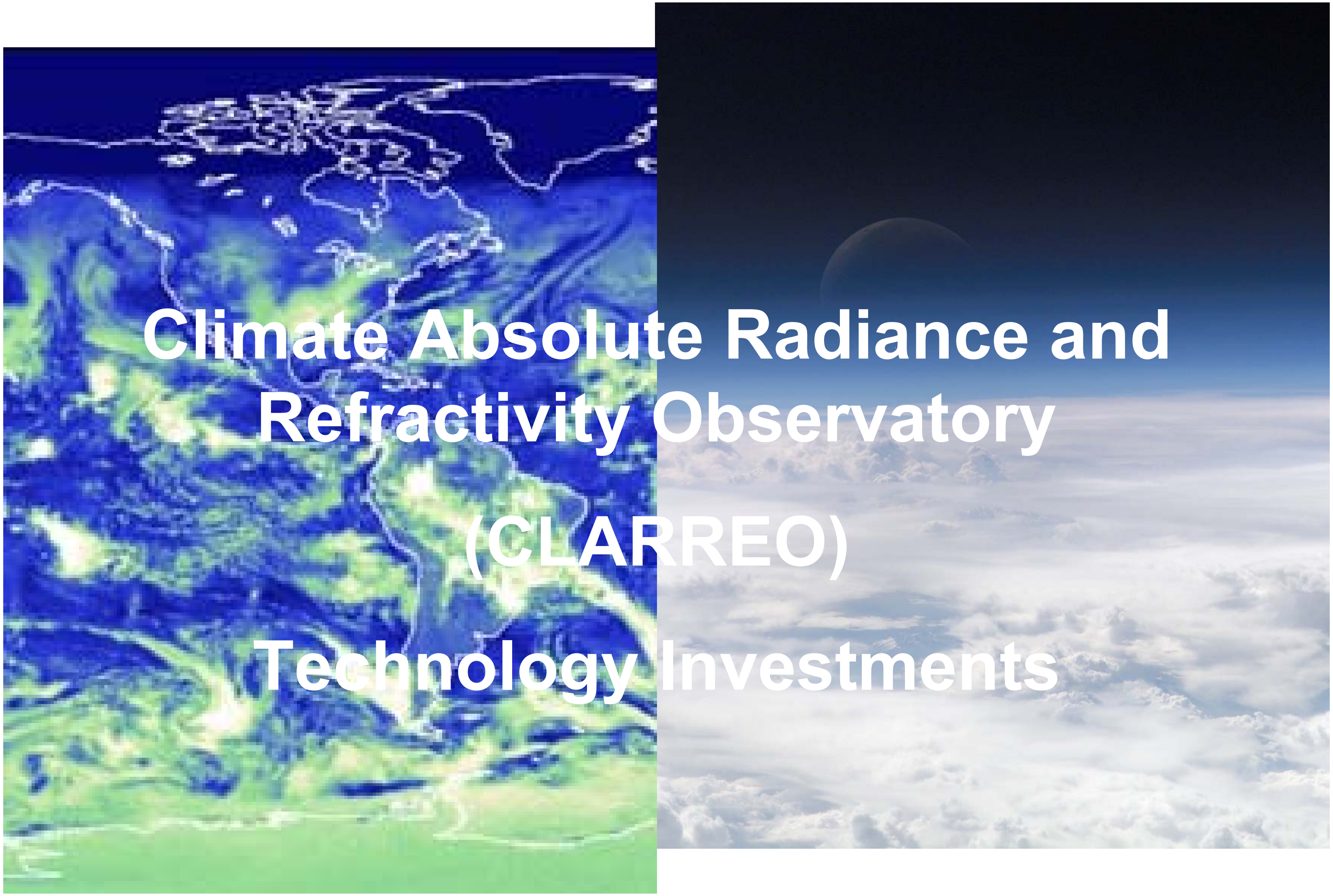


Climate Absolute Radiance and Refractivity Observatory

(CLARREO)

Technology Investments

ESTO
Earth Science Technology Office

Mission and Payload

Decision support for vital choices regarding water resources, human health, natural resources, energy management, ozone depletion, civilian and military communication, insurance infrastructure, fisheries, and international negotiations is necessarily linked to an understanding of climate. Effectively addressing each of these societal concerns depends on accurate climate records and credible long-term climate forecasts. Development of climate forecasts that are tested and trusted requires a chain of strategic decisions to establish fundamentally improved climate observations that are suitable for the direct testing and systematic improvement of long-term forecasts. That strategy sets the foundation of CLARREO.

CLARREO addresses three key societal objectives: (1) provision of a benchmark climate record that is global, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards; (2) development of a trusted, tested operational climate forecast through a disciplined strategy using state-of-the-art observations with mathematically rigorous techniques to establish credibility; and (3) disciplined decision structures that assimilate accurate data and forecasts into intelligible and specific products that promote international commerce and societal stability and security.

Ref: "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," National Academies Press, 2007

Mission Overview

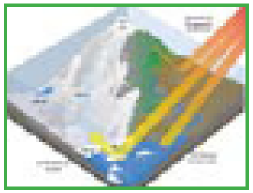
- **CLARREO Imperatives**
  - Initiate an unprecedented, high accuracy record of climate change that is tested, trusted and necessary to provide sound policy decisions.
  - Initiate a record of direct observables with the high accuracy and information content necessary to detect long term climate change trends and to test and systematically improve climate predictions.
  - Observe the SI traceable spectrally resolved radiance and atmospheric refractivity with the accuracy and sampling required to assess and predict the impact of changes in climate forcing variables on climate change.

