Investigation of Ice Particle Characteristics Through Comparison of APS and MODIS Measurements

SECOND YEAR REPORT
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Bryan A. Baum (PI), Space Science and Engineering Center
University of Wisconsin-Madison, Madison, WI 53705
bryan.baum@ssec.wisc.edu

Dr. Ping Yang (Co-I), Department of Atmospheric Sciences, Texas A&M University, College Station, TX 77843. Email: pyang@tamu.edu

Dr. Steve Platnick (Co-I), NASA Goddard Space Flight Center, Greenbelt, MD
Email: steven.e.platnick@nasa.gov

Dr. Jerome Riedi (Collaborator), Laboratoire d'Optique Atmospherique, Universite de Lille 1, Sciences et Technologies, Email: jerome.riedi@univ-lille1.fr

Dr. Zhibo Zhang, Physics Department, University of Maryland, Baltimore County.
Email: zhibo.zhang@umbc.edu (working with Steve Platnick)

Introduction

This report summarizes results for the period June 2012 – May 2013, encompassing most of the second year of funding for this particular effort. This has been another very active year for this team and we want to note two new papers that have been published this year.

Papers Submitted/Published in 2012-2013

Cole, B., P. Yang, B. A. Baum, J. Riedi, L. Labonnote, F. Thieuleux, and S. Platnick, 2013: Comparison of PARASOL observations with polarized reflectances simulated using different ice habit mixtures. *J. Appl. Meteor. Clim.*, **52**, 186-196.

Yang, P., L. Bi, B. A. Baum, K.-N. Liou, G. Kattawar, and M. Mishchenko, 2013: Spectrally consistent scattering, absorption, and polarization properties of atmospheric ice crystals at wavelengths from 0.2 µm to 100 µm. *J. Atmos. Sci.*, **70**, 330-347.

Baum, B. A., P. Yang, A. J. Heymsfield, A. K. Heidinger, and A. Morrelli: Ice cloud bulk scattering and absorption models for polar-orbiting and geostationary satellite imagers. In preparation for submittal to *J. Appl. Meteor. Clim.*

Status of Current Libraries of Ice Particle Single Scattering Properties

The library developed and now available for our team's use provides ice habit single-scattering properties at 445 discrete wavelengths from the ultraviolet (UV, 0.2 μm) to the far infrared (Far-IR, 100 μm). With this database, we have the information necessary to build ice cloud bulk scattering spectral models at each of the 445 wavelengths. What is most useful about this library is that it provides the full phase matrix at each of the individual wavelengths, including those wavelengths measured by POLDER and other polarization sensors. More specific details are provided below.

Second Year Progress

Both collectively and individually, this team has made some substantial progress over the past year, including the following tasks:

1. Drs. Bryan Baum and Ping Yang continue to develop ice cloud optical and polarization models, leveraging the availability of a state-of-the-science database of the optical properties of various ice crystals (Yang, Bi and Baum and co-authors, 2013). This effort includes merging the ice crystal single-scattering properties and habit/size distributions and validating the resultant bulk optical and polarization properties. The validation is essentially based on comparison of theoretical simulations of polarized reflectance and POLDER measurements. The validation effort, based on close collaboration between Dr. Bryan Baum and Dr. Ping Yang's group at Texas A&M University, is still ongoing.
2. Dr. Ping Yang's group has been conducting a global-scale survey of the degree of ice crystal surface roughness using POLDER measurements and modeling capabilities. We plan to document the relevant scientific findings through peer-reviewed publications in our third year effort. The findings of this effort will benefit a number of NASA projects related to ice clouds. For example, the MODIS Collection 6 ice model assumes ice crystals to be aggregates of roughened hexagonal columns. A recent study (Yi, Yang, Baum et al., 2013) illustrated the significant impact of ice particle surface roughness on the radiative forcing of ice clouds. Thus, there is a pressing need to quantify the degree of ice crystal surface roughness, particularly on a global scale.
3. Dr. Baum (PI) has disseminated the preliminary ice cloud full-polarization models that provide the full phase matrix for polarization sensors such as CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), PARASOL (Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar), and aircraft polarization sensors such as the RSP (Research Scanning Polarimter, NASA GISS) and the AirMSPI (Airborne Multi-angle SpectroPolarimeter Imager, Jet Propulsion Lab).
4. Dr. Baum built and populated new set of web pages to provide background information, software, and models as they become available (**http://www.ssec.wisc.edu/ice_models**). The web pages provide background and methodology information. While spectral models (between 0.4 and 3 μm at 0.01 μm resolution in wavelength) and imager models (currently for 35 different polar-orbiting and geostationary sensors) are currently available via web page access,

the PI will soon provide models from 0.2 to 100 μm that contain the full phase matrix. The paper that documents this full wavelength range of spectral models is under preparation (Baum et al. 2013).

