Cloud observations from the Arcs and EarthCARE project

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EarthCARE (Earth Clouds Aerosol Radiation Explorer)  
JAXA-ESA joint mission

launch date : 2018  
altitude : 393.14km  
repeat cycle: 25days

1. CPR: 94GHz Doppler cloud radar

2. ATLID: 355nm high spectral resolution lidar

3. MSI: Multi-spectral imager  
7 channels (0.69, 0.865, 1.65, 2.21, 8.8, 10.8, 12.0μm)

4. BBR: Broad band radiometer  
3 views

(Illingworth et al., 2015 BAMS)
Different features of EarthCARE from A-train (CloudSat and CALIPSO)

1. Doppler at w-band
2. **+8dB higher sensitivity** (-36dBZ) compared with CloudSat-> better water cloud detection, better overlap with lidar ->achieve better accuracy for microphysical retrievals by radar-lidar.
3. **No contamination due to surface clutter** found in CloudSat ->to better characterize surface process and convection?.
4. **High spectral resolution lidar at 355nm**->obtain extinction. Need to connect 532nm and 355nm information.
5. short life time.

**Doppler accuracy of EarthCARE CPR (Tentative)**
for 16km mode (PRF=7200Hz):

10km horizontal integration:
1.1m/s for -19dB (worst case).
0.6m/s for -19dB (best case).

1km horizontal integration:
1.3m/s for -14dBZ (worst case).
0.8m/s for -14dBZ (best case).
Theoretical limit =0.2m/s
respectively. While these figures represent a preliminary estimate of total LWP/LWC from CloudSat, it would be valuable to have a form of GCM validation for the "cloud" liquid fields, that isn't contaminated with larger liquid precipitating hydrometeors. As done by Waliser et al. (submitted manuscript, 2008), we consider conditionally sampling of the CloudSat LWP/LWC values to remove cases flagged as precipitating at the surface. This is intended to filter out columns that have larger falling hydrometeors in them and thus serve as a preliminary estimate of the LWP/LWC (Figures 2f and 4c) for "clouds" only profiles for model-data comparisons. Our preliminary method to exclude retrievals when precipitating hydrometeors are present is to use the CloudSat precipitation flag that identifies retrievals associated with precipitation at the surface. This can be either solid or liquid precipitation, with the latter including "drizzle" from boundary layer clouds (see Text S1 of the auxiliary material).1 Figure 2e (Figure 4b) shows the CloudSat annual mean LWP (zonal mean LWC) for retrievals flagged as "precipitating" at the surface. Note that for the Tropical regions, most of this LWP (90% in most areas) is also flagged as drizzle (not shown). The CloudSat LWP (LWC) for all cases not flagged as precipitating at the surface is shown in Figure 2f (Figure 4c). Figure S1 shows the percentage of total samples removed in the cases that are flagged as having precipitation at the surface (S1a) and total number of CloudSat samples (S1b). In regions of appreciable LWC (see Figure 4a), the samples removed account for about 5–30% of the total samples. In addition, a comparison of the different satellite LWP estimates in Figure 2 shows that over the boundary-layer stratocumulus regions (e.g., off coasts of California, Peru, Northwest Africa etc) the total CloudSat LWP values (Figure 2d) are considerably larger than those estimates based on passive techniques. However, in the ITCZ, SPCZ and oceanic storm track regions, the SSM/I LWP values are generally well over a factor of two larger than those from CloudSat, CERES/MODIS and ISCCP.

There is also considerable disagreement among the four products over the western Pacific and Indian Ocean warm pool regions, with the CERES/MODIS (SSM/I) being the lowest (highest) around 10 (100) g m\(^{-2}\). In terms of overall magnitude, CloudSat and ISCCP appear to agree best, although there are differences in morphology particularly in the stratocumulus regions mentioned above. The exact basis for the disagreements in these satellite estimates is beyond the scope of this paper but is likely to be associated with different sampling strategies, particle size sensitivities of the sensors, and retrieval algorithms, and how these account for the multi-layer and mixed-phase structures of clouds, when applying these estimates to model diagnosis and validation [e.g., Horváth and Davies, 2007]. Of particular relevance is that most of the estimates consider/include all liquid water in the column—to the extent their sensor/algorithms are sensitive to it.

