N92-10803

# Free Convection in the Martian Atmosphere

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We investigate the "free convective" regime for the martian atmospheric boundary layer (ABL). This state occurs when the mean windspeed at the top of the ABL drops below some critical value $U_c$ and positive buoyant forces are present. Such forces can arise either from vertical temperature or water vapor gradients across the atmospheric surface layer. During free convection, buoyant forces drive narrow plumes that ascend to the inversion height with a return circulation consisting of broad slower-moving downdraughts. Horizontal pressure, temperature, windspeed, and water vapor fluctuations resulting from this circulation pattern can be quite large adjacent to the ground (within the surface layer). These local turbulent fluctuations cause non-zero mean surface stresses, sensible heat fluxes, and latent heat fluxes, even when the mean regional windspeed is zero. Although motions above the surface layer are insensitive to the nature of the surface, the sensible and latent heat fluxes are primarily controlled by processes within the interfacial sublayer immediately adjacent to the ground during free convection. Thus the distinction between aerodynamically smooth and rough airflow within the interfacial sublayer is more important than for the more typical situation where the mean regional windspeed is greater than $U_c$. Buoyant forces associated with water vapor gradients are particularly large on Mars at low pressures ($P<30$ mb) and high temperatures ($T>250$ K) when the surface's relative humidity is 100%, enhancing the likelihood of free convection under these conditions. On this basis, Ingersol [1] postulated the evaporative heat losses from an icy surface on Mars at 273 K and current pressures would exceed the available net radiative flux at the surface, thus prohibiting ice from melting at low atmospheric pressures.

Recently, Schumann [2] has developed equations describing the horizontal fluctuations and mean vertical gradients occurring during free convection. However, his model is limited to the case where free convection is driven solely by thermal buoyancy and the surface is aerodynamically rough. Within these restrictions, model results compare very well with those of a detailed large-eddy simulation (LES) which in turn generally agree with available atmospheric observations [3]. Despite large horizontal wind velocities associated with the updraughts, the LES demonstrates that the time-derivatives for horizontal motion in the surface layer are small, validating the use of Monin-Obukhov theory in the model.

We have generalized Schumann's model to include convection driven by water vapor gradients and to include the effects of circulation above both aerodynamically smooth and rough surfaces. Applying the model to Mars, we find that nearly all the resistance to sensible and latent heat transfer in the ABL occurs within the thin interfacial sublayer at the surface. Free convection is found to readily occur at low pressures and high temperatures when surface ice is present. At 7 mb, the ABL should freely convect whenever the mean windspeed at the top of the surface layer drops below about 2.5 m $s^{-1}$ and surface temperatures exceed 250 K. Mean horizontal fluctuations within the surface layer are found to be as high as 3 m $s^{-1}$ for windspeed, 0.5 K for temperature, and $10^{-4}$ kg $m^{-3}$ for water vapor density. Airflow over surfaces similar to the Antarctic Polar Plateau (surface roughness length $z_0 \approx 0.03$ cm) is found to be aerodynamically smooth on Mars during free convection for all pressures between 6 and 1000 mb while surfaces with $z_0 \approx 1$ cm are aerodynamically rough over this pressure range.

Free convective latent-heat fluxes are of particular interest because they establish the *minimum* evaporative heat losses that will occur for an icy surface at a given temperature. Fig.1 shows the predicted latent heat fluxes during free convection for the limiting case where the ABL is isothermal and the surface temperature is 273 K. For a surface resembling average terrestrial polar snows (curve A), our predicted fluxes are a factor of 4 smaller than those given by Eq.(1) Ingersol [1], making it proportionally easier to melt ice on Mars. Fig.2 shows the albedo required for the net radiative flux at the surface to just balance the predicted latent heat losses at 273 K at the time of maximum incoming solar radiation. The lowest albedo that can be achieved for martian ice surfaces is about 0.2 [4]. Hence, atmospheric pressures need to be at least 100 mb at the poles and about 6 mb at the equator before ice can melt under the best of conditions.

**References:** [1] Ingersol, A.P. (1970) *Science*, **168**, 972-973; [2] Schumann, U. (1988) *Boundary-Layer Meteorol.*, **44**, 311-326; [3] Schmidt, H. and U. Schumann (1989) *J.Fluid Mech.*, **200**, 511-562; [4] Clow, G.D. (1987) *Icarus*, **72**, 95-127.

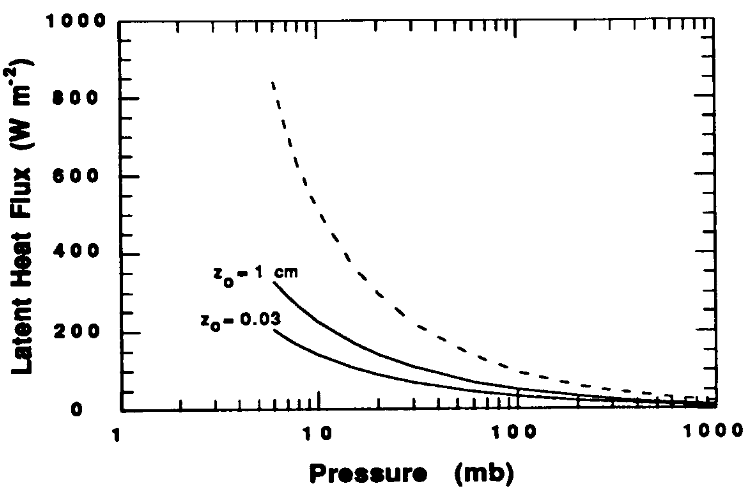


**Figure 1:** Predicted minimum evaporative heat losses from an icy surface at 273° K. Two surface roughness values are considered. Shown for comparison are the free convection predictions of Ingersol [1]. (dashed line).

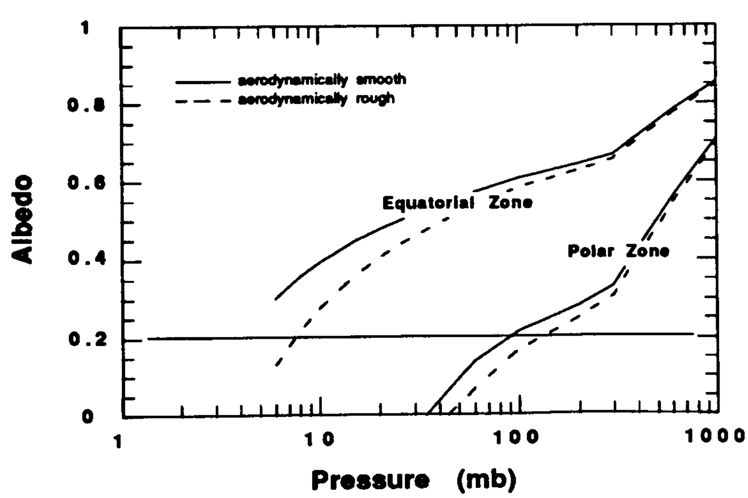


**Figure 2:** Highest albedos for which ice can melt under optimal conditions, assuming all the available net radiation is used to balance evaporative heat losses.