CERES CLOUD PRODUCTS

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CERES Cloud Products

Provide consistent dataset from TRMM, Terra, & Aqua to

- Relate cloud properties to the radiation budget

- Develop new bidirectional reflectance models for interpreting broadband radiance measurements

- Derive surface and atmospheric radiation budgets & the top-of-atmosphere ERB

- Provide data to initialize & validate climate & weather prediction models
BASIC APPROACH

CERES Matched Cloud-Radiation Data

• Determine cloud properties from imager data (2 km)

• Convolve & average imager cloud properties into CERES footprints (10 - 50 km)
METHODOLOGY

• Classify each imager pixel as clear or cloudy
  - determine the confidence of the classification (good, weak, glint, haze)

• Retrieve cloud micro- and macrophysical cloud properties
  - reclassify if no retrievals result (~4% of cloudy pixels)

• Combine imager cloud properties & broadband fluxes from satellite-observed radiances
  - convolve imager pixel results into CERES sensor footprint
  - select anisotropic correction models
  - compute shortwave & longwave fluxes
DATA

- TRMM VIRS 2-km pixels  
  Domain: 37°S - 37°N  
  - 2-30 overpasses per month at all times of daylight (1/98-7/01)

- MODIS 1-km pixels (sampled to 2 km)  
  Domain: Global  
  - 2 overpass/day (night-day), more over poles

- Input
  - 0.65 & 1.6 (2.1) μm reflectances
  - 3.7, 10.8, and 12-μm brightness temperatures
  - GMAO (ECMWF) $T(z)$, $q(z)$, $O_3(z)$ each 6 hr (3-hr skin temps)
  - Elevation, water %, ice/snow, IGBP type

- Results
  - averages on 1.0° grid & individual CERES footprints (~ 10 km)
  - some pixel-level output also available
CERES CLOUD PROPERTIES

1 SSF PIXEL w/CERES FLUXES
(SSF = Single Scanner Footprint)

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount</td>
<td>F</td>
</tr>
<tr>
<td>Effective Radiating Temp</td>
<td>Tc</td>
</tr>
<tr>
<td>Effective Height, Pressure</td>
<td>Zc, pc</td>
</tr>
<tr>
<td>Top Pressure</td>
<td>pt</td>
</tr>
<tr>
<td>Thickness</td>
<td>h</td>
</tr>
<tr>
<td>Emissivity</td>
<td>ε</td>
</tr>
<tr>
<td>Phase (0 - 2)</td>
<td>P</td>
</tr>
<tr>
<td>Water Droplet Effective Radius</td>
<td>re</td>
</tr>
<tr>
<td>Optical Depth</td>
<td>τ</td>
</tr>
<tr>
<td>Liquid Water Path</td>
<td>LWP</td>
</tr>
<tr>
<td>Ice Effective Diameter</td>
<td>De</td>
</tr>
<tr>
<td>Ice Water Path</td>
<td>IWP</td>
</tr>
</tbody>
</table>
OTHER DERIVED PARAMETERS FROM CLEAR PIXELS

- CLEAR-SKY ALBEDOS (0.6 & 1.6 µm)

- CLEAR-SKY TEMPERATURES (3.7, 11, & 12 µm)

- SKIN TEMPERATURE

- AEROSOL OPTICAL THICKNESS (ocean only)
  
  *additional MODIS-team-derived aerosol data included*

  (see Ignatov talk)

- SURFACE EMISSIVITY (3.7, 8.5, 11, & 12 µm)
CALIBRATION

• **Extensive ongoing intercalibration effort**
  - intercalibrate VIRS & MODIS; Terra & Aqua MODIS
  - determine stability by comparing imagers to CERES
  - examine all channels of interest (0.6, 0.86, 1.6, 3.7-3.9, 10.8, 12 \( \mu \text{m} \))
    
    *theoretically account for expected inter-satellite spectral differences*
  - use statistics to reduce noise and angular/time matching errors

