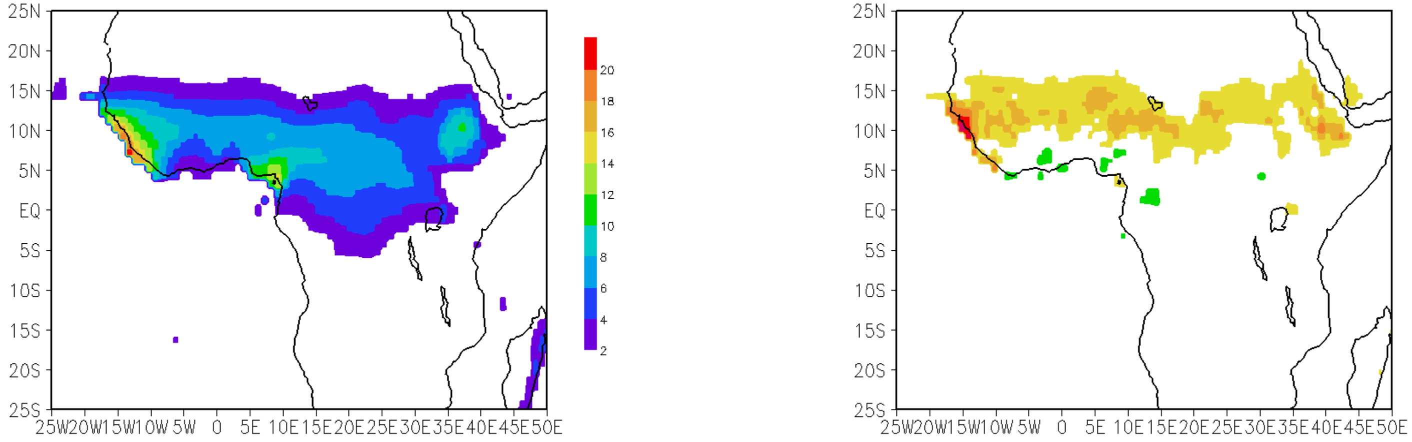
Ocean warming and late 20^{th} century Sahel droughts
A regional modeling study

Samson M. Hagos and Kerry H. Cook

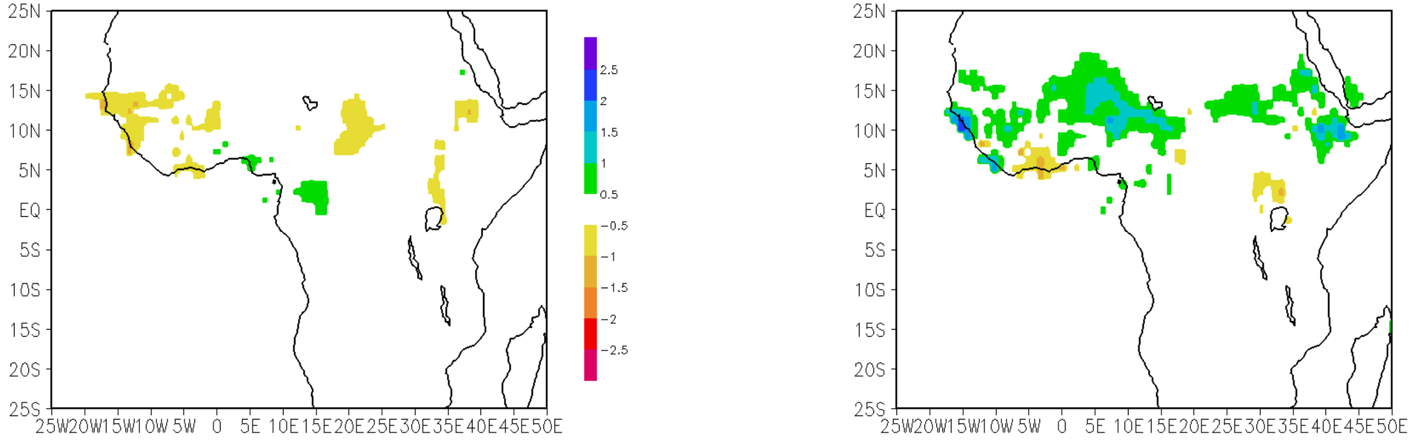
Cornell University
March 20 2007

Introduction



(a) CLIM

(b) 1980s-CLIM



(c) 1990s-CLIM

(d) 1990s-1980s

JAS Precipitation (mm/day) from CRU TS 2.1 (a) Climatological (1950-2002) average, (b) 1980s minus climatological, (c) 1990s minus climatological and (d) 1990s minus 1980s.

Background:

- Land use changes and albedo-precipitation feedback (Charney 1977).
- Statistical and Modeling links between Sahel precipitation and Tropical Atlantic SSTs (Folland et al. 1986, Rowell et al. 1995, Hoerling et al. 2006). Modulation the latitudinal position of the ITCZ.
- Global SSTs, primarily Indian ocean warming (Giannini et al. 2003, Bader and Latif 2003, Lu and Delworth 2005). Introduction of subsidence over the Sahel.

