the quality that we were hoping for. The GCPs need to be distributed over the extent of the image, with points located as far back into the corners as is feasible; in addition, we were told by the DigitalGlobe people that having GCPs in locations with good elevation variation produced a better ortho mode, something that appeared to be verified by our experience. We recognized from the outset that accessing the landscape covered by the imagery to establish GCPs would be especially challenging given the remote nature of much of the Tanana Valley. A QuickBird scene is roughly 10 X 10 miles; a scene acquired over a rural community may have boat or road access on a portion of the imagery, but there will inevitably be substantial portions of the image that will be difficult to access on the ground, and it was feared that use of a helicopter would exceed our budget limitations. A Spot 5 scene covers over 1300 square miles, so the access situation is even more pronounced on that imagery. However, DOF was able to get access to a helicopter contracted for wildfire suppression for us to use at a reasonable cost (when it wasn't being used on fires), and the bulk of the GCP collection was done by helicopter, with ground access also done to augment the number of GCPs.

DOF was processing several contiguous QuickBird images in the Fairbanks area and noticed problems in the overlap area between 2 images; one of the images was offset from the adjacent image by an average of 5m. Since we were hoping to achieve accuracies on the order of a meter or two, this was a disturbing discrepancy. Conversations with technicians at DigitalGlobe, who were conducting their own tests of the imagery, revealed that they were recommending that survey-grade GPS coordinates be collected for the ground control points. Some of us found it hard to believe that increasing the accuracy of the GCPs from 1m to 0.1m would have that profound an effect given that you have to locate each GCP on an image whose pixels are 0.6m wide, but field testing with a borrowed survey-grade GPS receiver revealed that the improvement in the final ortho product was substantial; average offset decreased to about 2.5m to 3m with survey-grade GCPS collected on one of the two overlapping images. Based on that, a survey-grade GPS receiver was purchased and used for all subsequent GCP collection

on QuickBird imagery. The offsets on the contiguous Fairbanks imagery continued to improve with use of more GCPs with a better elevation spread and access to better DEM data. We continued to collect resource-grade data on Spot 5 GCPs because we felt that the pixel size on the Spot imagery didn't warrant the increased accuracy.

The logistics of the helicopter work was such that the helicopter was available for periods of time before imagery was acquired, so the decision was made to place targets on the ground that would hopefully be viewable on the imagery. After some experimentation, we settled on placing targets made from 2 strips of white muslin sheets 18" X 8', crossed in an "X". There was some risk in this – there was no guarantee that the image would not have cloud cover over some of the targets, or that nothing would happen to the targets before the images were acquired. We hoped the imagery would be acquired within a month or two of placing the targets, but we knew it was likely that some of the images wouldn't be acquired until the following season, and we weren't sure how well all of the targets would weather a year or more on the ground. Overall, using the targets worked well for the first season's image acquisitions. Most of the imagery was acquired that season and most of the targets were visible. Some of the targets turned out to be in areas of high reflectance and were difficult to see, some of the targets seemed to mysteriously disappear, and several were under cloud cover, but on imagery acquired in summer 2003 about 90% of the targets were usable as GCPs. If we had it to do again, the targets would be made of longer, narrower strips to make more of an "X" on the image rather than a blob of white pixels. Orientation of the "X" turned out to be important for precisely defining the "X" on the image; the QuickBird scenes are oriented directly north-south, so that if the "X" is also oriented north-south, it lines up with the pixels better and makes the "X" more precisely defined on the image. The targets were only placed on the QuickBird imagery; we decided that the pixel size of the Spot 5 imagery made targets on that imagery infeasible.

For imagery that was acquired before GCP collection, we were put into the game of identifying and accessing features on the landscape that could be identified on the image and located on the ground for use as GCPs. This was often easier said than done; we were hoping to locate these points down to a single pixel on the image, so features as small as possible were desired. It was sometimes surprising what sorts of features were indeed visible on the imagery, and conversely, which ones weren't when we thought they should have been.

It was important that the GCP information be well documented so that the use of the GCP data in the ortho process go as smoothly as possible. At each GCP, in addition to the GPS data that were collected, digital photos were taken of the GCP on the ground and from the air (if using a helicopter), comments recorded, and the GCP's location was recorded in the field on the imagery (if available). The location of the imagery was sometimes recorded on paper prints of the imagery or on a display of the imagery on a notebook computer. All this information - processed GPS coordinates, digital photos, location images, comments, etc. – was stored in a MS Access database and made available online to both offices through active server page queries on TCC's web server.

As of October 2003, there had been data collected for 167 GCPs on QuickBird imagery and 52 GCPs on Spot 5 imagery.

Image Orthorectification

Both DOF and TCC use PCI Geomatica software to process the imagery. The panchromatic images are orthorectified using the GCP database and available DEM data, then the multi-spectral data are similarly processed using the same GCP data if the same GCP features or targets are viewable on the coarser multi-spectral imagery. Additional image-to-image points from the panchromatic orthoimages are sometimes used to ensure adequate registration between the panchromatic and multi-spectral orthoimages. After orthorectification, the panchromatic and multi-spectral images are fused together using the PANSHARP algorithm in PCI Geomatica. Metadata are created for all image products as they are produced.

