CALIPSO, CloudSat, CERES, and MODIS merged A-train data set

Seiji Kato<sup>1</sup>, Sunny Sun-Mack<sup>2</sup>, Walter Miller<sup>2</sup>, Fred Rose<sup>2</sup>, Yan Chen<sup>2</sup>, Seung Hee Ham<sup>2</sup>

<sup>1</sup>NASA Langley Research Center
<sup>2</sup>Science Systems and Applications, Inc.

EarthCARE, FLURB meeting, Toronto Canada, May 12 – 13
Outline of this talk

• Brief descriptions of the C3M data product
• How C3M is used in NASA and by others
• Improvements for the next version
• Spectral radiance computations
C3M (CCCM) product

- Contains:
  1. Merged CALIPSO, CloudSat derived clouds, CERES TOA radiative flux (SW, LW, and WN), MODIS (CERES_ST) derived cloud properties both along CALIPSO-CloudSat ground-track and over the whole CERES footprint,
  2. MODIS derived cloud properties by an enhanced cloud algorithm,
  3. CALIPSO and MODIS derived aerosol properties
  4. Vertical radiative flux profiles computed with CALIPSO, CloudSat, and MODIS derived cloud properties.

- 44 months of data (July 2006 through 2010) are available from http://eosweb.larc.nasa.gov/PRODOCS/ceres-news/table_ceres-news.html
Outline

- Merging process
- Data set provided to Howard
- Some results relevant to EarthCARE
C3M

• Format is similar to the CERES Level 2 data product SSF.
  – Share some inputs with CERES data products (T and Q, snow/ice map, aerosol transport model).
  – Heavily relies on CERES experiences and resources.
• Provides cloud and aerosol properties that are likely to be used in research.
  – Over 400 variables
  – Including not just best values (properties derived from passive and active sensors, multiple irradiances)
  – Mean values over the ground track and full footprint are kept
  – Including retrieval from an enhanced MODIS cloud algorithm (uses CLAIPSO CloudSat information)
• Make the origin transparent as much as possible
  – Cloud top and base source flags
  – Maintain original data quality (e.g. spatial resolution) as much as possible
  – Keep original quality flags as much as possible
• Try to provide all inputs used in irradiance profile computations
  – How we compute irradiance profiles is transparent.
  – User can reproduce our irradiance profile computations
  – Some variables and flags are included for our QC purpose (e.g. irradiance model source flag)
CERES point spread function is used to reduce FOV size difference. Same cloud profiles are grouped for the independent column approximation, i.e., horizontal resolution of CALIPSO and CloudSat products is maintained.
Input data

MODIS (retrievals are done by the CERES cloud algorithm)
MAC021S1.AYYYYJDY.HHMM.*.hdf, MAC_GEO
MAC03S1.AYYYYJDY.HHMM.*.hdf
MAC_AEROSOL: MAC04S1.AYYYYJDY.HHMM.*.hdf

CALIPSO
CALIPSO_VFM:CAL_LID_L2_VFM-Prov-V3-01.YYYY-MM-DDTHH-*hdf
CALIPSO_05kmALay:CAL_LID_L2_05kmALay-Prov-V3-01.YYYY-MM-DDTHH-*hdf
CALIPSO_05kmCLay:CAL_LID_L2_05kmCLay-Prov-V3-01.YYYY-MM-DDTHH-*hdf
CALIPSO_05kmCPro:CAL_LID_L2_05kmCPro-Beta-V3-01.YYYY-MM-DDTHH-*hdf

CloudSat
CLOUDSAT_CLDCLASS:YYYYJDY*_CS_2B-CLDCLASS_GRANULE_P_R04_E00.hdf
CLOUDSAT_CWC-RO:YYYYJDY*_CS_2B-CWC-RO_GRANULE_P_R04_E01.hdf

