Predicting Clear-Sky Reflectance Over Snow/Ice in Polar Regions

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Introduction

Satellite remote sensing of clouds requires an accurate estimate of the clear-sky radiances for a given scene to detect clouds and aerosols and to retrieve their microphysical properties. Knowing the spatial and angular variability of clear-sky albedo is essential for predicting clear-sky radiance at solar wavelengths. The Clouds and the Earth's Radiant Energy System (CERES) Project uses the near-infrared (NIR; 1.24, 1.6 or 2.13 µm), visible (VIS; 0.63 µm) and vegetation (VEG; 0.86 µm) channels available on the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) to help identify clouds and retrieve their properties in both snow-free and snow-covered conditions. Thus, it is critical to have reliable distributions of clear-sky albedo for all of these channels. In CERES Edition 4 (Ed4), the 1.24-µm channel is used to retrieve cloud optical depth over snow/ice-covered surfaces. Thus, it is especially critical to accurately predict the 1.24-µm clear-sky albedo α and reflectance ρ for a given location and time. Snow albedo and reflectance patterns are very complex due to surface texture, particle shapes and sizes, melt water, and vegetation protrusions from the snow surface. To minimize those effects, this study focuses on the permanent snow cover of Antarctica where vegetation is absent and melt water is minimal. Clear-sky albedos are determined as a function of solar zenith angle (SZA) from observations over all scenes determined to be cloud-free to produce a normalized directional albedo model (DRM). The DRM is used to develop α(SZA=0°) on 10' grid for each season. These values provide the basis for predicting ρ at any location and set of viewing & illumination conditions. This paper examines the accuracy of this approach for two theoretical snow surface reflectance models.

Objectives

- Determine errors in CERES Ed4 predicted clear-sky 1.24 µm reflectances over Antarctica

Data

- CERES MODIS products derived using Ed4 algorithms:
  Aqua: 9-11 January 2008; **Terra:** 3, 15, and 20 January 2008

Approach

Clear-sky reflectance

$$\rho = \rho(\mu_o, \mu, \phi) = \chi_m(\mu_o, \mu, \phi_o)\, \alpha(\mu_o), \qquad (1)$$

μ_o = cos(SZA), μ = cosine(viewing zenith angle VZA), ϕ_o = relative azimuth angle, χ is a normalized bidirectional reflectance distribution function (BRDF), α = SZA-dependent clear-sky albedo.

DRM

$$\delta(\mu_o) = \alpha(\mu_o) \,/\, \alpha(\mu_o{=}0^\circ) \qquad (2)$$

Overhead-sun albedo is estimated for a given area by measuring the clear-sky reflectance, then computing the albedo using (1), and applying the DRM from (2) to solve for $\alpha(\mu_o{=}0^\circ)$. Empirical (global averages) and theoretical (RTM) quite different (see below).

BRDF Models: $\chi_m(\mu_o, \mu, \phi) = \rho_m(\mu_o, \mu, \phi) \,/\, \alpha_m(\mu_o)$

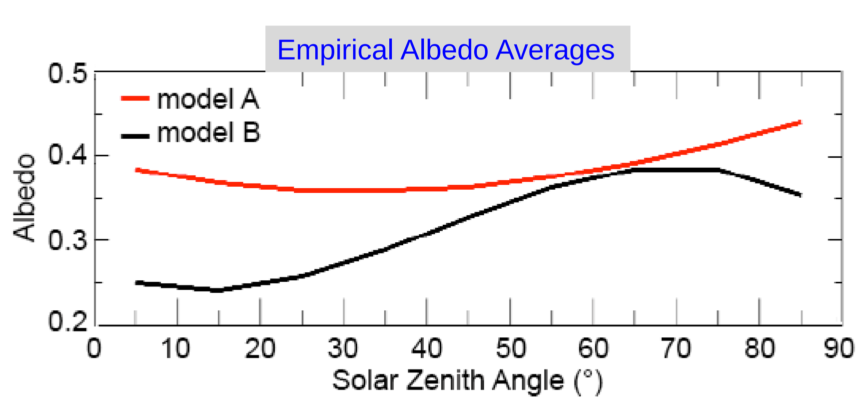
$\rho_m(\mu_o, \mu, \phi)$ computed using a radiative transfer model (RTM, adding-doubling or DISORT) with the optical properties corresponding to snow-free observations. Snow surface is assumed to be a layer of randomly oriented ice crystals with optical depth of 1000. Model accounts for atmospheric and surface absorption to yield a TOA reflectance.

