Impact of sea surface temperatures on African climate

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Outline:

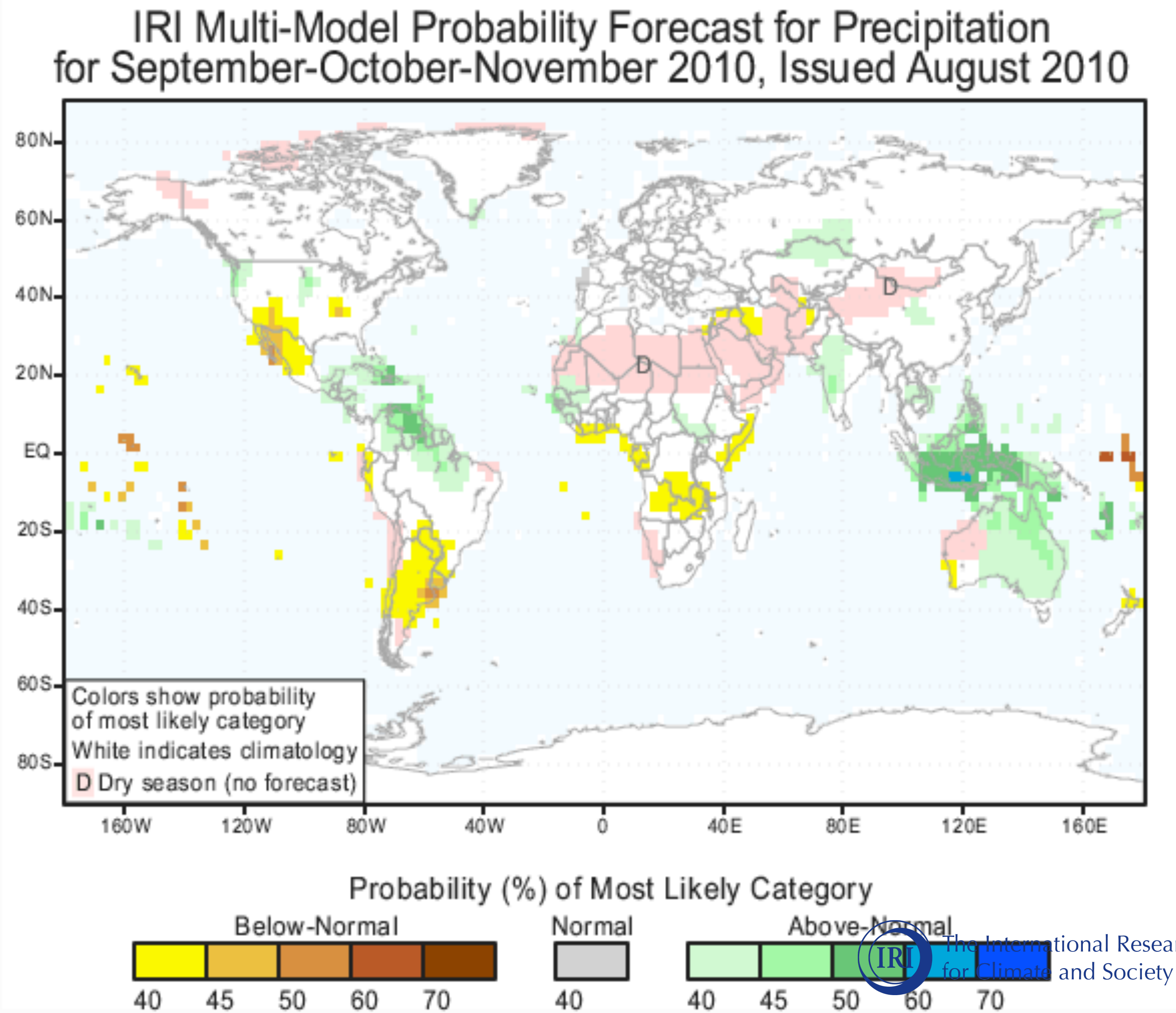
Intro/Motivation: demand-driven science, use of seasonal climate prediction, adaptation to climate change…

1. The influence of SST on African climate:
   ENSO on interannual time scale
   longer-term variations (e.g. drought in the Sahel)
   (time scales dictated by ocean dynamics)

2. Influences on Europe:
   Atlantic SST, convection (e.g. 2003 heat wave)
   Indian Ocean SST, convection (e.g. NAO trends)

3. Understanding projections of future change:
   the role of SST/remote v. land/local influences

working at the intersection of predictability and vulnerability…



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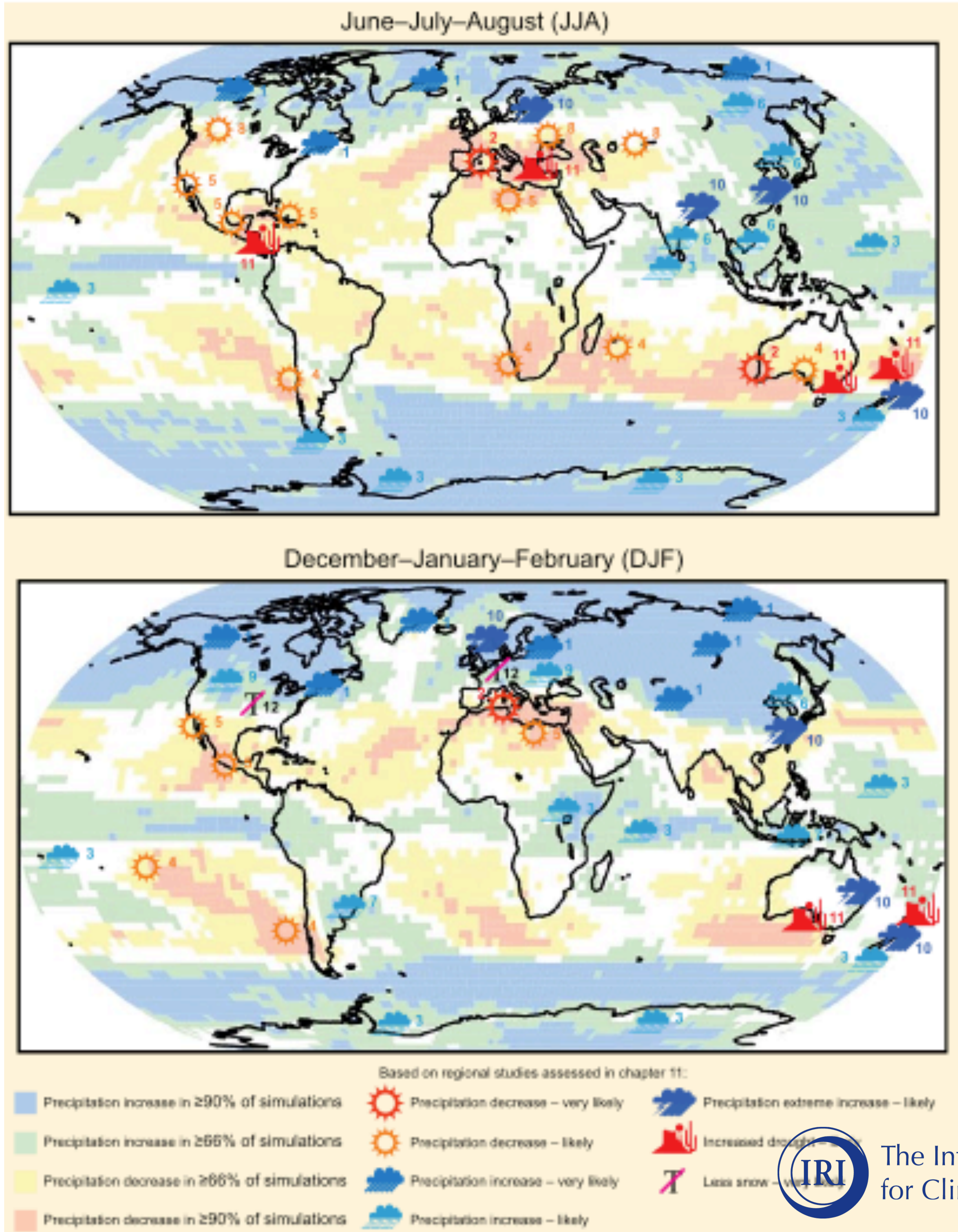
Projections of precipitation: incoherent in tropical regions



Christensen et al 2007, in IPCC AR4

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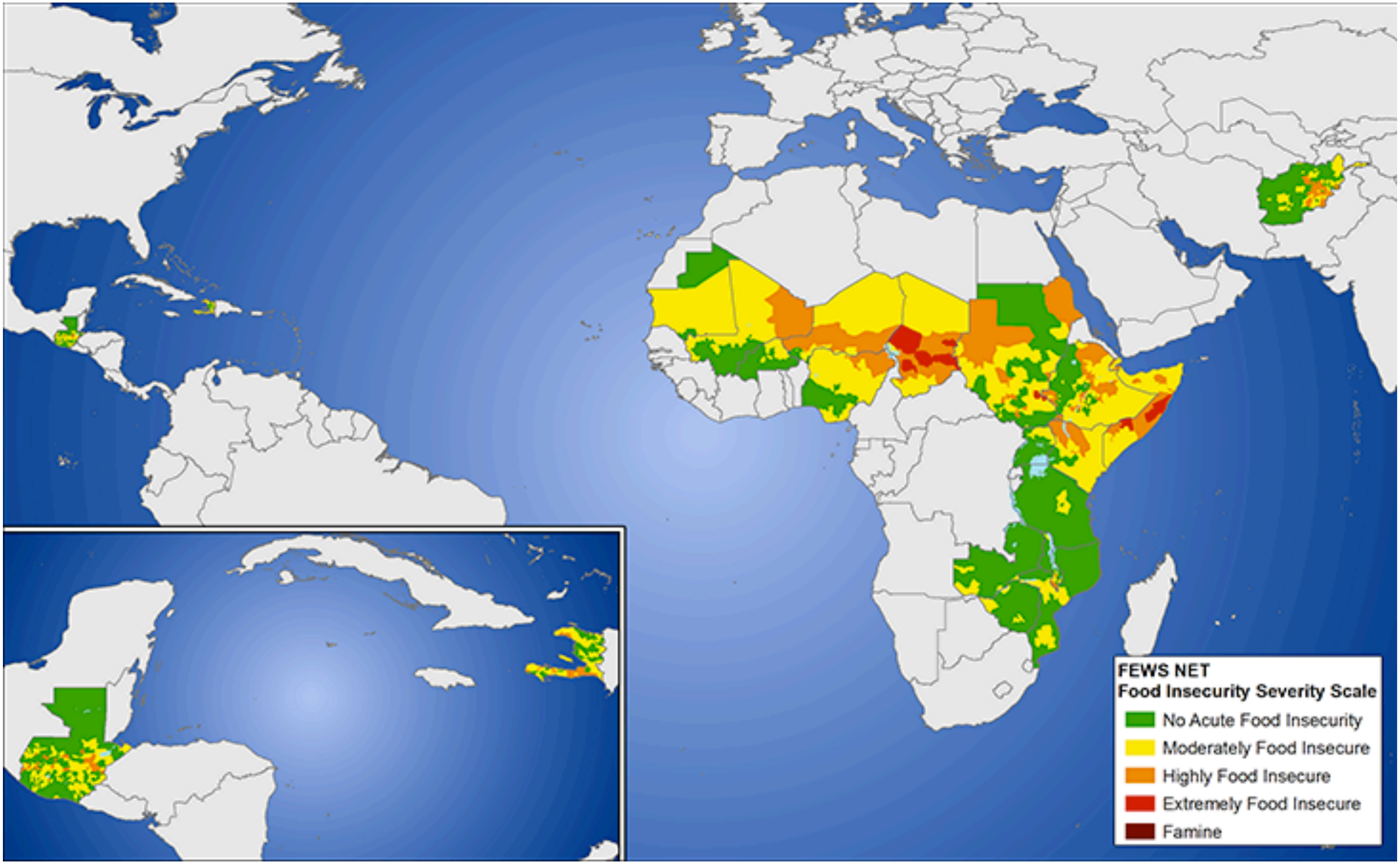
Famine Early Warning Systems: www.fews.net



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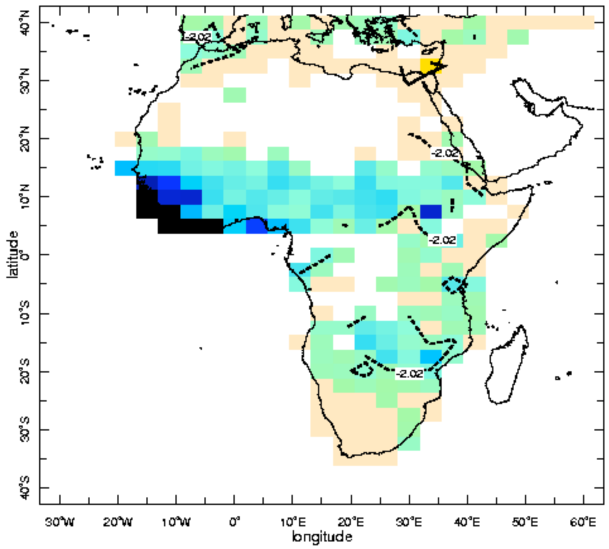
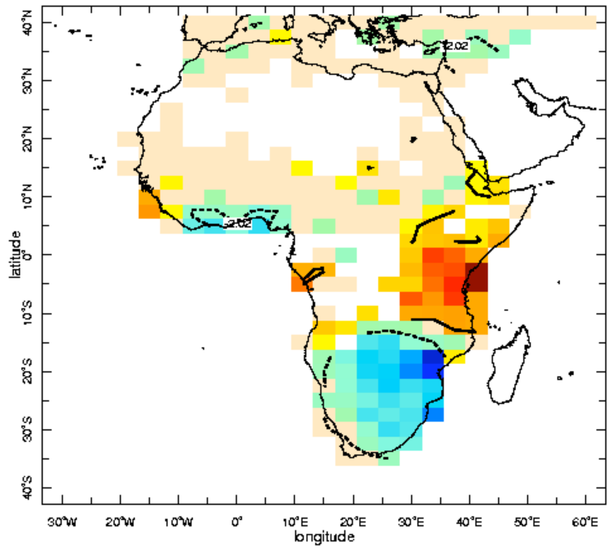
Dominant patterns of observed rainfall variability

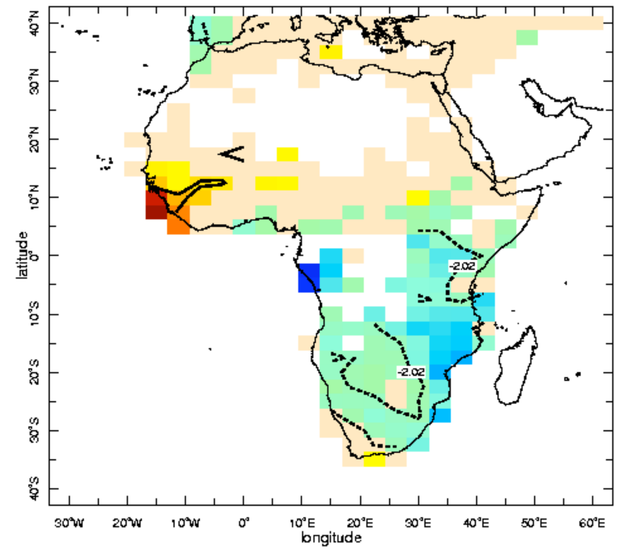
Jul-Jun 1930-1995



1.



