Carbon Dioxide Convection in the Martian Polar Night and its Implications for Polar Processes.

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Introduction: Each Martian year nearly 30% of the atmosphere is exchanged with the polar ice caps. This exchange occurs through a combination of direct surface condensation and atmospheric precipitation of carbon dioxide. It has long been thought the amount of condensation within the polar night is maintained by a balance between diabatic processes such as radiative cooling and latent heating from condensing CO_2. This assumption manifests itself in Mars General Circulation Models (GCM) in such a way as to never allow the atmospheric temperature to dip below the saturation temperature of CO_2. However, observations from Mars Global Surveyor (MGS) Radio Science (RS) and the Thermal Emission Spectrometer (TES) have demonstrated this assumption to be, at best, approximate. Both RS and TES observations within the polar nights of both poles indicate substantial supersaturated regions with respect to CO_2. The observed temperature profiles suggest conditionally unstable regions containing planetary significant amounts of potential convective energy. Presented here are estimates of the total planetary inventory of convective available potential energy (CAPE) and the potential convective energy flux (PCEF). The values for CAPE and PCEF are derived from RS temperature profiles and compared to Mars GCM results using a new convective CO2 cloud model that allows for the formation of CAPE.

CO_2 Convection: A rising air parcel will cool along the dry adiabat until saturated (Level of Condensation Lifting) at which time condensation and the release of latent heat force the parcel to cool along the wet adiabat. If the release of latent heat maintains the air parcel temperature above the environment temperature then it can become buoyant and freely convect (Level of Free Convection). Free convection will continue as long as the parcel remains warmer than its surroundings (Level of Neutral Buoyancy). The amount of free convection that can occur depends on the difference in temperature between the ascending air parcel and its environment. One measure of the ability of a parcel to freely convect is the convective available potential energy (CAPE). The CAPE of a parcel can be expressed as

$$CAPE = \int_{z_1}^{z_2} b\,dz \qquad 1.$$

where z_1 and z_2 are the initial and ending altitudes of the rising parcel of air and *b* is the buoyancy

$$b = g\frac{(T_p - T_e)}{T_e} \qquad 2.$$

with T_p and T_e being the temperature of the parcel and environment respectively. Within the Martian polar night the atmosphere is frequently at or above the CO_2 saturation temperature. If an air parcel near the surface is forced to rise it will very quickly become saturated and cool along the wet adiabat. However, since the surrounding atmosphere is already at the wet adiabat the parcel's buoyancy is nearly zero ($T_p - T_e$? 0). Therefore there is very little CAPE (with respect to CO_2 convection) within the Martian polar night and CO_2 convection would be shallow.

Not all of the Mars polar night atmosphere is at or above the saturation temperature, however. RS measurements indicate regions of CO_2 supersaturation in the lower atmosphere below about 1−2 mbar. Examples of RS observations showing supersaturations are shown in Figure 1. In Figure 1 four RS measurements, two for the South polar region and two for the North polar region, are shown with their corresponding CAPE (J kg^{-1}). These supersaturated regions can form if the air in the region is clear of any previously existing CO_2 cloud particles and new cloud particle nucleation has not yet occurred, or if atmospheric cooling rates are so high that the release of latent heat from growing CO_2 cloud particles is insufficient to compensate for the decrease in temperature. Under these conditions a rising parcel may be buoyant and will rise if condensation occurs. The CAPE for the profiles shown in Figure 1 varies from about 35 −250 J kg^{-1}. For comparison moderate to strong terrestrial convective systems have CAPE in the range from 500−1000 J kg^{-1}. Larger terrestrial thunderstorms can have CAPE greater than 2000 J kg^{-1}. On Earth, for similar amounts of CAPE as that calculated from the RS soundings in Figure 1, low to moderate levels of convection resulting in unorganized microbursts would be expected.

RS Observations: In the 6921 RS profiles analyzed thus far, approximately 25% of them show some amount of CAPE (as defined by Eq. 1). Figure 2 shows the location of the RS profiles which contained CAPE. The highest value of CAPE was in the North and had a value of 421 J kg^{-1}. If all 421 J kg^{-1} of CAPE in this profile was converted to convective motion (neglecting entrainment effects and possibly cloud particle drag) the resulting updraft would have a velocity of almost 30 m s^{-1}. The total integrated CAPE in the profiles shown in Figure 2 is approximately 28 kJ kg^{-1}. Due to the limited spatial and temporal nature of the observations, the temperature profiles studied only constitute a fraction of the total atmospheric volume and time that CAPE is present. An estimate of the total rate of CAPE formation was made by linearly interpolating, in time and space, observed CAPE tendencies between observation points. Assuming all CAPE is converted to heat a total potential convective energy flux (PCEF) was calculated and is shown in Figure 3. The periods of highest PCEF correspond to the mid to late winter periods at both poles. The PCEF magnitude is largest in the North being about twice that of the South. During the late winter period the PCEF constitutes approximately 10% the total latent heating budget, or approximately equal to the total meridional heat transport.

A new CO_2 cloud model recently implemented in the Ames GCM reproduces the observed supersaturated regions. The cloud model includes the microphysical processes of nucleation, condensation, and sedimentation. Proper treatment of ice nuclei (IN) nucleation, assumed here to be dust grains, is critical to reproducing the observed supersaturated regions. The supersaturation at which new CO_2 cloud particles will form was recently measured to be 35%, consistent with the maximum supersaturations observed in the RS temperature profiles. Integrated CAPE and PCEF from simulations utilizing this new CO_2 cloud model are consistent with those estimated from the observations.

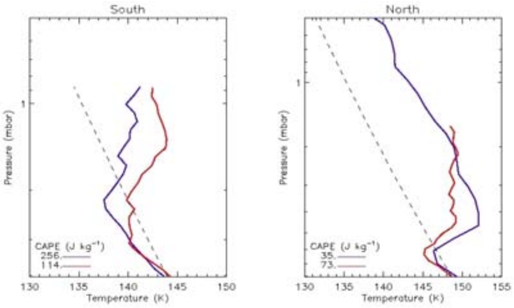

Figure 1. Examples of RS profiles (red and blue curves) showing supersaturated regions and the corresponding CAPE. The dashed curve is the frost temperature for CO2.

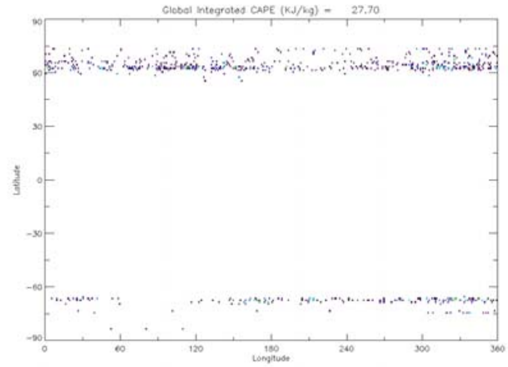

Figure 2: Location of RS profiles having CAPE associated with them.

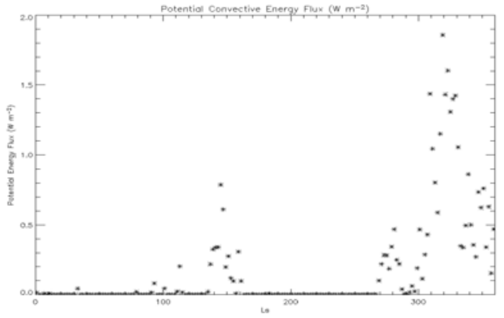

Figure 3. The estimated potential convective energy flux (PCEF) calculated from the total CAPE associated with all RS observations.