The Role of the Wind-Evaporation-Sea Surface Temperature (WES) Feedback in Tropical Climate Variability

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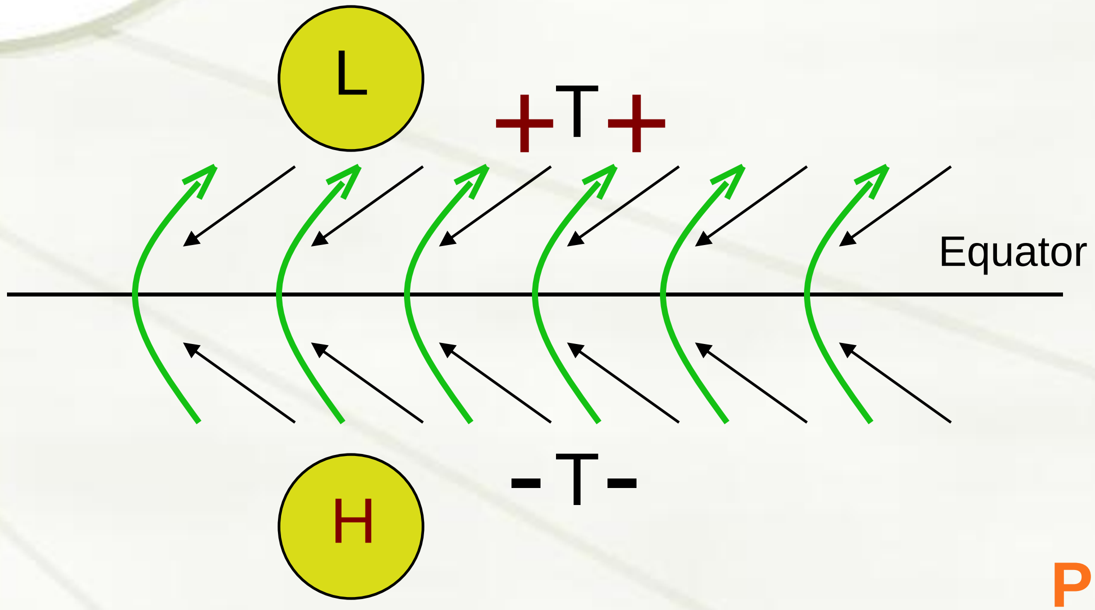
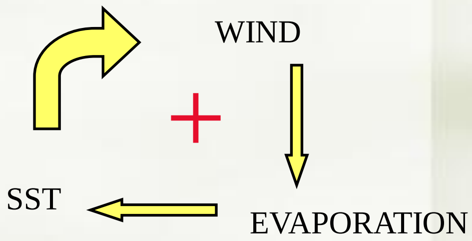
Wind Evaporation SST (WES) Feedback





Positive Feedback

Role of WES Feedback

The WES feedback is featured in several hypotheses to explain the tropical mean climate and variability

- **Asymmetric ITCZ about the equator (*Xie, 2004*)**
- **Westward seasonal propagation of equatorial SST anomalies (*Xie, 1994*)**
- **Tropical Atlantic variability (" Atlantic dipole") (*Chang et al., 1997*)**
- **Equatorward propagation of high-latitude cooling (*Chiang and Bitz, 2005*)**

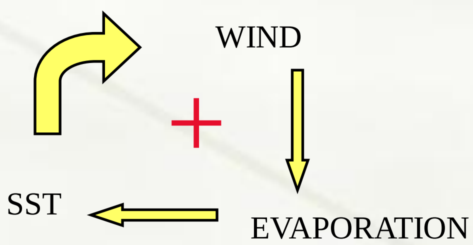
- **In previous studies, the role of the WES feedback has usually been inferred from statistical analysis or using simple analytical models.**

- **Our approach:** ***direct mechanistic tests***

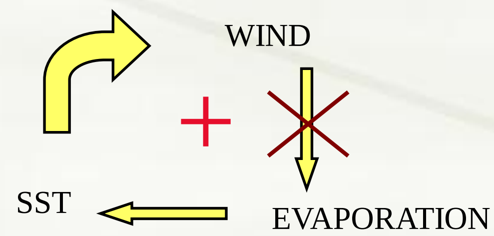
Mechanistic Experiments

CCM3-SOM:

- T42 Spectral Resolution (2.8 x 2.8)
- 18 vertical levels
- SOM: spatially varying mixed layer depth but constant in time
- Prescribed sea-ice
- Q-flux adjustment



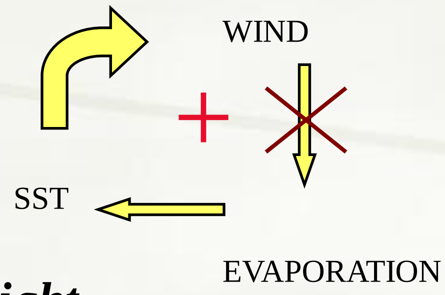
Control Run



WES off Run

Experimental Set-up

- **Heat Flux Bulk Formulations:**
  - ***LH Flux*** $= u^*(q_s - q^*)B$
  - ***SH Flux*** $= u^*(T_s - T^*)D$



u^* = reference height wind speed

q^* = specific humidity at reference height

q_s = specific humidity at surface

T^* = Temperature at reference height

T_s = Temperature at surface

B, D: Bulk Coefficients

- **WES off**: Prescribe u* while computing Fluxes

Experimental Set-up

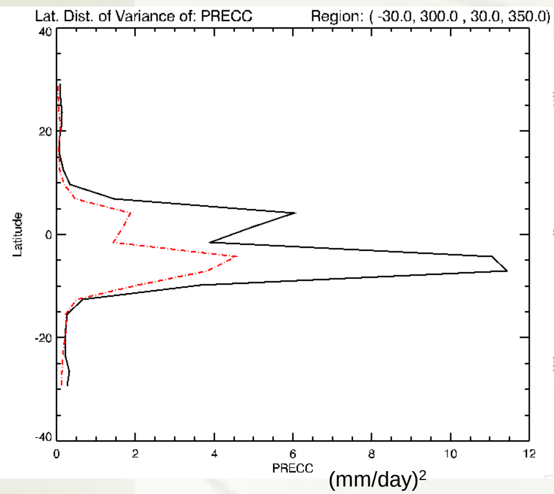
Experiment Set 1: **To understand the variability associated with WES feedback**

- **Control Run:** **80 years**
- **WES-off-SOM Run:** **80 years**

Experiment Set 2: **To study the Equatorial Annual Cycle**

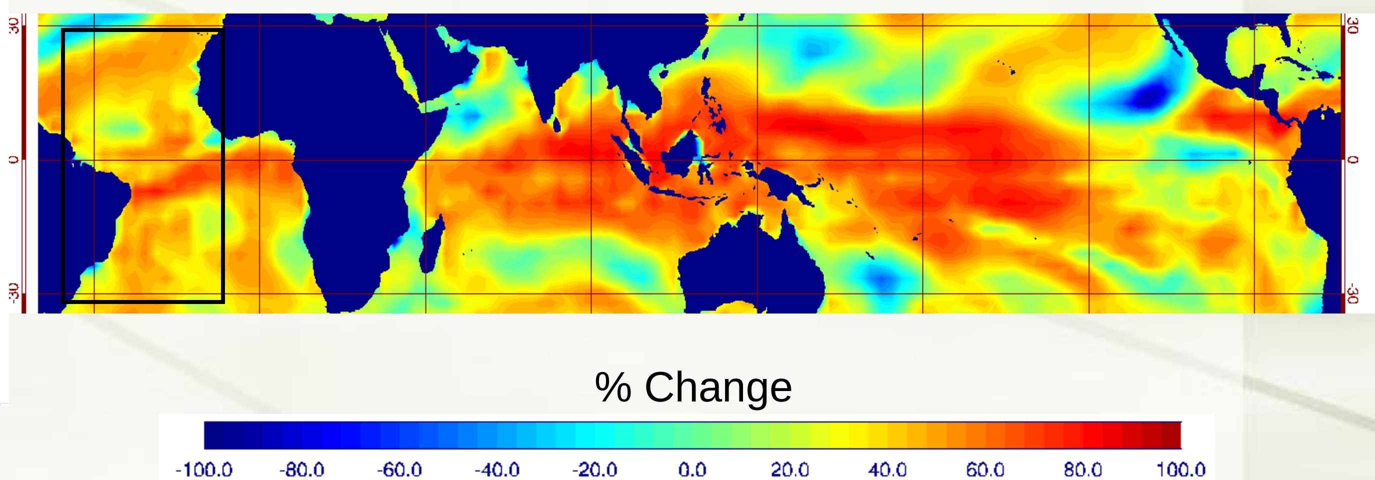
- **WES-off-NoANN Run:** **40 years**
  - ***u**** **prescribed as annual mean, no seasonal cycle**

WES Feedback and SST Variability

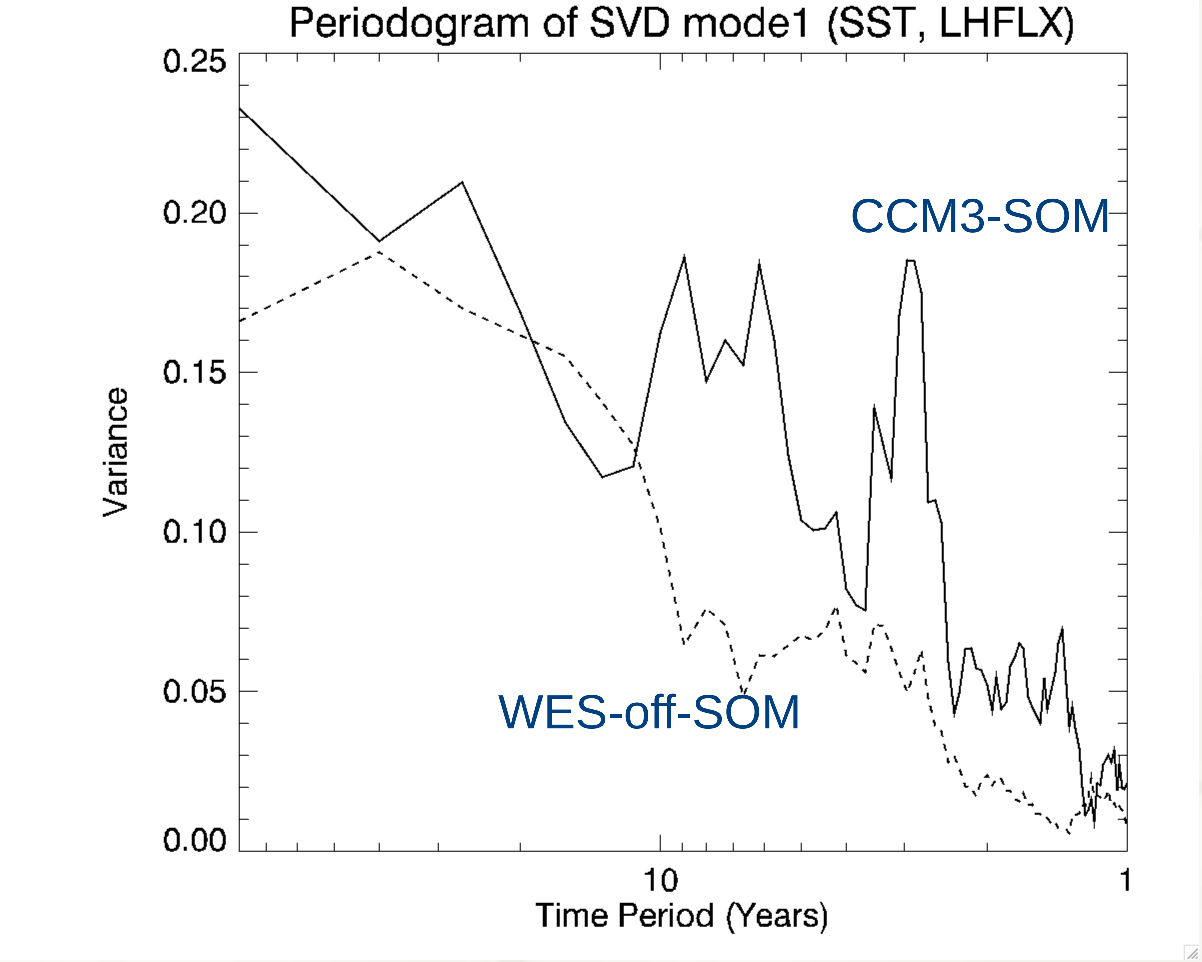


Spring Season

% Change in SST variance : Control run - WES off ANN Run



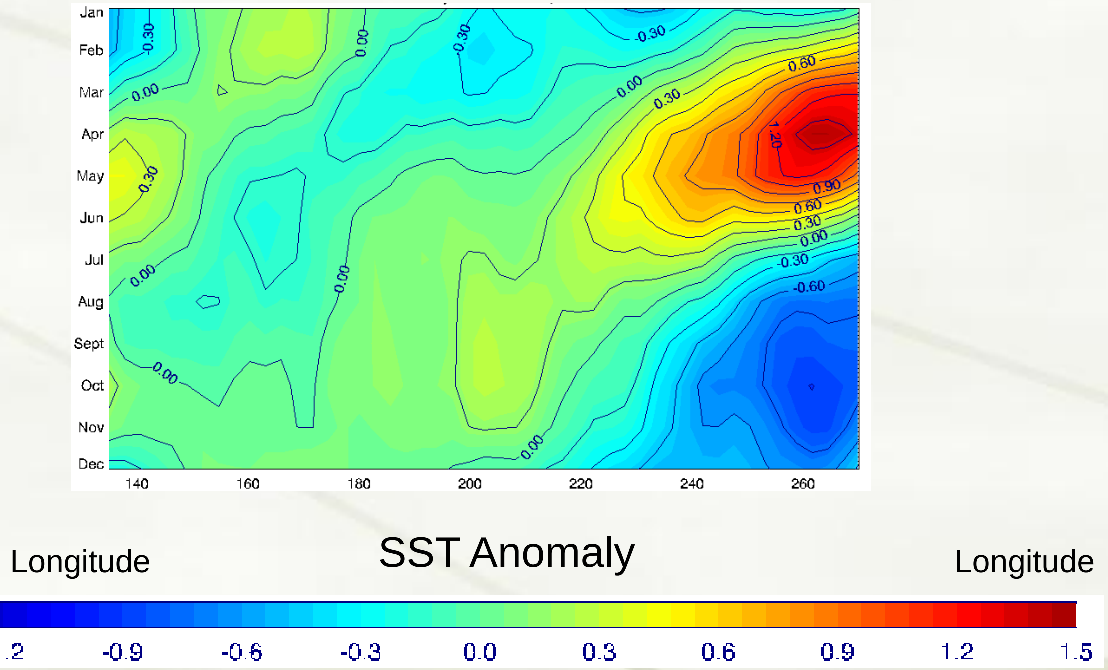
Tropical Atlantic Variability



WES Feedback and SST Anomaly Propagation

- ✓ Strong seasonal cycle in the E.Pacific because of shallow mixed layer
- ✓ SST anomalies propagate westward

