Climate Calibration Observatory Roadmap/Decadal Survey Mission Concept

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Climate Calibration Observatory Mission

- Why a Satellite Calibration Observatory?
  - Anthropogenic forcing is 0.6 Wm^{-2}/decade
  - Tropical 20S to 20N AMIP annual mean climate noise is 0.3 Wm^{-2}
  - Global net radiation annual mean sigma is 0.4 Wm^{-2} (ERBS)
  - 50% uncertainty in cloud feedback is change in cloud net radiative forcing of 0.3 Wm^{-2}/decade.
  - Suggests threshold of 0.3 Wm^{-2} global net cloud forcing and goal of 0.15 Wm^{-2} for stability per decade
    - 0.15 Wm^{-2} SW cloud forcing is 0.15/50 = 0.3% of global mean
    - 0.15 Wm^{-2} LW cloud forcing is 0.15/30 = 0.5% of global mean
    - 0.15 Wm^{-2} in clear-sky LW flux is ~0.1C temperature change/decade
  - Converting to cloud optical depth/height/temperature for imagers:
    - equivalent visible channel stability is 0.5% stability per decade
    - equivalent cloud height/temperature is 15m or 0.1K stability per decade
  - Temperature/Water Vapor Sounding: 0.04 to 0.08K per decade.
  - Vegetation and Ocean Color: 1% reflectance stability per decade.

What do current instruments Provide?

- Goal of 0.3% SW and 0.5% LW stability very tough to achieve
  - CERES nominal stability design is 0.5% per 6 year mission life
  - Correction of RAP data transmission loss is ~ 1% SW in 4 years and was possible only because of independent crosstrack/RAP data
  - AVHRR and geostationary imager visible channels: several % per year change. Constrained to 3-5% using clear sky desert, ice.
  - MODIS/MISR differ by 3% in absolute calibration and estimate stability at 2% per 6 years or better (using diffuser plates)
  - SeaWIFS ocean color using monthly lunar views estimates stability constrained to 0.1% for annual mean, but only for dark targets (lunar reflectivity 5 to 10%).
  - For dark lunar targets: need linearity of ~0.1% to transfer to much brighter scenes including clouds, snow, and desert.
- Current satellite instruments stress spatial/spectral resolution, not accuracy and stability of calibration. Detector linearity only ~ a few %.
- NPOESS VIIRS imager dropped lunar calibration (cost)
- Ocean color community can't use MODIS Terra: worried about VIIRS.
- NPOESS weather priority cannot afford critical climate calibration requirements: behind cost and schedule now.

Satellite Climate Calibration Observatory

- Major problem for climate is achieving both:
  - sufficient global sampling (large natural variability)
  - sufficient calibration and stability
  - no designed climate observing system currently exists.
- Current instruments focus on sampling first, calibration second
- Adding rigorous calibration sources and independence can double the size/cost of instruments
- Turn the problem around:
  - don't try to climate calibrate every satellite instrument
  - don't try to sample the entire earth
  - instead design instruments to be highly calibrated and stable transfer radiometers in orbit
  - essentially provide a NIST quality calibration standard laboratory in orbit.
  - design orbits, fields of view, pointing capabilities to optimize calibrating other instruments: not sampling earth's highly variable fields.

Satellite Climate Calibration Observatory

- What would such an observatory look like?
  - Precessing 67 degree inclined orbit
    - Changes local sampling time by 24 hours every 3 months
    - Allows underflight of all other spacecraft orbits: leo, geo, etc
    - Orbit period varies with altitude: choose an altitude different than other satellites to allow matched time/location calibrations with all satellites: for example 650 km.
    - Varying local time assures that intercalibration locations will vary from the equator to about 70 degrees latitide and will cover a complete range of climate conditions.
  - Two satellite calibration observatories at any time in orbit: 6 hours of local sampling time apart, altitudes can differ (e.g. 650, 750km) to allow each to have different phasing of orbit synchronization with other satellites.
  - Require +/-5 minute simultaneity in orbit crossing locations: same time/location/viewing angles. 10% of orbits (100 min period) will fill this criteria. Over long time periods this averages 1.4 calibrations per day with a low earth orbit spacecraft (e.g. sunsynch NPOESS) or more for geostationary.
  - Can predict a week ahead when matched calibration orbit crossings will occur, what location, and what viewing angles.
  - When one of the observatories or its instruments fail: launch a replacement within 3 months. Use small Pegasus launch vehicles (instruments are small) and have spare spacecraft ready.

Satellite Climate Calibration Observatory

- What types of instruments could be used for calibration standards?
  - must be highly linear detectors (0.1%): cavities, bolometers, etc
  - must be capable of handling most of the solar and thermal infrared spectrum, including spectral resolution to match imagers and other spectrometers
  - must be able to constrain total broadband energy
  - field of view must be large enough to allow very accurate integration of other radiometers to match its fov: nominally 100km
  - field of view must be narrow enough to allow close matching of viewing zenith and azimuth angles to within +/- 5 degrees/unbiased
  - instruments and/or spacecraft must be able to control pointing accurately enough to achieve 98% fov matching: ~ 2 km of 100 km fov. CERES is ~ 1km, MODIS is ~ 100m.
  - must have very accurate/stable independent calibration sources (e.g. deep cavity backbodies, lamps, solar viewing, lunar viewing)

Satellite Climate Calibration Observatory

- Example instruments:
  - ERBS active cavities have demonstrated 0.1% stability/decade, use solar constant checks every 2 weeks.
  - SORCE active cavities for solar irradiance, and prism spectrometer for spectral solar irradiance. Modify for earth viewing capability? Large fov?
  - Anderson/Goody interferometer for 4 to 20μm (bolometer detectors, 100km fov, nadir only). Reach 50- 100μm water vapor greenhouse?
  - Mlynczak FIRST Far-IR interferometer for 10 to 100um (May balloon test)
  - Leonardo reflectivity spectrometer concept: modify for calibration instead of angle/spatial sampling? 0.4 - 2.5μm.
  - Lunar stability monitoring requires ~ 1km fov to scan the roughly 6km lunar diameter (e.g. SeaWIFs). Also requires 0.1% linearity (dark target).
  - In calibration mode, there is more dwell time for intercalibration when compared to normal scanning: 10 to 100 times longer light gathering.
  - Suggests:
    - 2 cavities (SW, Total) 500km fov
    - IR spectrometer, 100km fov, dual deep cavity sources, 4 to 100μm wavelengths
    - SW spectrometer, 100km fov, diffuser, solar views
    - SW spectrometer, 1km fov/150km swath, lunar views, check 100km fov instrument

Climate Calibration Observatory Summary

- Calibration first design: linear, stable, full solar/ir spectra
- Intercalibration design for precessing orbit/large fov/pointing
- Launch on demand to reduce gap risk to < 1%.
- Two observatories allows independent calibration confirmation
- Provide a few hundred intercalibration samples for other instruments per year
- Allows a way to deal with uncertain NPOESS future calibration
- Allows calibration of geostationary imagers/sounders
- Allows calibration checks of international and U.S. missions
- CERES Rotating Azimuth plane scanner has demonstrated planned intercalibration campaigns for precessing vs. sunsynchronous vs. geo orbits for CERES and GERB. Matches in time/space/angle
- *Turns around our normal space mission design to a different paradigm to support climate change.*
- *For Climate Remote Sensing: Calibration is the 1st dimension.*
  - *The other 8 are: x, y, z, t, wavelength, s. zenith, v. zenith, v. azimuth angle.*