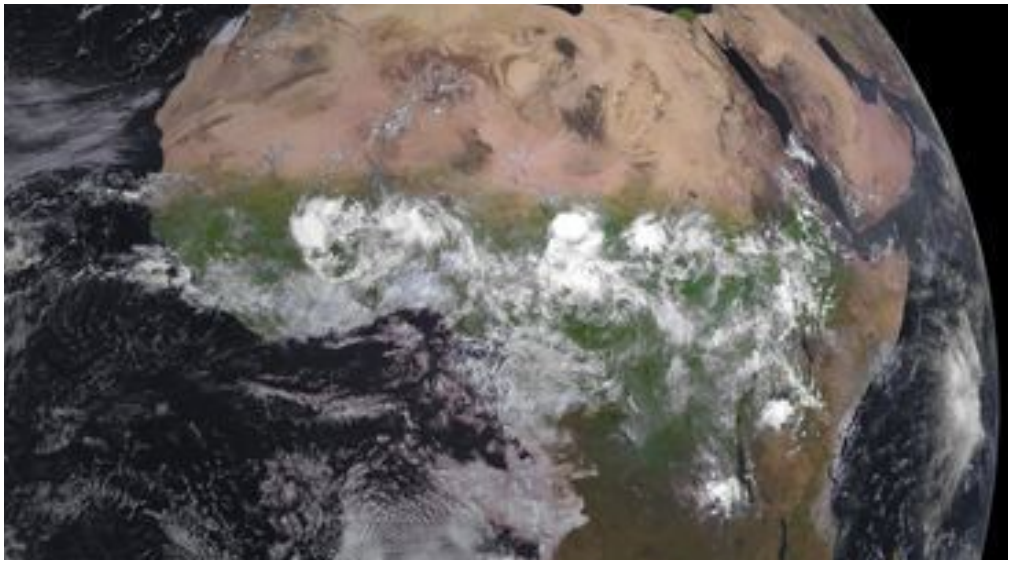
The role of soil moisture in the West African monsoon



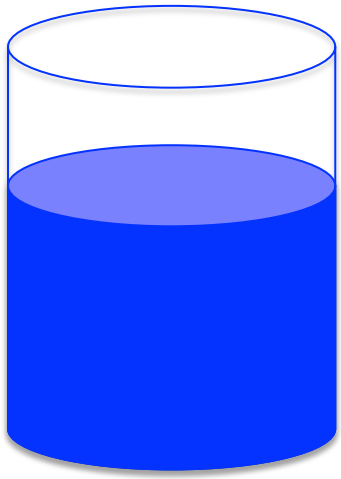
Alexis BERG

NSF postdoctoral Fellow

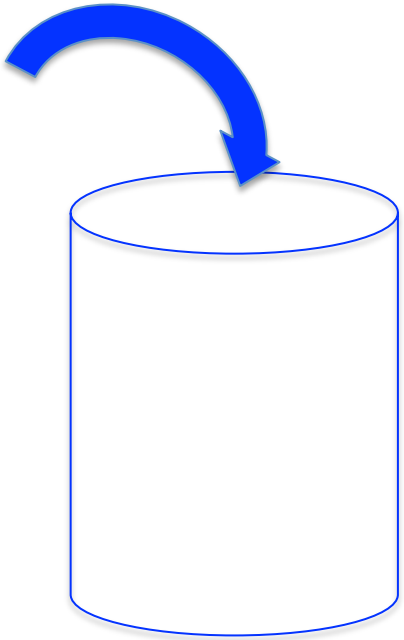
International Research Institute for Climate and Society @ Columbia University

With: A.Giannini (IRI), B. Lintner (Rutgers Univ.), K. Findell (GFDL), M. Biasutti (LDEO) and GLACE-CMIP5 participants.

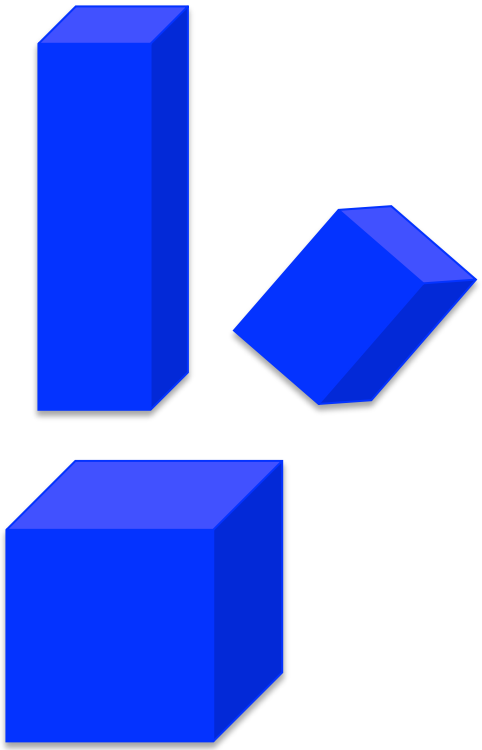
Some perspective: land surface processes



Theory: Glass (more than) half full



Observations: Glass nearly empty but the server is pouring

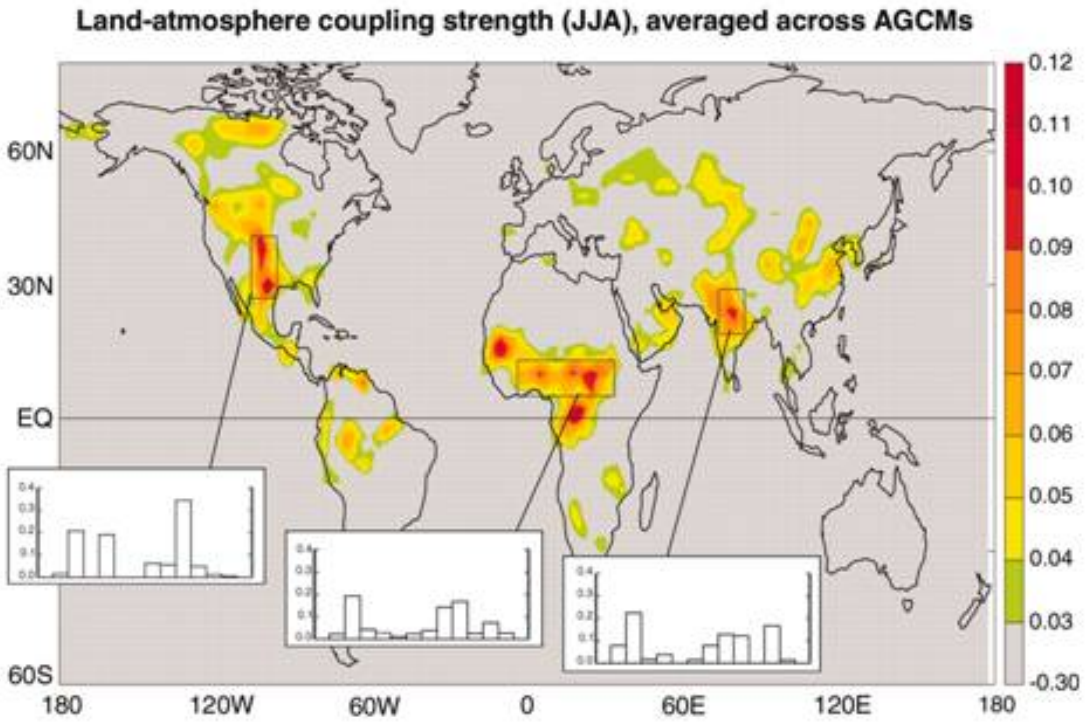


Models

Motivation

- West Africa has been identified as a “hotspot” of soil moisture-atmosphere coupling ***(Koster et al. 2004).***
- ***How do land-atmosphere (LA) interactions behave in monsoonal regimes?***
- *Shifting seasonality under future climate change [M. Biasutti]*

Experiment comparing AMIP – style seasonal runs with prescribed and interactive soil moisture (JJA 1994)



