Annual Seminar 2015
Physical processes in present and future large-scale models

1–4 September 2015

Summary

Impact of diffusion in stable layers and orographic drag - Irina Sandu

The drag exerted by the Earth surface on the atmospheric flow has long been recognised to play an important role in the general circulation of the atmosphere (Holton, 2004). The magnitude of surface stress1 controls for example not only the strength of surface easterlies and westerlies, but also the location of the surface westerly jet in the midlatitudes. Moreover, the drag exerted by topography affects the Northern Hemisphere (NH) winter extratropical circulation, through effects of the orographically generated stationary Rossby waves and gravity waves. Albeit very important for the general circulation, the drag exerted by the earth surface on the flow is particularly difficult to represent in models primarily because it not well constrained by observations - it obviously is hard or even impossible to measure momentum fluxes globally. Moreover, until recently the representation of surface stress in models has received relatively little attention compared to other processes such as clouds, convection or radiation.

Modeled stress is composed of resolved stress due to resolved orography and parametrized, or subgrid, stress due to unresolved elements of the Earth's surface. This talk focuses on the parameterized stress, its representation in models and the impacts of its components on different aspects, i.e. near surface parameters and large scale flow in NH winter. Models use several schemes to represent surface stress, as different schemes represent different drag related processes. In the Integrated Forecast System of ECMWF the planetary boundary layer (PBL) scheme represents stress associated with unresolved elements of the Earth surface from horizontal scales less than 5 km, while the subgrid orography scheme (SGO) represents stress associated with horizontal scales between 5 km and the model resolution. At their turn, each of these two schemes represents several processes. The PBL scheme uses a turbulence parameterization to represent turbulent drag associated with surface elements such as land use or vegetation, and a turbulent orographic form drag parameterization (TOFD) to represent drag associated with subgrid orography elements with horizontal scales less than 5 km such as hills (Beljaars et al., 2004). The SGO scheme (Lott and Miller, 1997) represents both subgrid stress associated with the propagation and breaking of the orographically generated gravity waves (the GWD part of the scheme) and effects of the blocking of the flow at low levels by orography (the BLOCK part of the scheme).

In 2014, the Working Group for Numerical Experimentation (WGNE) set up a model intercomparison exercise of subgrid surface stress, the WGNE Drag Project. The aim is to compare the total subgrid surface stress (τ_{100}) and its partitioning among the parameterizations that most models use to represent it. First results suggest parameterized surface stress in weather forecast models is highly model dependent, especially over orography. Models of comparable resolution differ over land by as much as 20% in zonal mean τ_{100}. The way τ_{100} is partitioned between the different parameterizations is also model dependent, and so is its diurnal cycle. This emphasizes the importance of better constraining the representation of subgrid surface stress in models, especially in regions with orography. It also highlights the need to better understand how the schemes contributing to surface stress, and their uncertainties, affect weather and climate predictions.

A few examples are given to illustrate the impacts of some of the schemes contributing to surface stress on the large scale circulation in NH winter. Emphasis is put on the turbulent diffusion in stable conditions and the orographic drag processes. The representation of these processes is still very uncertain and their impacts on the large scale flow are only poorly documented. Their representation depends indeed on a large number of parameters which are highly uncertain, and which are often tuned to obtain the desired answer (NWP skill, or model climate).

The degree of turbulent diffusion in stable layers has been used for years as a tuning knob in NWP: excessive diffusion is used to prevent near surface runaway cooling at night, and to maintain a desired level of synoptic activity, at the expense of a poor representation of near surface winds. It is shown that reducing the level of diffusion used in IFS in stable layers led to a better representation of low level jets (Sandu et al., 2013/2014). Moreover, the level of diffusion in stable layers not only affects the strength of individual cyclone or anticyclones, but it also affects the stationary waves in NH winter.

