Interhemispheric Thermal Gradients and Multidecadal variations in the Tropical Climate over the 20th Century and Future

John Chiang

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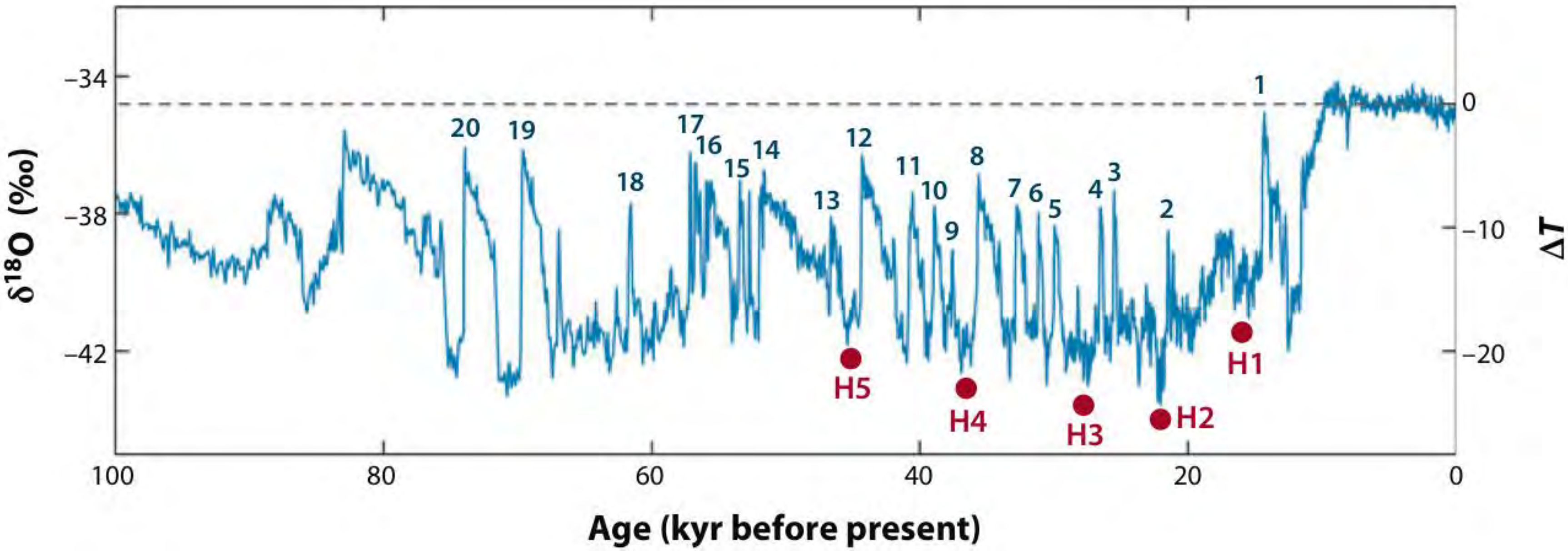
Paleoclimate Motivations

Greenland ice core temperature record (GISPII)

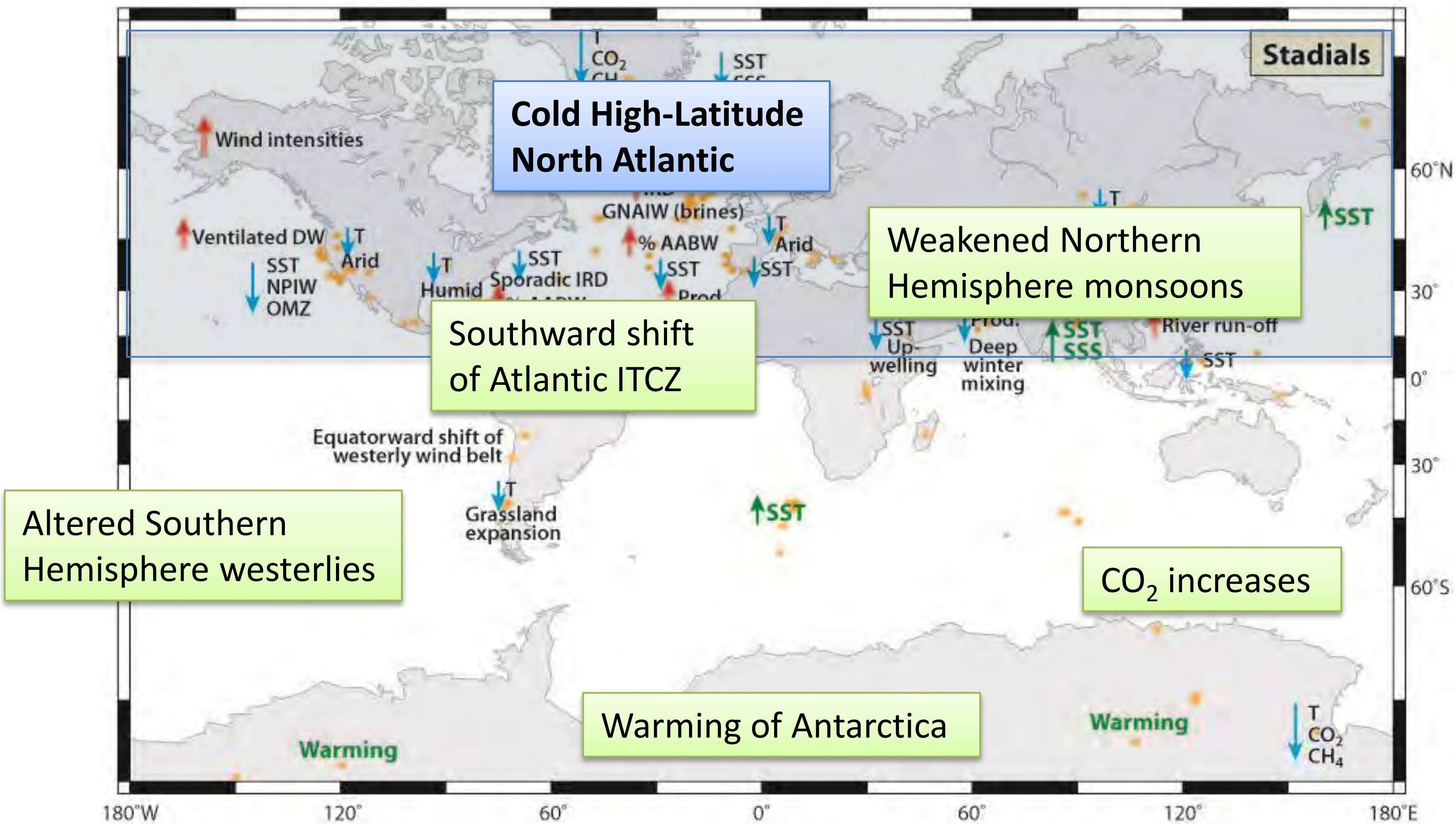


Dansgaard/Oeschger (D/O) events

Heinrich (H) events

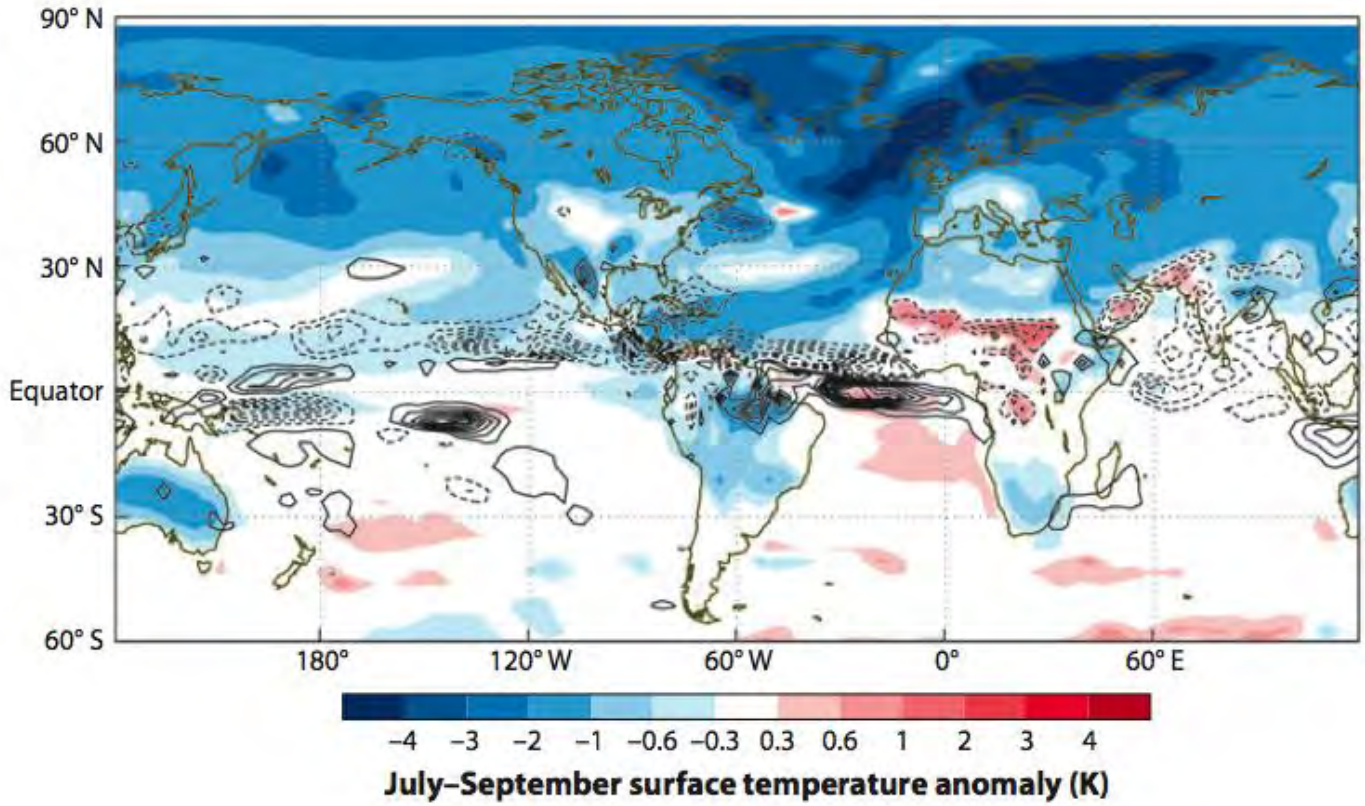
(figure source: Ganapolski and Rahmstorf 2001)

A global reorganization of climate



(Voelker et al. 2002)

JAS anomalies of a freshwater ‘hosing’ simulation in the CCSM3

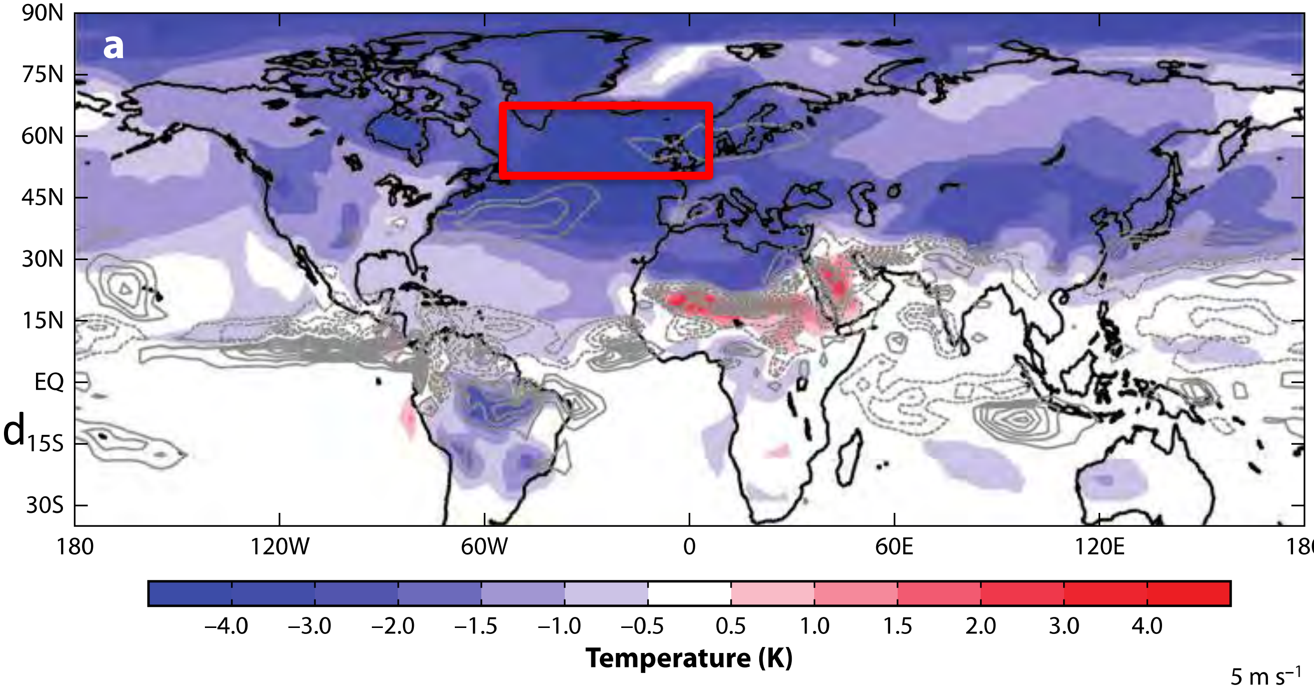


Years 10-14 after hosing

Temperature (shaded, K) and precipitation (contours, CI 0.5mm/d) anomalies

CAM3.1-slab ocean simulations of extratropical North Atlantic cooling

Surface temp and rainfall changes

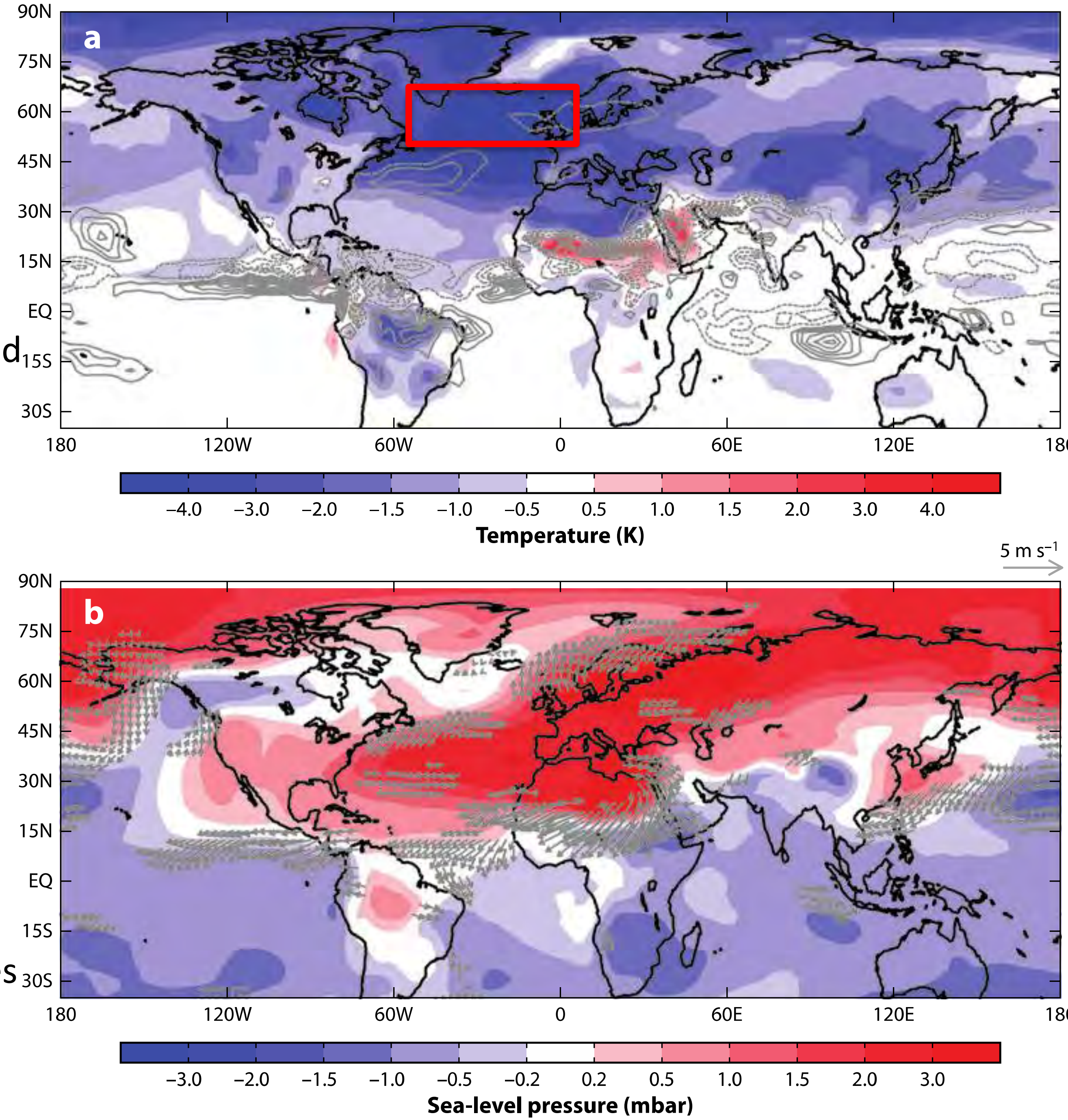


Chiang and Friedman 2012

CAM3.1-slab ocean simulations of extratropical North Atlantic cooling

Surface temp and rainfall changes

Surface pressure and wind changes



Chiang and Friedman 2012

Question

Can extratropical thermal forcing be usefully applied to understanding 20thC tropical climate variations?

