The role of land surface processes in the Indian summer monsoon: a high-resolution GCM study

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Introduction

The role of the land surface in the onset and evolution of the Indian summer monsoon is not completely understood and therefore difficult to simulate in global circulation models. This has become an important issue of climate research as the focus becomes more regional. In this study, we investigate this issue, using NUGAM; a high-resolution atmospheric version of the Hadley Centre's general circulation model HadGEM1. All resolution versions of HadGEM1 fail in simulating the monsoon. NUGAM has a better circulation and more rainfall events, but these are still weak and rare.

1. Resolution and representation of mountains

The experiments considered in this study are atmosphere-only AMIP-type simulations. The formulation is the same, so the only difference between models comes from the resolution (Fig. 1). Better representation of mesoscale mountains plays a role in the organisation of the monsoon convection, especially on the east coast of the Bay of Bengal, explaining the more intense rainfall over northeast India (Xie et al., 2005). Southwest India is also an important region of convergence due to the Western Ghats. In HiGAM and NUGAM, they are well represented, creating more convection and precipitation than in HadGAM in which the mountains are not resolved (Fig. 2).

HadGAM: 150 kms HiGAM: 100 kms NUGAM: 60 kms

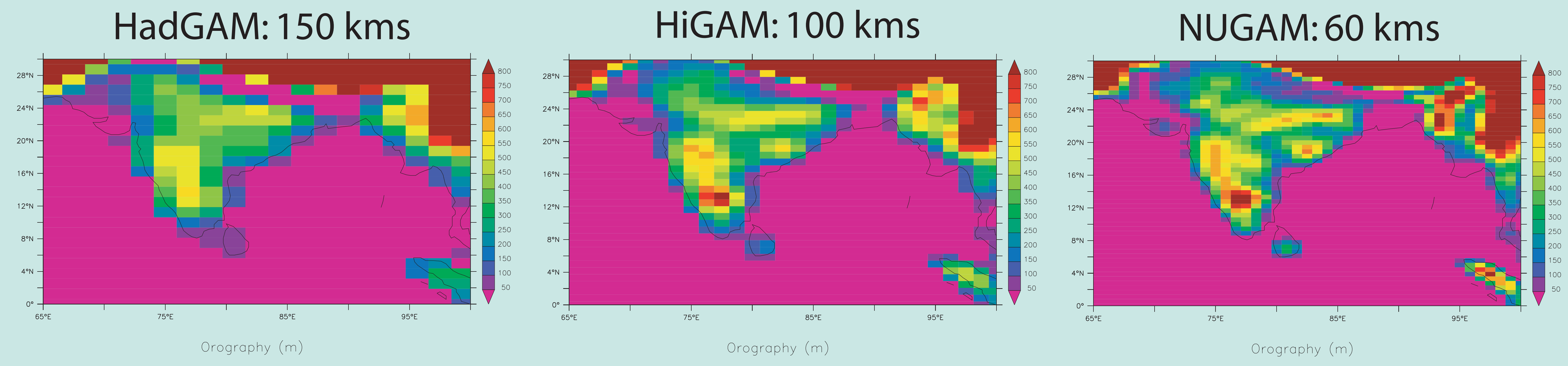

Fig. 1: Orography for HadGAM (left), HiGAM (center) and NUGAM (right)

