"Top-of-Atmosphere Albedo Estimation from POLDER Multi-Angle Measurements: Evaluation of Water and Ice Cloud Radiative Transfer Models "

Final Summary of Research Report

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1. LIST OF ACCOMPLISHMENTS

- Used multiangle POLDER measurements to produce narrowband angular distribution models and examined the effect of scene identification errors on TOA albedo estimates.
- Developed and validated an algorithm called the Multidirectional Reflectance Matching (MRM) model for inferring TOA albedos from ice clouds using multi-angle satellite measurements.
- Developed and validated an algorithm called the Multidirectional Polarized Reflectance Matching (MPRM) model for inferring particle shapes from ice clouds using multi-angle polarized satellite measurements.

2. LIST OF PUBLICATIONS (WHERE A CO-I IS LEAD AUTHOR)

Sun, W., N. G. Loeb, and P. Yang: On the retrieval of ice cloud particle shapes from POLDER measurements, *JQSRT* (in press).

Sun, W., N. G. Loeb, and S. Kato, 2004: Estimation of instantaneous TOA albedo at 670 nm over ice clouds from POLDER multidirectional measurements, *J. Geophy. Res.*, 109, D0221010.1029/2003JD003801.

Loeb, N.G., F. Parol, J.-C. Buriez, and C. Vanbauce, 2000: Top-of-atmosphere albedo estimation from angular distribution models using scene identification from satellite cloud property retrievals. *J. Climate*, **13**, 1269-1285.

3. ABSTRACTS OF PUBLISHED OR SUBMITTED PAPERS (WHERE A CO-I IS LEAD AUTHOR)

Sun, W., N. G. Loeb, and P. Yang, 2004: On the retrieval of ice cloud particle shapes from POLDER measurements, *JQSRT* (in press).

Shapes of ice crystals can significantly affect the radiative transfer in ice clouds. The angular distribution of the polarized reflectance over ice clouds strongly depends on ice crystal shapes. Although the angular-distribution features of the total or polarized reflectance over ice clouds implies a possibility of retrieving ice cloud particle shapes by use of remote sensing data, the accuracy of the retrieval must be evaluated. In this study, a technique, which applies single ice crystal habit and multidirectional polarized radiance to retrieve ice cloud particle shapes, is assessed. Our sensitivity studies show that the retrieved particle shapes from this algorithm can be considered good approximations to those in actual clouds in calculation of the phase matrix elements. Although a fractal poly-crystal shape or an inhomogeneous hexagonal column may also produce this type of phase functions, more representative single-scattering properties from combinations of natural particle shapes and size distributions may still be necessary in accurate retrieval of other cloud properties such as optical thickness and particle size.

Sun, W., N. G. Loeb, and S. Kato, 2004: Estimation of instantaneous TOA albedo at 670 nm over ice clouds from POLDER multidirectional measurements, *J. Geophys. Res.*, **109**, D0221010.1029/2003JD003801.

An algorithm that determines the 670-nm top-of-atmosphere (TOA) albedo of ice clouds over ocean using Polarization and Directionality of the Earth's Reflectance (POLDER) multidirectional measurements is developed. A plane-parallel layer of ice cloud with various optical thicknesses and light scattering phase functions is assumed. For simplicity, we use a double Henyey-Greenstein phase function to approximate the volume-averaged phase function of the ice clouds. A multidirectional reflectance best-fit match between theoretical and POLDER reflectances is used to infer effective cloud optical thickness, phase function and TOA albedo. Sensitivity tests show that while the method does not provide accurate independent retrievals of effective cloud optical depth and phase function, TOA albedo retrievals are accurate to within similar to3% for both a single layer of ice clouds or a multilayer system of ice clouds and water clouds. When the method is applied to POLDER measurements and retrieved albedos are compared with albedos based on empirical angular distribution models (ADMs), zonal albedo differences are generally smaller than similar to 3%. When albedos are compared with those on the POLDER-I ERB and Cloud product, the differences can reach similar to 15% at small solar zenith angles.

Loeb, N.G., F. Parol, J.-C. Buriez, and C. Vanbauce, 2000: Top-of-atmosphere albedo estimation from angular distribution models using scene identification from satellite cloud property retrievals. *J. Climate*, **13**, 1269-1285.

The next generation of Earth radiation budget satellite instruments will routinely merge estimates of global top-of-atmosphere radiative fluxes with cloud properties. This information will offer many new opportunities for validating radiative transfer models and cloud parameterizations in climate models. In this study, five months of POLarization and Directionality of the Earth's Reflectances (POLDER) 670 nm radiance measurements are considered in order to examine how satellite cloud property retrievals can be used to define empirical Angular Distribution Models (ADMs) for estimating top-of-atmosphere (TOA) albedo. ADMs are defined for 19 scene types defined by satellite retrievals of cloud fraction and cloud optical depth. Two approaches are used to define the ADM scene types: The first assumes there are no biases in the retrieved cloud properties and defines ADMs for fixed discrete intervals of cloud fraction and cloud optical depth (fixed-τ approach). The second approach involves the same cloud fraction intervals, but uses *percentile* intervals of cloud optical depth instead (percentile-τ approach). Albedos generated using these methods are compared with albedos inferred directly from the mean observed reflectance field.

Albedos based on ADMs that assume cloud properties are unbiased (fixed-τ approach) show a strong systematic dependence on viewing geometry. This dependence becomes more pronounced with increasing solar zenith angle, reaching ≈12% (relative) between near-nadir and oblique viewing zenith angles for solar zenith angles between 60° and 70°. The cause for this bias is shown to be due to biases in the cloud optical depth retrievals. In contrast, albedos based on ADMs built using *percentile* intervals of cloud optical depth (percentile-τ approach) show very little viewing zenith angle dependence and are in good agreement with albedos obtained by direct integration of the mean observed reflectance field (< 1% relative error). When the ADMs are applied separately to populations consisting of only liquid water and ice clouds, significant biases in albedo with viewing geometry are observed (particularly at low sun elevations), highlighting the need to account for cloud phase both in cloud optical depth retrievals and in defining ADM scene types. ADM-derived monthly mean albedos determined for all 5°×5° latitude/longitude regions over ocean are in good agreement (regional RMS relative errors < 2%) with those obtained by direct integration when ADM albedos inferred from specific angular bins are averaged together. Albedos inferred from near-nadir and oblique viewing zenith angles are the least accurate, with regional RMS errors reaching ~5-10% (relative). Compared to an earlier study involving ERBE ADMs, regional mean albedos based on the 19 scene types considered here show a factor of 4 reduction in bias error and a factor of 3 reduction in RMS error.

4. SUBJECT INVENTION DISCLOSURE

There are no inventions to be disclosed for this investigation.