



CLARREO (Climate Absolute Radiance and Refractivity Observatory) Status

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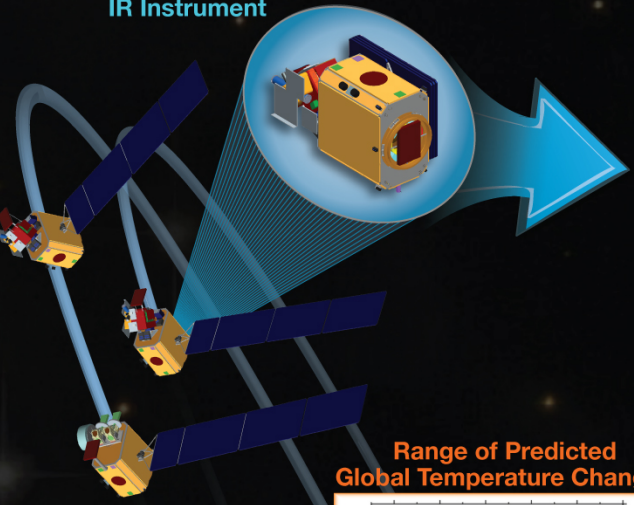
NASA CLARREO Solves the Climate Accuracy Challenge



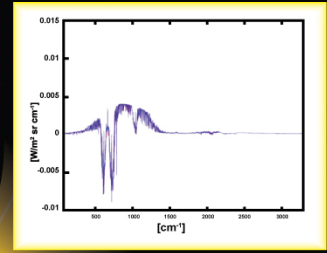
CLARREO: Calibrating Planet Earth

- ☞ Insufficient absolute accuracy remains an Achilles Heel for climate change observations
- ☞ Improved accuracy needed for
 - ❑ *Climate model testing*
 - ❑ *Climate model predictions of future change*
 - ❑ *Societal policy decisions.*

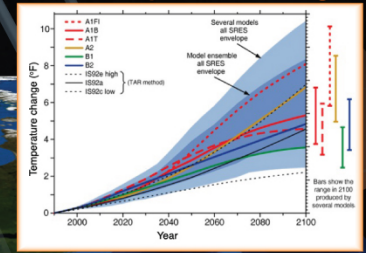
IR Instrument



CLARREO Anticipated Infrared Decadal Change



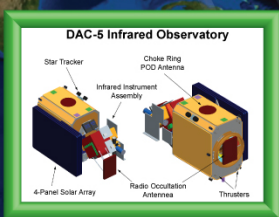
Range of Predicted Global Temperature Changes



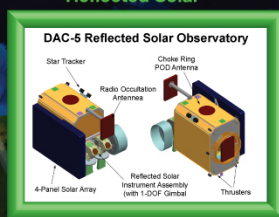
Informing Policy



IR Infrared

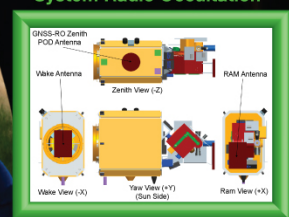


RS Reflected Solar



GNSS-RO

Global Navigation Satellite System Radio Occultation

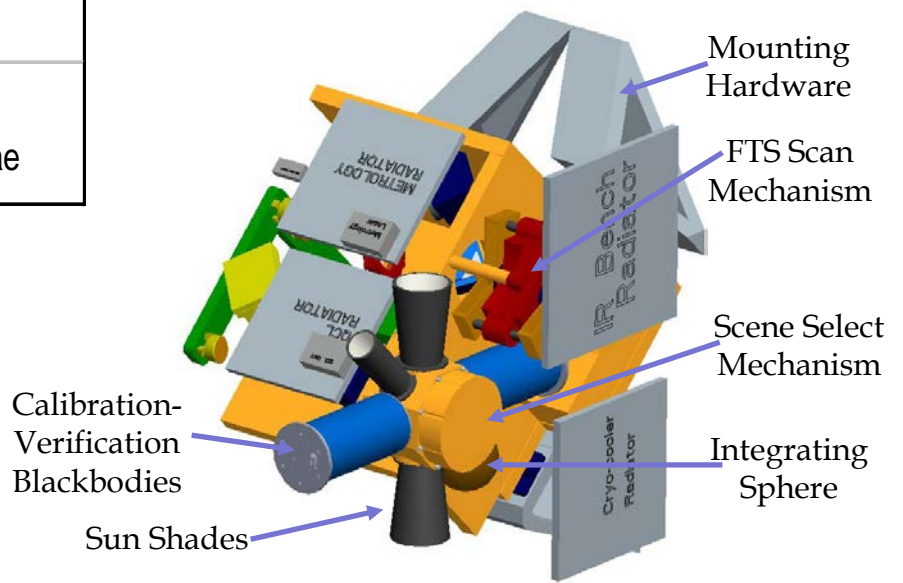
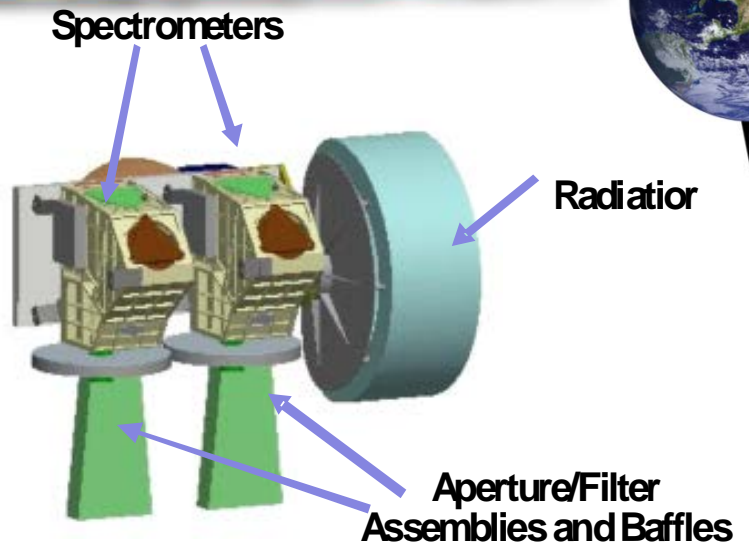