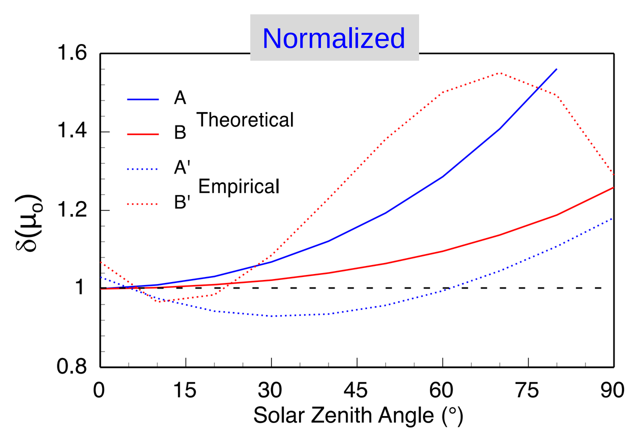
***Model A** (used in Ed4)*: Single hexagonal column: length/width ratio = 750µm/160µm, effective particle diameter, D_e ~ 310 µm (*Trepte et al.* 2002). Regional (10') values of $\alpha(\lambda,\phi;\mu_o{=}0^\circ)$ updated every 2nd day to keep up with observed changes in the clear-sky reflectance fields. λ = lat, ϕ = lon.

Model B: Mixed habits of hexagonal column and plate, bullet rosette, and aggregate, which vary with particle maximum dimension D_m. Surface roughness is 0.1. D_e ~ 200 µm for the mixture.

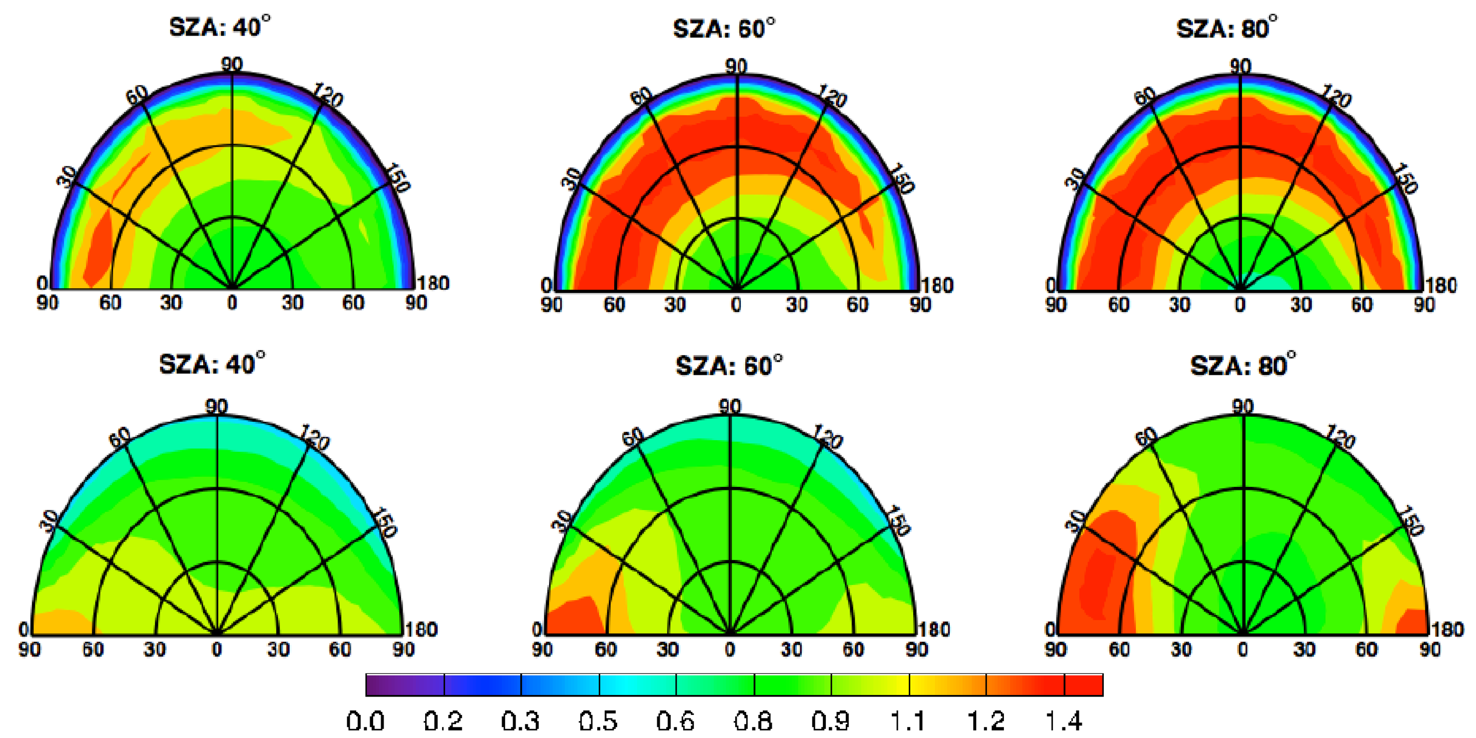
Estimating ρ_m: $\rho_m(\lambda,\phi;\mu_o,\mu,\phi_o) = \alpha(\lambda,\phi;\mu_o)\, \delta(\mu_o)\, \chi_m(\mu_o, \mu, \phi)$