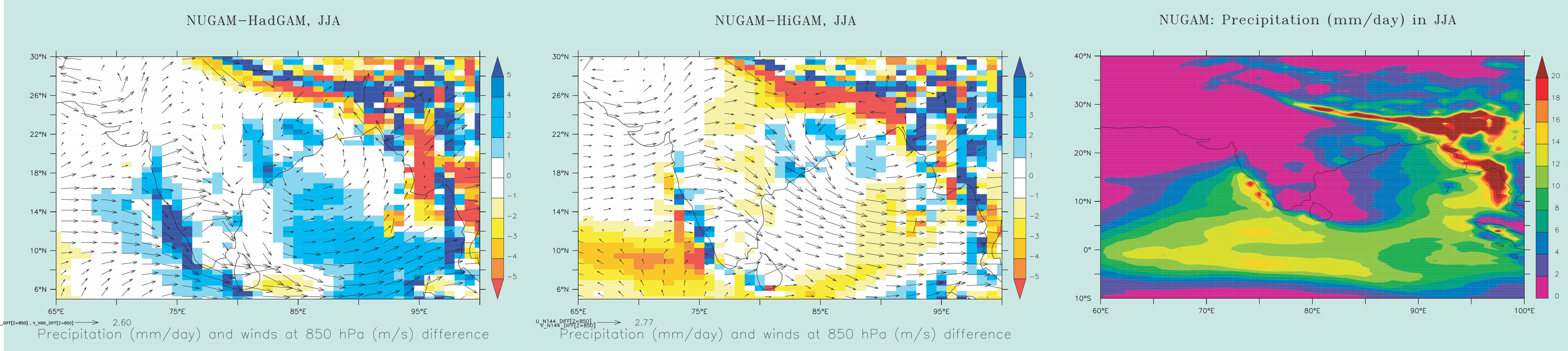

Fig. 2: Precipitation (mm/day) and wind (m/s) differences in summer, averaged over 5 years. NUGAM minus HadGAM (left), NUGAM minus HiGAM (center) and NUGAM (right)

2. Surface initial conditions at different resolutions

Himalayan and Eurasian snow cover and soil temperatures alter the meridional temperature gradient, which determines the direction of the jet over Eurasia. This may have a significant impact on the onset of the monsoon (Becker et al., 2001). NUGAM was initialised with 270 km resolution data, overestimating the snow cover in the Himalayas (Fig. 3), and creating numerical instabilities. This may explain why HiGAM (which started from proper resolution snow cover) has more precipitation over India than NUGAM (Fig. 2). A new set of NUGAM initial conditions, generated by multi-year model spin-up, show a better distribution of snow cover over the Himalayas, albeit still with excessive snow depth and too cold surface and deep soil temperatures.

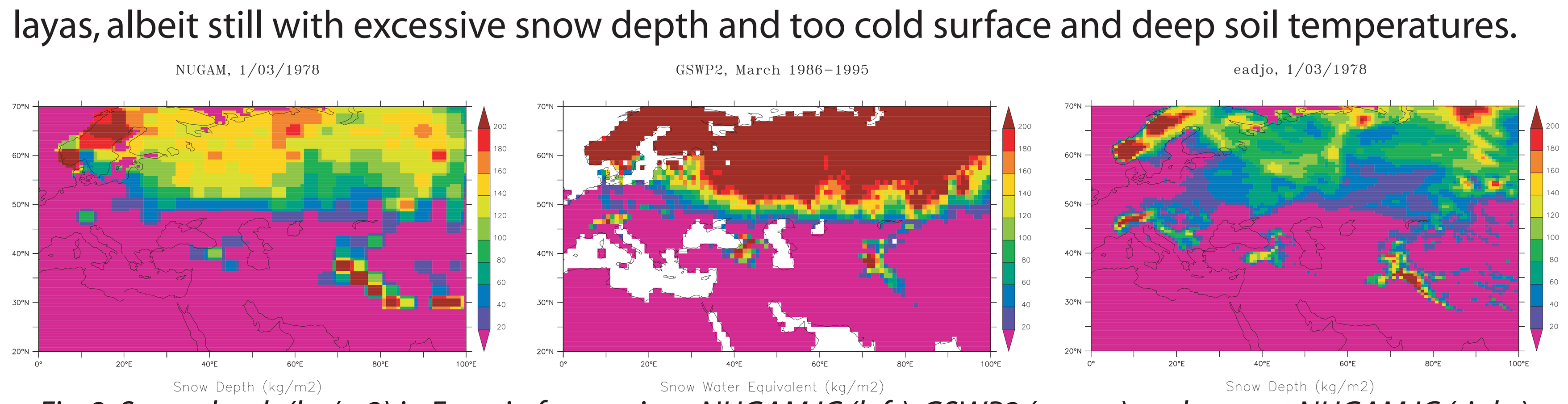

Fig. 3: Snow depth (kg/m2) in Eurasia for previous NUGAM IC (left), GSWP2 (center) and current NUGAM IC (right)

Over Eurasia, the distribution of the snow is similar to GSWP2, but the snow depth is underestimated in the previous and new sets of NUGAM initial conditions. This may have a significant impact on albedo and soil moisture, when the snow starts to melt later in spring.

