The Aerosol/Cloud/Ecosystems Mission (ACE)

Mark Schoeberl
NASA/GSFC

What is ACE?

ACE will help to answer emerging fundamental science questions associated with aerosols, clouds, air quality and global ocean ecosystems.

- Quantify aerosol-cloud interaction and assess the impact of aerosols on the hydrological cycle.
- Determine Ocean Carbon Cycling and other ocean biological processes.

Why two goals?

- Ocean biology measurements and Aerosols meet at the algorithm level
  - ➢ Accurate estimation of the aerosol contribution to the backscatter radiation are required to make precise ocean biosphere measurements.
  - ➢ Aerosol interference with ocean color measurements has been a major limitation in past missions
- But, there are common science problems between the two communities as well!
  - ➢ Fertilization of the ocean by dust; What is will happen in the future with climate change?
  - ➢ Aerosol formation by oceanic emitted DMS; How will ecosystem generation of aerosols affect the planetary energy budget?

Expected impacts

- ACE will narrow the uncertainty in aerosol-cloud-precipitation interaction and quantify the role of aerosols in climate change.
- ACE will measure the ocean ecosystem changes and precisely quantify ocean carbon uptake.
- ACE measurements will improve air quality forecasting by determining the height and type of aerosols being transported long distances.

NAS Decadal Survey Description of ACE

- Objective: "…reduce the uncertainty in climate forcing in aerosol-cloud interactions and ocean ecosystem CO_2 uptake" - Decadal Survey pg 4-4

- Mission and Payload: … LEO, sun-synchronous early-afternoon orbit. The orbit altitude of 500-650 km. The NAS mission consisted of four instruments:

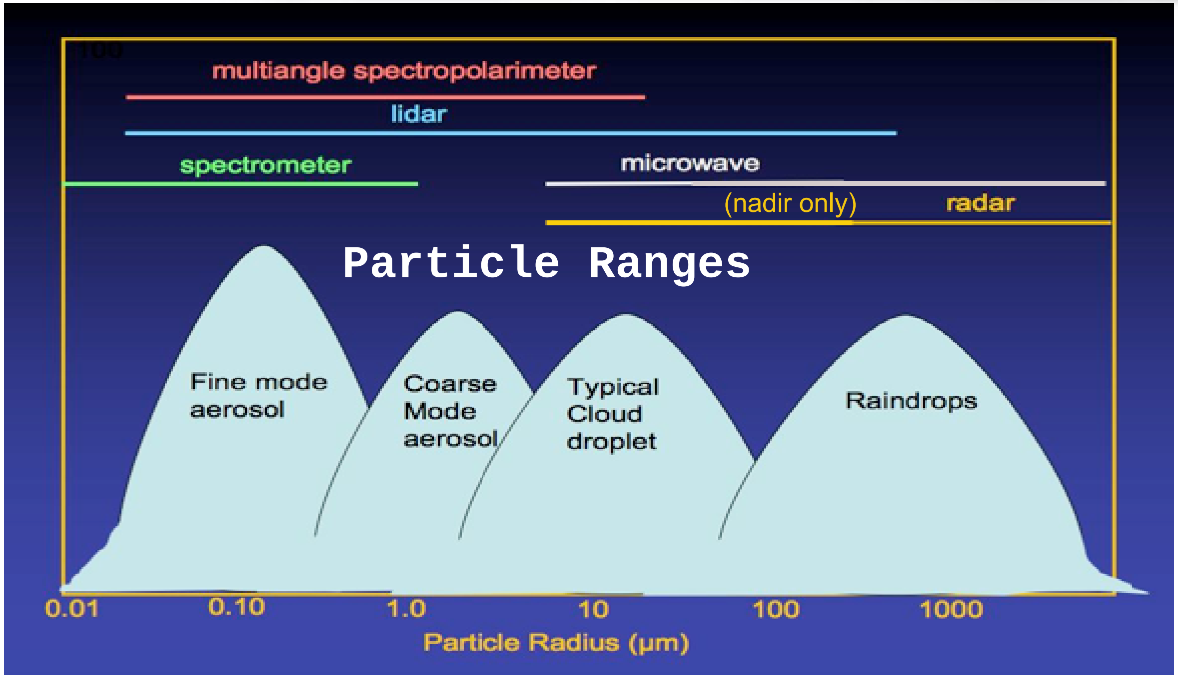
  - A multi-beam cross-track dual wavelength lidar for measurement of cloud and aerosol heights and layer thickness;
  - A cross-track scanning cloud radar* with channels at 94 GHz and possibly 34 GHz for cloud droplet size, glaciation height, and cloud height;
  - A highly accurate multiangle - multiwavelength polarimeter to measure cloud and aerosol properties (This instrument, would have a cross-track and along-track swath with ~1 km pixel size.)
  - A multi-band cross-track visible/UV spectrometer with ~1 km pixel size, including Aqua MODIS, NPP VIIRS, and Aura OMI aerosol retrieval bands and *additional bands for ocean color and dissolved organic matter*."

* Doppler would be desirable too

ACE Science Objectives Extended

- ACE Extended – the ACOB mission
  - NASA-sponsored workshops concluded that ACE should include more cloud measurement capabilities and assess the role of precipitation in aerosol-cloud interaction. This could be done by adding high and low frequency μ-wave radiometers to the potential payload.
    - The ACE SWG published a science White Paper that specifically addresses the rationale, requirements and resulting measurements associated with the ACOB mission.
  - Thus, Aerosol Climate and Ocean Biology (ACOB) is identical to ACE except for two μ-wave radiometers that strengthen the measurement of clouds and precipitation -- ACOB adds *significant* science.
    - The addition of the μ-wave radiometers broadens the ACE swath
    - Consistent with "Vital Skies" white paper recommendation that preceded the ACE white paper.
  - Adding μ-wave radiometers will increase the cost slightly

