Inter-calibration and concatenation of climate quality infrared cloudy radiances from multiple instruments

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ABSTRACT

A change in climate is not likely captured from any single instrument, since no single instrument can span decades of time. Therefore, to detect signals of global climate change, observations from many instruments on different platforms have to be concatenated. This requires careful and detailed consideration of instrumental differences such as footprint size, diurnal cycle of observations, and relative biases in the spectral brightness temperatures. Furthermore, a common basic assumption is that the data quality is independent of the observed scene and therefore can be determined using clear scene data. However, as will be demonstrated, this is not necessarily a valid assumption as the globe is mostly cloudy. In this study we highlight challenges in inter-calibration and concatenation of infrared radiances from multiple instruments by focusing on the analysis of deep convective or anvil clouds. TRMM/VIRS is potentially useful instrument to make correction for observational differences in the local time and foot print sizes, and thus could be applied retroactively to vintage instruments such as AIRS, IASI, IRIS, AVHRR, and HIRS. As the first step, in this study, we investigate and discuss to what extent AIRS and VIRS agree in capturing deep cloudy radiances at the same local time. The analysis also includes comparisons with one year observations from CrIS. It was found that the instruments show calibration differences of about 1K under deep cloudy scenes that can vary as a function of land type and local time of observation. The sensitivity of footprint size, view angle, and spectral band-pass differences cannot fully explain the observed differences. The observed discrepancies can be considered as a measure of the magnitude of issues which will arise in the comparison of legacy data with current data.

Ketwords: Climate, cloudy radiance, AIRS, TRMM,VIRS, diurnal cycle, hyperspectral

1. INTRODUCTION

A change in climate is expected to be seen first in changes in extreme events. Deep Convective Clouds (DCC) are extreme events related to severe storms. In the infrared, DCC can be recognized as cloud tops colder than 210K. The analysis of trends in DCC from 10 years of AIRS data [1] shows that DCC cover about 0.5% of the tropical zone and the change in this fraction has been less than 0.02%/year. Much larger and anti-correlated changes are detected if tropical land and ocean are analyzed separately. These changes are correlated with ENSO, but, at least during the 10 years of AIRS data, suggest an underlying multi-decadal trend or oscillation. If this is the case, the data from infrared instruments in polar orbits since1970 could be useful to evaluate trends in DCC spanning four decades. The analysis of these data will encounter several difficulties: (1) there are issues of absolute radiometric calibrationaccuracy, (2) There are issues of normalizing the data to the same spectral passband and footprint size. A larger footprint is likely to identify fewer cold clouds, although the details depend strongly on the threshold relative to the temperature of the cloud tops surrounding the DCC, (3) The data taken from different orbits sample different parts of the diurnal cycle, (4) The DCC frequencies using data taken from different times in the ENSO cycle are likely to differ. The difference could be miss-interpreted as a climate trend. Here we address these issues with two instruments which are taking data at the same time: the Atmospheric Infrared Sounder [2], and the Visible Infrared Scanner (VIRS) [3,4]. VIRS is potentially useful instrument to make correction for observational differences in the local time and foot print sizes thus could be applied retroactively to vintage instruments such as IRIS, AVHRR, and HIRS.

2. DATA

Data from Two instruments were used in this study: VIRS and AIRS. The VIRS on the Tropical Rainfall Measurement Mission (TRMM) was launched in late 1997 into a 35 degree inclination orbit. The orbit was raised to its current 400 km altitude in August 2001. The VIRS is a 5 channel cross-track scanning radiometer operating at 0.63, 1.6, 3.75, 10.8, and 12.0 microns with 2.4 km diameter Field Of View (FOV) at nadir. The cross-track scan width is 833 km is +/-45 degree. In order to decrease the sensitivity to changes in the satellite zenith angle t we use data only to +/-30 degree (2/3 of the cross-track width), which creates data with 2.4/cos(15)=2.5 km F0V on average. During any year VIRS observes every location between 35N and 35S at every local time. The VIRS data were obtained from University of Utah TRMM database [5] in brightness temperature units. The absolute accuracy of the VIRS data, particularly at extremely low brightness temperatures is not known.

AIRS [2] was launch in 2002 in to a 1:30 PM ascending node polar orbit at 705 km altitude. AIRS scans cross-track +/-49 degrees. In order to match the VIRS data we use only data within +/-16.5 degree of nadir. The FOV is 1.1 degree, which corresponds to a 13.5 km FOV at nadir, the mean data thus correspond to 13.6 km FOV limit the scan. The AIRS observations were obtained from the AIRS Calibration Data Subset (ACDS) available from the NASN/GSFC DIS. The AIRS absolute calibration uncertainty is less than 0.2K at all scene temperatures.

