CERES CLOUD PROPERTY RETRIEVALS

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NASA Clouds and Earth’s Radiant Energy System (CERES) Cloud Products

Monitor Earth’s radiation budget (ERB) at a higher accuracy with instruments on TRMM, Terra, & Aqua

- 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

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

- **Input**
  - 0.65 & 1.6 reflectances
  - 3.7, 10.8, and 12-μm brightness temperatures
  - ECMWF T(z), q(z), O₃(z) each 6 hr (3-hr skin temperatures)
  - 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>p_t</td>
</tr>
<tr>
<td>THICKNESS</td>
<td>h</td>
</tr>
<tr>
<td>EMISSIVITY</td>
<td></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></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)

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

• Extensive ongoing intercalibration effort
  - intercalibrate VIRS & 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 \( \mu m \))
    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)
  - \textit{GOES}-7, 8, 9, 10, 11, 12 (1993 - present)
  - AVHRR: \textit{NOAA}-9,10, 11, 12, 14, 15, 16, 17 (1985 - present)
  - \textit{GMS}-5, \textit{Meteosat}-7
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, ASR-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-µm 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 -> ~ 0.5 K difference
  - surface emissivity maps may need some tweaking

• Trend analyses will continue & include CERES vs MODIS

• Aqua MODIS intercalibrations to come
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, $r$
  - 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, $\bar{\omega}_o = \bar{\omega}(\mu_o = 1)$
  
  *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, $\bar{\omega}(\mu_o) = \bar{\omega}_o \bar{\bar{\omega}}(\mu_o)$

  *directional reflectance model $\bar{\bar{\omega}}(\mu_o)$ derived for each IGBP type using VIRS*

• Estimate reflectance for given viewing angles, $\bar{\omega}(\mu_o, \mu, \phi) = \bar{\omega}(\mu_o) \bar{\bar{\omega}}(\mu_o, \mu, \phi)$

  *bidirectional reflectance (BRDF) model $\bar{\bar{\omega}}(\mu_o, \mu, \phi)$ selected for each IGBP type from Kriebel (1978), Minnis & Harrison (1984), Suttles et al. (1988)*

• Add uncertainty to set reflectance threshold, $\bar{\omega}_T(\mu_o, \mu, \phi) = \bar{\omega} + \bar{\bar{\omega}}(\mu_o, \mu, \phi)$
PREDICTED CLEAR-SKY VIS ALBEDO
1700 UTC, 12/21/00
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, $L_s = \varepsilon_s B(T_{\text{skin}}) + (1-\varepsilon_s)L_{ad}$

  $L_{ad} = \text{downwelling atmo radiation}$, $T_{\text{skin}} = \text{skin temperature from model / obs}$

• Estimate TOA brightness temperature, $B(T_{cs}) = (1-\varepsilon_a)L_s + \varepsilon_a L_{au}$

  $L_{au} = \text{upwelling atmo radiation}$, $\varepsilon_a = \text{effective emissivity of atmo layer absorption emission computed using T/RH profile, correlated k-dist}$

• Add uncertainty to set T or BTD thresholds, $T_T(\mu) = T_{cs}(\mu) + \Delta T(\mu)$

  - 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

11µm Emissivity Map (Fillin)

Filtered & IGBP filled
Surface emissivity from Terra MODIS, April 2001, 8.5 µm

8.5µm Emissivity Map (Fillin)

Filtered & IGBP filled
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 (11μm) Threshold

VIRS run statistics

Colder

Good Cloud

Warmer

"B1" Test
11μm clear-sky threshold

"B2" Test
0.63μm clear-sky threshold

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

Σ

If = 0,
Good Clear

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

If = 3,
Good Cloud

Red=Hyperlink

NASA

CERES
NASA

CERES
NASA
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°)
STANDARD NIGHTTIME MASK ALGORITHM

Top Level Nighttime Flow Chart

"A" Test
Simple IR (11μ) Threshold

Colder

Good Cloud

VIRS run statistics

Warmer

"D1" Test
11μ clear-sky threshold

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

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

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

AMOUNT \(F\)

EFFECTIVE RADIATING TEMP \(T_c\)

EFFECTIVE HEIGHT, PRESSURE \(Z_c, p_c\)

TOP PRESSURE \(p_t\)

THICKNESS \(h\)

EMISSIVITY \(\varepsilon\)

PHASE (0 - 2) \(P\)

