First CLARREO Mission Study Team Meeting

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CLARREO Science Objectives
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THE THREE MOST SIGNIFICANT ACHIEVABLE SCIENCE OBJECTIVES

1. ASSESS GLOBAL CLIMATE CHANGE
   Detection, measurement, attribution of climate change
   Obtain decadal-length records of key climate variables
   AS IN 100+YR SURFACE TEMPERATURES, KEELING CO₂ RECORD

2. PERFORM CLIMATE GCM VALIDATION
   Comprehensive end-to-end validation of climate GCMs
   Field testing of climate GCM climate prediction accuracy
   Simultaneous checks on radiative and physical variables
   a. Cloud, aerosol radiative parameters, indirect effect
   b. Temperature, water vapor profiles, surface albedo
   c. LW, SW radiative fluxes, heating / cooling rates
   MOST COMPREHENSIVE CLIMATE GCM VALIDATION EVER PROPOSED

3. PROVIDE RETRIEVAL INTERCALIBRATION
   Improve calibration of operational satellite retrievals
   Establish accurate satellite retrieval benchmarks: a., b., c.
   MOST EFFECTIVE MEANS TO IMPROVE OPERATIONAL RETRIEVALS
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VS

GLOBAL CLIMATE CHANGE
(decadal-length records of climate variables)
(detection, measurement, attribution)

WHAT NEEDS TO BE MEASURED?

A. Direct Radiative Forcings
   1. Solar irradiance (operational measurement)
   2. LW - GHGs (direct sampling / operational measurement)
   3. SW - Aerosols, surface albedo (poorly defined)

B. Climate Feedbacks / Natural Variability
   1. LW - Temperature, water vapor, clouds, GHGs
   2. SW - Clouds, aerosols, surface albedo, indirect effect

C. Nadir Spectral Intensity / Polarization
REQUIRED INSTRUMENTATION

A. TSIS - Total Solar Irradiance

B. LW - Michelson Interferometer
   1. Temperature profile (surface temperature, emissivity)
   2. Water vapor profile (strat-trop differentiation)
   3. Cloud information (height, phase, size, optical depth)
   4. LW Radiative fluxes (heating / cooling rate profiles)

C. SW - Polarimeter / Spectrometer
   1. Aerosol properties (optical depth, size, composition, $\omega_0$)
   2. Surface albedo (spectral dependence)
   3. Clouds (phase, size, optical depth, indirect effect)
   4. SW Radiative fluxes (heating rate profiles)
The spaceborne TSI record is due to several instruments, which fortunately have sufficient overlap to provide continuity despite the relatively large differences between each instrument on an absolute scale. Correlations with sunspot number provide a proxy to extend TSI estimates back 400 years.
Solar and Thermal Radiation in a Climate GCM

(A) Spectral distribution of incident solar radiation at Top-of-Atmosphere (TOA) and at ground surface (BOA).

(B) Spectral distribution of thermal radiation at Top-of-Atmosphere (TOA) and at ground surface (BOA).

The global-mean absorbed Solar Radiation by the Earth (surface + atmosphere) is approximately 240 W/m². Global energy balance requires that the global-mean Thermal Radiation emitted to space is also 240 W/m².

Line-by-Line calculations of the SW and LW spectra use the HITRAN database of over $10^6$ spectral lines and provide a Reference Benchmark for verifying the GCM radiation model accuracy.
Radiative flux and cooling rate comparison between GCM (black) and Line-by-Line (red) calculations for a clear-sky Midlatitude Summer Standard Atmosphere. The cooling rate is the net flux divergence in a 23-layer atmosphere. GCM-LBL differences of the cooling rate, downwelling and upwelling flux are shown in the right hand panel.
Flowdown of science objectives into specific retrieval requirements

- **Science objectives**
  1. Global distribution of aerosol properties
  2. Aerosol effect on radiation budget
  3. Effect of aerosols on clouds and precipitation

- **Retrieval requirements**
  - **Aerosol retrievals**
    - Spectral optical thickness (±0.02)
    - Effective radius (±10%)
    - Effective variance (±50%)
    - Spectral behavior of the aerosol refractive index (±0.02)
    - Particle shape
    - Single-scattering albedo (±0.03)
  - **Cloud retrievals**
    - Optical thickness (±8%)
    - Effective radius (±10%)
    - Effective variance (±50%)
    - Cloud phase/particle shape

For two aerosol components
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LW SPECTRAL SIGNATURES
OF
KEY CLIMATE VARIABLES
ENCOUNTERED IN
PRINCIPAL CLARREO LW APPLICATIONS

