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Global and Planetary Change 38 (2003) 161–164

GLOBAL AND PLANETARY CHANGE

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Developments in the MOSES 2 land-surface model for PILPS 2e

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Received 17 November 2001; received in revised form 19 March 2002; accepted 8 May 2002

Abstract

Improved representations of snow processes in vegetation canopies and snow hydrology are implemented in the Met Office Surface Exchange Scheme 2 (MOSES 2) land-surface model. Snow falling on forests is partitioned between interception and throughfall; the intercepted snow is removed by sublimation, melt and unloading. A reduction in sublimation of wind-blown snow through trapping by shrubs is simply represented by reducing the scalar roughness length for shrubs with snow cover. Melt water may be retained and refrozen within snow packs. By reducing the amount of snow lost through sublimation and delaying the runoff of melt water, these modifications are found to improve the simulations of runoff for two Swedish catchments used in the PILPS 2e intercomparison project.

Keywords: PILPS; Land-surface models; Snow; Vegetation; Runoff

1. Introduction

The Met Office Surface Exchange Scheme (MOSES; Cox et al., 1999) is the land-surface model used in the Met Office General Circulation Model (GCM) for both climate modelling and numerical weather prediction. A tiled representation of subgrid heterogeneity and a prognostic snow albedo scheme were introduced with the current version, designated MOSES 2 (Essery et al., 2001). Two versions of MOSES 2 participated in PILPS 2e: the standard version and the MOSES-CEH version (Blyth, 2001) which includes the Moore (1985) Probability-Distributed Moisture (PDM) model of subgrid heterogeneity in soil moisture storage capacities.

Separate net radiative fluxes, sensible heat fluxes, moisture fluxes and snow masses are calculated for each surface type within a gridbox. MOSES 2 was designed to complement the TRIFFID vegetation dynamics model (Cox et al., 2000; Cox, 2001), so it normally uses the five TRIFFID vegetation types (broadleaf trees, needleleaf trees, temperate C_3 grass, tropical C_4 grass and shrubs) and four nonvegetated surface types (urban, inland water, bare soil and ice). In the GCM, a mapping onto these surface types from the classes in the University of Maryland (UMd) 1 km global land cover data set (Hansen et al., 2000) is used to derive maps of fractional gridbox coverage for each type. The same land cover data set was used in PILPS 2e, and a set of surface parameters was provided for each of the classes found in the intercomparison domain. MOSES 2 was therefore adapted to use the UMd classes as its surface types, allowing direct use

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0921-8181/03/$ - see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0921-8181(03)00026-2

of the provided parameters. Separate visible and near-infrared albedos are calculated, but they were simply averaged for the PILPS 2e simulations because separate fluxes in these bands were not available in the driving data.

Only a very simple model of snow cover is used in MOSES 2. Retention and freezing of liquid water in snow is neglected; snowmelt begins when the surface temperature reaches 0 °C and melt water generated by subsequent net energy input is removed immediately as runoff at the base of the pack. In a simulation of snowmelt at a site in the French Alps, this was found to predict runoff earlier than was observed (Essery et al., 1999). Snow falling on forests is effectively assumed to be held in the canopy, in the sense that the surface temperature cannot rise above 0 °C when there is snow cover and sublimation is not limited by transport through the canopy. A snow-covered forest thus presents a rough, wet, low-albedo surface, and the modelled sublimation may be excessive (Essery, 1998). Modelled sublimation from shrubs is greater than from shorter vegetation with lower surface roughness, but shrubs can trap wind-blown snow (not represented by any of the PILPS 2e models), and Liston et al. (2002) found that replacing tussock tundra with shrubs actually decreased the sublimation in a blowing-snow model.

In the next section, the impact of improved representations of canopy snow processes and snow hydrology motivated by the PILPS 2e results are discussed.

2. PILPS 2e results and MOSES 2 enhancements

Comparisons between PILPS 2e simulations and observations of runoff for the Torne and Kalix rivers are discussed by Bowling et al. (2003-this issue) and Nijssen et al. (2003-this issue). MOSES 2 underestimated runoff in summer because it produced little runoff from rainfall once the soil had thawed. Inclusion of PDM gave an improved simulation of summer runoff, which was increased because some fraction of each gridbox is assumed to be saturated even when the gridbox average soil moisture is below saturation. However, this had little impact on runoff during snowmelt, and both versions of MOSES 2 predicted peaks in runoff which were too early and too small. Compared with models that gave better simulations of runoff, the winter sublimation calculated by MOSES 2 was high.