3. METHOD AND RESULTS

In this study VIRS band 4 (10.8 micron) and AIRS data are compared with respect to frequency of DCCs identified by 210K threshold. The followings were considered for a thorough comparison:

3.1. Zonal distribution of samples

AIRS and IASI are in a polar orbit and the latitudes below 35 degrees are uniformly sampled during any 16 day orbit repeat cycle. However, the VIRS low inclination orbit creates a very non-uniform coverage of the latitudes. In order to create a sample uniformly distributed in latitude, the following procedure was used: (1) The number of the aggregated VIRS samples in each 5 degree wide latitude bins are counted, (2) the number of samples in the bin with minimum sample counts (i.e. the nearest bin to the equator) is determined as N, and (3) We then equalize the sample size at each 5 degree wide latitude (zonal) bins by randomly selecting N samples at higher latitudes. In average N was about 3500/day within 30 min of 1:30/13:30 local time.

3.2. Differences in spatial resolution

AIRS FOVs present a factor of $(13.5 /2.4)^2$=~32 larger area than VIRS in nadir. Therefore, about 32 VIRS points have to be aggregated before applying a threshold of 210K (to identify DCCs). The aggregation was performed by averaging radiances in 5 x 5 VIRS footprints, which were then converted to brightness temperatures. Figure 1 shows that the effect of FOV size on frequency of DCCs observed by VIRS for three cases: 4x4, 5x5 and 7x7. The DCC frequency is the count of aggregated footprints which are colder than 210K divided by the total number of aggregated footprints at a given local time, expressed as percent. At 1:30 AM, the AIRS night overpass time, the 4x4 frequency is ~0.7%, compared to ~0.67% for the 7x7. Similar small differences are seen at other times, except over land between 2pm to 8pm local time.

3.3. Differences in scan angles

The higher the local zenith angle, the more we look at the sides of convective towers. VIRS and AIRS fly in ~400km and ~705km altitudes. By considering the scan angle differences between VIRS and AIRS it was found that the middle 48 AIRS footprints approximately corresponds to the middle160 VIRS footprints. Therefore, the calculations of DCCs were conducted using corresponding footprints from the two sensors.

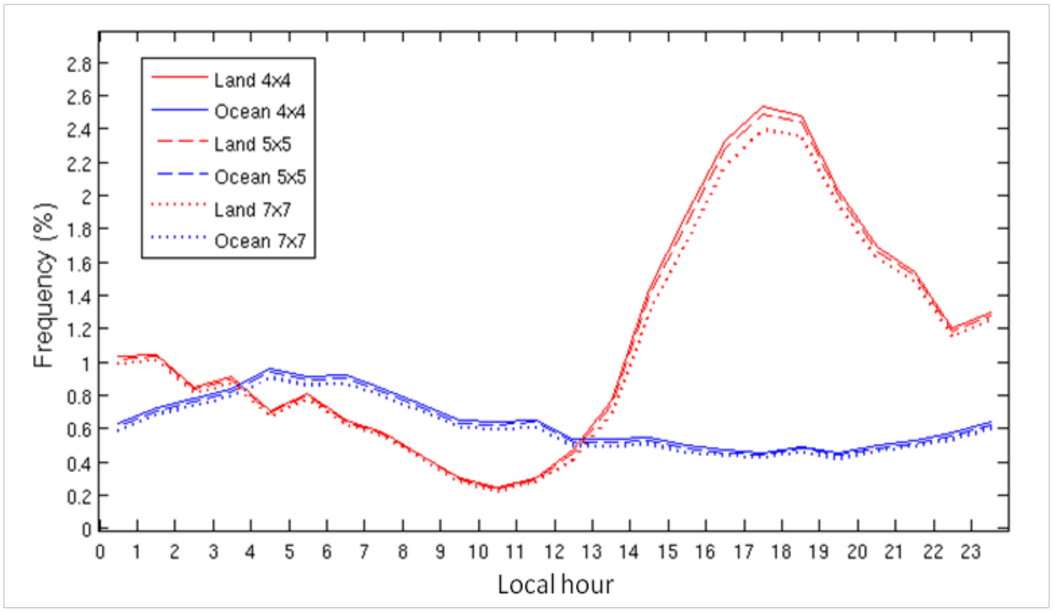

Figure 1. Sensitivity analysis of DCC frequencies with respect to FOV size calculated from 4x4, 5x5 and 7x7 VIRS FOVs.