Aerosol – Cloud Community Measurement Strategy

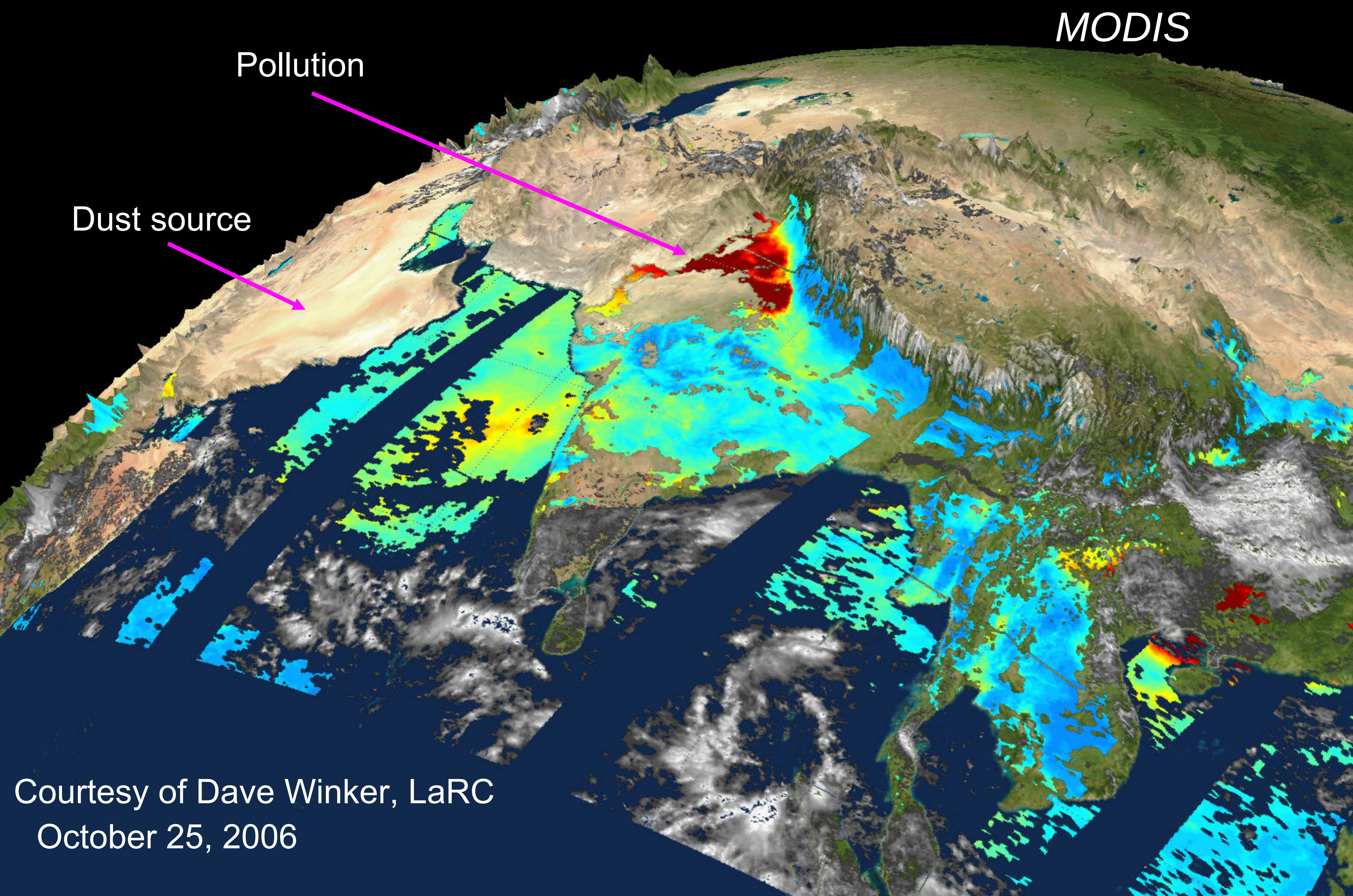


In order to understand the interaction between pollution, clouds and precipitation and to address air quality we need measurements that are sensitive to:

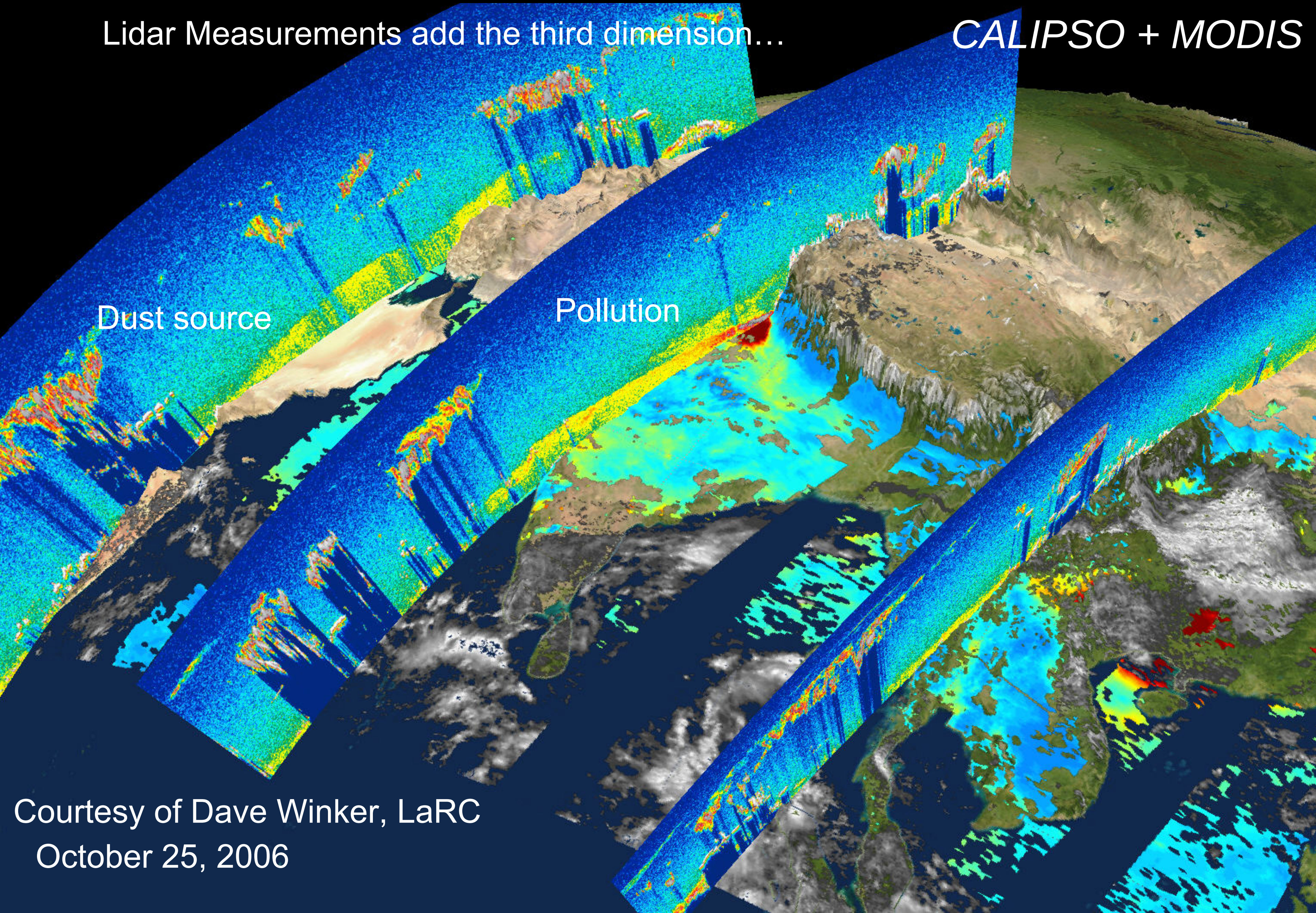
- particle distribution from fine mode to raindrops
- aerosol and cloud particle optical properties
- aerosol and cloud heights
- aerosol composition

