Response to Referee

We would like to thank Dr. Robert Iacovazzi, Jr. for his valuable comments to improve this paper. The following is a list of our responses to comments.

Editorial Comments

Q1) Use of the "~" symbol is typically associated with an approximate value of a measurement, not to represent a range of values. Please use a hyphen (-) or the word "to" in order to express a range. For example, "I run from 4-6 miles a day," or "I run from four to six miles a day."

A1) The text has been revised, as pointed out by Referee (AMTD; Page 7432 Line 10, Page 7433 Line 11, Page 7434 Line 22, and etc).

Q2) Page 7435 Line 15 - "-10C to -50C". Do you mean +50C here?

A2) Yes, +50C is correct. We revised it in the text (AMTD; Page 7435 Line 15).

Technical Comments

Q1) Page 7432 - The uncertainties related to the analysis shown in Tables 1 and 2 in many cases eclipse the significance of the results. This needs to be stated very clearly, even in the abstract.

A1) As pointed out by Referee, the text has been revised for uncertainties by showing confidence intervals in the trend values of the abstract, and by compensating a sentence in Table 2 and the conclusion, respectively (AMTD; Page 7432 Lines 10-11, Page 7441 Lines 1&4, Page 7448 Lines 4-5, and etc).

Q2) Page 7432 - The conclusion is that the difference between MODIS and AIRS/AMSU SST products lies mainly due to snow/ice emissivity. Don't both algorithms attempt to account for emissivity issues? The study clearly shows the effect happens over sea ice regions, as opposed to land ice regions. Why would this be so, if the microwave emissivity is effected by ice, regardless if it is over land or ocean?

A2) While AIRS/AMSU SST algorithm attempts to account for sea ice/snow emissivity, because of AMSU microwave (MW) window channels 1-3 and 15, MODIS one does not (Brown and Minnett, 1999). It is difficult to screen out sea-ice (e.g., seasonally varying broken sea-ice) at a given grid in the oceanic water background from MODIS channels. Details are provided below:

As shown in Table A1 next, infrared (IR) channels are not useful for the snow/ice detection in the oceanic water background, because IR emissivity (ε) values on snow/ice (ε=0.93-0.99) are not much different from those for water (ε=~0.98). On the other hand, AMSU MW channels can be suitable for the snow/ice detection over the ocean, because microwave (MW) emissivities (0.8-0.9) for snow/ice considerably differ from MW emissivites (0.5-0.7) for water. MODIS IR algorithms have been utilized to derive bulk-SST over the unscreened broken sea ice areas rather than surface skin temperature, due to the above IR optical characteristics. Thus, MODIS bulk SST is higher by ~0.5 K over the ice-free ocean of 50 N-50 S than AIRS/AMSU surface skin temperature, and much higher by 5.5 K over the polar sea-ice regions.

The snow/ice detection from AMSU microwave channels is more effective over ocean than over land, because the MW ε difference (Δε=~0.25) between snow/ice and water is significantly greater than the difference (Δε=~0.1) between snow/ice and land (Table A1). This issue has been discussed by Yoo et al. (2003) in their study on the Microwave Sounding Unit (MSU) data (see Figs. 2 and 3 in Yoo et al. (2003)). Additionally, as indicated in our paper (AMTD; Page 7436, Lines 23&24), the number of observations is relatively small over sea-ice regions possibility due to cloud clearing process, and the sampling problem may have caused the biased results.

Table A1. Infrared (IR) and microwave (MW) emissivity values on three types of surfaces. IR values are available in previous studies (Konda et al., 1994; Wang et al., 2005), and MW values (Hewison and English, 1999; Yan et al., 2008).

	Infrared	Microwave
Land	0.8-0.97	0.9-1.0
Snow/ice	0.93-0.99	0.8-0.9
Water	0.98	0.5-0.7

Q3) Page 7434 Section 2 - It is good that instrument specifications - swath width, orbit LECT, channels, etc. - have been added to the text for the reader. On the other hand, I don't think references to documents containing these instrument specifications are necessary. I would get rid of those references.
A3) Four references (Olsen, 2007, Wan, 2009, Susskind et al., 2003, Chahine et al., 2001) have been removed in the text, as suggested by Referee (AMTD; Page 7434 Paragraph 2).

Q4) Page 7434 Line 24 - AIRS/AMSU have measurements in radiance. What is the difference between AIRS/AMSU radiance measurements and cloud-cleared radiance?
A4) AIRS/AMSU radiance measurements are the combination of (a) upwelling radiance from surface and atmosphere below the clouds and (b) radiance from clouds. The former (a) has been derived by applying cloud clearing process (Susskind et al., 2003), and called cloud-cleared radiance. The AIRS/AMSU suite is used to derive cloud-cleared radiance in up to 90% cloud cover (Susskind et al., 2006, 2011). Please see AMTD (Page 7434 Lines 24-25).

