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From: Hank Revercomb
Date: 5 January 2012

Re: **First Annual Report for CLARREO SCIENCE DEFINITION TEAM MEMBERSHIPS** (NASA Award Number, NNX11AE70G), University of Wisconsin-Madison, Space Science and Engineering Center

This is the first Annual Report for NASA Award Number NNX11AE70G, entitled CLARREO Science Definition Team (SDT) Memberships, with the overall objective of helping CLARREO become a successful climate benchmark mission by providing expert guidance to the CLARREO project in the wide range of areas.

This effort includes four SDT team memberships. The primary focus areas for each SDT member are (1) Revercomb: SI-traceable uncertainty analyses and Post-launch validation; (2) Knuteson: Infrared benchmark product development and model comparisons; (3) Smith: Climate trend detection and attribution, especially using special regression inversion techniques; and also including involvement in model comparisons and (4) Tobin: Use of CLARREO data as reference calibration for operational and research sensors.

Progress is reported for each team member in the four subsections to follow. Each identifies the general task areas in which contributions were made. The general task areas proposed included the following list:

1. Refining and prioritizing the goals of the mission, consistent with resource constraints
2. Refining the prioritizing the definition of required measurements
3. Refining and prioritizing measurement requirements
4. Developing calibration and validation plans
5. Defining geophysical products, data sets, and related processing algorithms
6. Identifying and performing prelaunch studies supporting mission goals
7. Developing science data processing system requirements and approach
8. Defining approaches for using CLARREO data for testing and improving climate projections
9. Science team telecons
10. Approximately three SDT Meetings per year.

Each member regularly participated in team telecons and in both of the SDT Meetings held this year (Hampton, VA 17-19 May 2011 and Madison, WI 12-14 October 2011).

1. Revercomb: SI-traceable uncertainty analyses and Post-launch validation

Results of analyses demonstrating the readiness of recent technological advancements to (1) meet the demanding CLARREO IR Earth radiance accuracy requirements (0.1 K 3-sigma

brightness temperature calibration accuracy) and (2) allow this accuracy to be proven with on-orbit standards were refined and presented at two CLARREO SDT Meetings.

The climate benchmark approach for CLARREO includes the use of (1) a calibrated Fourier Transform Spectrometer (FTS) that we refer to as the Absolute Radiance Interferometer (ARI) to measure Earth emitted radiance over much of the IR spectrum, and (2) an On-orbit Absolute Radiance Standard (OARS) that can be operated over a wide range of temperatures to verify the ARI accuracy on orbit. The ARI makes use of full aperture views of a high emissivity ambient temperature blackbody and space to perform calibration of Earth views with a well-established approach (Revercomb, et al., Applied Optics, 1988). Using the same type of analyses that we developed for other calibrated FTS instruments (including, the UW Scanning HIS aircraft instrument and the CrIS sounder for the recently launched NASA/NOAA NPP mission), we have shown that the simpler ARI instrument (nadir only viewing and much looser noise specs) will be capable of the high accuracy needed for CLARREO. We also reported on our recent NASA Instrument Incubator Program test results that support this conclusion.

Also presented were analyses supporting that the expected performance of the OARS will meet the requirement of providing direct SI traceability to fundamental physical properties with better than 0.1 K 3-sigma radiance accuracy, traceable to on-orbit phase change standards.

Contributions were made to general tasks 1-4, 9 and 10.

2. Knuteson: Infrared benchmark product development and model comparisons

Results of analyses identifying and performing prelaunch studies in the area of CLARREO benchmark products were presented at two CLARREO SDT Meetings. Details of the analysis performed during the reporting time period are given in the following paragraph.

