Implementation of the Warner-McIntyre Scheme of gravity wave parametrization into COMMA-LIM, Part I: Code Transfer

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Zusammenfassung
Ein neues Schema für die Parametrisierung der Schwerewellen und ihres Einflusses auf die mittlere Atmosphäre ist für COMMA-LIM (COlogne Model of the Middle Atmosphere – Leipzig Institute for Meteorology) übernommen worden. Während das bisher in COMMA-LIM genutzte aktualisierte Lindzen-Schema (Lindzen, 1981) die Ausbreitung und das Brechen einzelner Wellen berechnet, geht das Warner und McIntyre–Schema von einem Spektrum der Schwerewellen aus. Beide Schemata gehen von Schwerewellen im mittleren Frequenzbereich zwischen Brunt-Väisälä Frequenz und Rotationsrate der Erde aus ($N \gg \hat{\omega} \gg f$). Erste Ergbnisse werden vorgestellt.

Summary
A new scheme for the parametrizing of the gravity waves and their impact on the mean circulation of the middle atmosphere has been adapted to COMMA-LIM (COlogne Model of the Middle Atmosphere – Leipzig Institute for Meteorology). The current version based on the Lindzen-scheme (Lindzen, 1981) calculates the propagation and breaking of 48 single waves while the new Warner and McIntyre – scheme uses a spectral approach of gravity waves. Both schemes are based on the medium frequency approach locating the gravity waves between the Brunt-Väisälä-frequency and the rotation rate of the earth ($N \gg \hat{\omega} \gg f$). First results are presented.

1 Introduction

The project GW-CODE is part of the DFG priority program CAWSES and focuses on long-term data sets of gravity wave (GW) activity from satellite measurements (SABER-satellite, GPS) as well as modeling the effects on the global circulation simulated in a global circulation model (COMMA-LIM).

GW play a crucial role in the dynamics of the middle atmosphere. During their upward propagation their amplitudes grow with height and if the waves break they deposit momentum and energy onto the mean circulation. Since only gravity waves propagating opposite to the mean wind in the middle atmosphere reach the mesopause region the

breaking waves are responsible for the wind reversal in the mesopause region. The adiabatic upwelling due to the imposed momentum and heat leads to the extreme cold polar summer mesopause.
The horizontal scale of GW is far too small to be resolved in global circulations models, therefore they have to be parameterized. Currently, the COMMA-LIM model uses an updated Lindzen scheme which calculates the momentum and energy depostion of the breaking GW and the related eddy-diffusion coefficient (Fröhlich et al., 2003). The physical reasonable description of convective overturning of a saturated wave and their subsequent deposition of momentum and energy on the mean flow has the disadvantage that the scheme deals with a certain number of single waves. Consequently, the fixed number of launched waves is an artificial information on the system that has to be 'tuned'. Additionally, the nonlinear processes between the GW are not considered. Observations can only provide estimates of GW–spectra (e.g. Ern et al. (2004); Fritts and VanZandt (1993)). In order to improve the physical information for the atmospheric system in COMMA-LIM an alternative scheme made by Warner and McIntyre (Warner and McIntyre, 1996) was transferred to the Fortran code used in COMMA-LIM. The IDL code was provided by the Forschungszentrum Jülich.

2 Warner-McIntyre Parameterisation

The idea of this spectral approach uses the midfrequency approximation, that neglects nonhydrostatic and Coriolis effects in the dispersion relation for gravity waves:

$$\hat{\omega}^2 = N^2 \frac{k^2}{m^2}, \tag{1}$$

with $\hat{\omega}$ as intrinsic frequency, N as the buoyancy frequency, k as horizontal and m as vertical wave number. This allows the full frequency – wave number spectrum of pseudomomentum flux to be integrated with respect to frequency, leading to a spectrum that only depends on m and azimuthal direction ϕ (Warner and McIntyre, 2001). A spectral shape for the vertical wavenumber is derived from observed gravity wave spectra, that often show a positive slope at small m (first part), and an m^{-3} behaviour at large m (Fritts and VanZandt, 1993) as a second part. A third part of the spectrum results from wave breaking followed by conservative propagation. The evolution of the launched gravity wave spectrum propagating upwards is assumed to be governed by conservative propagation under Doppler-shifting and wave breaking. An upward propagated GW spectrum in terms of the pseudomomentum flux $\rho\mathbf{F}_p(z, m, \phi_j)$ is compared with its quasi-saturated spectrum $\rho\mathbf{F}_{pS}(z, m, \phi_j)$ at each level under the condition