3.



17% of Jul-Jun variance

EOF1 of Apr-Jun (11%)
EOF1 of Jul-Sep (24%)

9% Jul-Jun variance

EOF1 of Oct-Dec (17%)
EOF1 of Jan-Mar (18%)

7% of Jul-Jun variance

Giannini, Biasutti, Held and Sobel 2008, in *Climatic Change*

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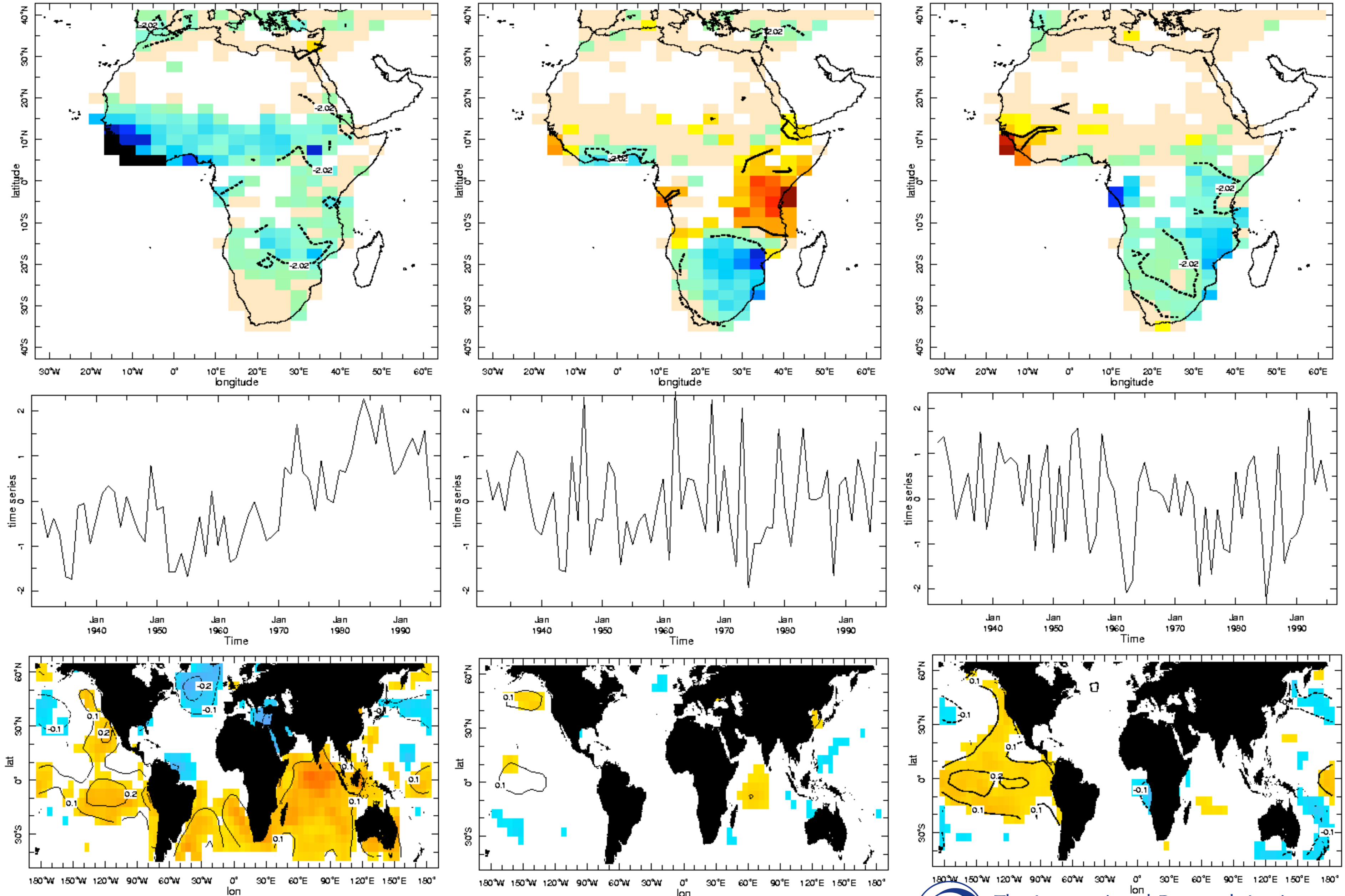
…and their relation to sea surface temperatures



1.

Giannini, Biasutti, Held and Sobel 2008, in *Climatic Change*

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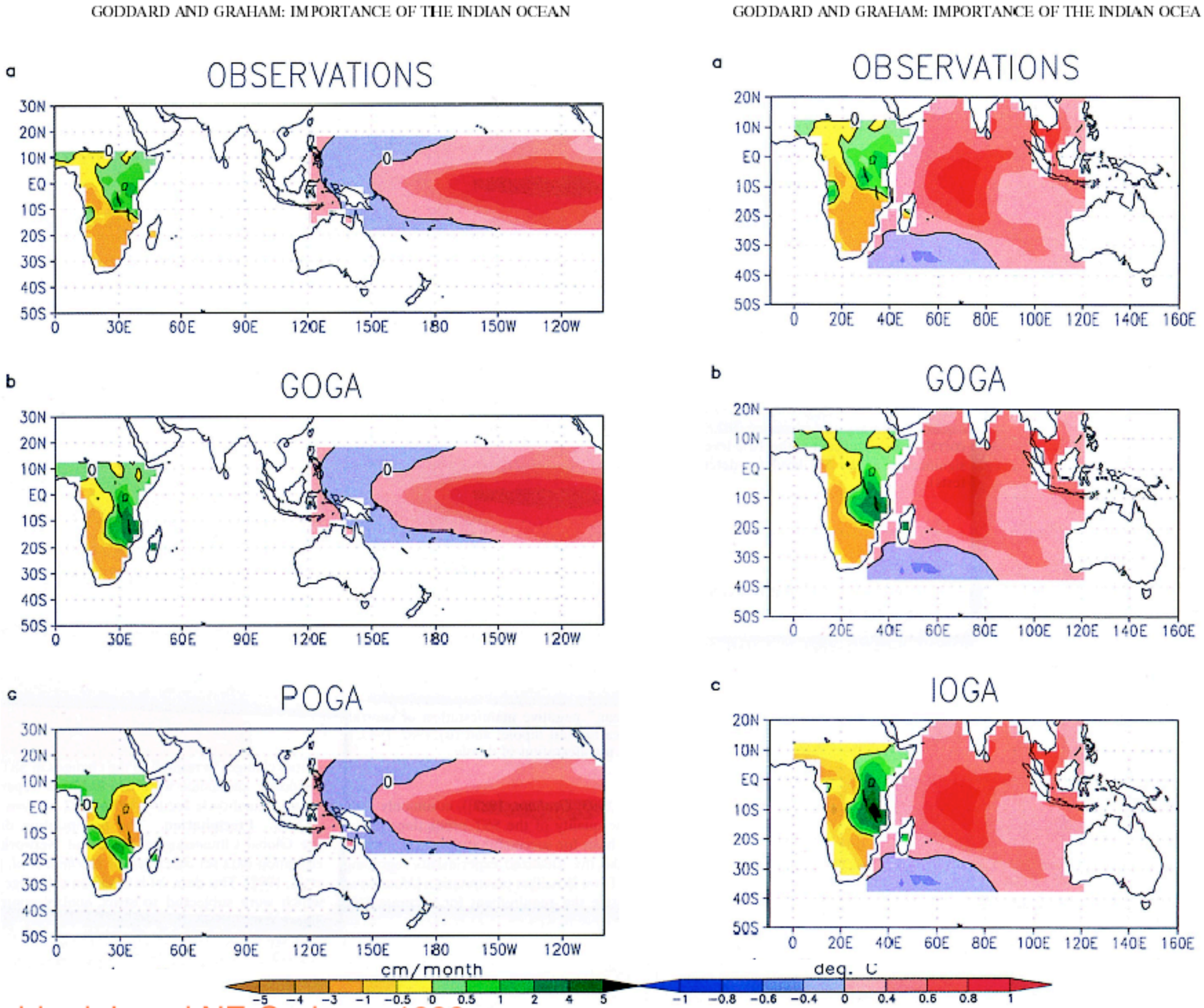
ENSO influence on eastern and southern Africa



Goddard, L and NE Graham, 1999. "Importance of the Indian Ocean for simulating rainfall anomalies over eastern and southern Africa", J Geophys Res, 104, 19099-19116

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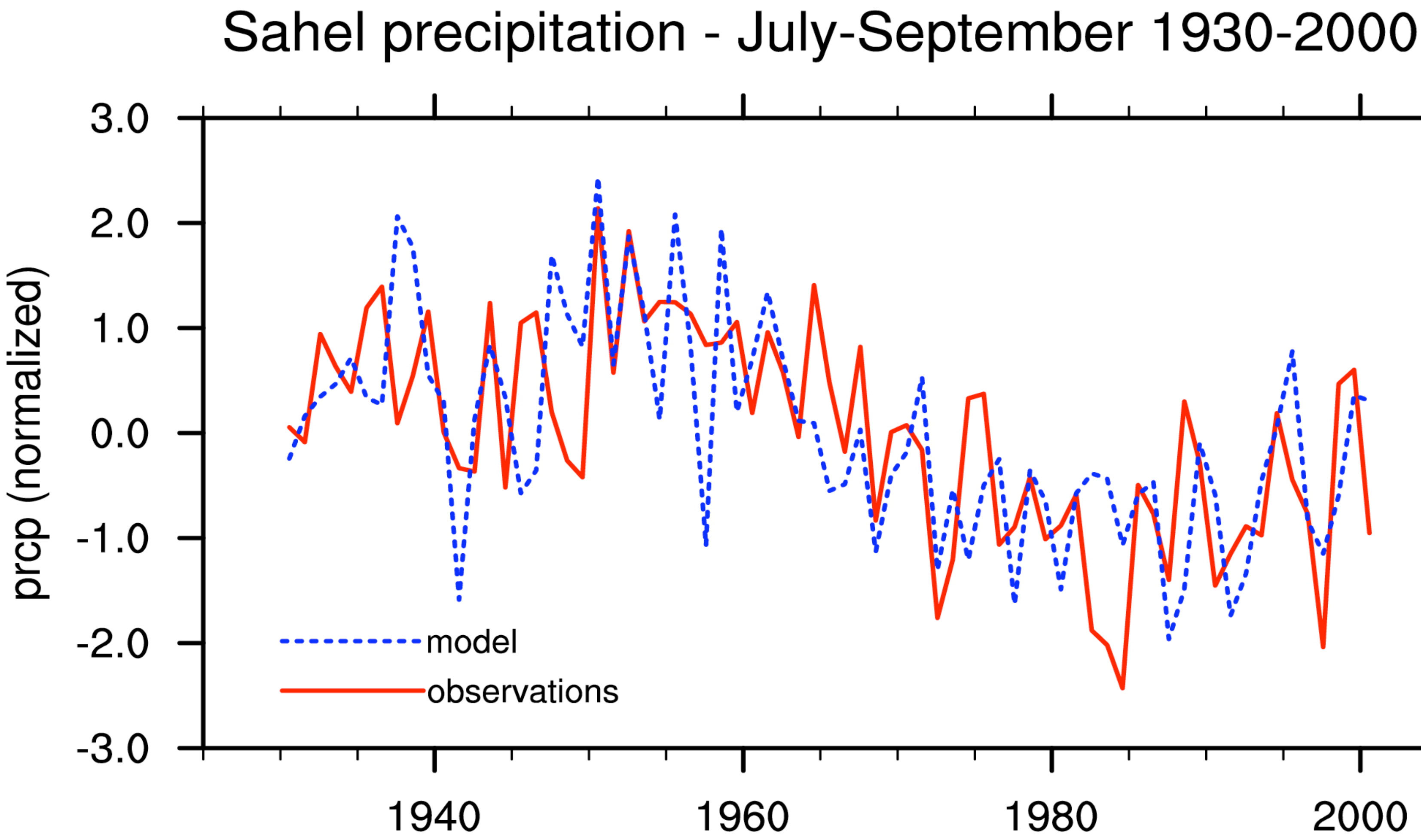