Control Run

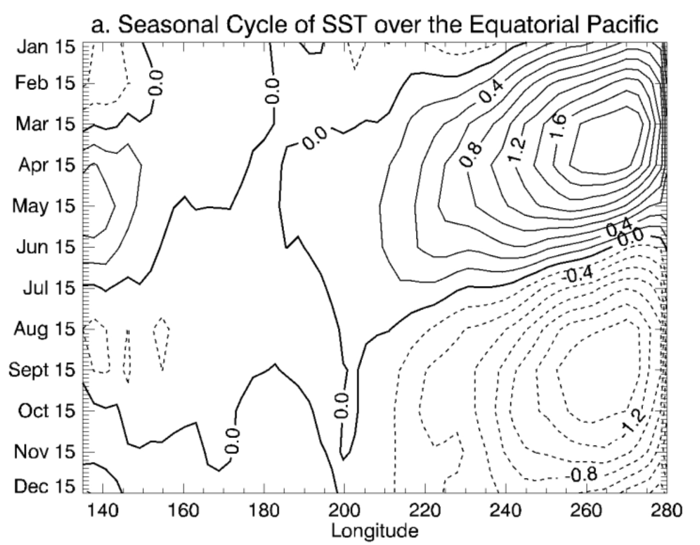


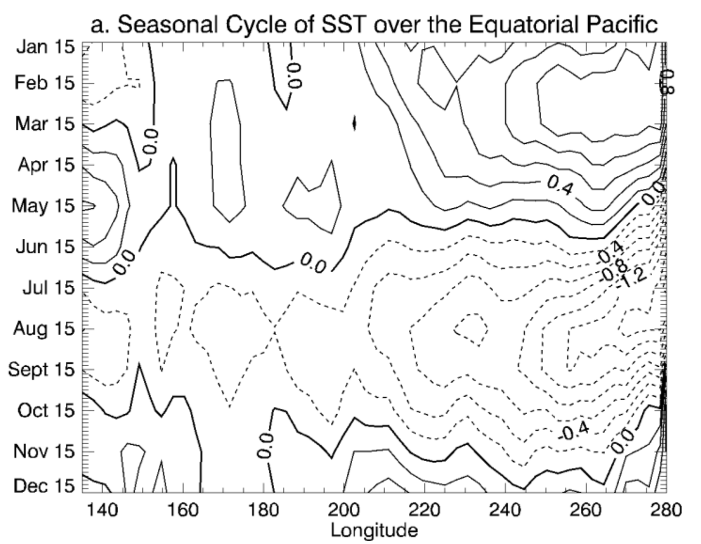
Annual Cycle of SST and LHFLX

SST

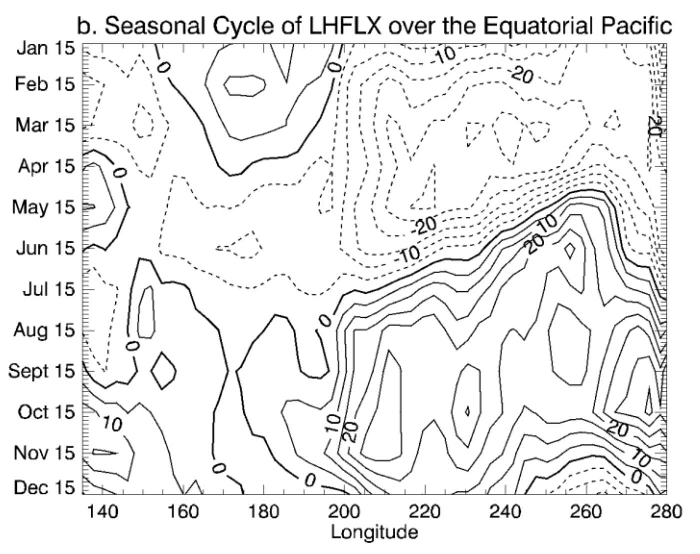
Equatorial Pacific

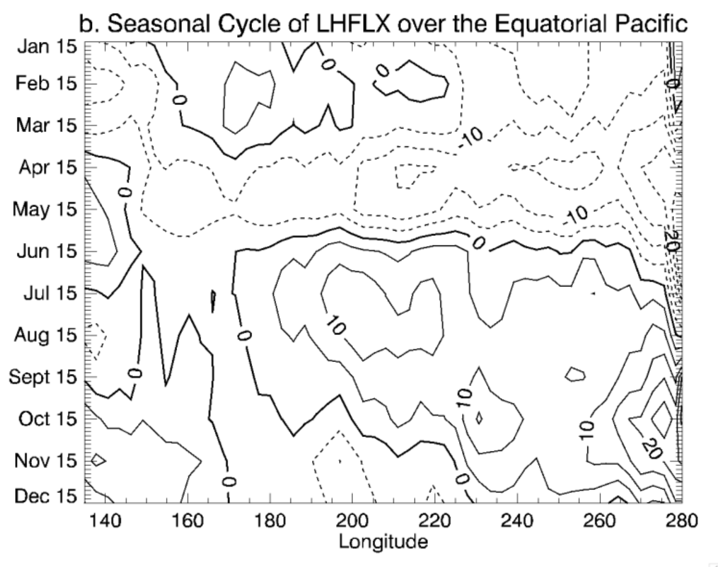
(2S-2N)





LHFLX

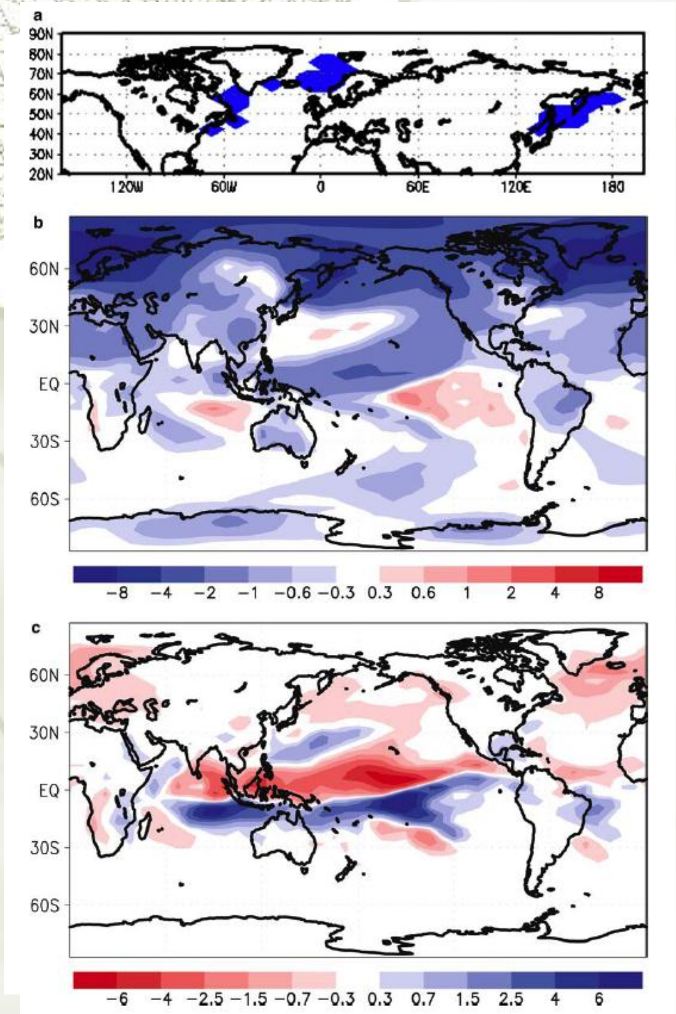




Control Run

WES-off-SOM Run

Equatorward propagation of cold anomalies



Chiang and Bitz (2005)

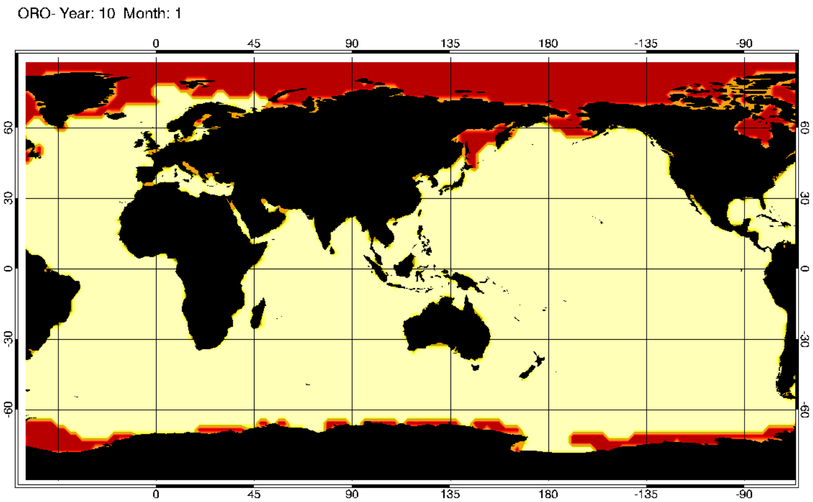
- ✓ Last Glacial Maximum (LGM) sea-ice anomalies
- ✓ Drier and colder higher and mid-latitudes
- ✓ Increased easterlies lead to evaporative cooling
- ✓ WES Feedback: SST front moves southwards and moves ITCZ southwards

Changes in surface temperature and precipitation as compared to a control run.

Experimental Set-up: Tropical Response to High Latitude Cooling

Sea-ice extent January:

Current conditions

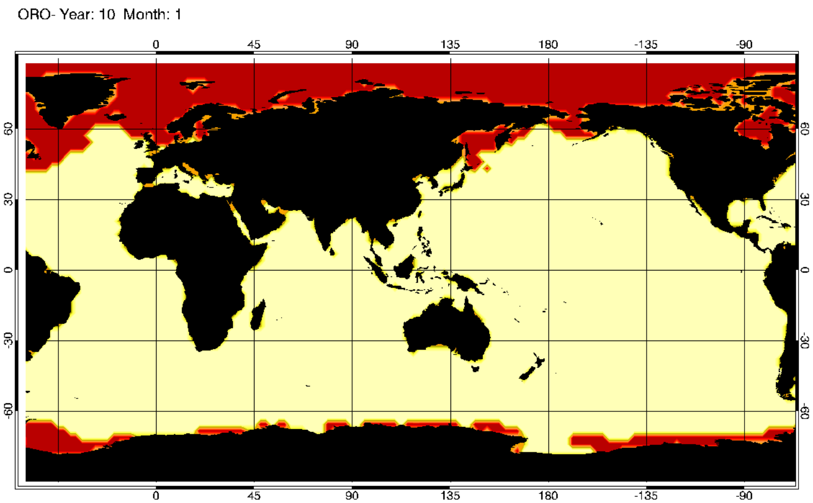


Experiment Set 4:

- Prescribe Last Glacial Maximum (LGM) sea-ice anomalies in the Northern Hemisphere:
  - Control Run: CCM3-SOM-SICE
  - WES-off Run: WES-off-SICE

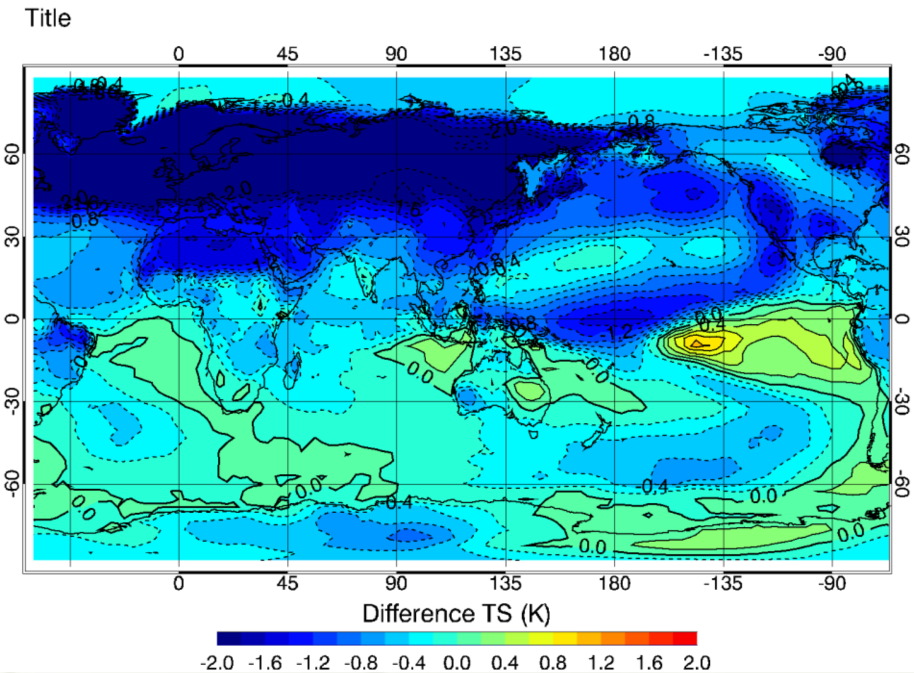
Sea-ice extent January:

