A SYSTEM FOR NEAR REAL TIME PROCESSING OF NOAA-AVHRR SATELLITE DATA: APPLICATION TO SNOW MONITORING IN SCOTLAND

A R S Marçal and M T Slater

University of Dundee, Scotland UK

ABSTRACT

A system for near real time processing of NOAA-AVHRR satellite data is described. The system allows for the final imagery, geometrically corrected and calibrated, to be obtained only a few minutes after the satellite pass. An application example is presented: the production of snow cover weekly composites for Scotland during the winter of 1996.

INTRODUCTION

Remote sensed data from NOAA meteorological satellites is being increasingly used for environmental monitoring. The most important instrument onboard NOAA satellites is the AVHRR (Advanced Very High Resolution Radiometer). This radiometer has five spectral channels: channel 1 in the red part of the spectrum, channels 2 and 3 in the near and mid-infrared, and channels 4 and 5 in the thermal infrared. The spatial resolution of AVHRR is 1.1 km at nadir and, with its scan angle of 110°, allows for the whole Earth to be covered twice every 24 hours.

The NOAA program is operational, guaranteeing that there are at least two satellites working at any time. Data collected by NOAA/AVHRR is transmitted to earth in real time, in the HRPT (High Resolution Picture Transmission) mode. A ground station is able to collect data from a large area, since the satellite orbits the earth at an height of approximately 850 km. The NERC satellite station at the University of Dundee collects daily AVHRR data, which cover most of Europe. The data is available, for registered users, through the INTERNET, shortly after the satellite pass. Many remote sensing applications require raw data to be pre-processed (calibrated and geometrically corrected) before any interpretation can be done. This very often leads to a substantial delay from data acquisition to the moment when the data is ready for interpretation. Time analysis of AVHRR data require a reasonable registration accuracy so that images from different dates can be consistently overlaid. The existing fully automatic methods do not provide 1 km resolution data reliable for time analysis. The aim of this project was to develop a system which allows for AVHRR data to be obtained and processed to a meaningful form in near real time.

The ANRTP (AVHRR Near Real Time Processing) system was developed at the University of Dundee, using a combination of PCI-Works scripts and UNIX C programs, running on a 'dux' machine. The system was developed with the aim of allowing fast and accurate processing with a minimum operator intervention. Another objective was to develop a flexible system, allowing future needs to be easily incorporated in the system. One application currently being undertaken on a regular basis is the production of 'Snow Cover Maps' for Scotland. This particular application will be described in detail. Other end products include, at the moment, calibrated imagery of the 5 AVHRR channels, NDVI (Normalised Difference Vegetation Index), brightness temperature from channels 3 to 5, sea surface temperature, hot spot detector imagery, and solar zenith angle and satellite viewing angle imagery.

IMAGE ACQUISITION

A 'quicklook' view of the AVHRR images available on-line can be accessed at the NERC Dundee satellite station web page (http://www.sat.dundee.ac.uk), using an appropriate browser. The user selects an image to order, as well as the channels and formats required. A sub-section, with the geographic area of interest, can be ordered instead of the full satellite pass. For each AVHRR channel collected, one image file and one text files is provided, named respectively *cNhhmmss* and *tNhhmmss*, where *N* is the AVHRR channel and *hhmmss* is the data collection time. The 'image' text files include orbital details which are necessary for processing.

Also available from the Dundee satellite station web page is a list of orbital parameters for various dates. This list is updated periodically and includes the satellite inclination angle to the earth's axis (γ) and the orbital period (T). These two parameters, both necessary for the ANRTP system to work, are stored in a 'orbit' text file. When these parameters are not directly available for a specific date, they are obtained by interpolation between the closest available dates.

NEAR REAL TIME PROCESSING

The whole process of obtaining the required AVHRR end product, can be devised in three stages:

- To collect an appropriate sub-section of an AVHRR image from the satellite station.
- To run the ANRTP system. It produces the required imagery from the raw data and performs an automatic geometric correction on the raw imagery.
- To identify one or more Ground Control Points (GCPs) using, for example, a digital map. This information is used to perform the final, more accurate, geometric correction of the raw data.

The characteristics of the final (georeferenced) imagery should be specified before running the ANRTP system. The relevant parameters, stored in a 'geographic' text file, are: map projection; geographical co-ordinates of the top left corner; number of pixels; number of lines; pixel size.