3. Soil moisture initial conditions

Ferranti et al. (1999) identified a positive feedback between soil moisture and precipitation, which may impact the predictability of the monsoon, pointing to the importance of starting from proper soil initial conditions. In NUGAM, although the Indian soil moisture initial conditions look fine when compared to GSWP2 (Fig. 4), it is starting with too dry soil in terms of the model wilting point (Fig. 5). Soil moisture in all layers is largely overestimated over Eurasia, as GSWP2 has probably not melted all the snow yet.

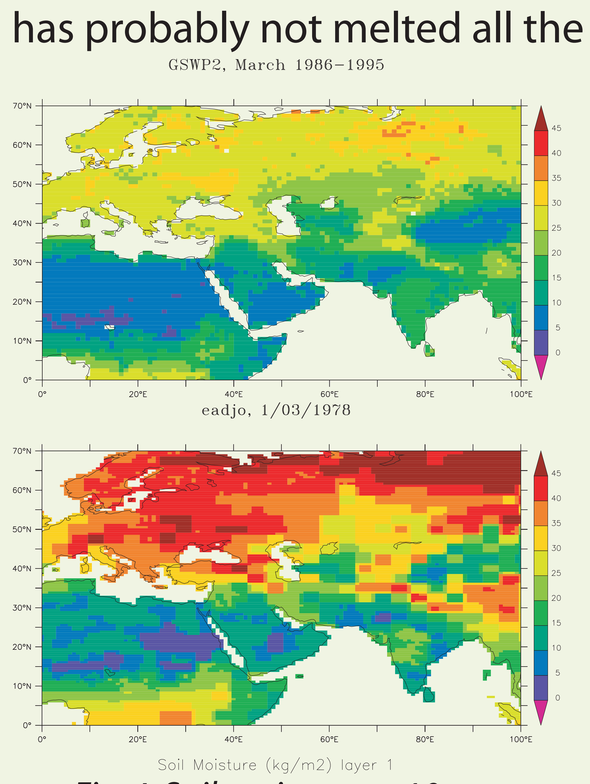

Fig. 4: Soil moisture at 10 cm NUGAM IC (left), GSWP2 (right)