• **Intercalibrate other satellites for CERES & other projects**
  - link all considered satellites to references (VIRS or MODIS)
  - GOES-7, 8, 9, 10, 11, 12 (1993 - present)
  - AVHRR: NOAA-9,10, 11, 12, 14, 15, 16, 17 (1985 - present)
  - GMS-5, Meteosat-7 & SEVIRI on Meteosat-8
USE CERES BROADBAND TO MONITOR TRENDS IN IMAGER CHANNELS

Compute slope for each day

Monitor slope variation
USE STABLE IMAGER AS REFERENCE FOR OTHER IMAGERS

VIRS, ATSR-2, MODIS have onboard cal for all channels

Compute gain each month

Derive trend in gain, repeat with other reference platform
CALIBRATION STATUS FOR CERES VIRS/MODIS

• 2.2%/yr degradation in VIRS 1.6-\(\mu\)m relative to Terra MODIS

• Terra MODIS VIS up to 3% greater at high end, 2% less at low end
  - additional theoretical study needed to warrant changes
  - decreased VIS ocean reflectance model for MODIS

• Spectral differences will introduce some inconsistencies in the VIRS-MODIS results
  - cloud emittance models -> \(\sim\) 0.5 K difference
  - surface emissivity maps may need some tweaking

• Trend analyses will continue & include CERES vs MODIS

• Aqua MODIS intercalibrations to come
CLOUD MASK

• To detect clouds, the radiances for cloud-free (clear) scene must be known

• Determine clear-sky albedos and surface emissivities after initial processing of data
  - determine means for each surface type to fill in missing areas

• Use ECMWF skin temperatures & profiles to estimate clear-sky brightness temperatures

• Use bidirectional reflectance models to estimate clear-sky reflectance for each pixel

• Estimate thresholds based on uncertainties in models & spatial/temporal variability of the clear radiances
CLEAR-SKY RADIANCE CHARACTERIZATION

• Predict radiance a given satellite sensor would measure for each channel if no clouds are present

• Estimate uncertainty based on spatial & temporal variability & angular model errors

• Develop set of spectral thresholds for each channel
  - Solar, uses reflectance, $\rho$
  - IR, use temperature, $T$
  
  brightness temperature difference, $BTD = T_{\lambda 1} - T_{\lambda 2}$

  *typically, $BTD(3.7-11)$ or $BTD(11-12)$*
CLEAR-SKY REFLECTANCE, SOLAR

• Estimate overhead-sun albedo, $\alpha_o = \alpha(\mu_o = 1)$
  
  derived empirically with initial runs using ISCCP AVHRR DX then updated for each month using VIRS, then Terra MODIS

• Estimate albedo at given local time, $\alpha(\mu_o) = \alpha_o \delta_o(\mu_o)$
  
  directional reflectance model $\delta_o(\mu_o)$ derived for each IGBP type using VIRS

• Estimate reflectance for given viewing angles, $\rho(\mu_o, \mu, \phi) = \alpha(\mu_o) \chi(\mu_o, \mu, \phi)$
  
  bidirectional reflectance (BRDF) model $\chi$ selected for each IGBP type from Kriebel (1978), Minnis & Harrison (1984), Suttles et al. (1988)

• Add uncertainty to set reflectance threshold, $\rho_T(\mu_o, \mu, \phi) = \rho + \Delta \rho(\mu_o, \mu, \phi)$
PREDICTED CLEAR-SKY VIS ALBEDO
1700 UTC, 12/21/00

CS_Overhead_Albedo

CS_Local_Albedo

Directional Model

BiDirectional Model

R: 0.6 um
G: 1.6 um
B: 11 um
PREDICTED CLEAR-SKY & OBSERVED VIS REFLECTANCE & CLOUD MASK
1700 UTC, 12/21/00
CLEAR-SKY TEMPERATURE, INFRARED

- Estimate surface emissivity, $\varepsilon_s(x,y)$
  
  *derived empirically with initial runs using ISCCP AVHRR DX*
  *then updated using VIRS, then Terra MODIS; water & snow theoretical*

- Estimate radiance leaving the surface, $L_s = \varepsilon_s B(T_{\text{skin}}) + (1-\varepsilon_s)L_{\text{ad}}$
  
  $L_{\text{ad}} = \text{downwelling atmo radiation}$, $T_{\text{skin}} = \text{skin temperature from model / obs}$

