The South Atlantic Meridional Overturning Circulation: A driver of climate variability and extremes.

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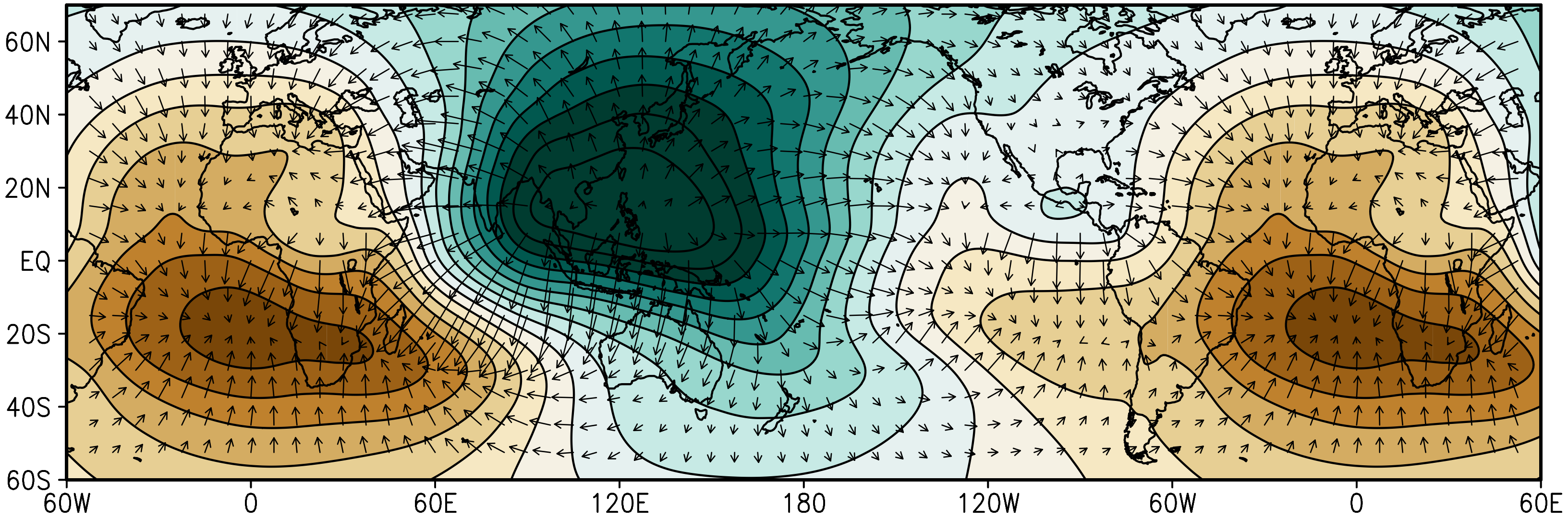
Global boreal summer atmospheric circulation: Monsoons

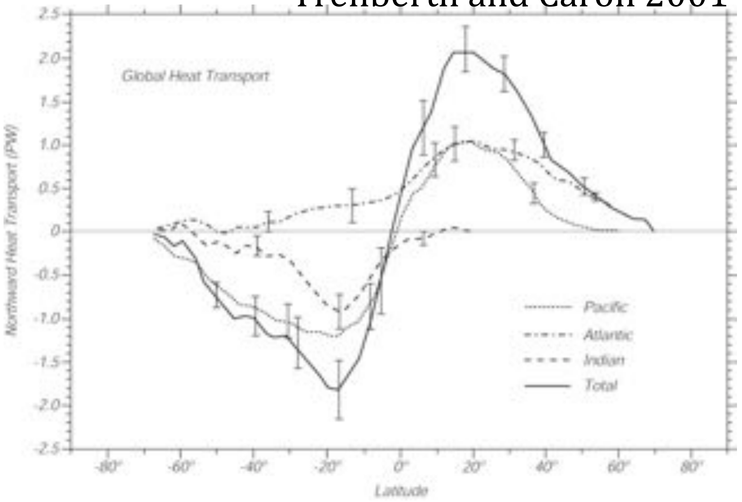
Boreal summer (June-July-August) 200mb velocity potential



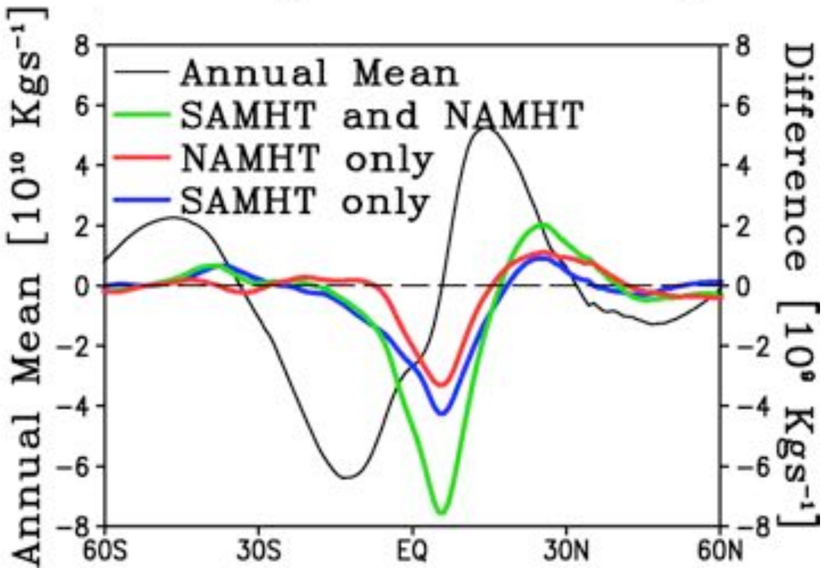
<u>Objective</u>: *Investigate if the South Atlantic MOC is linked (and can be used as a predictor) to global monsoons and heat wave events over North America.*

Meridional Overturning Circulation

Trenberth and Caron 2001



The South Atlantic MOC (SAMOC) is unique in that its upper branch carries heat equatorward (Talley 2003; Lumpkin and Speer 2007).