- **Key Measurements**
  - Absolute, spectrally resolved emitted thermal radiation
  - Absolute, spectrally resolved reflected solar radiation
  - Atmospheric refractivity

Ref:"Dave Young, CLARREO Science Study Lead" 17 Oct. 2008

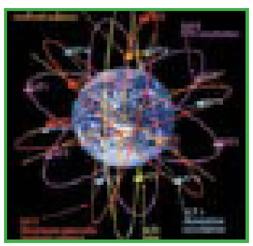
CLIMATE ABSOLUTE RADIANCE AND REFRACTIVITY OBSERVATORY (CLARREO)

Launch: 2010-2013   Mission Size: Small

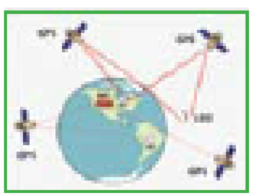


Absolute spectrally resolved infrared radiance

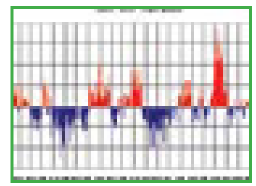
Incident solar and spectrally resolved reflected irradiance



Absolute calibration for operational sounders



Pressure, temperature, water vapor profiles



Benchmarking of climate record to improve climate predictions

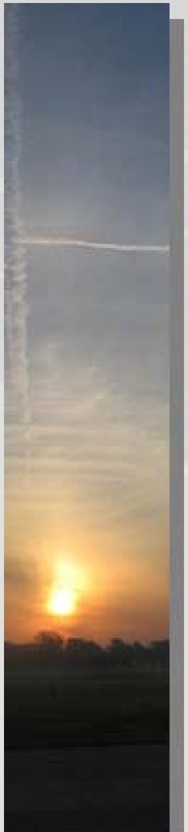
Changes in sea level, storm patterns, and rainfall associated with changes in temperature patterns

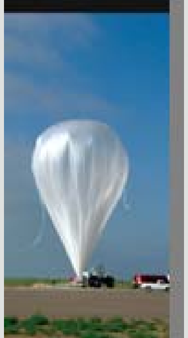
Ozone and surface radiation forecasts and public advisories

Ref: "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," National Academies Press, 2007

Radiation Balance Measurements

Missions Supported: CLARREO





Update 6-11-08

Measurement Approach

Polar Low Earth Orbit (LEO) downward-directed spectrometers to provide spectrally resolved signal of the outgoing irradiance. Interferometers with a spectral resolution of 1 cm^{-1} covering the thermal infrared in addition to spectrometers measuring the reflected solar component.

Earth Science Technology Office (ESTO) Investments

- Far Infrared Spectroscopy of the Troposphere. High altitude (30 km) balloon demonstration of advanced Fourier Transform Spectrometer Instrument. Two flights (6/2005; 9/2006); One ground-based campaign (3/2007); Selected by NASA and DoE for FORGE/RHUBC ground based campaign in 2009. Instrument covers 6 to 100 micrometers @ 0.625 cm^{-1} resolution (Mlynzak/LaRC – IIP01)
- Demonstration of a net radiant flux instrument using a Fourier Transform Spectrometer including a flight demonstration (Mlynczak/LaRC – IIP 04; Flight demonstration to occur in FY 2009)
- Development of sensitive 10-100 µm detectors to operate at 10 Kelvin. Far infrared technology advancement partnering. (Mlynczak/LaRC – ATIQRS06)
- Development and demonstration of the multi-disciplinary frameworks and observation simulations of an adaptive measurement strategy on a sensor web (Lee/JPL – AIST 05)
- Development and lab demonstration of a 300-1050 nm hyperspectral imager capable of cross-calibrating via direct solar irradiance measurements (Kopp/LASP-IIP07)
- Development and demonstration of key technologies (detectors for wavelengths between 15 and 50 um that can operate without cryogenic cooling; SI-traceable blackbody radiance standards for wavelengths beyond 15 um; and optical beamsplitters capable of covering the entire 5 to 50 um spectral range) for CLARREO mission (Mlynczak/LaRC-IIP07)
- Development and demonstration of technology necessary to measure IR spectrally resolved radiances with ultra high accuracy (<0.1 K, 3-sigma brightness temperature at scene temperature) for the CLARREO mission (Revercomb/University of Wisconsin-Madison-IIP-07)
- Produce reduced volume, reduced complexity summary data set from very large observational and model generated data sets **processing 3 years of atmospheric radiation measurements (Braverman/AIST)**
- Implemented cloud detection and atmospheric correction algorithms in C and on an FPGA (Ballou/AIST)
- Develop airborne Imaging Fabry-Perot Spectrometer GIFS instrument for 2D images of high resolution spectral line shapes of O2 at atmospheric band absorption in solar backscattered radiation (Yee/IIP)

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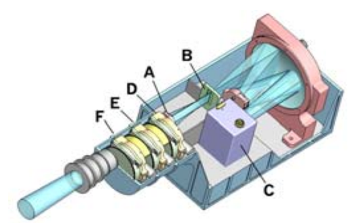
Instrument Technologies

(Current and Completed ESTO Investments)



CORSAIR: Calibrated Observations of Radiance Spectra from the Atmosphere in the far-InfraRed Description

- This task will demonstrate several technologies required to achieve the CLARREO mission defined by the recent Decadal Survey for Earth Science. Central to the objectives of CLARREO is the measurement from satellites of the spectral radiance (W cm-2 sr-1 cm-1) emitted by the Earth and its atmosphere. The CLARREO measurements are to be made across nearly the entire infrared emission spectrum at high accuracy and stability and are to be traceable to international measurement standards.

- Specifically this task is to demonstrate at TRL 6 detectors for far-infrared (far-IR) wavelengths between 15 and 50 μm that can operate without cryogenic cooling; SI-traceable blackbody radiance standards for wavelengths beyond 15 μm; and optical beamsplitters capable of covering the entire 5 to 50 μm spectral range.

