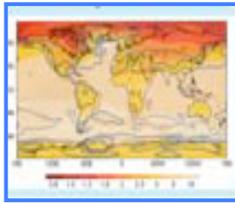
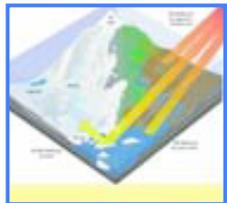


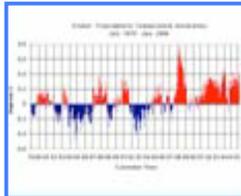
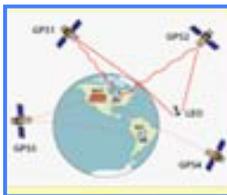


NRC Decadal Survey CLARREO Mission & Climate Calibration



8th CERES-II Science Team

**Victoria, B.C., Canada
November 14-16, 2007**





What is CLARREO?

- Climate Absolute Radiance and Refractivity Observatory
- One of the highest priority missions described in the NRC Earth Science Decadal Survey
- The next step in climate monitoring
 - Use recent developments in calibration to provide on-orbit traceable NIST-standard, calibrated spectral radiance observations in the visible, infrared, and for GPS
 - Absolute calibration will allow detection of long-term climate trends
 - Absolute calibration will also be used for calibrating operational satellite instruments
 - May provide the ability to bridge climate observatory gaps
 - Identifies NOAA as responsible for continuity of CERES and TSIS



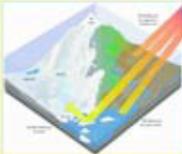
Climate Absolute Radiance and Refractivity Observatory (CLARREO)

Launch: 2010-2013

Mission Size: Small



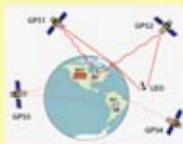
Absolute spectrally resolved IR radiance



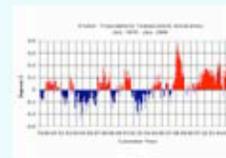
Incident solar and spectrally resolved reflected irradiance



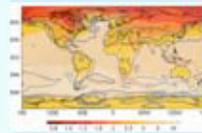
Absolute calibration for operational sounders



Pressure/ temp/ water vapor profiles



Benchmark climate record to improve climate predictions

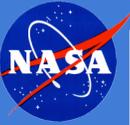


Changes in sea level, storm patterns, and rainfall associated with temperature pattern changes



Ozone and surface radiation forecasts and public advisories

“In establishing this set of missions, the committee recognized that a successful program is more than the sum of its parts...Robustness is thus measured by the strength of the overall program, not by the particular missions on the list. It is the range of observations that must be protected rather than the individual missions themselves. (Decadal Survey ES-7)”



- Overarching Science Objective for CLARREO
 - Measure long-term trends in key climate variables necessary to improve climate prediction accuracy.
- Science Objectives as stated in Decadal Survey
 - Absolute spectrally-resolved measurements of terrestrial thermal emission with an absolute accuracy of 0.1 K in brightness temperature (99% confidence limits.) The measurements cover most of the thermal spectrum.
 - Absolute spectrally-resolved measurements of the solar radiation reflected from Earth. The measurements cover that part of the solar spectrum most important to climate, including the near-ultraviolet, visible, and near-infrared.
 - Independent measurements of atmospheric temperature, pressure, and humidity using Global Positioning System (GPS) occultation measurements of atmospheric refraction.
 - Serve as a high accuracy calibration standard for use by the broadband CERES instruments on-orbit.



Possible set of mission configurations:

