OROGRAPHIC PARAMETRIZATIONS IN HIRLAM

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Abstract: The scale-dependent system of orography-related parametrizations of the High Resolution Limited Area Model (HIRLAM) comprises schemes for handling the effects of mesoscale (MSO, Rontu et al. (2002) and small-scale (SSO, Rontu (2006)) orographic effects on the simulated flow, and a scheme of orographic effects on the surface-level radiation fluxes (Senkova et al., 2007). We summarize the recent developments of these parametrizations. Main attention is paid to the parametrization of subgrid-scale momentum fluxes. Representation of orography, scale-dependencies of the simulated processes and interactions between the parametrized and resolved processes are discussed. From the high-resolution digital elevation data, orographic parameters are derived for both momentum and radiation flux parametrizations and for the definition of the model's vertical coordinate.

Keywords: *HIRLAM, parametrization, momentum, radiation, flux*

1. INTRODUCTION

Orography is always averaged, representing the surface elevation within the horizontal resolution of the model. In order to remove the smallest scales and steepest slopes, the continuous spectrum of orography is normally filtered (truncated) even more, typically beyond a few gridlengths of the model. This means that in the numerical weather prediction (NWP) models, there will always be subgrid-scale orography effects, which cannot be explicitly resolved by numerical integration of the basic equations, but require parametrization. In the subgrid-scale, different physical processes contribute in different scales. The parametrized processes interact with the resolved-scale processes and with each other. Advanced diagnostic tools are required for understanding these processes and interactions.

2. MOMENTUM FLUXES

The equation of horizontal hydrostatic motion in a pressure-based, terrain-following hybrid vertical ζ-coordinate system (Simmons and Burridge, 1981) is written, following Kasahara (1974):

$$\frac{\partial \vec{v}}{\partial t} = -\vec{v} \cdot \nabla_\zeta \vec{v} - \dot{\zeta}\frac{\partial \vec{v}}{\partial \zeta} - \frac{1}{\rho}\nabla_\zeta p - \nabla_\zeta \Phi - f\vec{k} \times \vec{v} - \frac{g}{p_s}\frac{\partial \vec{\tau}}{\partial \zeta}, \tag{1}$$

where $\vec{v}$ is the horizontal wind, $\dot{\zeta}$ is the generalized vertical velocity $\dot{\zeta} = \frac{\mathrm{d}\zeta}{\mathrm{dt}}$, ∇_ζ is the gradient operator applied along the constant ζ-surface, $\vec{k}$ is the unit vector in direction of $\vec{g}$, g is acceleration due to gravity, $\Phi = gz$ is geopotential, ρ is density of air, p is pressure and p_s surface pressure. The terms of Eq. 1 describe, from left to right, the local tendency (change in time) of the horizontal wind, horizontal advection, vertical advection, two components of the pressure gradient term, Coriolis term and vertical divergence of the subgrid-scale vertical momentum fluxes. $\vec{\tau} = -\rho\overline{\vec{v}' w'}$ is the stress vector related to the subgrid-scale vertical momentum fluxes; w is the geometric vertical velocity, an overline denotes gridbox average and a prime $'$ subgrid-scale deviation.

Parametrization of orographic effects in atmospheric motion aims at representing the stress $\vec{\tau}$ with the help of orography features and the resolved-scale wind and stability. The parametrized vertical divergence of the stress is used to modify (retard) the simulated flow. In HIRLAM, the parametrization schemes of subgrid-scale orographic effects are based on a few assumptions:

1. Different subgrid scales of orography are related to effects of different physical character.

2. The parametrizations should provide the three-dimensional stress vector $\vec{\tau}(x, y, z)$, consisting of the sum of momentum fluxes due to the different physical processes related to orography.

3. Orographic effects may be parametrized by combining suitable atmospheric grid-scale variables with parameters representing variation of surface elevation in the given scale within the given grid volume, e.g. properly filtered standard deviation of surface elevation or average slope angle.