When the ANRTP system is started, the user is asked to enter four items: (i) the processing data directory, (ii) the *output* file name, (iii) the *hhmmss* imagery identification time, (iv) the processing module to be performed. The information provided by the user allows the ANRTP system to obtain all the other relevant parameters from the text files ('image', 'orbital' and 'geographic' files). The important parameters for the processing are displayed on-screen, and the user is given the option to change the geographical details of the interest area.

The first stage of ANRTP system is the production of additional imagery from the raw data, which depend of the module selected. The following images can all be produced: reflectance calibrated from channels 1 and 2; Normalised Difference Vegetation Index (NDVI); brightness temperature from channels 3, 4 and 5; sea surface temperature; hot-spot detector; satellite viewing angle; solar zenith angle.

Three PCI files are automatically produced, with the appropriate size and number of channels for the processing module required. A *raw* PCI file is created, of the AVHRR sub-section size, to which the raw images are loaded. An *auto* file and an *output* file are also created, both with the pre-defined georeferenced characteristics.

IMAGE REGISTRATION

The geometric correction of the raw AVHRR imagery is done using a simplified satellite orbital model and the identification of Ground Control Points (GCPs). The orbital model used is based on that described by Brush (1) and Ho and Asem (2). Only the main equation used are presented here.

The orbital model allows for the latitude (Φ) and longitude (λ) of a raw image co-ordinate, pixel (p) and line (l), to be obtained, using equations (1) and (2):

$$\Phi = \sin^{-1}[\cos G.\sin\theta.\sin\gamma + \cos\gamma.\sin G] \quad (1)$$

$$\lambda = \cos^{-1}[\cos G.\cos\theta / \cos\Phi] + K'.t + L_{eq.} \quad (2)$$

The geocentric angle transversed from the equator (θ) is a linear function of the satellite orbiting period (T) and the time elapsed since equator crossing (t), which is $l/6$. The longitude of equator crossing ($L_{eq.}$) is available from the 'image text file', and the earth rotation constant (K') is known. The geocentric angle (G) is calculated from equation (3)

$$G = \sin^{-1}[(1+h/R).\sin M] - M \quad (3)$$

where the sensor mirror angle (M) is linearly related to p; the earth radius (R) is assumed to be constant; and the satellite height (h) is available from the 'image text file'.

A set Automatic Control Points (ACPs) is produced, by calculating the geographic co-ordinates of about 250 widespread points covering the area of interest on the raw image. The latitude and longitude obtained from equations (1) and (2) are converted to the appropriate map projection, such as the British National Grid (easting, northing) which was used for the application described here. This set of control points is used to perform a third order polynomial transformation (**f**) on the raw imagery. The data is stored in the georeferenced *auto* PCI file. This automatically produced image, although visually very similar to a map, is not geographically accurate.

The user is required to identify at least one Ground Control Point (GCP) on the automatically produced image. This can be easily done using the GCP-Works package on PCI software and a digital map. This set of GCPs is used to determine a polynomial transformation (**g**) between the automatic image and the map, of 0 or 1st order depending on the number of GCPs identified. Finally, the imagery on the *output* PCI file is obtained by a third order polynomial transformation (**h=gof**) from the raw imagery.

SNOW MONITORING IN SCOTLAND

The aim of the Scottish Snow monitoring project was to use AVHRR data to map the extent of snow cover in Scotland, with a weekly update. The snow cover map images were available on the World Wide Web (http://www.dundee.ac.uk/~mtslater/snow.html) and as bitmaps to interested organisations. Organisations to which images/bitmaps were provided included: Scottish Tourist Board, Scottish Hydro, Scottish Environmental Protection Agency (SEPA) and Anite Systems. A key requirement of this project was the capability for real time AVHRR image processing, including rectification to enable an operational update to be provided from partially cloudy images, with minimal operator time.

Snow mapping was based on the use of thresholds and registered Minimum Value Composites (MiVC). The criteria used were:

- Channel 1 10% albedo was used to define snow/cloud against none-snow/cloud.
- A weekly MiVC was used to differentiate between long term snow cover and passing cloud.
- Channels 1, 2, 3, 4 and NDVI were also processed for the creation of a registered archive, to be used in future snow cover classification and modelling.

One or two NOAA 14 early afternoon images were available daily from the Dundee satellite station. Images with clearly identifiable coastal features were downloaded as raw calibrated image files; Figure 1 shows an example of a raw image.

The spatial distortions associated with off-nadir viewing and the Earth's surface by the satellite sensor can be easily seen on the raw image (Figure 1). The raw image, typically about 700 pixels by 700 lines, is used by the ANRTP system to produce an automatically registered image, 760 pixels by 1060 lines with 500m resolution, covering mainland Scotland. A set of coastline GCPs are then identified on the *auto* file, using the PCI GCP-Works package and a previously produced digital map of Scotland. The layout of the PCI GCP-Works computer screen is illustrated on Figure 2.

