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RESEARCH ARTICLE

Land use changes and regional climatic impact over Sudd region

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Abstract

The expansion of urbanization leads to a drastic changes in land-use. The impact of land-use change on microclimate is inevitable, however its impact on regional climate is questionable. The Southern Sudan wet-land/swamps (Sudd) is considered the largest wet-land in Africa. Huge project like Jongli canal is intended to save the water wasted in such wet-land. This project results in dryness of the 30% of the Sudd. The question; Does the dryness of Sudd has any mirco or regional climatic impact ? is important for any future development plan. This question has been explored by using the ICTP Regional Climate Model RegCM3. Two simulations are performed to test the sensitivity of land-surface/atmosphere interaction to the land use change; the control run with the original land use and drain run by changing the whole Sudd wet-land (swamps) to be short grass land. Analysis of climatology of the seasonal cycle for precipitation shows that, the sudd region is the most sensitive region in the whole domain to the land use change. Precipitation changed by only 14% relative to the control run. Temperature is increased by 4 C in dry season and 0.5 C in wet season. However, outside this region no significant change has been observed over the whole domain. This result is very encouraging any development plan in the Sudd region to save the water resources in that region.

1. Introduction

Nile flows over 6500 km, it flows over the land of 10 countries. Nile provides the main source of water for such countries. Nile flows from 2 degrees south of equator to 32 degrees north of equator, such long distance span many climatic zones, from tropical climate to midlatitude climate. Basically Nile originated from the Ethiopian and Tropical highlands.

Sudd swamps is one of the largest swamp area in the world, the loss of Nile water across such swamps considered a major problem for the hydrologist who wants to mange the water resource in the future (Mohamed el al. 2005b).

Wet-land is a supplier for the relative humidity for the region, which they covered. The humidity recycling of wet-land contribute to the local and regional precipitation by different percentage. Due to urbanization and progressive development projects, wet-land areas going to decrease and become more dryer. This drainage processes will affect the local (micro) and regional climatology.

Strategic planner, suggest something like a canal to redirect the water from the Victoria lake across such Sudd area, such man made canal requires the dryness of Sudd swamp. However, such dryness of the swamp raises the question of the impact on the local climate of the region due to such land characteristic changes. **What is the climatic impact of drying the Sudd swamp on local climate?** We mean by local climate, the climatology of temperature, precipitation and moisture in the area of Sudd and its neighbors.

Land surface interact with the atmosphere via the exchange of surface fluxes (moisture, latent heat, sensible heat and momentum) any changes in those fluxes has direct impact on the feedback mechanisms. Drying of wetland produces a positive feedback i. e., decreasing of the moisture flux and sensible heat flux reduces the convection processes,

which inhibit the precipitation (Eltahir 1998). On the other hand, drying of wetland may produce a negative feedback, namely, increasing atmospheric temperature, increases the convection, which enhance the precipitation (Giorgi 1996). Regional climate models (RCMs) usually used to simulate such feedback mechanisms. RCMs can provide a detailed mechanism of land-surface atmosphere interaction by changing the surface boundary conditions and redo the simulation to calculate the difference between the original simulation (control run) and simulation scenario.
The recent study of land use change over eastern Africa shows the positive feedback mechanism (Otieno 2012) as a plausible mechanism to understand the reduction in precipitation due to deforestation.

The next section is the Methodology used to tackle the question, and include brief description of RegCM3, and the methods of analysis. Section 3 shows the results of comparison between the control run and drain run. We conclude with section 4.

2 Methodology

2.1-Numerical simulation using RegCM4

The model used in this experiment is the International Center for Theoretical Physics (ICTP) regional climate model, Version 3 (RegCM3) (Pal et al. 2007, Elguindi et al. 2011, Giorgi et al. 2012). RegCM3 is a 3-dimensional primitive equation atmospheric model based on the NCAR/Penn state mesoscale model, Version 5 (MM5; Grell et al. 1994). Thus, it is a compressible primitive equation model currently based on hydrostatic dynamics only. The model uses a terrain-following (sigma-pressure) vertical coordinate system. Large-scale precipitation parameterization is based on the subgrid explicit moisture scheme (SUBEX; Sundqvist et al. 1989, Pal et al. 2000), while parameterization of cumulus convection is based on the Grell convective scheme (Grell 1993), with the Fritsch & Chappell closure assumption. The radiative transfer scheme is derived from the NCAR CCM3 (Kiehl et al. 1996) package, and the land scheme is based on the biosphere--atmosphere transfer scheme (BATS 1e; Dickinson et al. 1993). The boundary layer physics is based on the nonlocal scheme of Holtslag et al. (1990). A detailed description of the RegCM4 model is available in (Giorgi et al. 2012 and Elguindi et al. 2011).