CCM3-SOM-SICE/ LGM

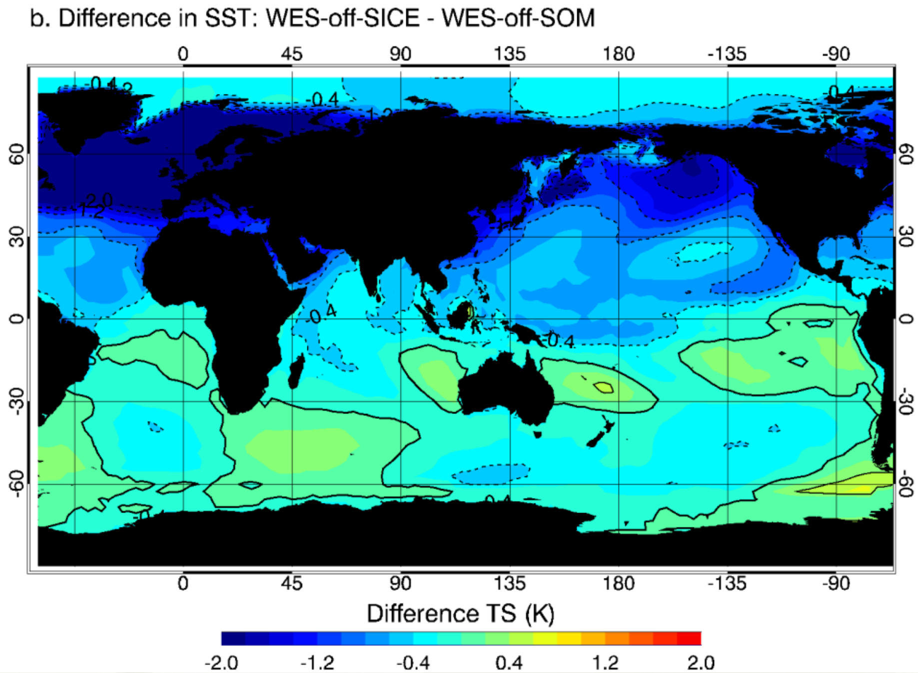


Surface Temperature Response to High Latitude Cooling

Control Case

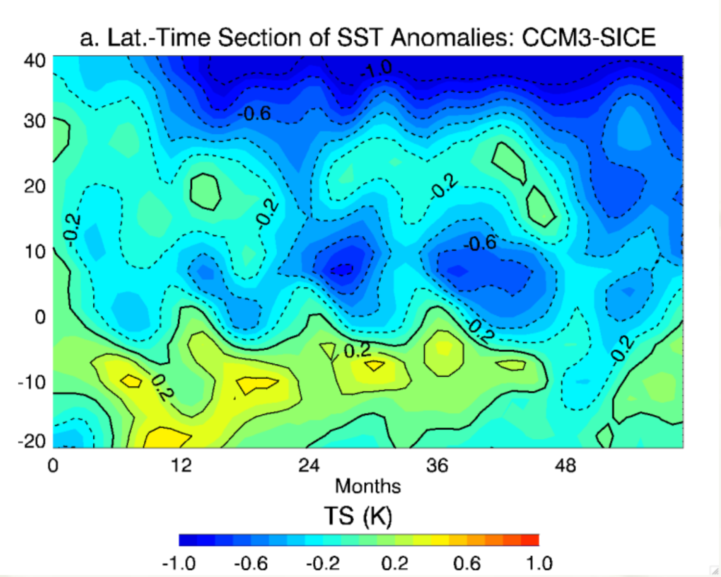


WES-off Case

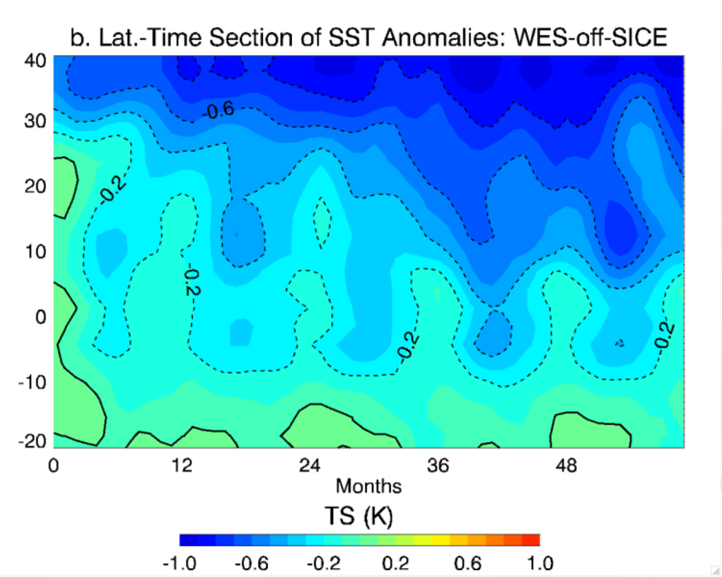


Tropical Response to High Latitude Cooling

Control Case



WES-off Case



SUMMARY

- Even though it is a boundary layer phenomenon, WES feedback can produce non-local (cross-equatorial) atmospheric response to SST anomalies
- Responsible for a significant portion of tropical Atlantic variability, and a smaller portion of tropical Pacific variability
- Controls the westward propagation of annual cycle of equatorial SST
- Plays a role in shifting ITCZ under LGM sea-ice conditions, but less so than originally proposed
- In addition to surface windspeed, near surface humidity is also a very important factor in controlling tropical variability.

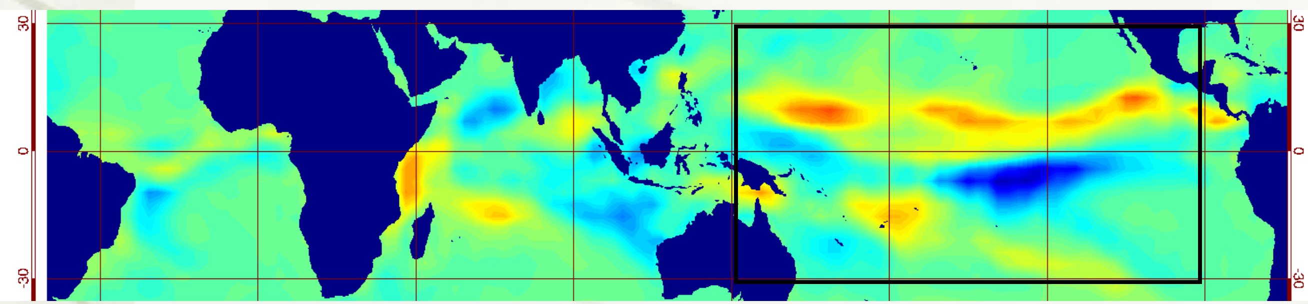
Introduction: WES Feedback

- ✓ **Thermodynamic air-sea coupling**
- ✓ **Weaker than dynamic coupling (Bjerknes feedback)**
- ✓ **Boundary layer phenomenon**
- ✓ **Non-local effects**

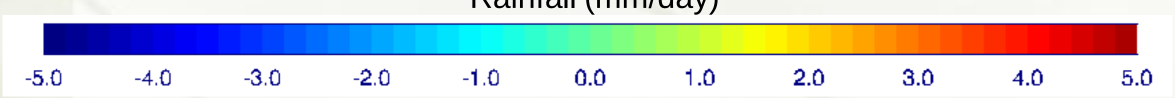
WES Feedback and ITCZ

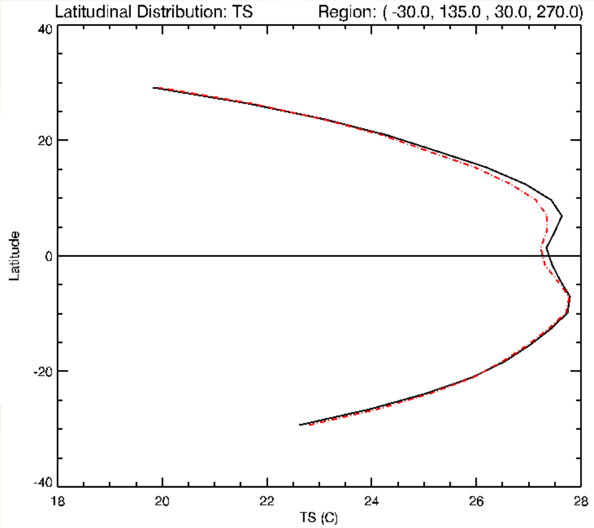
Spring Season

Rainfall: Control Run - WES off ANN Run



Rainfall (mm/day)

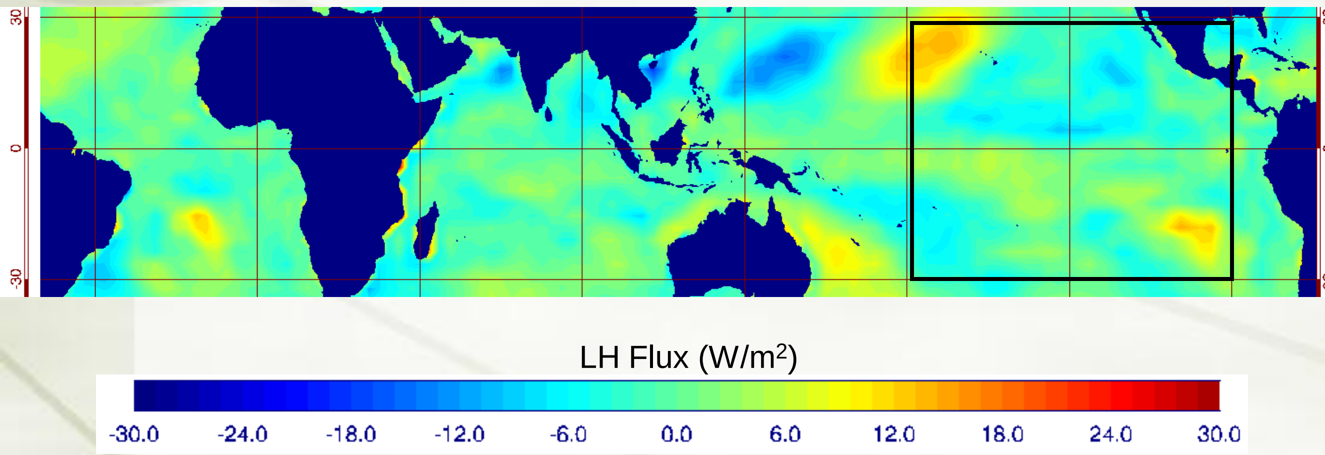


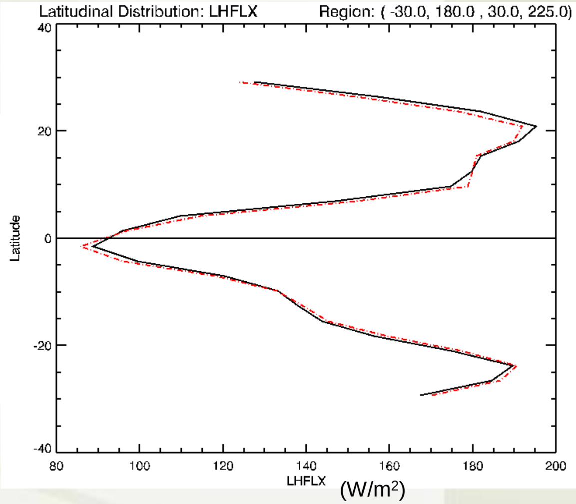


CCM3 Runs: Mean State

Spring Season

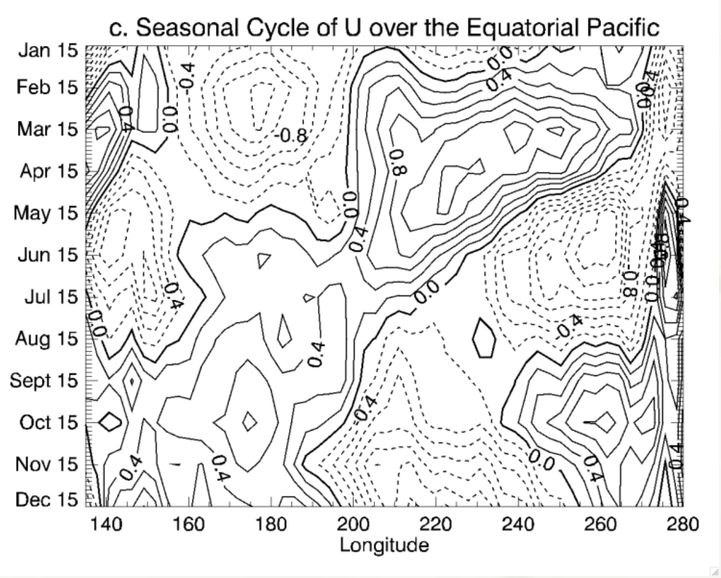
LH Flux: Control Run - WES off ANN Run



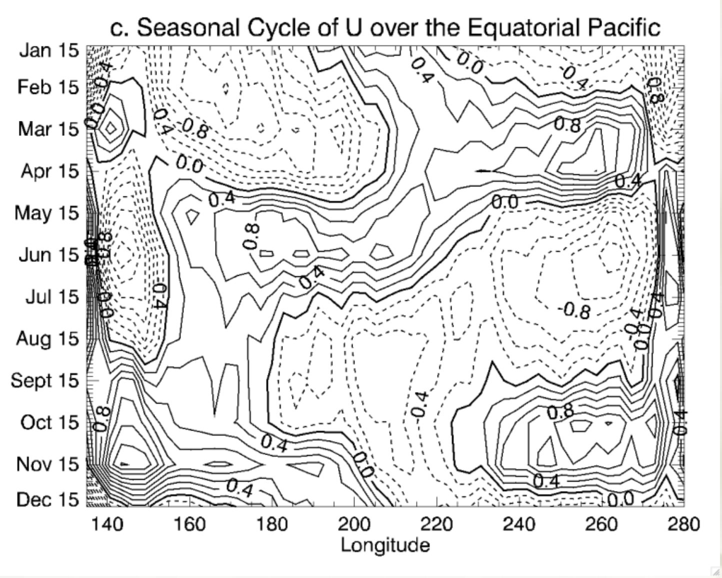


Equatorial Annual Cycle

Seasonal Cycle of zonal winds (U) over Equatorial Pacific (2S-2N) for Control Run and the WES-off-Run



