Tides, Rossby and Kelvin Waves simulated with the COMMA-LIM Model

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Abstract

A 48-layer version of the COMMA-LIM (Cologne Model of the Middle Atmosphere – Leipzig Institute for Meteorology) three-dimensional global mechanistic model of the Earth's atmosphere from 0 km to 135 km with logarithmic pressure height coordinates was developed. The model is capable of reproducing the global structures and propagation of different planetary waves in the middle atmosphere. The contribution of gravity waves, tides, Rossby and Kelvin waves into the zonally averaged momentum budget of the mesosphere / lower thermosphere region has been investigated.

Zusammenfassung

Eine neue Version des COMMA-LIM (Cologne Model of the Middle Atmosphere – Leipzig Institute for Meteorology) wurde im Zusammenhang mit der Erhöhung der vertikalen Schichtauflösung entwickelt. Das COMMA ist ein dreidimensionales globales mechanistisches Modell der Erdatmosphäre mit einer Ausdehnung von ca. 0 – 135 km in logarithmischen Druckkoordinaten. Damit können globale Eigenschaften der mittleren Atmosphäre sowie die Ausbreitung verschiedener planetarer Wellen nachvollzogen werden. Die Beiträge der Schwerewellen, thermischer Gezeiten, Rossby und Kelvin Wellen zur zonal gemitteltem Impulsbalance der Mesosphäre und unteren Thermosphäre wurden untersucht.

Introduction

To obtain a comprehensive picture of the global dynamical processes in the middle atmosphere, the planetary wave activity and possible feedback mechanisms between the waves and the mean flow have to be taken into account. The excitation and propagation of planetary waves are strongly dependent on the mean circulation and its spatial gradients, but in turn the waves influence the mean flow and temperature distributions, so that they provide a link between the atmospheric layers up to the lower thermosphere. To this aim, a new, 48-layer version of the COMMA-LIM 3D atmospheric circulation model has been developed to investigate mean flow and planetary wave propagation between the troposphere and lower thermosphere.

The most prominent planetary wave in the summer mesosphere and lower thermosphere (MLT) region is the quasi two-day wave (QTDW), which has been regularly measured since the early 1970s (Muller, 1972; Babadshanov et al., 1973). At Collm Observatory, the QTDW is also measured regularly, in sufficient detail it can be monitored since 1983 (Jacobi et al., 1997; Jacobi, 1998). Satellite and radar measurements show also that Kelvin waves play an important role in the low latitude dynamics.

The main purpose here is to demonstrate that COMMA-LIM is capable of reproducing the realistic distributions of the mean flow and temperature, and to simulate the propagation of different planetary waves, atmospheric tides, fast and ultra-fast Kelvin waves (FKW and UFKW, respectively), Rossby and Rossby-gravity waves. The influence of gravity waves (GWs) on the general circulation and planetary waves is discussed.

COMMA-LIM, the new Version

The COMMA-LIM (Cologne Model of the Middle Atmosphere – Leipzig Institute for Meteorology) model is a global mechanistic model from 0 - 135 km with logarithmic pressure coordinates $z = H \cdot \ln(p/p_0)$ and a scale height of H = 7 km. Horizontal resolution is 5.265° in longitude and 5° in latitude. The dynamics are described with the spherical non-linear primitive equations in flux formulation. Hydrostatic balance is assumed. The model contains a radiation scheme calculating solar heating and infrared cooling rates of the most prominent absorbers and emitters in the middle atmosphere. Thermal dissipation from turbulent mixing, ion drag, and molecular heat conduction are included. A basic version of the model has been described by Lange (2001), see also a comparison with measurements by Lange et al. (1999). Different travelling planetary waves (Rossby normal-mode, Rossby-gravity, Kelvin waves) can be included into simulation through the insertion of corresponding Hough functions at the lower boundary. To investigate stationary and propagating waves and also to consider the long-term variability of the wave amplitudes, a space-time Fourier analysis of the simulated fields is used.

To obtain a better representation of winds and tides, several developments and improvements have been introduced into the model:

- The vertical resolution was increased, now using 48 layers in log-pressure coordinates from 0 to 135 km. As lower boundary conditions monthly averaged climatological distributions of the geopotential height and parameters of stationary planetary waves (SPW) extracted from UKMO assimilated fields are used.
- The gravity wave (GW) parameterisation scheme, still basing on the Lindzen-type parameterisation, has been improved taking into account possible multiple breaking levels and wave propagation between the layers where the wave is saturated, as well as heating/cooling effects due to GW dissipation.
- Modifications are made in the radiative heating/cooling representation, including an updated parameterisation of solar heating in O_3 and Lyman-α bands, implementation of heating efficiencies and chemical heating in the MLT region as suggested by Mlynczak and Solomon (1993). Several modifications are included for turbulent cooling/heating, Rayleigh friction, ion drag and Lorentz deflection.