The registration process takes on average 10 minutes and involves the collection of up to 10 GCPs. Using the available scatter plot and GCP error ranking facilities, the most inaccurate GCPs are removed. Inaccurate GCPs can occur due to operator error or poor feature resolution associated with either high scan angles or atmospheric effects. The principal source of registration error was the poor feature identification associated with the high off-nadir angles. Images at the 20 to 24 degrees off-nadir produced regularly errors around 1 km. Collection and editing of GCPs was performed until the first order Root Mean Square (RMS) error between the *auto* image and the digital map remained below 0.75. After saving the set of GCPs, the ANRTP was re-run to create the final registered AVHRR image file.

The MiVC snow threshold and a MiVC False Colour Image (channels 1 and 2 and NDVI) created by the ANRTP system were then converted to a JPEG image file for placing onto the WWW. An illustration of the final product is presented on Figure 3.

Performance Testing

The visual inspection of the quality of the MiVC imagery produced by the ANRTP system was impressive. With 7 days of compositing the clear outline of many large Scottish lochs was able to be maintained with the spatial resolution used. A record of the first order potential error reports for the images collected between November 26 1996 and March 9 1997 (81 images) gave the following statistics:

- Mean RMS error
  pixel: 0.418 km, line: 0.426 km, distance: 0.626 km
- Standard Deviation
  pixel: 0.276 km, line: 0.246 km, distance: 0.335 km

The mean error falls well within the initial 1.1 km nadir AVHRR pixel resolution.

DISCUSSION

The full processing time, from the moment the ANRTP system is started until the production of the final imagery, will depend on the image size, the processing module selected, and most importantly on the number of GCPs identified. For the snow monitoring application described here, approximately 10 minutes are required for the full processing, with most of that time being taken by the identification of GCPs. If a high registration accuracy is not important, only 1 or 2 GCPs need to be inserted (or even none), the full processing takes only about 2 or 3 minutes. However, for the best possible registration accuracy to be achieved, the identification of GCPs should be done with extreme care, which is a considerable time consuming task.

The image rectification method used in the ANRTP system is based on a simplified version of the satellite orbital model. An extensive test of the accuracy of the orbital model was undertaken by Marçal (3). The calculation of geographic co-ordinates of a AVHRR raw image, using the orbital model, will have two types of errors:

- Low frequency error, typically a few kilometres in magnitude and constant for the whole image. This offset error can be removed by identifying a single GCP.
- High frequency error, typically around 1-2 km but variable throughout the image. This error can be reduced by inserting several GCPs. The best results are obtained when a large number of widespread GCPs is identified.

The combination of the orbital model with the identification of GCPs was also tested by Marçal (3). Two images of Scotland were rectified using the orbital model and 20 GCPs. The errors in the geographic co-ordinates were evaluated, using 92 independent control points. The mean error in easting and northing was found to be about 250-300 m (400m in distance). The maximum error on the 92 points tested was 1.7 km in easting and 1.1 km in northing (1.9 km in distance).

The use of a more complex satellite trajectory model will not produce major improvements in the final imagery, as there will still be a considerable amount of error due to the uncertainty of the sensor's attitude and satellite timing.

The ANRTP final imagery is produced from the raw imagery by a single image transformation. This avoids the introduction of excessive smoothing due to resampling. Another feature of the rectification method used is that only the geographic area of interest is considered for the automatic geometric correction. As the parameters of the polynomial transformation are more accurately obtained for small areas, the best results are obtained when the ANRTP system is used on a regional context, such as the example described here.

CONCLUSIONS

The AVHRR near real time processing system described here provides an efficient and flexible way of processing the very large amount of data provided daily by NOAA satellites. The raw imagery is processed to the desired final format with only a few minutes of the satellite pass and with a reduced operator intervention.

The ANRTP system enabled the quick and accurate creation of snow cover images within about 15 minutes of the satellites pass which was either integrated into the weekly MiVC or sent directly on request as JPEG image files or snow/hydrology bitmaps to interested organisations. The key benefit of the ANRTP system over alternative used systems was its potential to enable the accurate creation of registered images at high off-nadir scan angles with only small isolated cloud free coastal GCP windows.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the NERC (National Environmental Research Centre) Dundee Satellite Station for providing the AVHRR data. ARSM would like to thank the Portuguese Research Council JNICT (Junta Nacional de Investigação Científica e Tecnológica) for the financial support.