Following the measurement suite pioneered by the A-Train, a combination of active and remote multi-wavelength sensors is needed.

Aerosol and Cloud Observations over South Asia



Aerosol and Cloud Observations over South Asia



Courtesy of Dave Winker, LaRC
October 25, 2006

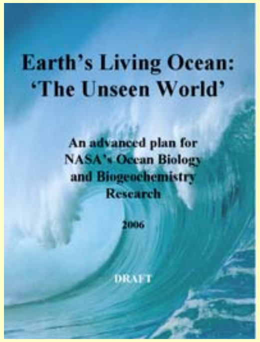
Ocean Biology Research Goals

ACE Ocean Measurements Trace Directly to *Science Goals*

NASA Strategic Plan

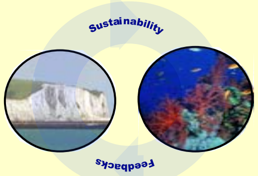
- Understand Earth system
- New observations to detect and predict change

Ocean Biology & Biogeochemistry Plan



- Ecosystems & biodiversity
- Carbon/elemental cycles
- Habitats
- Hazards

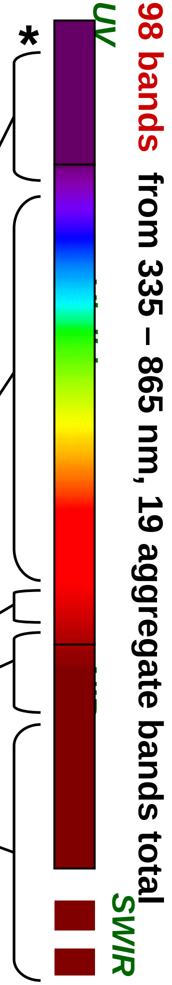
Key Biochemistry & Biology Properties



- Dissolved carbon
- Phytoplankton pigments
- Functional groups
- Physiology
- Particle size
- Calcite
- Fluorescence
- Coastal biology
- Atmospheric corrections*

* Short UV for advanced atmospheric correction

Ocean Radiometer



Research objectives for Earth Science → lead to → ***Ocean biology and biogeochemistry questions*** → lead to → ***Key environmental parameters*** → lead to → ***Measurement requirements***

STM-based ACE/ACOB Instrument Requirement

Science Requirement	Instrument Type	Mission
Characterization of aerosols types and modal distribution over a broad swath	Multi-angle polarimeter	ACE/ACOB
Altitude of and properties of aerosols/clouds	Backscatter multi-beam /HSR lidar (active)	ACE/ACOB
Cloud microphysics within the cloud	Dual frequency cloud radar (active)	ACE/ACOB
Ocean color	Multi-band spectroradiometer	ACE/ACOB
Cloud height in the IR	IR stereo sensor*	ACE/ACOB
Cloud particle type and ice water path over a broad swath	High frequency μ-wave radiometer*	ACOB
Precipitation and liquid water path over a broad swath	Low frequency μ-wave radiometer*	ACOB

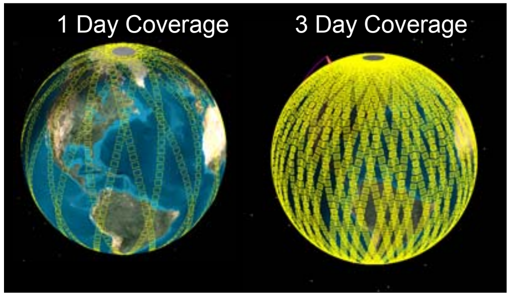
Multi-Beam Lidar

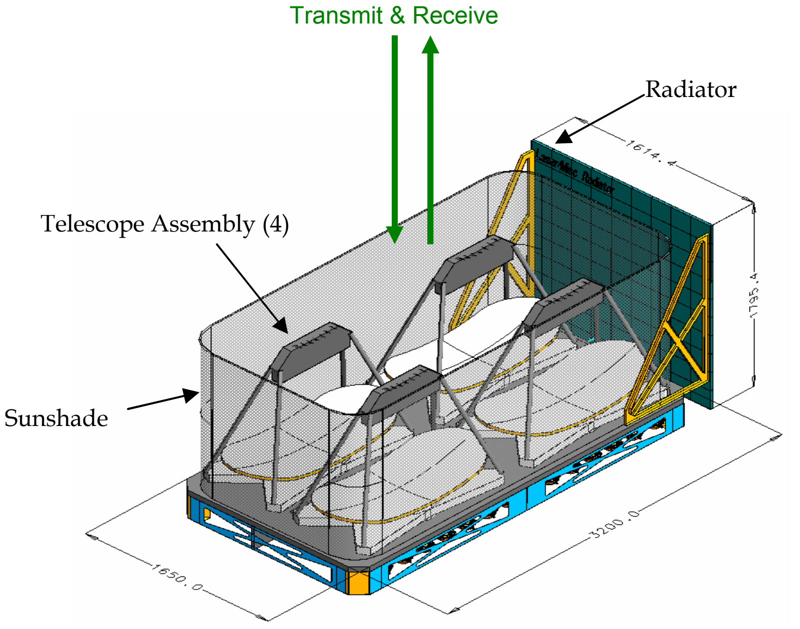
Continue profile observations after CALIPSO.