- Estimate TOA brightness temperature, $B(T_{\text{cs}}) = (1-\varepsilon_a)L_s + \varepsilon_a L_{\text{au}}$
  
  $L_{\text{au}} = \text{upwelling atmo radiation}$, $\varepsilon_a = \text{effective emissivity of atmo layer absorption emission computed using T/RH profile, correlated k-dist}$

- Add uncertainty to set T or BTD thresholds, $T_T(\mu) = T_{\text{cs}}(\mu) + \Delta T(\mu)$
  
  - reflected solar component included in 3.7-4.0 $\mu$m estimate
Surface emissivity from *Terra MODIS*, April 2001

3.7 µm

**Unfiltered**

**Filtered & IGBP filled**
Surface emissivity from Terra MODIS, April 2001, 11 µm

Filtered & IGBP filled
Surface emissivity from Terra MODIS, April 2001, 8.5 µm
PREDICTED CLEAR-SKY & OBSERVED IR TEMPERATURE
1700 UTC, 12/21/00
PREDICTED CLEAR-SKY & OBSERVED BTD (3.7 - 11)
1700 UTC, 12/21/00
CLOUD MASK

Classify each imager pixel as cloud / clear / bad using multiple cascading thresholds + Welch algo

DAYTIME & POLAR: SZA < 82°, 0.6, 1.6, 3.8, 11, 12 µm

NIGHTTIME & POLAR: 3.8, 11, 12 µm
STANDARD DAYTIME MASK ALGORITHM

Top Level Daytime Flow Chart

"A" Test
Simple IR (11μ)
Threshold

Colder

Good Cloud

VIRS run statistics

Warmer

"B1" Test
11μ clear-sky
threshold

"B2" Test
0.63μ clear-sky
threshold

"B3" Test
3.75-11μ clear-sky
threshold

Σ

If = 0,
Good Clear

If (1 < # < 3)
Apply "C" Tests

If = 3,
Good Cloud
ANCLILLARY DATA USED IN CLOUD MASK & RETRIEVALS

Snow map used as a guide, snow is determined independently if clear

Other

Elevation map (10')

T, q_v, O_3 profiles (1°)
CERES CLOUD MASK 1700 UTC, 12/21/00
STANDARD NIGHTTIME MASK ALGORITHM

Top Level Nighttime Flow Chart

"A" Test
Simple IR (11μ) Threshold

Red=Hyperlink

VIRS run statistics

Colder
Good Cloud

Warmer

"D1" Test
11 μ clear-sky threshold

"D2" Test
3.75-11 μ clear-sky threshold (high)

"D3" Test
3.75-11 μ clear-sky threshold (low)

Σ

If = 0,
Good Clear

If (1 or 2)
Apply "E" Tests

Cannot = 3,
D2 and D3 cannot
be equal to 1 at
the same time
CLOUD RETRIEVAL METHODOLOGY

- Compute ice & water solution, select most likely based on model fits, temperature, LBTM classification, 1.6-µm reflectance

- No retrievals: reclassify as clear or status quo, 3-4%

RETRIEVAL METHODS

DAY: Visible Infrared Solar-Infrared Split-Window Technique (VISST)

see Minnis et al. (1995, 1998)

NIGHT: Solar-infrared Infrared Split-Window Technique (SIST)

see Minnis et al. (1995, 1998)

SNOW (DAY): Solar-Infrared Infrared Near-Infrared Technique (SINT)

