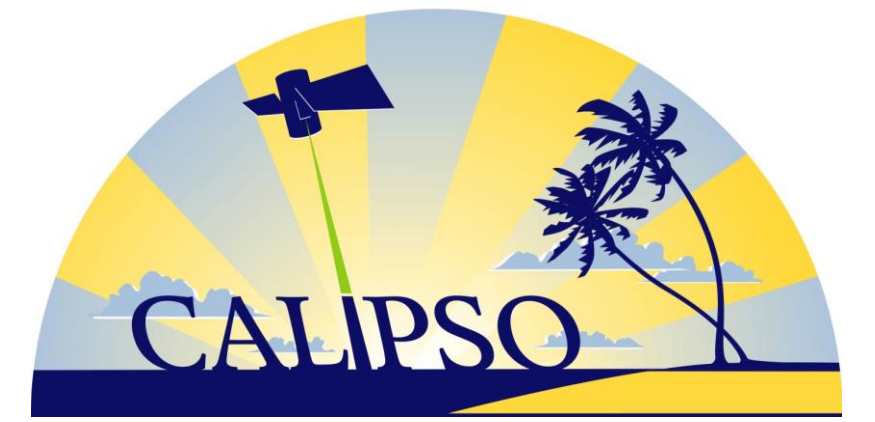




Introduction

Understanding the role of clouds in Earth's climate requires knowledge of the vertical distribution of clouds and their properties. Observations of vertically resolved cloud ice water content (IWC) are particularly important in light of the large discrepancies found between different climate models. Several cloud products from active sensors in the A-train are now available: the CALIPSO Level 3 Ice Cloud Product, based on CALIOP lidar observations, and the DARDAR and 2C-ICE products, both based on joint retrievals from CALIOP and the CloudSat W-band radar. Here, we present initial comparisons between these three products, focusing on ice water content (IWC).

CALIPSO Level 3 Ice Cloud Product (L3-ICE)

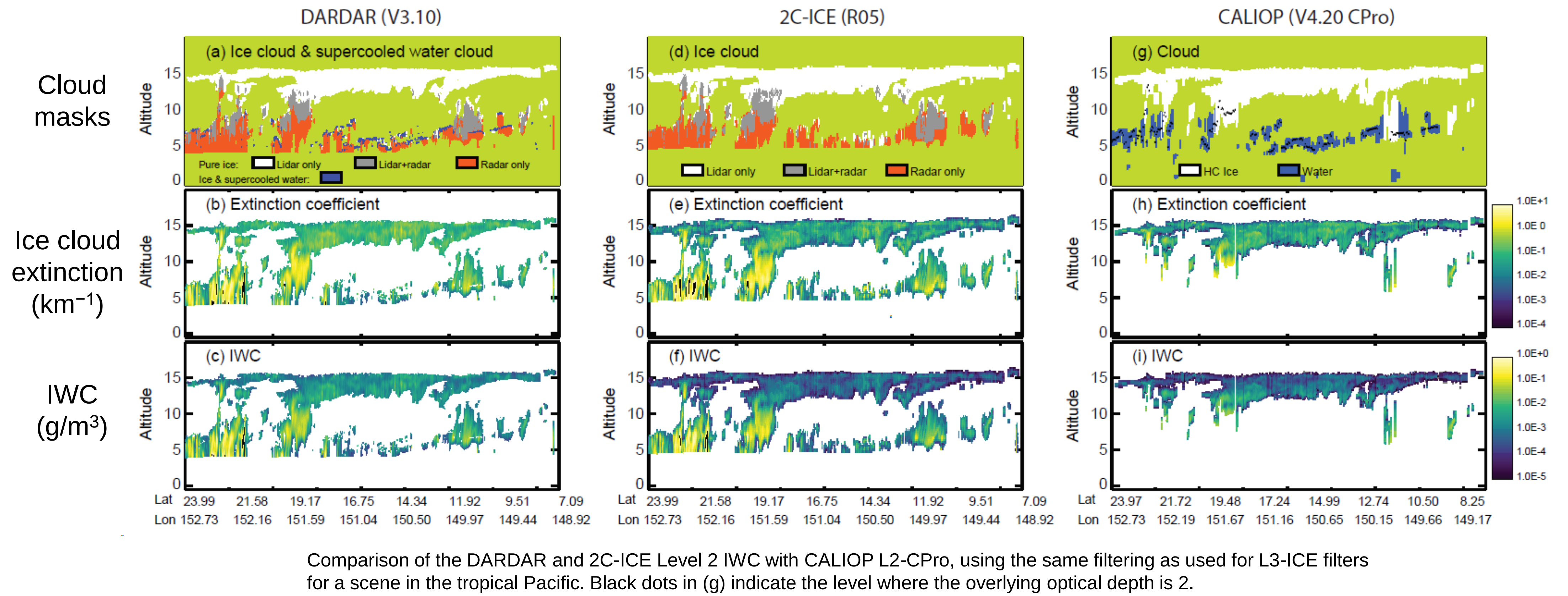
The CALIPSO L3-ICE product (Winker et al. 2023) reports monthly statistics in the form of vertically resolved histograms of ice cloud extinction and ice water content (IWC) on a uniform global $2^\circ \times 2.5^\circ$ lat-lon grid with 120 m vertical resolution. Quality screening is applied to remove artifacts. CALIOP extinction retrievals are converted to IWC using a parameterization based on in situ data from multiple field campaigns (Heymsfield et al 2014). Ice cloud extinction and IWC data are reported as histograms to facilitate comparisons with sensors having different detection sensitivities.

