Climate Variability & Predictability CLIVAR World Climate Research Programme

Exchanges

- Scientific Contributions -

Sensitivity of southern African climate to soil-moisture*

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Introduction

Feedbacks from the land surface have long been suggested to play a role in regional climate (e.g. Charney, 1975; Nicholson, 2000). Recently, a number of climate model studies have provided evidence that soil moisture can play an important role in modulating larger-scale forcing of regional climate, particularly in the interior of continental regions of North America (Hong and Kalnay, 2000; Oglesby et al., 2002), North Africa (e.g. Cook, 1999; Douville, 2002; Douville et al., 2001; Nicholson, 2000), and Australia (e.g. Timbal et al., 2002).

Mechanisms driving soil moisture feedbacks on regional climate are related to local moisture cycling, where the land surface can supply a considerable proportion of precipitable water to the lower troposphere, and through alterations of atmospheric thermodynamics and dynamics. For example, Cook (1999), has shown that the African Easterly Jet (AEJ) is primarily a function of temperature gradients magnified by meridional soil moisture gradients in Tropical North Africa; variations in these gradients affect the position and strength of the AEJ and its interactions with precipitation generating mechanisms.

Here we describe preliminary results from a study of the sensitivity of regional climate processes, especially precipitation, to soil moisture perturbations over Southern Africa (SA), using the fifth-generation Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) Mesoscale Model (MM5) (Grell et al., 1994).

Methods and data

We use MM5 coupled with the Oregon State University Land Surface Model (OSU-LSM) (Chen and Dudhia, 2001a; 2001b). MM5 was applied at 60km resolution, running at 120-second time steps, and forced with boundary conditions from NCEP reanalyses for the austral summer 1998/9 (Nov-Feb). This year was unusual in that the evolving Pacific El Niño did not markedly affect precipitation over the Southern Africa (SA) region: rainfall was close to the long term average (Curtis et al., 2001). This was at least partly due to SST conditions in the SW Indian Ocean favouring above-average rainfall.

Three main experiments were performed. In a control experiment, MM5 was run with a "normal" soil moisture that was allowed to vary in response to simulated precipitation. In a second "dry" run, soil moisture in MM5 was fixed at a level 10% above wilting point, effectively preventing moisture fluxes back into the atmosphere. A third "wet" experiment maintained soil moisture at 10% below field capacity, thereby permitting unlimited evaporation to occur.

In all experiments the vegetation and soil parameters were standard to the OSU-LSM; the PX (Pleim and Xiu, 1995; Xiu and Pleim, 2001) planetary boundary layer and Grell (Grell et al., 1994) convective schemes were used. Additional experiments using these same soil moisture conditions, but with alternative convective schemes were also performed, but are not described here. Results were not dependent on the convective precipitation scheme used.

Results

We present results from the "dry" versus "normal" runs only. The differences between "wet" and "normal" runs are generally of opposite sign. Simulations with a permanently dry soil produce the expected differences in surface energy fluxes and temperature. In the dry run, latent heat fluxes over the entire subcontinent are reduced in favour of sensible heating of the ground and near surface atmosphere. The anomalies are largest over the interior of the southern part of the sub-continent. Anomalies of opposite sign occur in a narrow strip along the west coast (Figure 1).

The surface heating over the interior produces a low-mid level heat anomaly of up to 3K and a cool anomaly above about 500hPa. The mixing ratio is generally reduced near the surface, but is increased at higher

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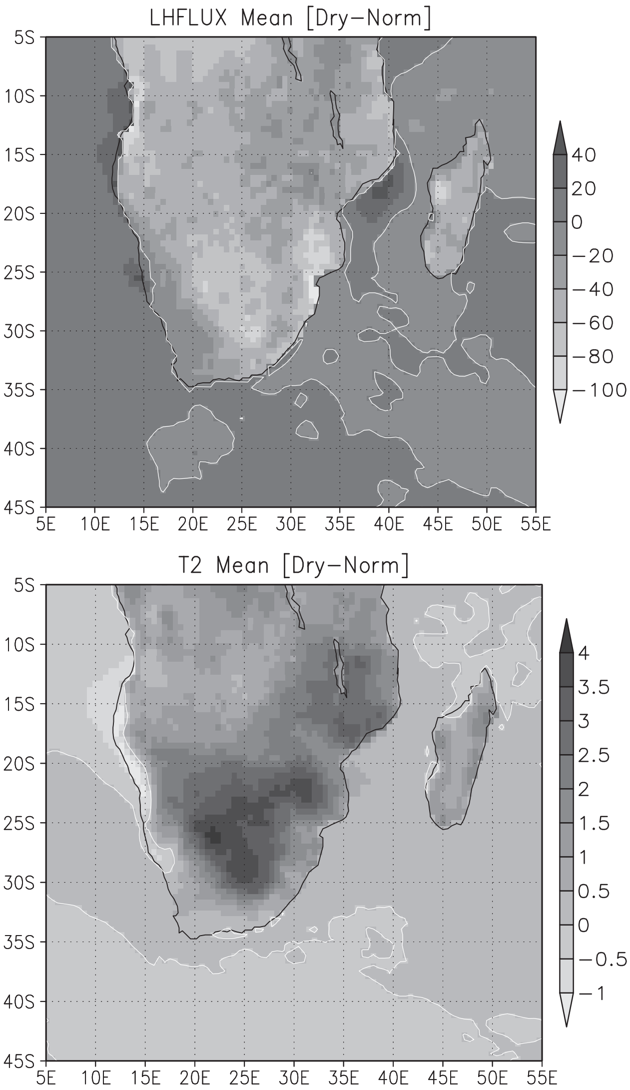

