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Simulation of high-latitude hydrological processes in the Torne–Kalix basin: PILPS Phase 2(e) 3: Equivalent model representation and sensitivity experiments

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Abstract

The Project for Intercomparison of Land Surface Parameterization Schemes (PILPS) Phase 2(e) showed that in cold regions the annual runoff production in Land Surface Schemes (LSSs) is closely related to the maximum snow accumulation, which in turn is controlled in large part by winter sublimation. To help further explain the relationship between snow cover, turbulent exchanges and runoff production, a simple equivalent model (SEM) was devised to reproduce the seasonal and annual fluxes simulated by 13 LSSs that participated in PILPS Phase 2(e). The design of the SEM relates the annual partitioning of precipitation and energy in the LSSs to three primary parameters: snow albedo, effective aerodynamic resistance and evaporation efficiency. Isolation of each of the parameters showed that the annual runoff production was most sensitive to the aerodynamic resistance. The SEM was somewhat successful in reproducing the observed LSS response to a decrease in shortwave radiation and changes in wind speed forcings. SEM parameters derived from the reduced shortwave forcings suggested that increased winter stability suppressed turbulent heat fluxes over snow. Because winter sensible heat fluxes were largely negative, reductions in winter shortwave radiation resulted in an increase in annual average sensible heat.

Keywords: Arctic regions; Modeling; Hydrology; Atmosphere

1. Introduction

The Project for Intercomparison of Land Surface Parameterization Schemes (PILPS) Phase 2(e) was designed to evaluate the ability of the current generation of land surface schemes (LSSs) used in numerical weather prediction and climate models to represent high-latitude processes. Twenty-one LSSs were tested using observed meteorological forcing data for 218 grid cells that represented the 58,000-km^2 Torne–Kalix River basin in northern Scandinavia at a spatial resolution of 1/4° in latitude and longitude (Bowling et al., 2003-this issue). The experimental design and summary experiment results are described in Bowling et al. (2003-this issue). Nijssen et al. (2003-this issue) compare the simulated results with observations and explore the inter-model differences in surface temperature, net radiation and runoff production.

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The analyses of Phase 2(e) results presented by Bowling et al. (2003-this issue) and Nijssen et al. (2003-this issue) show that among all the models, annual runoff production is closely related to the maximum snow accumulation, which in turn is controlled in large part by winter sublimation. Models that detain more of the snow meltwater, either as surface water storage or in the soil column, tend to generate a more attenuated hydrograph, which better matches observations (Nijssen et al., 2003-this issue). However, the analyses in Bowling et al. (2003-this issue) and Nijssen et al. (2003-this issue) are unable to reveal conclusive explanations for differences among the models in partitioning of latent and sensible heat, surface temperatures, and the effect of stability corrections for turbulent heat exchange. In addition, the design of the Phase 2(e) experiments did not tightly control model parameters, which complicates isolation of the contribution of specific parameterizations to the disparity among simulated results. The intent of this paper is to explore the nature of these relationships.

Koster and Milly (1997) analyzed a portion of the models from the PILPS Phase 2(a) experiment and found that regardless of LSS complexity, they could obtain a reasonable estimate of the simulated water balances through the application of a simple monthly water balance model. The LSS-specific parameters for the monthly model were derived from the full PILPS simulations performed by the individual, detailed LSSs. The LSS-specific parameters were then used to evaluate the interactions between evaporation and runoff processes within and among the LSSs. Gedney et al. (2000) used a similar methodology to evaluate predicted changes in surface hydrology as a result of climate change. In their experiment, equivalent simple bucket models were inferred for four LSSs in three regions, using two different climate scenarios.

In this paper, we process the PILPS 2(e) simulation results for each of the models into calibrated parameters for a set of simple equivalent models (SEMs), which in turn are used to stratify model properties. We expand on the analysis of Koster and Milly (1997) and Gedney et al. (2000) by using a simplified monthly model to evaluate the interaction between snow cover, evaporation, and runoff processes. Thirteen of the 21 models that participated in Phase 2(e) returned sufficient model output variables to be used in this analysis. The derivation of simplified characterizations of each of these LSS is summarized in Section 3 and Appendix A. The results of the SEMs as applied to the Torne–Kalix data sets are presented in Section 4. In Section 5, the SEMs are used to explore the results of an inadvertent reduced wind speed and shortwave radiation 'experiment' conducted as part of PILPS Phase 2(e).

6. Discussion and conclusions

To explain the relationship among snow cover, turbulent exchanges and runoff production among the LSSs participating in the PILPS Phase 2(e) intercomparison, a simple equivalent model was devised to reproduce the seasonal and annual fluxes of 13 PILPS LSSs. This analysis shows that for the high-latitude Torne–Kalix River basin, the annual partitioning of precipitation and energy in the LSSs can be related to three primary parameters: snow albedo, effective aerodynamic resistance and evaporation efficiency. These parameters were estimated from LSS-simulated variables and used to parameterize the SEM for five regions within the Torne–Kalix River basin. On average, the SEM is better able to reproduce annual evaporation in areas without overstory vegetation (Regions 1 and 2). Because these areas are also the regions that receive the least annual radiation, this may be a reflection of a greater energy limitation on evaporation at these latitudes, in addition to vegetation controls. Over all models, the SEM is better able to represent the seasonal snow cycle in regions with overstory (Regions 3, 4 and 5), as measured using the squared correlation coefficient. This may be due in part to a greater sensitivity to the aerodynamic resistance in Regions 1 and 2.

The estimated aerodynamic resistance parameters tended to be higher for Regions 1 and 2, and annual runoff production is most sensitive to the aerodynamic resistance in these regions. In Regions 3, 4 and 5, annual runoff production is most influenced by both the effective aerodynamic resistance and the partitioning of energy into evaporation in the summer. Interannual variability in summertime evaporation is more influenced by interannual variation in model parameters in regions with overstory vegetation than in regions without overstory. In all cases, however, interannual variation in available energy controls a larger proportion of the total variation in evaporation.

The SEMs were somewhat successful in reproducing the observed LSS response to a decrease in shortwave radiation forcings and changing wind speed. The simulated response indicates that a larger proportion of the change in available energy is taken from annual sensible heat. Changes in wind speed can counteract this effect, leading to subsequent decreases in latent heat.