The model simulation start from 1998 up to 2005 using ERA-Interim data with 1.5° X 1.5° resolution (Simmons et al. 2007, Uppala et al. 2008) as initial and boundary conditions.

The land surface model used to simulate the land-surface-atmosphere interaction is BATS, which is a surface package designed to describe the role of vegetation and interactive soil moisture in modifying the surface-atmosphere exchanges of momentum, energy, and water vapor (see *Dickinson et al.* [1993] for details). The model has a vegetation layer, a snow layer, a surface soil layer, 10 cm thick, or root zone layer, 1-2 m thick, and a third deep soil layer 3 m thick. Prognostic equations are solved for the soil layer temperatures using a generalization of the force-restore method of (*Deardoff* 1978). The temperature of the canopy and canopy foliage is calculated diagnostically via an energy balance formulation including sensible, radiative, and latent heat fluxes.

BATS land surface model has 20 land-use categories. The wet-land is denoted by Bogs and marsh land category which has land cover number 13. In the Drain run we replaced this land use category by the short grass category, which has land cover number 2.
The sensitivity experiment comprise of two runs (1) the control run (CTL), which has the original distribution of the land cover category, (2) the drainage run (DRA), which has the new configuration for the land cover of Sudd area to be short grass instead of wet-land. In the DRA run we have changed pixel by pixel the land use category from wet-land to short grass this change has a corresponding change in other parameters. Table 1 shows the differences between short grass and wet-land for some surface parameters which affect radiation balance.

	Roughness length	Min. Stomatal Resistance	Albedo < 0.7 um	Albedo > 0.7 um
Wet-land	0.03	45	0.06	0.18
Short grass	0.05	60	0.1	0.30

2.2-sensitivity analysis

The experiment based on changes in the land use category of the wet-land to be short grass of 100% of the Sudd area. These changes, produce a change in land-surface fluxes (e.g latent heat flux and sensible heat flux). Those fluxes affect air temperature and humidity, hence affect the precipitation. The hydrological annual cycle of the two cases have been analyzed to see how drainage could affect the hydrological budget. However, to see how the changes have regional and local impact, the sensitivity factor map have been produced for temperature and relative humidity.

3 Results

The experiments have been designed to have the Sudd area in its centre. The model domain is large enough to cover most potential regions, which could be affected by the Sudd land use changes Fig. 1. Land-use map is shown in Fig. 2 and the Sudd area are surrounded by a black rectangle.

