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SNOWMELT AND INFILTRATION DEFICIENCIES OF SSiB AND THEIR RESOLUTION WITH A NEW SNOW-PHYSICS SCHEME

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1. INTRODUCTION

A two-year 1987–1988 integration of SSiB forced with ISLSCP Initiative I surface data (as part of the Global Soil Wetness Project, GSWP, evaluation and intercomparison) produced generally realistic land surface fluxes and hydrology. Nevertheless, the evaluation also helped to identify some of the deficiencies of the current version of the Simplified Simple Biosphere (SSiB) Model (Xue *et al.*, 1991), as reported by Mocko and Sud (1998). The simulated snowmelt was delayed in most regions, along with excessive runoff and lack of an spring soil moisture re-charge. The SSiB model had previously been noted to have a problem producing accurate soil moisture as compared to observations in the Russian snowmelt region (Robock *et al.*, 1995; Xue *et al.*, 1997). Similarly, various GSWP implementations of SSiB found deficiencies in this region of the simulated soil moisture and runoff as compared to other non-SSiB land-surface models (LSMs).

The origin of these deficiencies was: 1) excessive cooling of the snow and ground, and 2) deep frozen soil disallowing snowmelt infiltration. The problem was most severe in regions that experience very cold winters. In SSiB, snow was treated as a unified layer with the first soil layer, causing soil and snow to cool together in the winter months, as opposed to snow cover acting as an insulator. In the spring season, a large amount of heat was required to thaw a hard frozen snow plus deep soil layers, delaying snowmelt and causing meltwater to become runoff over the frozen soil rather than infiltrate into it. The need for a separate thermal regime of snow in a LSM for a General Circulation Model (GCM) was shown by Verseghy (1991).

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2. NEW SSiB SNOW-PHYSICS SCHEME

A new snow-physics scheme was written by Sud and Mocko (1999) to solve the above problem. The snow layer is separated from the soil, with its own energy budget and temperature. Solar energy at the top of the snowpack not reflected by the snow is either absorbed by the snow or transmitted to the ground. An exponential transmittance function, as a function of snow depth, partitions the energy to the snow or ground. Surface fluxes occur at the top of the snow, while transfer of thermal energy between the snow layer and the ground is achieved by conduction through the snow and ground layers and by radiation through a small air gap between the two layers. Snowmelt can occur by: i) the conduction of heat from the ground, ii) warm precipitation falling on the snowpack, and iii) fluxes (especially of sensible heat and net radiation) at the top of the snow causing the snow temperature to be above freezing. All of this allows the ground to remain insulated under a deep snowpack, conserving soil heat during winter. In turn, the warmer ground leads to earlier snow melting and ground thawing, larger snowmelt infiltration, and reduced runoff.

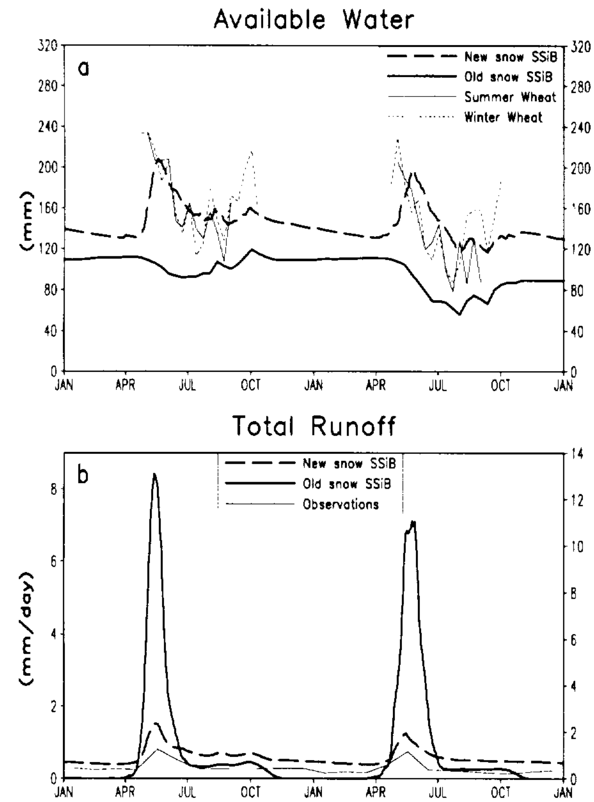

Figure 1: Time-series of area averaged values of a) available water (mm) and b) runoff (mm/day) for the Russia snowmelt region for the new (thick dashed) and old (thick solid) snow-physics schemes in SSiB, and for observations (thin).

The GSWP simulation (forced with ISLSCP data) was again performed, only with SSiB now using the new snow-physics scheme. Comparison to observations as seen in Fig. 1 in the Russia snowmelt region of both simulated soil moisture and runoff shows a significant improvement in the performance of new scheme in SSiB as compared to the old. The soil moisture now exhibits a strong spring re-charge.