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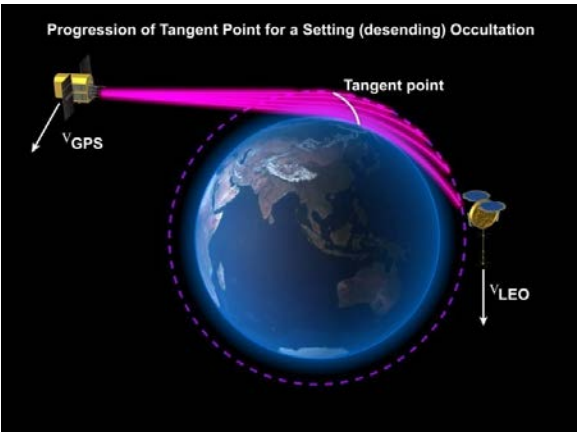


Payload Suite

Instrument	Features	
Infrared Spectrometer	Type	Fourier transform spectrometer
	Spectral Range	5 to 50 micron
	Configuration	Single combined instrument
Reflected Solar Spectrometer	Type	Grating spectrometer
	Spectral Range	320-2300 nanometer
	Configuration	Two box design
GNSS Radio Occultation System	Signal Range	GPS and Galileo
	Configuration	Receiver Two occultation antennae



IR Instrument Concept Design (BB Radiator and Enclosure Partially Removed)

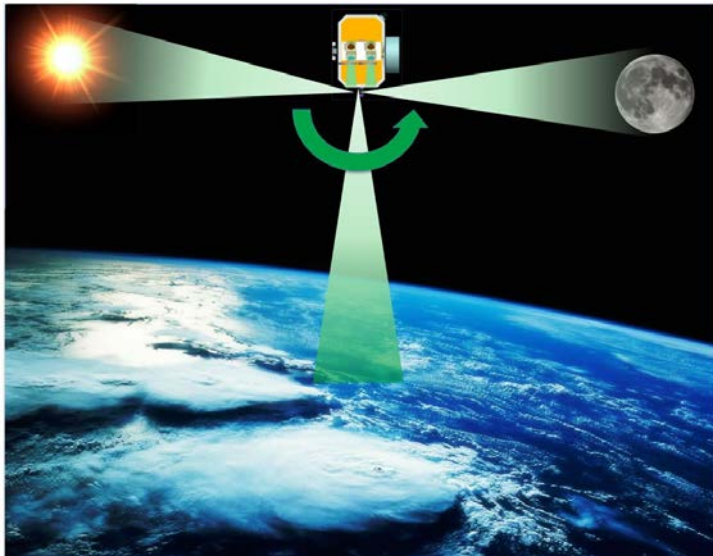
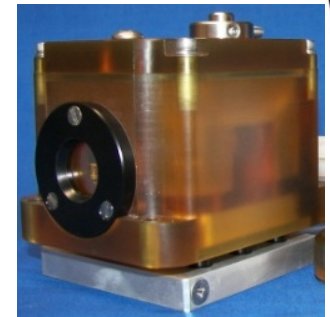


NASA CLARREO Solves the Climate Accuracy Challenge

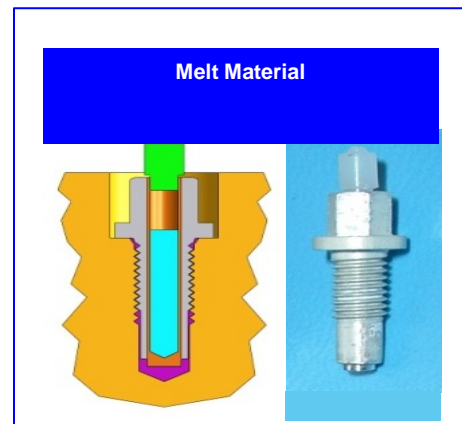


- Accuracy requirements provide observations to allow climate change detection within 20% of perfect observations
- CLARREO provides SI traceable high accuracy rigorous measurements of the entire solar and infrared spectrum ("NIST in orbit") to detect long-term climate change trends
 - ❑ *Approaches based on work of academia, government, and industry*
 - ❑ *Will not require overlapping data records*
 - ❑ *Gaps in record would not degrade climate records*

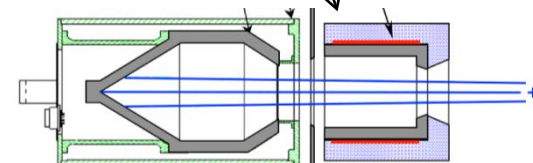
Quantum Cascade Laser (QCL)



