

# GEOCOMP, A NOAA AVHRR DATA GEOCODING AND COMPOSITING SYSTEM

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## Abstract

Research in the fields of global change and environmental monitoring requires timely delivery of data that is geocoded and radiometrically correct. To address this need, a system has been developed to generate near cloud-free composite images from NOAA AVHRR imagery. The system, named GEOCOMP, features many advanced capabilities including full 10-bit processing, automated sub-pixel precision geocoding, radiometric calibration with optional atmospheric correction based on the 5S atmospheric model, and production of composite images with user specified spatial, temporal, and viewing angle restrictions. The system has been installed and is being operated by the Manitoba Remote Sensing Centre in Winnipeg, Manitoba (Canada). This paper describes the radiometric and geometric corrections performed by GEOCOMP and analyzes the accuracy of the resulting products.

## 1 INTRODUCTION

The increased interest in global change and environmental monitoring has led to a demand for routinely generated, large area cloud-free composite images. Data from the Advanced Very High Resolution Radiometer (AVHRR) carried aboard the National Oceanic and Atmospheric Administration (NOAA) satellite series provides an ideal source for these composites as the daily global coverage provided by the sensors allow near cloud-free composite images to be constructed from 10 days of imagery. Further, the NOAA series provides a continuous, long term archive of data stretching from the late 1970s (NOAA-6) through today (NOAA-12).

Generating composite images over large areas presents a number of challenging problems. The first problem is data volume. The land mass of Canada is enormous spanning 88 degrees of longitude and 41 degrees of latitude, thus a typical country-wide composite image covers over 27 million square kilometers, and requires the processing of about 20 passes or 40 scenes of AVHRR imagery. The second problem is product accuracy. In order to perform quantitative analysis and intercomparison of composite images, the composites must be of high geometric and radiometric quality. This in turn exerts challenging demands on the image correction system as individual pixels in the composite will only be accurate if the corresponding pixels in the AVHRR images are located with sub-pixel accuracy, and all radiometric perturbations have been removed.

To meet these demands, MacDonald Dettwiler, under contract to the Canada Centre for Remote Sensing, has developed a geocoding and compositing system called GEOCOMP. The system is designed to routinely generate Canada-wide composite images from raw AVHRR imagery in an automated and timely manner. In the sections that follow, the key features of the system will be reviewed, and the quality of the resulting products described.

## 2 SYSTEM OVERVIEW

GEOCOMP's primary function is to generate large cloud-free composite images from NOAA AVHRR imagery. The

system takes as input raw AVHRR imagery on Computer Compatible Tapes (CCTs) or 8 mm. cartridge. The system's two primary outputs are geocoded, atmospherically corrected AVHRR scenes, and AVHRR composite images (again on both CCTs or 8 mm. cartridge).

The GEOCOMP hardware architecture was chosen to optimize the throughput, precision and ease of software development and maintenance. To this end, the hardware is based on a microVAX 4200 minicomputer augmented with a STAR VP-1 array processor. System peripherals include an image station for image display, manipulation, and quality assurance, a digitizer for creating control points from maps, and 8 mm. cartridge and CCT drives for data ingest and product output.

GEOCOMP's software architecture is divided into two functional subsystems:

- the image correction subsystem;
- the composite generation subsystem.

These subsystems may be operated independently on separate host computers, or in a tightly coupled manner with products from the image correction subsystem being passed automatically to the composite generation subsystem. Each of these subsystems is described in more detail below.

## 3 IMAGE CORRECTION SUBSYSTEM

The primary function of GEOCOMP's Image Correction Subsystem is to remove the geometric and radiometric effects from raw AVHRR images and generate products rotated to north up in a standard map projection. The system is based on MacDonald Dettwiler's existing Geocoded Image Correction System (GICS) [Friedel, 1987] with extensions to handle the large distortions inherent in AVHRR imagery.