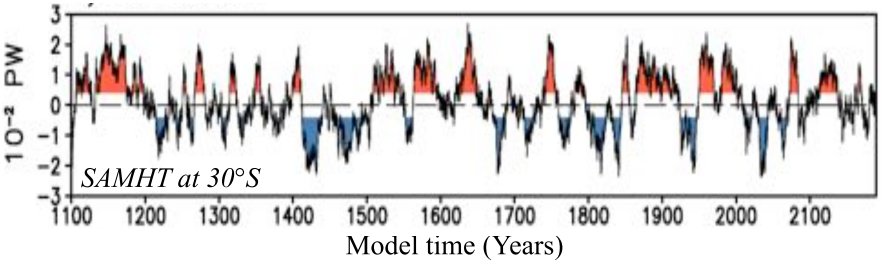


SAMOC as important as the North Atlantic MOC in modulating atmospheric circulation (Lopez et al. 2016).

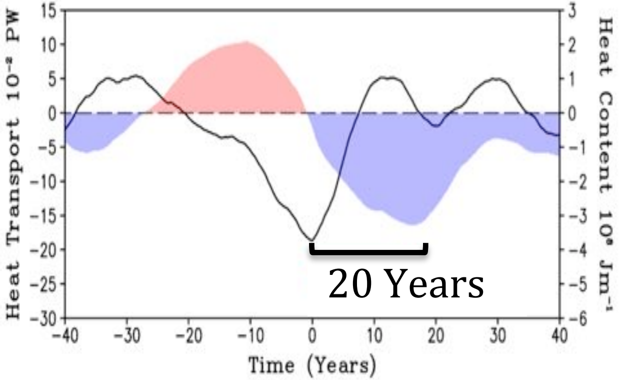
SAMHT surface fingerprint: A forcing of climate variability

Couple Model:

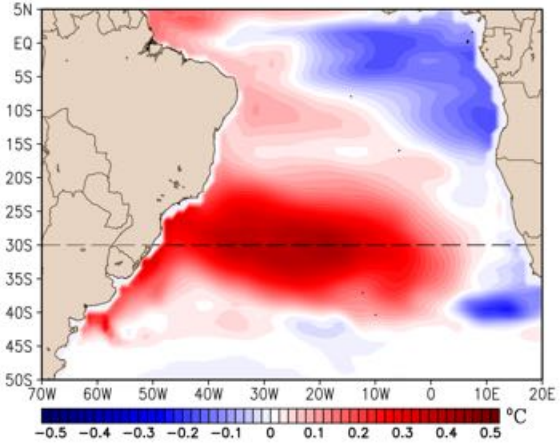
- Community Earth System Model (CESM1) large ensemble simulation (Kay et al. 2014)
- Use 1100 years of preindustrial control simulation at 1-degree resolution.



SAMHT and heat content

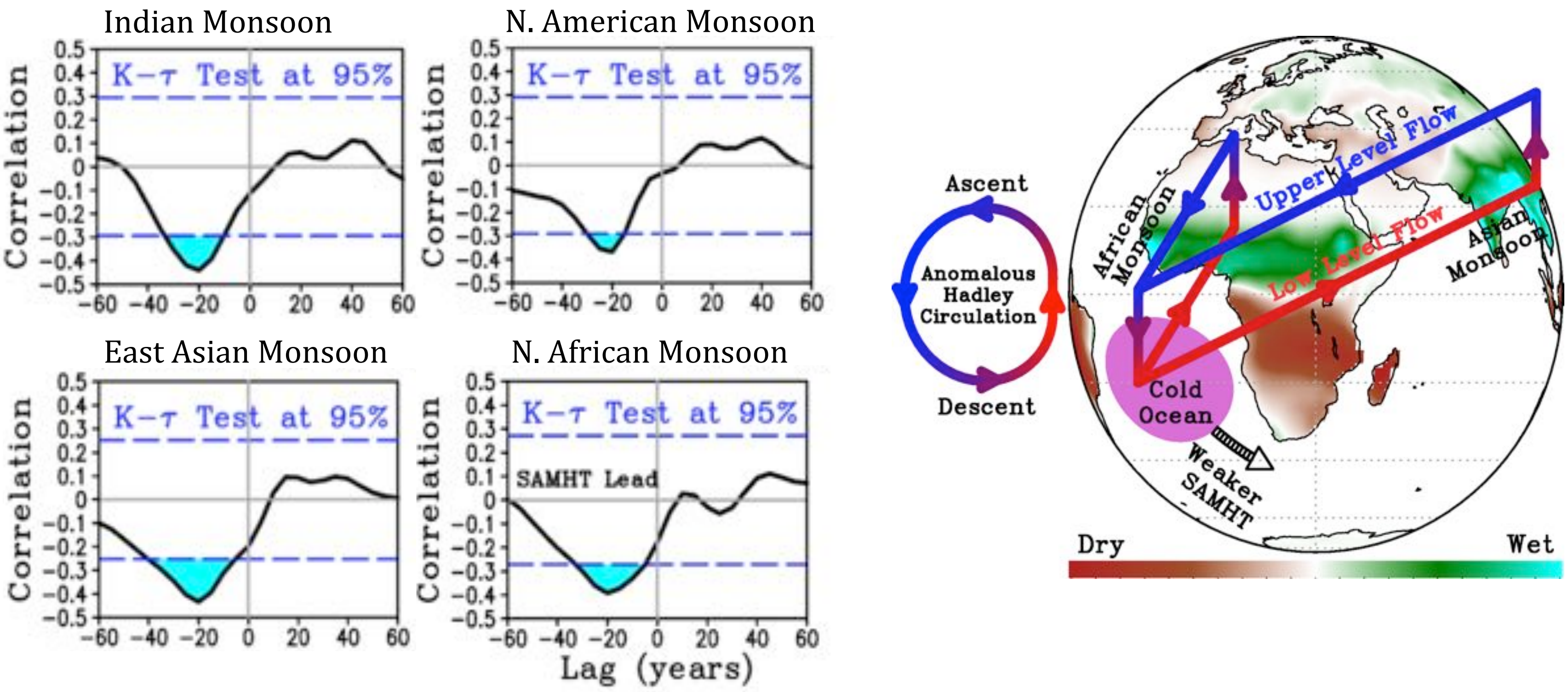


Regression[SAMHT, SSTA(t+20)]