Phase Change Cells



Heated Baffle

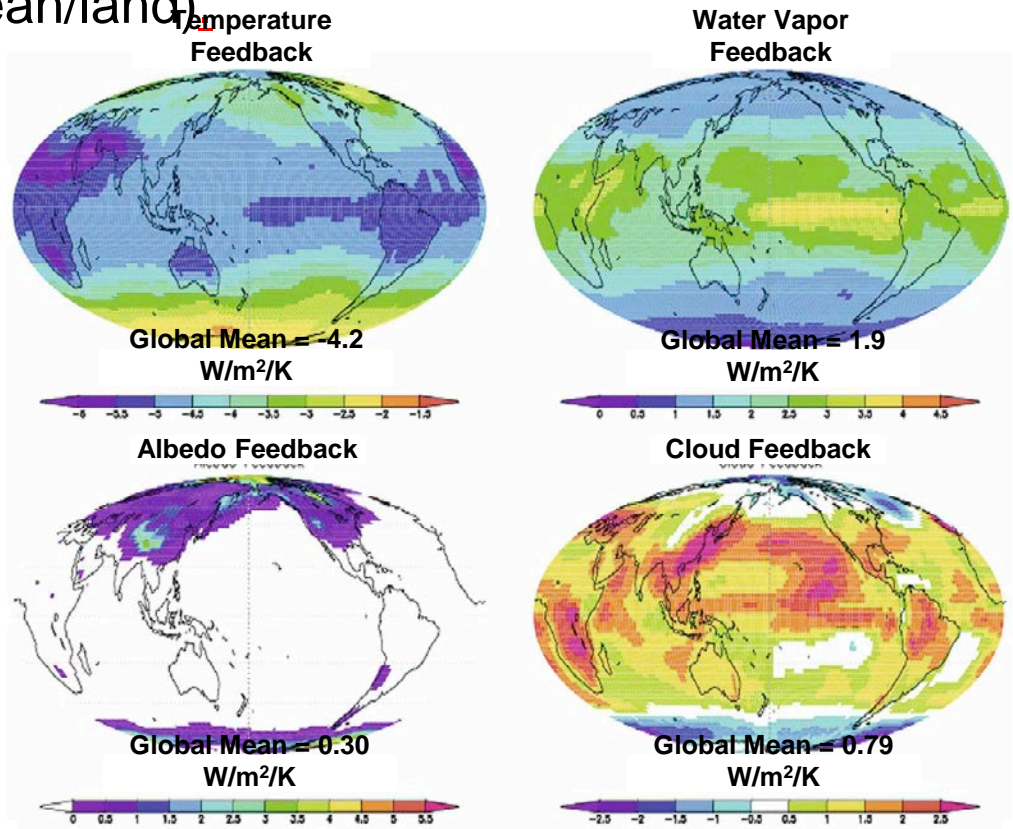




Benefits of CLARREO



☞ CLARREO provides the first high accuracy full spectra (> 95% of energy) across the reflected solar and infrared Earth emissions; includes climate change observations of temperature/water vapor profiles, cloud properties, broadband radiation, surface properties (ocean/land)



Multi-model ensemble-mean maps of the temperature, water vapor, albedo, and cloud feedback, computed using climate response patterns from the IPCC AR4 models and the GFDL radiative kernels

(Soden et al., 2008)

FIG. 8. Multimodel ensemble-mean maps of the temperature, water vapor, albedo, and cloud feedback computed using climate response patterns from the IPCC AR4 models and the GFDL radiative kernels.

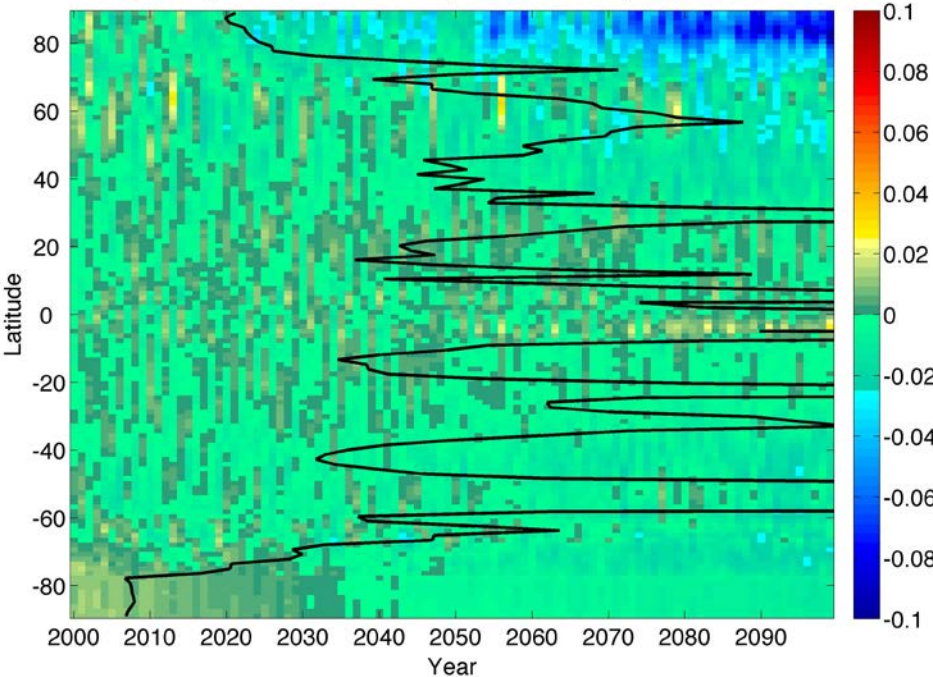


Benefits of CLARREO

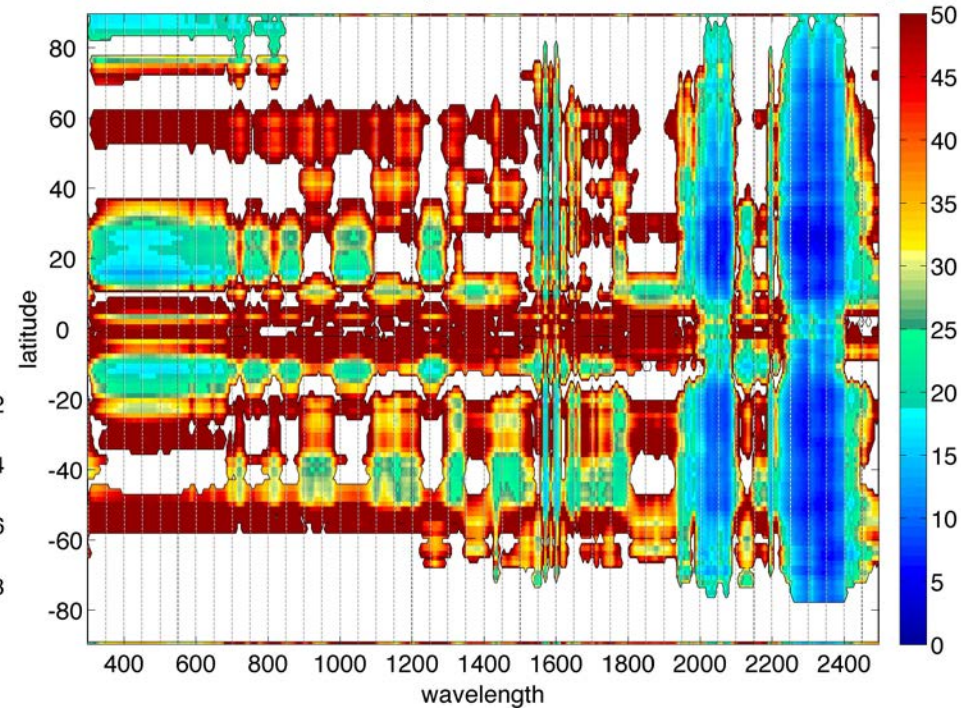


Provides new and unique spectral fingerprints of climate change for direct climate model testing (no retrieval required).