1. Tropical Atlantic ITCZ trends (C-Y Chang et al., *J Climate,* 2011)

2. Late 1960's shift in NH monsoons (Liu and Chiang, *J Climate,* 2012)

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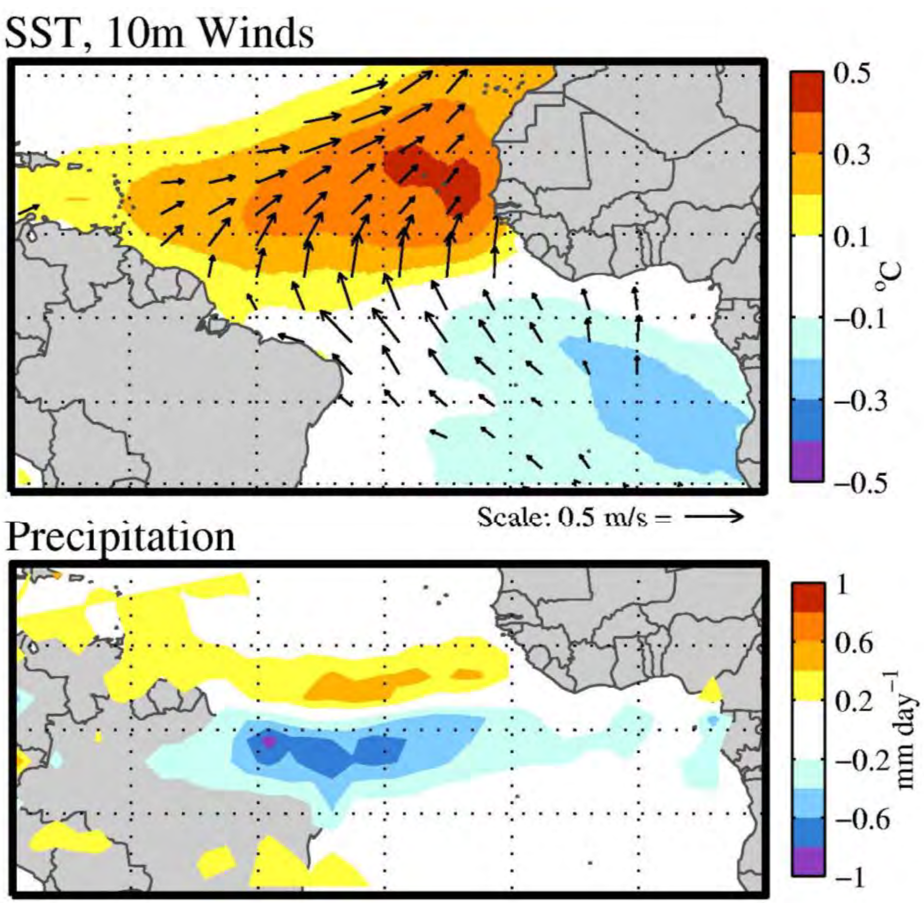
Atlantic Interhemispheric SST gradient



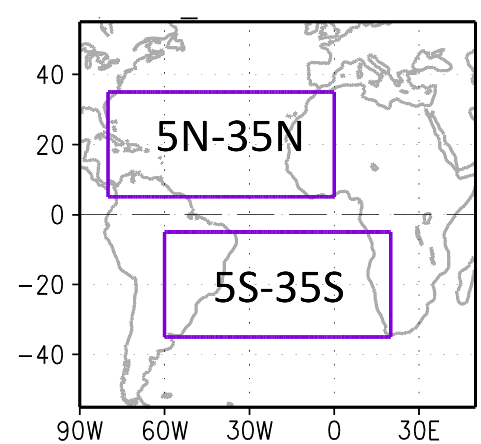
Define an index:

South Tropical Atlantic SSTA

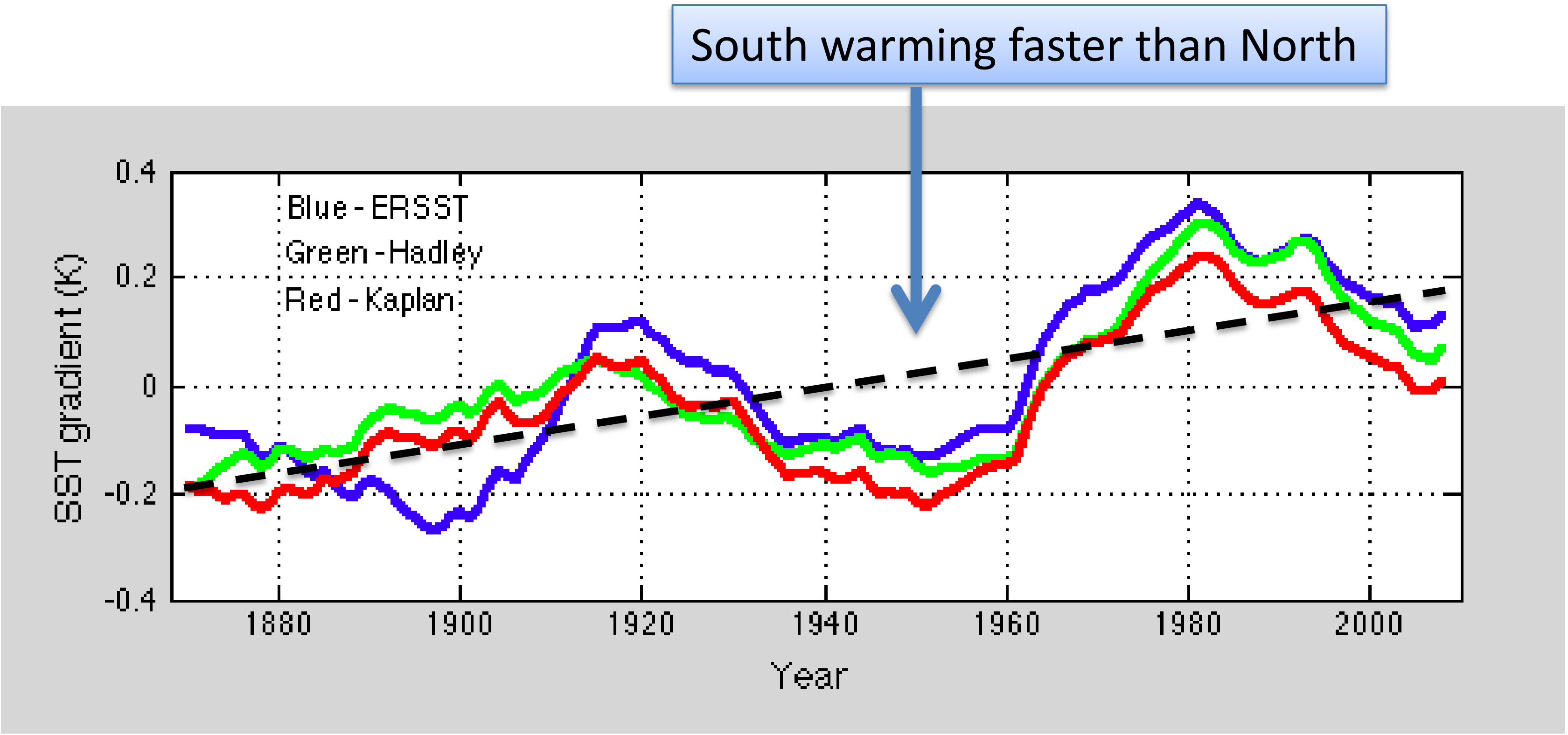
Minus

North Tropical Atlantic SSTA

21-year running mean applied

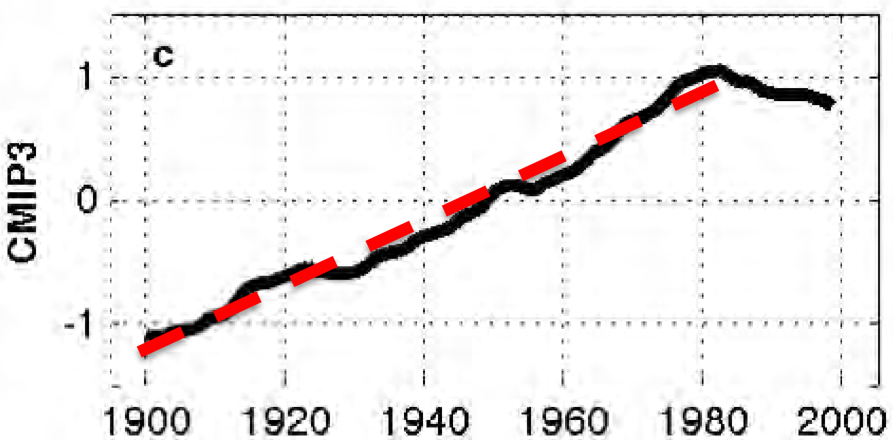


Observed Atlantic Interhemispheric SST Gradient index



CMIP3 20th century simulations show a forced trend in the Atlantic SST gradient

PC1



First EOF of the CMIP3 multimodel ensemble Atlantic Interhemispheric Gradient Index (71 members)

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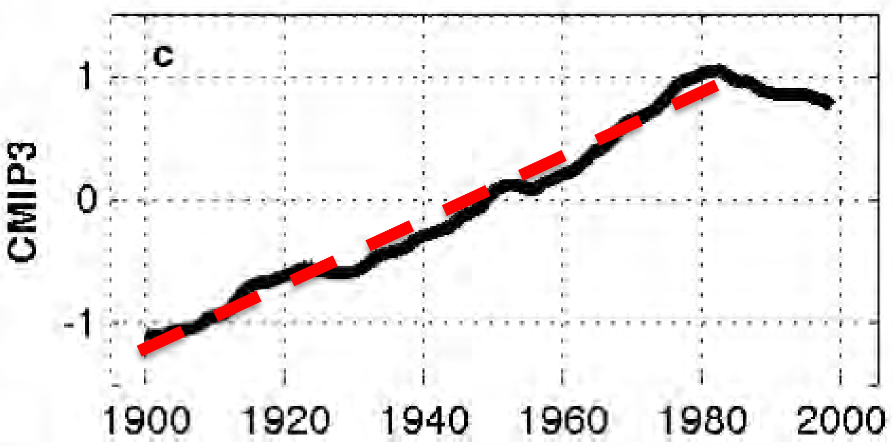
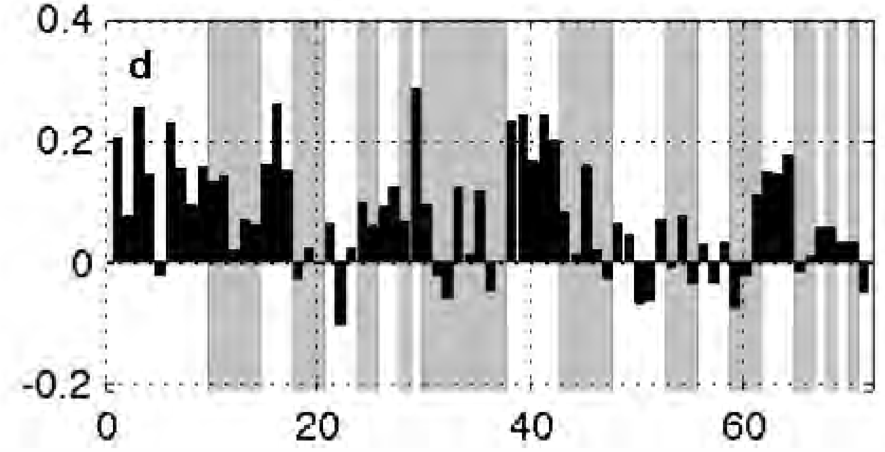


Projections onto each ensemble member



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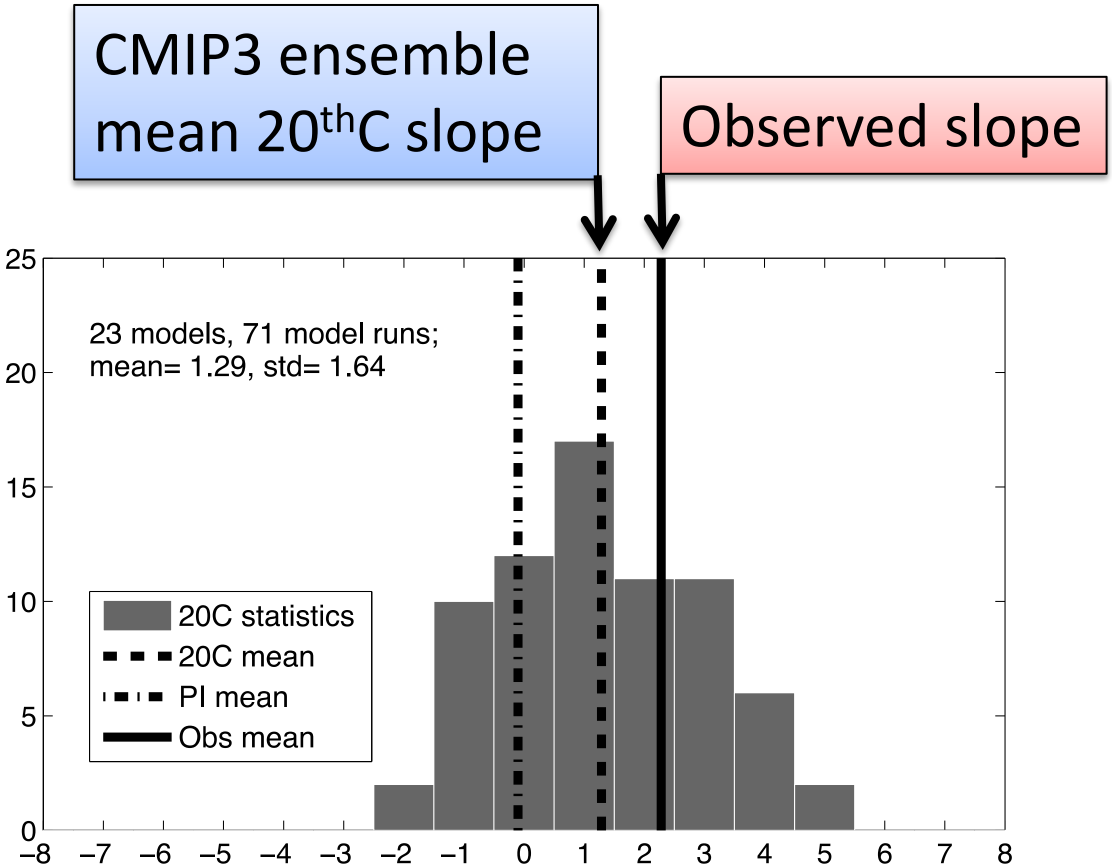
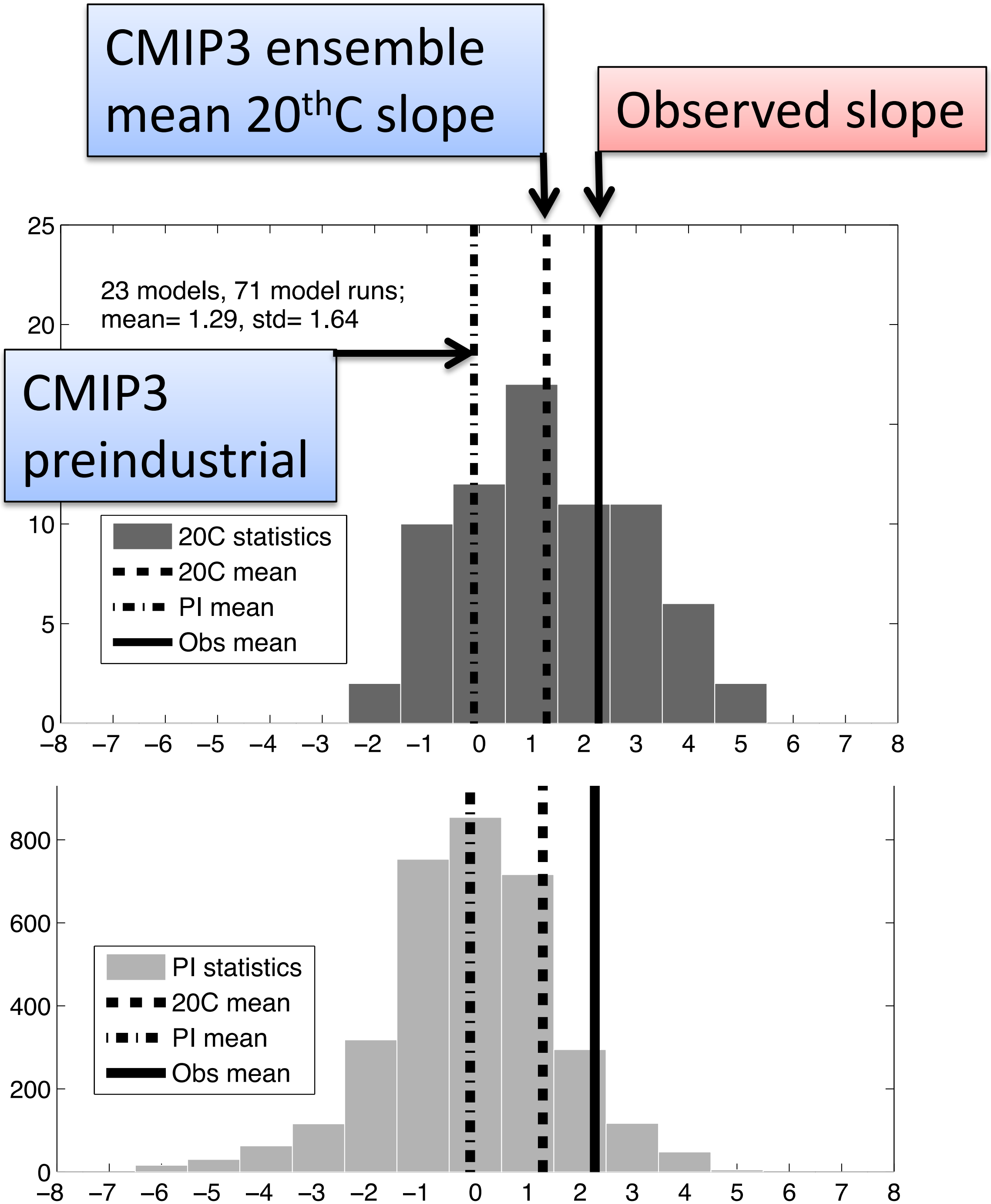