WATER DROPLET EFFECTIVE RADIUS \(r_e\)

OPTICAL DEPTH \(\tau\)

LIQUID WATER PATH \(LWP\)

ICE EFFECTIVE DIAMETER \(D_e\)

ICE WATER PATH \(IWP\)
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
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>
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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: 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>
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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>
# CLOUD MASK CLOUD 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>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: 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 2000

DAYTIME
MEAN EFFECTIVE CLOUD HEIGHT, MODIS, DEC 2000

DAYTIME

km
MEAN WATER CLOUD OPTICAL DEPTH, MODIS, DEC 2000, DAY
MEAN EFFECTIVE DROPLET RADIUS, MODIS, DEC 2000

Day

µm
Optical Depth Vs. Latitude

VIRS data Land Water Phase

- 199807 Avg = 10.7998
- 199907 Avg = 10.0692
- 200007 Avg = 9.143
- 200107 Avg = 10.5544
Range in southern ocean is 2 - 4 µm
1 - 2 µm elsewhere
Range over tropical land 1 - 2 µm
MEAN CLOUD COVER, MODIS, June 2001

night
EFFECTIVE CLOUD TEMPERATURE, MODIS, DEC 2000

DAY

T (K)
MEAN EFFECTIVE CLOUD HEIGHT, MODIS, DEC 2000

NIGHT

km
MEAN EFFECTIVE ICE CRYSTAL DIAMETER, MODIS, DEC 2000

DAYTIME

De, µm
MEAN CLOUD LIQUID WATER PATH, MODIS DEC 2000

Daytime
SEASONAL VARIATION OF EFFECTIVE ICE CRYSTAL DIAMETER

VIRS, 1998 - 2001

OCEAN

LAND
MEAN WATER PATH, MODIS, DEC 2000, DAY

200012 Terra-MODIS_ValR1_024023 Mean Zonal Cloud Water Path (g/m²)
Ocean (Water Phase)

Land (Water Phase)

Ocean (Ice Phase)

Land (Ice Phase)
VALIDATION (COMPARISONS)

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

• with surface-based retrievals
  - LWP, \( r_e, Z_c, T_c \), \( t \) 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, \( \theta \))
  - 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

MEAN CLOUD FRACTION, DEC

<table>
<thead>
<tr>
<th></th>
<th>SURFACE</th>
<th>CERES</th>
<th>ISCCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL</td>
<td>0.632</td>
<td>0.563</td>
<td>0.669</td>
</tr>
<tr>
<td>60N - 60S</td>
<td>0.606</td>
<td>0.625</td>
<td>0.696</td>
</tr>
<tr>
<td>YEAR</td>
<td>71-96</td>
<td>00</td>
<td>84-94</td>
</tr>
</tbody>
</table>
ISCCP: lower resolution => more cloud cover?
COMPARISON OF SFC-OBSERVED HIGH CLOUD AMOUNTS (1971-1996) AND VIRS-DERIVED COVERAGE BY ICE CLOUDS

**JAN**

**MAY**

**MAR**

**JUN**
Agreement in low latitudes consistent with VIRS

- discrepancy in midlatitudes due to definition of high?
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
DUAL-ANGLE RETRIEVAL TO TEST PHASE FUNCTION

For a pair of reflectances, the matched observations should coincide with a particular reflectance-pair line for a given phase function.

Chepfer et al. (JGR, 2002) found that CERES ice phase function explains observed reflectances as often or more so as any others tested.
Validation of Cloud Height over ARM SGP, VIRS 1998

Nighttime VIRS and Surface Comparison at ARM SGP Site (t<5)

Nighttime thin: 4 Ci too high, 1 too low; best agreement

Dong et al. (submitted JAS 2002)
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 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 2001

CERES average droplet sizes within $\pm 1 \mu m$ of surface-based values over ARM SGP site
Validation of CERES Cloud Droplet Size (Stratus)
ARM SGP, VIRS 1998; MODIS 2001

CERES LWP slightly greater than surface-based values over ARM SGP site
## COMPARISON OF CERES VIRS & SURFACE-DERIVED CLOUD PROPERTIES