Zonally-averaged annual mean all-sky albedo anomaly: experiment-control Δ



All-Sky Detection Time



Spectral measurements *shorten* time to detection over tropics and subtropics.

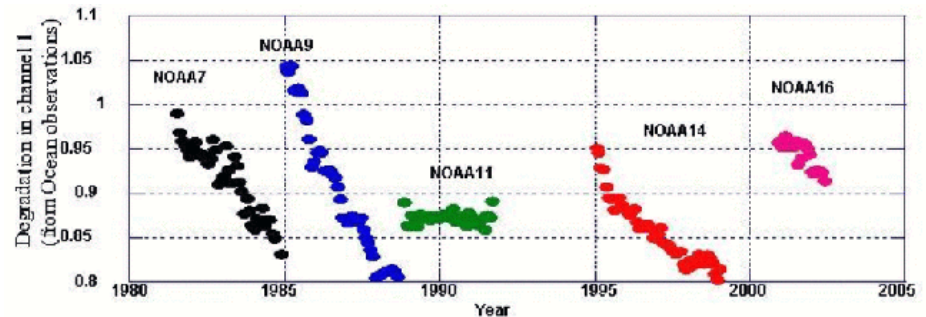
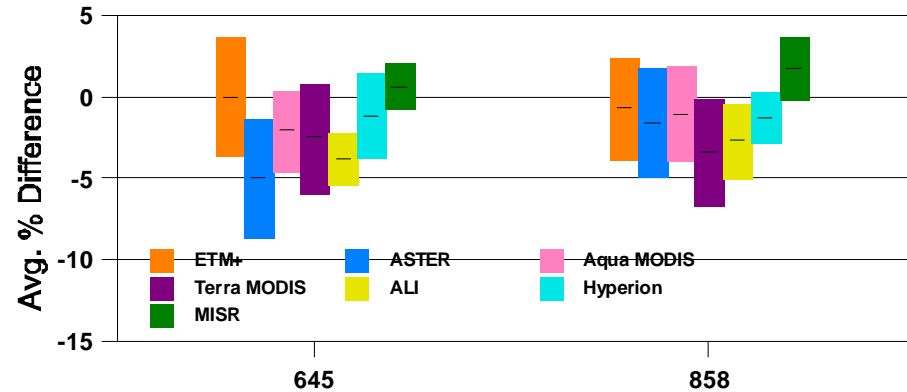
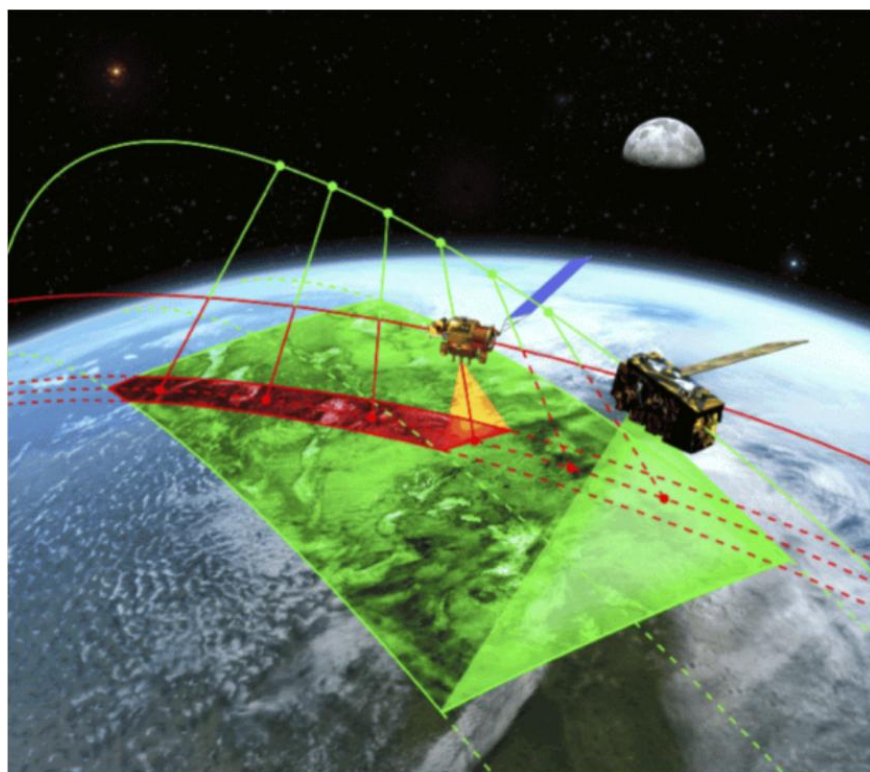
Collins et al, AGU Fall Meeting 2010



Benefits of CLARREO



Provides the anchor for international WMO GSICS program. The first SI standard transfer radiometer in orbit to match spectral response, space, time, and angle of view during orbit crossings for reference intercalibration of other Earth sensors in all LEO and GEO orbits.





CLARREO History



- ☞ July 2007, CLARREO open science workshop.
- ☞ 2008: NASA Langley directed to lead the mission.
- ☞ 2008 through 2010: mission and science studies, team included LaRC, GSFC, GISS, JPL, NIST, NOAA GFDL, Harvard, U. Wisconsin, U. Colorado, UC Berkeley, U. Maryland, Imperial College, UK, NPL, UK.
- ☞ November 2010: CLARREO passed Mission Concept Review on first attempt.
 - ◆ The project successfully demonstrated the need for the CLARREO mission and a feasible mission concept within imposed funding constraints (MCR Board Chair)
- ☞ February 2011: \$2B in NASA Earth Science Budget reductions held CLARREO in pre-phase A instead of phase A. Targeted funding for tech risk reduction and science.
- ☞ December 2012: NASA Headquarters Guidance Letter
 - *Support cross mission studies of possible ISS implementation options for advanced instrument demonstrations, including CLARREO-led accommodation studies for the individual IR and RS instruments. (S. Volz)*
- ☞ January 2013: Briefing to Freilich (NASA Earth Science director) and Grunsfeld (NASA Science director) on CLARREO International Space Station (ISS) mission concept. Received “green-light” to initiate discussion with ISS office. First presentation to ISS office, February 21, 2013.



