Operational Generation of the HIRS Outgoing Longwave Radiation Climate Data Record (Hai-Tien Lee, Arnold Gruber, and Joonsuk Lee) (NOAA Collaborator: W. Murray/CPO; Jeff Privette/CDR)

Period: July 1, 2009 – June 30, 2010

Background: Scientific Problem, Approach, and Proposed Work

The primary goals of this project are to prototype an operational production system for the outgoing longwave radiation climate data record and to continue the improvements and validation efforts for the existing HIRS OLR climate data record (CDR) algorithm and product. An end-to-end system is under implementation to generate OLR CDR product using HIRS Level-1b data input. The derivation of OLR CDR involves several carefully devised procedures: including the OLR retrieval algorithm applied at each HIRS field of view; determination of inter-satellite adjustments to maintain continuity; deriving and applying OLR time/area-dependent diurnal models to alleviate orbital drift effects during temporal integration; and a consistent radiance calibration method. New OLR algorithms will be developed for the operational sounders following the HIRS, including the IASI and CrIS, such that the OLR CDR time series can be extended into the foreseeable future (~2040) without possible data gaps.

This project is initially funded by the NOAA CPO program (Manager: Bill Murray) for three years. The continuing support is provided by NOAA CDR program (Manager: Jeff Privette).

Accomplishments Summary

<u>HIRS OLR CDR Quality Assurance</u>

The 30 years time series of HIRS OLR version 2.1 from 1979 to 2008 has been generated and compared well to the CERES Ed2 and Ed2.5 products. The slight trend (~1-2 Wm^{-2}/decade) in the OLR differences between HIRS and CERES Ed2 after year 2000 (i.e., w.r.t. Terra and Aqua data) is the focus of the validation studies. We are verifying if this trend is caused by the Ed2 CERES OLR biases related to the spectral response function degradation in SW and Total channels.

The new calibration method CERES devised is expected to fix this problem and a Ed2.5 product was generated for early phase assessment (the Ed.3 product that would be available at least in another 6 months will include the new calibration method as well as other improvements). Preliminary comparisons of HIRS OLR and CERES Ed2.5-Lite products showed consistent results traceable to the past HIRS/ERBS validation studies. However, it seems that there remains to have trending differences whose existence and causes are yet to be confirmed. We continue to collaborate with NASA colleagues to understand these results.

IASI/CrIS OLR Algorithm Development

The preliminary IASI *band-by-band OLR estimation model* has excellent performance that its spectral flux estimation errors are comparable to that in the CERES spectrum unfiltering processes, ~0.1% (0.3 Wm^{-2} flux equivalent). We are in collaboration with NESDIS/STAR for the ongoing validation of IASI OLR. The development of CrIS OLR model is currently pending for the CrIS fast transmittance coefficients for its latest spectral response function. The modeling concept and formulation developed for IASI is expected to be directly applicable in CrIS. We are also in the process of revising the HIRS OLR model using the new band-by-band approach, intending to fix the intrinsic scene- and angular-dependent biases that were discovered in recent analyses.

Inter-satellite Calibration Revisited

Currently the inter-satellite biases are defined as a constant difference between the HIRS OLR products derived from two satellites based on collocated observations in polar region. It is an assumption that the one constant value is applicable to all regions and all years. The possibility that the biases could be functional of, e.g., OLR, cannot be asserted due to limited data range span. We found rare opportunities of overlapping orbits in recent POES that can better characterize the inter-satellite differences and to assess the robustness of the inter-satellite calibration methodology using collocated data from all latitudes.

Radiance Calibration Method

For the HIRS radiance calibration problem, we have shown the significance of nonlinearity in HIRS instrument response and concluded that it is necessary to develop a new calibration algorithm that takes into account of non-linearity effect. We have attempted to use onboard calibration data to reconstruct nonlinearity properties, however, due to the narrow range of calibration temperatures of the internal warm target, the results are not very robust. We need to construct the nonlinear calibration algorithm using the thermal vacuum data and use onboard calibration for consistency check for possible instrument variation and degradation.