**ARM SGP JAN - AUG 1998 DAYTIME**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VIRS-sfc</th>
<th>std dev</th>
<th>SD(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin Tc vs mean</td>
<td>-11.8 K</td>
<td>11.7 K</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Thick Tc vs mean</td>
<td>-6.8 K</td>
<td>8.2 K</td>
<td>-</td>
<td>41</td>
</tr>
<tr>
<td>Thin Zc vs. mean</td>
<td>-1.1 km</td>
<td>1.7 km</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Thin Zc vs. top</td>
<td>-2.1 km</td>
<td>2.0 km</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Thick Zc vs. mean</td>
<td>0.4 km</td>
<td>1.3 km</td>
<td>-</td>
<td>41</td>
</tr>
<tr>
<td>Thick Zc vs. top</td>
<td>-0.4 km</td>
<td>1.6 km</td>
<td>-</td>
<td>41</td>
</tr>
<tr>
<td>Stratus</td>
<td>-1.5</td>
<td>6.2</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>Stratus re (µm)</td>
<td>0.7</td>
<td>1.8</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>LWP (gm⁻²)</td>
<td>-18</td>
<td>41</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>Cirrus</td>
<td>0.7</td>
<td>1.3</td>
<td>38</td>
<td>7</td>
</tr>
<tr>
<td>Cirrus De (µm)</td>
<td>0.5</td>
<td>17.0</td>
<td>72</td>
<td>7</td>
</tr>
<tr>
<td>IWP (gm⁻²)</td>
<td>4.3</td>
<td>18.3</td>
<td>49</td>
<td>7</td>
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</table>
## COMPARISON OF CERES VIRS & SURFACE-DERIVED CLOUD PROPERTIES

**ARM SGP JAN - AUG 1998 NIGHTTIME**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VIRS-sfc</th>
<th>std dev</th>
<th>SD(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin $T_c$ vs mean</td>
<td>-1.6 K</td>
<td>9.5 K</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Thick $T_c$ vs mean</td>
<td>-6.4 K</td>
<td>7.3 K</td>
<td>-</td>
<td>31</td>
</tr>
<tr>
<td>Thin $Z_c$ vs. mean</td>
<td>0.7 km</td>
<td>1.4 km</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Thin $Z_c$ vs. top</td>
<td>-0.5 km</td>
<td>1.5 km</td>
<td>-</td>
<td>31</td>
</tr>
<tr>
<td>Thick $Z_c$ vs. mean</td>
<td>1.6 km</td>
<td>1.1 km</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Thick $Z_c$ vs. top</td>
<td>-0.4 km</td>
<td>1.6 km</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Cirrus $t$</td>
<td>0.6</td>
<td>1.1</td>
<td>78</td>
<td>16</td>
</tr>
<tr>
<td>Cirrus De ($\mu m$)</td>
<td>-16.8</td>
<td>17.0</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>IWP (gm$^{-2}$)</td>
<td>2.0</td>
<td>27.5</td>
<td>97</td>
<td>16</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
COMPARISON OF OBSERVED & COMPUTED SW & LW FLUXES
ALL SCENE TYPES, TRMM VIRS/CERES, APRIL 18, 1998

$\text{SW} = 5.8 \pm 28 \text{ Wm}^{-2} \ (14\%)$

$\text{LW} = 0.7 \pm 8 \text{ Wm}^{-2} \ (3\%)$
COMPARISON OF OBSERVED & COMPUTED SW & LW FLUXES
ICE CLOUDS ONLY TRMM VIRS/CERES, APRIL 18, 1998

\[ \text{\( \Delta \text{SW} = 4.1 \pm 36 \text{ Wm}^{-2} \text{ (10\%)} \)} \]

\[ \text{\( \Delta \text{SW} = 1.6 \pm 11 \text{ Wm}^{-2} \text{ (6\%)} \)} \]
CERES-DERIVED CLOUD PROPERTIES

YIELD EXCELLENT AGREEMENT BETWEEN FLUX OBSERVATIONS & RADIATIVE TRANSFER MODELS
CONSISTENCY WITH VIRS
Scatter Plots for MODIS and VIRS Matchup
MODIS (200012021725) and VIRS (200012021654)
(stats for VIRS - MODIS)

Water Radius (μm)

- Number of boxes: 3329
- Mean: 0.4953
- Std: 2.4398

Ice Diameter (μm)

- Number of boxes: 1739
- Mean: 1.4022
- Std: 13.4658

Optical Depth (Water Phase)

- Number of boxes: 3329
- Mean: -3.7366
- Std: 9.3921

Optical Depth (Ice Phase)

