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Introduction

This final report describes the completion of NASA grant NNX08AP44G for a set of Pre-phase A studies in support of the CLARREO mission. The University of Wisconsin-Madison, Space Science and Engineering Center, with its teaming partner, Daniel Kirk-Davidoff of the University of Maryland proposed four studies that built upon earlier pioneering efforts to help define CLARREO mission requirements before the start of the Phase A study. These studies included:

1. Climate Product Evaluation Using AIRS and IASI Data Sets
2. Cross-Calibration Accuracy Evaluation using Aqua & Metop-A Data Sets
3. CLARREO Payload Requirements and Systems Study
4. Augmented Climate Product Orbital Sampling Study

Studies 1, 2, and 3 were conducted by the UW-SSEC, whereas study 4 was conducted by Daniel Kick-Davidoff. The Year 1 progress report contains attached presentations CLARREO team workshops that are not repeated here. Attached to this final report are a list of Science Requirements Reports completed under this study grant and available from the project NX website. In addition to attendance at Study Team meetings in Washington, D.C and Hampton, VA, the UW and Uni. of Maryland have participated in bi-weekly teleconferences lead by NASA Langley Research Center. We were quite active in the refinement of the CLARREO mission science questions and supported the development of presentations for the Mission Confirmation Review.

This report is organized into two main sections summarizing Year 1 and Year 2 accomplishments followed by a detailed list of references to presentations supported directly under this NASA grant.

Year 1 Accomplishments

The objectives and progress in each of the proposed study areas is briefly presented here. Further details can be found in the attachments to the Year 1 report. In addition to the study task reports, an SPIE conference presentation was prepared and a news summary was published by lead author Henry Revercomb with the title “Planning for a new US climate-benchmark mission”. A link to the SPIE newsroom article is given below:
http://spie.org/x31697.xml?highlight=x2420&ArticleID=x31697

Climate Product Evaluation using AIRS and IASI Data Sets

Measured, spectrally-resolved radiances are being used to investigate the characteristics of monthly and annual mean, regional spectral products. Although existing observations lack the full spectral coverage of CLARREO and do not provide unbiased temporal or complete spatial coverage, they do provide key spectral properties that we should study as part of our CLARREO development. The goal is to characterize the (1) fundamental information content that can be extracted from such products, and (2) short term climate and weather “noise” properties.

Progress in this task is summarized in the presentation by lead author Robert Knuteson (UW) titled; “Random errors: Sampling density for Infrared Spectra. [Simulating CLARREO footprints from satellite observations]” This addresses tasks TS375 – TS405 in the LaRC project schedule shown in Figure 1.

