P3.26 IMPACT OF OROGRAPHICALLY INDUCED GRAVITY WAVE DRAG PARAMETERIZATION ON SEASONAL AND WEATHER PREDICTION

Eun-Chul Chang[1], Song-You Hong[1] and Young-Joon Kim[2]

[1]Department of Atmospheric Sciences, Global Environmental Laboratory
Yonsei University, Seoul, Korea
[2]Naval Research Laboratory, Marine Meteorology Division
7 Grace Hopper Ave., Stop 2, Monterey, CA 93943, USA

1. INTRODUCTION

It has been recognized that parameterization of gravity waves due to sub-grid scale orography (GWDO) should be included in large-scale models of the atmosphere (e.g., Lilly 1972). Gravity waves can be exited when stably stratified air flows over irregular terrain. Such waves may propagate freely to considerable altitudes before being significantly dissipated or absorbed. An important property of vertically propagating gravity waves is that they are able to transport momentum between their source regions and regions where they are dissipated or absorbed. The wave momentum flux convergence or divergence which occurs in association with dissipation or absorption may be of sufficient magnitude and horizontal extent to substantially modify the larger-scale mean flow (McFarlane 1987).

GWDO parameterization schemes in atmospheric models are primarily based on the linear hydrostatic mountain wave theory together with the saturation hypothesis (Lindzen 1981). Some systematic errors in atmospheric model can be alleviated by adding GWDO which also produces a general improvement in model accuracy. The typical GWDO is implemented to National Meteorological Center's (NMC) Medium-Range (MRF) Forecast model (Alpert et al. 1988). This method parameterizes a typical gravity wave drag forcing in upper troposphere by considering standard deviation of orography.

On the other hand, Kim and Arakawa (1995; hereafter KA95) developed an enhanced low-level GWDO parameterization that considers drag due to asymmetry and convexity of sub-grid scale orography. This scheme has successfully been incorporated into the NCEP MRF model (Alpert et al. 1996). This method generates more effective drag in the downstream regions of mountains in low troposphere.

* *Corresponding author address*: Song-You Hong, Yonsei University, Dept. of Atmospheric Sciences, global environmental laboratory, Seoul, Korea;
e-mail: shong@yonsei.ac.kr

More recently, Kim and Doyle (2004; hereafter KD04) have suggested an extended KA95 that includes the effects of orographic anisotropy and flow blocking. This study examines the impact of GWDO by using the typical GWDO and lower-tropospheric enhanced GWDO of KA95, and a further revised KA scheme (KD04) on the seasonal prediction and the short-range forecasts.

2. MODEL AND EXPERIMENTAL DESIGN

The National Centers for Environmental Prediction (NCEP) Global Spectral Model (GSM) is used in this study. The GSM utilized in this study employs a resolution of T62L28 (triangular truncation at wave number 62 in the horizontal and 28 terrain following sigma layers in the vertical) and T126L28. The initial data are taken from the NCEP reanalysis II data (Kanamitsu et al. 2002). As the surface boundary condition, observed sea surface temperature (SST) data were used with a resolution of 1°×1° (Reynolds and Smith 1994) during the simulation period.

As common physical processes of every experiment, the non-local vertical diffusion scheme is used to calculate the vertical fluxes of sensible heat, latent heat, and momentum (Hong and Pan 1996). The simplified Arakawa-Schubert convection scheme (SAS) is also used to represent deep precipitating convection and feedback to large-scale. To examine the impact of gravity wave drag in GSM, four experiments are designed. Each experiment has same model configurations only except the gravity wave drag scheme.

2.1 Short-range simulation

A summary of the experiments is in Table 1. The NOGWD experiment does not implement any GWDO. The UPGWD run includes the typical wave drag in the upper troposphere. The LGWD1 and LGWD2 `runs employ the enhanced wave drag in the lower troposphere. A cyclogenesis even accompanying heavy snowfall over Korea during 2100 UTC 14 February - 1800 UTC 15 February 2001 is chosen. Model resolution is set to the T126L28. Model integration has been performed for 120 hours from 00UTC 13 February as initial time.