Q5) Page 7433 Line 14 and Page 7439 Line 27 - You bring up the fact that MODIS SST and AIRS/AMSU SST are actually not measuring the same parameter. The MODIS product measures bulk temperature, and AIRS/AMSU measures skin temperature. Could this account

for large temperature differences in the Arctic Ocean during sea ice conditions? Please provide and explanation to your answer.
A5) Yes, this could. As indicated by Yuan (2009), very few in situ measurements of the surface skin temperature are made on a regular basis, so the MODIS/Aqua SST data have been calibrated primarily by the bulk SST of in situ and ship-board measurements (Smith et al., 1996; Barton, 2011). Thus the MODIS SST can be regarded as the best representation of the bulk SST. Probably, there may not have been much calibration for the sea-ice condition in the Arctic and the Antarctic (Kilpatrick et al., 2004). Also, the surface emissivity that keeps changing depending on the surface condition (ice, partly ice, sea water) may be another reason bringing more errors.

MODIS SST as a 'bulk SST' is any temperature within the water column (1 cm-1 m) beneath the $SST_{subskin}$ at ~1mm (Donlon et al., 2002). AIRS/AMSU SST as a 'surface skin temperature' is a temperature measured by a radiometer at depth within a thin layer (~0.5 mm) at the water side of the air-sea interface, where the heat transfer and exchange between air and sea dominate. Under the ice-free oceanic condition of 50 N-50 S, the temperature difference between the two instruments is within ±0.5°C (Fig. 1c). However, in the Arctic ocean where surface air temperature over the sea ice is substantially below zero, AIRS/AMSU SST (i.e., surface skin temperature) is significantly low (-10°C - -20°C). On the other hand, since ice is a good insulator, MODIS bulk SST below ice is generally higher than ~-2°C.

Q6) Does the AIRS/AMSU SST product have a sea ice flag?
A6) It has the flag in the Level 2 (L2) data in terms of sea ice, snow, land, water, ocean, and coastline. However, the corresponding flags are not provided in the Level 3 (L3) data.

Q7) Page 7437 Line 6 - The phrase "are not shown." Do you mean "do not exist?"
A7) Yes, we do not think that MODIS data less than 271 K exist over the global ocean.

Q8) Page 7838-7840 Section 4 - It seems like there are many differences between the L3 data sets (cloud-cleared IR MODIS versus partially cloudy AIRS/AMSU, time of-day, etc.) that can add substantial variability. Are the authors aware of any SST or LST studies that compare MODIS SST or LST with those of AIRS/AMSU for exactly the same scenes, scan angles, time-of-day, etc.? This may shed more light on the actual biases between the data sets. If there are studies, I recommend to incorporate references to them into this paper.
A8) Tobin et al. (2006) reported the mean difference in Level 1b brightness temperatures of IR window channels between the MODIS and AIRS over the globe was within 0.1 K, based on two days of observations. For the comparison, they reduced the AIRS high spectral resolution and reduce MODIS high spatial resolution. Schreier et al. (2010) compared brightness temperature over the globe between MODIS and AIRS using spectrally and spatially collocated radiances on a day (AMTD; Page 7433 Lines 21-25). However, the above

previous studies did not focus on the detail comparison over the seasonally varying sea ice regions.

Q9) Section 4- Many effects are mentioned that cause discrepancy in the analysis. Are there other issues - e.g., instrument view angle differences, broken versus solid ice? I would recommend adding comments regarding these effects as well if they are relevant.
A9) Yes, there are. MW emissivity values on sea ice can depend on the following factors: snow/ice types, composition, edge, age, thickness, surface characteristics, incidence angle, frequency, polarization, ocean currents, weather, and etc (e.g., Weeks, 1981; Kidder and Vonder Harr, 1995; Isaacs et al., 1989; Grenfell, 1992). We added a sentence to the text for the issues (AMTD; Page 7439 Lines 12-16).

Q10) Page 7442 Conclusion - What is the next step? Would you give any advice to algorithm developers or climatologists? I would recommend to add this to the conclusions.
A10) Since AMSU channels 4 and 5 have been degraded (Fetzer and Manning, 2012), another microwave instrument (e.g., Advanced Technology Microwave Sounder; ATMS) are required for the sea-ice detection from AIRS.

Algorithm developers need to analyze the systematic difference in the two instrument temperature between ocean and land over 50 N-50 S, and furthermore the large discrepancies over the sea-ice regions between AIRS/AMSU surface skin temperature and MODIS bulk SST. It will be very useful, if the algorithm developers for the two instruments provide their users with both skin SST and bulk SST. Over the sea-ice regions, however, the attempt may still be possible for the AIRS/AMSU algorithm, but it would be more challenging for the MODIS algorithm, considering its current difficulty in detecting sea ice. Climatologists have to carefully use the surface skin temperature data from the two instruments, based on good understanding about the difference between the two datasets (AMTD; Page 7442 Lines 3-15).

Reference

Barton, I. J.: Improving satellite-derived sea surface temperature accuracies using water vapor profile data, J. Atmos. Ocean. Tech., 28, 85-93, doi:10.1175/2010jtecha1502.1, 2011.