Radar-Lidar Ice Cloud Products

DARDAR (Delanoë and Hogan 2020; Cazenave et al 2019) and 2C-ICE (Deng et al 2010, 2015) are based on optimal estimation retrievals from Level 1 radar-lidar profiles. Both algorithms make assumptions on ice particle mass-size relationships. The retrievals are applied to cloudy regions detected only by lidar and only by radar, as well as where the radar and lidar profiles overlap. Retrievals in each of these regions involve different sets of assumptions.

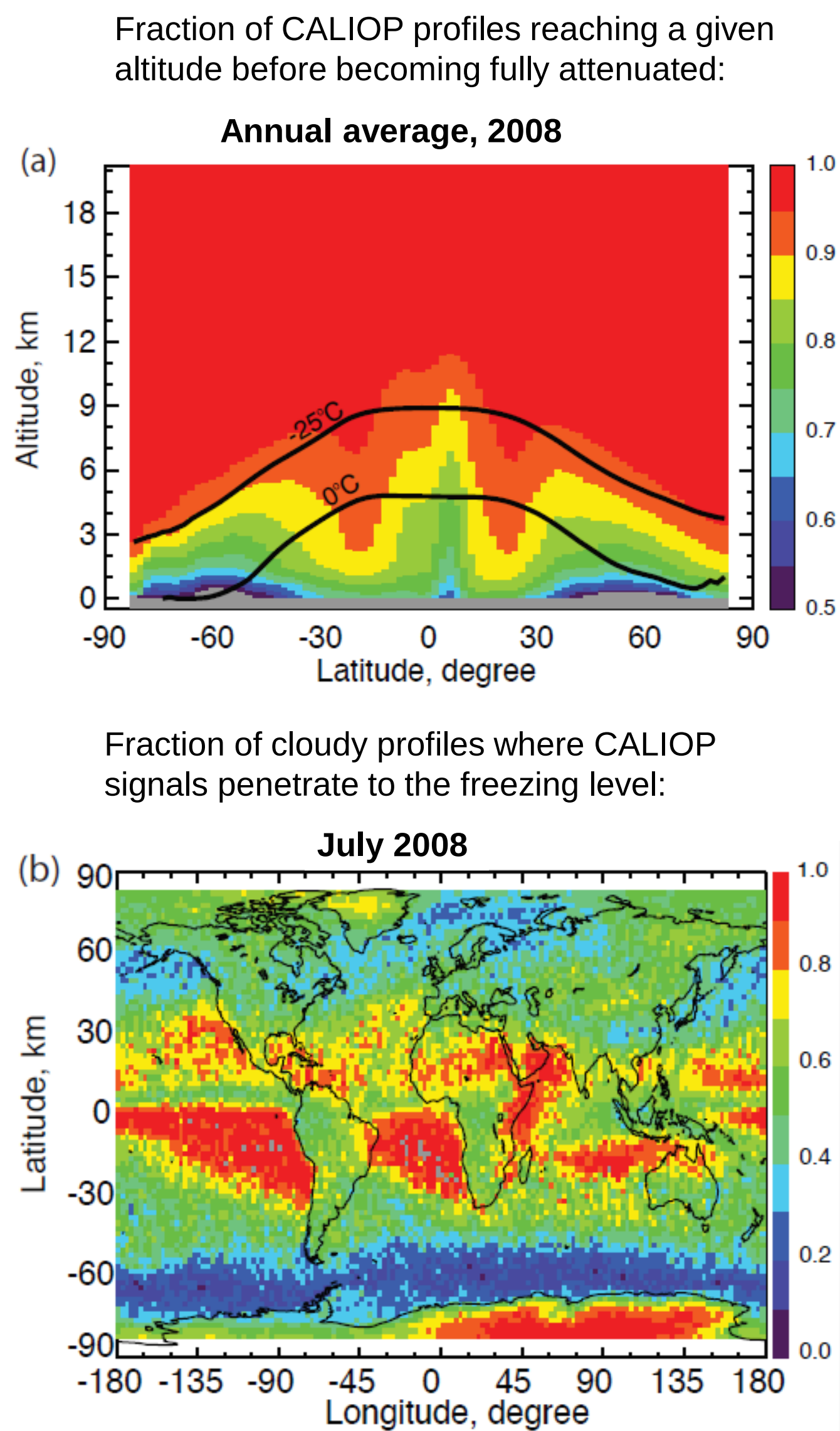
Lidar detects the prevalent optically thin ice cloud which drives radiative effects. W-band radar detects the dense ice clouds containing most of the ice mass of the atmosphere.

Lidar is often completely attenuated by water cloud, while W-band radar often sees ice within and beneath supercooled water clouds.