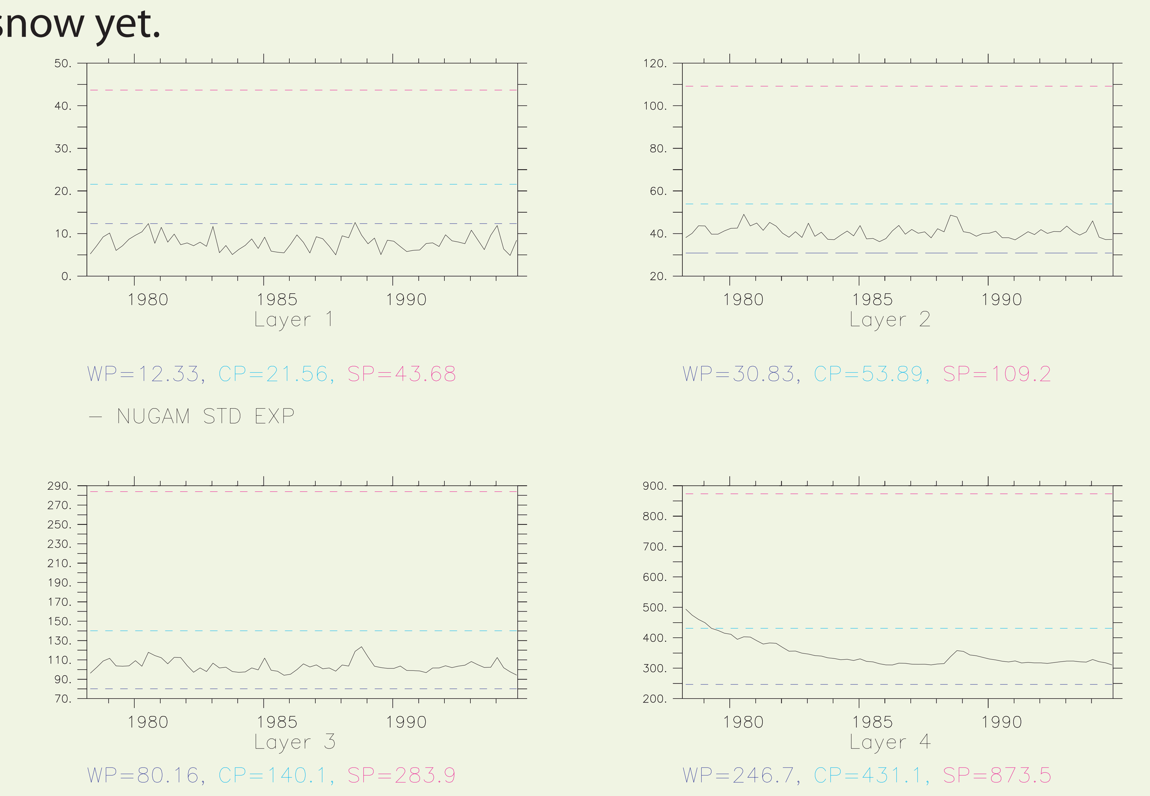

Fig. 5: Seasonal NUGAM soil moisture (kg/m2) averaged over India

4. Soil parameters

Osborne et al. (2004) showed the importance of the representation of soil properties and hydrology for climate feedbacks. It is hard, however, to obtain coherent soil parameters and soil initial conditions, as many uncertainties remain in the existing soil physical parameters. In NUGAM, as well as other resolution versions of HadGEM1, soil parameters are very different from those of more modern datasets, such as the Global Land Data Assimilation System (GLDAS), a recent NASA dataset (Fig. 6). Saturated soil water conductivity (KSAT) and soil porosity, for instance, are very important for simulating soil moisture dynamics. Previous experiments with NUGAM (not shown here) have shown that the soil in India was actually too conductive, allowing the water to drain through the soil layers very quickly.

