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Inflight Absolute Calibration of Visible and Near-infrared Sensors on Board NOAA-14

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Abstract The present paper applies the approach using ocean and cloud views to calibrating absolutely visible and near-infrared channels of the AVHRR on board NOAA-14. The results of the absolute calibration of the two channels demonstrate that the AVHRR channels 1 and 2 sensors have been deteriorated and show a degradation 7 percent and 11 percent, respectively, with respect to the preflight calibration. To verify the results of the absolute calibration, the ground measured spectral reflecnces in desert area in China have been appled to campare with the satellite data corrected by the calibration coefficients. Agreement within an error of measurement has been found between the ground measured reflectances and the corrected satellite data for NOAA—14. Both very high and very low reflectances have been used in the calibration approach, so that the calibration coefficients can be applied to the various sites with different reflective properties.

Key words Quantification of satellite data, Atmospheric correction, Radiative calibration

1 INTRODUCTION

Monitoring long term variation in land and atmospheric and oceanic processes is required to assess the impact of the human activity on climate change and other changes in the environment. To gain quantitative information about the variation of the Earth the satellite imagery is the most powerful. However, the response characteristics of satellite radiometers in flight are being changed due to cosmic dust impacts on the optics and others. Because of lack of reliable inflight calibration devices it is difficult to calibrate satellite sensors in the solar spectrum. Use of the prelaunch calibration data to convert satellite measured signal to radiance can bring a certain error. As a result there is need to develop an independent method for inflight sensor calibration to be able to apply satellite data quantitatively for a frequent survey of the Earth.

Various calibration methods[1-8] have been developed for the purpose of absolute calibration of visible and near-infrared satellite sensors. Among them the most direct calibration approach[1,5,7,8] is to rely on ground-based or aircraft measurements of the optical properties of the atmosphere and the spectral radiance of the Earth surface observed by the satellite in the same illumination and observation directions. Those methods are relatively expensive, complex and cannot be used to calibrate historical satellite data and performed on a frequent basis. Moreover, the above methods are affected by uncertainties in the calibration of the instruments that are used to calibrate the satellite sensor. Furthermore, it is difficult to ensure the same surface area that are observed simultaneously by the satellite and the aircraft or ground measurements because of the uncertainty of the satellite geographic registration. Also differences in the view direction and uncertainty in the surface bidirectional reflectance can bring additional errors.

Consequently, an alternative method for absolute calibration, that does not require aircraft or ground measurements, has been developed by several authors[9-15]. The approach is based on the large contribution (~80%) of molecular scattering over the ocean to the radiance detected by the satellite in visible spectrum. The rest of the radiance comes from aerosol scattering, glint of sky light, and underwater radiance that caused by suspending materials in the sea· The Rayleigh scattering can be calculated precisely by radiative transfer model· The remains can be obtained by climate data· The accuracy of the approach is limited by estimating the contribution of aerosol scattering imprecisely· To improve the calibration method over the ocean an approach of combined channels[13,15] has been proposed· The approach uses both AVHRR channels 1 and 2 simultaneously over the ocean and over high bright clouds to derive the AVHRR calibration of channels 1 and 2 simultaneously with the determination of the aerosol loading· The accuracy of the absolute calibration can be greatly improved by estimate of the aerosol effect correctly·

The present paper will apply this approach of the combined channels simultaneous over the ocean and over high and thick cloud for absolute calibration for AVHRR visible and near-infrared sensors on board NOAA-14· To verify the results of the absolute calibration derived by the above approach the measurement data of the ground reflectance in desert area will be used to compare with AVHRR data corrected by the calibration coefficients·

