SATELLITE Capabilities and Limitations
For the ACPC Box Experiment

Ralph Kahn
NASA/Goddard Space Flight Center
Overall Satellite Limitations

- Polar orbiters provide snapshots only
- Difficult to probe cloud base
- Typically ~100s of meters or poorer horizontal resolution
- Passive instruments offer little vertical information
- Active instruments offer little spatial coverage
- Little-to-no information about aerosol particle properties
- Bigger issues retrieving aerosols in the presence of clouds!
- Cloud property retrievals can be aliased by the presence of aerosols

These points are summarized in Rosenfeld et al. Rev. Geophys. 2014
Finer Points on Satellite Aerosol Retrieval **Limitations**

- Difficult to retrieve aerosols that are *collocated with cloud*
  -- *Cloud-scattered light* & cloud “contamination” can affect near-cloud aerosol retrievals
- Rarely can detect aerosol in *droplet-formation region* below clouds – need cloud & aerosol *vertical distributions*
- Aerosols smaller than about *0.1 micron diameter* look like atmospheric gas molecules – must *infer CCN* number
- Must deduce aerosol *hygroscopicity* (composition) from qualitative “type” – size, shape, and SSA constraints
- Environmental (Meteorological) Coupling – Factors can *co-vary*
  -- LWP can decrease as aerosol number concentration increases (also depends on atm. stability)
- Many aerosol-cloud interaction time & spatial scales do not match *satellite sampling*

*Satellites are fairly blunt instruments for studying aerosol-cloud interactions!!*
Satellite “Direct” Capabilities

• Polar orbiting imagers provide \textit{frequent, global coverage}
• Geostationary platforms offer \textit{high temporal resolution}
• Multi-angle imagers offer \textit{aerosol plume height & cloud-top mapping}
• Passive instruments can retrieve total-column \textit{aerosol amount (AOD)}
• Active instruments determine aerosol & some cloud \textit{vertical structure}
• UV imagers and active sensors can retrieve \textit{aerosol above cloud}
• Multi-angle, spectral, polarized imagers obtain \textit{some aerosol type info.}
• Active sensors can obtain \textit{some aerosol type info., day & night}
• Satellite trace-gas retrievals offer \textit{clues about aerosol type}
• Vis-IR imagers can retrieve \textit{cloud phase, }r\textsubscript{c}, T\textsubscript{c}, p\textsubscript{c}, \tau\textsubscript{c}, \alpha\textsubscript{c}, C\textsubscript{f}, \text{LWP}

\textbf{Need to be creative &}

\textbf{Play to the strengths of what satellites offer!!}
Historical Examples

(a) Ship tracks off the coast of California, from AVHRR.
(b) Retrieved $r_c$ and $\tau_c$ differences. [Coakley & Walsh JAS 2002].

(c) False-color AVHRR: Red indicates large droplets, yellow signifies smaller droplets [Rosenfeld, Sci. 2000]

(d) Correlation between AVHRR particle number ($N_a$) and cloud droplet ($N_c$) concentrations, for 4 months in 1990; Yellow indicates high $N_c$ with large $N_a$, red indicates high $N_c$ despite small $N_a$. [Nakajima et al., GRL 2001]