- About 20 years after weaker SAMHT at 30°S:
  - Anomalous cold SST in the Southern hemisphere
  - Anomalous warm SST in the Northern hemisphere

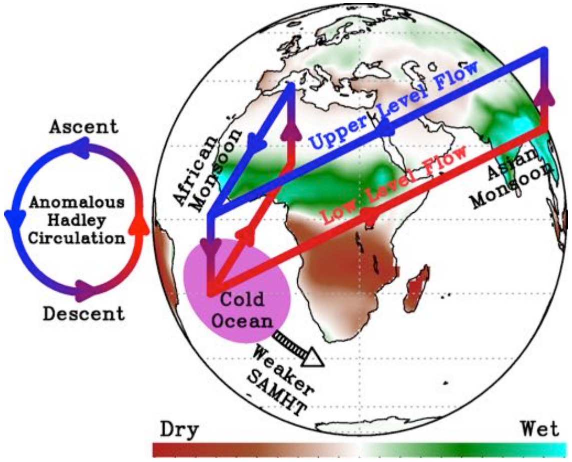
SAMHT surface fingerprint: A forcing of climate variability



Weaker SAMHT leads to stronger NH monsoons about 20 years later

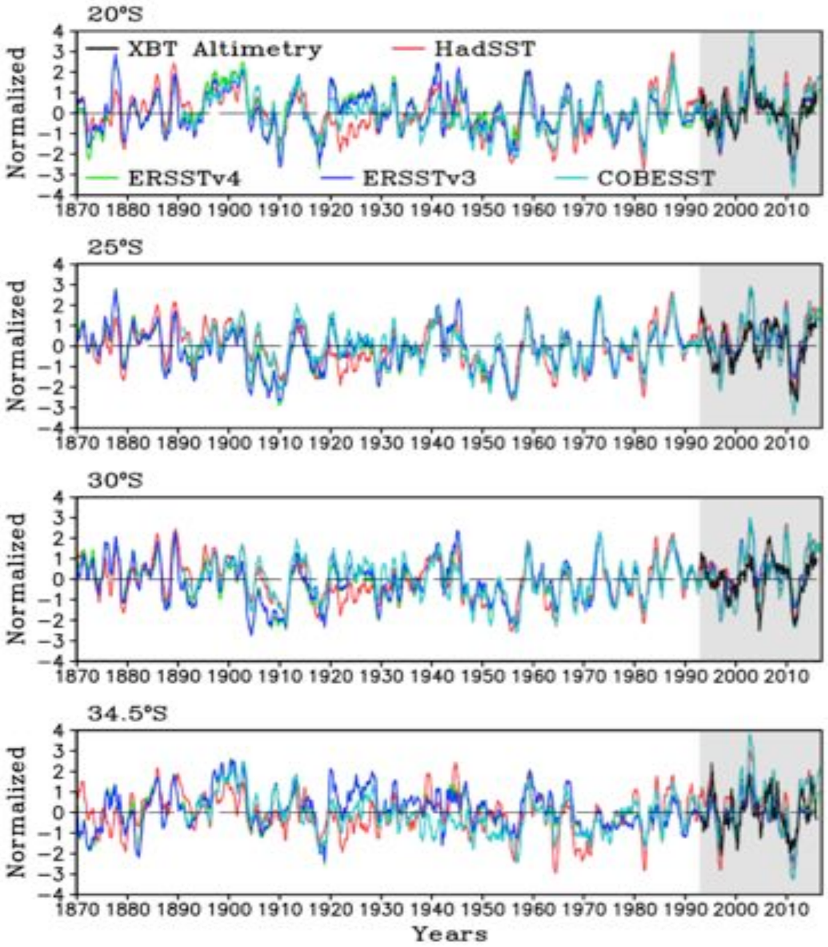
Does this mechanism exists in reality?

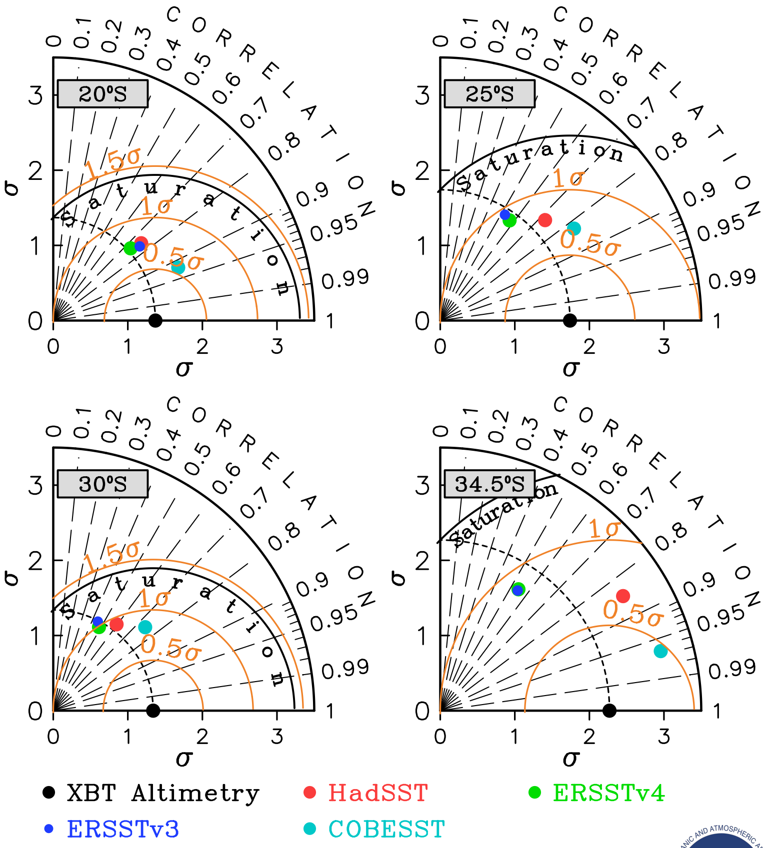
- **The problem:**
  - Short or limited observations of SAMOC
- **"The solution"**
  - Reconstruct SAMOC timeseries from other co-variant fields (e.g., SST here).
  - Perform AGCM modeling experiments to quantify the influence of SAMOC on monsoons.
  - Perform AGCM modeling experiments to test the influence of monsoons on heat waves.