Figure 1: Model domain

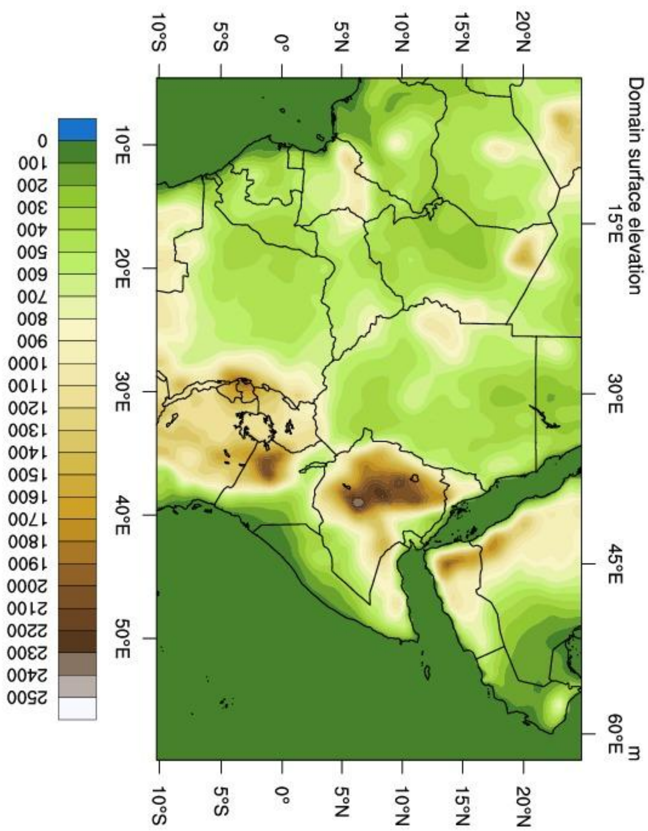
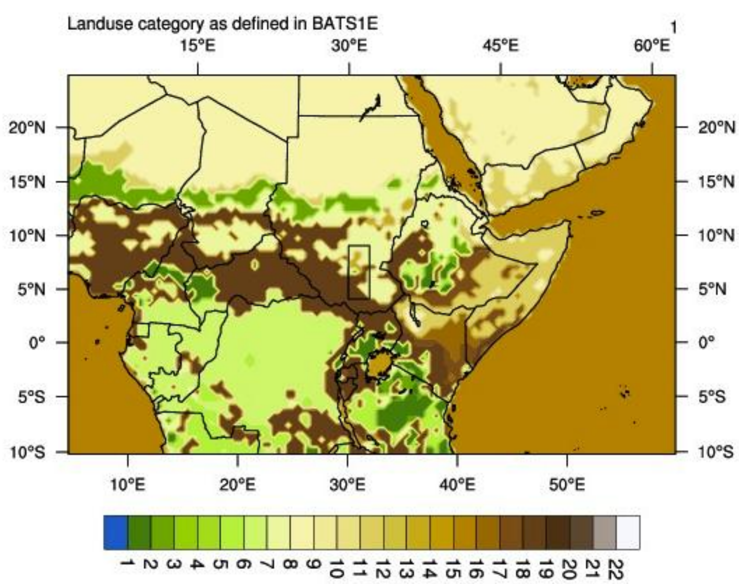


Figure 2: Model land use categories, the rectangle shows the area of Sudd region.

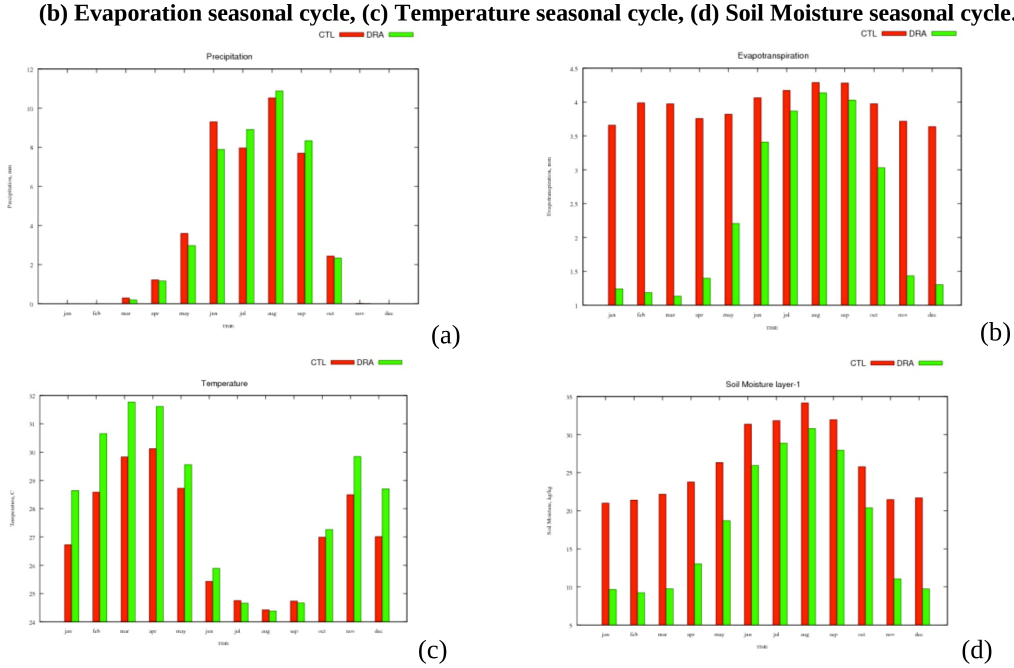


3.1-Time series analysis

To investigate the impact of Sudd land use change over the local climate and regional climate, the model domain has been divided into three sub-regions; (1) Sudd region shown in Fig. 2, (2) North Equatorial Africa (NEA) (0°-10° N), and (3) South Equatorial Africa (SEA) (-5° S-0°).

