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Technical note on studies of model differences

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LMD/AOPP

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First Draft

Abstract

This technical note presents a systematic comparison of the results of the LMD and AOPP versions of the model.

The model differences identified in the past have been significantly reduced by upgrading both versions on different points.

The differences are now acceptable in view of our present knowledge of the Martian atmosphere and in comparison with other sources of variability including diurnal variations, transient activity and interannual variability, in particular variability due to the seasonal variations of the atmospheric dust content.

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1 introduction

This technical note presents a systematic study of the differences between the results of the LMD and AOPP versions of the model developed for ESA in the frame of ESA contract (Ref. 11369/95/NL/JG(SC)). The use of two different codes was motivated by the possibility it offers to estimate model uncertainties. This comparison is thus an important step in the validation of the database.

This particular work was also motivated by very large differences in the simulated circulations of the middle atmosphere (above 30 km) which have been identified several months ago. The first part of the document presents the state of the model at that time and the improvements which have been made since.

We then present systematic comparisons concerning mean fields, their standard deviations due to transient activity and the diurnal variations. Those comparisons are made for the standard scenario for dust which corresponds to the Viking year without dust storms.

At the end, we show a comparison between model differences and other sources of uncertainties or variability such as diurnal cycle, transient atmospheric variations, distribution of dust and interannual variability.

2 Middle atmosphere at northern summer solstice

A few months ago, significant differences between the AOPP and LMD versions were identified in the middle atmosphere, above 30 km. Those differences are illustrated in Fig. 2 and Fig. 1 for northern summer solstice conditions.

Both figures show in a latitude-altitude diagram, the zonally averaged winds and temperature on the left and the associated standard deviations on the right. What we call standard deviation in all this document corresponds to the day-to-day variability at a given local time of day. Here, this standard deviation is also averaged in time on one day and in longitude. In particular, diurnal variations are not accounted for in those standard deviations.

At this season, the mean meridional circulation is dominated by a large Hadley cell with a positive (northward) meridional flow very near the surface and a negative (southward) meridional wind in the main part of the atmosphere. This Hadley cell, by transporting angular momentum, builds a strong zonal jet in the southern mid-latitudes.

The thermal structure is dominated by a strong latitudinal temperature gradient at the edge of the polar cap, near 50S, and very weak latitudinal variations in the summer hemisphere.

For the mean fields, the main differences between LMD and AOPP results are:
– a much weaker "retro-jet" (negative zonal wind) in the LMD version in the equatorial middle atmosphere,
– the absence, in the LMD version, of the weak positive jet in the northern mid-latitudes.

The differences are indeed larger for the standard deviation. Note that there was almost no transient activity in the LMD version at this season (which was chosen because it was the most extreme in that respect). These large differences have since been shown to be due to the use of a very strong dissipation in the LMD model.

Both models use horizontal dissipation operators to account for the non-linear interactions between explicitly resolved and subgrid-scale motions. Those operators are also important for models stability. In fact, because of stability problems which appeared when the top of the model was raised from 40 to 80 km, a very strong dissipation was introduced in the LMD version. The stability problem itself was shown to be due to the singularity of the grid at the pole. In grid point models, one must introduce a longitudinal filtering to ensure model stability with a reasonable time-step. However, the filtering was not efficient enough in the LMD version to avoid strong oscillations to occur near the pole, implying the use of a strong dissipation. This problem was solved by reformulating the longitudinal filtering allowing for the use of a much weaker dissipation.

Finally, the results of this new version are shown in Fig. 3. The differences with the AOPP version (Fig. 2) are generally much smaller above 30 km than for the old LMD version (Fig. 1). The improvement is particularly impressive for the intensity of shape of the retrograde equatorial jet and for the transient activity.

Note however the significant difference above the southern pole : just above the pole, there is a strong temperature inversion in the AOPP version which is much weaker in the LMD model. The differences between the LMD and AOPP versions are discussed systematically in the next section.

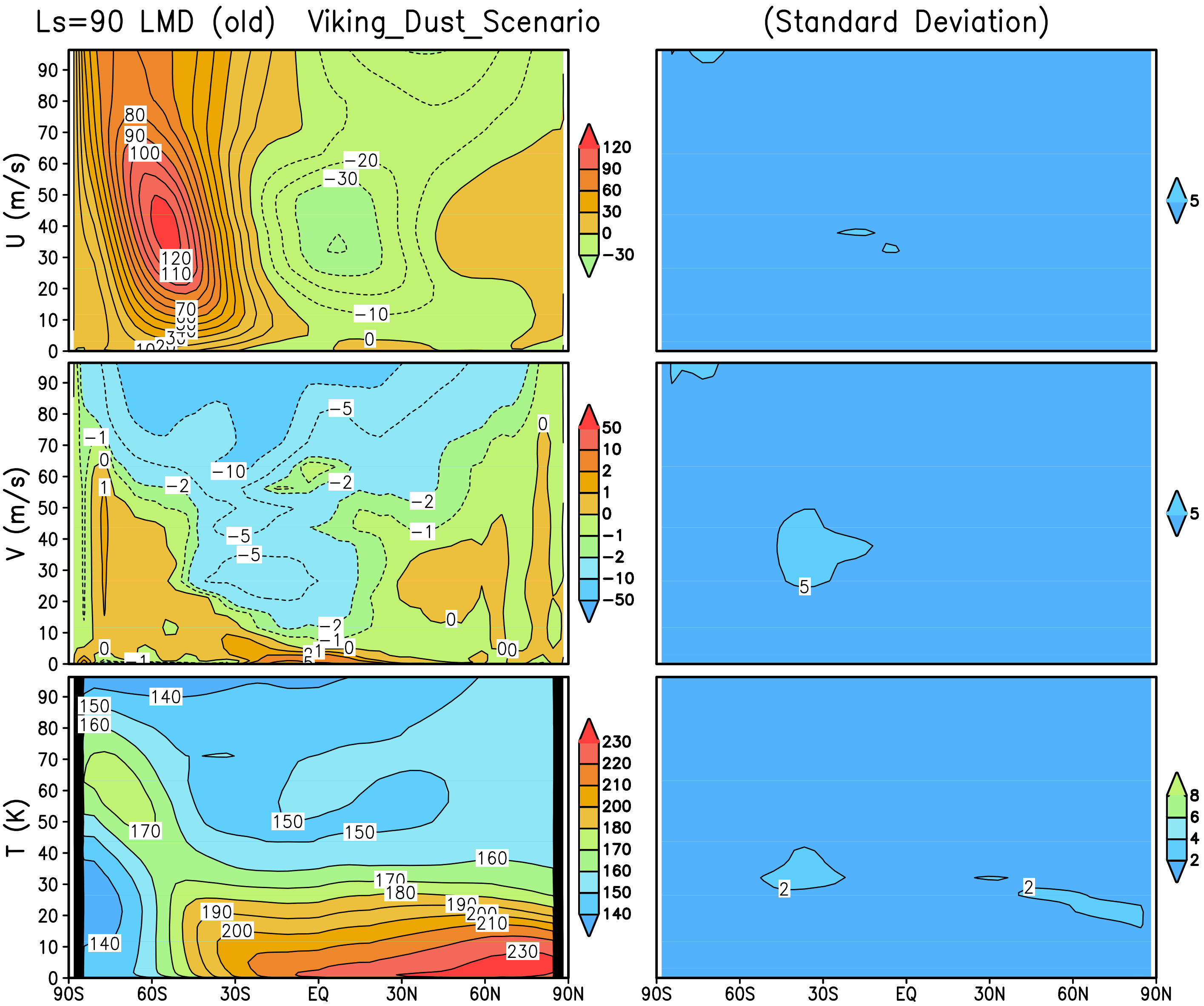

Figure 1: Latitude-altitude plotsr of the zonal and time average of the zonal wind (m/s), meridional wind (m/s) and temperature (K) on the left, and corresponding standard deviations (associated to transient activity) on the right.
LMD version before modifications at the pole.
Season: northern sumer solstice, $L_s = 90$.

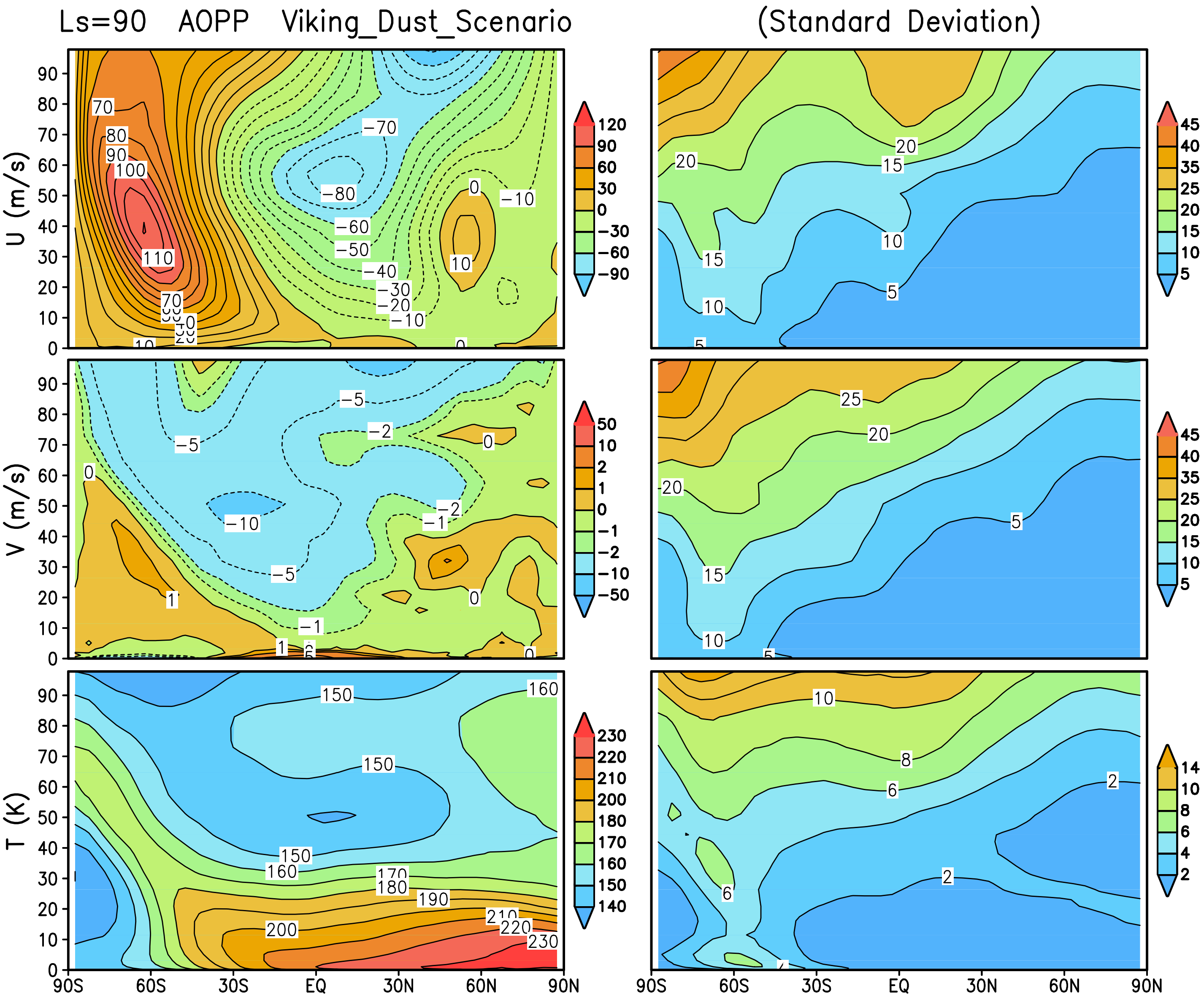

Figure 2: Latitude-altitude plots of the zonal and time average of the zonal wind (m/s), meridional wind (m/s) and temperature (K) on the left, and corresponding standard deviations (associated to transient activity) on the right.
AOPP version.
Season: northern sumer solstice, $L_s = 90$.