For more details, the reader is referred to Fröhlich et al. (2003).

Fig. 1 shows the simulated monthly averaged zonal wind and temperature fields for July conditions. The middle atmosphere is characterized by easterly jet in summer and westerly jet in winter hemisphere. At mesopause altitudes breaking gravity waves lead to a reverse of the zonal wind. This causes also a very cold summer polar mesopause due to meridional mass transport from summer to winter hemisphere. Whereas the summer stratosphere/stratopause region shows very high temperature values because of absorption of solar radiation by ozone. The results are in reasonable agreement with reference atmospheres (e.g., CIRA-86, Swinbank and Ortland).

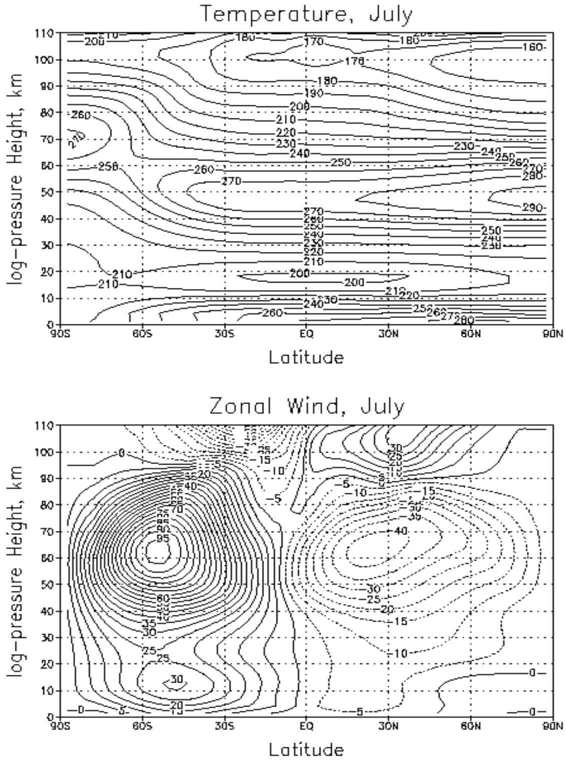

Fig. 1: Zonally and monthly averaged wind and temperature fields. Contour intervals are: 10 K for top panel, 5 m/s for lower panel.

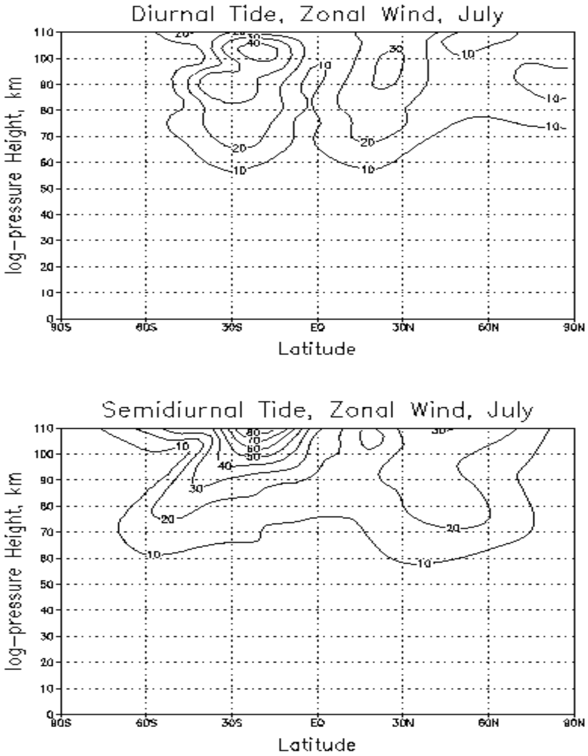

Fig. 2: Zonal wind amplitudes of the diurnal and semidiurnal tide. Contour intervals are 10 m/s.

Latitude-height cross-sections of amplitudes of zonal wind pertubations for diurnal and semidiurnal solar tides in July are shown in Fig. 2. These are two of the free global normal modes the atmosphere exhibits which are primarily forced by diurnal variations of the heating due to absorption of solar radiation. Note, that the diurnal tide is confined to equatorial latitudes but the semidiurnal tide shows strongest amplitudes at higher latitudes, especially in the winter hemisphere. The results of simulation for the diurnal tide compare well with the analysis of satellite measurements presented by Khattatov et al. (1997).