2 SUMMARY OF THE CALIBRATION METHOD USING OCEAN AND CLOUD VIEWS

In the spectral range 0.6—1.0 μm the reflective peoperties of clouds are spectrally neutral because the size of droplet are much larger than 1μm for the most of clouds· Generally，water vapour and aerosol concentrate mainly on the lower part of the atmosphere· Therefore，for satellite sensors，the higher cloud is，the less influence of water vapour and aerosol above the cloud· For higher than 10 km cloud the influence of water vapour absorption and aerosol scattering becomes negligible· If clouds are thick enough the radiative effect of the atmosphere and surface underlying the cloud on the signal recorded by satellite can be also neglected· Based on the above facts the apparent reflectance of cloud observed by the satellite，$\rho(Z)$，can be written as a function of the cloud top altitude Z for both AVHRR channels 1 and 2 as：

$$\rho^i(Z) = T^i_{goz}\left[T^i_{gox}(Z/2)\rho^i_r(Z) + T^i_{gox}(Z)T^i_r(Z)\frac{\rho_c}{(1-S^i_r(Z)\rho_c)}\right] \quad (1)$$

where $i=1,2$ for the channel number· T_{goz} is the gaseous transmission due to ozone layer· T_{gox} is the gaseous transmission due to oxygen· $\rho_r(Z)$ is the Rayleigh reflectance due to molecules located above Z· $T_r(Z)$ is the molecular scattering transmission· ρ_c is the cloud reflectance· $S_r(Z)$ is the atmospheric albedo·

To simplify equation (1) and introduce the degradation coefficient of the sensor r_i actural reflectance ρ^m_i measured by the satellite：

$$\rho^m_i = r_i\rho^i = T^i_{goz}T^i_{gox}(Z)\left[\rho^i_r(Z) + T^i_r(Z)\frac{\rho_c}{1-S^i_r(Z)\rho_c}\right]r_i \quad (2)$$

In fact，the contribution of the Rayleigh scattering to signal measured by satellite is very small relative to the cloud reflectance· Therefore neglecting the effect of calibration degradation on ρ_r can not cause large error· The corrected AVHRR measurements ρ' of the two channels are：

$$\rho'_i = \frac{\rho^m_i/(T^i_{goz}T^i_{gox}(Z)) - \rho^i_r(Z)}{T^i_r(Z)} \cong \frac{r_i\rho_c}{1-S^i_r(Z)\rho_c} \quad (3)$$

The correcting also for the atmospheric albedo，$S_r(Z)$，it is found that：

$$\rho''_i = \frac{\rho'_i}{1+S^i_r(Z)\rho'_i} = r_i\,\rho_c \quad (4)$$

Because the cloud itself is not dependent on the wavelength in the range from 0.6 to 1.0μm，so：

$$\rho''_1/\rho''_2 = r_1/r_2 = r_{12} \quad (5)$$

For the cloudless and clear ocean the contribution of molecular scattering is about 80% of the signal received by satellite in visible spectrum· The rest is mainly due to aerosol scattering· Therefore simultaneous use of the information from two channels can obtain absolute calibration of channel 1 and aerosol loading· According to the definition：

$$r_1 = \rho^m_1/\rho_1 \quad (6)$$

where ρ^m_1 is the ocean reflectance derived from the satellite data by using preflight calibration coefficient·

ρ_1^t is the true reflectance·

Giving an aerosol optical thickness and wind speed，the ocean reflectance (ρ^c) can be calculated by using radiative transfer model[16,17] and the geometrical conditions which taken from the satellite imagery· The difference between the true and the calculated reflectances is due to the unknown aerosol and wind speed· Therefore：

$$\rho_i^t = \rho_i^c + \delta\rho_i \tag{7}$$

where $\delta\rho_1$ is a perturbation that accounts for the difference in the atmospheric conditions from the assumption· The relationship between $\delta\rho_1$ and $\delta\rho_2$ is defined by the spectral dependence of the perturbation I_{12}：

$$\delta\rho_1 = I_{12}\ \delta\rho_2 \tag{8}$$

where I_{12} is derived from simulations of the signal for both channels 1 and 2 with aerosol optical thickness of 0.15 and 0.05，respectively· In fact，I_{12} is almost independent of the unknown parameters，e·g·，wind speed and aerosol optical thickness· Then it can be found that ：

$$r_1 = (\rho_1^m - r_{12} I_{12} \rho_2^m)/(\rho_1^c - I_{12} \rho_2^c) \tag{9}$$

