The influence of NCEP-data assimilated into COMMA-LIM on the 16-day wave

K. Fröhlich, A. I. Pogoreltsev, Ch. Jacobi, L.A. Nechaeva

Summary

The general circulation model COMMA-LIM solves the primitive equations on a sphere using gridpoints. The relative large interval between adjacent gridpoints ($5° \times 5.6°$ latitude versus longitude) causes an incorrect meridional temperature gradient in the coarsly resolved troposphere that leads to too weak winds there, particularly in the lower winter stratosphere above the polar region. By using the technique of nudging 11-year averaged NCEP zonal mean temperature data were assimilated into COMMA-LIM. This means that longitudinal dependent processes as calculated by the model still influence the atmosphere. The nudging method has improved not only the lower atmosphere, but also the middle atmospheric jets show a more realistic behaviour. A numerical experiment by forcing the 16-day wave was carried out in order to investigate the influence of an improved background circulation on the vertical propagation of planetary waves.

Zusammenfassung

Das globale Zirkulationsmodell COMMA-LIM berechnet die primitiven Gleichungen auf einem Kugelgitter. Der relativ große Gitterabstand von $5° \times 5.6°$ in Breite und Länge und die grobe vertikale Auflösung führen zu einem inkorrekten meridionalen Temperaturgradienten in der Troposphäre, so dass die troposphärischen Jets und der polare Winterwirbel zu schwach ausgeprägt sind. Mit Hilfe der Methode des Nudging wurden in den unteren 30 km der Atmosphäre 11-Jahres gemittelte NCEP Reanalysedaten des Temperaturfeldes assimiliert. Dabei wurde nur der zonale Mittelwert der berechneten Temperatur an die Reanalysedaten relaxiert, so dass die Antriebsterme, die von COMMA-LIM berechnet werden, erhalten bleiben. Durch diese Methode wurden Wind- und Temperaturfeld sowohl in der Troposphäre als auch in der mittleren Atmosphäre verbessert. Ein Experiment zur Ausbreitung der 16-Tage Welle wurde unter den neuen Bedingungen durchgeführt, und der Einfluß der veränderten Atmosphäre auf die vertikale Wellenausbreitung wurde untersucht.

1 Introduction

COMMA-LIM (Cologne Model for the Middle Atmosphere - Leipzig Institute for Meteorology) is a general circulation model designed to study dynamical processes in the middle und upper atmosphere. The model solves the primitive equations in flux form on a sphere under hydrostatic approximation. The Earth's atmosphere is descritized into a horizontal grid - $5.6° \times 5°$ longitude versus latitude - extending in the vertical up to 135 km in logarithmic pressure height with a vertical resolution of 2.8 km. Middle atmospheric processes
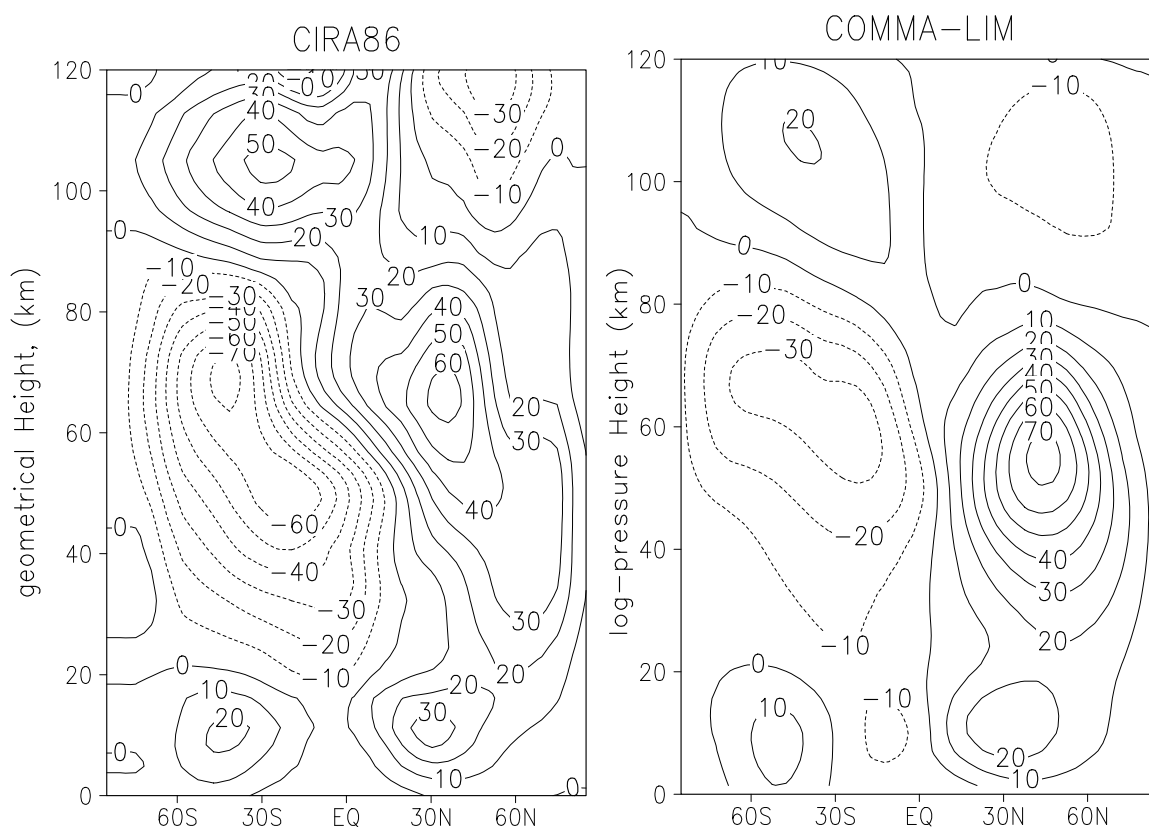
Figure 1: The January monthly and zonal mean wind field ($m\,s^{-1}$) as shown by CIRA86 (left) and COMMA-LIM (right). Please note the different height systems.

