On the spontaneous generation of gravity waves by vortical motions

Riwal PLOUGONVEN

School of Mathematics and Statistics, University of St Andrews, United Kingdom.

Chris SNYDER

National Center for Atmospheric Research, Boulder, Colorado, U.S.A.

Although atmospheric and oceanic flows at large scales are, to a very good approximation, predominantly balanced, it is known that they generate some inertia-gravity waves ([1] and references therein). This generation however remains poorly understood, and this hinders the development of parameterizations of gravity waves for General Circulation Models [2].

Observations and numerical simulations have found inertia-gravity waves generated in very different locations of the flow: in jet exit regions upstream of a ridge [11, 4, 7], or upstream of a trough [8], and near surface fronts [3, 10].

In order to understand why these different regions appear as favored source regions in different flow configurations we have simulated different idealized life cycles of baroclinic instability using the Advanced Research WRF Model (Weather Research and Forecast, *Skamarock et al 2005* [9]). From these simulations it will be possible to analyze how the gravity waves that are excited depend on the background flow. As a first step, the present paper (see also [6]) aims to describe the location and characteristics of gravity waves that appear in two very different life cycles (see Fig. 1). Thus we can isolate a case in which the waves clearly emanate from the upper-level jet (section 1) and a case in which they emanate from the surface fronts (section 2).

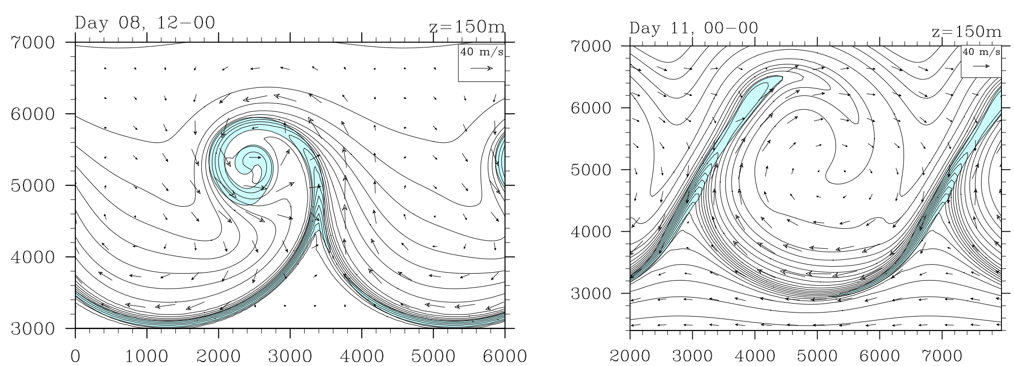

Figure 1: Potential temperature at $z = 150m$ once the baroclinic instability is mature, for the cyclonic life cycle (left, day 08, 12:00) and for the anticyclonic life cycle (right, day 11, 00:00). Also shown in light gray are the regions where the relative vorticity exceeds $1.25 \cdot 10^{-4} s^{-1}$.

1 Gravity waves generated in a cyclonic baroclinic life cycle

In the first life cycle, the development of the baroclinic wave is dominated by the cyclonic part of the flow (left panel in Fig. 1). The most conspicuous gravity wave activity appears in the highly sheared regions just above and below the jet core, as shown in Fig. 2. The presence of gravity wave packets above and below the jet strongly suggests that the source of the waves is the upper-tropospheric jet. In the horizontal and vertical, the phaselines are essentially parallel to the tropopause (Fig. 2).