Distribution of slopes 1900-1982

CMIP3 20th century multimodel ensemble



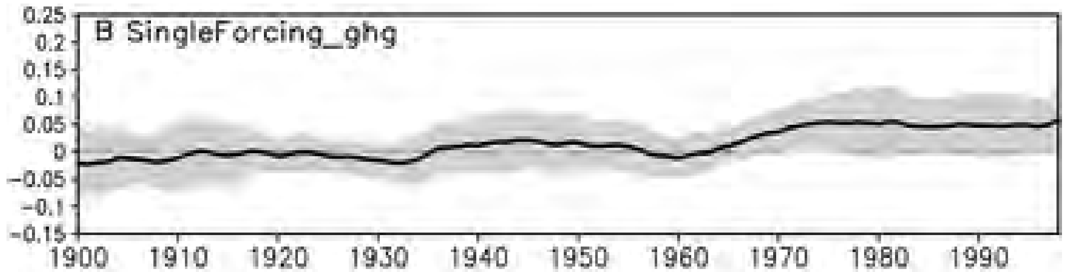
Distribution of slopes 1900-1982

CMIP3 20th century multimodel ensemble

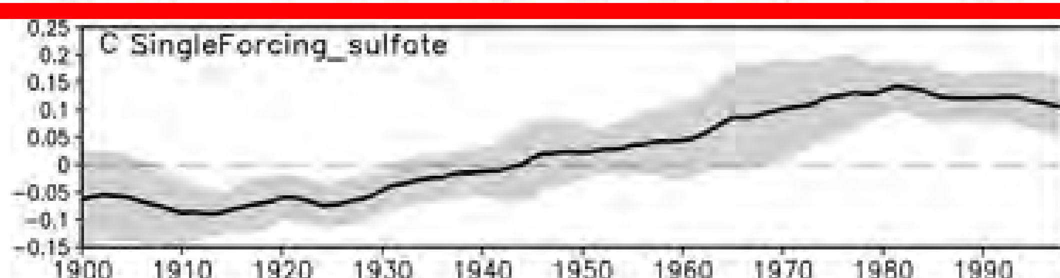
Distribution of slopes 83-year lengths

CMIP3 preindustrial runs (multimodel)

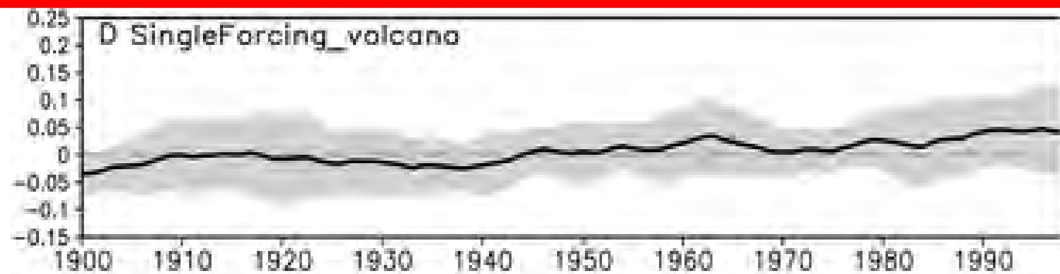
Single forcing runs indicate that sulfate aerosols are the leading cause



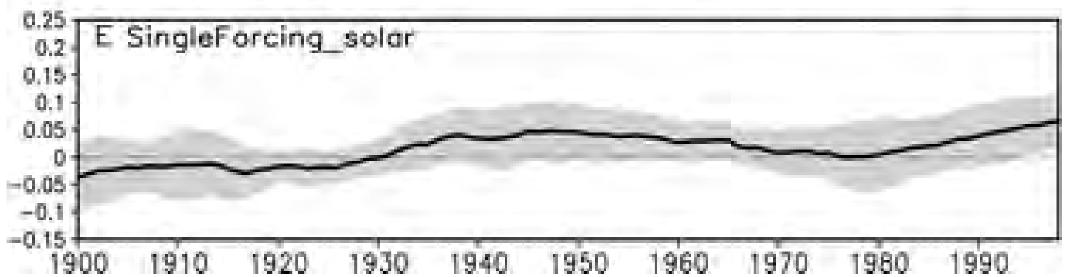
Greenhouse gases only



Sulfate aerosol only

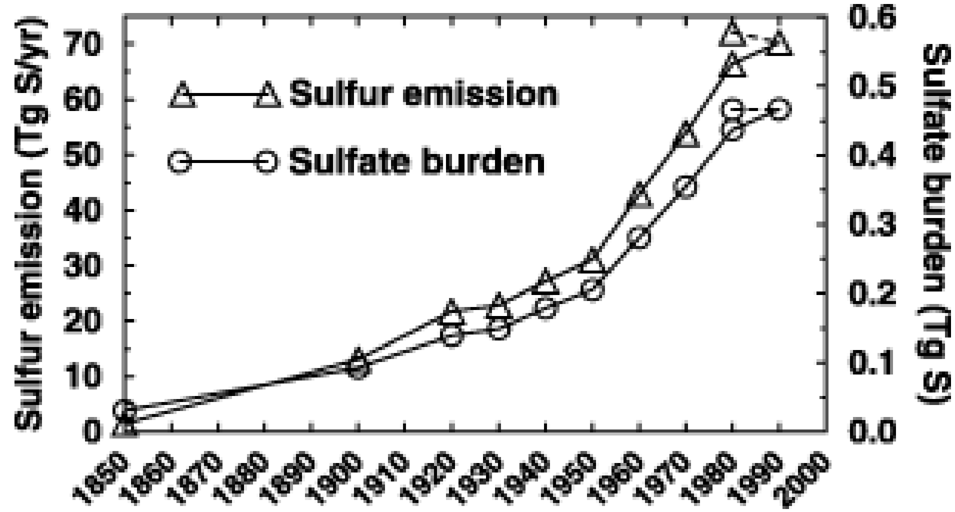


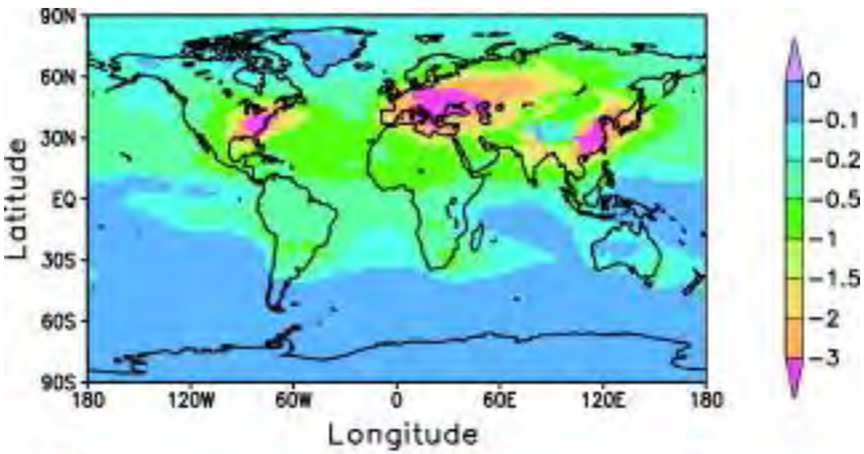
Volcano only



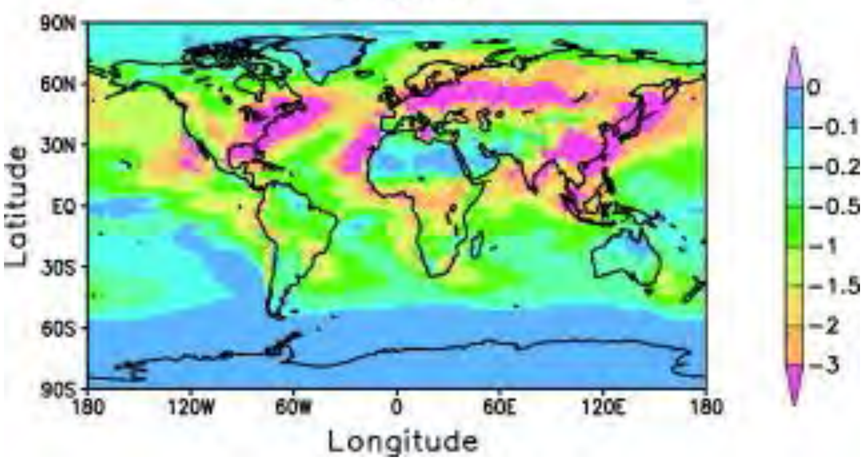
Solar forcing only

Anthropogenic sulfate aerosols





Direct radiative forcing for year 1990 (W/m^2)



Indirect radiative forcing for year 1990 (W/m^2)

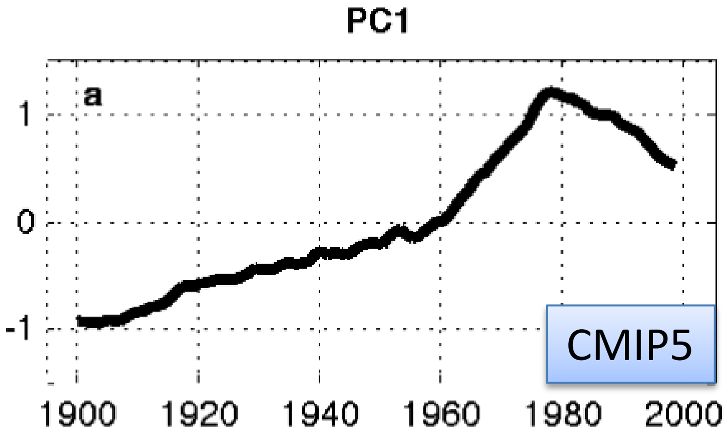
(Boucher and Pham 2002)

CMIP5 analysis

Essentially confirms the CMIP3 results *

CMIP5 analysis

EOF1 Atlantic Interhemispheric gradient timeseries



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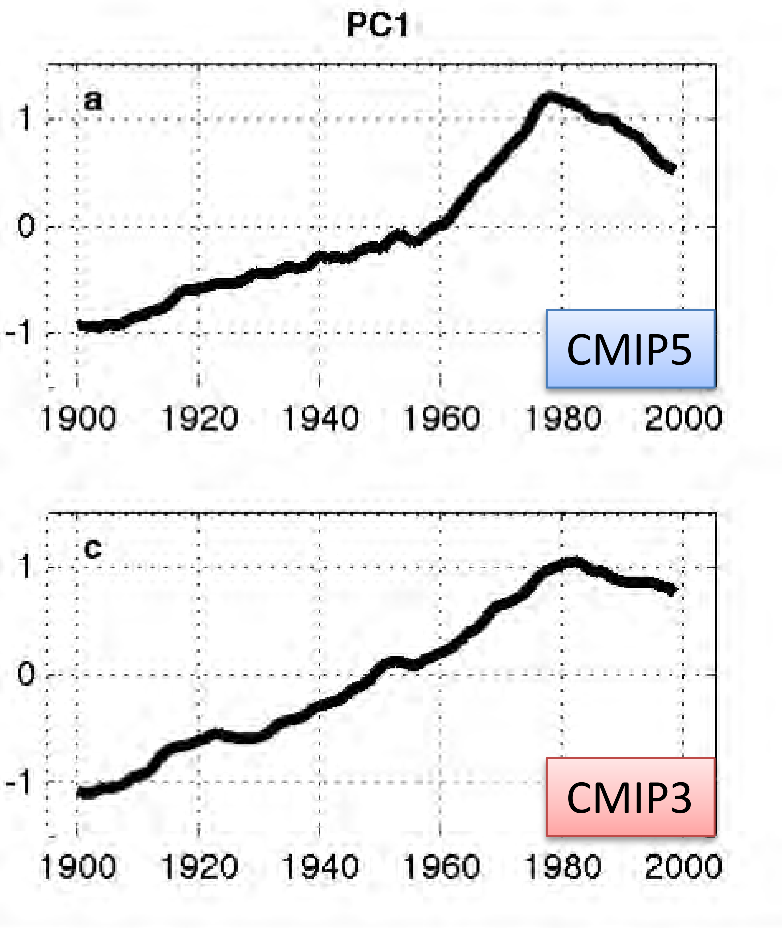