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FY2010 Milestones (Sept 1 2009 – Aug 31 2010):

- ATBD for Version 1 HIRS OLR CDR (continue)
- Inter-comparison and quality assessment (continue)
- Complete CrIS OLR algorithm development (pending)
- Operational production of HIRS OLR CDR (ongoing)
- Operational real-time monitoring (off-line analysis)
- Reprocessing for version 3 HIRS OLR CDR (v3 algorithms in development)

Planned Work

FY2011 Milestones (Sept 1 2010 – Aug 31 2011):

- Establish HIRS OLR CDR Operational Production System at CICS and ready for deliver to the NCDC
- Generate HIRS OLR CDR Product (1979-2010)
  a) In netCDF4 format
  b) Conform to Climate Forecasting (CF) metadata format following ISO 19115-2 procedure
- Prepare Technical Documents
  a) Operational Algorithm Document (OAD)
- Prepare source code package for OLR CDR production

- Proceed with NOAA-NP (N-prime, NOAA-19) OLR CDR production
  - Derive NOAA-NP OLR model
  - Generate off-line temperature-prediction coefficients for radiance calibration
  - Derive bias adjustment through inter-satellite calibration
- Continue HIRS OLR algorithm improvements following the nonlinear multi-band regression experiments reported in Lee et al. (2009).
- Evaluate IASI OLR
- Prepare journal articles and conference presentations
- Prepare Submission Agreement

Personnel Status

Dr. Joonsuk Lee worked on the project in December 2008 through November 2009.

Dr. Arnold Gruber has retired from University of Maryland in December 2009 and is off the project since.

Mr. Andrew Jongeward, a graduate student of the Department of Atmospheric and Oceanic Science, University of Mayrland, is recruited to work on data analysis and inter-comparison studies starting Fall 2010.

Details and Discussions

<u>HIRS OLR CDR Ver.2.1</u>

The NOAA-KLM HIRS/3 observations were reprocessed, with the revised prediction coefficients for McMillin radiance calibration algorithm. The OLR from HIRS/4 observations, including NOAA-18 (N) and MetOp-2 (A), were also generated. This brings to a 30 years worth of OLR time series, from 1979 to 2008 (referred as HIRS OLR CDR Ver. 2.1). The preliminary comparisons show good agreement with the CERES Scanner observations from TRMM, Terra and Aqua platforms (see Fig. 1). The CERES flux retrievals have known errors related to the contamination/degradation in the ‘total’ and ‘shortwave’ channel sensors that caused shortwave to bias high while the longwave being too low, and the bases are functions of time. The CERES expects to fix this problem in Ed.3 release. The CERES Ed.2 OLR is estimated to have a drift of about -3.5 Wm-2 per decade (but only for the first 5 years) and that is consistent with HIRS minus CERES OLR differences (Fig. 2)

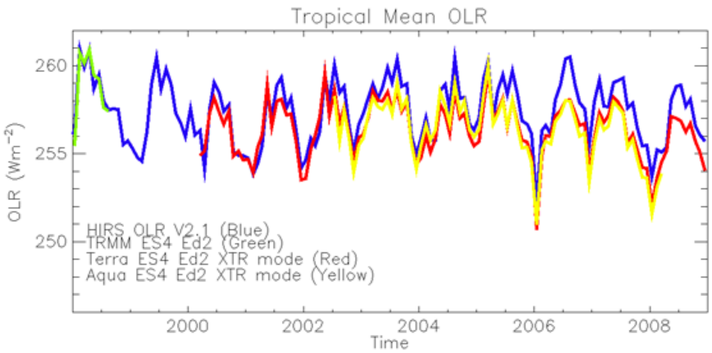

Fig. 1. Comparison of tropical mean OLR time series between HIRS v2.1 and CERES SSF Ed.2 products (in cross-track scanning mode) derived from TRMM, Terra and Aqua observations. The CERES spectrum unfaltering errors are in part responsible for the slowly enlarged deviations.