as the absorption and transmission of radiation, thermospheric processes and ionospheric processes are included. Gravity waves are parameterized while planetary waves can be forced and resolved. So the model reproduces the important features of the stratosphere, mesosphere and lower thermosphere. For details about the model structure the reader is referred to Fröhlich et al. (2003).

However, not all properties can be reproduced well enough and it is supposed that the badly resolved troposphere might partially be responsible for the discrepances. The troposhere is described only by 4 vertical gridpoints and the large horizontal intervals between adjacent gridpoints lead to an incorrect latitudinal temperature gradient which is responsible for too weakly developed tropospheric jets. Additionally, the stratospheric jet in the winter hemisphere does not extend to the polar latitudes and lower altitudes. This can be seen in Figure 1 where a comparison of the zonal-mean zonal wind fields between CIRA86 and COMMA-LIM for January conditions is presented. The tropospheric jets also deviate slightly in latitude which can be important for guiding the upward propagating planetary waves. In the middle atmosphere the winter jets compare well in extension and strenght, while the summer hemisphere looks different. The maximum summer wind speed of CIRA86 is approximately twice that of COMMA-LIM and there is no tilting of both jets in COMMA-LIM as shown by the CIRA climatology.

Planetary waves (PW) are very sensitive to background conditions that influence their horizontal and vertical propagation. PW propagate mainly through the winter

hemisphere up into the MLT (Mesosphere/Lower Thermosphere) region where they break. Several conditions influence the path and strenght of the PW as, for instance, the critical lines of eastward directed winds where the waves velocity meets the magnitude of the background wind and dissipate there (Dickinson, 1968). Regions of a weak meridional gradient of potential vorticity (PV), i.e., $\partial \bar{q}/\partial y$ may also form a barrier for the PW (Matsuno, 1970). A remarkable sensitivity of PW propagation was also found by Nigam and Lindzen (1989) for small variations in the subtropical jets.

If the subtropical jets as calculated with COMMA-LIM could be changed to a more realistic shape and lower stratospheric winds at polar latitudes exist it must have an effect on the PW propagation. In order to improve the wind and temperature fields without applying additional time consuming routines, the method of nudging has been used.