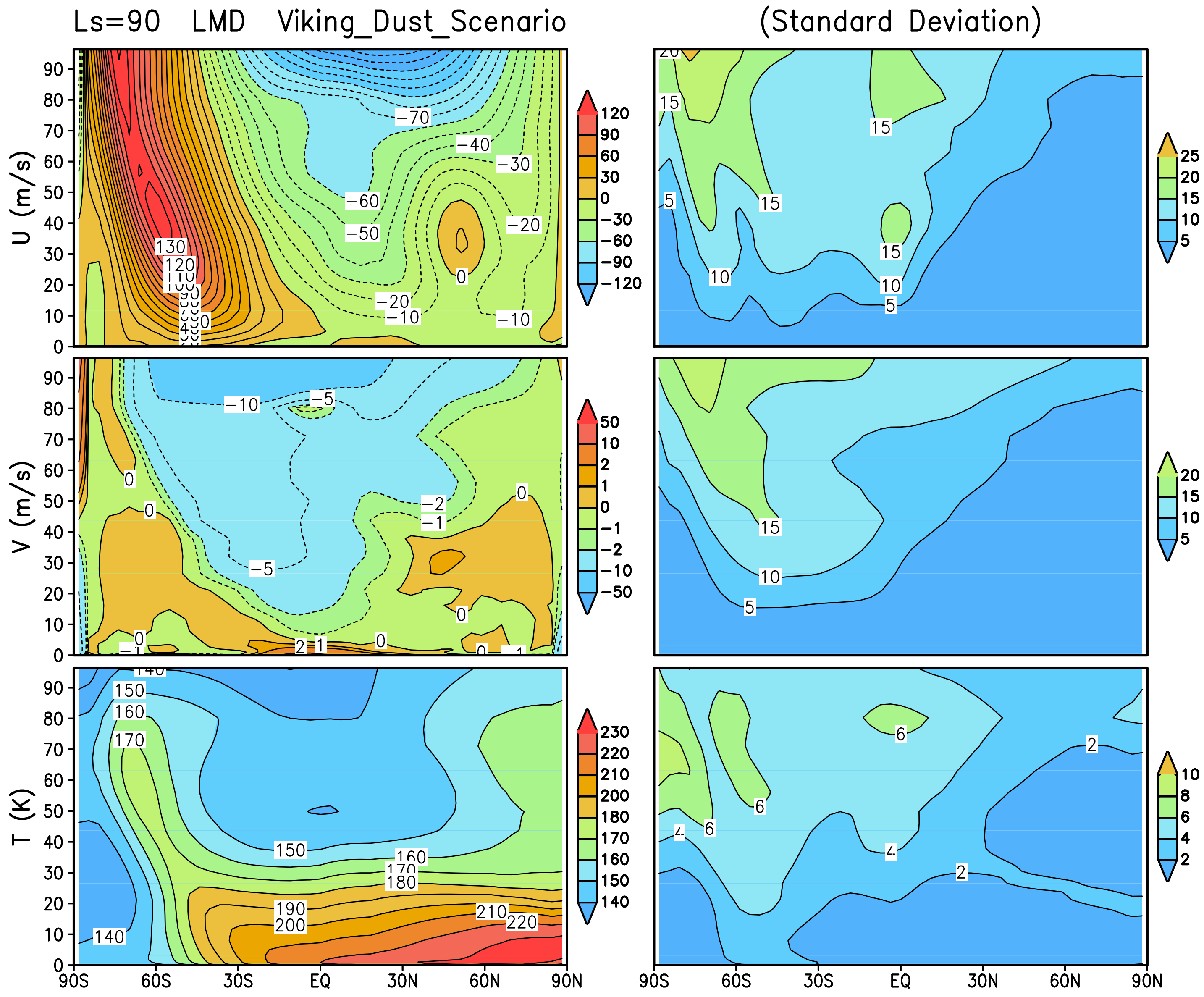

Figure 3: Latitude-altitude plots of the zonal and time average of the zonal wind (m/s), meridional wind (m/s) and temperature (K) on the left, and corresponding standard deviations (associated to transient activity) on the right.
New LMD version.
Season: northern sumer solstice, $L_s = 90$.

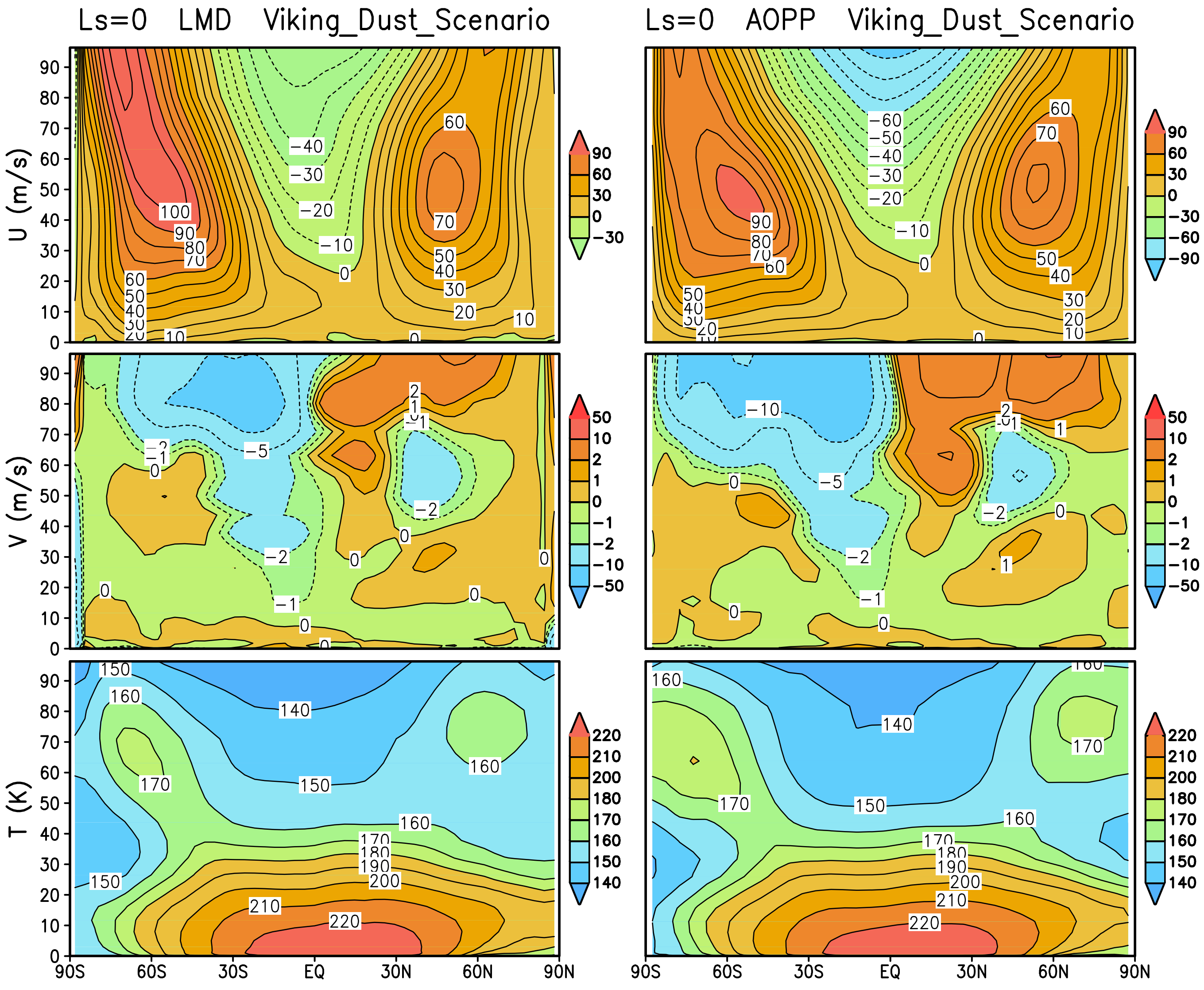

Figure 4: Zonal and time average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at $Ls = 0$ for the LMD (on the left) and AOPP (on the right) versions.

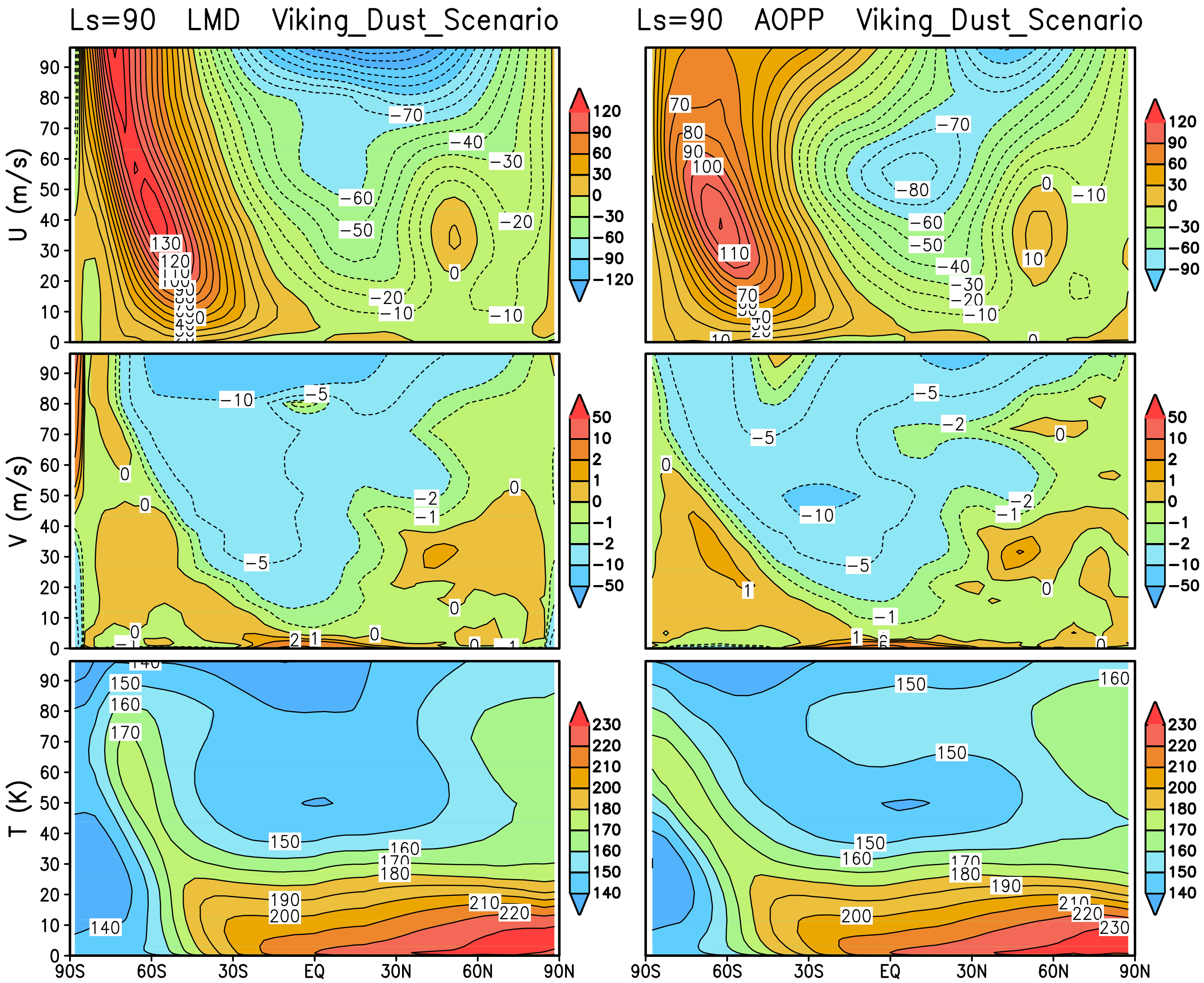

Figure 5: Zonal and time average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at Ls = 90 for the LMD (on the left) and AOPP (on the right) versions.