CLARREO Partnerships and Collaborations



☞ World Meteorological Organization (WMO)

- ☐ **GSICS (Global Space based Inter-Calibration System) has strongly endorsed the need for CLARREO** as the in-orbit reference to anchor all space based instruments in the infrared and reflected solar spectrum, both for climate change observations as well as operational weather and earth resources instruments
- ☐ These include ABI, AGRI, AHI, ASI, AVHRR, CERES, CrIS, ETM+, FCI, GIIRS, GOME-2, HIRS, IASI, IRAS, IRS, MERSI-2, MODIS, OLCI, SEVIRI, SGLI, SLSTR, VIIRS, and VIRR.)
- ☐ **Barbara Ryan, WMO Director for Space and GSICS sent a letter (Jan. 2012) to Dr. Freilich** at NASA HQ strongly endorsing the need for CLARREO to serve as the calibration anchor for GSICS and the rest of the observing system.
- ☐ **WMO has also endorsed CLARREO instruments on ISS as the most effective way to achieve these objectives.** A joint white paper on this topic was led by Jerome Lafeuille, Chief, Space-based Observing System Division, WMO Space Programme.

☞ United Nations (UN)

- ☐ Takao Doi, section chief for the UN Office of Outer Space Affairs has endorsed the white paper let by Lafeuille supporting CLARREO instruments on ISS.

☞ ECMWF (European Center for Medium Range Weather Forecasting)

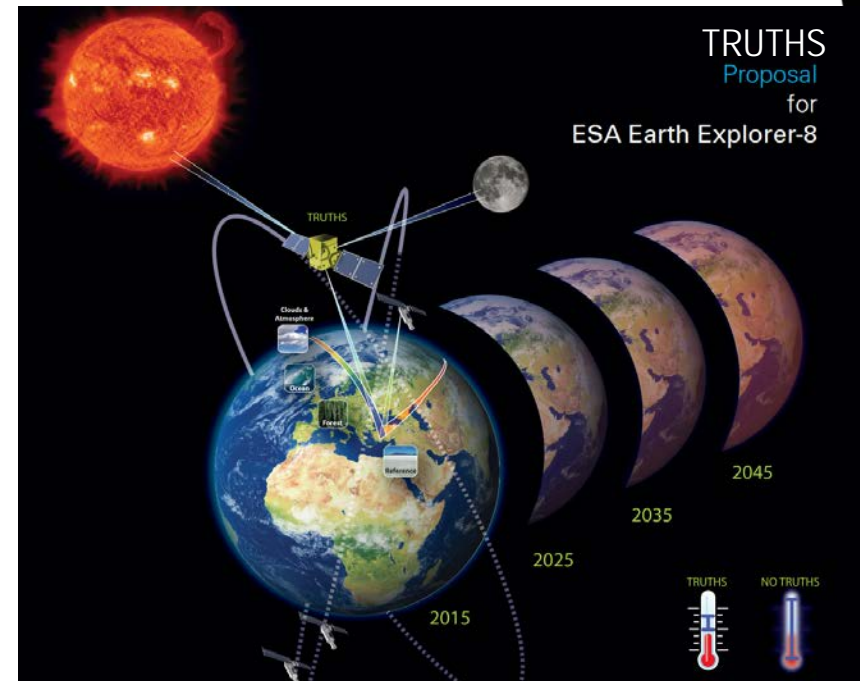
- ☐ ECMWF has written a letter of support for the Zeus proposal (a CLARREO quality IR spectrometer) stating that it needs higher accuracy IR spectra for weather prediction assimilation and climate re-analyses.



CLARREO Partnerships and Collaborations



- Multiple collaborations with organizations in the UK
 - Imperial College, National Physical Laboratory, and Hadley Centre (UK climate modeling and prediction center) are partners.*
 - Formal **Letter of Agreement** between NASA and Natural Environment Research Council.*
 - Coordinating with Nigel Fox at NPL on a UK Space Agency funding study of the reflected solar instrument science requirements for a potential **TRUTHS demonstration mission**.*
- Italian collaborations on IR spectrometer
 - Working with **Italian scientists from the FORUM ESA Explorer** proposal on future IR spectrometers for the far-infrared spectra. (FORUM finished 4th).





Status of Significant Pre-Formulation Products/Events



- ☞ Mission Concept Review successfully completed Nov 17, 2010
 - ☐ *All pre-formulation products completed for a monolithic mission concept*
 - ☐ *Continuing studies on distributed-mission concepts are producing the foundational products necessary to support new pre-formulation architectures*
- ☞ Selection and award of the Science Definition Team Jan 14, 2011
- ☞ Delivery of the extended pre-phase A mission study plan (white paper) March 28, 2011
- ☞ Major Budget reduction in mid 2012, slowing pre-phase A activities
 - ☐ *Maintained SDT funding in FY12/13*
 - ☐ *Reduced funding for engineering and slowed CDS development*
- ☞ Both IR and RS Calibration Demonstration Systems (CDS) are now operational and beginning calibration studies
- ☞ International Space Station option: 73% of baseline mission science value for ~35% of cost
- ☞ New results on the large economic value of CLARREO climate science to society: between \$3T and \$20T (2012 U.S.)



Key Science and Applications Accomplishments for 2012



☞ Science Studies

- ❑ *Science Definition Team has made broad advances in CLARREO climate change science in (21 journal papers published in 2012 alone, 8 more submitted and in review, and 26 more in preparation)*
- ❑ *CLARREO Mission Science Overview journal article revised and in review for Bulletin of the AMS: key to educating the climate science community*
- ❑ *First Pan Spectral (IR and RS combined) climate model Observation Simulation Experiments (OSSEs): journal paper submitted*
- ❑ *Development of new spectral radiative transfer modes: 30X faster in the IR and 120X faster for the reflected solar. Critical to future climate OSSEs*
- ❑ *Extension of the CLARREO accuracy requirements from broad spectral regions to high spectral resolution for the infrared*
- ❑ *New study on the economic value of CLARREO-like climate science advances*
 - ◆ *Interdisciplinary work with Roger Cooke, an IPCC lead author on economic impacts of climate change*
 - ◆ *Net Present Value of CLARREO advances in narrowing uncertainty in climate sensitivity have economic value between \$3 Trillion and \$20 Trillion (\$2012 U.S. dollars). Journal paper in preparation for submission*