MODIS only see Platnick (JGR, 2001)
## CERES CLOUD PROPERTIES

### 1 SSF PIXEL w/CERES FLUXES

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMOUNT</td>
<td>$F$</td>
</tr>
<tr>
<td>EFFECTIVE RADIATING TEMP</td>
<td>$T_c$</td>
</tr>
<tr>
<td>EFFECTIVE HEIGHT, PRESSURE</td>
<td>$Z_c$, $p_c$</td>
</tr>
<tr>
<td>TOP PRESSURE</td>
<td>$p_t$</td>
</tr>
<tr>
<td>THICKNESS</td>
<td>$h$</td>
</tr>
<tr>
<td>EMISSIVITY</td>
<td>$\varepsilon$</td>
</tr>
<tr>
<td>PHASE (0 - 2)</td>
<td>$P$</td>
</tr>
<tr>
<td>WATER DROPLET EFFECTIVE RADIUS</td>
<td>$r_e$</td>
</tr>
<tr>
<td>OPTICAL DEPTH</td>
<td>$\tau$</td>
</tr>
<tr>
<td>LIQUID WATER PATH</td>
<td>LWP</td>
</tr>
<tr>
<td>ICE EFFECTIVE DIAMETER</td>
<td>$D_e$</td>
</tr>
<tr>
<td>ICE WATER PATH</td>
<td>IWP</td>
</tr>
</tbody>
</table>
CLOUD HEIGHT ESTIMATION

• Cloud radiating temperature, T_{cld}
  - optically thin, corrected for semi-transparency
  - optically thick, T_{11} corrected for atmos attenuation

• Z_{cld} = Z(T_{cld})
  - boundary layer uses lapse rate method over ocean & land
  - 700 hPa and lower pressure, use T(z) from GMAO

• Z_{top} = empirical function of Z(T_{cld}), phase, T_{cld}, \tau

• Thickness = empirical function of phase, T_{cld}, \tau

• Z_{base} = Z_{top} - Thickness
LAPSE RATE METHOD

• OCEAN: Use SST as anchor for -7.1 K/km lapse rate
• LAND: Use 24-hr running mean for anchor
• Blend at 500 hPa

Example: ARM SGP
CERES CLOUD MACROPHYSICAL PROPERTIES
1700 UTC, 12/21/00
CERES CLOUD MICROPHYSICAL PROPERTIES 1700 UTC, 12/21/00
CERES Cloud Microphysical Properties
Eastern China
0002 UTC, 2/03/02

Terra MODIS
CERES Cloud Macrophysical Properties
Eastern China
0002 UTC, 2/03/02

Terra MODIS

R: 0.6 um
G: 1.6 um
B: 11 um

Cloud Particle Phase
Eff Cld Height[kml]
Eff Cld Pressure[mbl]
Eff Cld Temp[K]
Comparison of Optical Depths (OD) from VISST & SINT, *Terra* MODIS

**Northern Alaska**
**March 3, 2001**
**2100 UTC**

Visible channel overestimates OD over snow & ice

1.6-µm yields more realistic value for OD
RESULT EXAMPLES
## CLOUD MASK CLEAR STATISTICS, DECEMBER 2000

### Day: csz > 0.1

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Land</th>
<th>Desert</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clr Good</td>
<td>0.920</td>
<td>0.759</td>
<td>0.971</td>
<td>0.853</td>
</tr>
<tr>
<td>Clr Weak</td>
<td>0.009</td>
<td>0.010</td>
<td>0.015</td>
<td>0.009</td>
</tr>
<tr>
<td>Clr Smoke</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>Clr Fire</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Clr Snow</td>
<td>0.017</td>
<td>0.228</td>
<td>0.009</td>
<td>0.108</td>
</tr>
<tr>
<td>Clr Glint</td>
<td>0.052</td>
<td>0.001</td>
<td>0.000</td>
<td>0.028</td>
</tr>
<tr>
<td>Clr Shadow</td>
<td>0.000</td>
<td>0.001</td>
<td>0.005</td>
<td>0.001</td>
</tr>
<tr>
<td>Clr Aerosol</td>
<td>0.002</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

### Night: csz < 0.1

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Land</th>
<th>Desert</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clr Good</td>
<td>0.704</td>
<td>0.661</td>
<td>0.717</td>
<td>0.687</td>
</tr>
<tr>
<td>Clr Weak</td>
<td>0.076</td>
<td>0.032</td>
<td>0.211</td>
<td>0.062</td>
</tr>
<tr>
<td>Clr Snow</td>
<td>0.220</td>
<td>0.307</td>
<td>0.072</td>
<td>0.251</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
# CLOUD MASK CLOUD STATISTICS, DECEMBER 2000

