EQUATORIAL NEAR-SURFACE ATMOSPHERIC TEMPERATURE PROFILES: OPPORTUNITY MINI-TES OBSERVATIONS AND HIGH-RESOLUTION MARSWRF SIMULATIONS A. Toigo[1], T. Siili[2], M. Richardson[3], [1]Cornell University, Ithaca, NY 14850; toigo@astro.cornell.edu, [2]European Space Agency, Directorate of Science and Robotic Exploration, C/o NASA/GSFC, Mailcode 671.1, 8800 Greenbelt Road, MD, 20771, USA; tero.siili@esa.int, [3]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125; mir@gps.caltech.edu.

Introduction: The multifunctional Planetary Weather Research and Forecasting (planetWRF) atmospheric model [1] has been employed in its large eddy simulation (LES) mode to simulate the planetary boundary layer (PBL) of the Martian atmosphere at the Opportunity Mars Exploration Rover (MER) landing site in Terra Meridiani during the initial landing period, specifically at L_s = 6°–11°. Comparison to Mars Exploration Rover Mini-TES temperature data will be presented. We have specifically focused on the three dimensional structure of convection and the dominant length scales for heat and momentum transport.

Observations: The Mars Exploration Rovers' Miniature Thermal Emission Spectrometer (Mini-TES) observations of the atmosphere have provided information about vertical structure of atmospheric temperature, column-integrated aerosol optical depth and water vapor abundance in the martian planetary boundary layer, between altitudes of about 20-2000 m above the surface. Observations of near-surface and surface brightness temperatures have also been made [2,3].

The observational path has typically been at a 30° angle above the horizon, placing the horizontal distance of the 2000 m altitude to about 4000 m. The instrument can obtain a spectrum once every 2 s, but typically at least about a hundred spectra are averaged to improve the signal-to-noise ratio. The time resolution is of such observation sets is hence about 1 min or less. As a baseline we use averaged sets in our studies, but plan also to investigate the effects of averaging smaller number of spectra to perhaps identify shorter timescale phenomena. The MER rovers do not have pressure sensors on-board, hence the surface pressure estimate used in the retrieval is derived from Mars Global Circulation Model estimates. The uncertainties are estimated to be 2-4 K for the temperature profiles, the larger of 0.02 or 5% of the total for the optical depth, and 5 pr μm for the water vapor abundance.

Due to power and operational constraints most of the observations have been taken between 10:00 and 17:00 local time, though a small number are available from the nighttime. In this work we are focusing on observations taken by the Opportunity during the initial phase. Some sample Mini-TES temperature profiles are shown in Fig. 1.

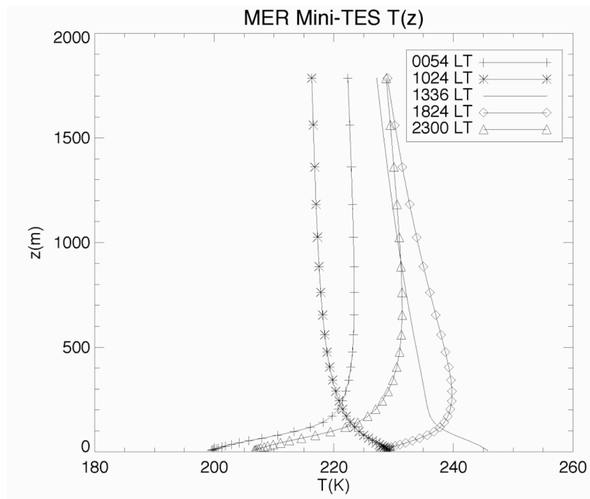

Fig. 1 Mini-TES vertical profiles at different local times from the initial landing period. The plus and triangle symbols show nighttime measurements, while the other symbols show measurements scattered through the morning, early afternoon and evening.

The MarsWRF model: The planetWRF model is an enhancement and generalization of the National Center for Atmospheric Research's (NCAR) Weather Research and Forecasting (WRF) model [1]. MarsWRF is a subset of the planetWRF model that uses Mars-specific physical parameterizations, including specific orbital constants, radiation (including dust), surface and subsurface heat budget with observation-derived properties, and a CO_2 cycle. The model can operate at a variety of scales, from the global to the micro, as well as simulating multiple scales at the same time through the use of either nesting or so-called "stretched" grids.

Large Eddy Simulations: In order to accurately simulate the boundary layer behavior, the model was operated in its microscale mode (horizontal resolution of 20-100 m) with boundary layer parameterizations turned off. In order to represent turbulence on scales smaller than the grid spacing, we use a three-dimensional diffusion scheme with diffusivities based on the formulation of Smargorinsky (1963) [4]. A surface layer parameterization is included to simulate heat and momentum exchange at the interface between soil and atmosphere.

