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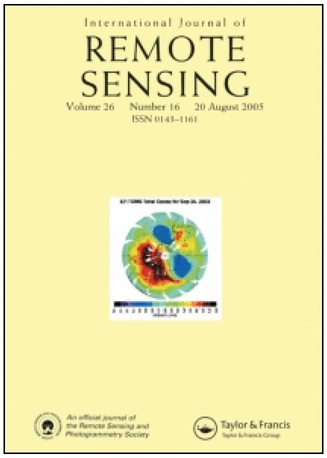

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Inter-satellite calibration linkages for the visible and near-infared channels of the Advanced Very High Resolution Radiometer on the NOAA-7, -9, and -11 spacecraft

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Inter-satellite calibration linkages for the visible and near-infared channels of the Advanced Very High Resolution Radiometer on the NOAA-7, -9, and -11 spacecraft

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Abstract. The post-launch degradation of the visible (channel 1: $\approx$0·58–0·68 μm) and near-infrared (channel 2: $\approx$0·72–1·1 μm) channels of the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-7, -9, and -11 Polar-orbiting Operational Environmental Satellites (POES) was estimated using the south-eastern part of the Libyan desert as a radiometrically stable calibration target. The relative annual degradation rates, in per cent, for the two channels are, respectively: 3·6 and 4·3 (NOAA-7); 5·9 and 3·5 (NOAA-9); and 1·2 and 2·0 (NOAA-11). Using the relative degradation rates thus determined, in conjunction with absolute calibrations based on congruent path aircraft/satellite radiance measurements over White Sands, New Mexico (U.S.A.), the variation in time of the absolute gain or 'slope' of the AVHRR on NOAA-9 was evaluated. Inter-satellite calibration linkages were established, using the AVHRR on NOAA-9 as a normalization standard. Formulae for the calculation of calibrated radiances and albedos (AVHRR usage), based on these interlinkages, are given for the three AVHRRs.

1. Introduction

One of the main objectives of the National Oceanographic and Atmospheric Administration (NOAA)/National Aeronautics and Space Administration (NASA) Advanced Very High Resolution Radiometer (AVHRR) Pathfinder program is the establishment of long-term, accurate records of environmental products such as vegetation cover, cloud morphology, aerosols, and sea surface temperature generated from broad-band spectral measurements made by the AVHRRs on board the NOAA Polar-orbiting Operational Environmental Satellites (POES) (Ohring and Dodge 1992). There is evidence (e.g., Brest and Rossow 1992) that the visible (channel 1: $\approx$0·58–0·68 μm) and near-infrared (channel 2: $\approx$0·72–1·1 μm) channels, which have no on board calibration devices, degrade in orbit, initially because of outgassing (e.g., water vapour from filter interstices) and launch associated contamination (e.g., rocket exhaust and outgassing), and subsequently because of the continued exposure to the harsh space environment. It is therefore necessary, in order to ensure the quality and continuity of the long-term records of AVHRR-derived environmental products, to evaluate the in-orbit degradation of the two channels, and develop correction algorithms; and to establish inter-satellite calibration linkages. Accordingly, we wish to present here the work done at the NOAA

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Satellite Research Laboratory to characterize the post-launch performance of the AVHRR visible and near-infrared channels as part of the AVHRR Pathfinder Calibration activity (Rao *et al.* 1993). We have confined our attention to the AVHRRs on NOAA-7, -9, and -11 spacecraft for programmatic reasons. It should be mentioned that the AVHRR Pathfinder Calibration activity is an integral part of the operational satellite calibration program presently underway at the Satellite Research Laboratory, Office of Research and Applications, National Environmental Satellite, Data, and Information Service, NOAA.

