

Introduction & Objectives

Considering that the Arctic is warming faster than any other region on Earth, the long-term monitoring of clouds and their radiative effects from satellite over polar regions is crucial to understanding climate change. Because of the often small contrast between clouds and snow or ice in the visible and infrared windows, it has been difficult to monitor cloud properties accurately in polar regions on a long-term basis. MODIS and VIIRS have several relevant NIR channels that can be exploited to retrieve cloud properties over snow and ice surfaces. The Clouds and the Earth's Radiant Energy System (CERES) uses the MODIS 1.24- μm channels on Terra and Aqua to retrieve cloud optical depth (COD) over snow and ice for its Edition 4 processing. CERES optical thickness over snow and ice surfaces seems to bias high compared to surface-based retrievals. This paper performs retrievals over Arctic sea ice using MODIS to study the sensitivity and accuracies of optical depths retrieved using the 1.24 and 1.6 μm channels. Retrievals using a new ice cloud scattering model are also tested. The results are assessed using independent measurements of cloud microphysics and radiative fluxes obtained from aircraft during the Arctic Radiation-Icebridge Sea and Ice Experiment (ARISE). An accurate characterization of the spectral surface bidirectional reflectance is also paramount to accurate cloud optical thickness estimates, particularly for the thinner clouds that are ubiquitous in polar regions. ARISE provides spectral albedo measurements of the Arctic surface that are used to test our current assumptions. The overall goal of this study is to develop optimal retrieval system for the next edition of CERES.

Data

CERES Cloud Retrievals:

Terra-MODIS L1 MOD02 & MOD03 products, September 2014 (ARISE period)

Comparison:

Terra-MODIS L2 MOD06 product, September 2014 (ARISE period and locations)

Validation:

C3M product (merged CALIPSO, CloudSat, CERES & MODIS), April 2009

The Approach

Current Issue:

CERES Edition 4 cloud optical depths (COD) bias high over snow and ice surfaces

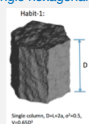
This study:

Ice Crystal Selection $\rightarrow$ from roughened single hexagonal column (SHM) to two habit model (THM)

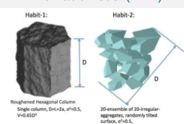
Channel Selection $\rightarrow$ from 1.24 μm to 1.6 μm

Ice Crystal Selection

CERES Ed4
Roughened single hexagonal column (SHM)



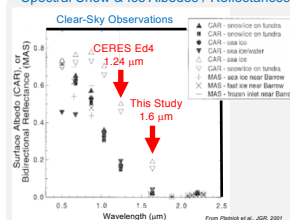
This study
Two-habit model (THM)



Compact particle, smaller asymmetry factor, hence smaller COD

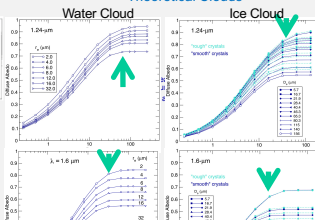
Wavelength / Channel Selection

Spectral Snow & Ice Albedos / Reflectances



1.24- μm snow albedo: 0.13 - 0.50
1.62- μm snow albedo: 0.02 - 0.19
Surface reflectance uncertainty much higher for 1.24 μm
Stronger snow absorber for 1.6 μm than 1.24 μm

Theoretical Clouds

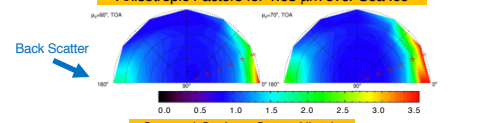


• Liquid COD saturation: 1.24 μm : ~64-96
1.63 μm : ~32-40
• Ice COD saturation: 1.24 μm : ~32-60
1.63 μm : ~8-16

Anisotropic Factor over Snow & Ice Surface

The snow model is developed using different mixes of ice crystal habits (hexagonal column and plate, bullet rosette, and aggregate) that vary with snow particle effective sizes. The microphysical properties of snow particles including soot inclusion, particle surface roughness, and particle size are considered in this snow model along with the macro-roughness of the snow surface (sastrugi) which has 3-D effects on snow surface BRDFs. Considering the 3-D sastrugi effect, the surface snow model is an input to a 3-D Monte Carlo radiative transfer model to compute the snow BRDFs. TOA BRDFs are computed by a radiative transfer model with inputs of atmospheric loading and surface BRDFs.

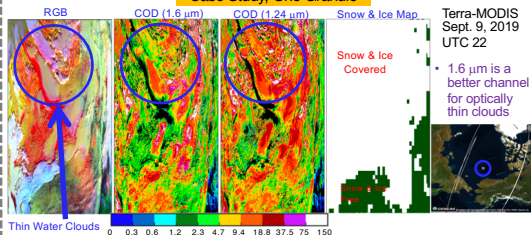
Anisotropic Factors for 1.63 μm over Sea Ice



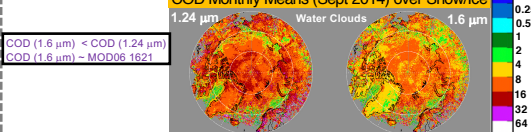
• CERES-MODIS predicted snow surface albedos bias low for both 1.63 & 1.24 μm , compared with SSFR measured values (ARISE) by ~20% for 1.63 μm & 30% for 1.24 μm
• The impact of the low bias on cloud retrieval is much less for 1.63 μm than 1.24 μm , because of larger contrast between snow surface and albedo for 1.63 μm .