Experiment Design: We chose to simulate the boundary layer at a location corresponding to the Opportunity landing site (using appropriate values of albedo, thermal inertia, elevation, and value of the Coriolis parameter) and corresponding in season to the beginning of the mission where the density of diurnal observations was relatively large. Periodic boundary conditions and uniform surface properties were chosen for simplicity.

Four simulations were undertaken, three of which were three-dimensional large eddy simulations, and one of which was a 1D version of planetWRF used as a 1D PBL model and employing a standard 2.5 order closure scheme used in other GCMs. The three large eddy simulations differed in resolution and extent. All models were run with a model top near 15 km.

Two of the large eddy simulations were undertaken with a horizontal extent of 10 km by 10 km. To test the importance of resolution, these were run at 100 m and 20 m horizontal resolution. Given that the aspect ratio of the largest convective cells is unknown (but expected to be in the range of 1 to 4), and the extent of the deepest eddy were not well grounded, we decided to also test the effects of horizontal confinement. Thus the third simulation had a 30 km by 30 km horizontal extent. Computational resources limited this simulation to 100 m resolution, as the use of 20 m resolution would have required a massive 1500 x 1500 grid.

Results: Here we show selected output from the MarsWRF LES runs. The simulations developed deep cellular convection and vertical vortices ("dust devils" had there been dust). We will show comparisons with the mini-TES data, highlight dust devil development, and examine how well the PBL parameterization scheme at order 2.5 closure works as compared to explicit simulation.

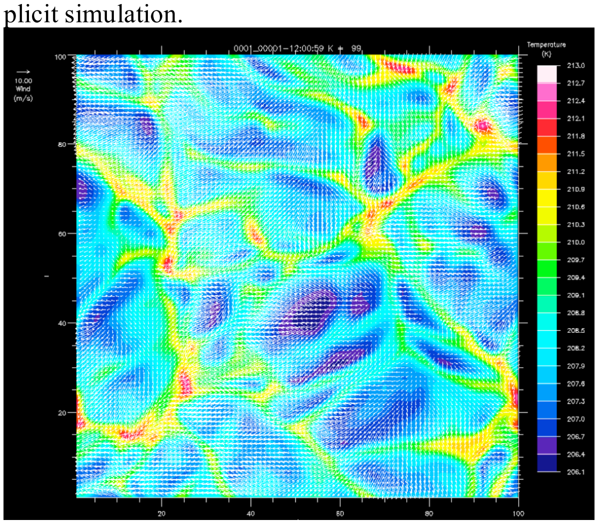

Fig. 2 Map of temperature near local noon at a height of 3 m from the 100 m resolution 10 km by 10 km simulation. Red colors show warmer temperatures, blues colder. An open cellular convective pattern can be observed.

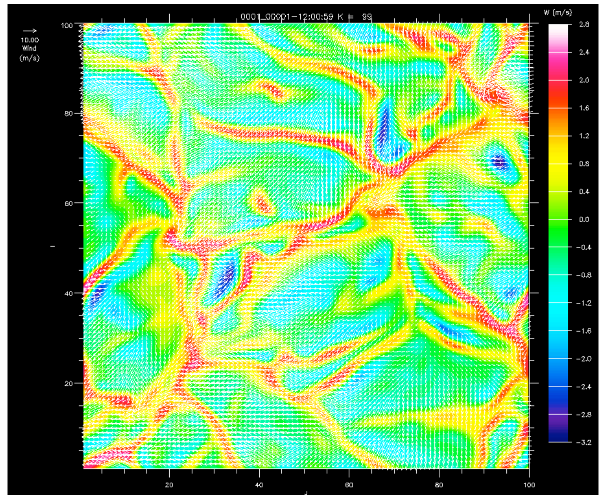

Fig. 3 Map of vertical velocity near local noon at a height of 3 m from the 100 m resolution 10 km by 10 km simulation. Red colors are upward motion, blues downward, and greens stationary. Upward motions correspond to warm temperature cell walls seen in the previous figure.

