Surface modelling in HIRLAM: heterogeneity aspects

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1.- Surface types: broad principles

The new HIRLAM surface scheme makes use of the so-called *mosaic* or *tile* approach, first introduced by Avissar and Pielke (1989), and adopted by Claussen (1991) and Koster and Suarez (1992). Such approach couples independently each land-use patch of the grid element to the atmosphere of the model, and patches affect each other only through the atmosphere. The grid averaged surface fluxes are obtained by averaging the surface fluxes over each land-use weighted by its fractional area. The *mosaic* approach circumvents the problem of finding effective value of surface parameters when surface conditions vary strongly. In fact such effective value obtained through aggregation of parameters fails in certain cases, as it has already been pointed out by Stössel and Claussen (1993) and Blyth *et al.*(1993).

The scheme may in principle treat an arbitrary number of surface types in each grid square (Bringfelt, 1996). At present, five surface types are considered within grid square: sea/lake water, ice, bare land, forests and agricultural terrain. For sea/lake, there is no energy balance involved and water temperature is kept constant. For ice, a three layer model for temperature is used based on the one-dimensional equation for vertical heat diffusion keeping heat capacity and diffusivity constant in time and in horizontal. For the three land-surface types the ISBA scheme is used (Noilhan and Planton, 1989). For each land-surface type the following surface variables are forecasted: surface temperature (including the vegetation canopy), mean surface temperature, near-surface soil moisture, bulk soil moisture, rain (dew) water retained on the vegetation canopy. Snow sub-fractions are allowed within the ice fraction and within each of the land-surface fractions. Additional equations for snow density and snow albedo are also computed (Douville *et al.*, 1995).

2.- Aggregation of surface fluxes

In each time step, the sensible (H_i) and latent (E_i) heat fluxes from each subgrid surface type are weighted according to their fractional share of the grid square to form the total surface fluxes. The surface fluxes H_i and E_i are based on the differences in temperature and humidity respectively, between the lowest model level and the surface values for each sub-surface type. For the calculation of H_i and E_i the local roughness length due to vegetation is used. The weighted momentum flux is calculated using z_0 obtained by averaging the local roughness lengths (z_{0_i}) for the subsurfaces according to Mason (1988): $1/(ln\frac{l_b}{z_0})^2 = \sum f_i/(ln\frac{l_b}{z_{0_i}})^2$, where l_b is the blending height or height at which the flow becomes approximately independent of horizontal position (Claussen, 1991). Assuming that the blending height is of the order of 1/100 of the horizontal scale of the roughness variations (Claussen, 1995), for typical landscape variations of 1000 m the blending height is of the order of 10 m, well below the lowest model level. The total grid momentum flux is then obtained by adding the orographic roughness length.

3.- Relevant parameters in land-surface processes

Collins and Avissar (1994) have first used the Fourier Amplitude Sensitivity Test (FAST) to estimate the relative importance of land-surface parameters and Rodriguez-Camino and Avissar (1998a) have compared, using also FAST, the relevant land-surface parameters of three schemes, namely ISBA (Noilhan and Planton, 1989), BATS (Dickinson, 1993) and LAID (Avissar and Pielke, 1989). This last analysis demonstrates that four parameters can explain most of the variance of surface heat fluxes under a broad range of environmental conditions. Soil wetness plays a predominant role for the heat fluxes. Roughness length is the most important parameter for the momentum flux. Leaf area index, in vegetated land, and texture, mainly in bare land, have also a significant impact on the fluxes. Roughness length is usually more important for sensible heat flux than for latent heat flux, and is mostly important under stable atmospheric conditions. Soil wetness and vegetation parameters are the dominant parameters under buoyant conditions.

4.- Parameter aggregation

Parameter aggregation is the averaging algorithm used to define efficient parameters. Since the dependence of surface fluxes on both surface parameters and soil water content is non-linear, estimations of the area averaged fluxes computed from the effective surface parameters do not yield the same result as averaging the fluxes themselves (Li and Avissar, 1994). Thus, the choice of a single effective value for land-surface characteristics, such as leaf area index or soil water, is not straightforward.