Table 1. A summary of experiments designed in this study

Experiments	Model description
NOGWD	No gravity wave drag
UPGWD	Typical GWDO forcing in upper troposphere and lower stratosphere (Alpert et al. 1988)
LGWD1	Enhanced low-level GWDO due to orographic asymmetry and convexity (Alpert et al. 1996; Kim and Arakawa 1995)
LGWD2	Extended KA95 with orographic anisotropy and low-level flow blocking (Kim and Doyle 2004)

2.2 Seasonal simulation

Seasonal simulation is the same to the short-range simulations except for model set up. Model integration period is 3 months starting from 1 December 1996 to 28 February of 1997. To avoid introducing uncertainties with the initial data, 5-member ensemble runs are performed for the NOGWD, UPGWD, and LGWD1 experiments. Ensemble members have 24 hours interval of initial time to each other. Model resolution is set to the T62L28.

3. RESULTS AND DISCUSSIONS

3.1 Impact of the GWDO in upper layer

The UPGWD experiment reduces the significant strong wind magnitude in upper troposphere and lower stratosphere (Fig. 1). It is the direct effect of gravity wave drag parameterization. The NOGWD experiment shows single core of northern tropospheric jet, whereas the UPGWD experiment shows separated jets of the stratosphere and the troposphere like the reanalysis data. However, the UPGWD experiment simulates northward leaned tropospheric jet core and weaker wind speed in the upper atmosphere in comparison of reanalysis-2 data.

The most of atmospheric models often suffer from some unrealistic aspects of their simulated features. Notable examples are the “cold-pole” problems associated with an unrealistically strong polar night jet in the stratosphere (e.g., Shepherd, 2000) which is closely linked to excessively zonal and strong surface westerlies, as first noted in the northern hemisphere winter (e.g., Palmer et al., 1986). Figure 2 shows that gravity wave drag can alleviate this problem. The UPGWD experiment simulates warm air over the polar region. The gravity wave drag makes more downward circulations above polar region and produces more upward circulations in lower stratosphere on lower latitude. It can occur due to the secondary meridional circulation induced by the westerly drag. However, systematic errors of model still remain. The result from the UPGWD experiment shows colder stratosphere and warmer low troposphere than reanalysis data over polar regions of north and south (not shown).

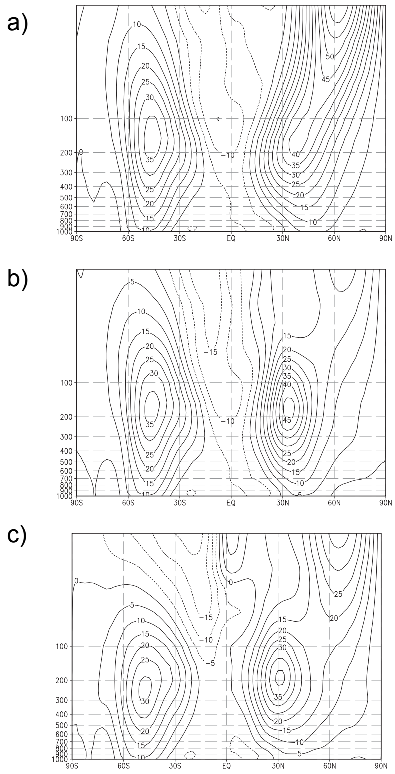

Fig. 1. Mean zonal wind (m s^{-1}) of December 1996 ~ February 1997. (a) NOGWD, (b) UPGWD and (c) Reanalysis -2.

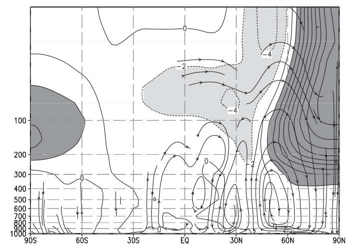

Fig. 2. Difference of zonal mean temperature (K) and vertical circulation from December 1996 to February 1997 between UPGWD and NOGWD.