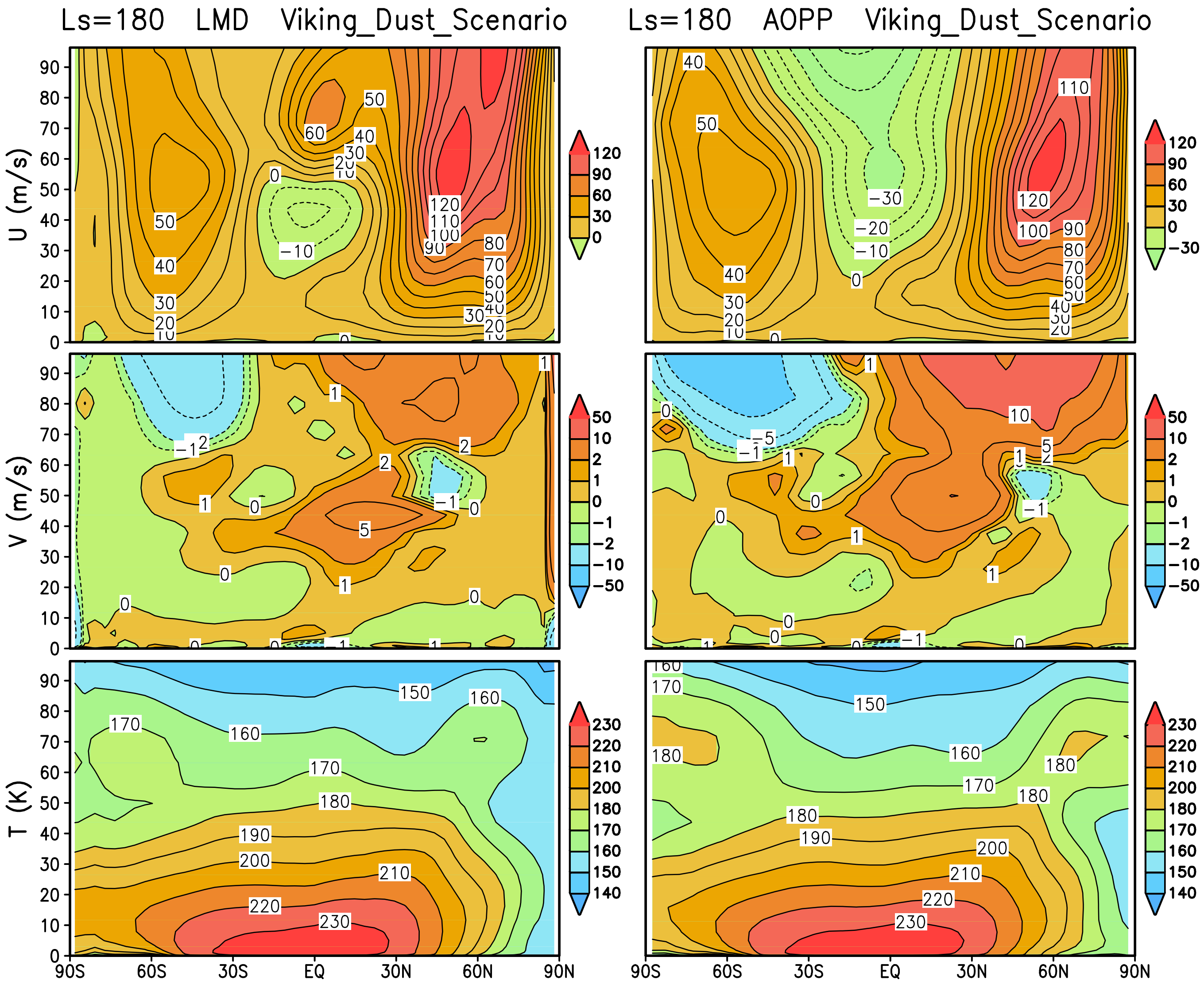

Figure 6: Zonal and time average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at $Ls = 180$ for the LMD (on the left) and AOPP (on the right) versions.

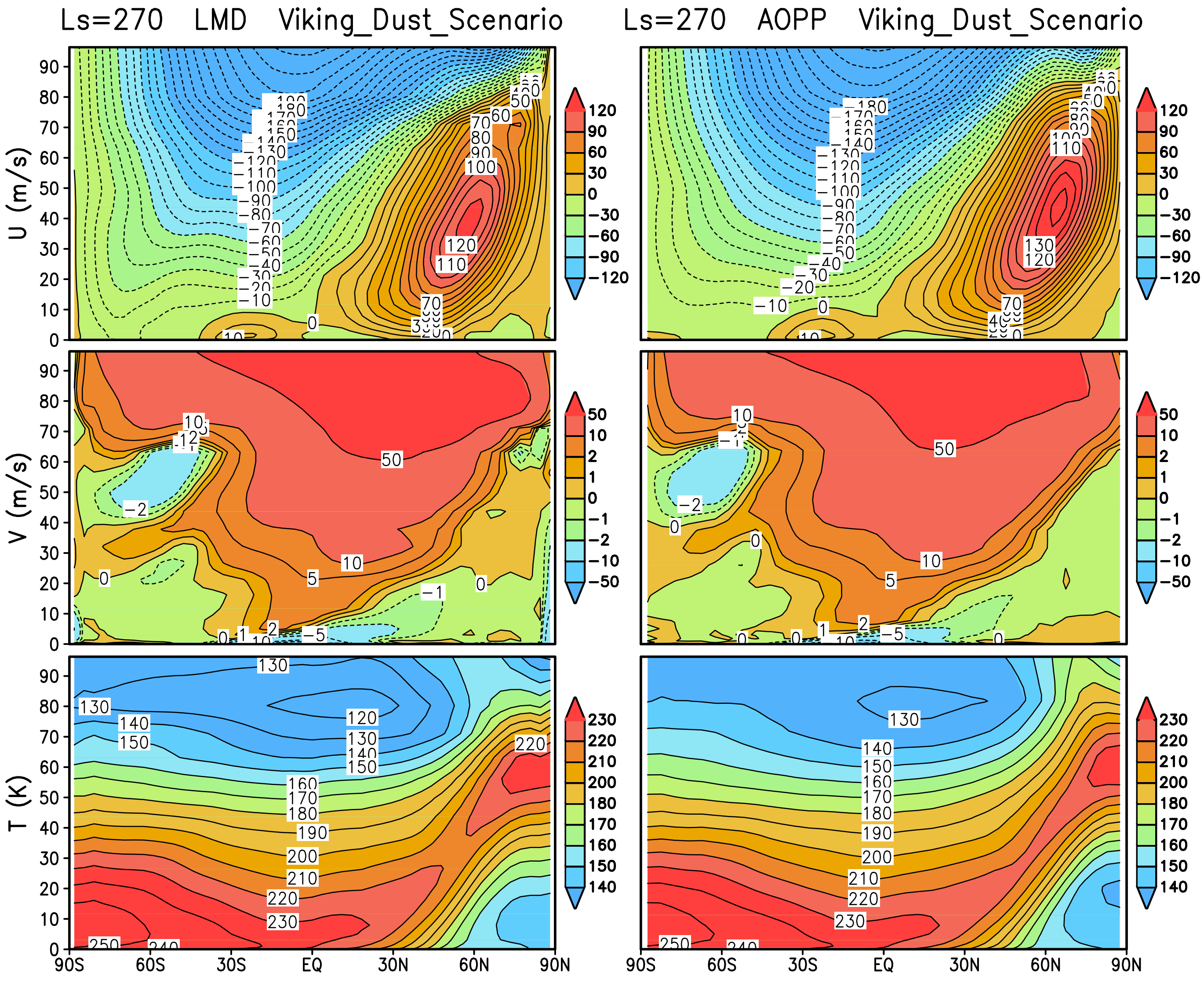

Figure 7: Zonal and time average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at $Ls = 270$ for the LMD (on the left) and AOPP (on the right) versions.

3 Zonally averaged winds and temperature

3.1 Mean structure

The present section is dedicated to a systematic comparison of the two models in terms of mean meridional structure. In Fig. 4, Fig. 5, Fig. 6 and Fig. 7 we compare the zonal and temporal means of the zonal and meridional components of wind, and of temperature, for four seasons (northern spring equinox, summer solstice, autumn equinox and winter solstice respectively).

Note the general very good agreement between the two models up to about 60 km. As said previously, there still are some significant differences in the upper atmosphere as well as in polar regions.

Generally speaking, the Oxford version predicts stronger temperature inversions at the pole near 60 km than the LMD does. More precisely, the temperature inversion is generally present in the two models near 60-70 degrees latitude (the temperature is 30 to 100 K larger at 60-70 km than above the surface) but extends farther to the pole in the Oxford version. This larger polar warming is also associated (through "thermal wind balance") with a strong decrease of the strong mid latitude jet above 60 km in the Oxford version; the decrease is much weaker in the LMD version. These differences are particularly marked in the north polar region for $L_s = 0$ and $L_s = 90$ and in the south for $L_s = 180$.

Another significant difference is in the zonal wind at northern autumn equinox ($L_s = 180$). At this particular season, the LMD model shows a strong pro-grade (positive) wind in equatorial regions between 60 and 90 km whereas the AOPP version just shows a negative jet. The reason for this important difference has not been clearly identified yet.

Finally, note the very good agreement between the two models, even for polar regions and upper atmosphere, at $L_s = 270$.

3.2 Standard deviations

In this section, we present the standard deviations corresponding to the fields shown in the previous section, Fig. 8, Fig. 9, Fig. 10 and Fig. 11 corresponding to northern spring equinox, summer solstice, autumn equinox and winter solstice respectively

Note that for the point of view of mission design, the standard deviations correspond to fluctuations which must be added on the basic profiles.

The first remark is that those perturbations are generally small if compared to the mean field at least for the zonal wind and temperature. Even the perturbations of the meridional wind, which are of the order of the meridional wind itself, are small if compared to the zonal wind. The ratio between the standard deviation and mean field is generally maximum above 60 km where it reaches values of about 10%.

Note the spectacular exception of the upper northern polar atmosphere at winter solstice, Fig. 11. At this particular season, in the north polar upper atmosphere, the wind perturbations have a typical amplitude of 50-100 m/s, comparable to the wind itself. This season is that corresponding to the largest atmospheric dust content.

Generally speaking, the standard deviations from the two models show similar spatial structures and intensities. Note the large differences in the upper atmosphere, above 70 km, where the AOPP version generally predicts larger standard deviations. This region is where the artificial "sponge layer" is introduced to avoid the problem of wave reflection at the model top.

Note that, as for the mean fields, the northern winter solstice correspond to a very good agreement between the two models.

In terms of mission design, the standard deviation is used as an amplitude to perturb the mean profile following Read et al. (1997). In that respect, the agreement between the two models seems fully satisfactory, at least up to 70 km.

4 Surface fields

This section is dedicated to comparisons of the surface fields. For this document we selected the most relevant fields. Surface pressure itself is strongly dominated by orography. The main differences between the two models come from the different grids which imply different latitude and thus different surface pressure. Note incidently that, before new orographic data become available, the knowledge of the surface altitude is probably the largest source of uncertainty for determining the vertical density profile at a given location.