Based on the Eqs· (9) and (5) the absolute calibration for AVHRR visible and near-infrared sensors can be obtained by performing radiative transfer model and satellite imagery·

3 ABSOLUTE CALIBRATION FOR AVHRR CHANNEL 1 AND 2 ON BOARD NOAA-14

To apply the approach of the combined channels simultaneous over the ocean and over high clouds for absolute calibration the key is how the high thick cloud to be selected for intercalibration between AVHRR channels 1 and 2，and how cloud to be screened for the clear ocean surface· If a lower and thinner cloud has been selected the intercalibration between AVHRR channels 1 and 2 is influenced both by aerosol and water vapour above the cloud and by surface and atmosphere underlying the cloud· It must be very careful to choose the AVHRR data for calibration·

A· We adopt the following criteria for selecting the high and thick cloud：

(a) Brightness temperature of AVHRR channel 4 must be less than 235 degK· Comparing the temperature with the temperature profile of the atmospheric model for the midlatitude summer one can find that the cloud extends to above 10 km height and that the cloud layer is thick·

(b) The visible reflectance measured by AVHRR channel 1，ρ_1^m (use of preflight calibration coefficient)，is higher than 0.50· This means that a bright cloud is chosen·

(c) The ratio of the reflectances derived from AVHRR channels 1 and 2，ρ_1^m/ρ_2^m，is less than 1.12· The smaller the ratio is，the less influence of aerosol and water vapour above the cloud·

According to the above criteria the AVHRR 1B data dated 3rd September 1995 was selected for absolute calibrations· In order to consider the cloud as a Lambertian reflector it needs to be located as close to the nadir as possible·

We use the fast and simplified 5S code to calculate the Reyleigh scattering，ozone and oxygen absorption，and the atmospheric spherical albedo for AVHRR channels 1 and 2，respectively· Based on the equation (5) we find r_{12} is 1.045 for the AVHRR on board NOAA-14·

B· In the present paper we use the following criteria[18] for selecting cloudless and clear ocean surface：

(a) $\rho_1^m < 0.05$· As we know，the cleaner ocean water is，the less reflectance of AVHRR channel 1· The reflectance of the channel 1 for cloud and land surface，generally，is much higher than 0.05.

(b) $T_{b4} > 290$ degK· The temperature of cloud，in general，is lower than surface temperature，especially for high cloud· Although the island and land is warmer than water in that time，the reflectance for the former is much higher than the later· Therefore we could distinguish between water and land or clouds·

(c) $1.75 < \rho_1^m/\rho_2^m < 2.0$· This ratio is appreciably greater than unity when there are no clouds present within the field of view of the sensor; on the other hand，when clouds are present this ratio tends to be very close to or slighly less than, unity·

(d) The standard deviation of a 3 pixel by 3 pixel array composed of brightness temperatures of channel 4 is less than a threshold, 0.2 degK· The idea is that the variability of brightness temperature over a cloud contaminated pixel array should be higher than for clear pixel array· It is very useful for the delineation of limits between land and sea·

Based on the above criteria the ocean located at 35.466°N, 63.656°E is selected as cloudless area· As we know, that area is relatively pollution free, far from sources of dust, smoke or anthropogenic pollution· The reflectances for AVHRR channels 1 and 2 can be derived from the satellite data for this area· Then, the fast and simplified 5S code is adopted for calculating the reflectance for model atmosphere in the same geometrical condition for the sun and observer as that recorded by the satellite·

From Eqs· (9) and (5) we find $r_1 = 0.93$, $r_2 = 0.89$. The value of r_1 is much greater than the value of the NOAA-11 AVHRR in the first two years[15].