The sheer size of the images creates a series of challenges; none of us were familiar with dealing with individual computer files of the size of these images. An unprocessed QuickBird panchromatic image is a little less than 2 GB in size, and the multi-spectral image is a little less than 0.5 GB. The imagery was orthorectified into UTM coordinates, meaning that the north-south orientation of the raw image resulted in little rotation in the orthoimage, so the orthoimages did not greatly increase in size. The pan-fusing adds 3 additional bands at the same 0.6m resolution, though, resulting in files approaching 7 GB in size. QuickBird comes in 16-bit bands, so about half the disk space can be recovered by converting the imagery to 8-bit bands, at the cost of losing some of the spectral detail. That still leaves QuickBird pan-fused 8-bit imagery at about 3.5 GB, which can be a little unwieldy. For example, ArcGIS software currently does not work with image files over 2 GB.

Orthoimage accuracy

We have had much discussion concerning the horizontal accuracy of the orthoimages and how to assess and describe it. On the QuickBird imagery, all factors notwithstanding, we had hoped to get any location represented on the images to within a couple meters (2m CE90); for comparison, this would be the equivalent of Space Imaging's precisionPlus product for IKONOS imagery, which Space Imaging says requires "high-precision ground control and precise terrain models". Given that we have fairly precise ground control but marginal DEMs in most areas, it would seem to be more realistic to aim for 4m CE90 accuracy, on par with IKONOS precision products. Traditionally, accuracy would be assessed by independently establishing the location of a number of points and measuring the deviations or offsets from the location of the points on the images. Currently, the only data we have that could serve that purpose are the GCPs that were used to produce the orthoimages. Since the robustness of the models used to generate the orthoimages is in large part driven by the number of GCPs and the expensive nature of the GCP data collection resulted in a fairly limited number of GCPs established per image, we were relunctant to hold back any of the GCPs to use for accuracy assessment; we would be in the situation of purposefully degrading the quality of the product so we could measure the quality of the product. The exceptions to this would be in those areas with adequate access, such as the Fairbanks area, where additional location data could be

gathered inexpensively, and we hope to evaluate the accuracy of some of the imagery in the Fairbanks project in that way, with some extrapolation of results to the remaining imagery. In the meantime, we are left with only a couple clues that we can use to evaluate the orthoimages – statistics of the models used to generate the orthoimages, and the offsets of the GCPs themselves on the final orthoimages.

The statistics in the models take the form of RMS errors describing the relative "fit" of the GCPs to each other in the model. Individual GCP RMS errors generally ran less than 2 pixels, with overall RMS errors less than 2 pixels. Excessive individual RMS errors are used to identify "bad" GCPs to allow refinement of the models. RMS errors were documented and recorded in metadata created for the orthoimages to allow users of the data to assess for themselves the integrity of the models used to generate the orthoimages.

After generating the orthoimages, GCP locations were checked against the orthoimages to determine how much they were offset in the final product. These deviations were also documented and recorded in the metadata. Since these deviations are measured on the points actually used in the model used to generate the ortho, they do not constitute a rigorous accuracy assessment, but we feel they do act as some sort of indication of accuracy. On the QuickBird imagery, the offsets averaged 1.4m, or 2.3 pixels, with a maximum of 5.1m; on the Spot 5 imagery, the offsets averaged 2.2m, or 0.88 pixels, with a maximum of 5.5m. In places where the deviations were higher the problems could often be traced to apparent errors on the DEM.

Wildland Fuels Classification
Although not the primary emphasis of this presentation, the final product anticipated as a result of this project are datasets representing wildland fuel cover types generated by classifying the orthoimages. This is essentially land cover classification, and of course has implications beyond the fire management activities that is the driving force behind this effort. This activity is being conducted by DOF staff, and is a work in progress, although some initial fuels mapping has been completed. The software being used is eCognition , which classifies based on
objects, which are either groups of pixels or another hierarchy of objects. This is distinctly different than the pixel-based classification normally conducted, and seems to be appropriate given the high amount of variability in pixel reflectance over small areas that is apparent with high-resolution imagery.

Summary
Nineteen QuickBird scenes were included in the original order, and DigitalGlobe included 2 more to ensure adequate coverage. To date, after 1 ½ seasons of image acquisition, of those 21 QuickBird scenes, 17 have been acquired, GCP collection is completed on 11 of the scenes, and orthorectification completed on 8 scenes. Of the 7 Spot 5 scenes ordered, 5 have been acquired, and 4 have completed GCP collection and have been orthorectified. Fused orthorectifed scenes are viewable on TCC's website at http://www.tananachiefs.org/maps. Methods of storage and dispersal of the image products are still being worked out. The orthoimage products being produced are already finding utility at our organizations. The project has allowed us to become familiar with

the utility of this type of imagery, for example, what sorts of detail we can identify on QuickBird imagery for purposes of community mapping and how well the Spot 5 imagery works for land cover interpretation or classification over large parts of the landscape. The experience gained from this project leaves us much better prepared for acquiring and using such imagery in the future.

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