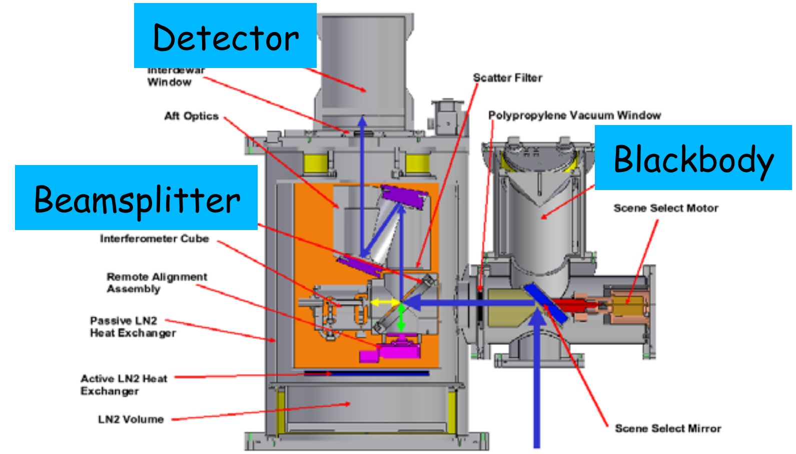
- These technologies will be ready for insertion into the CLARREO sensors upon completion of this IIP effort. Prior investments by the Defense Advanced Research Projects Agency (DARPA) and Raytheon Vision Systems in the development of far-IR detectors are leveraged. Also prior NASA investment in the Far-Infrared Spectroscopy of the Troposphere (FIRST) instrument that will be used as a testbed for demonstrating the detectors to be developed in this task is leveraged.

CORSAIR: Calibrated Observations of Radiance Spectra from the Atmosphere in the far-InfraRed

PI: Martin G. Mlynczak, LaRC

Objective

- Advance to TRL 6 technologies central to enabling the CLARREO mission as defined in the recent Earth Science Decadal Survey.
- Performance goals are 0.1 Kelvin absolute radiometric accuracy (3 standard deviations) over a spectral range from 200 to 2000 cm^{-1} with a resolution of 1.0 cm^{-1}.
- Technologies include infrared detector elements sensitive from 15 to 50 cm^{-1} that do not require cryogenic cooling; SI traceable blackbody radiance standards for wavelengths beyond 15 μm; and robust optical beamsplitters with continuous high efficiency over the full 200 to 2000 cm^{-1} spectral range.



System diagram highlighting technologies addressed by CORSAIR

Approach:

Advance TRL of key enabling technologies by:

- Develop antenna-coupled THz detectors and demonstrate performance in a working Fourier transform spectrometer (FTS) system;
- Use Low-Background Infrared facility at the National Institute of Standards and Technology to characterize existing specular-reflection blackbody;
- Develop multilayer coatings for broadband Cesium Iodide beamsplitter and demonstrate performance in existing laboratory FTS.

CoIs: David Johnson, Nurul Abedin, Xu Liu, LaRC; David Jordan, ITT; Jinxue Wang, Raytheon VS; Gail Bingham, Harri Latvakoski, USU SDL; Kevin Bowman, JPL; Simon Kaplan, NIST

Key Milestones

• Blackbody (BB) characterized at NIST	08/09
• Detector lot 1 characterization complete	12/09
• Beamsplitter design complete	08/09
• Flight BB prototype fabrication complete	08/10
• Detector lot 2 characterization complete	12/10
• Beamsplitter R and T measurements complete	12/10
• Prototype BB testing complete	08/11
• Detector lot 2 testing at LaRC complete	12/11
• Beamsplitter performance testing complete	05/11

TRL_{in} = 3

Far Infrared Spectroscopy of the Troposphere (FIRST) Description

- This task developed and field demonstrated the Far Infrared Spectroscopy of the Troposphere (FIRST) instrument. The FIRST instrument is a nadir-viewing Michelson Interferometer covering the spectral range from 10 to 100 μm (1000 to 100 cm-1) at 0.6 cm-1 spectral resolution.

- FIRST demonstrates the use of a broad bandpass beamsplitter, a passively cooled high throughput optical system, and a passively cooled detector system to achieve accurately calibrated measurements of the far-infrared (far-IR, 15-100 μm) portion of the Earth’s outgoing long-wave radiation that is virtually unobserved directly. The far-IR contains up to half the radiant energy emitted by the Earth and its atmosphere and is strongly modulated by water vapor (the main greenhouse gas) and cirrus clouds.

- The technology developed and demonstrated for FIRST resulted in an instrument that combines radiation budget sensing with temperature and moisture vertical profiling capability. The subsequent adaptation of FIRST to space as a next-generation research instrument for NASA will require only modest modifications to the design.

Far Infrared Spectroscopy of the Troposphere (FIRST)

PI: Marty Mlynczak, LaRC

Description and Objectives

- 3-year proposal to advance and demonstrate key technologies to make measurements of crucial component of Earth's radiation balance, the **far-infrared emission**, containing over 50% of the outgoing longwave radiation but rarely observed directly.
- The energy in this region is modulated by water vapor (the main greenhouse gas) and by cirrus particles.
- Perform system design and engineering modeling, fabrication, calibration, ground and flight testing.
- Demonstrate key technologies in a high-altitude (90,000 ft) balloon flight.

- **PI: Marty Mlynczak, NASA LaRC**
- Co-I's: Dave Johnson, NASA LaRC; Harri Latvakoski, Utah State SDL; Ken Jucks, Harvard Smithsonian; David Kratz, NASA LaRC; Xu Liu, NASA LaRC; Gail Bingham, Utah State SDL, Mike Watson, Utah State SDL.

