Observing Cloud Properties and Processes from the A-Train and Future Sensors

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Outline

- High clouds
  - Water budget and uncertainties of cloud ice in the upper troposphere
  - Aura MLS 240 and 640 GHz
    - Cloud-induced radiance (Tcir) and IWC morphology
  - CALIOP 532nm backscatter ($\beta_{532}$) and MLS-path integral ($\gamma_{532}$)
    - Derived $\gamma_{532}$-Tcir and $\beta_{532}$-IWC relation

- Low clouds
  - Blind side of the curtain and nadir views -> Multi-angular views
  - MISR high-res cloud height and cloud motion
  - A-Train and future sensors for observing cloud processes

- What is cloud?
High Clouds
Water Mass Budget in the Upper Troposphere

- 1 mg/m³ in IWC
- ≈ 10 ppmv in H₂O
- Deep convection as source of the UT H₂O and cloud ice
- Cloud ice vs precipitating ice

July 2006
IWC from MLS, CloudSat, ECMWF

Wu et al. (2009)

16.0 km

14.7 km

13.3 km

12.0 km

10.7 km
Sensitivity to Cloud Microphysics in Models

- Ice-phase supersaturation allowed
- New scheme for crystal sedimentation
- New scheme for snow autoconversion rate

Tompkins et al. (2007)
Waliser et al. (2009)
MLS, CloudSat, and CALIOP and on A-Train

**MLS IWC**

Volume average
- 200-300 km along track
- 4 km vertically

**MLS hiWP**

A partial column with 3° slant path

Approximate column

<table>
<thead>
<tr>
<th>Freq, (GHz)</th>
<th>bottom, (km)</th>
<th>cross, (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>118</td>
<td>8</td>
<td>12</td>
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<tr>
<td>190</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>240</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>640</td>
<td>11</td>
<td>3</td>
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\[ \beta_{532} \approx 0.4 \cdot IWC \quad \text{km}^{-1} \]
CALIOP-MLS: $\gamma_{532} - T_{cir}$ Relations

Monthly Statistics

240 GHz

$\gamma_{532} = 30 \cdot T_{cir}$

640 GHz

$\gamma_{532} = 3 \cdot T_{cir}$  $sr^{-1}$
Martian Lander System (MLS) Forward Model (ice cloud emission radiation)

\[ \beta_{c-e} \approx \beta_{c-a} = \int_{0}^{\infty} \pi r^2 N(r) (\xi_e - \xi_s) dr \]

\[ = \frac{6\pi \text{Im}(-K)}{\lambda} \int_{0}^{\infty} N(r) \frac{4}{3} \pi r^3 dr \]

\[ = 6\pi \frac{\text{Im}(-K) \ IWC}{\lambda \ \rho_i} \]

\[ = 2.1 \frac{IWC}{\lambda} \frac{3\varepsilon''}{(\varepsilon' + 2)^2 + \varepsilon''^2} \ (\text{km}^{-1}) \]

\[ \varepsilon''_{240} = 0.0081 \]

\[ \varepsilon''_{640} = 0.0243 \]

\[ \frac{\beta_{c-e}(640)}{\beta_{c-e}(240)} = \frac{\lambda_{240}}{\lambda_{640}} \frac{\varepsilon''_{640}}{\varepsilon''_{240}} \approx 8:1 \]

Old MLS mystery: Cloud or Clear?

Courtesy of Joe Waters
\[ \Delta T_{\text{cir}} = T_0 \Delta \tau_{\text{cir}} = \beta_{c-e} \Delta s = 2.1 \frac{IWC}{\lambda} \frac{3\varepsilon''}{(\varepsilon' + 2)^2 + \varepsilon''^2} \Delta s \]

\[ \Delta T_{\text{cir}}(240) = 0.015 \cdot IWC \cdot \Delta s \]

\[ \gamma_{532} = \beta_{532} \cdot \Delta s = 30 \cdot T_{\text{cir}}(240) \]

\[ \Delta T_{\text{cir}}(640) = 0.12 \cdot IWC \cdot \Delta s \]

\[ \gamma_{532} = \beta_{532} \cdot \Delta s = 3 \cdot T_{\text{cir}}(640) \]

\[ \beta_{532} \approx 0.4 \cdot IWC \quad \text{km}^{-1} \]
CloudSat and CALIOP IWC