Figure 3 shows the basic surface variables (i.e. Precipitation, Evapotranspiration, surface Temperature, and soil moisture) that affected by the land use change. The feedback processes of land-surface/atmosphere interaction interconnect those variables. The DRA precipitation is less than CTL precipitation at the onset of the wet season (March-April-May-June), and become more than CTL precipitation by 13 % in (July-August-September) Fig. (3a). For Evapotranspiration and Soil moisture the DRA run is always less than CTL run, which is reasonable due to the dryness of the soil Fig. (3a, 3d). However, Temperature of the DRA run is much higher than CTL run by 2 to 3 degrees most of the year except (July-August-September), Fig. (3c). Generally the positive feedback mechanism is the plausible explanation for precipitation change due to soil moisture changes. However, for this experiment the negative feedback mechanism has to play a role. Positive feedback mechanism is very clear in dry season and the onset of the wet season, where the soil moisture deficit result in increase in sensible heat flux, which leads to a higher surface temperature and substantial decrease in evapotranspiration, which result in decrease in precipitation. In July-August-September, precipitation of DRA run is higher than CTL run. This could be explained by a negative feedback mechanism. The evapotranspiration and soil moisture deficit in July-August-September is not so large compared to dry seasons, however, it is sufficient to induce a local moisture conversion in addition to the large scale moisture source come to the region. Soil moisture conversion results in more precipitation over the Sudd region.

Figure 3: Climatology (1998-2005) of the Seasonal cycle averaged over the Sudd region; (a) Precipitation seasonal cycle, (b) Evaporation seasonal cycle, (c) Temperature seasonal cycle, (d) Soil Moisture seasonal cycle.



To analyze the regional impact of Sudd land use change we first focused on North equatorial Africa (NEA). Fig. 4 shows the climatology of the seasonal cycle for Precipitation (4a), Evapotranspiration (4b), surface temperature (4c) and soil moisture (4d). North Equatorial Africa is characterized by two rainy seasons (i.e. short rain and long rain). Generally there are no significant differences between the DRA run and CTL run in that region. However, DRA run shows an increase in precipitation in April by 5%, August by 12 % and October by 5%. For soil moisture and evapotranspiration DRA run and CTL run show a good agreement except this odd months.

The second region of interest is Southern Equatorial Africa (SEA). Fig. 5 shows the climatology of the seasonal cycle for Precipitation (5a), Evapotranspiration (5b), surface temperature (5c) and soil moisture (5d). South Equatorial Africa is characterized by two rainy seasons (i.e. short rain and long rain). Generally there are no significant differences between the DRA run and CTL run in that region. However, DRA run shows an increase in precipitation in March by 2%, May and June by less than 2 % and November by 11%. For soil moisture and evapotranspiration DRA run and CTL run show a good agreement except these odd months.

Figure 4: Climatology (1998-2005) of the Seasonal cycle averaged over the North Equatorial Africa (NEA) region; (a) Precipitation seasonal cycle, (b) Evaporation seasonal cycle, (c) Temperature seasonal cycle, (d) Soil Moisture seasonal cycle