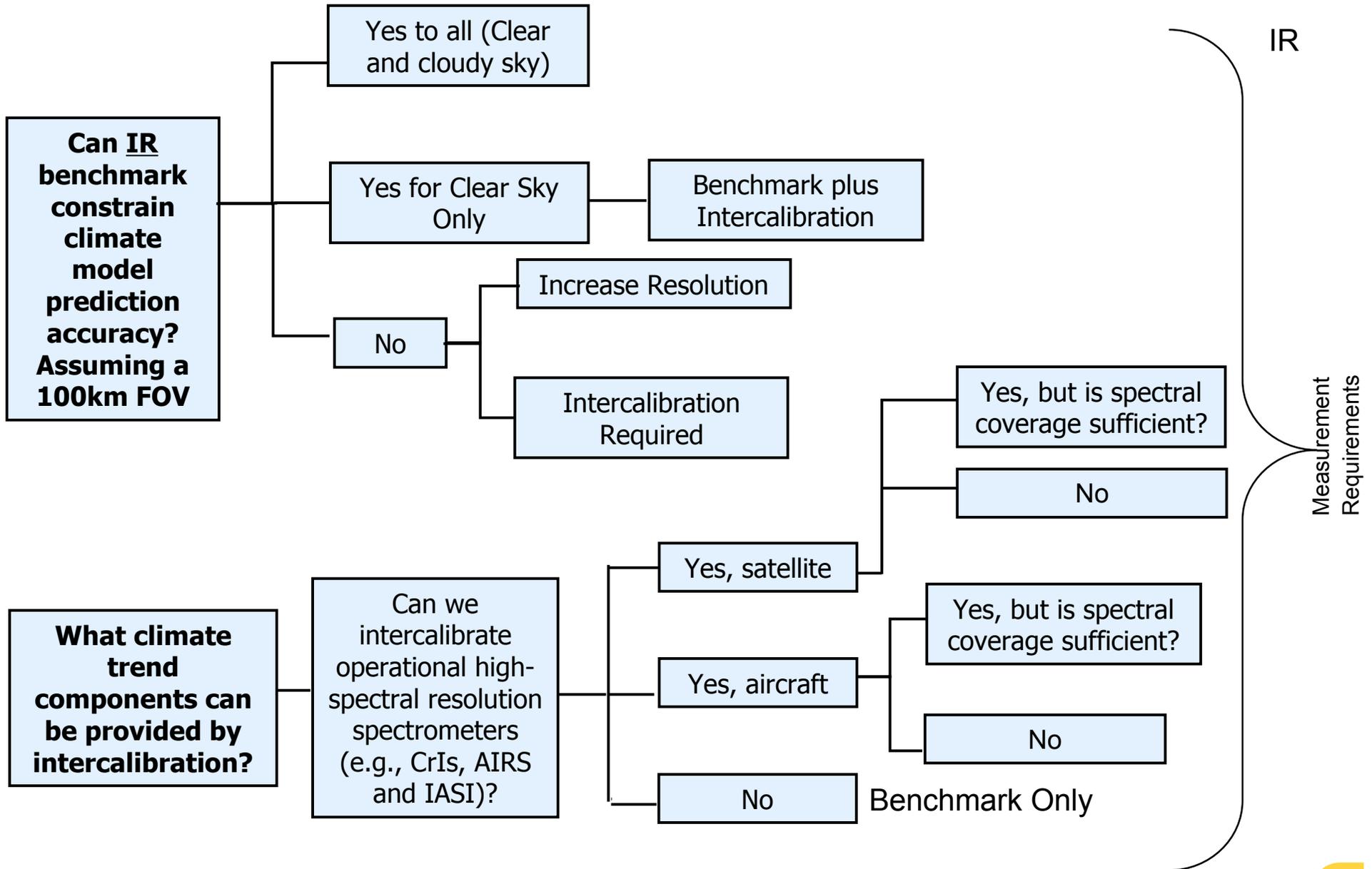
- IR Configurations
 - Pure Benchmark IR
 - Pure Intercalibration IR
 - Mix - Priority on Benchmark Measurement with Limited Intercalibration
 - Mix - Priority on Intercalibration Measurement (Cross calibrate against multiple operational assets) plus Benchmark Measurement
 - Demonstration Mission

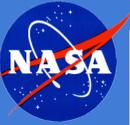
- Solar Configurations
 - Pure Benchmark Solar
 - Pure Intercalibration Solar
 - Mix - Priority on Benchmark Measurement with Limited Intercalibration
 - Mix - Priority on Intercalibration Measurement (Cross calibrate against multiple operational assets) plus Benchmark Measurement
 - Demonstration Mission

Decision trees based upon the trade study outputs will lead to mission requirements.