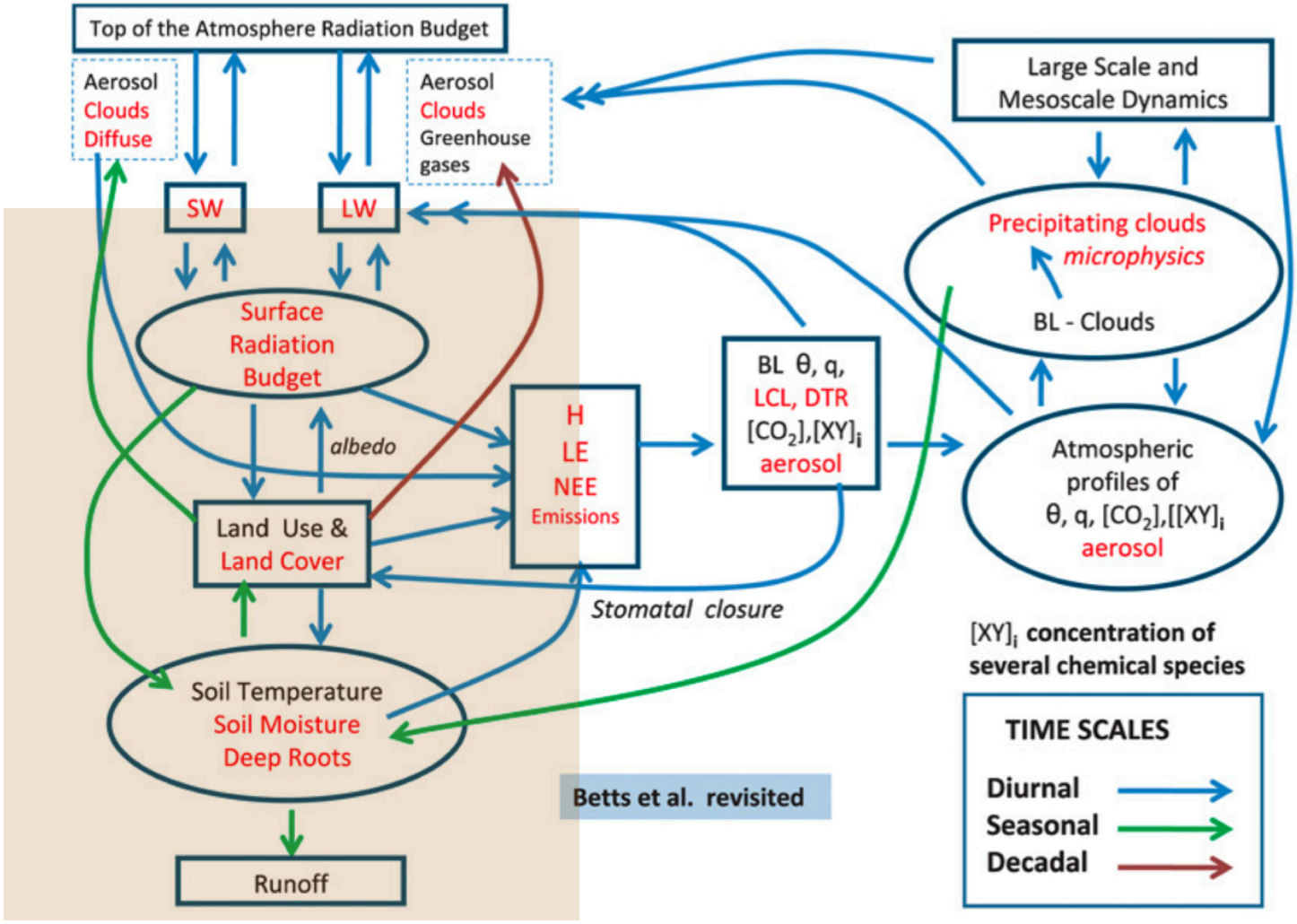
% of rainfall variability explained by soil moisture variability

Intraseasonal SM-P coupling

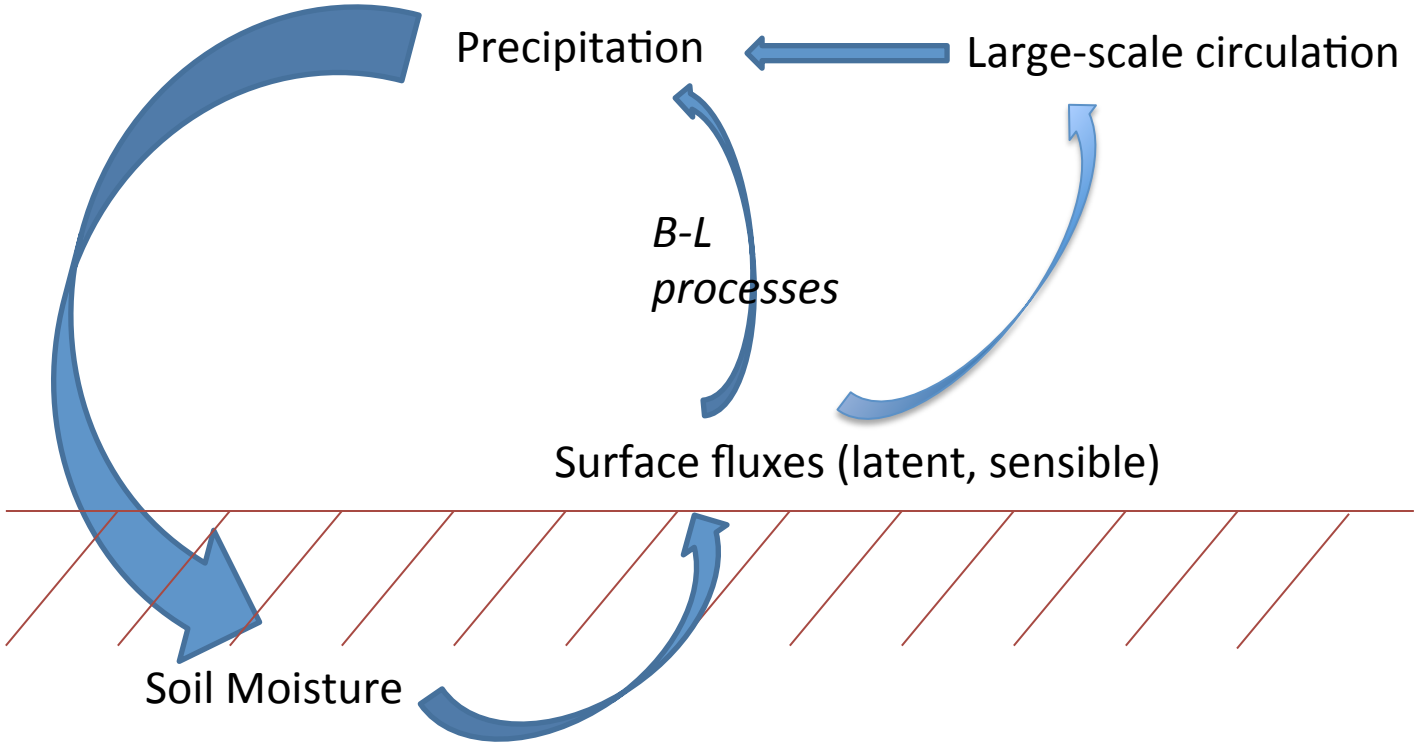
Multimodel Global Land Atmosphere Coupling Experiment (GLACE)-***Koster et al. 2004 (Science)***

Schematic of LA Interactions

(Betts and Silva Dias 2010)



A simplified view



Methodology

Climate model simulations with interactive / prescribed SM from GLACE-CMIP5
(Seneviratne et al. 2013, Geophys. Res. Lett.)

- 6 GCMs (ACCESS, ESM2M, MPI-ESM, EC-EARTH, CCSM4, IPSL-CM5A)

- 1951-2100 transient simulations: Historical + RCP8.5 (concentrations)

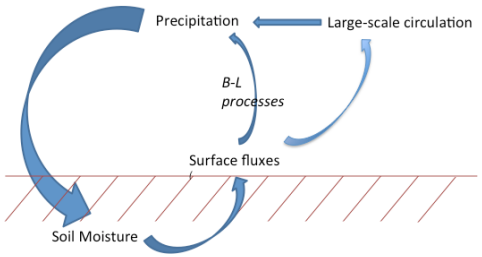
- SSTs prescribed from corresponding 'parent' CMIP5 coupled simulation

  > Simulation **INT**: **interactive** soil moisture
  > Simulation **FIX**: soil moisture prescribed to **1971-2000 climatological seasonal cycle** from corresponding parent CMIP5 simulation

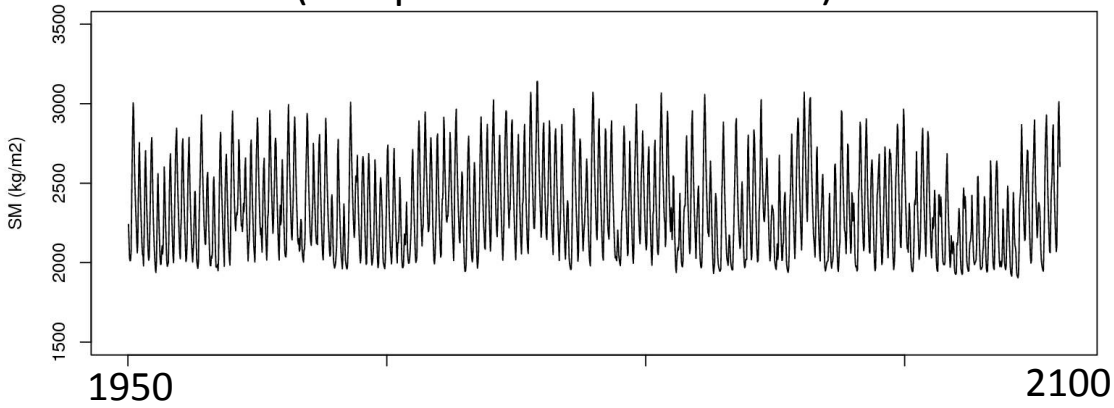
- Caveat: FIX simulations do not conserve total water.