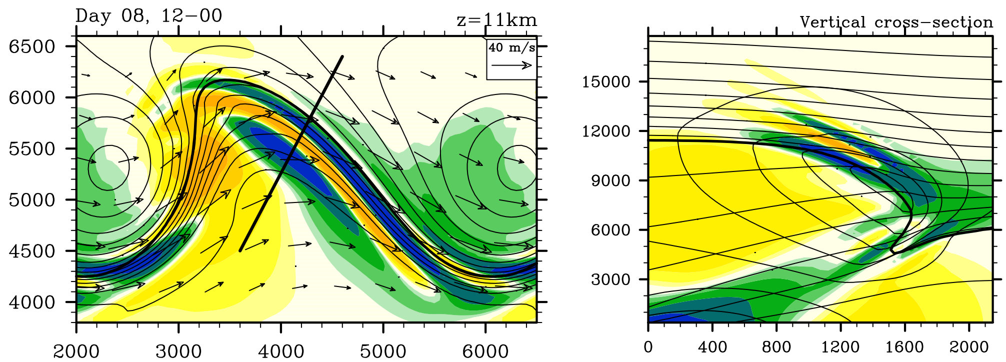

Figure 2: Left: horizontal cross-section of divergence (color, logarithmic contours) at $z = 11km$ for the cyclonic life cycle, day 08, 12:00. Also shown is potential temperature (contours every $5K$). Right: vertical cross-section of divergence through the thick line segment shown in the left panel. Also shown are the normal wind (contours every $10ms^{-1}$) and the potential temperature (contours every $10K$).

An important issue is the sensitivity of the gravity waves to the resolution of the simulations. The same baroclinic life cycle has been simulated at lower (half) and higher (double) resolutions. The gravity waves are qualitatively very comparable in all three simulations (time of appearance, location, orientation, intrinsic frequency), but their amplitudes and wavelengths are sensitive to resolution (see Table 1).

Resolution	λ_H (km)	λ_z (km)	$\tilde{\omega}$ f.d.r.
$\Delta x = 100km$, $\Delta z = 500m$	475 ± 51	2.32 ± 0.13	$(1.29 \pm 0.04)f$
$\Delta x = 50km$, $\Delta z = 250m$	331 ± 34	1.87 ± 0.13	$(1.36 \pm 0.04)f$
$\Delta x = 25km$, $\Delta z = 125m$	258 ± 28	1.23 ± 0.09	$(1.30 \pm 0.04)f$

Table 1: Characteristics of the inertia-gravity waves present in the upper-flank of the jet stream, in the lower stratosphere, for three simulations of the cyclonic life cycle. Horizontal and vertical wavelengths are given in kilometers, the intrinsic frequecy is given as a multiple of the Coriolis frequency $f = 1^{-4}s^{-1}$.

2 Gravity waves generated in an anticyclonic baroclinic life cycle

In contrast to the previous section, we will describe below gravity waves appearing in a very different baroclinic life cycle, for which strong anticyclonic shear has been added at lower surface in the the initial condition. Strong cold fronts develop at the surface, and advance southward into regions of surface easterly winds as the anticyclone that dominates the flow broadens (right panel in Fig. 1).

The most conspicuous wave signal in this case appears in the troposphere, just ahead of the cold front (see Fig. 3). In the upper-troposphere/lower-stratosphere region, no wave signal comparable to that described in section 1 is found.

