Institution:
University of Cambridge

Unit of Assessment:
UoA10

Title of case study:
Gravity-wave parametrization in weather forecast and climate models

1. Summary of the impact (indicative maximum 100 words)

The Warner-McIntyre parametrization scheme for non-topographic atmospheric gravity waves, developed at the Department of Applied Mathematics and Theoretical Physics (DAMTP), University of Cambridge, during the period from 1993 to 2004, has since 2010 been used by the UK Met Office in their operational models for seasonal forecasting and climate prediction .The parametrization is regarded by the Met Office as a vital part of improved representation of the stratosphere in those models, which in turn has been shown to lead to significant operational benefits.

2. Underpinning research (indicative maximum 500 words)

Numerical models used for weather forecasting and climate prediction cannot explicitly represent several processes that have small spatial scale but which have systematic effects on the larger scale. Instead these processes must be represented by parametrization, i.e. by extra terms included in the model equations. One such process is momentum transport by gravity waves, in particular by waves that are not associated with topography. (Gravity waves are small-scale waves that result from internal density gradients in the atmosphere. An example is the topographic gravity waves generated by flow over mountains that are manifested in cloud patterns. Non-topographic gravity waves are generated by processes such as thunderstorms.) The potential role of non-topographic gravity waves in determining aspects of the large-scale atmospheric circulation, particularly in the stratosphere and mesosphere, and consequently the need to represent such waves in numerical models was recognised in the 1980s and 1990s. In 1993 researchers at the University of Cambridge Department of Applied Mathematics and Theoretical Physics (DAMTP), C.D. Warner (DAMTP Research Associate from 1992, Senior Research Associate from 2003) and M.E. McIntyre (DAMTP Professor throughout the period), began work on the formulation of a parametrization scheme in which the propagation and dissipation of a field of waves made up of a broad spectrum of frequencies was calculated by following individual spectral elements [Ref 1]. Compared to other schemes existing at that time, this scheme (the 'full' scheme) gave the advantage of physical and mathematical clarity, but was too computationally expensive to be useable in numerical models of the large-scale atmosphere. In following work [Refs 2 and 4] an 'ultra-simple' version of the scheme, that required only a small number of variables to characterize the gravity wave field as a function of height and time at each horizontal location, was developed and validated by Warner and McIntyre by testing against their full scheme. Alongside this work developing a robust and properly formulated gravity-wave scheme there was a collaborative programme of work with the UK Met Office to establish, as new versions of the gravity-wave scheme became available, the effect on the circulation as represented by a global-scale model. (The equations describing the parametrization were added to the large computer code defining the model.) The global model was a version, at that time used for research purposes only, of the Met Office Unified Model, 'vertically extended' to include a detailed representation of the stratosphere. Results showing the effect of the gravity-wave scheme on the modelled circulation were reported in Refs 3, 5 and 6.

3. References to the research (indicative maximum of six references)

1. *Warner, CD; McIntyre, ME, 1996: On the propagation and dissipation of gravity wave spectra through a realistic middle atmosphere. J. Atmos. Sci., 53, 3213-3235. DOI: 10.1175/1520-0469(1996)053<3213:OTPADO>2.0.CO;2

2. Warner, CD; McIntyre, ME, 1999: Toward an ultra-simple spectral gravity wave parameterization for general circulation models. (Proceeding of International Symposium on Dynamics and Structure of the Mesopause Region, Kyoto Univ., Kyoto, Japan, March 16-21 1998. Earth, Planets and Space, 51, 7-8. 475-484.

3. Scaife, AA, Butchart, N, Warner, CD, Stainforth, D., Norton, WA, Austin, J., 2000: Realistic quasi-biennial oscillations in a simulation of the global climate. Geophys. Res. Lett., 27, 3481-3484. DOI: 10.1029/2000GL011625.

4. *Warner, CD, McIntyre, ME, 2001: An ultrasimple spectral parameterization for nonorographic gravity waves. J. Atmos. Sci., 58, 1837-1857. DOI: 10.1175/1520-0469(2001)058<1837:AUSPFN>2.0.CO;2

5. *Scaife AA, Butchart, N, Warner, CD, Swinbank, RC, 2002: Impact of a spectral gravity wave parameterization on the stratosphere in the met office unified model. J. Atmos. Sci., 59, 1473-1489. DOI: 10.1175/1520-0469(2002)059<1473:IOASGW>2.0.CO;2

6. Warner, CD, Scaife, AA, Butchart, N, 2005: Filtering of parametrized nonorographic gravity waves in the Met Office Unified Model. J. Atmos. Sci., 62, 1831-1848. doi: 10.1175/JAS3450.1

* References which best reflect the quality of the underpinning research

4. Details of the impact (indicative maximum 750 words)

The effect of the Warner-McIntyre (hereafter WM) gravity wave scheme was carefully considered by the Met Office during the period in which the desirability of using 'vertically extended' models, including a detailed representation of the stratosphere, for operational purposes was established and a robust, high-quality version of the extended model developed. Since 2006 the UK Met Office has used such 'vertically extended' models, including the WM gravity-wave scheme, for operational purposes, for numerical weather prediction (implemented in 2006), for seasonal forecasting (implemented in 2010, Fereday et al 2012) and for climate prediction simulations used for the 5th IPCC Assessment report (implemented in 2011, Hardiman et al 2012).