The difference of geopotential height on northern polar region is shown in Fig. 3. The introduction of the gravity wave drag improved the overall features by decreasing the meridional gradient of the geopotential and thus weakening the polar vortex consistently with the weakening of the mean zonal winds. The effect of gradient reduction is significant in upper troposphere, but not in lower troposphere.

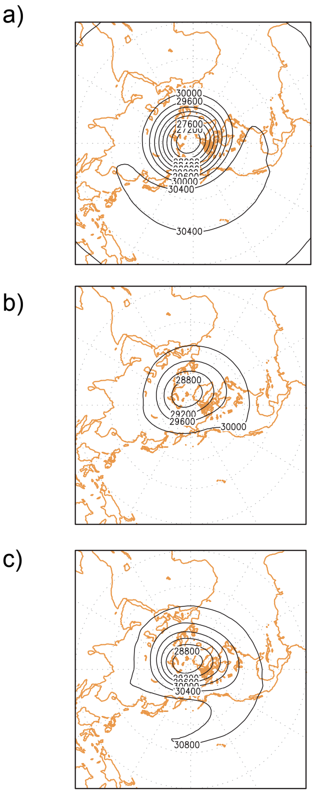

Fig. 3. Geopotential height on north hemisphere of 10 hPa for December 1996 ~ February 1997. (a) NOGWD, (b) UPGWD, and (c) Reanalysis -2.

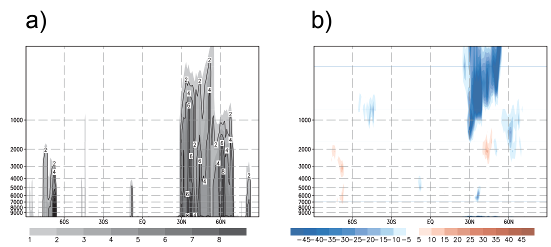

Fig. 4. Results of UPGWD at 0000UTC 15 February 2001. (a) Drag stress (10^{-5} N m^{-2}) and (b) zonal wind acceleration (10^{-6} m s^{-2}). Vertical level is sigma (pressure/surface pressure) in 10^{-4}.

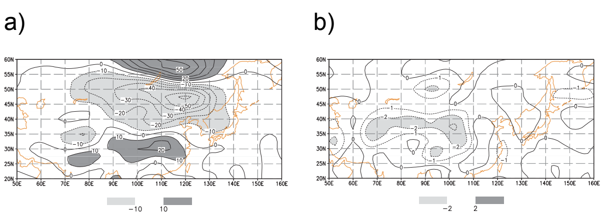

Fig. 5. Zonal wind (m s^{-1}) difference of UPGWD from NOGWD at 0000UTC 15 February 2001 at (a) 10 hPa and (b) 850 hPa.

Figure 4 shows vertical profiles of drag stress and wind deceleration due to wave drag. One can see that gravity waves play a role in generating momentum stress in the midlatitude (Fig. 4a). The deceleration is calculated from vertical gradient of drag. The UPGWD experiment shows most of deceleration in upper layers of northern midlatitude (Fig. 4b).

Figure 5 shows the difference of zonal wind fields of the UPGWD experiment from the NOGWD experiment. It is clear that the UPGWD experiment reduces the wind speed over mountain areas. But the effect of the lower troposphere is not significant as in upper troposphere (Fig. 5b).

3.2 Effect of the low level enhanced GWDO

It is clear that the LGWD1 experiment produces more abundant drag stress near the surface (Fig. 6a) than the UPGWD run (Fig. 4a), but more drag in the upper troposphere by the UPGWD case. It is because that the drag stress of the LGWD1 is dissipated in the low-level wave breaking region.

The LGWD1 experiment shows similar acceleration to the UPGWD experiment in upper layers, but the LGWD1 experiment shows more deceleration in the low troposphere (Fig. 6b).