(e) Atlantic convective cloud invigoration from MODIS; aerosol optical depth (AOD), cloud fraction ($C_f$), cloud droplet effective radius ($r_c$), water optical depth ($\omega_c$) vs. height; $p_c$ encoded in colors, increasing from blue to green. [Koren et al. GRL 2007]
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Marine Sc</th>
<th>Trade Wind</th>
<th>Deep Convective</th>
<th>Achievable Accuracy</th>
<th>Instrument</th>
<th>Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>2 Wm⁻² for SW instantaneous grid point measurement; 3.7 Wm⁻² for LW [Loeb et al., 2009JC]</td>
<td>MODIS, CERES</td>
<td>Satellite</td>
</tr>
<tr>
<td>Satellite measurements of TOA radiation, separated to cloud-free and cloudy conditions</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>1% SW; 2% (daily) [Wild et al., 2013] +3 Wm⁻² representativeness error of a point observation for regional (*) means [Hobbs et al., 2013] 10–30% [Hegglin et al., 2008; Stiller et al., 2012 and references therein]</td>
<td>Pyranometer (SW total), Pyrheliometer (SW direct), Pyrgeometer (LW)</td>
<td>Surface</td>
</tr>
<tr>
<td>Satellite measurements of water vapor, with emphasis on upper tropospheric vapor that is detainted from anvils.</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td></td>
<td>ACE-FTS, MIPAS, AURA-MLS, AIRS</td>
<td>Satellite</td>
</tr>
<tr>
<td>Satellite measurements of CO₂ and CH₄ (near-surface-sensitive column-averaged dry air mole fractions)</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>CO₂ 0.5–1%, CH₄ 1% [Buchwitz et al., 2014]</td>
<td>CO₂, CH₄: SCIAMACHY, GOSAT</td>
<td>Satellite</td>
</tr>
<tr>
<td>Tropospheric ozone: Tropospheric column or layer averaged mixing ratio</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Tropospheric ozone: 10–20% [Zhang et al., 2010; Boyard et al., 2009]</td>
<td>Tropospheric ozone: TES, OMI, IASI</td>
<td></td>
</tr>
<tr>
<td>Satellite measurements of cloud top temperatures, albedo and emissivity.</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Temperature: ~ ± 5 K for optically thin clouds ±1 K for optically thick clouds</td>
<td>AIRS and TOVS (T and Emissivity), CERES (Albedo)</td>
<td>EOS Aqua (AIRS)</td>
</tr>
<tr>
<td>Nonradiative heat transfer: Surface sensible and latent heat fluxes.</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Sensible and latent heat fluxes: ~15–20% half-hourly (~5% daily) random error, order of 10–20% surface energy balance closure deficit [Kesomkiat et al., 2013]</td>
<td>Sonic anemometer for fluxes</td>
<td></td>
</tr>
<tr>
<td>Atmospheric and oceanic heat storage and transport; atmospheric vertical profiles of latent heating.</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculation of heat advection, based on the atmospheric motions and soundings, and accounting for the latent heating.</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>0.25 K d⁻¹ of atmospheric heating</td>
<td>Soundings and satellites, aircraft</td>
<td></td>
</tr>
<tr>
<td>Air motions: The changes in air mass fluxes at the lateral boundaries determine the forcing of circulation systems. This requires the documentation of lateral mass and latent and sensible energy fluxes.</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>Divergence of 0.01 kg m⁻³ h⁻¹</td>
<td>Soundings and satellites, aircraft</td>
<td>Satellite</td>
</tr>
</tbody>
</table>

