Ocean – Atmosphere Interaction

杨海军
北京大学气候与海-气实验室
北京大学物理学院大气与海洋科学系
Email: hjyang@pku.edu.cn

LaCOAS
北京大学气候与海-气实验室

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Ocean-Atmosphere Interaction

1. Tropical-Extratropical, Interhemispheric Climate Interaction : Atmospheric Bridge and Oceanic Tunnel
2. Dynamics of Decadal Climate Variability and Tropical Decadal Variability
3. Ocean-Atmosphere Interaction: A Global Scale, Coupled Climate Dynamics and Bjerknes Compensation
4. Timescale and Reversibility of Climate Change

Tropical-Extratropical Interaction

Extratropical Control of tropical climate: Atmospheric Bridge and Oceanic Tunnel

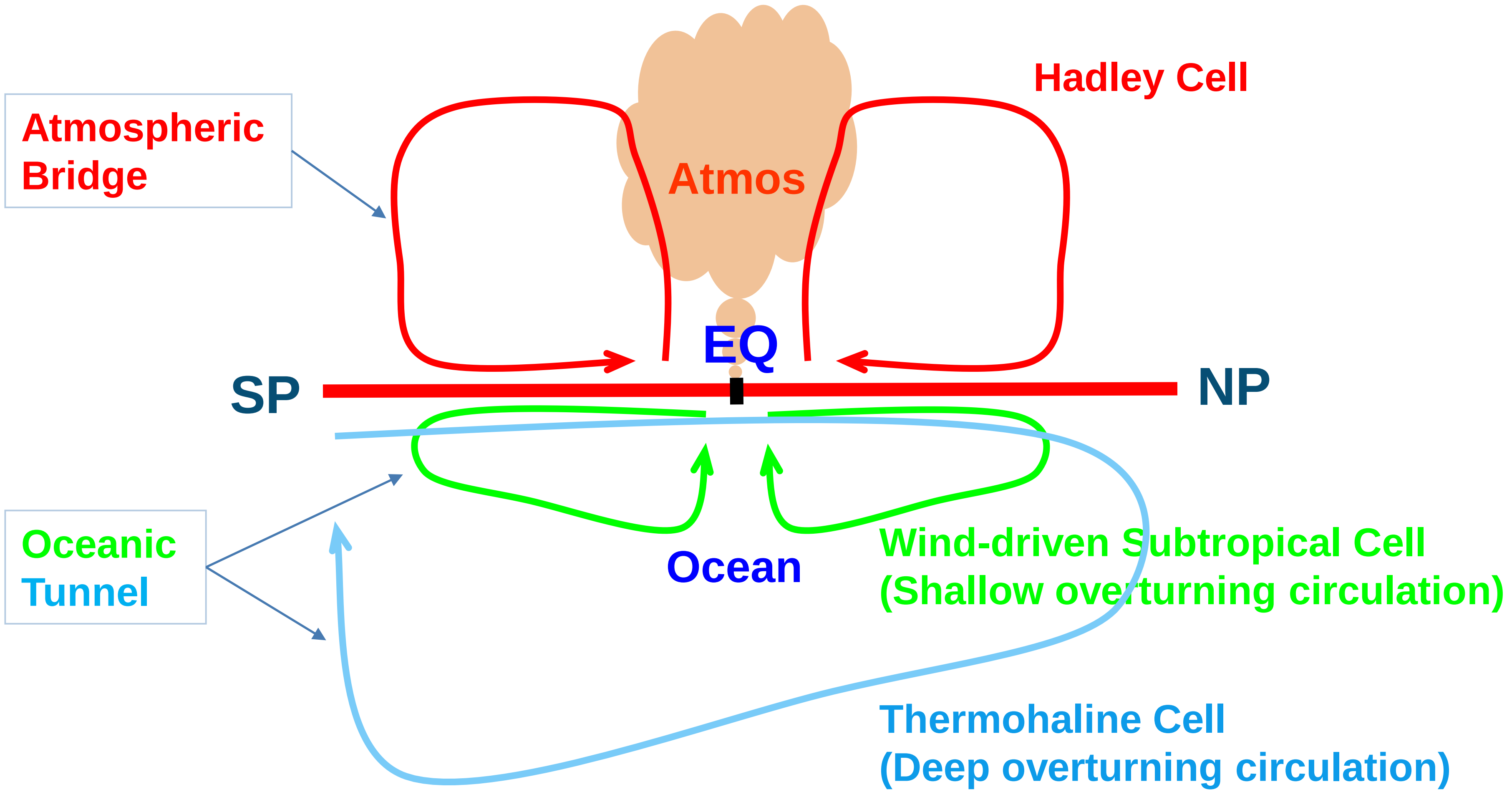
- Motivation

  How Extratropics affect Tropics?

- Implication

  1. ENSO could be controlled by extratropical climate
  2. PDO important to global climate
  3. PDO may be background of ENSO
  4. PDO may control or modulate ENSO

Tropics ⇔ Extratropics



Yang, H. and Z. Liu, 2005: Tropical-extratropical climate interaction as revealed in idealized coupled climate model experiments. *Climate Dynamics*, 24, 863-879.

Question: Quantitative Impact?

- Extratropics → Tropics *
- Tropics → Extratropics
- SH → Tropics → NH
- NH → Tropics → SH

Fundamentally Important !

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Traditional Approach

- AGCM

  Decoupled from full ocean dynamics

  (Lau 1997; Barnett et al. 1999)

- OGCM

  Decoupled from full atmosphere dynamics

  (Gu and Philander 1997; Liu 1998)

Our Model and Approach

- Fully coupled climate model (FOAM)