Improvement of Short-Term Weather Prediction and Seasonal Forecasting

On the short time scales of a few days accessible to conventional numerical weather prediction extending the model to include the stratosphere, including use of the WM scheme, provides significant advantages for data assimilation in the stratospheric levels of the model. On longer seasonal forecast time scales, e.g. months, the WM scheme gives skill in prediction of the evolution of the equatorial Quasi Biennial Oscillation (QBO) which has significant implications for the extratropical circulation, including the low-level circulation in the North Atlantic/European region. (Marshall and Scaife 2009).

The advantages of using the extended model for seasonal forecasting are discussed in detail by Fereday et al (2012) who show that the severe 2009/10 winter was better predicted by an extended version of the Met Office Glosea 4 seasonal forecast system which included the WM scheme than by the standard version that was in operational use in that winter. Fereday et al (2012) argue that the better representation of the QBO in the extended model, for which the WM scheme is absolutely essential, together with improved representation of the stratospheric aspects of the communication of a tropical El Nino signal to the extratropics were important in giving the improved prediction. For the 2010/11 and 2011/12 winters the Met Office implemented the vertically extended version of the seasonal forecast system and their seasonal predictions for these winters were correct insofar that the correct phase of the North Atlantic Oscillation pattern (which has a major controlling effect over UK and European weather) was predicted.

Seasonal forecasts are passed by the Met Office to UK government Departments such as the Cabinet Office, the Department of Energy and Climate Change (DECC), Department for Transport (DfT) and DEFRA where they are used for resilience planning purposes.

Impact on Climate Modelling

The Met Office Hadley Centre currently uses the HadGEM2 family of models for climate prediction (Met Office news item 2010). The vertically extended version of this model is one of the three models being used by the Hadley Centre in their contribution to the 5th Assessment Report of the Intergovernmental Panel for Climate Change (IPCC). This contribution is through the Coupled Model Intercomparison Project (CMIP5) which is an internationally coordinated activity to perform climate model simulations to a common set of specifications across all the world's major climate modelling centres. (Hardiman et al 2012, Met Office news item November 2012).

By comparing simulations with standard and extended versions of the climate model Hardiman et al (2012) show that the inclusion of a well-resolved stratosphere does improve the impact of atmospheric teleconnections on surface climate, in particular the response to El Nino–Southern Oscillation, the quasi-biennial oscillation, and midwinter stratospheric sudden warmings (i.e., zonal mean wind reversals in the middle stratosphere). Thus, including a well-represented stratosphere is expected to improve climate simulation on intraseasonal to interannual time scales.

Scaife et al (2012) show by considering several models, including the Met Office model, that the inclusion of a well-resolved stratosphere changes predictions for Northern Hemisphere winter regional climate change. In the models with a well-resolved stratosphere there is a weakening and equatorward shift of the stratospheric polar vortex and a corresponding equatorward shift of the typical path of tropospheric weather systems. There are corresponding differences in the predicted changes in low-level circulation, storminess and rainfall, with these differences being particularly large in western Europe. Scaife et al (2012) conclude, for example, that the increase in frequency under CO2 increase of 1 in 50 daily heavy winter rainfall events in western Europe (10 W–20 E and 40–55 N) is predicted, by the extended Met Office model to be twice as great as predicted by the standard model. Detailed representation of the stratosphere and the associated implementation of the WM scheme has, therefore, had a first order impact on European climate projections.

Participation in the IPCC as described above is the primary way in which the UK contributes to formulation of international policy on climate change and the WM scheme is an important component of the model used for these projections. The Met Office is also the primary source of climate information to UK government to advise on national policy formulation. For example, Met Office climate predictions are provided to the UK Climate Projections database.

The WM scheme is regarded by the Met Office as an essential component of this extended model. The Head of Monthly to Decadal Prediction at the Met Office Hadley Centre states, "*The Met Office regards the Warner-McIntyre gravity-wave parametrization as an essential part of the improved representation of the stratosphere in weather and climate prediction models which has given direct benefits for seasonal forecasting and climate prediction.*"

5. Sources to corroborate the impact (indicative maximum of 10 references)
Statement from the Head Monthly to Decadal Prediction at the Met Office Hadley Centre

Fereday, DR, Maidens, A, Arribas, A, Scaife, AA, Knight, JR, 2012. Seasonal forecasts of northern hemisphere winter 2009/10. Environmental Research Letters, 7, 034031: DOI: 10.1088/1748-9326/7/3/034031.

Hardiman, SC. Butchart, N, Hinton, TJ, Osprey, SM, Gray, LJ. 2012: The effect of a well-resolved stratosphere on surface climate: differences in CMIP5 simulations with high and low top versions of the Met Office climate model. J. Climate, 25, 7083-7099. DOI: 10.1175/JCLI-D-11-00579.1.

Scaife, AA, Spangehl, T, Fereday, DR, Cubasch, U, Langematz, U, Akiyoshi, H, Bekki, S, Braesicke, P, Butchart, N, Chipperfield, MP, Gettelman, A, Hardiman, SC, Michou, M, Rozanov, E, Shepherd, TG, 2011: Climate change projections and stratosphere–troposphere interaction. Climate Dynamics, 38, 2089-2097. DOI 10.1007/s00382-011-1080-7

Institute of Physics news item. http://www.iop.org/news/12/sep/page_57337.html

Marshall, AG, Scaife, AA, 2009: Impact of the QBO on surface winter climate. J. Geophys. Res., 114, D18110, doi:10.1029/2009JD011737.

Met Office news item 2010:
http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem2

Met Office news item 14 September 2012:
http://www.metoffice.gov.uk/news/releases/archive/2012/improved-winter-guidance

Met Office news item, 29 November 2012: Met Office delivers new climate simulations to international modelling activity. http://www.metoffice.gov.uk/research/news/cmip5