PARAMETRIZATION OF SNOW IN NWP AND CLIMATE MODELS : MOTIVATION, VALIDATION, APPLICATION

Hervé Douville
Météo-France/CNRM
42 Avenue G. Coriolis, 31057 Toulouse Cédex, France
email : herve.douville@meteo.fr

Abstract

Both observational studies and numerical experiments demonstrate the sensitivity of the atmosphere to variations in the extent and mass of snow cover. There is therefore a need for simple but realistic snow parameterizations in forecast and climate models. A new simple snow hydrology has been recently developed at Météo-France. It has been validated off-line against local field measurements and global satellite data sets, as well as in a fully interactive numerical climate experiment. The results indicate that the scheme is able to reproduce the snow cover evolution, both on the local and global scales. Some prospects for further improvements of the parametrization are suggested, and its implementation together with a snow analysis in a NWP model is discussed.

1 A simple snow scheme for use in GCMs

Most GCMs still show serious deficiencies in representing accurately the snow cover and snow mass distribution (Foster et *al.*, 1996). A new one-layer snow model has been introduced in the ISBA land-surface scheme (Noilhan and Planton, 1989), in order to improve the snow cover climatology simulated by the ARPEGE climate model of Météo-France. The aging process of the snow pack is considered through prognostic equations for snow density and snow albedo. The snow thermal properties depend on the density, which increases exponentially with time up to a maximum value of 300 kg/m^3. The snow albedo evolves between 0.50 and 0.85 as a function of the rates of snowfall and snowmelt. The scheme computes a single surface energy budget, but takes account of the vegetation cover when estimating the surface albedo and the snowmelt. More details about the parametrization may be found in Douville et *al.* (1995).

This simple snow model has first been tested in stand-alone experiments forced by observed radiative fluxes and meteorological variables at selected instrumented sites, thereby demonstrating its ability to predict the snow depth and snow albedo evolution over a wide range of surface conditions (Douville et al. 1995, Douville 1997). First tests have been based on the data collected at Le Col de Porte (Brun et al. 1989) in the French Alps during several winter seasons. The results indicate that, despite its simplicity, the scheme simulates the snow cover evolution in a reasonable way. During the cold periods, the settling of the snow pack is reproduced even if the fresh snow density (100 kg/m^3) is overestimated. During the warm events, the melting rate is realistic so that the erosion of the snow layer is well simulated. The scheme captures both the mean level and the large fluctuations of the snow albedo between successive snowfalls. The simulated surface temperature is also fairly consistent with the observations. Nevertheless, the melt water outflow is sometimes overestimated during the transition between cold and warm periods. This might be due to the neglect of the liquid water retention within the snow pack, which can delay the decrease of the snow depth and reflectivity through nocturnal refreezing. Another important test has been performed on a forested site in Japan (Ohta et al. 1993), where the vegetation was shown to play a critical role in the surface energy budget of snow-covered areas. It was demonstrated that the use of a realistic surface albedo over snow-covered forests (rather low due to the masking effect of the canopy) could induce a strong overestimation of the melting rate if no distinction is done between the vegetation and snow temperatures.

In the framework of the Global Soil Wetness Project, the ISBA land-surface scheme was forced on the global scale with observed precipitation (GPCP) and radiative fluxes (ISCCP) as well as with analysed near surface parameters (ECMWF) over the period 1987-1988. This experiment allowed to validate the snow scheme on the global scale at a $1° \times 1°$ resolution using an assumed perfect atmospheric forcing (Douville 1997, Douville et al. 1998). The simulated snow fields were compared to the US Air Force climatology (USAF) based on terrestrial measurements and to two satellite data sets : the NOAA weekly snow cover and the Nimbus-7 SMMR monthly snow depth. The global distribution of snow depth simulated by ISBA in 1987 does not agree very well with the SMMR data set. The snow lines (i.e. the southern boundaries of the snow cover) are similar but the snow depths are sometimes quite different, the ISBA values being closer to the USAF climatology. This suggests that the passive microwave data set is not very reliable, especially over vegetated areas. It is still a challenge to monitor snow depth on the global scale. The comparison with the weekly NOAA data indicates that the maximum and minimum snow cover areas are well estimated, both for the Eurasian and North American continents. The timing of snow accumulation and melting is also realistic, despite a delay in the springtime snowmelt, which might be due to a cold bias in the ECMWF analysis atmospheric forcing. This hypothesis was confirmed by the use of a much more sophisticated snow model developed for operational avalanche forecasting (Brun et al. 1989). The springtime snowmelt is slightly earlier with this reference snow model, but still late compared to the observations. In winter the accumulation is stronger than with the ISBA snow scheme, especially over mountainous areas where the refreezing of the melt water was shown to be important.

Finally, the ISBA snow parametrization was also validated within the ARPEGE climate model of Météo-France during a 3-year present-day climate simulation (Douville et al. 1995, part II). The results of this fully interactive experiment showed a positive impact of the parametrization. Both the geographical distribution and the seasonal cycle of the snow pack were improved, with a beneficial effect on the surface air temperature and precipitation distribution. The new scheme improved the atmospheric circulation not only in the mid-and-high latitudes but also in the tropics, showing a better simulation of the Asian summer monsoon.