CALIOP noise: \( \sim 0.1 \text{ mg/m}^3 \)

CloudSat noise: 1-4 mg/m³

Wu et al. (2009)
UT Ice Mass Probability Distribution

100 hPa

146 hPa

215 hPa
Limitations of Curtain and Nadir Views

- Cloud and Precipitation Processes:
  - 3D
  - 10s m – 100s km
  - Inhomogeneous
  - Dynamic

- Other dimensions
  - Doppler lidar/radar
  - Advanced vis/IR multi-angle imagers
  - High-frequency µ-wave radiometers

No, this is not a hurricane. Although the two sides of this storm are symmetrical, the cloud-free zone in the center is far too large to be the eye of a hurricane.

By comparing the Quicklook image above with the GOES-11 satellite image below, we see that CloudSat is viewing a vertical slice of a tropical convection off the Southwest coast of Mexico, a product of the Inter-Tropical Convergence Zone (ITCZ) near the equator.

Notice that the cloud-free zones can be seen on the GOES-11 image as well.
Low Clouds
Multiangle Imaging SpectroRadiometer (MISR)

Detecting cloud height and wind with stereoscopic techniques:

Along-track parallax:  
- cloud height

Cross-track displacement:  
- cloud motion

26° 26°
Multi-Angular Views

- MISR
  - Nadir ±26°, ±46°, ±60°, ±70°
  - 446, 558, 672, 866 nm
  - 400-km swath
  - 275 m - 1.1 km resolution

movies
Von Karman vortex street near Jan Mayen Island
Time lapse: moving boats off N. Carolina coast
Resolution: 1.1 km
Precision:
  height: ~100 m
  wind: ~0.3-1 m/s
Dynamics and Cloud Processes (2)

Height Profiles (ASL) for 047143-B114-P1

Cloud height (m)

Distance From Plume Source (Km)

Wind Profiles for 047143-B114-P1

Cloud wind speed (m/s)

Distance From Plume Source (Km)
Resolution: 1.1 km
Precision:
  height: ~100 m
  wind:  ~0.3 m/s
Inner-Core Dynamics of Hurricanes

- Non-uniform rotation revealed in MISR 1.1 km cross-track wind speed
- Higher rotation associated with the mesovortex
- Asymmetric rotations between southern and northern sides of Alberto’s eye

1 m/s = 1.94 knots
Vertical Distribution of Clouds

MISR
mid-level clouds
boundary-layer clouds

CALIPSO
mid-level clouds
boundary-layer clouds

Wu et al. (2009)
Vertical Profile of Winds

NCEP-DOE Reanalysis 2

MISR Height-Resolved Cloud-Track Zonal Winds

(Courtesy of Michael Garay)
Future Cloud Observations from Space
The Earth Clouds, Aerosol, and Radiation Explorer (EarthCARE)

Science objectives
- Cloud properties
- Aerosol properties
- Cloud vertical velocities
- Drizzle rain rate

Technologies
- Cloud profile radar (JAXA)
- Atmospheric lidar
- Multispectral imager
- Broadband Radiometer
Aerosol, Cloud, and Ecosystems (ACE)

- Science objectives
  - 3D cloud structure and occurrence
  - Microphysical and macrophysical cloud and aerosol properties
  - Cloud vertical velocities
  - Aerosol-cloud interactions
  - Cloud-precipitation interactions
  - Cloud-radiation interactions

- Technologies
  - Dual-Freq (94 and 35 GHz) radar
  - Lidar
  - Multiangle spectropolarimeter
  - Multiband spectrometer
  - Microwave radiometers
  - Others

What is cloud?
Future Cloud Observations from Space

- GOES-R
- Doppler dual-frequency cloud/precip radars
- Doppler lidars
- Advanced vis/IR multi-angle imagers (winds and clouds)
- High-frequency μ-wave radiometers
- GPS radio occultation of BL clouds

(Courtesy of David Diner)
spares
Multi-Angular Views

- MISR
  - Nadir ±26°, ±46°, ±60°, ±70°
  - 446, 558, 672, 866 nm
  - 400-km swath
  - 275 m - 1.1 km resolution

Cloud Front
Dynamics and Cloud Processes (4)