STATIONARY PLANETARY WAVES IN NORTHERN LATE WINTER: MRO/MARCI OBSERVATIONS AND MARS CLIMATE MODEL SIMULATIONS. J.L. Hollingsworth[1], M.A. Kahre[1], M.J. Wolff[2], R.M. Haberle[1], [1]NASA Ames Research Center, Space Science and Astrobiology Division, Planetary Systems Branch, Moffett Field, CA 94035, (jeffery.l.hollingsworth.nasa.gov), [2]Space Science Institute, (mjwolff@spacescience.org).

Introduction: Mars reveals similar, yet also rather different, atmospheric circulation patterns compared to those on Earth. In both atmospheres, solar differential heating drives global Hadley circulation cells. However during solstice on Mars, its Hadley cells are hemispherically asymmetric: an intense, deep, cross-hemisphere single cell dominates with rising motion in the summer hemisphere and sinking motion in the winter hemisphere. Both planets also exhibit thermally indirect (i.e., eddy-driven) Ferrel circulation cells in middle and high latitudes. In addition, Earth and Mars exhibit distinctive large-scale orography and, in a broadly defined context, continentality. For Mars' northern midlatitudes, Tharsis in the western hemisphere, and Arabia Terra and Elysium in the eastern hemisphere, are the primary large-scale topographic features. In the southern midlatitudes, Tharsis and Argyre in the western hemisphere, and Hellas in the eastern hemisphere are the key topographic features which can influence large-scale circulation patterns. Such underlying orographic complexes not only cause significant latitudinal excursions of the seasonal mean westerly circum-navigating polar vortex [1] but also significantly modulate the intensity and preferred geographic regions of traveling baroclinic weather systems [2].

Evidence for large-scale, quasi-stationary wave disturbances (i.e., forced Rossby modes) within the atmosphere of Mars has come from spacecraft measurements obtained from the Mars Global Surveyor (e.g., TES and RS) and Mars Reconnaissance Orbiter (e.g., MCS) [3]. Here we utilize observations from the "Mars Color Imager" (MARCI, [4]) instrument on board MRO. MARCI offers a UV channel that emphasizes the contributions of water ice clouds. As such, the MARCI data directly provide for the generation of ''daily global maps" (DGMs) of water-ice cloud optical depth for use in dynamical modeling studies and atmospheric remote sensing [5]. ''Band 7" data are utilized from the MARCI instrument which has a centroid of 321 nm, a radiometric accuracy of 6-8%, and a radiometric precision of 2-3%. The spatial sampling provides near-global daily coverage at 8 km/pixel (nadir). Such observations are placed into a global and climatological context by utilizing a state-of-the-art Mars global climate model with newly added physical processes and parameterizations developed and maintained at the NASA Ames Research Center [6].

Mars Climate Model: Major improvements have been made to the NASA ARC Mars global climate model (GCM) to enhance its capabilities and to standardized its infrastructure. Improvements include an updated radiation code based on a generalized two-stream approximation for radiative transfer in vertically inhomogeneous multiple-scattering atmospheres, together with a correlated-k method for calculating gaseous opacities. A sophisticated cloud microphysics package has been included. Typically, the cloud microphysics module 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 particles. The radiation code can be keyed to respond to a prescribed dust distribution based on an "opacity climatology" derived from MGS/TES 9 μm opacity measurements. The cloud microphysics code interacts with a transported dust tracer whose surface source is adjusted to maintain an atmospheric column abundance as observed by TES. Aerosols of dust and water ice, in addition to water vapor, can be separately or collectively either radiatively inert or radiatively active.

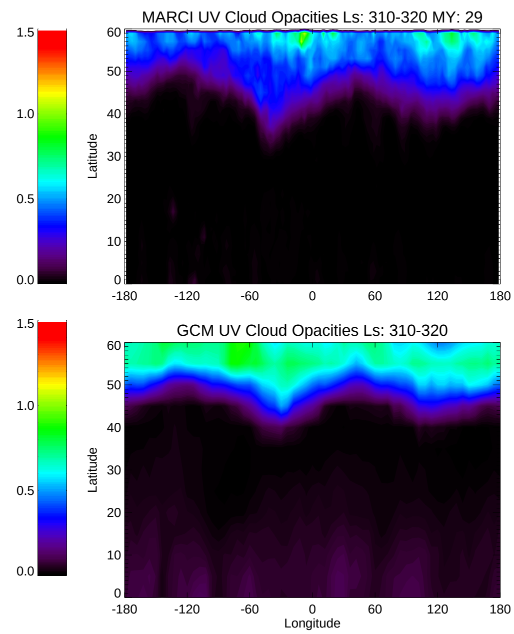

Fig. 1: The time averaged (a) MARCI UV cloud opacities from MY29 during late NH winter (L_s = 315°) and (b) time averaged GCM UV cloud opacities from simulation with radiatively active clouds (RAC).