4 DISCUSSION OF THE RESULTS

The calibration correction coefficients 0.93 and 0.89 have been obtained for AVHRR channels 1 and 2, respectively· It is rather difficult to find the appropriate measured data to verify above results because the calibration study for sensors on satellites have not been performed by using of field measurements in China· The spectral reflectances measured in desert area of China[19] may be applied to compare with satellite data corrected by our calibration coefficients· In order to invert the satellite data to the surface reflectivities the atmospheric correction has to be done by using of the meteorological parameters listed in [19]· Table 1 shows that the ground measured spectral reflectances and data corrected by atmospheric effects from NOAA-14 AVHRR channels 1 and 2 that inverted both by the preflight calibration and by our calibration, respectively· It needs to be assumed that the desert reflectances are not changing in time because the two different time data sets are adopted· From the table we can see obviously that there are some disagreement between the ground measurements and the satellite data corrected by our calibration coefficients· These errors may come mainly from different spectral bandwidth and responsibility and from the field measurement errors· The reference* reported that for 9 measured sites (27 sets of measurements)

Table 1 Reflectances of ground measurements and reflectances invented from the NOAA-14 AVHRR channels 1 and 2 by using the preflight and the corrected calibrations

Sourcec of data		Longitude and latitude	Solar zenith angle	wavelength(nm)								
				555	571	630	681	750	838	880	913	936
				reflectances(%)								
Ground mean value		94.703 °E 36.383 °N	25.75°	23.033	24.593	27.275	27.849	29.815	30.027	29.747	29.456	29.060
NOAA-14	preflight	94.720°E 36.386°N	34.50°			20.889			23.248			
	corrected					22.591			26.162			
	preflight	94.711°E 36.385°N	34.50°			20.888			23.408			
	corrected					22.590			26.335			
	preflight	94.702°E 36.383°N	34.50°			20.887			23.407			
	corrected					22.589			26.334			
	preflight	94.693°E 36.382°N	34.50°			20.886			23.715			
	corrected					22.588			26.681			

* Ground data measured in Ge Er-mu desert on 27 and 28 June 1994

* * NOAA-14 data is on 3 September 1995

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* 中国遥感卫星辐射校正场专题论证组,中国遥感卫星辐射校正场考察团,中国遥感卫星辐射校正场考察报告汇编,1994,10.

the error (r.m.s.) are 2.801% at 630nm and 3.157% at 838nm, respectively. Moreover, there are some errors within the measurements (e.g., the standard reference white board is not good Lambertian reflector; some dust contaminated the standard white board during the measurements, etc.). Also some errors exist in the approach for inflight calibration. From theoretical calculation the total error (r.m.s.) of the calibration approdch is less than 5% for AVHRR channel 1. Of course, it can introduce certain error if no enough satellite data could be selected.

Both very high and very low reflectivities (high cloud and ocean) have been used in the calibration approach, so that the calibration corrected coefficients can be applied at the various sites with different reflective properties (e.g., forests, snow, etc.) without any trouble.

5 CONCLUSION

The results presented in this study clearly demonstrate that the use of combined channels approach simultaneous over high cloud and over cloudless ocean is valid for calibration of AVHRR channels 1 and 2 on board NOAA-14. In comparison with single channel the accuracy of calibration can be improved greatly by use of the combined channels because the one of the channels can be used to correct the unknown aerosol effects. The agreement with certain error (<20%) between the satellite data corrected by our calibration corrected coefficients and the field measured data in desert area has been found even though there are some different properties between ground measurements and satellite data. The calibration corrected coefficients can be applied to the various targets with quite different reflective properties without any correction for nonlinearity of the sensors because both high and low radiative signal are used in the calibration method. The calibration approach is independent on the simultaneous ground or aircraft measurements in the same geometrical conditions as that for satellite observations. Therefore it is not only inexpensive in cost and easier in performance but also able to calibrate the historical satellite data with very high accuracy.

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NOAA-14 星载可见光和近红外遥感器的绝对定标

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摘　要　该文同时应用海洋和云层观测方法对 NOAA-14 AVHRR 的可见光和近红外遥感器进行绝对定标。定标结果显示了 AVHRR 通道 1 和 2 的遥感器已经受损，给出了这两个通道分别比发射前的定标系数退降 7% 和 11% 的结果。经定标系数修正的卫星资料与在中国沙漠地区实际测量的光谱反射率相比较，两者之差在测量误差范围之内。这种定标方法同时利用了很高和很低的反射率，推导的定标系数适用于具有不同反射率特性的地区。

关键词　卫星资料定量化，大气修正，辐射定标