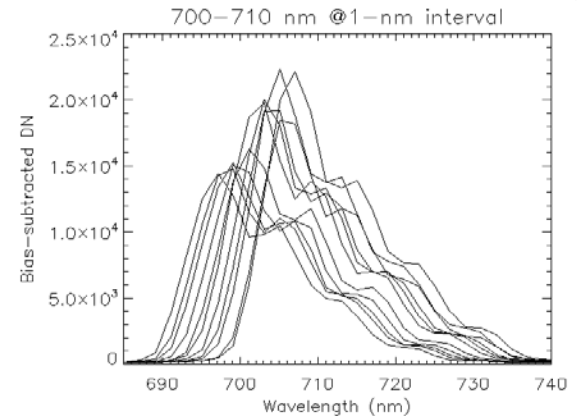
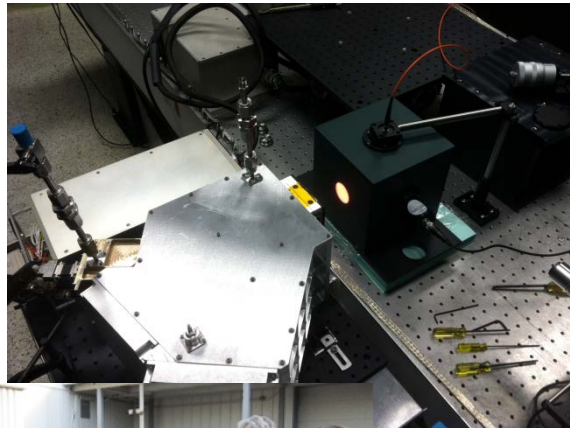
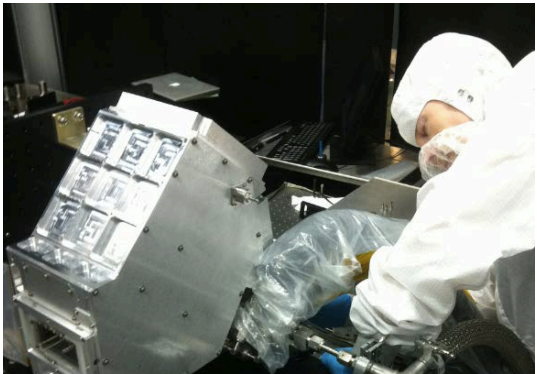


Reflected Solar (RS) Calibration Demonstration System

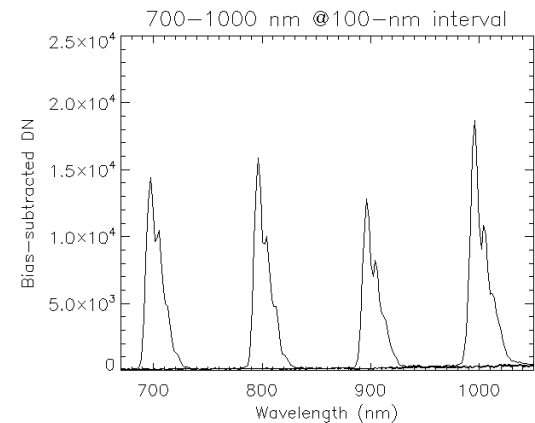


☞ Completed, thermally-stabilized RS CDS over 320-1100 nm (preliminary electronics)

- ❑ *Lunar and solar views*
- ❑ *Laboratory-based, 3% absolute calibration with improvements leading towards CLARREO-level accuracies*
- ❑ *SIRCUS-based spectral calibration*

