CALIBRATION OF AVHRR DATA GENERATED BY THE INSTRUMENT ON-BOARD TIROS-N USING OCEAN AND CLOUD VIEWS

Arthur P. Cracknell and Ibrahim Busu

Department of Applied Physics and Electronic and Mechanical Engineering,
University of Dundee, DUNDEE DD1 4HN, Scotland, UK.

Fax: ..01382 - 345415
E-mail: a.p.cracknell@dundee.ac.uk

ABSTRACT

Remote sensing images of the Earth have been regarded by many as an important source of data for environmental studies. In order to produce good quality data, all known errors should be removed or eliminated before any of the data are used, especially for time-dependent applications. Over the years a number of post-launch calibration methods and procedures have been suggested and used, particularly for the later spacecraft in the series; each of these has some advantages and disadvantages over the others. This paper reviews a post-launch calibration method which has been established using ocean and cloud views as the main calibration targets; it then applies this method to data from the earlier spacecraft in the series which are no longer in operation.

1.0 INTRODUCTION

In general, the problem addressed in this paper is associated with the data acquisition process with special reference to the archived AVHRR data, that is the data generated by the radiometers onboard the NOAA satellite series. The Dundee AVHRR archive contains data from late 1978 until the present time and it is an important source of data for various applications and has been referred to and used by many geographers and environmentalists. However, the archived AVHRR data set has been generated by about ten different instruments, each of which has been said to be suffering from degradation in responsivity over its lifetime. Therefore, the archived AVHRR data are subject to systematic or instrumental errors. If the archived data are going to be used as input data for time-dependent applications, the systematic errors should be eliminated before the data are blended with data from other sources. An example of such applications is the monitoring of change of the global climate which utilises information generated from long-term AVHRR data.

Satellite sensors in the solar spectrum are very difficult to calibrate due to lack of reliable on-board calibration devices. The pre-launch calibrations are subject to change due to the hostile environment of the sensor during launch, outgasing, deterioration in the sensor system and variation in the spectral characteristics. Some work has been carried out in order to provide alternative calibration methods, which are based on the knowledge of some Earth phenomena as well as on the processing of the digital imagery data generated by the sensor itself. Examples of such work are described in [1] and [2]; however, much of this work is concerned with AVHRRs on spacecraft that were still operating when the work was done.

This paper presents a calibration method for the AVHRR visible and near-infrared channels using oceans and clouds as the main target. An attempt is made to calibrate data from the earlier instruments in the series which are no longer active.

2.0 THE CALIBRATION METHODS

There are two main tasks involved in the proposed calibration method. The first task is to calibrate channel 1 of the AVHRR, which operates in the visible band of the solar spectrum. The second task is to establish the relation between the visible and near-infrared channels. The relation between the two channels is needed due to different radiation and propagation characteristics between them. Once the relation is established, calibration can be transferred between channels 1 and 2.

2.1 Background

Channel 1 of the AVHRR can be calibrated using a technique proposed in [1] using a selected ocean area as the target surface. The method used in the present study is based on radiances measured by the AVHRR over ocean areas, away from the sun-glint area. Theoretically, the upward radiance over a cloud-free ocean surface is greatly influenced by molecular scattering as well as by aerosol scattering. Of the two phenomena, the molecular scattering is more dominant; it contributes about 70 to 80 % of the upward radiance and the remaining 20-30 % is due to aerosol scattering, foam reflectivity and underwater reflectance as in [1]. Based on this background a radiative transfer code using a single order scattering

(SOS) technique has been developed to simulate the satellite-received radiance over a cloud-free ocean area.

The spectral characteristics of channel 2 of the AVHRR are different from those of channel 1; thus its calibration requires a different approach from that developed for channel 1. Sun-glint areas over the ocean have frequently been used to establish the relation between channels 1 and 2; examples can be found from [1] and [2]. The sun-glint area was selected due to the high reflectivity and it is estimated that about 87 % of the glint radiance is due to the specular reflection and it is independent of the radiation wavelength and, therefore, it can be used to determine the relative calibration of band 1 and 2 as mentioned in [1] and [2]. Besides sun-glint areas, cloud bodies were also used by workers for the same purposes of transferring calibration from channel 1 to channel 2 of the AVHRR instrument. Reference [3] indicated that good intercalibration between channel 1 and channel 2 of the AVHRR can be accomplished using high clouds. For the present study, where the area involved is located at high latitude and the chance of having a sun-glint area appearing in the image scene is very remote, the intercalibration between channels 1 and 2 has been established through the use of high altitude clouds.

