P2.18 THE INFLUENCE OF ANTARCTIC CLOUD AND SURFACE PROPERITES ON CLOUD RADIATIVE FORCING AT THE SURFACE

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1. INTRODUCTION

Model simulations have shown that the radiative properties of clouds over the Antarctic influence not only the south polar climate but global climate as well. Changes in cloud and surface properties can result in changes in the surface energy budget which in turn can alter the regional atmospheric and oceanic dynamics of the Antarctic. Lubin et al. (1998) showed that any significant warming or cooling at the surface over Antarctica will cause changes in temperature gradients that may then lead to changes in regional transport mechanisms. Another consideration of surface warming/cooling is the feedback on cloud properties and cloud amount. The purpose of this work is to learn how changes in cloud and surface properties affect the surface radiative budget in the Antarctic.

There are several factors that can influence the radiative effect of clouds (cloud "forcing") at the surface such as cloud optical depth, surface albedo, cloud amount, cloud temperature, and surface temperature. The net radiative effect of clouds on the surface will vary, in large part, according to the aforementioned parameters. However, it would be useful to determine which of those parameters most dramatically alter the net effect of clouds on the surface radiation budget if it were to change.

In this study, cloud and surface properties from the International Cloud Climatology Project (ISCCP) "D1" data set were used as input to a radiative transfer model which computed shortwave and longwave surface cloud radiative forcing. For more information about the ISCCP D−series data set refer to Rossow et al. (1996). The period 1989 to 1991 and the area between about 60ºS and 90ºS latitude were examined. Spatial and temporal variability of surface cloud forcing were then analyzed and model sensitivity studies were performed in order to access the relative importance of different surface and cloud properties.

2. METHODS

Cloud, atmospheric, and surface parameters from the ISCCP 3−hourly data set (D1) were used as input to FluxNet, a neural network implementation of the two−stream radiative transfer model Streamer (Key and Schweiger, 1998). Temperature and humidity profiles from the TOVS Pathfinder "Path−P" data set were used when and where available, primarily over the ocean around the Antarctic continent. Shortwave and longwave fluxes and cloud forcing at the surface and top of the atmosphere were computed with FluxNet because of its computational efficiency: it is up to 10,000 times faster than Streamer. Sensitivity studies were performed with Streamer.

Cloud forcing is calculated as the difference between the net fluxes for cloudy or partly cloudy conditions and clear skies:

$$CF = F(A_c) - F(0)$$

where *CF* is cloud forcing, *F* is the net shortwave, longwave, or all−wave flux, and A_c is the cloud amount.

3. SPATIAL AND TEMPORAL VARIABILTY

In order to evaluate both spatial and temporal trends in cloud forcing, zonal averages were calculated for each 2.5 degree latitude interval from 59.75ºS to 88.75ºS in the ISCCP data set and for each month. As can be seen in Figure 1, the presence of clouds leads to the greatest amount of surface cooling in the summer months at latitudes north (equatorward) of 70ºS. In the figure, the dark line marks the boundary between negative and positive values of cloud forcing. This is no surprise since the days are much longer and the surface is less reflective due to ice melt. However, the most prominent feature of the net cloud forcing is that at latitudes poleward of about 80ºS clouds were found to have a warming effect on the surface every month of the year. While clouds have a warming effect on the surface in the longwave and a cooling effect in the shortwave, the decrease in downwelling shortwave radiation due to reflection by clouds is much smaller because the bright surface increases the downwelling shortwave flux through multiple surface−cloud reflections. This year−round warming effect of clouds is not seen at comparable latitudes in the northern hemisphere.

4. SENSITIVITY ANALYSIS

Using Streamer, model sensitivity studies were conducted to determine the relative importance of various cloud and surface properties on the longwave and shortwave cloud forcing. More specifically, the

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sensitivity of cloud forcing to cloud fraction, cloud top temperature, cloud optical depth, surface albedo, and surface temperature were examined. For the baseline case, spatially averaged (88.75ºS to 59.75ºS) ISCCP cloud and surface parameters from the month of December were used when possible. The solar zenith angle was taken to be 60 degrees. An ice cloud with an effective particle radius of 30 microns and a ice water content of 0.07 g/m^3 was used in all simulations except when the cloud top temperature exceeded 258 K, where a liquid cloud with an effective particle radius of 10 microns and a liquid water content of 0.2 g/m^3 was used. These are the same effective particle sizes and concentrations used in the ISCCP processing. Table 1 shows the specific model input parameters.