The vertical coordinate of the climate model is a normalized pressure (σ) terrain-hugging one which enables the lower boundary with spatially-varying topography to coincide with a coordinate surface. The model's dynam-

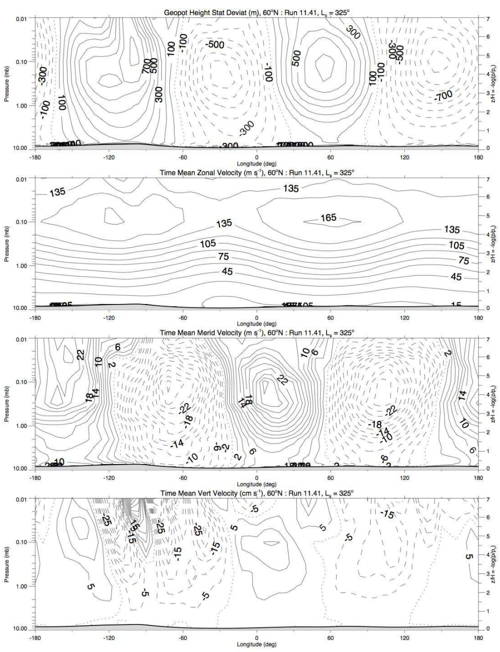

Fig. 2: The time averaged (a) zonal departures of geopotential height (m), (b) zonal wind (m s^{-1}), (c) meridional wind (m s^{-1}) and (d) vertical wind (cm s^{-1})from the Mars GCM simulation during NH late winter (L_s = 325°) with radiatively active clouds (RAC).

ical processor is modular finite-difference core based on an Arakawa "C"-grid and it incorporates improved tracer transport. The model configuration adapted has 24 unequally-spaced σ layers with a model "top" pressure of 5×10^{-4} mbar. Vertical spacing between layers increases from $\mathcal{O}$(10 m) at the surface to $\mathcal{O}$(5 km) in the upper-most part of the model. In the horizontal, a 5.0° × 6.0° longitude-latitude resolution is imposed yet higher resolutions are also possible. This latest version has been termed *Mars GCM, version 2.1*.

Results: As indicated in Fig. 1a, during late NH winter (L_s = 310–320°) MRO/MARCI UV cloud opacities from MY29 are highest in the middle and high latitudes. In addition, a very pronounced east-west "undulation" at planetary- and large-scales is apparent which has the appearance of a zonal wavenumber 2 to 3 pattern. Analysis of late winter Mars GCM simulations of seasonal mean UV cloud opacities (Fig. 1b) with radiatively active clouds (RAC) indicate similar patterns although the magnitudes are roughly 1–2 × larger. A large-scale atmospheric wave pattern in the NH extratropics also occurs during this season, commensurate with the observations, and it is longitudinally in phase with the measurements.

Continental-scale topographic relief and a resultant and quasi-stationary atmospheric wave feature appear to be responsible for the east-west undulation seen in the MARCI data. In the Mars GCM simulations, the analysis of model integrations in reference to these observations support similar large-scale, seasonal-mean wave patterns with regards to water vapor mixing ratio and water-ice cloud mean optical depths. The wave pattern is a signature of a strong zonal wavenumber ($s = 2$) stationary Rossby mode as can bee seen in Fig. 2.

The expression of a large (planetary scale) quasi-stationary mode is consistent with a mean zonal background state of westerly zonal winds and, one with conducive effects of horizontal mean curvature (u_{yy}) and vertical shear (u_z) [7,8,9]. Moreover, dynamical conditions exist that, even in the weakest sense of east-west asymmetries in geographic "continentality" (orography), and/or thermal contrasts in surface albedo and thermal inertia, suffice to provide near-surface "forcing" of such large-scale planetary (Rossby wave) modes. Results from radiatively passive cloud (noRAC) climate simulations show a very similar stationary wave pattern at this season. This is in direct contrast to a very intense enhancement of the traveling baroclinic waves in the radiatively active cloud case.

Summary: MRO/MARCI UV cloud opacity data are very useful data products that can be combined with Mars GCM simulations to help provide dynamical contexts for the observations. Further, large-scale wave structures are apparent in the data and they appear to have similar wave patterns produced by the climate model. The nature of the wave activity seen in seasonal-mean maps from MARCI appear to be forced, quasi-stationary Rossby wave disturbances which arise due to the planet's large relief and within a conducive planetary waveguide (westerly polar vortex). The imposition Mars' strong baroclinicity supports intense and vigorous quasi-stationary planetary wave modes particularly in northern late winter/early spring. Changes in such wave patterns during seasonal progression will be further examined.

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