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Observed Cloud Morphology and Inferred Microphysics Over the South Pacific from MISR and MODIS Measurements of Shortwave Reflectivity

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Abstract. A rapid study of boundary layer clouds over the Southern Ocean compared to their Northern Hemisphere counterparts reveals statistical differences in the probability of glaciation at the same cloud-top temperature, and in the respective plane parallel albedo biases. The preliminary study indicates that a more comprehensive study of these features is merited, with a view to improving the cloud parameterizations currently used in climate models.

INTRODUCTION

The Deep South Project is one of New Zealand's National Science Challenges. It addresses the question of how New Zealand's climate is affected by Antarctica and the Southern Oceans by developing and applying the New Zealand Earth System Model (NZESM). As with several other models, the NZESM shows strong biases, compared to observations, in the surface energy fluxes in the Southern Hemisphere, especially over the Southern Ocean (Bodas-Salcedo et al. 2012). A likely explanation for these biases relates to defects in the modeled treatment of clouds, especially boundary layer clouds that have high fractional coverage over the Southern Oceans. We suspect that Southern Ocean clouds may require different parameterizations compared with their Northern Hemisphere counterparts.

This study is an initial exploration of the observed differences between Northern Hemisphere and Southern Hemisphere marine boundary layer clouds. We seek clues that may affect the parameterization relating cloud albedo to cloud microphysics and cloud morphology. The two key areas of interest include the role of glaciation of supercooled clouds, and the role of cloud heterogeneity affecting the plane parallel albedo bias. As described below, we use data from MISR and MODIS to conduct an initial statistical study to evaluate whether a deeper analysis of these two areas of interest is warranted.

Glaciation of Supercooled Boundary Layer Clouds

It is well known that the probability of glaciation depends on the activation of ice nuclei, increasing from 0% at ≈0°C to 100% at ≈–40°C. But once glaciated, clouds remain so until they dissipate or warm above 0°C. At a given subzero temperature, the probability of observing glaciation depends on both the history of the cloud and the nature of its ice nuclei. We apply the MODIS cloud phase (King et al. 1997) to maritime boundary layer clouds between 35° and 70° latitude, in the respective summer and winter seasons, filtered to include only single-layer, coherent-phase boundary layer clouds. About 1800 cases were chosen between 2000 and 2016. Figure 1 shows an example of the filtering process, with panel 3 showing the remaining categories of ice (glaciated), water and undetermined (which were ignored).

Radiation Processes in the Atmosphere and Ocean (IRS2016)
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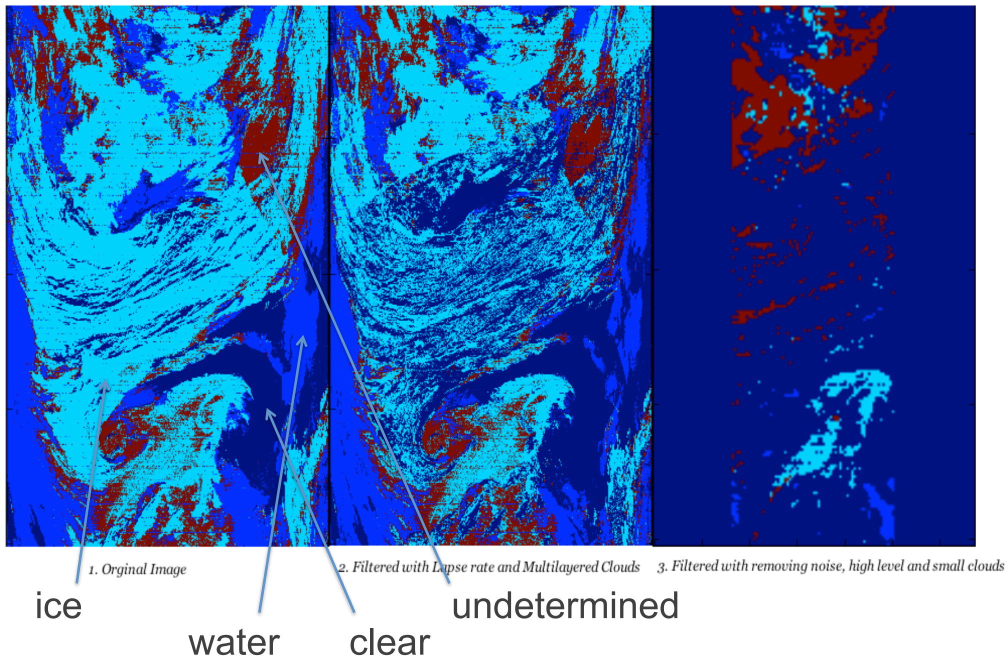

FIGURE 1. Example of the filtering process to yield coherent cloud-top phase.

For each case, the probability of glaciation was determined as a function of cloud-top temperature, *T*, as the realative fraction of clearly identified phases that were ice, $P(T) = f(ice)/[f(ice)+f(liquid)]$. We also used the derivative dP/dT as an indicator. The results are summarized in Fig. 2 for the latitude range 50°-70°. In the summer months, the southern hemisphere generally has a 10% higher probability of ice clouds than the northern hemisphere, mainly for cloud-top temperatures 265–273 K, and this reverses in the winter season. Of course, the summer season is more significant in terms of the potential effect on albedo. Both hemispheres show the greatest sensitivity at a cloud-top temperature ≈268K. Ice dominates the cloud-top phase for $T < 260$ K in both hemispheres from 35° to 50°, and for $T < 250$ K for 50° to 70°, consistent with earlier findings (Kay et al. 2014, Forbes and Ahlgrimm, 2014).