2. Degradation rates

2.1. *General*

Relative changes in the gains of the three AVHRRs, expressed in units of Counts/($W\,m^{-2}\,sr^{-1}\,\mu m^{-1}$), or equivalently, the relative changes in the 'slope', the reciprocal of gain, expressed in units of W/($m^2\,sr\,\mu m$ count), were determined using the south-eastern part of the Libyan desert (21–23° N latitude; 28–29° E longitude) as a radiometrically stable calibration target. It is assumed that the isotropic albedo, defined as $(\pi I_i/F_{i0}\cos\theta_0)$, does not vary in time; here I_i and F_{i0} are, respectively the in-band upwelling radiance and the extraterrestrial solar irradiance in the i^{th} channel; and θ_0 is the solar zenith angle. This is a reasonable assumption since the highly variable atmospheric contribution to the upwelling radiance at the top of the atmosphere is small compared to the contribution of the radiation reflected by the bright desert surface (e.g., Brest and Rossow 1992, Kaufman and Holben 1993). The recent work of Cosnefroy *et al.* (1993) on the radiometric stability of desert targets also lends support to this assumption; based on an analysis of Meteosat images for a 100 by 100 km area in the general vicinity of the calibration site, they found the reflectance of the region to be very uniform, with the ratio of the standard deviation to the mean value of the reflectance of the 2·5 km resolution pixels to be of the order of 3 per cent; temporal stability was found to be of the same order after the seasonal trends in reflectance had been removed.

The International Satellite Cloud Climatology Project (ISCCP) B3 data (Schiffer and Rossow 1983) for the region of the calibration target were used in the present study; the data comprised the measured counts in the visible, near-infrared, and thermal infrared channels of the AVHRR; the satellite and solar zenith angles, and the azimuth angle of observation; the latitude and longitude of the ISCCP B3 pixel; and the date of measurement. A variant of Minnaert's reflection law (Barkstrom 1972) was used to characterize the dependence of the upwelling radiance on the solar and satellite zenith angles. Following a scheme suggested by Staylor (1990) where it is assumed that the degradation of the radiometer in time is exponential in its nature, the degradation rates are estimated from solutions of the following equation:

$$Y = AX^B \exp(-kd) \quad (1)$$

where Y: $\rho^2(C_{10}-C_0)\cos\theta$; C_{10}: measured signal in 10-bit counts; C_0: offset in 10-bit counts; ρ: Earth–Sun distance in astronomical units for the date of measurement; X: $(\cos\theta\cos\theta_0)/(\cos\theta+\cos\theta_0)$, θ and θ_0 being the satellite and solar zenith angles, respectively; k: daily rate of the degradation of the gain of the radiometer, assuming it to be exponential in time; d: days after launch of the spacecraft; and A, B: regression parameters. Standard numerical techniques were used to determine the value of the daily degradation rate, k. We have confined our attention to the B3 data corresponding to satellite zenith angles $\leqslant 14°$ to minimize the effects, if any, of the azimuthal dependence of the upwelling radiation at the top of the atmosphere; also, only data corresponding to solar zenith angles $\leqslant 60°$ have been included in the analysis. Greater details of the method of determination of the degradation rates, of the quality control criteria adopted to detect the presence of clouds, and of the ISCCP B3 data used are found in Rao and Chen (1993).

2.2. *The AVHRRs on NOAA-7, -9, and -11 spacecraft*

The degradation rates k for the two channels of the three AVHRRs, determined using the method outlined in the previous section, and the relevant ancillary data are shown in table 1; the k values yield the daily rate at which the AVHRR signal associated with an Earth scene, set equal to unity (1) on the day of launch, would apparently decrease in time, all other conditions remaining unaltered, because of the degradation of the radiometer. Thus, the corrected AVHRR signal can be obtained from the uncorrected signal on day d after launch by multiplying the latter (uncorrected signal) by exp (kd).

We have compared in table 2 the annual rates of degradation in per cent, 100 [(1-exp $(-365k)$)], based on the daily degradation rates listed in table 1 with results reported by researchers elsewhere; this comparison is only representative and not complete. The choice of the data for comparison was mainly governed by our desire to compare our results with those obtained over desert calibration targets (Staylor 1990, Kaufman and Holben 1993, Wu and Zhong 1994); with the results of statistical analysis of a large body of global reflectance data (Brest and Rossow 1992); with results based on composite calibration data (Che and Price 1992); and with those based on measurements made over a variety of targets, and on model simulations (R. Santer, 1993, personal communication). Staylor (1990) used the monthly means of AVHRR channel 1 albedos extracted from the Heat Budget Parameter (HBP) data (Gruber and Winston 1978) for a broad region ($\approx 10^6\,km^2$) of the Libyan desert in his work. Kaufman and Holben (1993) used the AVHRR GAC data (nominal spatial resolution: ≈ 4 km; daily and monthly means) for several sites located in the Libyan desert to establish the rate at which the ratio of the pre-

Table 1. Relative degradation rates for the visible and near-infrared channels of the AVHRRs on NOAA-7, -9, and -11 spacecraft.