Figure 7 shows the differences of zonal wind fields of the LGWD1 experiment from the NOGWD experiment at 0000 UTC 15 February 2001. The LGWD1 experiment produces wind reduction in upper layer as the UPGWD experiment, but has more effects than the UPGWD experiment in lower troposphere. It is remarkable especially in the downstream region of the mountains. The effect of the LGWD1 experiment in lower troposphere is caused by the low-level wave breaking as shown in Fig. 6a.

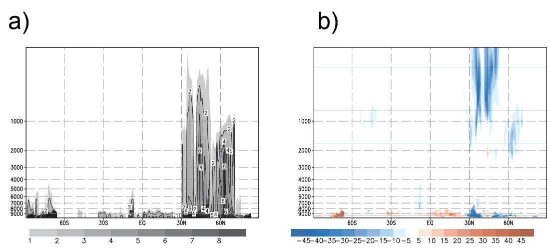

Fig. 6. Results of LGWD1 at 0000UTC 15 February 2001. (a) Drag stress (10^{-5} N m^{-2}) and (b) zonal wind acceleration (10^{-6} m s^{-2}). Vertical level is sigma (pressure/surface pressure) in 10^{-4}.

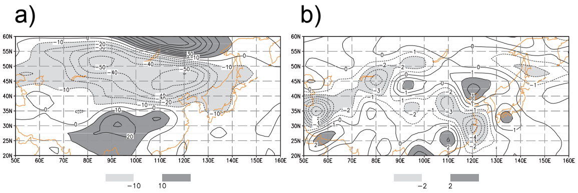

Fig. 7. Zonal wind (m s^{-1}) difference LGWD1 from NOGWD at 0000UTC 15 February 2001 at (a) 10 hPa and (b) 850 hPa.

Figure 8 shows sea level pressure at 84 hour forecast. The cyclone crossed the Korea peninsular and showed maximum development at 1200UTC 16 February 2001. The central pressures of cyclones in the NOGWD and UPGWD experiments are simulated lower than reanalysis data. But, the LGWD1 experiment generates result of minimum pressure of cyclone closer to the reanalysis. This is caused by the effect of low level drag. Alpert et al. (1996) suggested that insufficient effects of a mountain lead a fast movement of lows in the lee of the downstream of the mountains. The faster moving low expends baroclinic energy rapidly, and generates a strong or deep system, which advects the cold air outbreak.

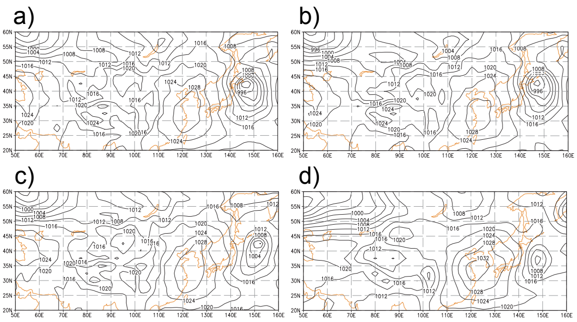

Fig. 8. Sea level pressure (hPa) at 12UTC 16 February 2001 (84 hr fcst). (a) NOGWD, (b) UPGWD, (c) LGWD1 and (d) Reanalysis-2.

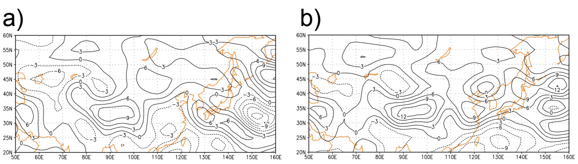

Fig. 9 Zonal wind (m s^{-1}) of 850 hPa for 00Z 15 February 2001. (a) LGWD1 and (b) LGWD2.

The differences between the LGWD1 and LGWD2 experiment are shown in Fig. 9. KD04 generates drag due to lower level flow blocking in the blocked layer. The wind reduction of zonal wind speed of KD04 is greater than that of KA95 in the upstream region of the mountains.

Earlier GWDO parameterizations considered flow blocking in a 2-dimensional sense in which flows cannot cross over the mountains. But recent parameterizations, including KD04, consider flow blocking in a 3-dimensional sense. When flow is blocked by mountains, flow can go around the mountains while increasing the surface drag.