Simulation

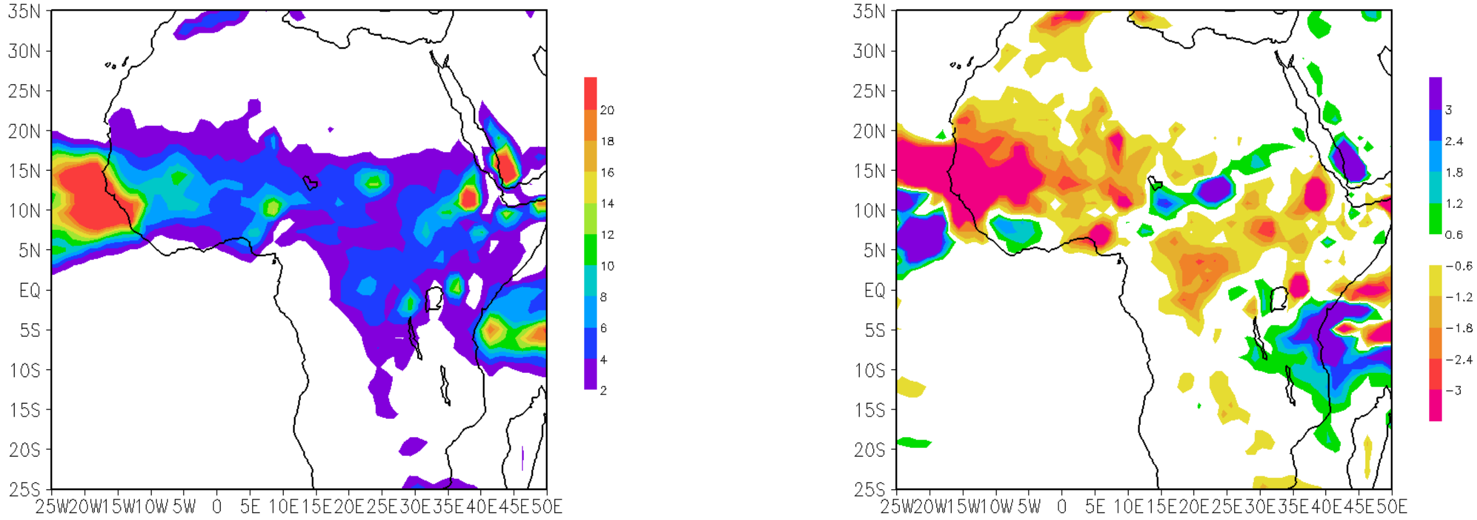
- Regional climate model adapted from PSU/NCAR MM5 (V3). Kain-Frisch convection, NOAH-LSM, MRF PBL and CCM2 radiation schemes.

- Rectangular domain bounded by 47^0E, 102^0W, 47^0S and 47^0N. 135kmx135km grid-size and 23 vertical levels, $\triangle t =$ 90sec.

- Initial conditions and SSTs from NCEP/NCAR reanalysis.

- Seven experiments, CTL (50-year mean SST), ATL+IND80s, ATL+IND90s, IND80s, IND90s, ATL80s, ATL90s. Annual SST cycles are produced by averaging over respective decades.

