United States
Department of
Agriculture

Forest Service

**Southern Forest
Experiment Station**

Research Note

SO-375
February 1994

Scan Angle Calculation and Image Compositing for the Mexico Forest Mapping Project

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SUMMARY

Data from the Advanced Very High Resolution Radiometer (AVHRR) were used in a cooperative project, sponsored by the U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, and the United Nations, Food and Agriculture Organization (FAO), to map Mexico's forest cover types. To provide satisfactory AVHRR data sets for the project, the sensor scan angle needed to be calculated for data points in the composite image data, and the clouds had to be removed and composite image data created from individual data sets. Techniques used to accomplish those two tasks are described here. Concepts illustrated here should be applicable to other similar projects.

INTRODUCTION

A mapping project was conducted in 1991 at the U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Forest Inventory and Analysis (SO-FIA) unit, to create a new forest map of Mexico. The project was part of a global forest assessment program coordinated by the United Nations Food and Agriculture Organization (FAO) and was linked with Mexico's nationwide forest survey effort.

Personnel at the SO-FIA unit assisted with the project by acquiring and preparing remotely sensed and other digital data and by providing computer support and training in image processing techniques to Mexican scientists. The Advanced Very High Resolution Radiometer (AVHRR) was the primary data source. Results of the project, most noticeably a new forest land cover map of Mexico, have been reported previously (Eggen-McIntosh and Zhu 1992, Evans and others 1992).

The AVHRR is a cross-track, scanning spectrometer located on polar-orbiting satellites of the National Oceanic and Atmospheric Administration (NOAA). The sensor's characteristics (e.g., large ground picture element [pixel] size and frequent Earth revisiting cycle) make the data particularly suitable to large area, land cover studies such as the Mexico project. While standard AVHRR data can be received at almost any point on Earth by a ground station, additional treatment (preprocessing) is often necessary to make the data more useful. For example, over a nominal scene (a scene is the area on the ground that is covered by satellite image data) of 2,048 by 3,600 kilometers (Kidwell 1991), clouds are likely to be present somewhere on any given day. With AVHRR's daily coverage of the same Earth location, there is the opportunity to create a composite image with minimal cloud cover from multiple sets of data from different dates. Furthermore, the sensor's scan angle (β) is large ($\pm$ 55.4° cross-track). Data at the extremes of this scan angle are more susceptible to attenuation caused by the atmosphere, and pixels from these areas become distorted (fig. 1). Thus, it is customary to include angular information for each pixel location in the compositing process. Generally, AVHRR preprocessing involves radiometric calibration, georeferencing, calculation of various sensor angular data, and compositing of multitemporal data.

Ten AVHRR data sets, georeferenced to a common Lambert azimuthal equal-area projection, were provided by the U.S. Geological Survey, EROS (Earth Resources Observation System) Data Center, Sioux Falls, South Dakota. Each data set included a local zenith angle data channel. The large number of clouds and cloud shadows present in all of the data sets necessitated the use of a compositing approach to reduce the total cloud coverage in the images of Mexico. Another

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task was to create a scan-angle channel to accompany the resulting composite images. As noted above, the angular information provided would serve as a reference for pixels that were scanned at large angles and used in the resulting composites. The techniques that were used to accomplish the two tasks are presented in this paper. The data processing steps were carried out within the ERDAS® (Earth Resource Data Analysis System) image processing software package. The concepts described should be applicable to other similar projects.

METHODS

Deriving the Sensor Scan Angle

As illustrated in figure 1, the sensor scan angle, β, is the angle through which the sensor oscillates from the nadir position to either side in a cross-track direction. The ground area represented by an AVHRR pixel at or near the nadir position is nominally set at 1.1 kilometers on each side of the square area. When resampled, this dimension is often set to 1 kilometer. As the sensor swings to a large scan angle (e.g., an angle greater than ± 35°), the area captured by the instantaneous field of view (IFOV or Θ) becomes greater and deviates from the standard pixel size and shape. Therefore, it is necessary to derive the size of the sensor scan angle for pixels in a composite data set. The local zenith angle supplied with the AVHRR data for the Mexico project was used to derive the sensor scan angle for each pixel.