Directional Models



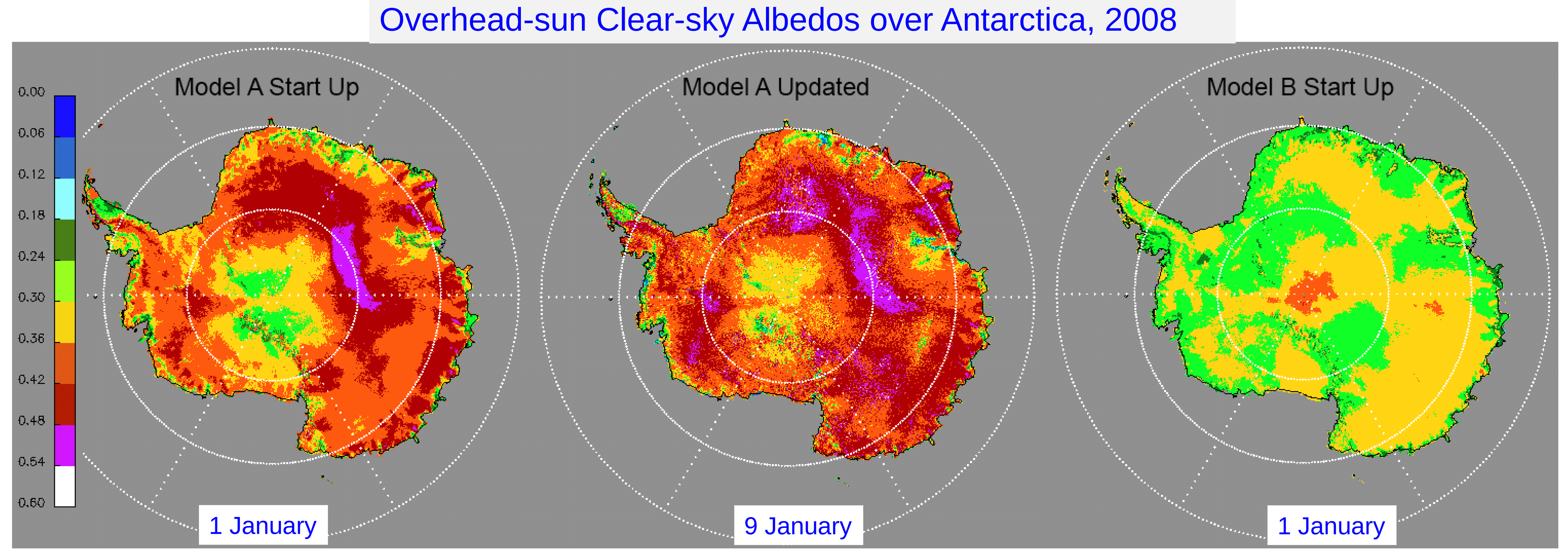


Normalized Snow BRDF Models



Model A produces more forward and side scatter than Model B, which generates more backscatter. Overall, Model B has the more complex scattering patterns.