The GLACE Approach

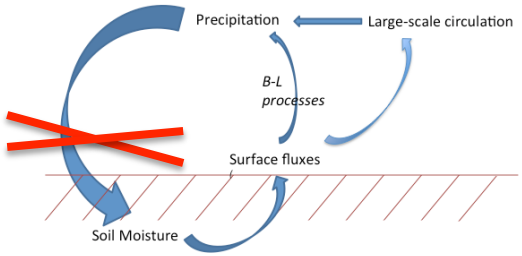
Climate model simulations with interactive / prescribed SM from GLACE-CMIP5

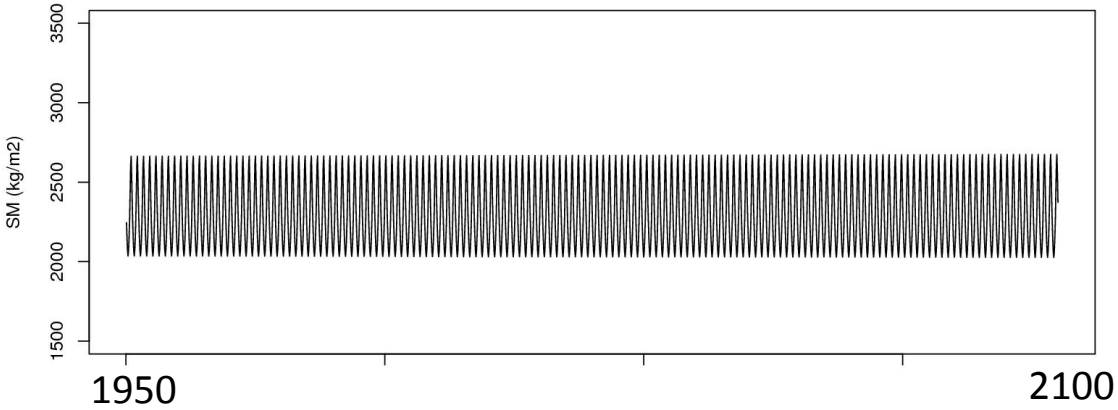


SM (one pixel over West Africa)



INT

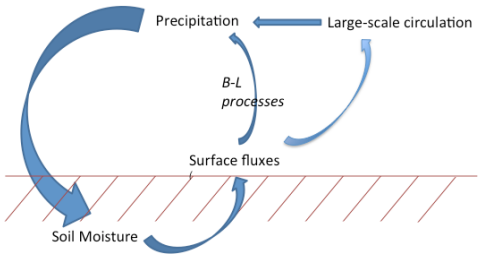


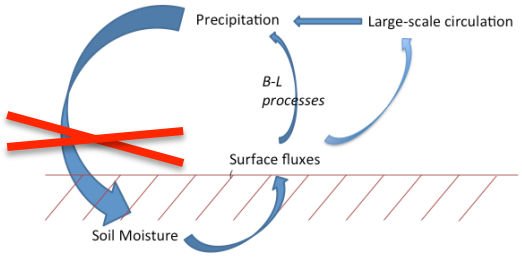


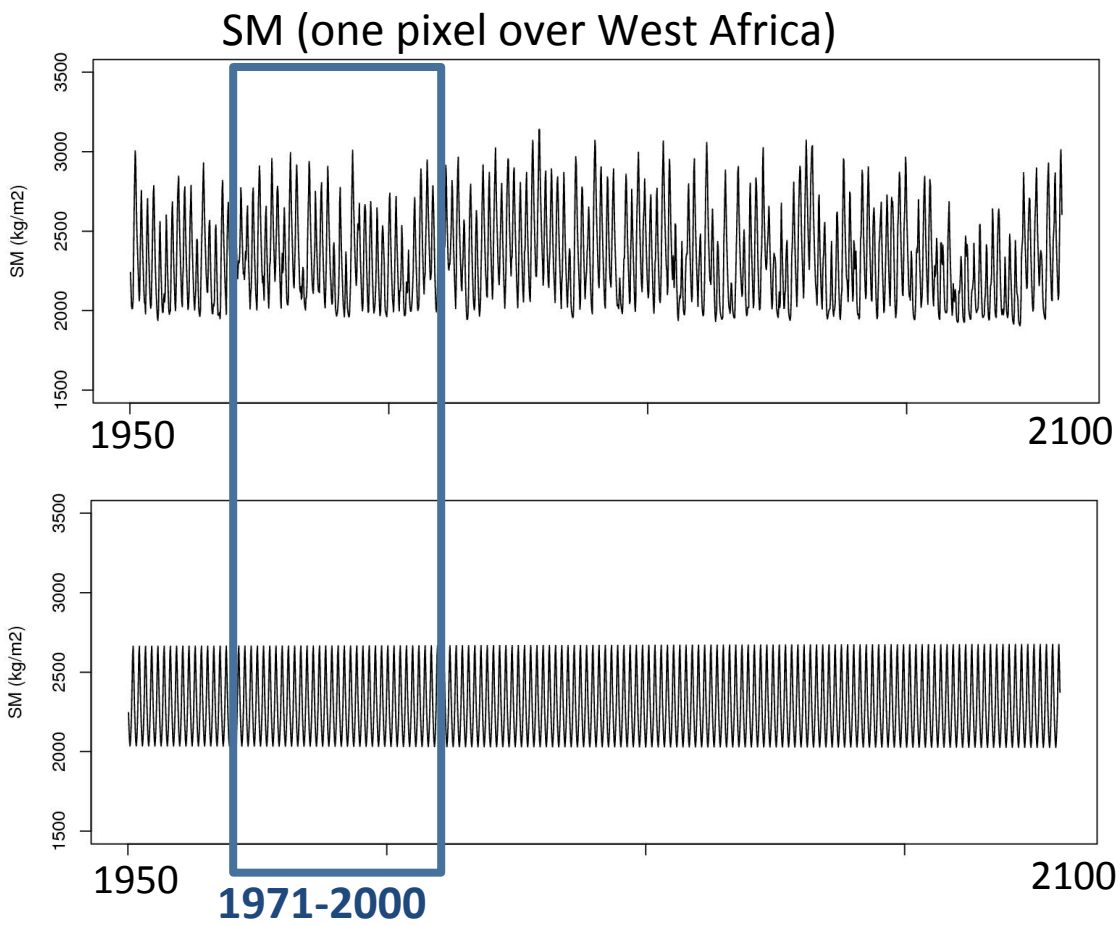
FIX

Methods

Climate model simulations with interactive / prescribed SM from GLACE-CMIP5



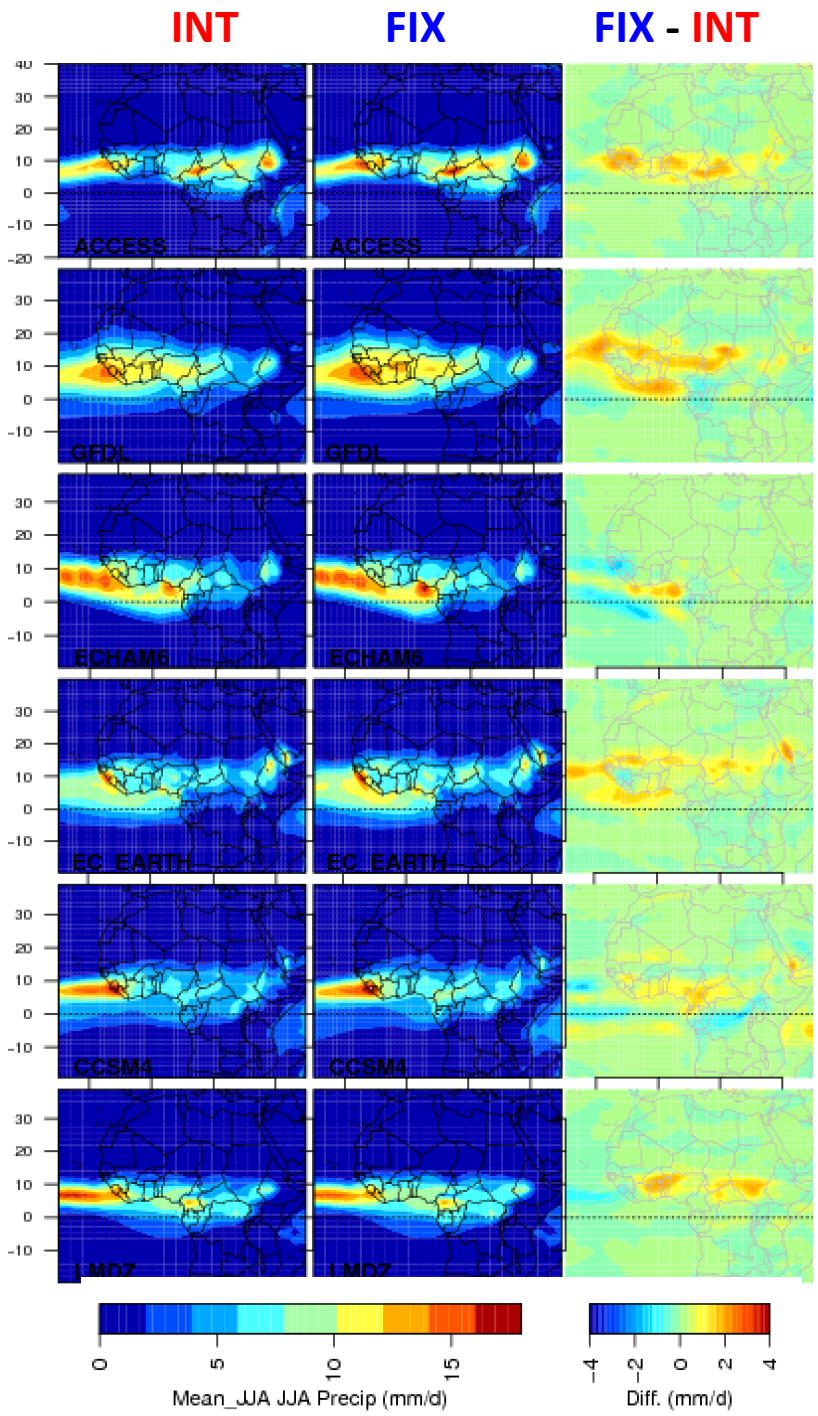




We compare both simulations over 1971-2000.

Mean JJA precipitation over 1971-2000

In **4 of 6 models**, mean JJA precipitation is enhanced in **FIX**.



