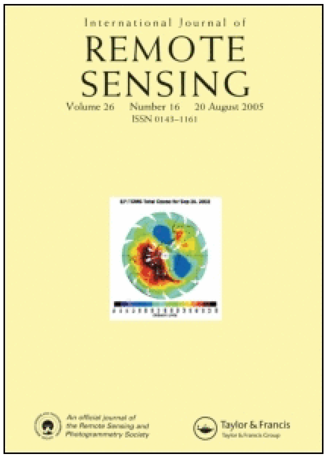

International Journal of Remote Sensing
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713722504

Revised post-launch calibration of the visible and near-infrared channels of the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-14 spacecraft

C. R. N. Rao; J. Chen

Online Publication Date: 15 December 1999
To cite this Article: Rao, C. R. N. and Chen, J. (1999) 'Revised post-launch calibration of the visible and near-infrared channels of the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-14 spacecraft', International Journal of Remote Sensing, 20:18, 3485 - 3491
To link to this article: DOI: 10.1080/014311699211147
URL: http://dx.doi.org/10.1080/014311699211147

INT. J. REMOTE SENSING, 1999, VOL. 20, NO. 18, 3485–3491

Revised post-launch calibration of the visible and near-infrared channels of the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-14 spacecraft

C. R. N. RAO
NOAA/NESDIS Office of Research and Applications, Washington, DC 20233, USA

and J. CHEN
QSS Group Inc., Lanham, Maryland 20706, USA

(*Received 2 September 1998*)

Abstract. Records of top-of-the-atmosphere albedo over several sites around the globe indicate that the formulae given in Rao and Chen (1996) to determine the post-launch calibration of the visible (channel 1, ≈ 0.58–0.68 μm) and near-infrared (channel 2, ≈ 0.72–1.1 μm) channels of the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-14 spacecraft overestimate the in-orbit degradation of the two channels, resulting in spurious upward trends in the albedo time series. Therefore, the calibration formulae have been revised to minimize the upward trends, utilizing a 3-year (1995–1997) record of albedo measurements over a calibration site (21–23° N, 28–29° E) in the southeastern Libyan desert. Formulae for the calculation of the revised calibration coefficients as a function of elapsed time in orbit are given. The revised calibration formulae presented here, and those presented in Rao and Chen (1996), yield radiance/albedo values within 5% (relative) of each other for about 900 days after launch in channel 1 and for about 500 days in channel 2.

1. Introduction

This paper presents revised post-launch calibration of the visible (channel 1, ≈ 0.58–0.68 μm) and near-infrared (channel 2, ≈ 0.72–1.1 μm) channels of the AVHRR on the NOAA-14 spacecraft, which was put into an afternoon orbit on 30 December 1994 with a nominal equator crossing time of 1:40 p.m. The revision was prompted by several observations of a small, but finite, upward trend in the time series of the top-of-the-atmosphere albedo derived from the calibration formulae given in Rao and Chen (1996)—henceforth referred to as RC—over several desert sites which could generally be considered radiometrically stable and of slight greening in records of the Normalized Difference Vegetation Index (NDVI) over the same and over vegetated areas (Koslowsky 1997, G. Gutman, personal communication 1998, H. Leglau, personal communication 1998). Therefore, the calibration equations for the two channels have been revised using a 3-year (1995–1997) record of top-of-the-atmosphere albedo over a calibration site (21–23° N, 28–29° E) in the southeastern Libyan desert.

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online ©1999 Taylor & Francis Ltd
http://www.tandf.co.uk/JNLS/res.htm
http://www.taylorandfrancis.com/JNLS/res.htm

2. Method of post-launch calibration

The method used to revise the post-launch calibration of the two channels of the AVHRR is the same as that reported in RC. The basic assumption is that the top-of-the-atmosphere albedo over the southeastern Libyan desert site remains the same over a long period of time. The reasonableness of this assumption has been established by the work done under the NOAA/NASA AVHRR Pathfinder Calibration Activity (e.g. Rao and Chen 1995) and independently by more recent albedo measurements made over narrow spectral intervals centred on 0.56, 0.66, 0.87 and 1.6 μm by the Along-Track Scanning Radiometer-2 (ATSR-2), which has an on-board calibration device (D. L. Smith, personal communication 1998, Smith et al. 1997).

