NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2010
NNH10ZDA001N-CLARREO
CLARREO Science Definition Team

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC, has selected proposals for the CLARREO Science Definition Team, Element A.38 in the Research Opportunities in Space and Earth Sciences, in support of the Earth Science Division (ESD). The CLARREO Science Definition Team will provide scientific advice and science study support to the NASA Climate Absolute Radiance and Refractivity Observatory (CLARREO) project through it's Phases A and B of mission development. These studies are required to ensure that NASA maximizes the science return from the mission while maintaining responsible budgetary and engineering constraints.

The ESD is awarding 11 proposals, for a total dollar value over a three-year period of approximately $1.6 million/year through the NASA's Shared Services Center (NSSC).

The NASA Climate Variability and Change and Atmospheric Composition research programs support numerous observational activities through satellites, airborne platforms, and internationally based ground networks, numerous data analysis and modeling studies that significantly utilize these observations, and laboratory based studies that enhance the scientific utilization and precision of the observations, data analysis, and modeling. Both modeling studies and instrumental support were solicited in this call. All the selected proposals showed that they will make significant progress in enhancing NASA's science priorities, improve our understanding of long term climate observations, provide key advise for NASA's satellite development, and ultimately improve our ability to produce high level products and models that enhance Earth Science decision support efforts.

Twenty one CLARREO Science Definition proposals were evaluated of which 11 have been selected for award.

They are:

Chi Ao/Jet Propulsion Laboratory
GNSS RO Analyses for CLARREO

We propose to be members of the CLARREO Science Definition Team (SDT). We will contribute to and support activities involving the formulation and refinement of mission requirements relating to GPS/GNSS RO measurements from CLARREO. Our proposal team has many years of experience and in-depth knowledge of GNSS RO instrumentation and data processing. We have developed the tools and capability in carrying out end-to-end simulations of GNSS RO observations that incorporate, among other things, receiver and orbital errors. Therefore, we are fully qualified to address the necessary issues that must be understood and quantified in meeting the CLARREO science objectives.

Our primary objective is to carry out SI-traceability analysis for GNSS RO measurements with our end-to-end simulation software. CLARREO has a very stringent requirement on the accuracy of the refractivity (current baseline requirements for refractivity call for less than 0.03% for 5-20 km and 0.1% for 2-5 km altitude). This level of accuracy has never been rigorously established with existing RO measurements, and further investigations are necessary to clarify what factors (instrument and/or processing) are most significant in reducing the refractivity uncertainty.

In this proposal, we identify two areas where additional error analyses are most critical. First, we need an updated, realistic assessment of the ionospheric residual errors in the retrieved refractivity. Second, we need better understanding of the lower troposphere biases and depth penetration and how they relate to receiver tracking as well as retrieval algorithms. We are particularly interested in the question: To what extent can these problems be solved with better instrumentation? Without a good answer for this question, it would be impossible to properly address mission design tradeoffs including receiver tracking and antenna configuration.

In addition, we will perform climate data analysis using existing GNSS RO measurements from CHAMP and COSMIC/FORMOSAT-3. We will examine the feasibility of using GNSS RO refractivity in climate trend detection and climate model testing, using both simple time series analysis as well as the optimal fingerprinting approach. With nearly a decade of continuous GNSS RO measurements currently available, significant insights for the CLARREO mission concerning optimal spatial and temporal sampling can be gained through such analyses.

Helen Brindley/Imperial College London
Feasibility and Sensitivity Studies for CLARREO: A New Opportunity for Climate Monitoring from Space

The work we propose to undertake here will assist colleagues in the USA in the design of a new mission, CLARREO, which will make extremely accurate observations of the Earth's climate from space: these observations will be used to improve our ability to predict (model) the future climate. The Earth's climate system represents a balance, when seen from space, between the incoming energy from our Sun (solar energy), which heats the Earth, and the cooling effect of the outgoing infrared (IR) energy. Visible light is composed of many different spectral colours, or wavelengths, and this is also true for the solar and IR energy. Just as we have identifying fingerprints, important climate variables, such as water vapour, carbon dioxide, ozone and methane have their own individual spectral signatures.
By making measurements of the relative amounts of energy at different wavelengths using a spectrometer, it is possible to determine the role that different climate variables have on the current state of the climate. By measuring these spectral signatures at different times and comparing them, it is possible to understand how the climate has changed over that time period and the role that the different climate variables have played. Current spectrometers do exist, but have limitations in terms of their accuracy or sampling. It is intended that the new mission proposed here will sample the entire Earth

with sufficient accuracy for the first time for the measurements to be used as a rigorous test of the ability of our current climate models to represent the current climate, and hence better predict future changes. Resources are limited, so it is essential that we specify exactly how these measurements are made. The most important points to consider are the accuracy of the measurements, the time between making measurements over the same area of the Earth, and how detailed these measurements are.