Cloud fraction, cloud top temperature, cloud optical depth, surface reflectance, and surface temperature were varied so that cloud and surface properties characteristic of both the Antarctic continent and the ocean poleward of 60ºS degrees would be accounted for. Table 2 shows the results of this sensitivity analysis including the difference between each case and the baseline case.

In the sensitivity studies, cloud amount was decreased from 50% to 10%. The increase in the shortwave cloud forcing (SWCF) was about twice as much as the decrease in longwave cloud forcing (LWCF), although both the SWCF and the LWCF are very sensitive to a 40% decrease in cloud amount. With 100% cloud cover the SWCF decreased by roughly 68 W/m^2 and the LWCF increased by about half as much. It should be noted that high cloud amounts are more typical of the ocean area surrounding Antarctica and lower cloud amounts are common over the Antarctic continent.

Table 1. Cloud and surface input parameters for baseline case.

Parameter	**Value**
Solar zenith angle	60 degrees
Cloud Fraction	0.50
Cloud top temperature	250 K
Cloud optical depth	10.0
Surface reflectance	0.60
Surface temperature	260 K
Effective particle size (ice)	30 microns
Ice water concentration	0.07 g/m^3
Effective particle size (liquid)	10 microns
Liquid water concentration	0.2 g/m^3

Next cloud top temperature was decreased by 35 K to 215 K. As expected, the change in the SWCF is small and insignificant. The LWCF decreases but by less than 3 W/m^2. Similarly, when the cloud top temperature is increased by 25 K the change in SWCF is negligible. The increase in the LWCF is larger than the decrease when cloud top temperature was decreased by 35 K, but it was still less than 3 W/m^2. Thus, neither the shortwave nor longwave cloud forcing are particularly sensitive to large changes in

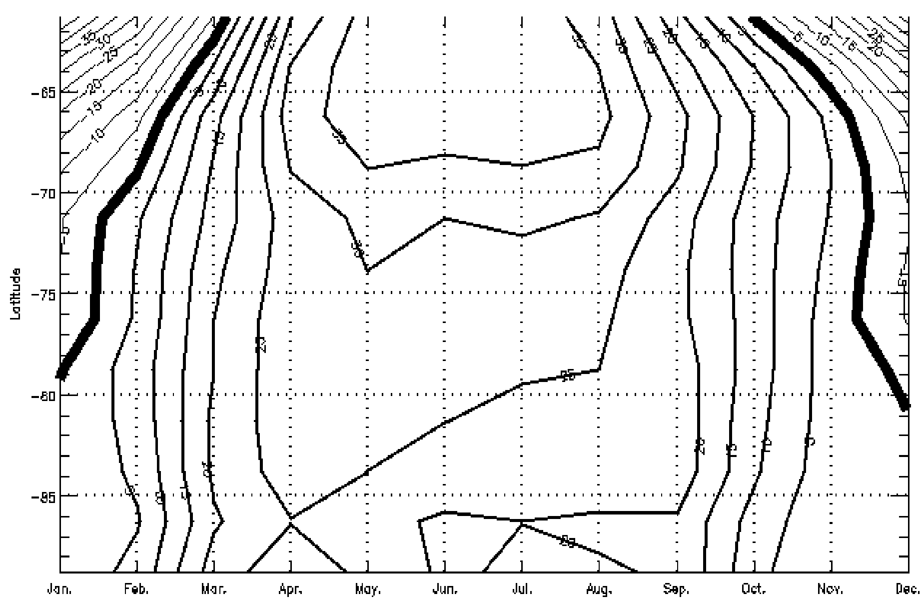

Fig. 1. Spatial and temporal distribution of net cloud forcing for the Antarctic (W/m^2).

cloud top temperature.

Table 2. Sensitivity of surface cloud forcing (W/m^2) to changes in cloud and surface parameters. Changes from the basline case are indicated for each parameter along with the actual values in parentheses. Shortwave (SWCF), longwave (LWCF), and net (NETCF) cloud forcing values are given along with their corresponding difference (diff) from the baseline case.

