NASA/CR-97- 205840

INTERCHANGE # NCC2-5111

(22 January 1995 - 21 January 1997)

FINAL REPORT

Surface Lander Missions to Mars: Support Via Analysis of the NASA Ames Mars General Circulation Model

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I) OVERVIEW

We have characterized the near-surface martian wind environment as calculated with a set of numerical simulations carried out with the NASA Ames Mars General Circulation Model (Mars GCM). These wind environments are intended to offer future spacecraft missions to the martian surface a data base from which to choose those locations which meet the mission's criteria for minimal near surface winds to enable a successful landing. We also became involved in the development and testing of the wind sensor which is currently onboard the Mars-bound Pathfinder lander.

We began this effort with a comparison of Mars GCM produced winds with those measured by the Viking landers during their descent through the martian atmosphere and their surface wind measurements during the 3+ martian year lifetime of the mission. Unexpected technical difficulties in implementing the sophisticated planetary boundary layer (PBL) scheme of Haberle et al. [1993] within the Mars GCM precluded our carrying out this investigation with the desired improvement to the model's treatment of the PBL. Thus, our results from this effort are not as conclusive as we had anticipated. As it turns out, similar difficulties have been experienced by other Mars modelling groups in attempting to implement very similar PBL routines into their GCMs [Mars General Circulation Model Intercomparison Workshop, held at Oxford University , United Kingdom, July 22-24, 1996; organized by J. Murphy, J. Hollingsworth, M. Joshi]. These problems, which arise due to the nature of the time stepping in each of the models, are near to being resolved at the present. The model discussions which follow herein are based upon results using the existing, less sophisticated PBL routine. We fully anticipate implementing the tools we have developed in the present effort to investigate GCM results with the new PBL scheme implemented, and thereafter producing the technical document detailing results from the analysis tools developed during this effort. Producing such a document now would be premature.

II) MISSIONS TO MARS

1) VIKING LANDER 1 WINDS

Comparison of Mars GCM winds at the model's Viking Lander 1 location with observed winds indicates that the model does not reproduce a number of important aspects of the VL1 winds. Upon further review, we note that this unsatisfactory fit also applies to the prediction paper of Pollack et al. [1976], at least as regards wind direction. During the initial part of the Viking mission (early northern summer), observed surface wind speeds varied between 1 and 8 m s^{-1}. Wind direction rotated in a counterclockwise fashion during most of the sol (martian day), with downslope (from the southwest) flow during morning hours, from the south in early afternoon, and winds from the southeast and east (upslope) in late afternoon/evening. Modelled winds at this location and time indicate a clockwise rotation of the wind vector during the sol, and wind speeds a factor of two larger than observed (taking account of the general increase in wind speed with inecreasing distance above the surface) . These model result occur under a variety of assumptions regarding dust loading, the nature of vertical mixing of wind in the PBL, and topographic data sets. The reasons for these discrepancies in the diurnal wind variations are not understood. It is hoped that inclusion of the new PBL scheme will answer these questions.

Seasonal wind variations produced in our simulations do exhibit general agreement with observations.

2) MARS PATHFINDER

In support of NASA's Mars Pathfinder lander mission, which is currently enroute to Mars, Mars GCM simulations were analyzed to provide information regarding winds to be expected during its descent and surface operation. [Caveats from the above comparisons with the Viking Lander 1 winds were noted, since the Pathfinder landing site is in the vicinity of the VL1 site]. This information was presented at a Pathfinder mission team meeting, attended by Project Manager Tony Spear (JPL), at NASA Ames in June, 1995. Predicted winds near the surface (the model's closest grid point to the surface is ~250 meters above the ground; extrapolation of winds to the near-surface requires that the model winds be reduced by a factor of 2-3) are 5-10 m s^{-1}. Early morning winds are from the east, while near sunrise winds are from the southeast (slope is down towards the northwest at the Pathfinder landing site) The clockwise rotation of the wind vector during these early morning hours continues through the entire sol, with winds from the west by midafternoon and winds from the north several hours before midnight. Wind speeds are largest near 8AM and 8 PM local time. Additionally, we provided information regarding the winds the spacecraft might experience during its descent through the lowest 40 km of the atmosphere at 3:15 AM local time. Maximum winds (> 50 m s^{-1}) occur above 30 km, with minima in wind speed at

15 kilometers (5 m s^{-1}) and 2 kilometers (2 m s^{-1}) above the surface. Winds below two kilometers increase downward to peak values near the 250 meter level (the lowest model level) of 12 m s^{-1}. These predicted Pathfinder landing site winds, and predictions for temperatures and pressures anticipated at the site, are included in a recently submitted paper [Haberle et al., 1997].