Spacecraft	Launch date	Dates of data availability	Number of data points	Degradation rate (k) per day	
				Channel 1	Channel 2
NOAA-7	23 June 1981	August 1981–December 1984	84	0·000101	0·000120
NOAA-9	12 December 1984	January 1985–November 1988	86	0·000166	0·000098
NOAA-11	24 September 1988	January 1989–December 1991	83	0·000033	0·000055

Note: Each data point is the average of measurements made over approximately 35 pixels in the 1^0 (longitude) $\times$ 2^0 (latitude) area of the calibration target in the course of the day; the entries in the 'Number of data points' column give the number of days of appropriate data availability.

Table 2. Comparison of annual relative degradation rates (in per cent) reported by different authors.

Source	NOAA-7		NOAA-9		NOAA-11	
	Channel 1	Channel 2	Channel 1	Channel 2	Channel 1	Channel 2
Present work	3·6	4·3	5·9	3·5	1·2	2·0
Staylor (1990)	3·5	—	6·0	—	—	—
Kaufman and Holben (1993)	4·2	5·6	5·7	3·1	1·3	2·9
Brest and Rossow (1992)	0	—	4·6	—	—	—
Che and Price (1992)	4·4	4·6	5·0	6·7	6·7	3·9
Santer (1993, personal communication)	4·7	4·7	7·5	4·5	—	—
Wu and Zhong (1994)	—	—	5·8	4·6	—	—

Note: It is assumed in Brest and Rossow (1992) that there was no degradation of channel 1 of the AVHRR on NOAA-7 over the period July 1983–January 1985.

launch value of the 'slope' to its actual value varied in time. Brest and Rossow (1992) based their findings on statistical analysis of a large body of ISCCP global reflectance data, assuming that 'the global aggregate of regional variations of surface visible reflectance is not changing with time'; their results indicate that the visible channel of the AVHRR on NOAA-7 did not exhibit any perceptible in-orbit degradation over the period July 1983 to January 1985. Che and Price (1992) used a composite of post-launch calibration results given by several authors, using different techniques, and established linear regression relationships between the published values of gains (or 'slopes'), and elapsed time since launch (in months) of the spacecraft, assuming similarity in the degradation of different AVHRRs. Santer (1993, personal communication) has used measurements of upwelling radiances over desert surfaces, stratus cloud decks, ocean targets, and model simulations to derive the degradation rates. Wu and Zhong (1994) used two sets of measurements made over desert sites in China, approximately 3 years apart, to derive the degradation rates for the visible and near-infrared channels of the AVHRR on NOAA-9; a bidirectional reflection model, appropriate for deserts, was used to account for the dependence of the reflected radiation on the solar and satellite zenith angles, and the azimuth angle of observation.

The range of values of the degradation rates is an indication of the complexity of post-launch calibration of sensors like the AVHRR in the absence of on-board calibration, and is also traceable to the differences in the techniques employed.

2.3. *Absolute calibration of the AVHRR on NOAA-9 spacecraft*

The in-orbit degradation of the visible and near-infrared channels of the AVHRR on NOAA-9 spacecraft has been studied very extensively (e.g., Whitlock *et al.* 1990) by researchers employing a variety of techniques since its effective operational life ($\approx$1985–1988) encompassed important, international, multi-agency, multi-platform experiments such as the First ISCCP Regional Experiment (FIRE), and the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE). Also, the availability of the results of several aircraft/

satellite congruent path radiance measurements over White Sands, New Mexico (U.S.A.) during October/November 1986 (Smith *et al.* 1988), employing a well calibrated spectrometer on board a U-2 aircraft, made it possible to translate the relative degradation rates into variations in time of the gain or 'slope'. Accordingly, using the aircraft-based absolute calibrations as anchors, and employing the relative degradation rates (table 1), the rate of variation of the 'slope' in time over the operational life of the spacecraft was determined. The resulting expressions for the calculation of radiances I_d (in units of $\mathrm{W\,m^{-2}\,sr^{-1}\,\mu m^{-1}}$) on day d after launch, are:

Channel 1:

$$I_d = 0{\cdot}5465 \times \exp[1{\cdot}66 \times 10^{-4} \times (d-65)](C_{10} - C_0) \tag{2}$$

