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Global constraints on radiative properties of ice clouds using MODIS and POLDER measurements

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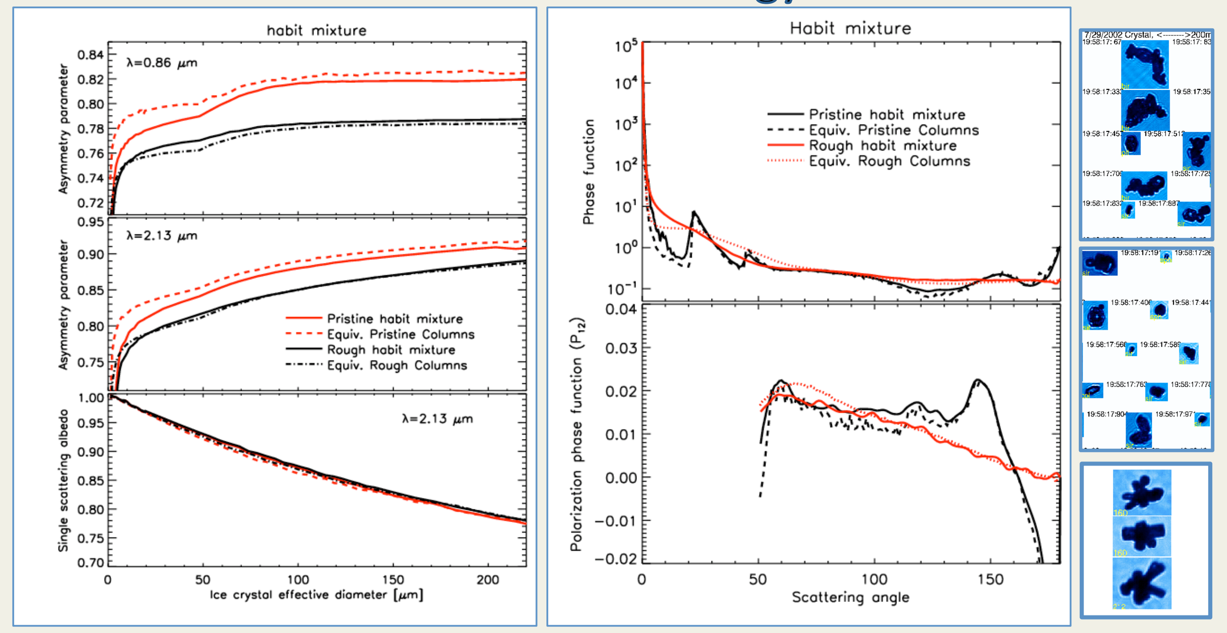
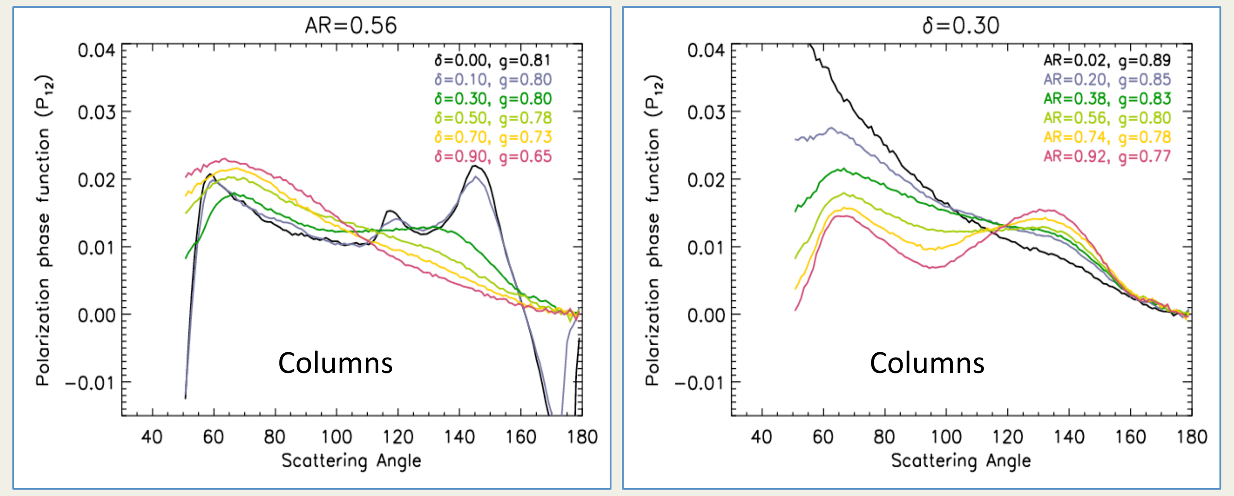
1: Introduction

