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An improved snow scheme for the ECMWF land surface model: description and offline validation

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A new snow scheme for the European Centre for Medium-Range Weather Forecasts (ECMWF) land surface model has been tested and validated. The scheme includes a new parameterization of snow density, incorporating a liquid water reservoir, and revised formulations for the sub-grid snow cover fraction and snow albedo. Offline validation (covering a wide range of spatial and temporal scales) includes simulations for several observation sites from the Snow Models Intercomparison Project-2 (SnowMIP2), global simulations driven by the meteorological forcing from the Global Soil Wetness Project-2 (GSWP2), and by ECMWF ERA-Interim re-analysis. This snow scheme was introduced in the ECMWF operational forecast system in September 2009 (CY35R3).

SnowMIP2 simulations revealed that the original snow scheme had a systematic early and late prediction of the final ablation in forest and open sites, respectively. The NEW scheme reduces the negative timing bias in forest plots from 15 to 1 day and the positive bias in open plots from 11 to 2 days. The new snow density parameterization has a good agreement with observations, resulting in an augmented insulation effect of the snowpack. The increased insulation and the new exposed and shaded albedo change the surface energy fluxes. There is a reduction of the basal heat flux that reduces the cooling of the underlying soil, which is warmer in NEW than in CTR (old scheme) during the cold season. Thus, reduced soil freezing decreased the surface runoff and increased soil water storage. The mean annual cycles of runoff and TSWV (terrestrial water storage) analyzed for the Ob and Mackenzie basins are closer to the observations in NEW. In ten Northern hemisphere basins, there is an average reduction of the monthly runoff RMSE from 0.75 to 0.51 mm day-1 when comparing CTR and NEW, respectively. These results illustrate the importance of the snow insulation on the hydrological cycle, even at regional scales.

On a hemispheric scale, the new snow scheme reduces the negative bias of snow-covered area, especially during spring. On a daily scale, using NOAA/NESDIS snow cover data, the early ablation in CTR is reduced by a factor of two in some identified regions over the Northern Hemisphere. The changes in snow-covered area are closely related with the changes in surface albedo. The original snow scheme had a systematic negative bias in surface albedo, when compared against MODIS remote sensing data. The new scheme reduced the albedo bias, consequently reducing the spatial (only over snow covered area) and time (October to November) averaged surface net shortwave radiation bias from +7.1 W m-2 in CTR to -1.8 W m-2 in NEW.

For each validation dataset, sensitivity experiments were performed to assess the impact of the new components of the presented snow scheme. Prognostic and diagnostic SLW (snow liquid water) representations display similar skill in SnowMIP2 (RMSE of SWE) and GSWP2 (RMSE of basin runoff) simulations. Simulated improvements of SWE in SnowMIP2 locations were mainly due to SLW representation on forest sites and due to the new exposed albedo on open sites. The increased snow insulation effect, due to the new snow density parameterization, had an important role on the basins water balance. Impacts of the new snow cover fraction and exposed and shaded albedo parameterizations were evident when validating against remotely sensed data. Sensitivity tests highlight the role of the different components of the snow scheme with the behavior conditioned

by the climate and vegetation conditions of each site. Thus, a robust verification of a LSM model should include a variety of different (and independent) validation datasets.