Precipitation response to decadal SST variations

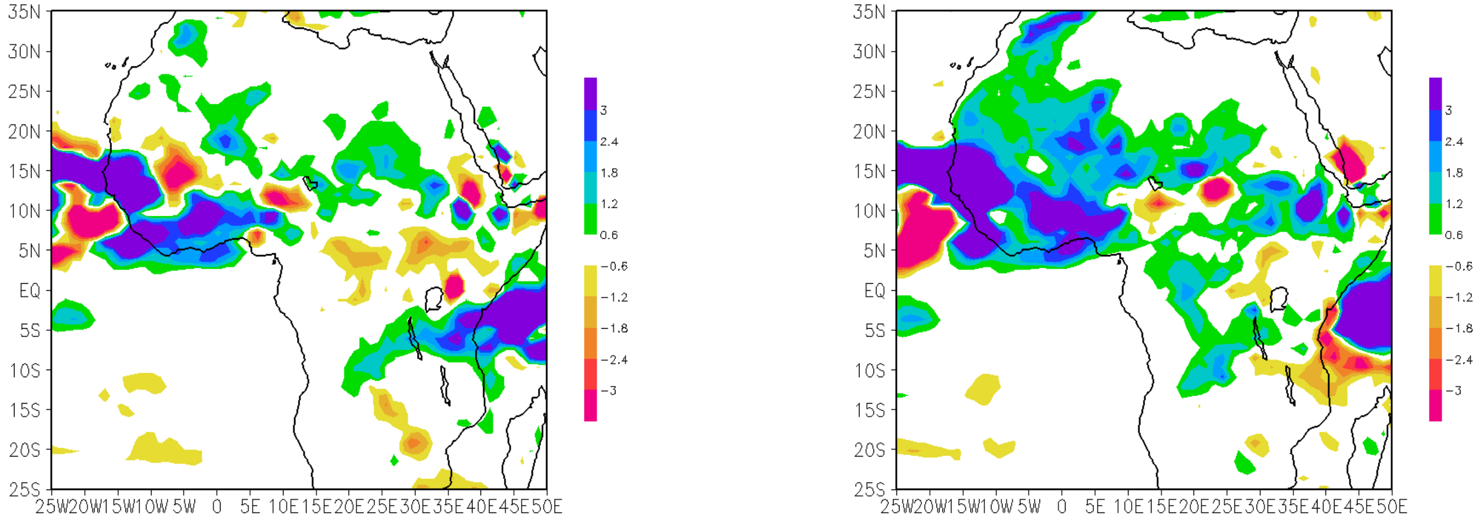


(a) CTL

(b) ATL+IND80s - CTL

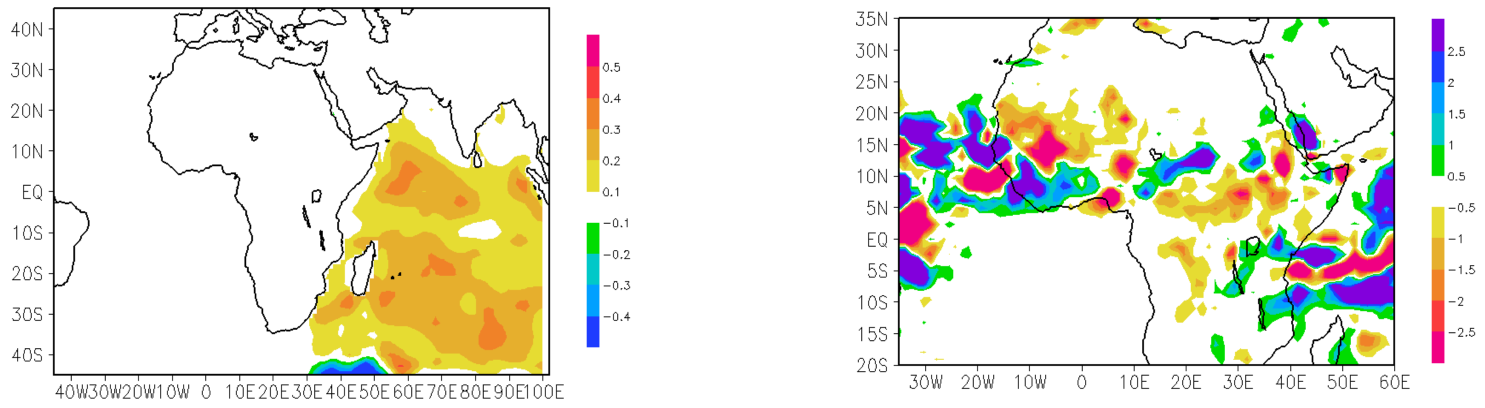
(c) ATL+IND90s - CTL

(d) ATL+IND90s - ATL+IND80s



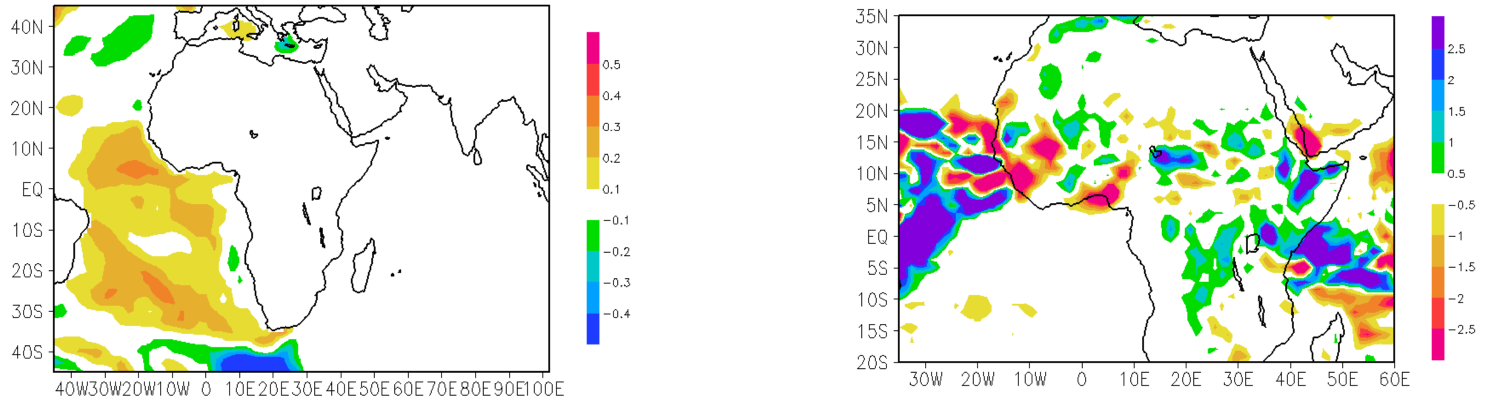
JAS Precipitation (mm/day) from the RCM (a) Control (with 1950-2002 mean SST), (b) 1980s minus control, (c) 1990s minus control and (d) 1990s minus 1980s.

Response to regional SST variations



(a) SST IND80s-CTL

(b) PCP IND80s-CTL

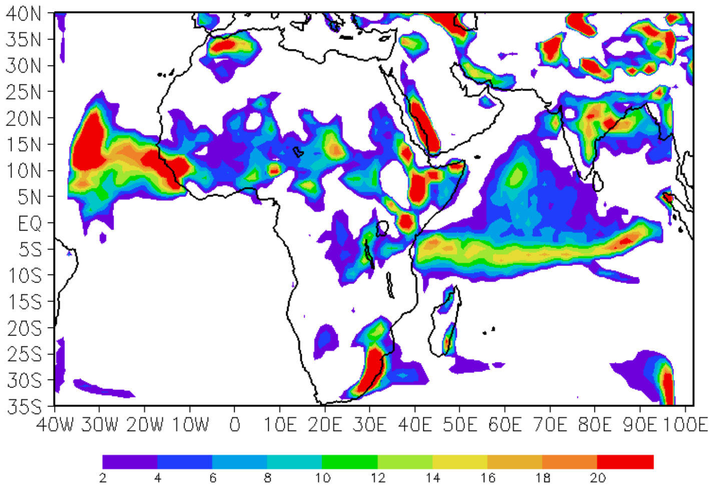


(c) SST ATL80s-CTL

(d) PCP ATL80s-CTL

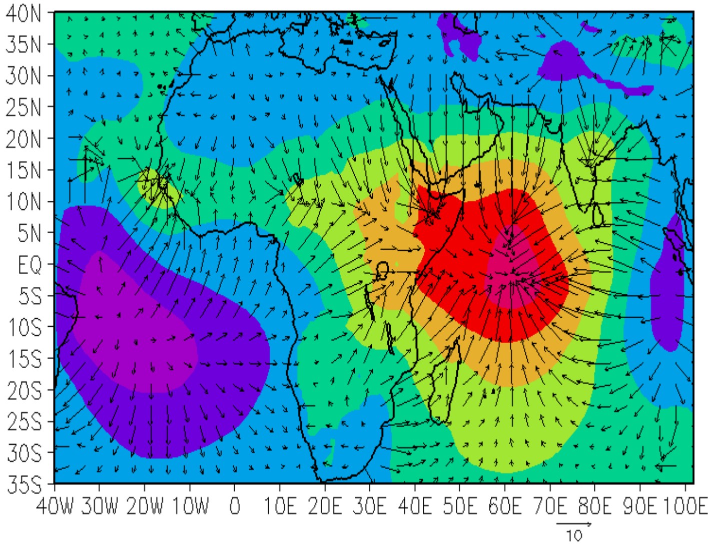
JAS Precipitation (mm/day) from the RCM (a) Control (with 1950-2002 mean SST), (b) 1980s minus control, (c) 1990s minus control and (d) 1990s minus 1980s.