In figure 2, β is the sensor scan angle with an absolute value range between 0 and 55.4°, λ is the local zenith angle with an absolute value range between 0 and 69° (Kidwell 1991), R_e is the equatorial radius of the Earth, and A_{sat} is the nominal altitude of the satellite. Given the trigonometric relationships observed in the diagram in figure 2, and that sin (180° − λ) = sin λ, the following equation is obtained:

$$\frac{\sin \lambda}{R_e + A_{sat}} = \frac{\sin \beta}{R_e} \qquad (1)$$

The inverse of equation 1 is:

$$\beta = \arcsin \left[\sin \lambda \left(\frac{R_e}{R_e + A_{sat}}\right)\right] \qquad (2)$$

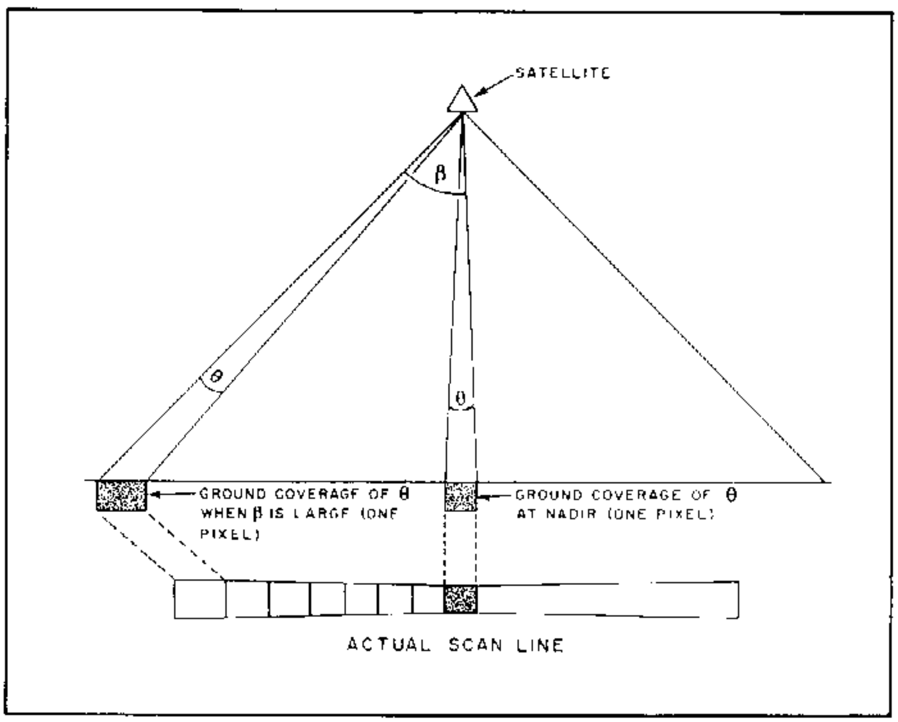

Figure 1. – *Relationship between the satellite scan angle and ground pixel size (after Hill and others 1985). In the diagram, β = satellite scan angle, and Θ = instantaneous field of view (IFOV) angle. One pixel is the area covered by one Θ. Note that the pixel at nadir (the point on the ground directly beneath the satellite) is a square; pixels at a large β become distorted.*