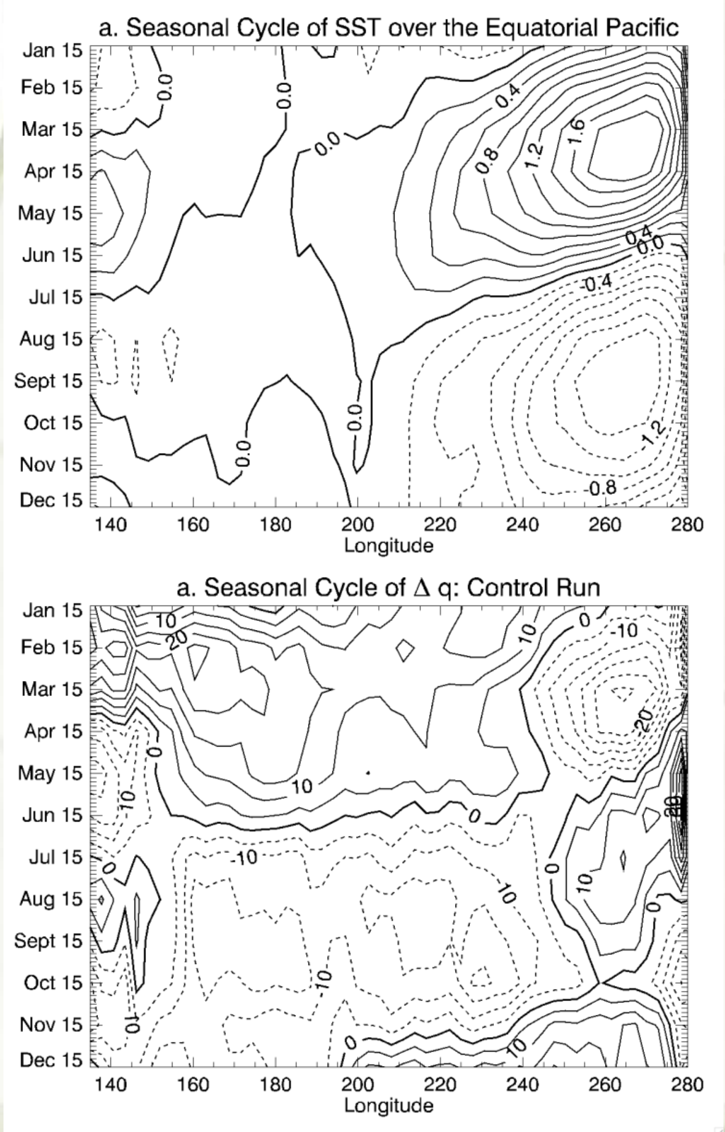
Control Run



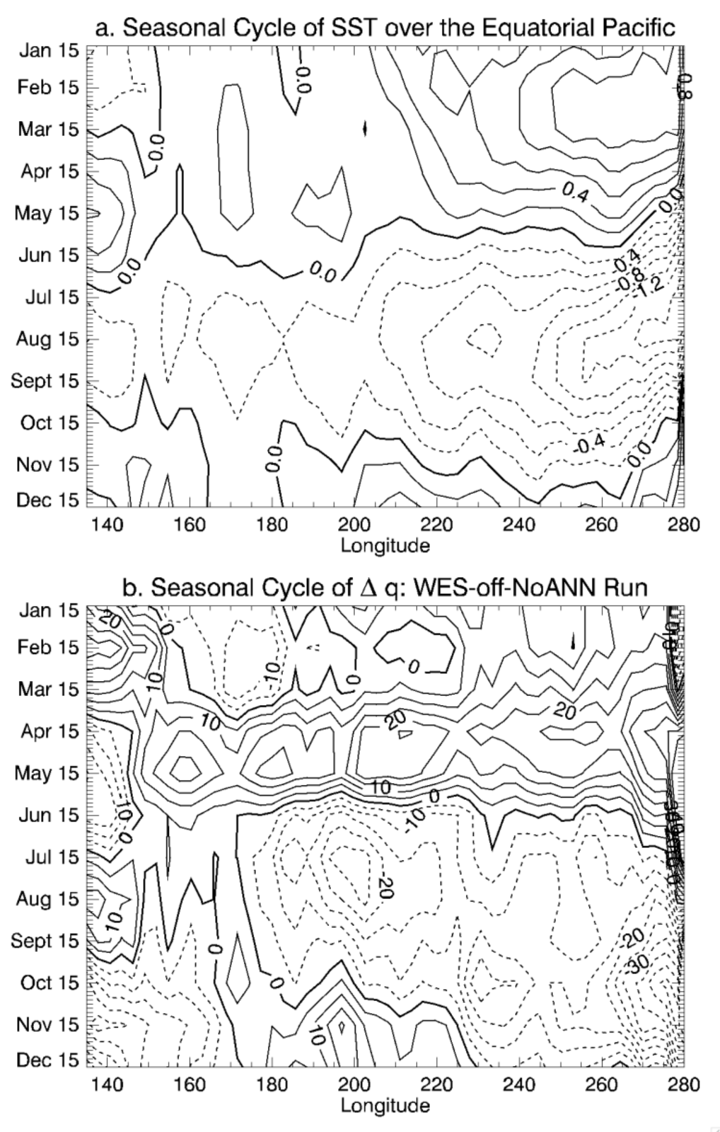
WES-off-SOM Run

Equatorial Annual Cycle

Seasonal Cycle of SST, Δq over Equatorial Pacific (2S-2N) for Control Run and the WES-off-Run



Control Run

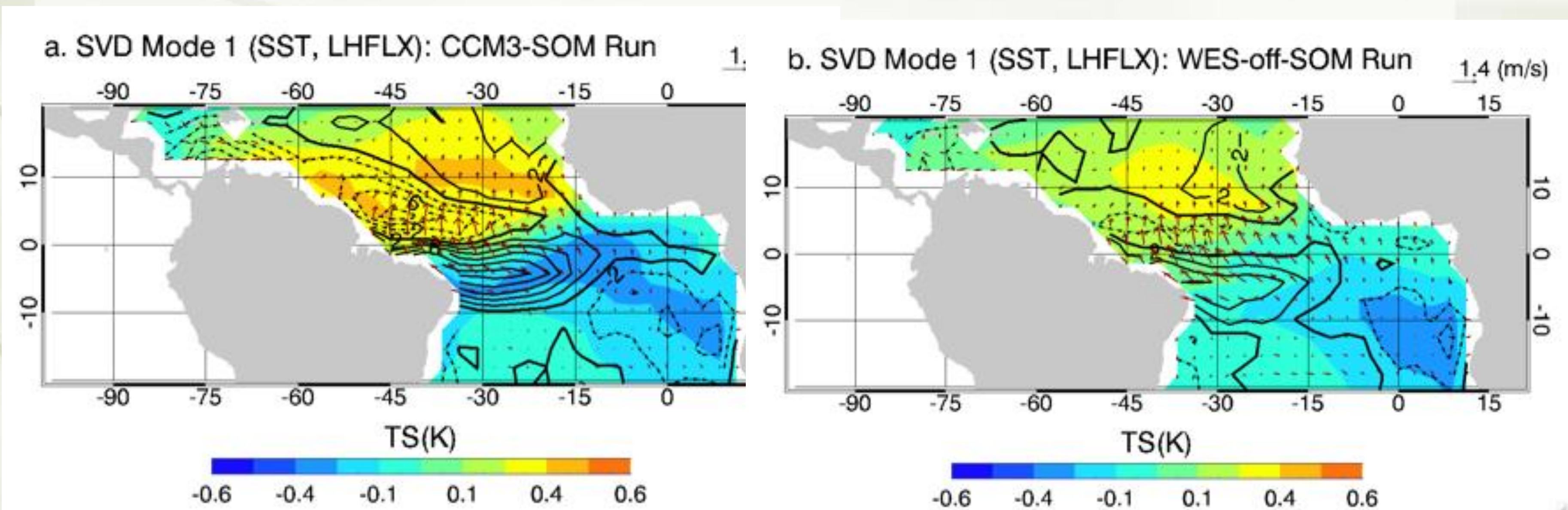


WES-off-SOM Run

Atlantic Meridional Mode

Coupled Mode Variability:

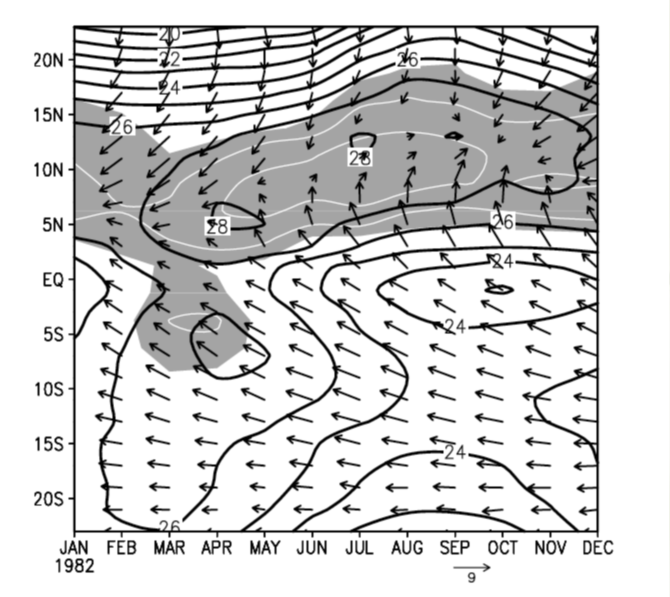
- SVD pattern of SST (color) and LHFLX (contours) for Control Run and the WES-off-Run.
- Regression of surface winds on first PC of SST



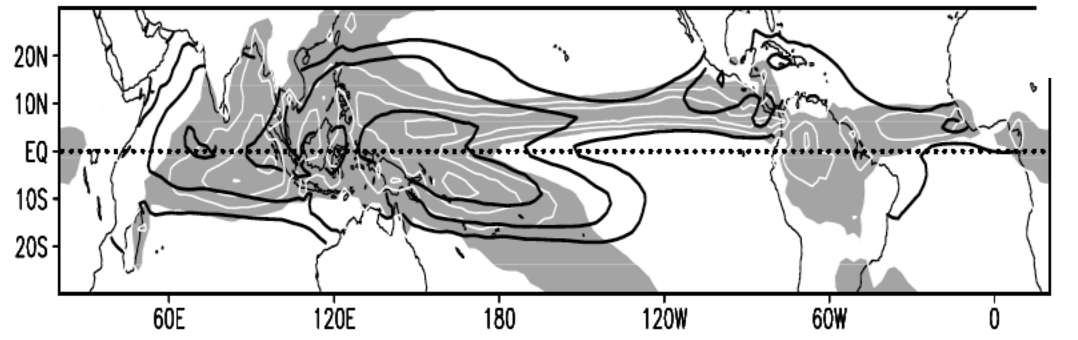
Introduction: Roles of WES Feedback

1. ITCZ Asymmetry:

- ✓ Equatorial Ocean upwelling (*Xie and Philander, 1994*)
- ✓ North-west alignment of Americas and north-west African bulge (*Philander et al. 1996*)
- ✓ Stratus cloud-SST feedback (*Philander et al., 1996*)
- ✓ WES feedback (*Xie, 1996*)



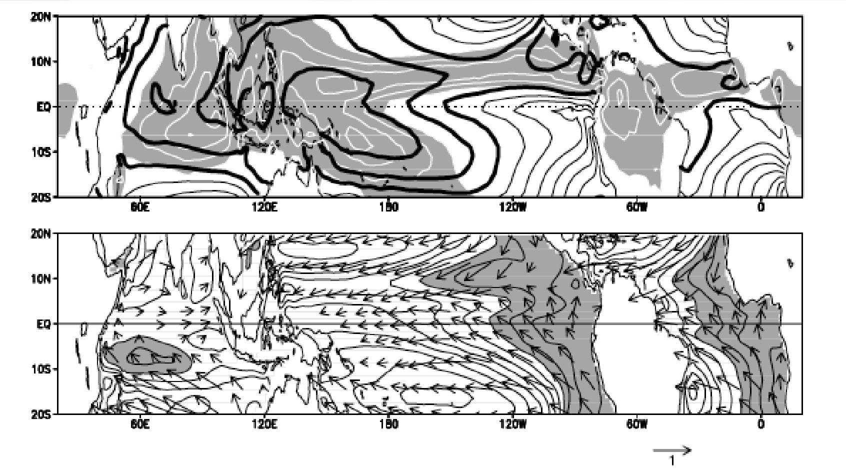
Time-Latitude section of SST, winds and precipitation over the eastern Pacific and Atlantic (*Source: Xie 2005*)



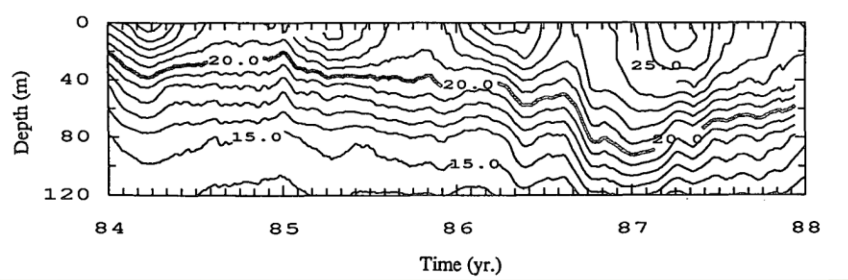
Annual Mean Climatological SST and Rainfall (*Source: Xie 2005*)

Introduction: Roles of the WES Feedback

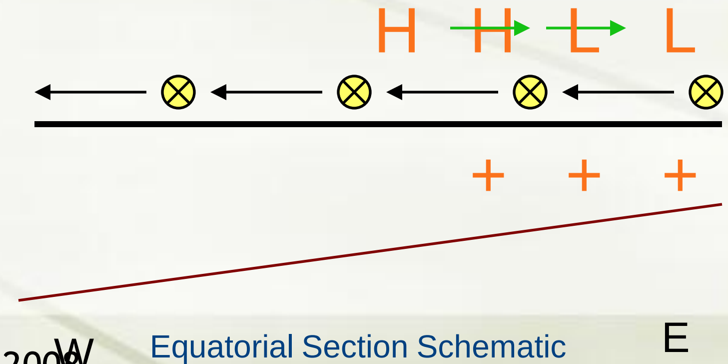
2. Equatorial Annual Cycle: Westward Propagation



Annual Mean Climatology: SST (Reynolds and Smith), precipitation (CMAP) and winds (SODA) (*Wang et al., 2004*)



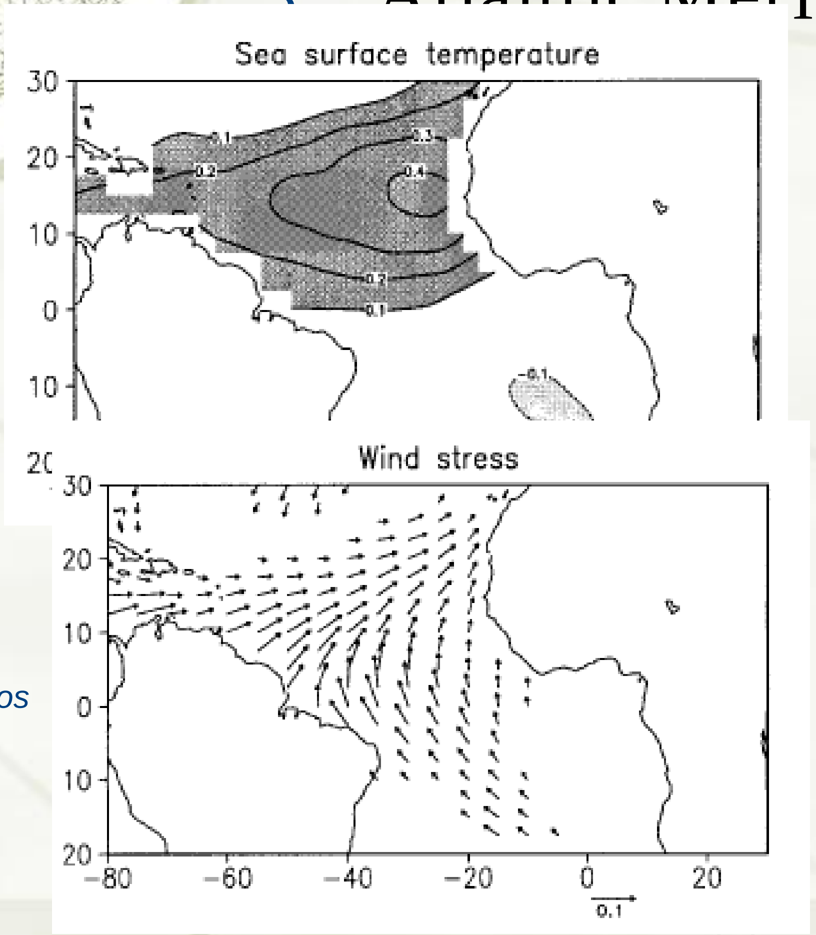
Ocean Temperature: TOGA-TAO mooring data at the equator and 110 W *(Xie, 1994)*