If successful, our proposal would allow representatives from Imperial College to join the IR benchmarking and calibration/validation working groups of the CLARREO Science Definition Team. The series of studies we propose here will use a combination of existing observational data and our best knowledge of the atmospheric state (obtained by the assimilation of observational and model data) in order to determine the minimum requirements of the measurements that will be needed to achieve the goal of detecting decadal scale climate change, and attributing the changes seen to specific causes. These studies will enable us to provide advice to our NASA colleagues as to the composition of the mission, given the available budget, in terms of the optimal satellite orbital configuration, the frequency and detail (spectral resolution) of the measurements made and the accuracies required to overcome natural climatic variability. Through our experience in Earth Observation instrument calibration/validation we will also be in a position to contribute to a number of different strategies to ensure that the ability of CLARREO to meet its accuracy goals can be demonstrably proven. In addition, we propose to build a UK CLARREO Project Team of interested UK parties to facilitate greater involvement in the US-led project across the UK as a whole.

William Collins/University of California, Berkeley

Shortwave and Pan-Spectral Observing System Simulation Experiments in Support of the CLARREO Science Definition Team

We propose to use our team's existing Observing System Simulation Experiments (OSSEs) capability to analyze simulated spectra in support of the CLimate Absolute Radiance and REfractivity Observatory (CLARREO) Science Definition Team (SDT). We will use simulated shortwave and pan-spectral (shortwave and infrared) spectra for optimal detection using spectral fingerprints of decadal change based directly on the CLARREO data. Consistent with the directives from the National Research Council's Decadal Survey [Space Studies Board, 2007], we will examine the feasibility of detecting forcings and feedbacks in globally- and zonally-averaged annual-mean and seasonal-mean simulated spectra. Specifically, we will focus on the forcings by natural and anthropogenic aerosols and on the feedbacks from changes in cloud amounts, cloud water content, cloud microphysical properties, snow cover, water vapor, and the areal extent of sea ice.

These efforts will benefit the CLARREO SDT in several different ways. First, our team will use our OSSE capabilities to quantify changes that can be anticipated in the solar spectral reflectance of the Earth under future climate change scenarios. We will initially focus on simulations performed with the Community Climate System Model [CCSM; Collins et al, 2006]. Second, we will assess the ability to detect and separately attribute shortwave and pan-spectral forcings and feedbacks from the simulated spectra. Third, we will examine how different orbital configurations impact the detection and attribution results. Finally, we will evaluate the utility of the CLARREO instrument as a means of testing the detectability of differences in forcing and feedback strengths among global climate models by adapting the OSSE tool to use output from the Geophysical Fluid Dynamics Laboratory (GFDL) model [Delworth et al, 2006] and from the Cloud Forcing Model Intercomparison Project (CFMIP) archive [McAveney et al, 2003] and/or the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model dataset [Meehl et al, 2007]. This will allow us to use a common analytical framework with multiple plausible realizations of the Earth's future climate system. We will use the OSSE results and analysis thereof to provide input to the shortwave-science working group and provide inputs to the reference intercalibration efforts. Our team will also provide simulated spectra to the entire CLARREO SDT for present and future conditions to ensure transparency and to utilize the SDT's expertise to gain additional insights from the simulations.

Because of the extreme computational expense associated with the shortwave OSSE calculations (which can only be managed using massively parallel computing systems such as those operated by NASA High-End Computing facilities), our team's effort will represent the first comprehensive effort to study the evolution of the reflected solar spectrum of the Earth under climate change scenarios. Additionally, our team's efforts will break new ground by studying the possible synergies between collocated and/or temporally coincident measurements of the solar and infrared spectrum to detect low-cloud, high-cloud, and water-vapor feedbacks.