The system is designed to be highly automated to minimize the need for operator interaction. To initiate the image correction process, the operator enters a work order which de-

scribes the input scene, and the processing to be applied to the data. Image correction parameters include:

- location of output product [optional];
- map projection;
- geometric correction level (systematic or precision);
- radiometric correction level (raw, calibrated, or atmospherically corrected);
- resampling kernel;
- elevation correction;
- composite images to update [optional].

Once initiated, the work order controls all aspects of image correction including data ingest, radiometric and geometric correction, and product generation, thus minimizing the operator load.

The location and size of the output products can be specified in three manners:

1. the operator can specify the center latitude and longitude and the size of the product during work order entry;
2. the operator can interactively define the product while viewing the input imagery (and thus avoid processing large areas of cloud);
3. the operator can elect to have the system automatically determine the location and extent of the product based on the input available.

If automatic product definition is selected for full passes of the satellite, the system will automatically break the input down into a set of output products which cover the full pass.

### 3.1 Geometric Correction

Accurate sub-pixel geometric processing is critical to achieving high quality composite images. GEOCOMP employs advanced spacecraft modelling techniques to correct for geometric distortions introduced during image acquisition. The geometric errors corrected are:

- spacecraft orbit and attitude;
- spacecraft velocity and altitude;
- earth rotation;
- earth curvature;
- panoramic distortion;
- first order terrain displacement.

Correction parameters for the above distortions are derived from a combination of the input imagery, auxiliary data, and known satellite/sensor parameters. In particular, the satellite position and orientation can be predicted by a spacecraft model based on TBUS orbital information obtained from NOAA. This level of accuracy is sufficient for systematically

corrected products (with absolute accuracies in the 3 to 15 kilometer range).

Precision products require a greater accuracy than can be achieved by the systematic spacecraft model. Ground truth is used to obtain this accuracy by locating ground control points (GCPs) with accurately known ground coordinates in the image. The relationship between the image and ground coordinates is then used to refine the parameters of the spacecraft model.

GEOCOMP attempts to automatically generate precision spacecraft models using a library of image chips which it maintains with the GCPs. After a raw image is read in, the system automatically geocodes small subregions of the input image and correlates them against the image chips in the library. The system attempts to correlate at least 10 control points uniformly distributed about the input image. Only if the system cannot mark enough control points or if the model is not accurate enough is the operator requested to intervene and mark points manually.

To achieve the required 800 meter RMS geometric accuracy with only 10 GCPs, each control point must be marked with sub-pixel accuracy. The automatic marking of GCPs in AVHRR imagery has traditionally been difficult due to three sources of errors:

1. digitization error on small scale maps (typically 1:250,000, or 1:1,000,000);
2. error in identifying the location of the control point in the image chip;
3. correlation error between the library chip and the input image.

To minimize these errors, GEOCOMP provides a utility to synthesize pseudo AVHRR image chips from Landsat Multi-Spectral Scanner (MSS) and MOS-1 Multispectral Electronic Self Scanning Radiometer (MESSR) data using techniques developed in [Cracknell, 1989]. To reduce digitization error, control points are created by digitizing larger scale 1:50,000 scale maps leading to accuracies in the 20 meter range. These control points are then marked on georeferenced Landsat MSS or MOS-1 MESSR images which, assuming a one pixel marking accuracy, introduces a further 50 meter error. A  $64 \times 64$  pseudo-AVHRR image chip is then synthesized by decimating the MSS/MESSR image using a low-pass filter which emulates the AVHRR modulation transfer function (MTF).

The resulting pseudo-AVHRR image chip has a location accuracy of less than 70 meters RMS (versus the  $> 1$  kilometer location error associated with a traditional AVHRR image chip) thus all but eliminating the first two sources of control point marking error. The only remaining significant error is the uncertainty in the image correlation which has been measured at approximately 500 meters RMS. Using this technique, a full pass of AVHRR imagery can be geocoded to better than 800 meters RMS accuracy (within the view angle limits of  $\pm 45$  degrees) with only 10 control points. This error is below the measurement accuracy of traditional control point marking techniques, and thus these pseudo-AVHRR chips must also be used during geometric quality assurance.