Investigation of propagation conditions of QTDW and their influence on the mean flow

The results of simulations with a 2D linearized model show that propagation of the QTDW from the lower atmosphere to the upper atmospheric layers strongly depends on the background wind conditions in the equatorial stratosphere (Pogoreltsev, 1999). A possible source of modification of the mean circulation is variable GW activity. To investigate the influence of GW drag on the mean flow and the QTDW, simulations with different GW amplitudes in the troposphere have been performed.

Increase in GW activity leads to weaker easterlies at low latitudes near the stratopause because of frequent breaking of the GW (Fig. 3a). These changes of the general circulation above the equator modify QTDW-propagation conditions in such a way that in the case of stronger GW activity the QTDW propagates more effectively into the northern hemisphere MLT region (Fig. 3b and Fig. 4). For the latter case one can see a maximum of about 18 m/s at 20°N in approximately 90 km height. This in good agreement with measurements.

To estimate a possible influence of the QTDW on the mean flow, the force per unit mass due to its dissipation, represented through the divergence of the Eliassen-Palm (EP) flux has

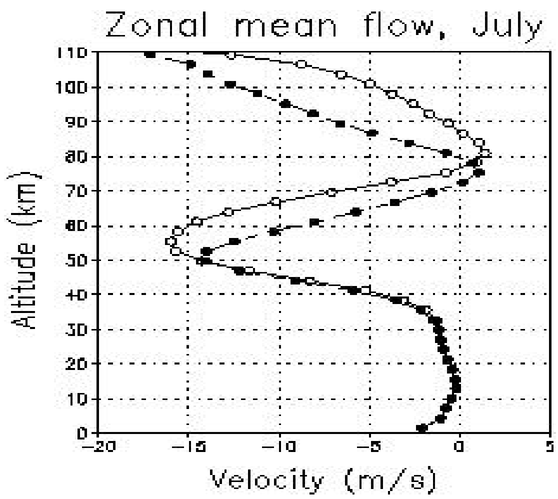

Fig. 3a: Equatorial zonal wind for regular (0.75 cm/s, bright line) and enhanced (1 cm/s, black line) GW amplitudes in the troposphere.

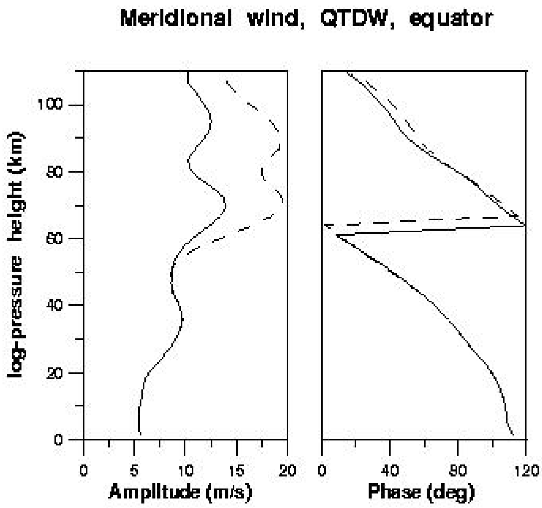

Fig. 3b: Amplitudes and Phases of the QTDW, solid line: regular GW, dashed line: enhanced GW.

been calculated (Fig. 5). This divergence of the EP-flux has to be equal zero if the disturbances are steady, linear, frictionless, and adiabatic in a purely zonal basic flow. As you can see, in the Northern Hemisphere the QTDW exerts a westward acceleration on the mean flow (negative divergence of EP flux) up to the MLT region.

That is what we expect from a westward traveling planetary wave. This forcing of the mean flow is stronger (about 12m/s/day) in cases with enhanced GW amplitudes (lower panel) than for regular GW amplitudes (upper panel).

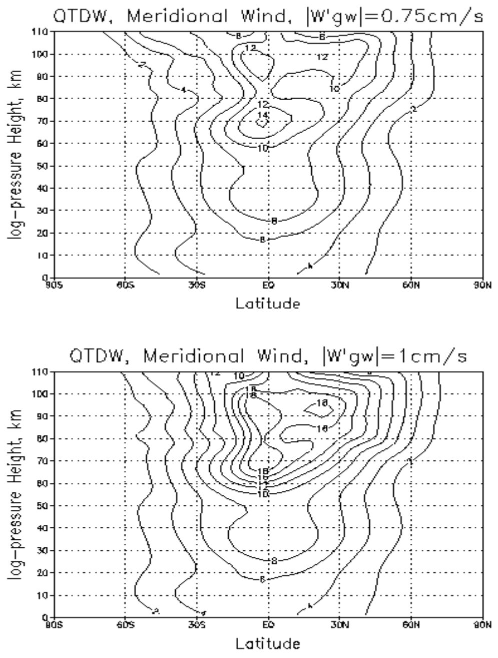

Fig. 4: Amplitudes of meridional wind perturbation for QTDW. Upper panel: regular, lower panel enhanced GW. Contour intervals are 2 m/s.