REFERENCES

1. Brush, R.J.H., 1985, IEEE Trans. Geoscience and Remote Sensing, GE-23, 876-887

2. Ho, D. and Asem, A., 1986, Int. J. Remote Sensing, 7, 895-904

3. Marçal, A.R.S., Int. J. Remote Sensing, submitted for publication on Feb.1997

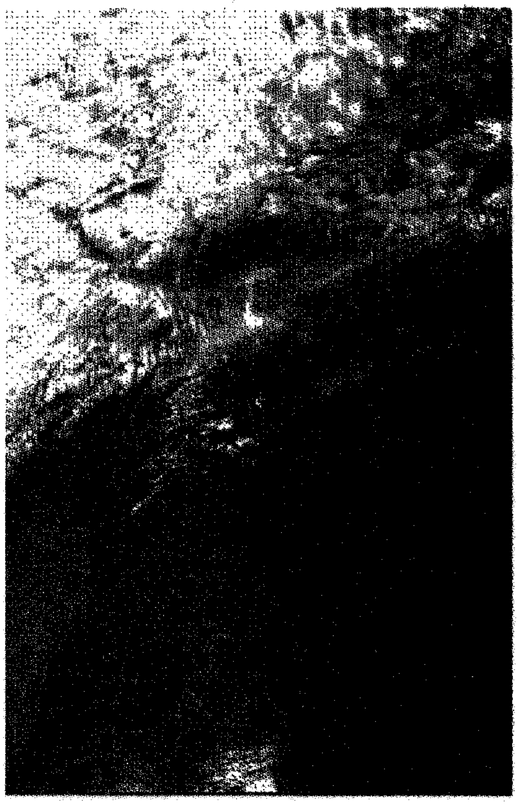

Figure 1: NOAA 14 raw image, 8 March 1997

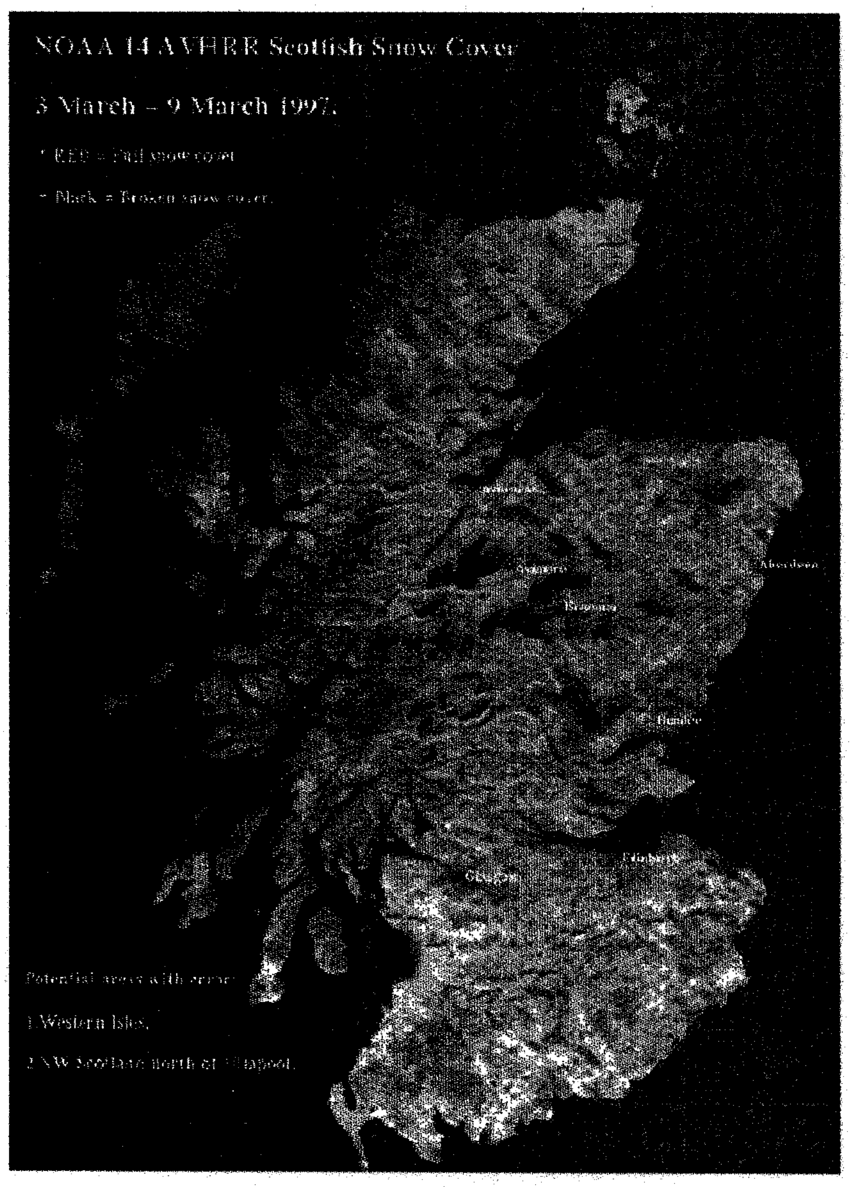

Figure 2. Weekly Snow Cover Composite

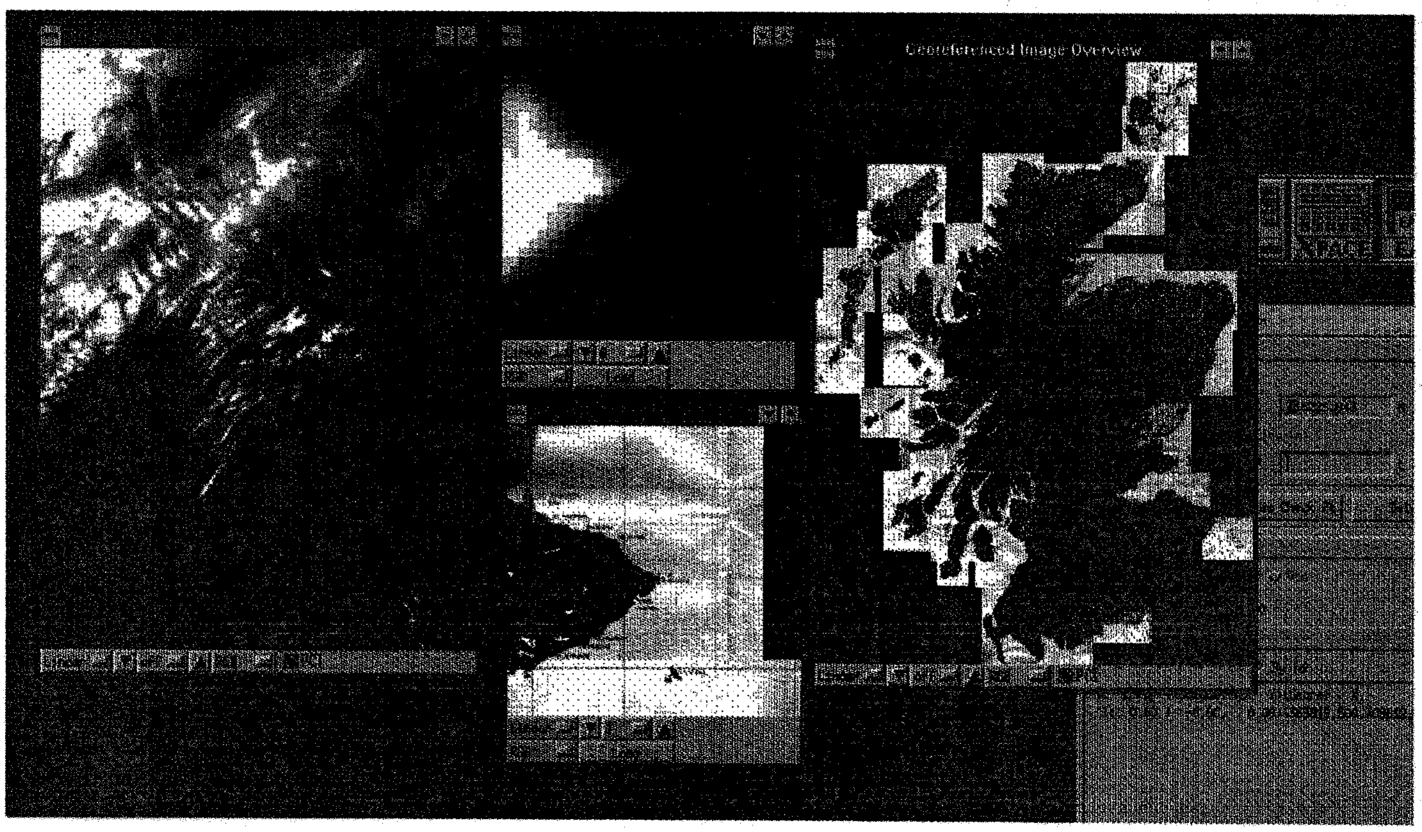

Figure 3: Computer screen sample of the GCP identification stage