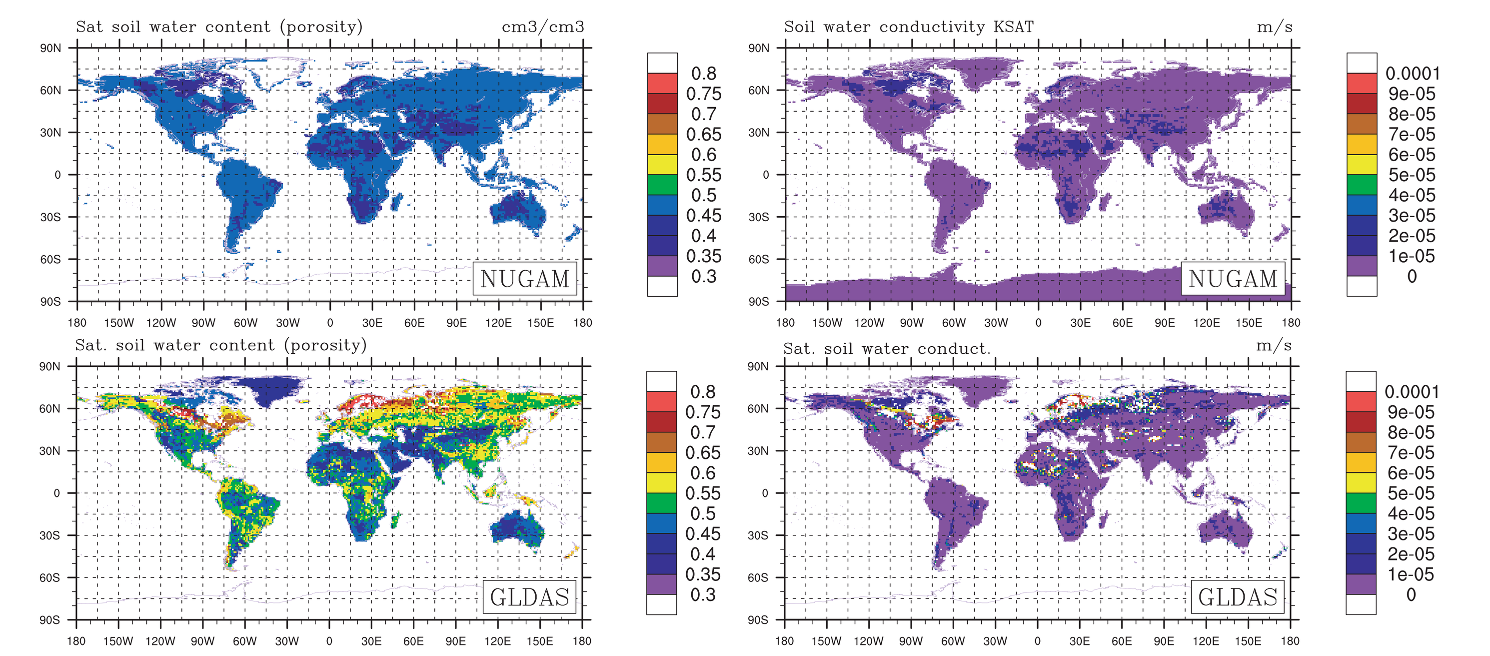

Fig. 6: Soil parameters of porosity and saturated soil water conductivity for NUGAM (top) and GLDAS (bottom)

5. Importance of soil water dynamics for the Indian monsoon

In a first test (SAT CONST EXP, green line), soil moisture is kept saturated over India. Due to high surface temperatures, the excess soil moisture evaporates quite easily, creating large latent heat fluxes (Fig. 7, top). The precipitation in India (Fig. 7, bottom) tends to start earlier than the standard model (black line) and is longer maintained. However, the amount of rain is still too small, which may indicate a weak coupling between land surface fluxes and the local atmosphere, very likely due to lateral transport out of the regional sub-domain.
Fig. 8 shows the strong impact of this test on the circulation over India. NUGAM tends to have too much rainfall over the southwest peninsula and the east coast of the Bay of Bengal. The westerly winds are too strong in North India, bringing dry air over India and the Bay of Bengal. In SAT CONST, most of the rainfall biases are corrected, and the circulation is better.

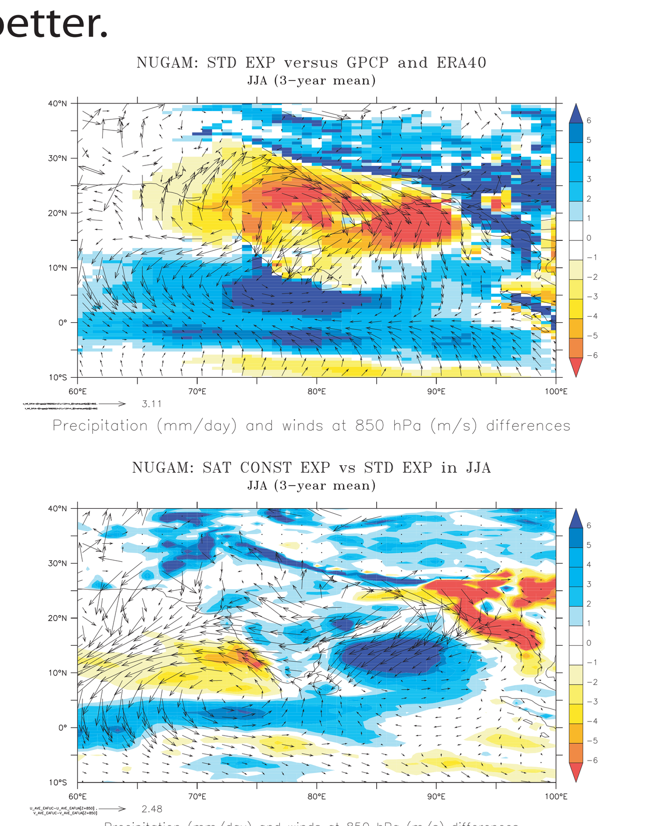

Fig. 8: Differences in precipitation and winds at 850 hPa in summer. STD EXP NUGAM minus observations (top) SAT CONST EXP minus STD EXP (bottom)

