

**MODELING MARS CYCLOGENESIS AND FRONTAL WAVES: SEASONAL VARIATIONS AND IMPLICATIONS ON DUST ACTIVITY.** J.L. Hollingsworth<sup>1</sup>, M.A. Kahre<sup>1</sup>, <sup>1</sup>NASA Ames Research Center, Planetary Systems Branch, Moffett Field, CA 94035, (jeffery.l.hollingsworth@nasa.gov; melinda.a.kahre@nasa.gov).

**Introduction:** Between late autumn through early spring, middle and high latitudes on Mars exhibit strong equator-to-pole mean temperature contrasts (i.e., “baroclinicity”). Data collected during the Viking era and observations from both the Mars Global Surveyor (MGS) and Mars Reconnaissance Orbiter (MRO) indicate that such strong baroclinicity supports vigorous, large-scale eastward traveling weather systems (i.e., transient synoptic period waves) [1, 2]. For a rapidly rotating, differentially heated, shallow atmosphere such as on Earth and Mars, these large-scale, extratropical weather disturbances are critical components of the global circulation. The wave-like disturbances serve as agents in the transport of heat and momentum between low and high latitudes of the planet. Through cyclonic/anticyclonic

frontal waves also exhibit extended meridional structure. The parenting cyclones and anticyclones tend to develop, travel eastward, and decay preferentially within

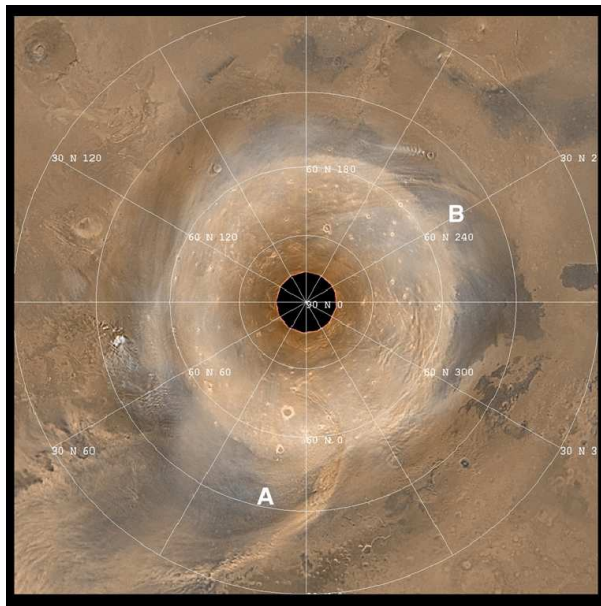


Fig. 1: MGS/MOC image obtained on 30 March 2002 when the season on the planet was near northern spring equinox ( $L_s = 350.0^\circ$ ), and shows an intense large-scale frontal wave disturbance and accompanying dust storm that extends from the north polar region into the subtropics.

winds, intense shear deformations, contractions-dilatations in temperature and density, and sharp perturbations amongst atmospheric tracers (i.e., dust, volatiles (e.g., water vapor) and condensates (e.g., water-ice cloud particles)), Mars’ extratropical weather systems have significant sub-synoptic scale ramifications by supporting atmospheric frontal waves (Fig. 1).

The northern weather systems with accompanying

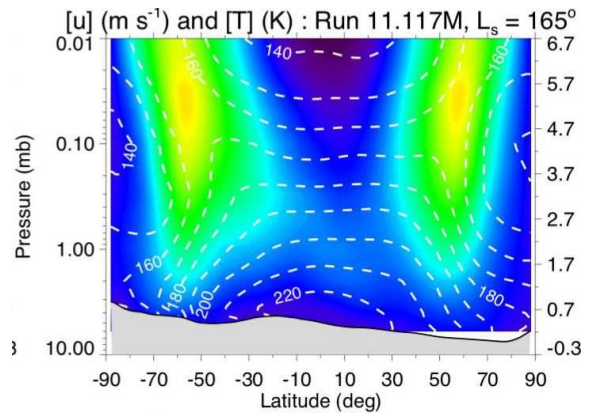


Fig. 2: The time and zonally averaged zonal wind ( $m s^{-1}$ ) and temperature (K) during late northern summer ( $L_s = 165^\circ$ ) from the ARC Mars GCM simulation. Zonal wind is indicated in color and the temperature contour interval is 10 K.

certain geographic regions (i.e., “storm tracks” or “storm zones”), where the intensity of, and associated atmospheric variability with such disturbances is most intense.