Rosenfeld et al. Rev. Geophys. 2014
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Marine Sc</th>
<th>Trade Wind Cumuli</th>
<th>Deep Convective</th>
<th>Achievable Accuracy</th>
<th>Instrument</th>
<th>Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite-retrieved winds at various heights, based on tracking clouds and moisture features (Atmospheric Motion Vectors).</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>1 km, 1 m/s</td>
<td>Surface radars</td>
<td></td>
</tr>
<tr>
<td>Doppler S-Band radar measurements (clear air motions)</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>1 km, 1 m/s</td>
<td>Surface radars</td>
<td></td>
</tr>
<tr>
<td>Hydrological cycle</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>10% of the rainfall accumulation</td>
<td>Polarimetric Radar and rain gauges</td>
<td>Surface and satellite radars</td>
</tr>
<tr>
<td>Precipitation measurements are required for obtaining a vertical profile of the latent heat and moisture fluxes.</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>20% of MVD</td>
<td>Polarimetric radar</td>
<td>Surface radar</td>
</tr>
<tr>
<td>3D coverage of Doppler and polarimetric hydrometeor type and size measurements</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>Sensitivity of $-15 \text{ dBZ}$</td>
<td>Cloud radars</td>
<td>Surface and satellite radars</td>
</tr>
<tr>
<td>3D evolution of drizzle in MSC, with a cloud radar</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>10% of the rainfall accumulation</td>
<td>Radar data analysis</td>
<td></td>
</tr>
<tr>
<td>Separate to convective and stratiform components</td>
<td>NA</td>
<td>NA</td>
<td>M</td>
<td>10%</td>
<td>Stream flows</td>
<td></td>
</tr>
<tr>
<td>Hydrologic measurements of soil moisture, runoff, and stream flows.</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>see latent heat flux: $15\text{--}20%$ half-hourly ($\sim5%$ daily) random error</td>
<td>Link to latent heat</td>
<td></td>
</tr>
<tr>
<td>Measurements of evaporation and evapotranspiration.</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>$0.0001\text{ kg m}^{-3}\text{ h}^{-1}$</td>
<td>Link to soundings lateral fluxes</td>
<td></td>
</tr>
<tr>
<td>Atmospheric height-dependent moisture convergence, as measured by the sounding network and satellite measurements of moisture soundings.</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>10% of the rainfall accumulation</td>
<td>Monitor instruments</td>
<td>Airplane, surface</td>
</tr>
<tr>
<td>Aerosols and their precursors: Measurements of precursor gases</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>For most inorganic precursors gasses typically better than 5%: e.g., 1% or 0.2 ppb for SO$_2$</td>
<td>Monitor instruments</td>
<td>Airplane, surface</td>
</tr>
<tr>
<td>Aerosol size distribution</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>$\pm 10%$ in number size distribution in submicron ranges from 20 to 200 nm</td>
<td>SMPS or DMPS APS, PCASP (supermicron)</td>
<td>Airplane, lidar, surface</td>
</tr>
<tr>
<td>Measurements of size-resolved aerosol chemistry</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>At best $0.1 \mu g/m^3$ for size specific speciation, 25% for PM1 [Canagaratna et al., 2007], Lower detection limit varying with species, $0.03 \mu g/m^3$ (nitrate, sulfate, and chloride) up to $0.5 \mu g/m^3$ (organics) [Drewnick et al., 2009]</td>
<td>AMS, time of flight mass spectrometer</td>
<td>Airplane, surface</td>
</tr>
<tr>
<td>Measurements of aerosol hygroscopicity and CCN-activity</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>Better than $\pm 20%$ in hygroscopicity parameter [Su et al., 2010]. For hygroscopic growth factor, typically $\pm 0.05$ [Srivastava et al., 2008]. For hygroscopic growth factor, typically $\pm 0.05$ [Srivastava et al., 2008]</td>
<td>CCNC, HTDMA</td>
<td>Airplane, surface</td>
</tr>
<tr>
<td>CCN activation spectra including giant CCN</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Similar to aerosol hygroscopicity, above</td>
<td>DMPS, SMPS, CCNC, PCASP INC</td>
<td>Airplane, surface</td>
</tr>
<tr>
<td>Ice nucleating activity of the aerosols</td>
<td>N/A</td>
<td>N/A</td>
<td>H</td>
<td>Better than order of magnitude in the activated fraction [Jones et al., 2011],</td>
<td>Monitor instruments</td>
<td>Airplane, surface</td>
</tr>
</tbody>
</table>
Table 1. (continued)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Marine Sc</th>
<th>Trade Wind Cumuli</th>
<th>Deep Convective</th>
<th>Achievable Accuracy</th>
<th>Instrument</th>
<th>Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface sun photometers (spectral AOD)</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>14% for activated fraction in deposition freezing [Kanji et al., 2013]</td>
<td>sun photometers</td>
<td>Airplane, surface</td>
</tr>
<tr>
<td>Satellite measurements of aerosol parameters: AOD, SSA, spectral AOD,</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Microtops 0.02 [Ichoku et al., 2002]</td>
<td>Cimel</td>
<td>Satellite</td>
</tr>
<tr>
<td>depolarization ratio, UVAAI.</td>
<td></td>
<td></td>
<td></td>
<td>AOD: The larger of 0.05 or 20% over land; the larger of 0.03 or 10% over dark water.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud-aerosol interactions</td>