2.2 The calibration of channel 1

The method described in this section is applied to the image data generated by the AVHRR on-board the TIROS-N satellite which have been received and archived at the receiving station at the University of Dundee. Image data from the Atlantic Ocean have been used for this study. Roughly, the extent of the study area is between latitudes 40^0 N to 55^0 N and longitudes 10^0 W to 25^0 W. However the actual points selected are scattered within this area. In terms of time, the selected image data are from April 1979 to October 1980.

Calibration for channel 1 is performed based on the method described in [1]. The calibration coefficients are defined the following equations:

$$L_i^N = \pi L_i d^2 / E_{oi} \qquad (1)$$

where L_i is the radiance observed in channel i, d is the distance between the Sun and the Earth in astronomical units and E_{oi} is the solar exoatmospheric band average solar irradiance for d = 1.

The normalized radiance L_i^N is equal to the surface reflectance for no atmosphere and for the Sun at zenith. The calibration equation for L_i^N is:

$$L_i^N = \gamma_i (C_i - C_{oi}) \qquad (2)$$

where $\gamma_i = \alpha_i \pi d^2 / E_{oi}$.

The change in the sensor calibration between the true, γ_i (true), and the pre-launch, γ_i (pre-launch), calibration coefficients is given by the calibration ratio (r_i):

$$r_i = \gamma_i(\text{pre-launch}) \big/ \gamma_i(\text{true}) \qquad (3)$$

The pre-launch calibration coefficient is given by NOAA [4]. Therefore, the calibration coefficient α_i can be computed by using the following relation:

$$\alpha_i = \gamma_i(\text{pre-launch}) E_{oi} \big/ (\pi r_i d^2) \qquad (4)$$

In this case the pre-launch surface reflectance is determined using the information provided on the AVHRR magnetic tape and the pre-launch calibration coefficients; digital counts of channels 1 and 2 can be converted to surface radiance and then further converted to reflectance, see [1] and [4]. The surface radiance at the top of the atmosphere is determined using the radiative transfer codes based on the single order scattering (SOS) with the meteorological parameters provided by the archives of climate data kept at the NOAA Climatic Data Center (NCDC) and other organisations related to meteorological and climatic research.

Using information provided on the magnetic tape and ephemeral data, a normalized radiance for each pixel in the selected areas is computed and divided into the one calibrated using the pre-launch calibration coefficients given by NOAA to produce the calibration ratio (r_1) for channel 1. Therefore the post-launch calibration coefficient for channel 1 of the AVHRR can be determined using (4). On the other hand if calibrated radiances are plotted against the theoretical radiance, the slope of the graph will define the calibration ratio for channel 1 (r_1).

2.3 Intercalibration between channels 1 and 2

In the case where the cloud is high enough (above 12 km) the aerosol and water vapour have a negligible influence on the signal because they are located mainly at a much lower layer of the atmosphere. Thus, the main contributions to the signal received by a sensor are from the cloud reflectance, molecular scattering and absorption by oxygen and ozone. The only contributions to the observed signal are from the cloud reflectance, molecular scattering and absorption by oxygen and ozone. In order to relate the AVHRR measurement directly to the cloud reflectance, the measurements have to be corrected for the atmospheric scattering and absorption. The method described in [3] has been adopted to establish the relation between channels 1 and 2 in this study.

3.0 RESULTS

A graph in fig. 1 shows the calibration coefficients for channel 1 for both pre-launch and post-launch periods. The best fit line for the post-launch calibration coefficient increases with time. The equation of the best fit line determines the calibration coefficient for channel 1:

$$\alpha_1 = 0.5724456 + 0.0052692 * D \quad (5)$$

where D is the month after launch date.

