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N94-27889

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WHY IS THE NORTH POLAR CAP ON MARS DIFFERENT THAN THE SOUTH POLAR CAP?

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Introduction. One of the most puzzling mysteries about the planet Mars is the hemispherical asymmetry in the polar caps. Every spring the seasonal polar cap of CO_2 recedes until the end of summer, when only a small part, the residual polar cap, remains. During the year that Viking observed Mars, the residual polar cap was composed of water ice in the northern hemisphere [Kieffer et al., Science, 194, 1341, 1976] but was primarily carbon dioxide ice in the southern hemisphere [Kieffer, J. Geophys. Res., 84, 8263, 1979]. Scientists have sought to explain this asymmetry by modeling observations of the latitudinal recession of the polar cap and seasonal variations in atmospheric pressure (since the seasonal polar caps are primarily frozen atmosphere, they are directly related to changes in atmospheric mass). These models reproduce most aspects of the observed annual variation in atmospheric pressure fairly accurately. Furthermore, the predicted latitudinal recession of the northern polar cap in the spring agrees well with observations, including the fact that the CO_2 ice is predicted to completely sublime away. However, these models all predict that the carbon dioxide ice will also sublime away during the summer in the southern hemisphere, unlike what is observed. This paper will show how the radiative effects of ozone, clouds, and airborne dust, light penetration into and through the polar cap, and the dependence of albedo on solar zenith angle affect CO_2 ice formation and sublimation, and how they help explain the hemispherical asymmetry in the residual polar caps. These effects have not been studied with prior polar cap models.

Ozone, Clouds, and Airborne Dust. Since O_3 is more prevalent in the northern hemisphere than in the southern hemisphere, O_3 was suggested as a cause for the hemispherical asymmetry in the residual polar caps by Kuhn et al. (J. Geophys. Res., 84, 8341, 1979). However, Lindner (submitted to Icarus, 1991) has shown that O_3 has a minor effect on the atmospheric temperature, and hence on the infrared radiation which strikes the polar cap, and Lindner (J. Geophys. Res., 95, 1367, 1990) has shown that O_3 absorbs less than 1% of the total solar radiation absorbed by the polar cap. Thus, O_3 is not an important consideration in the polar cap energy budget.

Lindner (1990) has computed the solar and thermal flux striking the polar cap of Mars for various ozone, dust, and cloud abundances and for three solar zenith angles. These calculations have been inserted in the polar-cap models of Lindner (Eos Trans. AGU, 67, 1078, 1986) and Jakosky and Haberle (J. Geophys. Res., 95, 1359, 1990). Vertical optical depths of dust and cloud ranging from zero to 1 cause little change in the total flux absorbed by the polar cap near its edge but increase the absorbed flux significantly as one travels poleward. Observed hemispherical asymmetries in dust abundance, cloud cover, and surface pressure combine to cause a significant hemispherical asymmetry in the total flux absorbed by the residual polar caps, which helps to explain the dichotomy in the residual polar caps on Mars.

Light Penetration. Penetration of solar radiation into the cap itself is included in my polar cap model, based on the theoretical work of Clow (Icarus, 72, 95, 1987). I find that the inclusion of light penetration slightly decreases the albedo needed in the model to keep CO_2-ice year-round at the south pole by on the order of 1%. The required albedo is decreased because some solar radiation is used to heat the subsurface, and not all of this heat is transported back to the surface. Overall, I conclude that penetration of light into the polar cap has only a small effect on the polarcap energy budget.

Albedo and the Solar Zenith Angle. Warren et al. (J. Geophys. Res., 95, 14717, 1990) has computed the dependence of the albedo of the martian polar caps on solar zenith angle, and these calculations have been included in my polar cap model. Since the albedo of ice increases and becomes more forward scattering at higher solar zenith angles, and since the solar zenith angle becomes higher as one approaches the pole, the albedo is greatest at the pole. This decreases absorption of sunlight, hence increasing survivability of CO_2 ice. In fact, this increases the survivability of ice enough to offset the decrease in survivability of ice due to the radiative effects of clouds and dust.

Discussion. The combination of the effects of solar zenith angle on albedo and the radiative effects of clouds and dust act to extend the lifetime of CO_2 ice on the south pole relatively more than on the north pole, explaining the hemispherical asymmetry in the residual polar caps without the need of a hemispherical asymmetry in polar cap albedo. Another positive aspect this solution is that neither the inclusion of solar zenith angle effects on ice albedo nor the radiative effects of clouds and dust should appreciably change model predictions of the annual cycle of pressure or polar cap recession equatorward of 75° latitude, since approximately 90% of the seasonal CO_2 frost is equatorward of 80° latitude. Hence, the good model agreement noted by prior researchers to the seasonal cycle in atmospheric pressure and to the recession of the polar cap equatorward of 80° latitude is retained.