A study conducted by graduate student Ms. Jacola Roman was performed that identified a methodology for the regional validation of Global Climate Model (GCM) moisture fields in the U.S. Great Plains and Midwest. The study results have identified an important regional difference among climate models in the IPCC AR4 comparison in their ability to reproduce observed seasonal and regional distributions of water vapor over North America. A poster of this work was presented at the World Climate Research Program (WCRP) meeting in Denver during October 2011. In addition, Ms. Roman was invited to attend the Inaugural Summer School for “Using Satellite Observations to Advance Climate Models” hosted by the Jet Propulsion Laboratory Center for Climate Sciences and held at CalTech, 8-12 August 2011. Ms. Roman is pursuing a graduate degree in the University of Wisconsin-Madison Atmospheric and Oceanic Sciences department. Her research is partially supported by the NASA CLARREO mission through a research assistantship funded by this project within the UW Space Science and Engineering Center. The results of Ms. Roman’s study have been submitted to the Journal of Climate, the publication citation is given below;

Roman, J. A., R. O. Knuteson, S. A. Ackerman, D. C. Tobin, and H. E. Revercomb, 2012: Validation of Regional Global Climate Model (GCM) Water Vapor Bias and Trends Using Precipitable Water Vapor (PWV) Observations from a Network of Global Positioning Satellite (GPS) Receivers in the U.S. Great Plains and Midwest, *J. Climate*, *in review*.

Figure 1 illustrates the seasonal and regional differences of precipitable water vapor among four climate models participating in the IPCC AR4 comparison for a latitude and longitude cross-section centered at the U.S. DOE ARM Southern Great Plains site near Lamont, Oklahoma. The square symbols represent the ground-truth measurements from surface-based GPS receivers (SuomiNet). In this A2 scenario, all models appear to reproduce the observations during the winter months but the GISS model best reproduces the observations the moist summer-time conditions. Future work in this area includes the use of AIRS radiances and products to extend the validation spatially from land to ocean areas. Assessment of regional climate model differences will be an important factor in the determination of appropriate CLARREO benchmark product grid domains.

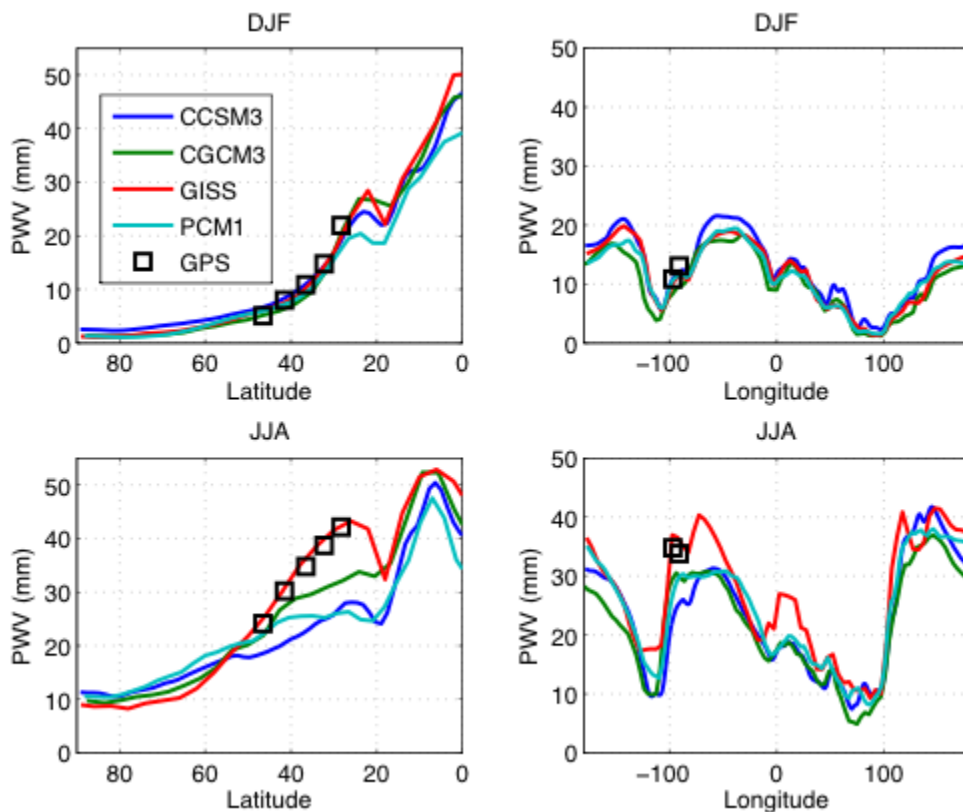


Figure 1. The left hand panels show the winter (DJF) and summer (JJA) latitude cross-section comparison of GCM PWV at the longitude of the DOE ARM SGP site (97.5 W) for the period 2005-2009 with the observed Suominet GPS PWV regional means in the U.S. Great Plains (shown as square symbols). A longitude cross-section comparison, at the latitude of 37 N (between 34 and 40), are shown in the right hand panels with the Great Plains

and Midwest regional GPS mean values overlaid. All models are in good agreement with observations in the winter season but only the GISS model captures the PWV magnitude in the summer season.