(a) $-\int \nabla \cdot (q\mathbf{V})dp$ **(mm/day)**



Vertically integrated moisture convergence accounts for almost all of the precipitation.

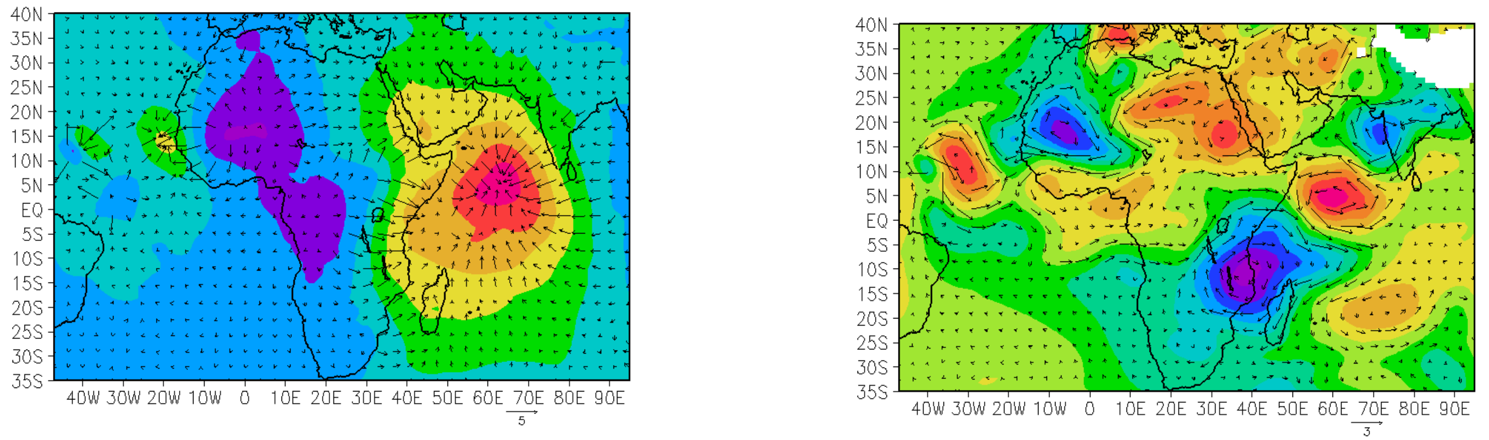
(b) $-\int \chi dp$ **and** $[q \cdot \mathbf{V}]_{irr}$ **(gm/kgs)**



$$\nabla^2 \chi = \nabla \cdot (q\mathbf{V}) \tag{1}$$

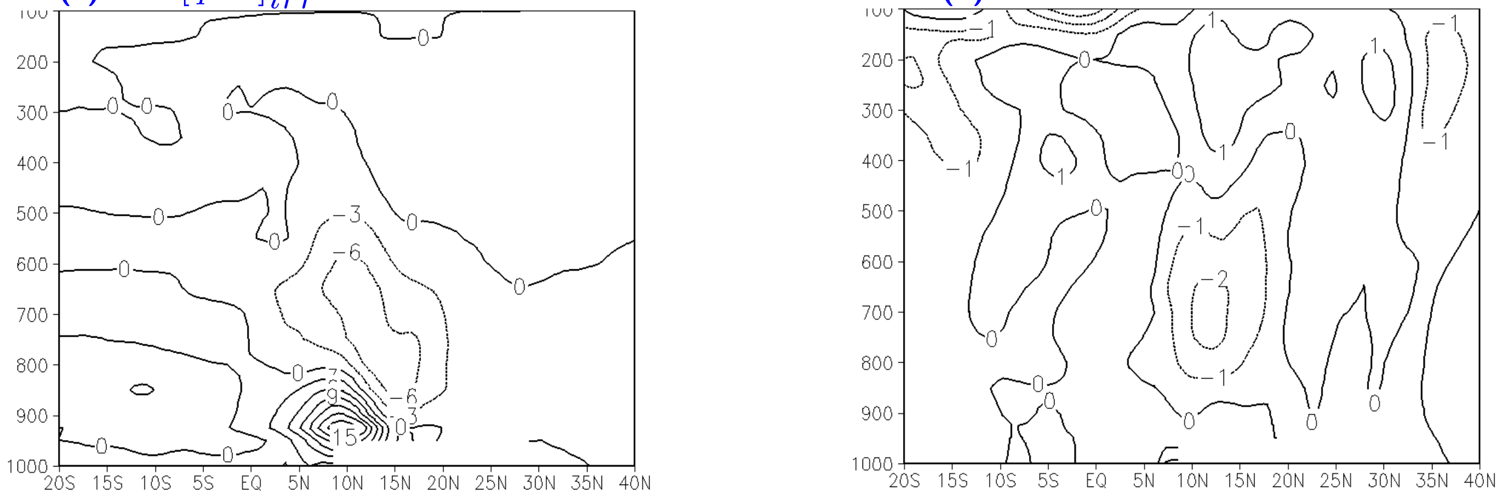
$$\nabla^2 \psi = -\nabla \times \mathbf{V} \tag{2}$$

Southern tropical Atlantic is the source of the moisture, Africa and Indian ocean are the sinks.