"It is worth noting that the reconstruction presented here is not a replacement of the current observing systems."

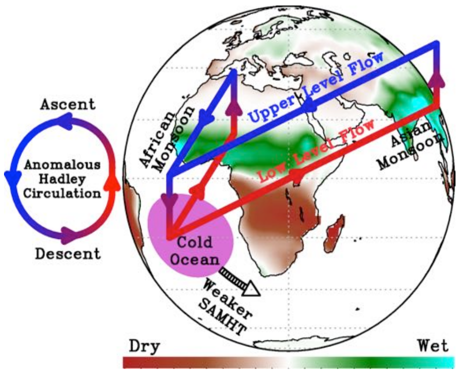
Statistical reconstruction of the SAMOC from SST



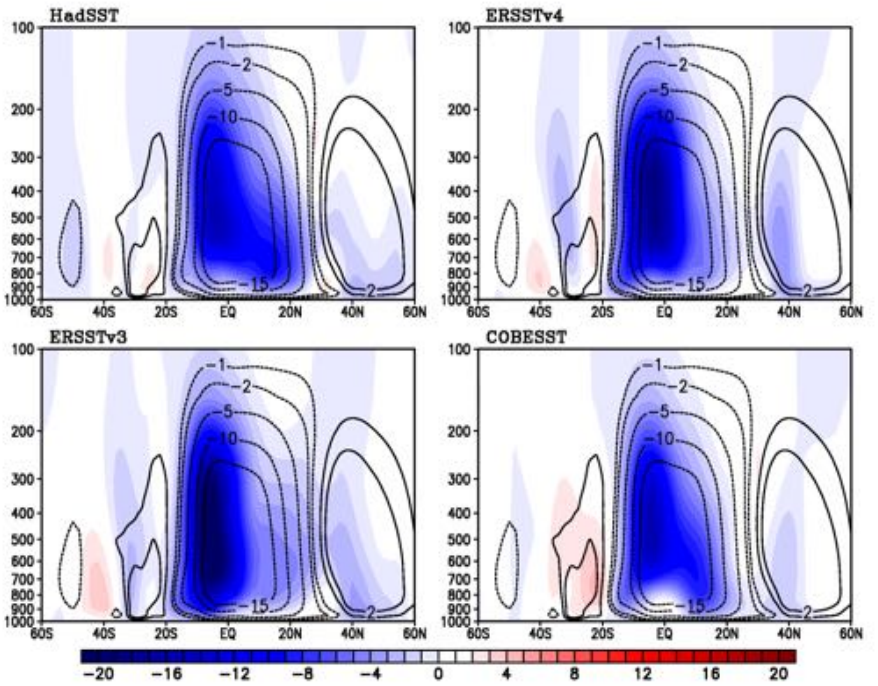


Lopez et al. 2017

Validating the Inter-hemispheric mechanism



Weak minus strong SAMOC, 20-years lead



Atmospheric Summer Meridional Circulation and reconstructed SAMOC:

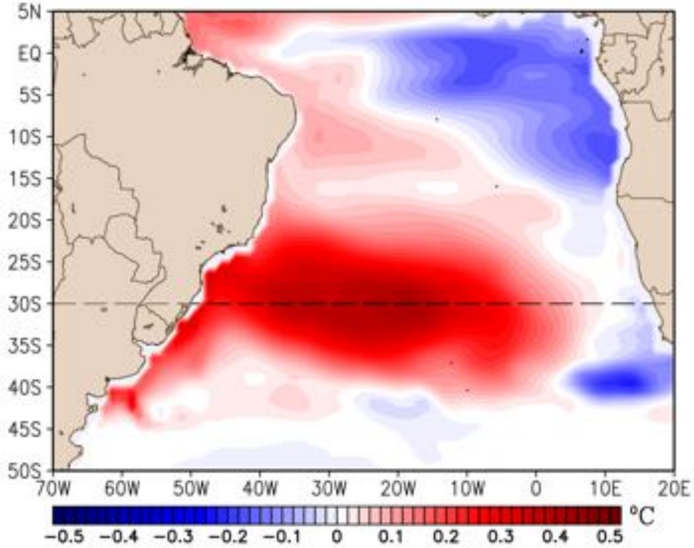
- Weak SAMOC leads to:
    - Acceleration of the Hadley circulation
    - Heat transport from NH to SH.
    - Moisture transport from SH to NH
- Stronger NH Monsoons

AGCM experiment: SAMOC influence on atmospheric circulation

Community Atmosphere Model (CAM5)* coupled to an active land model (CLM4)* and prescribed climatological boundary forcing.

- Add SST anomaly in the South Atlantic associated with SAMOC fingerprint.
- Test positive and negative phases.
- 20-years simulation for both cases.