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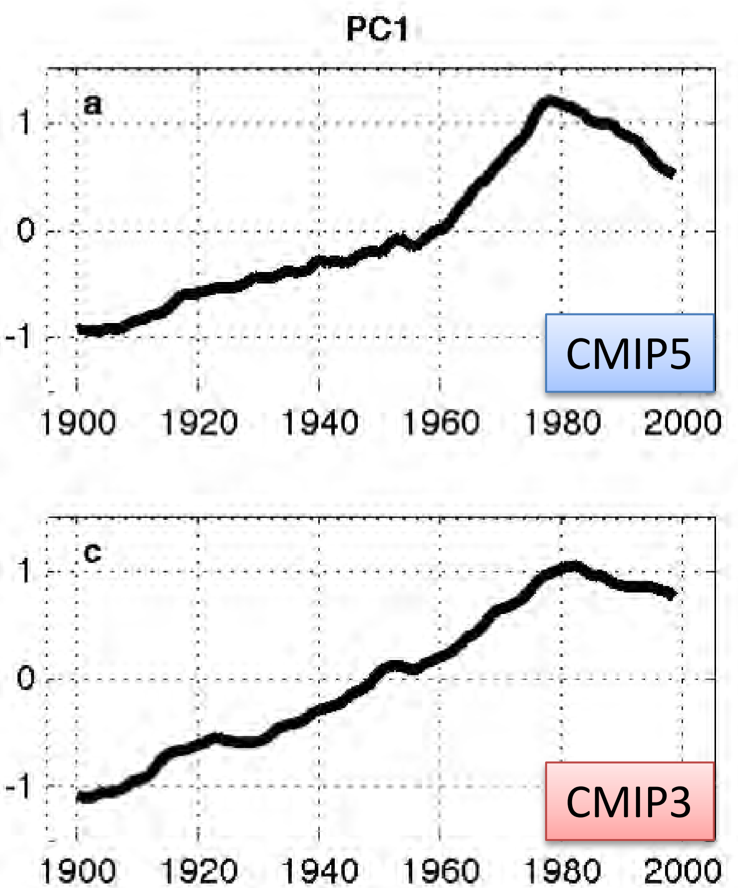
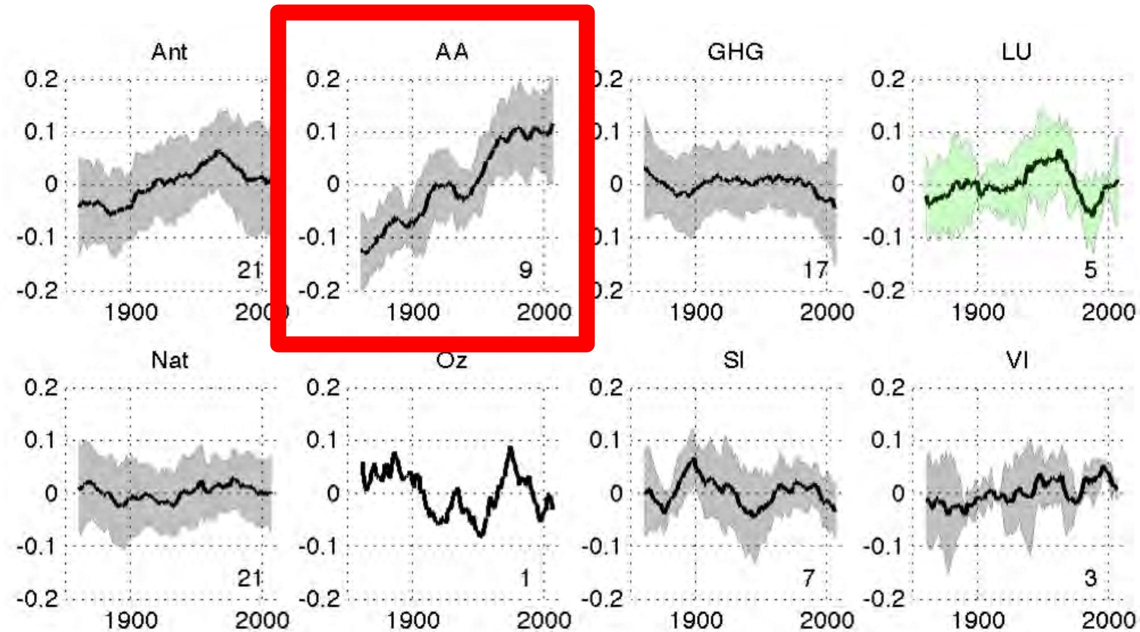


CMIP5 single forcing runs



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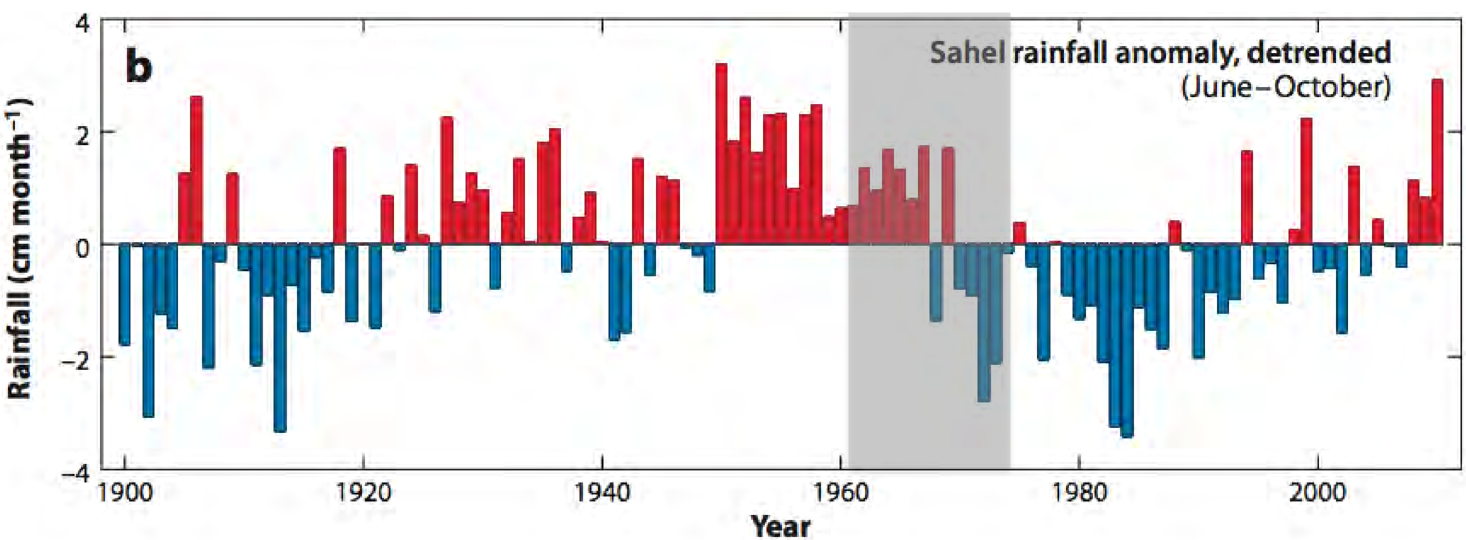
The late 1960's Sahel drought and links to the North Atlantic



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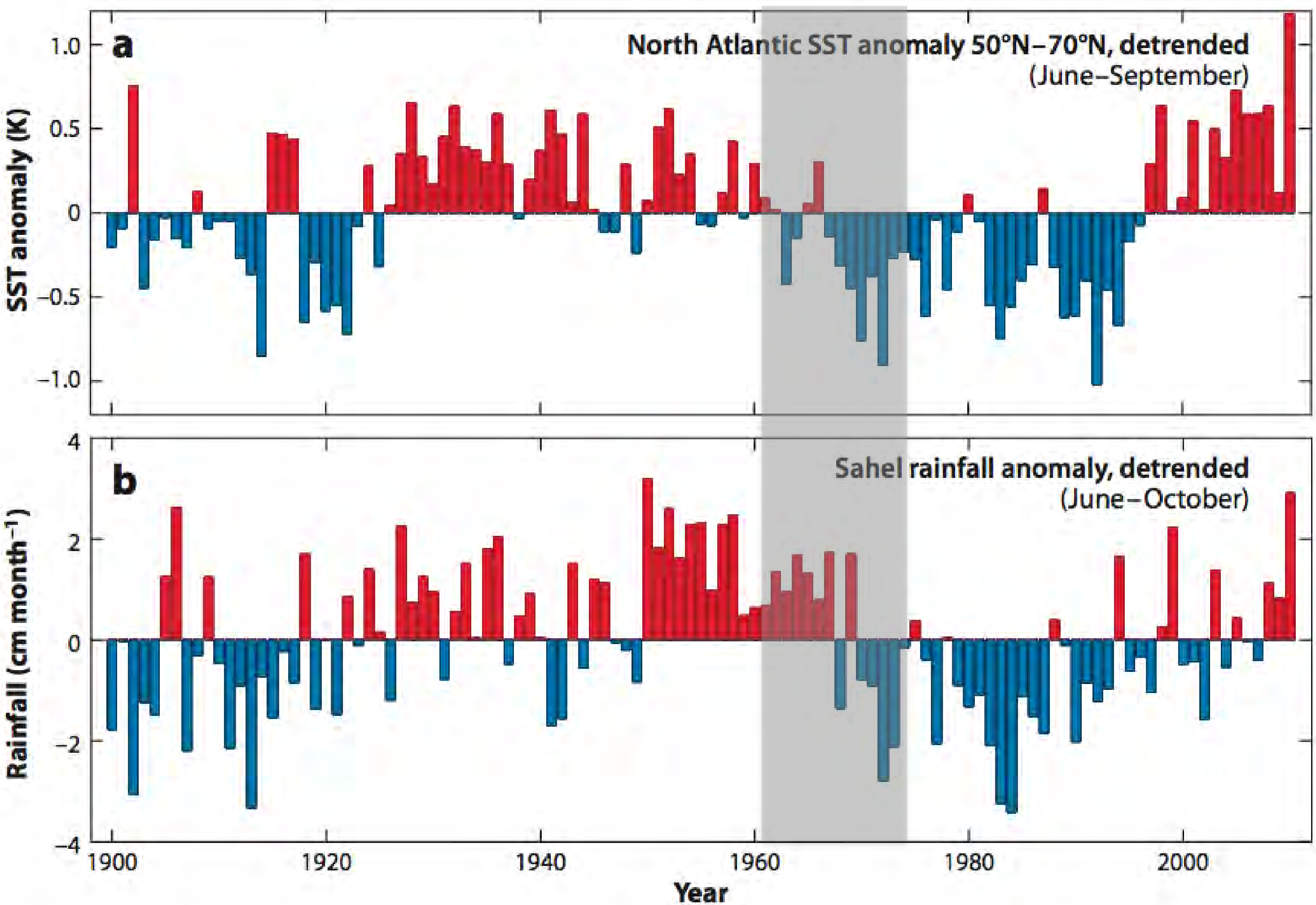
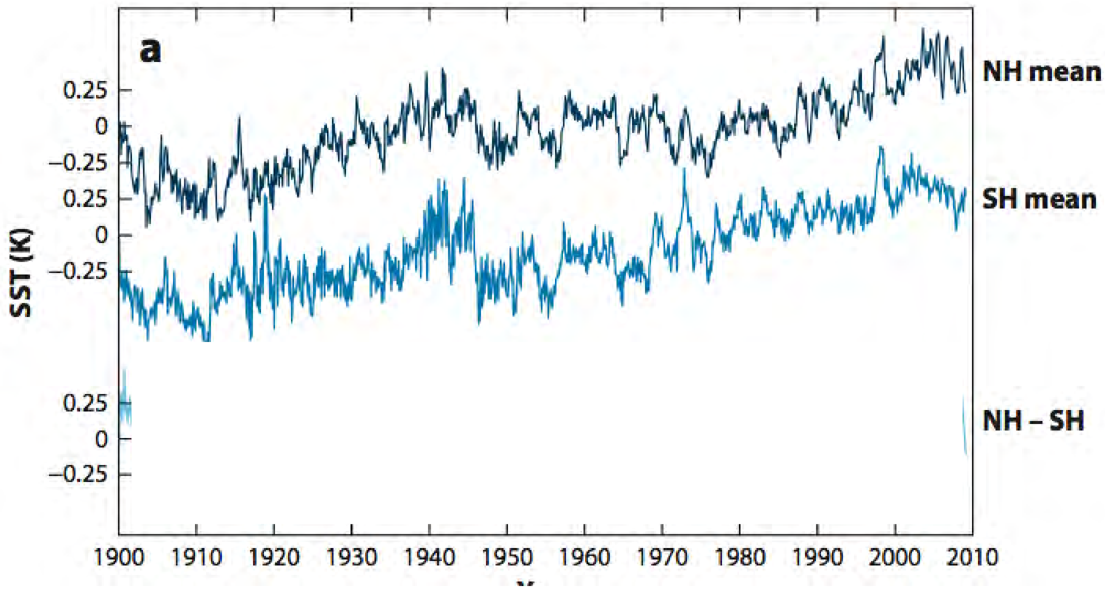


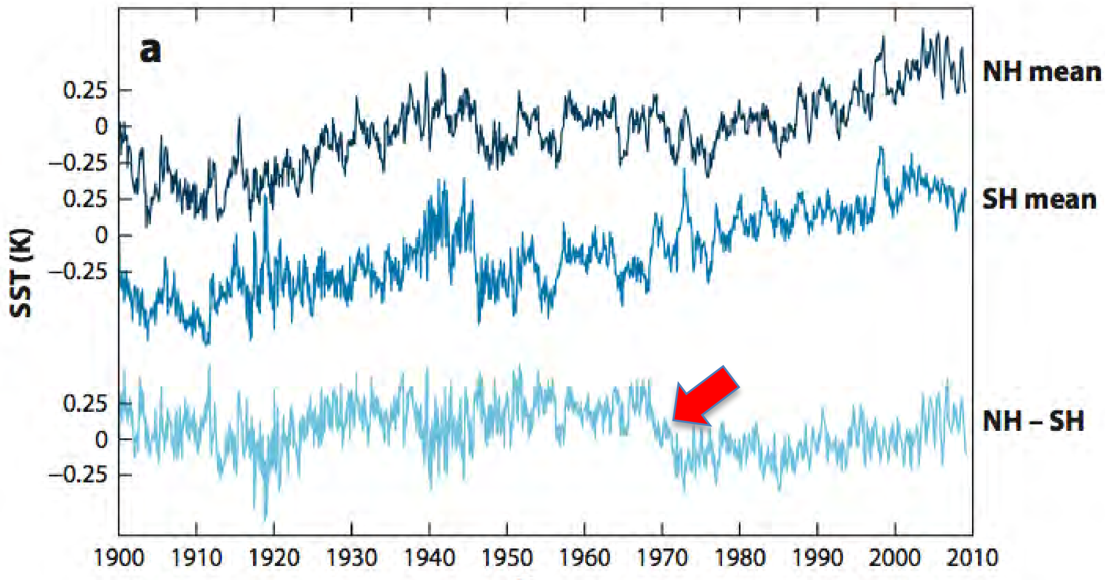
Late 1960's shift in the Interhemispheric SST Gradient



Hemispheric mean SST

(Thompson et al. *Nature* 2010)

Late 1960's shift in the Interhemispheric SST Gradient

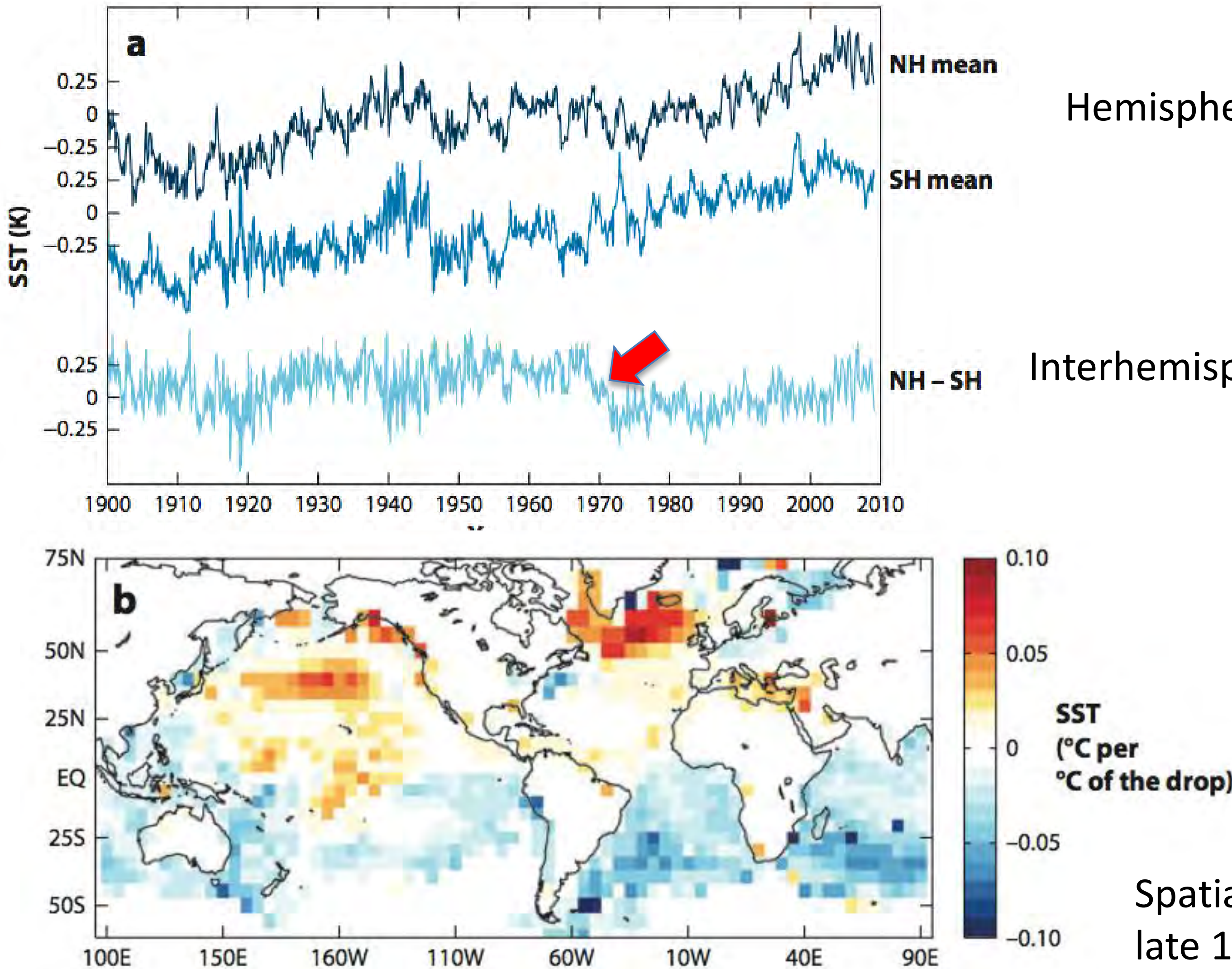


Hemispheric mean SST

Interhemispheric SST difference

(Thompson et al. *Nature* 2010)