Overhead-sun Clear-sky Albedos over Antarctica, 2008

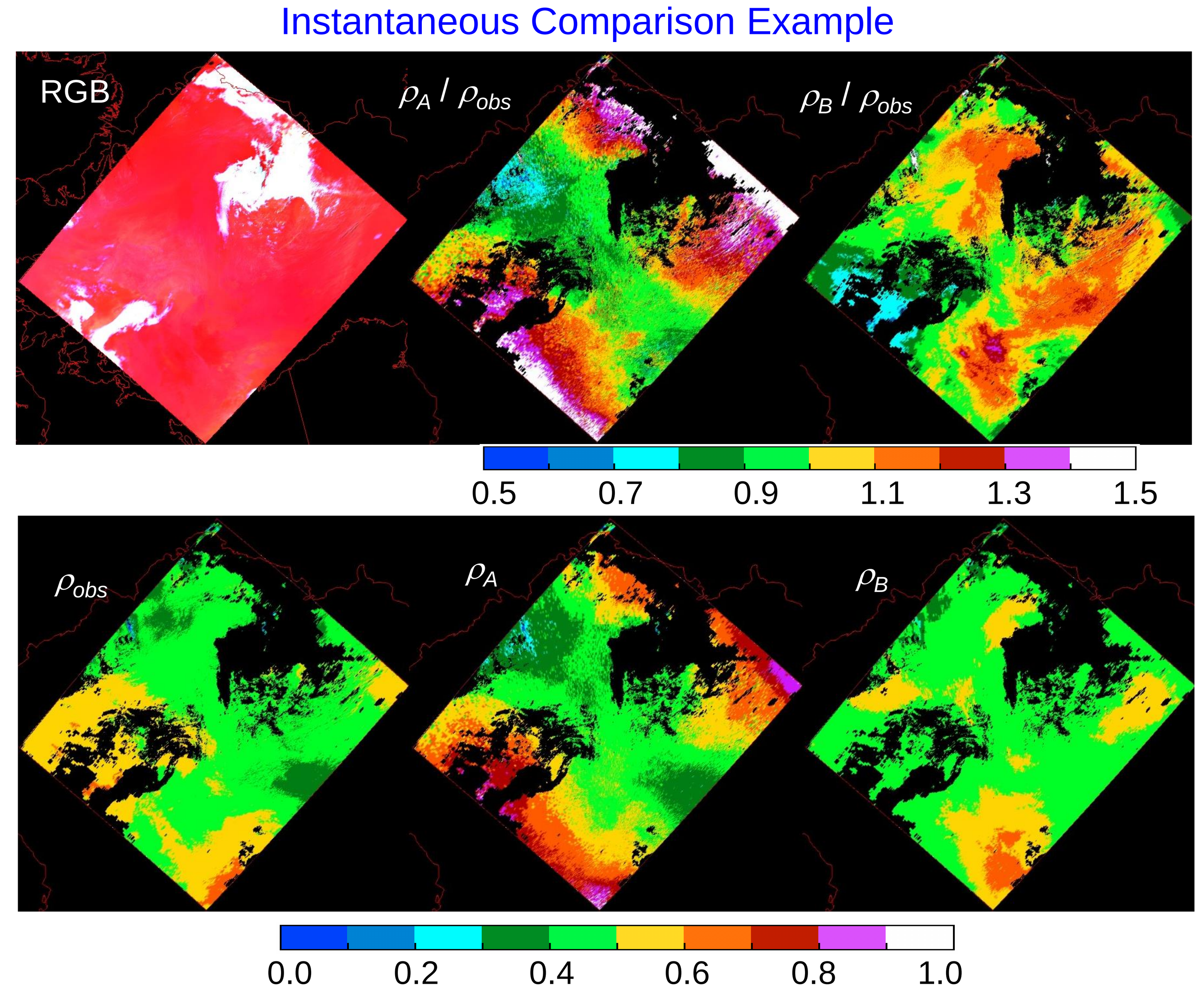


Model A updating tends increase the overhead albedo everywhere. Model A values are larger because the model-A DRM is nearly flat. The lower model-B values are much lower because the DRM increases with SZA.