5. Drs. Platnick and Zhang computed an extensive look-up-table (LUT) of cloud *total and polarized* reflectances (i.e., I, Q, U, V) based on MODIS-consistent (Collection 6) cloud microphysical properties. They are validating this LUT by comparing the total cloud reflectances with those in the MODIS operational LUT.
6. Drs. Zhang and Platnick, leveraging another NASA project, have developed a large-eddy-simulation (LES)-polarimeter simulator. This simulator simulates multi-angular polarimetric cloud reflection observation from cloud fields generated by a LES model developed by Andrew Ackerman (NASA GISS). They are using this simulator to study the differences between polarized-based (e.g., POLDER) and spectral-based (e.g., MODIS) sensors in terms their sensitivity to cloud vertical structure, cloud phase, and horizontal heterogeneity.
7. Our long-time collaborator Dr. Jerome Riedi has helped us to collocate one year (2007) of multi-angle polarization measurements from POLDER with other A-Train sensors, including MODIS (Collection 5 for now), CALIOP, and CloudSat. Two research highlights from this collocated data set are provided below.
8. Zhibo Zhang is the lead author on a book about polarimetric remote sensing of cloud and aerosol properties. Drs. Platnick, Yang, and Baum are co-authors of this effort, and we each have writing assignments that need to be completed in the summer.

Research Highlights

We studied the polarimetric characteristics of nine cloud types using collocated POLDER and MODIS data. Cloudy pixels in collocated data are classified into nine groups according to their cloud top pressure and cloud optical thickness (both provided from MODIS) on the basis of the International Satellite Cloud Climatology Project (ISCCP) cloud classification scheme. Subsequently, the polarized cloud reflectances, as a function of scattering angle, are provided from collocated POLDER data. As shown in Figure 1, the three low cloud types (Cumulus, Stratocumulus and Stratus) display a conspicuous rainbow feature at a scattering angle of about 142°, indicating they are mainly liquid-phase, whereas the three high cloud types (Cirrus, Cirrostratus and Deep convective) have dramatically different polarized reflectances because these clouds mainly consist of non-spherical ice particles. Interestingly, the three midlevel cloud types (Altocumulus, Altostratus and Nimbostratus) have both liquid-phase (i.e., rainbow) and ice-phase features (i.e. enhanced polarized reflectance around 60°~80°).

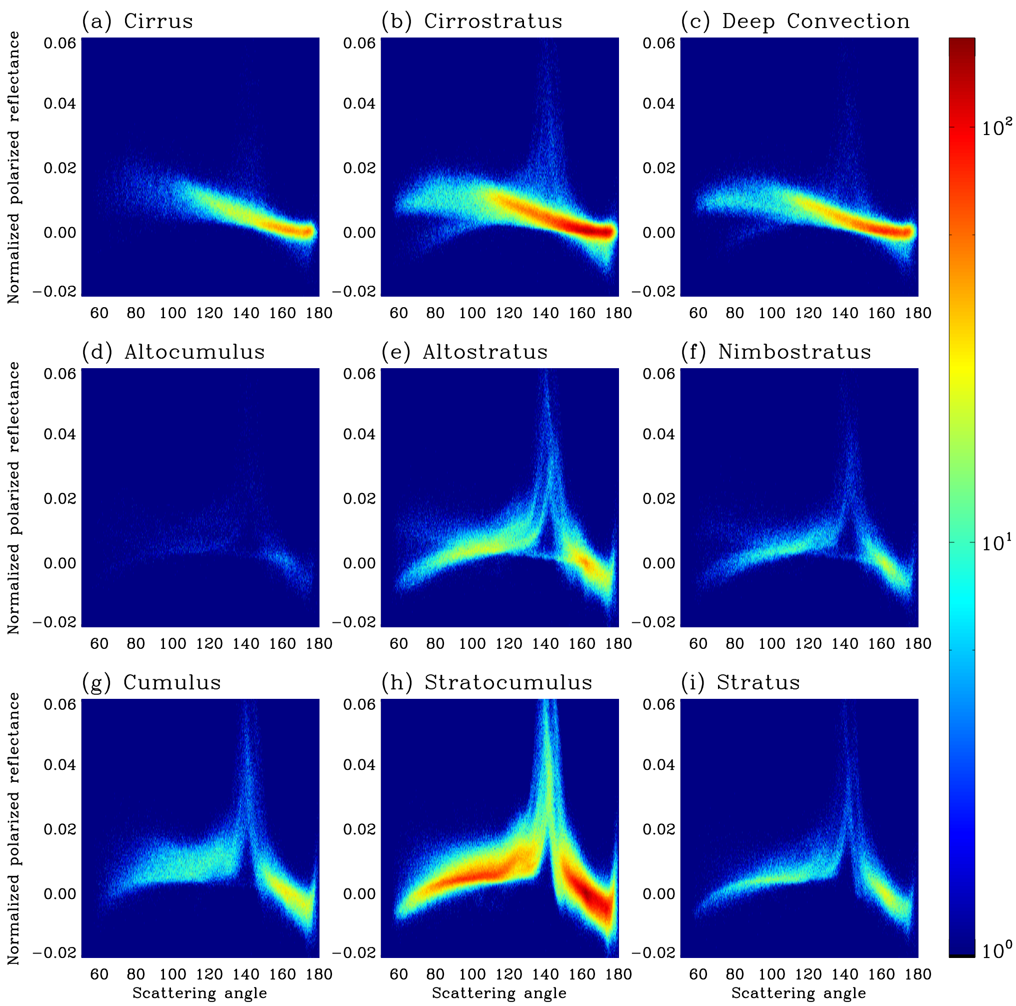

Figure 1: Polarimetric characteristics of nine cloud types derived using collocated POLDER and MODIS observations.