Giannini, A, R Saravanan, P Chang 2003, in *Science*

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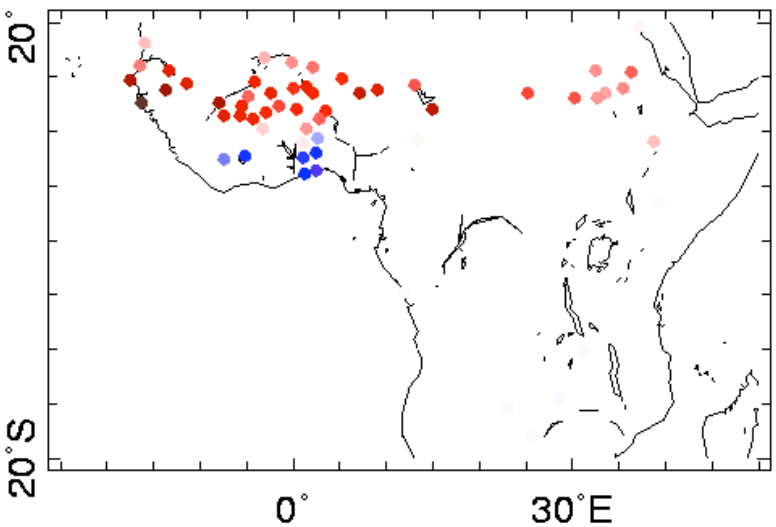
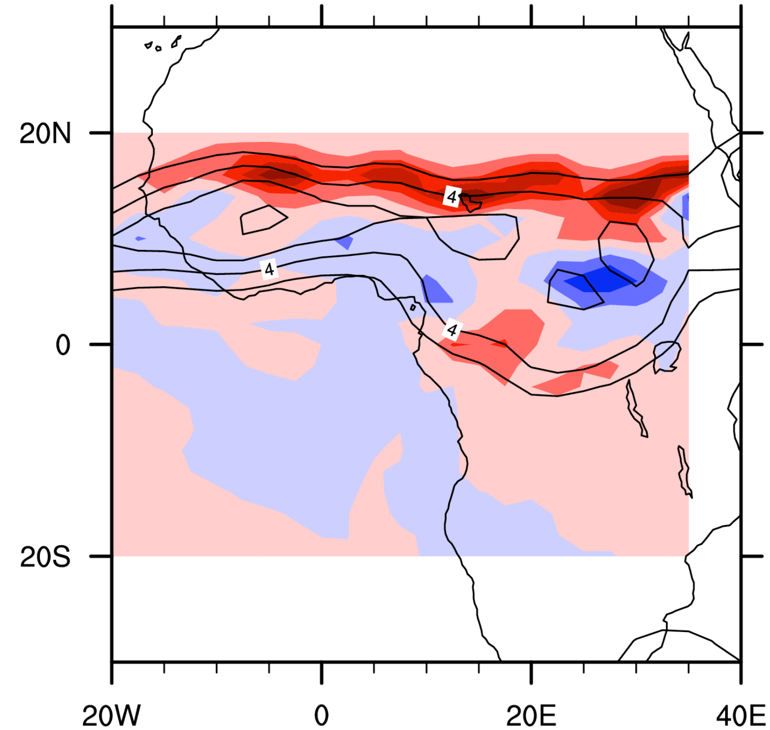
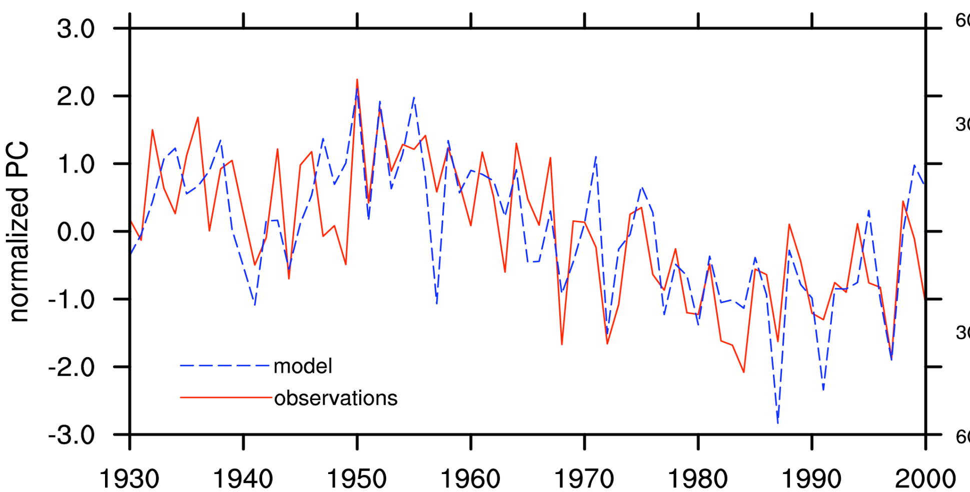
Variability in Sahel rainfall

(25% in obs, 21% in ens-mean)

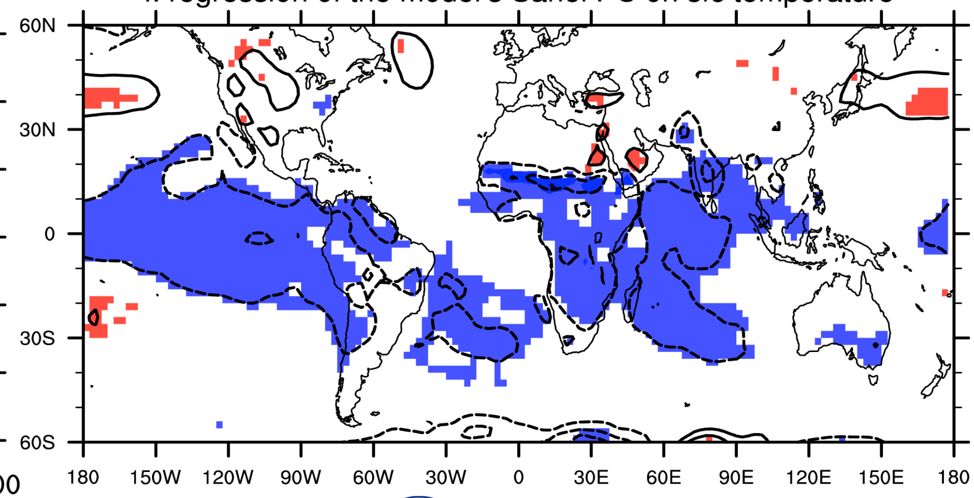




e. Sahel PC of 1930-2000 precipitation



f. regression of the model's Sahel PC on sfc temperature



Giannini, A, R Saravanan, P Chang 2005 in Clim. Dyn.

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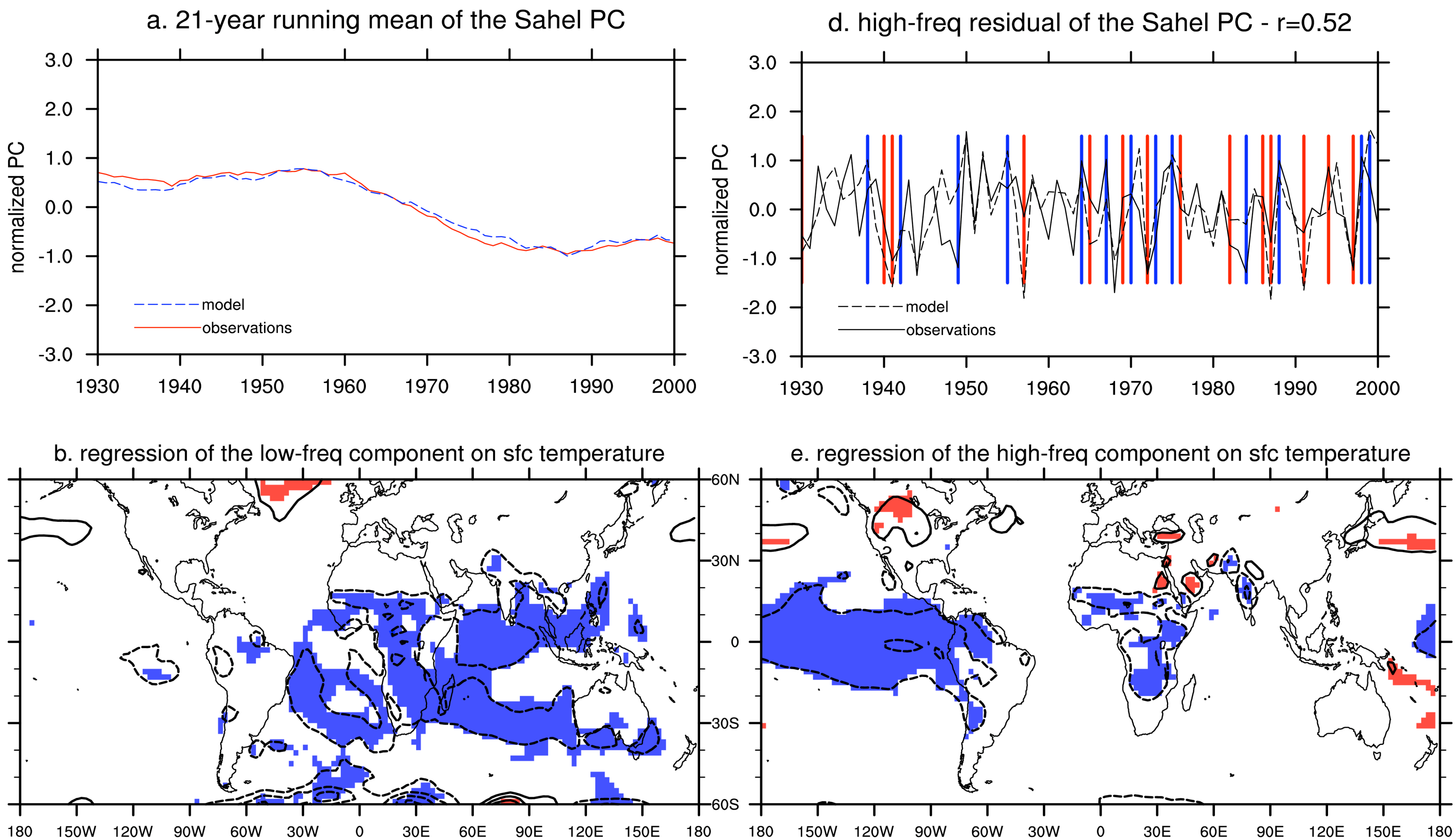
Variability in Sahel rainfall: interdecadal and interannual time scales



Giannini, A, R Saravanan, P Chang 2003 in *Science*

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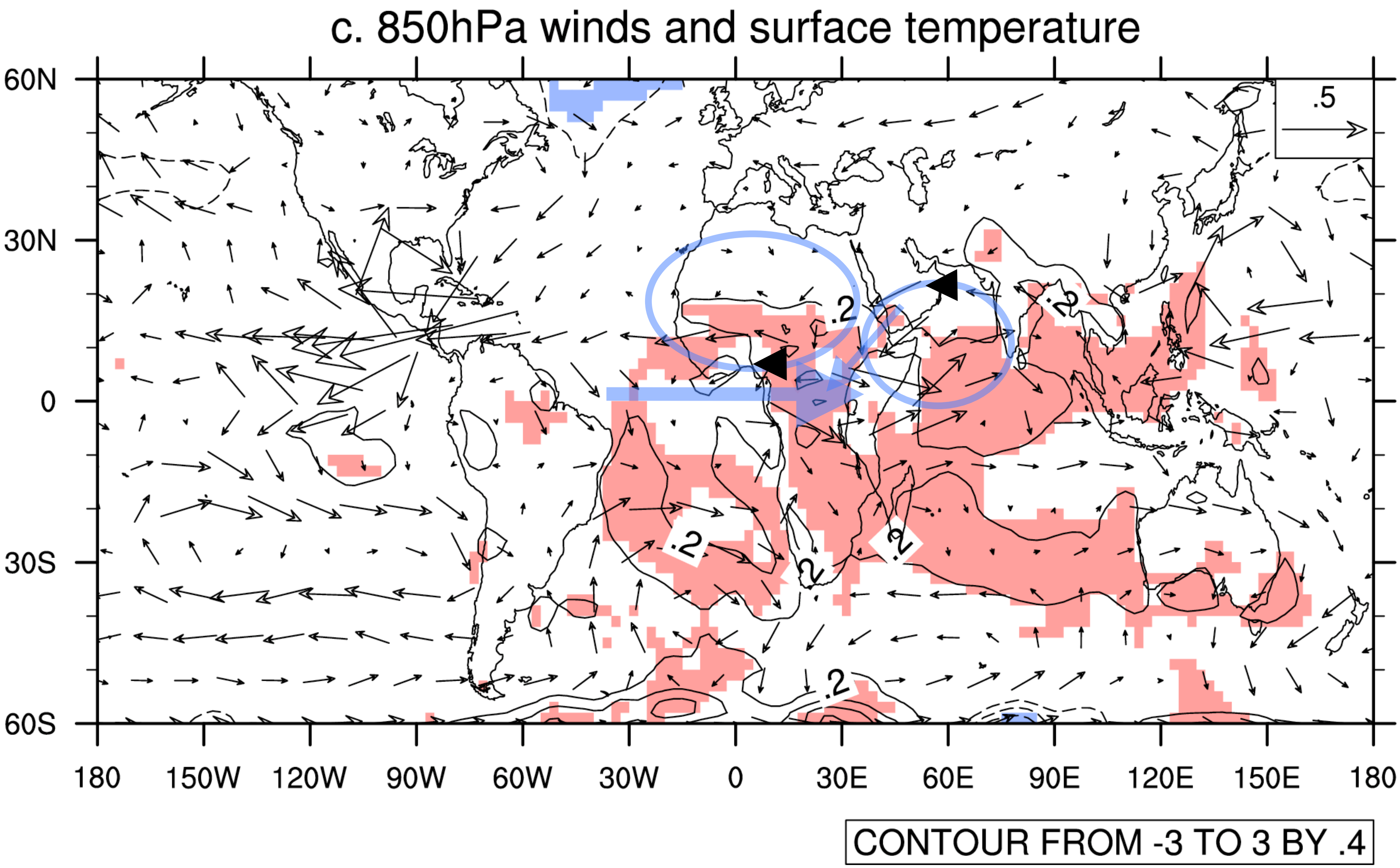
Response to diabatic heating in the equatorial Indian Ocean



Bader and Latif 2003, in Geophys. Res. Lett.
Hagos and Cook 2008, in J. Climate

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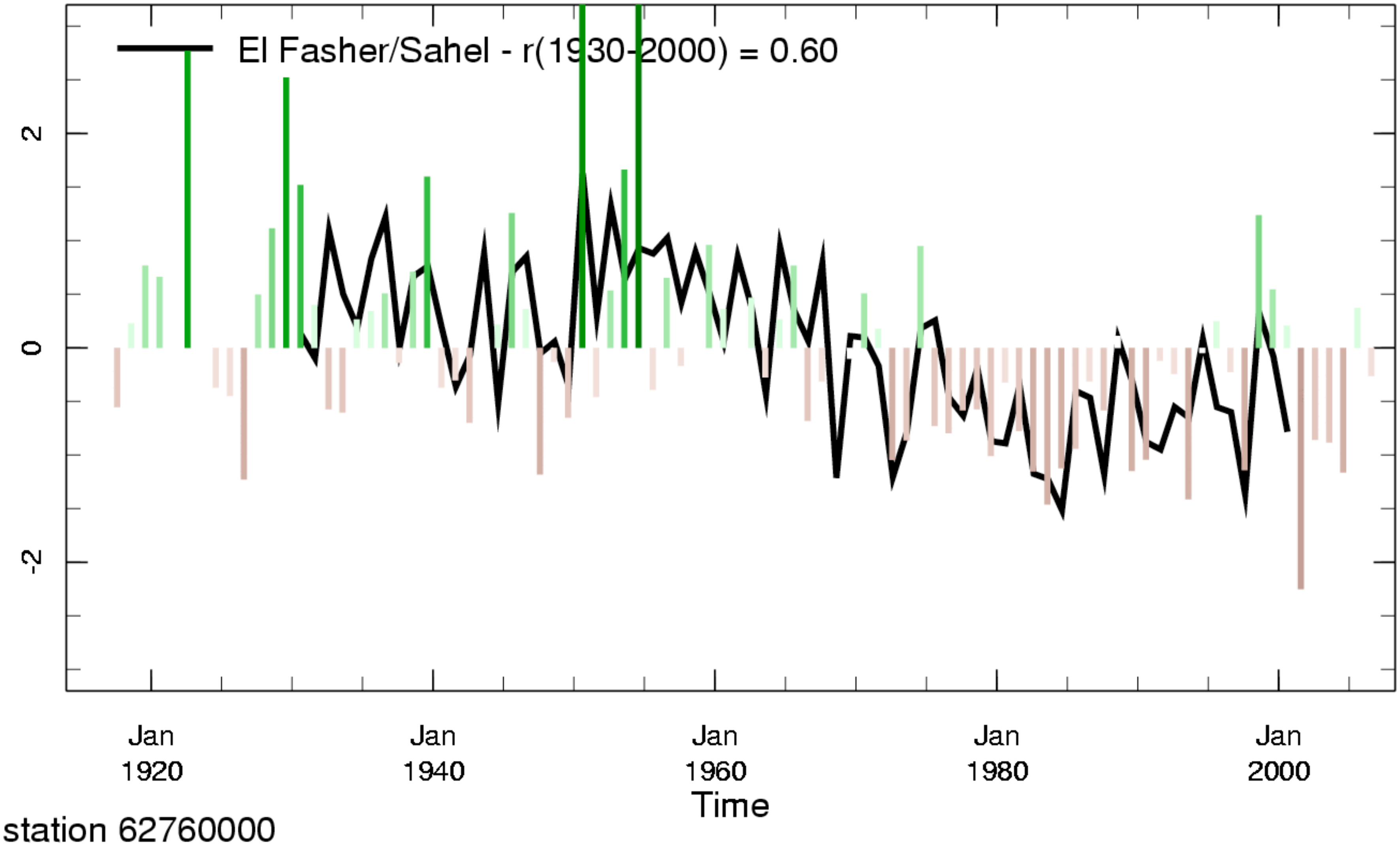