## Day: $\text{csz} > 0.1$

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Land</th>
<th>Desert</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cld Good</td>
<td>0.940</td>
<td>0.855</td>
<td>0.662</td>
<td>0.912</td>
</tr>
<tr>
<td>Cld Weak</td>
<td>0.038</td>
<td>0.042</td>
<td>0.088</td>
<td>0.047</td>
</tr>
<tr>
<td>Cld Glint</td>
<td>0.009</td>
<td>0.001</td>
<td>0.000</td>
<td>0.007</td>
</tr>
<tr>
<td>Cld N/R</td>
<td>0.030</td>
<td>0.068</td>
<td>0.250</td>
<td>0.042</td>
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<tr>
<td>Total</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

## Night: $\text{csz} < 0.1$

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Land</th>
<th>Desert</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cld Good</td>
<td>0.909</td>
<td>0.906</td>
<td>0.909</td>
<td>0.908</td>
</tr>
<tr>
<td>Cld Weak</td>
<td>0.084</td>
<td>0.084</td>
<td>0.038</td>
<td>0.084</td>
</tr>
<tr>
<td>Cld N/R</td>
<td>0.007</td>
<td>0.009</td>
<td>0.053</td>
<td>0.014</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
MEAN CLOUD COVER, MODIS, June 2001

Day
DAYTIME CLOUD FRACTION
MODIS (15 days) & VIRS, JUNE 2001
MEAN CLOUD COVER, MODIS, DEC 2002, NIGHT
MEAN EFFECTIVE CLOUD HEIGHT, TERRA MODIS DEC, DAY

2000

2002
MEAN WATER CLOUD OPTICAL DEPTH, MODIS, DEC 2002, DAY
MEAN EFFECTIVE DROPLET RADIUS, MODIS, DEC 2002

Terra

Aqua
Ice Cloud OD
Aqua Dec 2002

Ice Cloud De
Aqua Dec 2002
EFFECTIVE CLOUD TEMPERATURE, MODIS, DEC 2000
MEAN EFFECTIVE CLOUD HEIGHT, MODIS, DEC 2000
NIGHT

km
MEAN EFFECTIVE ICE CRYSTAL DIAMETER, MODIS, DEC 2000 DAYTIME
MEAN CLOUD PRESSURE, AQUA MODIS DEC 2002

Daytime

hPa
SEASONAL VARIATION OF EFFECTIVE DROPLET RADIUS

VIRS, 1998 - 2001

Range in southern ocean is 2 - 4 µm
1 - 2 µm elsewhere

Range over tropical land 1 - 2 µm
SEASONAL VARIATION OF EFFECTIVE ICE CRYSTAL DIAMETER

VIRS, 1998 - 2001

OCEAN

LAND
VALIDATION (COMPARISONS)

- with climatological datasets (surface, ISCCP)
  - cloud amount, optical depth

- with surface-based retrievals
  - LWP, $r_e$, $Z_c$, $T_c$, $\tau$ from radiometers, radar, lidar

- with aircraft measurements
  - in situ microphysics
  - remotely sensed macrophysics, radiation

- with other satellite measurements
  - different type of retrievals (e.g., LWP from $\mu$-wave)
  - dual angle retrievals (phase function, phase, $\tau$)
  - intersatellite consistency

- with theoretical calculations (consistency)
  - TOA fluxes (e.g., SARB results from Charlock)
  - angular variations (e.g., ADMs from Loeb)
COMPARISON OF TOTAL CLOUD AMOUNTS


MAY TOTAL CLD AMT

<table>
<thead>
<tr>
<th>CLOUD AMOUNT (%)</th>
<th>LATITUDE (°)</th>
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</thead>
<tbody>
<tr>
<td>B SFC 55.0</td>
<td>-40 -30 -20 -10 0 10 20 30 40</td>
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<tr>
<td>J VIRS 55.8</td>
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JAN TOTAL CLD AMT

<table>
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<tr>
<th>CLOUD AMOUNT (%)</th>
<th>LATITUDE (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B SFC 55.5</td>
<td>-40 -30 -20 -10 0 10 20 30 40</td>
</tr>
<tr>
<td>J VIRS 56.4</td>
<td></td>
</tr>
<tr>
<td>B ISCCP 63.2</td>
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MARTOTAL CLD AMT