Results

Instantaneous Comparison Example

Terra 1305 UTC 9 January 2008



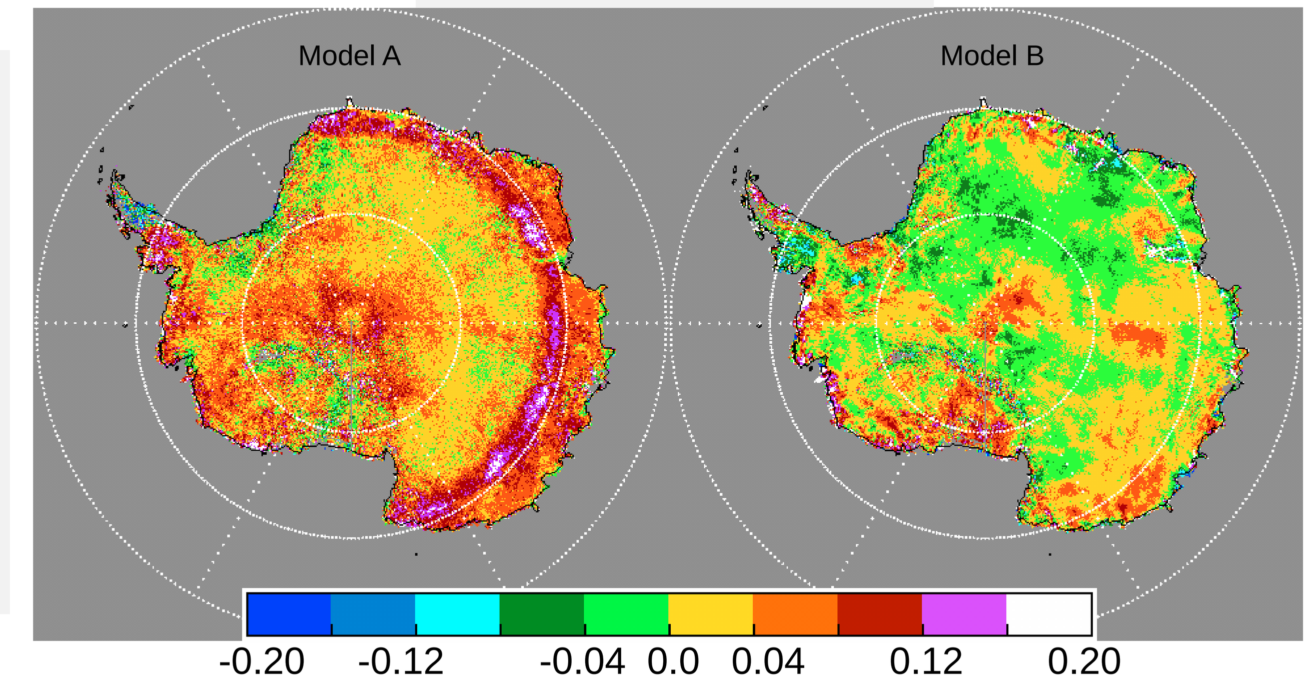
Model A yields much lower reflectances in center of image and higher values near the ends of the granule. Model B looks more like the observations except in lower left corner.