Contributions were made to general tasks 5-10.

3. Smith: Climate trend detection and attribution, especially using special regression inversion

Significant progress was made in the development of a fast and stable cloud classified linear regression atmospheric state parameter retrieval program for application to satellite infrared radiance spectra, such as those to be obtained by CLARREO. For climate applications, the retrieval algorithm must be linear such that the variation in the retrieved variables depends solely on the variation in the observed radiance spectra. It must also be able to provide retrievals under all sky conditions (i.e., 0 – 100% cloudiness) and be independent of the instrument field of view size so that it can be applied to the observations from different satellite instruments. The climate variables to be retrieved are: surface temperature and spectral emissivity, atmospheric profiles of temperature, water vapor, and ozone, the total concentration of carbon dioxide, and cloud height and optical depth.

An algorithm for accomplishing the climate measurement objectives of CLARREO has been developed which handles the non-linear nature of the radiative transfer equation inverse problem through statistical classification with respect to cloud height and associated water vapor profile characteristics. Linear regression retrieval coefficients are defined from a global set of atmospheric soundings and associated calculated radiance spectra for clear sky conditions as well as eight different overlapping cloud height classes between 100 hPa and the Earth's surface. The cloud optical depth and effective particle size are specified for each sounding using a temperature and moisture profile parameterization. Solutions are produced for all cloud condition classes with the optimal cloud class selected for the final climate variable retrieval as that one for which the regression predicted cloud height agrees closest to the median value of the same cloud class providing the regression solution used.

Figure 2 shows annual trend results for 10 degree latitude by 10 degree longitude regions obtained using seven years of AIRS nadir observations. The results indicate a general warming of the lower troposphere over western arctic, eastern Asia, and Australian regions with compensating cooling trends over southern Alaska, southeaster Greenland, and northeastern Europe. Precipitable water and mid-tropospheric humidity are steady except for the eastern Pacific coast of South America where an El Nino signature is found. Carbon dioxide concentration is shown to be increasing for all regions with the highest spatial variability occurring across the tropics. It was found that the seven year globally averaged temperature trend was very small, being slightly positive (~ 0.01 K/yr) in the lower troposphere, slightly negative (~ -0.02 K/yr) in the upper troposphere and lower stratosphere, and zero throughout the middle troposphere (500-850 hPa).

During 2012, the AIRS climatology will be extended to include all the years through 2011. The algorithm will be applied to Nimbus 4 IRIS data to investigate regional differences between 1971 and 2011. Investigations will also be conducted to determine the algorithm can be successfully be applied to the multi-spectral HIRS data for which a continuous 30 year record of observations are available.

Contributions were made to general tasks 5-10.