2 Assimilating data with the method of Nudging

The NCEP reanalysis data set is used for this method of assimilation. First, at the lower boundary the monthly mean fields of geopotential height and temperature at 1000 hPa were averaged over 11 years (1992-2002) and the zonal mean field and the stationary PW with zonal wave number 1, 2 and 3 were composed. Second, up to a height of about 30 km the monthly and zonal mean temperature is relaxed to the calculated zonal mean temperature by inserting an additional term into the first law of thermodynamics:

$$
\begin{aligned}
\frac{\partial T}{\partial t} &= F(T,t) - K(\bar{T}_{COMMA} - \bar{T}_{NCEP}) \\
K &= \varepsilon/\tau,
\end{aligned}
\tag{1}
$$

where $F(T,t)$ refers to the other terms in the equation, $\tau = 5$ days and $\varepsilon = 1 - \exp^{-(t/\tau)^2}$ are the relaxation factors. This method was first suggested by Kurihara and Tuleya (1978) and also used by Morel et al. (2004). We only used the zonal mean temperature of COMMA-LIM to be relaxed to the reanalysis data in order to not suppress other terms as radiation as well as contributions from gravity waves and planetary waves.

Figure 2 presents a comparison of the January temperature fields between the standard COMMA-LIM (now referred as control run) and a simulation of COMMA-LIM with assimilated NCEP temperatures (in the following referred as NCEP run). The main feature in the NCEP run troposphere is a local temperature minimum in the polar winter hemisphere, a warmer polar summer hemisphere as in the control run, and the isoline of $210\,K$ centered around the equator extends into midlatitudes. This causes a latitudinal temperature gradient in contrast to the control run.
The upper panels of Figure 3 show the comparison for the January zonal mean wind fields. Here we concentrate on the northern hemisphere. The subtropical jet in the troposphere is now about $10\,m\,s^{-1}$ stronger and is shifted towards to the equator. The middle atmosphere winter jet in the NCEP run extends into polar regions of the lower stratosphere in contrast to the control run where the zonal wind is weaker there. The wind structure of the whole middle atmosphere is now much closer to the CIRA climatology (compare with Figure 1) although the temperature relaxation reaches only up to 30 km. If we investigate the structure of the meridional gradient of potential vorticity $\partial \bar{q}/\partial y$ in the winter hemisphere for both cases then it turns out that the tropospheric maximum
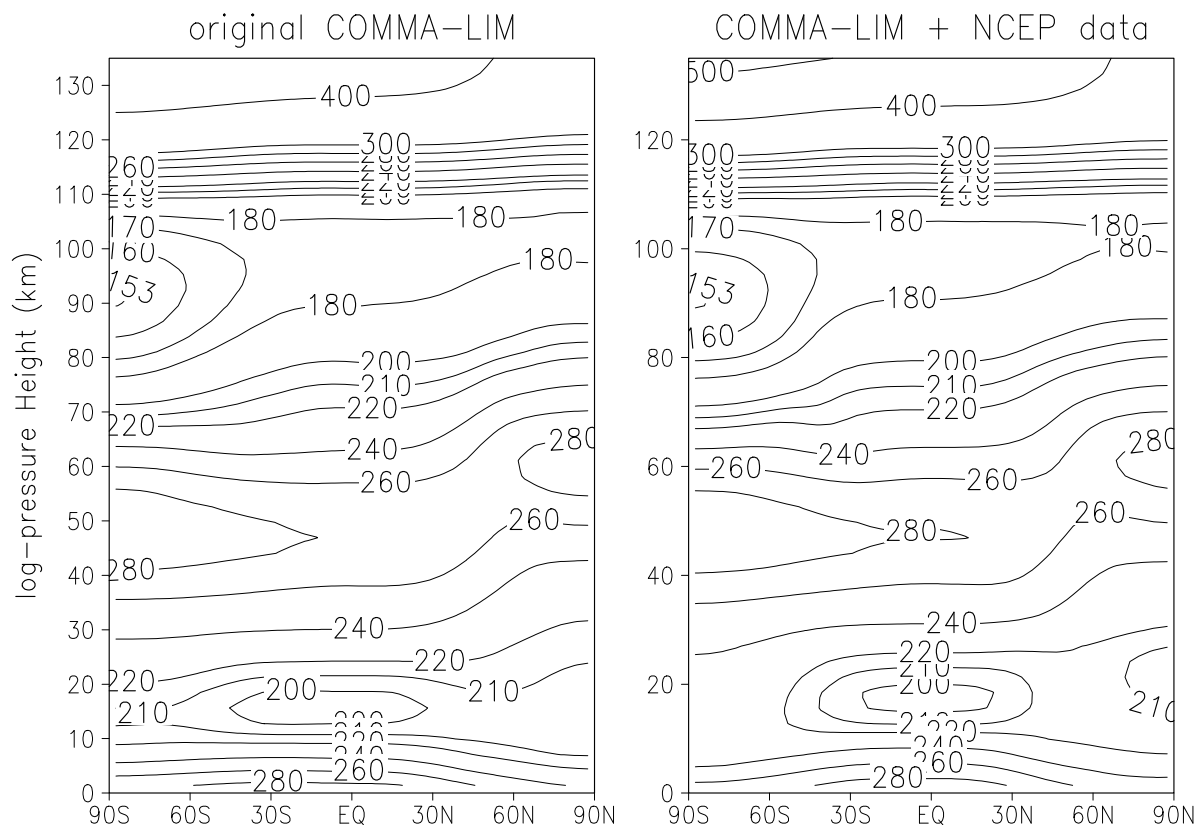
Figure 2: The January monthly mean temperature field calculated for original COMMA-LIM conditions (left) and under inclusion of NCEP Temperature data (right).

