Sea Surface Temperature Measurements with the Atmospheric Infrared Sounder (AIRS) and Aerosol [1].

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Summary

Atmospheric Infrared Sounder (AIRS) measurements of the sea surface temperature at 2616cm-1 show an unexpected global cold bias compared to the Global Real Time SST. This cold bias is globally distributed in large scale regional patterns which are stable on the time scale of several months. The satellite zenith angle (sza) independent component of this bias is strongly temperature dependent above 300K. It is most likely related to a larger than expected gradient between the bulk and the skin temperature, due to not understood regional seasonal weather pattern. The sza dependent component of about 0.4K is most likely due to some form of aerosol which is not included in the radiative transfer. AIRS was launched 4 May 2002 on the EOS Aqua into polar orbit.

Introduction

The Atmospheric Infrared Sounder (AIRS) (Aumann et al. 2003) covers the 650cm-1 to 2650cm-1 region of the spectrum with spectral resolution $\Delta\nu/\nu$=1200. AIRS was launched on the EOS Aqua into a polar orbit on 4 May 2002. After on-orbit calibration the routine global data gathering mode started August 31, 2002. The AIRS calibrated radiances (Level 1b data) have been distributed to NMC since October 2002, and have been made available through the GSFC/DAAC since July 2003.

One of the first results of the analysis of sea surface temperature measurements under cloud-free night conditions using the 2616cm-1 super clear window channel (Aumann and Pagano, 2002), was the discovery of larger than expected cold bias relative to the NCEP Real Time Global Sea Surface Temperature (RTG.SST) (Thiebaux et al. 2002). . Since the RTG.SST measures the day/night average bulk temperature, while the AIRS data measure the skin at night, a cold bias of 0.3K was expected. The observed bias is about 0.4K colder. Further analysis showed a strong dependence of the cold bias on the satellite zenith angle (sza) (Aumann et al. 2003). This suggested that at least part of the observed cold bias was due to an atmospheric layer, possibly thin cirrus and/or marine aerosol. In the following is paper we analyze the correlation between the surface temperature and the cold bias.

Approach

We define the bias as d2616=sst2616-rtg.sst, where sst2616 is based on the brightness temperature measured at 2616cm-1, corrected for water vapor and emissivity (Aumann et. al 2004). The correction is based on first principles, using the January 2003 version of

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the radiative transfer developed for AIRS by Strow et al. (2002, 2003) and the Masuda (1986) emissivity model. For the analysis of d2616 as function of RTG.SST we use all clear night ocean footprints collected between 2002.12 and 2003.02 within +/-50 degree latitude. The statistics of d2616 are: 836267 points, median=-0.64K , stdev= 0.44K and 98% of the data are contained in the range of -2.0 to +0.5K. A global image of this data set is shown in Figure 1. There are large areas where d2616 is close to the expected value (green) and there are large areas where d2616 is as cold as -2K, particularly off the East coast of Australia.