Much more significant is the standard deviation of the surface pressure which is the best signature of the "transient activity" as on Earth. The other important parameter for near surface conditions is the wind velocity.

Very recently, large differences were identified between the two versions concerning those surface fields. These differences have been since attributed to a problem in the interface of the parametrisations developed at LMD with the AOPP version. These problems have since been solved. We present the new results below.

4.1 Surface pressure standard deviations

The surface pressure standard deviations are compared in Fig. 12 for four seasons. They show very similar structures for both versions and a similar seasonal behavior.

The differences are of the order of 10-20%.

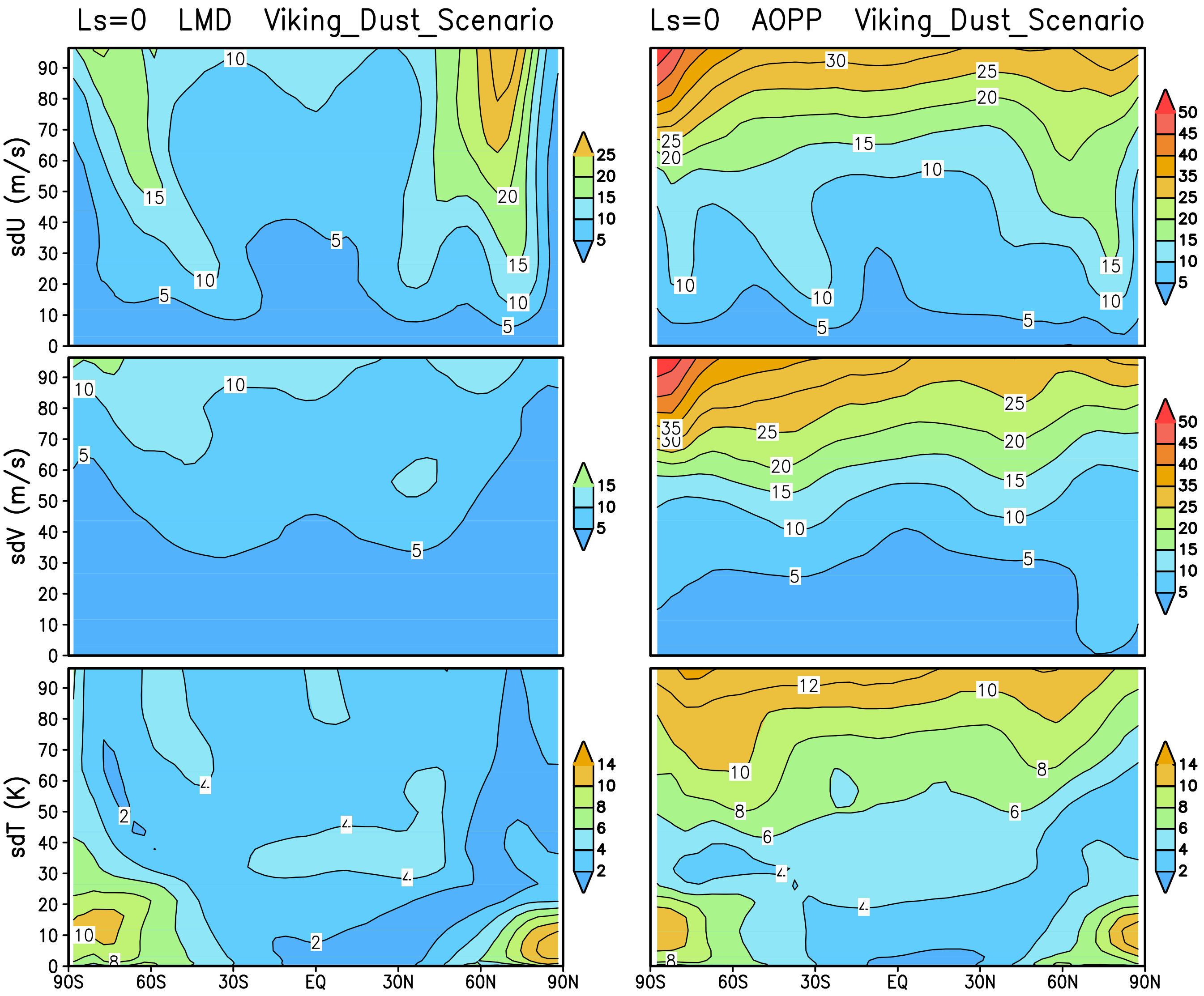

Figure 8: Zonal and temporal average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at $Ls = 0$ for the LMD (on the left) and AOPP (on the right) versions.

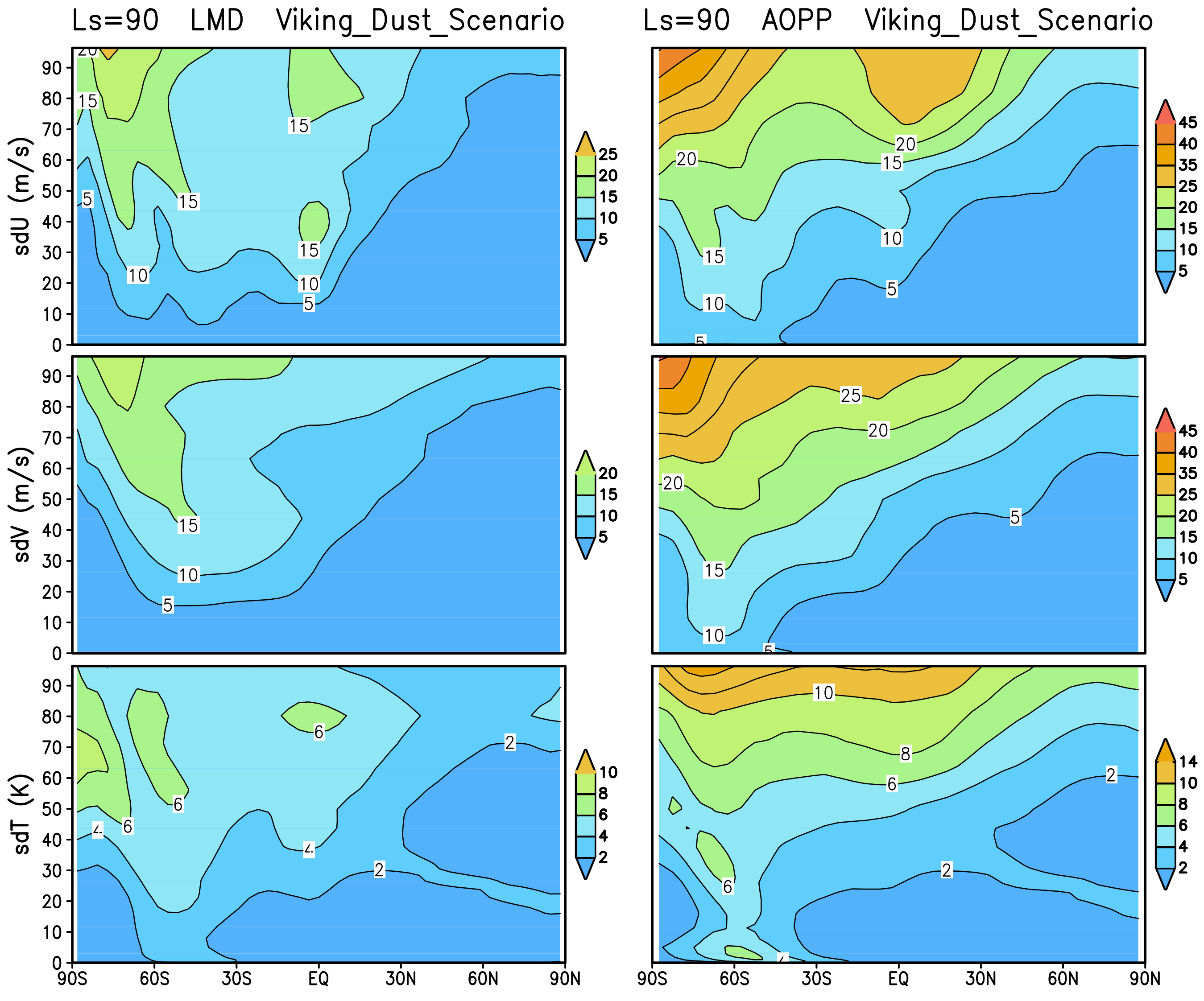

Figure 9: Zonal and temporal average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at $Ls = 90$ for the LMD (on the left) and AOPP (on the right) versions.

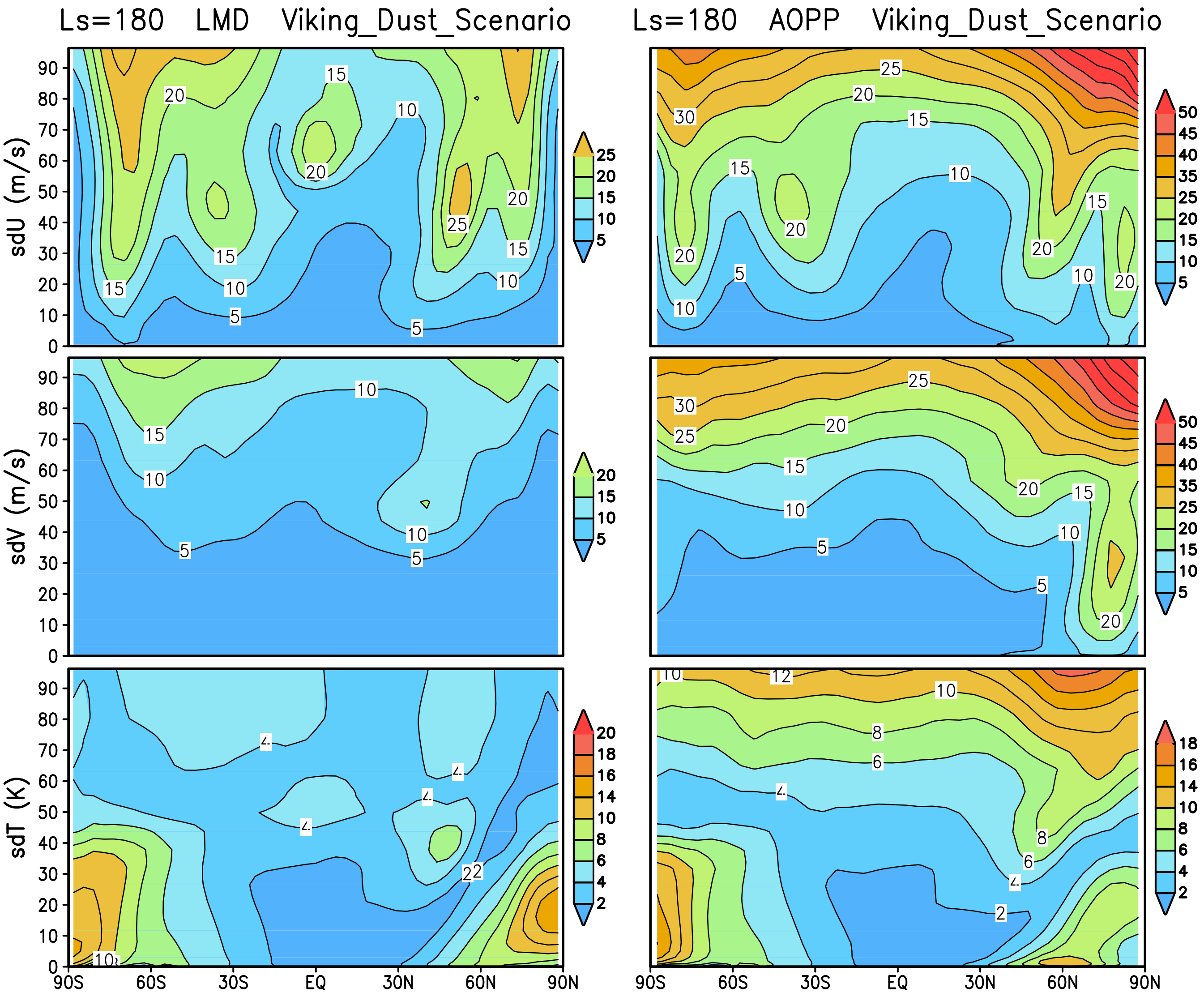

Figure 10: Zonal and temporal average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at $Ls = 180$ for the LMD (on the left) and AOPP (on the right) versions.