  Atmos. – R15, NCAR-CCM2

  Ocean – 1.4°×2.8°×32-level, GFDL-MOM

  Control Run: 1000 years

  Experiments: 200 years

- ***Partial C**oupling technique*

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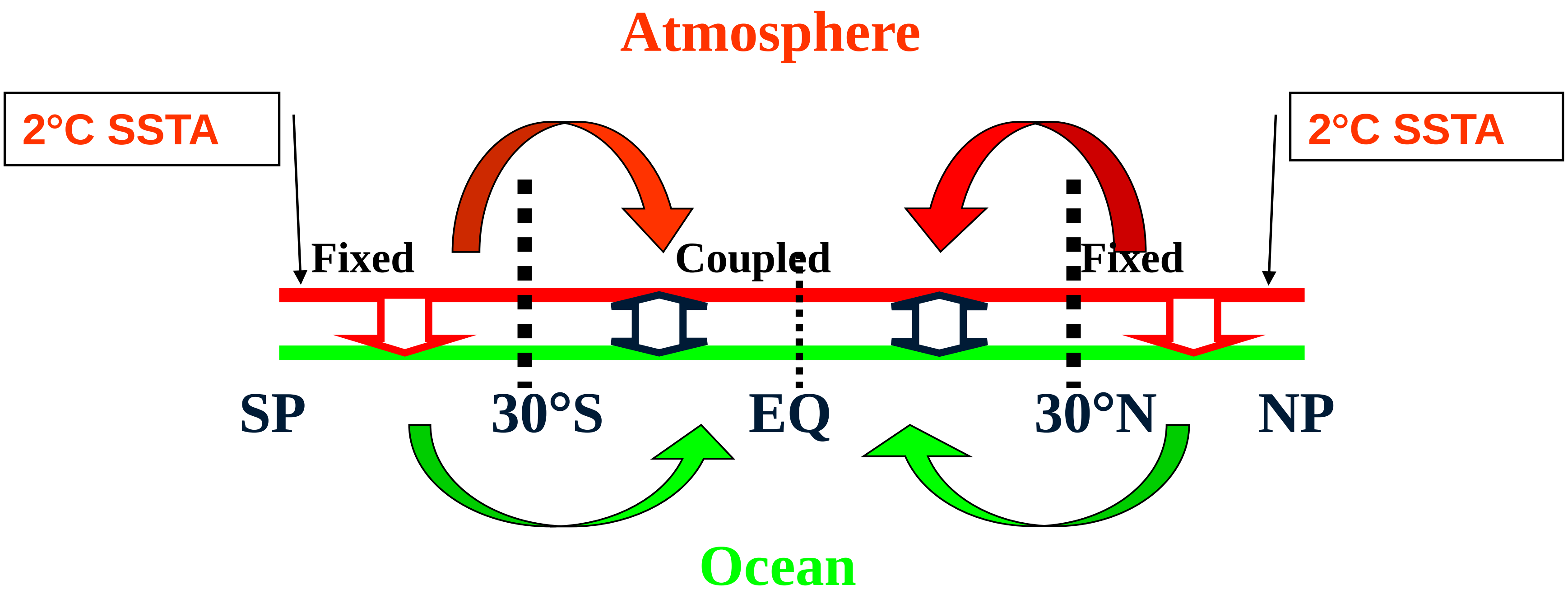
Partial Coupling

Full ocean-atmosphere coupling is allowed only in some selected region; elsewhere, the coupling is suppressed and the fixed climatology from model CTRL is prescribed to force the model atmosphere or ocean. It provides an important modeling surgical technique for assessing the individual role of the atmospheric bridge and oceanic tunnel in the interaction between different geometry regions (Wu et al. 2003; Liu and Yang 2003).