CERES
SSF, CRS
## Cloud properties

<table>
<thead>
<tr>
<th>Calipso cloud mask</th>
<th>CALIPSO VFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CloudSat cloud mask</td>
<td>CloudSat CLDCLASS</td>
</tr>
<tr>
<td>C05kmCPro_ExtinCoef532</td>
<td>CALIPSO 5 km cloud profile</td>
</tr>
<tr>
<td>C05kmCLay_ExtinctionQC_532</td>
<td>CALIPSO 5 km layer</td>
</tr>
<tr>
<td>C05kmCLay_CAD_Score</td>
<td>CALIPSO 5 km layer</td>
</tr>
<tr>
<td>C05kmCLay_Layer_Top_Altitude</td>
<td>CALIPSO 5 km layer</td>
</tr>
<tr>
<td>C05kmCLay_Layer_Base_Altitude</td>
<td>CALIPSO 5 km layer</td>
</tr>
<tr>
<td>Cloud class</td>
<td>CloudSat CLDCLASS</td>
</tr>
<tr>
<td>Precp flag</td>
<td>CloudSat CLDCLASS</td>
</tr>
<tr>
<td>ROLiqEffRadius</td>
<td>CloudSat CWC-RO</td>
</tr>
<tr>
<td>ROiceEffRadius</td>
<td>CloudSat CWC-RO</td>
</tr>
<tr>
<td>ROLiqWatContent</td>
<td>CloudSat CWC-RO</td>
</tr>
<tr>
<td>ROLiqWatContentUncert</td>
<td>CloudSat CWC-RO</td>
</tr>
<tr>
<td>ROiceWatContent</td>
<td>CloudSat CWC-RO</td>
</tr>
<tr>
<td>ROiceWatContentUncert</td>
<td>CloudSat CWC-RO</td>
</tr>
</tbody>
</table>
Aerosol properties

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A05kmALay_OptDepth532</td>
</tr>
<tr>
<td>A05kmALay_OptDepthUncer532</td>
</tr>
<tr>
<td>A05kmALay_OptDepth1064</td>
</tr>
<tr>
<td>A05kmALay_OptDepthUncer1064</td>
</tr>
<tr>
<td>A05kmALay_Layer_Top_Altitude</td>
</tr>
<tr>
<td>A05kmALay_Layer_Base_Altitude</td>
</tr>
<tr>
<td>A05kmALay_Relative_Humidity</td>
</tr>
<tr>
<td>A05kmALay_ExtinctionQC_532</td>
</tr>
<tr>
<td>A05kmALay_ExtinctionQC_1064</td>
</tr>
<tr>
<td>A05kmALay_CAD_Score</td>
</tr>
<tr>
<td>A05kmALay_Opacity_Flag</td>
</tr>
<tr>
<td>A05kmALay_Horizontal_Averaging</td>
</tr>
<tr>
<td>A05kmALay_Number_Layers_Found</td>
</tr>
</tbody>
</table>

All from CALIPSO 5 km aerosol layer product
How C3M is used in NASA

• Evaluation of passive sensor only surface and atmospheric irradiance estimate
• Validation of MODIS retrieval
  – Intermediate pixel level product helps
• Analysis of the effect of scene ID to irradiance derived from ADMs
• Aerosol direct radiative effect analysis (sensitivity study)
• Determine instrument requirements for the CLARREO mission (simulating CLARREO observations with realistic clouds)
Estimating the effect of the scene I.D. error to ADM irradiance estimate (SW)

Figure 10. TOA SW flux error (W m\(^{-2}\)) caused by scene identification uncertainty (standard – enhanced) (a) only using near-nadir viewing geometries, (b) using extended viewing geometries that are similar to the CERES observations.

Su et al. AMT, 2015
Estimating the effect of the scene I.D. error to ADM irradiance estimate (LW)

Figure 12. TOA LW flux error (W m\(^{-2}\)) caused by scene identification uncertainty (standard – enhanced) (a) daytime LW flux error only using near-nadir viewing geometries, (b) daytime LW flux error using extended viewing geometries that are similar to the CERES observations, (c) same as (a) but for nighttime LW flux error, (d) same as (b) but for nighttime LW flux error.

Su et al. AMT, 2015
View zenith angle of CERES instrument

Figure 11. Distributions of grid-averaged viewing zenith angle for CERES data (blue), C3M data (green), and the C3M extended data (red), using data of April 2010.

Su et al. AMT, 2015
Low-level cloud fraction comparison (Jan. 2010)

- Cloud fraction and base height difference will be converted to the downward longwave irradiance change.
- The longwave irradiance change will be used for the bias correction
Boundary layer lapse rates derived from CALIPSO and MODIS

FIG. 6. Daytime boundary layer lapse rates (K km$^{-1}$) over snow–ice-free scenes for DJF, MAM, JJA, and SON: July 2006–June 2007 and June 2009–May 2010 (2 yr).