- Number of boxes: 1739
- Mean: -3.7669
- Std: 10.4462

\[ t = 31 \text{ min} \]
Scatter Plots for MODIS and VIRS Matchup

Cloud Height (km) (20001202)

mean(virs-modis) = -0.239
std (virs-modis) = 0.9745
number of matching boxes = 4645
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%

LATITUDE (°)

CLOUD FRACTION
Cloud optical depth, June 2001, MODIS (week 1) vs. VIRS (month)

V = VIRS
M = MODIS
O = Ocean
L = Land
W = Water
I = Ice

Ocean
- M - V: 0.1 ± 1.5
- M - V: 0.4 ± 2.2

Land
- M - V: 2.0 ± 2.0
- M - V: -2.0 ± 5.5
Cloud particle sizes, June 2001, MODIS (week 1) vs. VIIRS (month)

Liquid

Effective Radius (μm)

μm
- VOw, 14.7
- MOw, 14.0
- VLw, 11.3
- MLw, 10.8

MO-VO: -0.7 ± 0.9 μm
ML-VL: -0.5 ± 0.6 μm

Ice

Effective Diameter (μm)

μm
- VOi, 53.5
- MOi, 54.4
- VLi, 49.7
- MLI, 44.6

MO-VO: 0.9 ± 2.2 μm
ML-VL: -5.1 ± 2.7 μm

V = VIIRS
M = MODIS
O = Ocean
L = Land
W = water
I = ice
Cloud heights, June 2001, MODIS (1-16) vs. VIIRS (month)

Ocean

- Vw, 2.2 km
- Mw, 2.2
- Vi, 8.7
- Mi, 9.1

Land

- Vw, 3.7 km
- Mw, 3.5
- Vi, 8.7
- Mi, 9.0

Legend:
- V = VIIRS
- M = MODIS
- O = Ocean
- L = Land
- w = water
- l = ice
Cloud water path, June 2001, MODIS (1 - 16) vs. VIRS (month)

Liquid water path (g m\(^{-2}\))

Water:
- VO 64.4
- MO 66.5
- VL 69.1
- ML 82.8

Ice:
- VO 261
- MO 288
- VL 295
- ML 272

Legend:
- V = VIRS
- M = MODIS
- O = Ocean
- L = Land
- w = water
- l = ice
## SUMMARY OF ZONAL DIFFERENCES, JUNE 2001

**Edition 1a**

<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>
SUMMARY

• Cloud amount: **VIRS detects more cloud cover**
  - orbit times (MODIS designed for clear sky)
  - resolution differences, slight mask differences

• Optical depth: **VIRS has variable agreement with MODIS**
  - MODIS slightly greater on average (calibration, resolution), < 10% mean diff

• Effective size: **VIRS generally larger than MODIS** (ice over land greatest)
  - 0.5K difference in 3.7-µm cal => 0.5 µm [r_e] (< 10% bias)
  - Need updated 3.7-µm emissivity maps for thin clouds

• Water path: **Mixed results, < 10% difference on average, sampling differences**

• Heights: **Small differences on average, -0.2 km to 0.4 km (ice)**

• Future: examine calibration differences more closely & impact of cloud emittance models & surface emissivity data
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 properties for thick clouds at night (t > 8)

• Nighttime polar cloud amounts underestimated

  Look for discontinuities at 60° latitude

• Nighttime ice cloud heights somewhat greater (~ 0.5 km for ice)

• Cloud temperature better than height for low clouds over land (missing inversions in profiles)

• Others, see Data Quality Summary
CONCLUDING REMARKS

• CERES archived cloud/radiation data now available
    CERES fluxes only for Jan-Aug 98, March 2000
  - Terra MODIS Edition 1a: Nov 2000 -

• Validation so far indicates very reasonable values for results
  - Validation continues
  - MODIS & VIRS results very consistent

• Use the dataset you'll like it
  - Read caveats!
SUMMARY OF PRELIMINARY AQUA MODIS ANALYSES

• MODIS CHANNELS LOOK CLEAN EXCEPT FOR 1.6 µm
  - SELECT OTHER CHANNEL (2.13 µm)
  - NEW MODELS DEVELOPED FOR 2.13 µm

• ALGORITHMS WORK WITH NO SIGNIFICANT PROBLEMS
  - NEED TO VERIFY CALIBRATIONS

• FIRST BETA RESULTS WILL BE OUT SOON
FUTURE RESEARCH

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

• VIRS (Edition 2)
  With CERES fluxes: Jan - Aug 1998, March 2000

• Terra MODIS (Edition 1a)
  March & April 2000
  November, December 2000
  January - September 2001
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/
TERRA/AQUA SSF AEROSOLS