ACCESS

ESM2M

MPI-ESM

EC-EARTH

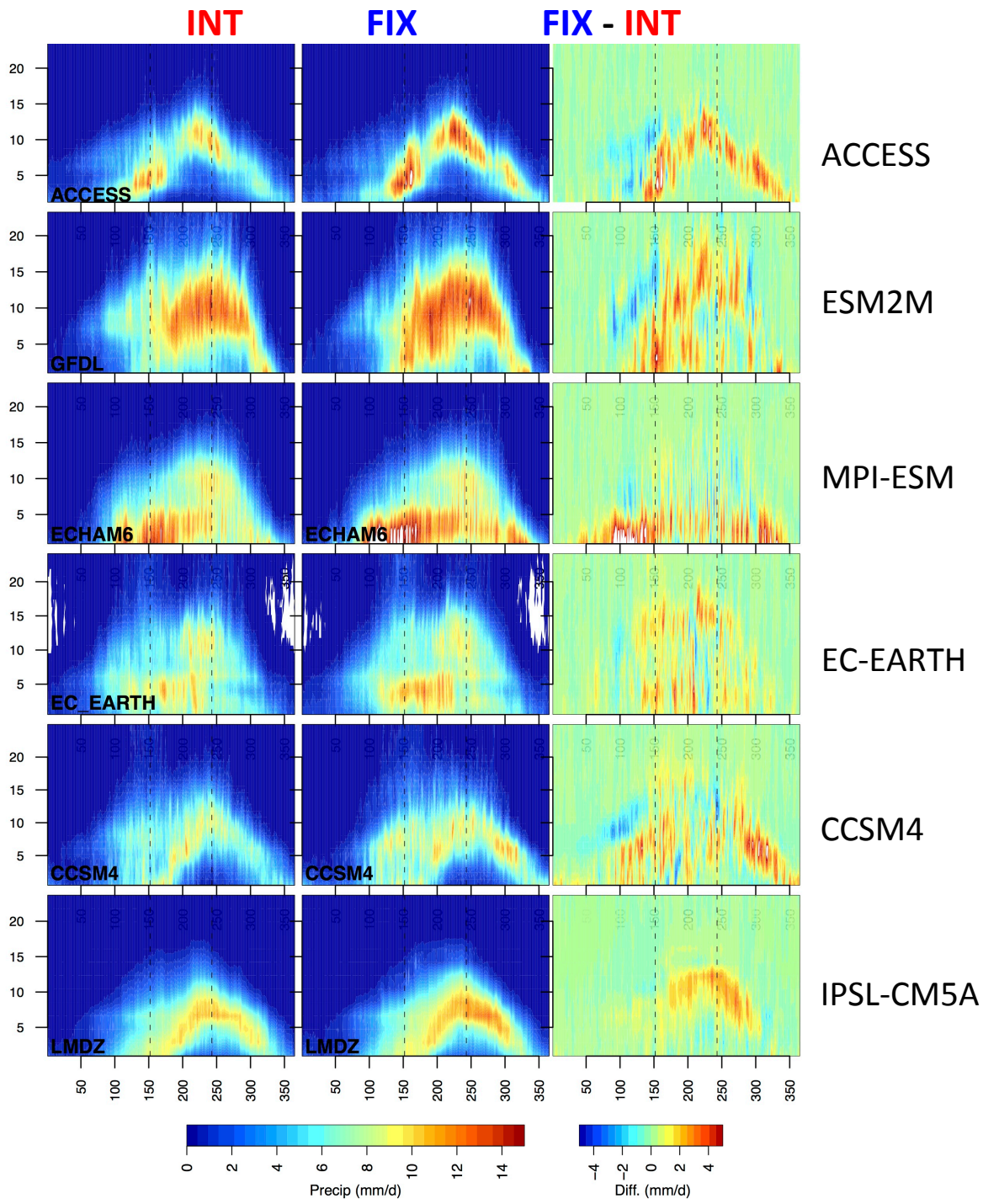
CCSM4

IPSL-CM5A

Mean JJA precipitation over 1971-2000
Time-latitude view over 10W-10E

In **4/6 models**, mean rainfall intensity in the "core"/toward the end of the monsoon season in **FIX**.

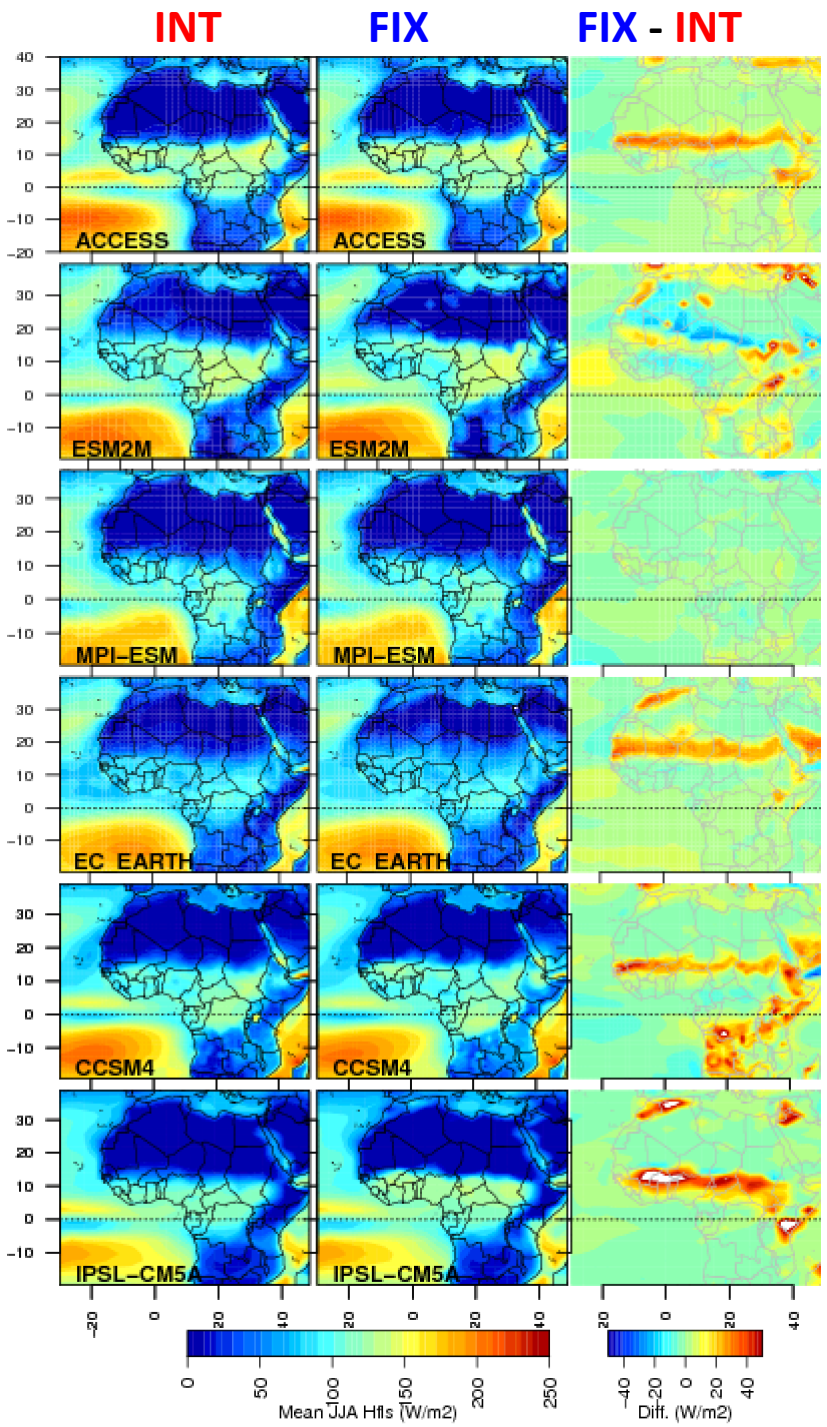
In **3/6 models**, rainfall intensity is reduced in the early monsoon season (April, May) in **FIX**.



Mean JJA surface latent heat flux 1971-2000

In **5/6 models**, mean JJA evaporation is enhanced along the poleward (dry) margin of the monsoon in **FIX**.