El Fasher long-term mean = 255 mm/year
El Fasher standard deviation = 35 mm/month
Sahel standard deviation = 22 mm/month

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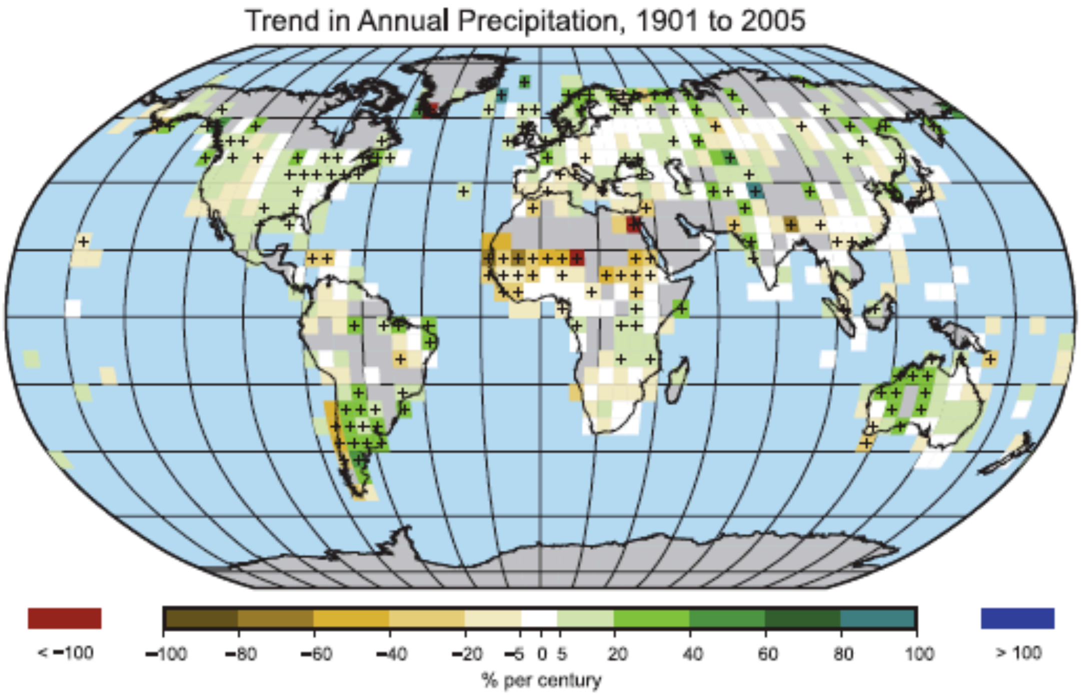

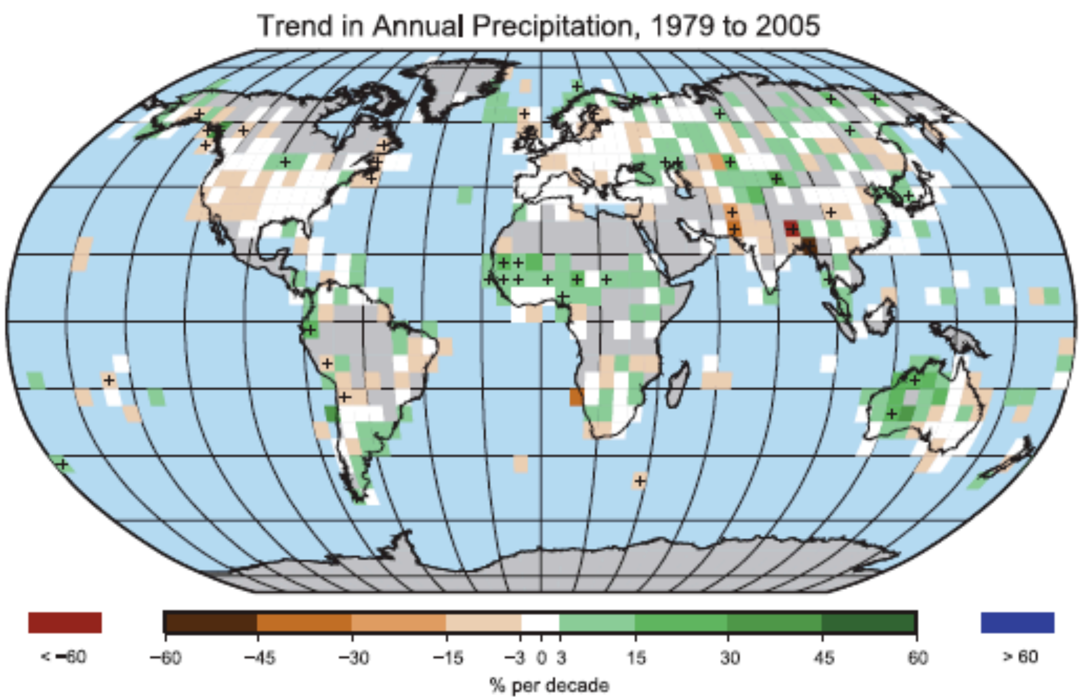

IPCC/AR4/WG1, Ch.3
(Trenberth et al, 2007)
trends in
annual precipitation

1901-2005

1979-2005

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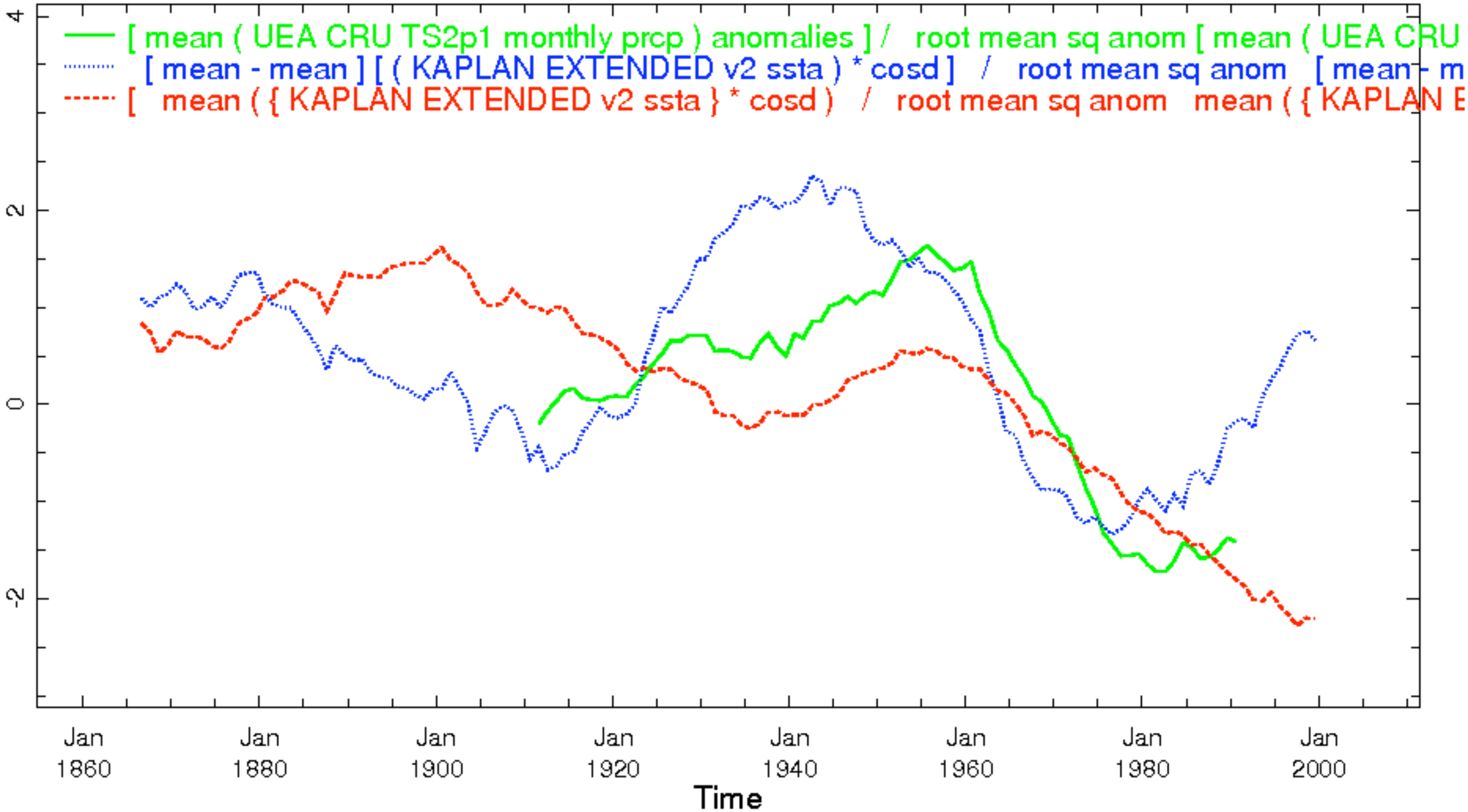
Roles of Atlantic and Indian Ocean SSTs

attribution: natural (decadal) variability or global warming?



green – Sahel rainfall

blue – north Atlantic SST (minus global mean)

red – equatorial Indian Ocean SST (with sign reversed)

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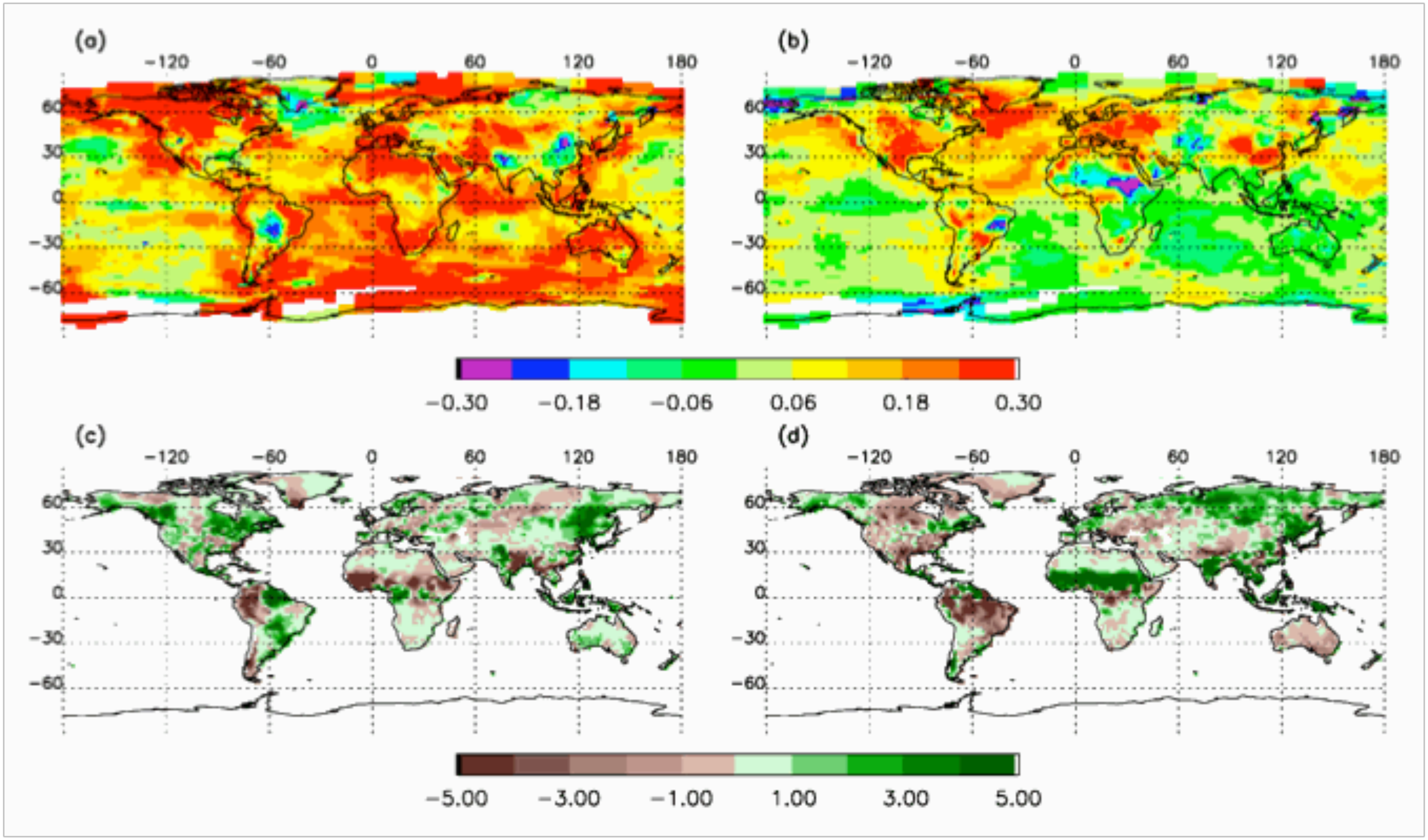
The relative roles of external forcing and internal variability

Mingfang Ting (LDEO), personal communication



Ting et al 2009, in J Climate

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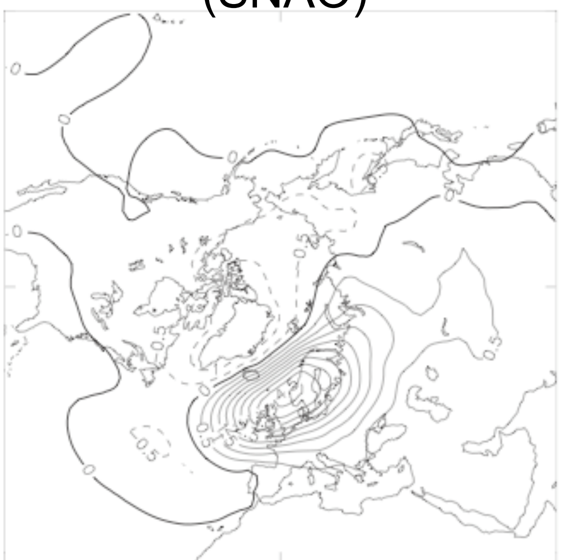
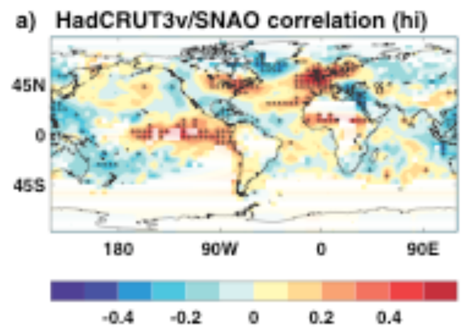
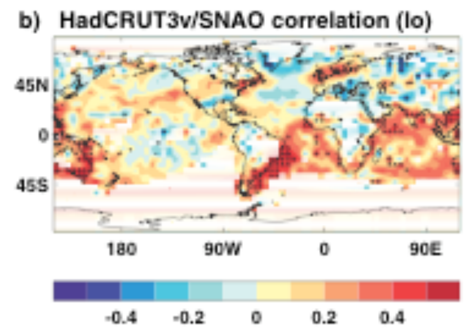
Tropical SSTs influence European, African climate independently