Sun-Mack et al. 2014 JAMC
Atmospheric heating rate

• Starting point is cloud fields derived from MODIS only.
  – Limitation of the passive sensor is known. Active sensors are used to improve the limitation.

• Many if statements
  – If CALIOP retrieval is not available or if CloudSat retrieval is not available etc...

• Heating rates are under utilized perhaps because
  – Radiation is one component (needs latent heat and advection).
  – Covers only nadir view.
  – Diurnal correction is needed.
How C3M is used by others

- Aerosol (indirect effect) and polar studies
- Evaluation of cloud parameterization in a climate model
- Evaluation of passive sensor derived cloud properties
- Use cloud, aerosol, and atmospheric properties provided by C3M, users can compute radiative flux by themselves.
Cloud fraction, LWC, and IWC comparisons

Figure 10. Composites by MODIS-Aqua CR of C3M volumetric cloud fraction profile defined in the text. Also shown is the profile of this quantity averaged across all MODIS-Aqua CRs (curve labeled “C3M”).

Oreopoulos et al. 2014 JGR
Aerosol effect on clouds

Figure 13. (a) Temporal linear correlation coefficients between \( r_e \) and \( A \) (colors), and LWP and \( A \) (contours). (b) Albedo susceptibility \( S_R \).

Figure 5. Correlations between aerosol and cloud related quantities. (a) Temporal linear correlation coefficients between \( r_e \) and \( H_a - H_c \) (\( \Delta H \)) calculated over 6°×2.5° regions. Values reported for regions with at least 30 samples, and dots are as in Figure 2. (b) Bivariate histogram of \( H_a - H_c \) and \( r_e \) over the dashed blue rectangle in Figure 5a, colors in \( \ln \) (number of samples). (c) As in Figure 5b, but for \( r_p \) and \( r_e \). Correlation coefficient \( r \) shown at top of Figures 5b and 5c.

Painemal et al. 2014 JGR
Future improvements

- Gridded (Level 3) product
- Lidar horizontal averaging and the signal attenuation level (affect cloud base)
  - Currently 5 km averaging is used. This might be too low for warm boundary layer clouds (need a study).
- Consider using more aerosol type derived from CALIOP
  - Current version only use dusts, all others comes from an aerosol transport model (MATCH)
Potential use of active sensor derived cloud fields

• Spectral radiance closure.
• Use spectral fingerprinting and spectral radiance anomalies.
• Derive T and Q deviations from climatological mean.
• This approach might be used to improve T and Q.
MERRA DATA

• 1983 – 2010 : 28 years
  – Global (540,361) ( 0.66 Lon x 0.50 Lat )
  – 6 Hourly:
    • T, Q, O₃ Profiles at 42 vertical levels
  – Hourly :
    • Tskin, T2m, Q2m, Sfc_emiss
    • Random Overlap Cloud Fraction (High, Mid, Low)
    • Cloud Optical Depth (High, Mid, Low)
    • Cloud Pressure ( 1ˢᵗ layer seen from space)
    • NO Phase, NO Particle Size, Limited Cloud Height info.
      – No Cloud LWC/IWC profile files
    • Clear and Total Sky OLR ( MERRA Rt code)
  – Files used :
    • inst6_3d_ana_Np., tavg1_2d_slv_Nx, tavg1_2d_rad_Nx
    • On /ASDC_archive
Spectral radiance change difference

30S-40S

40N-50N

Spectral radiance change computed by perturbing the monthly 10° zonal mean values indicated at the top of each plot and averaging over a year (blue line). The red line indicates the spectral radiance change computed by perturbing monthly 10° zonal value and averaging over a year minus the change computed by perturbing corresponding instantaneous values sampled by a 90 inclined polar orbit.
Retrieved T and Q anomalies (10° zone of 40° S to 30° S)

<table>
<thead>
<tr>
<th>Level</th>
<th>Temperature Anomalies</th>
<th>Relative WV Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 hPa</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>100 hPa</td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>200 hPa</td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>500 hPa</td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
</tr>
<tr>
<td>850 hPa</td>
<td><img src="image9" alt="Graph" /></td>
<td><img src="image10" alt="Graph" /></td>
</tr>
<tr>
<td>Surface</td>
<td><img src="image11" alt="Graph" /></td>
<td><img src="image12" alt="Graph" /></td>
</tr>
</tbody>
</table>

Red: retrieved
Blue: Truth

Retrieved from all-sky spectral radiance anomalies
Kato et al. 2014 J. Climate