Boundary Layer Cloud Heterogeneity Differences

The plane parallel albedo bias (Oreopoulos and Davies, 1998) arises from the non-linear dependence of albedo, α, and optical thickness, τ, such that $\alpha(\langle\tau\rangle) > \langle\alpha(\tau)\rangle$, with the bias equaling the difference. As a result most model clouds are either too bright or too dry, due to averaging over large horizontal domains. This is typically accounted for in the model parameterization, but assumes a constant degree of heterogeneity. Here we examine whether there is a significant difference in heterogeneity between the two hemispheres that might affect the plane parallel albedo bias. In this rapid study, we examined scenes from 35°S to 75°S north of the Ross Sea, and a similar latitude range south of the Bering Strait and Greenland, during their respective summer seasons. About 280 scenes were obtained for each hemisphere using MISR red band radiances. The scenes chosen were of boundary layer clouds on a 100 x 100 km domain, measured at 275 m resolution. Fig. 3 shows an image of open cells, and the resulting distributions of reflectivities and optical depths, obtained using a simple 1D algorithm and invoking the Independent Pixel Approximation. The plane parallel albedo bias for this case was 0.05. Other scenes involving closed cells and frontal clouds typically had a smaller percentage bias. The overall results are summarized in Fig. 4, which shows the difference between the NH and SH plane parallel albedo bias as a function of latitude. Despite a large degree of variability, the regression as a function of latitude shows that there appears to be a difference in heterogeneity between the hemispheres, with the negative value indicating that the Southern Hemisphere, on average, has a smaller heterogeneity bias than the Northern Hemisphere.

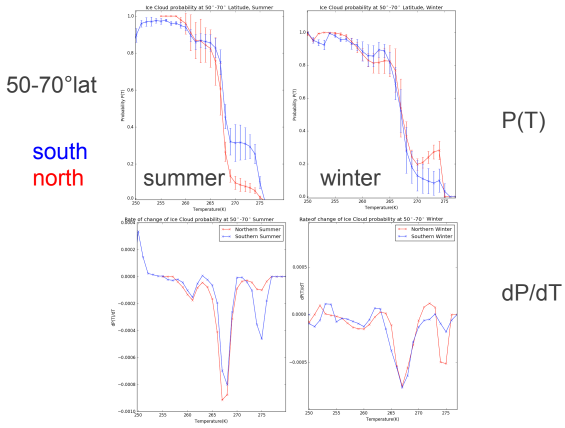

FIGURE 2. Ice phase probability as a function of cloud-top temperature, for respective summer and winter seasons in either hemisphere.

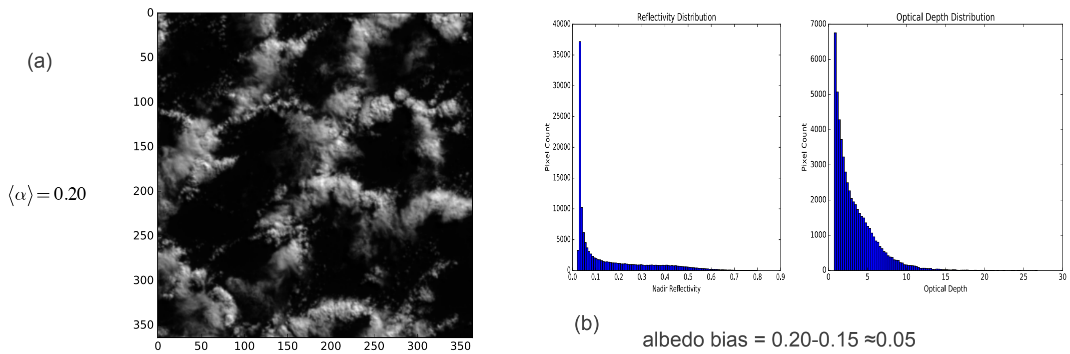

FIGURE 3. Example of a 100 x 100 km domain of open cell convection with an average albedo of 0.2 (a). Distributions of reflectivity and optical depths (b).

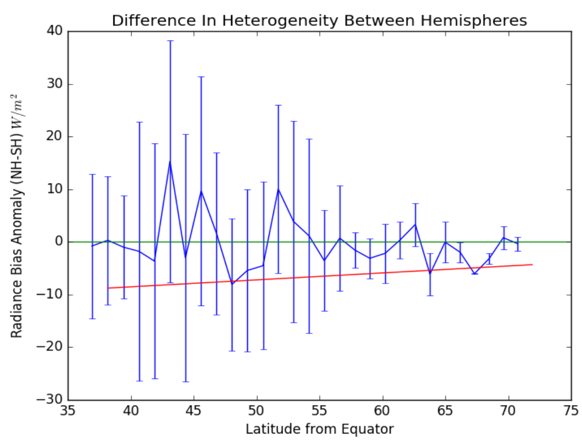

FIGURE 4. Differences in the radiance bias between hemispheres as a function of latitude, expressed in terms of equivalent irradiance (W m^{-2}). Negative values imply a smaller heterogeneity bias in the Southern Hemisphere.

SUMMARY

Both the glaciation and heterogeneity studies appear to show differences in observed cloud properties between the two hemispheres that would be significant for model parameterizations. The southern hemisphere has a higher probability of cloud glaciation, at the same cloud-top temperature, than the northern hemisphere in their respective summers. The southern hemisphere also appears to have less heterogeneity than the northern hemisphere.

The current study was a rapid exploration of the differences between the hemispheres, using simplified algorithms and a subset of the available data. The glaciation study raises the question: why does the hemispheric difference appear to reverse with season? The heterogeneity study appears to be significant, but is quantitatively quite approximate, and could easily be improved.

Both studies will benefit from additional data, as well as stratification by cloud regime, and direct comparison against model output. This will be the next phase of this work.

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