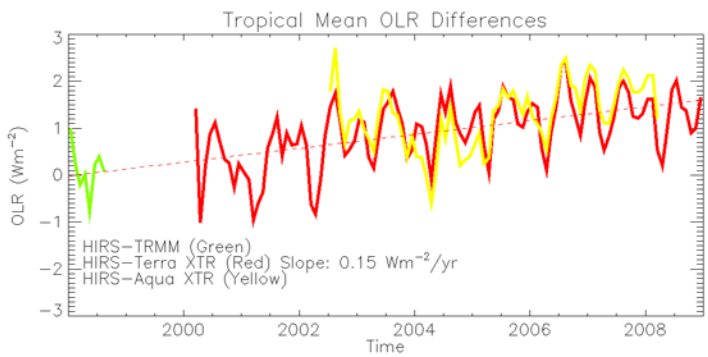

Fig. 2. Differences of tropical mean OLR time series between HIRS v2.1 and CERES SSF Ed.2 products derived from TRMM, Terra and Aqua observations. A linear fit for HIRS minus CERES Terra shows a slope of about 0.15 Wm-2/year. The drift in CERES OLR product is expected to level off because after year 2005 the RAP operation mode was no longer employed.

CERES Terra SSF/SYN Lite Ed2.5 data is released in June 2010 that uses Ed.3 calibration algorithm with the rest processing components stayed on Ed.2. This intermediate release is meant to allow scientific community to examine the impacts of the corrections for instrument degradation problem. We compared the HIRS OLR CDR v2.1 to CERES Ed.2.5 and found the agreement is consistent with the earlier studies (see Fig. 3) that they have a correlation coefficient of 0.936, with a rms differences in OLR anomalies of about 0.5 Wm^{-2} — a better result comparing the 1.0 Wm^{-2} rms differences of tropical OLR anomalies between HIRS with the ERBE Non-scanner time series (1985-1998). Although the OLR anomalies differences (Fig. 4) show similar range as in the HIRS/ERBS comparison (Fig. 5), we have reasons to worry about the HIRS OLR quality due to various instrument problems since NOAA-15. We need to further examine the OLR retrievals from individual satellite to assure that poor quality OLR retrievals (resulted from bad or poor quality radiance observations) were not entering the CDR time series.

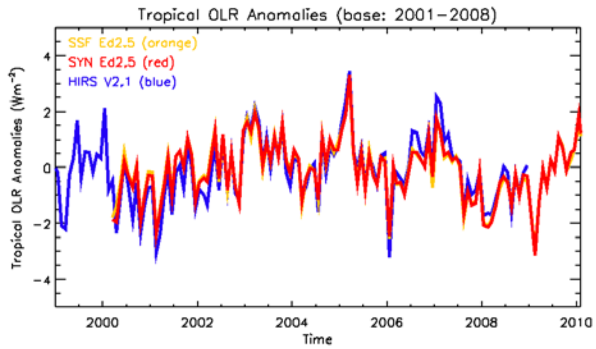

Fig. 3. Comparison of tropical mean OLR time series between HIRS v2.1 and CERES SSF and SYN Ed.2.5 Lite products derived from Terra observations. The correlation between HIRS and CERES is 0.936. The rms differences is about 0.5 Wm^{-2}.

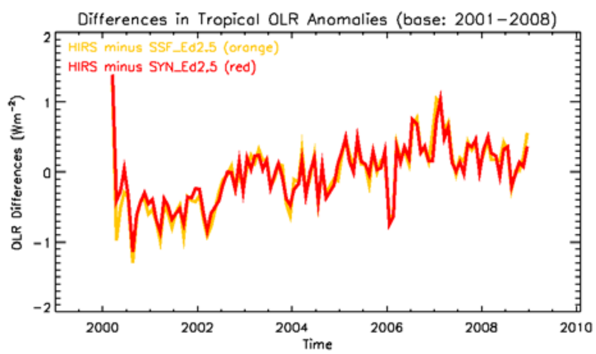

Fig. 4. Differences of tropical OLR anomalies for the data shown in Fig. 3.