The impacts of various orographic drag processes is also discussed. The representation of orographic gravity wave drag was shown to affect the NH winter zonal mean flow both in the troposphere and the lower stratosphere in numerous studies (Wallace et al., 1983; Palmer et al., 1986; McFarlane, 1987; McLandress and McFarlane, 1993; Shaw et al., 2009; Sigmond and Scinocca, 2010). The parameterization of orographic low level blocking effects was also shown to influence the representation of the NH winter circulation in both weather forecast and climate simulations (Lott and Miller, 1997; Zadra et al., 2003; Sandu et al., 2013; Pithan et al., 2015).

Finally, the impact of the orographic low level drag on the representation of the NH winter circulation is discussed in more detail based on the recent study of Sandu et al. (2015). This study is based on a set of experiments in which τ_{100} is increased by an amount comparable to the inter-model spread found in the WGNE Drag project. This increase was simulated in two ways, namely by increasing independently the contributions to τ_{100} of the TOFD and of the BLOCK schemes. It is shown that such an increase in τ_{100} significantly affects the representation of the Northern Hemisphere winter circulation, both in ten-day weather forecasts and in seasonal integrations. However, the magnitude of the changes in circulation strongly depends on which of the schemes is modified. In short and medium range forecasts, the response is stronger when the TOFD stress is increased, while on seasonal timescales the effects are of comparable magnitude, although different in detail. At these time scales, the BLOCK scheme affects the lower stratosphere through changes in the resolved planetary waves which are associated with surface impacts, while the TOFD effects are mostly limited to the lower troposphere. These results suggest that the partitioning of τ_{100} between the two schemes plays an important role at all timescales.

References

Beljaars, A., A. Brown, and N.Wood (2004), A new parameterization of turbulent orographic form drag, Quart. J. Roy. Meteor. Soc., 130, 1327–1347.

Holton, J. (2004), An introduction to dynamic meteorology.

Lott, F., and M. Miller (1997), A new subgrid orographic drag parameterization: Its formulation and testing, Quart. J. Roy. Meteor. Soc., 123, 101–127.

McFarlane, N. (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.

McLandress, C., and N. McFarlane (1993), Interactions between orographic gravity wave drag and forced stationary planetary waves in the winter northern hemisphere middle atmosphere, J. Atmos. Sci., 50, 1966–1990.

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

Pithan, F., W. Angevine, and T. Mauritsen (2015), Improving a global model from the boundary layer: Total turbulent energy and the neutral limit prandtl number, Journal of Advances in Modeling Earth Systems, 7(2), 791–805, doi:10.1002/2014MS000382.

Sandu, I., A. Beljaars, P. Bechtold, T. Mauritsen, and G. Balsamo (2013), Why is it so difficult to represent stably stratified conditions in numerical weather prediction (nwp) models?, Journal of Advances in Modeling Earth Systems, 5, 117–133.

Sandu, I., A. Beljaars, and G. Balsamo (2013/2014), Improving the representation of stable boundary layers, ECMWF Newsletter, 138.

Sandu, I., P. Bechtold, A. Beljaars, A. Bozzo, F. Pithan, T. Shepherd, and A. Zadra (2015), Impacts of parameterized orographic drag on the northern hemisphere winter circulation, Technical memorandum 763, ECMWF, Reading, UK.

Shaw, T., M. Sigmond, T. Shepherd, and J. Scinocca (2009), Sensitivity of simulated climate to conservation of momentum in gravity wave drag parameterization, Journal of Climate, 22, 27262742.

Sigmond, M., and J. F. Scinocca (2010), The influence of the basic state on the northern hemisphere circulation response to climate change, Journal of Climate, 23, 1434–1446.

Wallace, J. M., S. Tibaldi, and A. J. Simmons (1983), Reduction of systematic forecast errors in the ecmwf model through the introduction of an envelope orography, Quart. J. Roy. Meteor. Soc., 109, 683–717.

Zadra, A., M. Roch, S. Laroche, and M. Charron (2003), The subgrid-scale orographic blocking parametrization of the gem model, Atmosphere-ocean, 41, 155–170.

[1]Surface stress is defined here as the force parallel to the surface, per unit area, as applied by the earth's surface on the wind