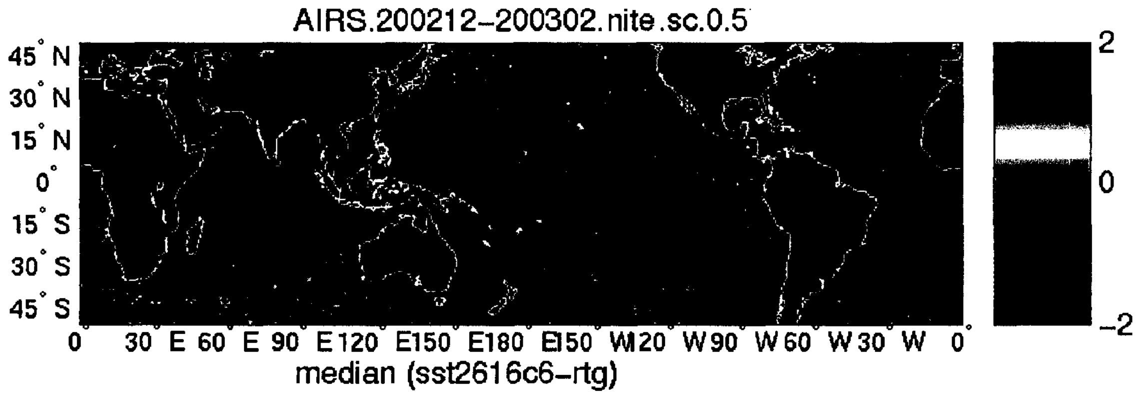

Figure 1. Image of d2616=median(sst2616-rtg.sst) using one degree lon/lat bins

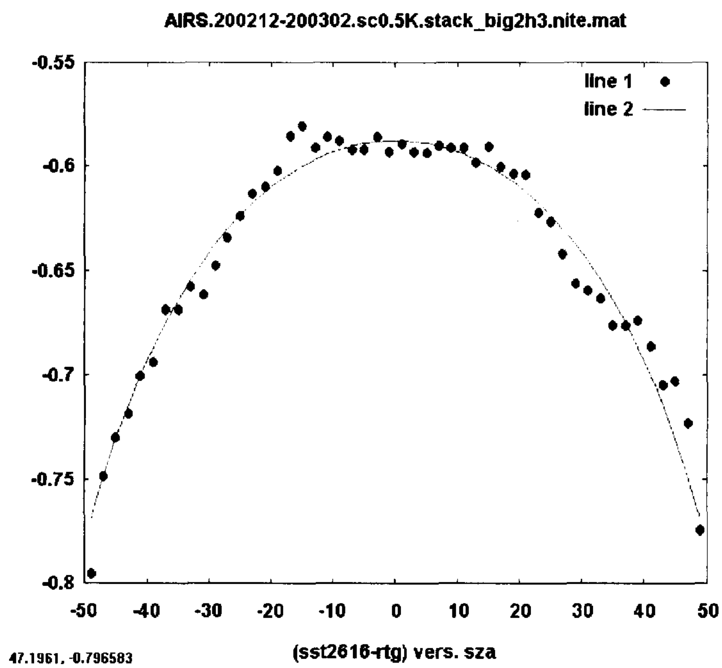

Figure 2. d2616 as function of sza with a+b/cos(sza) superimposed.

The dependence of d2616 can be expressed as d2616=a+b/cos(sza), where a=-0.242, b=-0.346. This is illustrated in Figure 2. on the right. The constant term is consistent with the expected 0.3K cold bias. The coefficient of the 1/cos(sza) term has the appearance of an atmospheric absorbing layer, which is not included in the AIRS radiative transfer calculations, which causes 0.346K of additional absorption at nadir.

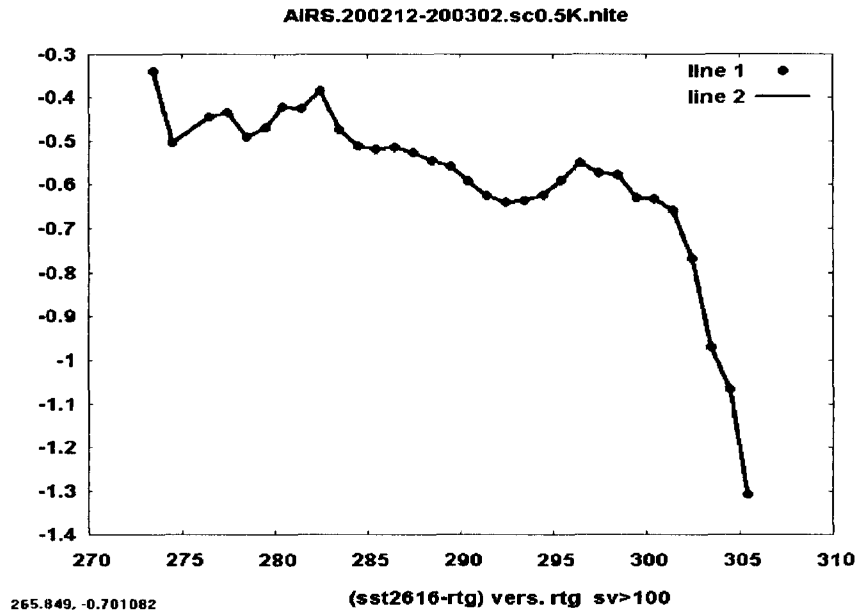

Figure 3. d2616 as function of rtg.sst

Figure 3. shows a surprisingly strong correlation between d2616 and the rtg.sst. Between 270K and 300K bulk temperature d2616 decreases from -0.4K to -0.6K, then drops steeply to -1.3K as the temperature increases to 305K. In order to investigate potentially surface temperature correlations we divided the data into a "hot" group at sst larger than 302K and "cold" group with sst colder than 290K. The two groups roughly represent the coldest and the hottest 10% of the data. For the "hot" group we find d2616=-0.83K stdev=0.45K with 112366 points, while for the cold group we have s2616=-0.51K stdev=-0.35K with 60438 points. The "hot" group has 0.3K more cold bias. In order to test the origin of this cold bias we look at the sza dependence for the three groups. Figure 4. shows the sza dependence of d2616 for the warm group (o) and the cold group (x). The formal fit of d2616=a+b/cos(sza) gives

"hot" group	a=-0.520K	b=-0.270K
all data	a=-0.242K	b=-0.346K
"cold" group	a=-0.120K	b=-0.347K

From this we see that the effect due to the absorbing layer is only weakly temperature dependent, but the constant term increases steadily from -0.12K to -0.52K as the surface temperature increase from cool to very warm.