These assumptions differ from the historically developed, standard assumptions behind subgrid-scale orography parametrizations, by 1) differentiation of the subgrid orography scales and processes, and 2) considering all effects essentially three-dimensional. In earlier times, the bulk effect of all subgrid-scale processes was represented by the effective orographic roughness (Fiedler and Panofsky, 1972; Mason, 1985; Taylor et al., 1989). Parametrization of the orographic gravity wave drag (Boer et al. , 1984; Palmer et al., 1986) then followed. Additional improvements were reached with the application of so-called envelope orography (Tibaldi, 1986), that leads to enhancement of the resolved orography effects. The value of the orographic roughness, height of the envelope orography and the surface value of orographic drag were all based on the same standard deviation of orography height, representing all scales within each grid-square. The magnitude of this standard deviation was determined only by the model's horizontal resolution and availability of the fine-scale orography information. Different physical effects generated by mountains were obtained by the differently formulated dependencies of parametrized wave and form drag on the grid-scale atmospheric parameters. However, these formulations were developed independently of each other. A systematic analysis of the possible interactions seems to be lacking in these early parametrizations.

We will further assume that the smallest-scale variations, due to orography of the scales below a few kilometres can be described as turbulent form drag. Parametrization of small-scale orography (SSO) effects is formulated to take care of this effect. The scales between a few kilometres and a few grid-scales are related to vertically and horizontally propagating orographic buoyancy waves and flow blocking. Parametrization of mesoscale orography (MSO) effects is intended to handle the resulting buoyancy wave drag and mesoscale form drag. Below the smallest scale, there remains the turbulent surface friction due to trees, rocks and other elements of the rough surface. The classical parametrizations of the turbulent surface layer should take care of this surface stress, by using the concept of (vegetation) roughness. Above the MSO scale, the model's resolved dynamics is responsible for modelling of the orographic effects.

Division of the processes and flow dynamics only according to the horizontal scale of the orography is a simplification. In fact, when the effects of earth's rotation are neglected, two nondimensional parameters govern the behaviour of the mesoscale orographic flow: the nondimensional width G_a and height G_h. Both of these parameters combine the upstream flow velocity and stability with the scale of the mountain. The relation $G_h : G_a$ reduces to the simple relation of the height and width of the obstacle ($h : a$, or some kind of mean slope). A schematic diagram (Fig. 1) classifies orographic phenomena according to these parameters. In principle, a unified turbulence-wave parametrization should be able to handle the disturbances forced by the whole spectrum of the underlying orography in varying conditions of the resolved-scale stability and flow velocity. Development of such unified parametrization schemes remains a task for future research.

3. RADIATION FLUXES

Thermal effects related to orography are due to differential heating of (sloping) surfaces at different elevations, mainly due to the differences in solar radiation. Modelling of the orographic effects on surface radiation becomes more important with increasing resolution. The surface radiation balance in a location at or in the vicinity of mountains is influenced by the local surface elevation, local horizon and by steepness and direction of surrounding slopes. Different heating of the slopes, mountain tops and valleys creates local temperature differences and may influence the local circulations, formation of fog, clouds and precipitation.

The parametrized radiation effects enter into the model via the equation of thermodynamics, together with the parametrized turbulence and condensation:

$$\frac{\partial T}{\partial t} = -\vec{v} \cdot \nabla_\zeta T - \dot{\zeta} \frac{\partial T}{\partial \zeta} - \frac{1}{c_p} \left(\frac{g}{p_s} \frac{\partial F_r}{\partial \zeta} + \frac{g}{p_s} \frac{\partial F_t}{\partial \zeta} + F_c \right), \tag{2}$$

where F_r denotes the net radiation flux, $F_t = -\rho \overline{T' w'}$ is the turbulent sensible heat flux and F_c is related to the latent heat changes due to condensation and evaporation.