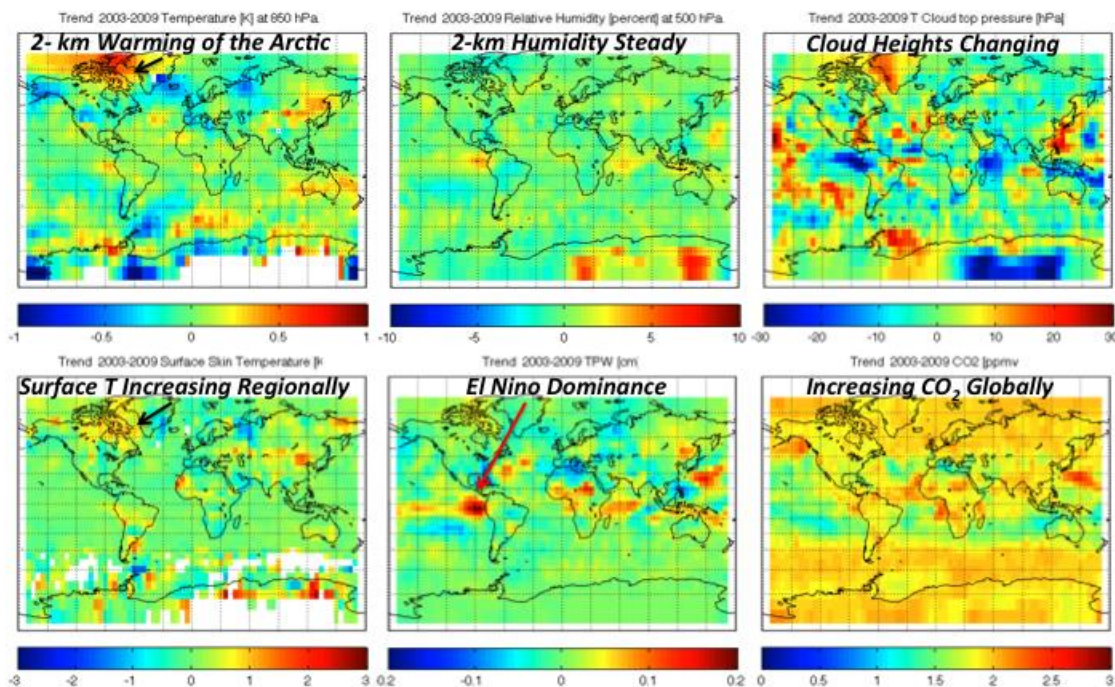


Figure 2. 7-year (2003-2009) annual trends (i.e., change per year) of various climate parameters produced from AIRS nadir radiance spectra averaged over 10-degree latitude by 10-degree longitude grid squares. The upper left hand panel shows the 1.5-km (850 hPa) temperature trend, the upper center panel shows 6- km (500 hPa) relative humidity trend, and the upper right hand panel shows cloud height trend. The lower left hand panel shows the surface skin temperature trend, the lower center panel shows the precipitable water, and the lower right hand panel shows the total carbon dioxide concentration.

4. Tobin: Use of CLARREO data as reference calibration for operational and research sensors

Recent efforts have focused on showing the benefits of a CLARREO mission for intercalibration objectives. This has included the use of existing data to show intercalibration results, and simulation studies to show how well intercalibration can be achieved with CLARREO. These types of results were presented at CLARREO science team meetings this year. A sample result using existing data is shown in Figure 3. Figure 3 shows assessments of Terra and Aqua MODIS radiometric calibration using Simultaneous Nadir Overpasses comparisons with IASI, and shows the improvement in both MODIS data sets when moving to new calibration

coefficients/algorithms in Collection 6. This same type of comparison, although with better absolute accuracy, will be attainable with CLARREO.