Channel 2:

$$I_d = 0{\cdot}3832 \times \exp[0{\cdot}98 \times 10^{-4} \times (d-65)](C_{10} - C_0) \tag{3}$$

C_0 has been given values of 37·0 and 39·6 in channels 1 and 2, respectively, and d is taken to be zero on the day of launch. Also, the effective counts $(C_{10} - C_0)$ have been normalized to mean Earth–Sun distance in the above formulae. The formulae have been recommended to the user community by the NOAA/NASA AVHRR Pathfinder Calibration Working Group (Rao *et al.* 1993); it was also the aim of the Working Group that the AVHRR on NOAA-9 should be used as the reference or normalization standard in the post-launch calibration of the AVHRRs on NOAA-7 and -11.

3. Inter-satellite calibration linkages

We have used the AVHRR on NOAA-9 as the normalization standard to establish interrelationships among the visible and near-infrared radiances measured by the three AVHRRs. The method is based on the use of matched data sets consisting of the measured counts, satellite zenith and solar zenith angles, and the dates of measurements over the south-eastern part of the Libyan desert, which was used as the calibration target in the present study. The following selection criteria were used to generate two sets of matched data, one for the NOAA-7/NOAA-9 combination, and the other for the NOAA-9/NOAA-11 combination:

(*a*) The solar zenith angle, θ_0, and the satellite zenith angle, θ, for the measurements made by the AVHRRs on NOAA-7 and NOAA-11 should be within 1° of the corresponding angles for measurements by the AVHRR on NOAA-9;

(*b*) The two measurements should have been made in the same calendar month, with the days of the month being as close to one another as was practicable, to allow for seasonal variations, if any, in the radiometric characteristics of the target. It is thus likely that measurements made by the AVHRR on either NOAA-7 or -11 in a given calendar month in the ith year in orbit of the relevant spacecraft could be matched with measurements made in the same calendar month, but in a different year (jth) in orbit of NOAA-9.

These selection criteria resulted in 11 sets of matched data for the NOAA-7/NOAA-9 combination, and 10 sets of matched data for the NOAA-11/NOAA-9 combination.

The method of normalization of the AVHRRs on NOAA-7 and NOAA-11 to the AVHRR on NOAA-9 is illustrated below, using the NOAA-7/NOAA-9 matched data set as an example:

(*a*) For either channel, the effective counts $(C_{10}-C_0)$ were corrected for the NOAA-7 AVHRR degradation, using the k values listed in table 1; the elapsed time in days, d, since launch was calculated from the known dates of launch and of the measurements in the matched data set.
(*b*) The matched, calibrated radiance measured by the AVHRR on NOAA-9 was calculated, using either (2) or (3) as was appropriate.
(*c*) A linear regression relationship was established between the NOAA-9 radiances from (*b*), and the corrected effective counts for the NOAA-7 AVHRR from (*a*).

The regression relationship established in (*c*) above links the AVHRR on NOAA-7 to the AVHRR on NOAA-9, and yields the 'slope', in units of W/m^2 sr μm count), for the given channel on the day of launch of NOAA-7. The AVHRR on NOAA-11 was linked to the AVHRR on NOAA-9 in a similar manner. The regressions had correlation coefficients in excess of 0·9. The resulting formulae for the calculation of radiances are given in table 3. The reflectance factor (Rao 1987) (or albedo (AVHRR usage) or scaled radiance (Brest and Rossow (1992)), given by $(100\pi I_i/F_{i0})$, is also used in different applications of AVHRR data; to facilitate this activity, we have listed in table 4 the formulae for the calculation of the albedos; the extra-terrestrial solar spectral irradiance values given by Neckel and Labs (1984) were used in the conversion of the radiance formulae (table 3) to the albedo representation; the conversions are effected by multiplying the radiances by $(100\pi w_i/F_{i0})$, w_i being the equivalent width of the ith channel. We have given in table 5 the values of w_i and F_{io} used in the conversion of the radiance formulae given in table 3 to the albedo (AVHRR usage) representation (table 4).

It is felt that the attainable accuracies in the radiance or albedo calculated using the formulae we have given (tables 3 or 4) are at best comparable to the estimated

Table 3. Formulae for the calculation of calibrated radiances.