Linear averaging of leaf area index and soil wetness gives higher latent and lower sensible heat fluxes than the corresponding flux averaging over all surface types existing in one square grid. This is a consequence of the convex and concave shape of latent and sensible heat fluxes, respectively, considered as functions of leaf area index and soil wetness. Linear averaging of roughness length under unstable conditions provides higher latent and lower sensible heat fluxes than flux averaging, whereas under stable conditions gives higher sensible and lower latent heat fluxes. The systematic biases appearing in the linear aggregation of soil wetness and leaf area index let open the possibility of applying non-linear algorithms to simulate the convex and concave shape of latent and sensible heat fluxes, respectively, when they are plotted as functions of leaf area index and soil wetness. Such non-linear algorithms are able to reduce errors in the computation of latent and sensible heat fluxes from the effective parameters (Rodriguez-Camino and Avissar, 1998b).

5.- Physiographic data bases used

The successful implementation of the new surface scheme is crucially dependent on the availability of mesoscale physiographic data, such as topography, roughness length, *lai*, minimum stomatal resistance, soil texture, albedo, etc. The HIRLAM Project assumed the responsibility of creating a high resolution physiographic data base covering the whole European area for mesoscale numerical weather prediction purposes (Bringfelt *et al.*, 1995).

Existing data bases contain a few specialized parameters only and most of them cover limited geographical areas only. Within most European countries, the existing physiography data sets cover only their national area. The access to these national physiographic data sets involves a significant monetary cost.

The strategy of the work to establish a new physiography and climate data base for HIRLAM has been to start from the old HIRLAM Climate System and to develop a system to add locally available data sources. The old HIRLAM Climate System was derived from the corresponding ECMWF Climate System. New parameters fields have been designated: fraction of forest, fraction of open land, fraction of lake, soil type and Henderson-Sellers land use classes. Furthermore, the fractions of forest and open land, called main classes, are divided into a number of subclasses.

The following data bases are more or less global, *i.e.*, they cover relative large areas. Some of them are merged with data from the U.S. Navy tape.

- FAO-UNESCO Soil database. Nine textural classes are used in the HIRLAM climate system. Resolution: 15' x 30'. Coverage: Europe and North-Africa.
- Remote sensing forest map of Europe. Information about forest, open land and water. Used resolution: 0.1^o x 0.1^o. Coverage: Europe and North-Africa.
- The NOAA elevation map of Europe. Information about geopotential height. Resolution: 0.1^o. Coverage: Europe.
- Reduced Wilson and Henderson-Sellers land-use data base. Information about 18 land-cover classes. Resolution: 1^o. Coverage: global.

Many national databases are also merged with the global or regional datasets. Algorithms to merge data from different data sources and to obtain derived quantities were also developed. This data base is currently under development. A general data format for adding national datasets has been developed.

6.- Assimilation of soil moisture

Mahfouf (1991) proposed an optimal interpolation scheme for initialising the soil water, relating the increments of soil moisture to short-range forecast errors of 2m surface temperature and dew-point, which has been adopted for HIRLAM. In bare ground areas the error in 2m temperature and relative humidity is associated to error in the surface soil layer, whereas in vegetated areas it is related to the root layer soil moisture errors. Two aspects are critical in this method. First, the definition of the optimum coefficients in the matrix relating the errors in 2m temperature and relative humidity and the analysis increment errors in the surface and root layer soil moisture. Second, the elimination of systematic errors on 2m temperature and relative humidity not due to incorrect soil moisture. The optimum coefficients relating errors originally proposed by Bouttier *et al.*(1993a) were further smoothed and adapted by Giard and Bazile (1997). Big jumps and daily oscillations in soil moisture analysis are prevented by 24 h averaging of soil moisture increments computed at 6 hours cycles. Systematic errors can recursively be computed and eliminated before soil moisture analysis (Bazile and Giard, 1998).

This method for initialising soil water content can only be applied when 2m temperature and relative humidity is mainly forced by the ground, *i.e.*, sunny weather and weak winds. The algorithm for the analysis of screen variables is also an essential ingredient of this approach.