Status Date: 9/30/08

CLARREO Pre-Phase A
Trade Study Schedule

Line #	UID	Task Name	Overdue	% Complete	Duration	Start	Finish
252	**TS375**	**Climate Product Eval Using AIRS and IASI Data Sets**		**25%**	**344 d**	**5/1/08**	**9/8/09**
253	TS380	Dataset of CLARREO Proxy Data Prepared		70%	122 d	5/1/08	10/21/08
254	TS385	Report on the Relationship between CLARREO FOV Sizes & the Magnitude of Observed Natural Variability		0%	0 d	10/21/08	10/21/08
255	TS390	Obtain Model fields and/or Computed Radiances & Prepare Dataset of Simulated CLARREO Data		0%	120 d	10/24/08	4/17/09
256	TS395	Report on Preliminary Results of the Model Simulation of CLARREO Radiances Completed		0%	0 d	4/17/09	4/17/09
257	TS400	Investigate Sampling Differences Between AM (IASI) and PM (AIRS) Orbits for Observed Model Data		0%	100 d	4/20/09	9/8/09
258	TS405	Report on Comparison of Observed & Model Variability on Several Space and Time Scales as a		0%	0 d	9/8/09	9/8/09
259	**TS410**	**Cross-Calibration Accuracy Evaluation Using Aqua & Metop-A Data Sets**		**30%**	**343 d**	**5/1/08**	**9/4/09**
260	TS415	Investigate Relationship Between CLARREO FOV Sizes on the Cross-Cal Uncertainties		70%	122 d	5/1/08	10/21/08
261	TS420	Continue Metop-A (IASI)/AQUA SNO Investigation		70%	122 d	5/1/08	10/21/08
262	TS425	Report on Cross-Cal and Noise Requirements for Three 90 Degree Polar CLARREO Orbits Completed		0%	0 d	10/21/08	10/21/08
263	TS430	Investigate Relationship Between Orbits Selection and Number of CLARREO Satellites		0%	112 d	10/24/08	4/7/09
264	TS435	Investigate Relationship Between Spectral Averaging and Cross-Cal Uncertainties		0%	112 d	10/24/08	4/7/09
265	TS440	Separate Calibration Uncertainties by Scene Temperature		0%	25 d	4/8/09	5/12/09
266	TS445	Integrate MODIS-derived Spatial Sampling Uncertainties into the Metop-A (IASI)/AQUA SNO		0%	26 d	5/13/09	6/18/09
267	TS450	Investigate Feasibility of Identifying & Correcting Cal Biases in Sounder Measurements		0%	56 d	6/19/09	9/4/09
268	TS455	Report Summarizing the Cross-Cal Investigation Completed		0%	0 d	9/4/09	9/4/09
269	**TS460**	**CLARREO Payload Requirements and Systems Design**		**0%**	**320 d**	**1/2/09**	**3/31/10**
270	TS465	Support Requirements Definition and Flow Down. Develop Subsystem-Level Block Diagrams Identifying		0%	210 d	1/2/09	10/28/09
271	TS470	Develop Top-Level Draft of Payload Layout		0%	20 d	10/29/09	11/25/09
272	TS475	Develop Draft of Mass and Power Budgets for Candidate Payload Concept		0%	20 d	10/29/09	11/25/09
273	TS480	Refine Requirements Definition and Flow Down and subsystem -Level Block Diagrams		0%	90 d	11/26/09	3/31/10
274	TS485	Refine Top-Level Payload Layout		0%	90 d	11/26/09	3/31/10
275	TS490	Refine Mass and Power Budgets		0%	90 d	11/26/09	3/31/10
276	TS495	Research and Develop Preliminary Spacecraft Radiator Coupling Concept of the OARS		0%	90 d	11/26/09	3/31/10
277	TS500	Participate in Development of Top-Level Cost Estimate for Low-End Candidate Mission		0%	0 d	3/31/10	3/31/10
278	**TS505**	**Augmented Climate Product Orbital Sampling Study**		**37%**	**336 d**	**5/1/08**	**8/26/09**
279	TS510	Complete Analysis of GCM Simulated Brightness Temperatures		70%	122 d	5/1/08	10/21/08
280	TS515	Compile a Year of GOES Imager Channel 3 and 4 Datafor 6 Chosen Regions		70%	122 d	5/1/08	10/21/08
281	TS520	Perform Simulations of Satellite Sampling. Prepare for Presentation at AGU or AMS Meeting		70%	122 d	5/1/08	10/21/08
282	TS525	Submit Results of GCM Simulated Brightness Temperatures Analysis for Publication		0%	0 d	1/5/09	1/5/09
283	TS530	Complete Analysis of Footprint & Sampling Rate Dependence of Sampling Accuracy		0%	120 d	10/22/08	4/15/09
284	TS535	Design Plan for Similar Studies in the Visible		0%	120 d	10/22/08	4/15/09
285	TS540	Conduct Similar Analysis in the Visible		0%	94 d	4/16/09	8/26/09

Figure 1. LaRC project schedule for Pre-phase A CLARREO trade studies of the University of Wisconsin and University of Maryland. All tasks were on schedule at the end of the first year reporting period.

Cross-Calibration Accuracy Evaluation using Aqua & Metop-A Data Sets

An important component of the CLARREO mission is the capability to transfer the CLARREO calibration to operational sounders such as AIRS, IASI and CrIS to enhance the observations available for process studies. In this proposal we investigate the impact of CLARREO field of view size on sampling uncertainties and to refine estimates of CLARREO noise requirements. The accuracy assessment for the inter-comparison make use of results obtained in a MODIS-data sampling accuracy study. In addition, we review

an inter-comparison of METOP-A IASI and Aqua AIRS using simultaneous nadir overpasses (SNOs) to test the framework for cross-calibration and to investigate the accuracy of the comparison methods.

Progress in this task is summarized in the presentation by lead author David Tobin (UW) titled; “Inter-calibration of Operational IR Sounders using CLARREO” This addresses tasks TS410 – TS455 in the LaRC project schedule shown in Figure 1.