<td></td>
<td></td>
<td></td>
<td>SSA—qualitative two-to-four bins between very absorbing and nonabsorbing,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud cover, optical depth, albedo and radiative effects under different</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Particle size—qualitative fine/coarse ratio over water from MODIS; qualitative,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerosol conditions in as similar meteorology as possible. Study of</td>
<td></td>
<td></td>
<td></td>
<td>three-to-five size bins from MISR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>adjacent clouds in and out of aerosol plumes can be effective.</td>
<td></td>
<td></td>
<td></td>
<td>UVAAI—Prediction of 0.1 for AI &gt; 0.8 over ocean, and for AI &gt; 0.5 over land.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For layer clouds: satellite retrieved cloud top effective radius, liquid</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>LWP, ( r_p ), ( N_d ), cloud optical depth for convective and layer clouds</td>
<td>Data processing</td>
<td></td>
</tr>
<tr>
<td>water path and cloud drop concentrations. Validation with aircraft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>measurements and cloud radar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For convective clouds: satellite-retrieved vertical profiles of cloud</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>10% of the effective radius</td>
<td>Data processing</td>
<td></td>
</tr>
<tr>
<td>particle effective radius and thermodynamic phase. Validation with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aircraft measurements.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud base updraft spectra, by vertically pointing radar and lidar, and</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>On the order of 0.1 m s(^{-1})</td>
<td>Radar, lidar</td>
<td>Surface and aircraft</td>
</tr>
<tr>
<td>by aircraft and UAVs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud base CCN, as obtained from cloud base updrafts and drop number</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>30% of drop concentrations at cloud base</td>
<td>Data processing</td>
<td></td>
</tr>
<tr>
<td>concentrations.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary activation of aerosols in deep convective clouds. This can be</td>
<td>N/A</td>
<td>M</td>
<td>M</td>
<td>30% of small drop and ice concentrations at any level</td>
<td>Data processing</td>
<td></td>
</tr>
<tr>
<td>inferred by the satellite retrieved vertical profiles of cloud particle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>effective radius, and validated in more detailed by aircraft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Marine Sc</td>
<td>Trade Cumuli</td>
<td>Deep Convective</td>
<td>Achievable Accuracy</td>
<td>Instrument</td>
<td>Platform</td>
</tr>
<tr>
<td>---------------------------------------------------------</td>
<td>-----------</td>
<td>--------------</td>
<td>------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>New particle formation</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>Qualitative in smallest sizes (diameter &lt; 3 nm), similar to particle number size distribution measurements in larger sizes (<a href="#">Kulmala et al., 2012</a>)</td>
<td>AIS, NAIS, DMPS, PSM</td>
<td>Surface and aircraft</td>
</tr>
<tr>
<td>Vertical profile of hydrometeor types, concentrations and sizes, by surface and space borne radars. Detrained aerosols from the clouds at various heights, as measured by aircraft.</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>20% of MVD</td>
<td>link to polarimetric radar measurements</td>
<td></td>
</tr>
<tr>
<td>Scales</td>
<td></td>
<td></td>
<td></td>
<td>Similar to the size distribution measurements (above)</td>
<td>SMPS, PCASP</td>
<td>aircraft</td>
</tr>
<tr>
<td>Horizontal along wind</td>
<td>1500 km</td>
<td>500 km</td>
<td>500 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal across wind</td>
<td>200 km</td>
<td>200 km</td>
<td>500 km?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>50 m</td>
<td>100 m</td>
<td>100-400 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>50 m</td>
<td>100 m</td>
<td>1000 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal scale</td>
<td>3 days</td>
<td>1 day</td>
<td>1 day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential locations</td>
<td>Offshore California, Offshore Chile, Canary Islands or Cape Verde</td>
<td>South China Sea, Gulf of Mexico, Indonesia, Amazonas, Congo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The importance codes in columns 2–4 are as follows: H (high), M (medium), L (low) priority. Instrument names are as follows: AIS, Aerosol and Air Ion Spectrometer; AMS, Aerosol Mass Spectrometer; CCNC, Cloud Condensation Nuclei Counter; Cmel, Sun photometer; DMPS, Differential Mobility Particle Sizer; HTDMA, Hygroscopic Tandem Differential Mobility Analyzer; INC, Ice Nuclei Counter; NAIS, Nanometer aerosol and Air Ion Spectrometer; PCASP, Passive Cavity Aerosol Spectrometer Probe; PSM, Particle Size Magnifier; SMPS, Scanning Mobility Particle Sizer.*
Hoped-for Satellite Products; Rosenfeld et al. 2014*