FIRST Balloon Launch – June 2005

Accomplishments

- **Interferometer**: Demonstrated Michelson interferometer optimized to perform In far-IR (10-100 um) with passively cooled optical system.
- **Detectors:** Demonstrated focal plane array of silicon bolometers coupled to Winston cones.
- **Beamsplitters:** Demonstrated flight performance of germanium coated polypropylene beamsplitter giving broad spectral bandpass (10 to 100 um) Balloon Flight:
- **Balloon Flight Demonstration:** Measurement of the Far-Infrared spectrum of the Atmosphere and Earth (15 to 100 um). Tested at 90,000 ft for 5.5 hours, measuring 15,000 spectra in 10 channels over 20 to 1600 cm^{-1} (6 to 500 um). Underflight of AQUA satellite yielded 1K correlation with AIRS, MODIS, and CERES measurements.
- **Impact:** Far-IR observations are the key to understanding the greenhouse effect and the radiative feedbacks associated with increased anthropogenic forcings and cirrus clouds. ***Demonstrated first complete thermal emission spectrum of the Earth at high spatial and spectral resolution.***

TRL_{in} = 3; TRL_{out} = 6

Far-Infrared Technology Advancement Partnering Description

- The Far-Infrared Detector Technology Advancement Partnering (FIDTAP) is an effort to develop and demonstrate prototype detector technology to enable space-based high spectral resolution measurements of the far-infrared spectrum (10 to 100 um).

- To achieve sufficient sensitivity and sampling speed, current detector technology requires cooling to liquid helium temperatures, and is not suitable for a spaceborne sensor. The FIDTAP effort seeks to extend the current wavelength response of Blocked Impurity Band (BIB) detectors. In addition, the intent is to achieve sufficient sensitivity and speed at a temperature of 10 Kelvin, so that focal plane cooling may be achieved by mechanical cryocoolers now becoming available.

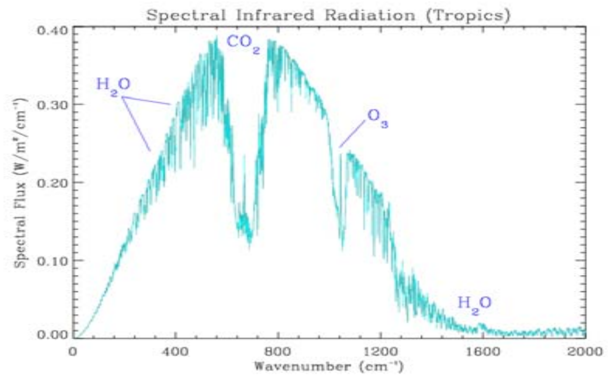
- FIDTAP is a cost-sharing partnership between the NASA Earth Science Technology Office, NASA Langley Research Center, and DRS Technologies, Inc.

Far-Infrared Technology Advancement Partnering

PI: Marty Mlynczak, LaRC

Objective

- Develop far-infrared detectors operating between 10 and 100 mm wavelength
- Develop detectors that will operate at 10 Kelvin, but with sensitivity and response of Liquid Helium cooled detectors
- Enabling technology applicable to Climate Absolute Radiance and Refractivity Observatory (CLARREO)



Measurement Goal: Far-IR spectra from Space

Approach

- Extend wavelength response of doped Silicon: Antimony (Si:Sb) blocked-impurity-band (BIB) detectors
- Increase doping of Sb to achieve extended wavelength response beyond 40 mm.

Co-Is/Partners:
DRS Technologies, Inc., Cypress, CA

DRS matching NASA contribution 100%

Key Milestones

• Design, fabricate, and test discrete detectors on existing far-IR detector wafers	08/07
• Design, fabricate, and test custom-designed far-IR detectors 10-100 mm on new material wafers	03/08
• Deliver 12 detectors with final report	05/08

TRL_{in} = 2, $TRL_{current}$ = 3

In-Situ Net Flux within the AtMosphere of the Earth "INFLAME" Description

- The task is to develop and demonstrate an instrument that directly measures the net radiative flux within the Earth's troposphere and lower stratosphere.

- Accurate net flux measurements, and accurate determination of the flux divergence and atmospheric heating rates, are central to validating atmospheric general circulation models (GCMs), to understanding the role of aerosols in climate forcing, and to understanding the role of clouds (including cirrus) in climate.

- The proposed instrument measures separately the net flux for both the visible and infrared streams of radiation, and operates on an Uninhabited Aerial Vehicle (UAV) so as to enable measurement of the vertical profile of net flux, from which the net flux divergence may be computed and rates of atmospheric radiative heating and cooling may be determined. By directly measuring the net flux, the proposed instrument eliminates potentially large uncertainties in net fluxes, which are sometimes larger than the net fluxes themselves, determined using extant conventional techniques.

In-Situ Net Flux within the AtMosphere of the Earth "INFLAME"

PI: Marty Mlynczak, LaRC

Objective

- INFLAME provides the ONLY direct measurement of the net radiative flux within the atmosphere
- INFLAME is a Fourier Transform Spectrometer (FTS) for measuring upward and downward radiation fluxes simultaneously in the lower atmosphere.
- INFLAME will be aircraft-borne, designed for studying effects of pollution, aerosols and clouds on radiation, providing fundamental verification of radiative transfer codes for climate models
- INFLAME will provide CLARREO cal-val support

INFLAME payload on LearJet wing tip pods

Approach

- Develop two separate Fourier Transform Spectrometers, one for infrared radiation, one for visible radiation
- Mount on wing tip pods of an aircraft
- Cycle up and down in altitude recording vertical profile of net flux
- Derivative of net flux w/r/t altitude is the atmospheric heating rate due to radiation
- Small enough, and low cost, to enable several to be deployed at once to address issues of cloud noise, inhomogeneous nature of aerosol layers.