John Dykema/Harvard University
Providing Advice on Issues of Infrared SI Traceability to the Science Definition Team for the CLARREO Mission

The central objective of the proposal is to provide expert guidance to the CLARREO mission on obtaining credible, comprehensive estimates of the measurement uncertainty for the infrared instrument suite. This expert guidance will assist the CLARREO project in formulating calibration and validation plans that utilize the best available technology and relevant new developments in basic research in a cost-effective and timely manner. The method proposed to accomplish these objectives is to execute mathematical analysis and numerical modeling based on existing laboratory results (and on new results, as they become available from other activities) to address questions as they arise during the period of performance of the proposal about infrared sensor characteristics, performance, and susceptibility to environmental effects. This work directly addresses the request in the solicitation for "guidance for the development of calibration and validation plans for the mission" in making "highly accurate and SI traceable decadal change observations." The proposed work is essential to the success of the overall CLARREO mission because it provides unique capabilities and experience that have made fundamental contributions to the formulation of practical methods for achieving high accuracy climate observations that are SI traceable. The proposed work is highly relevant in general to NASA interests and programs because it supports the capability to make the type of decadal climate change measurements that were explicitly identified as a top priority by the National

Research Council (NRC) Decadal Survey (DS) of 2006. These decadal climate change measurements allow the detection of human influence on climate in a robust new fashion. These measurements can also be used to test climate models in a mathematically rigorous way to improve forecasts by reducing in the uncertainty associated with key physical processes in the climate system.

Xianglei Huang/University of Michigan
Proposal for Participation in the Science Definition Team for the CLARREO Mission

CLARREO is a top-priority mission in the NRC Decadal Survey of Earth Science. It addresses the imperative need to acquire irrefutable observational records of climate change over the decadal time scales through two avenues: reference inter-calibration and optimal detection as well as the attribution of spectral fingerprints. The PI has been working on various aspects of IR spectrally resolved radiances and their applications in evaluating general circulation models (GCMs) since his graduate study. Based on these works and studies, he has published six first-authored papers (plus one more now under minor revision for JGR) on the peer-reviewed journals, covering detailed data analysis of observed radiances, satellite-GCM comparisons in the radiance domain and innovative usages of spectral radiances in GCM evaluation. The PI has extensive experience with spectral radiances observed by IRIS, IMG, and AIRS and keeps archiving AIRS radiances with careful quality control. He runs GFDL and NCAR models and extensively uses the GFDL GCMs in his other research projects and publications. He has worked with UCLA GCM and recently NASA GEOS-5 GCM and has infrastructure developed for offline simulation of IR radiance based on GCM outputs. Meanwhile, the PI has acquired knowledge about the IR instrumentation and calibration from his work with IRIS and IMG spectra and with AIRS and CERES radiances. Such balanced expertise on IR spectrally resolved radiances and GCM simulations, together with enough understanding of calibration and instrumentation, makes the PI strongly qualified for contributing to the Science Definition Team for the CLARREO mission.

The PI proposes to participate in the Science Definition Team and to contribute in following two topics:

(1) Testing and validating global climate models using CLARREO data: The PI proposes to explore information contents of CLARREO that can be used to critically evaluate and validate GCMs, as well as the optimal strategy to carry out such evaluation. The soon-to-be publicly available CMIP5 (Coupled Model Intercomparison Project, Phase 5) archives for the next IPCC AR5 will have daily 3-D cloud diagnostics fields for certain numerical experiments, which makes it an ideal test bed for such exploratory studies. The PI proposes to generate synthetic radiances from CMIP5 outputs, to survey the spread of such synthetic spectra in terms of both the mean states and the spatial-temporal variability and to understand to what extent the future CLARREO measurement can help distinguish such performances of these GCMs.

(2) Simulations of CLARREO data using climate models: The PI proposes to explore the merit of high-resolution GCMs (i.e. grid box at 25-50km, comparable to the proposed CLARREO footprint) in assisting CLARREO mission definition and scientific requirements. The PI also proposes to contribute to the development of CLARREO simulators based on CMIP5 data archives, with an emphasis on the correct and flexible handling of the cloud overlapping schemes and cloud spectral properties to ensure maximum consistency between such radiance simulator and the radiation scheme of corresponding GCM (i.e. to avoid "re-interpret" a GCM output with incorrect consistent spatial and radiative properties).

The PI is also interested in and willing to contribute to the usage of CLARREO data as reference calibration for operational sensors, primarily based on his work on analyzing currently available AIRS and CERES radiances. The PI can provide the eight-year AIRS radiance dataset as well as the GCM outputs to other team members upon their requests.

The most unique strength of the PI is his equal proficiency in the space-borne observations of spectrally resolved radiances and GCM simulations. Therefore, the PI proposes to participate in the Science Definition Team with an focus on the climate modeling applications of CLARREO and usage of such tools in assisting the scientific definition of CLARREO.