LAND: 1 Product
- MODIS (Kaufman et al. *JGR* 1997)

OCEAN: 2 Products
- MODIS (Tanre et al. *JGR* 1997)
- VIRS-like (Ignatov Stowe *JAM* 2000; *JAS* 2002)

MOTIVATION FOR “VIRS-like”

1) LEARN BY COMPARISON
2) HEREDITARY: NOAA/AVHRR & TRMM/VIRS
3) MULTI-SPECTRAL IMPROVEMENTS
Cloud Screening

MODIS (Ref?): Done by MODIS Team
VIRS-like (Minnis et al): Consistent w/ TRMM/VIRS

Sampling

MODIS: Beyond 40° glint
VIRS-like: Beyond 40° glint & Anti-solar side of Orbit

Aerosol Retrievals

MODIS (Tanre et al. 1997)
- Spectral: 6 bands from 0.55-2.13 μm
- Aerosol: Var Bi-LogNormal (Mode Location/Ratio)
- Surface: Fresnel (V=7 m/s) + Black (except 0.55 μm)
- RT Model: Ahmad-Fraser (JAS 1981)

VIRS-like (Ignatov Stowe 2000, 2002)
- Spectral: Single-Channel: 0.659 & 1.640 μm
- Aerosol: Prescribed (Fixed) Mono-LogNormal
- Surface: Fresnel (V=1 m/s) + Small Diff.Ref.
- RT Model: Vermote et al. 6S (IEEE/TGARS 1997)
# OF AEROSOL FOOTPRINTS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VIRS-like</td>
<td>14%</td>
<td>14%</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>MODIS</td>
<td>42%</td>
<td>47%</td>
<td>43%</td>
<td>47%</td>
</tr>
<tr>
<td>MODIS</td>
<td>44%</td>
<td>39%</td>
<td>53%</td>
<td>48%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VIRS-like</th>
<th>MΩV=100%</th>
<th>MΩV=100%</th>
<th>MΩV=100%</th>
<th>MΩV=100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIRS-like</td>
<td>N=2,268,474</td>
<td>N=2,217,566</td>
<td>N=2,652,508</td>
<td>N=2,542,214</td>
</tr>
</tbody>
</table>
SUB-SAMPLES: POPULATION

TERRA/SSF MODIS AEROSOLS: PROPORTION OF POPULATION

P, %

~10%
~45%
~45%

FM1 15–21 DEC, 2000
FM2 1–7 JUN, 2001


- **VIRS – MODIS** ($\delta \tau_1$~0.004; $\delta \tau_2$~0.003)
  - Lat/Lon Domain: Identical
  - Sun/View/Scatter/Glint: Identical
  - Cloud Condition/Sampling: Close
  - Aerosol Algorithm: **DIFFER**

- **VIRS – VIRS** ($\delta \tau_1$~0.01; $\delta \tau_2$~0.002)
  - Lat/Lon Domain: **DIFFER**?
  - Cloud Condition: **DIFFER**?
  - Sun/View/Scatter/Glint: **DIFFER**?
  - Aerosol Algorithm: Identical

- **MODIS – MODIS** ($\delta \tau_1$~0.03; $\delta \tau_2$~0.03)
  - Lat/Lon Domain: **DIFFER**?
  - Cloud Condition: **DIFFER**?
  - Sun/View/Scatter/Glint: **DIFFER**?
  - Aerosol Algorithm: Identical
CLOUD AMOUNT

TERRA/SSF MODIS PERCENT CLOUD AMOUNT

\[ A_T, \% \]

\[ \sim 40\% \]
\[ \sim 40\% \]
\[ \sim 60\% \]

FM1: 15-21 Dec, 2000
FM2: 1-7 Jun, 2001
SCATTER ANGLE

TERRA/SSF MODIS
SCATTERING ANGLE

$\chi$

160
140
120
100

~141°
~144°
~120°

FM1 15-21 DEC, 2000
FM2 2000
FM1 1-7 JUN, 2001
FM2 2001

VIRS
VIRS AND MODIS
MODIS NO VIRS
NO MODIS

VIRS
NO MODIS
MODIS NO VIRS
CONCLUSION TO MODIS

Cloud/Sampling
VIRS-like NO MODIS: ~10%
VIRS-like AND MODIS: ~45%
MODIS NO VIRS-like: ~45%