Co-Investigators:
Dr. David G. Johnson, Dr. David P. Kratz – NASA LaRC Science and Technical: Prof. Judy A Curry, Dr. Gary Gimmestad, Ga. Tech, Dr. Warren Wiscombe, NASA GSFC

Key Milestones

• PDR/1st Annual Review	11/06
• Flight Vehicle selected	03/07
• Optics Designs completed	09/07
• CDR	10/07
• Mechanical Fabrication completed	08/08
• Instrument assembly completed	10/08
• System test & integration completed	01/09
• FRR / Flight Test	02/09

$TRL_{in} = 4$, $TRL_{current} = 4$

Hyperspectral Imager to Meet CLARREO Goals of High Absolute Accuracy and On-Orbit SI Traceability Description

- The proposed technique enables improved radiometric accuracy for hyperspectral imaging required in Earth climate studies. This approach, which achieves on-orbit end-to-end instrument calibrations and degradation tracking, will be validated with ground tests of a prototype hyperspectral imager meeting the accuracy levels for benchmark climate measurements on CLARREO.

- The project will design and build a 300-1050 nm hyperspectral imager to validate this calibration approach, increasing its TRL from 3 to 6. The proposed calibration technique will be validated using the hyperspectral imager and a NIST calibrated detector.

- The calibration method proposed improves the SI-traceable accuracy by the factor of >10 to the required levels for the CLARREO Scientific Objective of measuring the solar radiation reflected or scattered by the Earth. This Earth-viewing hyperspectral imager will trace its calibration on-orbit through the solar spectral irradiance recommended in the Decadal Survey as a NOAA component of CLARREO. By cross-calibrating a hyperspectral imager with solar spectral irradiance, using techniques LASP has proven on other spaceflight instruments, the Earth-viewing imager can be calibrated, validated, and tracked on-orbit to the required accuracy and traceability levels.

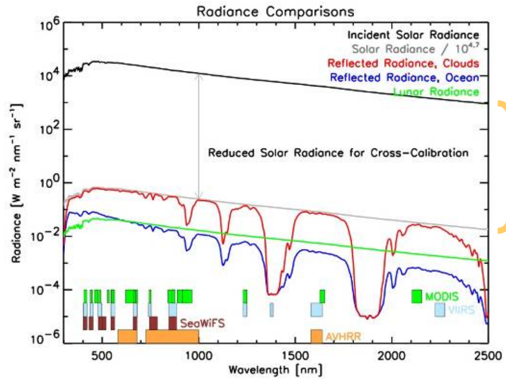
- A hyperspectral imager capable of cross-calibrating via direct solar irradiance measurements will be prototyped. Accurate attenuation methods allowing such cross-calibrations will be demonstrated and validated using a NIST-calibrated detector. This calibration technology will enable the creation of a climate data record that can be linked to future observations and thus establish a benchmark for detecting climate change.

A Hyperspectral Imager to Meet CLARREO Goals of High Absolute Accuracy and On-Orbit SI Traceability

PI: Greg Kopp, Laboratory for Atmospheric and Space Physics (U. Colorado)

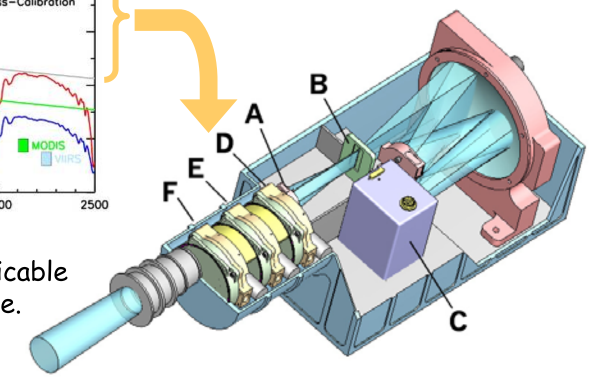
Objective

- Improve radiometric accuracy of visible & Near-Infrared hyperspectral imaging needed for Earth climate studies via cross-calibrations from spectral solar irradiances.
- Enable on-orbit end-to-end spatial/spectral imager radiometric calibrations and degradation tracking with 0.2% SI-traceable accuracy.



Cross-calibration method applicable to 300-2500 nm spectral range.

Hyperspectral imager components accurately attenuate solar radiances (black) to Earth-viewing radiance levels (red, blue).



Approach

- Investigate attenuation methods and accuracies allowing a hyperspectral imager to view the Sun and transfer spectral solar radiance measurements to Earth-viewing observations.
- Validate solar cross-calibration approach provides desired SI-traceable accuracies using a prototype 300-1050 nm hyperspectral imager with precisely known attenuation methods and a detector calibrated by NIST for linearity across 6 orders of magnitude.

Key Milestones

• Optical Design & Detector Selection	03/09
• NIST Photodiode Calibrations Complete	09/09
• Detector Array Tested	06/10
• Operating Spectrometer	08/10
• Quantified Attenuation Uncertainties	04/11
• Lab Calibrations & Field Studies	06/11

CoI: Peter Pilewskie, LASP

$TRL_{in} = 3$

A New Class of Advanced Accuracy Satellite Instrumentation (AASI) for the CLARREO Mission Description

- The objective is to develop and demonstrate the technology necessary to measure IR spectrally resolved radiances with ultra high accuracy (< 0.1 K 3-sigma brightness temperature at scene temperature) for the CLARREO benchmark climate mission. The ultimate benefit to society is irrefutable quantification of climate change and a solid basis for improving climate model forecasts.

