THE COUPLED ROLES OF DUST AND WATER ICE CLOUDS IN THE MARS APHELION SEASON.
A.V.Rodin (IKI, Profsoyuznaya 84/32, 117810 Moscow, Russia. e-mail rodin@irn.iki.rssi.ru), R.J.Wilson (GFDL/NOAA, P.O. Box 308, 08542 Princeton, NJ), R.T.Clancy (SSI, P.O. Box 3075, Bald Head Island, NC 28461), M.I.Richardson (GPS/Caltech, 1200 E, California Blvd, Pasadena, CA 91125)

Introduction: A new picture of the Mars aphelion season is increasingly becoming evident. A combination of data sources indicate a cooler atmosphere than had been inferred from Viking lander and IRTM observations. Revised IRTM T_{15} estimates [1] now indicate temperatures consistent with microwave[2] and MGS/TES[3] observations and show little diurnal temperature variation in this season which is consistent with a cooler, and presumably, less dusty (at 0.5 mb) atmosphere. These cooler temperatures imply a relatively low water ice cloud condensation level. Extensive cloud coverage has been observed during NH spring and summer season [2, 4], consistent with lifting associated with the Hadley circulation.

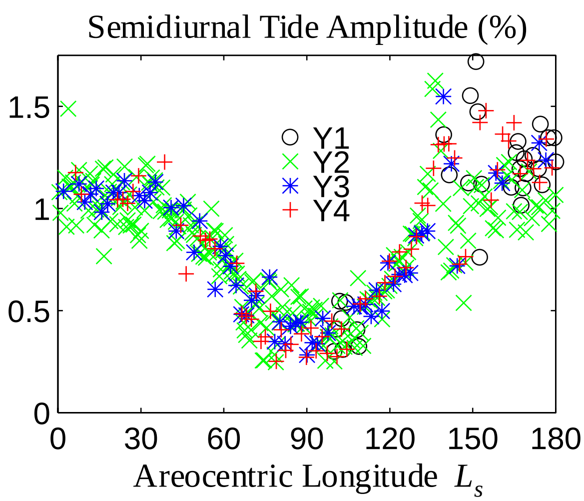

Figure 1. VL1 semidiurnal tide amplitude for 4 Mars years.

The aphelion season is apparently characterized by little interannual variability [5], especially relative to the perihelion dust storm season. This is further indicated by consideration of the 4 year record of tidal surface pressure oscillations at the VL1 site (see Fig.1). Viking IRTM and Mariner 9 IRIS temperatures indicate a rapid atmospheric cooling following solstitial dust storms so that by mid NH spring temperatures are consistent with those following winter seasons without dust storms. The Viking IRTM data indicate a rapid temperature increase of ~10 K at Ls~147 in two consecutive years that is coincident with transient changes (Tillman transients) in the surface pressure tides at the Viking landers[1]. There do not appear to be any obvious opacity changes at the VL sites in this season. MGCM simulations of the semidiurnal zonal wave two Kelvin mode [6] suggest that the tide amplitude variation observed by VL1 are consistent with a fairly invariant column-integrated optical depth through the NH spring and summer seasons i.e. a period centered around aphelion (L_s=70). We speculate that the temperature jump (at 0.5 mb; 25 km) may be associated with a discrete shift in the depth of the layer of dust heating. We envision that the dust cloud is "capped" by water ice clouds that nucleate on dust cores. Thus we propose that water ice clouds provide a major impact to the thermal balance of the atmosphere, particularly in aphelion season. This impact is a combination of three different mechanisms working together and each being involved in the positive feedback with thermal field.

Under Martian conditions, the main source of nucleation centers for the clouds are dust particles, which are the major absorber of solar radiation. As a particle nucleates, it dramatically increases its albedo, from 0.8-0.9 to 0.97, damping solar heating. Another effect consists of intensifying IR cooling; in thermal infrared the albedo remains low, typically about 0.1-0.2. Provided that condensational growth of particles results in increasing infrared opacities, the cloud layer appears to be an efficient radiator. Finally, condensational growth of icy shells around dust particles changes their mass and consequently, gravitational settling rate, so that the particles settle much faster above condensation level than below it. In effect, the dust layer, a source of solar heating, is efficiently limited by cloud processes.

All the above processes lead to the cooling of the atmosphere, with each having its typical time-scale. Condensational growth rate ranges from almost instantaneous to 10^6 *sec*, and the radiative response of the atmosphere is about 10^5 *sec*. In turn, the vertical structure of the aerosol layer typically equilibrates with a characteristic timescale of $H^2/K \approx 10^6$ *sec*, which is also comparable to the settling time. Thus the changes of temperatures we expect to occur while Mars switches between ‘aphelion’ and ‘perihelion’ climate modes may be accompanied by complex transient events, which temporal evolution reflects the interactions of all those processes.