An additional clue for this difference comes from the plot of d2616 as function of the spatial coherence parameter cloud2616, shown in Figure 5. The spatial coherence parameter is the difference between the maximum and the minimum brightness temperature in the 3x3 footprint pattern centered on the footprint being evaluated for cloud contamination (Aumann et al. 2004). Under perfect ocean conditions the surface temperature would be uniform within the 3x3 footprint pattern, which covers 45 km in the case of AIRS. If sc>0.5K, the degree of non-homogeneity suggests potential contamination due to clouds, and the footprint is rejected.

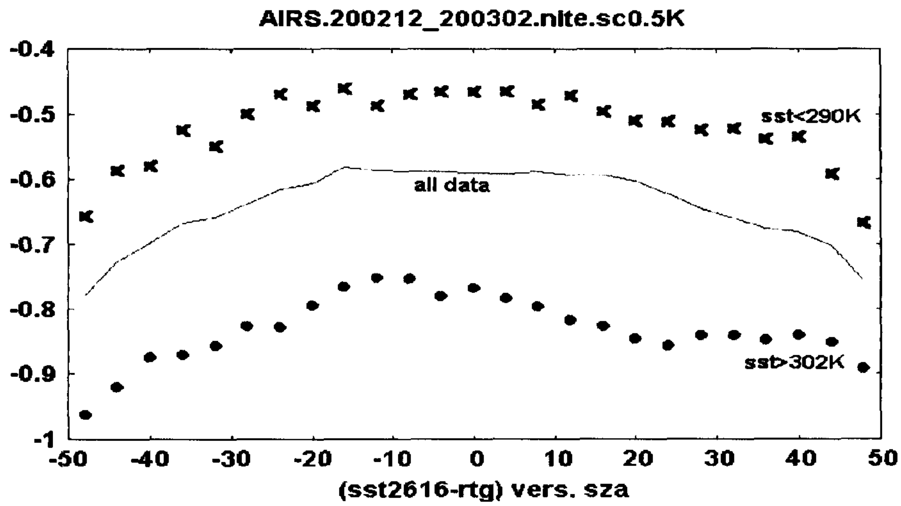

Figure 4. sza dependence of d2616 for the warm group (o) and the cold group (x).

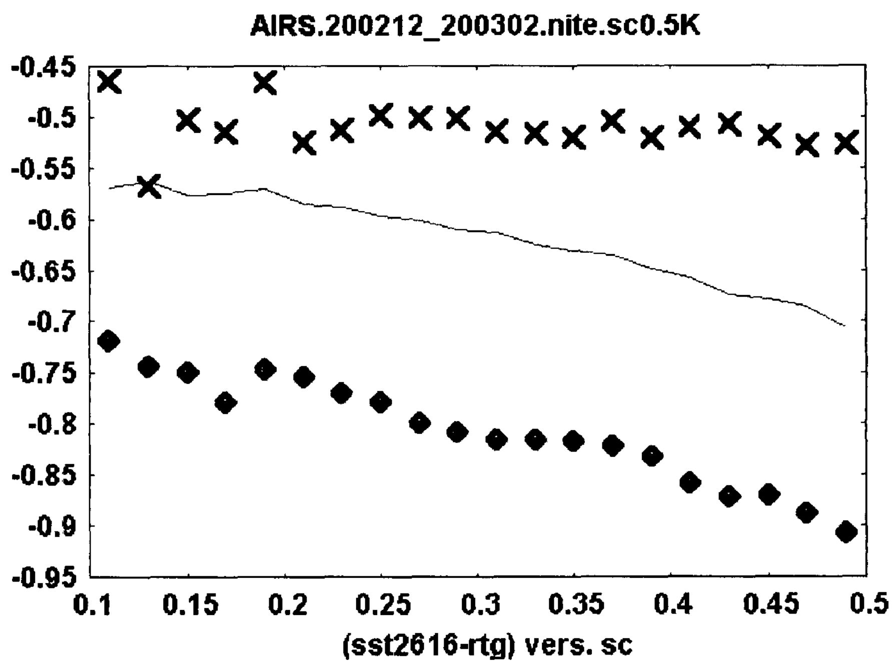

Figure 5. d2616 as function of the spatial coherence parameter sc for the footprints with sst>302K (o), all data (solid line) and sst<290K (x) .