(a) $[q \cdot \mathbf{V}]_{irr}$ IND80s-CTL

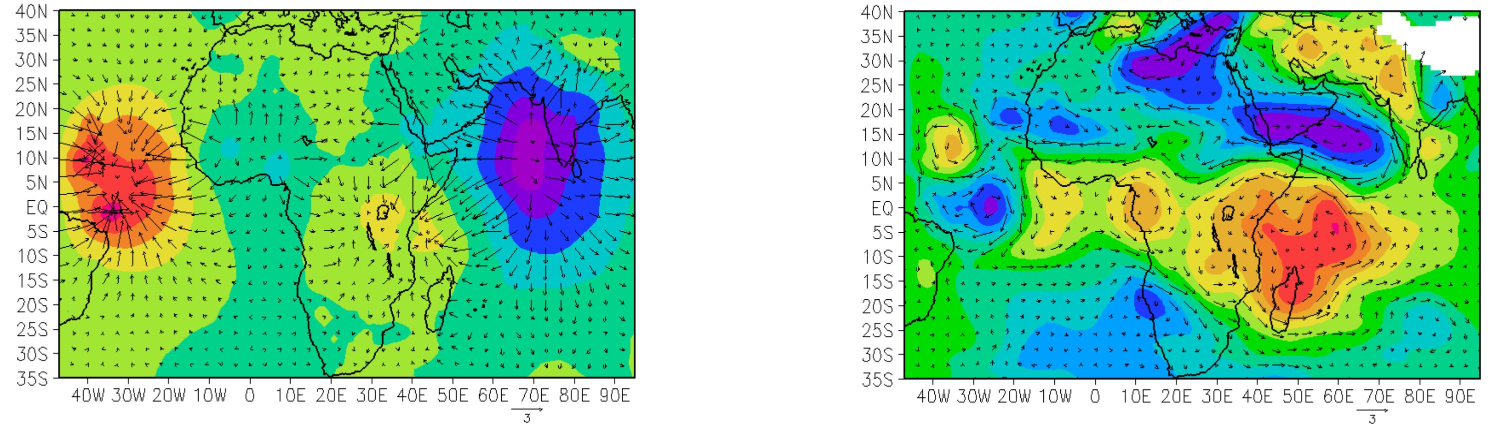
(b) $\mathbf{V}_{[nd]}$ IND80s-CTL



(c) 15E $[q \cdot u]_{irr}$ IND80s-CTL

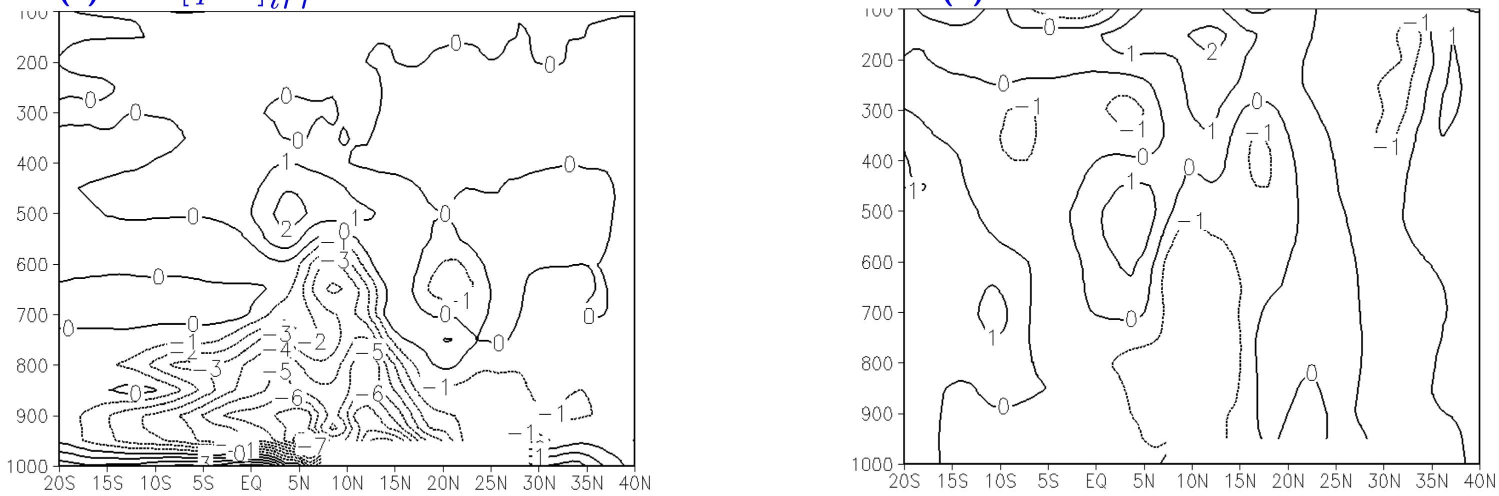
(d) 15E u IND80s-CTL

IND80s minus CTL, JAS mean (a) vertically integrated irrotational moisture flux (gm/kgs), (b) nondivergent wind at 700hpa (m/s), (c) zonal moisture flux (gm/kgs) and (d) u-wind at 15E (m/s).