With stringent geometric accuracies, it is important that displacement due to terrain elevation be corrected. To accom-

plish this, GEOCOMP uses a coarse elevation model tabulated on a 0.5 degree of longitude by 0.25 degree of latitude grid. While this correction does not explicitly characterize the elevation induced errors on a pixel by pixel error, it is sufficient to remove the bulk of the error over all but the most rugged terrain (eg. in the Western Rocky Mountains).

### 3.2 Radiometric Correction

Radiometric integrity is vital to enabling the quantitative analysis of multi-date composite images. To meet these requirements, GEOCOMP maintains the full 10-bit dynamic range of AVHRR imagery throughout the processing chain. Further, GEOCOMP employs time-varying absolute calibration techniques together with state-of-the-art atmospheric correction techniques to remove radiometric effects in raw AVHRR imagery [Teillet, 1992a]. The radiometric processing includes:

- absolute calibration using time-varying and on-board calibration data;
- spatially varying atmospheric correction including terrain elevation effects.

Absolute calibration of the thermal infra-red channels is accomplished using on-board calibration data [NOAA, 1979]. No such calibration information is available for the solar reflective channels. Further, investigations have shown that preflight calibrations are incorrect for post-launch data, with substantial decreases in sensitivity after launch compared to prelaunch values [Teillet, 1990]. To overcome these deficiencies, GEOCOMP uses a time-varying database of calibration parameters developed to track the decay in sensor response [Teillet, 1992b].

To correct for spatially and temporally varying atmospheric effects, GEOCOMP provides the capability to atmospherically correct the calibrated AVHRR imagery. The correction is based on coefficients generated by the 5S atmospheric model [Tanré, 1987] updated to account for the elevation of the surface [Teillet, 1991]. The correction accounts for variations in atmospheric effects including:

- local solar geometry;
- local viewing geometry;
- local elevation;
- molecular (Rayleigh) scattering;
- nominal aerosol scattering and absorption;
- latitudinal and monthly varying ozone and water vapour absorption.

The output of this process is digital counts,  $D$ , in the range 0 to 1024 that can be directly converted to percent surface reflectance using the simple formula:

$$\text{reflectance } \rho = D/10. \quad (1)$$

## 4 COMPOSITE GENERATION SUBSYSTEM

The primary function of GEOCOMP's Composite Generation Subsystem is to combine the precision geocoded AVHRR images generated from the the Image Correction subsystem into a single composite image. The system is based on MacDonald Dettwiler's existing MERIDIAN Image Analysis System with extensions to handle the manipulation and generation of multi-scene composite images.

As with the Image Correction Subsystem, the Composite Generation Subsystem is designed to be highly automated to minimize the need for operator interaction. Typically, operator input is required only during the composite definition, and the output product generation stage. Once defined, the composite images are updated automatically as the geocoded products are produced.

The Compositing Subsystem maintains a database of all the composite images currently being compiled. Any number of composites image can be simultaneously generated, each with its own distinct set of attributes. In this manner, the operator can simultaneously generate multiple composite images covering different geographic locations or different date windows without having to process the geocoded AVHRR images more than once.

New composite images are defined interactively by the operator. For each composite, the operator specifies the following parameters:

- the sensor and satellite combination (eg. NOAA 11 AVHRR);
- the date window;
- the geographic extent (in latitude/longitude or map coordinates);
- the bands and pseudo-bands;
- the compositing criterion.

GEOCOMP supports the generation of composites with any combination of the five NOAA AVHRR channels along with up to five pseudo-bands which include:

- the solar zenith angle;
- the view zenith angle;
- the relative sun-view azimuth angle;
- the Normalized Difference Vegetation Index (NDVI);
- the absolute date (in days since 1970).