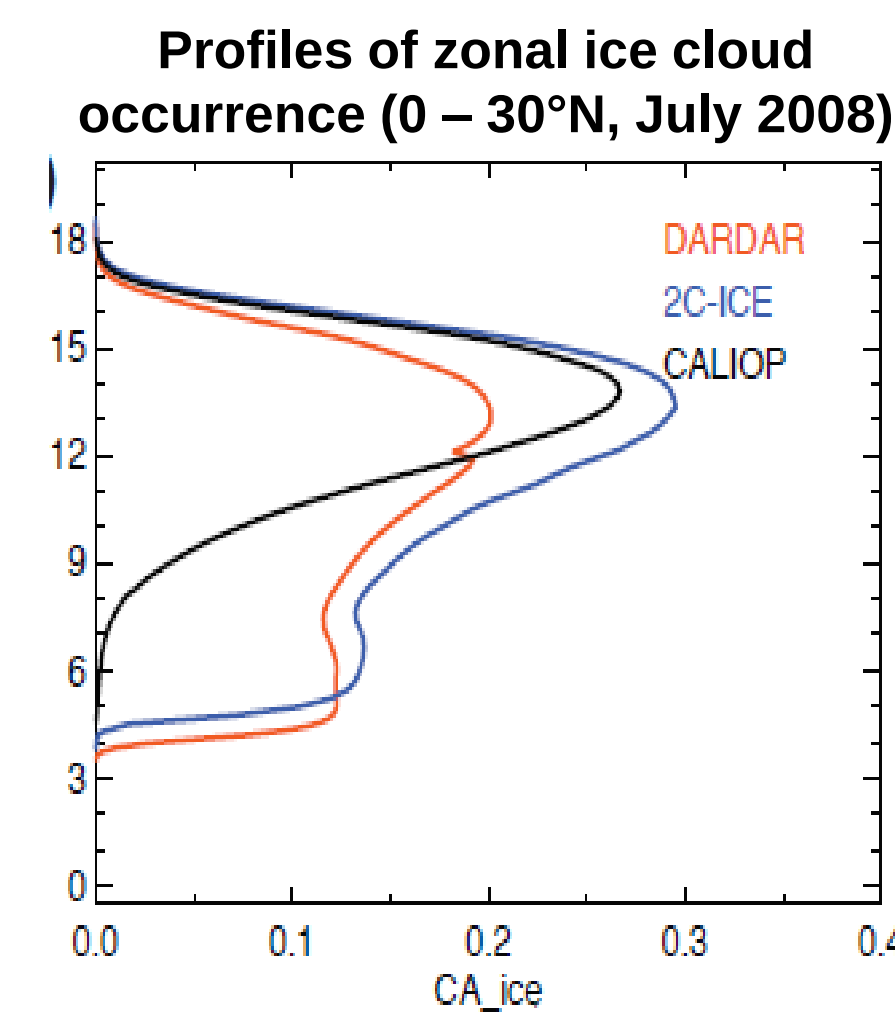
Lidar attenuation in supercooled water

Unlike W-band radar, lidar is blocked by optically thick clouds. The upper figure shows significant blockage begins at altitudes where supercooled liquid clouds form. The map below shows regions where CALIOP is able to fully probe for ice clouds (red) and regions (blue) where ice