The origin of mesoscale gravity waves observed in the polar middle atmosphere

In-Sun Song, Geonhwa Jee, Baek-Min Kim

Korea Polar Research Institute

1. Introduction

Topography, convection, and jet-front systems are believed to be the major sources of atmospheric gravity waves (GWs) in the troposphere (Fritts and Alexander 2003; Kim et al. 2003). GWs excited by the major tropospheric sources can propagate long horizontal and vertical distance and can deposit the momentum in the middle atmosphere when they experience instabilities in the rarefied atmosphere and/or near the critical levels. Effects of GWs are particularly essential in the upper mesospheric circulations. The momentum transport due to GWs induces the summer-to-winter cross-hemispheric meridional flow near the mesopause regions, driving the adiabatic warming (cooling) in the winter (summer) polar mesosphere off the radiative-equilibrium temperature and wind structure.

In this study, mesoscale GWs are explicitly simulated using the global whole atmosphere model at the horizontal resolution of 25 km and the vertical resolution of about 600 m above the lower stratosphere. Model time integration starts from a balanced atmospheric state without significant wave activities (see Daley 1991). Hence, simulation results can clearly demonstrate the generation of GWs from particular sources, especially in the early periods of the time integration. Examination of the spatiotemporal progression of the GW phases allows for tracing the propagation trajectories of the tropospheric GWs in the middle atmosphere.

2. Global whole atmospheric modeling

Numerical model employed in this study is the Specified Chemistry Whole Atmosphere Community Climate Model (SC-WACCM; Smith et al. 2014). The SC-WACCM is a light-weighted version of WACCM (Marsh et al. 2013) and developed for scientists who are more interested in the global atmospheric dynamics than chemistry. As a result of this simplification, the SC-WACCM handles the significantly reduced number of chemical species and uses the pre-computed climatological data for the spatial distributions of radiative forcing due to major chemical constituents.

For the explicit simulation of mesoscale gravity waves, the SC-WACCM is run at the horizontal resolution of about 25 km and the vertical resolution of about 600 m above the lower stratosphere (210 layers in total from the ground to about z = 140 km). The vertical distribution of the layers in the troposphere remains unchanged so that the tropospheric circulations associated with the generation of the GWs can be reasonably simulated by the model that has been extensively validated for the default layer distribution.

Dynamical core used in this study is the spectral element (SE) core (Dennis et al. 2012) that computes the time evolution of the hydrostatic atmospheric flow using the unstructured quadrilateral meshes on the cubed-sphere (CS) grid. The SE core on the CS grid enables the far better parallel scalability (speedup per cpus) than the other cores on the lat-long (LL) grid. The CS grid is a globally quasi-uniform grid. That is, grid points are not densely clustered around singular points such as the poles in the LL grid. Thus, the SE core on the CS grid does not require the polar filter to smooth out small-scale signals around the singular points, which may justify the use of the CS grid for the polar atmospheric researches.

The high-resolution SC-WACCM is initialized using a whole atmospheric balanced state at specific date and time. The balanced state is consistent with model dynamics and obtained through the nudging data assimilation (e.g., Lakshmivarahan and Lewis 2013). The nudging method (Newtonian relaxation) drives the dynamical model toward a constructed whole atmospheric analysis that does not include GW activities. The whole atmosphere analysis is constructed through a data fusion method that combines the ECMWF Interim (Dee et al. 2011) and MERRA (Rienecker et al. 2011) reanalyses below the lower mesosphere and empirical model results for the horizontal wind (HWM; Drob et al. 2014) and temperature (NRLMSISE-00; Picone et al. 2007) above. The vertical data fusion is achieved by fitting a smooth curve represented by a linear combination of the cubic B-spline functions (Piegl and Tiller, 1997) to the three atmospheric data sets.

3. Results

The model is initialized at 0600 UTC, 3 May 2014, and run for 3 days. Sea-surface temperature and sea-ice fraction are specified at the initial time using the NOAA OISST data (Reynolds et al. 2002). Output files are generated every 450 s (model physics time interval). GW perturbations, defined as residuals from mean over a spherical area of the radius of about 300 km (Kim et al. 2016), are extracted from the output files for analysis.