It has long been known that global climate model projections are sensitive to the simulated properties of ice clouds, such as those of widespread cirrus. The asymmetry parameter of the scattering phase function is one of the fundamental radiative properties of ice clouds, but no global estimates of the asymmetry parameter of ice clouds exist to date. The asymmetry parameter of ice clouds can be represented in terms of the aspect ratio and surface roughness of simple hexagonal ice particles. Here we outline a new study that will combine MODIS-Aqua reflectivity and POLDER polarized reflectivity observations in order to obtain a global climatology of ice cloud asymmetry parameters. This climatology can be stratified by cloud optical thickness, cloud top temperature and particle size. Here we show some preliminary modeling and retrieval results, and discuss potential error sources.

2: Methodology



Natural ice crystals generally take on complex aggregated forms. However, their optical properties are mainly determined by their volume, projected area, aspect ratio and small-scale surface roughness (Fu et al., 1996; Fu 2007). As demonstrated in the figures above, optical properties of complex ice habit mixtures, including bullet rosettes, aggregates of columns and single columns, can be represented by simple equivalent hexagonal particles that have the same volume, projected area, aspect ratio and small-scale surface roughness



The figures above illustrate the variation in the polarized phase functions (P_{12}) and asymmetry parameter with crystal surface roughness δ (left) and aspect ratio (right). Multi-directional polarized reflectivity as measured by POLDER is particularly sensitive to P_{12}. This allows the retrieval of ice crystal aspect ratio and roughness, and consequently the asymmetry parameter, from observed polarized reflectances.