- TOA radiation – cloud-free & cloudy conditions
- Precipitable water vapor
- Upper tropospheric water vapor
- CO$_2$ and other greenhouse gases
- Cloud-top temperature, albedo, emissivity
- Cloud-top $r_{c\_eff}$ and thermodynamic phase
- Height-resolved winds
- Moisture soundings
- AOD, SSA, ANG, polarization – Aerosol Type
- Cloud vertical profile $r_{c\_eff}$ and thermodynamic phase
- Vertical profile hydrometeor type
- Composition & longevity of supercooled cloud layers
- Cirrus radiative effects and dependence on CCN, IN

*Table 1
Would you believe the answer if it were a surprise?
MISR Aerosol Type Discrimination

January 2007

July 2007

Mixture Group

Spherical, non-absorbing
Non-spherical
Spherical, absorbing

Kahn & Gaitley JGR in press
Seasonal Change in *Aerosol Type* over India

Anthropogenic vs. Natural based on MISR-retrieved Particle Size & Shape

### Winter (Dec-Feb)
- Increased wintertime transport of anthropogenic pollution
- Himalayan foothills - advection of anthropogenic particles from Indo-Gangetic Basin

### Pre-monsoon (Mar-May)
- Pre-monsoon influx of dust from the Great Indian Desert and Arabian Peninsula

### Monsoon (Jun-Sep)
- Large influence of anthropogenic particles due to pre-monsoon biomass burning
- Additional influence of maritime particles produced by high surface wind

### Post-monsoon (Oct-Nov)
- Reduced dust loading due to monsoon precipitation
- Large influence of anthropogenic particles due to seasonal peak in biomass burning and reduced dust transport

Small, spherical = anthropogenic
Large, non-spherical = natural

*Dey & Di Girolamo* JGR 2010
Five Aerosol Air Masses:
- Three Smoke Plumes
- Continental Bkgnd.
- Continental-Smoke Mix

Smoke Plume 1
AOD 0.35-0.9
ANG 1.5-1.9 (small)
SSA 0.94-0.98 (absorbing)
FrNon-Sph 0-0.2 (mostly sph.)

Smoke Plume 2
AOD 0.35-0.6
ANG 1.6-2.0 (smaller)
SSA 0.96-0.98 (less abs.)
FrNon-Sph 0-0.1 (more sph.)

Continental Background
AOD 0.15-0.2
ANG 1.0-1.5 (medium)
SSA 0.99-1.0 (non-abs.)
FrNon-Sph 0.0 (spherical)

Effectively larger, less absorbing particles in Plume 2 than Plume 1. Larger yet in Plume 3. Largest in background.