*This enhanced evaporation is not caused by increased rainfall in **FIX**.*



ACCESS

ESM2M

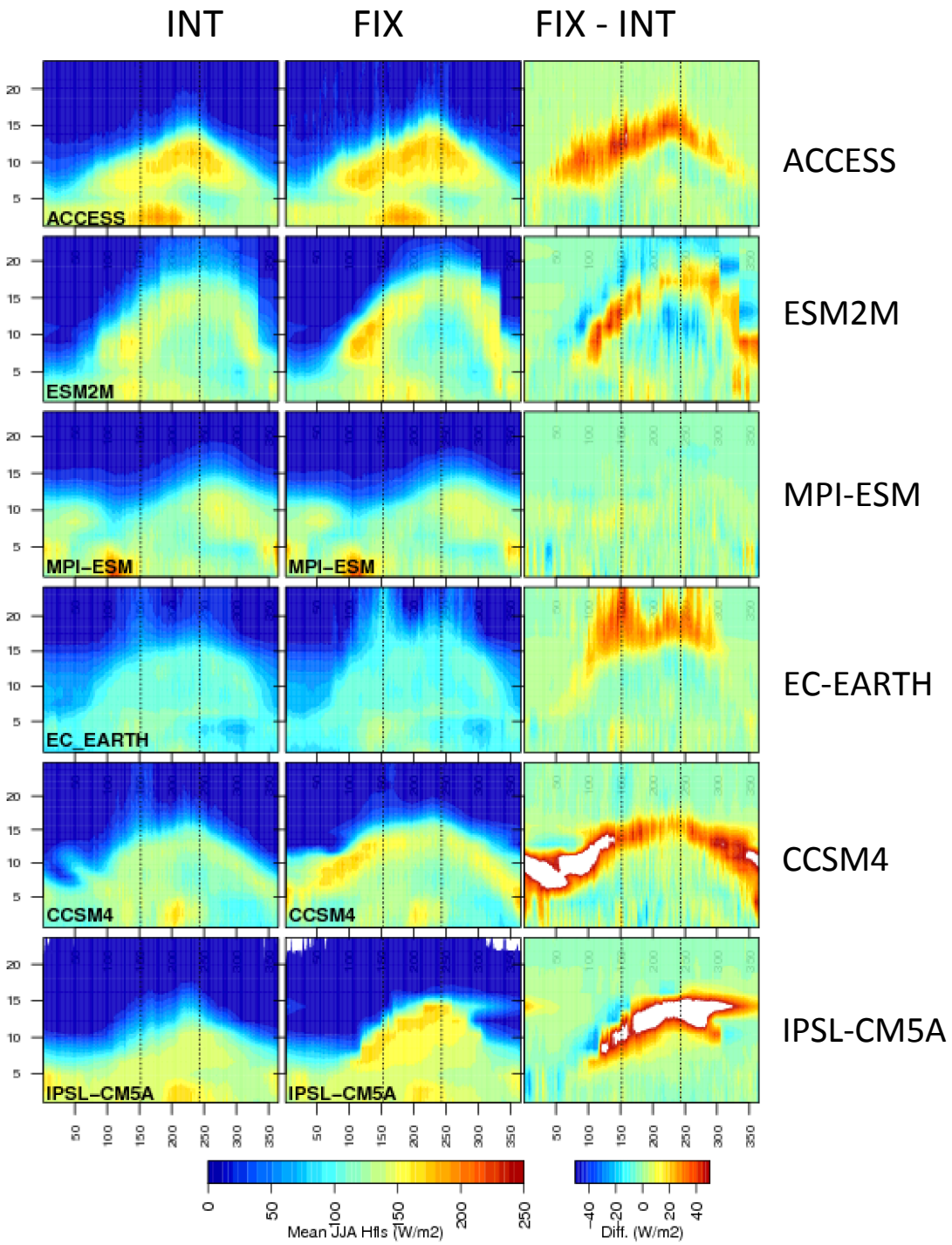
MPI-ESM

EC-EARTH

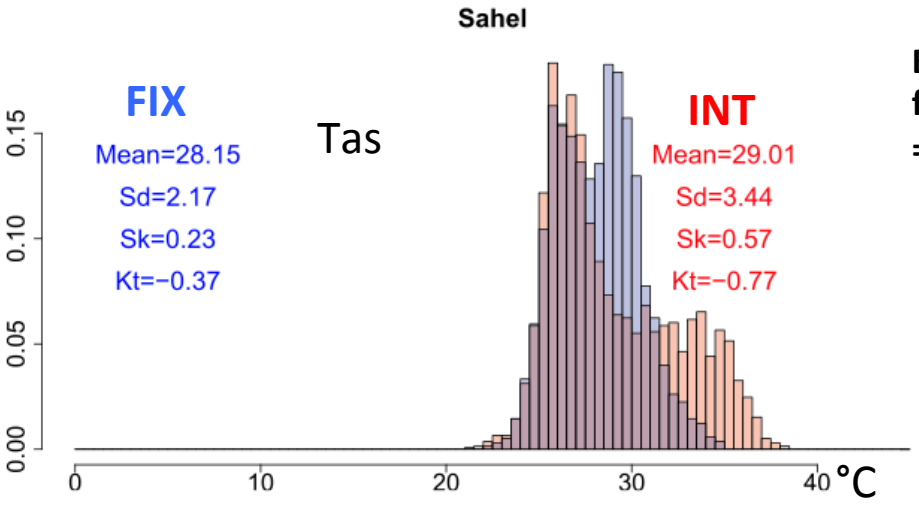
CCSM4

IPSL-CM5A

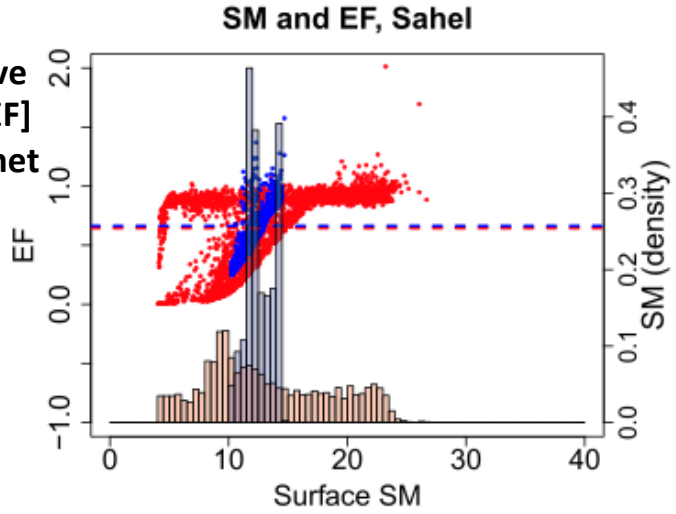
Mean JJA surface latent heat over 1971-2000
Time-latitude view over 10W-10E

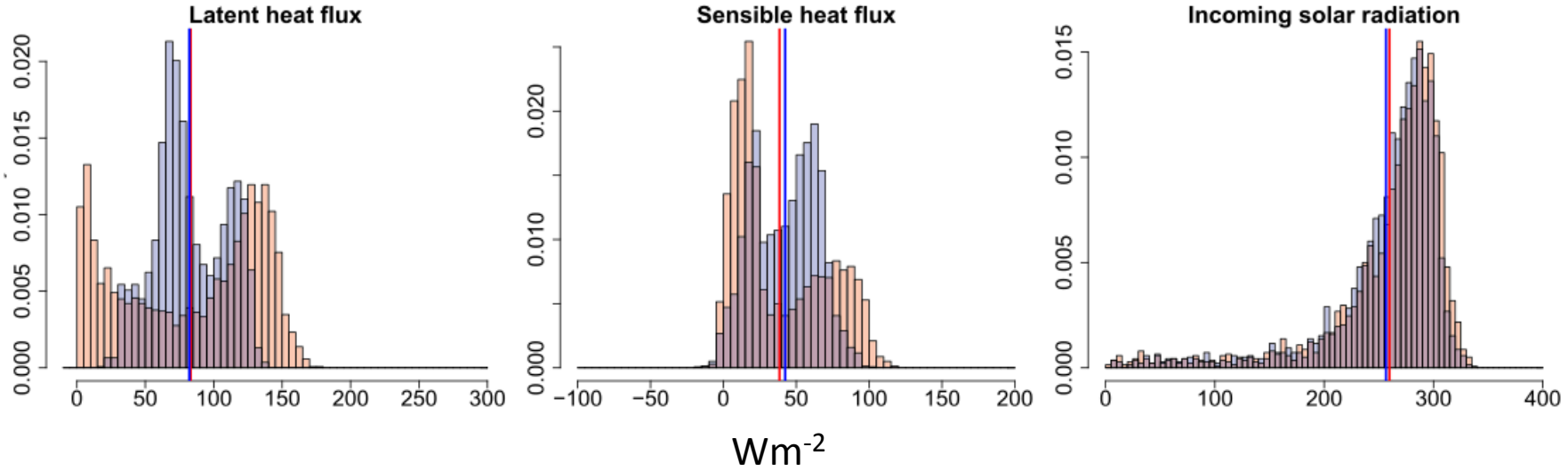


*Why does prescribing climatological soil moisture lead to greater evaporation in dry regimes?**