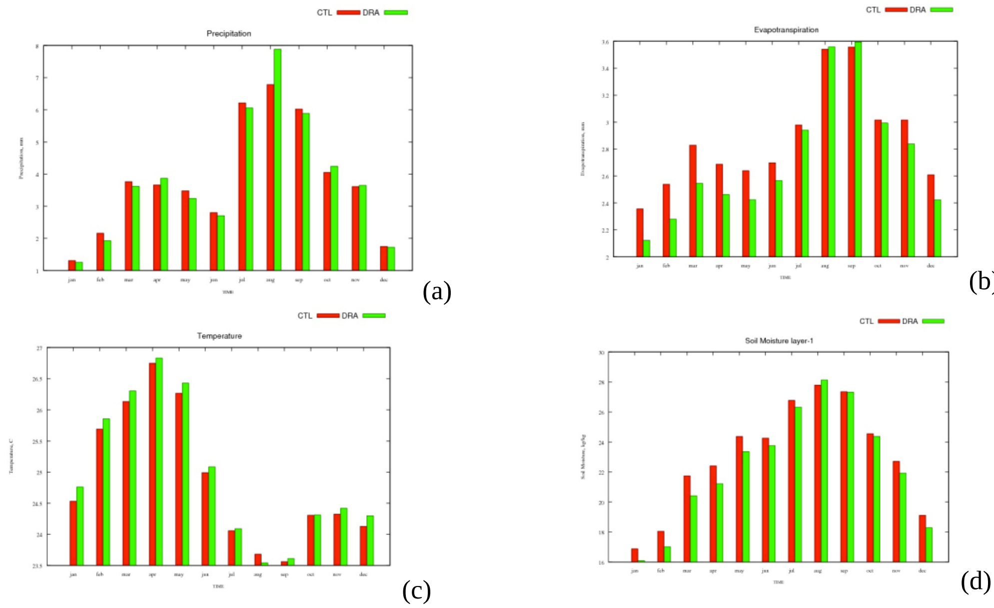
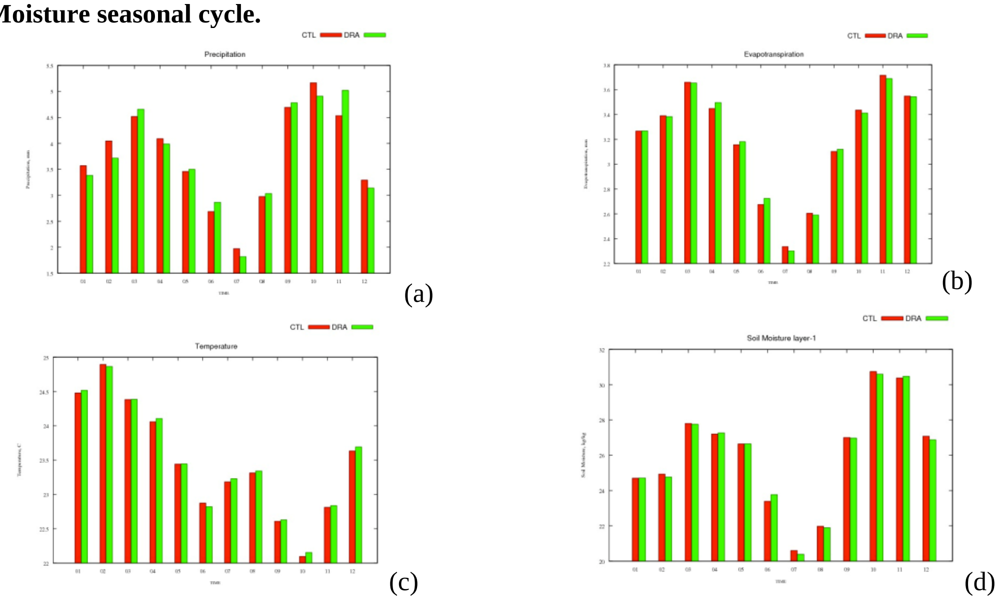


Figure 5: Climatology (1998-2005) of the Seasonal cycle averaged over the South Equatorial Africa (SEA) region; (a) Precipitation seasonal cycle, (b) Evaporation seasonal cycle, (c) Temperature seasonal cycle, (d) Soil Moisture seasonal cycle.



3.2-Spatial and seasonal Sensitivity analysis

The seasonal cycle of precipitation, evapotranspiration, temperature and soil moisture have a local (micro) and regional climatic impact. This section will discuss the central question of this report "**to what spatial scale does the land use change has a significant impact?" or in other words does Sudd land use changes has a regional climate impacts?**

The adapted method to measure the significance of change is the division of the differences between the control run (CTL) and the drain run (DRA) by the standard deviation of the CTL run for the years (1998-2005), namely ($\Delta T/2\sigma_T$). The ratio $\Delta T/2\sigma_T$ is the measure of statistical significance of the mean (ΔT) against the natural variability in the 7-years record (Mohamed et al. 2005).

3.2.1 Temperature difference and normalized standard deviation

The reduced evaporation over Sudd region in DRA run results in increase in sensible heat flux, which in turn increase the 2 m temperature between 2°C to 4°C indry season in the middle of the Sudd, and less than 0.5°C beyond the Sudd region (Fig. 6). However in wet season, DRA run does not affect so much the evaporation over Sudd region. The 2 m temperature differences reach a maximum of 1°C outside the Sudd region (Fig. 6). Does such differences is significant? The significant charts of temperature differences are the division of ΔT by 2σ of standard deviation to account for 90% of variability. Fig. 7 shows the significant charts of temperature differences and shows no significant impact outside the Sudd region, given that, the significant change should be greater than 1.