3.4. Differences in spectral resolution

The VIRS Band#4 pass-band goes from 885 to 971 cm^{-1}, centered at 925 cm^{-1}. Figure 2 shows the brightness temperature spectrum of a typical DCC between 720 and 1000 cm^{-1}. The 1K warming between 790 and 980 cm^{-1} from 205.5K to 206.5K is a particle size related optical depth effect. The clouds tops are just above the tropopause, and the 790 cm^{-1} penetrates deeper into the cloud top than 980 cm^{-1}. Below 790 cm^{-1} we see CO$_2$ in emission, above 980 cm^{-1} we see Ozone in emission at the warmer lower stratospheric temperatures. Since the spectrum between 800 and 980 cm^{-1} is relatively featureless (ignoring noise spikes) the calculation of the VIRS equivalent brightness temperature is not sensitive to the details of the VIRS pass band using for integrating over the passband. We emulated the VIRS band#4 pass band by integrating each AIRS radiance spectrum over the VIRS pass-band, and converting the result to a brightness temperature spectrum. The difference between the emulated VIRS#4 and the AIRS brightness temperature at 900 cm^{-1} is less than 50mK. We conclude that the radiance conversion uncertainty is less than 0.1K. This is less than the AIRS absolute radiance uncertainty of 0.2K.

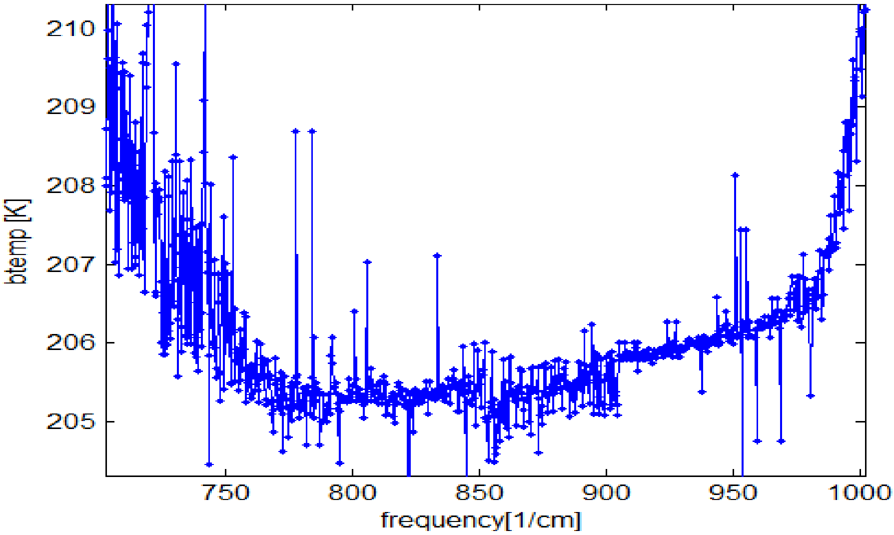

Figure 2. Typical DCC spectrum from AIRS 20030906 granule 176

3.5. Sensitivity of DCC's frequency to changes in brightness temperature

In analysis of DCC frequencies it is important to understand the sensitivity of DCCs to the accuracy of the absolute calibration. Outcome of such analysis is valuable to relate the discrepancies in the observed DCC frequencies to radiometric shifts between the two instruments as will be discussed later. The DCC sensitivities radiometric shift were analyzed using VIRS and 3 thresholds of 209K, 210K, and 211K, separately over land and ocean (Figure 3a). Figure 3b shows the sensitivity of DCC frequencies to radiometric shift of 1K calculated by dividing the DCC frequency differences at 211K and 210K by the DCC frequencies at 210K. The sensitivities vary for land and ocean and local time. The maximum sensitivity over land is around 10 a.m. while over ocean is around 1p.m. However, the sensitivities range between 8% to 14% for both land and ocean. We note that the diurnal cycle correction required to shift legacy data to current data is particularly large for land, and needs to be included in an overall uncertainty analysis.