3. Results

Analyses data from ECMWF and NASA Goddard Global Modeling and Assimilation Office (GMAO) Modern Era Retrospective-Analysis for Research and Application (MERRA) as well as GCMs from NCAR Community Atmosphere Model V.3 (CAM3), Goddard Earth Observing System V.5 (GEOS5) and the multi-scale finite volume multi-scale-modeling framework (fvMMF) [Tao et al., 2008] are used in this study. All the model data have been converted from cloud water mixing ratio (kg kg\(^{-1}\)) to LWC using model temperature and pressure and re-gridded to a common 2\(^\circ\) latitude-longitude grid.

Figure 2. Multi-year mean values of cloud liquid water path (LWP; g m\(^{-2}\)) from the all-sky LWP of (a) CERES/MODIS (2001–2005), (b) SSM/I (7/2002–6/2007), (c) ISCCP (Annual mean: 2005), as well as (d) CloudSat (8/2006–7/2007) for total LWP, (e) CloudSat LWP associated with precipitation at the surface, and (f) CloudSat non-precipitating LWP.

(Li et al., GRL 2008)
Liquid water retrieval by lidar

Retrieval of vertical microphysical structure form CALIPSO $\beta$ and $\delta$

- super-cooled layer (mixed phase)
- bimodal size distribution

- CloudSat standard water cloud microphysics: LWC/IWC partition based on temperature (Austin et al., 2006 etc)

- CALIPSO: phase discrimination (Yoshida et al., 2009, Hu et al., 2007)

- CALIPSO water cloud retrieval
  CALIPSO+MODIS (Hu et al., ) $\tau$ and LWC from layer integrated depolarization ratio.
Refined cloud mask scheme: KU-mask

Determination of strongly attenuating and fully attenuated pixel in lidar cloud mask

Liquid cloud fraction from CALIPSO

Former

New

Latitude

Latitude

(S. Katagiri)
Analysis of lidar depolarization

Inversion for inhomogeneous cloud microphysics
  - Monte Carlo-base LUT method

\[
\int l(z, t) \, dt
\]

\[
\log_{10} \beta \text{ [1/m/sr]}
\]

\[
\text{apparent penetration depths}
\]

\[
\frac{z}{d}
\]

\[
\text{return from cloud depth } z
\]

\[
z = d
\]

\[
z = 0
\]

\[
\text{apparent penetration depths}
\]

(sato et al., ILRC 2016)
Development of a physical model

applicable to different lidar systems and inhomogeneous cloud layers

\[ l(t) = l_{\text{reduced}}(t) + l_{\text{diffused}}(t, z) \]
Performance: attenuated backscattering coefficient

\[ \log_{10} \beta \ [1/m/sr] \]

\( d \) [m]

apparent penetration depths

- **model**
- **Monte Carlo**

**color:** maximum penetration depths

- layer3
- layer2
- layer1
Performance: depolarization ratio
Return from molecule layer beneath cloud base
ARCS: Arctic Challenge for Sustainability Project 2015-2020

(NIPR, JAMSTEC, Hokkaido University and cooperation with other institutions)

Ground-based lidar and 95GHz radar obs. started at Ny-Alesund since 2013

- PMPL lidar β
- 95GHz radar Ze Falcon-A
- lidar dep.
Comparison with PMPL/FALCON-A and CloudSat/CALIPSO

candidate for EarthCARE validation site

FALCON-A/CloudSat
Vertical profile of supercooled liquid cloud

![Graph of vertical profile with reff in [μm] and LWC in [g/m³].]
Optical thickness

MODIS optical thickness
Particle size

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- **CALIOP retrieval**
- **MODIS (2.1 μm)**

![Graph showing particle size distributions for CALIOP retrieval and MODIS (2.1 μm) as a function of record number. The x-axis represents record number, the y-axis represents reff [@2nd layer], and the graph includes a log scale for reff [μm].]
In-situ observation of super-cooled drizzle drops

(Cober et al., 1996)
Bi-modal size distribution by CloudSat and CALIPSO

LWC1

LWC2
Summary

- Physical model for depolarized lidar return is developed.
- Lidar-only retrieval of water microphysics are performed along with the improved water cloud detection scheme.
- Evaluation with MODIS and other sensors as well as synergy, and Information content analysis are ongoing.

Thank you