PC Exp. I

- ABOT

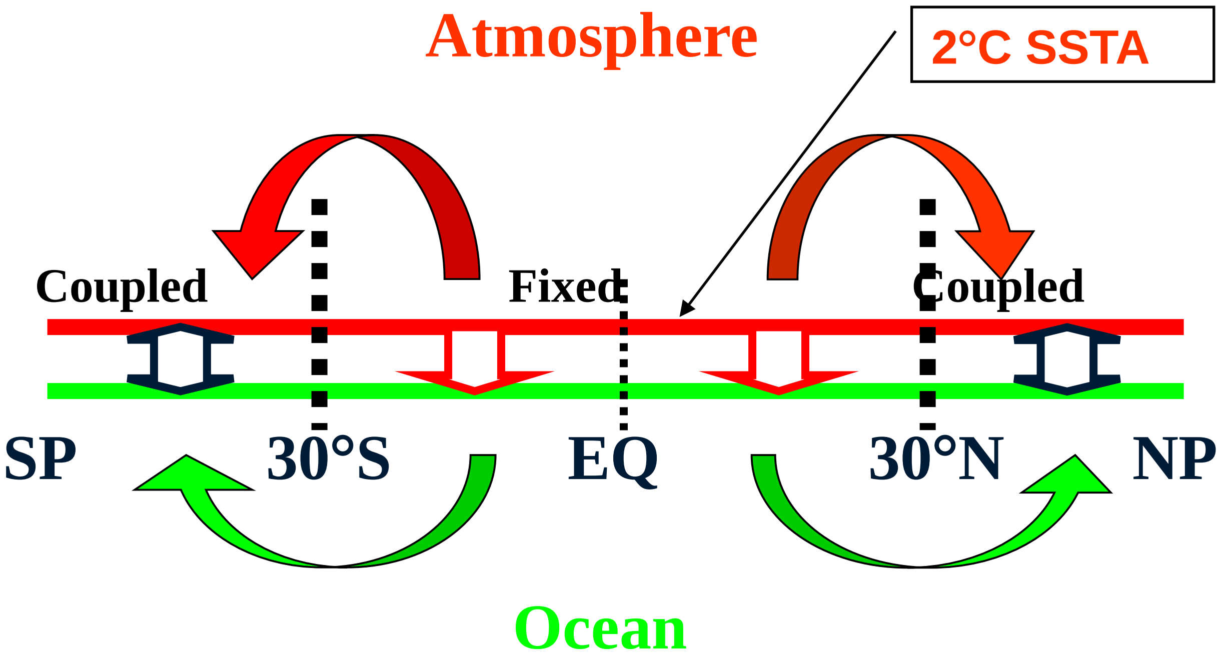
  Atmospheric Bridge + Oceanic Tunnel



PC Exp. II

- T-ABOT

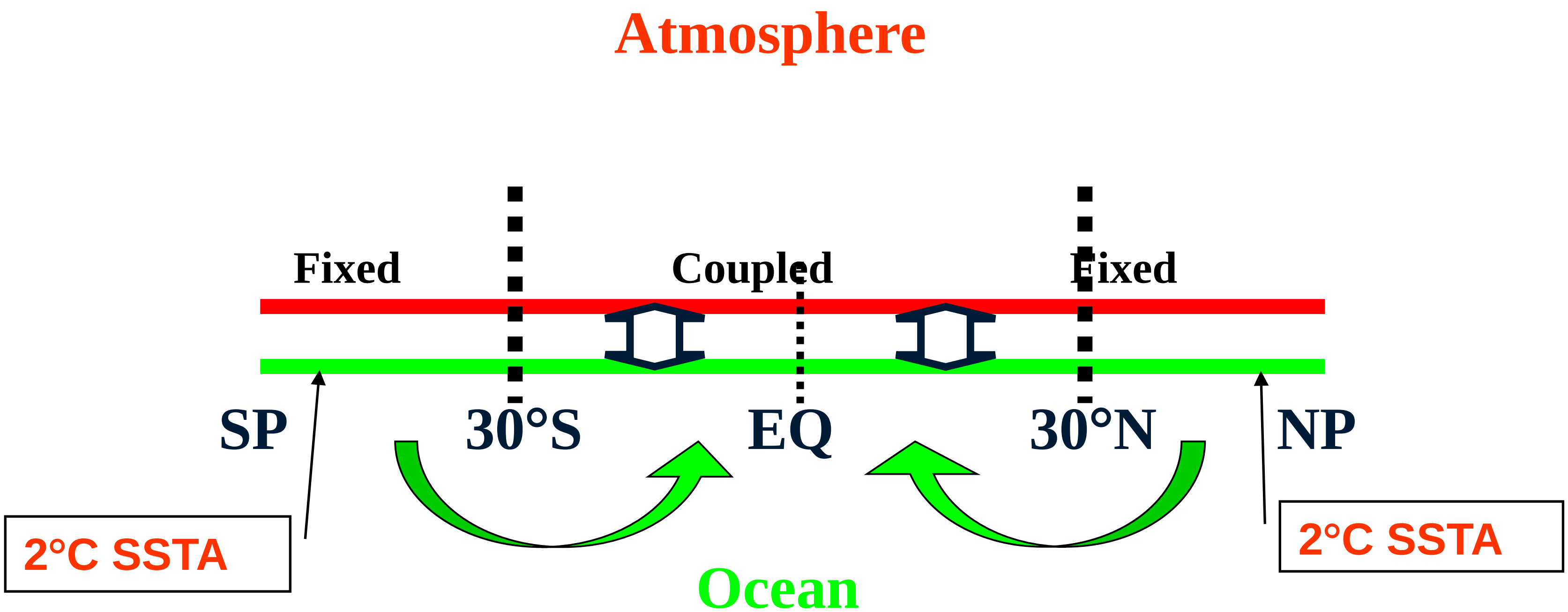
Tropical Atmospheric Bridge + Ocean Tunnel



PC Exp. III

- OT

  Ocean Tunnel only



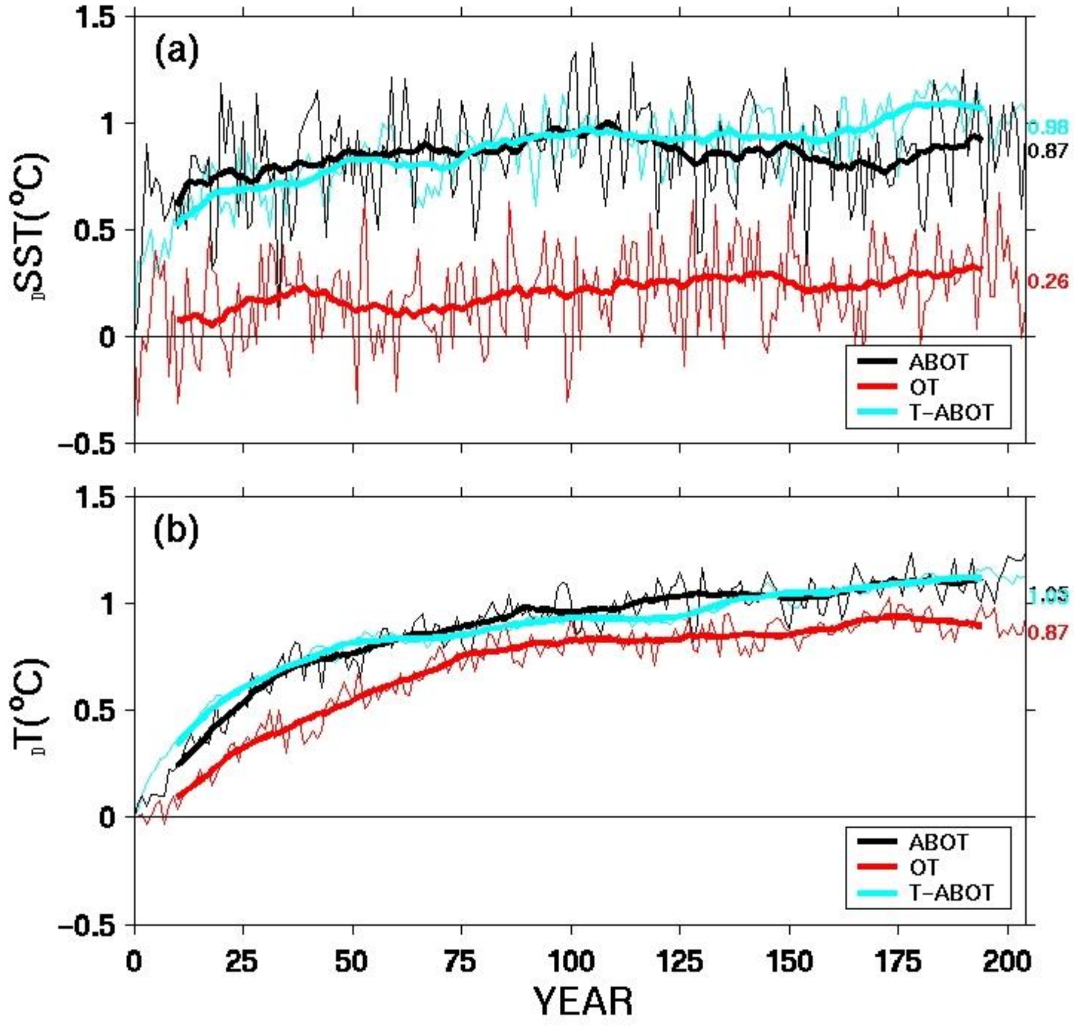
Extratropics ➔ Tropics

Liu, Z. and H. Yang, 2003: Extratropical control on tropical climate, the atmospheric bridge and oceanic tunnel. *Geophys. Res. Lett.*, 30(5), 1230, doi: 10.1029/2002GL016492.

Yang, H., Z. Liu and H. Wang, 2004: Influence of extratropical thermal and wind forcing on equatorial thermocline in an ocean GCM. *J. Phys. Oceanogr.*, 34(1), 174-187.

Yang, H. and Z. Liu, 2005: Tropical-extratropical climate interaction as revealed in idealized coupled climate model experiments. *Climate Dynamics*, 24, 863-879, doi: 10.1007/s00382-005-0021-8.