Evaporative fraction [EF] =Evap/Rsnet



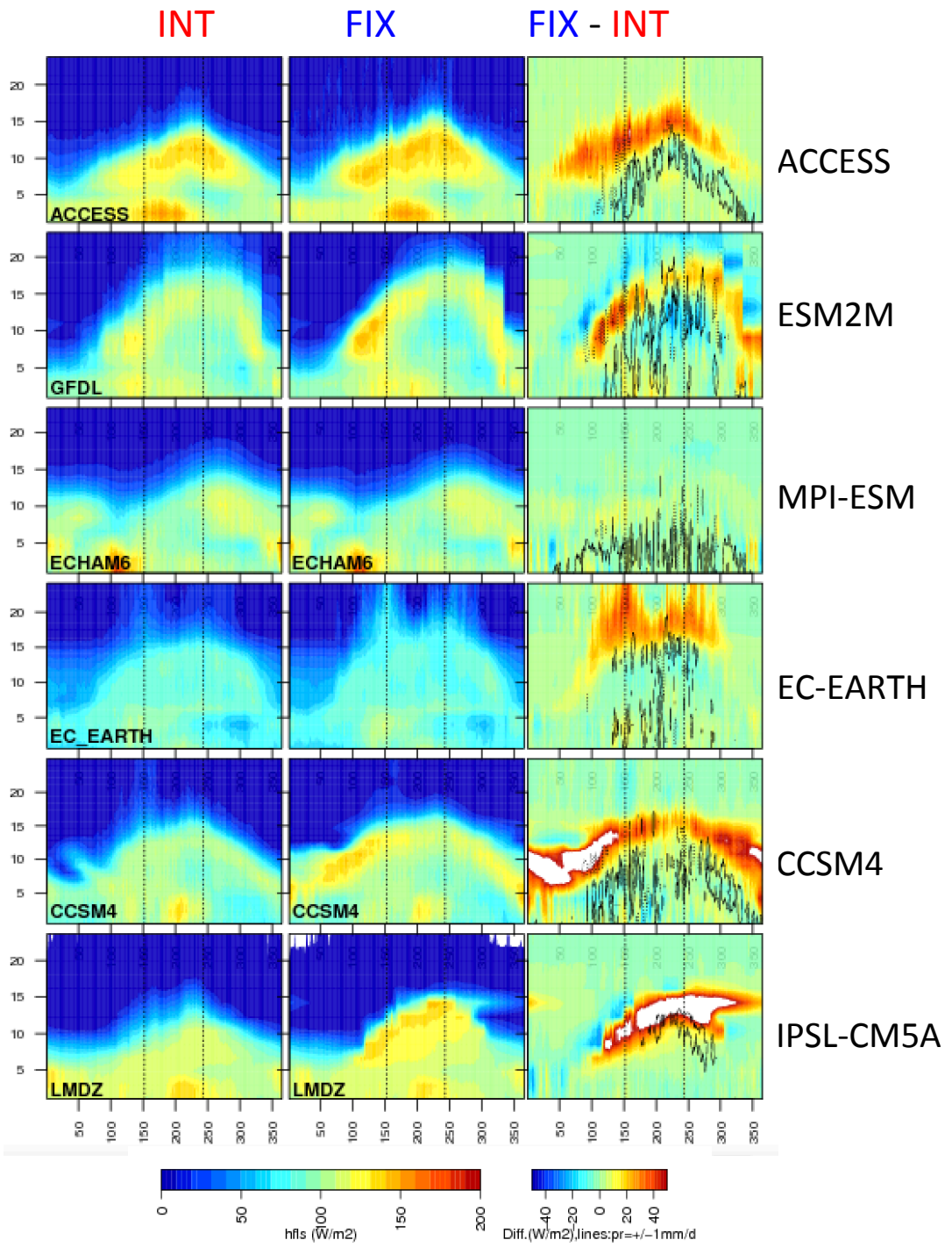


At least in the GFDL model

Surface latent heat flux (shading) and precipitation (contours)

During the core/late season monsoon, enhanced evaporation generally occurs poleward of enhanced rainfall in **FIX**.

In the early season, enhanced evaporation is generally co-located with reduced rainfall in **FIX**.



One possible core/late season: reduced dry air (or low MSE) ventilation

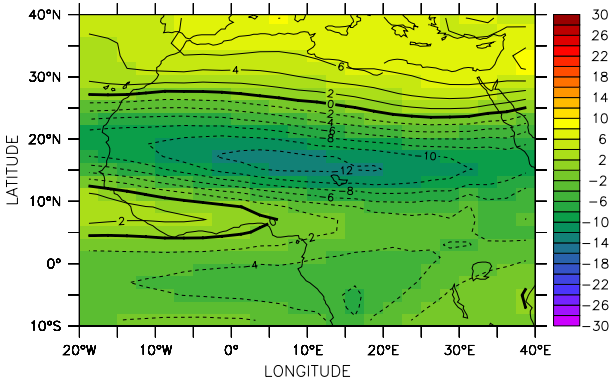
[Previous work by D. Neelin, H. Su, C. Chou; also talks by O. Pauluis and S. Hill]

Essentially, the poleward edge of the monsoon is ventilated by very dry air from the Sahara. In FIX, the enhanced evaporation moistens the influence, raising its MSE.

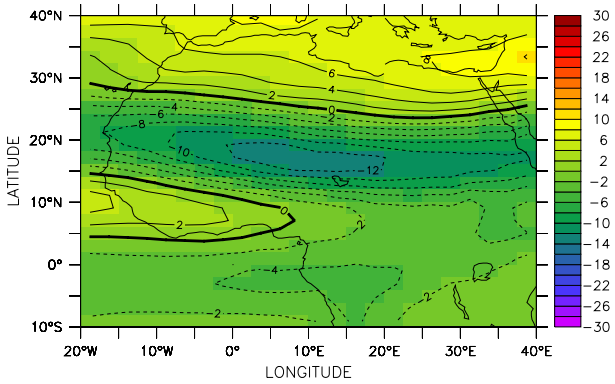
TBD: Moisture budget

Core/Late Season: 600 mb Zonal Wind

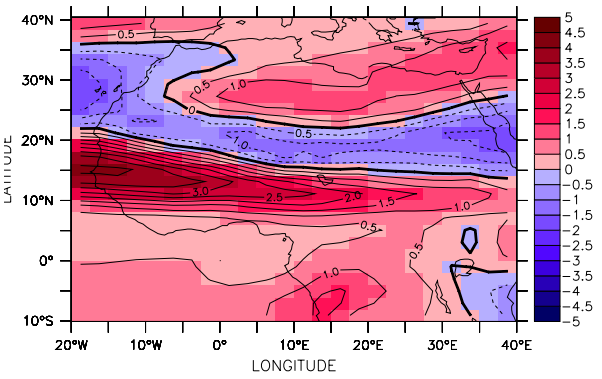
Lon-Lat View



ucomp, 600mb, August,1971–2000, INT

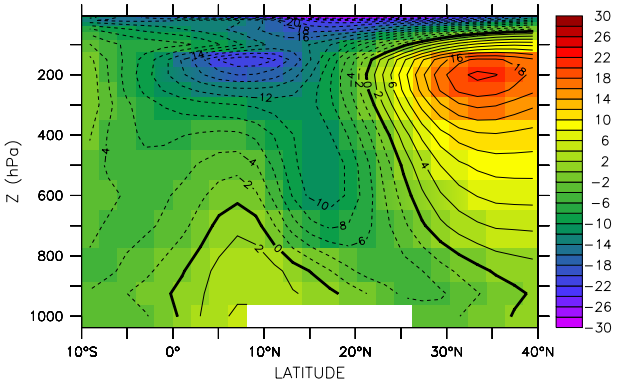


ucomp, 600mb, August,1971–2000, FIX

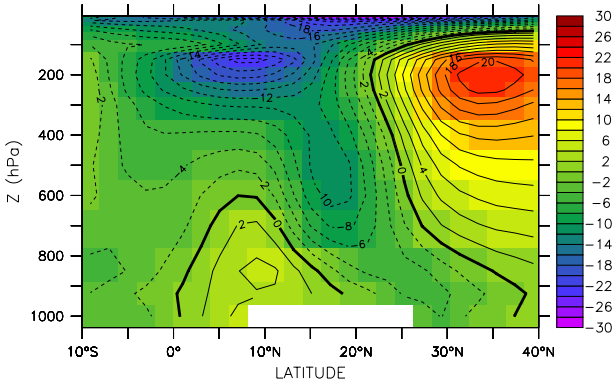


ucomp, 600mb, August,1971–2000, FIX–INT

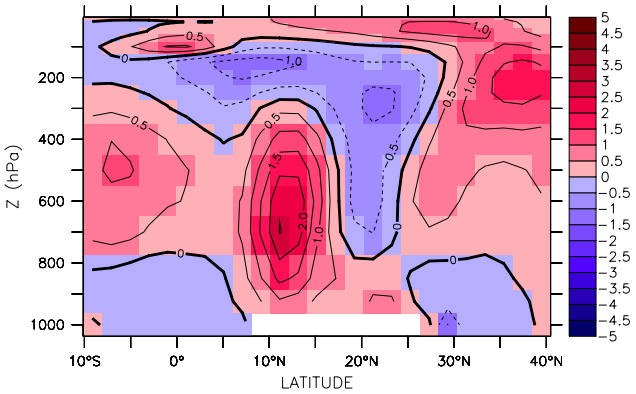
Lat-Height View



ucomp, August, 1971–2000, INT



ucomp, August, 1971–2000, FIX



ucomp, August, 1971–2000, FIX–INT

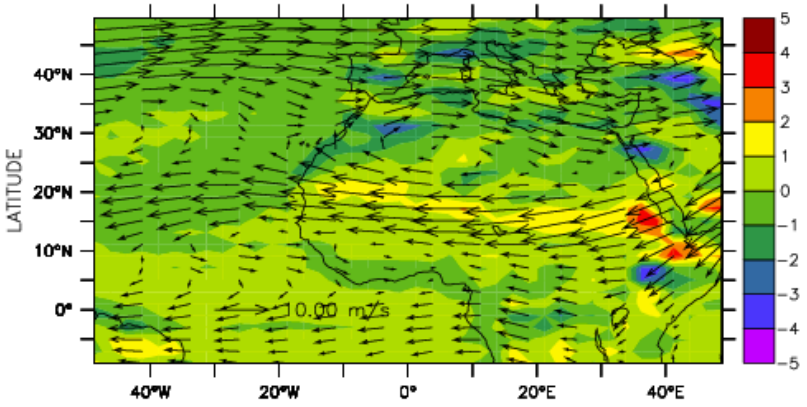
INT

FIX

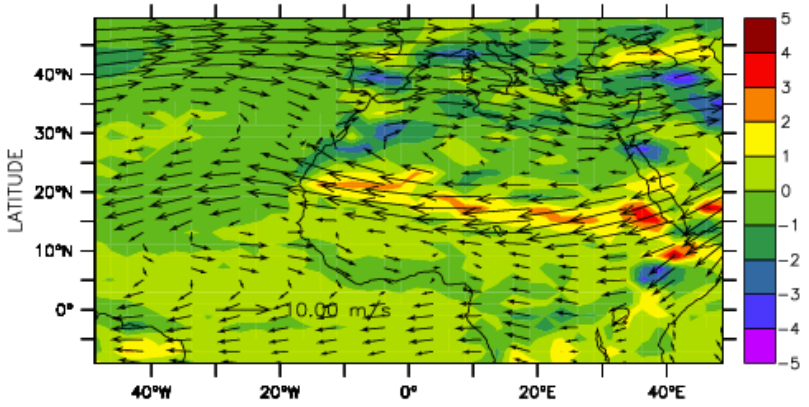
FIX - INT

The African Easterly Jet (AEJ) is shifted poleward in **FIX**.