Late 1960's shift in the Interhemispheric SST Gradient



Hemispheric mean SST

Interhemispheric SST difference

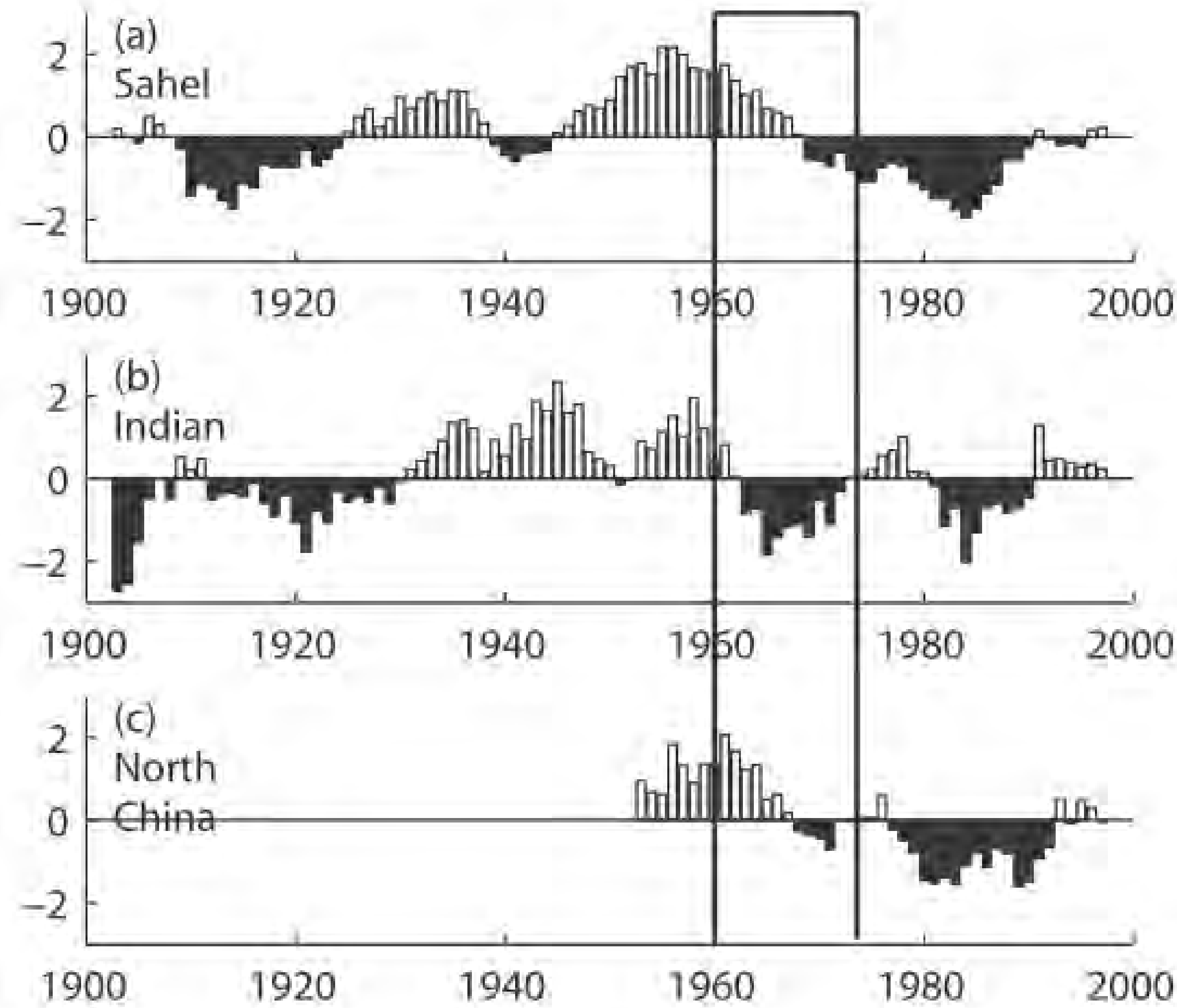
Spatial pattern of the late 1960's shift

(Thompson et al. *Nature* 2010)

Indian and North China JJA rainfall also suggest a late 1960's shift

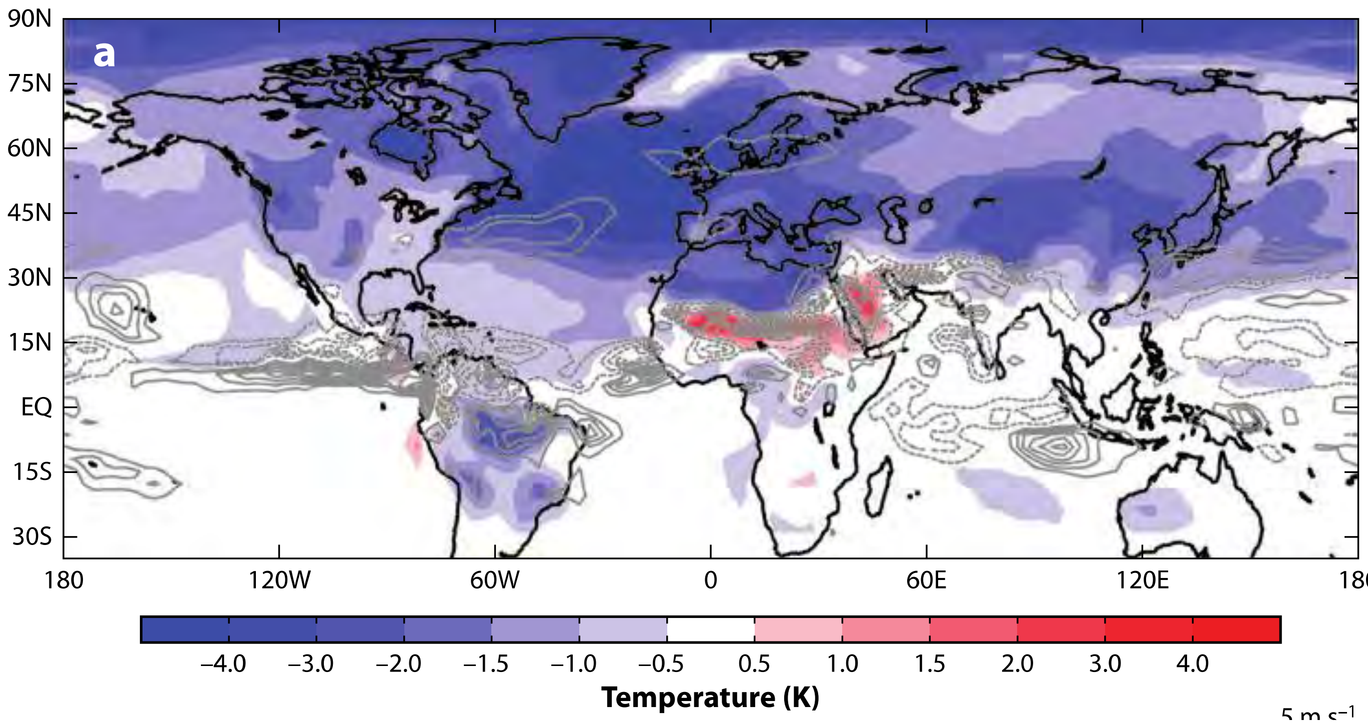
Normalized June-July-August rainfall anomalies

All indices are smoothed by applying 7-year-running mean



Data source:
Sahel: Joint Institute for the Study of the Atmosphere and Ocean, using NOAA Global Historical Climatology Network data
China: Wang et al. (2000)
India: Parthasarathy et al. (1994)

Tactic – objectively analyze observational data over Eurasia for similar patterns in surface temp, pressure, and rainfall



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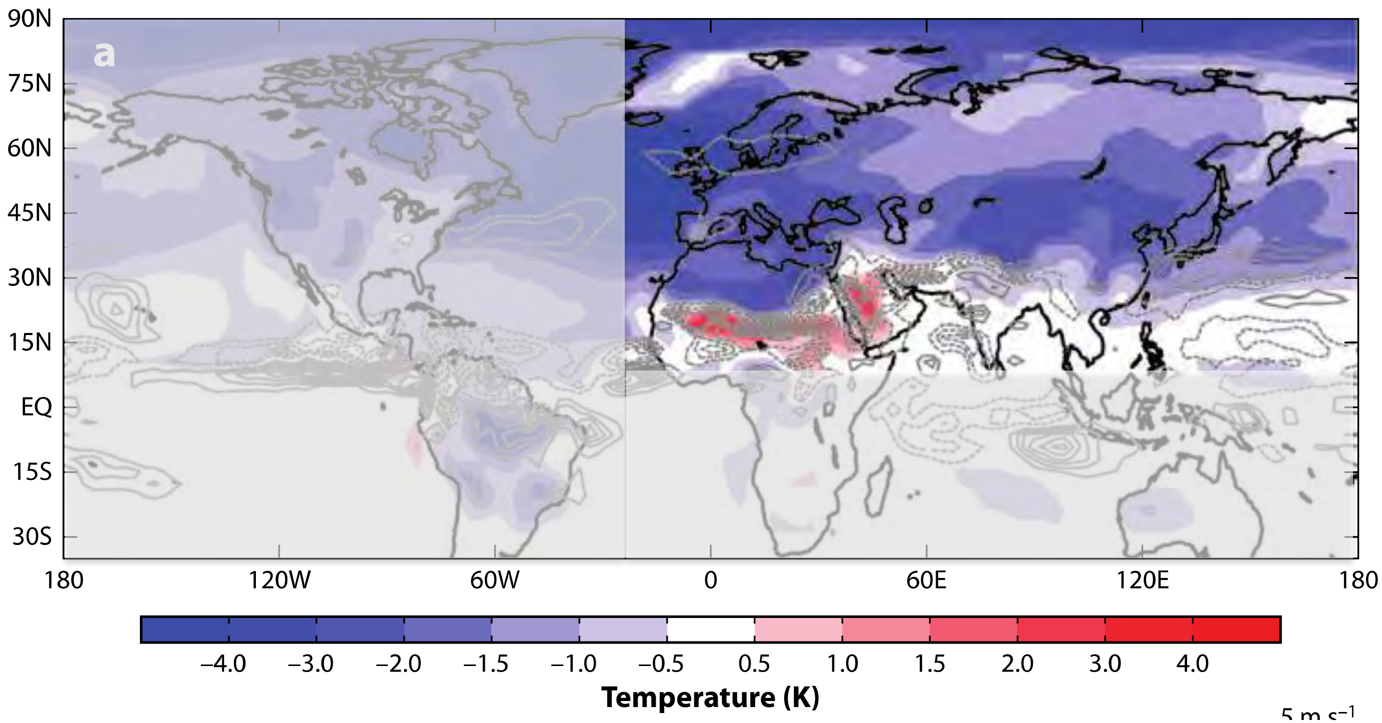
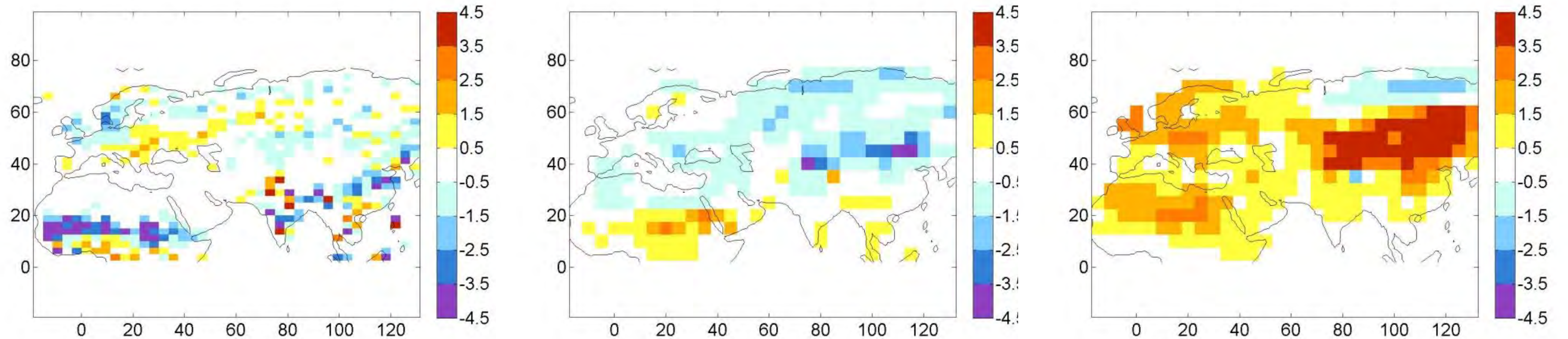


Summertime (JJA) climates before and after the 1960's

JJA Difference: 1970-1979 minus 1950 - 1959



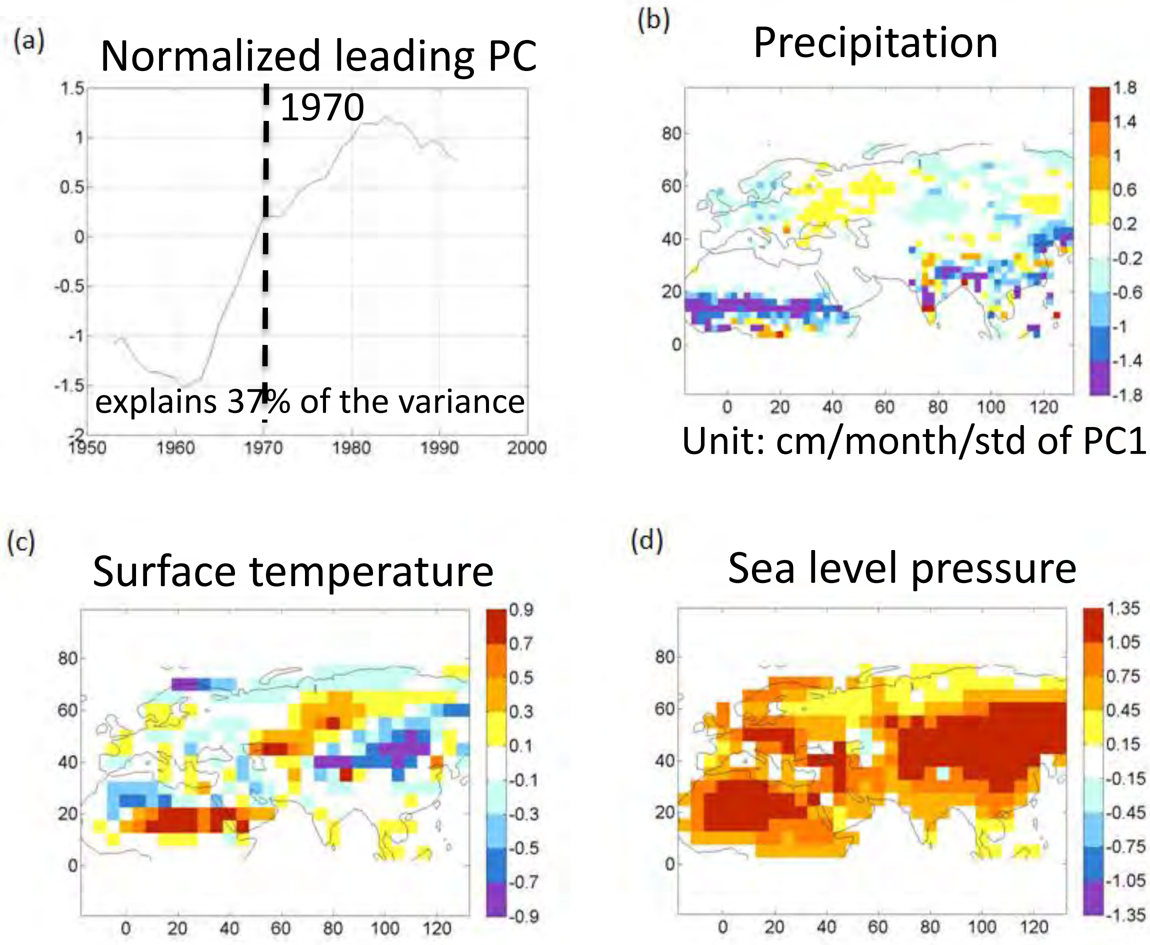
Precipitation (cm/month) **Surface temperature (degree C)** **Sea level pressure (hPa)**

More objectively – apply a **Combined Principal Component Analysis** (CPCA) to these JJA fields (w/ 7-year running mean applied)