Two composite criteria are supported to determine which pixels are to be included in the final image:

- **Maximum NDVI:** at each location, the pixel with the highest NDVI is added to the composite;
- **View Restricted NDVI:** as above, with the further restriction that only pixels whose view angles are less than a user specified tolerance are included in the composite.

Composite images may be generated either sequentially, or in parallel. In sequential mode, geocoded images are merged into the composite one at a time according to the compositing criterion. In parallel mode, the composite image is created in a single step by merging all geocoded images simultaneously. This mode allows for the future addition of more robust compositing criteria such as choosing the pixel with the second highest NDVI. With this in mind, the system has been implemented in such a manner as to allow new compositing criteria to be added with minimal effort.

## 5 OPERATIONAL RESULTS

Insight into the typical quality of GEOCOMP composite images can be gained by reviewing the results obtained in generating a composite image over the 12-day period from August 11, 1990 to August 22, 1990. A total of 39 NOAA AVHRR scenes and passes went into the generation of this composite image.

The bar chart in Figure 1 illustrates the geometric accuracy of the geocoded products generated by GEOCOMP. The first set of bars (Figure 1a) illustrates the accuracy of the precision spacecraft model, annotated by the number of control points required to generate the model. This number is in effect the model residual after refining the model with the control points. Notice that the system was routinely able to generate models with residual errors in the 600 meters RMS range with less than 10 GCPs.

The second set of bars (Figure 1b) represents the RMS error measured in the final geocoded product over an independent set of GCPs, again with the number of quality assurance (QA) control points annotated above the bars. This measure includes both the residual geometric errors in the image (eg. residual terrain distortion, and unmodelled attitude variations) and the marking uncertainty for the QA control points (about 500 meters RMS). These results illustrate that GEOCOMP is routinely capable of generating geocoded products with sub-pixel geometric accuracy over a wide variety of terrain and cloud-cover conditions.

The final composite image generated from these 39 images is shown in Figure 2. The digital image contains 5700 pixels by 4800 lines, and includes all 5 AVHRR channels and the 5 pseudo-bands.

## 6 SUMMARY

Implementation of GEOCOMP began in September 1990 and was completed in March 1992 after a successful trial operation period. Since then, the system has been installed at the Manitoba Remote Sensing Centre where it is currently being operated.

GEOCOMP provides an automated, high throughput system for generating high precision AVHRR composite images. It is seen as a major milestone in the drive to create quality cloud-free composite images which allow quantitative analyses of multi-temporal datasets. Key features of the system include the ability to routinely geocode AVHRR images to sub-pixel (800 meter RMS) accuracy in an automated environment, the advanced absolute calibration and atmospheric correction algorithms, and the ability to automatically update composite images on a pixel by pixel basis.

## References

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# GEOCOMP Geocoded Product Accuracy Precision Model Residuals