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<th>CLOUD AMOUNT (%)</th>
<th>LATITUDE (°)</th>
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<tr>
<td>B SFC 54.8</td>
<td>-40 -30 -20 -10 0 10 20 30 40</td>
</tr>
<tr>
<td>J VIRS 98 55.7</td>
<td></td>
</tr>
<tr>
<td>H VIRS 00 54.2</td>
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</table>

FEB TOTAL CLD AMT

<table>
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<th>CLOUD AMOUNT (%)</th>
<th>LATITUDE (°)</th>
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<tbody>
<tr>
<td>B SFC 56.1</td>
<td>-40 -30 -20 -10 0 10 20 30 40</td>
</tr>
<tr>
<td>J VIRS 54.7</td>
<td></td>
</tr>
</tbody>
</table>
MEAN CLOUD FRACTION, DEC

<table>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL</td>
<td>0.632</td>
<td>0.611</td>
<td>0.612</td>
<td>0.669</td>
<td></td>
</tr>
<tr>
<td>60N - 60S</td>
<td>0.606</td>
<td>0.623</td>
<td>0.619</td>
<td>0.696</td>
<td></td>
</tr>
</tbody>
</table>
COMPARISON OF JUNE CLOUD AMOUNTS

ISCCP: lower resolution ⇒ more cloud cover?
CLOUD AMOUNT AT SOUTH POLE

South Pole, July 05, 2001

South Pole, July 26, 2001

South Pole, Jun-Jul 2000

NASA CERES AND THE EARTH RADIATION BUDGET PROJEST

COMPARISON OF SFC-OBSERVED HIGH CLOUD AMOUNTS (1971-1996) AND VIRS-DERIVED COVERAGE BY ICE CLOUDS

**JAN**

**MAY**

**MAR**

**JUN**

[CLOUD AMOUNT (%) vs LATITUDE (°) graphs for January, May, March, and June showing a comparison between SFC and VIRS data]
CLOUD OPTICAL DEPTH COMPARISONS

March 2000

July 2000

Ice Optical Depth

Liquid Optical Depth

Latitude (°)
MONTHLY MEAN CLOUD LWP FROM VIRS & TMI OVER OCEANS

overcast, water cloud only, Tc > 273 K, SZA < 78°, no sunglint

TMI - TRMM Microwave Imager, LWP from method of *Lin et al.*, *JGR*, 1998
Validation of Cloud Height over ARM SGP, Terra 2000-01

\( \tau > 5 \)

Height \(_{30\times30 \text{ km}^2}\) (Lapse rate)

- Top Eff = 0.16, Std = 1.13
- Mean Eff = 1.12, Std = 1.55

\( \tau < 5 \)

Height \(_{30\times30 \text{ km}^2}\) (Lapse rate)

- Top Eff = 2.25, Std = 1.78
- Mean Eff = 1.39, Std = 1.83

Height \(_{30\times30 \text{ km}^2}\) (ECMWF)

- Top Eff = 0.23, Std = 1.23
- Mean Eff = 1.51, Std = 1.55

Daytime thin: 
Ci too low; night best agreement

* Dong et al. (submitted JAS 2004) *
Nearly all thin cloud heights are within boundaries of cloud:

- Clouds higher at night due to greater errors in skin temperature
- Boundary-layer cloud heights sometimes too high due to inversions
- Implies cirrus optical depths are quite reasonable
Validation of CERES Cloud Optical Depth (Stratus)

ARM SGP, VIRS 1998; MODIS 2000-2001

Excellent correspondence between CERES and surface-derived optical depths over ARM SGP site
Validation of CERES Cloud Droplet Size (Stratus)
ARM SGP, VIRS 1998; MODIS 2000-2001

CERES average droplet sizes within ± 1 µm of surface-based values over ARM SGP site
Validation of CERES LWP (Stratus)

ARM SGP, VIRS 1998; MODIS 2000-2001

CERES LWP within 20% of surface-based values over ARM SGP site

LWP from μ-wave not very accurate at small LWP

snow cases not identified yet
COMPARISON WITH SURFACE RADAR RETRIEVALS OF THIN CIRRUS