The 'slope' S_i (W m^{-2} μm^{-1} sr^{-1} count^{-1}) in either channel was calculated by requiring that the AVHRR signal (expressed in digital counts), after it had been corrected for the instrument offset and Earth–Sun distance variations, should yield the mean albedo A_i of the Libyan desert site in either channel, derived from the results of analysis of a 10-year (1981–1991) record of measurements made by the AVHRRs on the NOAA-7, -9 and -11 spacecraft (Rao and Chen 1995). The albedo A_i is given by

$$A_i = 100(\pi I_i \omega_i / F_{i0} \cos\theta_0)$$

where I_i is the upwelling radiance (W m^{-2} μm^{-1} sr^{-1}) in the *ith channel,* ω_i is the effective width of the channel, F_{i0} is the extraterrestrial solar irradiance (W m^{-2}) in the passband of the channel and θ_0 is the solar zenith angle. The mean values (%) and the corresponding standard deviation (in parentheses) of the albedo in channels 1 and 2 are 37.8 (0.7) and 42.6 (1.5), respectively. The inband F_{i0} is 207.1 W m^{-2} in channel 1 and 251.01 W m^{-2} in channel 2; the corresponding values of ω_i are 0.129 and 0.244 μm.

The slope is calculated from

$$S_i = (A_i F_{i0} \cos\theta_0)/[100\pi\omega_i (C_{10} - C_0)\rho^2] \qquad (2)$$

where C_{10} and C_0 are, respectively, the AVHRR signal and offset in 10-bit counts and ρ is the Earth–Sun distance in astronomical units. Thus, any decrease in the AVHRR signal ($C_{10}-C_0$) caused by instrument degradation in orbit results in an increase in the value of S_i, all other conditions remaining unaltered.

A regression relationship (calibration formula) of the form

$$S_i = m_i d + k_i \qquad (3)$$

is established between S_i and the elapsed time in orbit, expressed in days (d) after launch, to determine the trend in calibration; the intercept k_i gives the slope on the day of launch. The reader is referred to RC and to Rao and Chen (1995) for greater details.

3. Revised calibration

The variation of S_i with d, along with the linear regression lines based on the data obtained during a 1-year period (1995) and over a 3-year period (1995–1997), is shown in figure 1. The revised calibration equations proposed here for the calculation of the upwelling radiance, based on the 3-year regression, are

$$\text{Channel 1: } S_1 = 0.0000690d + 0.566 \qquad (4)$$

and

$$\text{Channel 2: } S_2 = 0.0000435d + 0.440 \qquad (5)$$

where S_1 and S_2 are the slopes in channels 1 and 2, respectively, and d is the elapsed time in orbit, with $d = 0$ corresponding to the day of launch. In the AVHRR albedo representation, the calibration equations are

$$\text{Channel 1: } S_1 = 0.0000135d + 0.111 \qquad (6)$$

$$\text{Channel 2: } S_2 = 0.0000133d + 0.134 \qquad (7)$$

where S_1 and S_2 are expressed in units of (albedo(%) count–1). For easy reference, the above results, along with those from RC, are summarized in table 1. Users who have access only to the RC-calibrated radiance/albedo data, and who cannot access the raw radiometric data (counts) and related information to which equations (4)–(7) can be applied directly, may recover the more accurate AVHRR radiance/albedo by multiplying the RC-derived values by the correction factors given below:

$$\text{Channel 1: } CF_1 = (1.015 - 8.8 \times 10^{-5}\, d + 1.3 \times 10^{-8}\, d^2) \qquad (8)$$

$$\text{Channel 2: } CF_2 = (1.037 - 1.8 \times 10^{-4}\, d + 3.2 \times 10^{-8}\, d^2) \qquad (9)$$

The above correction factors are based on a quadratic fit between the ratio of the slope reported here to the slope reported in RC for either channel and the elapsed time in orbit. It should be noted that the correction factors given above, when applied to the RC-derived values, yield radiance/albedo values which are within 1% (relative) of those obtained with equations (4)–(7) for up to 1500 days after launch; the discrepancy between the two increases at greater values of d; thus, it is advisable not to use the correction factors beyond the end of 1998.