Figure 1 demonstrates the temperature perturbations of the mesoscale GWs at z = 25, 50, 75, and 95 km at 1530 UTC, 3 May 2014. Around the South Pole, significant amount of GW perturbations are found in association with the frontal systems in the Southern Ocean as well as the mountain GWs generated along the Andes and Antarctic Peninsula. The frontal GWs are found to propagate slowly westward relative to the ground. Their phases are tilted westward with respect to the vertical direction (see yellow arrows in Figure 1). It seems probable that these frontal GWs are frequently observed in the middle atmosphere over the King Sejong station in the Antarctic Peninsula.

Around the North Pole, GWs associated with frontal systems are seen quite often. Additionally, GWs emanated from convective activities in the subtropical areas (~35°N) are found in the mesosphere, due to the radial propagation of GWs from a point source such as convection. GWs in the polar middle atmosphere seem to be substantially associated with the jet-front systems in the storm-track regions in both Hemispheres and convective activities in the summer subtropics.

5. Acknowledgement

This work was supported by research funds PE16090 and PE16100 from Korea Polar Research Institute. This work was also supported by the National Institute of Super computing and Network/Korea Institute of Science and Technology Information with supercomputing resources including technical support (KSC-2015-C3-025, KSC-2016-C2-0010).

0

6. References

Daley, R., 1991: *Atmospheric Data Analysis*. Cambridge University Press.

Dee, D. P., and Coauthors, 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quart. J. Roy. Meteor. Soc.*, **137**, 553-597, doi:10.1002/qj.828

Dennis, and Coauthors, 2012: CAM-SE: A scalable spectral element dynamical core for the Community Atmospheric Model. *Intl. J. High Perf. Comput. Appl.*, **26**, 74-89, doi:10.1177/109434201142 8142.

Drob, D. P., and Coauthors, 2014: An update to the Horizontal Wind Model (HWM): The quiet time thermosphere. *Earth and Space Sci.*, **2**, doi:10.1002/ 2014EA000089.

Fritts, D. C., and M. J. Alexander, 2003: Gravity wave dynamics and effects in the middle atmosphere. *Rev. Geophys.*, **41**, 1003, doi:10.1029/2001RG000106.

Kim, Y.-J., S. D. Eckermann, and H.-Y. Chun, 2003: An overview of the past, present and future of gravity-wave drag parameterization for numerical climate and weather prediction models, *Atmos. Ocean*, **41**, 65-98, doi:10.3137/ao.410105.

Kim, Y.-H., H.-Y. Chun, S.-H. Park, I.-S. Song, and H.-J. Choi, 2016: Characteristics of gravity waves generated in the jet-front system in a baroclinic instability simulation. *Atmos. Chem. Phys.*, **16**, 4799-4815, doi:10.5194/acp-16-4799-2016.

Lakshimivarahan, S., and J. M. Lewis, 2013: Nudging methods: A critical overview, in *Data Assimilation for Atmospheric, Oceanic and Hydrological Applications*, Volume II, edited by S. K. Park and L. Xu, pp. 27-57, Springer.

Marsh, D. R., M. J. Mills, D. E. Kinnison, J.-F. Lamarque, N. Calvo, and L. M. Polvani, 2013: Climate Change from 1850 to 2005 Simulated in CESM1 (WACCM). *J. Clim.*, **26**, 7372-7391, doi:10.1175/JCLI-D-12-00558.1.

Picone, J. M., A. E. Hedin, D. P. Drob, and A. C. Aikin, 2002: NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues. *J. Geophys. Res.*, **107**, 1468, doi:10.1029/200 2JA009430.

Piegl, L., and W. Tiller, 1997: *The NURBS Book*. Springer.

Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes, and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. J. Clim., 15, 1609-1625, doi: 10.1175/1520-0442(2002)015<1609:AIISAS>2.0.CO;2.