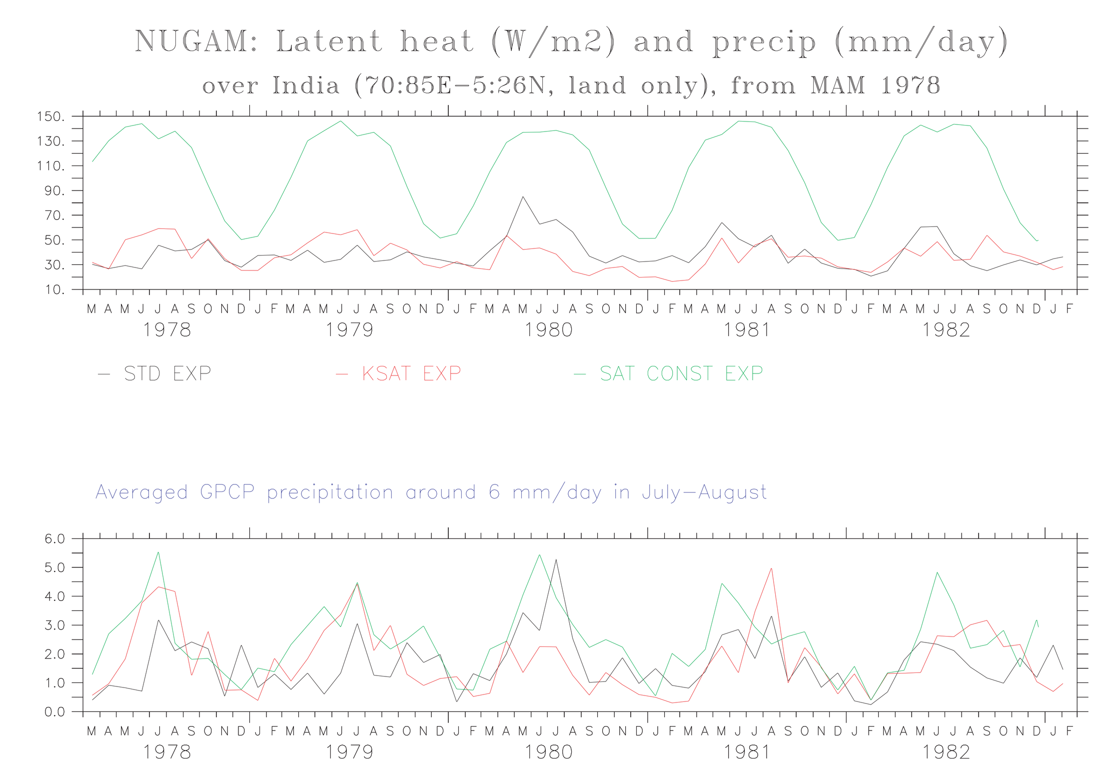

Fig. 7: Latent heat (W/m2) (top) and precipitation (mm/day) (bottom) for standard (black), saturated moisture (green) and alternative KSAT (red) experiments

In a second experiment (KSAT EXP, red line), the saturated soil water conductivity (KSAT) has been decreased. The first two years of the experiment simulate a monsoon over India (Fig. 7, bottom), albeit weak, but with a better onset (April-May). However, soil conductivity, which depends on KSAT but also on soil moisture itself, is now too low and most of the moisture goes into surface runoff, leaving the soil as dry as before. The model tends to come back to the previous equilibrium.

Conclusion

Using a chain of high-resolution climate simulations we have shown that land surface initial and boundary conditions play a role in the simulation of the Indian summer monsoon. Better-resolved mountains help to organise low-level convergence and convection. Other impacts are manifested via land surface processes: snow albedo affects the onset of the monsoon, but also the continental-scale distribution of soil moisture, which may influence the evolution of the monsoon later in the season. To test this hypothesis, we have investigated the role of soil moisture specification and transfer (e.g. by applying soil physical parameters at different resolutions), finding that large changes in latent heat release at the surface are not linearly related to precipitation increases. The SSTs used to drive the model may also play an important role, especially for the distribution of snow cover. Future work will include simulations with climatological SSTs and a full soil physics ensemble.

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