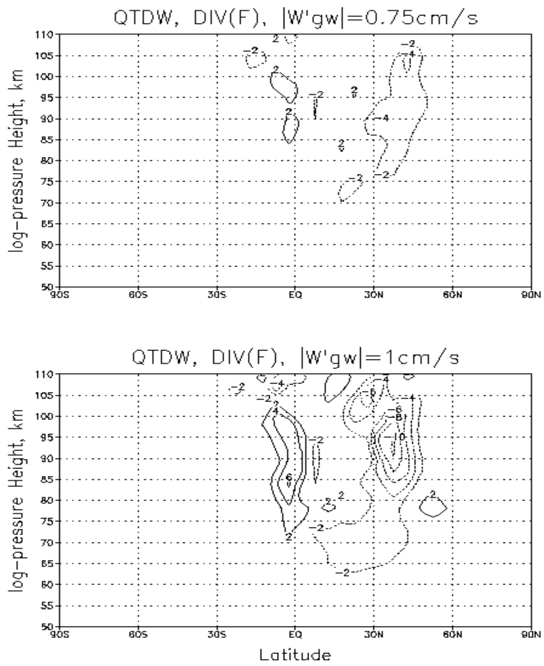

Fig. 5: Force per unit mass due to dissipation of QTDW (EP flux -divergence). Contour intervals are 2 m/s/day.

At equatorial latitudes in the middle and upper atmosphere the EP flux divergence is positive and the eastward acceleration of the mean flow amounts to about 6 m/s/day. The positive EP flux divergence can be explained by an interaction of the QTDW with other waves (tidal oscillations, SPW), which excites a set of secondary waves. These secondary waves propagate to the upper atmosphere and transfer their energy back to the QTDW. Another possible explanation of the QTDW forcing in the low-latitude MLT region (positive EP flux divergence) is a modulation of GW propagation by QTDW winds in the stratosphere. Modulated GWs dissipate in the upper atmosphere and produce secondary planetary waves with characteristics of the primary QTDW.

Fast and Ultra-fast Kelvin Waves

Kelvin waves are a striking feature of the equatorial atmosphere. These eastward traveling waves are bounded to equatorial latitudes and some of them are able to propagate upward to higher altitudes. Because of the excitation in the stratosphere due to convective disturbances in the troposphere the energy flux goes upward. We force our Kelvin waves at the lower boundary with calculated Hough-functions which are the eigenfunctions of Laplace' tidal equation. The so obtained latitudinal structure is inserted in the geopotential at the lower boundary, the same procedure as for the QTDW.

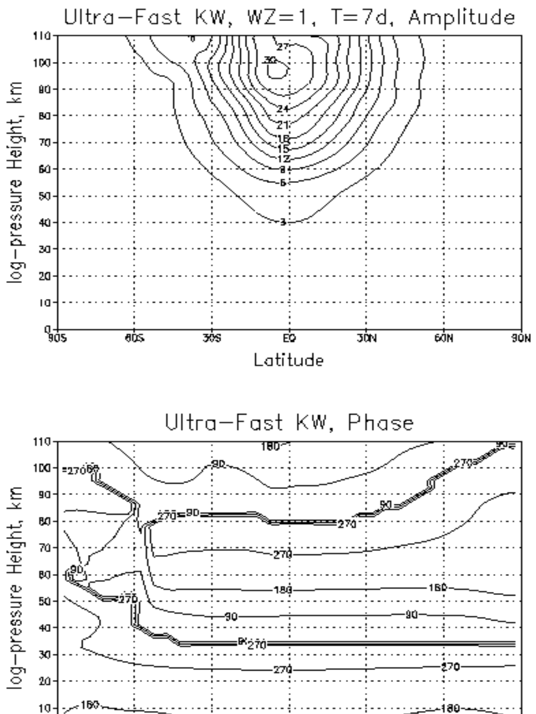

Fig. 6: Amplitude and Phase of UFKW. Contour intervals are 3 m/s for upper panel and 90° for lower panel.