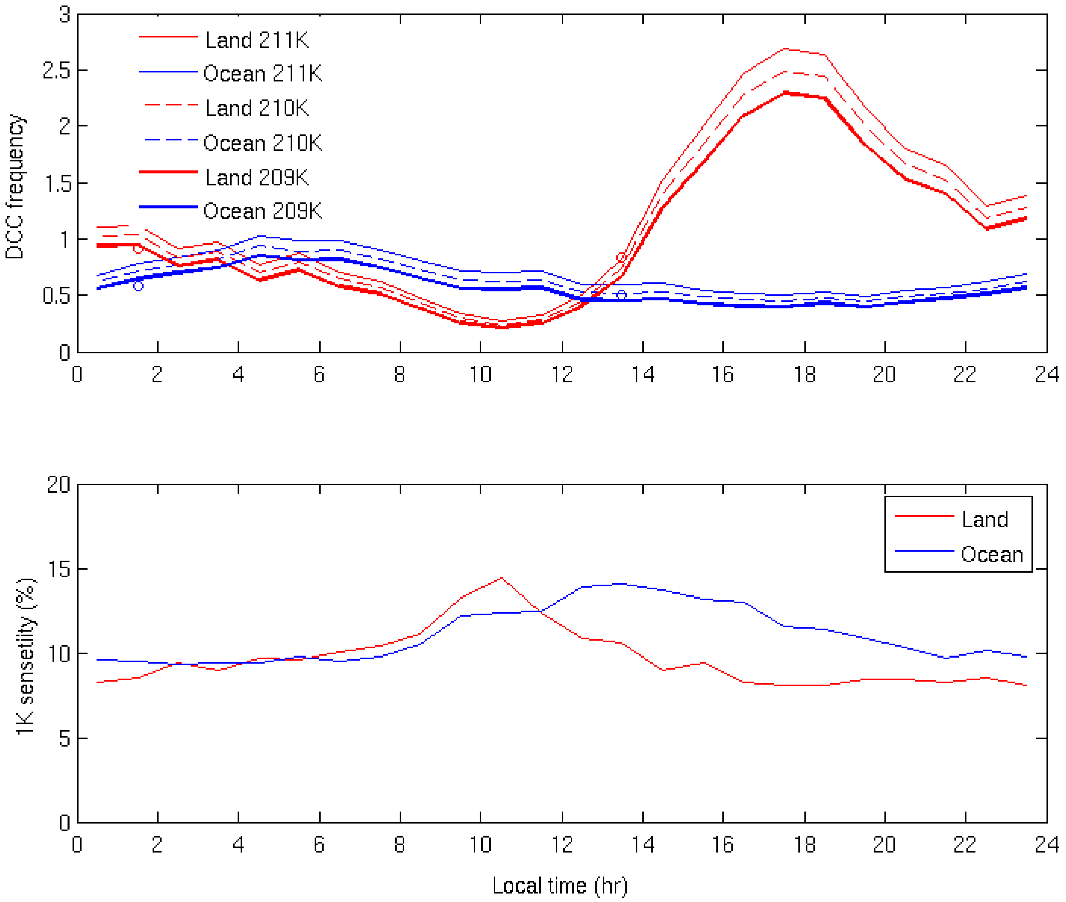

Figure 3. Sensitivity of DCC frequencies with respect to temperature threshold using 2011 VIRS radiances

4. DISCUSSION

In Figure 3a AIRS 210K DCC frequencies for land and oceans are also plotted for comparison. It is observed that there is more than1K (~10% frequency) difference between VIRS and AIRS DCC counts at ~1:30 over both land and ocean. However, the differences are less than 1K at 13:30. This is important in analysis of change in climate, especially the extremes. In the case of DCC, which are detected with a threshold, a shift from 210K to 211K results typically in a 10% increase in fraction of DCCs. A radiometric shift of 1K between two instruments separated by 40 year could therefore be miss-interpreted as a 10%/40=0.25%/yr trend. The comparison of DCC frequencies between AIRS and VIRS for 2006-2012 is shown in Tables 1 and 2 together with probable errors.