Stephen Leroy/Harvard University
Advising GNSS Radio Occultation and Climate Modeling Studies for the CLARREO Science Definition Team

The P.I. intends to participate as a member of the Science Definition Team for the Climate Absolute Radiance and Refractivity Observatory. Dr. Yi Huang, the Co-Investigator, will also participate as a member of the SDT. The P.I. has already played a prominent role in CLARREO in its pre-phase A, having provided its intellectual foundation of testing climate models by long term determination of the climate's radiative feedbacks in peer-reviewed articles and having served as Acting Instrument Scientist for the radio occultation (RO) instrument. Dr. Huang, in pre-phase A, has contributed important peer-reviewed articles on methods of inferring maps of longwave feedbacks using CLARREO data types as well as the interpretation of climate change from long term trends in the infrared spectrum. The P.I. intends to lead the radio occultation Working Group and contribute to the climate modeling working group. He, with the assistance of Dr. Michael Gorbunov, will diagnose RO tracking difficulties in the lower troposphere, continue sampling studies for RO as required, and advise on measurement requirements until they are finalized. The P.I. will also continue his involvement with information content and optimal detection studies. Dr. Huang intends to contribute to the infrared and climate modeling working groups. He will engage in activities necessary to arrive at theoretical detection time for usefully con- straining climate's radiative feedbacks and analyze existing data to validate CLARREO's approach to testing climate models. Both the P.I. and Dr. Huang will be able to advise on many other issues pertinent to CLARREO during Phases A and B.

Peter Pilewskie/University of Colorado
LASP CLARREO Science Definition Team Studies: Using Measurements of Scattered Spectral Shortwave Radiation to Define Requirements, and to Develop Methods for Trend Detection and Attribution

We propose to build on our prior CLARREO science studies to develop new tools for extracting trends in the existing reflected solar radiance data record. The climate benchmarking methodology relies on using directly measurable variables, rather than retrieved or model derived, in order to minimize uncertainty and link to future measurements. Unfortunately, the Earth's albedo or even the scattered shortwave irradiance cannot be obtained from a direct measurement. The fundamental science question for our proposed study is then, are there climate trends that can be detected in the directly measured scattered spectral shortwave radiance? And the subsequent question, can the causes of observed trends be unambiguously determined? These form the basis for our continuing studies.

There are three primary tasks we propose. The first is to examine time series of eigenvectors derived using Principal Component Analysis (PCA) and Singular Spectrum Analysis (SSA) applied to large sets of reflected radiance spectra. Because current shortwave hyperspectral imagers lack the stability to extract long term global climate trends in reflected shortwave radiance (for example, those due to water vapor or cloud feedbacks), we will focus on regional trends that have very large signals. For example, changes in Arctic sea ice extent are readily observed from space and may provide an ideal testbed for some of the proposed methodologies. The second task will be to determine the intersection between linear subspaces in large sets of observed and modeled shortwave radiance data. Here we draw from studies first applied to atmospheric correction procedures, which are really techniques for the separation of variables. The consequence of finding the common eigenvectors between measurements and models is that the source of variability is known in the model, thus paving the way for component attribution, often intractable from standard PCA. The third task will be to develop new methods for the difficult problem of extracting the influence of aerosol particles on the spectral signature from heterogeneous cloud fields. Data to be applied in this task come from aircraft measurements of hyperspectral irradiance and the output from a Large Eddy Simulation model. In addition to these three focused study tasks, one of the Co-investigators on this proposal, Greg Kopp, will apply to lead the Reflected Solar Benchmarking Working Group.

Henry Revercomb/University of Wisconsin-Madison
CLARREO Science Definition Team Memberships

We propose four CLlimate Absolute Radiance and REfractivity Observatory (CLARREO) Science Definition Team (SDT) memberships from the University of Wisconsin-Madison, Space Science and Engineering Center (SSEC), including Drs. Hank Revercomb, Robert Knuteson, William L. Smith, Sr., and David Tobin. All have extensive experience from previous and current satellite instruments, from Pre-Phase-A efforts that helped to define the CLARREO Mission, and from activities similar to the type of tasks identified as key duties of the CLARREO SDT. Our primary focus will be on the IR spectral radiance measurements, but the synergy among the IR and Solar radiances and GPS refractivity observations is also of high interest. Specialized areas of focus for each are (1) Revercomb: SI-traceable uncertainty analyses and Post-launch validation approaches; (2) Knuteson: IR benchmark data product development including involvement in 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. These activities therefore span a wide range of important topics from ensuring the basic calibration and traceability of the measurements, to creating the benchmark radiance products, to determining geophysical attribution of observed radiance trends, and intercalibration. All of these activities are based on successful demonstrations that have involved the use of existing satellite, aircraft or laboratory data sets.