Extratropical synoptic scale weather systems occur in both hemispheres of Mars. Northern hemisphere disturbances are significantly more intense than their counterparts in the southern hemisphere [1, 2]. With regards to atmospheric dust, frontal waves appear to be key agents in the lifting, lofting, organization and transport of this particular atmospheric aerosol. The northern frontal waves can also serve as a mechanism for the inter-hemispheric exchange of dust between northern and southern latitudes (i.e., so-called “flushing” dust storms).

Ascertaining the nature of extratropical weather systems via carefully-selected numerical experiments with a highly-sophisticated Mars global circulation model, and comparing such simulations with recent spacecraft observations, can improve our understanding of the roles such weather disturbances play in Mars’ dust cycle, and their overall effect on the present climate.

**Climate Model:** We extend our initial work on modeling Mars’ cyclogenesis and frontal-wave development, and its effects on atmospheric dust [3] by performing analyses of a small suite of annual, high resolution simulations utilizing the NASA ARC Mars gen-

eral circulation model (GCM). We utilize the NASA ARC Mars GCM version 2.1 to investigate the lifting,

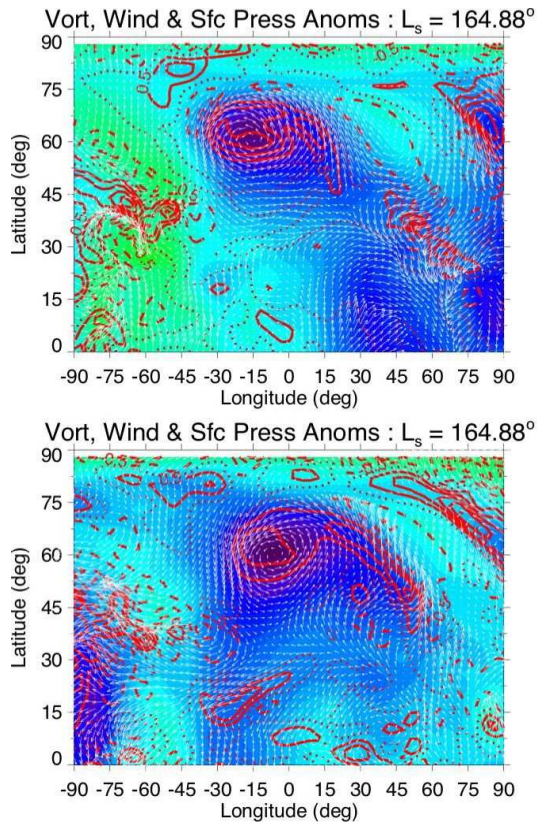


Fig. 3: Time slices of instantaneous relative vorticity, near-surface horizontal winds and surface pressure anomalies at late northern summer ( $L_s = 165^\circ$ ) from the Mars GCM simulation at  $t = t_0$ ,  $t = t_0 + 12$  hr.

lofting, transport and sedimentation of dust within extratropical weather systems and associated frontal wave disturbances. This version runs with an updated radiation code based on a two-stream approximation with correlated  $k$ 's, and a cloud microphysics scheme that assumes a log-normal particle size distribution whose first two moments are carried as tracers, and which includes the nucleation, growth and sedimentation of ice crystal. Dust is fully “interactive”; that is, it is lifted from the surface via a stress-based dust lifting scheme, and once lofted into the atmosphere it is radiatively active. Our model configuration is G60L24 which corresponds to a horizontal resolution of  $2 \times 3^\circ$  latitude-longitude, with 24 unequally-spaced vertical layers that have higher vertical resolution near the surface. For initialization, the simulation is started from an isothermal, circulation-free and dry atmosphere. The source of water vapor in the climate simulations is the north polar residual cap (NPRC) with a better geographic representation that accounts for both surface-ice and bare-soil components.