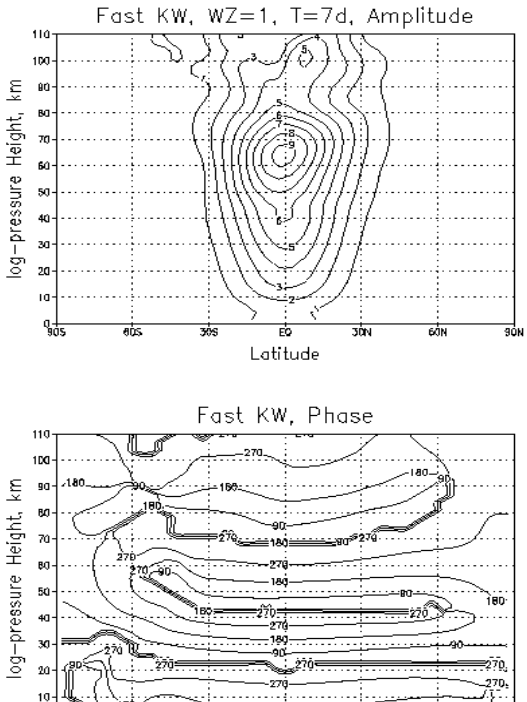

Fig. 7: As Fig. 6, but for FKW. Contour intervals are 1 m/s (upper panel) and 90° (lower panel).

Figs. 6 – 8 show the amplitudes and phases of the ultra-fast (UFKW, T=3.5 days) and fast (FKW, T=7days) Kelvin waves with zonal wave number m=1, as well as latitude-height sections of the forcing per unit mass due to dissipation of these waves. Both waves are confined to equatorial latitudes, which is more strictly the case for the FKW than for the UFKW. The UFKW is able to propagate to the MLT region and has larger vertical wavelength (about 40 km) than the FKW has (about 25 km). These results are in good agreement with predictions from the theory of equatorially trapped planetary waves (Lindzen, 1967).

The UFKW excerts a significant positive acceleration on the mean flow in the low-latitude MLT region. The calculated structure of the UFKW and the magnitude of EP flux divergence match well with the results of simulation obtained by Forbes (2000) using the Global Scale Wave Model.

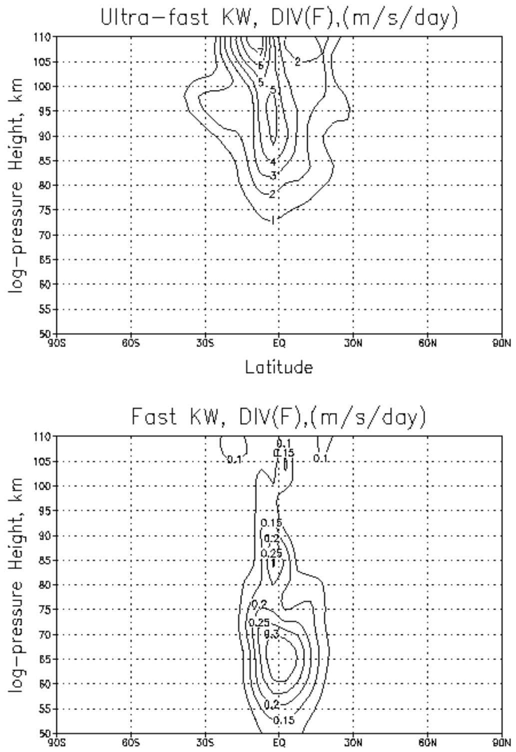

Fig. 8: As Fig. 5, but for the Kelvin waves. Contour intervals are 1 m/s/day.

Conclusions

The new version of COMMA-LIM is able to reproduce the global structures and propagation of different planetary waves in the middle atmosphere and may be used to investigate the wave-mean flow and wave-wave interactions, as well as the influence of GW the on these large-scale motions.

Results of analysis of QTDW propagation suggest that one of the reasons of the QTDW variability in the MLT region is the change of mean flow in the equatorial stratosphere, which is dependent on GW activity in the troposphere. It has, however, to be taken into account that the QTDW in these model runs has been forced at the lower model boundary, which not necessarily need to be realistic, if the wave is considered as an in situ middle atmosphere phenomenon. Additional investigation of the behaviour of such waves is necessary.

The propagation of Kelvin waves of different type has also been investigated. It was found that COMMA-LIM model is capable of reproducing these waves in a realistic manner, and may be used for the more detailed investigation of wave propagation, as well as their interaction with other waves and the mean flow.

Acknowledgements

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