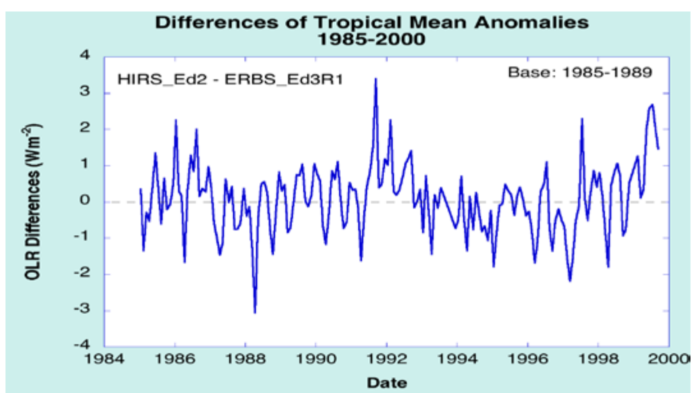

Fig. 5. Differences of tropical OLR anomalies between HIRS OLR CDR v2.0 and ERBE-Non-scanner Ed3-Rev1.

There is a problem in the NOAA-14 level-1b data after March 2000 that the stored local zenith angle (LZA) seems to be in error. Normally, the outermost HIRS scan spot has a LZA of about 59 degrees. This value was found to become about 39 degrees in NOAA-14 level-1b data since March 1999. We cannot find any documentation of this problem. The HIRS OLR CDR v.2.0 has used the NOAA-14 OLR retrieval with the inclusion of this error (it is necessary to include NOAA-14 data since the NOAA-15 has a one month of gap in November 2000). In the v2.1 production, we decided not to use NOAA-14 data past September 2003, although its data is available through October 2006. If the LZA problem cannot be explained and corrected, we plan to assign a theoretical LZA value to the HIRS scans so that the limb dependence in NOAA14 OLR retrievals would be less erroneous for the 1999-2006 period.

IASI OLR Algorithm Development

A band-to-band IASI OLR estimation model is developed to make use of all available IASI radiances to estimate spectral radiances or spectral fluxes. When estimating the spectral radiances, only the un-observed portions of the longwave spectrum is needed, that is, 0-645 cm^{-1} (far-IR) and 2760 to 3000 cm^{-1} (near-IR). Due to the energy distribution, most uncertainties are in the far IR spectrum. The band-to-band OLR model can be best fitted with log-log transformation, or, equivalently, the nonlinear regression model with power law. Fig. 6 shows an example of the IASI OLR models and their performance on estimating the spectral fluxes. The theoretical assessment shows that such band-to-band IASI OLR model can have radiance or flux estimation errors very comparable to that of the CERES broadband spectral retrieval errors, about 0.1%, or 0.2 to 0.3 Wm^{-2} for equivalent flux. This result is very encouraging. Validation studies against CERES and HIRS OLR products will be performed.

This approach may ultimately remove the viewing angle dependent biases that were shown in our simulations for current HIRS OLR models. As were shown in earlier studies that the viewing angle dependent biases are functions of scene type. This property will lead to discontinuity and decreased confidence in the inter-satellite bias determination. The new OLR retrieval method can separate water vapor and temperature variations by band-to-band estimation that it may ultimately remove the undesired scene- and angular-dependent errors. This will further improve the consistency and ultimately the continuity of the HIRS OLR when derived from different versions of HIRS instruments.