CLARREO Payload Requirements and Systems Design

In addition to the previous studies to refine the overall mission requirements for CLARREO, we proposed a high level systems study for a candidate payload concept. This task was not funded during the year 1 reporting period however a report was created under this project which summarizes previous work done on this topic.

Progress in this task is summarized in the presentation by lead author Henry Revercomb (UW) titled; “CLARREO Climate Benchmarking, SI traceability, and Flowdown Requirements” This addresses tasks TS460 – TS500 in the LaRC project schedule shown in Figure 1.

Augmented Climate Product Orbital Sampling Study

Subsampling of course-resolution geostationary satellite data sets and modeled spectrally resolved radiances has demonstrated the advantages of precessing 90 degree orbits for CLARREO's mission of compiling highly accurate radiance statistics. We use high spatial (4 km-8km) and temporal (15 minutes to 1 hours) data from GOES imager channels to estimate the dependence of the sampling error on orbit height, instrument aperture, and sampling frequency. We determine the dependence of the sampling errors on the separation of the two ground points. This may vary as a function of season, latitude and longitude, depending on the spatial and temporal decorrelation scales. We use GOES data from several representative regions: Tropical, subtropical, and extra-tropical seas, and dry and moist land areas at low and mid-latitudes.

Progress in this task is summarized in the presentation by lead author Daniel Kirk-Davidoff (Uni. of Maryland) titled; “Systematic Errors: dependence of sampling bias on orbital configuration” This addresses tasks TS505 – TS540 in the LaRC project schedule shown in Figure 1.

Year 2 Accomplishments

The same set of tasks started in year 1 and shown in figure 1 were continued and completed in year 2 of this proposal.

Climate Product Evaluation using AIRS and IASI Data Sets

Inter-annual variability estimates from spectrally resolved infrared satellite observations were estimated using a CLARREO proxy dataset generated at the Uni. of Wisconsin with AIRS observations from the Aqua satellite to simulate a range of field of view diameters. Zonal averaging was recommended in the pre-Phase A study to reduce the all-sky observed inter-annual variability for tropospheric water vapor and IR window channels to less than 0.1 K for mid-latitude and tropical zones and less than 0.2 K for Arctic and Antarctic zones. Table 1 estimates inter-annual brightness temperature variability at wavelengths selected from the CLARREO proxy data shown in Figure 4. Zonal averaging is less effective at reducing the inter-annual variability for lower stratospheric channels (e.g. the 15 μm CO2 band) which may require a more sophisticated analysis approach taking into account regional variability within latitude zones. These results were presented to the CLARREO science team in May 2009 and contributed to the mission requirements definition (Kato et al. 2009). Further analysis is required to separate ocean and land areas and to characterize regional variations in natural variability.

Table 1. AIRS CLARREO-proxy inter-annual variability by latitude zone (100 km diameter FOV)

Latitude Zone	Stratospheric (Temperature and CO_2)	LW Window (Cloud/Surface/WV)
Global (-85°, +85°)	0.1	0.05
Arctic (+66.5, +85)	> 1.0	0.6
NH Mid-Lat (+23.5, +66.5)	0.25	0.15
Tropical (-23.5, +23.5)	0.1	0.11
SH Mid-Lat (-66.5, -23.5)	0.25	0.05
Antarctic (-85, -66.5)	0.2	0.2

The CLARREO proxy dataset created at UW-SSEC from observations of the NASA AIRS high-resolution infrared sounder was used to investigate the field of view size dependence and the mid-IR spectral variability in observed all-sky brightness temperatures. A very slight dependence on field of view was determined in the range of 13.5 km to 100 km FOV diameter (ref. Science Engineering Reports). We found that the orbit-to-orbit variation dominates over the along-track orbit variability, which explains why the CLARREO FOV diameter has only a second order effect on the monthly statistics. This pre-Phase A study on FOV size will be expanded to characterize the differences between ocean and land regions in future work. The CLARREO proxy dataset was also used to illustrate the spectral nature of ALL-SKY inter-annual variability and trend detection in the mid-infrared as shown in Figure 2.