Equatorial Ocean Response



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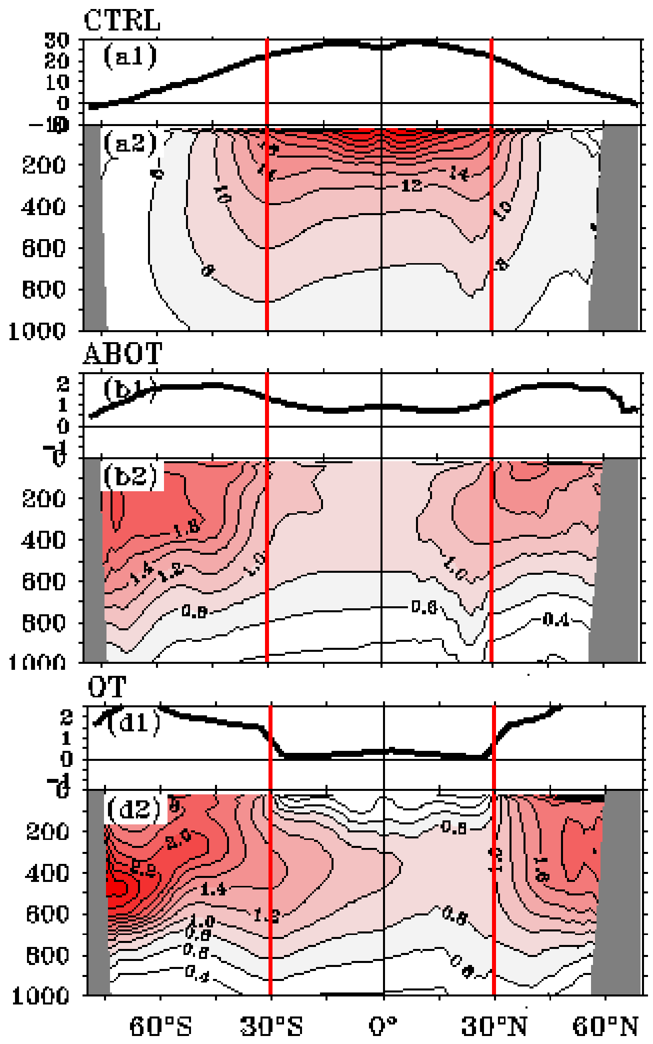
Summary

- Equal impact: Tropics ⇔ Extratropics
- Extratropics → Tropics

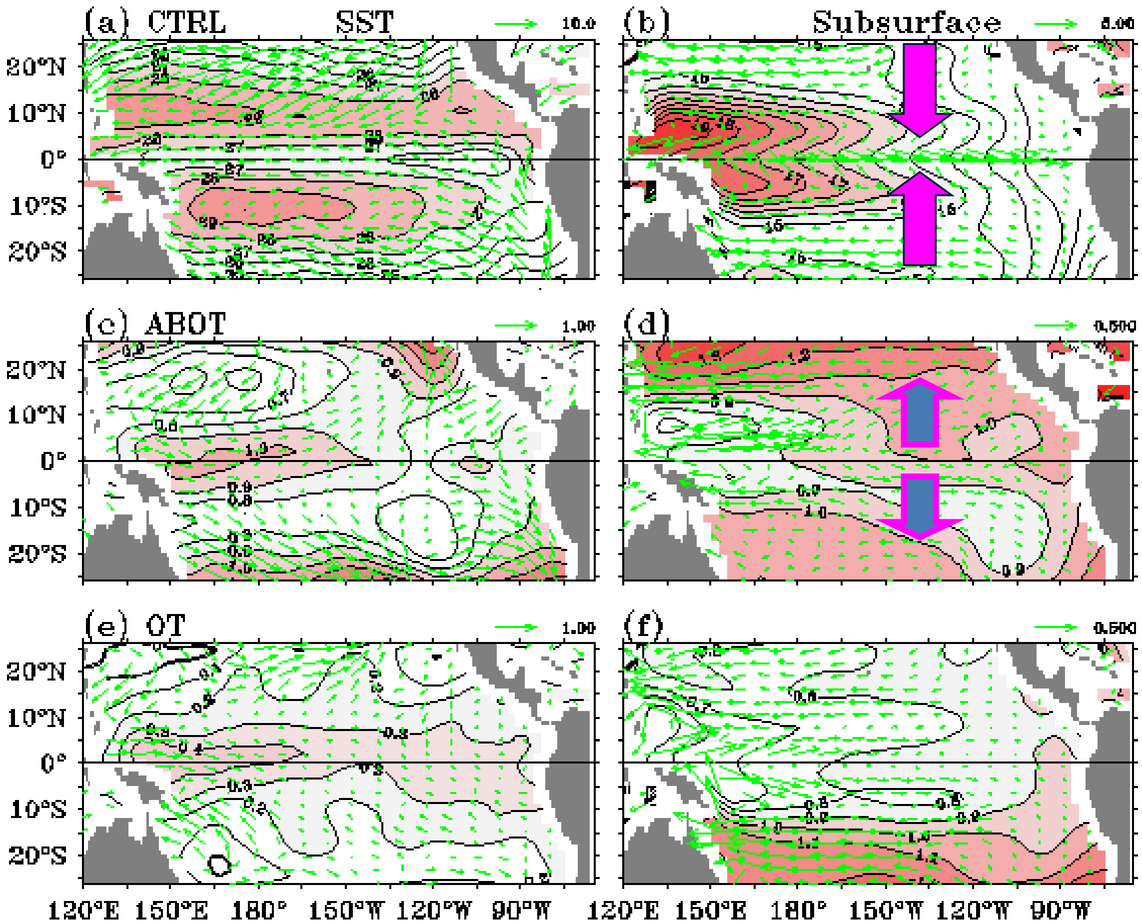
Atmos. Bridge: 70%

Ocean Tunnel: 30%

Latitude - Depth Section



Horizontal Pattern



Mechanisms

- **ABOT**

  Atmos. Bridge:

  Ex-SST↑ ⇒ ∇SST↓ ⇒ HC (SH)↓ ⇒ ITCZ↓ ⇒ Trade Wind↓ ⇒ LH↓ ⇒ EQ-SST↑

  *Ocean. Tunnel:

  HC↓ ⇒ STCs↓ ⇒ Cold Water Trans. (*V'T*)↓ ⇒ EQ-SST↑

  Warm Anomaly Subduction (*VT', WT'*)↑ ⇒ EQ-SST↑

- **OT**

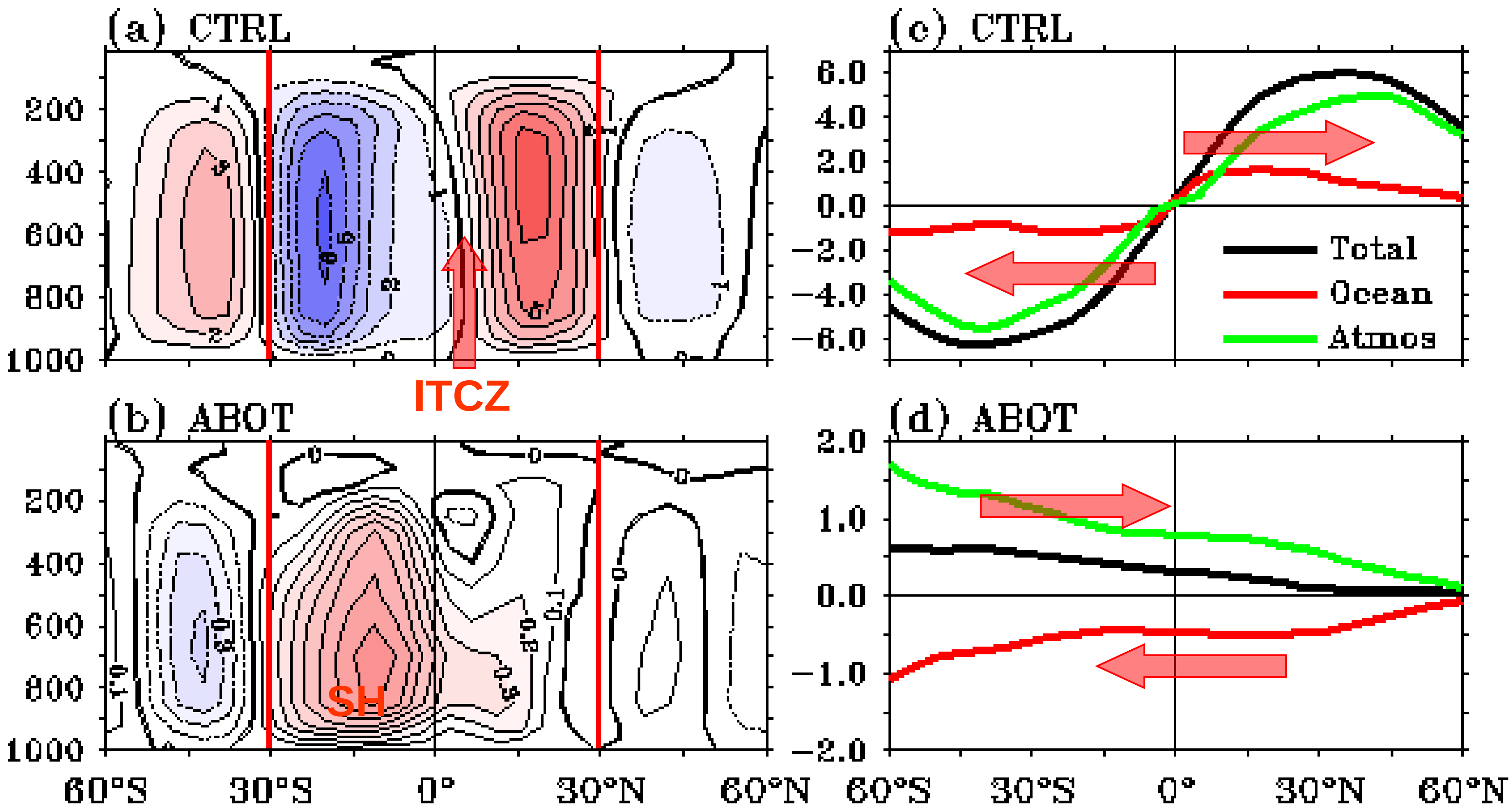
  Ocean. Tunnel:

  Warm Anomaly Subduction (*VT', WT'*)↑ ⇒ EQ-SST↑

Atmosphere Bridge

- Ensemble experiments:
  12-member, 12-year/exp
- Same as ABOT
- Ensemble mean
  1st year

Hadley Cell and Heat Transport



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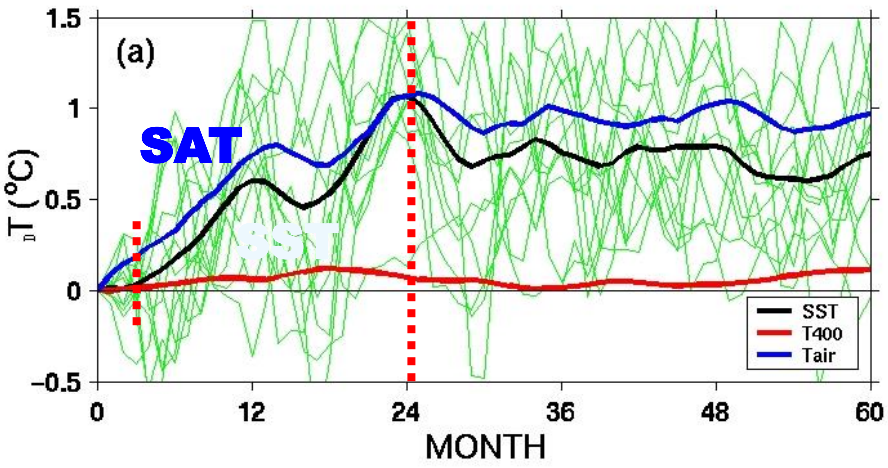
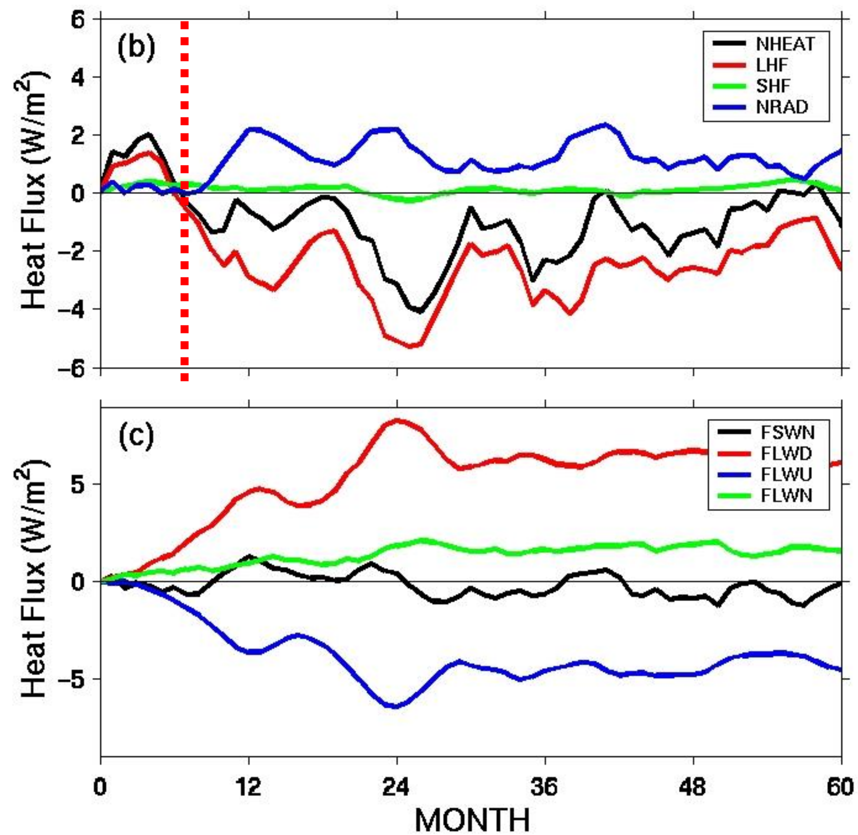
Thermodynamics: Surface Heat Budget