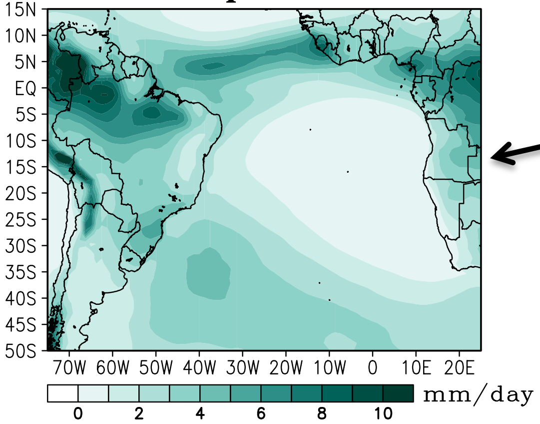
SST anomaly at 20 years lead



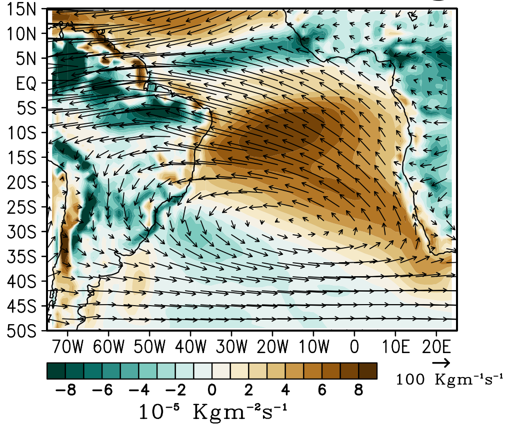
*Same model components of the NCAR CESM1 coupled model.

AGCM experiment: SAMOC influence on atmospheric circulation

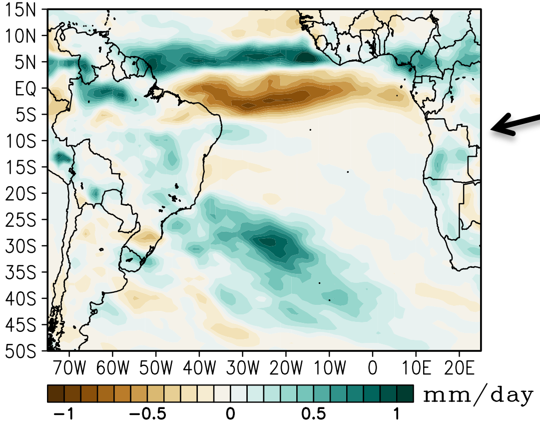
Precipitation



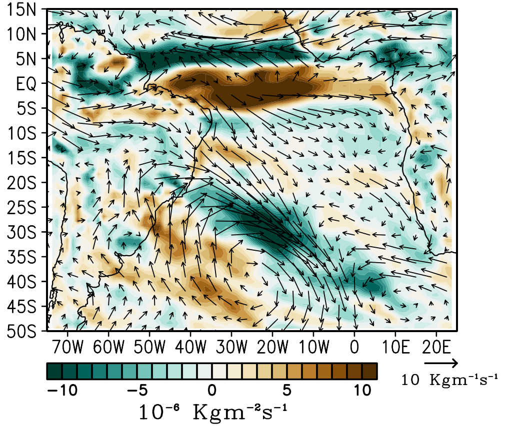
Moisture flux and divergence



Climatology



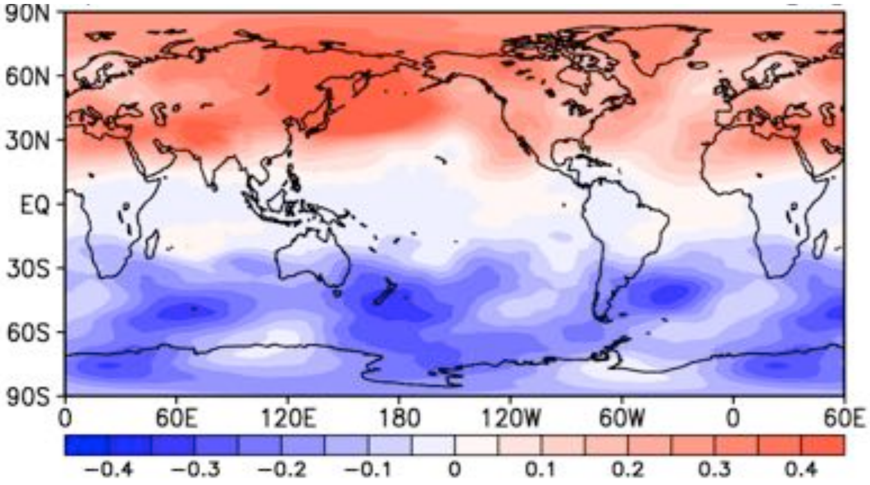
Weak-strong SAMOC



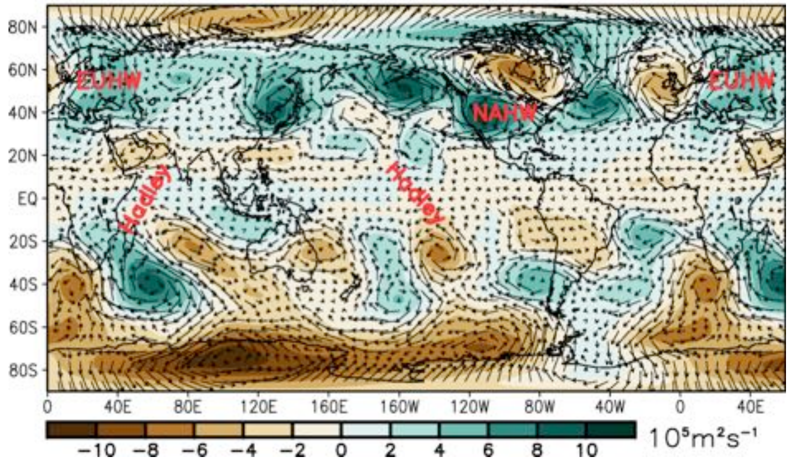
AGCM experiment: SAMOC influence on atmospheric circulation

- SAMOC anomaly generate an inter-hemispheric distribution of heat and moisture in the atmosphere, with important consequences on global climate and monsoons.
- Diabatic heating from these monsoons could force stationary waves pattern, leading to anomalous anticyclonic circulation and heat waves over the U.S.

