Using MODIS to Track Calibration Stability of the AVHRR on NOAA 15-18

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ABSTRACT

The NOAA-KLM (15 to 18) AVHRR are current operational sensors with observations used for many remote sensing applications. This paper examines the on-orbit calibration consistency and stability of the NOAA-15 to 18 AVHRR using MODIS aboard the NASA EOS Terra and Aqua spacecraft as transfer radiometers. Coincident and co-located observations collected from the middle of 2002 to the beginning of 2006 at orbital crossovers between AVHRR and MODIS are used for trend analysis. Uncertainties in the AVHRR and MODIS comparison data sets due to mismatch in pixel footprint, band spectral differences and BRDF effects are discussed. Possible biases among these AVHRR sensors are determined for the visible channel at 0.6 µm, the near-IR channel at 0.8 µm and the two longwave infrared channels at 11.0 and 12.0 µm. Trending results show that there is an agreement of within 2% in reflectance for the AVHRR visible channels onboard NOAA-15 to 17, and the most recently launched NOAA-18 (2005). Large differences of up to 15% in trending comparison are found for the near-IR channel, illustrating problems for this channel due to a lack of on-board calibration capabilities for AVHRR. For the longwave infrared channels, NOAA-17 has the most stable performance. NOAA-16 to 18 AVHRR agree with within 0.30 K in scene temperature estimation, while NOAA-15 AVHRR is 0.4 to 0.6 K lower than the other AVHRR.

Keywords: AVHRR, sensor, calibration, comparison, MODIS

1. INTRODUCTION

The Advanced Very High Resolution Radiometers (AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA) KLM (15 to 18) satellites are current operational sensors. A series of 12 AVHRR onboard NOAA satellites has provided data for many remote sensing applications for over 20 years. These data sets become unique sources for studies of long-term changes in key geophysical parameters related to climatic and environmental issues[1-5]. In view of the importance of the data sets, calibration and validation of AVHRR sensors throughout their observational periods are critically important to ensure the data accuracy and consistency.

The NOAA series of satellites are placed in Sun synchronous orbits with a mean altitude of ~850 km. These orbits are either in descending node at 7:30 am (local time) or ascending node at 1:30 pm. The AVHRR uses a traditional Cassegrain telescope and has an instantaneous field of view of 1.3 milliradians, corresponding to a nominal spatial resolution of 1.1 km at nadir. The scan mirror rotates at six revolutions per second and Earth scene observations are collected for a scan angle range from -55.4^o to 55.4^o off of nadir. A total of 2048 pixels are obtained per channel every scan. The AVHRR of the KLM series have three reflected solar channels (1: 0.58-0.68 µm, 2: 0.73-1.00 µm, 3A: 1.58-1.64 µm) and three thermal channels (3B: 3.55-3.93 µm, 4: 10.3-11.3 µm, 5: 11.5-12.5 µm). The AVHRR on previous satellites did not have channel 3A. For the NOAA-KLM AVHRR, channels 3A and 3B can not operate simultaneously, so only five channels are available at any given time.

The calibration of the AVHRR reflected solar channels is based on vicarious approaches by collecting a time series of observations over radiometrically stable surface targets[6,7]. Observations over desert sites have been applied for

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calibration since NOAA-7 AVHRR. Potential use of other sites such as bright clouds and ice covered sheets are demonstrated[8,9]. The limitation of these approaches is that they require a certain period of time to accumulate enough data points to characterize any temporary and seasonal variations of the selected targets. Secondly, additional uncertainties may be introduced if any assumptions or models to describe the bi-directional reflectance distributions (BRDF) of the target surfaces are applied to calibration data sets. In addition, natural variations in target surface reflectances and atmospheric conditions also affect the calibration accuracy. One study indicates that different vicarious calibration results can differ relative to each other by as much as 10%[10]. For the AVHRR thermal channels, on the other hand, there are less concerns on calibration, since they are calibrated on a scan-by-scan basis using measurements from the on-board internal blackbody (BB) and the cold space.