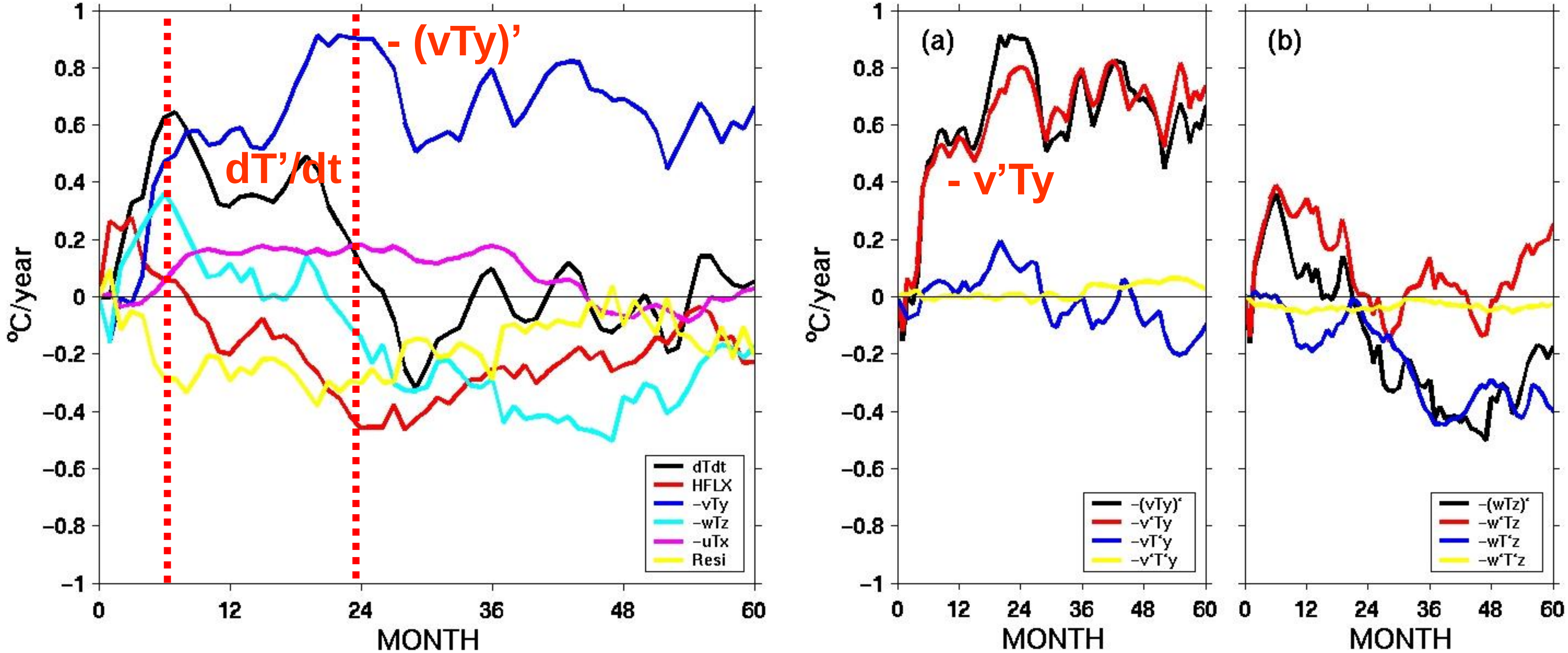


$$HFLX = F_{SW} + F_{LW} + F_{LH} + F_{SH}$$



$$dT/dt = HFLX + (- uTx - vTy - wTz) + (+ AhTxx + AhTyy) + Residual$$

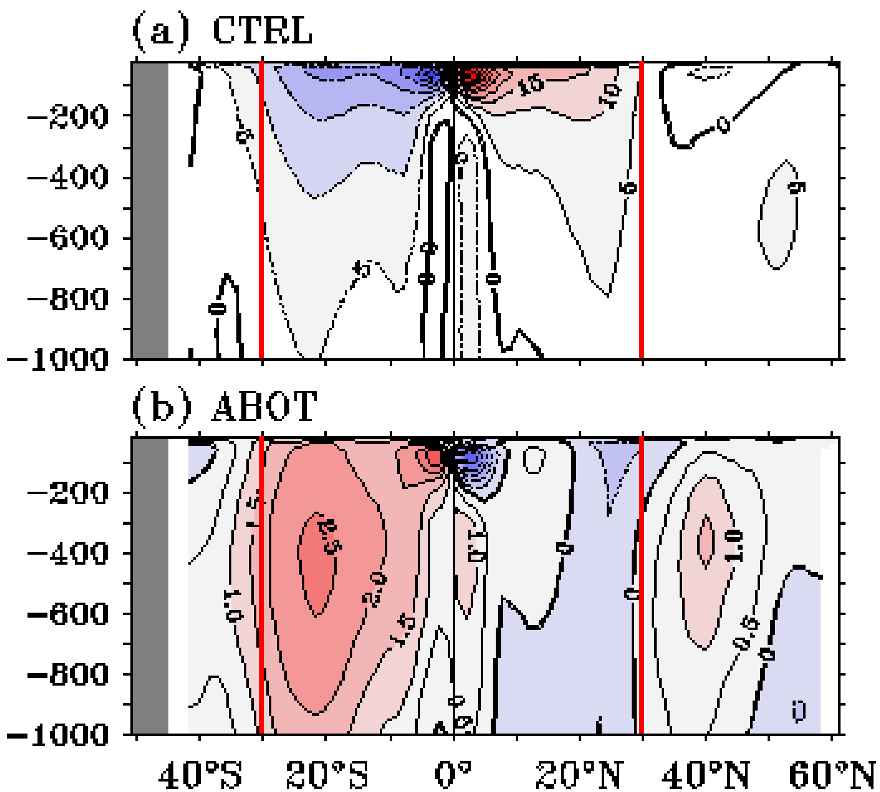
Ocean Dynamics: Term Balance



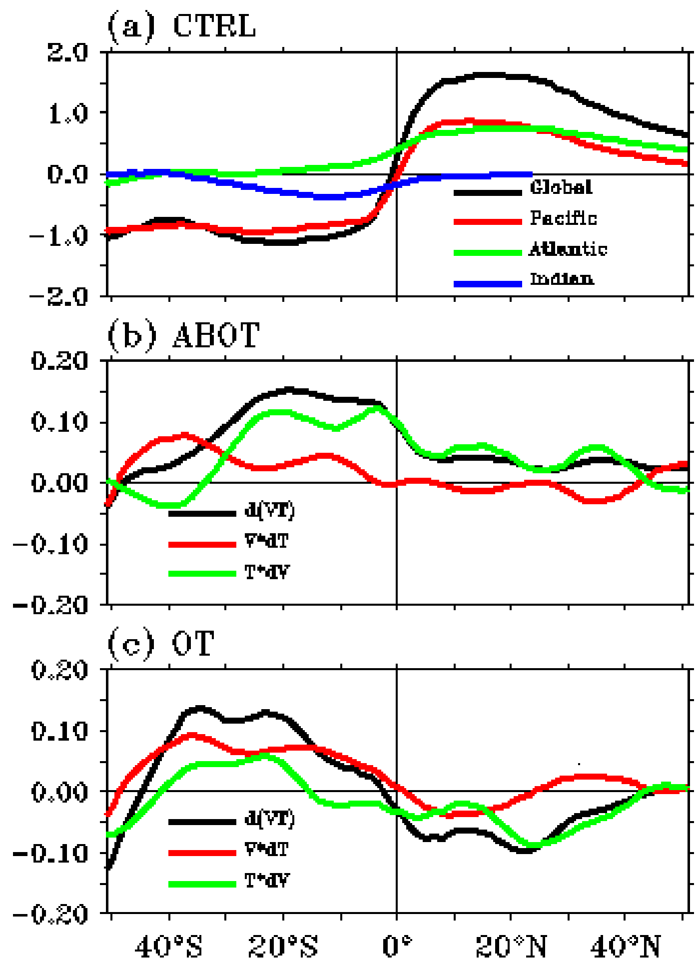
Before 6 months: Heat Flux ➔ T↑

After 6 months: -(vTy)' ➔ T↑ or -v'Ty (STC)