Table1. AIRS DCC frequencies

	2006		2007		2008		2009		2010		2011		2012	
AIRS	2006	PE	2007	PE	2008	PE	2009	PE	2010	PE	2011	PE	2012	PE
Day/ocean	0.50	0.01	0.49	0.01	0.48	0.01	0.49	0.01	0.47	0.01	0.46	0.01	0.50	0.01
Night/ocean	0.60	0.01	0.60	0.01	0.58	0.01	0.59	0.01	0.58	0.01	0.56	0.01	0.59	0.01
Day/land	0.82	0.02	0.78	0.02	0.88	0.02	0.91	0.03	0.89	0.03	0.87	0.02	0.80	0.02
Night/land	0.93	0.02	0.91	0.02	0.95	0.02	0.92	0.03	0.99	0.02	0.94	0.02	0.87	0.02

Table 2. VIRS DCC frequencies

	2006		2007		2008		2009		2010		2011		2012	
VIRS	2006	PE	2007	PE	2008	PE	2009	PE	2010	PE	2011	PE	2012	PE
Day/ocean	0.53	0.03	0.55	0.01	0.61	0.04	0.62	0.03	0.56	0.03	0.53	0.01	0.57	0.03
Night/ocean	0.69	0.03	0.84	0.04	0.70	0.03	0.70	0.03	0.71	0.06	0.76	0.01	0.81	0.04
Day/land	0.79	0.04	0.72	0.04	0.76	0.05	0.64	0.04	0.84	0.07	0.90	0.03	0.69	0.03
Night/land	0.85	0.07	1.03	0.06	0.81	0.06	1.17	0.11	1.01	0.07	1.26	0.11	1.14	0.12

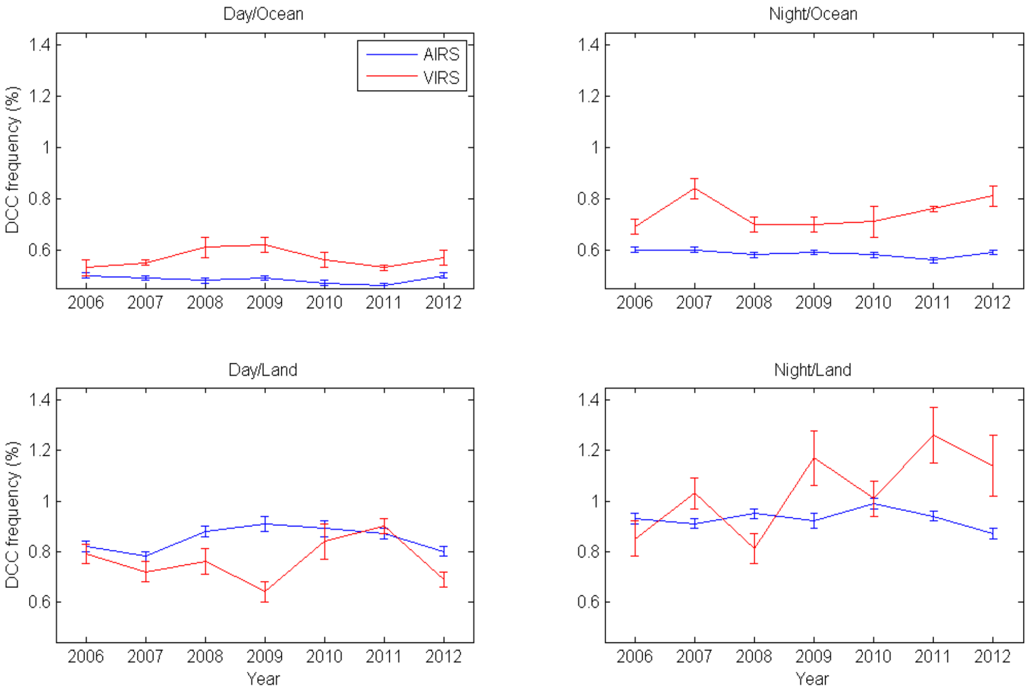

Figure 4 VIRS and AIRS DCC frequency plots between 2006-2012.

Figure 4 shows the data from Tables 1 and 2. While the AIRS data show almost no change, the VIRS data show a bias which is day/night land/ocean dependent, typically of the order of 10%. A simple calibration offset would cause a bias consistently in the same direction, but this is not the case for VIRS and AIRS studies here

5. SUMMARY

The analysis of data for cold extremes taken with two different instruments at different times has to be corrected for absolute radiometric calibration errors, the data have to be normalizing to the same spectral passband and footprint size and the data have to be corrected for local time differences. Our comparison of AIRS and VIRS data refer to the same time period and the same local time, but difference of about 10% in the frequency of DCC is observed. They are much larger than estimated uncertainties in the footprint size or spectra pass band correction. At this point the reason for the differences is unknown, but they are data interpretation artifacts. If the AIRS and VIRS data were taken to be representative of two instruments in orbit separated by a decade, the observed differences would be miss-interpreted as a climate trend.

5. ACKNOWLEDGMENTS

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