4. Results and discussion

It is apparent from the results shown in figure 1 that the revised calibration formulae yield lower rates of degradation in orbit and higher values of the slope on the day of launch ($d = 0$) than those reported in RC. The higher value of the slope on the day of launch offsets to some extent the effect of the lower rate of degradation in orbit; thus, the radiance/albedo values calculated using the formulae given here are within 5% (relative) of those calculated using the RC formulae for about 900 days after launch in channel 1 and for about 500 days in channel 2. Also shown in figure 1 is the absolute calibration of channel 1 based on congruent path

Table 1. Calibration parameters for channels 1 and 2 of the NOAA-14 AVHRR.

	k_i (intercept)		m_i (multiplier)	
Channel	Present work	RC	Present work	RC
1 Radiance	0.566	0.557	0.0000690	0.0001180
Albedo	0.111	0.109	0.0000135	0.0000232
2 Radiance	0.440	0.423	0.0000435	0.0001220
Albedo	0.134	0.129	0.0000133	0.0000373

The intercept k_i and multiplier m_i are keyed to equation (3).

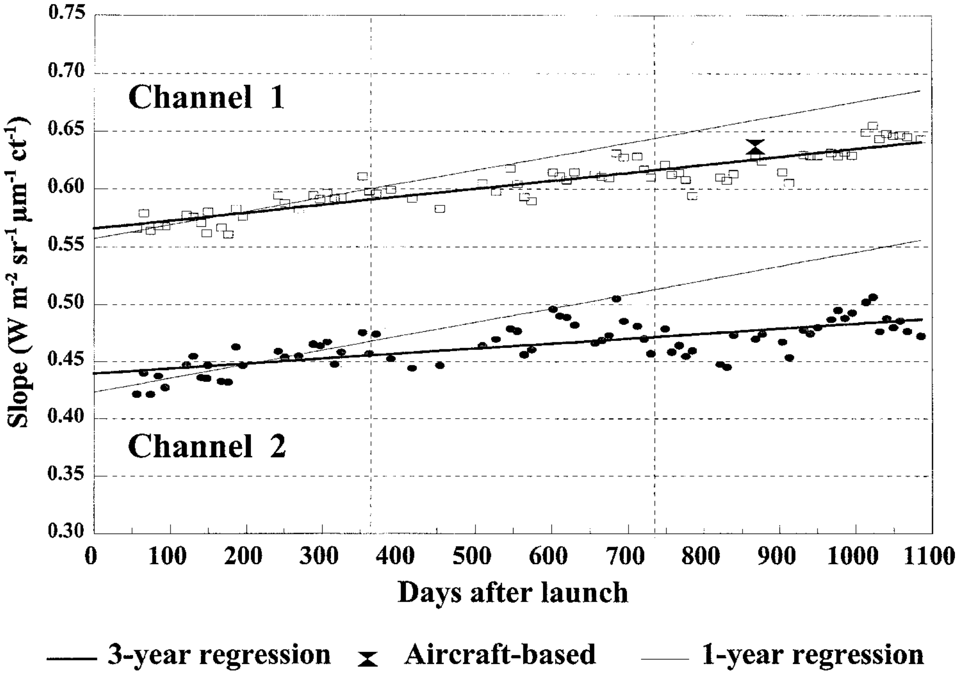

Figure 1. Comparison of post-launch calibration trends; dots and squares indicate the observed slopes.

aircraft–satellite radiance measurements (Abel *et al.* 1993) made over Railroad Valley, Nevada, USA (36° N, 119° W) in mid-May 1997 ($d=839$, P. Abel, personal communication 1998). It is within 3% (relative) of the values estimated using the RC and present calibration formulae; similar, aircraft-based calibration of channel 2 is not presently available.

To illustrate the impact of the revisions to the calibration of the two channels on AVHRR-derived geophysical products, figures 2 and 3 show the time series of top-of-the-atmosphere albedo in channels 1 and 2 and of the Normalized Difference Vegetation Index (NDVI), defined as the ratio of the difference to the sum of the albedos in channels 2 and 1, for a site in the western Sahara (24–25° N, 0–1° W, about 2400 km to the west of the Libyan desert calibration site) and for an agricultural site (39–40° N, 88–89° W, in Illinois, USA). The time series are based on the operational Global Vegetation Index (GVI) data (Kidwell 1994). It is apparent from the data for the desert site (figure 2) that the upward trend in the albedo in the two channels is considerably reduced with the application of the revised calibration, and the greening of the desert is essentially eliminated, as seen in the NDVI record. In the data for the agricultural site (figure 3), the impact of the revision is not very apparent in channel 1 because of the low value of the albedo, whereas it is discernible in channel 2. The impact on the NDVI is much less pronounced than for the desert site, with the revised calibration leading to slightly lower NDVI values. The large spikes in the albedo records, and the accompanying near-zero NDVI values, are attributed to clouds; due allowance must also be made for the natural variability of the two regions studied (F. Kogan, personal communication 1998).