For the sst<290K group the bias is -0.5K, essentially independent of sc. For the sst>302K group the bias is -0.7K as sc approaches zero, increasing to 0.9K at sc=0.5K, the "clear" cutoff. The 0.2K difference between the two cases is due to scene inhomogeneity related to the surface.

The unique property of the unexpected absorbing layer is its unusual spatial homogeneity, which suggests marine aerosol or optically thin cirrus.

Discussion

We discuss the potential causes of the unexpected cold bias between sst2616 and the rtg.sst in terms of the sza independent and dependent terms.

a) The sza independent term:

This term could be due to calibration error, incorrect surface emissivity correction in sst2616, a systematic bias in the rtg.sst, or unusual conditions which would make the skin - bulk gradient considerably larger than expected. The large scale correlated patterns of cold bias shown in Figure 1. for 3 months of data rule out calibration error, emissivity correction error and a systematic bias in the rtg.sst. The dependence of the constant term on the rtg.sst indicates that it is related to the surface. This suggests a much larger than expected gradient between the skin and bulk at sst warmer than 300K as the most likely explanation. The persistence of the effect on a months time scale with large regional patters suggest a correlation with regional seasonal weather effects.

b) The sza dependent term.

The sza dependent term of about 0.4K could be is due to a scan angle calibration issue, inadequate transmission correction or an absorbing atmospheric layer, cirrus or some form of aerosol.

1. Calibration: The highly spatially correlated patterns of unusually large cold bias indicate that this is not a calibration issue, since the image in Figure 1. is based on data collected at all scan angle. A scan angle dependent calibration error would globally average, rather than produce spatially coherent patterns.

2. Transmission correction: The absorbing layer could simply be due to an inadequate atmospheric transmission correction. Figure 6. shows the atmospheric transmission correction (Tsurf-bt2616) as function of the water burden predictor (bt2616-bt2607) for two radiative transfer models: The official AIRS model from Strow et al. (2003) (S2003) and a model proposed by Tobin and Clough (2003) (TC2003). For the global median value of (bt2616-bt2607) of 2.5K the TC transmission correction 0.18K, while the S correction 0.22K. For the "cold" group with sst<290K median(bt2616-2607)=1.2K, the atmospheric transmission correction is about the same, 0.1K in either case. For the "hot" group at sst>302K, (bt2616-bt2607)=4.4K, corresponding to a TC correction of 0.27K, while the S2003 correction is 0.42K, a difference of 0.15K. The difference of 0.04K in the global bias between S2003 and TC2003 is small compared to the 0.4K unexpected bias. However, the temperature dependent difference between S2003 and

TC2003 under extreme temperature and humidity conditions, typical of the very humid and hot ITCZ, would increase the magnitude of the absorbing layer using the TC2003 model to about 0.5K under ITCZ conditions.

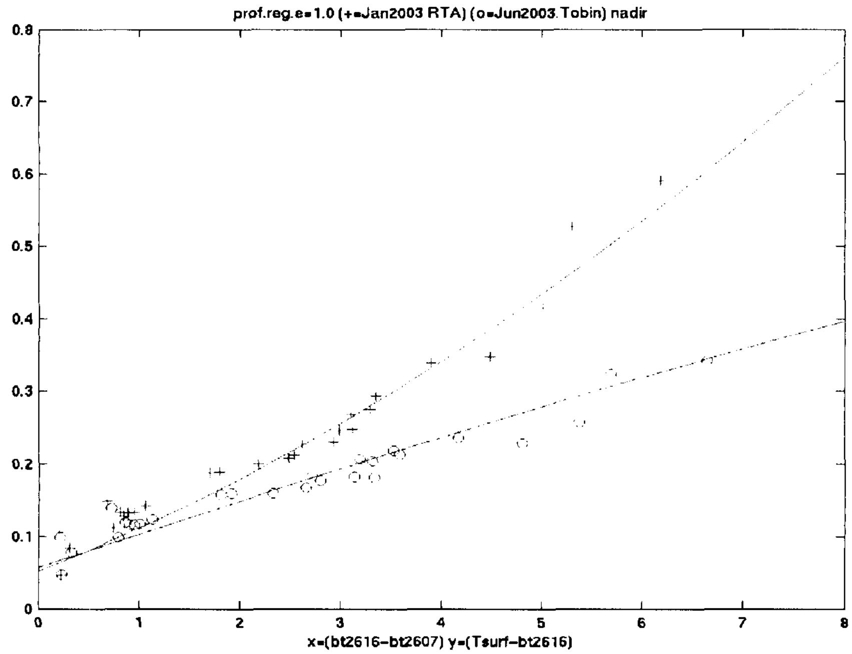

Figure 6. The atmospheric transmission correction (Tsurf-bt2616) as function of the total water predictor (bt2616-bt2607) for the Strow et al (2003) (o) and the Tobin/Clough (2003) (+) radiative transfer calculation for 28 temperature and moisture profiles representative of the global oceans. For 1% of the three month data set the depth of the weak waterline at 2607cm-1 exceeds 6.6K.