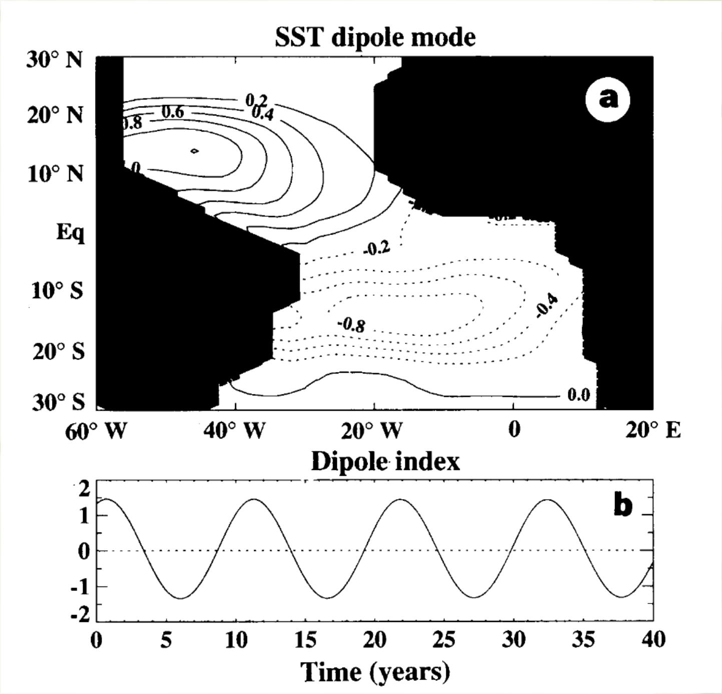
Equatorial Section Schematic

Introduction: Roles of the WES Feedback

3. Atlantic Meridional Mode



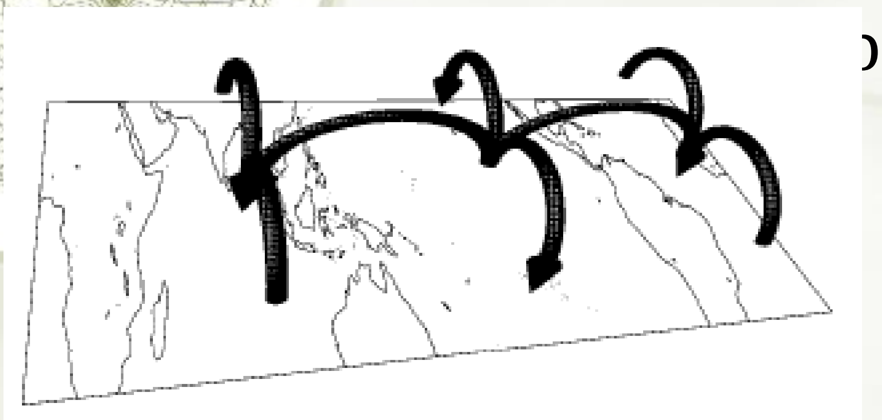
PC analysis (*Ruiz-Barrados et al., 2000*)

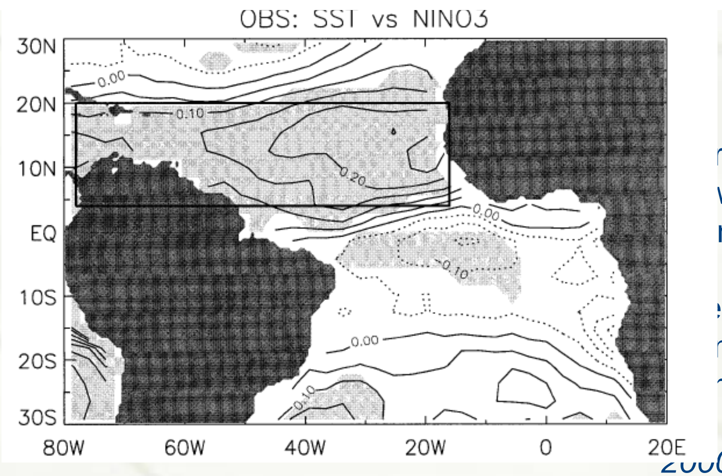


Dipole Mode: Regression of dipole index onto SST for a RGO coupled to an empirical atmospheric model with no dynamic feedback but allowing for thermodynamic feedback (*Chang et al., 1997*)

Introduction: Roles of the WES Feedback

ponse to ENSO





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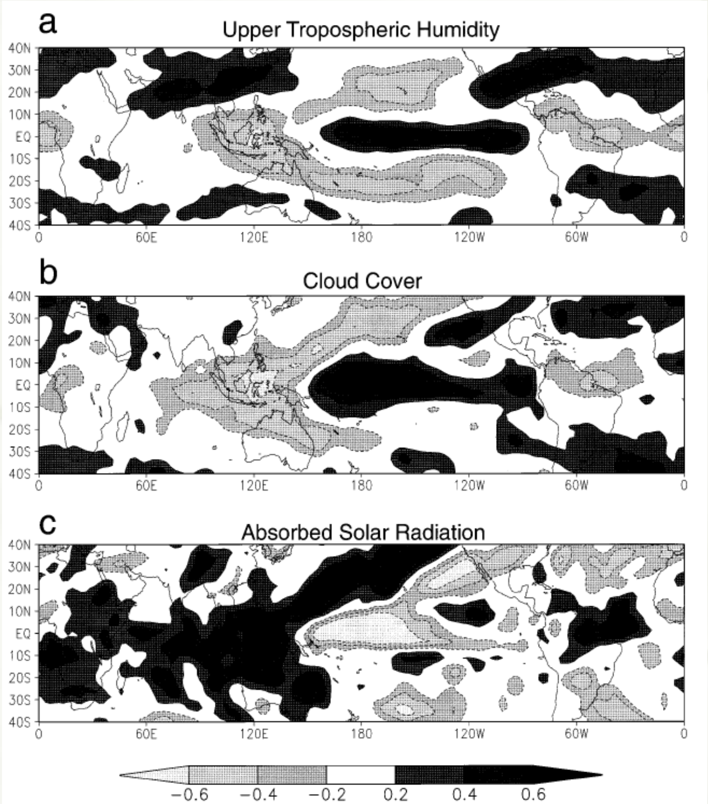
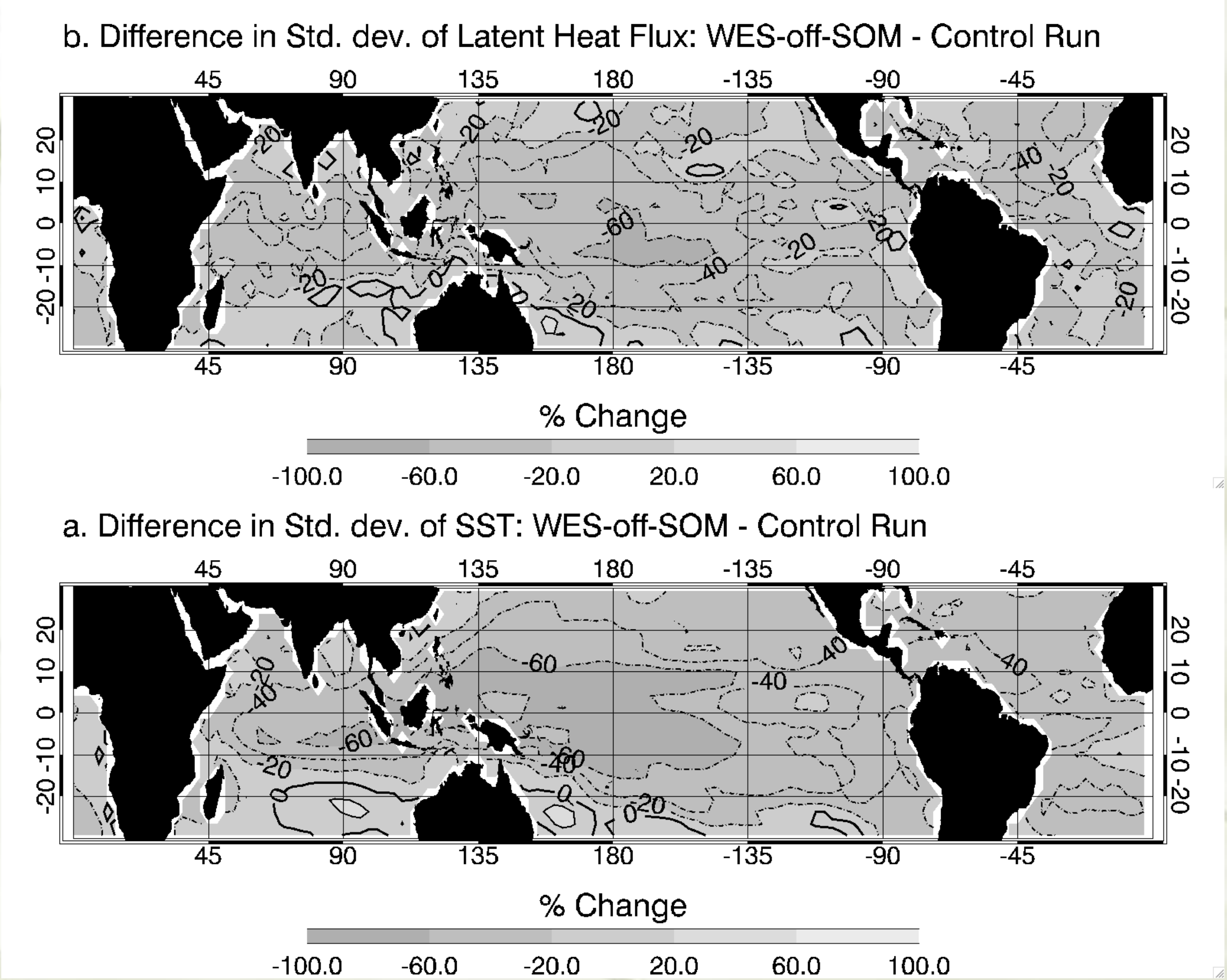


Correlation between ENSO index and upper tropospheric humidity, cloud cover (ISCCP) and insolation (ERBE) (*Klein et al., 1999*)

WES Feedback

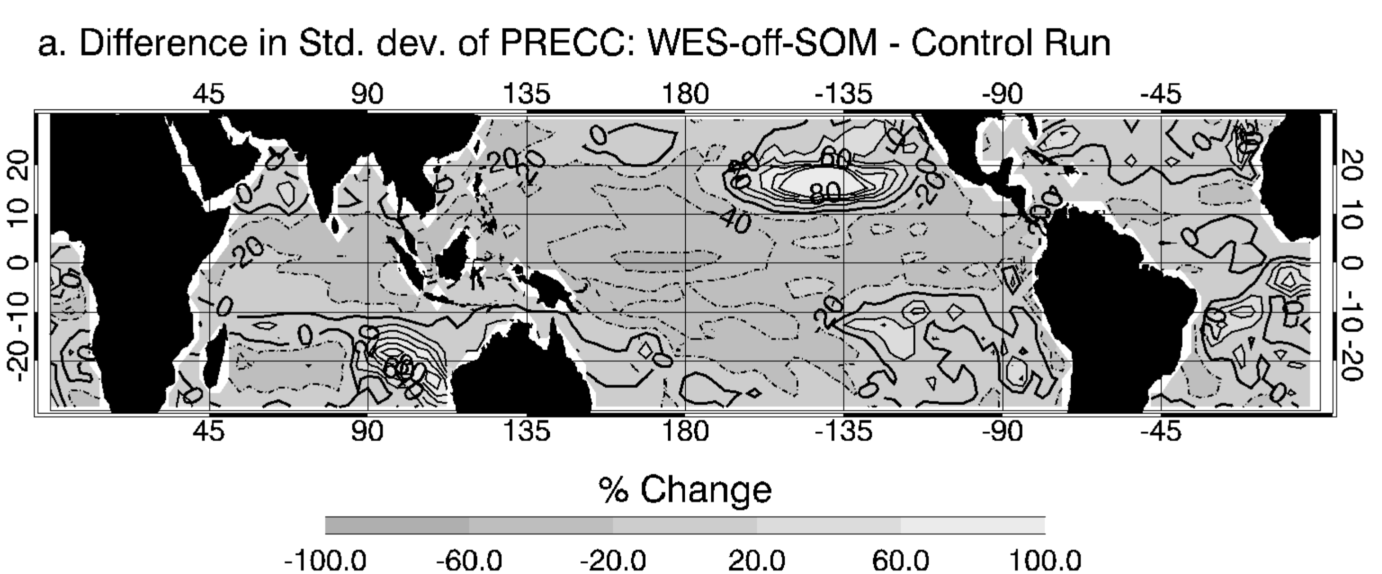
- ✓ Traditional Approach:
  - Stand-alone AGCM or OGCM
  - Coupled Model
    - Enhanced variability of the coupled model indicates feedback mechanisms.
- ✓ Our Approach: WES-off-Experiments:
  - CCM3 coupled to a Slab Ocean Model (SOM)
  - Switch off the WES feedback
  - Comparison would reveal its role

WES Variability

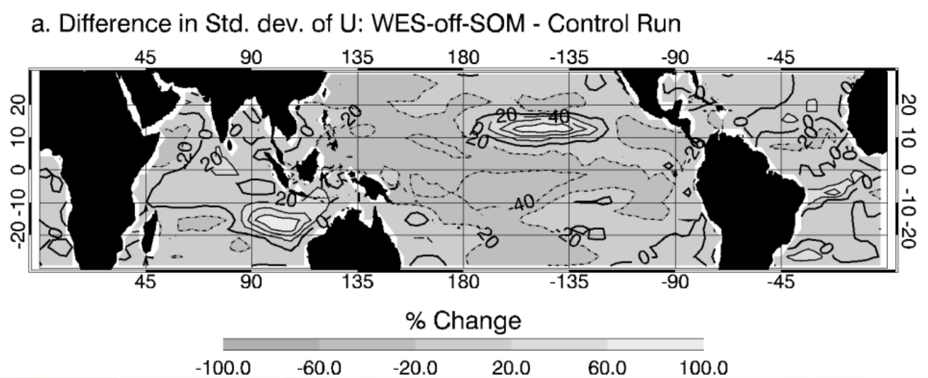


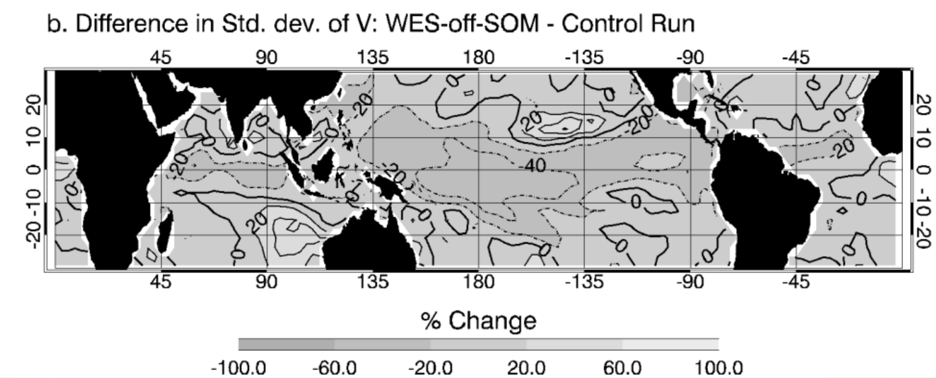
Change in the variability of Latent Heat Flux, SST for the spring season between a Control Run and the WES-off-Run