3: Preliminary results

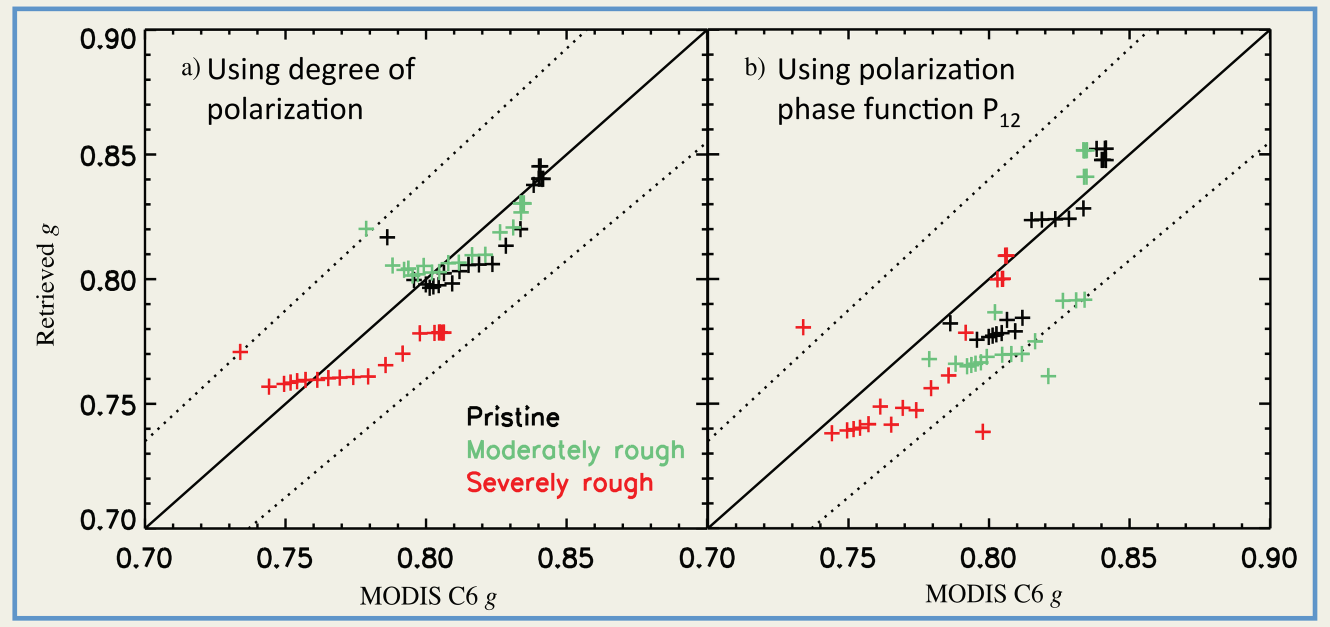


Figure top left: This figure demonstrates the retrieval of asymmetry parameters of complex ice crystals from their degree of polarization or P_{12} functions.

The properties of complex ice crystals are taken from the preliminary MODIS collection 6 habit mixtures dataset with three orders of crystal roughness [Baum et al., JAMC, in press]. Mixtures include bullet rosettes, columns, aggregates, and hollow particles, that have aspect ratios varying with size.

The retrieval procedure:

1. Seek the aspect ratio and surface roughness of a hexagonal column with a polarization function that fits that of the complex ice crystals best.
2. The asymmetry parameter of this hexagonal column is the retrieved value plotted in the figure.

Here, the degree of polarization functions are sampled between scattering angles of 100° and 155° at ~5° intervals (typical for POLDER).