3.2.2 Mixing ratio difference and normalized standard deviation

The surface Relative Humidity difference between the DRA run and CTL run for the wet seasons and dry seasons are shown in Fig. 8. The impact of Sudd land use change is more pronounced over the Sudd itself even the far neighbors. The largest differences are in dry seasons (DJF and MAM) up to 80%, however, the least differences are in wet seasons (JJA and SON). This differences are also clear over western Sahel and a pronounced increases of surface relative humidity over Congo basin which is very similar to results of (Mohamed 2005a).

Is such difference significant? The significant charts of surface relative humidity differences are the division of ΔRH by 2σ of standard deviation to account for 90% of variability. Fig. 9 shows that, most of region has not any significant change except the Sudd region itself. Dry season shows the most sensitivity to wet-land drainage.

Figure 6: The 2m Temperature difference between DRA run and CTL run for the four seasons.

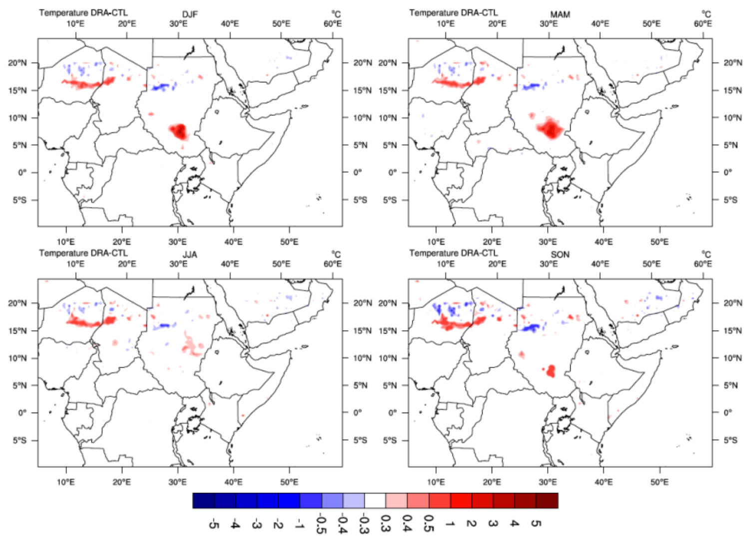


Figure 7: The significant charts for 2m Temperature for four seasons

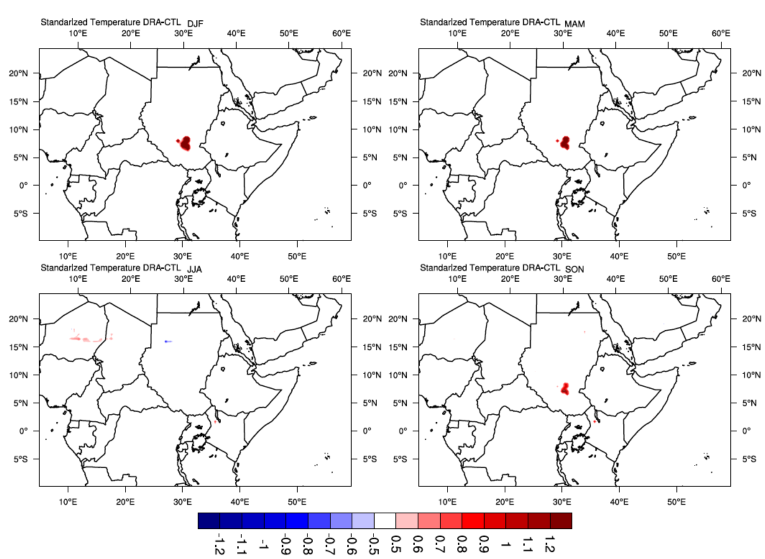


Figure 8: Surface Relative Humidity difference between DRA run and CTL run for four seasons