Ocean Dynamics: Subtropical Cell



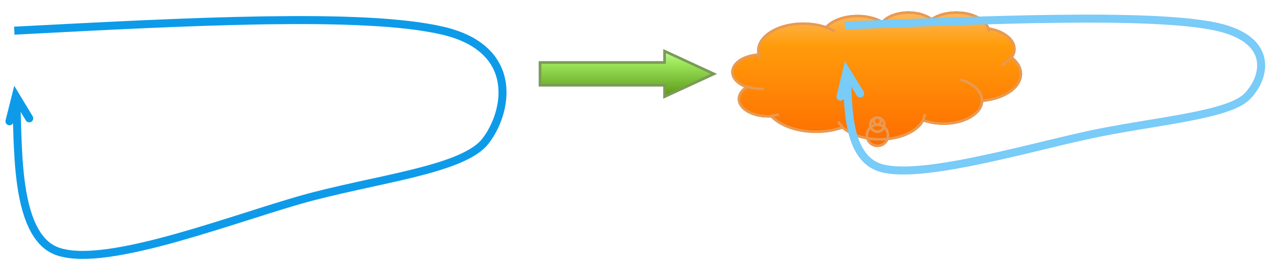
Ocean Dynamics: Heat Transport



Ocean Dynamics: Difference in ABOT and OT

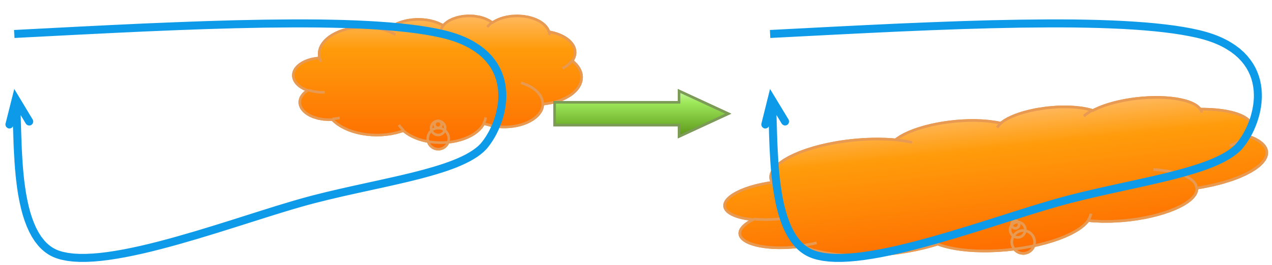
- ***Ocean. Tunnel in ABOT**

Perturbation advection (*V'T*) ↓ ⇒ **EQ-SST** ↑

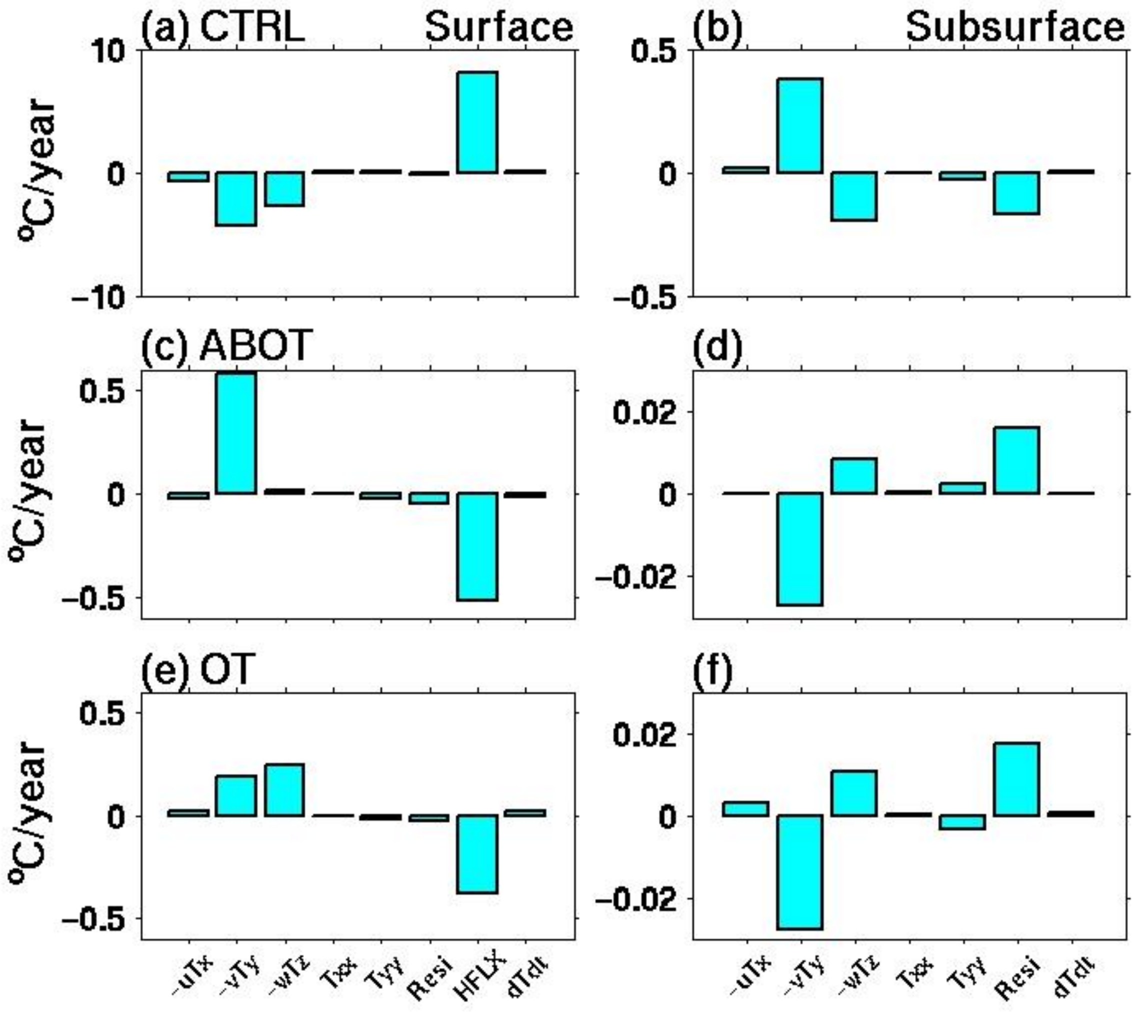