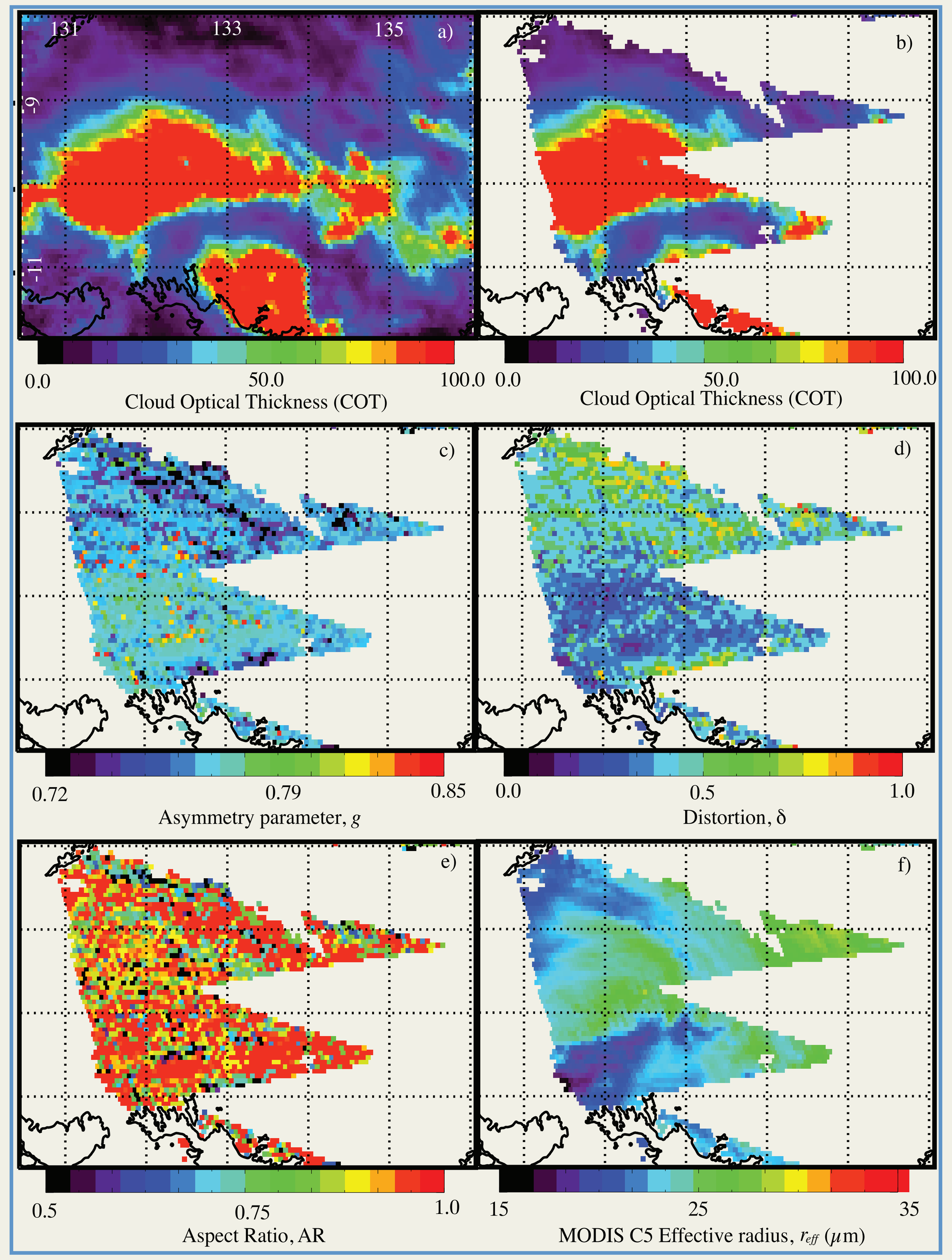


Figure bottom left: As a first test, we apply a simplified version of the proposed retrieval algorithm to POLDER data observed over a large mesoscale convective system. Ice crystal roughness (d), aspect ratio (e) and asymmetry parameter (c) are retrieved.

The single scattering approximation is used to simulate polarized reflectances. The measured polarized reflectance function is fit by adjusting the aspect ratio and surface roughness of a hexagonal column.

Only POLDER observations that include scattering angles <120° and >155° are used (**Fig. b vs a**). Data are normalized by their values near 155°.

The proposed algorithm will use look-up tables including multiple scattering and will retrieve cloud optical thickness, ice effective size and asymmetry parameter simultaneously from combined MODIS and POLDER data.

4: Addressed science questions

• **What is the natural variation in ice asymmetry parameter, aspect ratio and surface roughness?**
Ice crystal aspect ratio, surface roughness and consequently asymmetry parameter possibly vary with, e.g., cloud type, cloud top temperature, and particle size. The examples below illustrate observed variations in polarized reflectances linked to varying ice habits.