may frequently be blocked by supercooled liquid clouds.



Comparison of global zonal-mean profiles from L3-ICE, DARDAR, and 2C-ICE

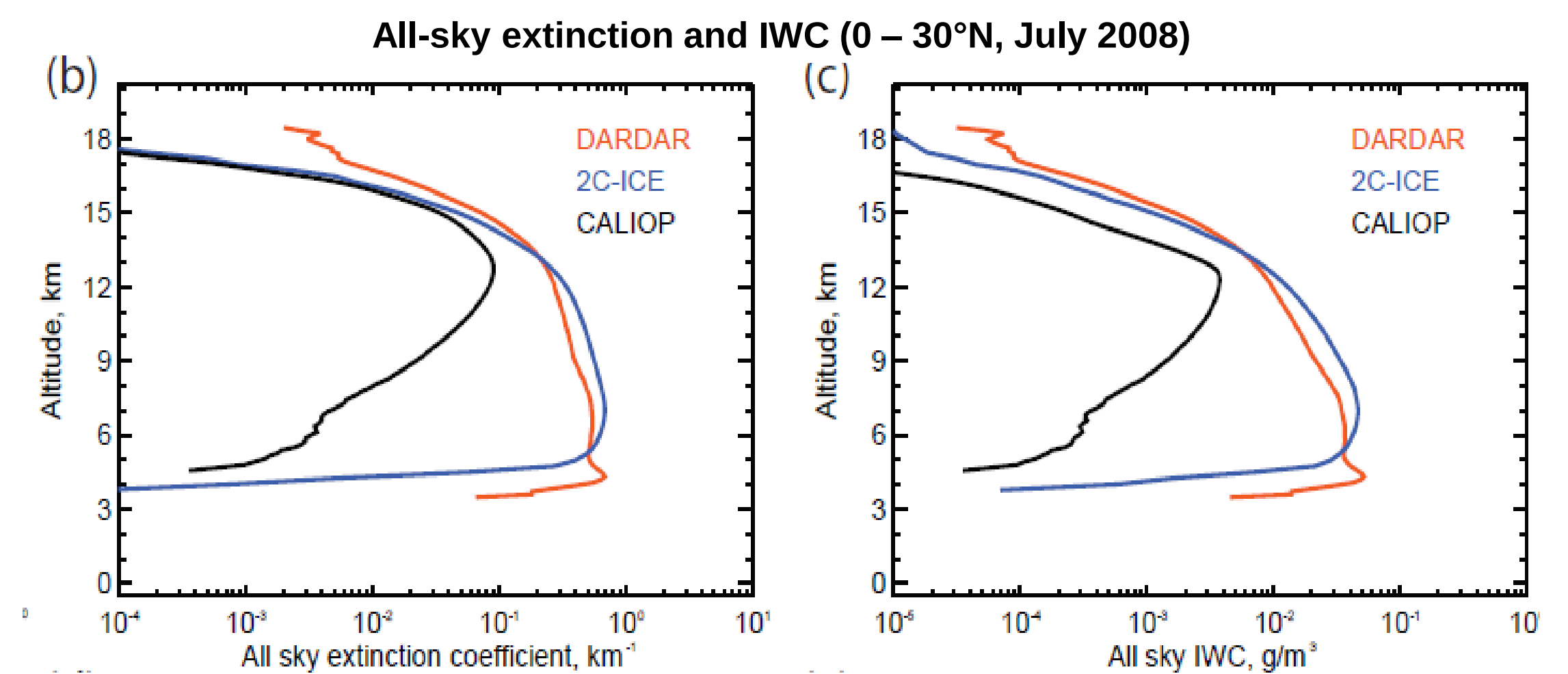
Global mean profiles have been computed from DARDAR and 2C-ICE, using the same gridding and filtering algorithms as used for L3-ICE. Even the ice-cloud masks show significant differences.