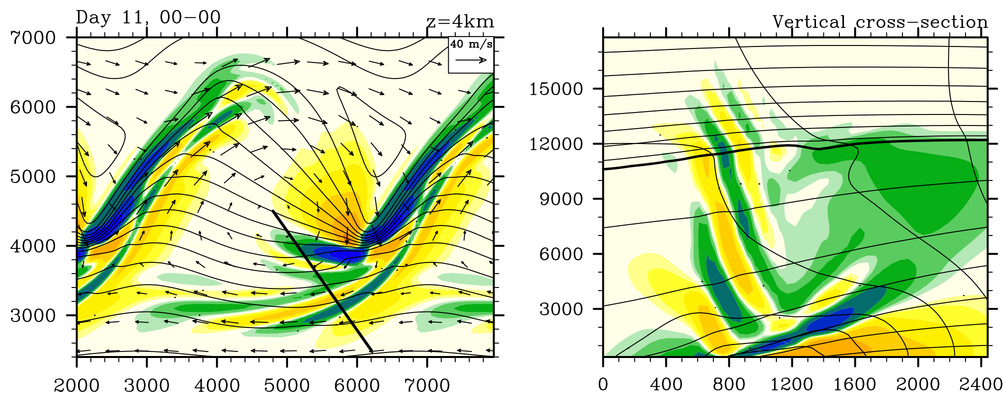

Figure 3: *Inertia-gravity waves appearing in the vicinity of the surface fronts, in the life cycle with added anticyclonic shear (day 11, 00:00). Plots are as in Fig. 2, except that horizontal cross-sections of* $\nabla \cdot \mathbf{u}_H$ *(left column) are shown at* $z = 4km$*.*

3 Summary and perspectives

The spontaneous generation of gravity waves from jets and fronts in simulations of idealized baroclinic life cycles has been described. In order to bring together contrasting results from previous studies, two contrasting life cycles were analyzed.

It was shown that different baroclinic life cycles could give rise to spontaneous generation of gravity waves in very different regions of the flow. Two cases were analyzed, which allowed to isolate generation from the upper-level jet (section 1, Fig. 2), or from the surface fronts (section 2, Fig. 3).

Hence, the different life cycles emphasize different source regions and quite likely different generating mechanisms. The challenge remains to explain quantitatively the generation of these waves, and this can be decomposed into two different problems: one is to determine the amplitude of the waves that will be excited. This is the subject of ongoing investigations.

The other is to determine the characteristics of the waves that appear. Important elements of answer can be obtained for this problem just from linear considerations of propagation, as shown in [5].

References

[1] R. Ford, M. E. McIntyre, and W. A. Norton. Balance and the slow quasimanifold: some explicit results. *J. Atmos. Sci.*, 57:1236–1254, 2000.

[2] D.C. Fritts and M.J. Alexander. Gravity wave dynamics and effects in the middle atmosphere. *Reviews of Geophysics*, 41(1):1003, 2003.

[3] D.C. Fritts and G.D. Nastrom. Sources of mesoscale variability of gravity waves. Part II: Frontal, convective, and jet stream excitation. *J. Atmos. Sci.*, 49(2):111–127, 1992.

[4] F. Guest, M. Reeder, C. Marks, and D. Karoly. Inertia-gravity waves observed in the lower stratosphere over Macquarie Island. *J. Atmos. Sci.*, 57:737–752, 2000.

[5] R. Plougonven and C. Snyder. Gravity waves excited by jets: propagation versus generation. *submitted to Geoph. Res. Lett.*, 2005.

[6] R. Plougonven and C. Snyder. Inertia-gravity waves spontaneously generated in idealized baroclinic life cycles. *in preparation for J. Atm. Sci.*, 2005.

[7] R. Plougonven and H. Teitelbaum. Comparison of a large-scale inertia-gravity wave as seen in the ecmwf and from radiosondes. *Geophys. Res. Let.*, 30(18):1954, 2003.

[8] R. Plougonven, H. Teitelbaum, and V. Zeitlin. Inertia-gravity wave generation by the tropospheric mid-latitude jet as given by the fastex radiosoundings. *J. Geophys. Res.*, 108(D21):4686, 2003.

[9] W.C. Skamarock, J.B. Klemp, J. Dudhia, D.O. Gill, D.M. Barker, W. Wang, and J. G. Powers. A description of the Advanced Research WRF Version 2. *NCAR Technical Note*, June 2005.

[10] C. Snyder, W.C. Skamarock, and R. Rotunno. Frontal dynamics near and following frontal collapse. *J. Atmos. Sci.*, 50(18):3194–3211, 1993.

[11] L.W. Uccelini and S.E. Koch. The synoptic setting and possible energy sources for mesoscale wave disturbances. *Mon. Wea. Rev.*, 115:721–729, 1987.