2 Interest for NWP models

Such a simple snow parametrization has a potential interest for implementation in NWP models, in which snow is generally represented by a single layer with a prescribed albedo. The single prognostic variable is the snow mass or water equivalent of snow, which cannot be directly compared with in situ observations of physical snow depth. An explicit consideration of the snow density is therefore useful not only for estimating the thermal properties of the snow pack, but also for improving the snow depth analysis. In NWP models, snow models should actually be designed by thinking of both forecast and analysis. The complexity of the model should be compatible with what can be observed, as well as with the accuracy of the atmospheric inputs. Every 6 hours, the predicted snow field must be corrected by a consistent snow analysis, using in situ and possibly satellite observations.

At ECMWF, the operational snow analysis is a three step procedure. First, a snowfall analysis is performed using the precipitation and 2 meter temperatures from the SYNOP reports. The spatial interpolation is done according to a successive correction method. Then, a "first guess" of the snow depth is derived from the analysed snowfall, the previous snow depth analysis (persistence), the climatological snow depth (relaxation with a 12-day time scale), and an empirical snow melting fuction. Finally, the snow depth analysis itself is done by successive corrections. Therefore, the predicted snow mass is not used in the production of the "first guess" (from the analysis view), which could change if a more physical and therefore more reliable snow scheme was introduced in the ECMWF model.

A more physical snow scheme would be beneficial not only for the short and medium range forecasts, but also for the seasonal forecasts since the snow cover provides an important "memory" at the lower boundary of the atmosphere. This is relevant for the mid-and-high latitudes, as well as for some low latitude regions such as the Asian monsoon area, due to the possible teleconnections between the extratropics and the tropics (Douville and Royer 1996a, Ferranti and Molteni 1998).

3 Conclusions and prospects

The one-layer snow model included in the ISBA land surface scheme seems to capture the main physical mechanisms governing the snow pack evolution. However, some improvements could be investigated, such as the retention and refreezing of liquid water within the snow pack. Preliminary tests have been conducted by adding a prognostic equation for the liquid water content in the snow, showing the importance of the percolation process. Small improvements have been obtained in the timing of the runoff from the snow pack. Further improvements would require a multi-layer snow model or at least an additional energy budget for the entire snow layer.

On longer term, more attention should be paid to the interaction between snow and vegetation, which could require a separate energy budget for the canopy. The use of a realistic rather low albedo over snow-covered forests has a strong impact on the atmosphere (Douville et al. 1996b, Viterbo and Betts 1998), which can be however overestimated if the snow and vegetation temperature are lumped together. The representation of subgrid snow distribution within the models should be also improved. This distribution is strongly dependent upon orography, which will influence both snowfall and snowmelt (exposure). Improvements in this field could also be helpful for data assimilation, since more and more accurate satellite snow cover data should be available in a near future.

Finally, improvements in the snow scheme and snow analysis at ECMWF should be considered before the forthcoming 40-year reanalysis project. If successful, the combination of the improved snow scheme and snow analysis should allow the production of a reliable high resolution global snow depth climatology, which cannot be obtained through direct in situ or satellite observations. Such a climatology would be very useful in order to study the interannual variability of the Northern Hemisphere snow cover and its relationship with various components of the climate system.

Acknowledgements : The author would like to thank Pedro Viterbo for its invitation to this ECMWF workshop and for his helpful comments. Thanks are also due to E.Brun, E.Martin and T.Ohta for providing in situ meteorological and snow data.

References

Brun, E. et *al.*, 1989 : An energy and mass model of snow cover suitable for operational avalanche forecasting, *J. Glaciol.*, **35** (121), 333-342.

Douville, H., J-F. Royer and J-F. Mahfouf, 1995 : A new snow parameterization for the Météo-France climate model, Part I : Validation in stand-alone experiments, Part II : Validation in a 3D GCM experiment, *Climate Dyn.*, **12**, 21-52.

Douville, H. and J-F. Royer, 1996a : Sensitivity of the Asian summer monsoon to an anomalous Eurasian snow cover within the Météo-France GCM, *Climate Dyn.*, **12**, 441-448.

Douville, H. and J-F. Royer, 1996b : Influence of the temperate and boreal forests on the Northern Hemisphere climate in the Météo-France climate model, *Climate Dyn.*, **13**, 57-74.

Douville, H., 1997 : Local and global stand-alone tests of the Météo-France snow parameterization, *Annals Glaciology*, **25**, 165-169.

Douville, H., 1998 : Validation and sensitivity of the global hydrologic budget in stand-alone simulations with the ISBA land-surface scheme, *Climate Dyn.*, **14**, 151-171.

Ferranti, L. anf F. Molteni, 1998 : Springtime snow depth anomalies over Eurasia : their predictability and implications for the Asian summer monsoon, *PROVOST European Project 2nd year report.*

Foster, J. et *al.*, 1996 : Snow cover and snow mass intercomparisons of GCM and remotely sensed datasets, *J. Climate*, **9**, 409-426.

Noilhan, J. and S. Planton, 1989 : A simple parameterization of land surface processes for meteorological models, *Mon. Weather Rev.*, **117**, 536-549.

Ohta, T., T. Hashimoto and H. Ishibashi, 1993 : Energy budget comparison of snowmelt rates in a deciduous forest and an open site, *Annals Glaciology*, **18**, 53-59.

Viterbo, P. and A.K. Betts, 1998 : The forecast impact of changes to the snow albedo of the boreal forests, *JGR* (submitted)