MOD06

\[ \Delta r_e = 1.5 \, \mu m + 8 \]

\[ \Delta IWP = 13 \pm 39 \]

\[ \Delta \tau = 0.8 \pm 1.6 \]

CERES

\[ \Delta r_e = -3 \, \mu m + 6 \]

\[ \Delta IWP = -3 \pm 16 \]

\[ \Delta \tau = -0.2 \pm 0.8 \]

Over ARM SGP Central Facility, (see Mace et al. 2004)
## COMPARISON OF CERES MODIS & SFC-DERIVED CLOUD PROPERTIES

**ARM SGP 2000-2001 DAYTIME**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MODIS-sfc</th>
<th>std dev</th>
<th>SD(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin Tc vs mean</td>
<td>7.0 K</td>
<td>6.4 K</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Thick Tc vs mean</td>
<td>-5.0 K</td>
<td>10.5 K</td>
<td>-</td>
<td>41</td>
</tr>
<tr>
<td>Thin Zc vs. mean</td>
<td>-1.4 km</td>
<td>1.8 km</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Thin Zc vs. top</td>
<td>-2.1 km</td>
<td>1.8 km</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Thick Zc vs. mean</td>
<td>0.2 km</td>
<td>1.1 km</td>
<td>-</td>
<td>41</td>
</tr>
<tr>
<td>Thick Zc vs. top</td>
<td>-1.1 km</td>
<td>1.5 km</td>
<td>-</td>
<td>41</td>
</tr>
<tr>
<td>Stratus $\tau$</td>
<td>-0.8</td>
<td>6.2</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>Stratus re ((\mu m))</td>
<td>-1.1</td>
<td>1.8</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>LWP (gm(^{-2}))</td>
<td>-29</td>
<td>41</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>Cirrus $\tau$</td>
<td>0.2</td>
<td>0.8</td>
<td>40</td>
<td>9</td>
</tr>
<tr>
<td>Cirrus De ((\mu m))</td>
<td>6.0?</td>
<td>17.0</td>
<td>72</td>
<td>9</td>
</tr>
<tr>
<td>IWP (gm(^{-2}))</td>
<td>3.0</td>
<td>16.2</td>
<td>51</td>
<td>9</td>
</tr>
</tbody>
</table>
### COMPARISON OF CERES MODIS & SURFACE-DERIVED CLOUD PROPERTIES

**ARM SGP 2000-2001 NIGHTTIME**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MODIS-sfc</th>
<th>std dev</th>
<th>SD(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin Tc vs mean</td>
<td>-1.6 K</td>
<td>9.5 K</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Thick Tc vs mean</td>
<td>-6.9 K</td>
<td>14.5 K</td>
<td>-</td>
<td>31</td>
</tr>
<tr>
<td>Thin Zc vs. mean</td>
<td>0.6 km</td>
<td>2.1 km</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Thin Zc vs. top</td>
<td>-0.6 km</td>
<td>2.2 km</td>
<td>-</td>
<td>31</td>
</tr>
<tr>
<td>Thick Zc vs. mean</td>
<td>-1.3 km</td>
<td>2.1 km</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Thick Zc vs. top</td>
<td>-0.2 km</td>
<td>1.7 km</td>
<td>-</td>
<td>49</td>
</tr>
</tbody>
</table>
CONSISTENCY WITH RADIATIVE TRANSFER CALCULATIONS

• MEASURE BROADBAND RADIANCE AT ONE ANGLE & CONVERT TO FLUX

• DETERMINE CLOUD PROPERTIES FROM ANOTHER ANGLE & COMPUTE FLUX USING CLOUD PROPERTIES AS INPUT TO RADIATIVE TRANSFER MODEL

  (Fu and Liou, 1993)

• DIFFERENCE IS MEASURE OF UNCERTAINTY IN PHASE FUNCTION USED TO RETRIEVE CLOUD PROPERTIES, CLOUD DETECTION, BIDIRECTIONAL REFLECTANCE MODEL, SURFACE & ATMOSPHERIC PROPERTIES