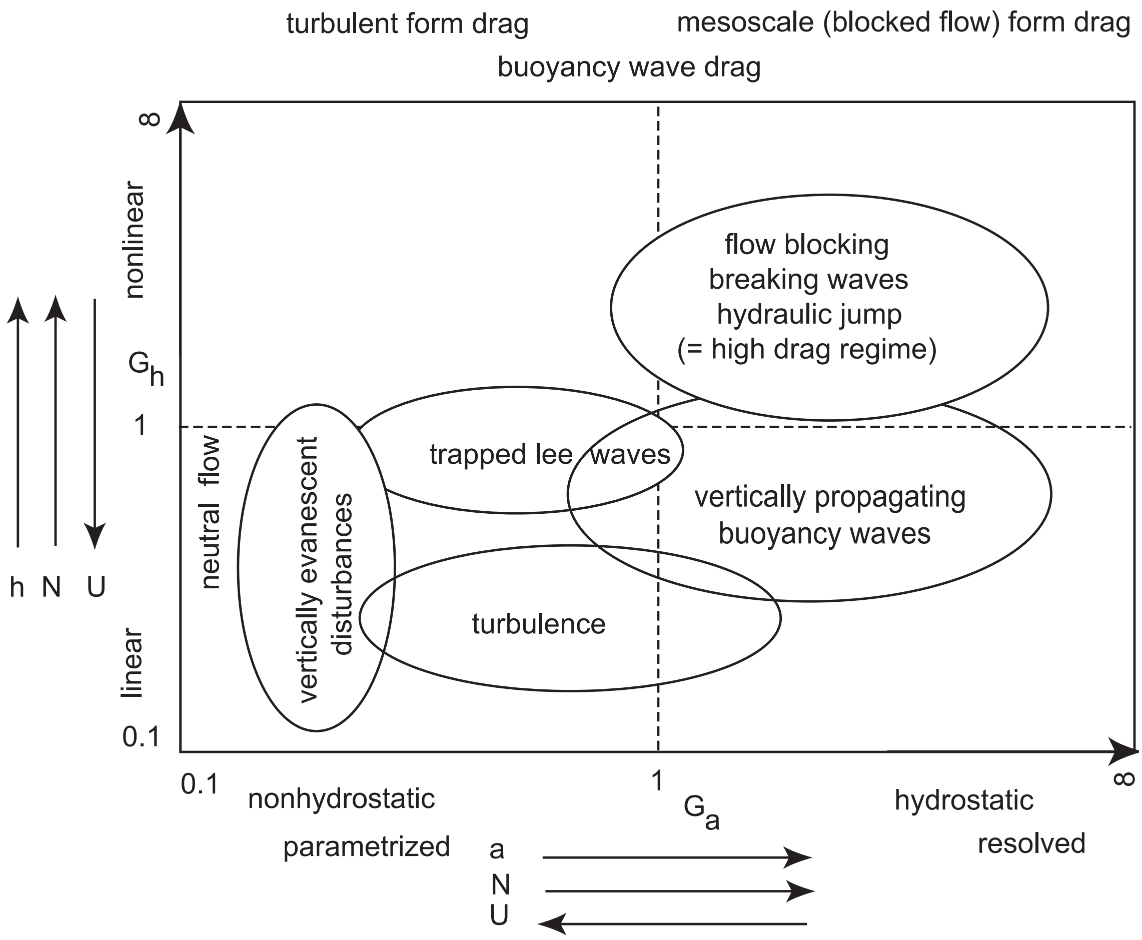

Figure 1: Orographic flow classified according to G_a (x-axis) and G_h (y-axis), c.f. text for details and discussion. Note that the existence of trapped lee waves or hydraulic jump would require vertically non-constant (layered) upstream stability/flow velocity.

The aim of a radiation parametrization is to calculate the profile of the net radiation flux $F_r(z)$ in each grid-column, due to the solar and terrestrial radiation. In addition, it provides components of the surface radiation balance, i.e. the upwelling and downwelling radiation fluxes at the surface. These are used in calculation of the surface energy balance over different types of surface. In HIRLAM, as in most of the operational NWP models, the radiation parametrizations assume the surface is flat and effectively homogeneous.

Senkova et al. (2007) describe how the present HIRLAM radiation scheme (Savijärvi, 1990; Sass et al., 1994; Wyser et al., 1999; Räisänen et al., 2000; Järvenoja and Rontu, 2003; Rontu and Järvenoja, 2003; Rontu and Senkova, 2003) was enhanced to take into account the slope, shadow and sky view effects on surface radiation fluxes, following the approach by Müller and Scherer (2005). Directional fraction of slopes and slope angle in each direction, directional coefficients and the average sky view factor are calculated from high-resolution digital elevation data and aggregated to the model grid. Time-dependencies of some of the parameters are converted to direction-dependencies by using the idea of directional fractions.

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