(a) $[q \cdot \mathbf{V}]_{irr}$ ATL80s-CTL

(b) 700hPa $\mathbf{V}_{nd}$ ATL80s-CTL

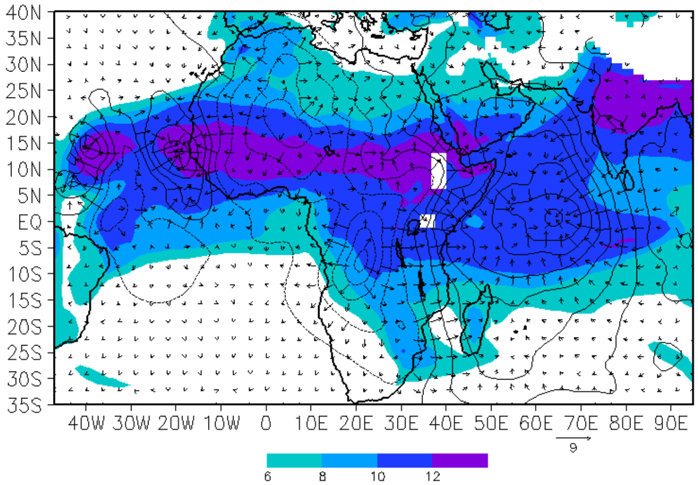


(c) 15E $[q \cdot u]_{irr}$ ATL80s-CTL

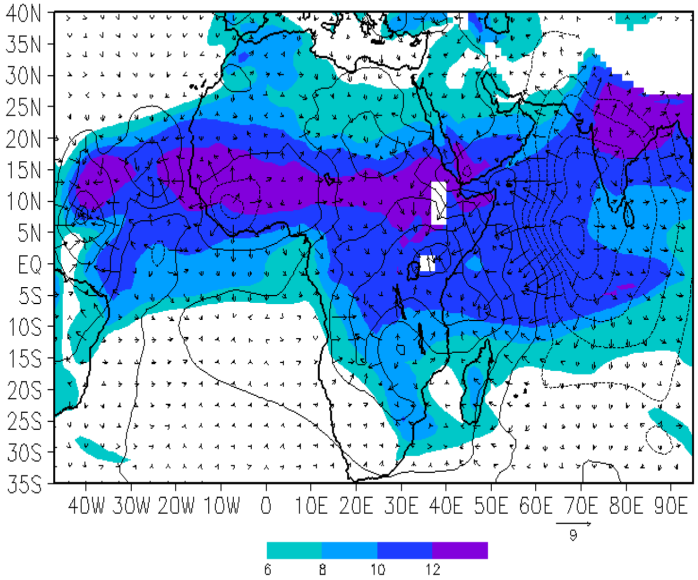
(d) 15E u ATL80s-CTL

ATL80s minus CTL, JAS mean (a) vertically integrated irrotational moisture flux (gm/kgs), (b) nondivergent wind at 700hpa (m/s), (c) zonal moisture flux (gm/kgs) and (d) u-wind at 15E (m/s).

(a) 700hPa $[q \cdot \mathbf{V}]_{irr}$ IND80s-CTL and $\overline{q}$



(b) 700hPa $[q \cdot \mathbf{V}]_{irr}$ ATL80s-CTL and $\overline{q}$



$$q = \overline{q} + q' \qquad (3)$$

$$\mathbf{V} = \overline{\mathbf{V}} + \mathbf{V}' \qquad (4)$$

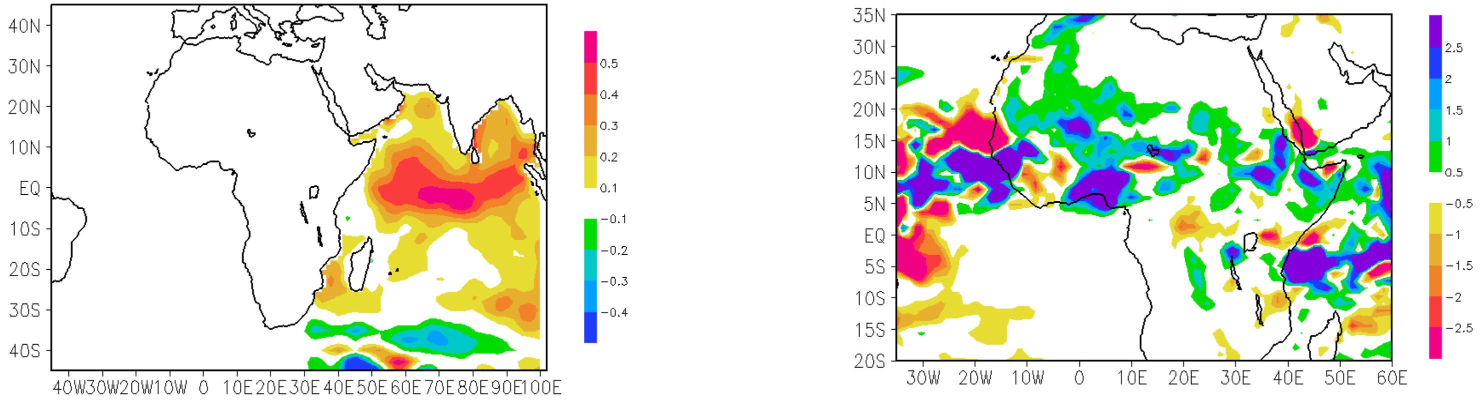
$$\nabla \cdot [q\mathbf{V}]' = \nabla \cdot [\overline{q}\mathbf{V}'] + \nabla \cdot [q'\overline{V}] + \nabla \cdot [q'\mathbf{V}'] (5)$$

The response of an ocean region to SST anomalies is partly determined by the background mixing ratio. In the summer over the Atlantic the latitude of mixing ratio maximum is near the Sahel.