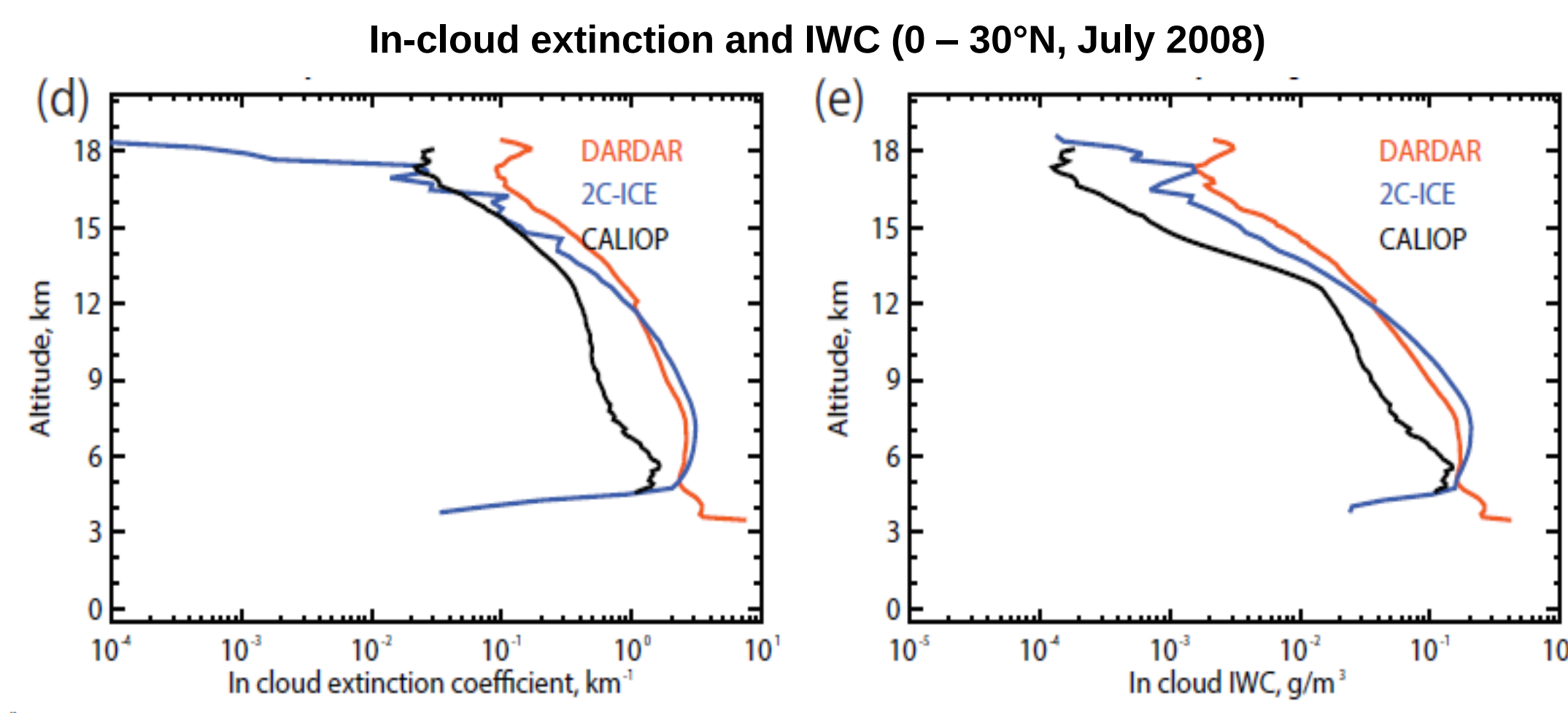
Primary cloud mask differences are due to:

