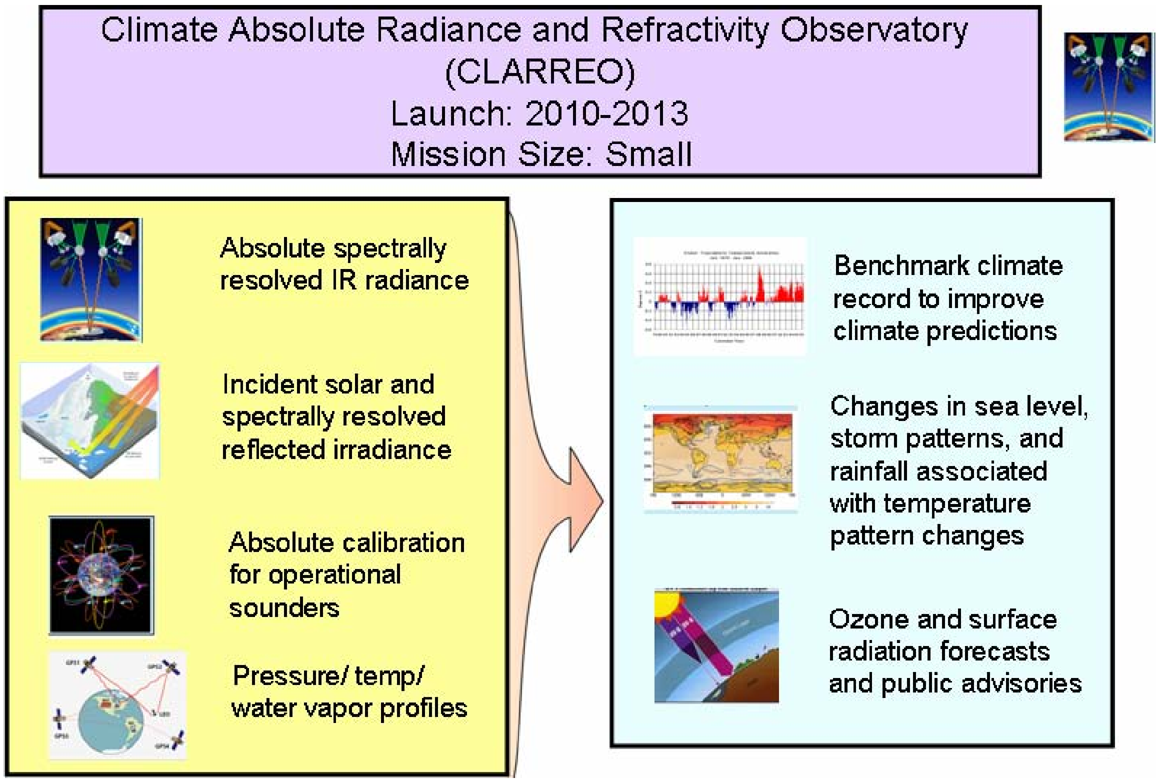
Climate Absolute Radiance and Refractivity Observatory (CLARREO)



The Climate Absolute Radiance and Refractivity Observatory (CLARREO) will provide a benchmark climate record that is global, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards.

Decision support for vital choices regarding water resources, human health, natural resources, energy management, ozone depletion, civilian and military communications, insurance infrastructure, fisheries, and international negotiations is necessarily linked to our understanding of climate. Effectively addressing each of these societal concerns depends upon accurate climate records and credible long-term climate forecasts. To this end, *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 forecast performance. This strategy sets the foundation for the CLARREO mission.

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

Background: Stripped to its fundamentals, the climate is first affected by the long-term balance between (1) the solar irradiance absorbed by the Earth, ocean, atmosphere system, and (2) the infrared (IR) radiation exchanged within that system and emitted to space. Thus, key observations include the solar irradiance, incident and reflected, and the spectrally resolved IR radiance emitted to space that carries the spectral signature of IR forcing of climate and the resulting response of that climate system. As a key part of the recognized imperative to develop long-term, high accuracy time series with global coverage of critical climate variables, this mission addresses the objective of establishing global, long-term climate records that are of *high accuracy and tied to international standards* maintained in the U.S. by the National Institute of Standards and Technology (NIST). In addition, it is essential for societal objectives that require the long-term climate record, that the accuracy of the core benchmark observations be verified against absolute standards *on-orbit* by fundamentally independent methods.

Scientific Objectives: Four elements constitute the CLARREO scientific strategy.