	SWCF	**diff**	**LWCF**	**diff**	**NETCF**	**diff**
Baseline case	−67.81	–––––	34.32	–––––	−33.59	–––––
Cloud fraction						
−0.4 (0.1)	−13.58	+54.33	6.86	−27.46	−6.72	+26.87
+0.5 (1.0)	−135.82	−67.91	68.64	+34.32	−67.18	−33.59
Cloud top temperature						
−35 K (215 K)	−67.68	+0.23	32.27	−2.05	−35.41	−1.82
+25 K (275 K)	−68.49	−0.58	36.63	+2.31	−31.86	+1.73
Cloud optical depth						
−9.0 (1.0)	−16.81	+51.10	17.40	−16.92	0.59	+34.18
+20.0 (30.0)	−103.34	−35.43	37.20	+2.88	−66.14	−32.55
Surface albedo						
−0.4 (0.2)	−124.16	−56.25	34.32	0.00	−89.84	−56.25
+0.3 (0.9)	−36.04	+31.87	34.32	0.00	−1.72	+31.87
Surface temperature						
−35 K (225 K)	−67.91	0.00	33.81	−0.51	−34.10	−0.51
+20 K (280 K)	−67.91	0.00	34.79	+0.47	−33.12	+0.47

The sensitivity of cloud forcing to cloud visible optical depth was tested by first decreasing the optical depth from 10.0 to 1.0. Both the shortwave and longwave cloud forcing are sensitive to the decrease in optical depth, with the decrease in SWCF being about 15 W/m^2 greater than the increase in LWCF. When the cloud optical depth was increased from 10.0 to 30.0 the changes in both the SWCF and LWCF are much smaller than when the optical depth was decreased from 10.0 to 1.0. This is due to the logarithmic relationship between cloud optical depth and cloud forcing. In the shortwave, model runs reveal that the greatest changes in cloud forcing per unit change in optical depth occur at optical depths less than 10.0. In the longwave, the greatest variability occurs for optical depths less than 5.0. Hence, the sensitivity of cloud forcing to cloud optical depth is highly dependent on the magnitude of the optical depth, not the unit change in optical depth.

Only the SWCF will be sensitive to changes in surface reflectance. When the surface reflectance is reduced to from 0.6 to 0.2, which is a typical albedo for open water surfaces south of 60ºS, the SWCF is decreased by about 56 W/m^2. Conversely, when the surface reflectance was increased to 0.9, which is typical of the Antarctic continent, the SWCF increased significantly. As can be seen in Table 2, surface albedos as large as 0.9 result in values of SWCF that are much smaller in magnitude as so the net cloud forcing approaches zero or becomes positive. This is the case over the Antarctic continent. In addition, one of the main reasons for the sharp gradient in the net cloud forcing in the summer months north of 70ºS is the abrupt change in surface albedo due to sea ice melt (Figure 1).

Finally, changes in cloud forcing due to changes in surface temperature were examined. As expected, the SWCF is unaffected by changes in surface temperature. Similarly, even large changes in surface temperature produce negligible changes in the LWCF. This is probably due to the fact that changes in surface temperature will bring about changes in atmospheric temperatures which almost completely compensate for any increase or decrease in surface temperature.

It is apparent from this sensitivity analysis that any changes in the net cloud forcing due to changes in the cloud top temperature and surface temperature are negligible and can be ignored. It is also clear that the SWCF is much more sensitive to changes in cloud fraction and cloud optical depth than the LWCF. Thus, changes in cloud fraction and cloud optical depth during the daylight months will lead to large changes in the net cloud forcing even though the changes in the SWCF and LWCF are opposite in sign. However, changes in the net cloud forcing due to changes in optical depth can vary significantly depending on the magnitude of the optical depth. Changes in surface albedo will also produce fairly large changes in the net cloud forcing.

5. SUMMARY

Cloud fraction, cloud optical depth, and surface reflectance have a significant influence on the surface radiation budget of Antarctica. Any changes in these parameters can mean the difference between clouds having a warming or a cooling effect on the surface. Over much of the Antarctic continent these parameters combine such that clouds have a warming effect on the surface year−round. This effect is unique to the Antarctic.

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6. REFERENCES

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