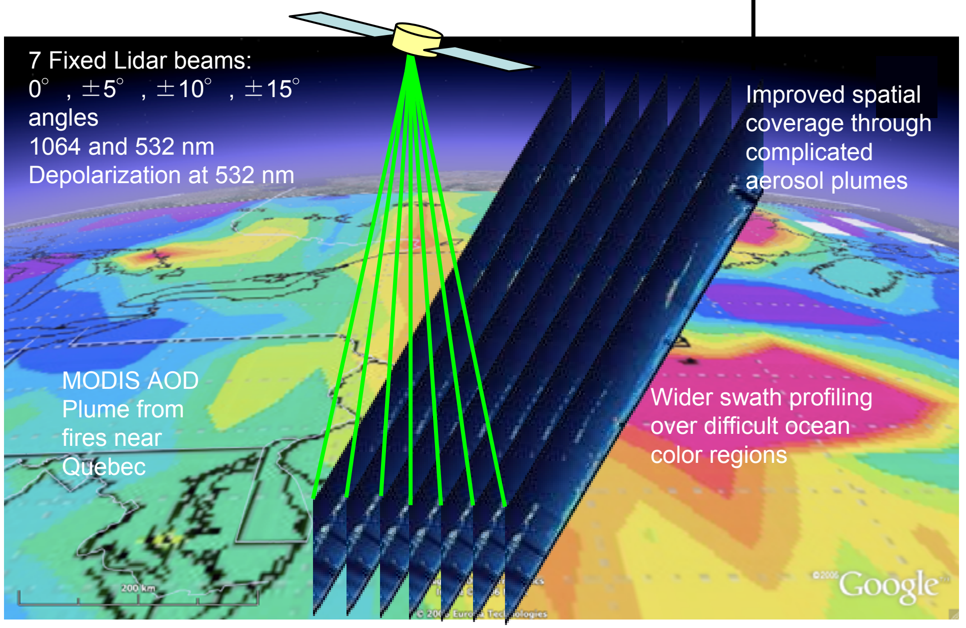
Wider swath for better global coverage:

- multiple beams increase number of statistical-based mission observations
- enables better aerosol emission/source identification
- improved ability to track plumes during long-range transport
- combined lidar and imager observations (e.g. ocean biology)

Beam spacing fine enough to resolve aerosol structure across most plumes, near sources, and for downwind advection





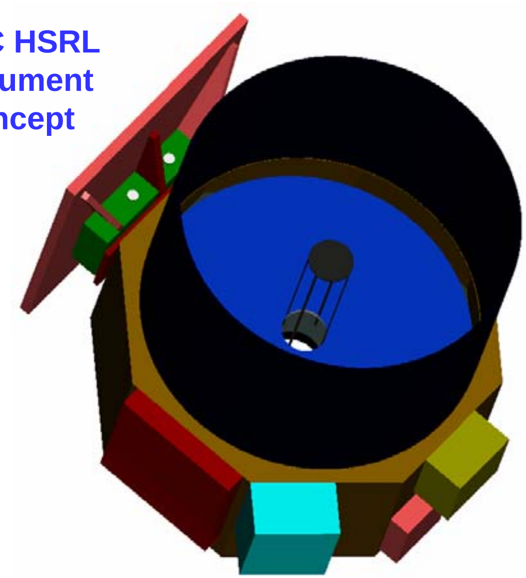


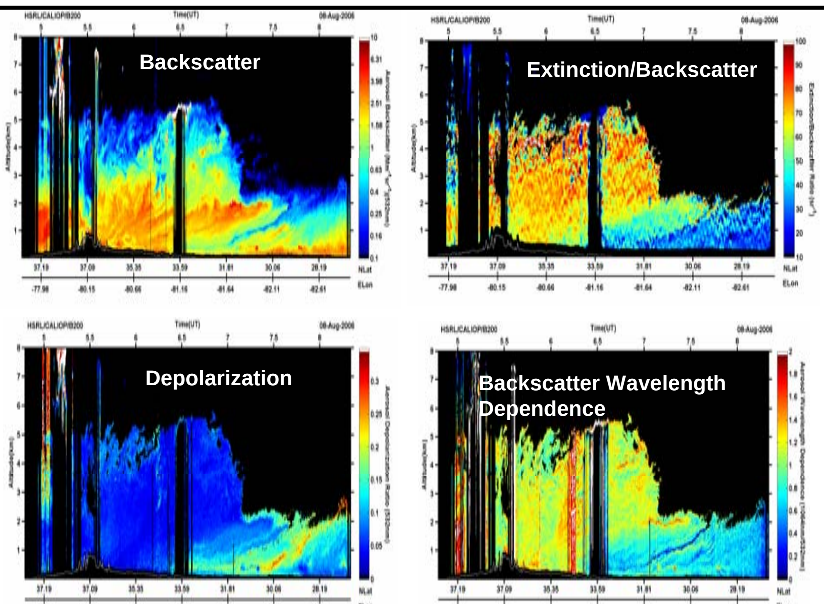
Multiwavelength High Spectral Resolution Lidar (HSRL)