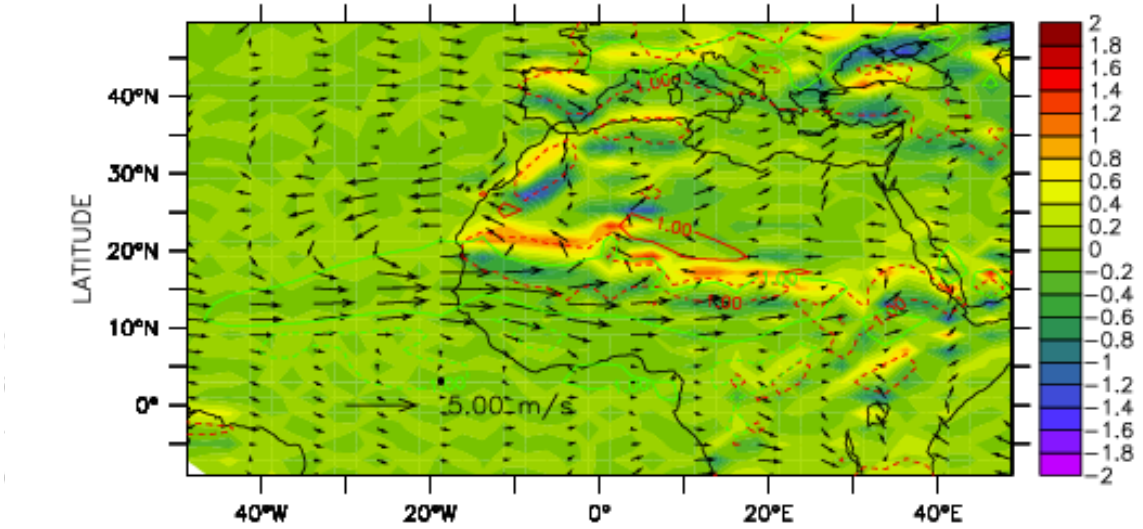
Core/Late Season:
600 mb Zonal Wind and Surface Air Temperature



august, INT, merid. T grad(K/100km) and u600mb,1971−1990,GFDL



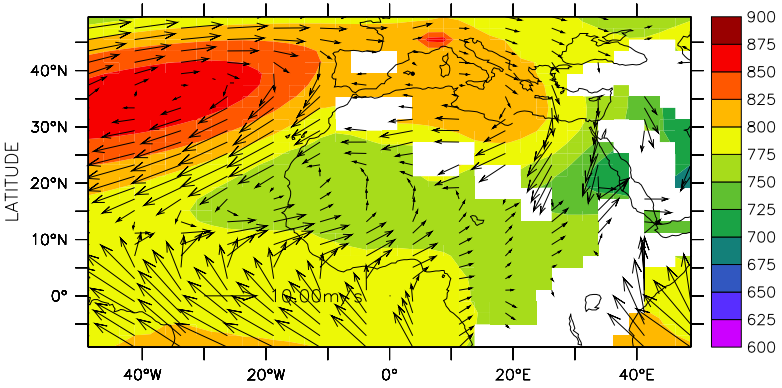
august, FIX, merid. T grad(K/100km) and u600mb,1971−1990,GFDL



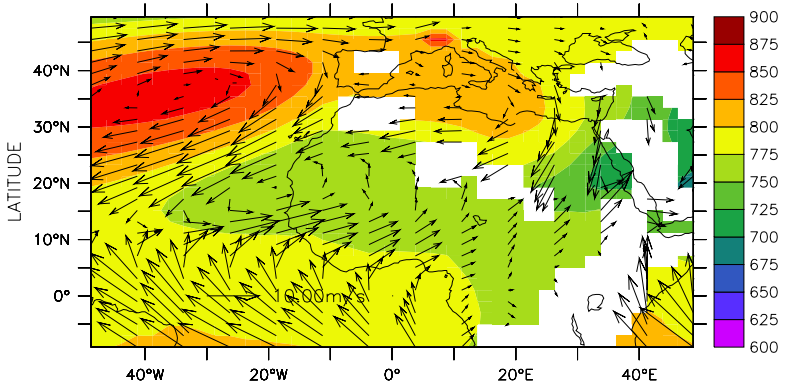
CONTOUR: tas (red)
CONTOUR: pr (green)
august, FIX−INT, merid. T grad(K/100km) and u600mb,1971−1990,GFDL

The poleward shift is consistent with a poleward displacement of the maximum surface temperature gradient.

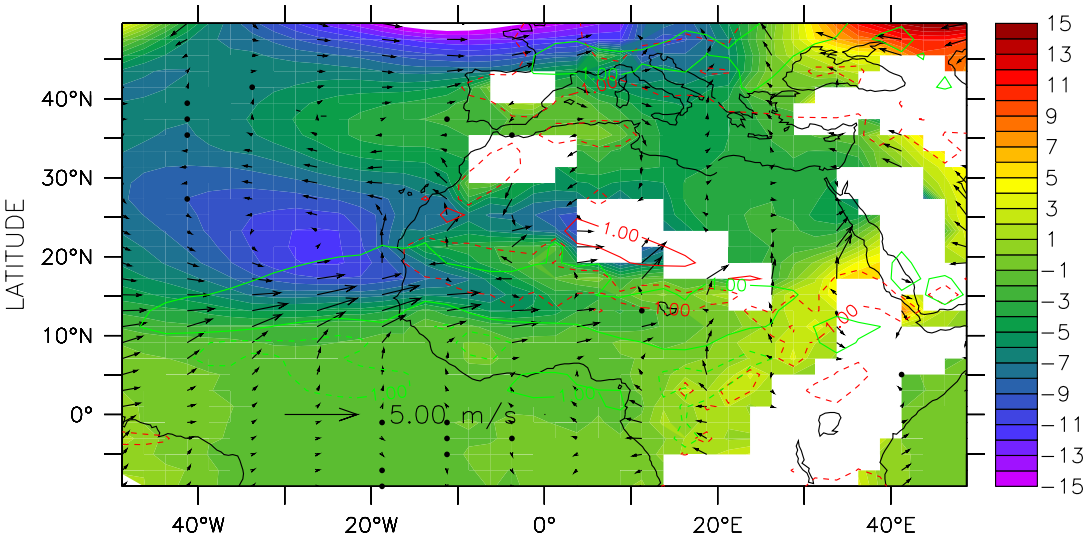
Core/Late Season:
925 mb Winds and Geopotential Height