3) MVACS

In late 1998, the Mars Volatile and Climate Surveyor (MVACS) lander will be launched towards Mars. It will touch down on the martian surface at high southern latitudes (~70° S) during the spring season there and provide the first *in situ* observations of that region of the planet.

In order to have as complete an understanding as possible of the environment the spacecraft will endure, the MVACS project requested information about weather conditions near the proposed landing site. We conducted a series of numerical simulations with the Mars GCM, and made our results available to the project. The MVACS project has utilized these wind results, in conjunction with model generated surface temperature values, to establish design criteria for their spacecraft. One concern is the possibility of very strong near-surface winds generated by both the strong thermal contrast between the ice-covered polar cap (the equatorward edge of which our model predicts to be near the landing site at touchdown) as well as the flow of mass away from the cap as it sublimes (ice changes phase from solid to vapor). The near-surface winds generated in the Mars GCM were not excessive (< 40 m s^{-1}). Our results did indicate that the temperatures at the surface were cold enough to possibly affect the performance of the spacecraft. Based upon these results, and other inputs, the latitude of landing was pushed as far poleward as possible to take advantage of the greater length of sunlight experienced there during spring/summer.

III) SURFACE WIND CLIMATOLOGY

A primary focus of this work was to develop a climatology of near-surface martian winds which would be of use to mission planning for spacecraft headed to the martian surface. As noted above, we have not yet completed inclusion of the more sophisticated treatment of the planetary boundary layer into the Mars GCM. We did, nevertheless, carry out our wind climatology analyses in order to have some information to offer mission planners, as well as to have an analysis of the current model to compare with results obtained with the improved PBL treatment.

We analyzed several year-long simulations with the focus of identifying those seasons at each model location during which winds speeds were largest, weakest, most variable, etc. For this effort, wind direction was not a considered parameter. Our nominal annual simulation, which possesses in a prescribed manner the two global dust storms observed during the initial year of the Viking mission, was our baseline experiment. Averaged 250 meter elevation wind speeds at each model location was determined for ten sol intervals (sols 1-10, 11-20,..). Figures were constructed showing the season (vector orientation) and magnitude (vector length) of the ten sol interval with the largest (Figure 1) averaged wind speed, the smallest averaged wind speed, and time of maximum variability (not shown). Early northern autumn through early northern winter (southern spring and summer) is the time interval during which wind speeds peak at most locations. This interval encompasses the two global dust storms (which began in mid-autumn and very early winter, respectively), with the winter storm being the more intense event. The latitude belt from 45° S to 10° N predominantly experiences peak winds in conjunction with the development of the second global dust storm (vectors pointing towards left in the figure). At very high southern latitudes, peak winds occur near in time to the spring equinox, apparently in conjunction with the sublimation of the seasonal carbon dioxide ice polar cap.

Analysis of daily wind variations at the start of the winter dust storm indicates pronounced spatial patterns in the time of day of maximum winds (Figure 2): southern subtropical latitude maxima shortly after midnight, northern subtropical latitude maxima in the evening, late morning maxima at northern middle latitudes, and early afternoon maxima at middle and high southern latitudes. These variations can be understood in conjunction with slope induced flows, growth and collapse of the boundary layer through the sol, and thermal contrasts between ice-covered and neighboring bare ground.

IV) MARS PATHFINDER WIND SENSOR DEVELOPMENT

The Mars Pathfinder lander, currently enroute to Mars, possesses a meteorology instrument package including a wind speed and direction sensor. This instrument was implemented by a NASA-apointed Sience Advisory Team, of which R. Haberle was a member. Beginning in early 1995, J. Murphy was invited to participate in the development and testing of the wind sensor. Dr. Murphy played a significant role in wind tunnel testing of design concepts, and in the testing and calibration of the sensor design currently enroute to Mars. Wind tunnel testing took place in June 1995 and April 1996. J. Murphy has been responsible for most of the analysis of the data collected during these testing events. Results of this testing, as well as a description of all the meteorology instruments onboard Pathfinder, are described in Seiff et al., 1997.

V) PUBLISHED PAPERS RELATED TO THIS JRI

1. The Atmosphere Structure and Meteorology Instrument on the Mars Pathfinder Lander, A. Seiff, J.E. Tillman, J.R. Murphy, J.T. Schofield, D. Crisp, J.R. Barnes, C. LaBaw, J.D. Mihalov, G.R. Wilson, and R.M. Haberle, Journal of Geophysical Research (Planets), Vol. 102, Num. E2, pages 4045-4056, 1977.