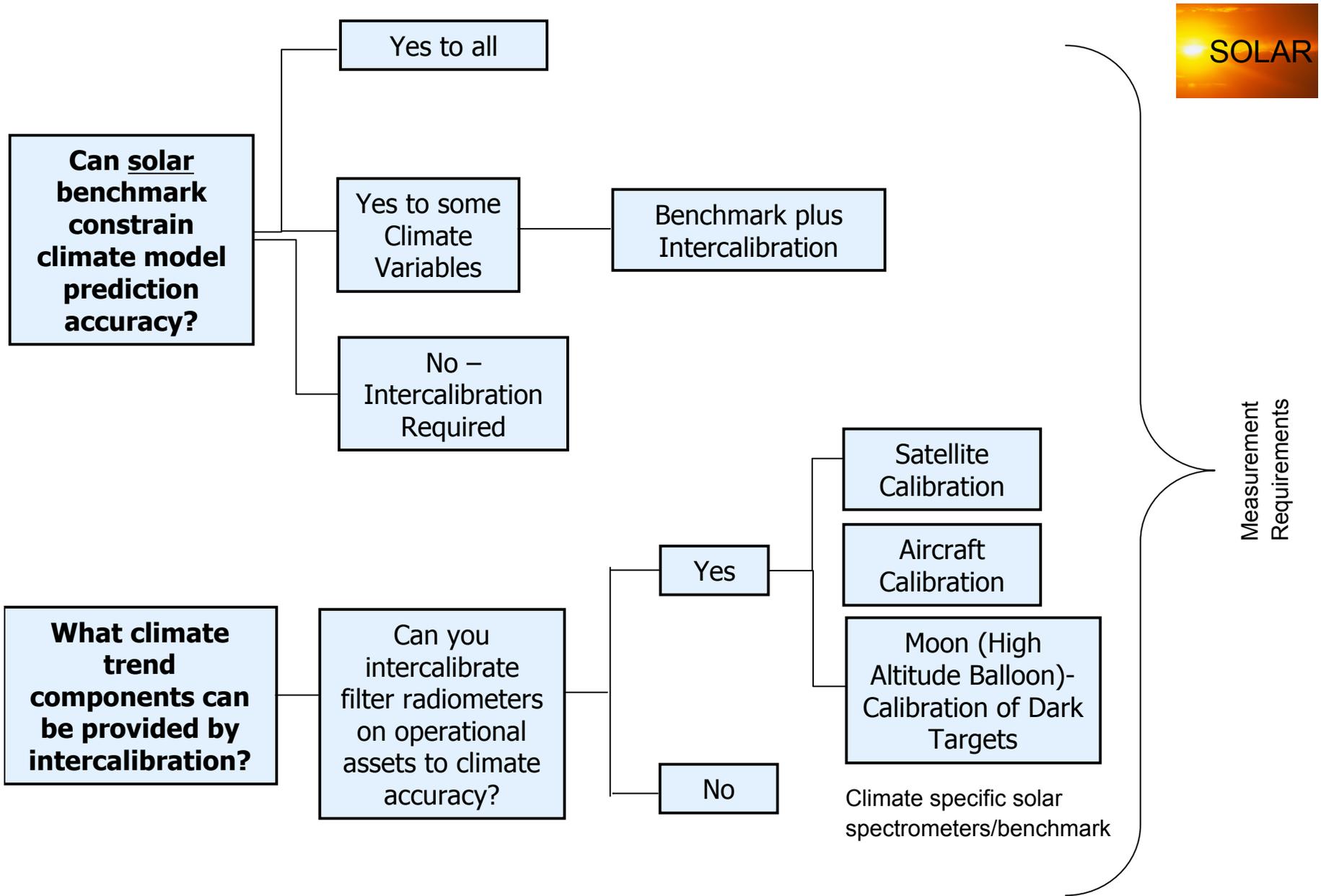


Decision Tree – Path to IR Measurement Requirements





Decision Tree – Path to Solar Measurement Requirements



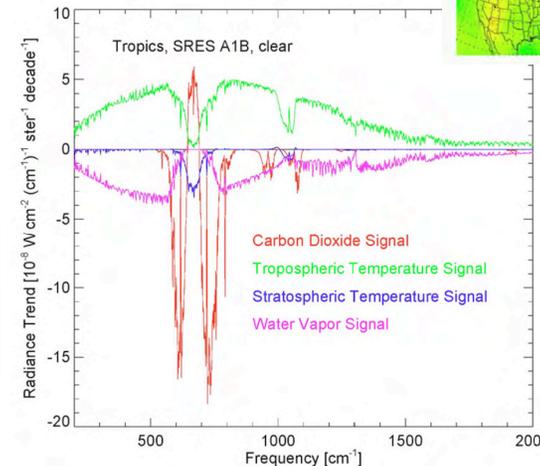
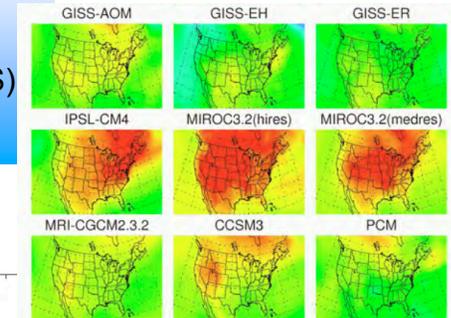


CLARREO Benchmark Radiance Climate Model OSSEs

- CLARREO Mission Objectives include monitoring of climate change using SI-traceable spectral radiance benchmarks at high absolute accuracy
 - Solar and infrared high spectral resolution and broad spectral coverage
 - Use to monitor critical climate change forcing, response and feedback variables
 - Accuracy requirements for decadal change taken from previous reports (NISTIR, GCOS)
 - Use climate model Observing System Simulation Experiments (OSSEs)

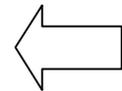
- Key benchmark radiance trade studies:
 - Add CLARREO simulators to major climate models to test CLARREO decadal change spectra signals.
 - Verify accuracy of simulators using monthly mean properties versus individual time steps.
 - Improve surface albedo spectral resolution in climate models to improve accuracy as CLARREO OSSE
 - Test clear-sky versus all-sky (with clouds) capability for varying CLARREO field of view assumptions.
 - Verify sampling requirements (time/space/angle/spectral)