The difficulties of near-real-time, post-launch calibration of the visible and

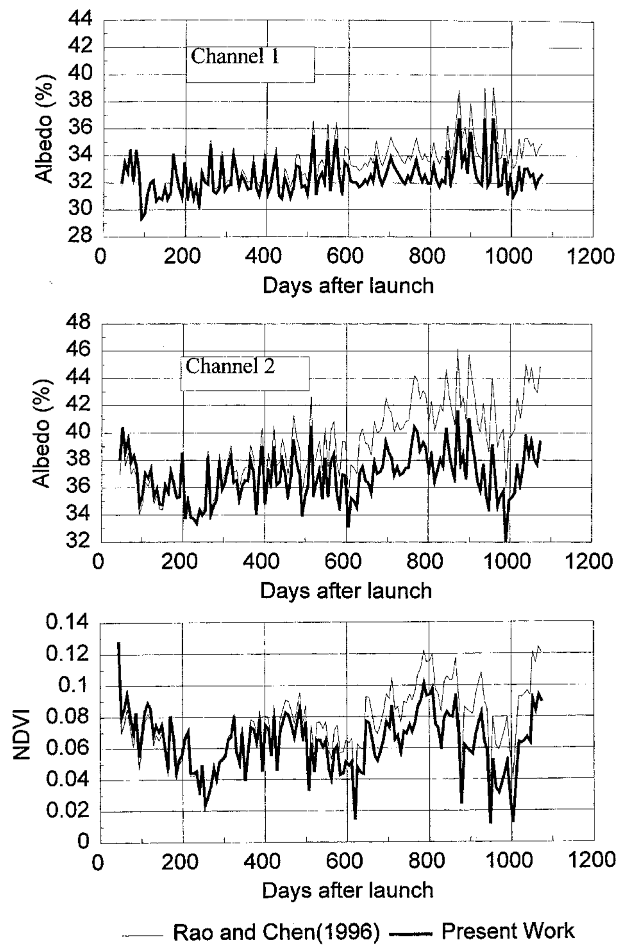

Figure 2. Time series of the top-of-the-atmosphere albedo and Normalized Difference Vegetation Index (NDVI) for a desert site (24–25° N, 0–1° W) in Algeria (Africa).

near-infrared channels of the AVHRR have been discussed by investigators elsewhere (e.g. Cihlar and Teillet 1995). Thus, the primary objective of the work reported in RC was to evaluate the feasibility of updating in near-real-time the post-launch calibration of the two AVHRR channels using observations made over a limited period of time of the order of 1 year. There has been reasonable success in that the RC calibration compares favorably with independent determinations of channel slopes by other investigators; Loeb (1997) used the spatially and temporally uniform ice surfaces (albedo of the order of 75–80% in the two channels) of Greenland and Antarctica as calibration sites and found that the calibration coefficient for channel 1 was within 3% (relative) of the RC calibration and that for channel 2 the two calibrations were within 4% (relative) of each other during 1995. Similar results have been reported for early 1997 by Koslowsky (personal communication 1998), who used the top-of-the-atmosphere albedo record established with the NOAA-11 AVHRR as the calibration standard to derive the in-orbit degradation of the two channels of the NOAA-14 AVHRR. The present authors are examining several methods of improving the ability to provide near-real-time calibration updates for