We also propose to support the SDT Working Groups by providing leadership. We nominate Dr. David Tobin as the Working Group Leader for Infrared reference intercalibration, and Dr. Robert Knuteson as Co-Leader of the Infrared benchmarking working group.

The previous accomplishments of these individuals prove the high value of the proposed SDT memberships and Working Group Leadership roles.

Brian Soden/University of Miami

Feedback Analyses using Radiative Kernels in Support of the CLARREO Science Definition Team

The extent to which the climate will change due to an external forcing depends largely on radiative feedbacks, which act to amplify or damp the surface temperature response. Differences in the representation of these feedbacks are directly responsible for the uncertainty in current model estimates of climate sensitivity. To facilitate the analysis of climate feedbacks, Soden et al. (2008) outlined a method for quantifying them based on “radiative kernels” which describe the differential response of the top-of-atmosphere radiative fluxes to incremental changes in the feedback variables. The use of radiative kernels enables one to decompose a feedback into two parts: one that depends on radiative transfer and the unperturbed climate state, and a second factor that arises from the climate response of the feedback variable. By cleanly separating the radiative feedback in this manner, the relative importance of different responses of the feedback variables can be readily quantified

The objective of this proposal is to apply spectrally-resolved radiative kernels to AR5 climate model simulations to: (1) apply temporal band-pass filtering to analyze the time-scale dependence of feedback processes; and (2) guide the temporal sampling strategy of CLARREO such that it can satisfactorily constrain the range of model-simulated feedbacks to within acceptable levels of uncertainty. Particular emphasis will be placed on reducing uncertainty in cloud feedback, which remains the largest source of uncertainty in model projections. A key aspect of this work will involve the use of AR5 model simulations to identify those aspects of cloud feedback which are time-scale invariant; that is, they exhibit similar behavior in both observable climate variability and anthropogenic climate-change. The use of radiative kernels will also help in elucidating the physical mechanisms leading to these similarities.

To minimize the duplication of effort, our work will be coordinated with existing and planned activities that are developing spectrally-resolved LW and SW radiative kernels for CLARREO. By applying spectral radiative kernels developed for CLARREO to climate model output from AR5 we hope to provide a quantitative framework for defining the space-time sampling requirements needed for CLARREO to reduce uncertainty in the representation of key climate feedbacks in models.

Lawrence Strow/University of Maryland Baltimore County
CLARREO: Development Guided by Existing Hyperspectral Satellite Knowledge Base

The infrared hyperspectral benchmark measurements proposed for the CLARREO mission will require detailed examination of a wide range of instrument and data analysis issues. While many fundamental instrument and data analysis issues are being addressed by the early developers of the CLARREO concept, many uncertainties remain. We propose to leverage our considerable experience in the development and use of infrared hyperspectral satellite sounders (AIRS, IASI, CrIS) to help achieve the scientific goals of the CLARREO program. Our experience includes thermal vacuum testing, radiative transfer algorithms, spectral calibration, validation, retrieval of dust and CO_2, and more recently climate trending using radiance time derivatives. We are also working to produce an AIRS Level 1C radiance product for climate trending, early versions of this product will be provided to the CLARREO team for real-world data analysis testing. We will focus on a combination of topics that (1) leverage our experience, (2) are not receiving considerable current attention, and (3) are essential for CLARREO scientific success.

Xiaoxiong Xiong/NASA Goddard Space Flight Center
Science Definition Support for the CLARREO Reflected Solar Instrument and Measurements

The CLimate Absolute Radiance and REfractivity Observatory (CLARREO) mission is specifically focused on the observation and measurement of decadal climate change. As a result, the absolute accuracy of CLARREO observations relative to the International System of Units (SI) is of primary importance in achieving its science goal of the ultimate formulation of a fundamental climate data record. In addition to producing highly accurate and SI traceable data products of its own, CLARREO will realize its climate goals through intercalibration of temporally and spatially coincident measurements from other on-orbit sensors. Compared to previous missions, an accuracy of 0.3% (2-sigma) for the CLARREO reflected solar measurements is extremely challenging. We propose to participate in the Science Definition Team (SDT) for the CLARREO mission with a focus on the reflected solar SI-traceable benchmark measurement and reference intercalibration. Specifically, we plan to serve as liaisons with the broader science and remote sensing community, identify and quantify challenging issues to be resolved for high quality sensor calibration and intercalibration, and provide guidance on traceable measurement requirements and uncertainty analyses.