around 30° N is stronger for the NCEP run (lower panels of Figure 3). The stratopause maximum around $50-60$ km looks quite similar in both figures. However, in between, i.e. above the tropospheric jet and south of the polar night jet the local minimum of $\partial \bar{q}/\partial y$ is more pronounced in the NCEP run. In his investigations about vertical propagation of planetary waves Matsuno (1970) found that a region of weak meridional potential vorticity gradient can act as a barrier for wave propagation and confines the wave energy to polar regions. This means, that the propagation of PW is now stronger prescribed as upward propagation rather than horizontal propagation.

3   Forcing of the 16-day wave

The 16-day wave (16DW) is a regular feature of the the winter middle atmosphere. The planetary wave with zonal wave number 1 and periods of around 16 days belongs to the set of Eigenmodes of the atmosphere. The 16DW can propagate upwards through the winter hemisphere (i.e., through westerly winds) into the mesopause region where it breaks. Wave amplitudes in the zonal wind maximise in the mesosphere at around 70–75 km height with values up to $15-18\,m\,s^{-1}$ (e.g., Namboothiri et al. (2002); Luo et al. (2002)).

The 16DW is forced in COMMA-LIM by inserting an additional heating term h_{16dw} again
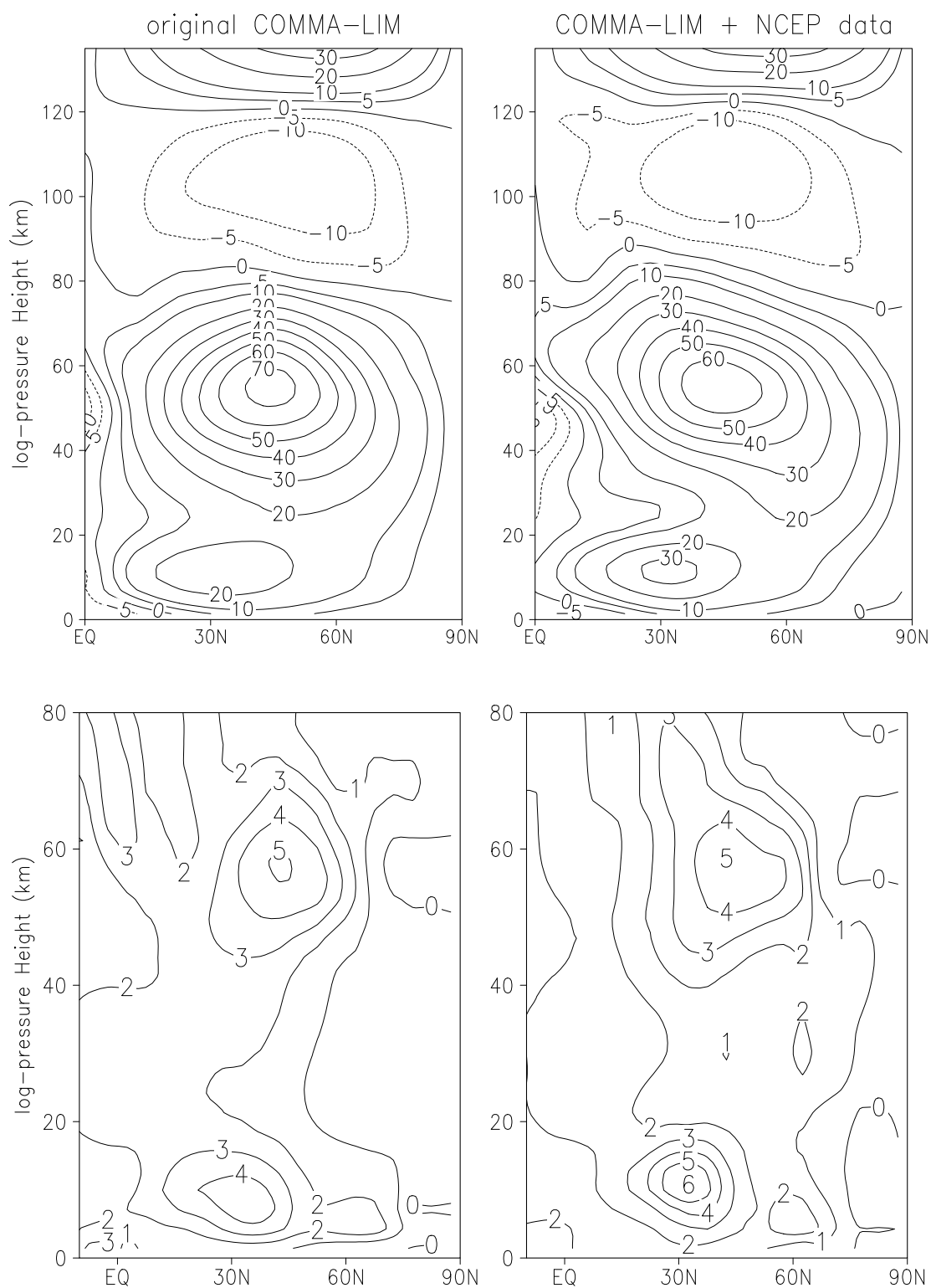
Figure 3: Upper panels: The January monthly mean zonal mean wind field $(m\,s^{-1})$ calculated for original COMMA-LIM conditions (left) and under inclusion of NCEP Temperature data (right). Lower panels: meridional gradient of potential vorticity $\partial \bar{q}/\partial y \times 10^{10}$ $(m^{-1}\,s^{-1})$ in the same appearence.

into the first law of thermodynamics:

$$h_{16dw} \; = \; A \, \Phi(\phi) \, F(z) \, \cos(k \, x \, - \, \omega \, t) \tag{2}$$

with

- $A = 6.4 \, \text{K/day}$, an empirical defined amplitude in order to meet the observed values,

- $\Phi(\phi)$, Hough mode (1,3), describing the latitudinal structure of the wave,

- $F(z) \; = \; \exp[-\frac{(z-10)^2}{25}]$ defines the smoothed height of forcing,

- $k \; = \; 1$ is the zonal wave number, and frequency $\omega \; = \; - \, 2 \, \pi/T$, with the period $T = 360 \, \text{h}$.

Now the 16DW is forced for both cases in order to investigate the influence of the assimilated NCEP-temperature on the propagation of planetary waves. The wave is forced when the basic state of January has been established and the model runs additionally 30 days to let the model atmosphere to be tuned with the wave. Afterwards, the full month of January is calculated. The following figures of the 16DW represent a monthly mean.

4   Results

In Figure 4 the 16DW amplitudes are displayed for the original and the NCEP experiments. Upper panels show the amplitudes of zonal wind and lower panels of the temperature perturbation. A remarkable difference can be seen in the behaviour of wave propagation. In the troposphere the wave is stronger pronounced in the orignial run while the NCEP run shows a much stronger amplitude of the 16DW in the mesosphere. There, the wave also propagates higher up to 120 km. This indicates that the so changed background temperature and wind fields support upward planetary wave propagation while in the original case a large part of the wave energy is trapped in the troposphere. Furthermore, the results obtained with the NCEP run are quite close to the observations reported by Namboothiri et al. (2002) and Luo et al. (2002).