PILPS 2e participants were provided with daily time series of observed runoff from two subbasins over the period of 1989–1998 to allow partial calibration of the models; Ovre Lansjarv is a forested catchment and Ovre Abiskojokk is a high-altitude catchment dominated by shrubs and bare ground. Monthly averages of the observed runoff are shown by thick solid lines in Fig. 1. For both catchments, the snowmelt peak in the runoff simulated by MOSES 2 with PDM, equivalent to MOSES-CEH, was underestimated and too early (dotted lines). Average and root mean square (rms) errors for the MOSES 2 + PDM simulations are given in Table 1. Adjustment of model parameters within reasonable ranges did not significantly reduce the errors, so MOSES 2 and

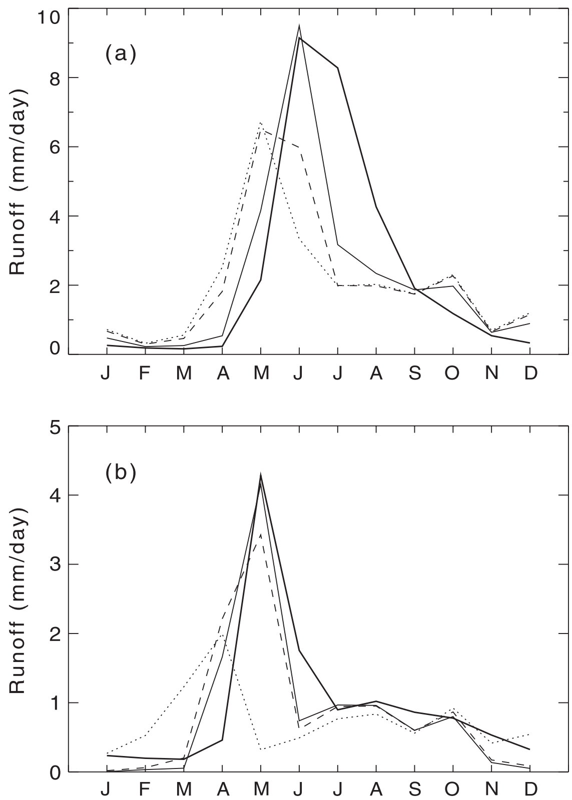

Fig. 1. The mean monthly runoff for (a) Ovre Abiskojokk and (b) Ovre Lansjarv from observations (heavy solid lines) and versions of MOSES 2 with PDM (dotted lines), canopy modifications (dashed lines) and snow hydrology (thin solid lines).

Table 1
Average bias and root mean square errors (mm/day) for the simulations shown in Fig. 1

	Abiskojokk		Lansjarv	
	bias	rms	bias	rms
MOSES 2 + PDM	− 0.37	3.10	− 0.22	1.37
+ canopy	− 0.26	2.66	− 0.11	0.69
+ snow hydrology	− 0.22	1.77	− 0.11	0.50

MOSES-CEH results were returned for PILPS 2e without calibration.

Since the PILPS 2e results were generated, an improved model of forest canopy snow processes, based on the models of Pomeroy et al. (1998) and Storck and Lettenmaier (1999), has been implemented in MOSES 2 (Essery et al., 2003). Snowfall is partitioned into interception by the canopy and throughfall, and intercepted snow may be removed from the canopy by sublimation, unloading or melting. Sublimation of intercepted snow is limited by a resistance for transport of water vapour between the snow and the canopy air space. The canopy snow model reduces the sublimation from forests, making more snow available for melt, and delays the melt of snow beneath the canopy. Lacking a model of snow trapping by shrubs, the scalar roughness length for shrubs is simply reduced to a third of the recommended value whenever there is snow cover; a similar procedure was used by Samuelsson et al. (2002) to investigate the role of the roughness length in the sublimation of snow in coupled and uncoupled simulations using the RCA model. The dashed lines in Fig. 1 and statistics in Table 1 show that the forest and shrub canopy modifications reduce the bias and rms errors for both catchments.

A simple model of snow hydrology was additionally implemented in MOSES 2 for this study. A snow pack is allowed to store up to 10% of its mass as liquid water. If the bulk temperature of the snow is below 0 °C, liquid water is refrozen, releasing latent heat. Storage and refreezing do not greatly change the amount of snow available for melt but delay the runoff of melt water, so there is little change in the bias but rms errors are reduced (Table 1). The peak runoff amounts simulated for both catchments, shown by the thin solid lines in Fig. 1, are close to the observations. Delay by routing and storage, not represented in MOSES 2, could further improve the simulations.

For the entire PILPS 2e domain, the combined average annual runoff for the Torne and Kalix rivers was measured as 403 mm, and the annual average latent heat flux was estimated from the water balance as 24 W m^{-2} (Bowling et al., 2003-this issue). These values were simulated as 333 mm and 34 W m^{-2} by MOSES 2 including PDM. The modifications described above decrease the average latent heat flux to 27 W m^{-2} and increase the annual runoff to 380 mm, much closer to the observations.

In conclusion, PILPS 2e has provided valuable opportunities to identify problems in representations of snow cover on vegetated surfaces and to assess enhanced representations in MOSES 2.

Acknowledgements

This work was supported by the UK DEFRA Climate Prediction Programme under contract PECD 7/12/37.

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