Recovery of precipitation in the 1990s

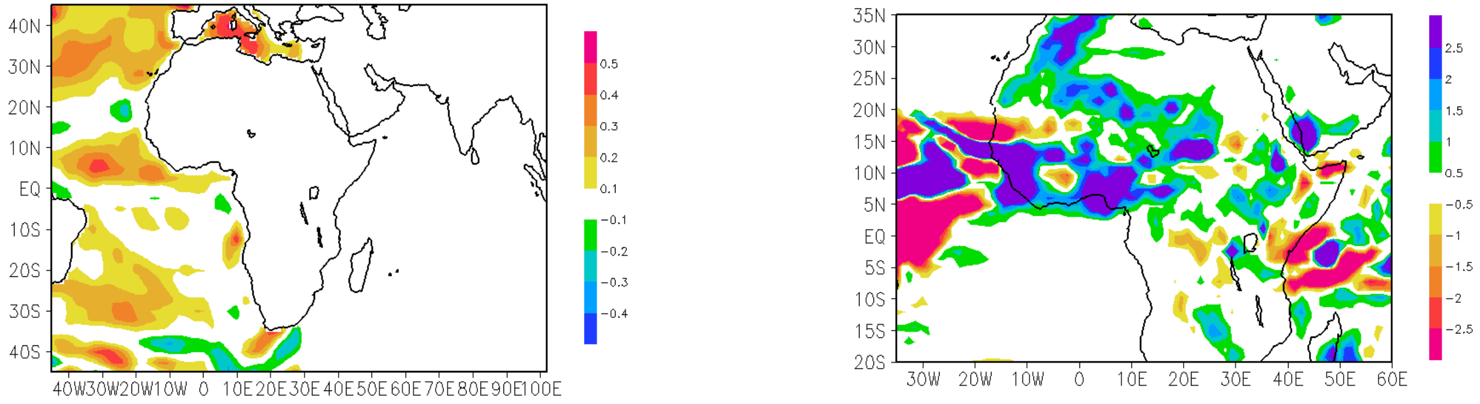
(a) SST IND90s-CTL

(b) PCP IND90s-IND80s



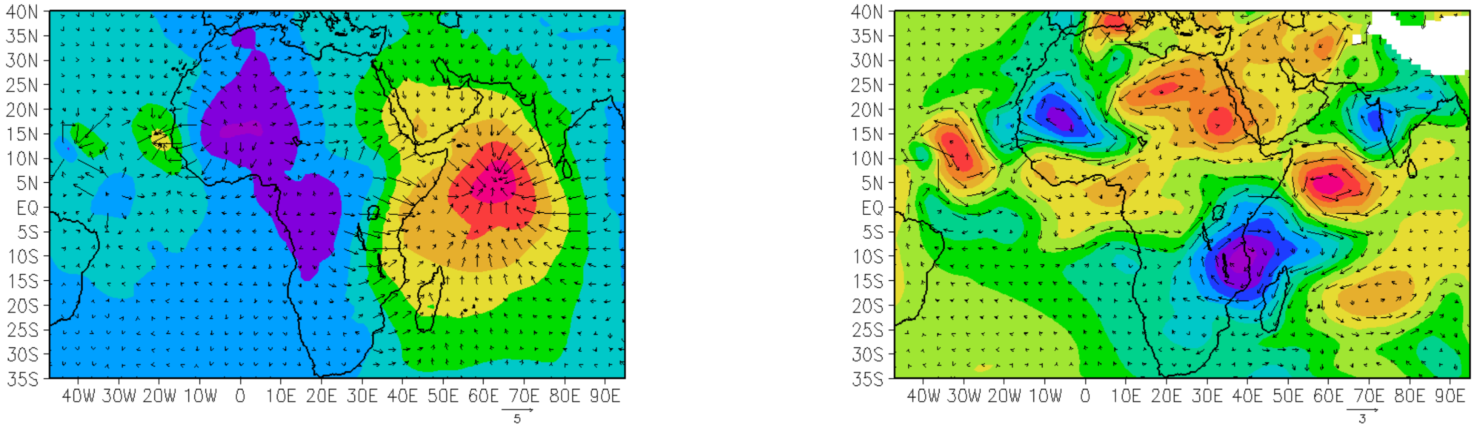
(c) SST ATL90s-CTL

(d) PCP ATL90s-ATL80

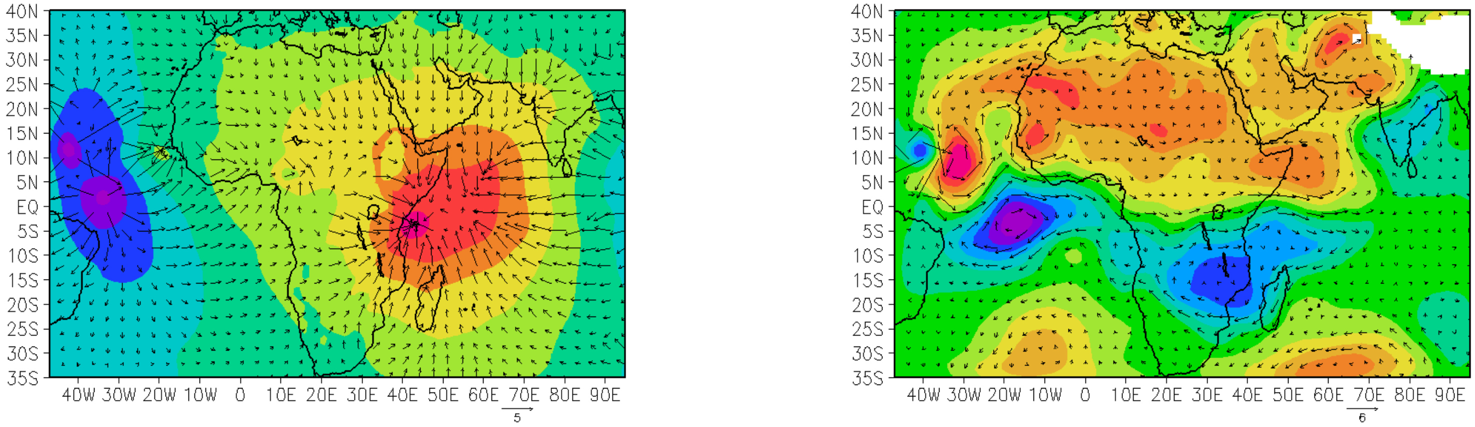


JAS Precipitation (mm/day) from the RCM (a) Control (with 1950-2002 mean SST), (b) 1980s minus control, (c) 1990s minus control and (d) 1990s minus 1980s.