Goddard Space Flight Center

- Multiwavelength HSRL
  - Backscatter at 3 wavelengths (3 β) : 355, 532, 1064 nm
  - Extinction at 2 wavelengths (2 α) : 355, 532 nm
  - Depolarization at 355, 532, and 1064 (dust and contrails/cirrus applications)
- Retrieved, layer-resolved, aerosol microphysical and macrophysical parameters
  - Effective and mean particle radius (errors < 30-50%)
  - Concentration (volume, surface) (errors < 50%)
  - Complex index of refraction (real: $\pm$0.05 to 0.1; imaginary (<50% if > 0.01)
  - Single scatter albedo (SSA) ($\pm$0.05)

LaRC HSRL Instrument Concept





Data from LaRC Airborne HSRL

Aerosol Lidar Information Content

Backscatter Lidar
- Aerosol layer heights
- Qualitative vertical distribution (backscatter profile)
- Qualitative aerosol typing information
- Extinction profile derived from backscatter

Backscatter Lidar + Passive
- Extinction profile using column constraint
- Fine-coarse mode fraction vs. altitude

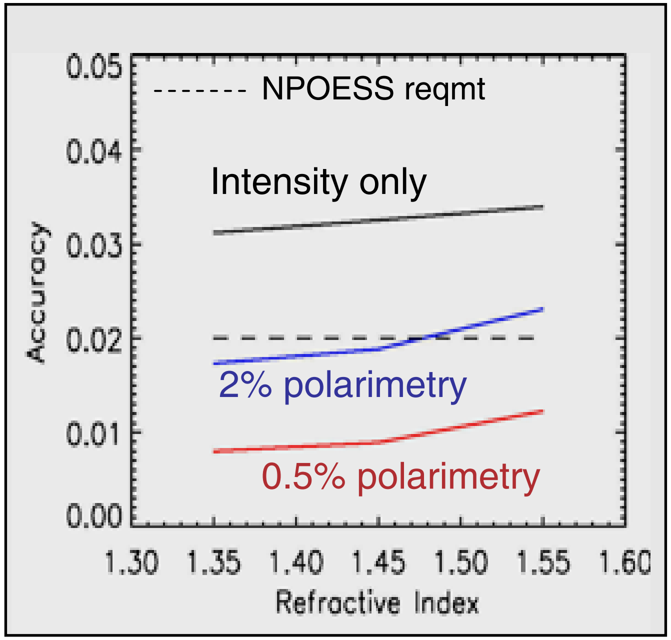
Multiwavelength HSRL
- Extinction profile
- Complex refractive index vs. altitude
- Aerosol size vs. altitude
- Single scatter albedo vs. altitude
- Concentration vs. altitude

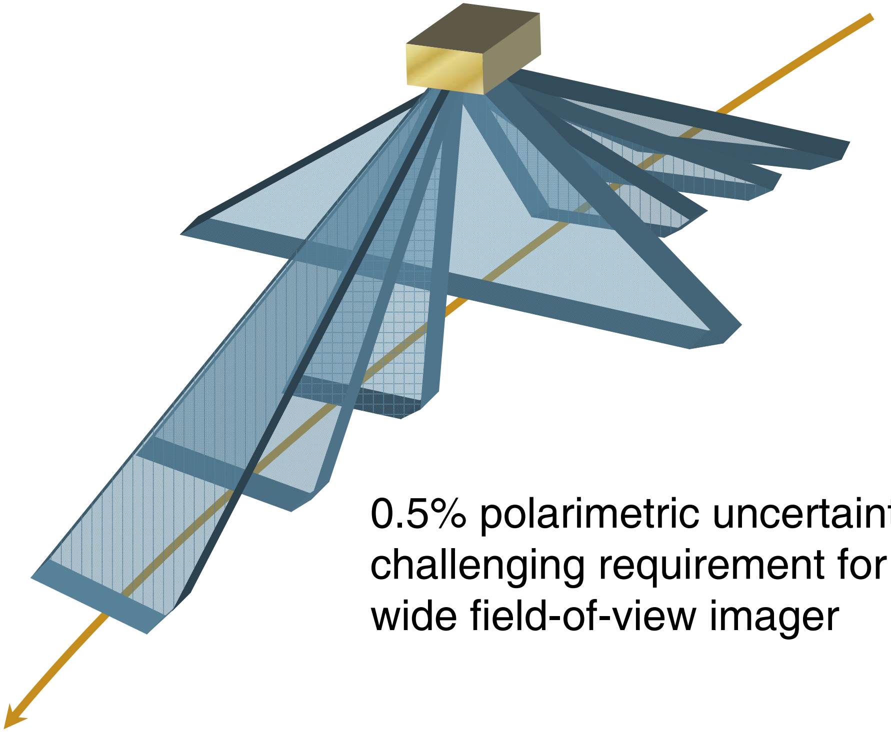
MSPI - Advanced MISR Instrument

Multiple cameras with extended spectral range, polarimetry, and wider swath

Synergistic use of multiple techniques reduces retrieval indeterminacies

- multiangle: particle size, shape, retrievals over bright regions (deserts, cities)
- multispectral: particle size (visible and SWIR), absorption and height (near-UV)
  - nominal bands: 380, 412, 446, 558, 650, 865, 1375, 1610, 2130 nm
- polarimetric: size-resolved refractive index and size distribution width
  - nominal bands: 650, 1610 nm





0.5% polarimetric uncertainty is a challenging requirement for a wide field-of-view imager

Ocean Color Instrument (ORCA)