- CPCA taken over land regions only
- Global mean temp is removed from each sfc temp gridpoint prior to analysis (to emphasize spatial gradients)

Data: NCEP Reanalysis surface temperature and SLP; GISS/Dai precipitation
Domain: Eurasia and North Africa continental interior

Combined PCA extracts the late 1960's climate shift as the dominant mode



Unit: cm/month/std of PC1

Unit: degreeC/std of PC1

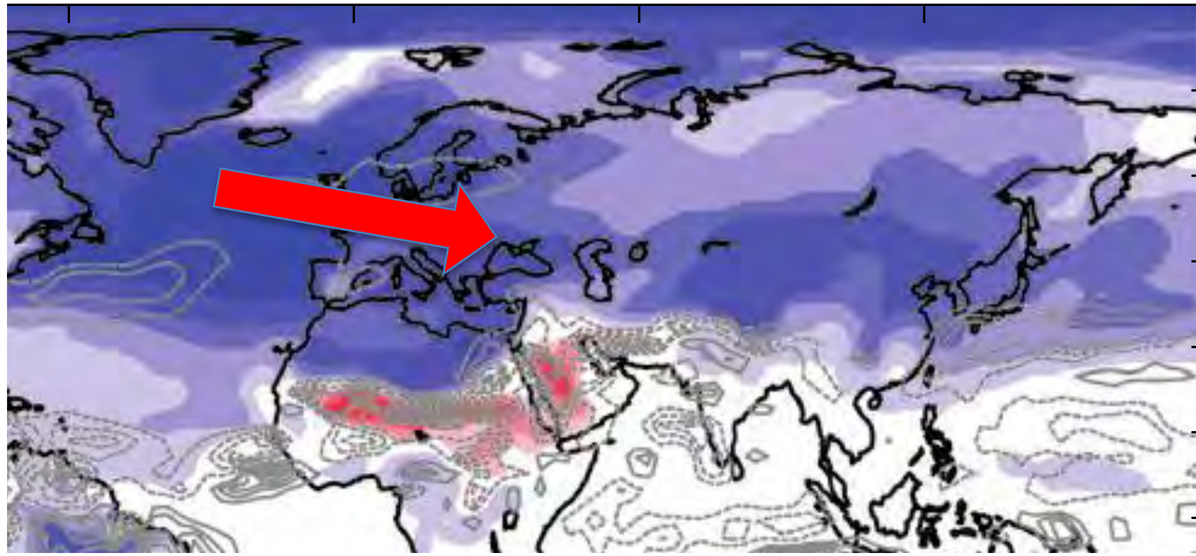
Unit: hPa/std of PC1

Sanity checks

1. Repeating CPCA with **non-NCEP obs data** gives similar results
2. Repeating CPCA with **tropospheric temp** rather than surface temperature gives a uniform temperature signal over Eurasia
3. Repeated with **20th century forced SST simulations**

Teleconnection Mechanisms

Working hypothesis: The North Atlantic influence is mediated by ***air temperature***



Preliminary analysis (of CAM3-slab ocean simulations)***:***

Radiative feedback analysis (using a radiative kernel method) indicates that positive cloud and water vapor feedbacks act to amplify the cooling over North Africa and Eurasian continents

Moisture budget analysis (w/ Chia Chou) shows that In central North Africa (away from the Atlantic ITCZ), the ***direct moisture effect is the largest term,*** consistent with the influence of temperature on moisture.

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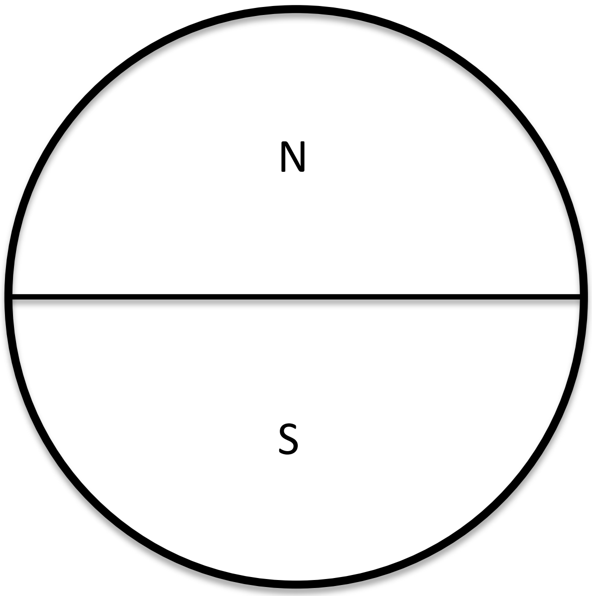
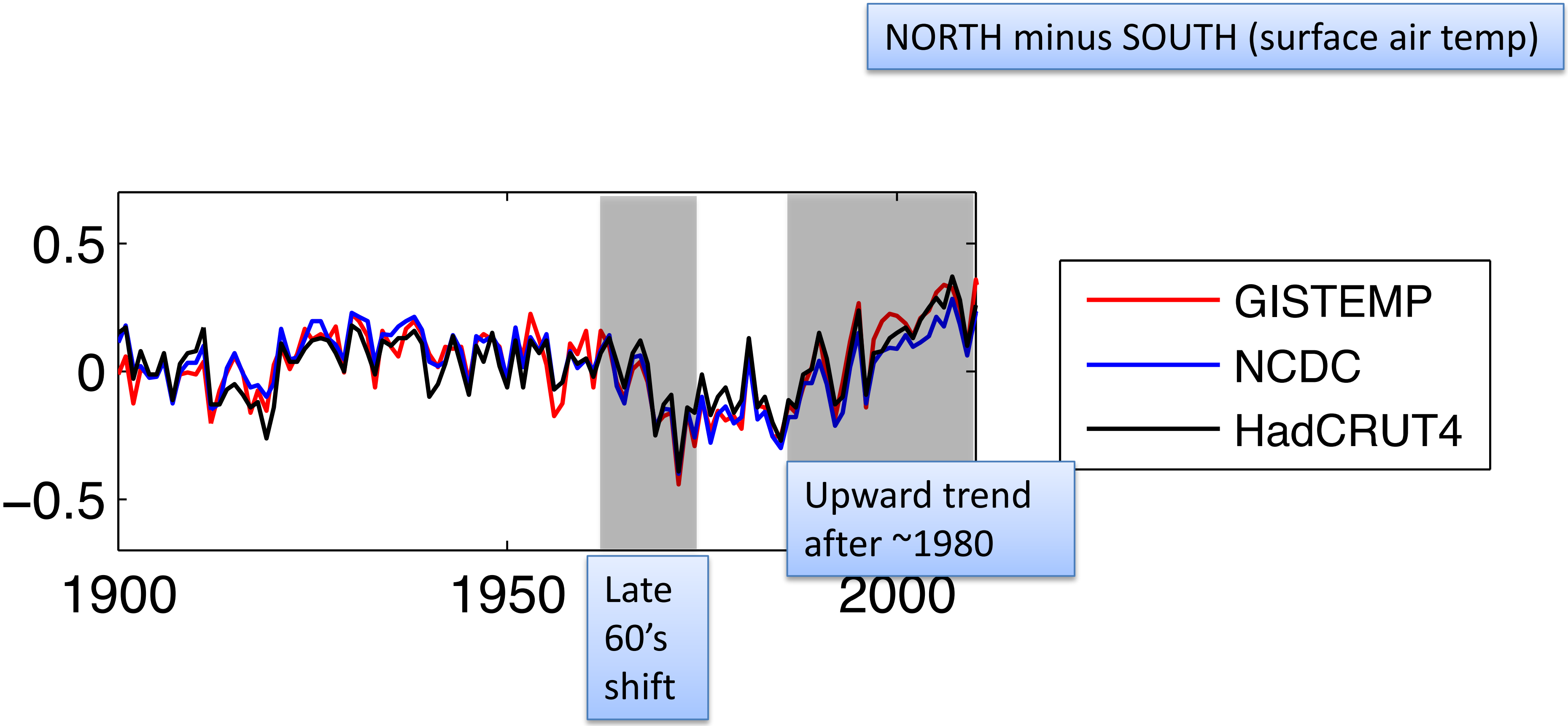
‘Global’ Interhemispheric Thermal Gradient index

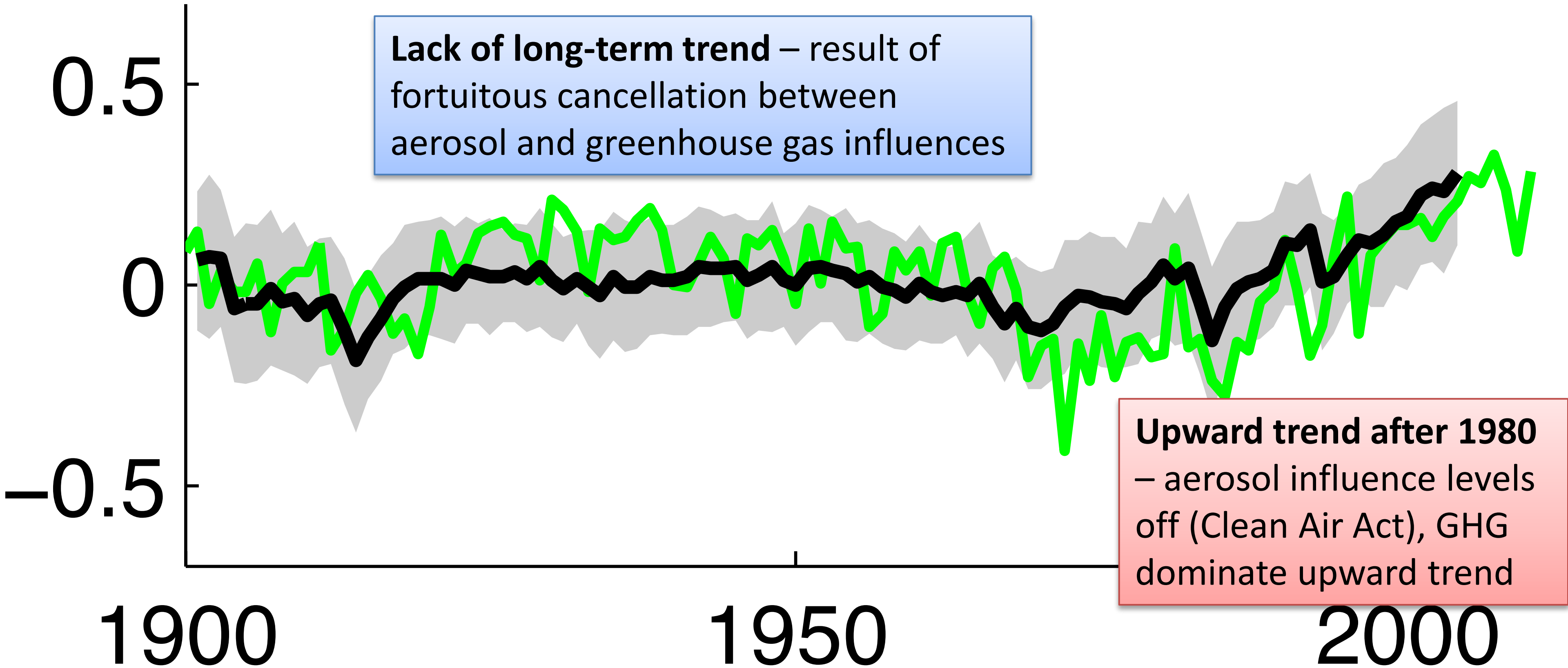


- ITG index = N minus S hemispheric ***surface air temp***
- 20th century mean subtracted
- Observations: GISTEMP, NCDC, HadCRUT4
- CMIP3/5: one ensemble member per model

Interhemispheric Thermal Gradients: observed 20th century

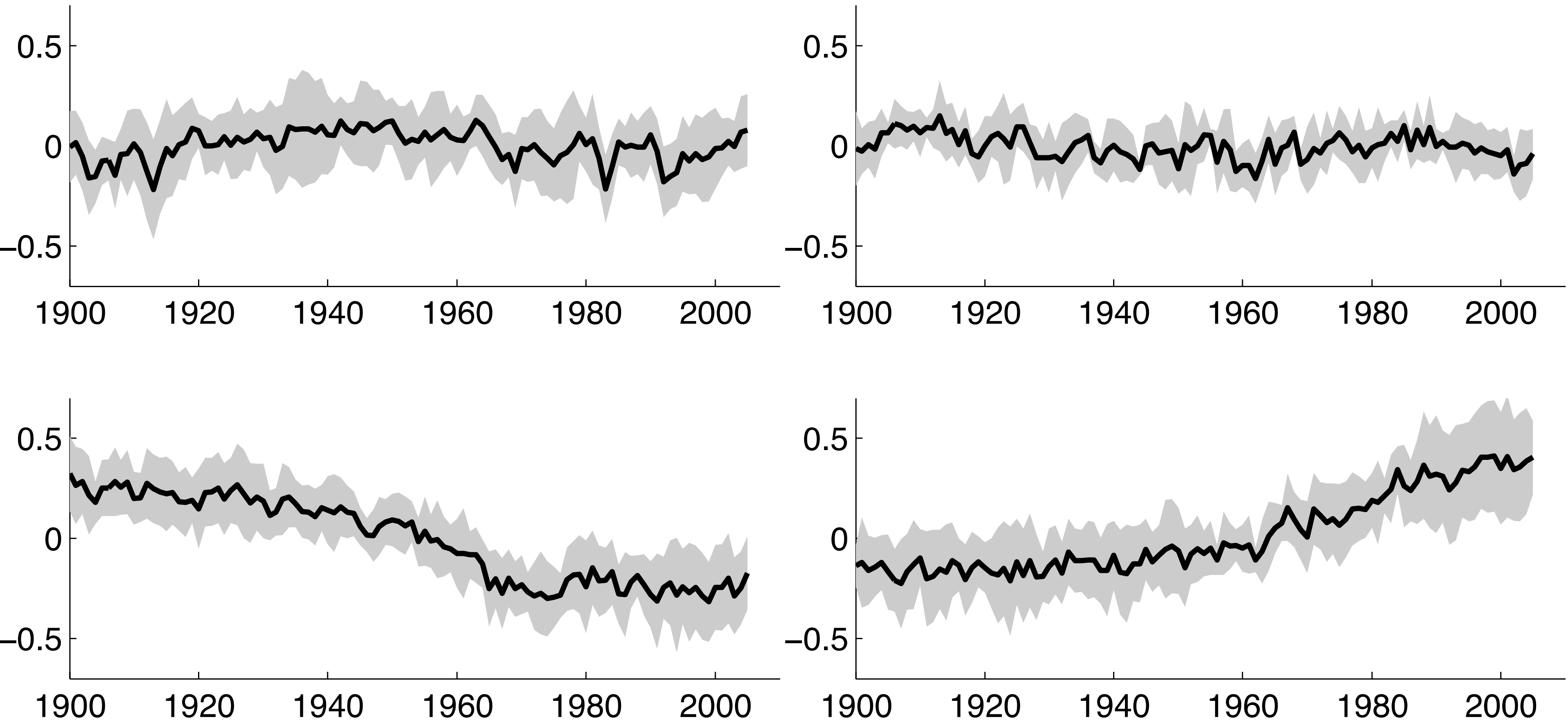


CMIP5 Interhemispheric Thermal Gradient index, historical simulations

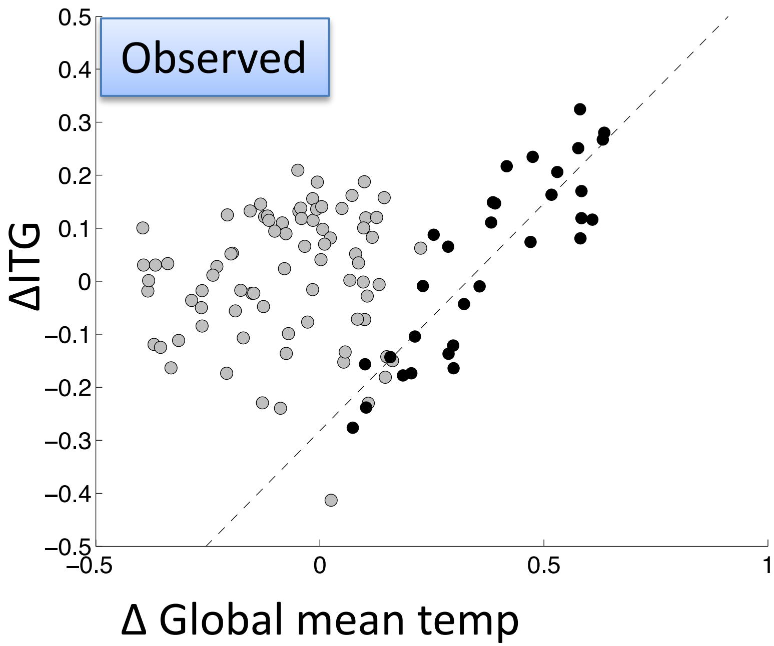


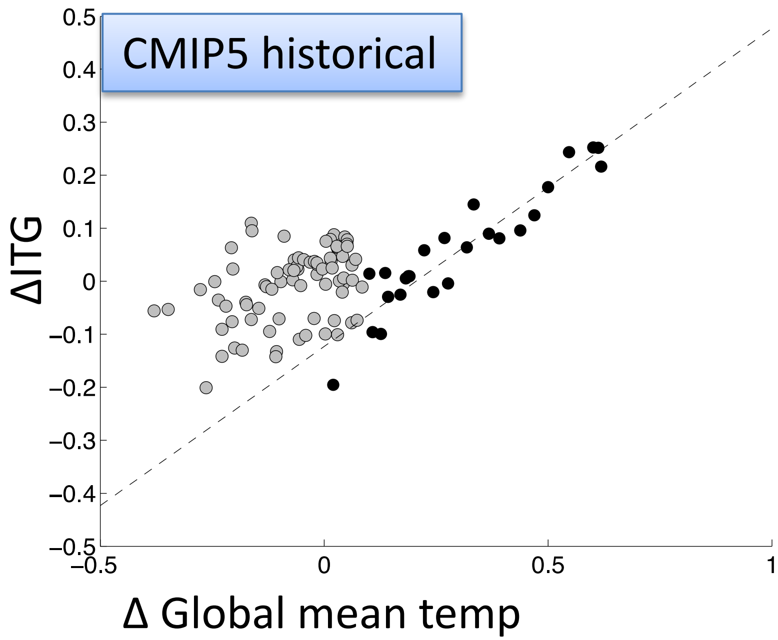
NORTH minus SOUTH
(surface air temp)