Rienecker, M. M., and Coauthors, 2011: MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. *J. Climate*, **24**, 3624-3648.

Smith, K. L., R. R. Neely, D. R. Marsh, and L. M. Polvani, 2014: The Specified Chemistry Whole Atmosphere Community Climate Model (SC-WACCM). *J. Adv. Model. Earth Syst.*, **6**, 883-901, doi:10.1002/2014MS000346.

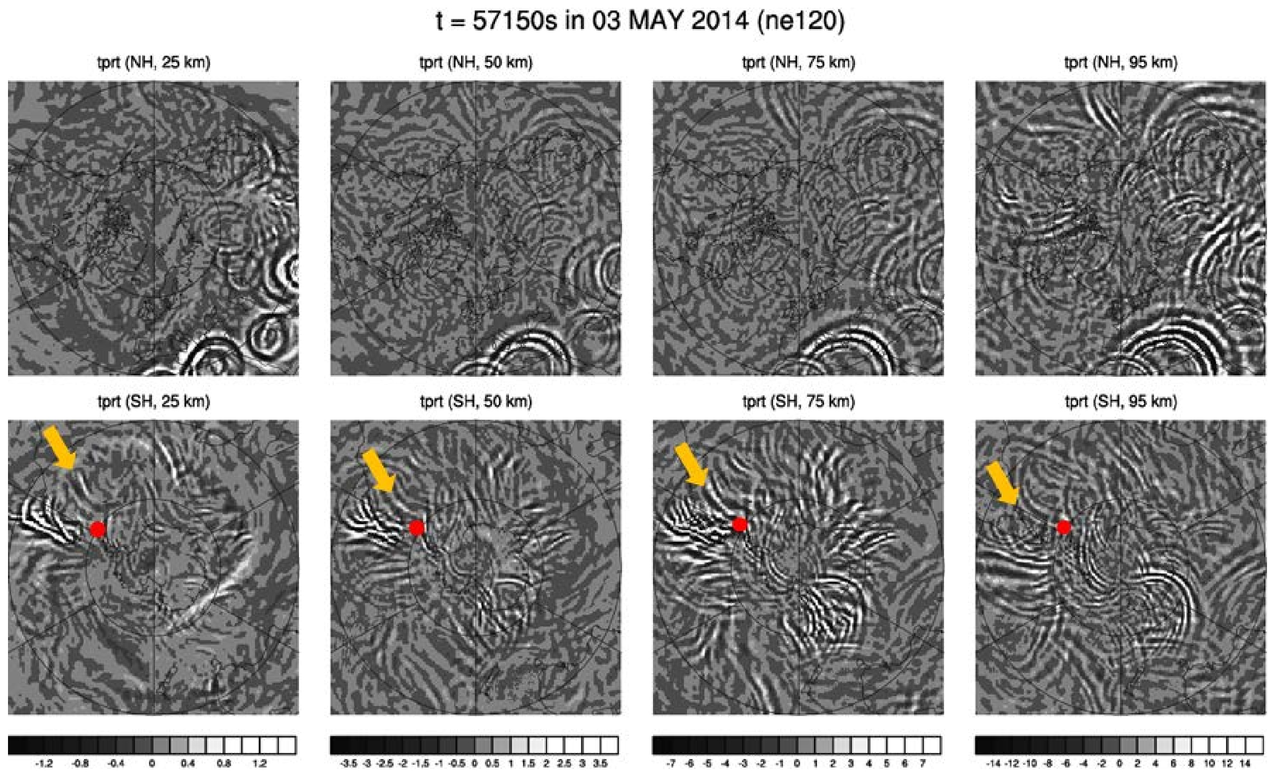

Figure 1: Horizontal distributions of the GW temperature perturbations over (top) the North Pole and (bottom) the South Pole at z = 25, 50, 75, and 95 km at 15.5 UTC in 3 May 2014. Yellow arrows show the evolution of the phases of the GWs generated from a particular frontal system. Red dot denotes the location of the King Sejong station.