- The work will develop four primary technologies to assure SI traceability on orbit:
  - **(1) On-orbit Absolute Radiance Standard (OARS), a high emissivity blackbody source that uses multiple miniature phase-change cells to provide a revolutionary on-obit standard with absolute temperature accuracy proven over a wide range of temperatures,**
  - **(2) On-orbit Cavity Emissivity Modules (OCEMs), providing a source (quantum cascade laser, QCL, or heated halo) to measure any change in the cavity emissivity of the OARS,**
  - **(3) On-orbit Spectral Response Module (OSRM), a source for spectral response measurements using a nearly monochromatic QCL source configured to uniformly fill the sensor field-of-view, and**
  - **(4) Dual Absolute Radiance Interferometers (DARI), one covering from 6 to 50 µm and other from 3 to 14 µm, that can be inter-compared to dissect any unexpected systematic errors in overlapping spectral regions.**

- Methodologies will range from materials compatibility, contamination, and lifetime testing for the OARS to combined module testing that uses the interferometer sensors to demonstrate emissivity measurements with the OCEMs and spectral instrument line shape measurements with the OSRM. The absolute calibration of the two interferometer sensors will also be demonstrated with the OARS.

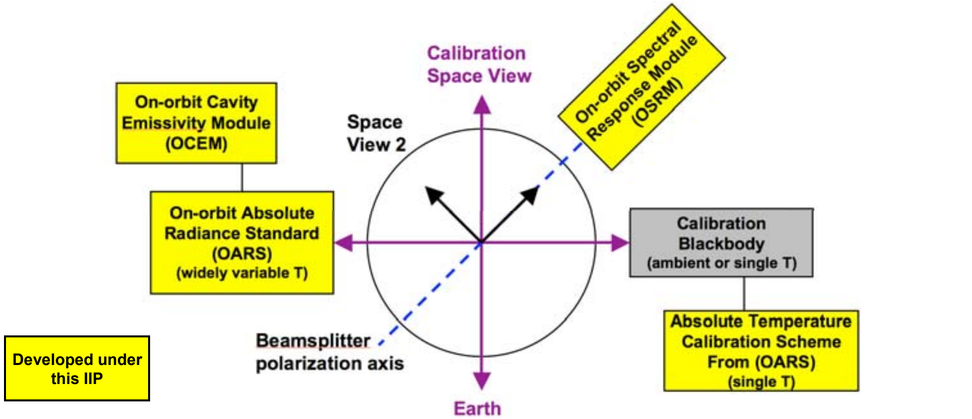
A New Class of Advanced Accuracy Satellite Instrumentation (AASI) for the CLARREO Mission

PI: Hank Revercomb, University of Wisconsin, SSEC

Objective

Develop and demonstrate key technologies necessary to measure IR spectrally resolved radiances with ultra-high accuracy (<0.1 K 3 sigma) brightness temperature (at scene temperature) for the CLARREO climate benchmark mission. Technologies include:

- On-orbit Absolute Radiance Standard (OARS) including Miniature Phase Change Cells
- On-orbit Cavity Emissivity Module (OCEM) using quantum cascade laser (QCL) and heated halo reflection
- On-orbit Spectral Resp. Module (OSRM) using QCL
- Dual Absolute Radiance Interferometers



CLARREO FTS Scene Mirror Provides Earth and Space Views as well as Views to Targets Involving Technologies Developed Under this IIP, That Give Unprecedented Absolute Calibration Accuracy on-orbit.

Approach:

Develop the independent technologies that provide on-orbit absolute calibration:

Radiometric - OARS, and OCEMs

Spectral - OSRM

Develop 2 FTS systems (High Performance and Far IR) and integrate with above for testing to:

-Demonstrate performance in relevant environment

-Demonstrate absolute calibration technologies (radiometric and spectral) in end-to-end testing in a relevant environment.

CoIs: Fred Best and John Perepezko, Univ. of Wisconsin; John Dykema, Harvard Univ.

Key Milestones

• OCEMs integrated to breadboard & tested	5/09
• OARS Mini Cells life test	10/09
• OSRM to cavity and lab test demo.	10/09
• FTS systems integrated & tested in lab	2/09
• All technologies tested in relevant envir.	10/10
• All technologies integrated and demonstrated together in an end-to-end test with FTS	5/11

$TRL_{in} = 3$

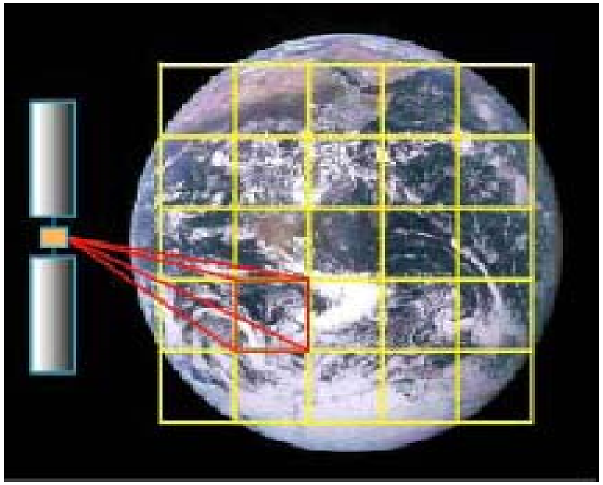
Geostationary Imaging Fabry-Perot Spectrometer, GIFS

- **A part of the energy balance equation is looking at cloud cover. This task looks at various aspects of cloud properties – optical depth, cloud fraction. It would be an associated measurement in determining the reflected solar irradiance and cloud radiative forcing (not directly radiometry measurement called for in CLARREO, but one that's related to using the data in determining climate change)**

Geostationary Imaging Fabry–Perot Spectrometer, GIFS

PI: Dr Jeng-Hwa Yee, Johns Hopkins Univ. APL

- Aid in the understanding of how cloud cover impacts the Earth's climate.
- Develop GIFS instrument prototype to measure 2D images of high resolution spectral line shapes of O2 at atmospheric band absorption in solar backscattered radiation
- Investigate all aspects of the GIFS instrument design from instrument requirements to construction, characterization, and aircraft testing
- Develop a next-generation GEO satellite instrument concept for continuous hemispheric imaging of cloud properties, including cloud top pressure, cloud optical depth, and cloud fraction.