500mb temperature, SAMHT leads by 20 years

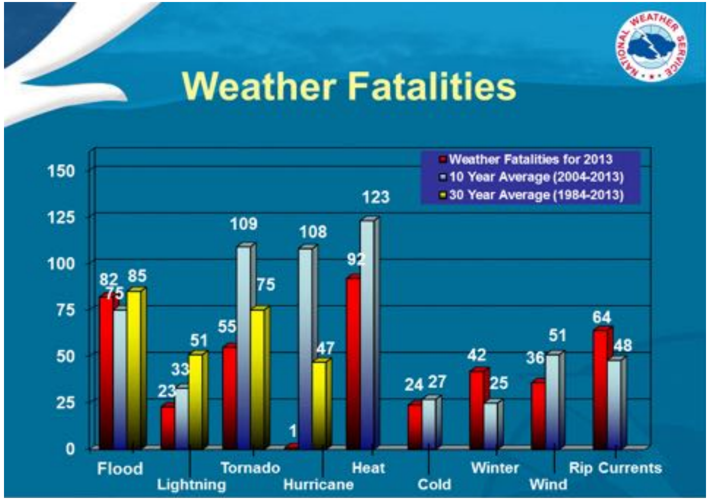


500mb circulation, SAMHT leads by 20 years

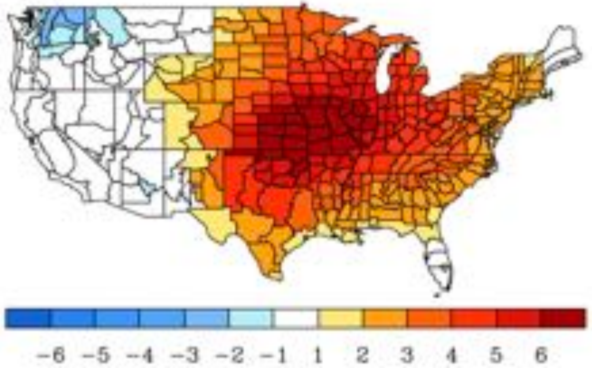


AGCM experiment: SAMOC influence on heat waves

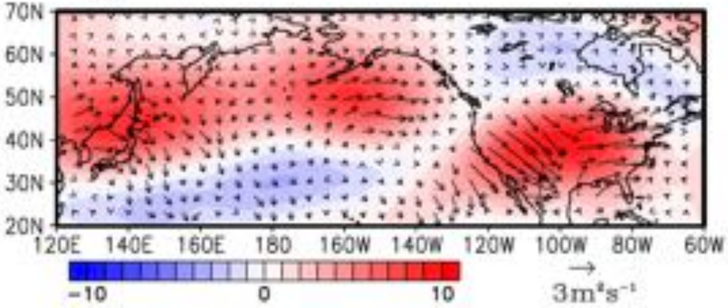
- Heat waves are the leading weather related cause of death in the U.S.
- The number of heat waves and their severity has increased in recent decades and is projected to continue increasing into the 21st Century.
- Large uncertainty in future projections over the Great Plains (Lopez et al. 2018).



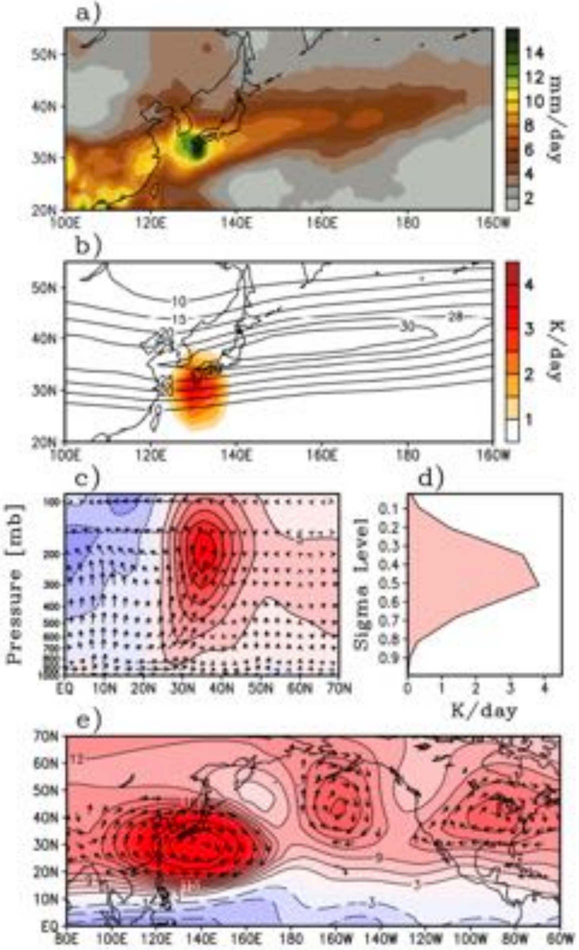
Temperature Anomaly ^{0}C



Circulation (streamfunction) Anomaly



LBM experiment: Monsoon influence on heat waves



Atmospheric Linear Baroclinic Model (LBM) experiment to test the influence of the monsoon on U.S. summer weather.

a) Climatological boreal summer precipitation showing the active East Asian Monsoon (EAM).

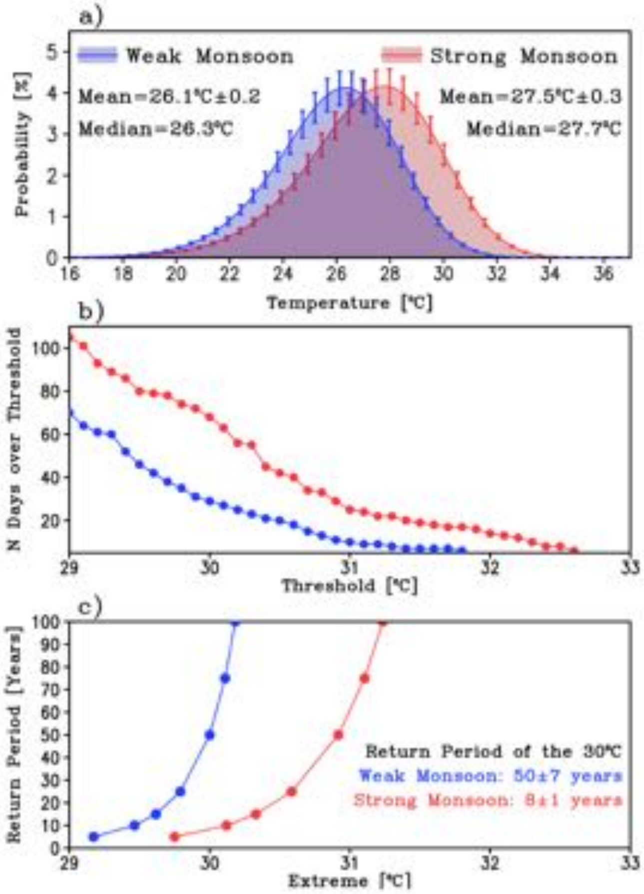
b) Climatological boreal summer zonal wind at 200mb showing jet circulation (contour). Also, idealized EAM diabatic heating (color).