COD Results

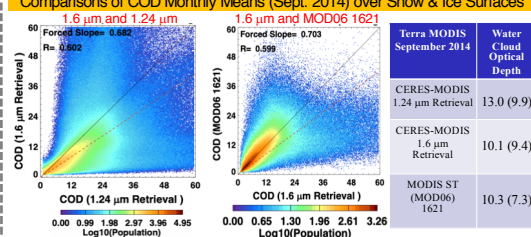
Case Study, One Granule



COD Monthly Means (Sept 2014) over Snow/Ice

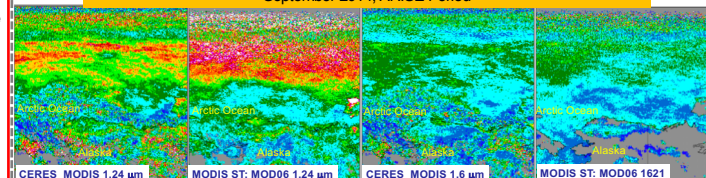


Comparisons of COD Monthly Means (Sept. 2014) over Snow & Ice Surfaces



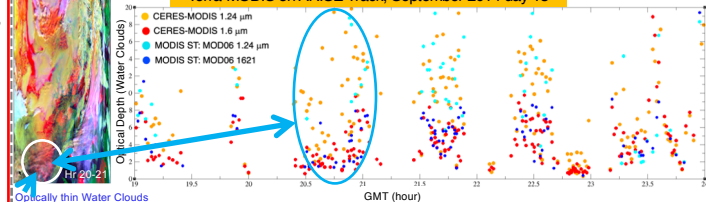
COD Results - Continued

Monthly Means Liquid COD over Alaska & Arctic Ocean: 60N - 90N, 120W - 180W September 2014, ARISE Period



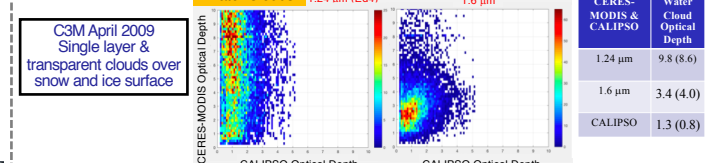
• Cloud optical depths from CERES-MODIS 1.63 μm largely agree well with MOD06 1621 from MODIS Science Team (ST) over snow and ice surfaces.
• But large differences for 1.24 μm with smaller COD from CERES-MODIS.

Terra-MODIS on ARISE Track, September 2014 day 13



COD Validation with CALIPSO

Water Clouds 1.24 μm (Ed4) 1.6 μm

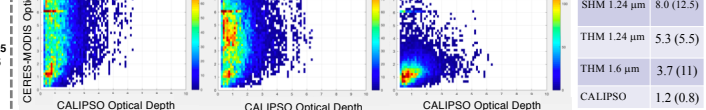


C3M April 2009
Single layer & transparent clouds over snow and ice surface

1.6 μm is a better channel for optically thin clouds

CERES-MODIS 1.24 μm 9.8 (8.6)
CERES-MODIS 1.6 μm 3.4 (4.0)
CALIPSO 1.3 (0.8)

Ice Clouds



SHM 1.24 μm (Ed4) THM 1.24 THM 1.6
CERES-MODIS 1.24 μm 8.0 (12.5)
CERES-MODIS 1.6 μm 5.3 (5.5)
CALIPSO 1.2 (0.8)

Summary

- Snow anisotropic factors for both 1.6 μm and 1.24 μm biased low by ~20% for 1.6 μm and 30% for 1.24 μm
- 1.6 μm cloud retrieval: the best to pick up optically thin clouds, but saturates at Tau (ice) ~ 16-20, Tau (water) 32-40
- 1.24 μm COD have sensitivities up to 32-60 for ice clouds, 64-96 for water
- 1.6 μm COD comparable with MOD06 COD 1621 (MODIS Science Team)
- CALIPSO Validation (for single transparent clouds):
CALIPSO: 1.3 (water) & 1.2 (ice), 1.6 μm : 3.4 (water) & 3.7 (ice), 1.24 μm : 9.8 (water) & 8.0 (ice)

Future Plans

- Combine 1.6 μm (for optically thin clouds) & 1.24 μm
Ice Clouds:
tau < 8 - 16 $\rightarrow$ use THM 1.6
tau > 8 - 16 $\rightarrow$ use THM 1.24
Water Clouds:
tau < 32 - 40 $\rightarrow$ use 1.6 μm
tau > 32 - 40 $\rightarrow$ use 1.24 μm
- More Validations