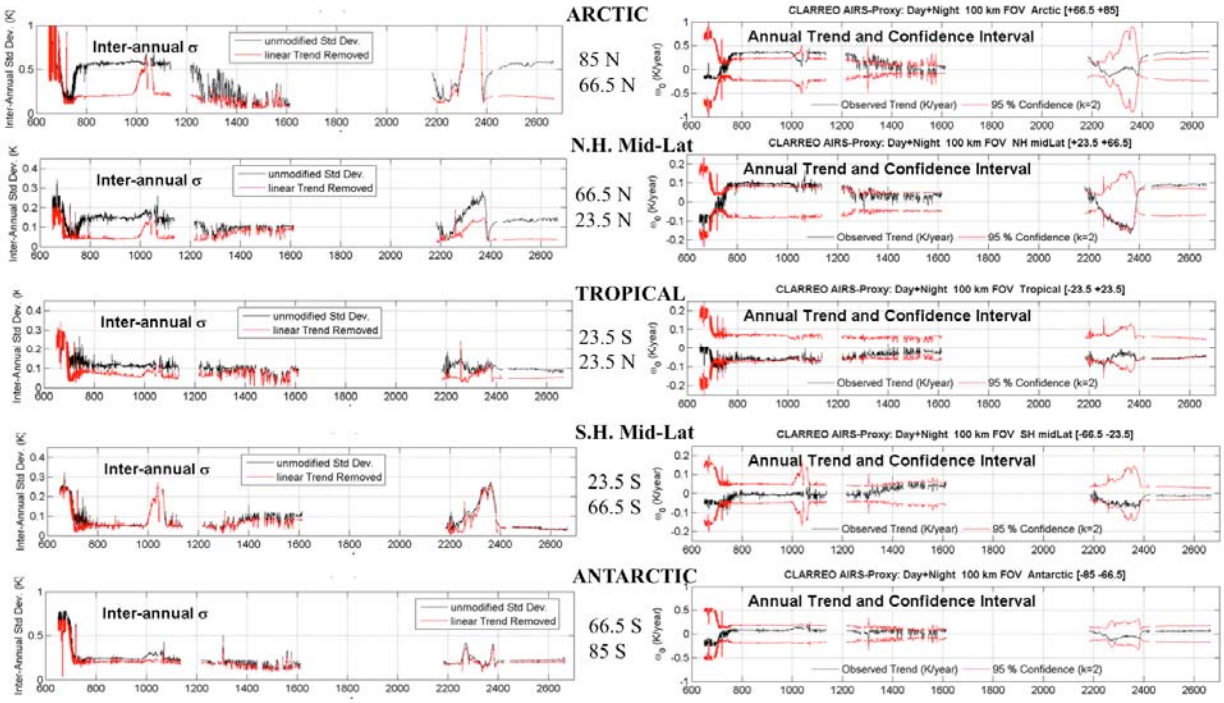

Figure 2. A CLARREO proxy dataset developed at UW-SSEC using AIRS observations was used to investigate the natural variability,and radiance trends and uncertainties the CLARREO infrared sensor will be required to observe (Knuteson et al. 2009). The trend uncertainty is the 95% confidence interval defined in Weatherhead et al. 1998. A significant warming trend is seen in the Arctic for the time period 2003-2007. A limitation of the AIRS dataset is the sun-synchronous time sampling, additional study on the diurnal radiance signal is proposed.

Cross-Calibration Accuracy Evaluation using Aqua & Metop-A Data Sets

As part of the CLARREO team efforts, we performed studies to determine the impact of key sensor parameters on the ability of CLARREO to serve as an inter-calibration reference for operational infrared sounders (Tobin et al. 2008c; Holz et al. 2007, 2008, 2009). The studies, which have been presented at numerous CLARREO meetings, have considered the case where three or less CLARREO satellites in 90-degree polar orbits are used to transfer the absolute calibration from the CLARREO infrared sensor to an operational advanced IR sounder in a sun-synchronous orbit, e.g. IASI on MetOp or CrIS on NPOESS. This particular inter-calibration goal addresses the needs of the operational weather community for improved absolute accuracy while opening the possibility of using the weather observations to contribute to the long-term climate record. Here we provide a brief summary of the study methodology and conclusions. The results are believed to be very credible as they are based an entire year of MODIS Earth observations and represent the actual spatial variability of the atmosphere and a realistic sampling approach.