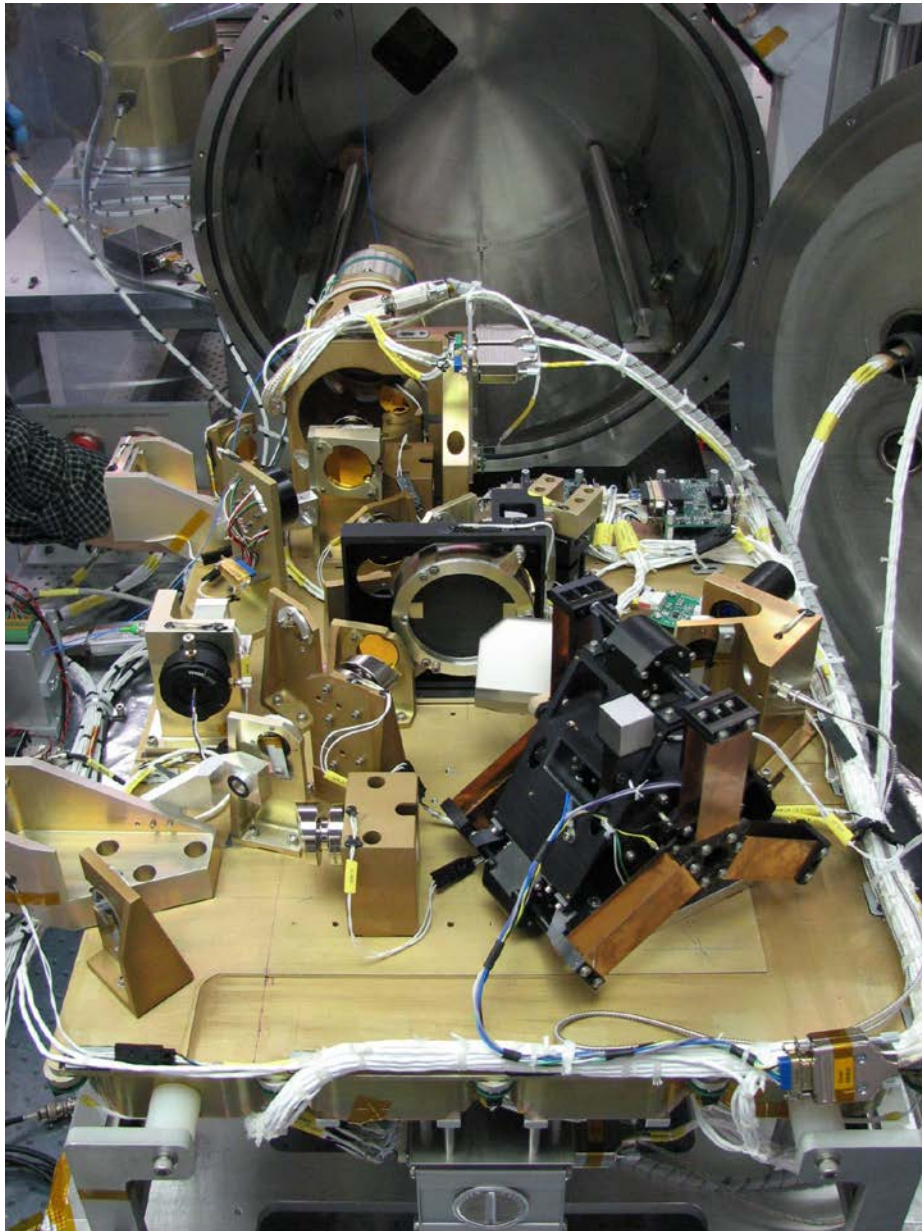


Multiple single wavelength images for single band

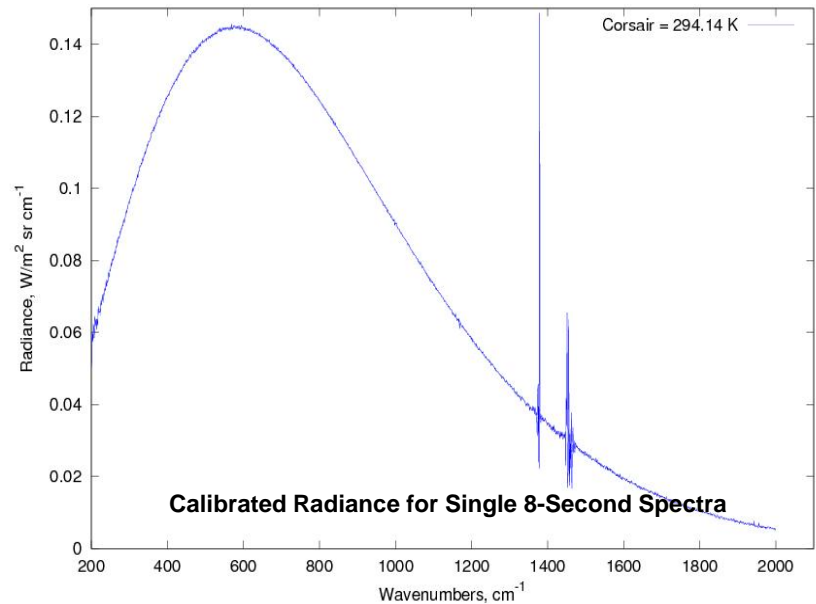


Results for multiple bands

Infrared (IR) Spectrometer Calibration Demonstration System



- ☞ Completed the design, fab, assembly and integration of the IR CDS and vacuum test system
- ☞ Began vacuum testing of the IR CDS on September 21, 2012
 - ☐ *Infrared interferograms were immediately detected showing that the system is fully functional*
 - ☐ *Instrument operations are proceeding with the near-term goal of obtaining calibrated infrared interferograms*





Technology Maturation



☞ Calibration Demonstration Systems

- ☐ *Completed Infrared and Reflected Solar CDS design, fabrication, assembly and integration: critical to demonstrate new accuracy levels*
- ☐ *Testing is underway on both systems, with initial verification by NIST in the next few months*
- ☐ *Provide risk reduction test beds for improved understanding of instrument specifications and trades relative to absolute accuracy*

☞ Other funded activities

- ☐ *Calibration of Langley FIRST instrument to NIST standards and deployment to Table Mountain in 2012*
- ☐ *LASP Instrument Incubator Project is progressing to a balloon test of their RS instrument*
- ☐ *University of Wisconsin is performing system testing of their IR instrument*



Alternative Mission Concepts



- ☞ Studies encompass all mission cost drivers to find less expensive options
 - ☐ *Simplified instruments (reduced spectral coverage, simplified cal/val systems)*
 - ☐ *Alternative platforms & orbits (e.g. ISS, FASTSat, international partners)*
 - ☐ *Alternative access to space (e.g. rideshare (ESPA), hosted payload (Iridium NEXT))*

- ☞ Have identified options that are cost-effective yet yield compelling science
 - ☐ *Best option to date: ISS version of the CLARREO Minimum Mission: 1 IR spectrometer, 1 RS spectrometer, RO uses COSMIC-2*
 - ☐ *Cost ROM for ISS option \$340M to \$390M, versus Baseline \$900M to \$1100M.*
 - ☐ *73% of Baseline mission science for ~ 35% of the cost*



CLARREO Mission Options



Mission	% of CLARREO MCR Baseline Mission Science	Mission Cost Estimate (\$RYM)
Decadal Survey Concept (2007) (11 instruments, 4 spacecraft, 4 launches)	112%	~ \$1.6B Launches 2017, 2019
MCR Baseline Mission Concept (6 instruments, 4 smaller spacecraft or 2 larger)	100%	\$800 - \$1000 + Launch Vehicle(s) Launches 2018, 2020
MCR Minimum Mission Concept (3 instruments, 1 spacecraft, e.g. DAC-4 free flyer)	62%	\$675 - \$750 + Launch Vehicle Launch 2021
ISS Mission Concept (2 instruments on ISS, RO is obtained from COSMIC-2)	73%	\$400 - \$420 cost includes launch EV-2 ISS full cost guidelines

Cost estimates are full mission cost in real year dollars.