Passive-remote-sensing Aerosol Type is a Total-Column-Effective, Categorical variable!!
Correlation Between AOD from Space and CCN in Remote & Polluted Regions

\[ y = 0.0027x^{0.640} \]
\[ R^2 = 0.88 \]

Andreae ACP 2009
Using $AI (= \tau_a \times \text{Ang})$ to Estimate CCN

Kapustin, Clarke, et al., JGR 2006

- Test Idea: Smaller particles more likely to become CCN; Ang is a smaller quantity for larger particles
- ACE-Asia, Trace-P in situ field data – CCN proxy
- AI does not work quantitatively in general, but can if the data are stratified by:
  -- RH in the aerosol layer(s) observed by satellites
  -- Aerosol Type (hygroscopicity; pollution, BB, dust)
  -- Aerosol Size (Ang is not unique for bi-modal dist.)

Practically, in addition to $\tau_a$ and Ang, this requires:

-- Vertical humidity structure
-- Height-resolved aerosol type
-- Height-resolved size dist.
  [extrapolated to small sizes(?)]

This study includes enough detail to assess $AI \sim N_a$ and $AI \sim CCN$
AIRS - Temperature & Water Vapor Profiles

Temperature Profiles
Accurate to 1K/km to 30 mb

Ocean, Mid Latitude vs ECMWF

AIRS Bias

AIRS RMS

Instrument Spec. Requirement

(T. Hearty/JPL)

Water Vapor Profiles
Match Observations 15%/2km

Nauru Island Radiosondes

AIRS Bias

AIRS RMS

Radiosonde RMS

(E. Fetzer/JPL)

Mean Clear Air Precipitable Water
AIRS data, January 2003

Millimeters

10 20 30 40 50
The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)

- Lower AOD sensitivity than SAGE
- But *higher space-time resolution* than SAGE
- 15 orbits per day, ~100 m wide sampling *curtain*; averaged to 333 m
- 532 and 1064 nm + polarization (at 532 nm); to ~40 km elevation
- Layer height for AOD $\geq 10^{-2}$; AOD for layers having AOD $\leq 3$
- For low AOD, need the higher S/N of *nighttime*, 532 nm observations

<table>
<thead>
<tr>
<th>Vertical Range (km)</th>
<th>Horizontal Resolution (km)</th>
<th>Vertical Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.1 – 40</td>
<td>5</td>
<td>300</td>
</tr>
<tr>
<td>20.2 - 30.1</td>
<td>1.7</td>
<td>180</td>
</tr>
<tr>
<td>8.2 – 20.2</td>
<td>1.</td>
<td>60</td>
</tr>
<tr>
<td>-0.5 – 8.2</td>
<td>0.33</td>
<td>30</td>
</tr>
</tbody>
</table>

Launched April 2006

*Winker et al., JAOT 2009*
The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)

Omar et al., JAOT 2009
MISR Stereo Imaging Cloud-top Height

Colors indicate different camera combinations used
**Vertical Structure**

$r_c$ – Cloud ‘Top’ vs. Cloud Column, & LTS

- **TRMM** data, March-May, 2000; 37°N to 37°S
- Vis-IR Radiance Imager (**VIRS**) for $r_c$ (top), $\tau_c$
- Microwave Imager (**TMI**) for $r_c$ (col), **LWP** (19, 37GHz)
- Warm clouds only ($T_c > 273$ K)
- **VIRS** to find cloud-filled TMI pixels
- **AI** from MODIS
- **Lower Trop. Stability** (**LTS**) from NCEP

- **IE** appears larger for $r_c$ (col) than $r_c$ (top)
- Higher **LTS** and/or **AI** ~ reduced $r_c$ and suppressed rain conditions
- Aerosol effect ~ 50% larger than LTS effect
- **TMI** **LWP** decreases with reduced $r_c$ $\rightarrow$ net change in cloud albedo SMALL
  