Spacecraft	Radiance ($W\,m^{-2}\,sr^{-1}\,\mu m^{-1}$)
NOAA-7	
Channel 1	$0{\cdot}5753 \exp(1{\cdot}01\times10^{-4}\,d)\,(C_{10}-36)$
Channel 2	$0{\cdot}3914 \exp(1{\cdot}20\times10^{-4}\,d)\,(C_{10}-37)$
NOAA-9 (Set A)	
Channel 1	$0{\cdot}5465 \exp[1{\cdot}66\times10^{-4}\,(d-65)]\,(C_{10}-37)$
Channel 2	$0{\cdot}3832 \exp[0{\cdot}98\times10^{-4}\,(d-65)]\,(C_{10}-39{\cdot}6)$
NOAA-9 (Set B)	
Channel 1	$0{\cdot}5406 \exp(1{\cdot}66\times10^{-4}\,d)\,(C_{10}-37)$
Channel 2	$0{\cdot}3808 \exp(0{\cdot}98\times10^{-4}\,d)\,(C_{10}-39{\cdot}6)$
NOAA-11	
Channel 1	$0{\cdot}5496 \exp(0{\cdot}33\times10^{-4}\,d)\,(C_{10}-40)$
Channel 2	$0{\cdot}3680 \exp(0{\cdot}55\times10^{-4}\,d)\,(C_{10}-40)$

Note: The two sets of formulae given for NOAA-9 yield the *same* radiances; the quantity $\exp(-65k)$ occurring in Set A has been incorporated into the numerical coefficient appearing at the beginning of the formulae in Set B to render their format the same as that of the formulae for the AVHRRs on NOAA-7 and NOAA-11.

Table 4. Formulae for the calculation of calibrated AVHRR albedos.

Spacecraft	Albedo (per cent)
NOAA-7	
Channel 1	$0{\cdot}1100 \exp(1{\cdot}01\times10^{-4}\ d)\ (C_{10}-36)$
Channel 2	$0{\cdot}1169 \exp(1{\cdot}20\times10^{-4}\ d)\ (C_{10}-37)$
NOAA-9 (Set A)	
Channel 1	$0{\cdot}1050 \exp[1{\cdot}66\times10^{-4}\ (d-65)]\ (C_{10}-37)$
Channel 2	$0{\cdot}1143 \exp[0{\cdot}98\times10^{-4}\ (d-65)]\ (C_{10}-39{\cdot}6)$
NOAA-9 (Set B)	
Channel 1	$0{\cdot}1039 \exp(1{\cdot}66\times10^{-4}\ d)\ (C_{10}-37)$
Channel 2	$0{\cdot}1136 \exp[0{\cdot}98\times10^{-4}\ d)\ (C_{10}-39{\cdot}6)$
NOAA-11	
Channel 1	$0{\cdot}1060 \exp(0{\cdot}33\times10^{-4}\ d)\ (C_{10}-40)$
Channel 2	$0{\cdot}1098 \exp(0{\cdot}556\times10^{-4}\ d)\ (C_{10}-40)$

Note: The two sets of formulae given for NOAA-9 yeild the *same* albedos; the quantity $\exp(-65k)$ occurring in Set A has been incorporated into the numerical coefficient appearing at the beginning of the formulae in Set B to render their format the same as that of the formulae for the AVHRRs on NOAA-7 and NOAA-11.

accuracies of the order of a few per cent (G. Smith, 1993, personal communication) of the Fall 1986 aircraft-based absolute calibrations of the AVHRR on NOAA-9 which we have used as the normalization standard in the present work.

Staylor (1990) has established linkages among the visible channels (channel 1) of the AVHRRs on NOAA-6, -7 and -9, using the instrument on NOAA-7 as the normalization standard. Starting with the regions of overlap in the X variable in the plots of Y on X (1), he determined adjustment factors (multipliers) for Y that would force the regression plots for the radiometers on NOAA-6 and -9 to coalesce with the regression plot for the AVHRR on NOAA-7. The ratio of the adjustment factors he has given for the AVHRRs on NOAA-7 and NOAA-9 is 1·07 which is very close to the ratio (1·064) of the channel 1 slopes for the day of launch ($d=0$) listed in table 3 for the two AVHRRs. Brest and Rossow (1992) have also established a linkage between the visible channels of the AVHRRs on NOAA-7 and -9, using reflectance data from the two satellites, obtained over a 3-week overlap period from 18 January to 8 February 1985; it should however be noted that they have assumed that there was no perceptible degradation in the performance of NOAA-7 AVHRR channel 1 over the period from the middle of 1983 to early 1985.