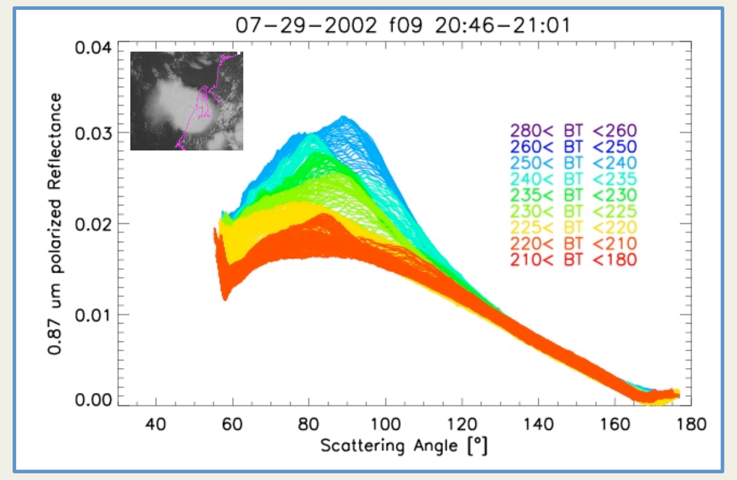
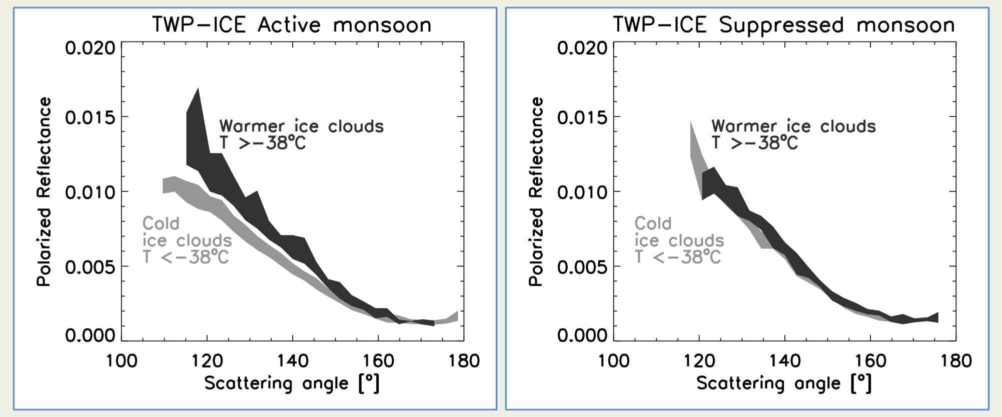
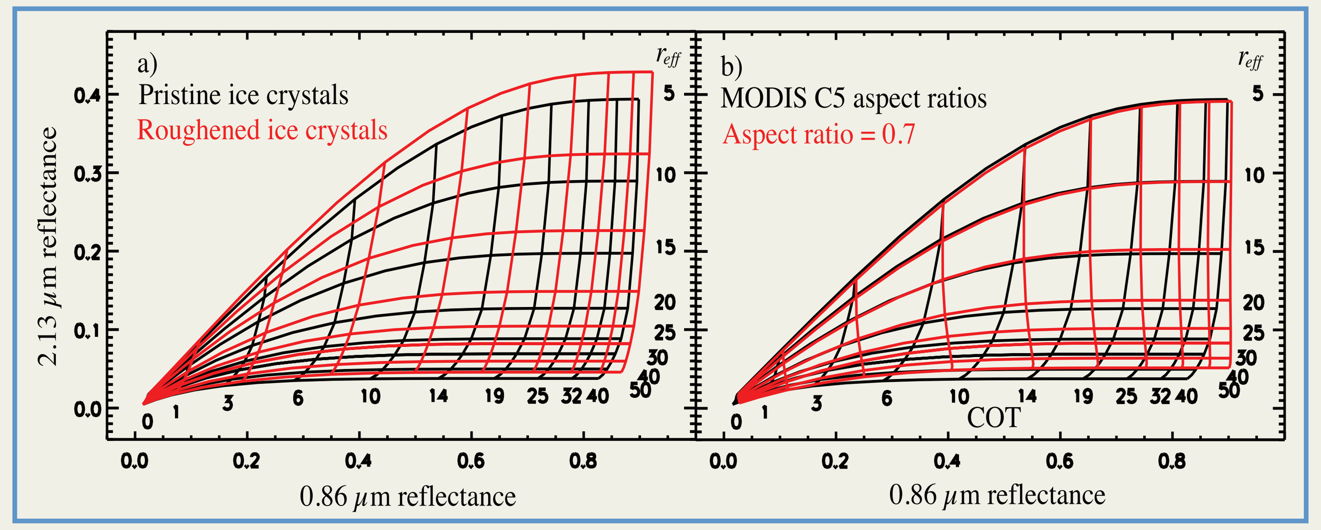