august, INT, z925mb(m),1971-1990,GFDL



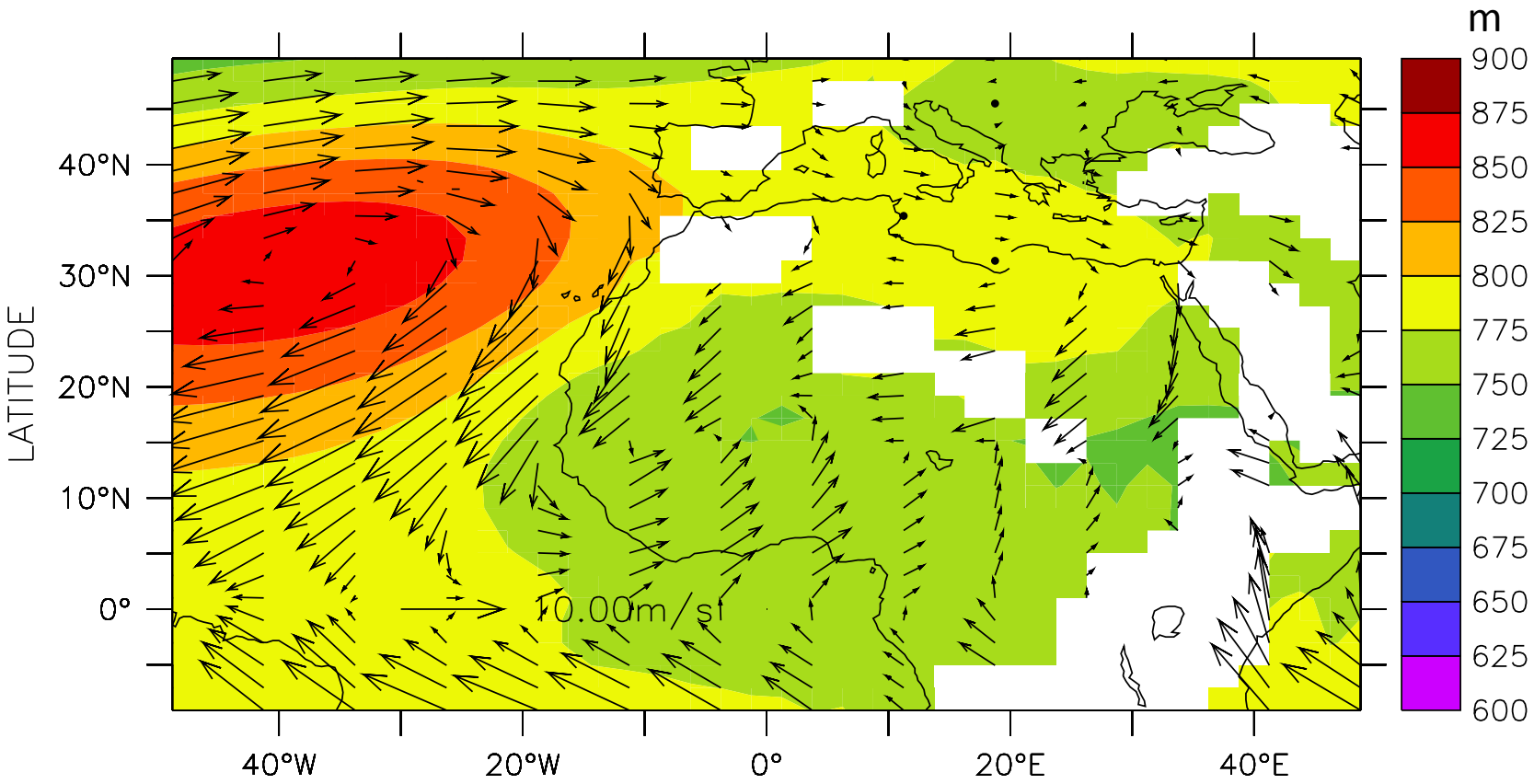
august, INT, z925mb(m),1971-1990,GFDL



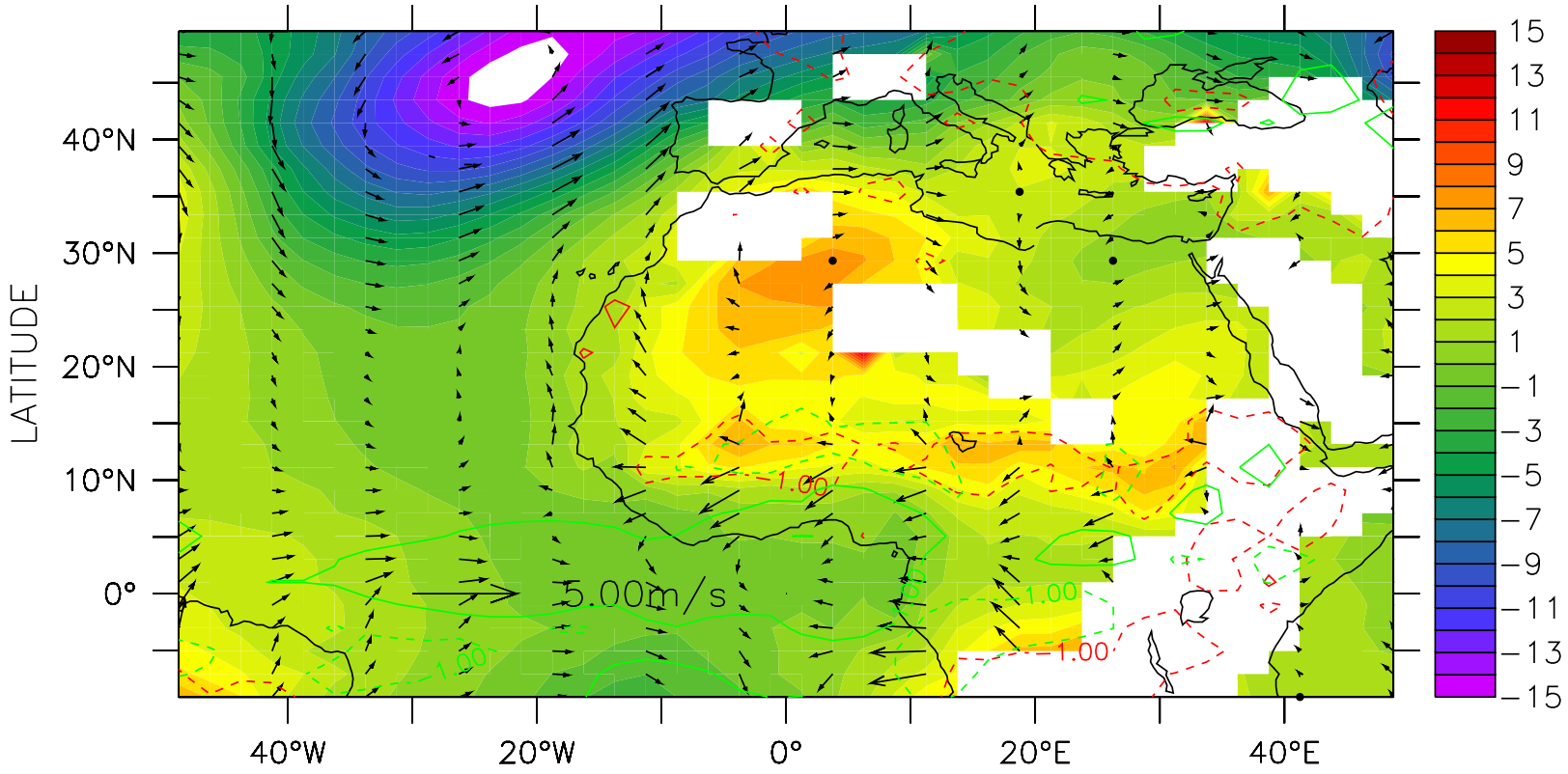
CONTOUR: tas (red)
CONTOUR: pr (green) august, FIX-INT, z925mb(m),1971-1990,GFDL

There is also an enhancement of low level westerlies.

Early season:
925mb Winds and Geopotential Height for May (INT)



Early season:
925mb Winds and Geopotential Height for May (FIX - INT)



[Tas= red contours; Pr = green contours]

Enhanced evaporation in FIX cools the near surface relative to INT and contributes to building high surface pressure over continent, suppressing monsoon onset.

Conclusions

- Model simulations suggest that the interactivity of soil moisture fundamentally influences the West African Monsoon.

- The apparent impacts vary over the course of the monsoon season:

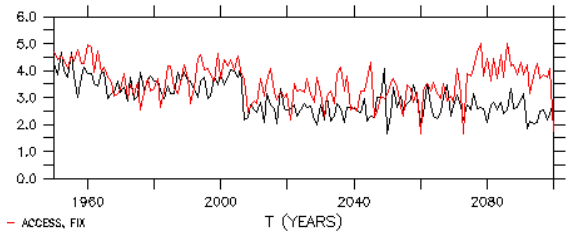
  - *At the onset of the monsoon, interactive soil moisture may promote warming of the surface and the development of favorable land-sea contrast necessary to initiate the monsoon.*

  - *During the core of the monsoon, it seems to be more about the modulating effect of soil moisture and associated evaporation on dry air inflow and/or circulation changes associated with the AEJ and low-level westerlies.*

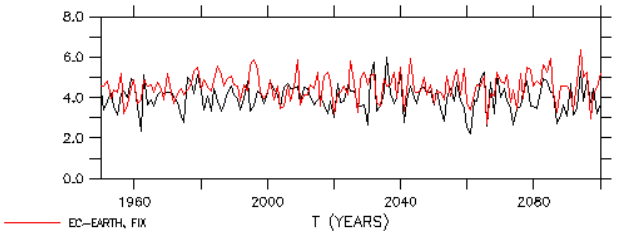
- A take home message here is that its not local recycling of enhanced evaporation but rather interplay of soil moisture and attendant surface changes with large-scale circulation - more reliable in models than local/ mesoscale soil moisture-convection feedbacks ? (cf. C.Taylor's work).

- Need to confirm processes in all participating models / understand model differences in precipitation response.

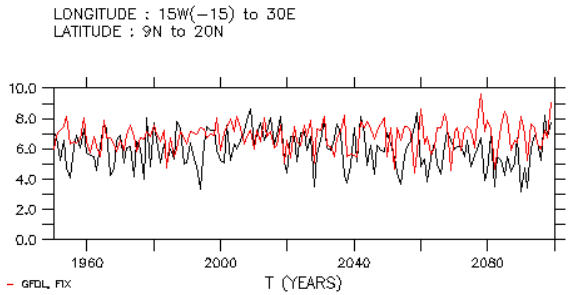
Mean JJA Precipitation over the Sahel



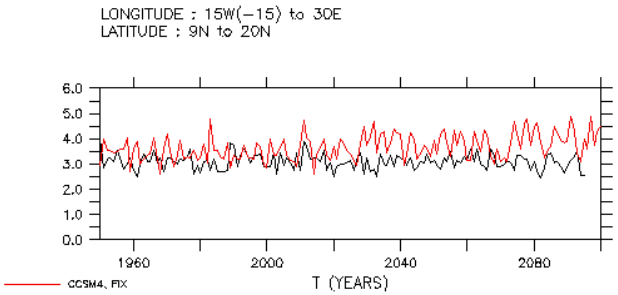
ACCESS (INT, JJA)



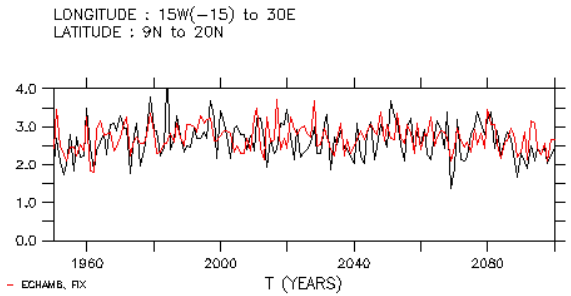
EC−EARTH (INT, JJA)



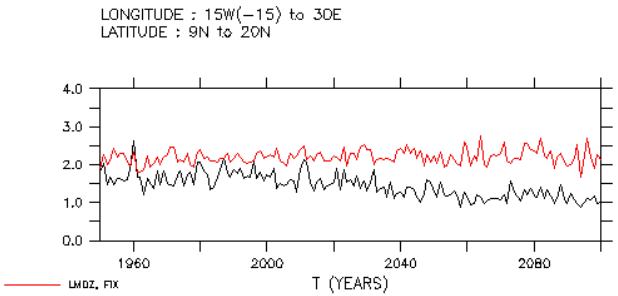
GFDL (INT, JJA)



CCSM4 (INT, JJA)



ECHAM6 (INT, JJA)



LMDZ (INT, JJA)

- A range of future projections in the control simulations.
- Simulations with prescribed late 20th century soil moisture tend to dry less in the future.