1. DECADAL CLIMATE RECORD INFORMATION CONTENT
2. EXPECTED CLARREO RETRIEVAL DATA PRODUCTS
3. GCM PERFORMANCE VALIDATION COMPARISON DATA
4. OPERATIONAL SATELLITE RETRIEVAL CALIBRATION DATA
Spectral signature of ice cloud optical depth
Spectral signature of water cloud optical depth
Spectral signature of cloud ice / water phase

(Water - Ice) Difference

Planck Reference (260K)

IRIS Noise at Given Wavelength

\( \tau_{\text{cd}} = 1, R_{\text{eff}} = 10 \mu\text{m} \)
Spectral signature of ice cloud particle size
Spectral signature of water cloud particle size
Spectral signature of ice cloud height change
Spectral signature of surface temperature increase
Spectral signature of lower tropospheric water vapor
Spectral signature of upper tropospheric water vapor
Spectral signature of tropospheric ozone
Spectral signature of stratospheric ozone
NIMBUS-4 IRIS sample retrieval - marine stratus
NIMBUS-4 IRIS sample retrieval - thick anvil cirrus

THICK CIRRUS

$T_r = 220.0 \, \text{K}$

$P_h = 210.0 \, \text{mb}$

$R_r = 25.0 \, \mu\text{m}$

$\tau_c = 6.12$
Spectral location of principal GHG absorption bands
NIMBUS-4 IRIS peak emission level
Left: Normalized sample spectral GHG contribution functions.

Right: Normalized spectral cloud signature components for water (top left) and ice (bottom right) clouds, respectively: (1) self emission, (2) direct transmission, (3) diffuse transmission, (4) reflection.
Left: Real (top) and imaginary (bottom) refractive index for water and for ice.

Center: Mie scattering extinction efficiency factor for water (top) and ice (bottom).

Right: Mie scattering single scattering albedo for water (top) and ice (bottom).
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SW CLIMATE VARIABLES
RETRIEVAL LIMITATIONS
OF INTENSITY ONLY MEASUREMENTS

1. Can’t measure global aerosol change
2. Can’t measure surface albedo change
3. Can’t address aerosol indirect effect

SW MEASUREMENT REQUIREMENT
Polarimetric / Spectral Capability
Left: one month of MISR vs MODIS same-spacecraft, co-located pixel-level AOTs (January 2006). Right: Research Scanning Polarimeter (APS aircraft prototype) AOTs vs sunphotometer results over land (circles) and ocean (squares) at 410/443 (blue), 500 (turquoise), 673 (green), and 865 nm (red). The error bars correspond to sunphotometer measurement uncertainty.
Research Scanning Polarimeter in ALIVE

- Low altitude reflectance and polarized reflectance

- Measurements of two different surface types at 410, 470, 555, 670, 865, 1590 and 2250 nm (blue, mauve, turquoise, green, red, magenta, black) with different viewing geometries.
  
  - Solid lines are bare soil, dashed lines are vegetation. These are single aggregated scans of a single pixel. Imperfection are primarily due to yaw.
  
  - Reflectances of different surface types show significant variations in color. Polarized reflectances of different surface types is dominated by geometry.
Previous measurements over Dismal Swamp showed that at least heavily vegetated surface are relatively colorless in terms of their polarized reflectance.

- Residuals are the difference between the other bands and the 2250 nm polarized reflectance.
- Planned aerosol retrieval will use 2250 nm polarized reflectance as a proxy for the surface polarized reflectance.
- Important to know how grey the surface polarized reflectance is and what viewing geometries should be excluded (e.g. backscatter).
Research Scanning Polarimeter in ALIVE

- ALIVE provides increased angular range of measurements and better atmospheric correction
  - Raman Lidar to determine burden between ground and plane, AATS to determine burden above and spatial gradients, CIMEL/MFR for size distribution/refractive index estimate.
  - Preliminary atmospherically corrected a) vegetation and b) soil polarized reflectance. AATS not incorporated and CIMEL is our analysis of sun/sky radiance Level 1 measurements.
  - Results may get better, or worse with more accurate (AATS) correction, but it is certainly the case that the surface polarized reflectance color is very weak.
Global annual-mean distribution Sulfate, Sea Salt, Nitrate, Dust, Black Carbon, and Organic Carbon aerosols in the GISS ModelE aerosol climatology. Upper right hand numbers give global-mean per cent of each aerosol.

GISS GCM aerosol climatology at SGP site
Seasonal phase mismatch of aerosol optical depth variability between GCM (sea salt) and satellite observations - suggests retrieval problem.
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