Figure left: Polarized reflectances varying with cloud top temperature as measured during the CRYSTAL-FACE campaign near Florida by the airborne Research Scanning Polarimeter (RSP) over a deep convective cloud. These suggest aspect ratios near 1 for cold cloud tops near the storm core and more extreme aspect ratios for warmer tops in the anvil outflow.

Figures right: Interquartile-ranges of polarized reflectances measured by POLDER/PARASOL during the TWP-ICE campaign. In the active monsoon phase (**left**) polarized reflectances vary with cloud top temperature, while during the suppressed monsoon (**right**) no such variation with temperature is observed.



• **To what extent are MODIS ice cloud optical thickness and effective radius retrievals affected by natural variation in ice crystal habits?**
MODIS collection 5 retrievals use mixtures of pristine ice crystals with varying aspect ratios (**black lines**). Using roughened crystals (**red lines, left**) or pristine columns with a fixed aspect ratio of 0.7 (**right**) yields significantly different reflectances. The differences in ice effective radius and cloud optical thickness retrievals using these different ice models (black vs red) would be about 20%.



• **Can MODIS ice cloud retrievals be improved using retrieved information on ice crystal asymmetry parameter, aspect ratio and roughness?**
For MODIS collection 6 cloud properties retrievals, optical properties of roughened ice crystals will probably be used. Also several different mixtures of habits will be considered (Baum et al., in press). However, insufficient observations are currently available to effectively determine the appropriate levels of crystal roughness and ice geometries in varying conditions. The results of this project are expected to help making such choices.

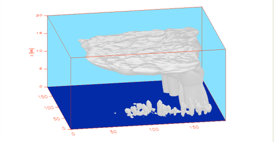
5: Error discussion

We aim to obtain an accuracy of the retrieved asymmetry parameter within 5%, as required for quantifying the radiative effect of ice clouds on climate (Vogelmann and Ackerman, 1995). The results in box 3 suggest this accuracy can be met.

Possible error sources include:

• **Noise and calibration**: Applying 5% noise or 10% offset on simulated data used in box 3 does not lead to significantly different results

• **Vertical inhomogeneity of ice crystal sizes and habits**
• **3D radiative transfer effects**
We will investigate such errors by the use of simulated measurements based on results from the NASA GISS cloud-resolving model (DHARMA, Fridlind et al., 2004) that includes size-resolved microphysics and several different classes of ice particles.



• **Oversimplification of ice shapes**
Some properties of natural, complex ice crystal mixtures might not be adequately represented by simple hexagonal structures (box 2). This issue will be studied with simulated measurements based on calculated optical properties of complex ice mixtures (thanks to Ping Yang & Bryan Baum). Also *in situ* CPI and 2DC optical probes will be used for evaluation of retrieval results during field campaigns.

6: Outline of planned work

○ **Create look-up tables** of MODIS and POLDER and RSP band reflectances using doubling-adding for varying cloud optical thicknesses, ice sizes, aspect ratios and crystal roughness values.

○ Test algorithm on **simulated measurements** based on cloud-resolving model simulations

○ Apply algorithm to airborne **RSP measurements** from several campaigns, and make use of extensive remote sensing and *in situ* measurements for evaluation

○ Apply algorithm to **MODIS and POLDER data above well-instrumented locations** for evaluation

○ Apply algorithm **to global MODIS and POLDER data**

○ Report on recommendations **for improving operational MODIS ice cloud retrievals**

○ Unfortunately we cannot (yet?) apply it to the **Aerosol Polarimetry Sensor** as planned, due to the failed launch of the Glory mission.

Acknowledgements

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