  $[d\alpha/dLTS \sim 9\%; \text{LTS effect dominates}]$

---

Matsui et al., GRL 2004
The Clouds and the Earth’s Radiant Energy System (CERES) Short-Wave (SW) Albedo

- Instruments on 3 satellites (Terra, Aqua, S-NPP) [formerly TRMM; future JPSS-1, 2]
- **Channels**: SW (0.3-5 µm), IR (8-12 µm); Total (0.3-200 µm)
- **Daily global coverage in across-track mode** (+ along-track & rotating az options)
- **Spatial Resolution**: ~ 20 km at nadir

March 2002 CERES SW TOA Clear-sky flux (w/MODIS cloud-clearing)

CERES SW Albedo **Absolute Calibration accuracy**: ~1%
Instantaneous SW TOA Flux **Uncertainty**: ~ 4% for all-sky
**Stability**: ~0.3 Wm⁻²/decade (0.001/decade in *global* albedo)

MODIS global cloud regimes

CTP vs. TAU Cluster Analysis
(10 “Cloud Regimes”; MOIDS V5.1)

Courtesy of Lazaros Oreopoulos
Precipitation vs AI per CR (50° S to 50° N)

Ocean

Land

1Q

3Q

 Courtesy of Lazaros Oreopoulos
# Summary

**Observed trends when going from low aerosol index (1Q) to high (3Q)**

<table>
<thead>
<tr>
<th></th>
<th>$\text{CR}_{\text{ice}}$ Land/Ocean (CR 1, 2, 3)</th>
<th>$\text{CR}_{\text{liq}}$ Land/Ocean (CR 6, 7, 8)</th>
<th>$\text{CR}_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prcp</td>
<td>$\uparrow$</td>
<td>$\downarrow$</td>
<td>$\uparrow$</td>
</tr>
<tr>
<td>CF</td>
<td>$-$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
</tr>
<tr>
<td>CTH</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
</tr>
<tr>
<td>Tau</td>
<td>$\uparrow$</td>
<td>$\downarrow$</td>
<td>$\uparrow$</td>
</tr>
<tr>
<td>Re</td>
<td>$\downarrow$</td>
<td>$-$</td>
<td>$\downarrow$</td>
</tr>
<tr>
<td>PrcpNZ</td>
<td>$\uparrow$</td>
<td>$\downarrow$</td>
<td>$\downarrow$</td>
</tr>
</tbody>
</table>

*red arrow:* consistent with invigoration; *blue arrow:* consistent with 1st and 2nd indirect effect

*Courtesy of Lazaros Oreopoulos*
Box Model Considerations

• Spatial Domain: $5^\circ \times 5^\circ$ (~500 km)
  3-D Spatial Resolution: ~10 – a few 100 m
• Temporal Coverage: (at least) 24 hours, multiple times
  Temporal Resolution: ~ (at least) 1-3 hours
• *Need top, bottom, and *side* fluxes*

Satellites *Cannot* Provide All This

But satellites can provide *context* over the domain … and some *validation* of the modeling

What is the *fractional coverage* of different cloud types in the domain?
How do the TOA *radiative fluxes* *vary* with atmospheric conditions?
  What are the *background AOD* and aerosol type gradients?
What are the cloud-top, aerosol layer, and aerosol *plume heights*?
Satellites

Model Validation
- Parameterizations
- Climate Sensitivity
- Underlying mechanisms

Remote-sensing Analysis
- Retrieval Validation
- Assumption Refinement

CURRENT STATE
- Initial Conditions
- Assimilation

Regional Context

Aerosol-type Predictions

Suborbital
- Targeted chemical & microphysical detail
- Point-location time series

Models


Remote-sensing Analysis
- Retrieval Validation
- Assumption Refinement

Frequent, global snapshots; aerosol amount & aerosol type maps, plume & layer heights


DARF & Anthropogenic Component
calculation and prediction