3. Cirrus clouds in the clear footprints:

The contamination of "clear" footprints by thin cirrus would produce a sza effect. The AIRS high spectral resolution provides excellent cirrus detection capability. The characteristic signature of cirrus is a slope in the 900 cm-1 region (Eldering et al. 2003 cirrus paper). We use the slope between the micro window channels at 900cm-1 and 790 cm-1 for cirrus detection. We define

cirrus=(bt790-bt900).observed - (bt790-bt900).predicted,

where bt900 and bt790 are the brightness temperatures in the 900cm-1 and 790 cm-1 micro window channels, and the prediction is based on the depth of a weak water line, (bt2616-bt2607). The typical magnitude of the cirrus signal in these "clear" data is 0.87, with 98% of the data between zero and 2K. An optical depth at 900cm-1 of one percent corresponds to cirrus signature (slope) between 900cm-1 and 790cm-1 of about one degree Kelvin.Figure 6. shows d2616 for all data (solid line), sst<290K (x) and sst>302K (o). It can be seen that correlation between detectable of cirrus in the "clear" AIRS footprints and d2616 is very weak. Less than 0.05K of unexplained bias in d2616 can be attributed to thin cirrus. This leaves some form of marine aerosol as currently the only reasonable explanation for the sza dependent unexpected absorption at 2616cm-1.

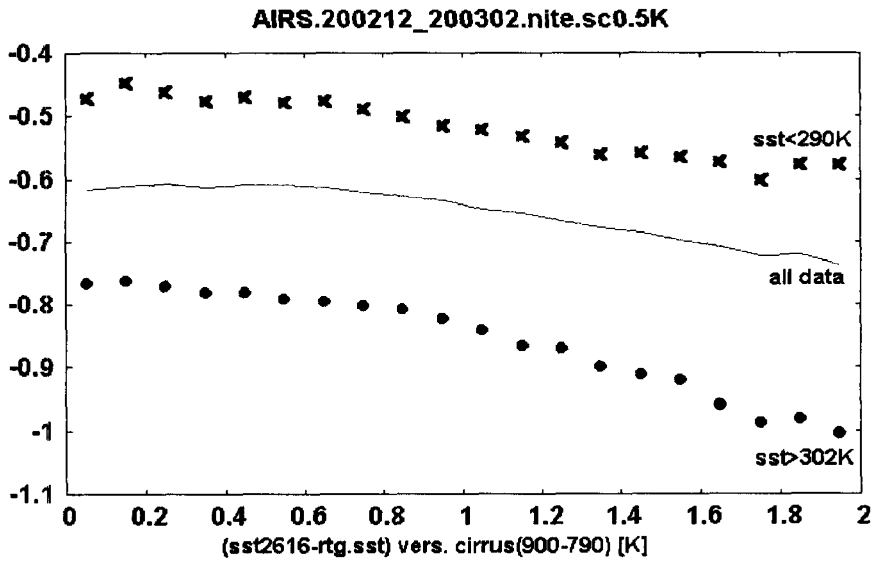

Figure 7. d2616 as function of cirrus.

The high spectral resolution of AIRS provides for a large number of micro windows between 2650 cm-1 and 713 cm-1. The slope of the emissivity or transmission terms as function of frequency should allow identification of particle size distribution.

Conclusions

The comparison of AIRS measurements of the sea surface temperature at 2616cm-1 compared to the Global Real Time SST product from NCEP show a sza independent and a sza dependent cold bias. This bias is globally distributed in large scale correlated patterns which are stable on the time scale of several months. The sza independent component is strongly temperature dependent above 300K. It is most likely related to a larger than expected gradient between the bulk and the skin temperature, due to a not understood regional seasonal weather pattern. The sza dependent component of about 0.4K is most likely due to some form of marine aerosol. The large number of micro-windows in the atmosphere made possible by high spectral resolution of AIRS should allow future refinements in the characterization of this absorbing layer in the atmosphere.

Acknowledgements

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