- First, absolute spectrally resolved radiance in the infrared measured with high accuracy (0.1 K 3σ brightness temperature) by downward-directed spectrometers in Earth orbit. Both the radiative *forcing* of the atmosphere resulting from greenhouse gas emissions and aerosols and the *response* of the atmospheric variables are clearly observable in the spectrally resolved signal of the outgoing radiance. Similarly, large differences among model projections of temperature, water vapor, and cloud distributions imply, for each model, different predicted changes in absolute, spectrally resolved radiation. The spectrum of IR radiance, if observed accurately and over the full thermal band, carries decisive diagnostic signatures in frequency, spatial distribution and time.
- Second, solar radiation, reflected from the Earth-atmosphere system back to space constitutes a powerful and highly variable forcing of the climate system through changes in snow cover, sea ice, land-use, aerosol, and cloud properties. Systematic, spatially resolved observations of the time series of absolute spectrally resolved flux of near ultraviolet, visible, and near infrared radiation returned to space by the Earth system tied to NIST standards in perpetuity underpin a credible climate record of the changing Earth system. In combination with the establishment of the absolute spectrally resolved solar irradiance reflected from the Earth-atmosphere system to Space, it is essential to continue the long-term, high accuracy time series of incident solar irradiance.
- Third, Global Navigation Satellite Systems (GNSS) radio occultation offers an ideal method for benchmarking the climate system because much of the infrastructure for this active limb sounding technique already exists, or soon will, in the form of the U. S. Global Positioning System (GPS) and the European Galileo satellites, because orbiting GNSS receivers are comparatively inexpensive, and because the technique is a measurement of frequency shift against a time standard, it is directly traceable to international standards. GNSS radio occultation profiles the refractive properties of the atmosphere by observing the timing delay of GNSS signals induced by the atmosphere as the ray descends into the atmosphere in a limb-sounding geometry. The index of refraction is directly related to pressure, temperature, and water vapor concentration in a way wherein the refractive index can be easily simulated from model output. Moreover, both GNSS and absolute, spectrally-resolved radiance in the thermal IR are accurate to 0.1 K traceable to SI standards on-orbit so that they represent completely independent, absolute records that allow, for the first time, the determination of systematic error in the climate record.
- Fourth, CLARREO will serve as a high accuracy calibration standard for use by the broadband CERES instruments on-orbit. In addition, the suite of infrared operational sounders launched on NPP and NPOESS can use the Climate Observatory to (1) establish SI traceable accuracy on-orbit, (2) establish an independent analysis of time-dependent bias in calibrated radiance, and (3) form a basis for intercomparison of all operational sounders now and in the future.

Mission and Payload: The mission requires three satellites, each of which requires a specific orbit, and each of which includes an occultation GNSS receiver. In the first category of climate benchmark radiance measurements, two of the satellites contain redundant interferometers that have a spectral resolution of 1 cm^{-1}, and encompass the thermal infrared from 200 to 2000 cm^{-1}, are in true 90° polar orbits to provide a full scan of the diurnal harmonics as well as high latitude coverage from low Earth orbit (750 km), and each of the interferometers have an internal scene selection that includes redundant blackbodies with programmable temperatures and an external scene selection that includes deep space viewing for radiance zeroing and nadir viewing with a 100 km footprint for Earth observations. Each of these satellites is gravity gradient stabilized without additional pointing, with a separation in orbital planes of 60˚. This mission requires an SI-traceable standard for absolute radiance. Each of the interferometers carry, on-orbit, phase transition cells for absolute temperature, high aspect ratio blackbodies with direct surface emissivity measurements within the blackbodies, detector linearity, polarization and stray light diagnostics, etc., such that the key climate observations are obtained globally from space with SI traceability to absolute standards on-orbit.

In the second category of benchmark radiance measurements, the third satellite carries the IR benchmark instruments deployed in the first category, but with the addition of redundant interferometers that have a spectral resolution of 15 nm, and encompasses the near UV, visible and near IR from 300 to 2000 nm. That satellite is in a true 90˚ polar, low Earth orbit with an orbital plane 60˚ from that of the first two IR satellites. This mission also requires an SI-traceable standard for absolute radiance, but in the near UV/visible/near IR, and employs continuing work at NIST that has significantly improved the accuracy (absolute) of radiance measurements in the visible and near IR through the use of detector-based technology using helium cooled bolometers in combination with the Spectral Irradiance and Radiance Responsivity Calibrations with Uniform Sources (SIRCUS) approach that provides accuracies to 3 parts in 10^3 in the visible and near IR. These standards can be employed, in a series of independent observations, to directly determine lunar irradiance that in turn will provide an evolving absolute benchmark for high (absolute) accuracy small satellites in Earth orbit. The redundant interferometers in the visible have scene selection that includes 1) simultaneous forward-backward viewing angles about the nadir, 2) deep space, and 3) episodic lunar observations to pin the absolute calibration in perpetuity. Incident solar irradiance measurements have an extended history of development and require follow-on missions. Broadband CERES instruments comprising both the shortwave and longwave spectral regions will be flown on both NPP and NPOESS as follow-on missions, and the orbit selection is such that a direct intercomparison between the NPP and NPOESS instruments can be executed against the benchmark observations on CLARREO.

The CLARREO mission has 2 components. The first consists of 3 small satellites--two to obtain absolute, spectrally resolved radiance in the thermal IR and a 3rd to continue the IR absolute spectrally resolved radiance measurements, but with the addition of benchmark observations to obtain the reflected solar irradiance. Each of the small satellites would also include a GPS receiver. The second component of CLARREO is the re-flight of the incident solar irradiance and CERES broadband instruments on NPP and NPOESS.

Cost: ~$65M (NOAA, for the TSIS and CERES broadband instruments) + ~$200M (NASA)

Schedule: Technology readiness for the absolute spectrally resolved IR radiance small satellite component of CLARREO is consistent with a 2008 new start, including the GPS receiver. Technology readiness for the absolute spectrally resolved visible radiance small satellite component is consistent with a 2010 new start, including the GPS receiver. Both the CERES and incident solar irradiance components of CLARREO have a complete flight heritage and are ready as the NPP and NPOESS schedules demand.

Further Discussion: Climate Change and Variability (Chapter 9) Sections 9.2.1.1.1 and 9.3.1.2.1

Related RFI(s): 16, 18