c) Cross-section of the jet region.

d) Vertical profile of idealized EAM diabatic heating used to force LBM.

e) LBM response, 200mb streamfuction (color) and wind (vector).

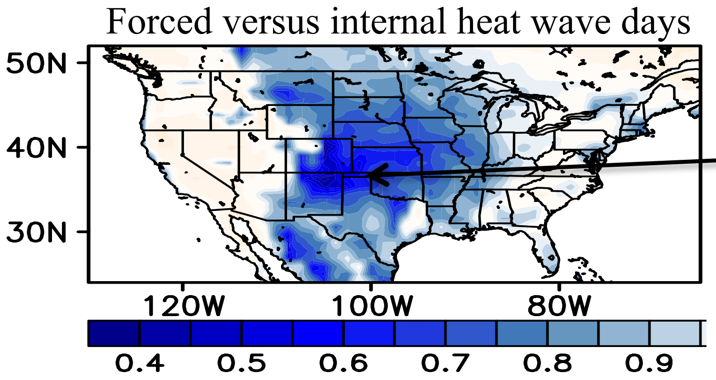
Monsoon influence on heat waves



We assess changes in the probability density function (PDF) of summer temperature extremes associated with the EAM.

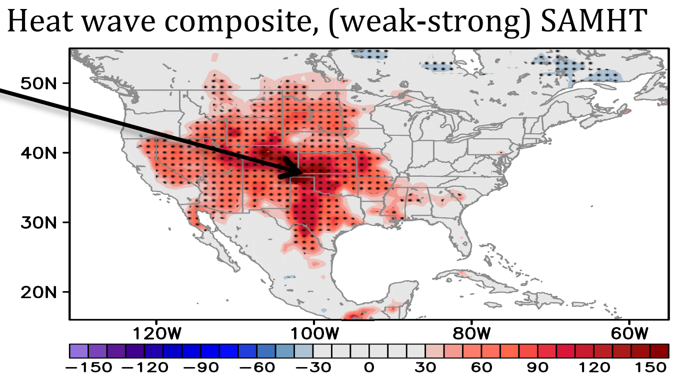
a) Significant shift to warmer temperatures over the Great Plains during those summers where the EAM is stronger.
b) Increase in the frequency of extreme temperature events over a high threshold for those summers in which the EAM is strong.
c) High-temperature extremes occurs more often during those summers with more active EAM.

North American heat wave and SAMHT



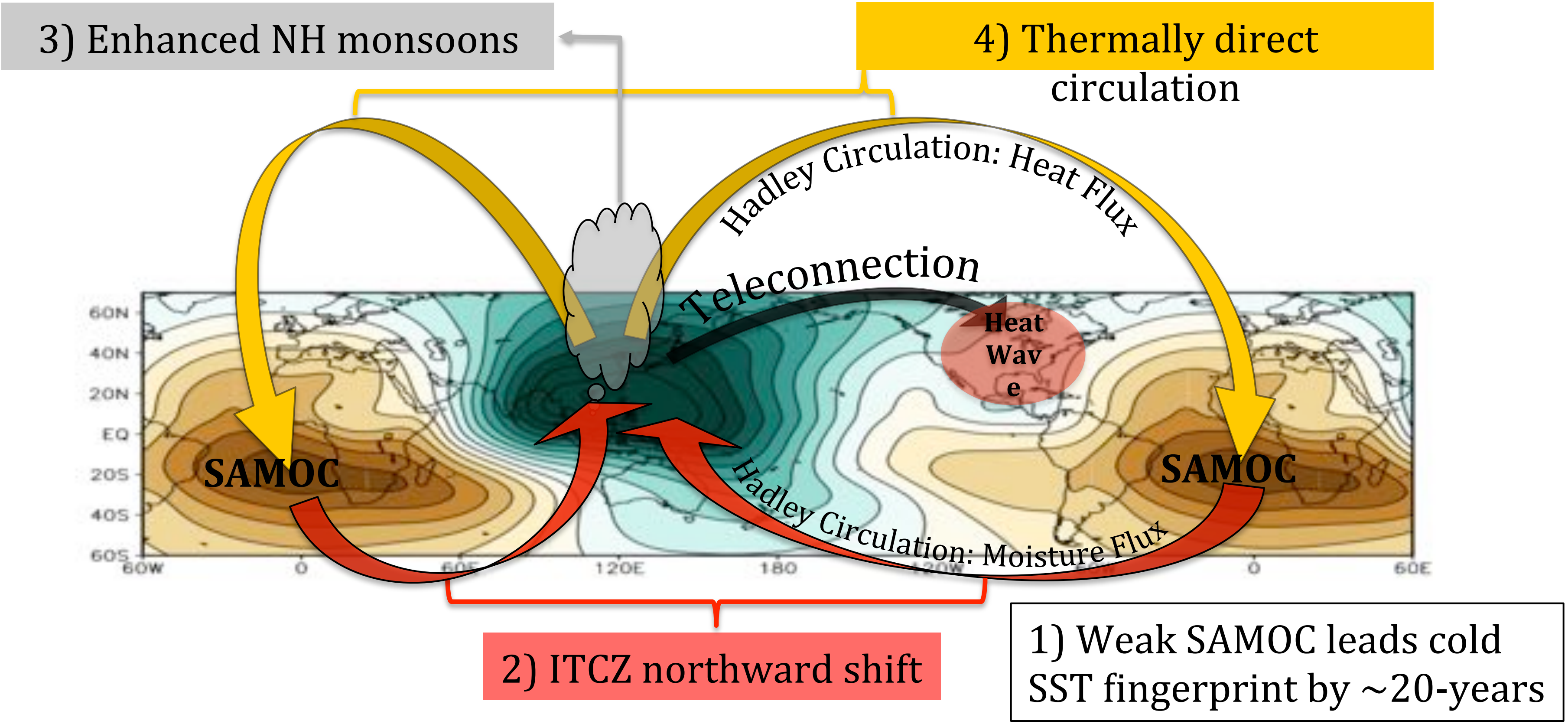
- Forced vs. internal:
  - Forced=ensemble mean
  - Internal=ensemble spread
- Region where future projection of heat waves is most uncertain.
- Internal variability >> external forcing.