Table 5. Equivalent widths and in-band extraterrestrial solar irradiances.

	$W_i(\mu m)$		F_{i0} ($W\,m^{-2}$)	
Spacecraft	Channel 1	Channel 2	Channel 1	Channel 2
NOAA-7	0·108	0·249	177·5	261·9
NOAA-9	0·117	0·239	191·3	251·8
NOAA-11	0·113	0·229	184·1	241·1

4. Validation

To evaluate the reasonableness of the inter-satellite calibration linkages we have established using the AVHRR on NOAA-9 as a normalization standard we shall first compare the variation in time of the 'slopes' of channels 1 and 2 of the AVHRR on NOAA-11, derived from these formulae, with the absolute calibrations based on congruent path aircraft/satellite radiance measurements over the White Sands area, New Mexico, U.S.A. (Abel *et al.* 1993). The results are shown in figure 1; we have also included results of several other investigators for purposes of comparison. It should be mentioned that Mitchell *et al.* (1992) obtained their results using the split-pass imagery technique and model simulations of the upwelling radiation over an oceanic target in the Southern Ocean off the north-west coast of Tasmania.

The noticeable feature is that the variation in time of the 'slope', expressed in units of $W/(m^2 \, sr \, \mu m$ count), is within one standard deviation of the mean values of the majority of aircraft-based absolute calibrations in both channels. This behaviour can be taken as an indicator of the viability of the method we have used to develop interrelationships among the three radiometers, using the AVHRR on NOAA-9 as a normalization standard. The differences, practically systematic, between the trends in 'slope' in the present study, and those reported in Kaufman and Holben (1993) may perhaps be due to differences in the absolute calibration anchors used.

We used about 15 per cent of the ISSCP B3 (table 1) data for the south-eastern Libyan desert calibration site in the establishment of the matched data set; we thus felt it may be scientifically meaningful to apply the inter-satellite calibration linkages to the entire set of data to determine the impact of in-orbit degradation on the calculated albedos. Accordingly, the time series (1981–1991) of albedos $100\pi I_i/(F_{i0}\cos\theta_0)$ in channels 1 and 2 of the calibration target site obtained using the pre- and post-launch calibrations are shown in figure 2; we have included the albedo values calculated using the post-launch calibrations reported by Kaufman and Holben (1993) and by Che and Price (1992) for purposes of comparison. The noticeable feature is that the calibrated radiance formulae given here (table 3) establish continuity of record of the isotropic albedo among the three satellites, and also remove the spurious downward trends in the albedos obtained with the pre-launch coefficients. The mean and standard deviation (in parentheses) of the corrected albedos (in per cent) in AVHRR channels 1 and 2 are found to be, respectively 37·8 (0·7) and 42·6 (1·5). It has been observed that channel 2 data are generally noisier than those for channel 1; this may be due to the uncertainties introduced by the variations in the atmospheric precipitable water, which exhibits absorption in the spectral region of channel 2.

It may rightfully be argued that the time seris of the albedos of the calibration target site should not be used to validate our results. However, the calibrated radiance/albedo formulae we have given here have been implemented in the reprocessing of the Normalized Difference Vegetation Index (NDVI) global climatology at NOAA (Gutman *et al.* 1995); in the NOAA experimental clouds from AVHRR (CLAVR) product (L. Stowe and P. Davis, 1994, personal communication); in the validation of the NOAA aerosol product using shipboard aerosol optical thickness measurements (Ignatov *et al.* 1994); and in the generation of the NOAA/NASA Pathfinder AVHRR Land Data Set (Agbu and James 1994, James *et al.* 1994). Results to date of the above application are very encouraging (personal communications from different users) in terms of establishment of continuity