WES Variability

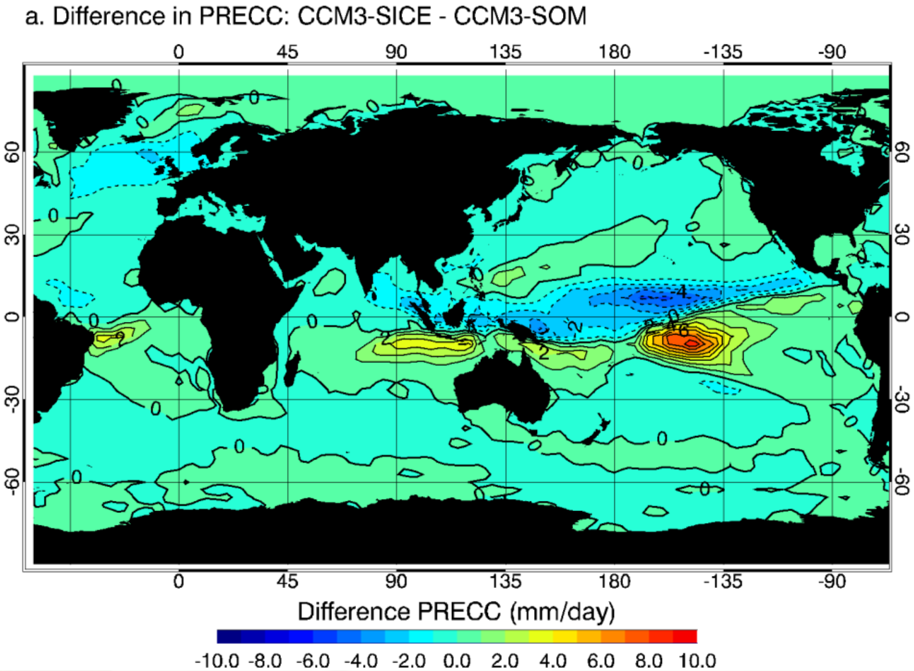


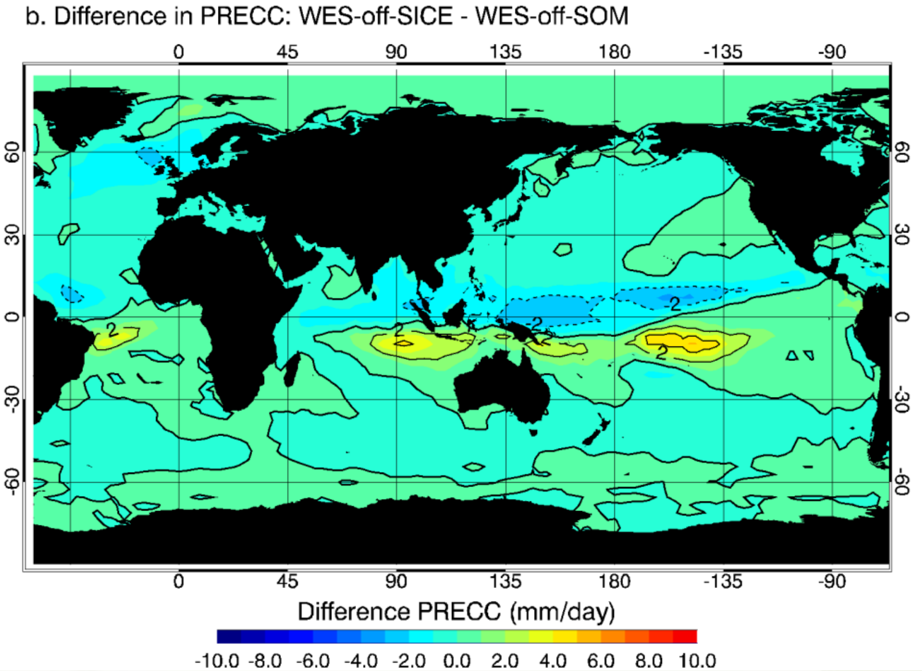
Change in the variability of Precipitation, Surface Winds for the spring season between a Control Run and the WES-off-Run





WES: Tropical Response to High Latitude Cooling





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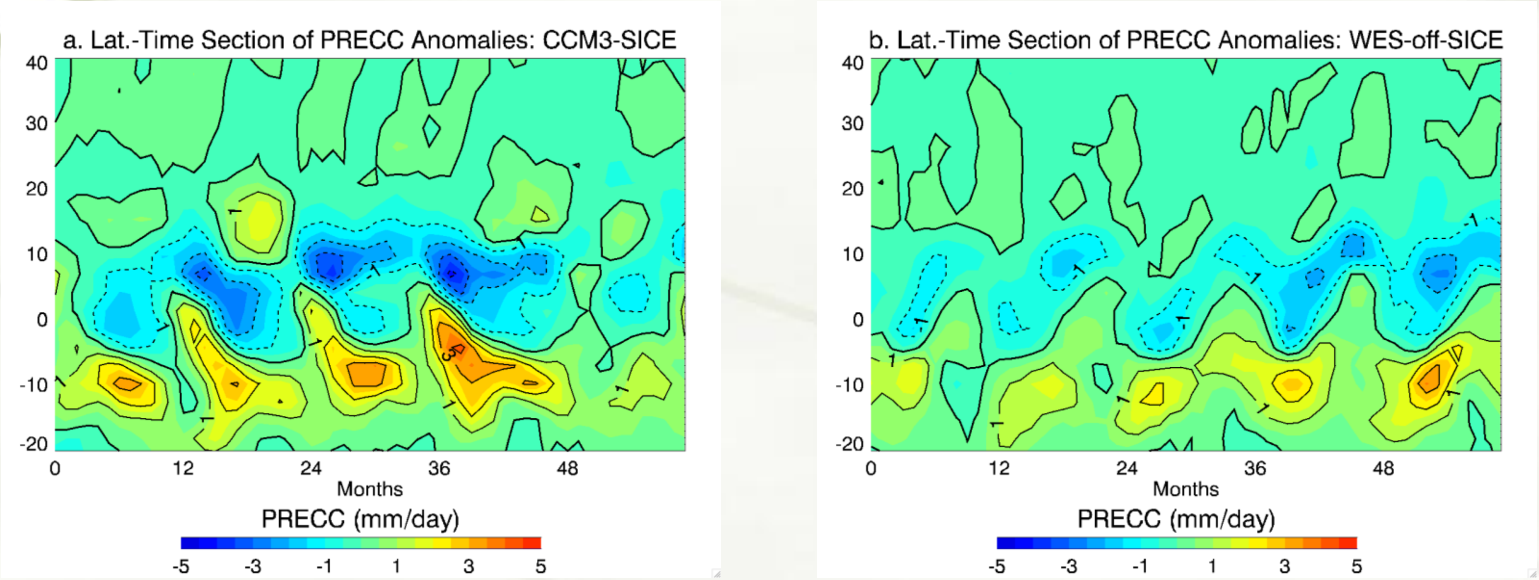

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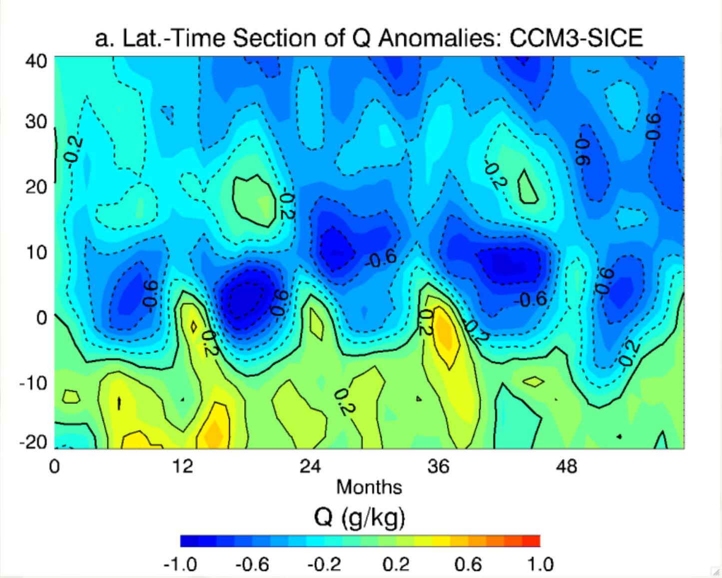
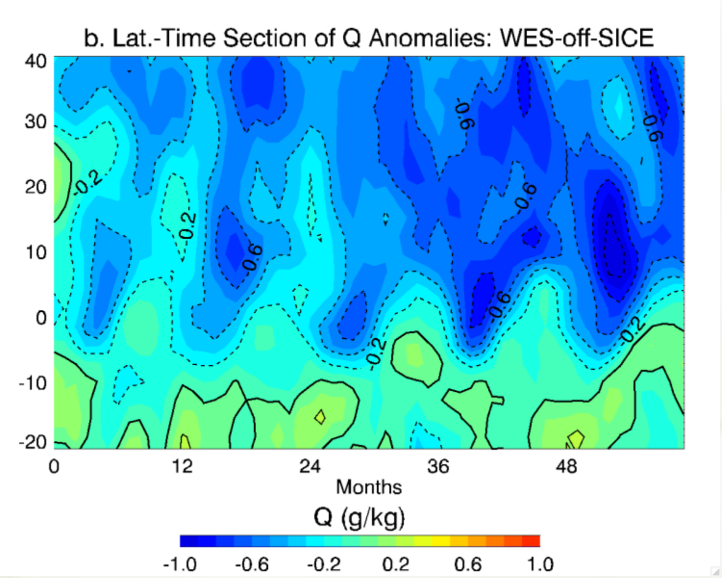
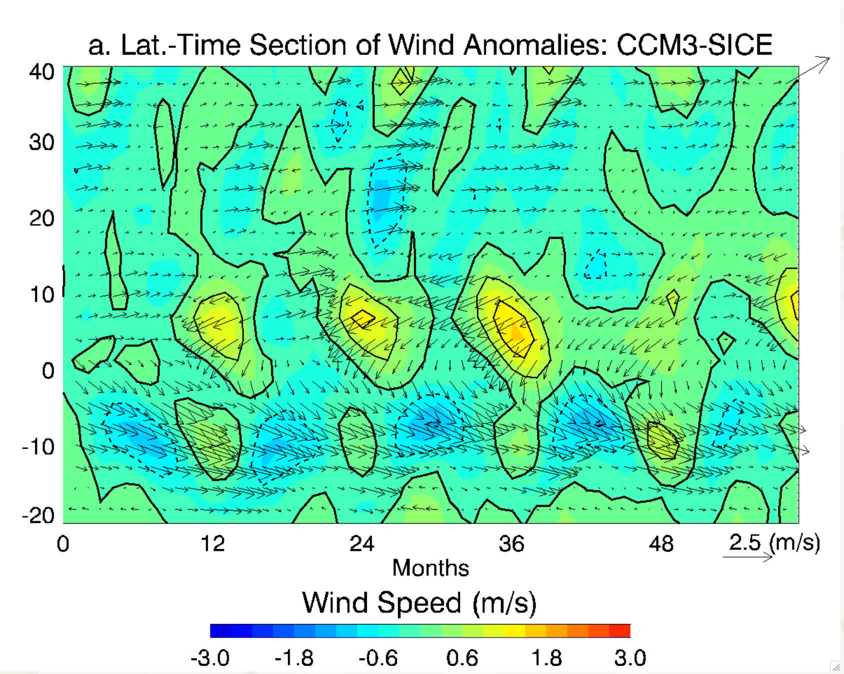
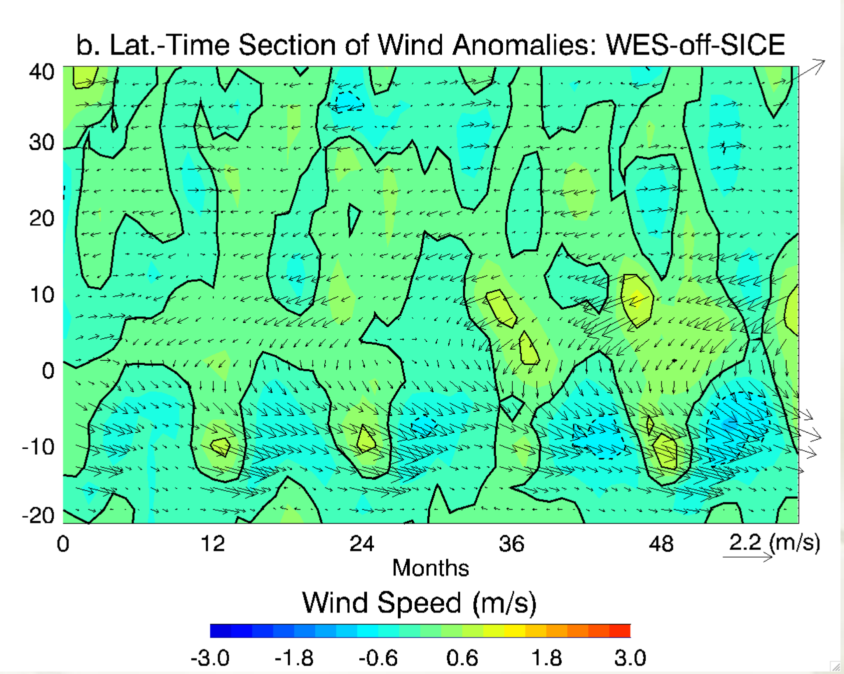