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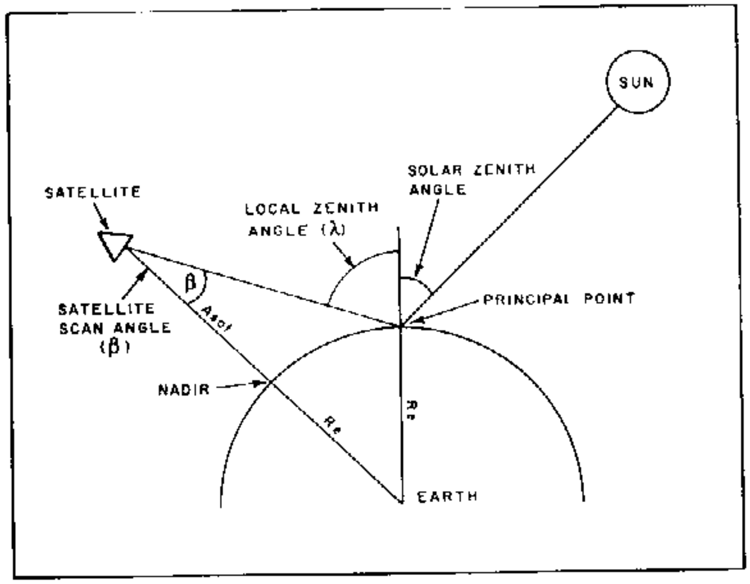

Figure 2. – *Angular relationships of satellite to Earth and Sun (after Kidwell 1991). Nadir is the point on the ground directly beneath the satellite, R_e is the equatorial radius of the Earth, and A_{sat} is the nominal altitude of the satellite.*

A value of 90° was usually added to the local zenith angle by the EROS Data Center to put it in a range of 21 to 159°. Therefore, when equation 2 was entered in ERDAS to solve for β, 90° was subtracted from λ prior to calculation.

The value of *degree (°)* and the arcsin function were not supported by ERDAS. Thus, the following trigonometric equations were used:

$$degree(^\circ) = radian \left(\frac{(180)}{\pi}\right) \qquad (3)$$

where π is equal to 3.1416, and

$$\arcsin X = \arctan \left(\frac{X}{\sqrt{1 - X^2}}\right) \qquad (4)$$

where X is any given value.

Substitution of equations 3 and 4 into equation 2 gives equation 5, which was used in ERDAS to calculate the sensor scan angle:

$$\beta = \left(\arctan \frac{\sin\left(\frac{|\lambda - 90|\,\pi}{180}\right)\left(\frac{R_e}{R_e + A_{sat}}\right)}{\sqrt{1 - \left[\sin\left(\frac{|\lambda - 90|\,\pi}{180}\right)\left(\frac{R_e}{R_e + A_{sat}}\right)\right]^2}}\right)\frac{180}{\pi} \qquad (5)$$

Given the λ value, and by using $R_e \approx 6{,}378$ km and A_{sat} for the NOAA satellites ≈ 850 km, equation 5 can be solved for β.

The above process created 1 sensor scan-angle channel for each of the 10 AVHRR data sets. The scan-angle channel was then appended to the regular data set and included for use in the second task (i.e., removing clouds and creating the composite data sets). Thus, pixels in a resulting composite included five spectral channel data points as well as the corresponding scan angle.

During the compositing process, scan-angle values were used as one of the factors for consideration in selecting pixels from different AVHRR dates. The inclusion of scan-angle data also provided an opportunity for users, among other things, to identify potential atmospheric effects and to adjust area statistics represented by classified pixels.

Cloud Removal and Compositing

Among the 10 available 1990 AVHRR data sets of Mexico, 3 were acquired in March, 4 in May and June, and 3 in December. To preserve spectral differences due to the different vegetation growing seasons, compositing was done using acquisition dates close to the dates of the original image files. Therefore, three composites were created: one based on the three sets of March images, one on the four sets of May and June images, and one on the three sets of December images.

The general strategy for creating a composite from several original image files was to overlay and overwrite the image files in a hierarchical order based on the amount of clouds (including cloud shadows) present in the images, as well as on the relative sizes of scan angles. Images with heavy cloud cover or larger scan angles were overwritten in those pixel locations by clearer images or images with smaller scan angles. First, all images were examined visually for the amount and location of clouds and for the size of scan angles to decide the order of overlay for each compositing period. Then each image was classified according to the amount of clouds, and the resulting cloud classification was in turn used to mask the original image at cloud locations. Finally, masked image files were combined to create a composite in the overlay order as defined in the above process. The following steps detail techniques used in the compositing procedure.

