CARNOT THERMODYNAMICS OF THE MARTIAN ATMOSPHERE.

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Introduction:

While many details of Martian meteorology and climatology can be studied with GCMs and other detailed numerical models, a useful perspective can still be offered by simple thermodynamic considerations. The dissipation exerted by the atmosphere in modifying the surface, and in levitating opacity sources against gravity, must relate to the capability of the atmosphere to produce work, which in turn is governed by the energy (heat) flows available, and the Carnot efficiency with which these heat flows can be converted into work.

Radiative Setting:

Mars' distance from the sun sets fundamental limits on the energetics of the atmosphere. However, it should be noted that the energy budget is only a modest factor smaller than Earth. Furthermore, the low infrared opacity of the atmosphere implies a small (~2K) greenhouse effect : this means meridional (latitudinal) heat transport from low to high latitudes, or pole-to-pole at high obliquity, is comparatively more effective than on Earth, while vertical convection is less effective. Some simple expressions for these heat flows and the work they can generate will be presented. It is instructive to compare these figures with Earth, Venus and Titan.

Manifestation of Heat Flow:

The low mass density of the Martian atmosphere means that to transport a given amount of heat (only a modest factor smaller than on Earth) the atmosphere must move correspondingly faster. This is indeed the case, and the skewed (e.g. Weibull [1]) windspeed distributions observed on Mars can be compared with those on Earth.

Another important factor is latent heat transport – the annual pressure cycle and the growth and decay of the seasonal polar caps involves a substantial pole to pole transport of latent heat. When latent heat transport is taken into account, the surprising conclusion that Mars' atmospheric heat transport is not much less than that of Earth's is reached. It may not be coincidence, in that both (and that of Titan) correspond to the heat transports associated with a maximum power output, or maximum dissipation, in these 3 climate systems [2].

Applications:

Since the driving force of winds is heat transport, and the frictional dissipation associated with winds can be equated to the work made available by the heat transport, it follows that limits can be placed on the windspeed distributions on the Martian surface. For a given average wind velocity (speed and direction) there are many possible histories or distributions of direction and speed – many of which will have dissipations larger than are permitted by the capacity of the atmospheric engine. This limit may therefore be a useful constraint or check on more detailed dynamical models.

Furthermore, since many of the processes of interest on Mars (dust raising, sand transport etc.) are mechanical processes, thermodynamic limits on mechanical work can make useful and easy estimates of the extent to which they occur, without invoking detailed mechanistic calculations.

Furthermore, these simple considerations are readily extensible to other climate regimes – e.g. higher obliquity or thicker atmosphere. One application being explored by the author is the vigour of the Martian hydrological cycle, and the likely resultant salt transport, which may have left a global geochemical signature.

[1] R. D. Lorenz,'Martian Surface Windspeeds, described by the Weibull distribution', *Journal of Spacecraft and Rockets,* vol. 33, pp.754-756, 1996
[2]R. D. Lorenz, J. I. Lunine, C. P. McKay and P G Withers, Entropy Production by Latitudinal Heat Flow on Titan, Mars and Earth, *Geophysics Research Letters* 28, 415-418, 2001