Simulations: 1D modeling [7], which incorporates the expected thermal and dynamical feedbacks, has suggested that bistable dust and temperature distributions are a possible consequence of these physical mechanisms. We anticipate that water ice clouds during the

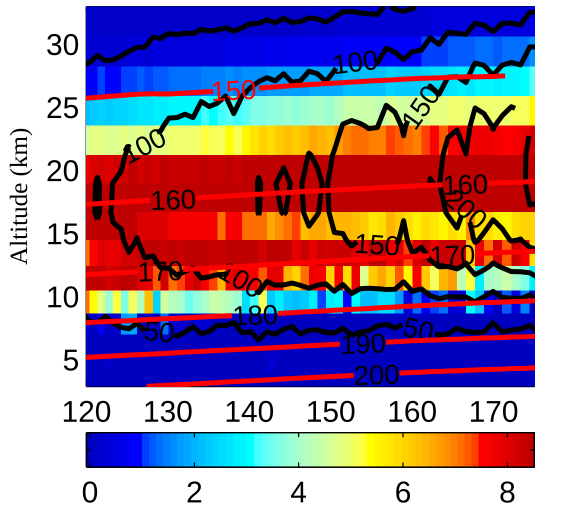

Figure 2. 1D simulation of cloud (black contour), pure dust (color map) and temperature (red contour) for L_s=120°-180° and ϕ = 9°N.

aphelion season serve to stabilize the middle atmosphere (above 25 km) to temperature perturbations by confinement of dust below the condensation level. On the other hand, the strong nonlinearity of the thermal feedback mechanisms may provide a threshold-like behavior of temperature during the transition period when the atmosphere is warming up and radiatively active dust is released to higher altitudes.

Fig. 2 shows the 1D simulation of dust, ice aerosol and temperature fields near aphelion. The low-altitude cloud layer appears to confine virtually all the dust, which mixing ratio is as low as of ten ppb, while the coated particle mixing ratio is becoming about 100-200 ppm, so that the actual aerosol opacity increased from 0.2 to approximately unity. The lack of ice-free dust near the surface may be a result of intense turbulent mixing between saturated and nonsaturated layers and scavenging the particles by morning fogs. There is no evidence of any transition of the thermal regime like tidal data indicated in Fig. 1 show, that suggests that in the 1D calculations the atmosphere remains in the 'cold' mode dominated by clouds. However, the rising diurnal–average temperature is followed by gradual lifting of dust by eddy diffusion, which at some point will result in release of large amounts of dust particles following the subliming water. Figure 3 shows zonally-averaged temperatures from a MGCM simulation employing simple approximations of the physics for the dust/ice cloud processes. The model simulation, which does not properly represent microphysics but does incorporate the essence of the feedback mechanism, yields a minimum 0.5 mb temperature at L_s~70. The dominant contribution to the

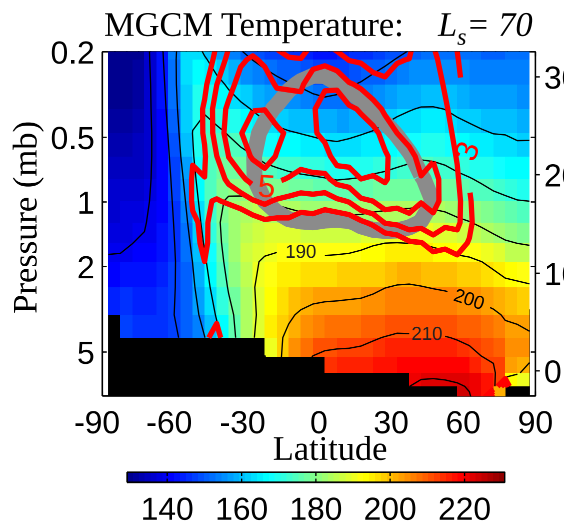

Figure 3. GCM simulation of thermal effect of clouds

atmospheric opacity (~0.5) comes from 1.6-µm particles. The resulting thermotidal forcing yields a semidiurnal surface pressure oscillation similar to Fig.1. A parallel simulation without the cloud influence was also carried out and the cooling effect due to the clouds is indicated by the red contours with a maximum of 6 K. The region of cooling closely corresponds to the vicinity of the water ice cloud enclosed within the grey contour. The simulation indicates that a cool middle atmosphere may coexist with a modestly dusty troposphere, with thermotidal heating consistent with the Viking lander tide observations.

Discussion: Interannual repeatability of the thermal pattern in the aphelion season followed by numerous perturbations suggests that dust is continuously supplied into the lower atmosphere by stochastic events, while the post-perihelion traces of dust storms are efficiently settled out. We envision the dust injection to be a consequence of dust devil activity, which may maintain the background dust distribution in the Mars atmosphere. The dynamical response of the atmosphere to the dust mobilization is known to play a role in the genesis of dust storms. In turn, the interaction with aphelion cloud system might be a significant mechanism of its damping. We intend to explore this hypothesis by means of MGCM involving comprehensive microphysics of clouds.

References: [**1**] Wilson R.J. and Richardson M.I. (1999) *Icarus*, in review. [**2**] Clancy R.T. et al. (1996) *Icarus*, 122, 36-62. [**3**] Clancy R.T. et al. (1999) submitted to *JGR*. [**4**] James P.B. et al. (1996) *JGR*, 101, 18883-18890. [**5**] Richardson, M.I. (1999) *JGR*, 103, 5911-5918. [**6**] Wilson, R.J. and Hamilton K.P. (1996) *JAS* 53 1290-1336. [**7**] Rodin A.V. et al. (1999) *JASR* in press.