Interhemispheric Thermal Gradients: 20th century attribution



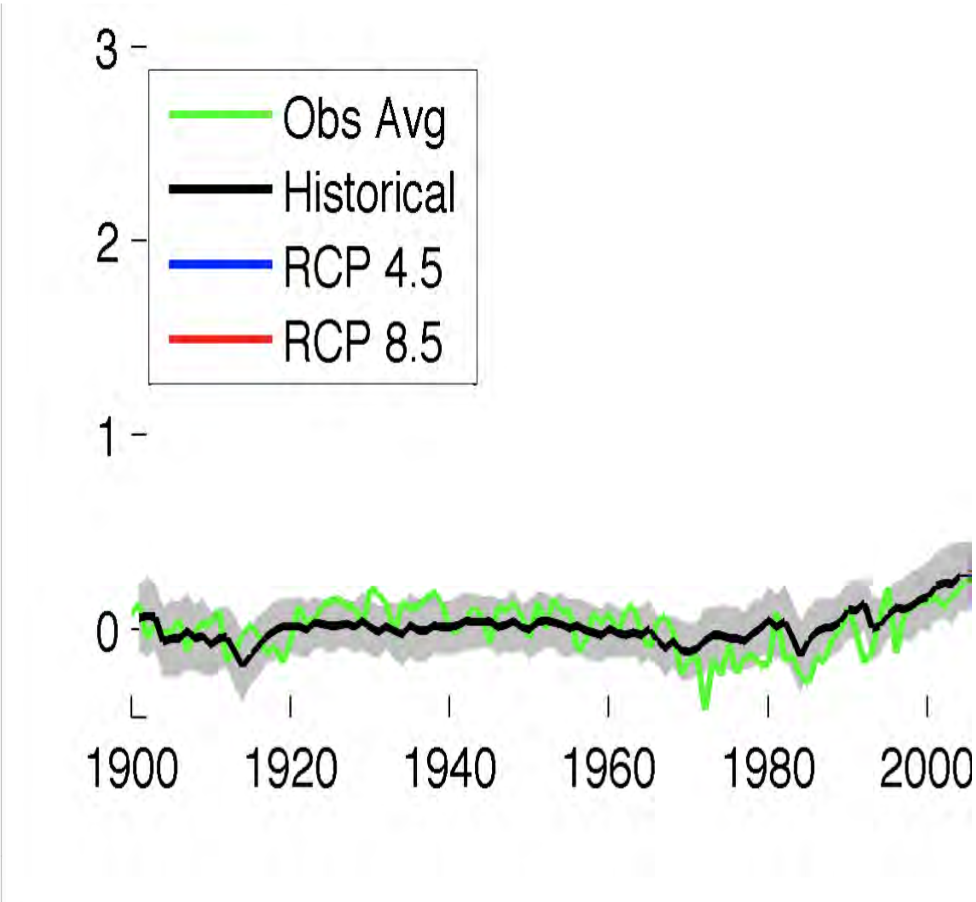
ITG vs Global mean temperature





Filled dots – post-1980

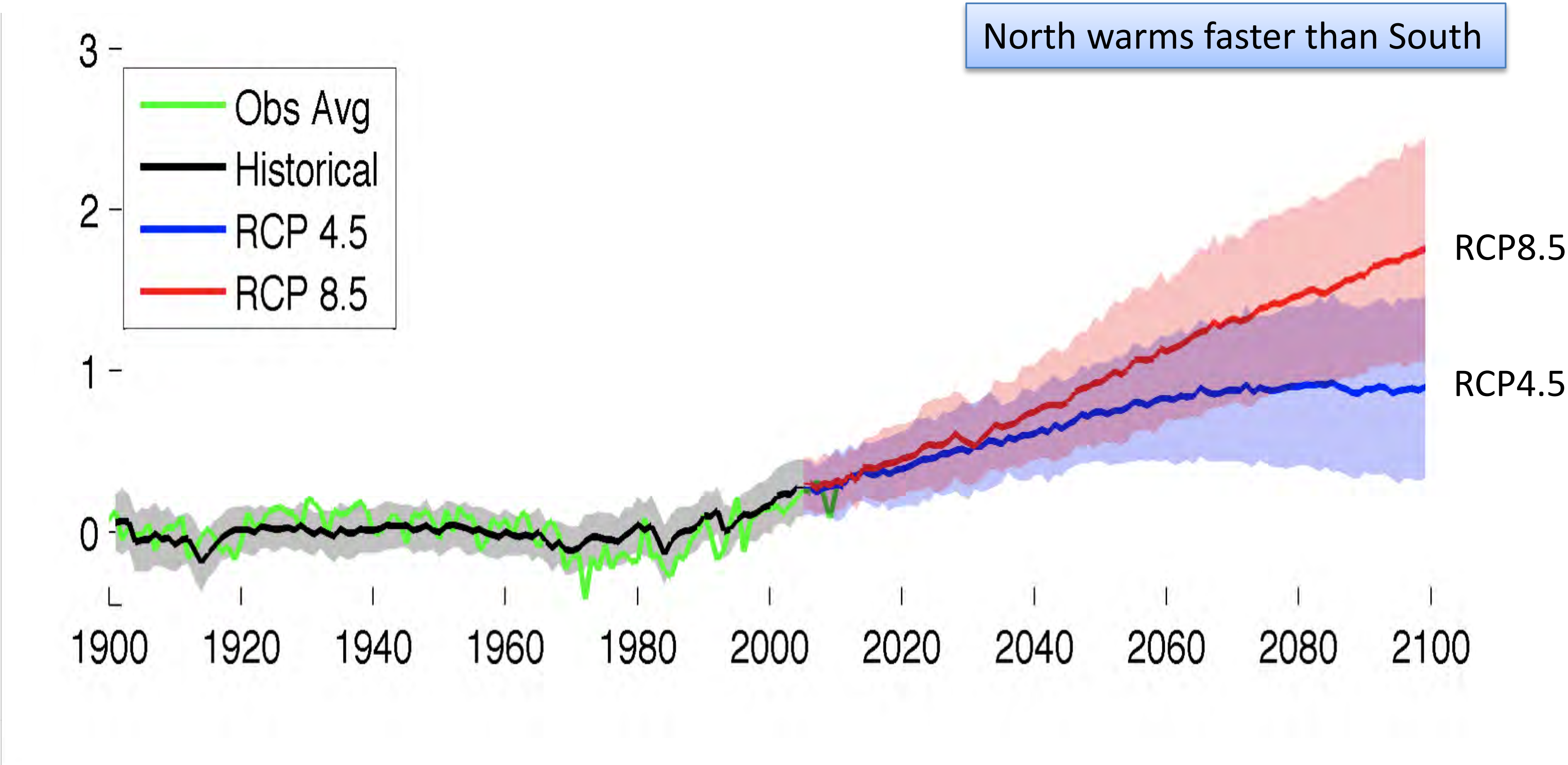
Interhemispheric Thermal Gradients simulated by CMIP5: the future



North warms faster than South

Interhemispheric Thermal Gradients simulated by CMIP5: the future

North warms faster than South



Summary

1. Paleoclimate studies suggest an influence by extratropical thermal forcing influence on tropical rainfall climate

1. The Tropical Atlantic ITCZ has been progressively shifting southwards over 20th century prior to ~1980. This behavior is at least partially driven by anthropogenic aerosols (presumably from northern industrialized nations)

2. An observed abrupt late 1960's weakening of the North African and South/East Asian monsoons is consistent with the teleconnected influence of abrupt cooling over the high latitude North Atlantic. Teleconnection mechanisms remain to be elucidated, however.

3. There is essentially no long-term trend in the 20th century global interhemispheric thermal gradient because of the cancellation between anthropogenic aerosol and GHG forcings. The future gradient will be dominated by GHG forcing (started ~1980).

Acknowledgements

Collaborators

Ching-Yee Chang, Andrew Friedman, Yuwei Liu, Michael Wehner, Yen-Ting Hwang, and Dargan Frierson

Funding

NSF, Comer Science and Education Foundation, DOE

Papers (available at http://www.atmos.berkeley.edu/~jchiang/)

Review Paper: Chiang, J. C. H., and A. R. Friedman: "Extratropical Cooling, Interhemispheric Thermal Gradients, and Tropical Climate Change. Annual Reviews of Earth and Planetary Sciences, 2012

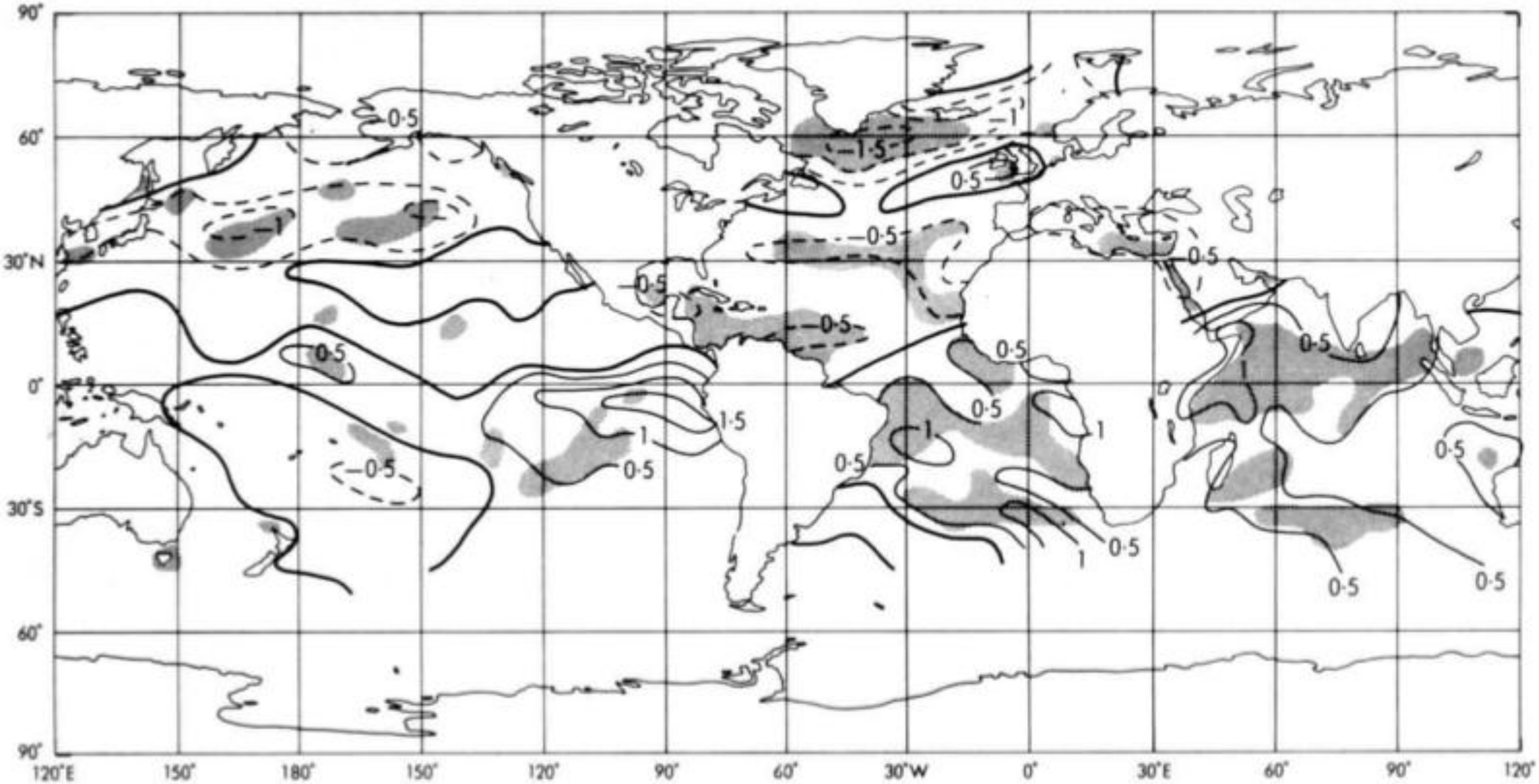
Chang, C.-Y, J.C.H. Chiang, M.F. Wehner, A.R. Friedman, and R. Ruedy: "Sulfate aerosol control of Tropical Atlantic climate over the 20th century." *J. Climate*, **24**, 2540-2555 (2011)

Chiang, J. C. H., C.-Y. Chang, and M. F. Wehner: "Long-Term Trends of the Atlantic Interhemispheric SST Gradient in the CMIP5 Historical Simulations. Submitted to *J. Climate*

Liu, Y., and J.C.H. Chiang: Co-ordinated abrupt weakening of the Eurasian and North African Monsoons in the 1960's and links to extratropical North Atlantic Cooling. *J. Climate*, **25**, 3532-3548 (May 2012).