In the Northern Hemisphere, the new snow-physics scheme in SSiB caused snowmelt to occur earlier in the season and in better agreement with observations from satellite, as shown in Fig. 2. Although much of the delay in the model of snowmelt is reduced, some still remained. In addition, the earlier melt, together with a warmer soil allowing the melt to infiltrate, produced wetter and warmer soil conditions in the spring as shown in Fig. 3.

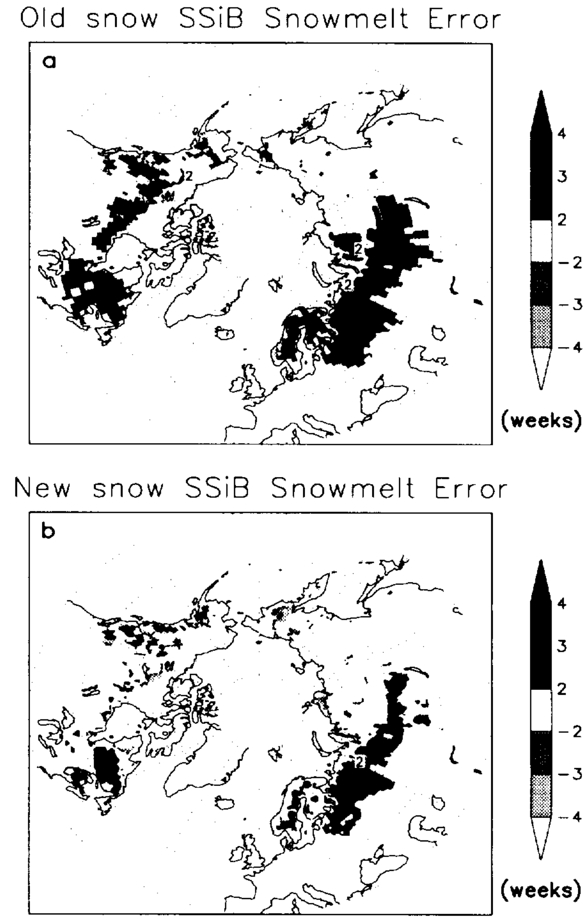

Figure 2: Difference in weeks of snowmelt date of a) old and b) new snow-physics schemes in SSiB minus snowmelt date observations from satellite. Only points with a peak of 100 mm in snow cover during the winter are shown.

3. JJA GCM SIMULATIONS

The 1 June conditions for both the new and old snow-physics schemes in SSiB produced by the GSWP-style simulations were used as initial soil moisture (ISM) data. An ensemble of 90-day JJA simulations for 1987 and 1988 were performed with the GEOS II GCM using both the new ISM/snow-physics scheme in SSiB (NSGCM) and the old ISM/snow-physics scheme (OSGCM).

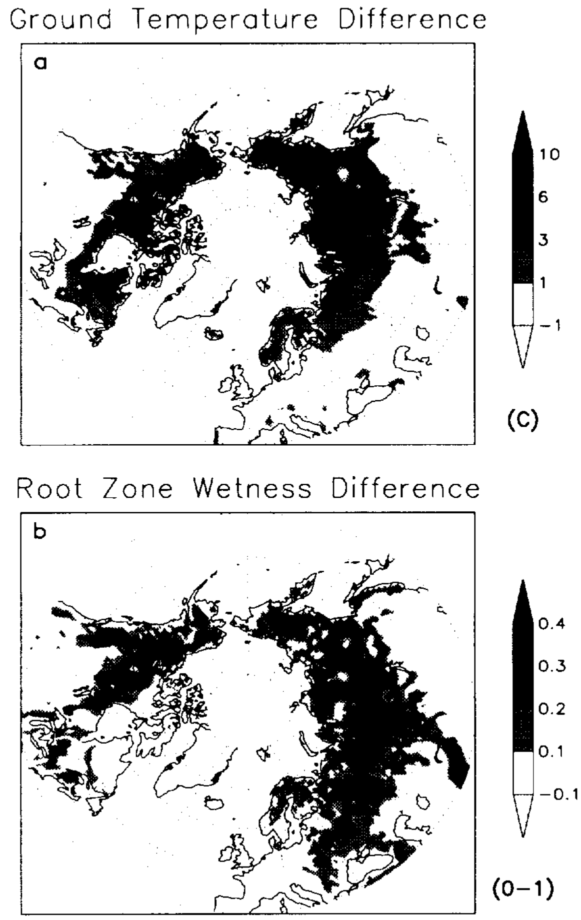

Figure 3: Difference in 1 June conditions of a) ground temperature (C) and b) root zone soil wetness (0–1) for new minus old snow-physics schemes in SSiB.

NSGCM produced higher precipitation (as observed) in northern regions that have large snowmelt, as shown by Mocko *et al.* (1999). NSGCM also produced more realistic land surface hydrology in many snowmelt regions. A statistical significance test (Fig. 4) shows in the top two panels the increase of precipitation and evapotranspiration the new ISM/snow-physics has made. The bottom two panels show that NSGCM also slightly increases the interannual variability of precipitation in both the central U.S. and northern India.