4. SUMMARY

We described the effects of gravity wave drag due to the subgrid-scale orography. It is found that the typical gravity wave drag (UPGWD) has an effect that reduces the wind speed at upper troposphere. The gravity wave drag can separate the stratospheric polar and tropospheric sub-tropical jets, which are closer to observation. The meridional gradient of geopotential height can be reduced by the gravity wave drag in the north polar region. Moreover, the significantly cold polar region in atmospheric models can be alleviated. In case of snowstorm, it is shown that the low-level enhanced GWDO parameterization can alleviate excessively low pressure of cyclone in lower troposphere. The KD04 shows stronger drag due to flow blocking than KA95 implemented by Alpert et al (1996). In upstream region of the mountains, drag due to flow blocking is added to drag of KA95. It produces more effective drag near the mountains.

5. ACKNOWLEDGEMENTS

This study has been supported by the project, “Development of the Technology for the Improvement of Medium-Range Forecast”, one of the Research and Development on Meteorology and Seismology Studies funded by the Korea Meteorological Administration (KMA).

6. REFERENCES

Alpert, J. C., M. Kanamitsu, P. M. Caplan, J. G. Sela, G. H. White, and E. Kalnay, 1988: Mountain induced gravity wave drag parameterization in the NMC medium-range forecast model. *Preprints, Eighth Conf. on Numerical Weather Prediction*, Baltimore, MD, Amer. Metero. Soc., 726-733.

---------, S. -Y. Hong and Y. -J. Kim, 1996: Sensitivity of cyclogenesis to lower tropospheric enhancement of gravity wave drag using the environmental modeling center medium range model. *Preprints, 11th Conference on NWP*, 19-23 August 1996, Norfolk, Virginia, Amer. Meteor. Soc., pp 322-323.

Hong, S.-Y., and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Mon. Wea. Rev.*, **124**, 2322-2339.

Kanamitsu, Masao, Ebisuzaki, Wesley, Woollen, Jack, Yang, Shi-Keng, Hnilo, J. J., Fiorino, M., Potter, G. L.. 2002: NCEP–DOE AMIP-II Reanalysis (R-2). *Bulletin of the American Meteorological Society*, Vol. **83**, No. 11, pp. 1631–1643.

Kim, Y.-J., and A. Arakawa, 1995: Improvement of orographic gravity wave parameterization using a mesoscale gravity wave model. *J. Atmos. Sci*., **52**, 1875-1902

---------, and J. D. Doyle, 2004: Extension of an orographic drag parameterization scheme to incorporate orographic anisotropy and flow blocking, *Quart. J. Roy. Meteor. Soc*., *submitted*.

Lilly, D. K., 1972: Wave momentum flux: A GARP problem. *Bull. Amer. Meteor. Soc*., **20**, 17.

Lindzen, R. S., 1981: Turbulence and stress owing to gravity wave and tidal breakdown. *J. Geophys. Res*., **86**, 9707-9714

McFarlane, N. A., 1987: The effect of orographically excited gravity wave drag on the general circulation of the lower stratosphere and troposphere. *J. Atmos. Sci*., **44**, 1775-1800

---------, C. Girard, and D. W. Shantz, 1987: Reduction of systematic errors in NWP and general circulation models by parameterized gravity-wave drag. *J. Meteor. Soc. Japan,* (special volume for WMO/IUGG Numerical Weather Prediction Symp.), 713-728.

Palmer, T. N., G. J. Shutts, and R. Swinbank, 1986: Alleviation of a systematic westerly bias in circulation and numerical weather prediction models through an orographic gravity-wave drag parameterization. *Quart. J. Roy. Meteor. Soc.*, **112**, 1001-1039

Reynolds, Richard W., and Smith, Thomas M. 1994: Improved Global Sea Surface Temperature Analyses Using Optimum Interpolation. *Journal of Climate*, Vol. **7**, No. 6, pp. 929–948.

Shepherd, T.G. 2000. The middle atmosphere. *J. ATmos.-Terr. Phys.* **62**: 1587-1021