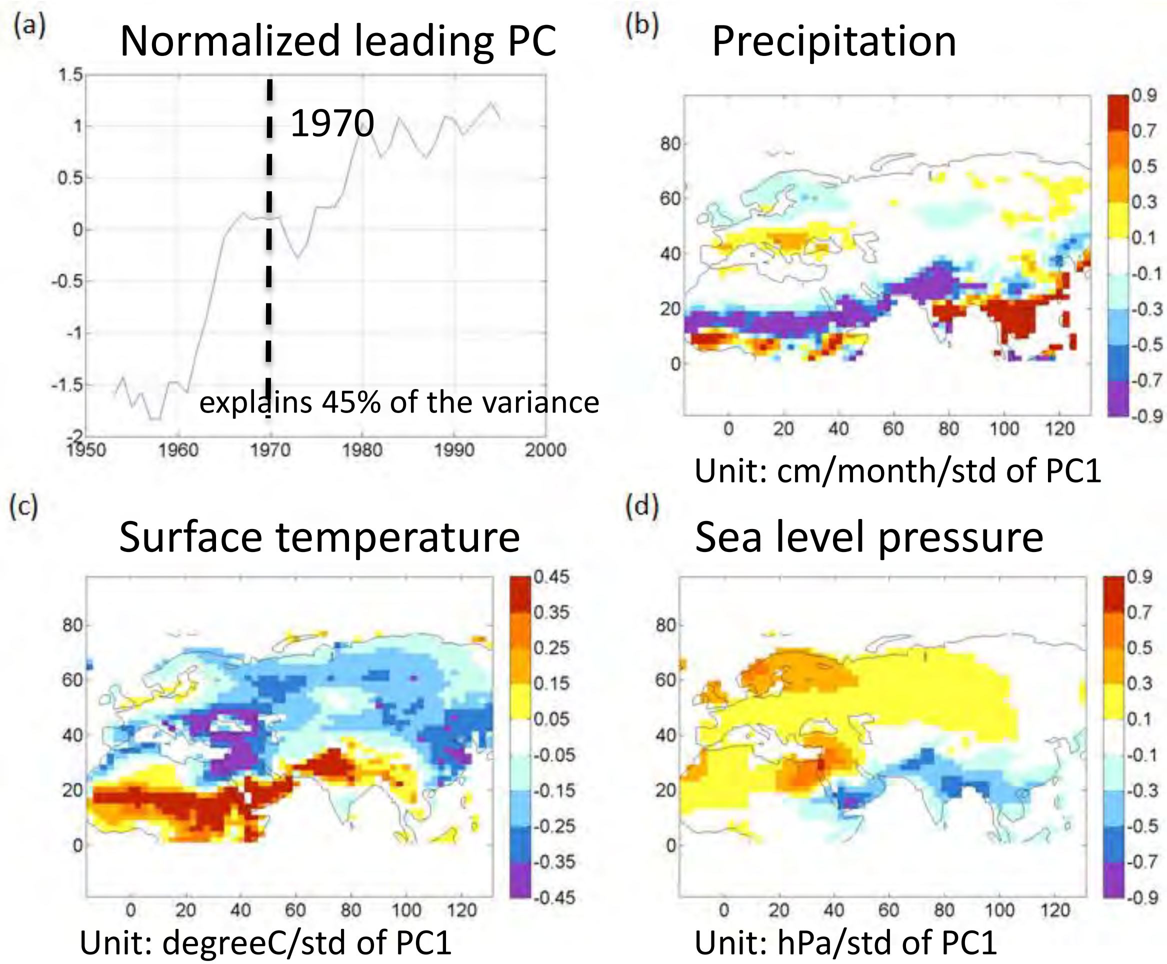
Friedman, A. R., Y.-T. Hwang, J. C. H. Chiang, and D. M. W. Frierson: "The Interhemispheric Thermal Gradient over the 20th Century and in Future Projections". In revision for J. *Climate*

The late 1960's Sahel drought and links to the North Atlantic



From ***Folland et al. 1986*** - Difference of global boreal summer SST averaged over 5 Sahel dry years with that over 5 Sahel wet years

CPCA results similar in AGCM simulations with observed SST and climate forcings



Checks

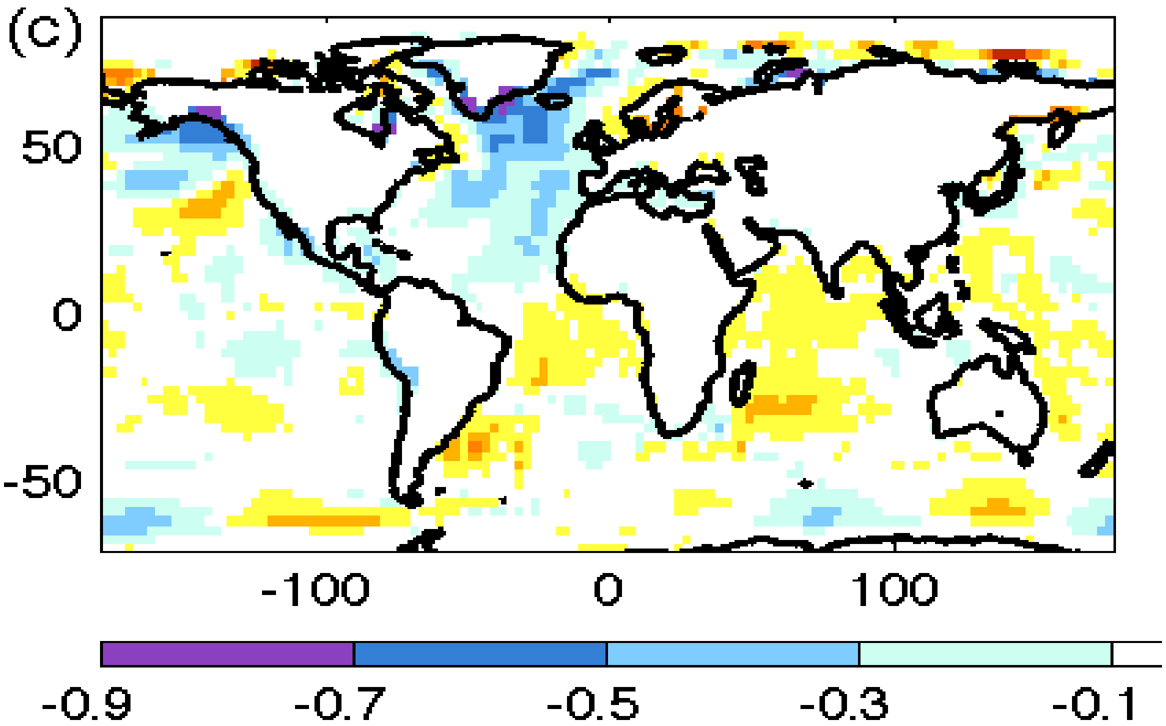
1. Repeating CPCA with 20th century all-forcing runs w/ prescribed SST in the **CAM3** gives similar results

2. Repeating CPCA with **CAM3 with only 20thC prescribed SST** also gives similar results – suggests **origins of this change is in the SST**

Data: ensemble mean of 10 members of 20th century all-forcing runs from the GFDL AGCM AM2.1 with prescribed SST

SST origins of the 1960's shift

Regression of observed PC1 against observed SST, 1950-1975



Teleconnection Mechanisms
(ongoing work, with Chia Chou)

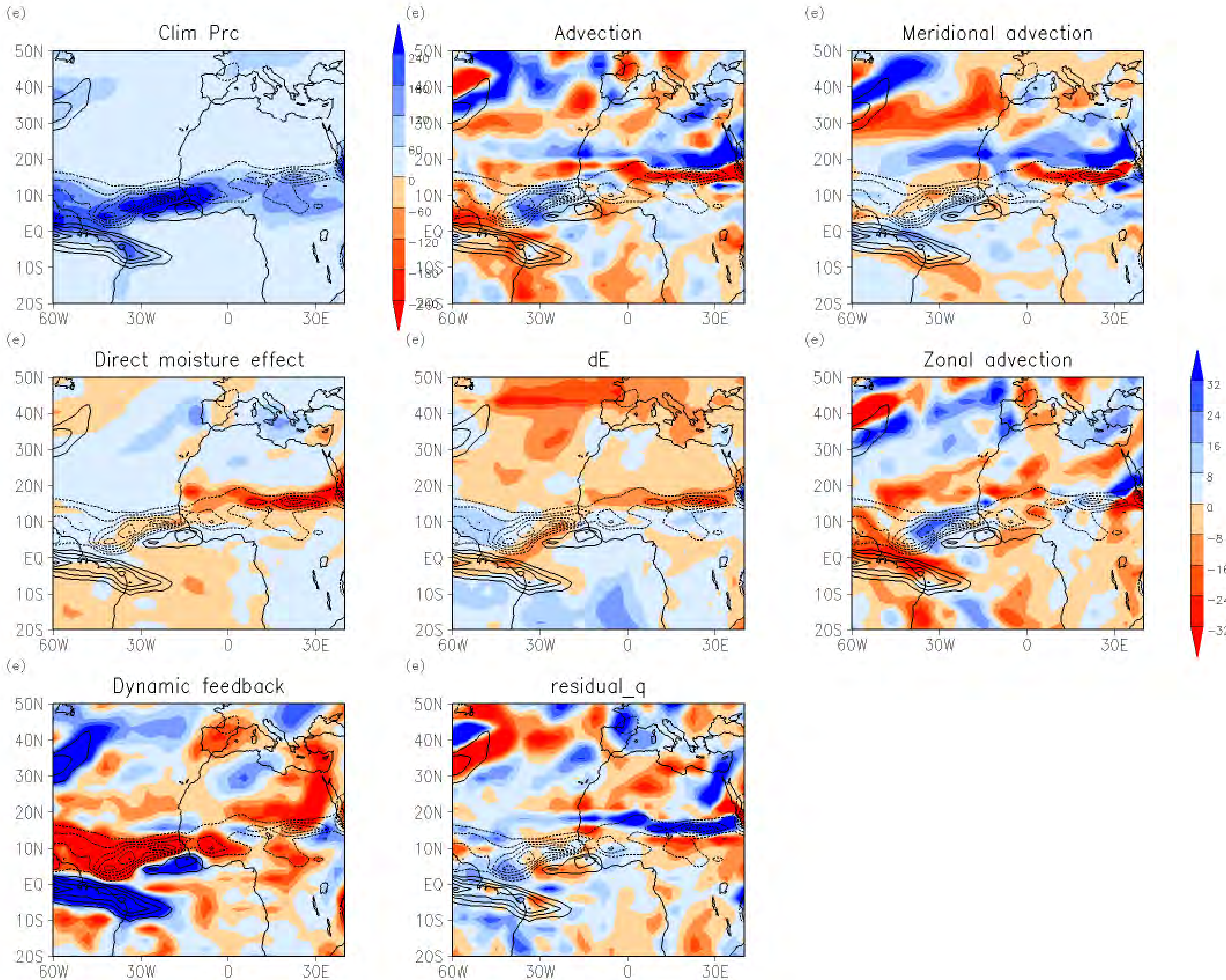
$$P' = -\langle \bar{\omega} \partial_p q' \rangle - \langle \omega' \partial_p \bar{q} \rangle - \langle \mathbf{v} \cdot \nabla q \rangle' + E' + \text{residual\_}q$$

Rainfall change	Direct moisture effect	Dynamic feedback due to change in GMS	Upped-ante:advection	Evaporation	Transient and nonlinear terms

A moisture budget analysis (e.g. Chou et al. 2008) of North Africa shows that

1. In central North Africa (away from the Atlantic ITCZ), the ***direct moisture effect is the largest term,*** followed by advection, evaporation, and dynamic feedback.

2. In the western Sahel, ***the dynamic feedback term dominates the budget***; this response is directly linked to the southward shift of the Atlantic ITCZ.



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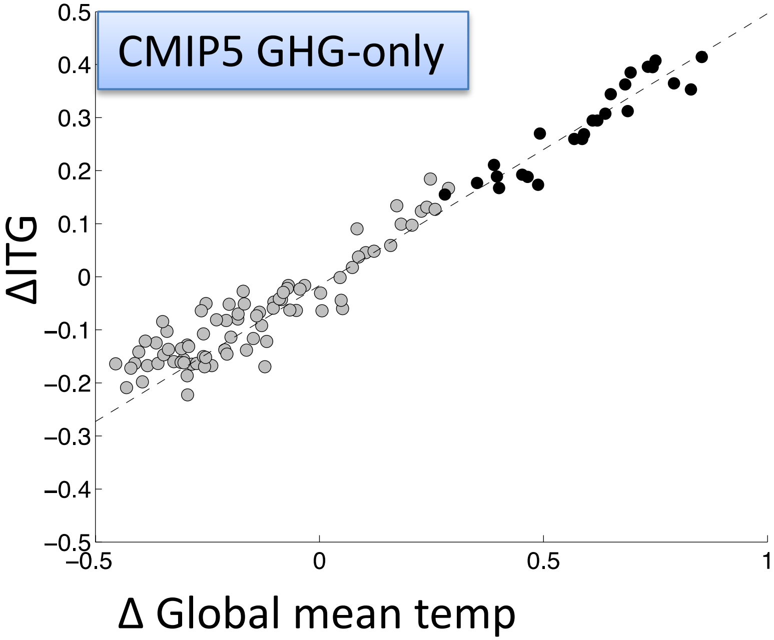
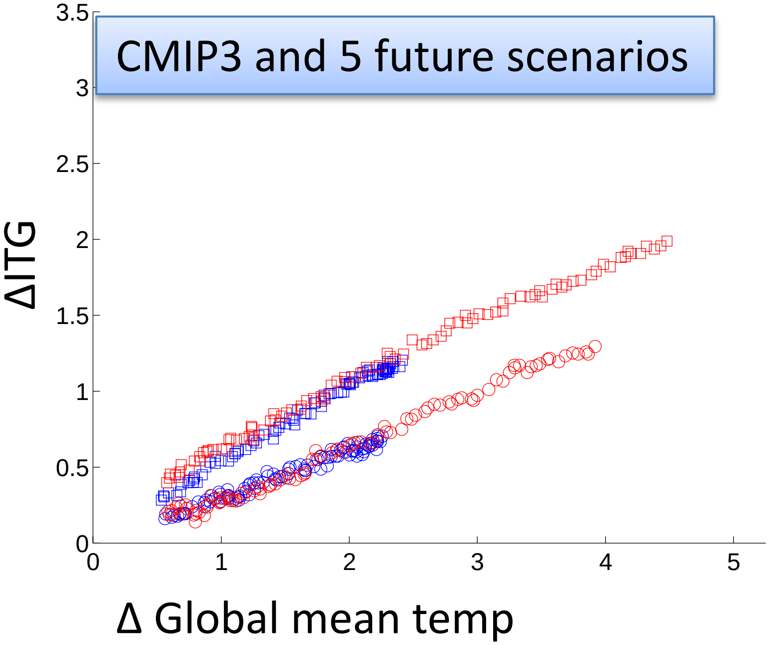
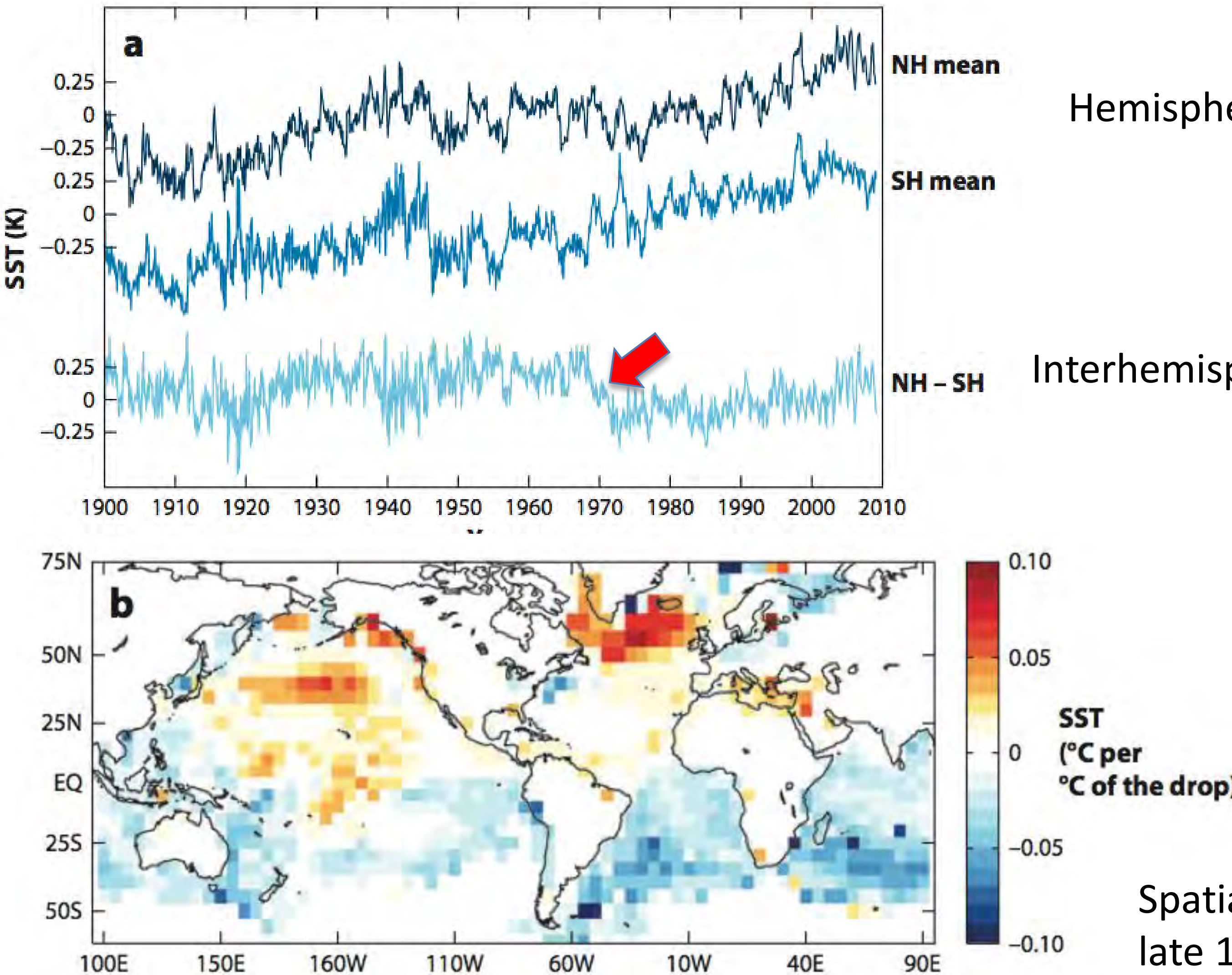




Interhemispheric SST Gradients (Thompson et al. 2010)



Hemispheric mean SST

Interhemispheric SST difference

Spatial pattern of the late 1960's shift

(Thompson et al. *Nature* 2010)

Regression of global mean temp onto zonal mean surface air temperatures