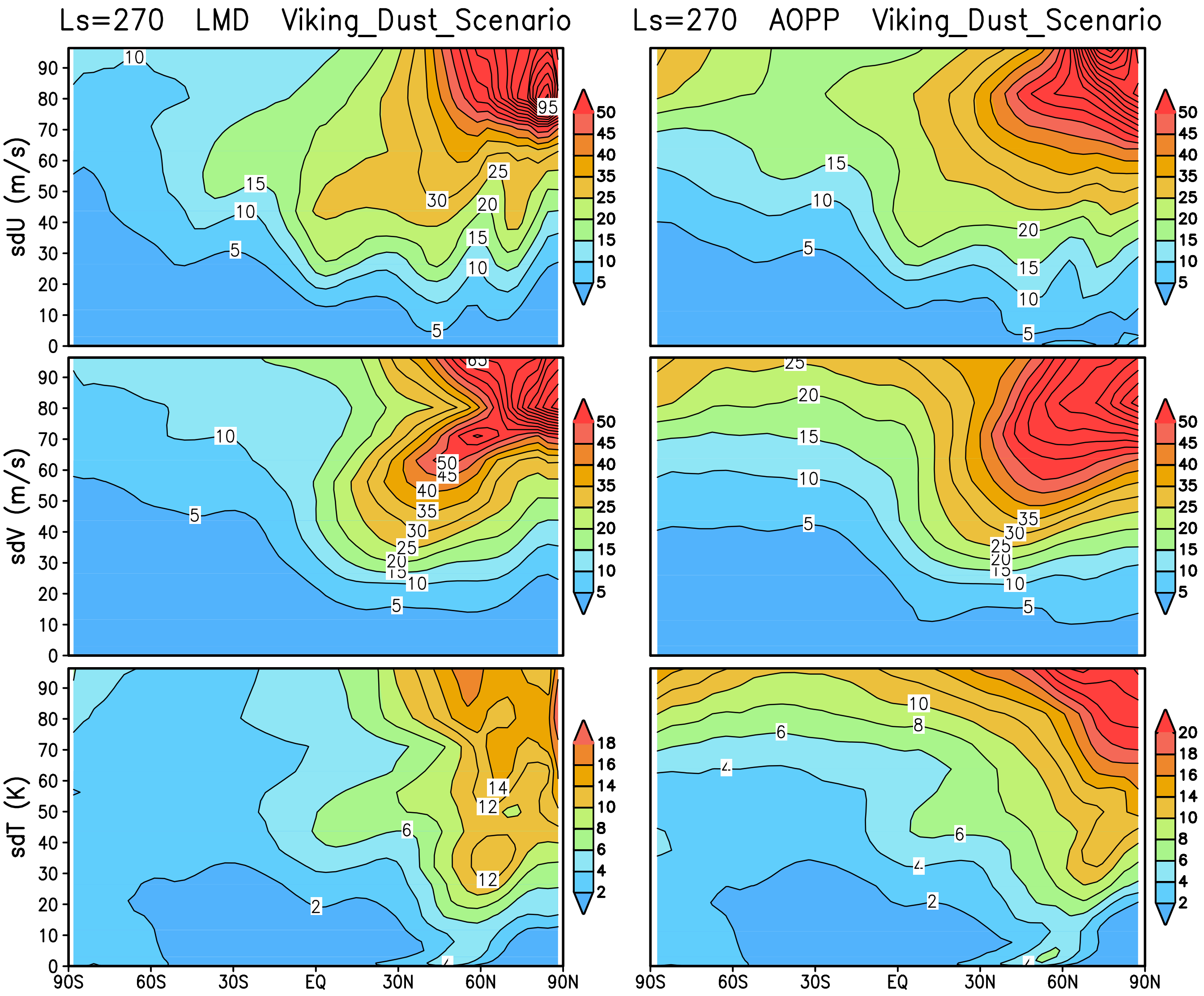

Figure 11: Zonal and temporal average of zonal wind (upper panel, m/s), meridional wind (middle panel, m/s) and temperature (lower panel, m/s) at $Ls = 270$ for the LMD (on the left) and AOPP (on the right) versions.

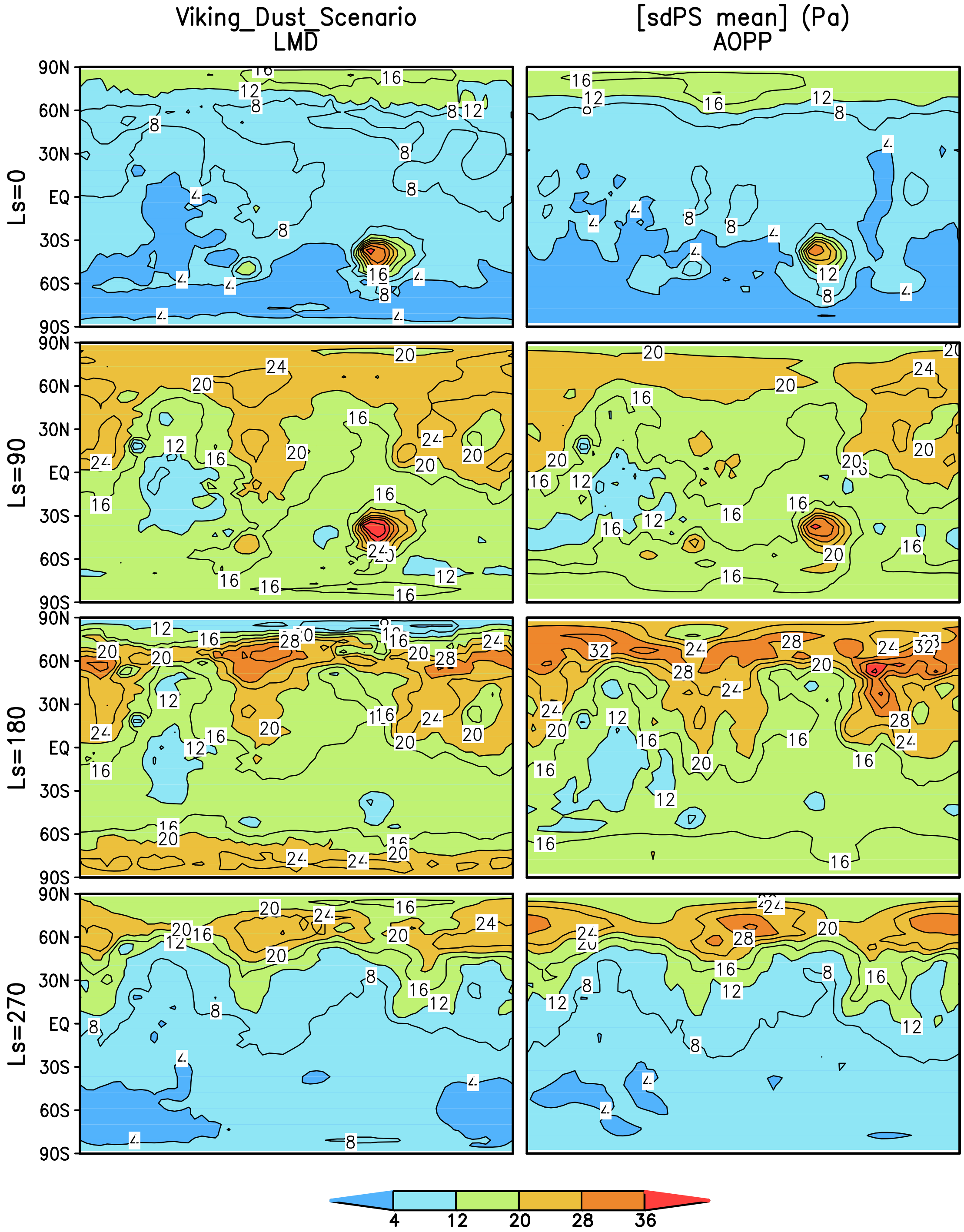

Figure 12: Time average of the surface pressure standard deviation (Pa) for the four martian seasons.

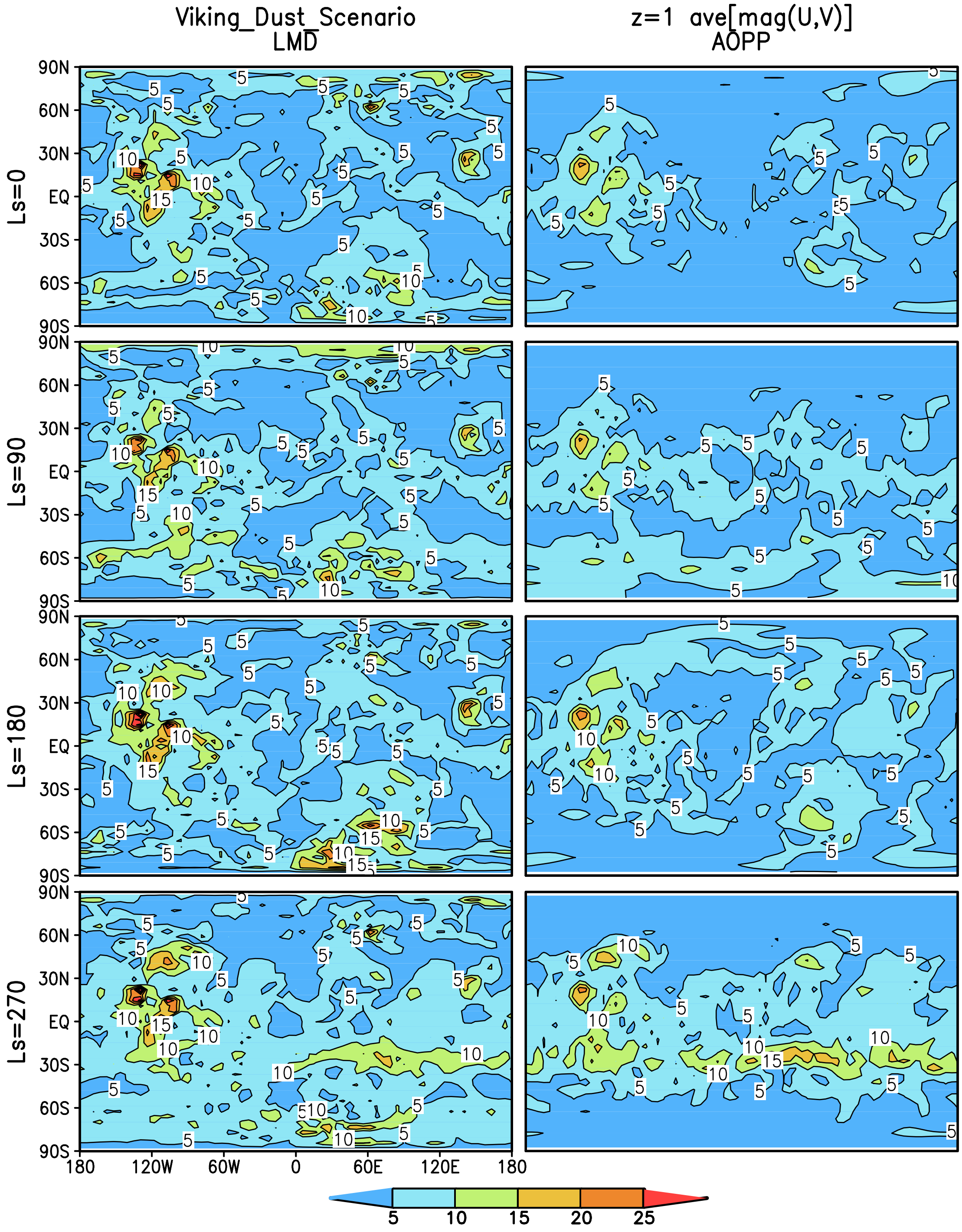

Figure 13: Time average of the surface wind velocity (m/s) for the four martian seasons.