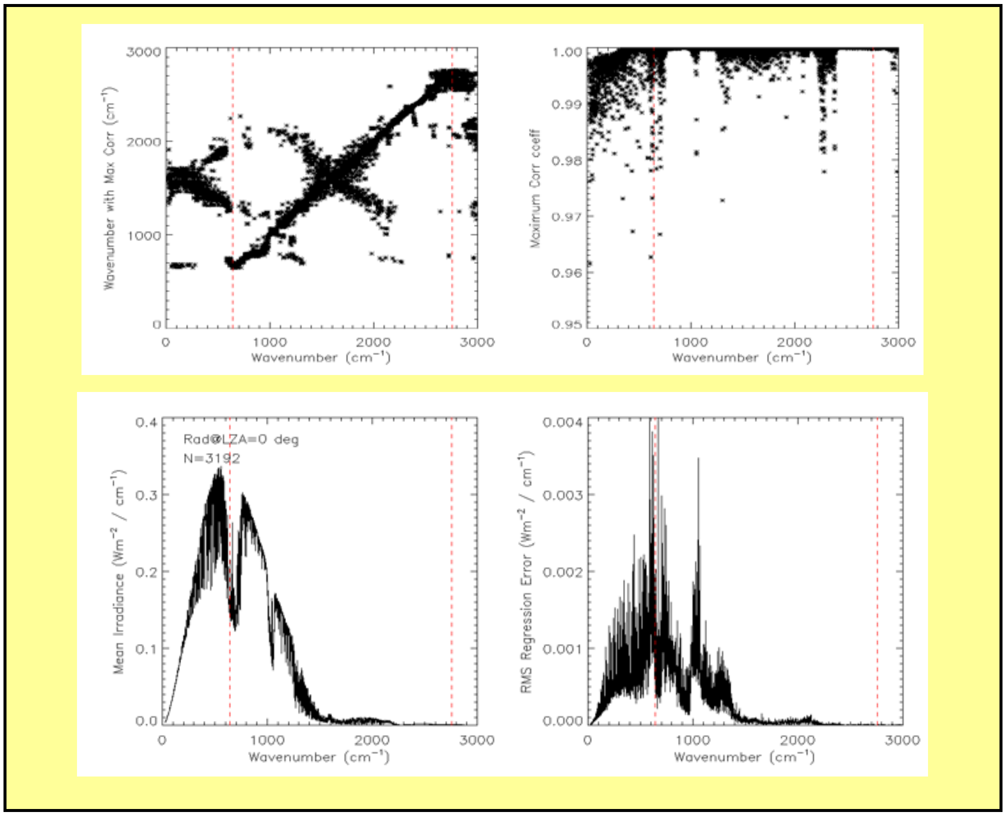

Fig. 6. An example of IASI OLR Modeling and performance. The IASI radiance observations are taken at an effective 0.5 cm-1 resolution (level-1c data) spanning continuously between 645 and 2760 cm^{-1} that indicated by the two dashed red lines in each of the panels. The upper left panel shows the predicting channels for the band-to-band OLR estimation models to be fitted with Power law. Their corresponding linear correlation coefficients between the IASI predicting radiances and spectral fluxes (with log-log transformation) are shown in upper right that for most frequencies the values are greater than 0.99. The estimated OLR spectral fluxes predicted from simulated IASI radiances at local zenith angle 0° are shown in the lower left panel. The associated estimation errors are shown in the lower right approximately proportional to their spectral flux values. The overall flux estimation error is about 0.2 Wm^{-2}, or about 0.1%, which is in similar magnitude for the spectral retrieval errors of the CERES LW flux.

Inter-satellite Calibration

The current inter-satellite adjustment in HIRS OLR is defined as a constant value between any two satellites with overlapping observations. These biases are determined using near simultaneous and collocated OLR retrievals mostly found in the polar region, due to the nature of the intersection of orbital planes of a morning and an afternoon polar-orbiting satellite. Only until recently that we have the opportunity to perform inter-satellite calibration using data from all latitudes, not just the polar region, when two orbital planes overlap. These incidences occurred when two satellites drifted to a point that they share the same equator crossing time. Four such occurrences can be found in recent years (see Fig. 7).

Two such occurrences have been studied: 1) NOAA-15 and 16 in August 2008, and 2) NOAA-17 and MetOp-2 in April 2009. Figures 8 and 9 show the results of the inter-satellite OLR calibration for these two cases. Both cases show variations of OLR differences as functions of latitude, however, with very different magnitude. The standard deviation of the zonal mean OLR differences is 1.1 Wm^{-2} for NOAA15/16 versus a merely 0.2 Wm^{-2} for NOAA-17/MetO-2 comparisons. The N15/N16 OLR differences showed very profound linear dependence in OLR, while no sign of such dependence exists in N17/M2 case. Interestingly that the mean inter-satellite differences of both cases agree to what have been determined for these pairs to 0.3 and 0.2 Wm^{-2}, respectively.
We will be comparing the OLR retrievals for the other two occurrences, hoping that more defined commonality can be found and can be used to improve the accuracy of inter-satellite bias adjustment. We suspect that the OLR retrieval might be persistently biased in either NOAA-15 or NOAA-16. This can be indirectly confirmed with the results from the other two cases if the zonal OLR differences do not vary by a magnitude as large as seen in the NOAA-15/16 differences.