Brown, O. B., and Minnett, P. J.: MODIS infrared sea surface temperature algorithm, Algorithm Theoretical Basis Document (ATBD) Version 2.0, available at: http://modis.gsfc.nasa.gov/data/atbd/ocean_atbd.html, 1999.

Donlon, C. J., Minnett, P. J., Gentemann, C., Nightingale, T. J., Barton, I. J., Ward, B., and Murray, M. J.: Toward improved validation of satellite sea surface skin temperature measurements for climate research, J. Clim., 15, 353-369, 2002.

Fetzer, E. J., and Manning, E.: Failure of AMSU-A channel 4 and degradation of AMSU-A channel 5 NeDT affecting AIRS retrieval performance, available at: http://disc.sci.gsfc.nasa.gov/AIRS/documentation/AMSU-A_NeDT_Update_2012-06-28.pdf, 2012.

Grenfell, T. C.: Surface-based passive microwave studies of multiyear sea ice, J. Geophys. Res., 97, 3485-3501, 1992.

Hewison, T. J., and English S. J.: Airborne retrievals of snow and ice surface emissivity at millimeter wavelengths, IEEE T. Geosci. Remote, 37, 1871-1879.

Isaacs, R. G., Jin, Y.-Q., Worsham, R. D., Deblonde, G., and Falcone, V. J. Jr.: The RADTRAN microwave surface emission models, IEEE T. Geosci. Remote, 27, 433-440, 1989.

Kidder, S. Q. and Voner Harr, T. H.: Satellite Meterology: An Introduction, Academic Press, 1995.

Kilpatrick, K., Kearns, E., Evans, B., and Minnet, P.: SST from MODIS AQUA and TERRA, MODIS Science Team Meeting, available at: http://modis.gsfc.nasa.gov/sci_team/meetings/200407/ocean.php, 2004.

Konda, M., Imasato, N., Nishi, K., and Toda, K.: Measurement of the sea surface emissivity, J. Oceanogr., 50, 17-30, 1994.

Schreier, M. M., Kahn, B. H., Eldering, A., Elliott, D. A., Fishbein, E., Irion, F. W., and Pagano, T. S.: Radiance comparisons of MODIS and AIRS using spatial response information, J. Atmos. Ocean. Technol., 27, 1331-1342, doi:10.1175/2010jtecha1424.1, 2010.

Smith, T. M., Reynolds, R. W., Livezey, R. E., and Stokes, D. C.: Reconstruction of historical sea surface temperatures using empirical orthogonal functions, J. Clim., 9, 1403–1420, 1996.

Susskind, J., Barnet, C. D., and Blaisdell, J. M.: Retrieval of atmospheric and surface parameters from AIRS/AMSU/HSB data in the presence of clouds, IEEE T. Geosci. Remote, 41, 390-409, doi:10.1109/Tgrs.2002.808236, 2003.

Susskind, J., Barnet, C., Blaisdell, J., Iredell, L., Keita, F., Kouvaris, L., Molnar, G., and Chahine, M.: Accuracy of geophysical parameters derived from Atmospheric Infrared Sounder/Advanced Microwave Sounding Unit as a function of fractional cloud cover, J. Geophys. Res., 111, D09S17, doi:10.1029/2005JD006272, 2006.

Susskind, J., Blaisdell, J. M., Iredell, L., and Keita, F.: Improved temperature sounding and quality control methodology using AIRS/AMSU data: The AIRS science team version 5 retrieval algorithm, IEEE T. Geosci. Remote, 49, 883-907, doi:10.1109/Tgrs.2010.20705 08, 2011.

Tobin, D. C., Revercomb, H. E., Moeller, C. C., and Pagano, T. S.: Use of atmospheric infrared sounder high-spectral resolution spectra to assess the calibration of MODerate resolution Imaging Spectroradiometer on EOS Aqua, J. Geophys. Res., 111, D09S05, doi: 10.1029/2005JD006095, 2006.

Wang, K., Wan, Z., Wang, P., Sparrow, M., Liu, J., Zhou, X., and Haginoya, S.: Estimation of surface long wave radiation and broadband emissivity using Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature/emissivity products, J. Geophys. Res., 110, D11109, doi:10.1029/2004JD005566, 2005.

Weeks, W. F.: The potential remote sensing, Oceanus, 24, 39-48, 1981.

Yan, B., Weng, F., and Meng, H.: Retrieval of snow surface microwave emissivity from the advanced microwave sounding unit, J. Geophys. Res., 113, D19206, doi:10.1029/ 2007JD009559, 2008.

Yoo, J.-M., Prabhakara, C., and Iacovazzi, R. Jr.: Surface emissivity and hydrometeors derived from microwave satellite observations and model reanalyses, J. Meteor. Soc. Japan, 81, 1087-1109, 2003.

Yuan, D.: Science focus: Sea surface temperature measurements of the MODIS and AIRS instruments onboard of Aqua satellite, available at http://disc.sci.gsfc.nasa.gov/ oceans/additional/science-focus/modis/MODIS_and_AIRS_SST_comp.shtml, 2009.