1. Creating a Cloud Mask Image File

Image files were evaluated on a display screen to determine the amount and location of clouds. As stated previously, the best image had the most complete coverage of Mexico and the fewest clouds. At the same time, AVHRR spectral channels were noted for the highest contrast in separating clouds from ground types. The near-infrared and thermal channels provided the best monochrome display for cloud identification.

Histogram matching was used if the general brightness levels of compositing images were visibly different due to temporal differences in spectral values. In this process, the clearest image in a compositing period was used as a model image. The histograms of spectral statistics of the other image files were compared to the histogram of the model image file to create separate look-up tables (tables that perform certain functions on input image data) for each of the other images. Pixel values of the other image files were mapped through their respective look-up tables to adjust the resulting spectral characteristics to that of the model image file.

Spectral signatures were extracted for cloud classes using the spectral distance threshold option. Clouds tended to be spectrally heterogeneous; thus, the threshold was adjusted accordingly. Separate classes were created for different illumination levels due to cloud type and position (e.g., bright cloud tops or cloud shadows). In extracting spectral signatures, as well as in subsequent classification, using the two channels (near-infrared and thermal) was more effective than using all available spectral channels.

A simple parallelepiped classification routine (ERDAS 1991) was used to separate cloud types from the rest of the data with the spectral signatures. Because cloud pixels were easy to identify on the computer screen, using this classification routine permitted adjusting the lower and upper spectral limits interactively while cloud pixels were classified. The resulting classified cloud mask had only cloud classes, with the rest of the pixels set to zero.

2. Masking Original Image Files

Where the images did not overlap, it was desirable to preserve the clouds rather than leave open areas after masking. This task was accomplished by changing the values of the cloud classes in the mask file to zero, which was the value for the rest of the masking pixels not affected by clouds.

The edited cloud-mask image was used to eliminate clouds from each of the original image files. The masked image files had zero values in areas where clouds had existed, whereas the rest of the data remained unchanged.

3. Compositing and Smoothing

Masked image files from step 2 were superimposed in the order determined by the visual evaluation in step 1. The image file with the largest amount of masked cloud locations was overwritten by image data from masked files that had progressively smaller amounts of cloud cover. The image that had the least amount of masked clouds was added last. The process resulted in a composite image from which most of the cloud patches were removed and replaced by good data values from the overwritten images.

Edges of some areas where clouds had been replaced by compositing images occasionally appeared quite distinct despite the effort of matching histograms from raw image files. To reduce the edge effect, the following three steps were taken:

a. A convolution routine with a low-pass filter was applied to the composite image to suppress the distinctive appearance of transition areas.

b. Boundaries of clouds in the cloud-mask image files in step 2 were low-pass filtered. The resulting cloud boundary image was used to mask the filtered composite image. The result was a masked image file that contained only smoothed compositing edges.

c. The masked-edge image file was overlaid on the first composite image file to create the final composite.

CONCLUSIONS

Good image data are the basis for a land cover mapping project that employs remote sensing. Often raw image data require preprocessing treatments before they can be effectively used. Such was the case in the project to map the forests of Mexico conducted by the SO-FIA unit, where cloud removal and image compositing, as well as calculation of an accompanying sensor scan-angle channel were needed. Overall, the work conducted in this project demonstrated that: (1) the calculation and use of the sensor scan angle enabled use of the most reliable data for mapping/compositing and (2) the cloud masking approach was an easily implemented method to create multiscene AVHRR composites. Furthermore, the cloud masking approach was a useful tool for AVHRR projects such as this one, which did not require an automated operation for image compositing.

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