These overlapping orbital planes also provide good opportunities to perform inter-satellite comparison of the radiance observations. Results can be compared to the recent simulation studies reported by Cao et al. (2009).

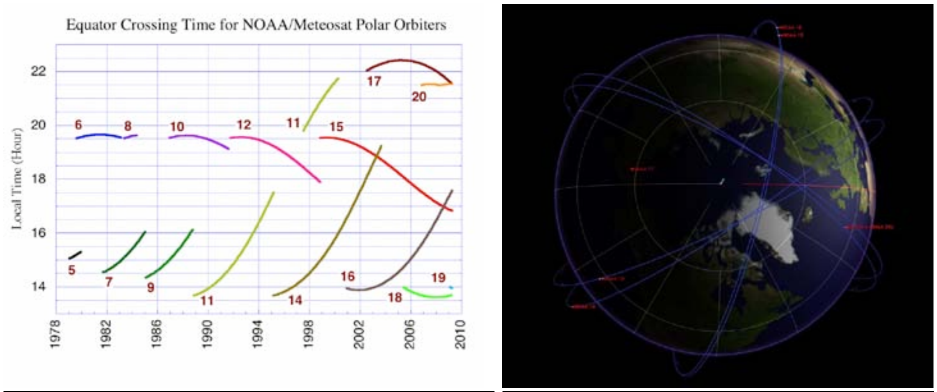

Fig. 7. Equator crossing time of the POES (ascending node, left) shows that there are four occurrences that two satellites would have common orbital planes (right, example orbits as of August 15, 2009). These incidences provide opportunities for inter-satellite calibration over the entire globe opposed to only the polar region where the intersections of the orbital planes of an afternoon and a morning satellites can be found.

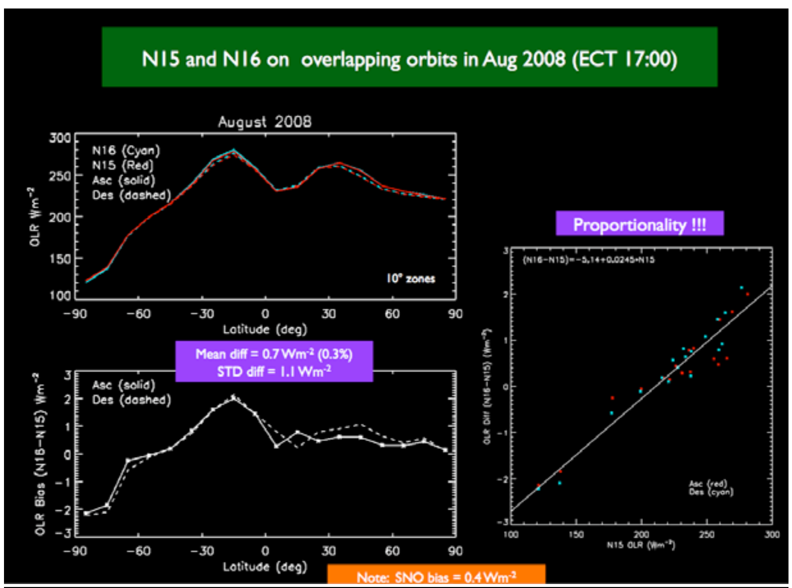

Fig. 8. OLR differences between NOAA-15 and 16 in August 2008 when these two satellites have near common orbital planes.