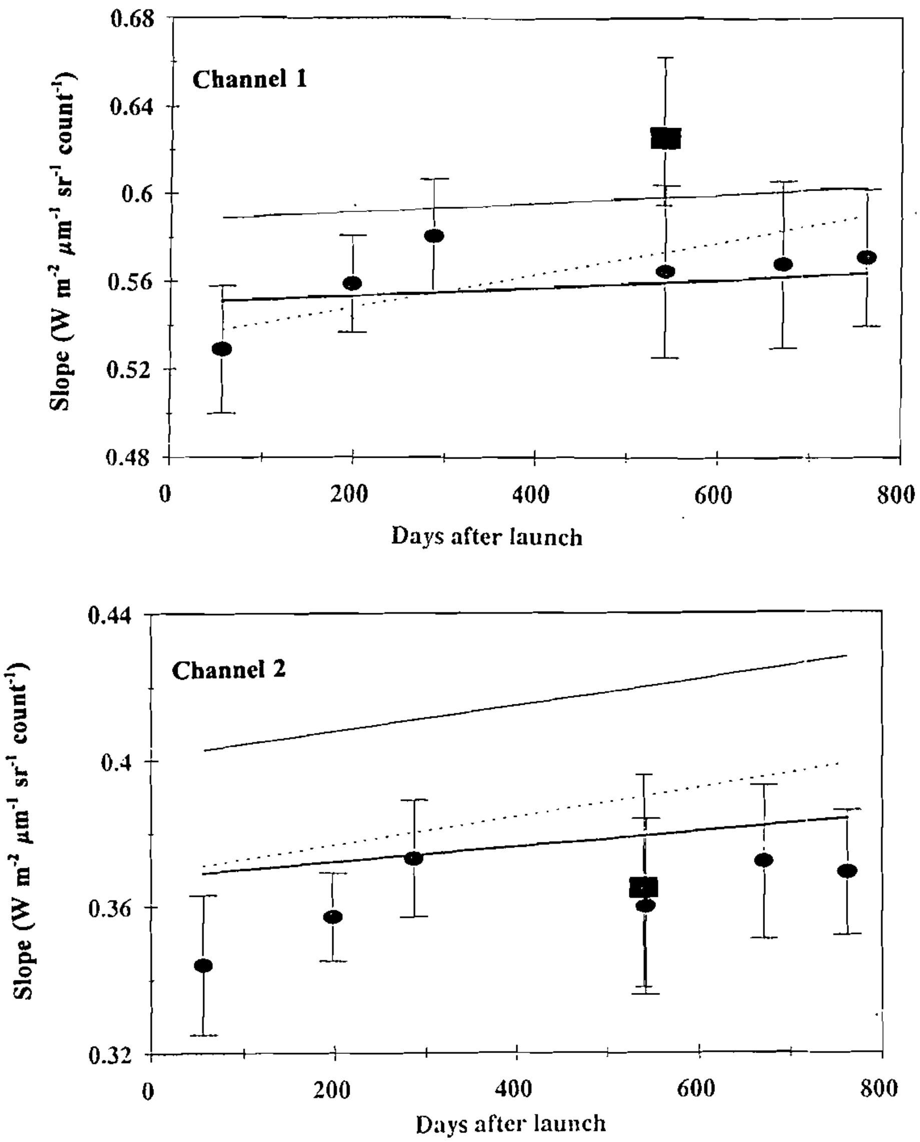
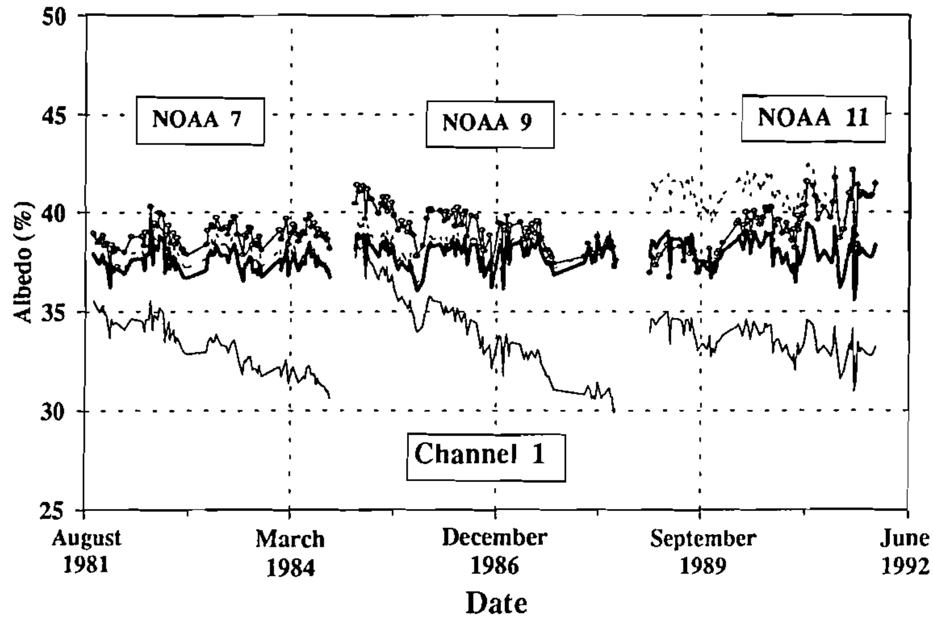