- High altitudes: algorithmic differences between DARDAR and 2C-ICE
- Low altitudes: blockage of lidar by dense clouds

All-sky extinction and IWC are sensitive to differences in algorithm assumptions as well as cloud mask differences:

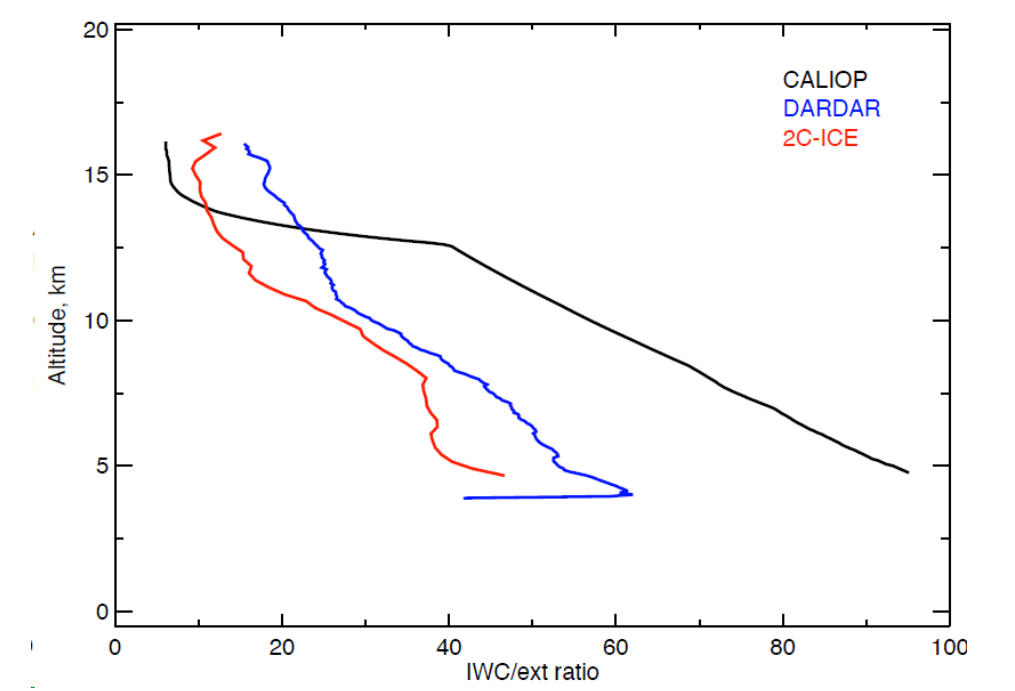


In-cloud extinction and IWC are insensitive to cloud mask differences. The majority of tropical profiles above 14 km are in the lidar-only region.