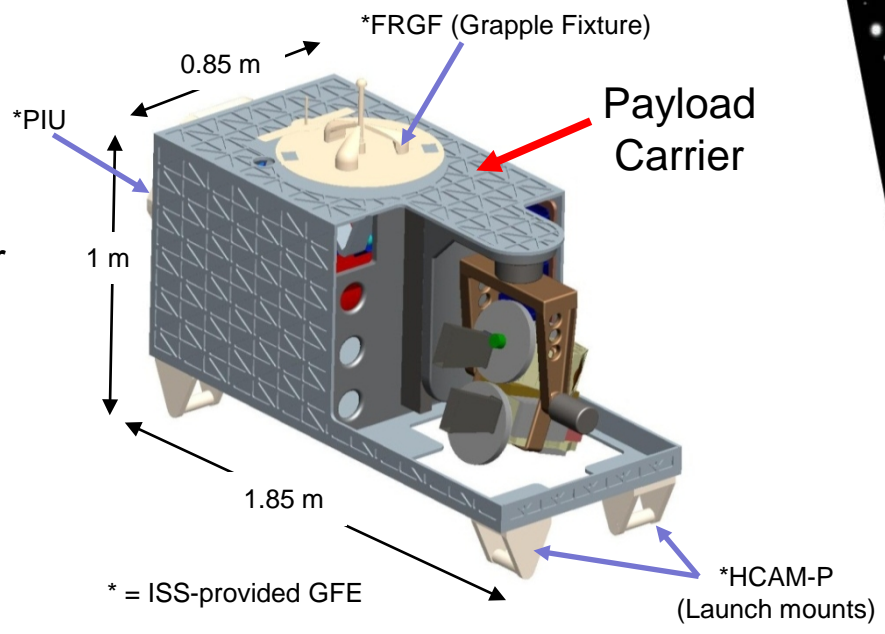
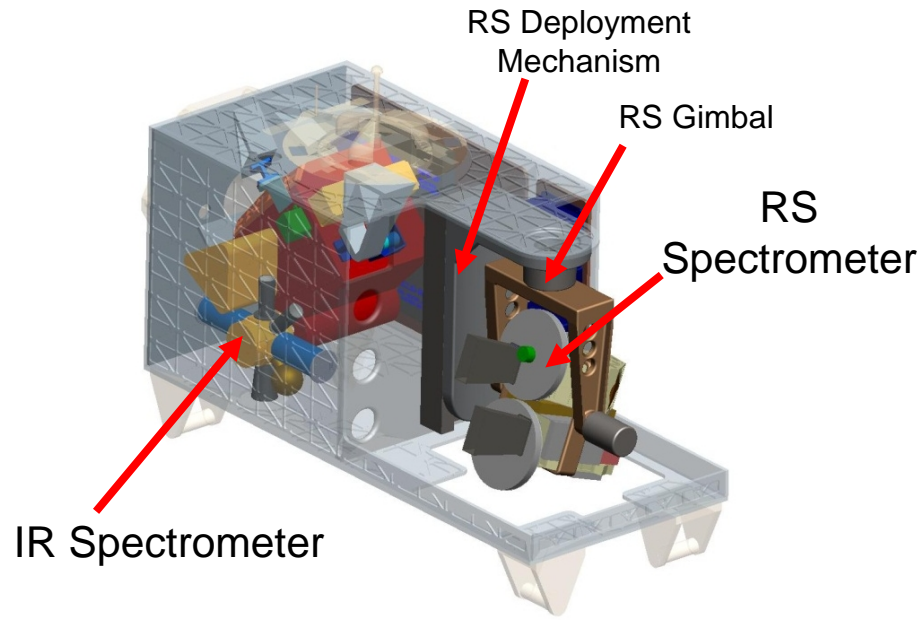
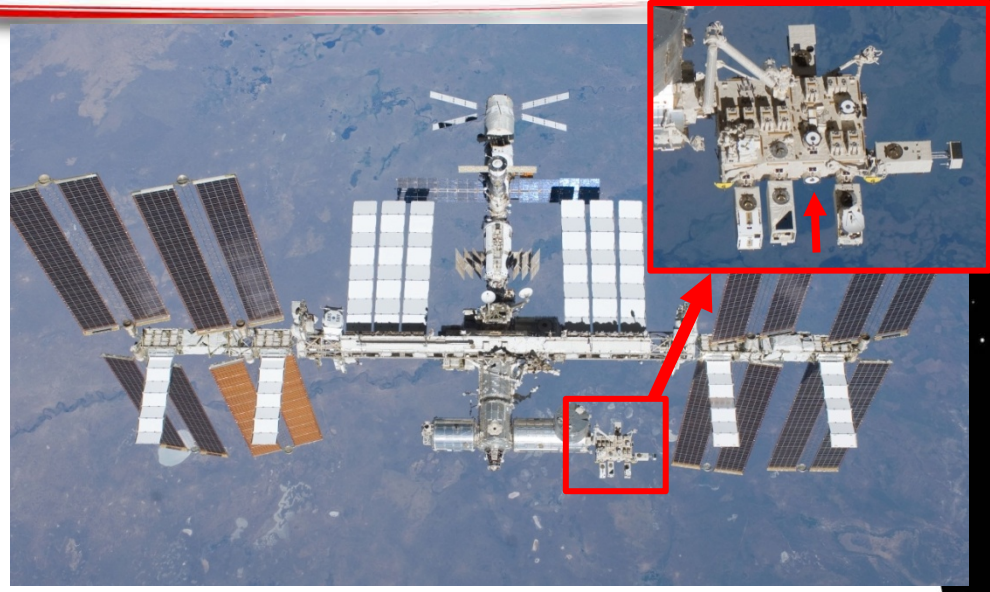
For MCR baseline and minimum mission, launch vehicle not included



ISS Mission Concept



- ☞ Multiple sites on ISS are viable
 - ☐ *Ram-side of JEM-EF (shown at right) is optimal for maximizing viewing opportunities*
- ☞ Both instruments fit into one box occupying one experiment location





CLARREO is Ready



- ☞ CLARREO has systematically completed the steps charted in the white paper of March 28, 2011
 - ☐ *Science analysis, simulation and modeling work has achieved substantial advances in IR, RS and RO climate change science*
 - ☐ *Calibration Demonstration Systems are meeting schedule milestones (as replanned per mid-FY12 budget cuts) for addressing the primary risks and uncertainties in the measurement and calibration approaches*
 - ☐ *Broadening of the Science Value framework and mission trade space has provided flexible options for mission implementation that achieve compelling science in a cost effective manner*
- ☞ The new Science Economic Value framework provides much clearer understanding of mission public value as an investment with very large payback: factors of 10 to 50
- ☞ **The CLARREO investment is providing substantial advances in the science and significantly reducing instrument risk**
- ☞ **CLARREO is ready to begin Formulation with multiple mission options that provide compelling science for a fraction of the cost**