 In order to check the distribution of wave energy in the winter hemisphere the Eliassen-Palm flux (EP-flux) is calculated. The EP-flux represents momentum and heat fluxes of the atmospheric disturbances:

$$F^\phi \quad = \quad \rho_0 a \, cos\phi \, (\overline{u_z} \, \frac{\overline{v' \, \theta'}}{\overline{\theta_z}} \; - \; \overline{v' \, u'}), \tag{3}$$

$$F^z \quad = \quad \rho_0 a \, cos\phi \, \{[f \; - \; \frac{1}{a \, cos\phi}(\overline{u} \, cos\phi)_\phi] \, \frac{\overline{v' \, \theta'}}{\overline{\theta_z}} \; - \; \overline{w' \, u'}\}. \tag{4}$$

Here, F^ϕ and F^z refer to the horizontal and vertical component in spherical coordinates. The Eliassen-Palm Flux is presented in Figure 5 for the two experiments. For the control run one can see a downward directed flux in the polar lower stratosphere and also some poleward downward propagation in the layers above. The upward propagation in the middle atmosphere is weaker than in the NCEP run, where no downward movement can be seen. This shows clearly that the background circulation in the troposphere and stratosphere plays an important role for the starting conditions of a planetary wave.
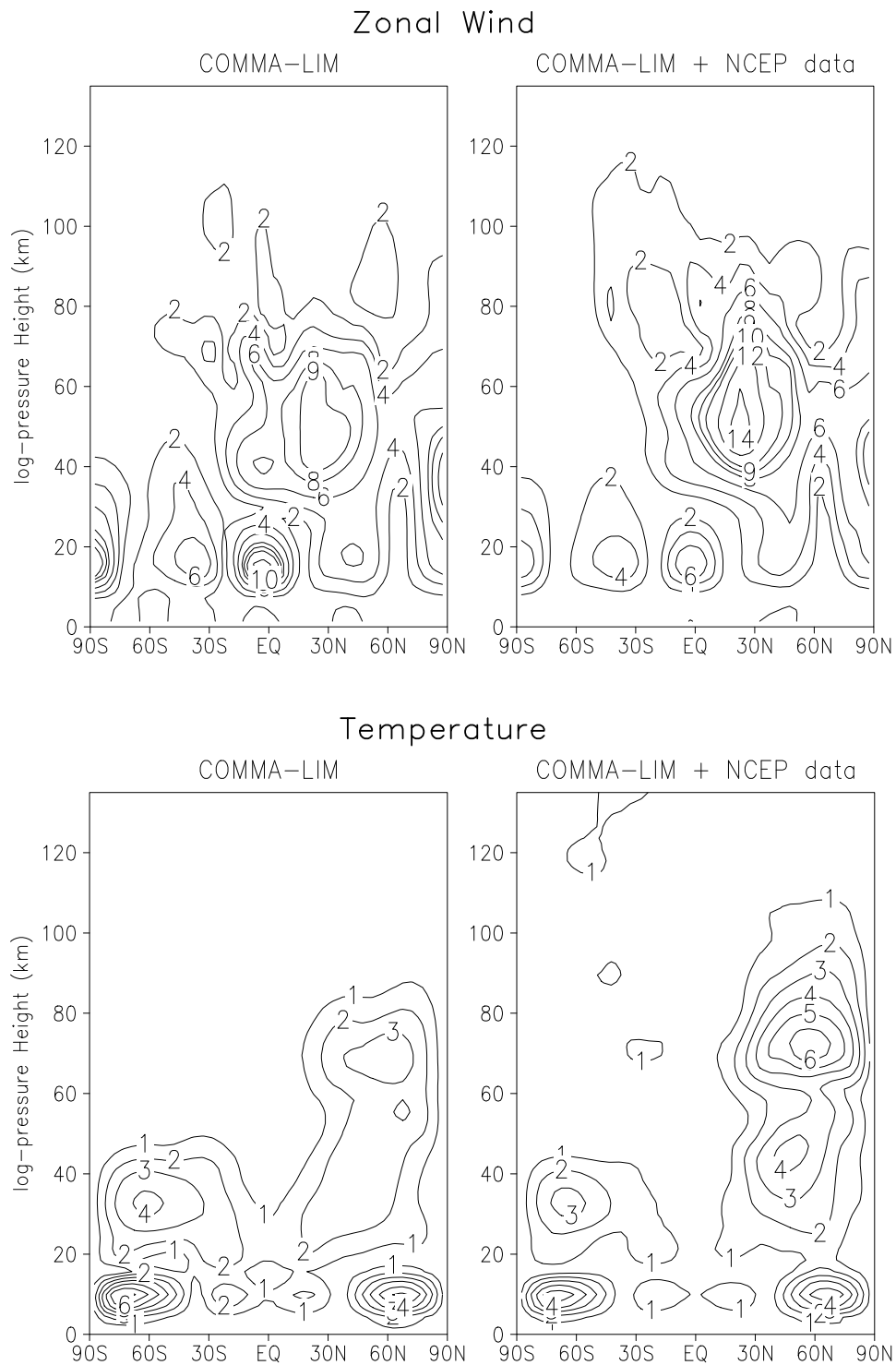