2. Meteorological Predictions for the Mars Pathfinder Lander, R.M. Haberle, J.R. Barnes, J.R. Murphy, and J. Schaeffer, Journal of Geophysical Research (Planets), submitted January, 1997.

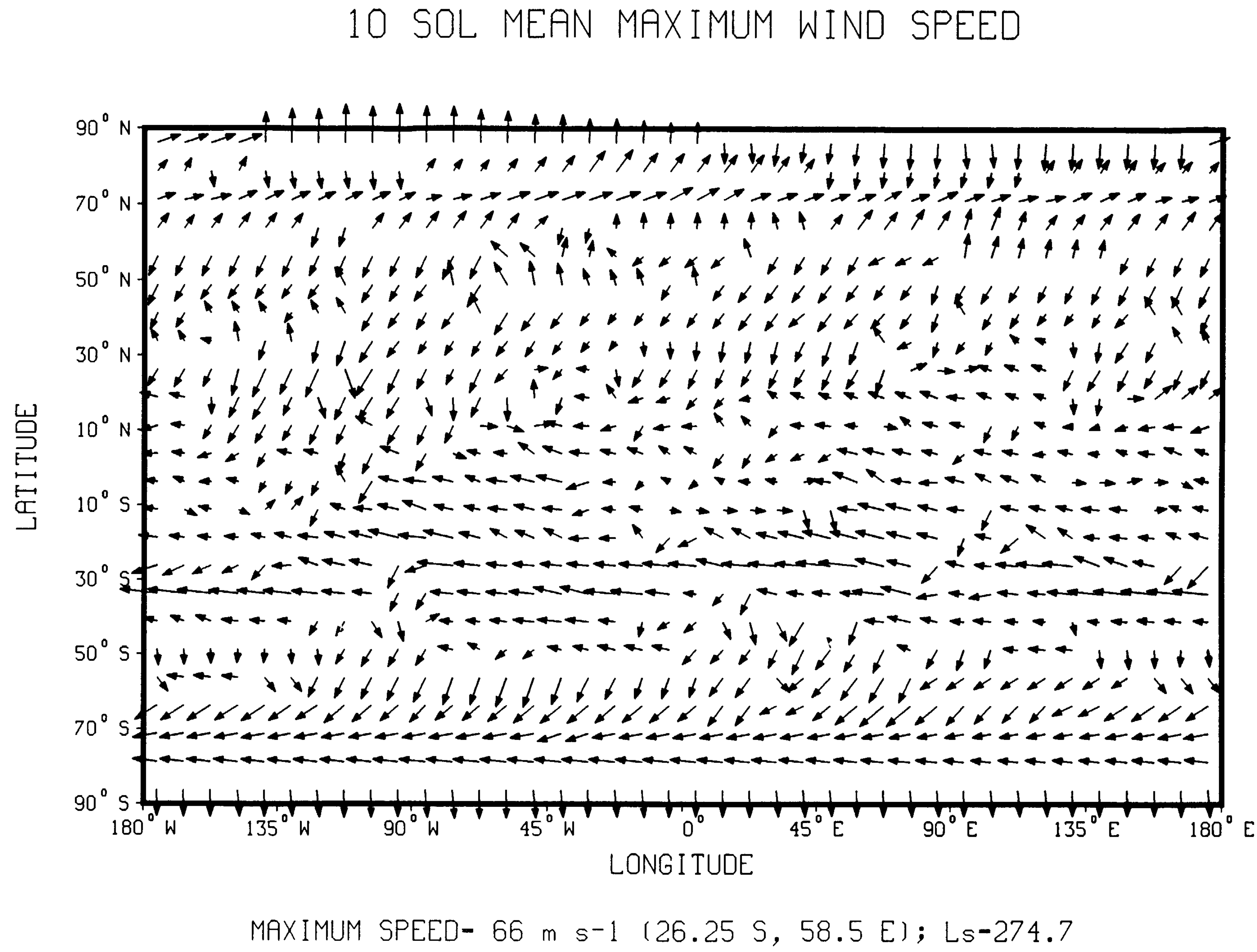

Figure 1. Maximum ten-sol averaged winds from an annual simulation of the Ames Mars GCM. Vector orientation represents season of the maximum ten-sol averaged wind speed at each model location (upward pointing: Northern Vernal Equinox; pointing to the right: Northern Summer Solstice; downward pointing: Northern Autumnal Equinox; pointing left: Northern Winter Solstice). Vector length represents ten-sol averaged wind speed (m s^{-1}).