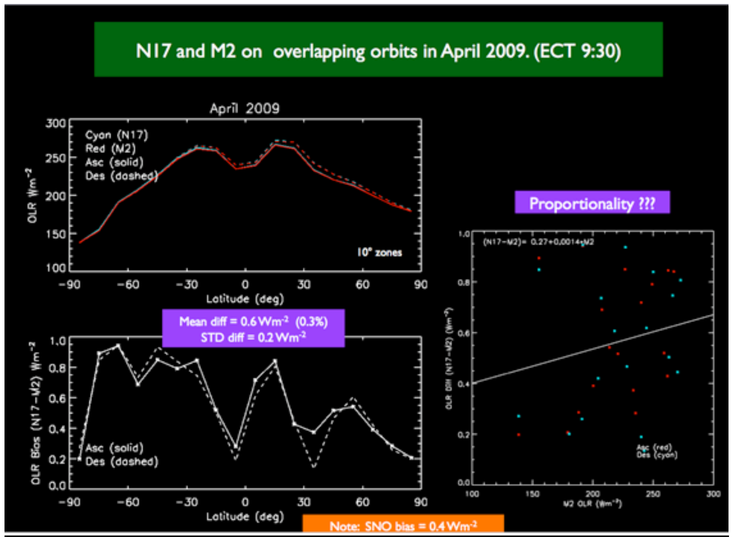

Fig. 9. OLR differences between NOAA-17 and MetOp-2 in April 2009 when these two satellites have near common orbital planes.

HIRS Radiance Calibration Issues

For the HIRS radiance calibration problem, we have shown the significance of nonlinearity in HIRS instrument response and concluded that it is necessary to develop a new calibration algorithm that takes into account of non-linearity effect. We have attempted to use onboard calibration data to reconstruct nonlinearity properties, however, due to the narrow range of calibration temperatures of the internal warm target, the results are not very robust. We need to construct the nonlinear calibration algorithm using the thermal vacuum data and use onboard calibration for consistency check for possible instrument variation and degradation. It is necessary to conduct the investigations of nonlinear calibration and possible spectral response function deviations at the same time to avoid aliasing effect. These problems are out of scope of the current OLR CDR project. Other resources are required to continue pursuing these problems.

Computation and IT System

- The Apache Subversion Version Control System (SVN) is adapted for source codes and documents tracking purposes.

- NetCDF-4 Fortran API (application programming interface) has been installed. The HDF-5 component is yet to be included.

Publication & Presentations

Lee, Hai-Tien, R. G. Ellingson, A. Gruber, 2010: Development of IASI outgoing longwave radiation algorithm. Proceedings of the 2nd IASI International Conference. Annecy, France, Jan 25-29, 2010.

Lee, H.-T., A. Gruber, R. G. Ellingson and I. Laszlo, 2007: Development of the HIRS Outgoing Longwave Radiation climate data set. J. Atmos. Ocean. Tech., 24, 2029-2047.

Lee, H.-T., I. Laszlo, and A. Gruber, 2009: Recent improvements in the HIRS outgoing longwave radiation climate data record. 16th Conference on Satellite Meteorology and Oceanography / 89th AMS Annual Meeting, January 11-15, 2009. Phoenix, Arizona.

Operational Generation of the HIRS Outgoing Longwave Radiation Climate Data Record

Hai-Tien Lee, Arnold Gruber, and Joonsuk Lee; (NOAA Collaborator: W. Murray) – HLHL_HIRS10

Background: Scientific Problem, Approach, and Proposed Work

The primary goals of this project are to prototype an operational production system for the outgoing longwave radiation climate data record while continue the improvements and validation efforts for the existing product and algorithms. An end-to-end system has been proposed to produce OLR CDR product using HIRS level-1b data input. The derivation of climate data record involves several careful procedures with OLR retrieval performed for each HIRS pixel, including intersatllite calibration to maintain continuity; use of diurnal models to minimize orbital drift effects in temporal integral; and consistent radiance calibration. OLR algorithms will be developed for the operational sounders following the HIRS, including the IASI and CrIS, such that the OLR CDR time series can be extended into the foreseeable future (~2040) without data gaps.