Comparison Summary

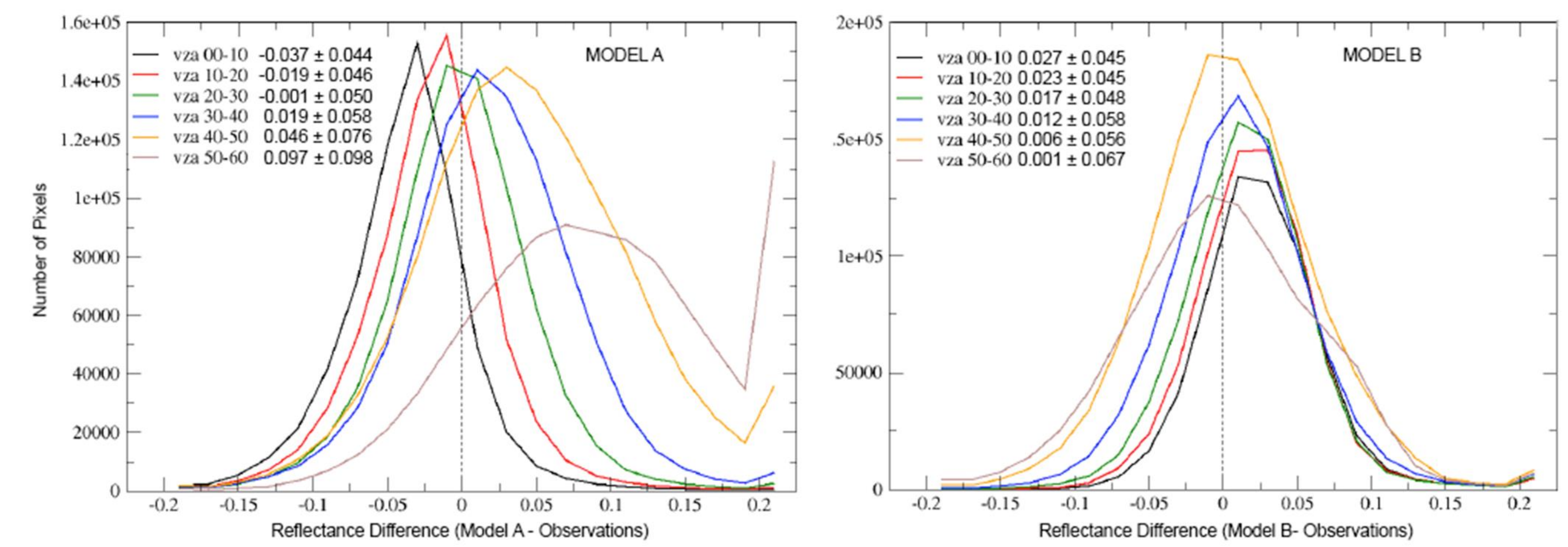
Mean Reflectance Difference

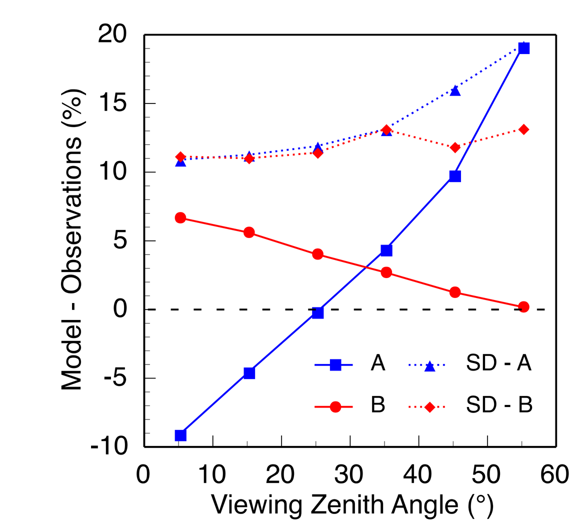
For **model A**, a large portion of the domain has differences between ±0.04, with more areas on the positive side. Extreme differences are seen in eastern Antarctica north of 75° S. Overall positive bias.

For **model B**, more areas having differences ±0.04 with a better balance than model A. Error pattern is substantially different from that of model A. Many of the largest errors occur in areas with significant altitude gradients or mountain ranges.



Differences as Function of Viewing Zenith Angle





DRM accounts for SZA dependence; BRDF accounts for VZA and RAA variation. Errors in the predicted reflectance clearly vary with VZA. For **model A**, the bias increases monotonically with VZA from -10% at nadir to +19% at VZA = 55°. Standard deviation (SD) of the differences rises from 11 to 19%. For VZA > 50°, a large portion of the differences 0.2 or 40%.

Model B errors are less extreme with biases dropping from 6% at nadir to 0% at 55°. The SD values are relatively steady with VZA at ~11%. Few errors > 0.2 are seen for this model.

Larger model A biases suggest DRM is not accurate. Error variations with RAA and SZA need further analysis.

	Ratio of Obs/Pred		Difference of Obs - Pred	
	MEAN	STDEV	MEAN	STDEV
Model A Predicted	1.1099	0.5639	0.0442	0.0988
Model B Predicted	1.0541	1.1897	0.0067	0.0591

Summary & Future Work

- Model B clearly represents reflectance field better than model A. Model A optimizes mid VZA regions.
- Future work will focus on adjusting model B based on Aqua and Terra observed clear snow reflectances to minimize SZA, VZA, and RAA-dependent errors
  - *errors to be assessed for other areas: Arctic sea ice and land, IGBP types with seasonal snow*
  - *sastrugi and terrain roughness will also be considered in model adjustment*
- Revised model will be used in future CERES Editions

References

Trepte, Q., P. Minnis, and R. F. Arduini, 2002: Daytime and nighttime polar cloud and snow identification using MODIS data. *Proc. SPIE 3rd Intl. Asia-Pacific Environ. Remote Sensing Symp. 2002: Remote Sens. of Atmosphere, Ocean, Environment, and Space*, Hangzhou, China, October 23-27, Vol. 4891, 449-459.