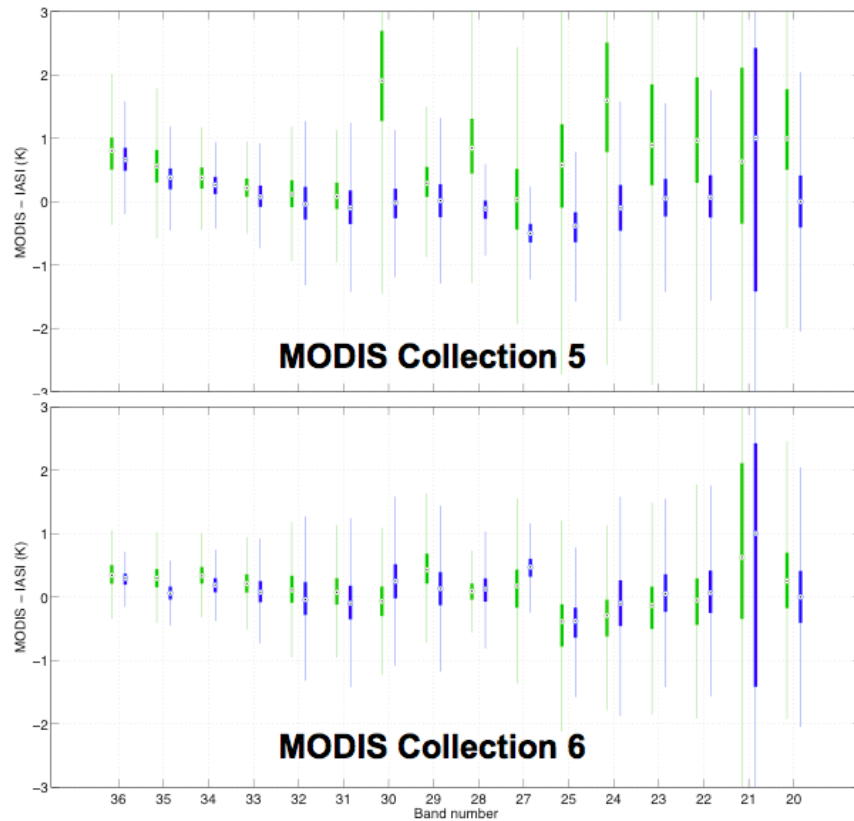


Figure 3. Simultaneous Nadir Overpass based assessments of Terra (green) and Aqua (blue) MODIS with IASI for MODIS collection 5 (top panel) and collection 6 (bottom panel).

The intercalibration simulation studies for CLARREO demonstrate that very useful intercalibration results can be achieved within several months of the mission. This is shown in Figure 4, where the single channel uncertainty of using CLARREO to intercalibrate CrIS is shown as a function of months since CLARREO launch. This is for a single 90 degree polar orbit mission. After just one month, 3-sigma uncertainties of less than 0.1K are achieved.

In summary, combining (1) complete and continuous spectral coverage with Nyquist sampling, (2) good intercal spatial and temporal sampling from a 90 degree polar orbit, and (3) very high absolute accuracy and traceability, intercalibration is a very strong selling point for CLARREO.

Contributions were made to tasks 1, 2, 3, 5, 6, 7, 9, and 10.

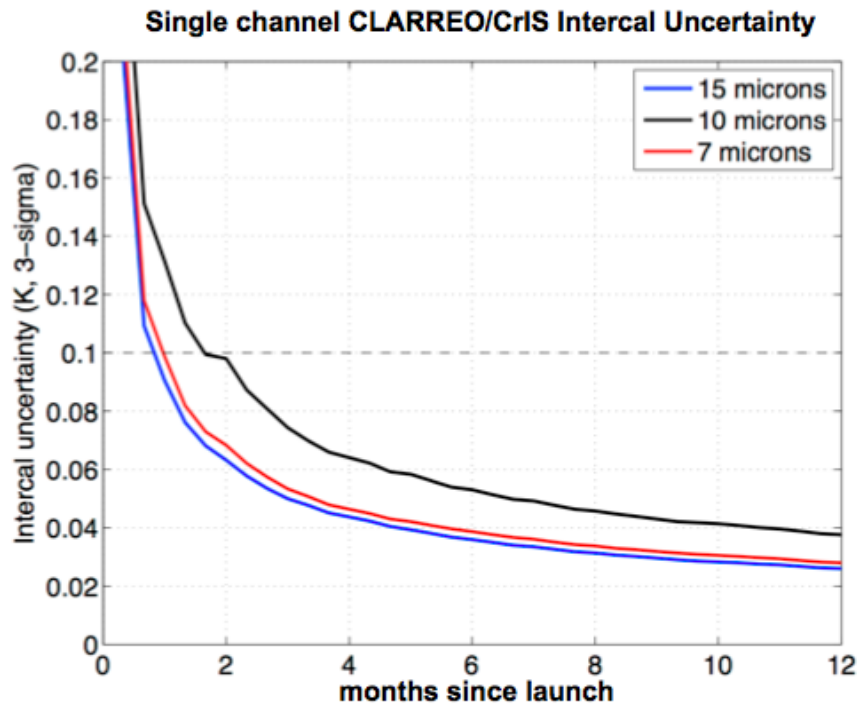


Figure 4. CLARREO/CrIS single channel intercalibration uncertainty as a function of months since CLARREO launch.