The SAMHT is identified as a source of heat wave predictability over the Great Plains.



Heat wave return period (Summers)	
ERA-20th Century	13 ± 8
Pre-industrial (strong SAMHT)	73 ± 6
Pre-industrial (weak SAMHT)	14 ± 7
Random Error Range	± 12 at 95th percentile

SAMOC->monsoon->heat wave mechanism



Summary:

- A physical mechanism on how SAMOC may influence decadal variability of atmospheric circulation and heat waves was presented.
- Motivated by such mechanism, we reconstructed a century-long SAMOC time-series. We also performed AGCM experiments to test the above mechanism.
- Weaker SAMOC produces anomalous ocean heat transport divergence over the South Atlantic, resulting in negative heat content anomalies about 20 years later. This forces a thermally direct anomalous interhemispheric Hadley circulation, shifting the ITCZ northward.
- This shift in the ITCZ enhances the Northern Hemisphere Monsoons through moisture transport.
- The enhanced monsoons increases the likelihood of heat waves over the Great Plains of the U.S. through atmospheric teleconnections.

Thank you

Statistical reconstruction of the SAMOC from SST

Perform SVD between the altimetry-derived SAMOC (Dong et al. 2015) and SST in the South Atlantic for the period of 1993-2015 (i.e., trained period).

X is a *(p x m)* data vector -> SST, where *p*=grid points, *m*=temporal record
Y is a *(q x n)* data vector -> SAMOC, where *q* = 4 -> 20°S, 25°S, 30°S, and 34°S and *n*=temporal record. Build correlation matrix C_{xy} *of SST and SAMOC*

$$\mathrm{SVD}(C_{xy}) = \boldsymbol{U\Sigma V^T}$$

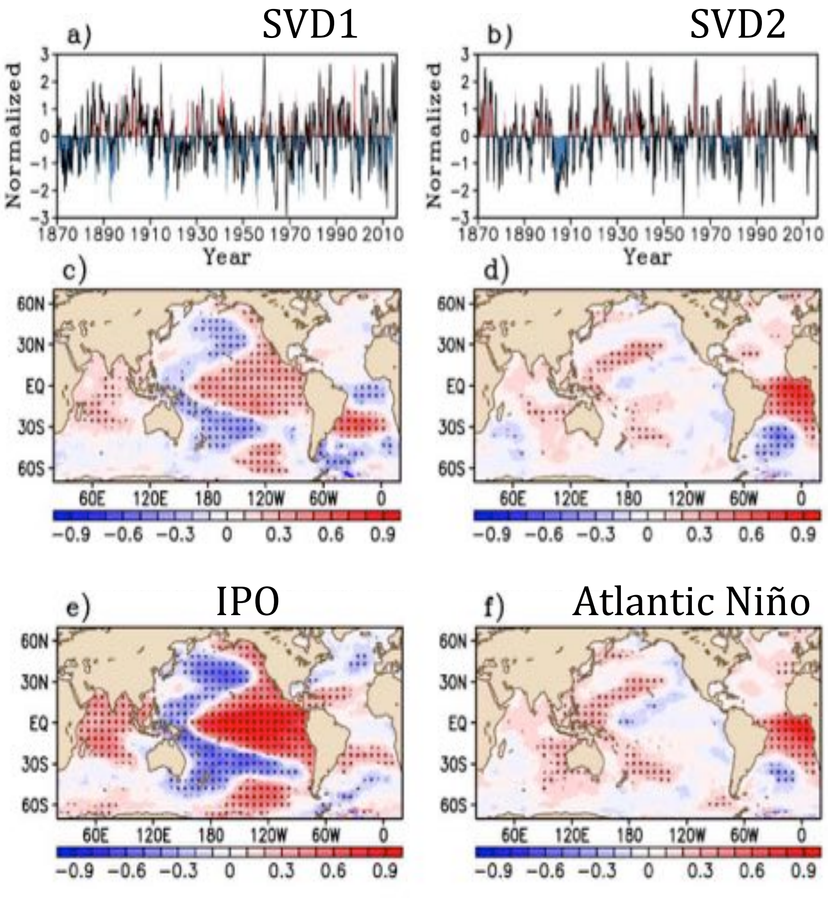
U and V are singular vectors of SST and SAMOC respectively. Given this, sets of expansion coefficients can be obtained by projecting the singular vectors to their respective data matrix

$$a_k(t) = \boldsymbol{U}_k^T x(t) \qquad b_k(t) = \boldsymbol{V}_k^T y(t)$$

Reconstruct the SAMOC for the untrained period (i.e., 1870-2015) prior to the altimetry era for 20°S, 25°S, 30°S, and 34°S latitude.

$$\hat{y}(t) = \sum_{k=1}^{q} \frac{cov(a_k, b_k)}{var(a_k)} \boldsymbol{U}_k^T x(t) \boldsymbol{V}_k \;, \quad q = 4\,, t = 1870{:}\,2015$$

Leading joint-modes of SAMOC-SST variability



Linear projection of reconstructed MOC indices and SVD1 and SVD2