A second research highlight demonstrates the temperature dependence of cloud phase transition as observed by collocated POLDER and MODIS data. As shown in (Riedi et al., 2007), polarimetric cloud reflectances are useful for inferring cloud top thermodynamic phase. The advantage of polarimetric-based cloud phase retrieval is that it is independent on cloud top temperature and therefore can be used as an independent reference to study the temperature dependence of the cloud phase transition from water to ice. In light of previous studies, we investigated how the angular pattern of the POLDER polarimetric cloud reflectances varies with cloud top temperature (CTT) from MODIS. As shown in Figure 2, when CTT is between 0° ~ −15°C, POLDER polarimetric cloud reflectances display a clear rainbow pattern, suggesting clouds in this temperature range are mostly supercooled water. When CTT is below −35°C, POLDER reflectances suggest a clear ice-phase pattern. Interestingly, the rainbow pattern exists in clouds with CTT as low as −25 ~ −35 °C, suggesting that supercooled water can exist at fairly low temperatures.

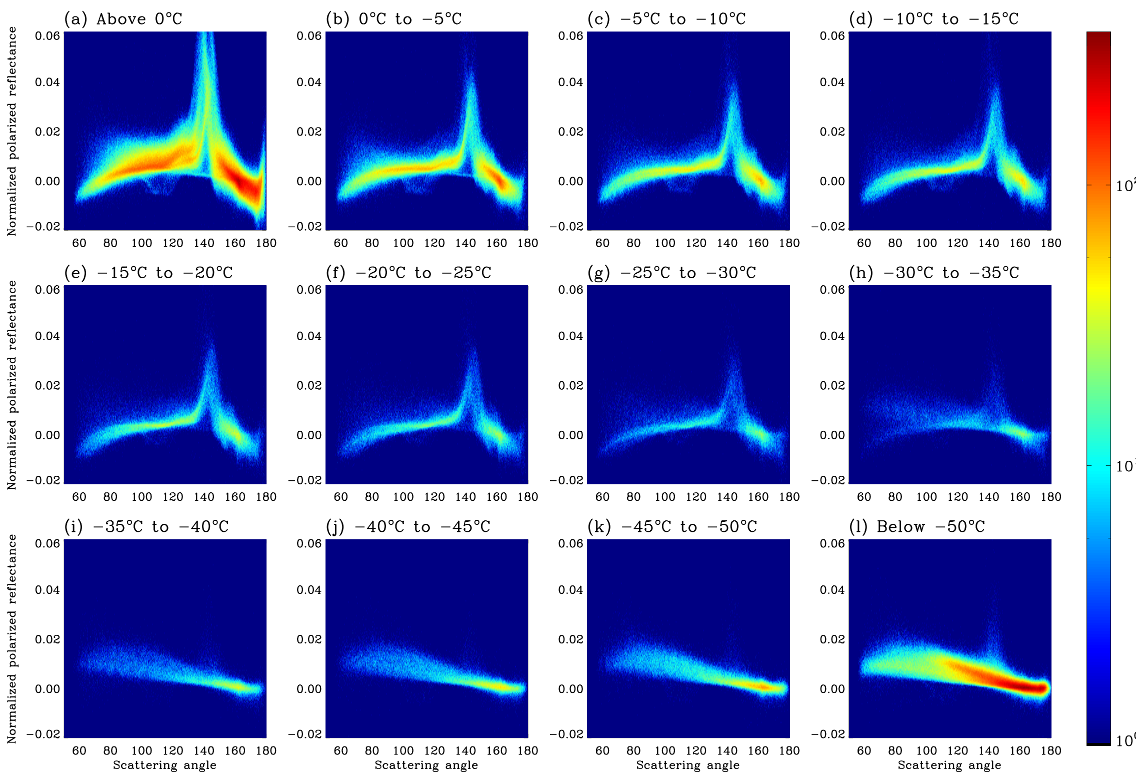

Figure 2 Angular patterns of polarized cloud reflectance as a function of cloud top temperature.

References

Riedi, J., Marchant, B., Platnick, S., Baum, B., Thieuleux, F. and co-authors 2007. Cloud thermodynamic phase inferred from merged POLDER and MODIS data. *Atmos. Chem. Phys. Discuss* **7**, 14103-14137.

Yi, B., P. Yang, B. A. Baum, T. L'Ecuyer et al., 2013: Influence of ice particle surface roughening on the global cloud radiative effect. *J. Atmos. Sc*. (accepted and in press)/