The MODerate Resolution Imaging Spectroradiometer (MODIS) is a key instrument for the Earth Observing System (EOS) mission operated by the National Aeronautic and Space Administration (NASA), onboard the Terra (launched on 18, December 1999) and Aqua (launched on 4 May 2002) spacecraft[11,12]. MODIS is in a Sun-synchronous orbit and makes morning and afternoon observations over the entire Earth in less than two days via 36 spectral bands with a nadir resolution of 250 m (2 bands), 500 m (5 bands) and 1000 m (29 bands). MODIS observations provide the science community comprehensive data sets for the study of land, ocean and atmospheric processes[13,14].

MODIS has advanced onboard sensor calibration systems used for calibration of the reflective solar bands[15-17]. The MODIS instrument contains four onboard calibration components: a Solar Diffuser (SD) and a Solar Diffuser Stability Monitor (SDSM), the Spectroradiometric Calibration Assembly (SRCA), a Black Body (BB) and a Space View (SV) port. The calibration of the MODIS reflective solar bands depends on measurements made by the SD and SDSM and periodic lunar observations obtained from the SV port. Measurements from the SD and SDSM are used for absolute calibration, while lunar observations are used for relative calibration to track on-orbit changes. This is a significant improvement over many operational satellites such as AVHRR which rely on vicarious calibration due to the lack of onboard calibration capabilities in measuring the reflected solar irradiance from the visible to near-IR spectral range. Uncertainty analysis showed that MODIS has a combined calibration uncertainty of within 2% in reflectance at typical scenes for the reflective solar bands[18], compared to uncertainties of at least a few percent larger for AVHRR sensors without on-board calibration systems.

This study examines possible calibration stability and biases among the NOAA-KLM AVHRR using MODIS as a transfer radiometer. Observations from coincident orbital crossovers between AVHRR and MODIS are used to determine relative observational differences between AVHRR and MODIS[19-21]. This allows examining all AVHRR channels as they match spectrally with the corresponding MODIS bands. Results obtained in this study are useful to verify current existing biases among all AVHRR and demonstrate potential applications for validation and characterization of the calibration consistency of other sensors.

5. CONCLUSIONS

This study examines instrument stability and calibration consistency among the AVHRR onboard the NOAA-KLM series satellites (15 to 18) using Terra and Aqua MODIS as transfer radiometers. Coincident and co-located observations obtained from orbital crossovers are used. MODIS is used because its reflective solar bands are well calibrated on-orbit using the on-board calibrators of the SD and SDSM, while the AVHRR reflected solar channels are calibrated based on a vicarious calibration approach. This allows examining all AVHRR channels, since they match spectrally with MODIS bands.

This study discussed the impacts of the mismatch in pixel footprint and band spectral differences between AVHRR and MODIS and variations in surface and atmospheric combined BRDF due to the changes in sensor viewing angle in collected data sets on AVHRR comparison results. No corrections are applied for these differences since the comparisons made in this study are based on a long-term trend analysis in which their impacts are considered to be small.

Trending results from 2003 to 2006 show that the agreement of channel 1 among NOAA-15, 16, 17, and 18 AVHRR is within 2%. For channel 2, the vicariously calibrated NOAA-16 and 17 AVHRR still have large discrepancies in reflectances, while NOAA-15 gives significant lower reflectances than NOAA-16 and 17. Some of these discrepancies are significantly large (~ 15%) due to a lack of necessary adjustment of the calibration coefficients. These results illustrate problems any sensors can have if there is a lack of on-board calibration capabilities for the reflected solar channels. For channels 4 and 5, NOAA-17 AVHRR is the most stable channel, while NOAA-15 AVHRR gives the lowest temperature observations by about 0.4 to 0.6K. NOAA-16 to 18 agree with each other to within 0.3K in scene temperature estimations.