WES: Tropical Response to High Latitude Cooling





Experimental Set-up: ENSO

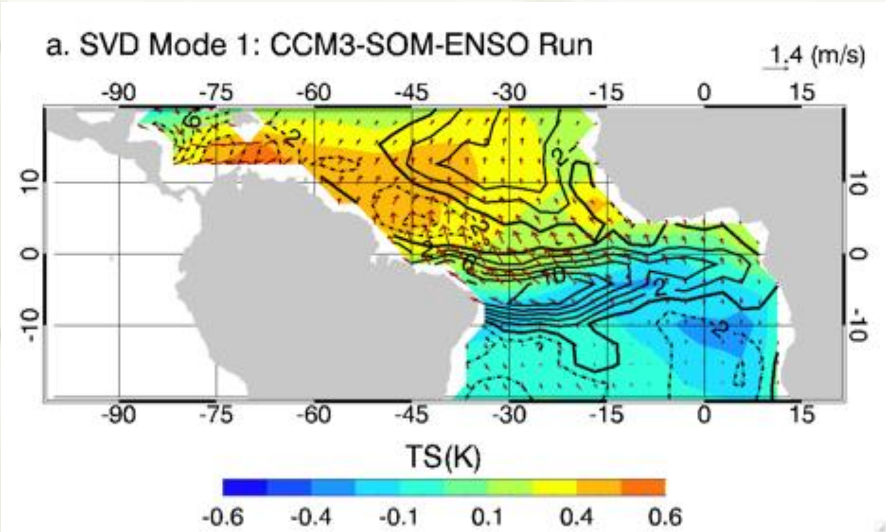
- ✓ Experiment Set 3:
  - Forced ENSO variability over the Atlantic:
    - Artificial 4 year ENSO SST cycle prescribed over Tropical Pacific
      - EOF pattern from observations
      - Multiplied with a cosine function:
        - Time period: 4 years
        - Amplitude: 1♦ of Nino 3 index
    - ENSO forced control run: CCM3-SOM-ENSO
    - ENSO forced WES-off run: WES-off-ENSO

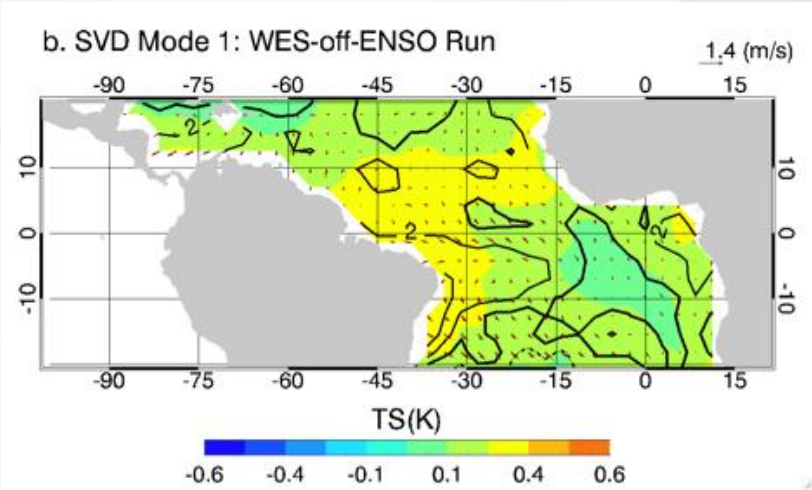
WES: Atlantic Response to ENSO

ENSO Response: Coupled Mode Variability:

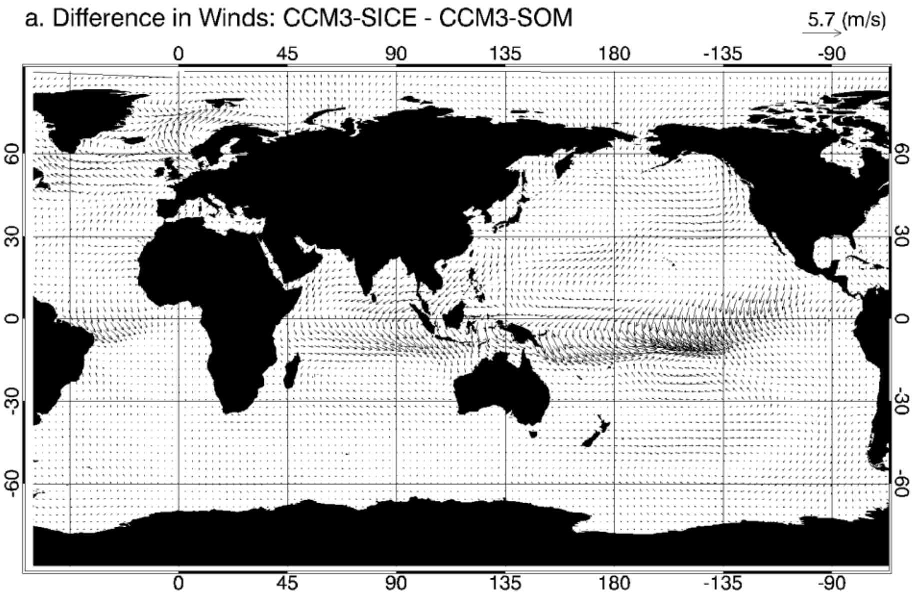
• SVD pattern of SST (color) and LHFLX (contours) for CCM3-SOM-ENSO and the WES-off-ENSO.

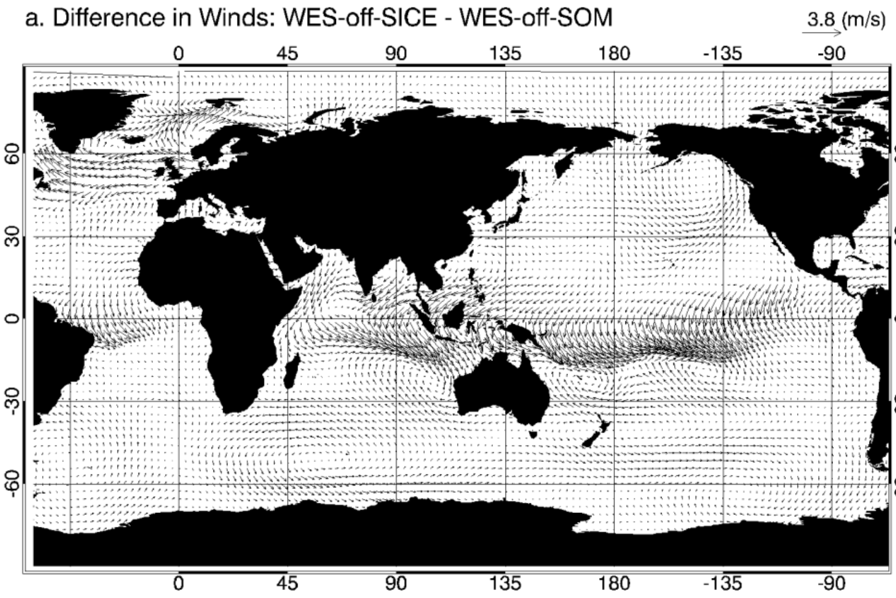
• Regression of surface winds on first PC of SST





WES: Tropical Response to High Latitude Cooling

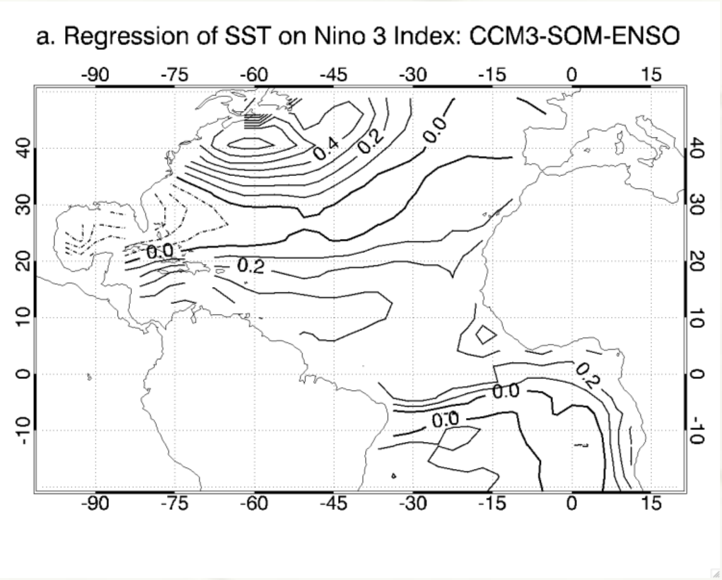


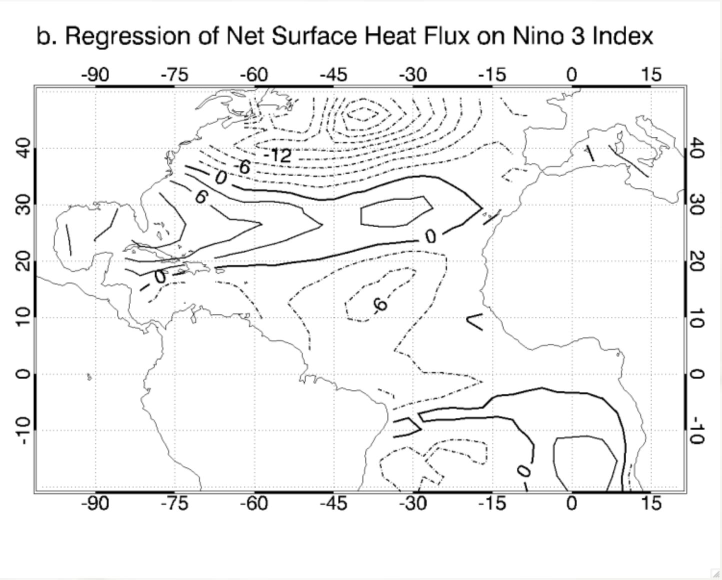


WES: Atlantic Response to ENSO

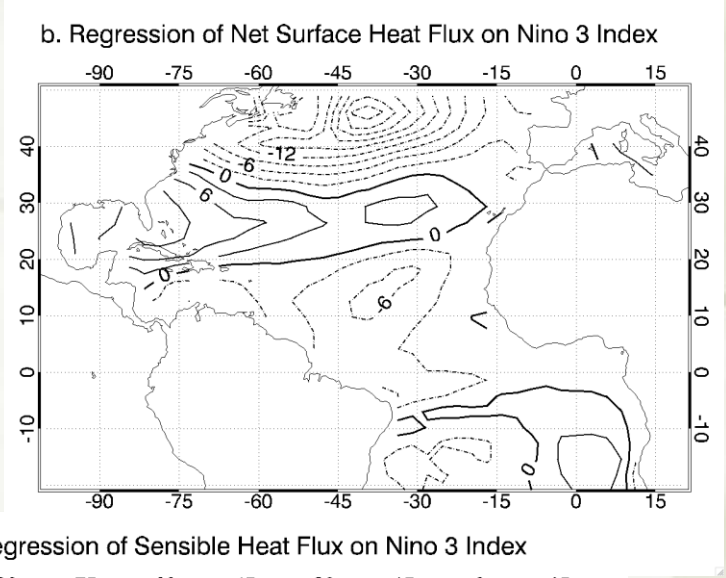
Atlantic Response to ENSO:

- Regression of April-May-June SST(K) and January-Feb-March net surface heat flux (W/m^2) on January ENSO index for CCM3-SOM-ENSO



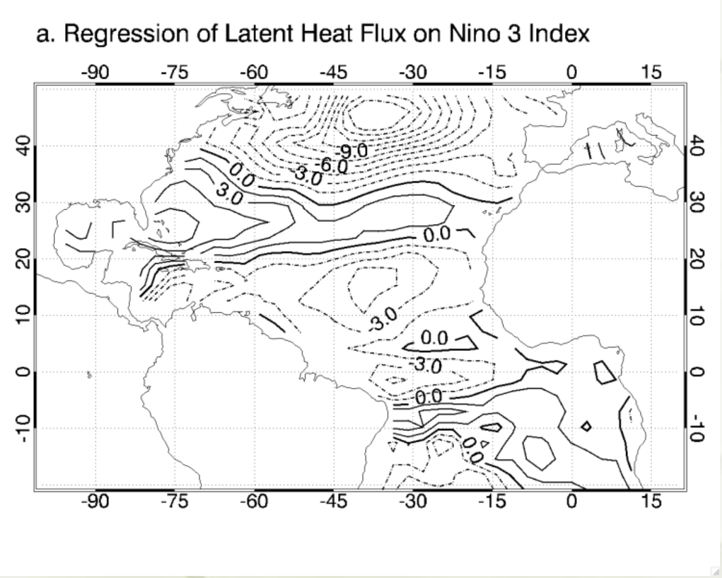


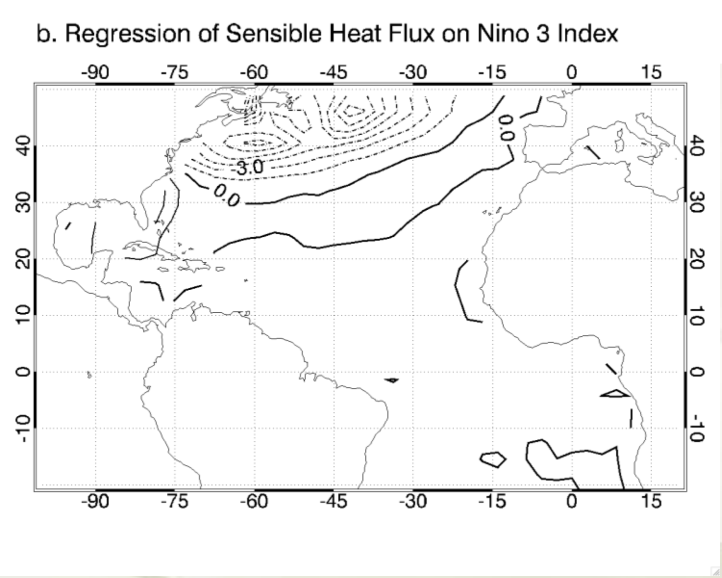
WES: Atlantic Response to ENSO



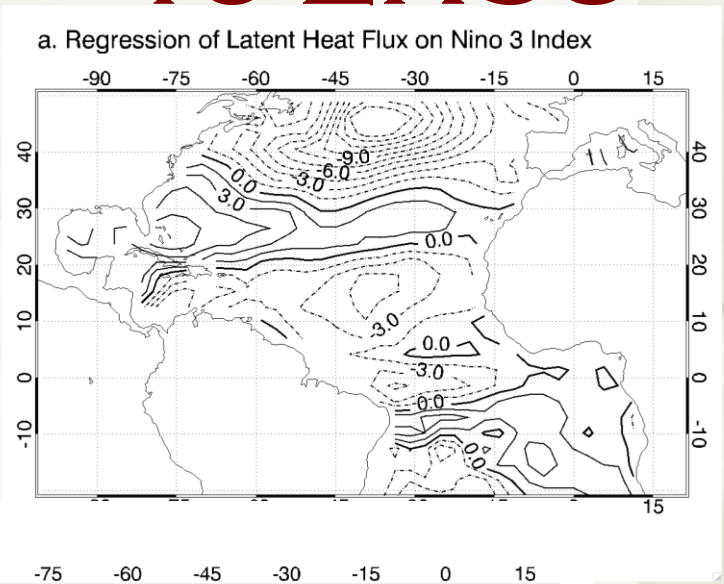
Atlantic Response to ENSO:

- Partitioning of January-Feb-March net surface heat flux (W/m^2)
- Regression of LHFLX and SHFLX on January ENSO index for CCM3-SOM-ENSO



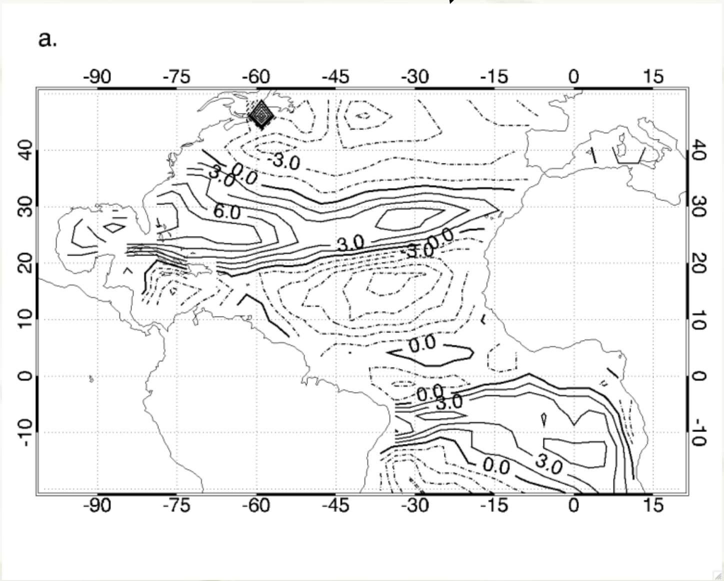


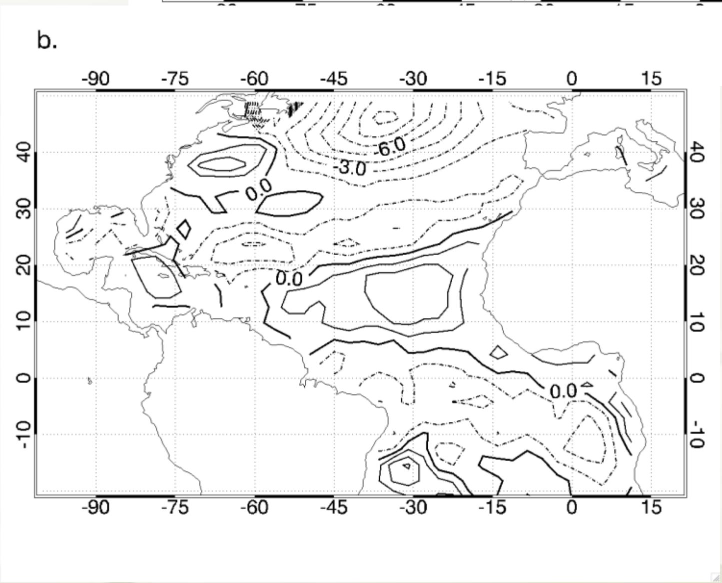
WES: Atlantic Response to ENSO



Partitioning LHFLX:

- $LHFLX = -(u^{*}\Delta q)$ ❒ L_{vap}
- $LHFLX' = -(u^{*\prime} \langle \Delta q \rangle + \langle u^{*} \rangle \Delta q')$ ❒ L_{vap}

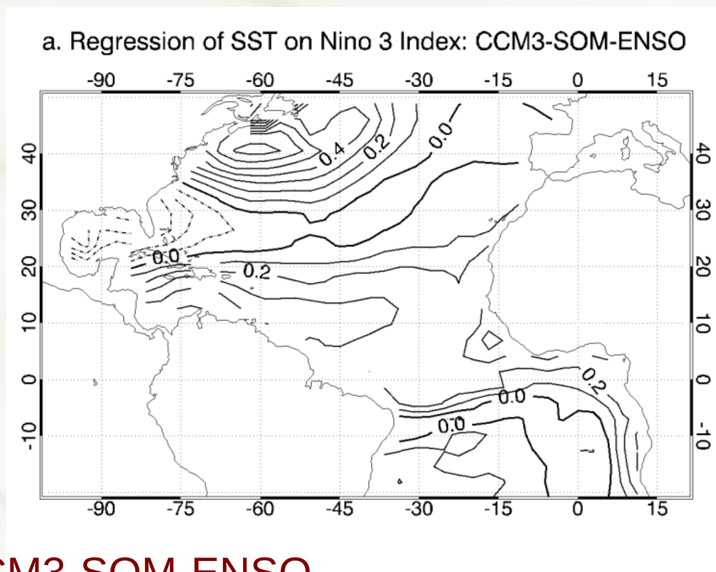




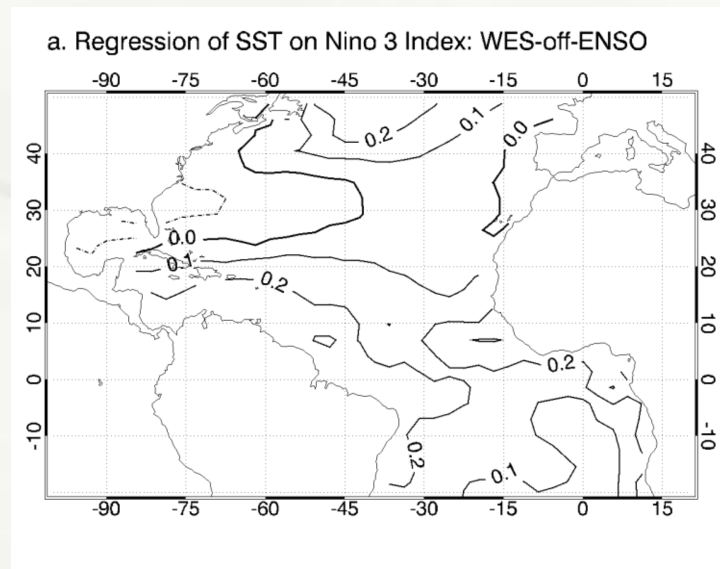
WES: Atlantic Response to ENSO

Role of the WES Feedback:

- Reduced SST response in the WES-off-SOM run



CCM3-SOM-ENSO

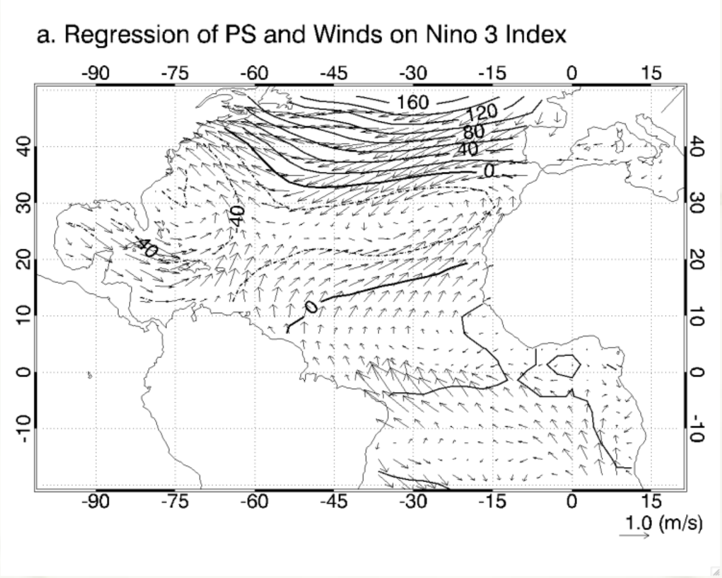


WES-off-ENSO

WES: Atlantic Response to ENSO

Role of the WES Feedback:

• Amplification of wind response in the presence of WES feedback



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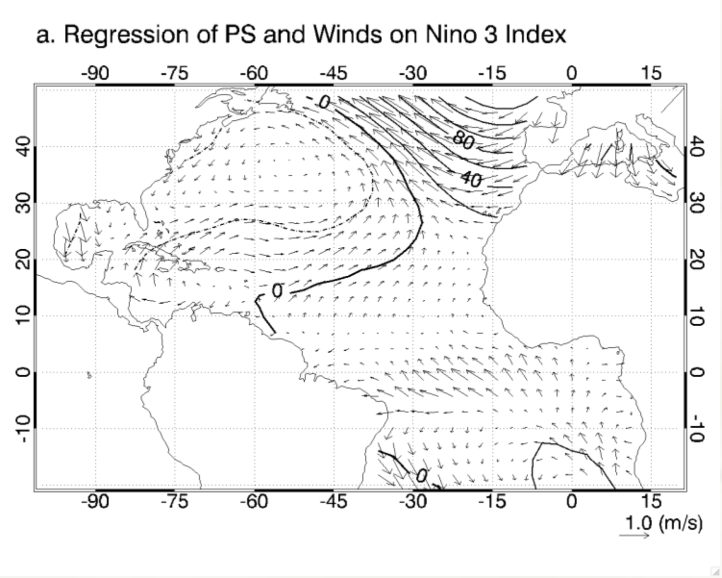
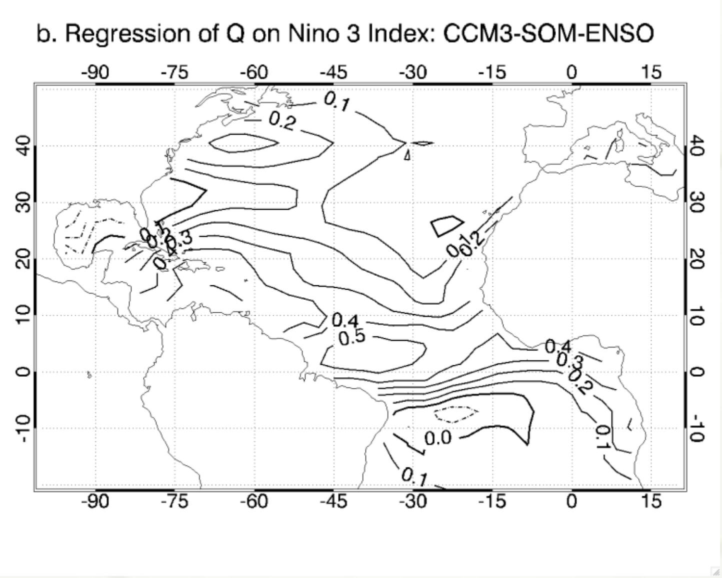


WES-off-ENSO

WES: Atlantic Response to ENSO

Role of the WES Feedback:

- Regression of April-May-June surface specific humidity on the ENSO January index for CCM3-SOM-ENSO and WES-off-ENSO runs.
- Less cross-equatorial transport of moisture in the absence of WES feedback



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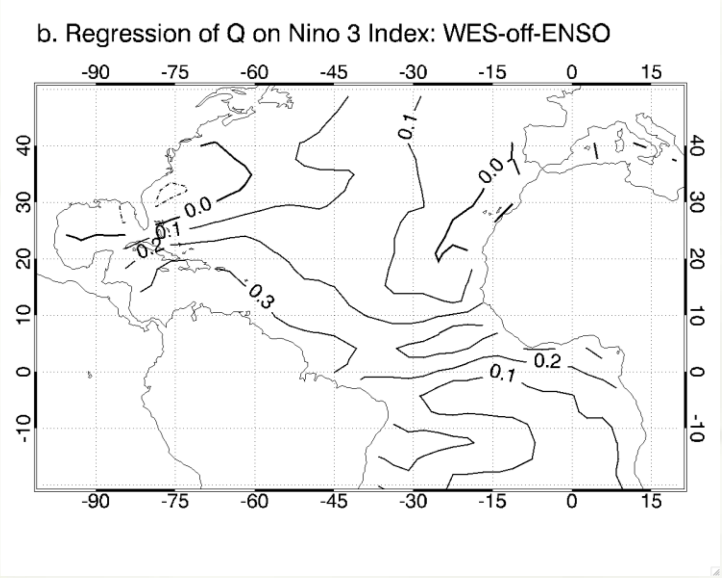
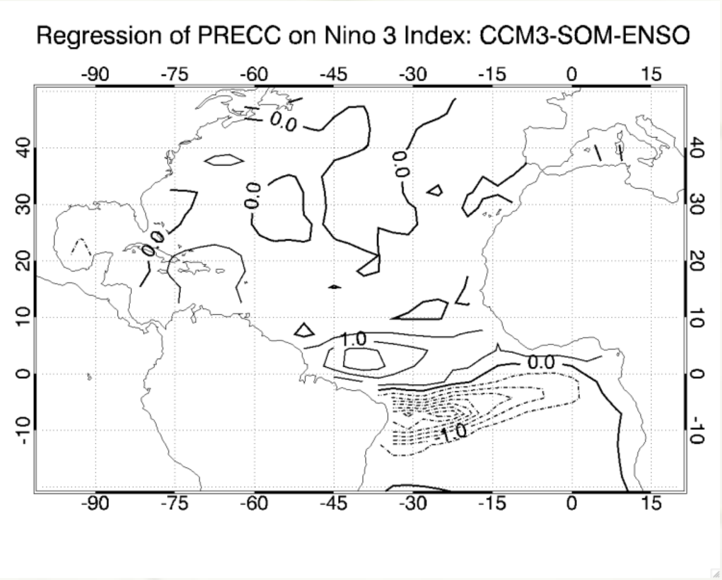


WES-off-ENSO

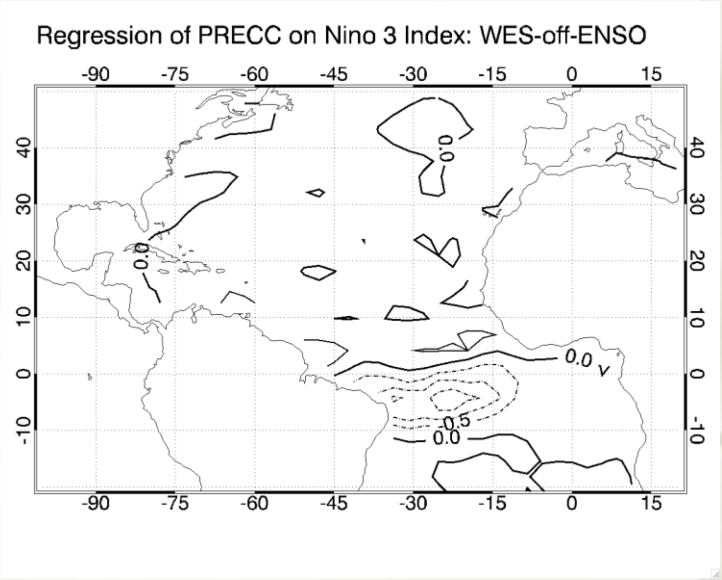
WES: Atlantic Response to ENSO

Role of the WES Feedback: ITCZ response

- Regression of April-May-June precipitation on the ENSO January index for CCM3-SOM-ENSO and WES-off-ENSO runs.
- Subsidence during El-Nino events
- Northward movement of the ITCZ during El-Nino events only in the presence of WES feedback



CCM3-SOM-ENSO



WES-off-ENSO