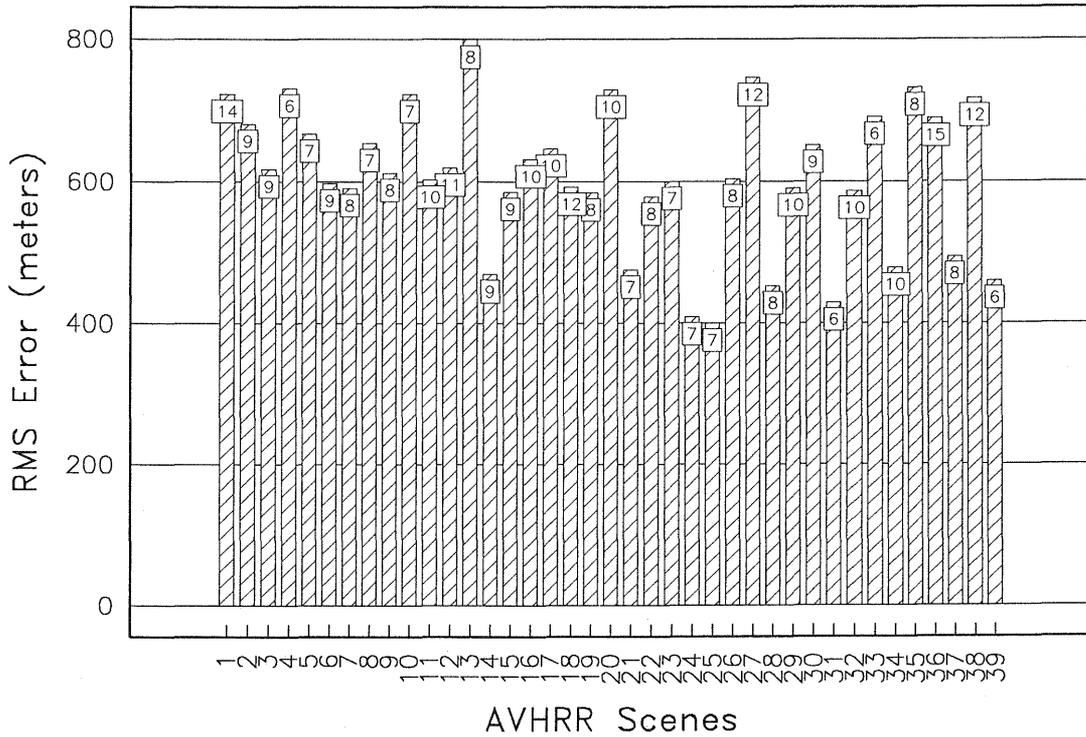
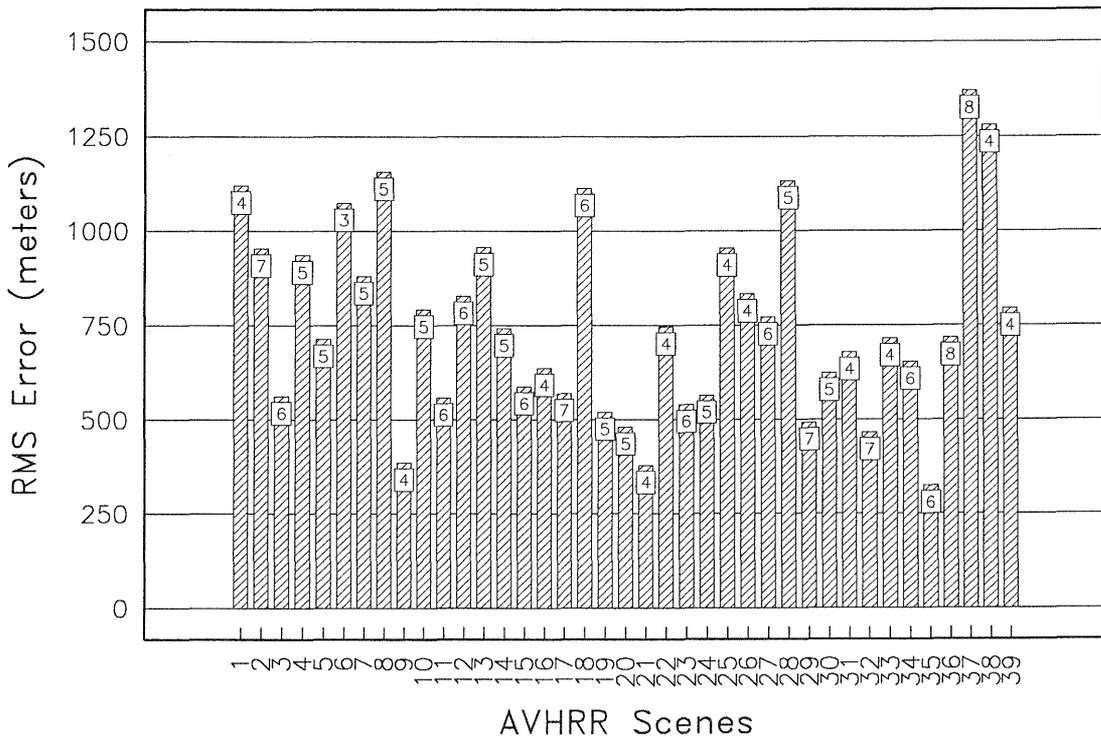