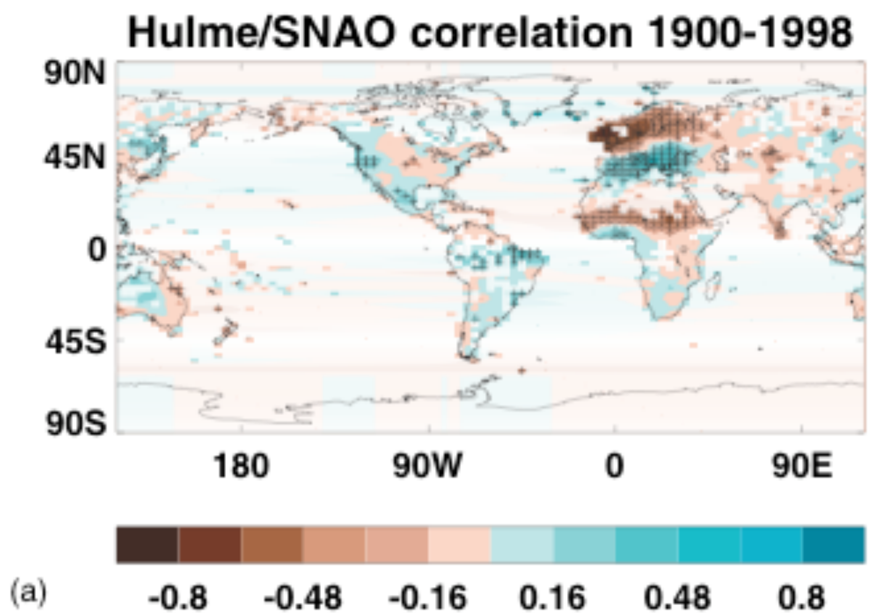
The summertime NAO (SNAO)







correlation w/ sfc temp



correlation w/ precipitation

Folland et al 2009, in J Climate

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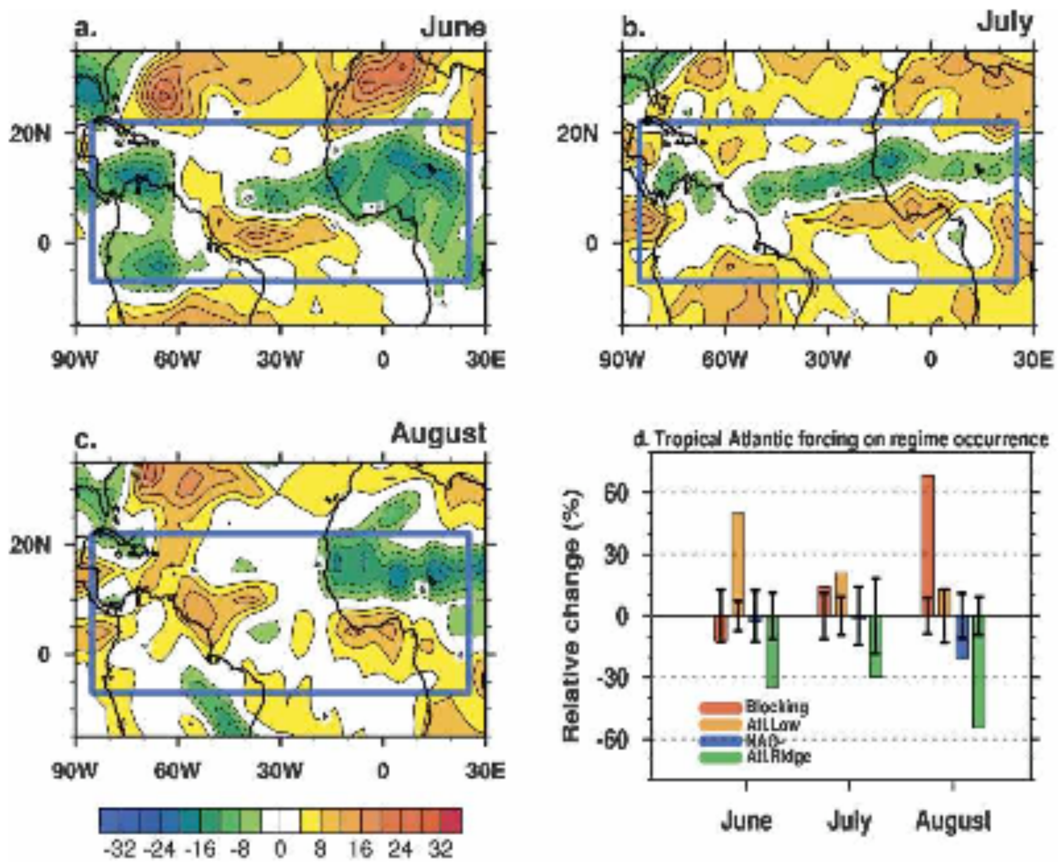
Tropical Atlantic convection shifts frequency of occurrence of European summer weather regimes



Cassou et al 2005, in J Climate

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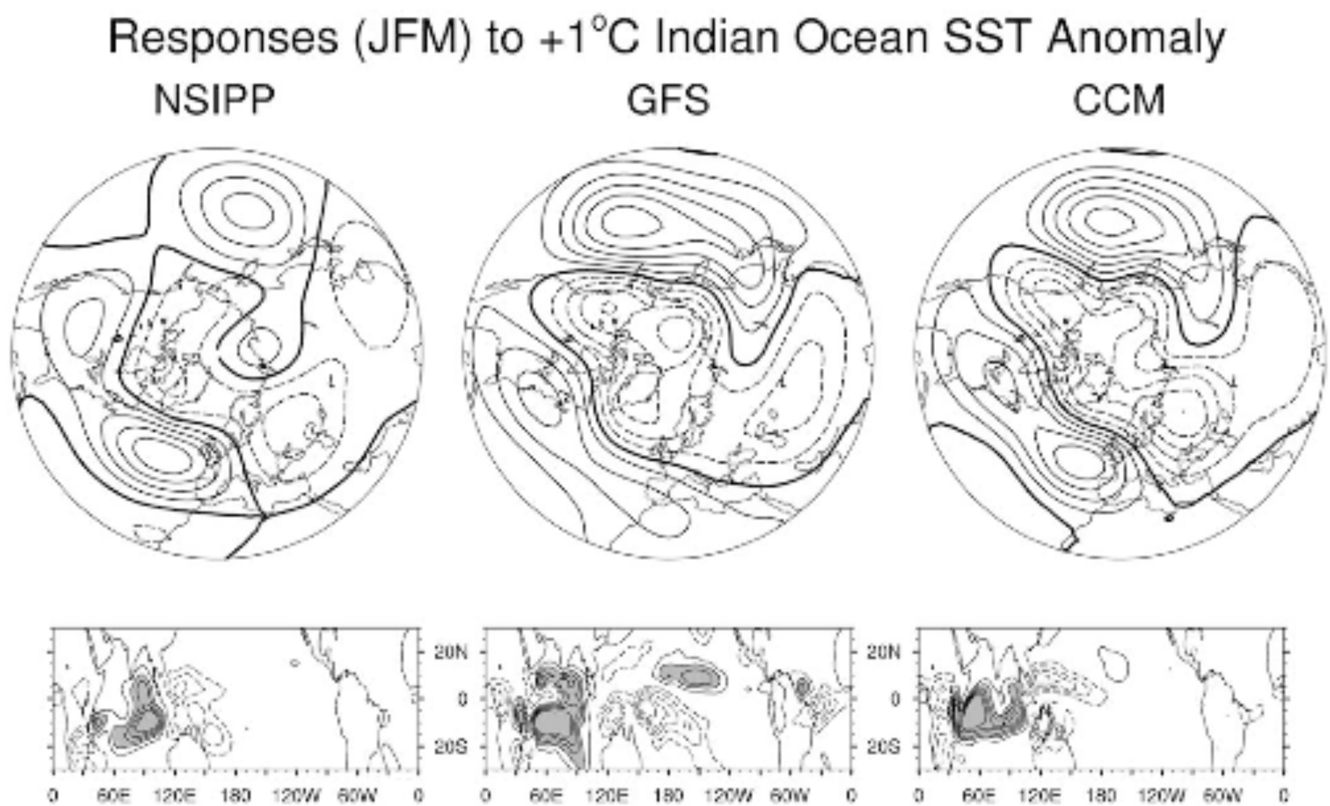
Indian Ocean warming favors the positive NAO phase

500 hPa height – contours every 15m

precipitation – contours every 1mm/day



Hoerling et al 2004, in Clim Dyn
Also see Bader and Latif 2003, in Geophys Res Lett

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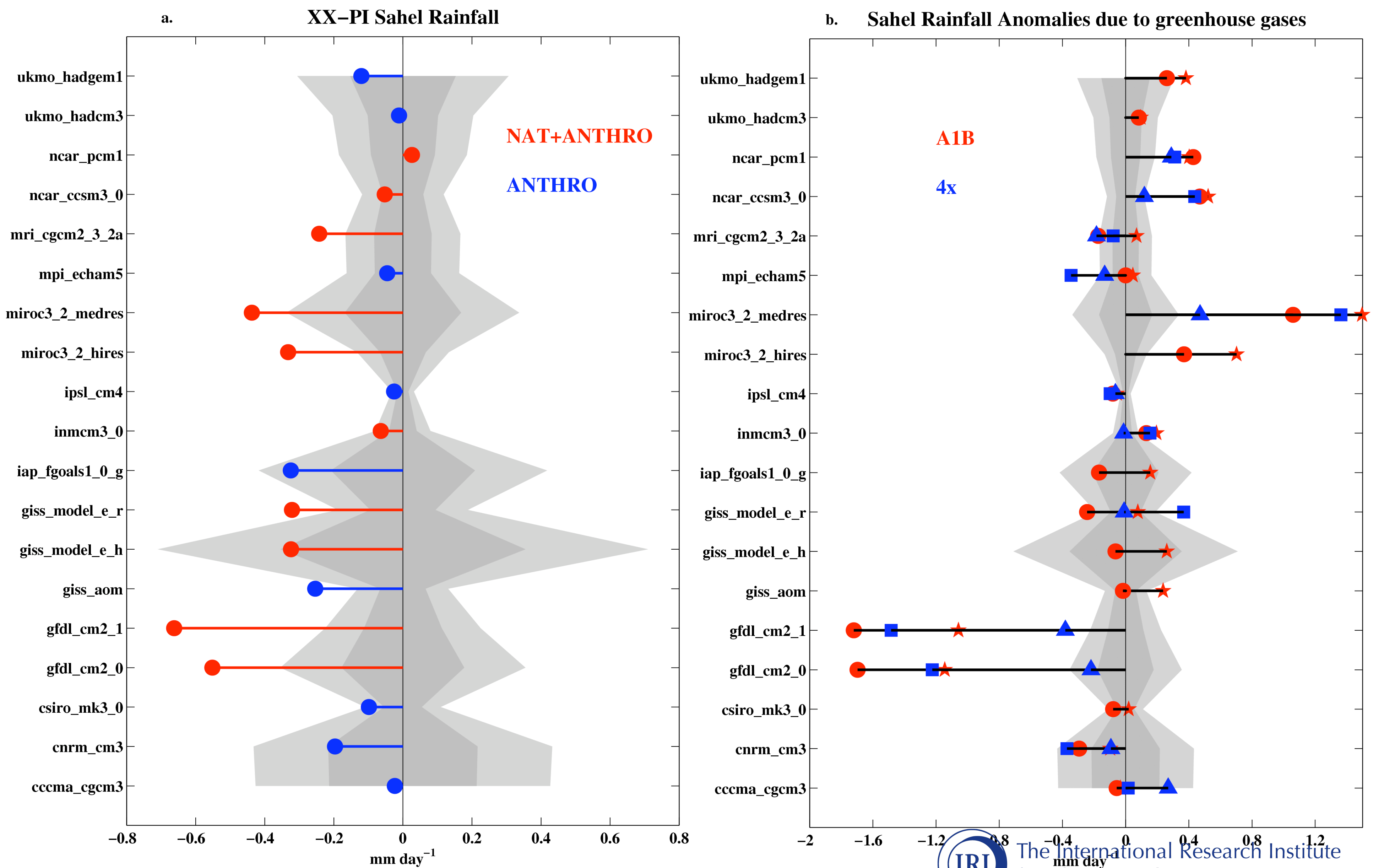
IPCC AR4 simulations: from coherence to divergence



Biasutti, M and A Giannini, 2006 (Geophys. Res. Lett.)