Accomplishments

In the OLR algorithm improvement, we continued to explore the multispectral algorithm by identifying the source of errors in the OLR estimation as well in the inter-satellite calibration. A new OLR model that uses higher order radiance predictors in estimating spectral fluxes seems to present a more uniform residual pattern that could have eliminated most of the scene dependencies. The residual analysis also suggested that it is necessary to treat semi-transparent cirrus condition separately.

The preliminary IASI OLR model has excellent performance that it has a theoretical spectral flux estimation error comparable to that of the CERES spectrum retrievals, ~0.1% (0.3 Wm^{-2} flux equivalent). The ongoing validation of IASI OLR will be in collaboration with NESDIS/STAR. More information about IASI OLR model development will follow. The development of CrIS OLR model is currently pending.

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The current release is Ver. 2.1 that spans from 1979 to 2008 and it continues to compare well to the CERES ERBE-like product.

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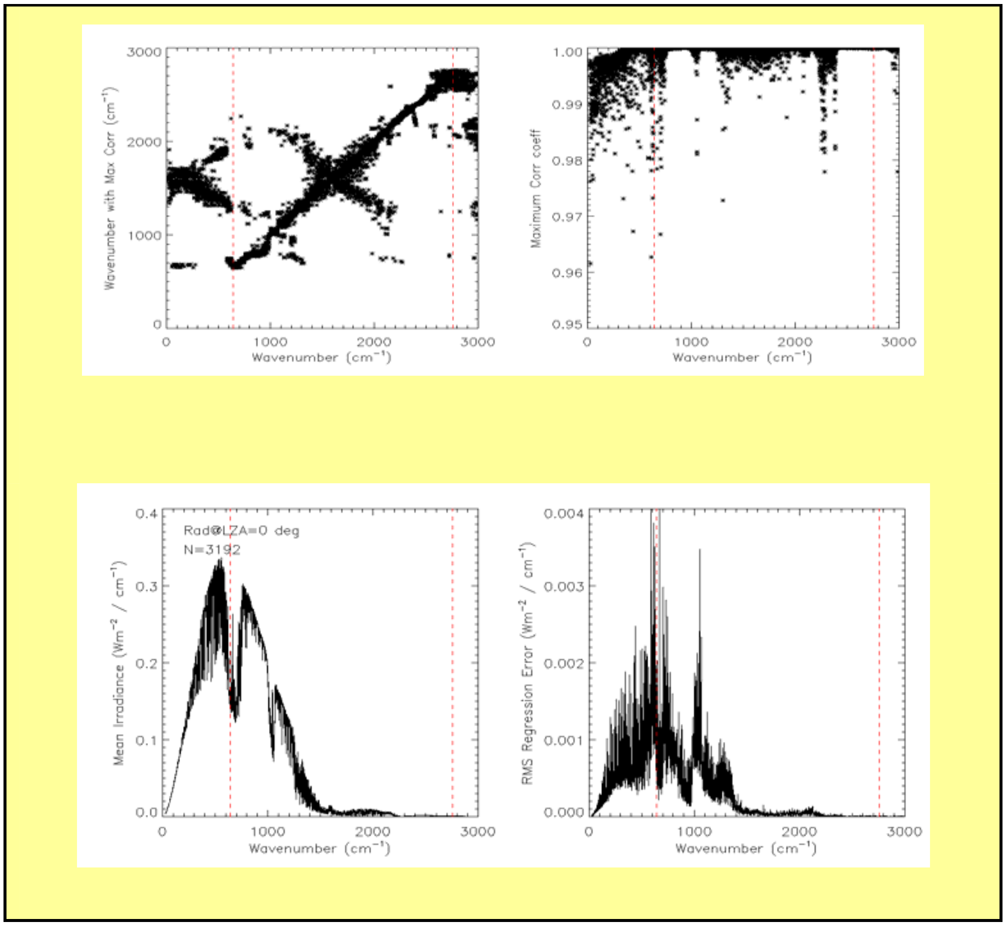

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- Continue IASI OLR algorithm development (see Lee et al., 2010)
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Presentations

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