6.- Analysis of 2m temperature and relative humidity

The accurate analysis of 2 m temperature and relative humidity is the necessary first step to assimilate soil variables. The analysis of 2m temperature and relative humidity developed in HIRLAM (Navascues, 1997) is based on optimal interpolation. Observations of 2m temperature and relative humidity are usually of very local nature. They depend critically on surface characteristics. To palliate such local effects, a correction to the observation increments was introduced taking into account the vertical distance between the station height and the model interpolated orography. Such reduction is specially beneficial in the case of complex terrain. The anisotropy of the structure function includes the effect of coastline and inland topography.

7.- Snow processes

The effect of the snow mantle is taken into account over land and sea-ice fractions. Those fractions admit the possibility of being partially covered with snow. Currently 3 predictive equations are introduced to simulate the evolution of snow: snow depth, snow density and snow albedo (Douville *et al.*, 1995). No effect of snow "masking" by the vegetation is considered in the computation of the albedo, to reduce the snow covered area when tall vegetation is present. Melting conditions are met when the equilibrium ground temperature is above 0^oC.

New tests are being conducted with a more complex scheme (Fernandez, 1998) This scheme takes into account both the heat balance at the snow surface and that of the entire snow cover. The model was initially developed to predict the rapid snow-melt rates, in order to be coupled with a hydrological model. During the snow-melt season the snow-pack can be divided into two layers: one with dry snow above and another with wet snow below. Both layers are separated by the freezing depth. The lower layer has a uniform temperature of 0^oC and can store liquid water. This stored liquid water percolates to the soil when it exceeds certain limits and can also re-freeze, *e.g.*, due to nocturnal cooling.

8.- Future developments

As resolution is increased, some types of terrain could be misrepresented with the current 5 allowed types of surface within each grid square. This is the case of inland lakes. The Northern European area is of particular interest in this connection. Sweden and Finland have lakes covering around 10% of the land area. HIRLAM take lake effects into account in a very crude way by assuming a climatological variation of the lake temperature and ice conditions. As climatological values are not a very promising approach, since there is a significant inter-annual variability, a combination of lake modelling and observations of lake conditions has been tested (Ljungemyr *et al.*, 1996). Available lake observations are today very sparsely distributed, but satellite observations are a potentially important data source. Parameterization of lake temperatures and lake ice thickness has been conducted simulating lakes with a slab model based upon energy conservation. Lakes are treated as well mixed boxes with depths represented by mean depths. Results modelling the lake-size distribution by four lake models with different surface areas and depths show that the impact of lake effects can reach several ^{o}C in air temperatures close to the surface.

Irrigated terrain is the dominating land-use in some Mediterranean regions. Soil moisture is then steered by the irrigation practices which assign some optimum value of soil moisture for growing to each plant species. Some term of bogus precipitation when soil moisture decreases below some prescribed value allows to mimic irrigation. Effects in Bowen ratio and 2m temperatures are appreciable. The increase of soil moisture as a result of irrigation has been reported to hinder the development and intensity of sea-breeze circulation and consequently the precipitation associated to such mesoscale effects (Lohar and Pal, 1995).

The effect of freezing and melting of soil water content has been reported as relevant by Bazile and Giard (1998). The parameterization of soil water freezing requires a new prognostic variable for frozen soil water, and modifies the surface temperature equation, the total soil water content equation and the bare-ground thermal coefficient. Effects of freezing and melting in minimum and maximum temperatures, respectively, can reach several degrees.

The current snow scheme (Douville *et al.*, 1995) introduces snow albedo and snow density as predictive variables. More complex snow models introducing extra predictive variables are intended to be tested in 3D simulations. Tests in 1D considering liquid water retained by the snow mantle, and its possible re-freezing, suggest that this process cannot be ignored (Fernandez, 1998).

The heterogeneity aspects for a given grid-box are contemplated both by the tile approach and by the aggregation of parameters. The tile approach assumes that each fraction is randomly distributed to prevent mesoscale circulations. Successive improvements will be conducted within each of the fractions or tiles, *e.g.*, ice, lakes, etc. Each tile has associated a set of evolution equations and a set of surface and soil parameters. The set of parameters corresponding to each tile will be obtained by aggregation following the lines sketched en Section 4. The aggregation of parameters incorporates the information supplied by high resolution data bases.

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