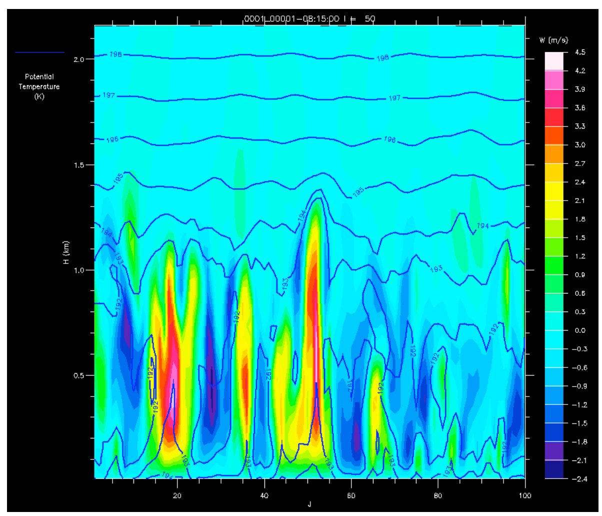

Fig. 4 Vertical cross section of vertical velocity (w) and potential temperature (θ) from around 8 AM local time from the 100 m resolution 10 km by 10 km simulation. Colors show w amplitude (red upward, cyan motionless, purple downward), and blue contours show θ. Warm upwelling plumes deflect θ contours upward, and vice versa.

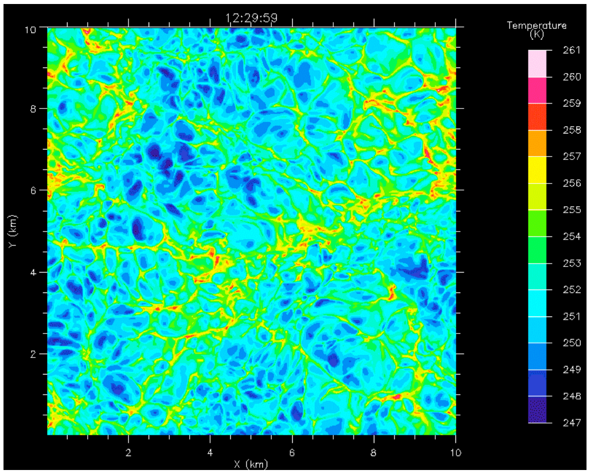

Fig. 5 Map of temperature near local noon at a height of 3 m from the 20 m resolution 10 km by 10 km simulation. Compare with Fig. 2 above. A similar large-scale open cellular convective pattern can be observed along with better-resolved smaller eddies.

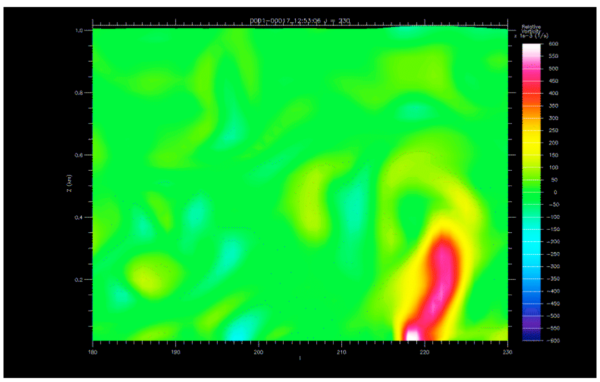

Fig. 6 Vertical cross-section of vertical vorticity ($\nabla\times V_h$) taken near local noon from the 20 m resolution 10 km by 10 km simulation. A strong 400 m tall and 100 m wide vortex ("dust devil"), which tilts with height, can be seen on the right side of the figure.

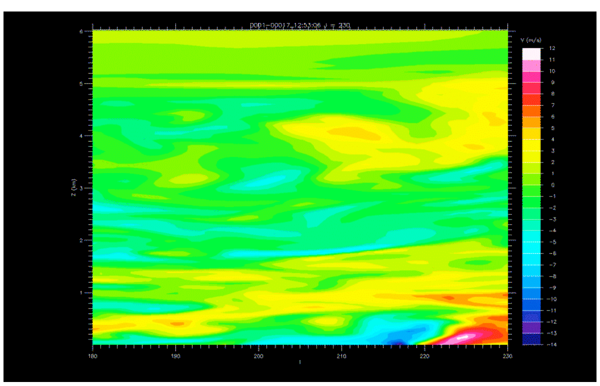

Fig. 7 Vertical cross-section of one component of horizontal wind velocity (into and out of the page) near local noon from the 20 m resolution 10 km by 10 km simulation, covering the same area as the previous figure. The presence of the "dust devil" vortex can be seen in the near-surface tangential wind speeds at the bottom of the figure, which get up to about 12 m/s.

References: [1] Richardson M. I. et al. (2007), *J. Geophys. Res.*, *112*, doi: 10.1029/2006JE002825. [2] Smith M. D. et al. (2004), *Science*, *306*, doi: 10.1126/science.1104257. [3] Smith M. D. et al. (2006), *J. Geophys. Res.*, *111*, doi: 10.1029/2006JE002770. [4] Smagorinsky, J. (1963), *Mon. Wea. Rev., 91*, pp. 99-164.

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