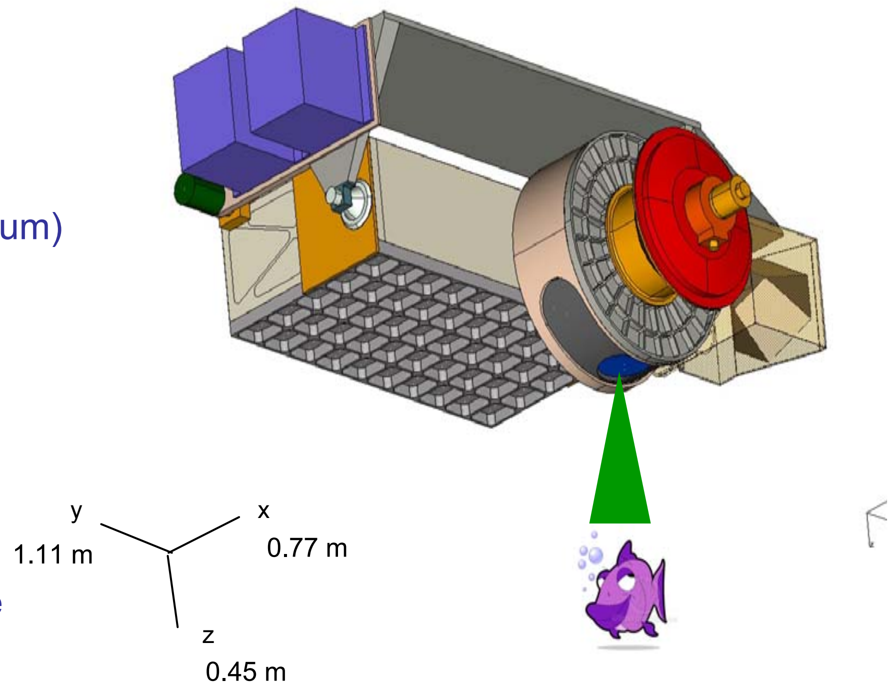
ORCA is a spectroradiometer designed for ocean remote sensing

Instrument Concept

- Scanning Spectrograph
  - +/-58.3 deg. cross-track scan
  - 2500 km swath
- 98 bands from 335 – 865 nm
- 19 aggregate bands total for ocean science (minimum)

Spectral Range	SNR Specs
Near UV (335-400nm)	750-1500
Visible (400-700nm)	1000-1500
NIR (700-1640 nm)	750-180

- Other bands can be used for aerosol/cloud science



- Two day global coverage from 650km orbit
- Data collected to 75 deg. latitude of sub-solar point
- Monthly lunar calibration maneuver (dark side)
- Daily solar calibration (pole)
- Spectral calibration (solar-based)
- Sun glint avoidance (sensor tilting)
- Five year design life

All instrument technologies are TRL $\geq$ 6

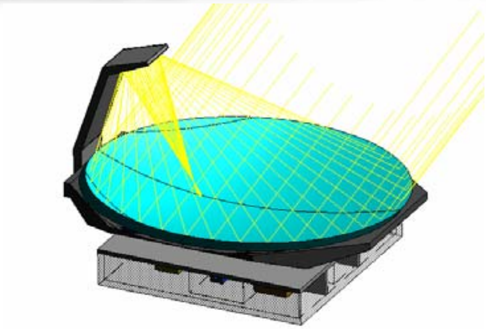
Dual Frequency Cloud Radar

Products:

- Cloud top height
- Microphysical profile information
- Particle phase/glaciation height
- Ice Water Content and Cloud Water Content
- Precipitation detection

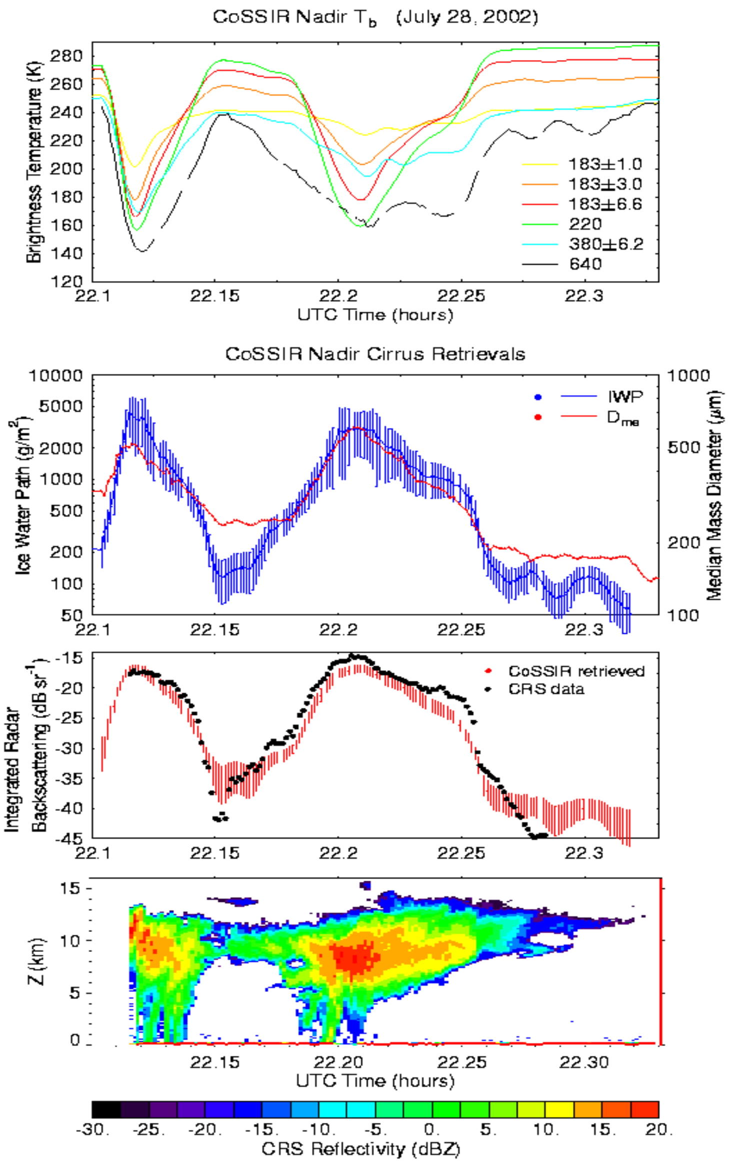
Scientifically Desirable:

- Swath
    - Even a narrow swath will be difficult because of the narrow back scattering phase function
    - It is unlikely that the cloud radar can point more than 10º off nadir
- More sensitivity to precipitation
- Sensitivity to low clouds (aerosols probably have more effect on them)
- Doppler capability not a requirement