4. CONCLUSION AND FUTURE WORK

The new snow-physics scheme in SSiB more accurately simulates snowmelt, ground temperatures, precipitation, soil moisture, and runoff in areas with cold winters and deep snowpack. Further development of the snow-physics scheme continues in an effort to better simulate the heat conduction and absorption in the snowpack. This is likely to further improve the snowmelt timing and runoff. Early studies have found that the sub-grid distribution of snow is also important, as well as the time-varying density of the snowpack. A temperature profile in the snowpack can also cause earlier snowmelt, as solar radiation is absorbed mostly in the upper section of the snow.

Handling the runoff versus infiltration of snowmelt is also important. In some basins, the new snow-physics scheme has produced an over-correction and now runoff is too low. These basins are generally areas with a high standard deviation of topography. The addition of some snowmelt to surface runoff as a function of topography variance helps to reduce this over-correction. This is discussed in an accompanying paper by Sud and Mocko.

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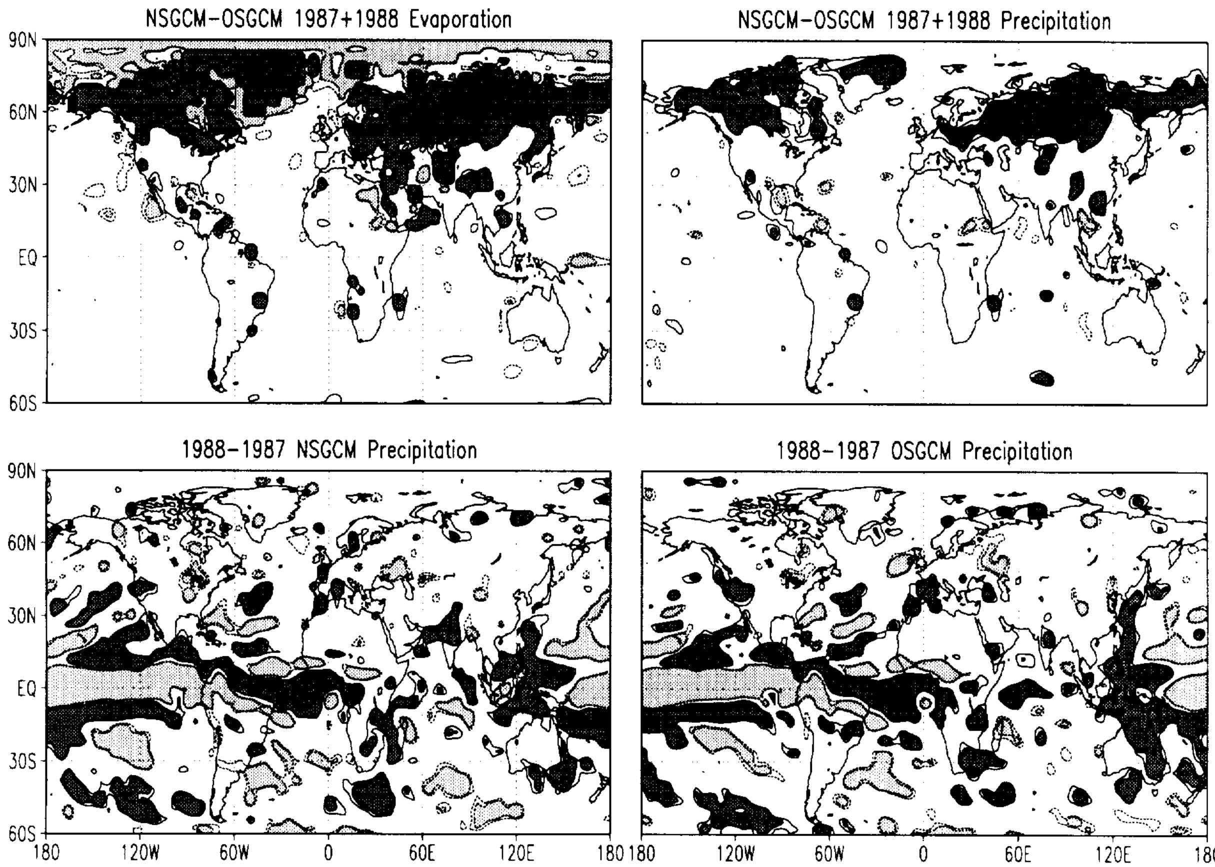

Figure 4: Student's t-test value of effect of (top) NSGCM minus OSGCM on evapotranspiration and precipitation and (bottom) 1988–1987 precipitation for NSGCM and OSGCM. Shaded areas indicated ±95% statistical significance. Dashed lines and light shadings are negative, solid lines and dark shadings are positive.

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