Figure 4: Upper panels: Amplitudes of the 16-day wave in zonal wind calculated for original COMMA-LIM conditions (left) and under inclusion of NCEP Temperature data (right). Lower panels: amplitudes of the 16-day waves in the same appearance.
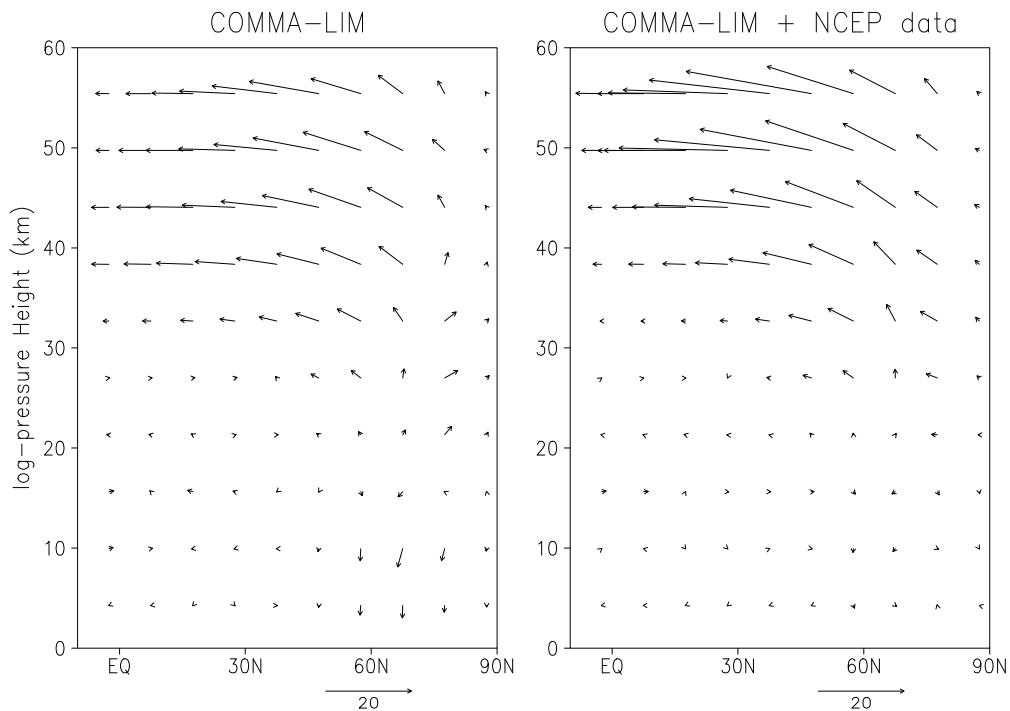
Figure 5: The Eliassen-Palm flux (m^2/s^2) calculated for original COMMA-LIM conditions (left) and under inclusion of NCEP Temperature data (right). The vertical component is increased $(F_z \times 50)$ in order to highlight the up- and downward propagation.

5   Conclusions

It has been shown that the method of nudging NCEP reananalysis temperature data into COMMA-LIM provides an easy and effective tool for improving the temperature and wind field in the lower atmosphere. This has also a large impact on the structure of the middle atmospheric jets so that the propagation conditons of the planetary waves are changed remarkably. Particularly, the subtropical jets and the polar night jet act as waveguides that allow the 16DW to propagate upwards. With the new stage of COMMA-LIM we generate a more realistic description of the middle atmosphere.

Adress of Author
K. Fröhlich (kfroehlich@uni-leipzig.de), Institut für Meteorologie, Universität Leipzig, Stephanstr.3, 04103 Leipzig

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