4.2 Wind velocity

The comparison of the mean surface wind velocity is shown in Fig. 13. Between -50 and 50 degrees latitude, the behavior is very similar with surface wind velocities of the order of 0-10 m s^{-1} with much higher values on the elevated terrains such as volcanos (the air at the surface of volcanos is coming from an high altitude above the surrounding terrains). Note in particular the representation of similar large surface winds near 30S in both models at $L_s = 270$, in regions which correspond to the growing of global dust storms. In this latitude band, the largest differences probably occurr at $L_s = 180$ where the LMD version generally perdicts larger surface winds.

The agreement is not as good in high latitudes with much stronger winds in the LMD version. Once again, this is probably due to the noise introduced by the grid point model in polar regions, pressure gradients creating or beeing balanced by horizontal winds.

5 Diurnal variations

In the previous sections, we concentrated on the mean fields and standard deviations but the diurnal variations were removed from the analysis. We now concentrate on variations within a day. Those variations are particularly large on Mars due to the very small thermal inertia of the atmosphere and surface. Thus, the surface temperature exhibits diurnal variations of the order of 100 K which generate strong atmospheric thermal tides which propagate in the atmosphere (Wilson and Hamilton, 1996).

Because an extensive presentation would be boring and out of the scope of this document, we just give an illustration for a particular season ($L_s = 90$) of the behavior of the diurnal variations in the two models.

5.1 At the surface

This section presents instantaneous maps of the surface temperature minus the diurnal mean (Fig. 14) and the same thing for the surface pressure (Fig. 15).

The diurnal variations of the surface temperature are dominated of course by the very intense diurnal cycle of insolation and is essentially dependent on radiative transfer which is the same in both versions and of surface albedo and thermal inertia. Consequently, the diurnal cycle of surface temperature is very similar in both models.

The very similar behavior in terms of intensity and spatial distribution of the diurnal pressure fluctuations (Fig. 15) is more significant of the good model agreement. Note the cohexistence of zonal wave numbers one (for instance at t = 6h) and two (for instance at 12 h in the band between equator and 40S).

5.2 In the atmosphere

Here we illustrate the differences bewteen both models in representing the tides at higher altitudes by concentrating on the equator. In Fig. 16, Fig. 17 and Fig. 18, we show, for 4 times a day, snapshots of the difference between instantaneous values of T, u and v respectively and the corresponding diurnal mean, as a function of longitude and altitude.

The general tilted structure, oriented from the right lower corner of the figure to the upper left corner is similar in both models. The wave intensity is also rather similar, particularly for temperature.

Note that the wind fluctuations are very intense. For the meridional wind, this tidal component is often stronger than the mean meridional wind.

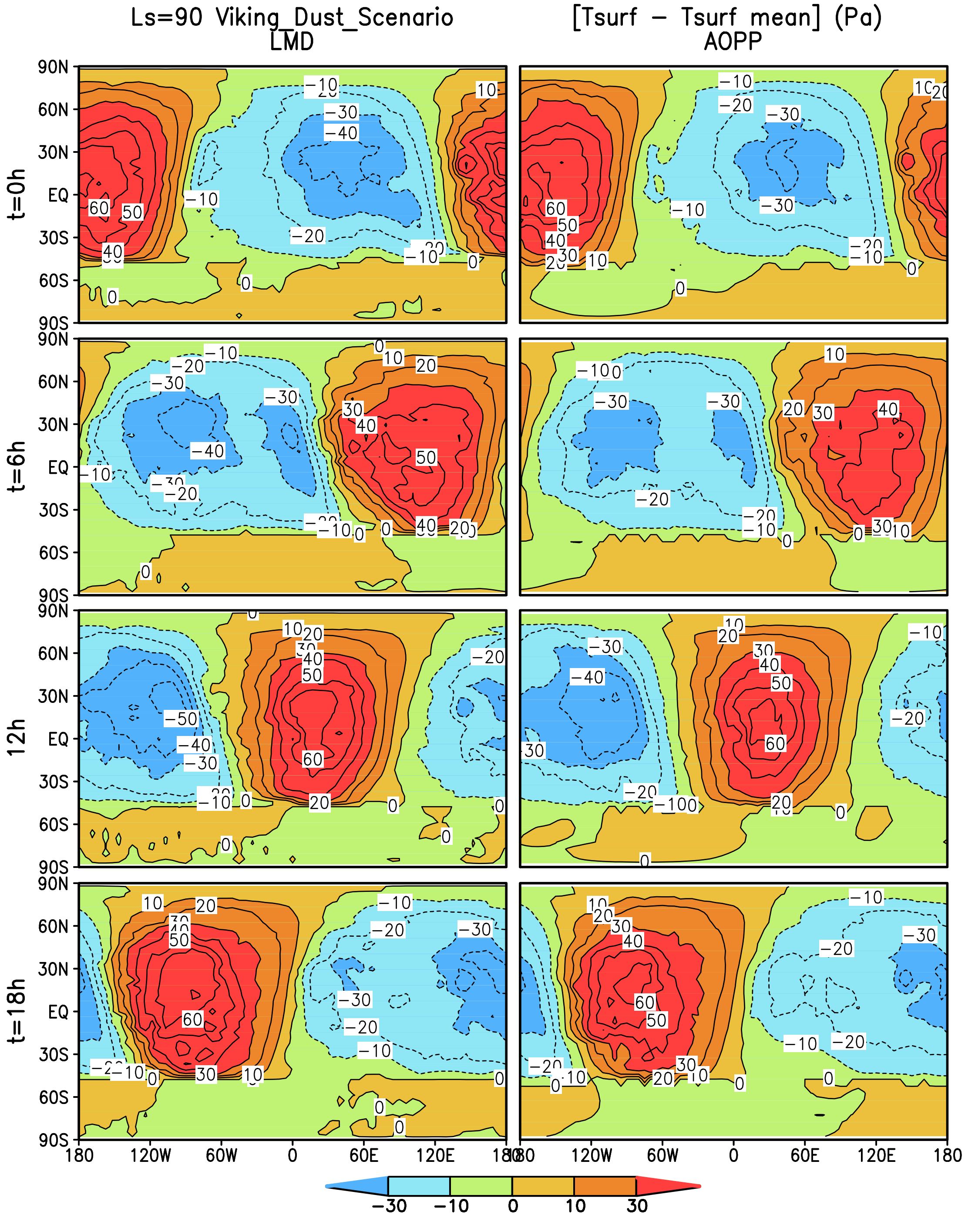

Figure 14: Diurnal evolution (4 snapshots) of the surface temperature fluctuation (difference with the diurnal mean, in K) at $L_s = 90$.

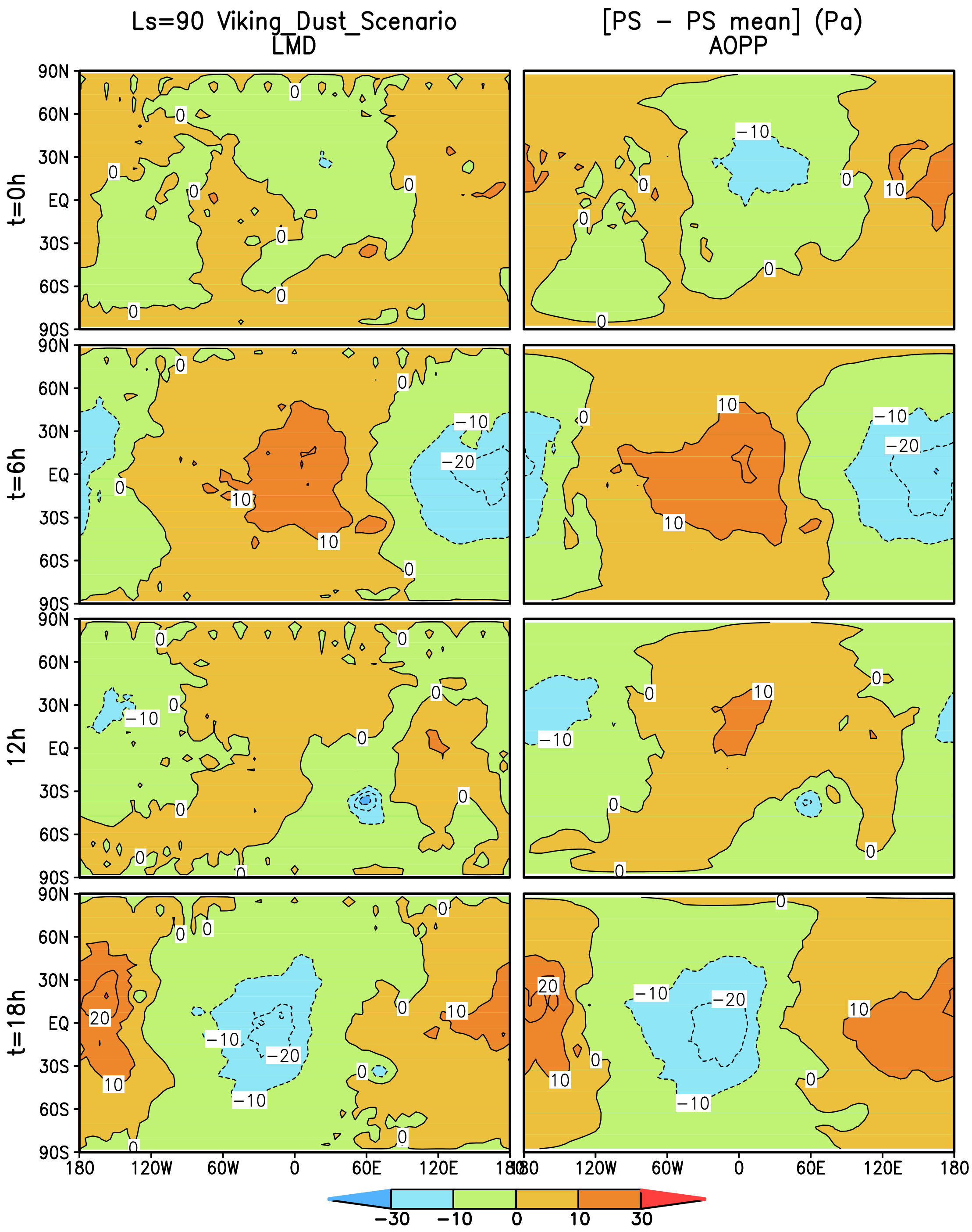

Figure 15: Diurnal evolution (4 snapshots) of the surface pressure fluctuation (difference with the diurnal mean, in Pa) at $L_s = 90$.