GIFS Mapping Global Cloud Properties

- Develop cloud sensing technique.
- Develop instrument/mission concept.
- Identify critical subsystems.
- Fabricate prototype
- Conduct an airborne campaign with correlative measurements
- Verify performance and sensing concept.
- Design GIFS instrument and define spacecraft interfaces.

CoIs: Frank Morgan, Elsayed Talaat, JHU/APL; Michael Pitts, Chris Hostetler, LaRC; Wilbert Skinner, U. of Michigan

- Instrument Definition and Contract Initiation. 6/05
- Prototype Development and Fabrication. 3/07
- Prototype Characterization and Calibration. 9/07
- Prototype Aircraft Testing and Validation. 1/08
- GIFS Design and Interface Definition 4/08

TRL_{in}=3 $TRL_{current}$ = 5

4/08

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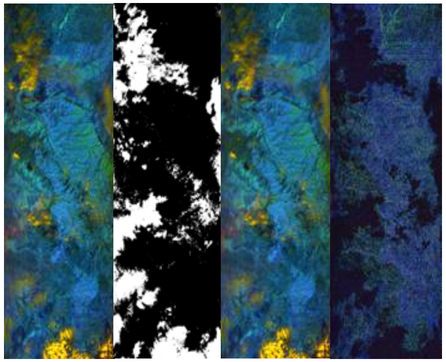
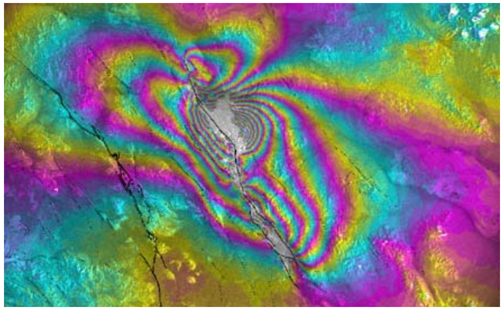


Information Systems Technologies

(Current and Completed ESTO Investments)



Sensor-Web Operations Explorer (SOX) Description

- Processes governing the distribution and evolution of trace gases and aerosols have a profound impact on air quality and climate. Trace gases and aerosols cannot only affect air quality, but they may also impact regional and global climate through longer-lived greenhouse gases, e.g., $O3$, $CO2$, and $CH4$ Aerosols can have a net cooling or heating effect depending on their type and vertical distribution. The quantification of these processes requires an integrated approach that combines observations from satellites, aircraft, sondes, and surface measurements with chemistry and transport models acting on both regional and global scales. The SOX system is an integrated software infrastructure that combines these observations with models and data-assimilation tools, that permit a focused analysis of the chemical state and that can adapt to meteorological and chemical “events” over daily time scales.

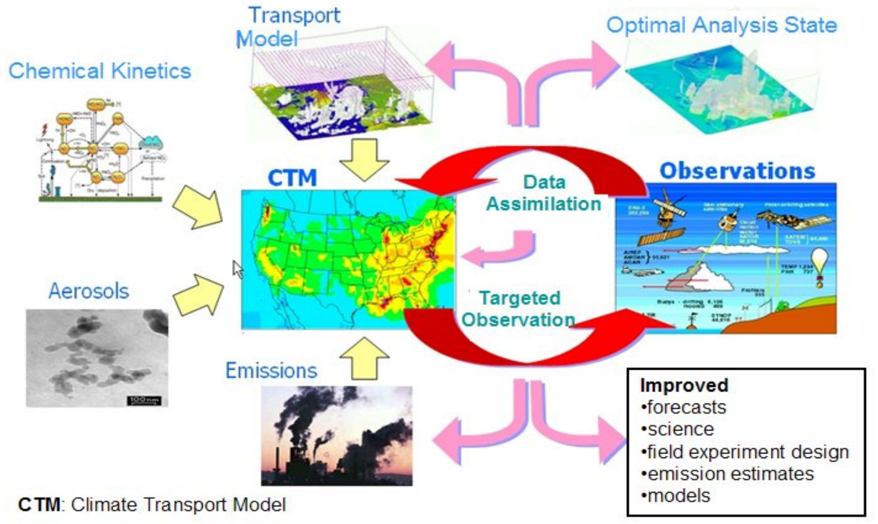
- The Sensor-web Operations Explorer (SOX) is to provide an advanced observation system simulation experiment (OSSE) capability for the global and regional Earth atmospheric science community. A three-step approach has been devised to achieve the goal. The first step is to develop a flexible concept design exploration space for sensor-web system architectures and operational scenarios. The second step is to develop a science impact metric that can be applied to quantitatively evaluate science-return from the explored system architectures and operational scenarios. The final step is to establish a process that coordinates interdisciplinary collaboration between scientists and engineers to develop optimal observation scenarios.

Sensor-Web Operations Explorer (SOX)

PI: MeeMong Lee, JPL

Objective

- Enable adaptive measurement strategy exploration on a sensor web for rapid air quality assessment.
- Provide a comprehensive sensor-web system simulation with multiple sensors and multiple platforms.
- Provide quantitative science return metric that can identify where and when specific measurements have the greatest impact.
- Provide collaborative campaign planning process among distributed users.