Figure 1: Geometric accuracy of the 39 AVHRR scenes included in the August 1990 composite image of Canada. Figure a) shows the RMS residual modelling errors, annotated with the number of control points in the model, for each of the geocoded images. Figure b) shows the RMS error of the final geocoded products measured with an independent set of control points (again annotated with the number of QA control points). The results illustrate the high geometric quality routinely achieved in GEOCOMP products.

## Quality Assurance GCP Errors



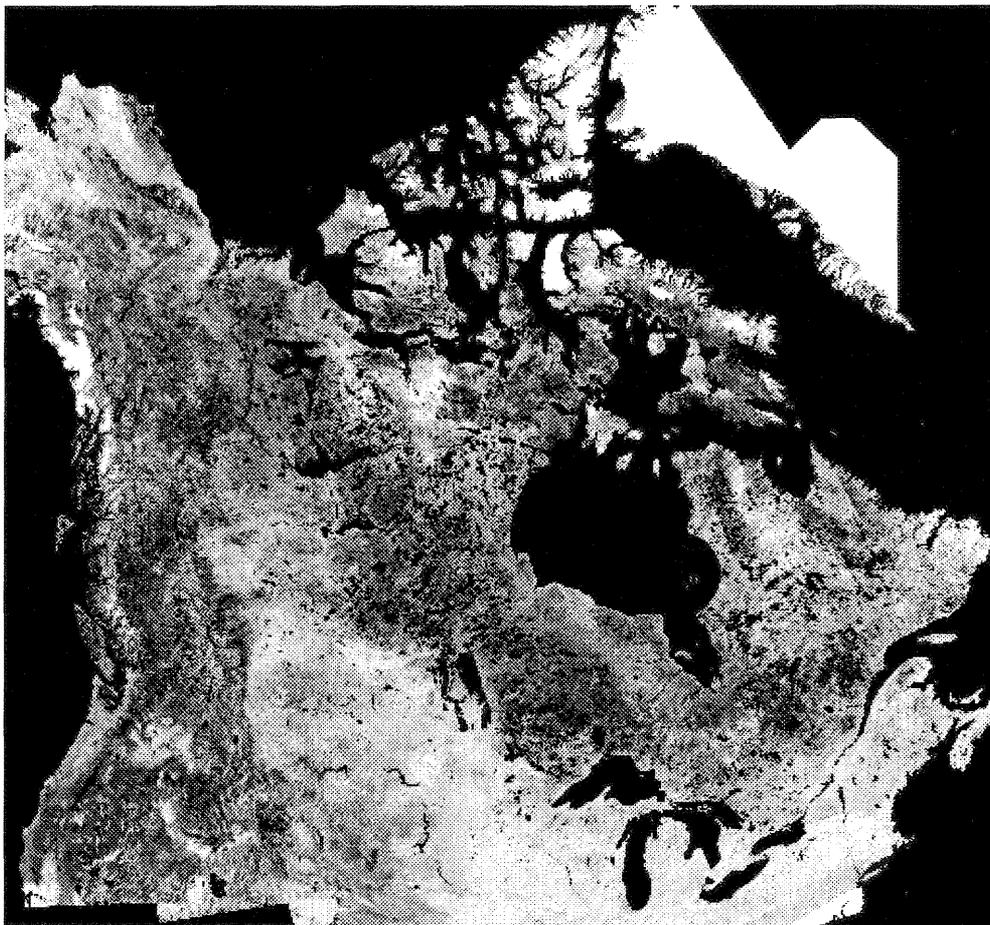


Figure 2: GEOCOMP composite image of Canada generated from 39 NOAA AVHRR scenes acquired between August 11, 1990 and August 22, 1990.