Climate Model Predicted Change



Simulate Decadal Spectral Signals

Determine Climate Model Prediction Accuracy, Needed Improvements



Test Climate Model Predicted Spectral Signals Against CLARREO Spectral Benchmarks

- Approach
 - Climate OSSE using CLARREO simulator in climate model for decadal change ($< 1\text{nm } \Delta\lambda$; 200 km grid box)
 - NCAR and NASA GISS climate models likely key participants
 - IR clear-sky already published, IR all-sky underway, Solar is new.
- The first use of the OSSE concept with decade to century climate models



CLARREO Solar Spectral Intercalibration Trades

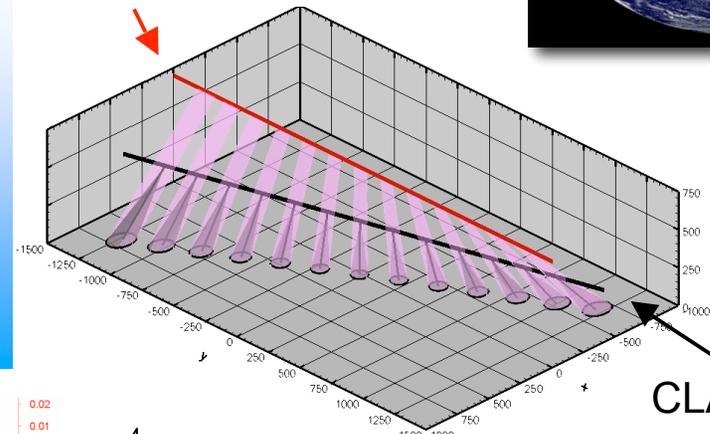
Climate Change



- CLARREO Mission Objectives require that climate variables remotely sensed from space using reflected solar radiation be at accuracies sufficient for decadal change.
 - Key climate forcing variables include aerosols, vegetation, clouds (indirect effect)
 - Key climate feedback variables include clouds, surface albedo (especially snow and ice)
 - Accuracy requirements for decadal change taken from previous reports (NISTIR, GCOS)
 - A potential method to achieve climate accuracy is for CLARREO to calibrate other sensors.

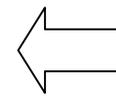
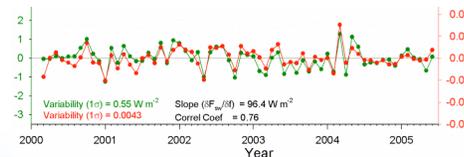
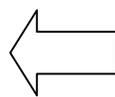
- There are several key intercalibration trades:
 - Does spectral response of filters change enough over time to alias climate change (e.g. MODIS, VIIRS)?
 - Can CLARREO detect and correct spectral response changes of other sensors?
 - Can CLARREO achieve sufficient space-time-angle sampling for intercalibration of other sensors?
 - High altitude aircraft as independent validation of accuracy
 - Moon as validation and calibration transfer target

Aqua MODIS, CERES
705km orbit



CLARREO
600km orbit

Cloud Feedback
Observations



CLARREO Calibrates
CERES/VIIRS

- Three approaches
 - Climate OSSE using CLARREO simulator in climate model for decadal change ($< 1 \text{ nm } \Delta\lambda$; 200 km grid box)
 - Simulate MODIS and VIIRS using Schiamachy in orbit spaceborne spectrometer ($< 1 \text{ nm } \Delta\lambda$; 30 by 60km fov)
 - Simulate CLARREO using MODIS surface/aerosol/cloud properties + radiative transfer theory ($< 1 \text{ nm } \Delta\lambda$; 1km fov)
- Active international collaboration with UK TRUTHS concept, ESA Schiamachy mission



At the end of the first phase (~12 months) we will have defined threshold and goal requirements for these cost drivers. The follow-on mission definition studies will examine the cost/benefit trade between threshold and goal requirements.

The key cost drivers include:

- Pointing versus nadir only
- Number of orbits required (e.g., diurnal cycle and overlap of operational assets for intercalibration)
- Spectral range and resolution (e.g., do you need the full spectrum or simply chunks of the spectrum)
- Spatial and temporal sampling
- Footprint size
- GPS requirements
- Validation approach (e.g., aircraft, satellite, high-altitude balloon)
- Level of international partnering
- Scope of mission – demo versus full mission
- Possible inclusion of other instruments (e.g., CERES, TSIS)



- NASA Earth Science budget uncertainty
- Cost constraints (\$200M price in Decadal Survey)
- Congressional / Agency support
- Community support
- Planned acquisition strategy
- TSIS/CERES continuity (NOAA responsibility)
- International participation