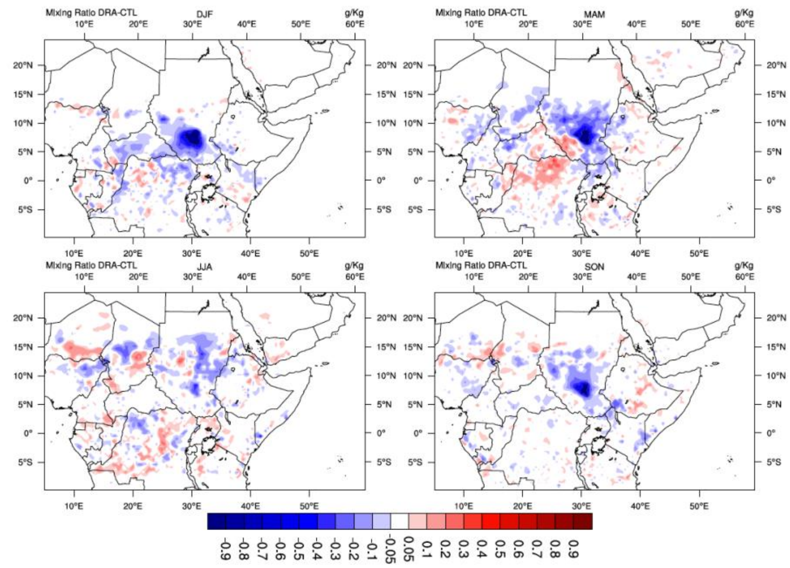
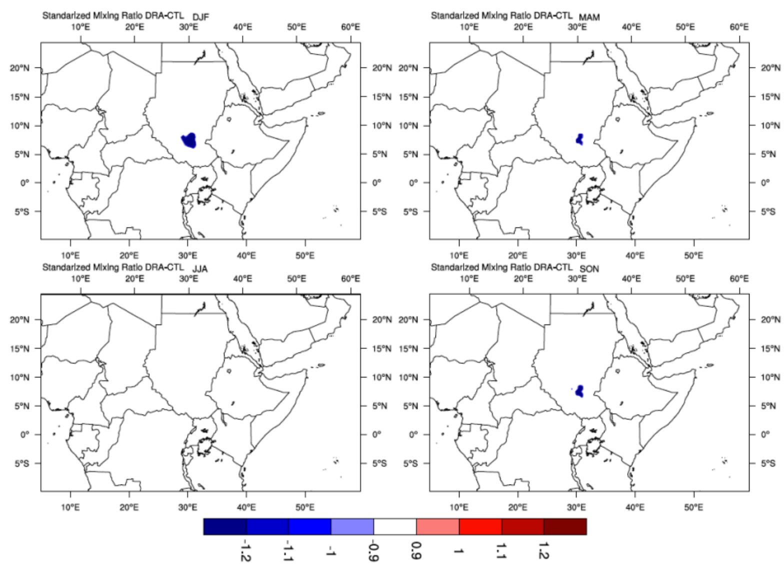


Figure 9: Significant chart for the surface Relative Humidity for four seasons.



4 Summary and Conclusion

Due to continuous development and increasing demands for natural resources in rural region in southern Sudan, the impact of land use change on climate become important issue. To investigate the local and regional impact of land use change of Sudd region we have conducted climate simulations using ICTP-RegCM3 model.

The first simulation is the control run simulation (CTL), which has a default configuration for surface boundary conditions (i.e. the true land use and vegetation cover). The second simulation is the drain simulation (DRA), which assumes a change in land use of the Sudd region to be short grass land instead of wet land.

The domain has been divided into three region, Sudd region, Northern Equatorial Africa, and Southern Equatorial Africa. To study the local and regional impact of the land use change, the model has been run for seven years (1998-2005).

The analysis of the climatology of the seasonal cycle for Precipitation over the Sudd region shows that, precipitation has been increased by 13 % at the peak of the wet season. However, precipitation has been increased by 5% on the average for the wet seasons in the NEA and SEA regions.

The significant analysis has been performed to show the significance of such changes on local and regional scales. The Sudd region is the only region, which has significant change in surface temperature and relative humidity only in the dry season. However, most of the region including southern Sudan, Congo basin and Kenya did not show any significant changes for temperature and relative humidity.
The expected Sudd dryness due to Jongli canal is only 30% at most. This study shows that even by 100% change of Sudd land use change from wet-land to short grass has not any significant climate impact locally or regionally.

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