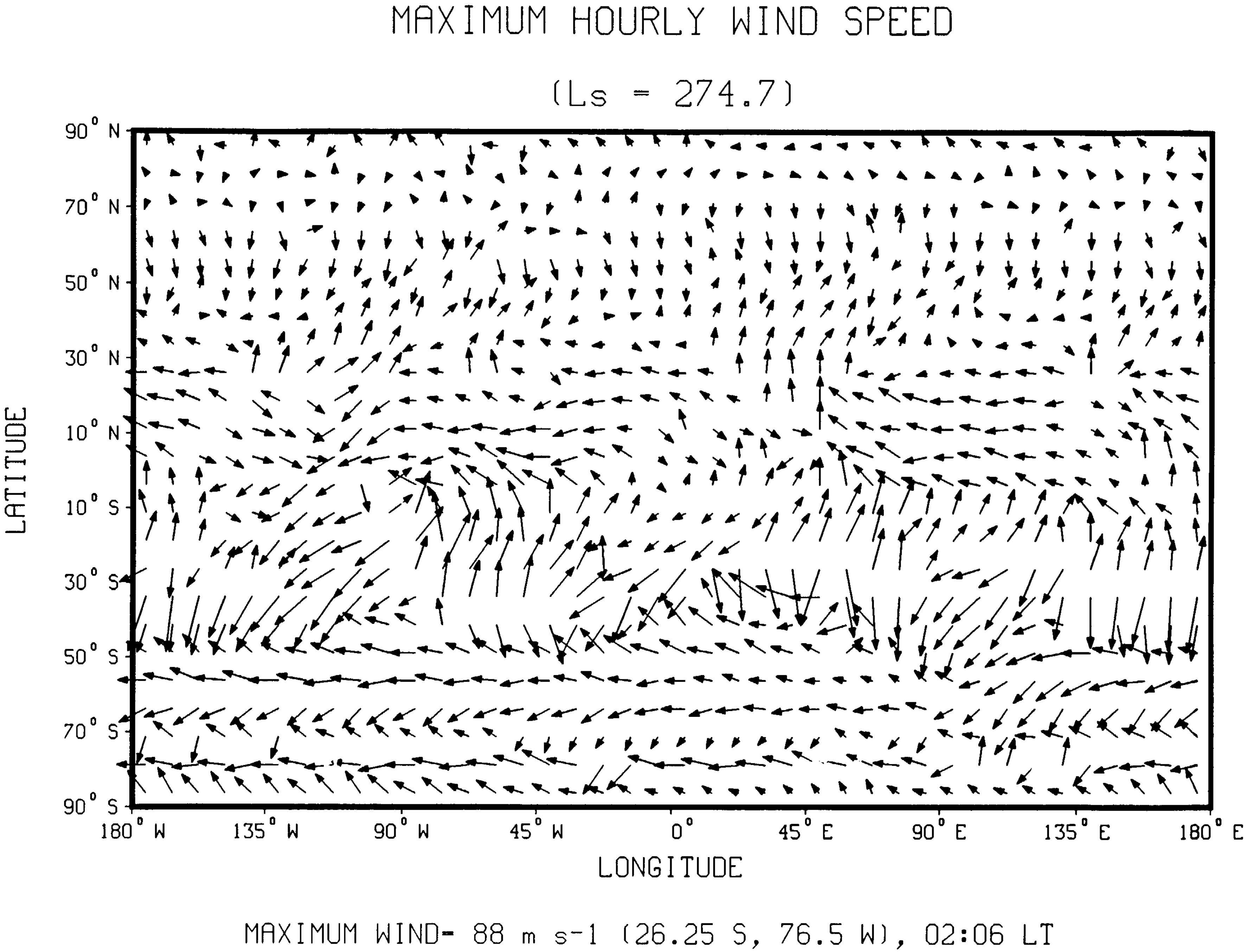

Figure 2. Time of day and magnitude of sol maximum wind speed at each model location during the initial stages of the early winter dust storm from the Mars GCM simulated martian year. Vector orientation represents the local time of day (on a 24 hour clock) of the maximum wind speed at each model location (upward pointing: midnight; pointing to the right: 6 AM; downward pointing: 12:00 Noon; pointing left: 6 PM). Vector length represents wind speed (m s^{-1}).