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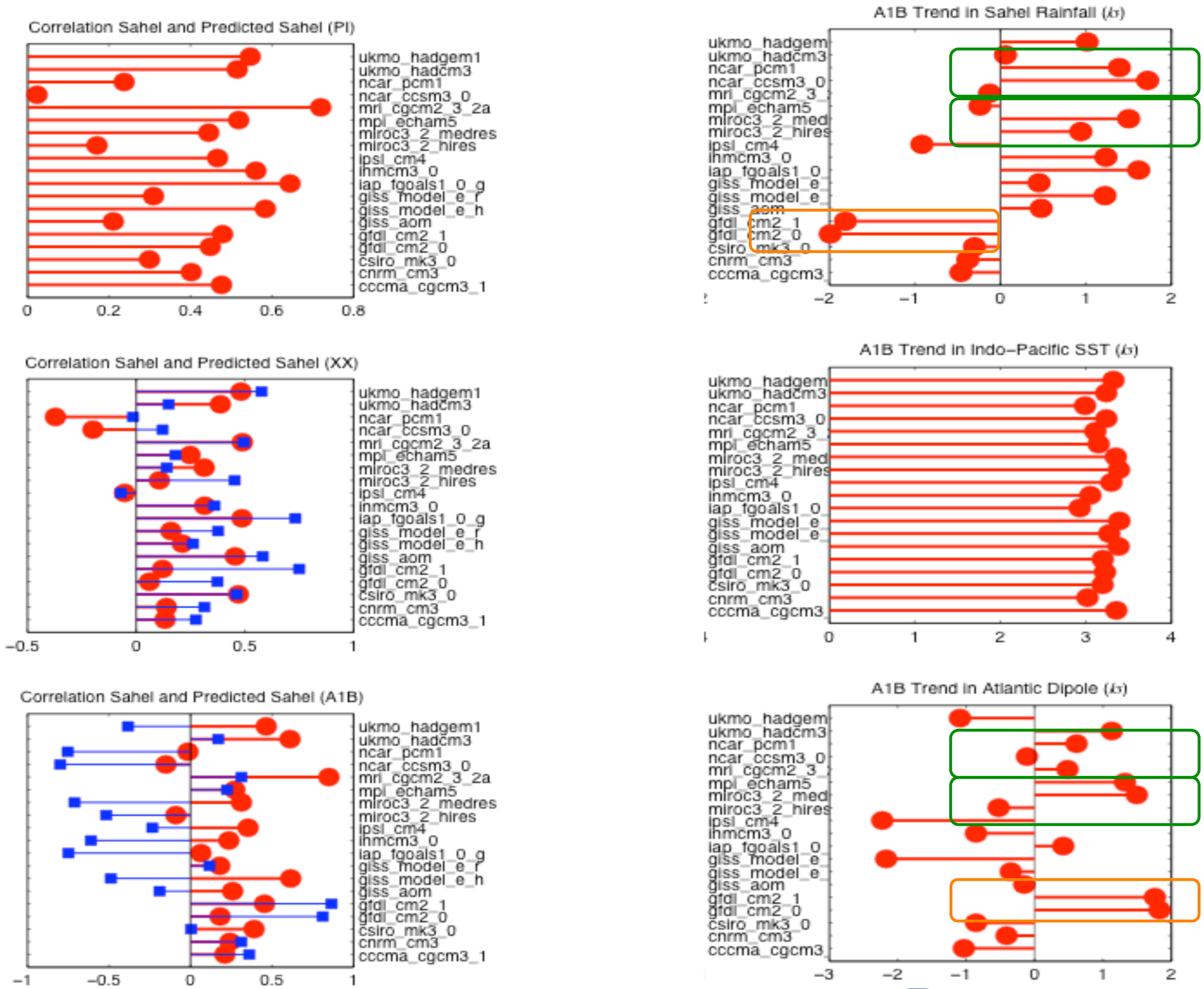
Differences in SST projections do not explain the divergence in projections of regional precipitation



Biasutti et al 2008, in *J Climate*

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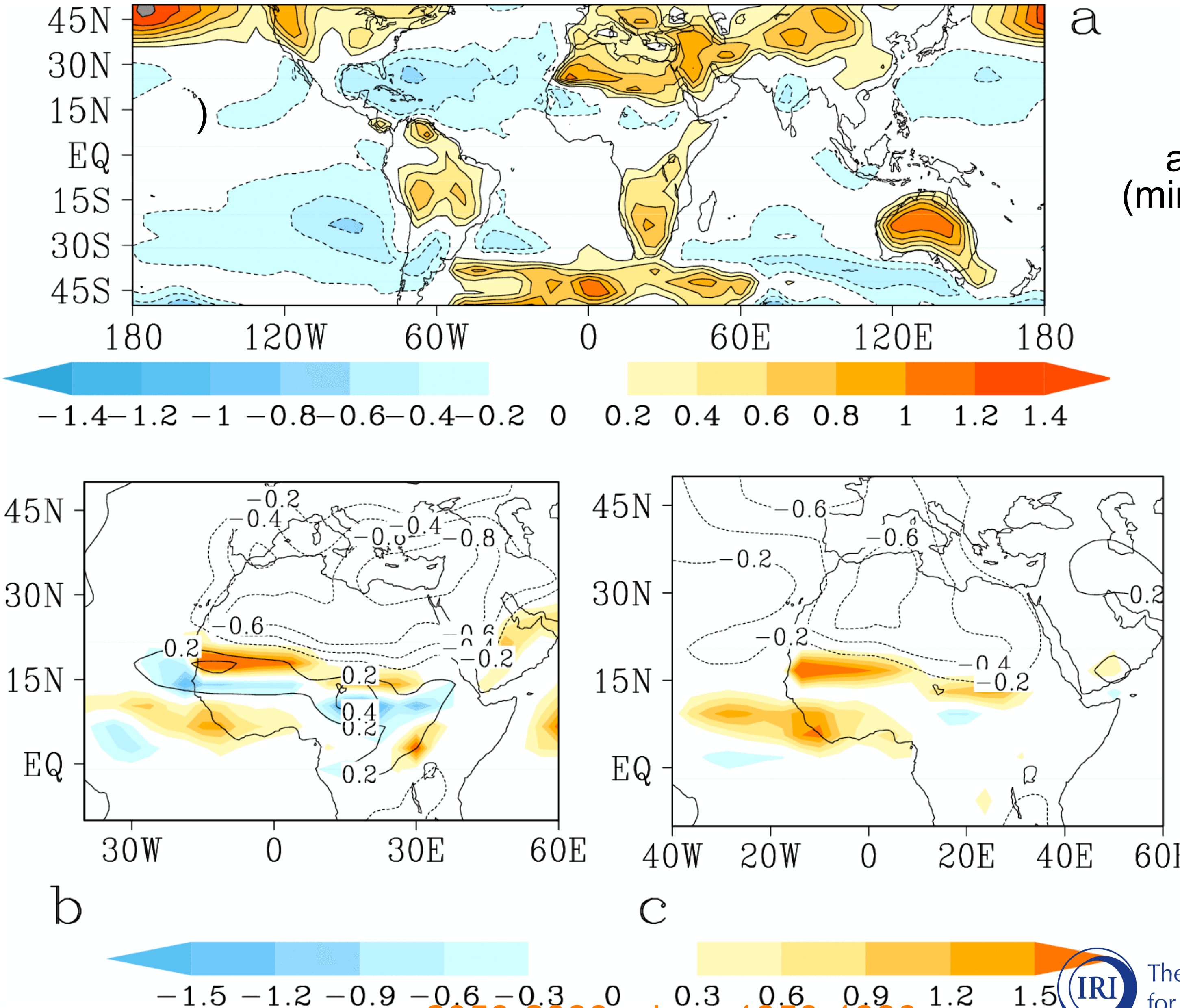
Will the African monsoon strengthen?

Haarsma et al, 2005 (Geophys. Res. Lett.)



surface
air temperature
(minus global mean)

precipitation

2050-2080 minus 1950-1980

Or will warmer oceans dry out continents?

Held et al, PNAS 2005

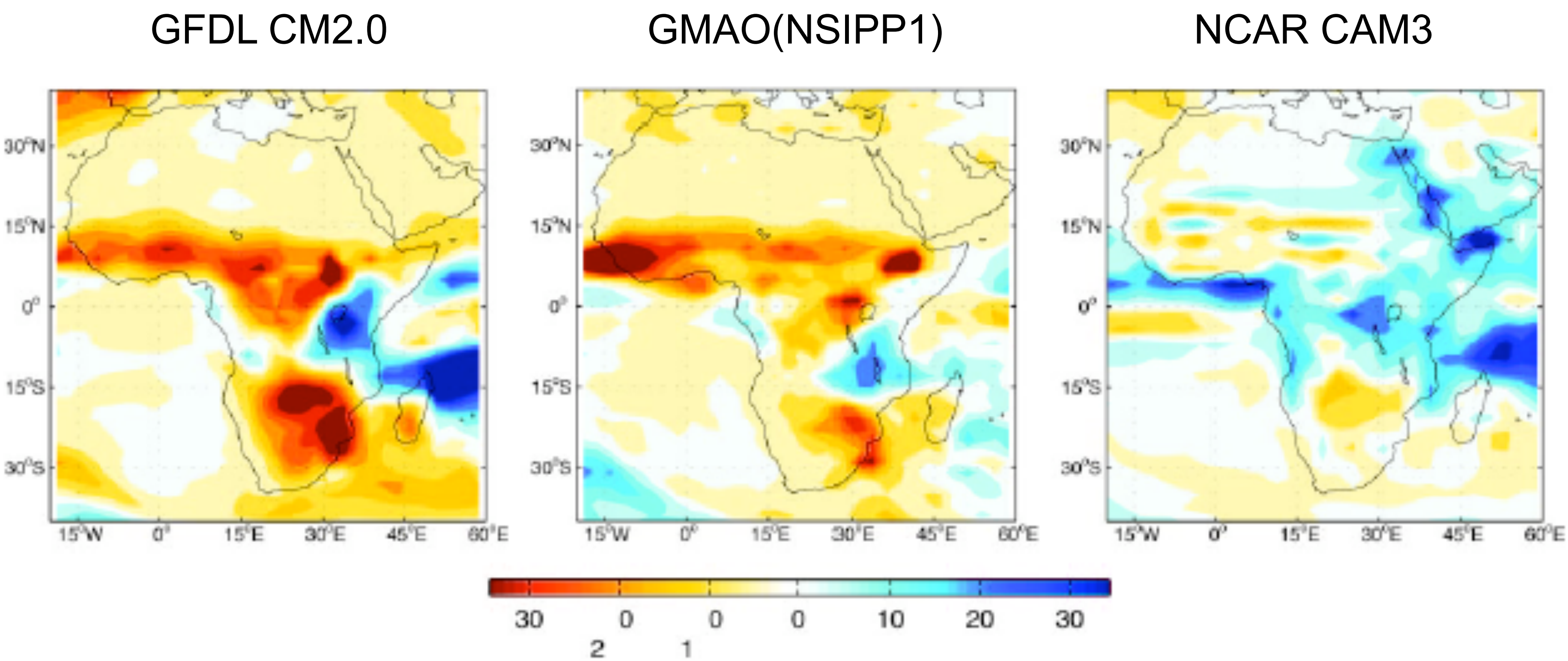


Fig. 5. The annual mean precipitation response of three atmospheric models to a uniform warming of ocean temperatures. (*Left*) The atmospheric component of CM2.0. (*Center*) A model developed at National Aeronautics and Space Administration's Global Modeling and Assimilation Office (J. Bacmeister, personal communication). (*Right*) The CAM3 model developed at the National Center for Atmospheric Research (J. Kiehl, personal communication).

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Connecting **energy and water cycles** in the moist static energy framework (Neelin and Held 1987; Zeng and Neelin 1999; Liepert et al 2004)

$$\partial_t m + \nabla \bullet m\mathbf{v} + \partial_p m\omega = g\, \partial_p F$$

where $m = gz + c_p T + Lq$ is moist static energy and $g\, \partial_p F$ is the net energy flux

Giannini 2010, in J Climate

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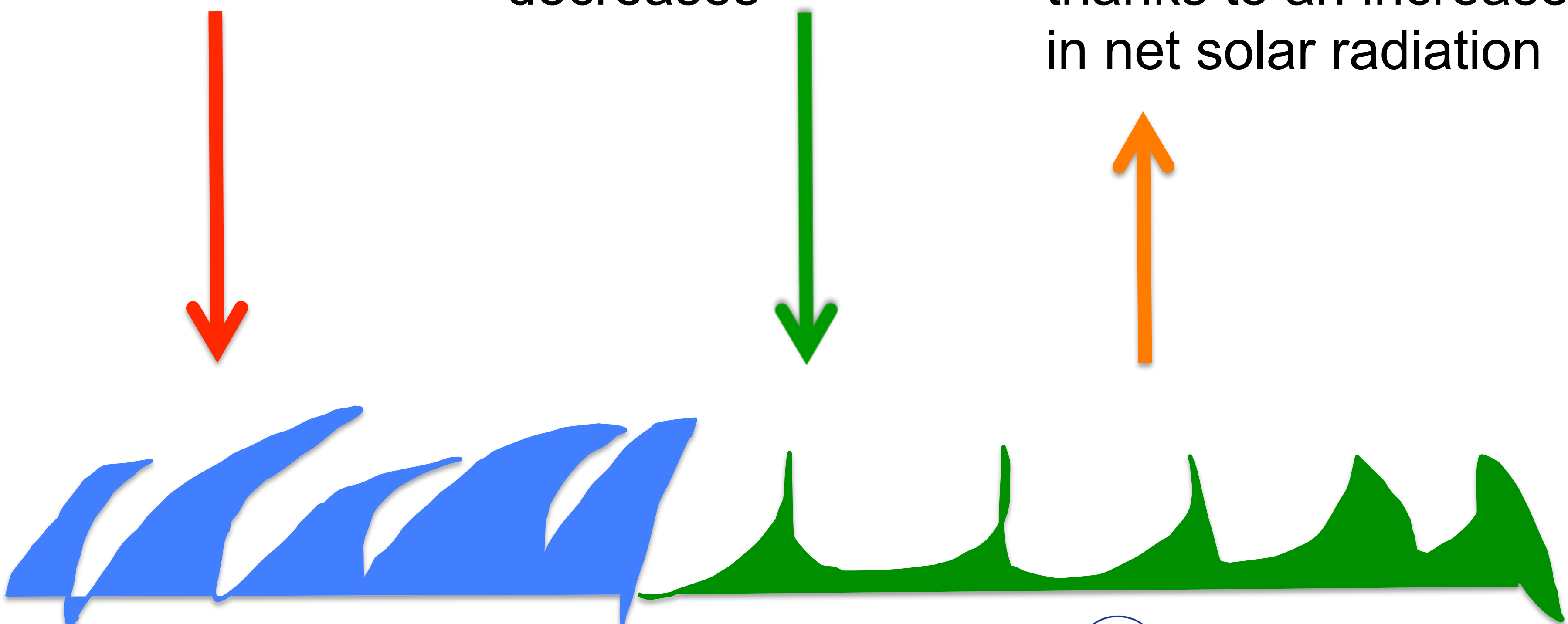
The dominance of
a remote/ocean top-down mechanism
leads to projection of a drier Sahel:

this is consistent with studies that highlight
the connection between sea surface temperature and rainfall:
in the climate change context
vertical stability is set globally, from the top
in a way analogous to the impact of ENSO
on the global tropical troposphere

Warming of the oceans warms the tropical troposphere, setting vertical instability globally

When the energy requirement for deep convection to occur cannot be met over land, because moisture is lacking, precipitation decreases

With reduced precipitation and evaporation, reduced cloud cover and net surface terrestrial radiation, the surface warms thanks to an increase in net solar radiation