τ -Retrievals:
• VIRS-like compares to MODIS
  (Aerosol algorithm: Effect Small)
• MODIS differ from MODIS
  (Cloud/Scat Angle Differ)

Paper to JAS-2003 in preparation
TRMM/VIRS AEROSOLS

AVHRR: $\lambda_1 = 0.63 \, \mu\text{m}$, $\lambda_2 = 0.83 \, \mu\text{m}$ ([$\lambda_{3\lambda} = 1.61 \, \mu\text{m}$])

NOAA: 1981–pr; 70°S–70°N; ~1:30 pm; H=870 km; 9 lays

VIRS: $\lambda_1 = 0.63 \, \mu\text{m}$, $\lambda_2 = 1.61 \, \mu\text{m}$

TRMM: 1997–pr; 40°S–40°N; full day; H=350 km; 45 day

Cloud Screening: Accurate / Different

Ignatov Stowe JAS 2002:

$\tau_1$: 6S–based (Vermote et al. **IEEE 1997**) single-channel (scaled to 0.63 μm)

*Atmosphere*

Aerosol: Log-Normal $R_m=0.1 \, \mu\text{m}$, $\sigma=2.03$; $n=1.4-0i$ (Empirical Phase Function; Ignatov JAM 1997)

Rayleigh/Gas: Mid-Latitude Summer

*Surface*

Lambertian: $\rho_{sfc}=0.002$ (0.2%)

Bi-directional: Cox-Munk $V=1 \, \text{ms}^{-1}$
Why Single-Channel?

\[ \rho = \frac{\pi L}{F \mu_s} ; \quad \rho = \frac{P^R(\chi) \tau^R}{4 \mu_s \mu_v} + \frac{\omega_0 P^A(\chi) \tau}{4 \mu_s \mu_v} \]

**Single-Channel:** \( \tau \)
- \( \omega_0 P^A \): fixed globally non-variable
  (average aerosol type \( \pm 30\% \))

**Two-Channel:** \( (\tau, \alpha) \) (Def: \( \tau(\lambda) = \tau_0 \times \lambda^{-\alpha} \))
- \( \omega_0 P^A \): adjusted coherently with retrieved \( \alpha \)
  (as accurate as \( \alpha \))

**Information Content/Signal-To-Noise Ratio:** \( \eta = \sigma_{\alpha_0} / \sigma_{\alpha} \)
(Westwater Strand JAS 1968; Rogers RGSP 1976)
- \( \sigma_{\alpha_0} \sim 0.3 ; \quad \sigma_{\alpha} \sim k / \tau \) (Ignatov et al. ASR 1997; Ignatov Stowe JAS 2002)
- \( \eta = \tau / \tau_0 ; \quad \eta \sim 1 \) at \( \tau \sim \tau_0 \)
- AVHRR/AEROBS (8 km)\(^2 \) \( \tau_0 \sim 0.18 \) (Ignatov Stowe JAS 2002)
- AVHRR/PATMOS (110 km)\(^2 \) \( \tau_0 \sim 0.11 \) (Ignatov Nalli JTech 2002)
- TRMM/VIRS (>10 km)\(^2 \) \( \tau_0 \sim ? \) (Thermal Leak)
LATITUDE

- **VIRS**: 20°S - 40°N
- **AVHRR**: 40°S - 60°N
- **AVHRR**: 60°S - 60°N

- **Minimum**
  - **VIRS** noisier (drop-outs)
  - Min(VIRS) ~ min(AVHRR): No Cal Error?
- **Average**
  - AVHRR - AVHRR: + Anomaly Apr98 (0-20°S)
  - **VIRS**: anomaly exaggerated
CLOUD AMOUNT

- **VIRS**: ~15%
- **AVHRR**: ~40%

**Average**
- Reproducible pattern for 2 datasets
- Increasing trend with cloud amount

**Minimum**
- Increasing trend (residual cloud?)
CONCLUSION TO VIRS

$\tau_1$ 0.63 $\mu$m: Biased w/t to AVHRR by $\sim+0.04$

$\tau_2$ 1.61 $\mu$m: Bad (thermal leak). Recommend against using.

$\alpha$ Bad (thermal leak in $\tau_2$).

Paper to JAM-2003 in preparation