An Inter-calibration simulator was developed capable of simulating the proposed CLARREO orbits, intersecting CLARREO with existing operational platforms (Aqua MODIS), and then using real MODIS IR measurements to characterize the spatial and

temporal sampling uncertainties. Using this simulator, an in-depth investigation of the CLARREO orbit selection, FOV size, and noise characteristics with respect to inter-calibration was completed. Figure 3 shows an example from the simulator of how CLARREO, IASI, and CrIS sample observations are constructed from real MODIS observations.

It was found that spatial and temporal sampling uncertainties are not a limiting factor for inter-calibration, being significantly smaller then 0.1 3-sigma with the selection of the CLARREO FOV size (25 – 100 km diameter) not significantly impacting the results. Accounting for spatial sampling uncertainties, CLARREO noise performance of better than 1.2 K for window channels for a 10 second sampling interval is adequate for validating radiances to better than 0.1 K 3-sigma in a month with CLARREO in 3 90º polar orbits (this NEΔT performance for 10 sec sampling intervals could be scaled to other sampling times by scaling NEN by sqrt(10sec/sample time). Being a window region, the 11 um channel used in this investigation represents one of the more challenging spectral regions to calibrate because of the large BT variability. More opaque spectral regions will have reduced BT variability resulting in a larger number of usable fields of view, reducing the required noise performance. Future work will include keeping the inter-calibration simulator current with the changing CLARREO baseline.

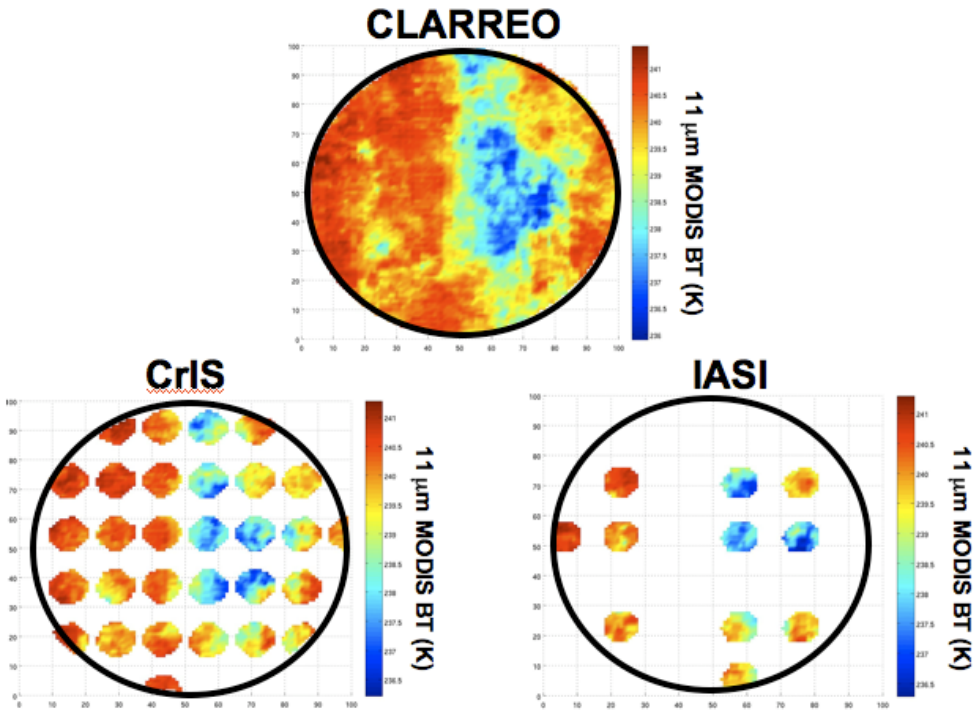

Figure 3. An example from the inter-calibration simulator demonstrating how CLARREO, IASI, and CrIS sample observations are constructed from real MODIS observations. For any given SNO of CLARREO with CrIS or IASI, a primary contributor to the uncertainty budget is the relatively sparse spatial sampling of the CrIS and IASI. In this case of 100km CLARREO FOVs, CrIS and IASI provide approximately 55% and 18% coverage of the CLARREO FOV, respectively.

CLARREO Payload Requirements and Systems Design

Funding for this task was removed from this grant support.

Augmented Climate Product Orbital Sampling Study

A report on this topic from the subgrant from UW-SSEC to the Uni. of Maryland is provided as an attachment to this final report.

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