Radar Measurement	Cloud/precip structure & microphysics	
Wavelength	94GHz (CloudSat, EarthCare)	94GHz and 34 GHz
Cloud top height (± 1 km)	⊞	⊞
Glaciation level	⊞	⊞
Precipitation		⊞
Droplet distribution to 300μ		⊞
Cloud water content profile	⊞	⊞

High Frequency μ-wave Radiometer



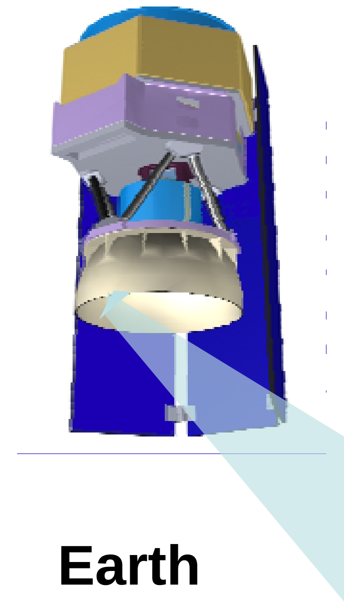
Submillimeter/Millimeter (SM4) Radiometer

- Conical Scanning Imager with 1600 km swath
- 10-km spatial resolution => 0.36□ pencil beam
- 6 Receivers > 12 Channels
- Vertical + Dual Polarization at 643 GHz

{183V, 325V, 448V, 643 V&H, and 874V GHz}

- Three-point calibration (hot, cold, space cold)

- Heritage: MLS, CoSSIR, HERSHEL, MIRO



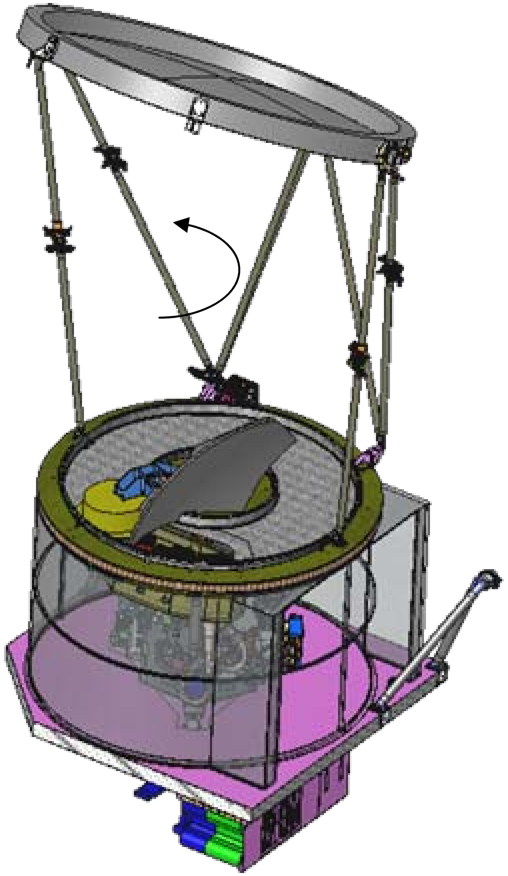
Low Frequency μ-wave Radiometer (GMI)

GPM Microwave Imager (GMI)
Key Products

- Rain rates from ~0.3 to 110 mm/hr
- Increased sensitivity to light rain over land and falling snow