The r_{12} values computed using the method described in [3] are then used for transferring the calibration ratio (r_1) from channel 1 to channel 2 and the calibration ratio (r_2) for channel 2 can be determined by the following relation:

$$r_2 = {r_1}/{r_{12}} \, . \quad (6)$$

Furthermore, the calibration coefficient for channel 2 can be determined using (4), similar to channel 1. Both pre-launch and post-launch coefficients are then plotted against the month of the year in Fig. 2. A significant variation is portrayed by those computed using model predictions. The calibration coefficient for channel 2 can be derived using the equation of its best fit line which is:

$$\alpha_2 = 0.4647135 + 0.0043156 * D. \quad (7)$$

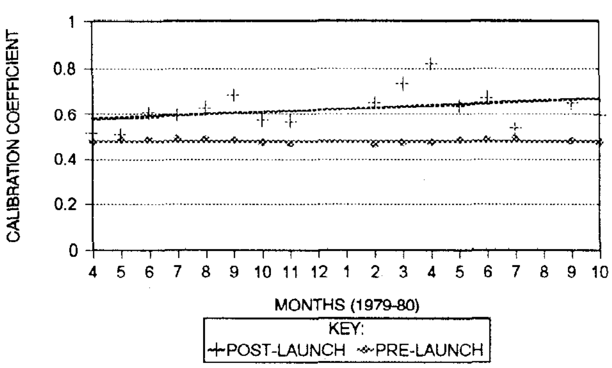

Fig. 1. The calibration coefficients for channel 1 of the AVHRR on-board TIROS-N, based on model prediction (+) and pre-launch information (•)

5.0 CONCLUSION

The applications of AVHRR channel-1 and channel-2 data are gaining in popularity, especially for studies of global vegetation, environmental and other phenomena at regional or continental scale. However, AVHRR users have been hampered by the problems of systematic errors. Now the availability of post-launch calibration methods will enable users to eliminate or minimise these systematic errors. After correcting for the systematic errors, the archived AVHRR data can then be used with confidence for time-dependent applications over long periods. At that stage the validity of the data will be known to the users and then the archived data will be much more valuable than before the calibration.

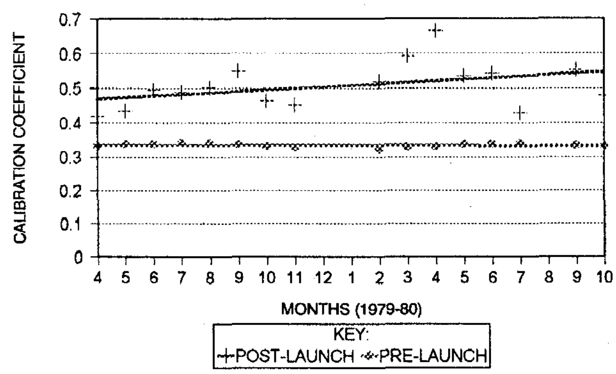

Fig. 2. The calibration coefficients for channel 2 of the AVHRR on-board the TIROS-N, based on model prediction (+) and pre-launch information (•)

REFERENCE

[1] Kaufman, Y. J., and Holben, B. N., "Calibration of the AVHRR Visible and Near - IR bands by atmospheric scattering, ocean glint and desert reflection", International Journal of Remote Sensing, vol. 14, pp. 21 - 52, 1993.

[2] Rao, C. R. N., and Chen, J., "Post-Launch Calibration of the Visible and Near Infrared Channels of the Advanced Very High Resolution Radiometer on NOAA -7, -9, and - 11 Spacecraft", NOAA Technical Report NESDIS 78, p.22, 1994.

[3] Vermote, E. and Kaufman, Y. J., "Absolute calibration of AVHRR visible and near-infrared channels using ocean and cloud views", International Journal of Remote Sensing, vol.16, pp. 2317-2340, 1995.

[4] Kidwell, K. B., "NOAA Polar Orbiter Data Users Guide", U.S. Department Of Commerce, NOAA,1991.