All three products make assumptions on relationships between mass and extinction, which are related to effective ice particle size and width of the size distribution. M-D relationships in DARDAR and 2C-ICE are constrained by the combined radar-lidar profiles, but mostly in the overlap region. The IWC-extinction parameterization in L3-ICE is based on in situ measurements from a large number of field campaigns (Heymsfield et al 2014).

See Dolinar et al. (2022) for additional discussion on this topic.



References

- Cazenave, Q., M. Ceccaldi, J. Delanoë, J. Pelon, S. Groß and A. Heymsfield, 2019: "Evolution of DARDAR-CLOUD ice cloud cloud retrieval: new parameters and impacts on the retrieved microphysical properties", *Atmos. Meas. Tech.*, **12**, 2819–2835, <https://doi.org/10.5194/amt-12-2819-2019>
- Delanoë, J. and R. J. Hogan, 2010: "Combined CloudSat-CALIPSO-MODIS retrievals of the properties of ice clouds", *J. Geophys. Res.*, **115**, D00H29, <https://doi.org/10.1029/2009JD012346>.
- Deng, M., G. G. Mace, Z. Wang and H. Okamoto, 2010: "Tropical Composition, Cloud and Climate Coupling Experiment Validation for Cirrus Cloud Profiling Retrieval Using CloudSat Radar and CALIPSO Lidar", *J. Geophys. Res.*, **115**, D00J15, <https://doi.org/10.1029/2009JD013104>.
- Deng, M., G. G. Mace, Z. Wang and E. Berry, 2015: "CloudSat 2C-ICE Product Update with a New Z_e Parameterization in Lidar-only Region", *J. Geophys. Res. Atmos.*, **120**, 12,198–12,208, <https://doi.org/10.1002/2015JD023600>.
- Dolinar, E. K., J. R. Campbell, J. W. Marquis, A. E. Garnier, and B. M. Karpowicz, 2022: "Novel parameterization of Ice Cloud Effective Diameter from Collocated CALIOP-IIR and CloudSat Retrievals", *J. Appl. Meteor. Climatol.*, **61**, <https://doi.org/10.1175/JAMC-D-21-0163.1>
- Heymsfield, A., D. Winker, M. Avery, M. Vaughan, G. Diskin, M. Deng, V. Mitev and R. Matthey, 2014: "Relationships between Ice Water Content and Volume Extinction Coefficient from In Situ Observations for Temperatures from 0° to -86°C: Implications for Spaceborne Lidar Retrievals", *J. Appl. Meteor. Climatol.*, **53**, 479–505, <https://doi.org/10.1175/JAMC-D-13-087.1>
- Winker, D., X. Cai, M. Vaughan, A. Garnier, B. Magill, M. Avery, and B. Getzewich: "A Level 3 Monthly Gridded Ice Cloud Dataset Derived from a Decade of CALIOP Measurements" (submitted ESSD)
- Young, S. A., Vaughan, M. A., Garnier, A., Tackett, J. L., Lambeth, J. B., and Powell, K. A.: Extinction and Optical Depth Retrievals for CALIPSO's Version 4 Data Release, *Atmos. Meas. Tech.*, **11**, 5701–5727, <https://doi.org/10.5194/amt-11-5701-2018>.

Summary

Several vertically-resolved ice cloud products based on A-train active sensors are now available. Our knowledge of the global distribution of cloud ice has improved due to these observations, but uncertainties remain. Mass-diameter relations used are critical, and uncertain, and require further study. Comparisons presented here are discussed in a recent paper (Winker et al. 2023).

These IWC data products are available from one or both of:
 NASA Langley ASDC: <https://eosweb.larc.nasa.gov>
 ICARE Data and Service Center: <https://www.icare.univ-lille1.fr>