ACOB-B would be a GPM daughter satellite

Ball Aerospace and Technology Corporation (BATC) is developing GMI

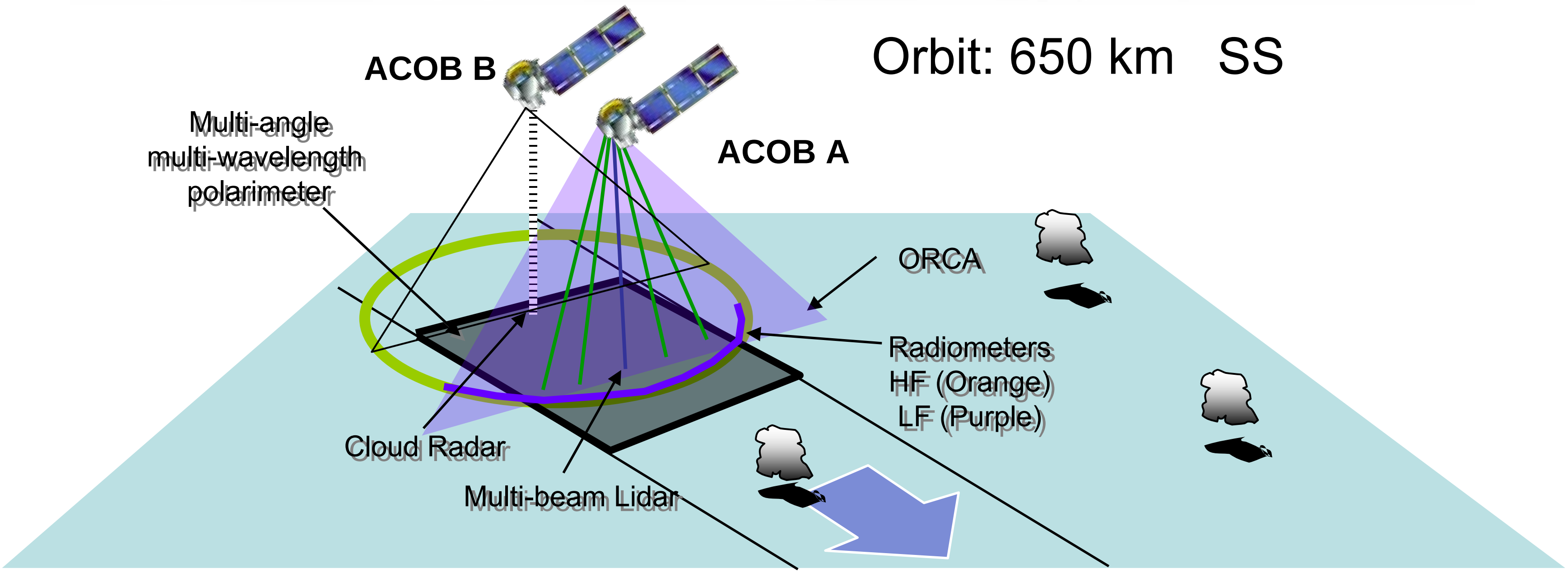


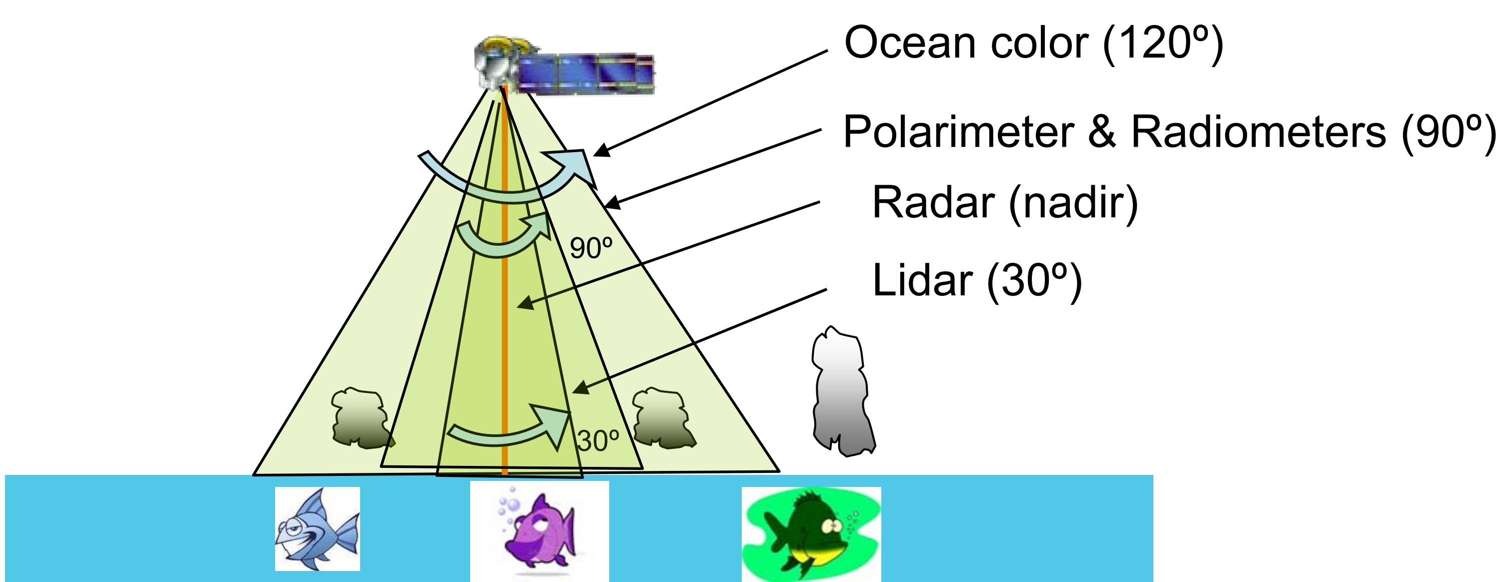
GMI Key Parameters

Mass (with margin):~150 kg
Power:~125 W
Data Rate:~30 kbps
Antenna Diameter:~1.2 m
Channel Set:
10.65 GHz, H & V Pol
18.7 GHz, H & V Pol
23.8 GHz, V Pol
36.5 GHz, H & V Pol
89.0 GHz, H & V Pol
166 GHz, H & V Pol,
183±3 GHz, V (or H) Pol
183±8 GHz, V (or H)
(166 and 183 GHz to have same resolution as 89 GHz)

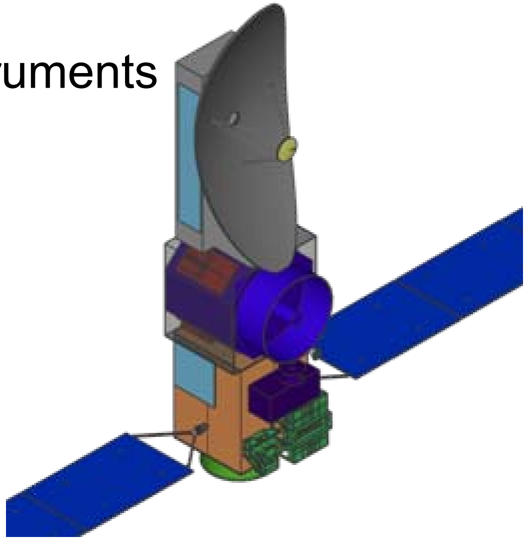
Overlaps with the HF radiometer

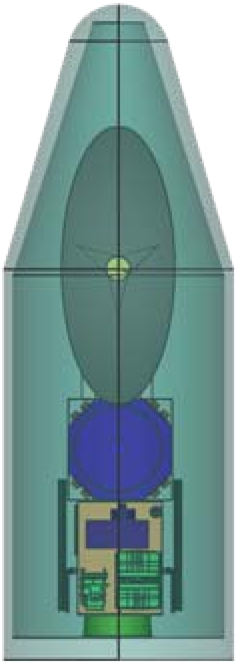
ACE/COB: Two Spacecraft Observing Geometry





Single Platform ACE Mission





- This JPL version of ACE has four instruments
  - Cloud radar
  - MSPI
  - HSR Lidar
  - Ocean color radiometer
- Modified RSDO spacecraft bus
- 480 km altitude SSO
- Strengths
  - Optimizes orbit for atmospheric science and improves atmospheric measurement sensitivity compared to higher altitude orbit
  - Single Platform is more cost effective (cheaper)
- Weakness
  - Does not include IR measurements or μ-wave radiometers
  - Does not include multi-beam lidar

Next Steps with ACE

- June ‘08 science definition team meeting (by invitation)
  - Continue to refine measurement requirements
    - Polarimeter accuracy
    - Radar requirements
    - Lidar requirements
    - Combining instruments (e.g. ocean color and polarimeter)
- 2008-2009
  - Additional instrument and payload studies
  - Development of schedule
- ACE is the most critical climate mission in the 2’d tier NAS group