Figure 1. Comparison of the predicted variation in time of the 'slopes' of channels 1 (top) and 2 (bottom) of the AVHRR on NOAA-11 (launch date: 24 September 1988) with aircraft-based absolute calibrations. ● Abel *et al.* (1993), — present work, — Kaufman and Holben (1992), --- Che and Price (1992), ■ Mitchell *et al.* (1992).



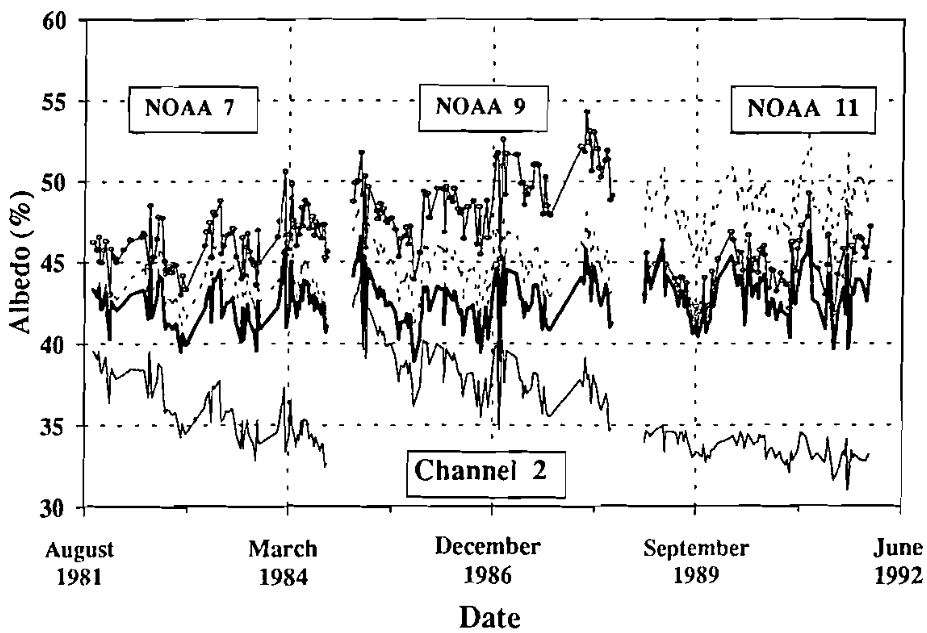


Figure 2. Time series of the isotropic albedo of the Libyan desert calibration target. —— present work, --- Kaufman and Holben (1993), —•— Che and Price (1992), —— Pre-launch.

amongst the three AVHRRs and in terms of removal of spurious trends in the different products.

5. Conclusion

The validity and usefulness of the inter-satellite calibration linkages we have established, and of the radiance and albedo formulae we have given can be evaluated only after they have been applied to the reprocessing of long-term records of different AVHRR-derived geophysical products by a large community of users. Several activities along these lines, some of which have been mentioned earlier, are presently underway both within NOAA, and at other institutions elsewhere. It should also be recognized that the improvements in the products brought about by the use of the radiance and albedo formulae we have given are also determined by the nature of the data (e.g., skewness or bias, composite nature) to which they are applied, and the approximations and assumptions made in the product-generation algorithms. Also, in continuation of the present investigation, a sensitivity analysis of the post-launch calibration of the AVHRR visible and near-infrared channels using desert calibration targets is presently underway to evaluate the impact, if any, of uncertainties or changes in the various physical parameters used in the derivation of the degradation rates (§2.1); results of this investigation will be published in a forthcoming paper.

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