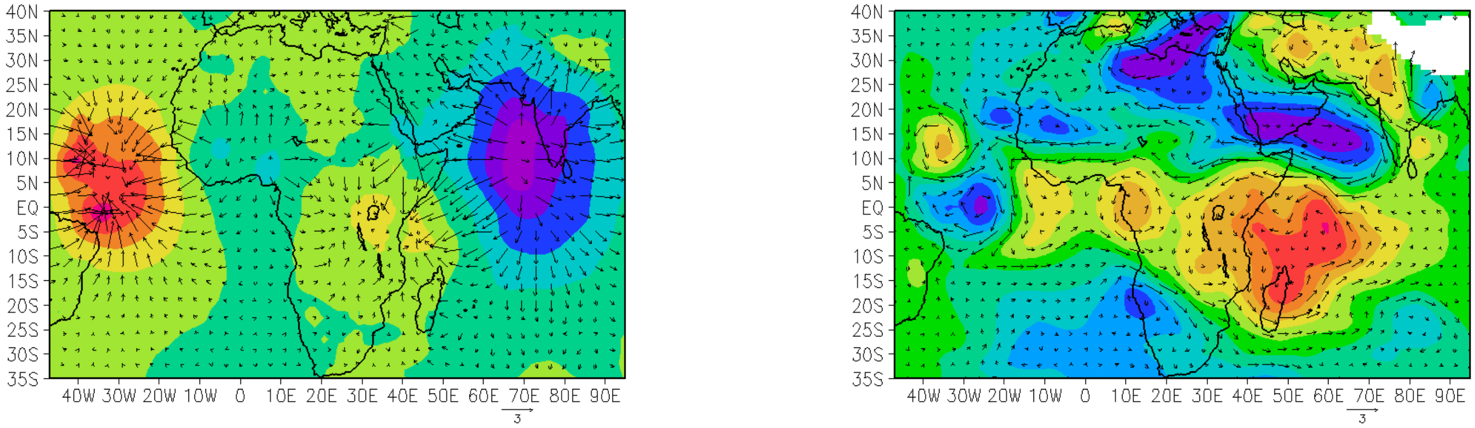
(a) Irr $q \cdot u$ IND80s-CTL **(b) 700hPa non-div V IND80s-CTL**



(c) Irr $q \cdot u$ IND90s-CTL **(d) 700hPa non-div V IND90s-CTL**

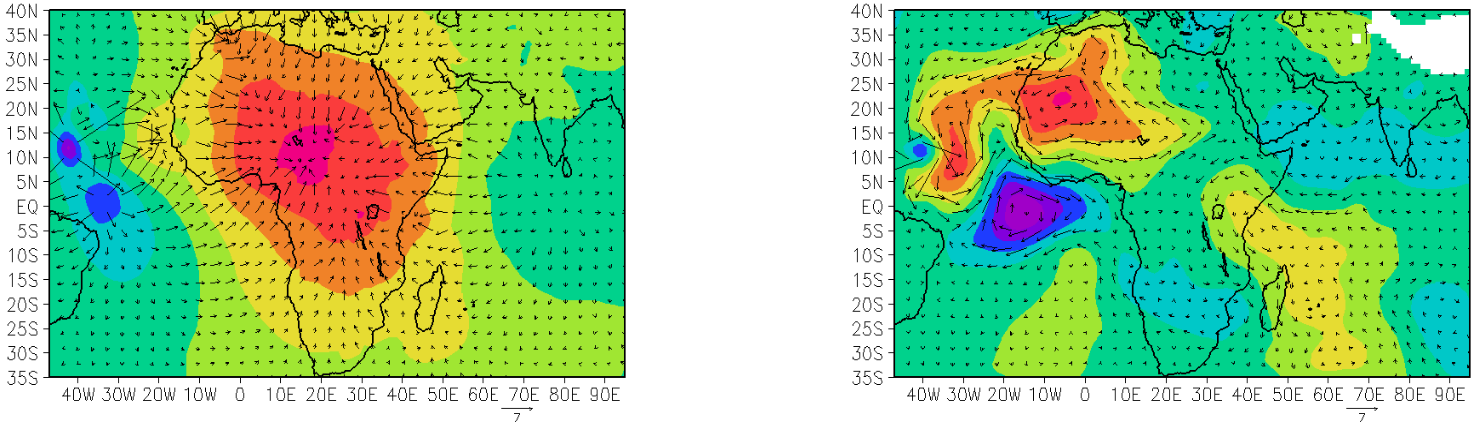


Model atmospheric response to 1980s (a, b) and 1990s (c,d) Indian ocean warming.



(a) Irr $q \cdot u$ ATL80s-CTL

(b) 700hPa non-div V ATL80s-CTL



(c) Irr $q \cdot u$ ATL90s-CTL

(d) 700hPa non-div V ATL90s-CTL

Model atmospheric response to 1980s (a, b) and 1990s (c,d) Atlantic ocean warming.

Summary:

- While the main source of moisture for the Sahel region is Southern Atlantic Ocean, both Atlantic and Indian Ocean SSTs control moisture flow into and precipitation over the Sahel.
- In the 1980s simulations the subsidence due to Indian ocean warming and the associated anomalous anticyclonic circulations block flow of moisture from the Atlantic ocean into the continent and cause wide-spread drought. By directly competing for moisture warm Atlantic ocean also contributed to the Sahel drought.
- In the 1990s simulations the changes in the scale Indian ocean warming moved the subsidence to the Tropical Atlantic and led to the recovery precipitation. The warm northern Atlantic during this period also also favored the flow of moisture into the continent.