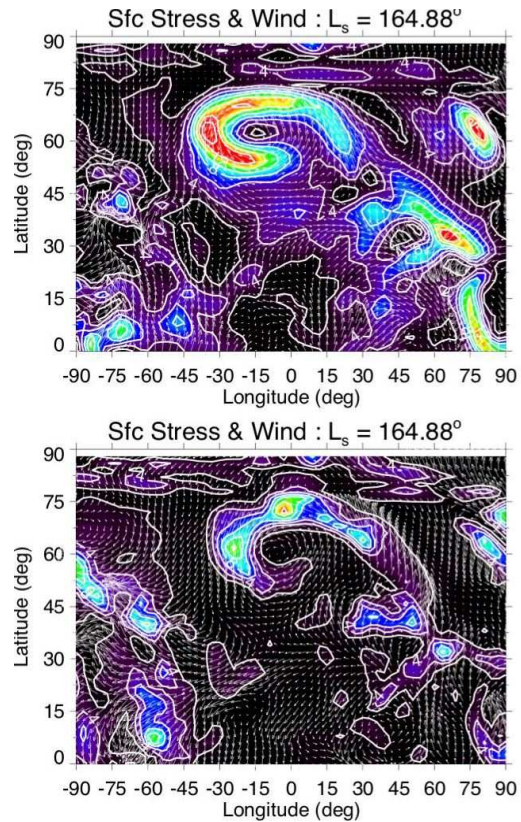


Fig. 4: Time slices of instantaneous surface stress and near-surface horizontal winds at late northern summer ( $L_s = 165^\circ$ ) from the Mars GCM simulation at  $t = t_0$ ,  $t = t_0 + 12$  hr.

**Results:** It is found that during late autumn, late winter and early spring, the simulated synoptic weather systems are most intense and have the largest scales. There is a significant relative minimum in synoptic-period wave activity close to northern winter solstice, even though the background baroclinicity is at its peak and extends vertically over several scale heights.

Extratropical surface stress fields associated with the weather systems are the greatest and more spatially coherent (i.e., long-lived) at seasons bracketing the winter solstice period, and they often exceed the dust lifting threshold value. At winter solstice, maximum surface stresses frequently occur over the western hemisphere highlands and are associated with significant upslope/downslope flows.

Fig. 2 shows the mean zonal wind and thermal structure during northern late summer. It can be seen that there is considerable baroclinicity in the northern and southern extratropics. Shown in Fig. 3 are instantaneous fields of surface pressure anomaly from a global mean value (color shading), the near-surface horizontal winds (white vector arrows) and the relative vorticity

(red contours). Similarly, shown in Fig. 4 are instantaneous surface stress magnitude (color shading) and the near-surface horizontal winds in the northern hemisphere. In this time sequence of meteorological fields, a long-lived cyclonic vortex is apparent, and associated with this particular large-scale weather system the surface stress values exceed the threshold lifting value.

We examine the seasonality of northern hemisphere synoptic weather systems in our Mars global climate model simulations, the nature of cyclogenesis and frontal wave activity (development, maturation and decay), and the impacts on dust lifting, lofting and transport. We adapt frontal wave circulation diagnostics to examine the nature of Mars' cyclogenesis, frontal wave intensity and correlations between dust lifting/lofting, organization and transport.

**Further Work:** We plan to further investigate the

nature of such spatial asymmetries in atmospheric dust, and, to perform correlative studies and diagnostics with large-scale circulation patterns, in order to identify physical mechanisms for such spatial variability.

Mars GCM studies related to coupling the dust and water cycles (i.e., in particular, with radiatively active water vapor and water ice clouds) is presented at this workshop in [4].

**References:** [1] Banfield, D., et al. (2004): *Icarus*, 170, 365. [2] Barnes J.R., et al. (1993): *J. Geophys. Res.*, 98, 3125. [3] Hollingsworth, J.L., and M.A. Kahre: *Geophys. Res. Lett.*, 37, L22202. [4] Kahre, M.A., et al. (2012): (this workshop).

**Acknowledgements:** This research has been supported by NASA and the Mars Fundamental Research Program (MFRP) within the Planetary Science Division.