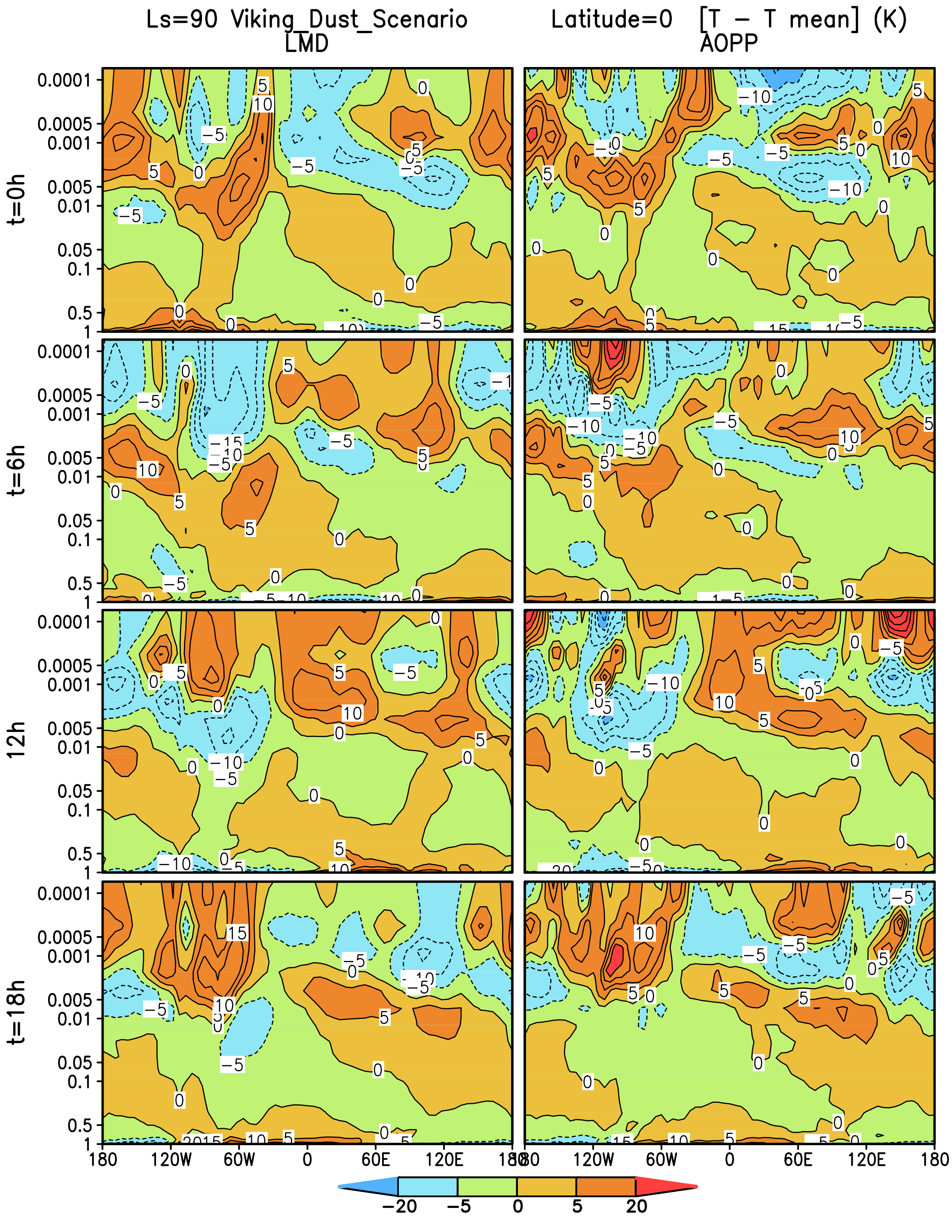

Figure 16: Diurnal fluctuations of temperature as a function of longitude and height for $L_s = 90$ and at the equator.

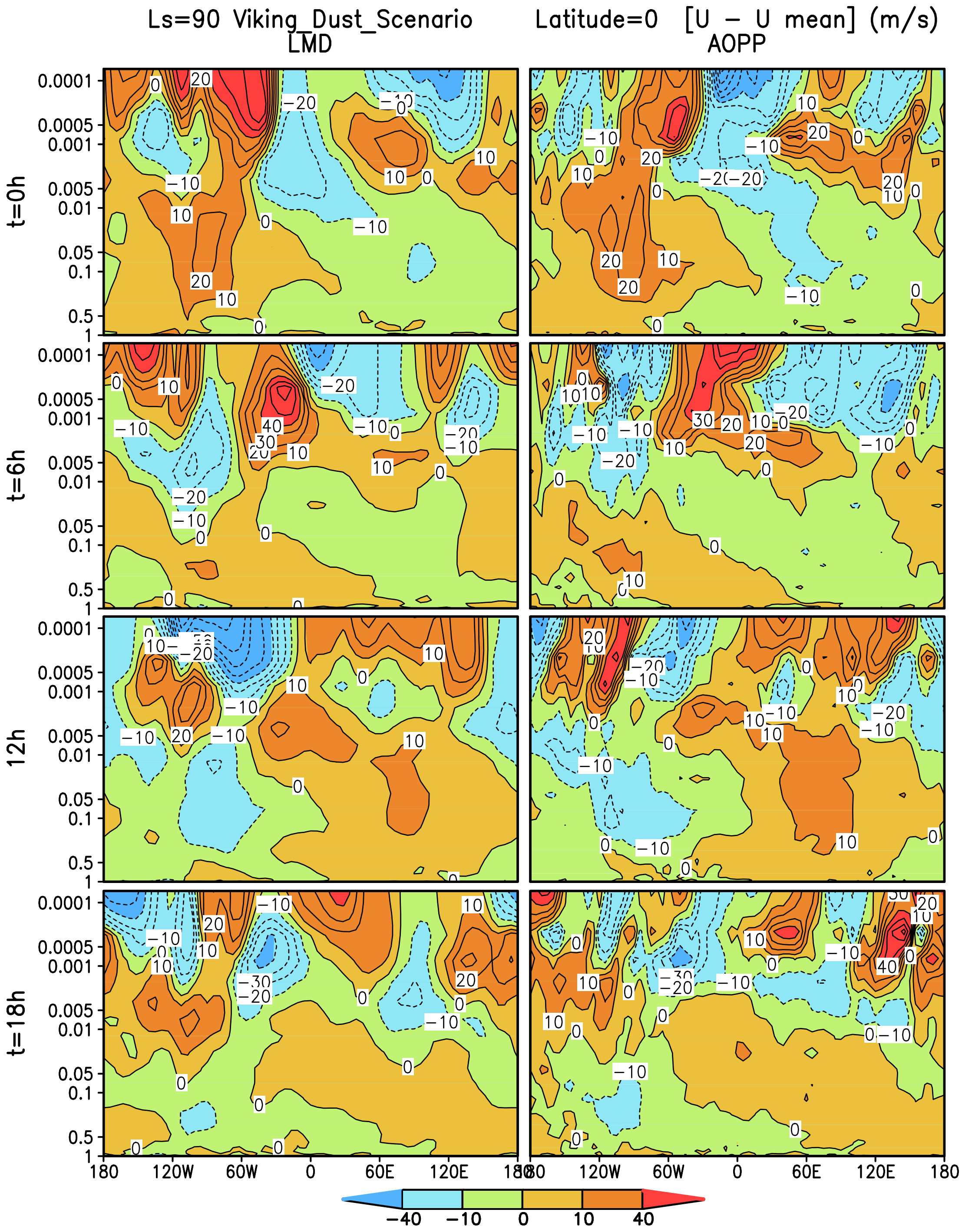

Figure 17: Diurnal fluctuations of the zonal wind U (m/s) as a function of longitude and height for $L_s = 90$ and at the equator.

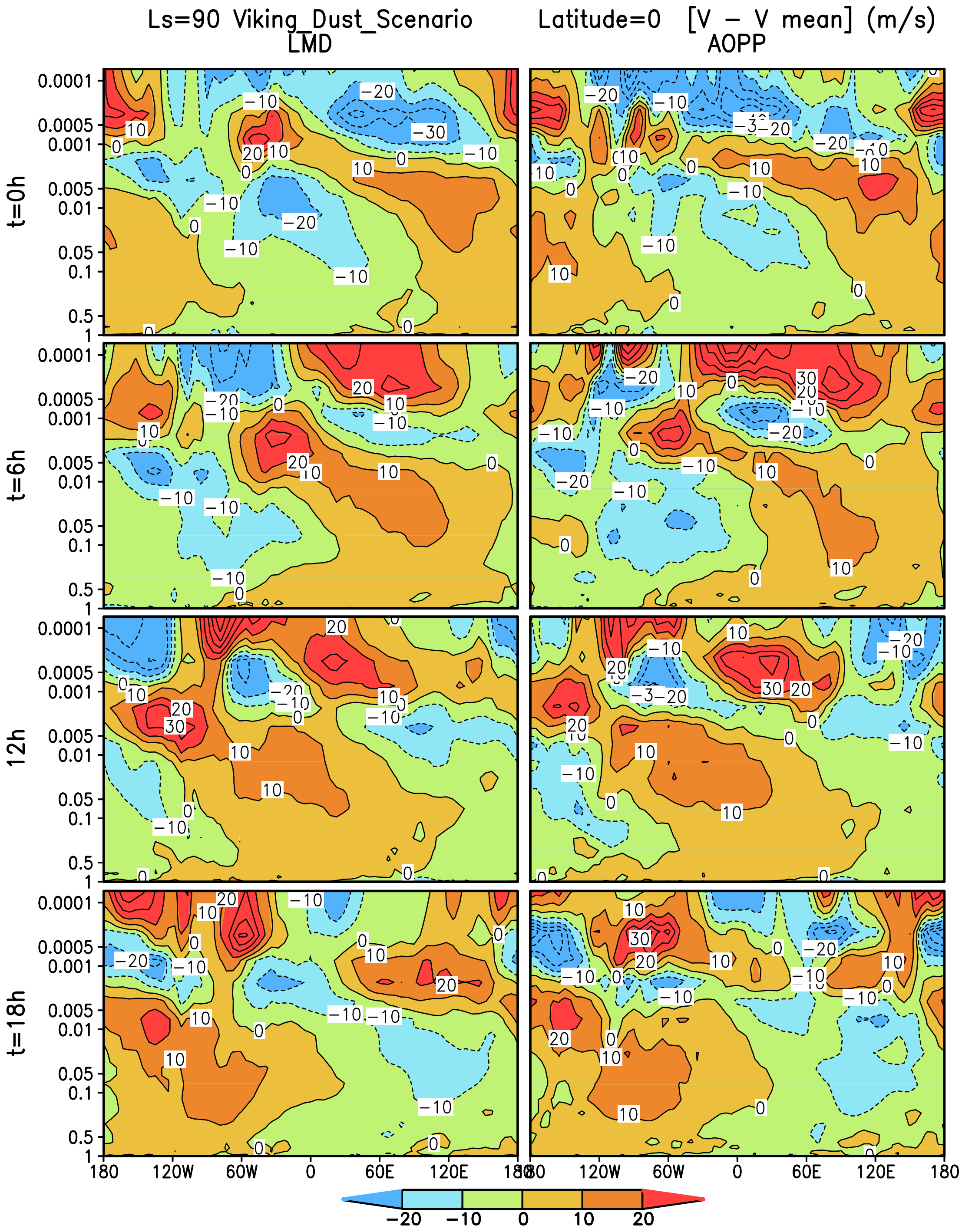

Figure 18: Diurnal fluctuations of the meridional wind V (m/s) as a function of longitude and height for $L_s = 90$ and at the equator.