$$\rho\mathbf{F}_p(z, m, \phi_j) \leq \rho\mathbf{F}_{pS}(z, m, \phi_j). \tag{2}$$

The wave number interval, where $\rho\mathbf{F}_p(z, m, \phi_j)$ is chopped by $\rho\mathbf{F}_{pS}(z, m, \phi_j)$ as ceiling for the vertical wave number spectrum, is called wave breaking-part and the final spectrum will be called 'evolved spectrum', propagating further upwards. Computational efficiency is improved by assuming that the evolved spectrum can be divided in not more than three parts, each integrable analytically, separated by crossover and cutoff vertical wave numbers. In this way the pseudomomentum flux $\rho\mathbf{F}_p$ is computed, and the wave-energy flux $\rho\mathbf{F}_E$ and the turbulent energy disspiation rate ε due to wave breaking are derived.

The wave-induced forces per unit mass are calculated by the one-dimensional divergence of the pseudomomentum flux

$$\mathbf{G}(z, \phi_j) = -\frac{1}{\rho}\frac{\partial}{\partial z}\rho\mathbf{F}_p(z, m, \phi_j) \tag{3}$$

This term is the acceleration rate that contributes to the middle atmospheric wind balance. For a full description of the approach the reader is referred to Warner and McIntyre (1996, 2001).
For a complete transfer to COMMA-LIM a derivation of the eddy-diffusion coefficient is necessary as well as the contribution to heating due to breaking gravity waves. These terms are not included in the original IDL-code and have to be formulated for a spectral approach in future. Currently, the acceleration rates can be calculated separately with COMMA-LIM input data. The code correctness has been checked among other things by running the original IDL-code with the same COMMA-LIM data that serve as input for the Fortran code.

3 First results

Figure 1 shows the acceleration rates provided by the Lindzen-scheme on the left side and by the Warner and McIntyre – scheme (WM – scheme) on the right side. The latitude – height cross – sections show zonal means for a day in July; the zonal direction at top, the meridional direction at bottom. One has to take into account, that the WM-scheme was testet offline, therefore input data are based on an established July atmosphere with the contribution of the Lindzen-scheme; that can make a difference for the WM-scheme. Therefore, the results have to be considered as preliminary. In principle, both structures are quite similar, however, it can be seen clearly, that the Lindzen acceleration rates are stronger and located higher in altitude while in the WM-scheme the drag reaches only up to $\pm 40\,ms^{-1}d^{-1}$ at approximately $5 - 10\,km$ lower levels. For the winter Hemisphere (here, Southern Hemisphere) this means a reduction of GW drag of 50% compared to the Lindzen scheme. In addition, it seems, that gravity waves in the WM-scheme grow up again in the lower thermosphere and reimpose momentum there. Whether this structure appears also for a complete COMMA-LIM run with the WM-scheme fully implemented will be investigated in future work.

4 Outlook

The IDL-code of the WM-scheme has been successfully transferred to Fortran. The code-transfer will be completed by adding the eddy-diffusion coefficient and the heating contribution for COMMA-LIM needs. After that, first numerical studies and a thorough comparison between the two schemes are possible.

Acknowledgement
This work is supported by the DFG under grant JA 836/21-1. Especially, I would like to thank Dr. M. Ern for his help during the compilation process.