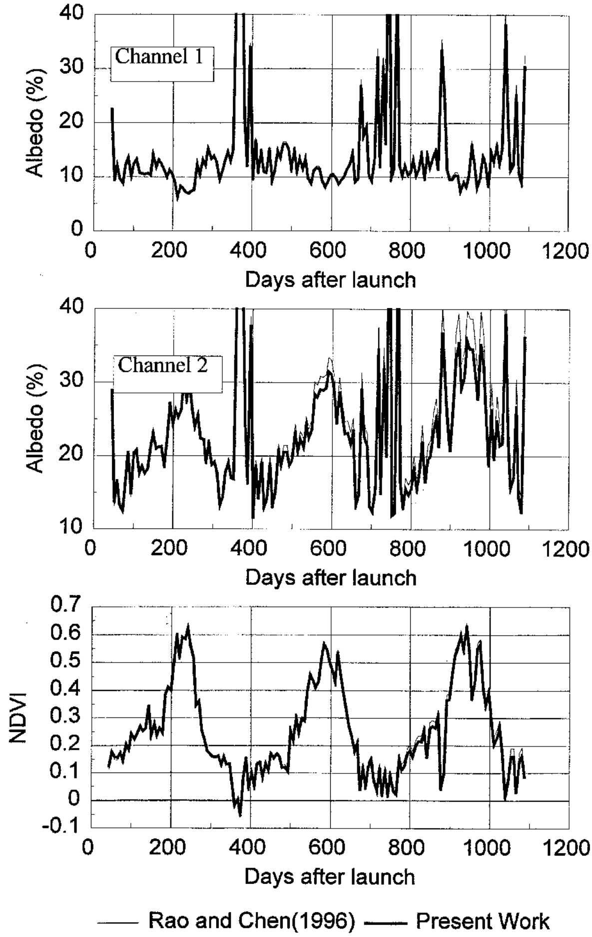

Figure 3. Same as figure 2, but for an agricultural site (39–40° N, 88–89° W) in Illinois (USA).

the visible and near-infrared channels of the AVHRR. One of them is to base the near-real-time calibration updates on top-of-the-atmosphere albedo time series over a number of radiometrically stable sites over the globe, with the albedo ranging from $\approx$ 20 to 70%. Toward this end, they have recently initiated the task of evaluating the radiometric stability of 11 sites around the globe, utilizing the measurements made by the well-characterized AVHRRs on the NOAA-7, -9 and -11 spacecraft (RC) and those made by the ATSR-2. They propose to use the most stable of these sites to develop a multi-site-based, near-real-time calibration update procedure for the AVHRR on the NOAA polar-orbiting spacecraft.

Acknowledgments

The work reported here was supported in part by the NOAA Office of Global Programs. The authors wish to acknowledge useful discussions with Dr J. T. Sullivan, NOAA/NESDIS Office of Research and Applications. They are thankful to Dr Felix Kogan, of the same office, and Mr Guo Wei, Visiting Scientist from the National Satellite Meteorological Center, Chinese Meteorological Administration, Beijing, for providing the data shown in figures 2 and 3.

References

Abel, P., Guenther, B., Gallmore, R. N., and Cooper, J. W., 1993, Calibration results for NOAA-11 AVHRR channels 1 and 2 congruent path aircraft observations. *Journal of Atmospheric and Oceanic Technology*, **10,** 493–508.

Cihlar, J., and Teillet, P. M., 1995, Forward piecewise linear calibration model for quasi-real time processing of AVHRR data. *Canadian Journal of Remote Sensing*, **21,** 22–27.

Kidwell, K., 1994, Global Vegetation Index User's Guide. US Department of Commerce, Washington, DC.

Koslowsky, D., 1997, Signal degradation of the AVHRR shortwave channels of NOAA-11 and NOAA-14 by daily monitoring of desert targets. *Advances in Space Physics*, **19,** 355–1358.

Loeb, N. G., 1997, In-flight calibration of the NOAA AVHRR visible and near-ir bands over Greenland and Antarctica. *International Journal of Remote Sensing*, **18,** 477–490.

Rao, C. R. N., and Chen, J., 1995, Inter-satellite calibration linkages for the visible and near-infrared channels of the Advanced Very High Resolution Radiometer on the NOAA-7, -9, and -11 spacecraft. *International Journal of Remote Sensing*, **16,** 1931–1942.

Rao, C. R. N., and Chen, J., 1996, Post-launch calibration of the visible and near-infrared channels of the Advanced Very High Resolution Radiometer on the NOAA-14 spacecraft. *International Journal of Remote Sensing*, **17,** 2743–2747.

Smith, D. L., Read, P. D., and Mutlow, C. T., 1997, The calibration of the visible/near infra-red channels of the Along-Track-Scanning-Radiometer-2 (ATSR-2). *Proceedings of the SPIE Conference on Sensors, Systems, and Next Generation Satellites, London, July 1997* (SPIE, Bellingham, Washington, USA), **3221,** 53–62.