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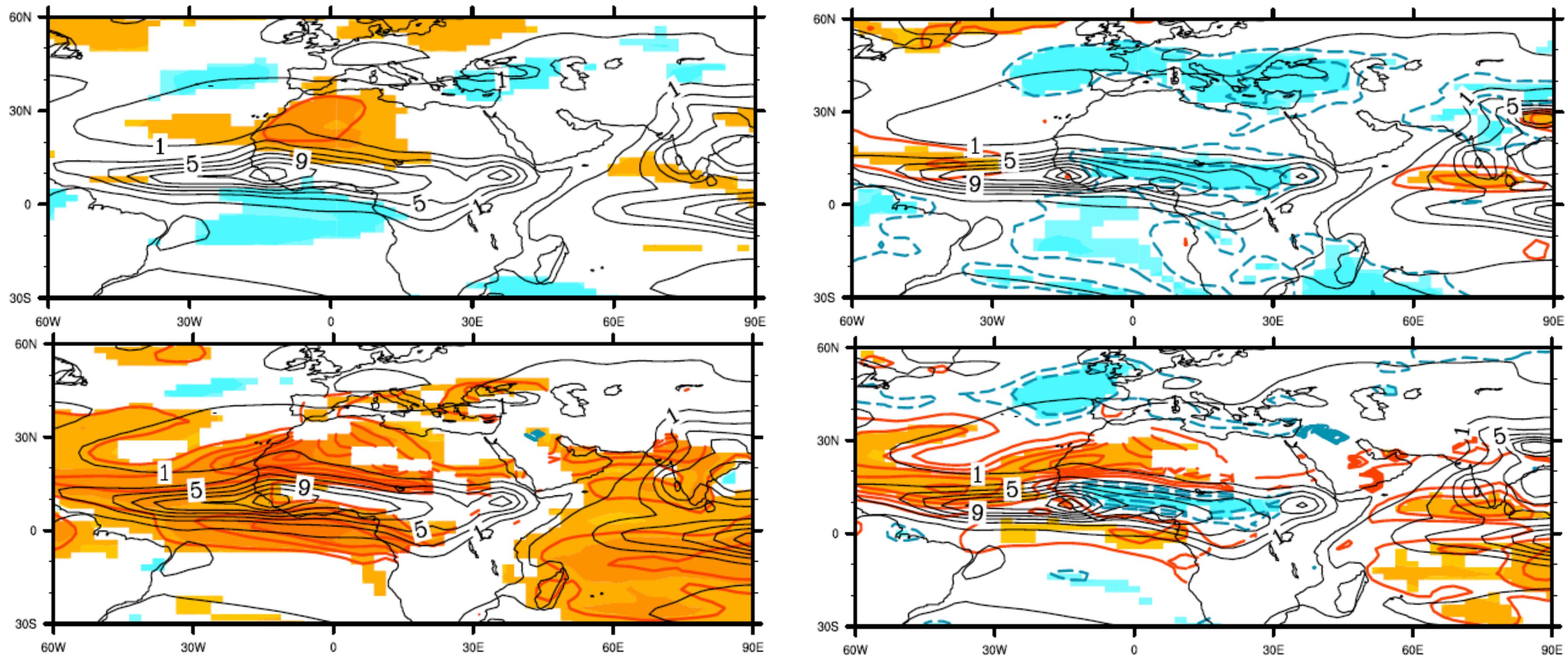
The projection of a drier Sahel:

Near-surface and upper-level moist static energy as measures of vertical instability

Gridbox-by-gridbox regressions of precipitation on MSE

20th century | 21st century



NB: the change is in the upper level (top panels), and is consistent with warming of the global tropical troposphere leading to increased stability inducing reduced precipitation

The dominance of
a local/land bottom-up mechanism
leads to projection of a wetter Sahel

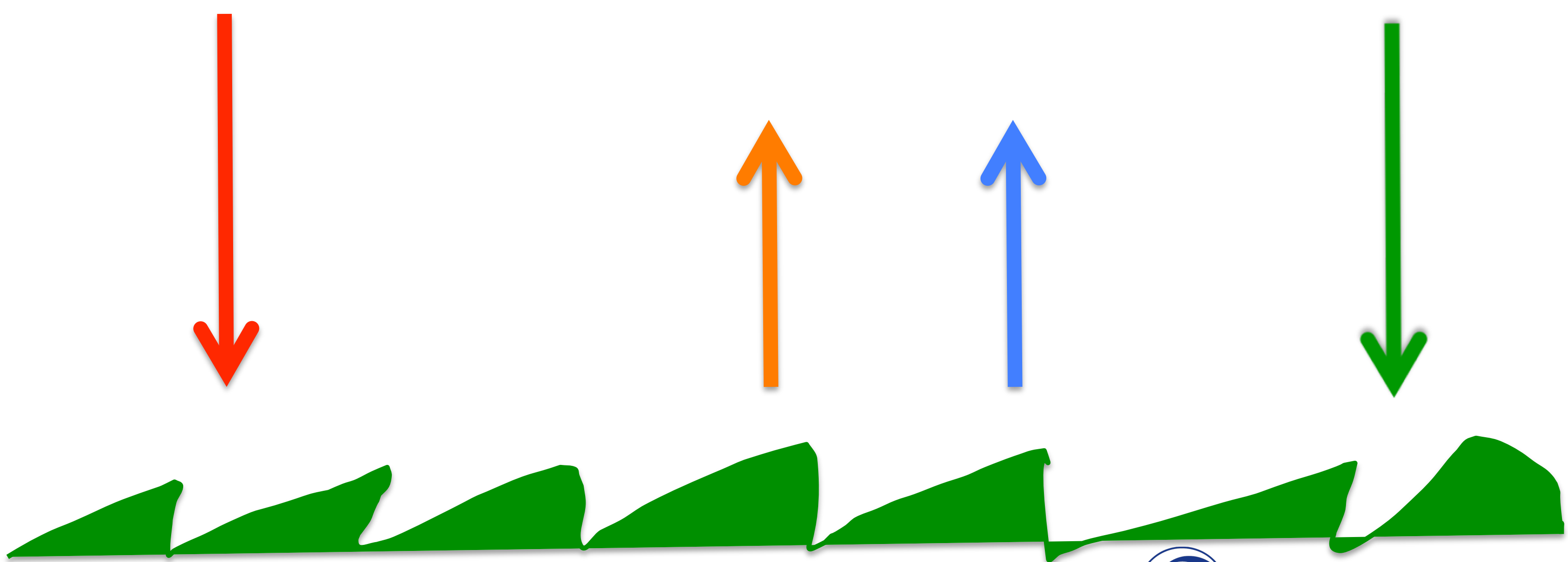
This is an analogue to studies that relate perturbations in land surface properties to changes in the atmospheric energy budget, and to orbital forcing of monsoons.

The local net surface energy balance is crucial:
(Solar + Terrestrial)R – (Latent + Sensible)H
especially net terrestrial radiation and latent heat

An increase in net radiation at the surface, dominated by the terrestrial component directly related to the increase in GHGs

drives increases in evaporation and near-surface moisture convergence

ultimately increasing vertical instability and precipitation, as well as surface temperature



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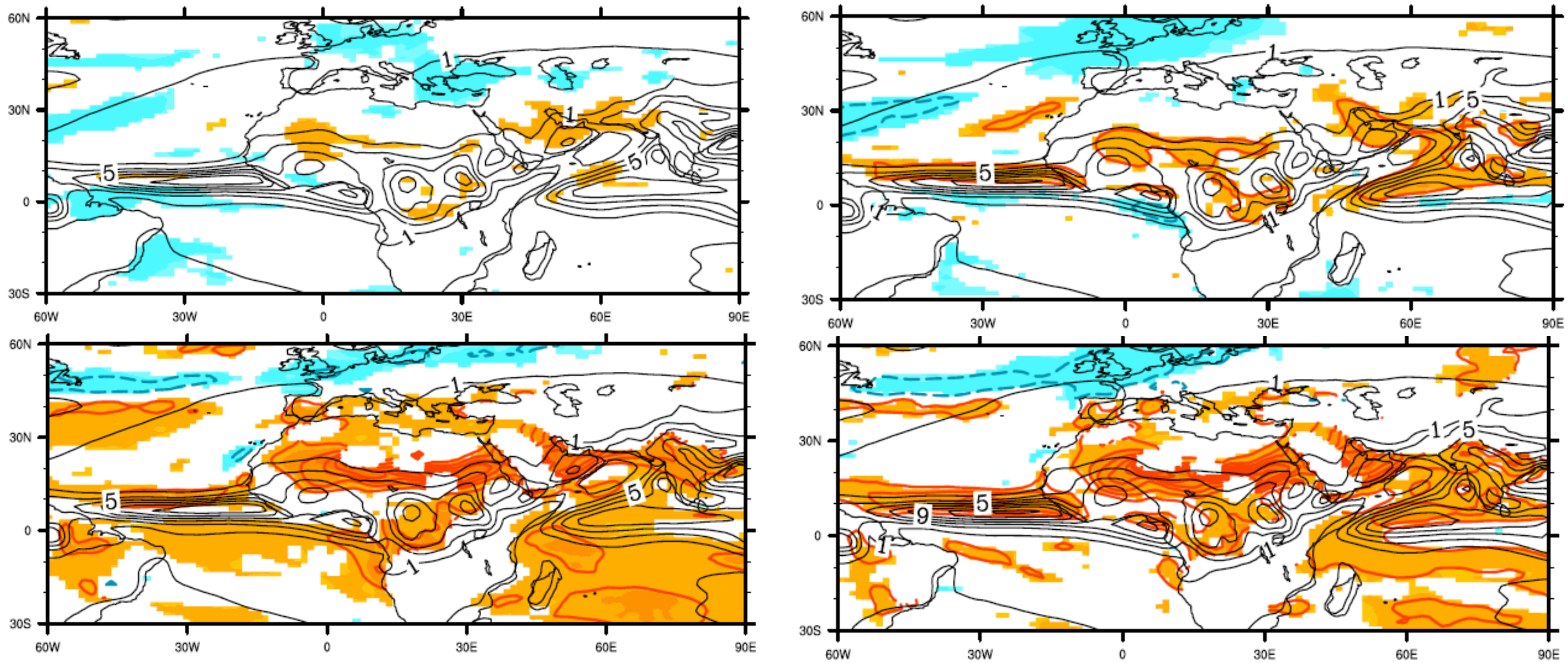
The projection of a wetter Sahel:

Near-surface and upper-level moist static energy as measures of vertical instability

Gridbox-by-gridbox regressions of precipitation on MSE

20th century | 21st century



NB: the strong positive near-surface relationship (in the bottom panels) follows moisture, not temperature

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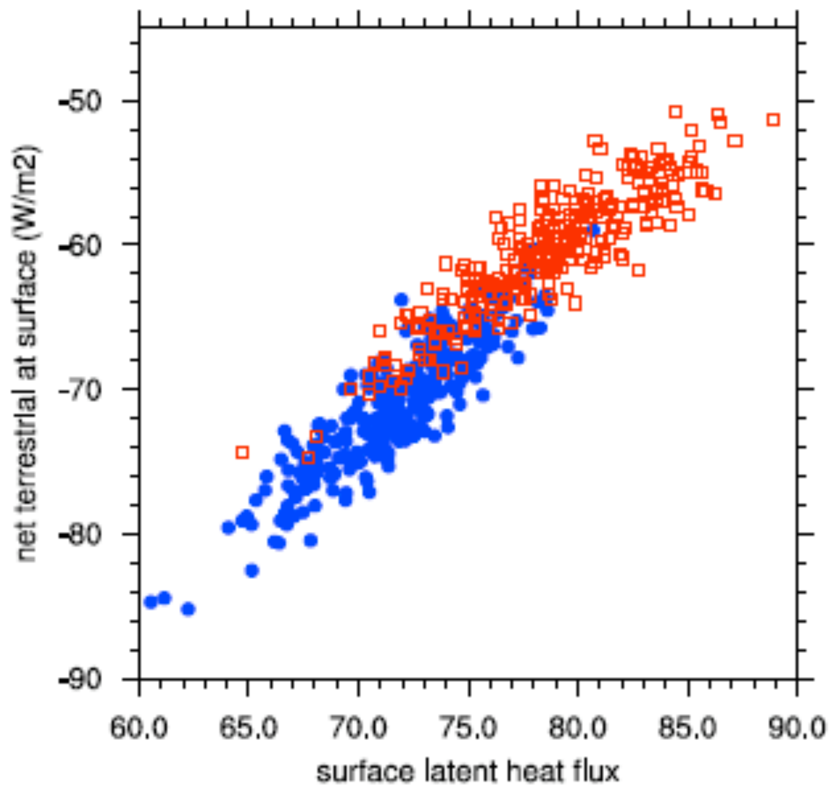
The projection of a wetter Sahel



blue is 20th century, red is 21st century (A1B)
each dot is the regional average across the Sahel (10-20N, 20W-40E)

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Concluding remarks:

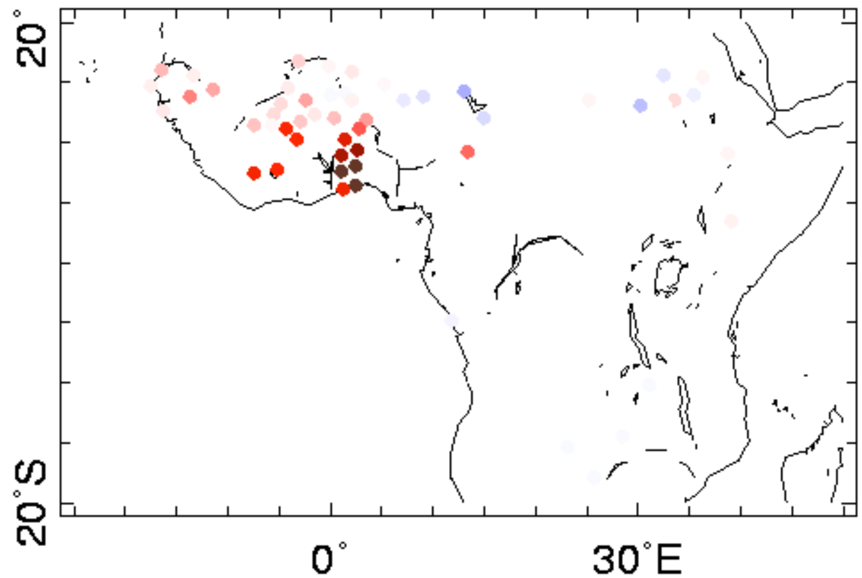
Our understanding of 20th century African climate, which is based on the relationship between SST forcing and rainfall response, is challenged by the uncertainty in projections

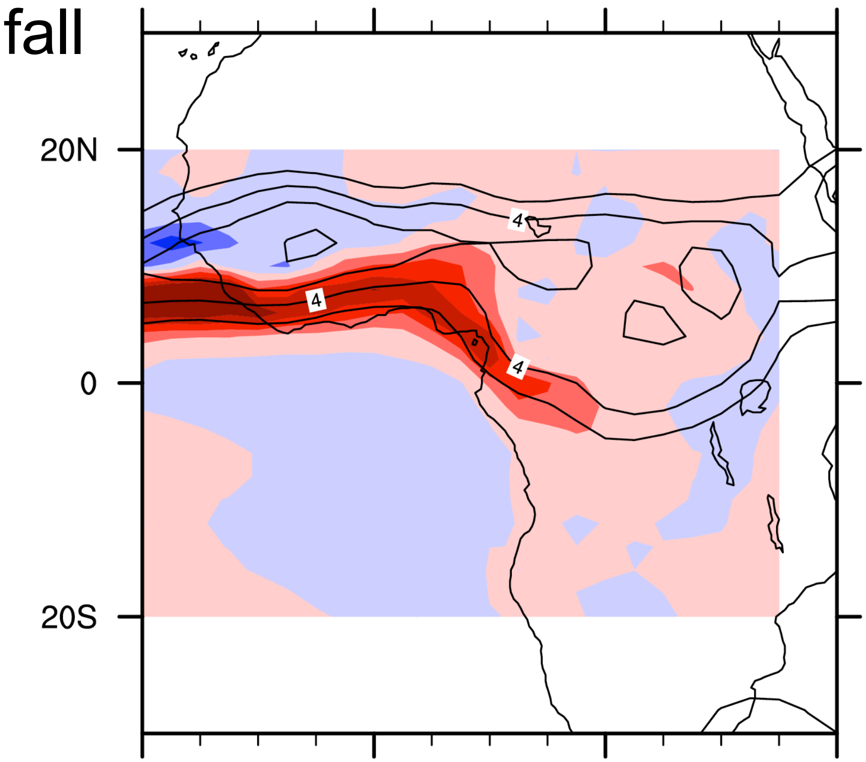
predictability: to advance our physical understanding, we need to work across spatial and temporal scales

vulnerability: at the same time, why not build resilience on the ground that is informed by lessons learned in adapting to persistent drought?