• UNCERTAINTY TELLS US HOW ACCURATE A CLIMATE OR WEATHER MODEL SHOULD COMPUTE THE INSTANTANEOUS FLUX IF THE CLOUD PROPERTIES ARE PROPERLY COMPUTED IN THE MODEL
NIGHTTIME FLUXES IN ARCTIC
COMPARISON OF OBSERVED & COMPUTED SW & LW FLUXES
ALL SCENE TYPES, TRMM VIRS/CERES, APRIL 18, 1998

ΔSW = 5.8 ± 28 Wm⁻² (14%)
ΔLW = 0.7 ± 8 Wm⁻² (3%)
COMPARISON OF OBSERVED & COMPUTED SW & LW FLUXES
ICE CLOUDS ONLY TRMM VIRS/CERES, APRIL 18, 1998

$\Delta SW = 4.1 \pm 36 \text{ Wm}^{-2} \ (10\%)$ $\Delta LW = 1.6 \pm 11 \text{ Wm}^{-2} \ (6\%)$
CERES-DERIVED CLOUD PROPERTIES

YIELD EXCELLENT AGREEMENT BETWEEN FLUX OBSERVATIONS & RADIATIVE TRANSFER MODELS
CONSISTENCY
Cloud fraction, June 2001, MODIS (day 1 - 16) vs. VIRS (month)

V = VIRS
M = MODIS
O = Ocean
L = Land
T = total

MT 52.2%
VT 54.0%
VO 59.2%
MO 56.5%
VL 42.5%
ML 42.0%
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>MODIS (2 week) - VIRS (1 month)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ocean</td>
</tr>
<tr>
<td>Cld amt</td>
<td>-0.028</td>
</tr>
<tr>
<td>Ice height (km)</td>
<td>0.4</td>
</tr>
<tr>
<td>Water height (km)</td>
<td>0.0</td>
</tr>
<tr>
<td>Ice tau</td>
<td>2.8</td>
</tr>
<tr>
<td>Water tau</td>
<td>0.1 (+ 1.5)</td>
</tr>
<tr>
<td>$r_e$ (µm)</td>
<td>-0.7 (+ 0.9)</td>
</tr>
<tr>
<td>$D_e$ (µm)</td>
<td>0.9 (+ 2.2)</td>
</tr>
<tr>
<td>LWP (gm⁻²)</td>
<td>2.1</td>
</tr>
<tr>
<td>IWP (gm⁻²)</td>
<td>17, 7%</td>
</tr>
</tbody>
</table>
Some Caveats!

• Everything is retrieved: ice over water/ mixed phase ->
  if overlap, large re (1-2 µm overestimate) or small De (3-5 µm under)
  Zc may be underestimated

• IWP overestimated when water cloud under ice

• Don't use cloud µ-physical properties at night

• Nighttime polar cloud amounts & near-terminator still uncertain
  Look for discontinuities at 60° latitude

• Nighttime ice cloud heights somewhat greater (~ 1.0 km for ice)

• Optical depths, De over snow tres uncertain

• Others, see Data Quality Summary
FUTURE RESEARCH

• **multilayer cloud detection & interpretation**
  - combined microwave / VISST over ocean
  - secondary processing using info on BTD(11-12), $\tau$, $D_e/r_e$
  
  => **improved IWP assessment**

• **improvement of nighttime/twilight everywhere including poles**
  - revise thresholds, include VIS in twilight, include 8.5 $\mu$m
  - improve surface emissivities

• **continued validation**
  - more continuous assessment at ARM sites
  - CALIPSO cloud height/amt global comparison
  - additional multiangle studies including MSG & GOES
  - in situ icing / microphysics field programs

• **subpixel cloud amounts**
  - combine hi-res VIS with lo-res multispectral (MODIS)
REFERENCES

List of references and pdfs given on the following web page.

http://www-pm.larc.nasa.gov/ceres/ceres-ref.html

Only imagery and summaries are available for CERES at the Cloud Working Web Page

http://lposun.larc.nasa.gov/~cwg/

Digital data available at the LaRC DAAC

http://eosweb.larc.nasa.gov/HPDOCS/