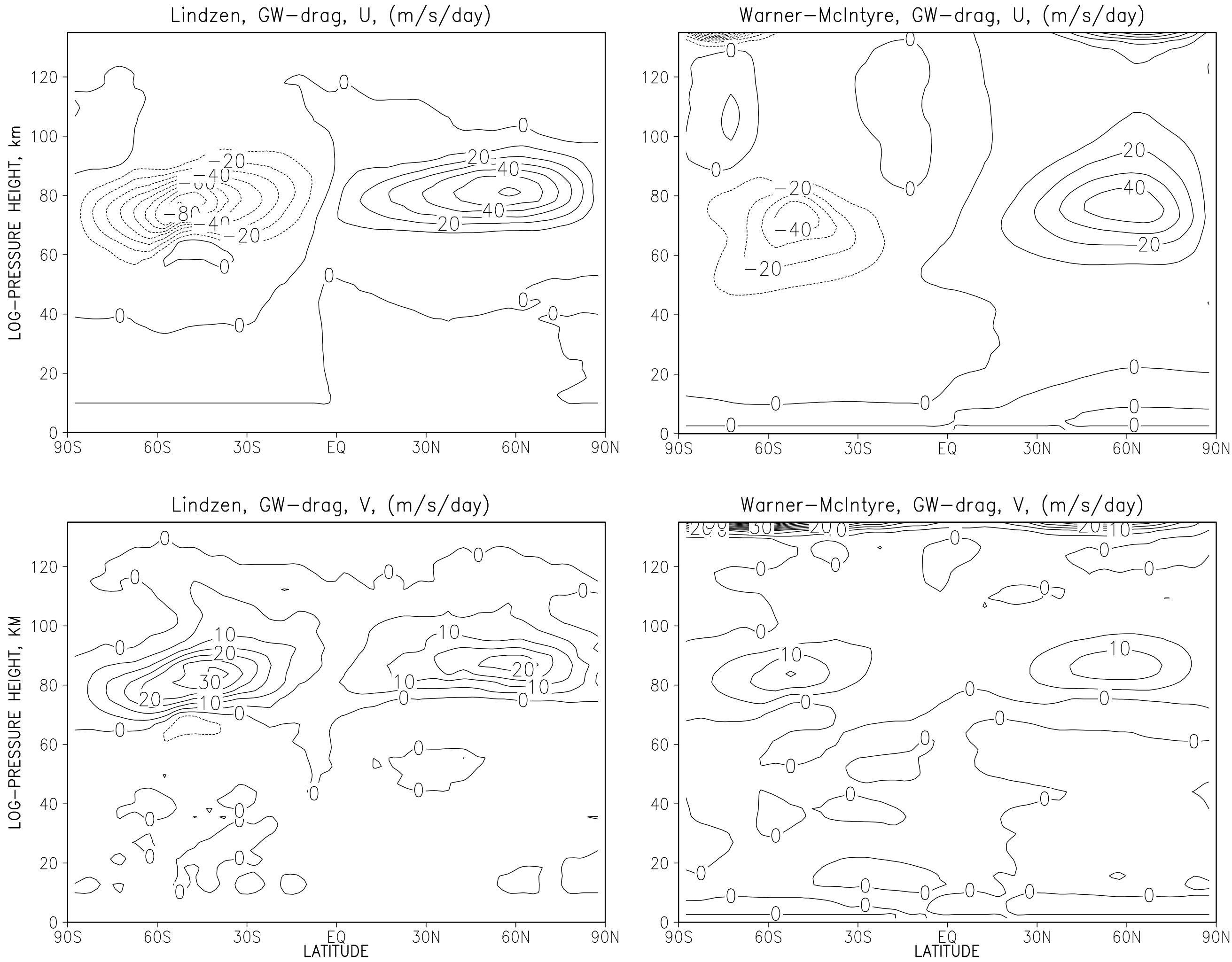

Figure 1: Acceleration rates in $ms^{-1}day^{-1}$ for the zonal and meridional direction as calculated by the Lindzen-scheme (left) and by the Warner-McIntyre-Scheme.

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Wiss. Mitteilungen
Aus dem Institut f. Meteorologie der Universität Leipzig Bd. 37, 2006