SOX Optimizes Observation Strategies for Air Quality Information Content

Approach

- Develop multi-disciplinary frameworks and link observation simulations, reference models, science retrieval and analysis algorithms, data assimilation software, forecasting code, and assessment code.
- Develop scalable system modules with asynchronous interface protocols and create a "system of systems" providing flexible system configuration and operation.

Co-I's/Partners

- Charles Miller, Kevin Bowman, Richard Weidner (JPL)
- Adrian Sandu (Virginia Polytechnic)

Key Milestones

• SOX software Architecture Design	12/06
• SOX Interface Definitions	2/07
• SC-borne Sensor-web Ops. Explorer	9/07
• Air-borne Sensor-web platform simulation	3/08
• Dual platform campaign planner	9/08
• In-situ platform simulation	3/08
• Multi-platform campaign planner	6/09
• Complete SOX system	9/09

$TRL_{in} = 3$ $TRL_{current} = 4$

Mining Massive Earth Science Data Sets for Climate and Weather Forecast Models

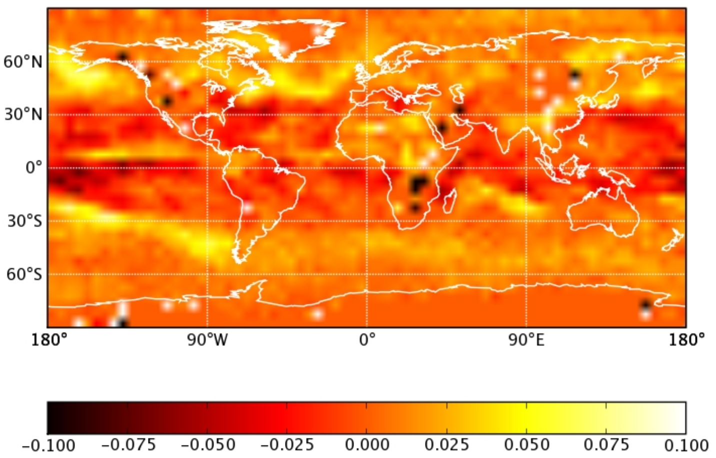
- **This task looks at reduced volume data sets from very large observational and model generated data sets. It's more relevant to the application of the data rather than to the actual mission itself. One of the accomplishments was processing 3 years of atmospheric radiation measurements, so this task may be useful in the processing of data and interactions with climate models.**

Mining Massive Earth Science Data Sets for Climate and Weather Forecast Models

PI: Amy Braverman, JPL

Objectives:

• Produce reduced volume, reduced complexity summary data set from very large observational and model generated data sets. Ensure summaries approximately preserve multivariate, statistical and distributional properties of the original. Users can then calculate with summaries as if using the raw data, and estimate the error incurred. Demonstrate on 3 months' data.
• Facilitate user defined custom data products through an interface with the Genesis (a JPL REASoN project for distributed computing and remote access) SciFlo analysis environment.
•Facilitate more informative comparisons of observations and model output, also via SciFlo.



Estimated correlation of AIRS atmospheric temperature and water vapor at 300 mb computed from compressed summaries.

Accomplishments:

- Processed 3 months of *global, high-resolution* model output for 2 major atmospheric models (Geophysical Fluid Dyamics Lab, FDL, National Center for Atmospheric Research) achieving compression ratios of about 70:1.
- Processed 3 full years of ground station data for one site (Atmospheric Radiation Measurement Program Southern Great Planes site) and corresponding high-resolution model output.
- Developed and implemented algorithms for i) hierarchical summarization (summarize the summaries to coarser resolution in time and space); ii) visualization of summaries and comparison of model vs. observational summaries; iii) hypothesis testing to determine whether distributions (summaries) from model and observations differ significantly and if so why; and iv) calculation of Atmospheric Infrared Sounder "Level 3 Products on Demand" using the SciFlo distributed computing environment.

Collaborators:

Robert Pincus and Cris Batstone, NOAA; Tim Barnett and Dave Pierce, Scripps; Brian Wilson and Eric Fetzer, JPL.

TRL_{in} = 4; TRL_{out} = 6

- **A part of the energy balance equation is determined from reflections off of cloud cover. While this task is looking more at developing a cloud mask, part of the work is in developing a cloud detection algorithm. It would be an associated measurement in determining the reflected solar irradiance and cloud radiative forcing**

On-Board Cloud Contamination Detection with Atmospheric Correction

PI: Kevin Ballou, GSFC

Objectives

- **Determine the feasibility of performing satellite on-board cloud masking and atmospheric correction algorithms on 3 general types of computing devices:**
  - **Microprocessor**
  - **Field Programmable Gate Array**
  - **Application Specific Integrated Circuit**

- **Landsat or similar spacecraft would be a likely beneficiary of an on-board cloud cover look ahead sensor which could reject data acquisition above a defined threshold or alternately, a cloud cover assessment score included in the telemetry stream which could reduce database storage and data buy.**

NOAA14 AVHRR GAC cloud mask produced by 5 cloud detection algorithms:
- Infrared Threshold Test
- Spatial Coherence Test
- Fog/Low Stratus Test
- Med/Hi Level Cloud Test
- Thin Cirrus Test

Accomplishments

- Delivered cloud detection and atmospheric correction algorithms (in C programming language)
- Determined relative performance of both algorithms on three commercial processors
- Assessed accuracy of cloud masking algorithms on three data sets
- Implemented all of the individual test routines required for cloud detection on an FPGA
- Verified FPGA results for individual tests were identical to those of the C program

Co-I: Pat Stakem, QSS

TRL_{in} = 2 **TRL_{out} = 3**