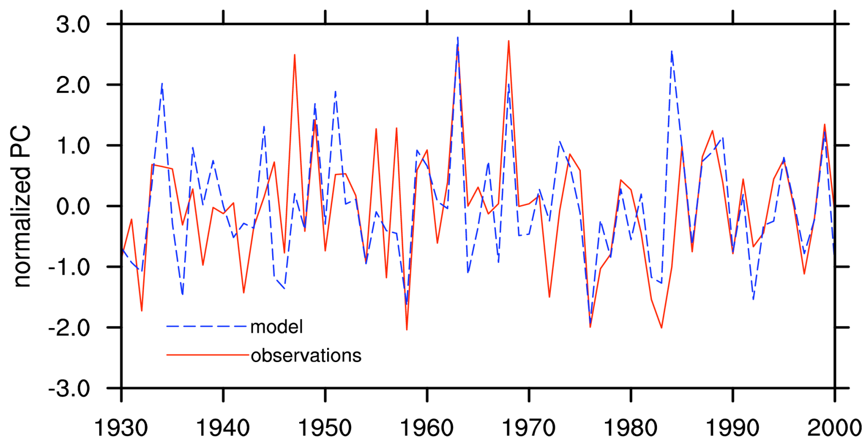
Variability in Gulf of Guinea rainfall

(15% in obs, 32% in ens-mean)

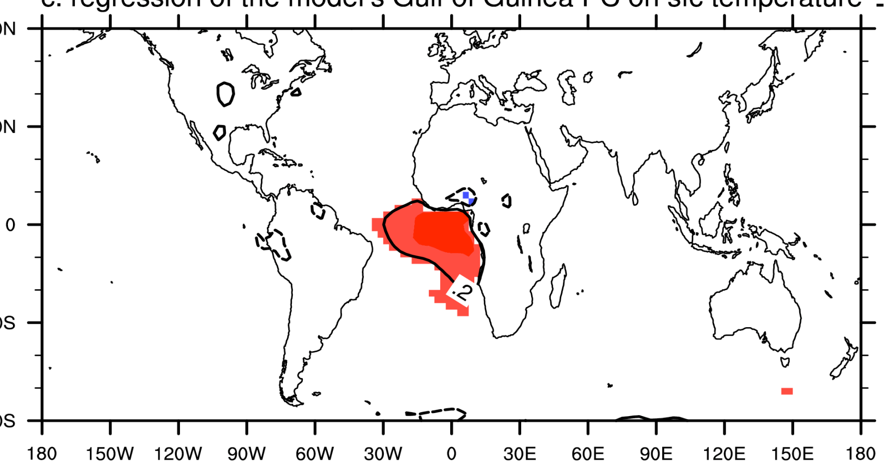




b. Gulf of Guinea PC of 1930-2000 precipitation



c. regression of the model's Gulf of Guinea PC on sfc temperature



Giannini et al. 2005, in Clim. Dyn.

The role of (sulfate) aerosols

Rotstayn and Lohmann, *2002 (J Climate)*

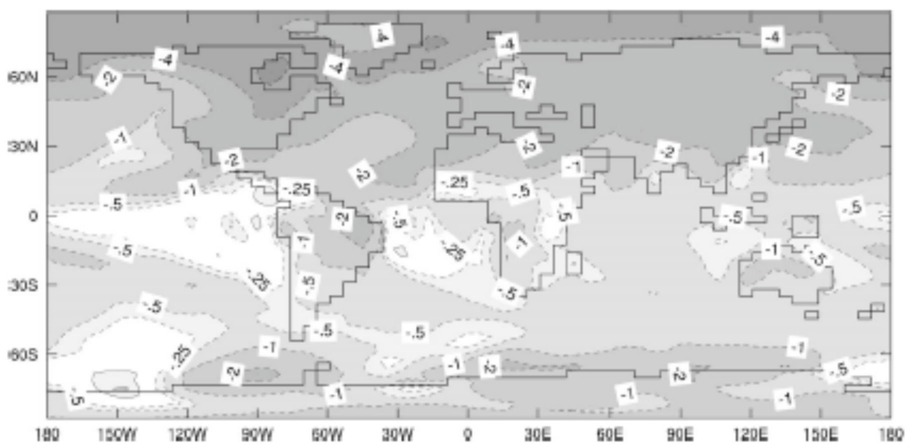


FIG. 2. Difference in annual-mean, near-surface air temperature between the PD and PI runs. Contours are −8, −4, −2, −1, −0.5, −0.25, and 0.25 K.

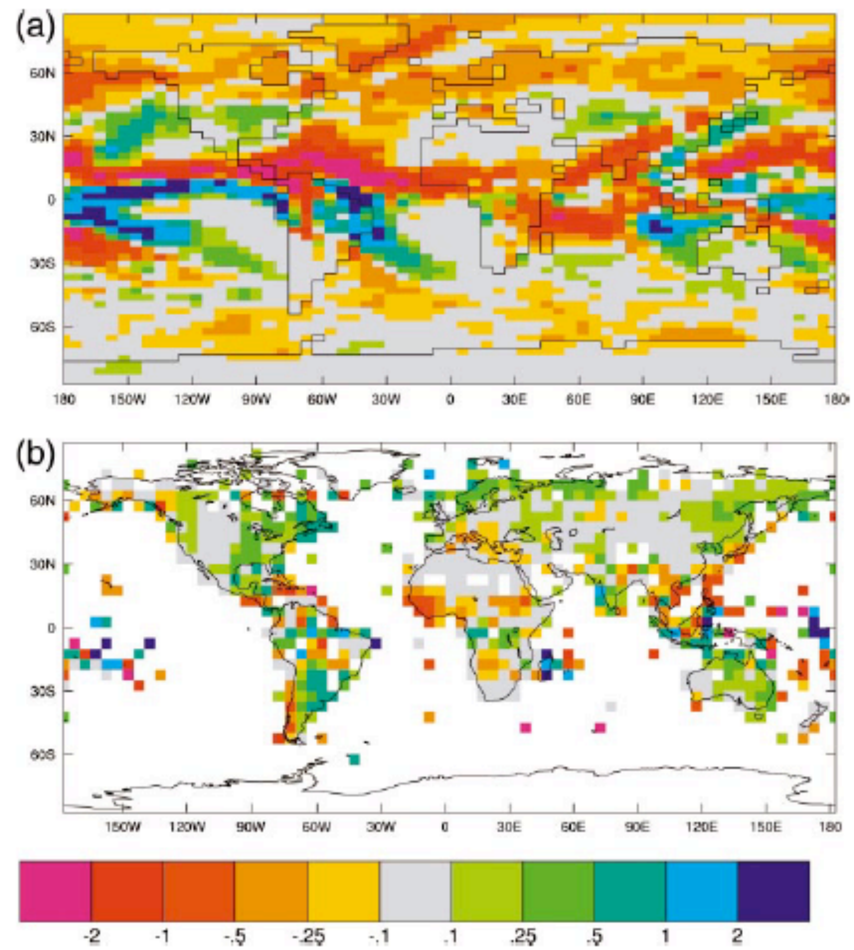
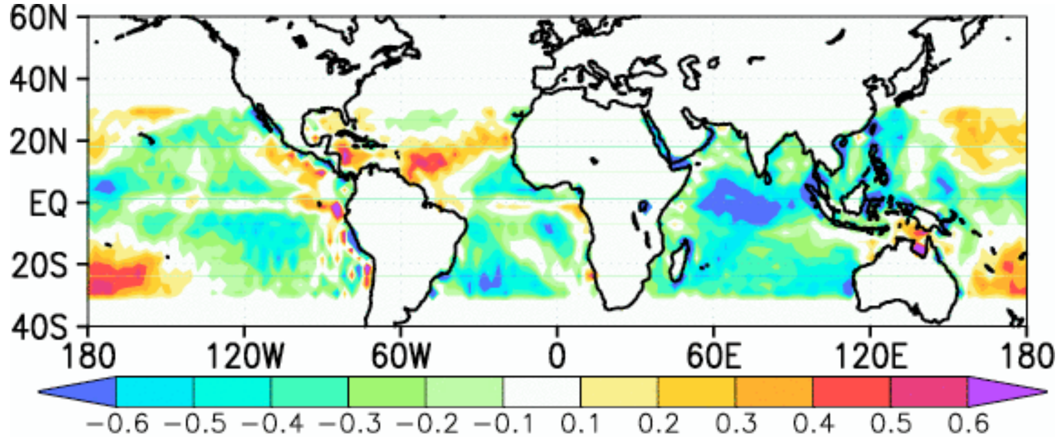


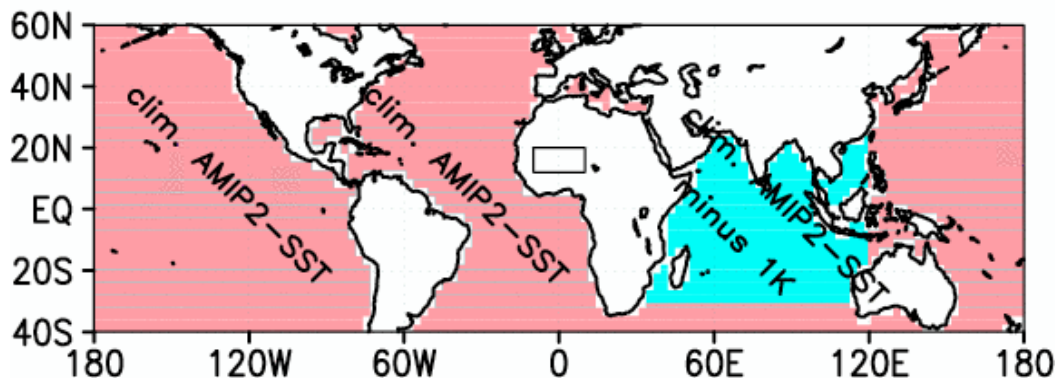
FIG. 4. (a) Difference in annual-mean precipitation between the PD and PI runs in mm day^{-1}. (b) Trend in observed annual-mean precipitation over the period 1901–98 in mm day^{-1} century^{-1}.

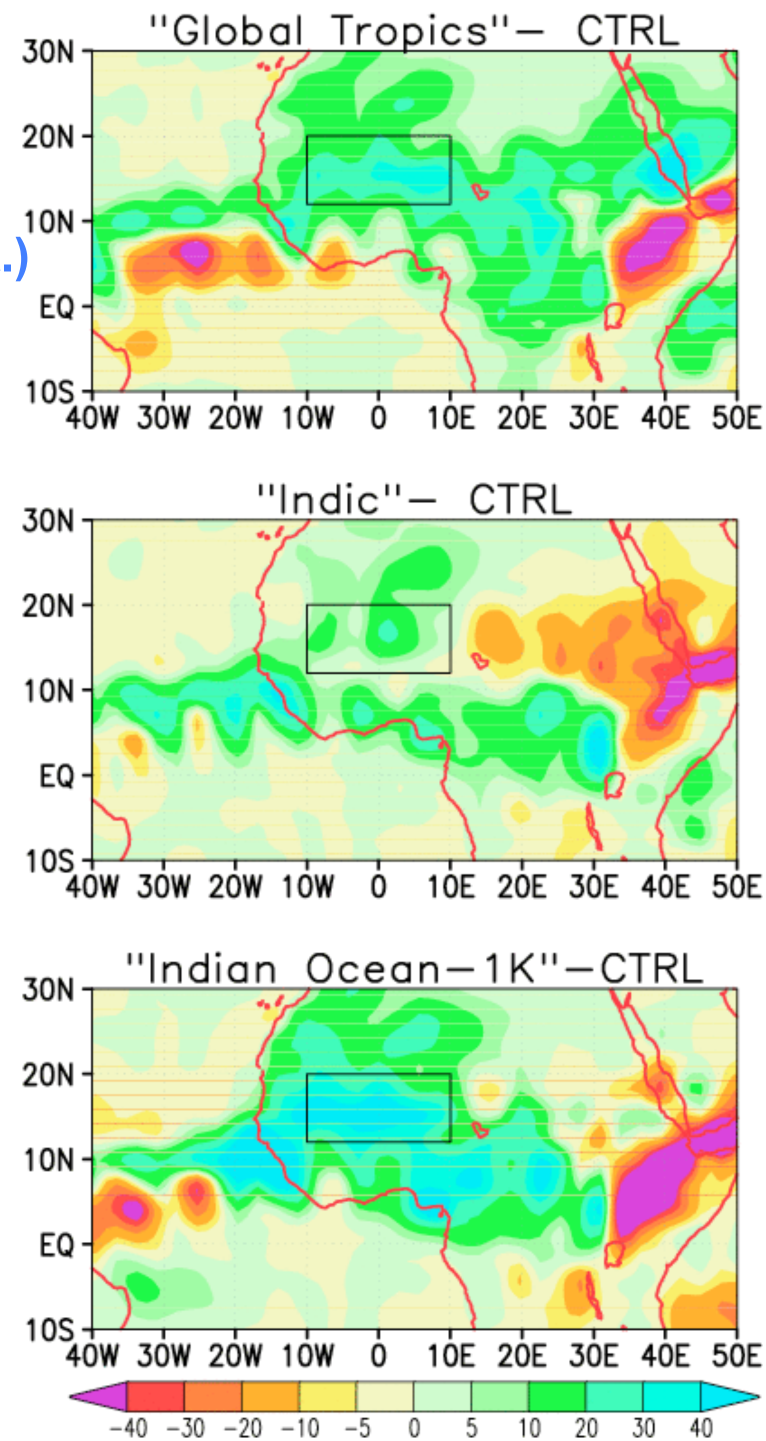
The role of Indian Ocean SSTs

20 years of <u>cold SST</u> minus climatology

Bader, J and M Latif, 2003 (Geophys. Res. Lett.)







The relative roles of the Atlantic, Indian and Pacific Oceans

Lu, J and TL Delworth, 2005 (Geophys. Res. Lett.)