Figure 1: Nov-Feb mean latent heat flux and surface temperature anomalies forced by a "dry" soil (anomalies relative to the "normal" run).

levels, driven by an enhanced low level moisture flux from the N and E associated with an anomalous cyclonic circulation around the core of the surface heating anomaly (Figure 2). This enhanced Q-flux produces increased horizontal moisture convergence over the areas where rainfall has increased.

Positive rainfall anomalies occur in a broad NW-SE band stretching from the north of the interior heating anomaly into the SE Indian ocean (Figure 3). Rainfall is reduced to the west of the area of heating, along the entire west coast, in the Mozambique channel, and to the north of Madagascar. The anomalies over land are predominantly due to changes in convective rainfall, while over the ocean they are from a combination of convective and non-convective rainfall. Areas with enhanced rainfall are associated with a change in the probability distribution of rainfall towards larger totals.

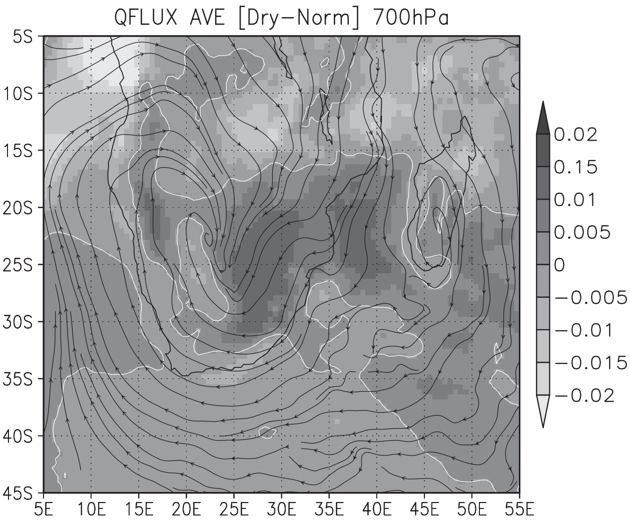

Figure 2: Nov-Feb 700hPa Q-flux (shaded) and wind-stream anomalies forced by a "dry" soil.

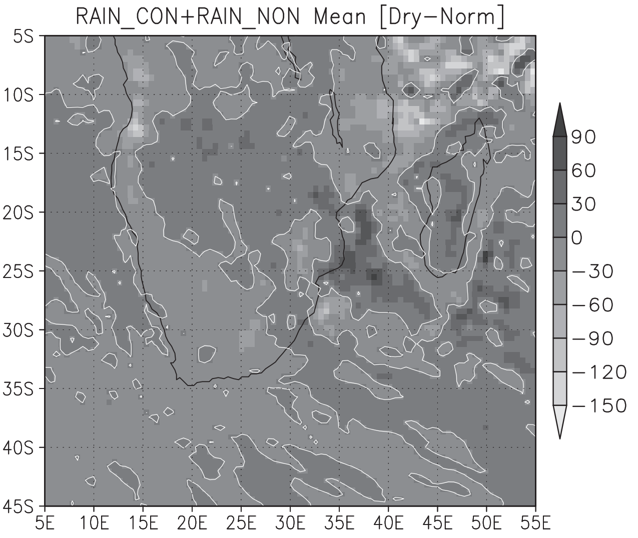

Figure 3: Nov-Feb rainfall anomalies forced by a dry soil.

Processes producing enhanced precipitation

Despite effectively shutting-off local soil moisture recycling over southern Africa, rainfall is enhanced over a large part of the region. This appears to be for at least two reasons. First, the surface heating increases the environmental lapse rate, and hence the chance of instability and convective rainfall; this is confirmed through analysis of total static energy profiles (not shown). Second, the anomalous moisture convergence arising from the low level cyclonic circulation anomaly feeds the conditional instability, particularly to the N and E of the heat low.

The rainfall response indicates an enhanced Hadley circulation and increased frequency of tropical-temperate cloud bands, which are the dominant mode of poleward energy and momentum transfer in the southern African sector. (Todd and Washington, 1999).

These results suggest that there is potentially a negative feedback operating in soil-moisture–atmosphere interactions over the region. Rather than causing drought conditions to persist as has been noted for the US (Hong and Kalnay, 2000), the proximity of southern Africa to moist maritime air means that surface heating and reduced local recycling of moisture are compensated by advection of moisture from the NE. This moisture is then available for convection in conditions that favour instability. These processes may be enhanced by a shift or phase-locking of tropical-temperate cloud bands over the continent, in preference to their preferred position further east.

This leads us to speculate that the observed location of tropical convection and tropical-temperate cloud bands depends on the distribution of heating resulting from land-surface conditions, which in turn is derived from feedbacks from the basic state of the regional climate.

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