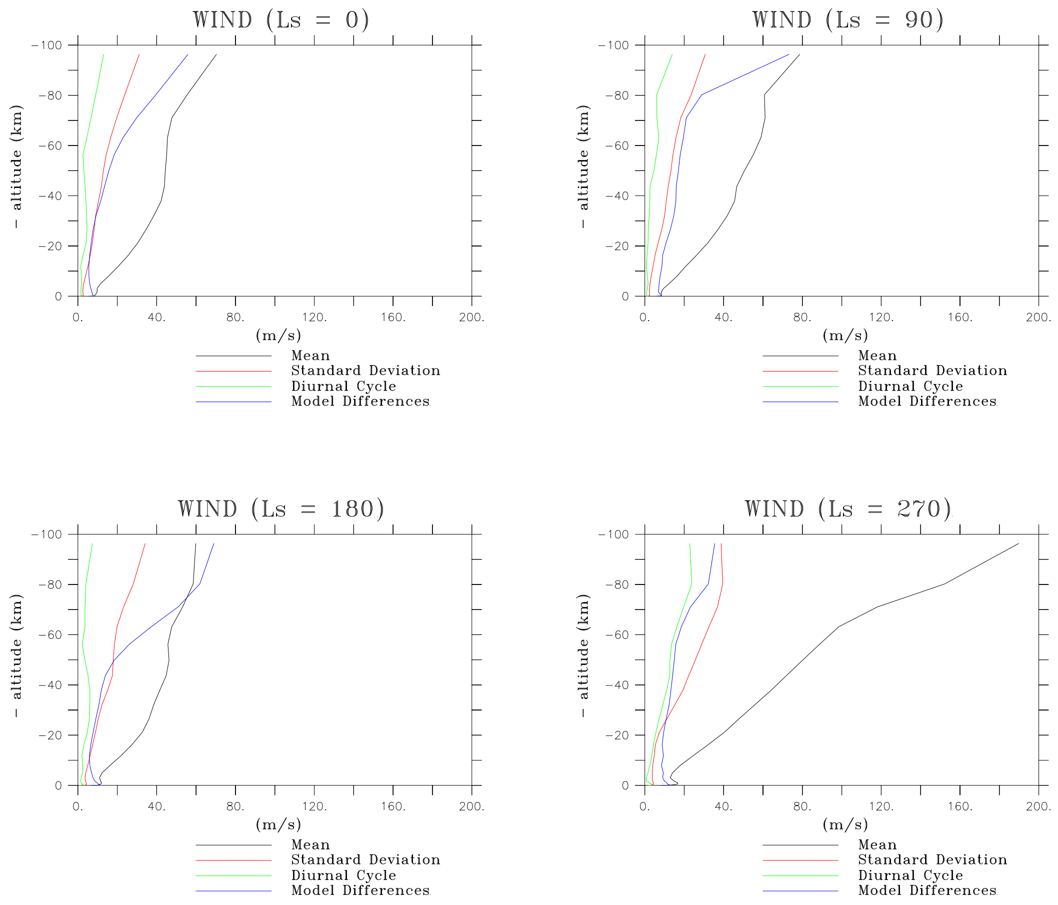

Figure 19: Vertical profiles of globaly averaged wind velocity (m/s) for four seasons : mean values, standard deviation associated with transient activity, amplitude of the diurnal variations and model differences.

6 Summary of the errors in terms of vertical profiles

This final section presents a summary of the model differences as well as of the internal variability of the models in terms of vertical profiles. This gives directly the order of magnitude of the fluctuations which have to be add on the mean values from the database in order to deteremine the possible range of entry profiles for a probe.

More precisely, we compare for the wind velocity (Fig. 19), temperature (Fig. 20) and density (Fig. 21), the global average of 1) the mean value, 2) the standard deviation, 3) the root-mean-square amplitude of the diurnal variations and 4), the quadratic difference between the models (computed on a common 3D-gird after interpolation and for each time of day).

General comments:

- The model differences are generally of the order of 10% of the absolute values. Note the important exception, already metioned, of the wind velocity at L_s

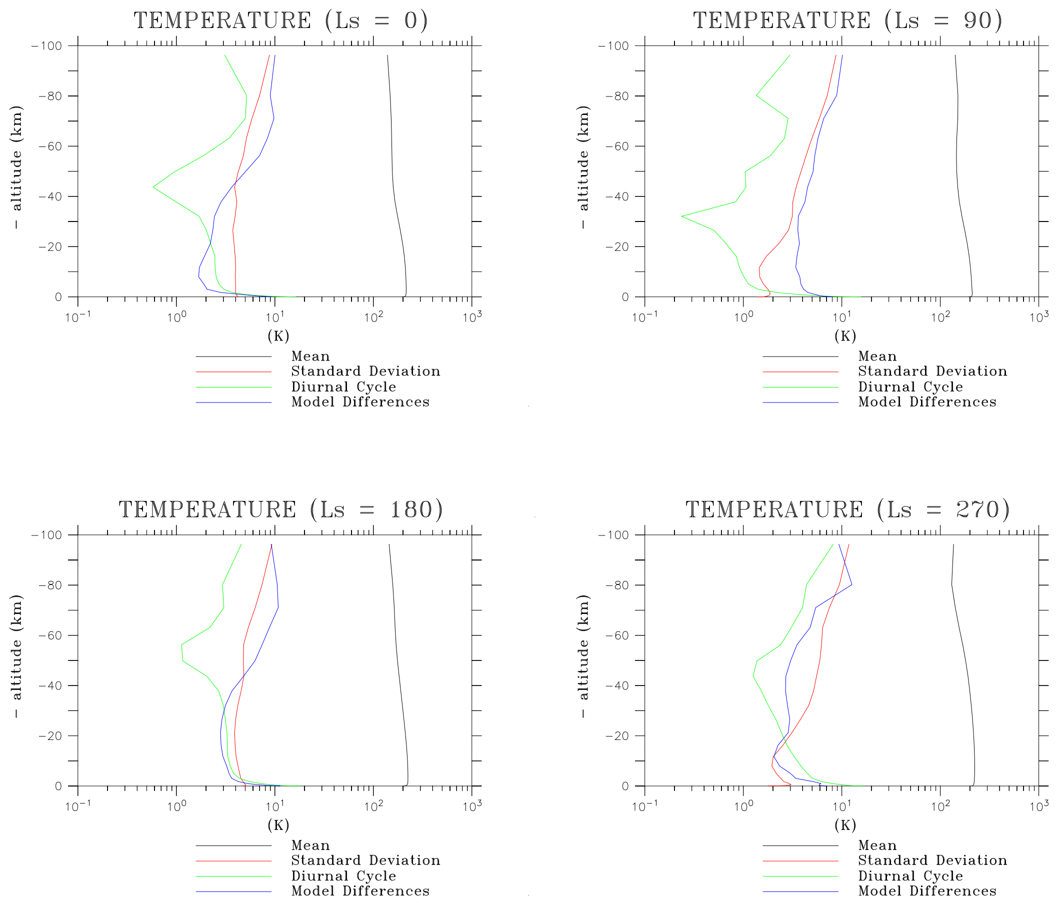

Figure 20: Vertical profiles of globaly averaged Temperature (K) for four seasons : mean values, standard deviation associated with transient activity, amplitude of the diurnal variations and model differences.

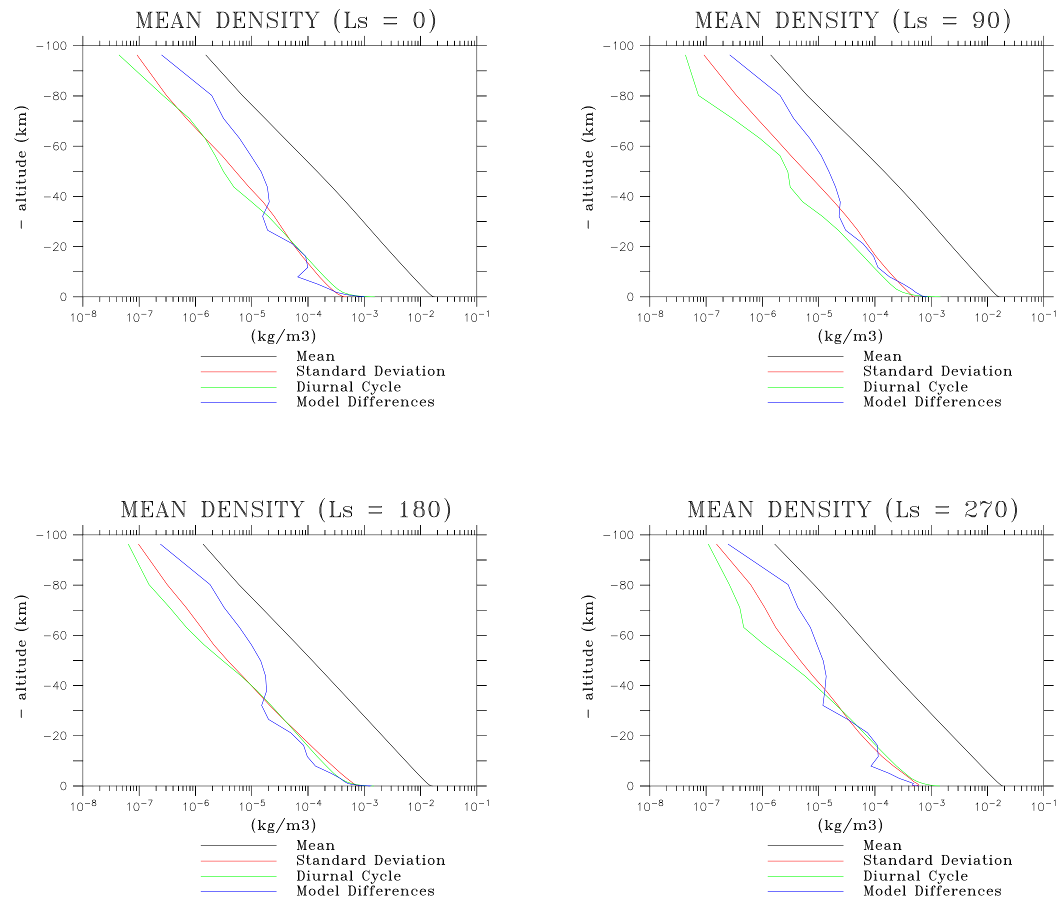

Figure 21: Vertical profiles of globaly averaged density (kg/m^3) for four seasons : mean values, standard deviation associated with transient activity, amplitude of the diurnal variations and model differences.

180.

- The model differences are often of the order of magnitude of the transient or diurnal variability.
- The model differences are generally much smaller bellow 60 km than above.

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7 Conclusion

The initial choice of using two versions of the model is completely justified a posteriori in that sense that the detailed comparison of the moddel results has led to the identification of a number of errors or numerical problems (numerical stability near the poles for the LMD grid point dynamics, problems with the implemenation of the physical package in the Oxford version). This approach is especially important on a planet as Mars were observations are far from sufficient to contrain the numerical results.

The important effort which has been made in the last few months has resulted in a much better agreement between the two model versions, which also correspond to significant improvements of the models.

In the present state, the differences are acceptable : of the order of 10% of the mean value and of the order of the transient and diurnal variability.

Some significant differences are still present near the surface in high latitudes. They are probably related to the very different grid used by the two models in this region : The grid point model uses a very fine grid but with introduction of significant amount of noise whereas the spectral model works with a constant horizontal resolution.

The other significant differences lie in the upper atmosphere and are difficult to interpret at this stage. The main difference in that respect which we will analyse in more details is the opposite sign of the equatorial zonal wind at northern autumn equinox (see Fig. 6).

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Wilson, R. W., and K. Hamilton, 1996, Comprehensive model simulation of thermal tides in the Martian atmosphere, *J. Atmos. Sci.*, *53*, 1290–1326, 1996.