- **Ocean. Tunnel in OT**

Mean Subduction (*VT', WT'*) ↑ ⇒ **EQ-SST** ↑

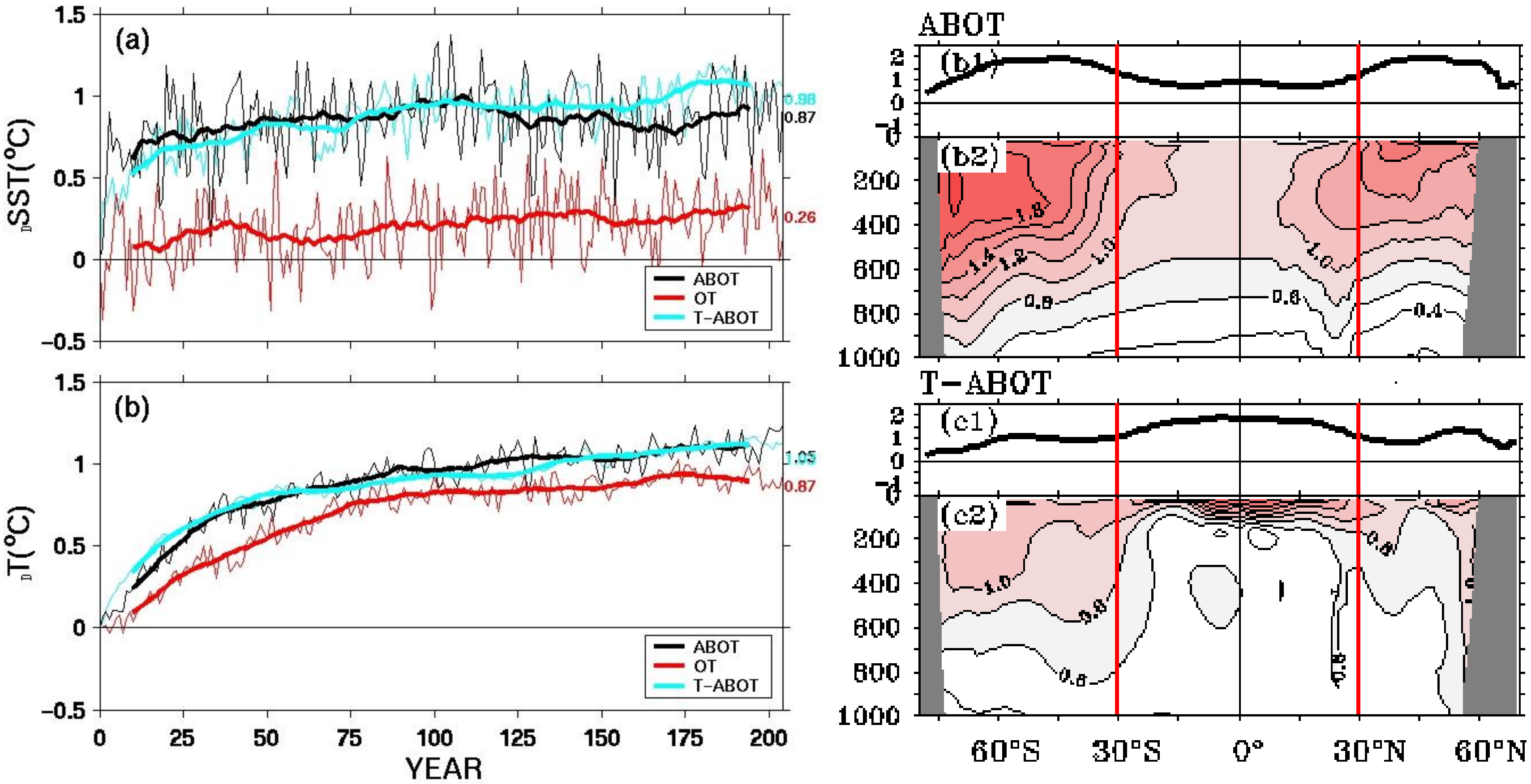


Term Balance in Final Steady State



Tropics ➔ Extratropics

Extratropical Response



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Mechanisms

- **T-ABOT**

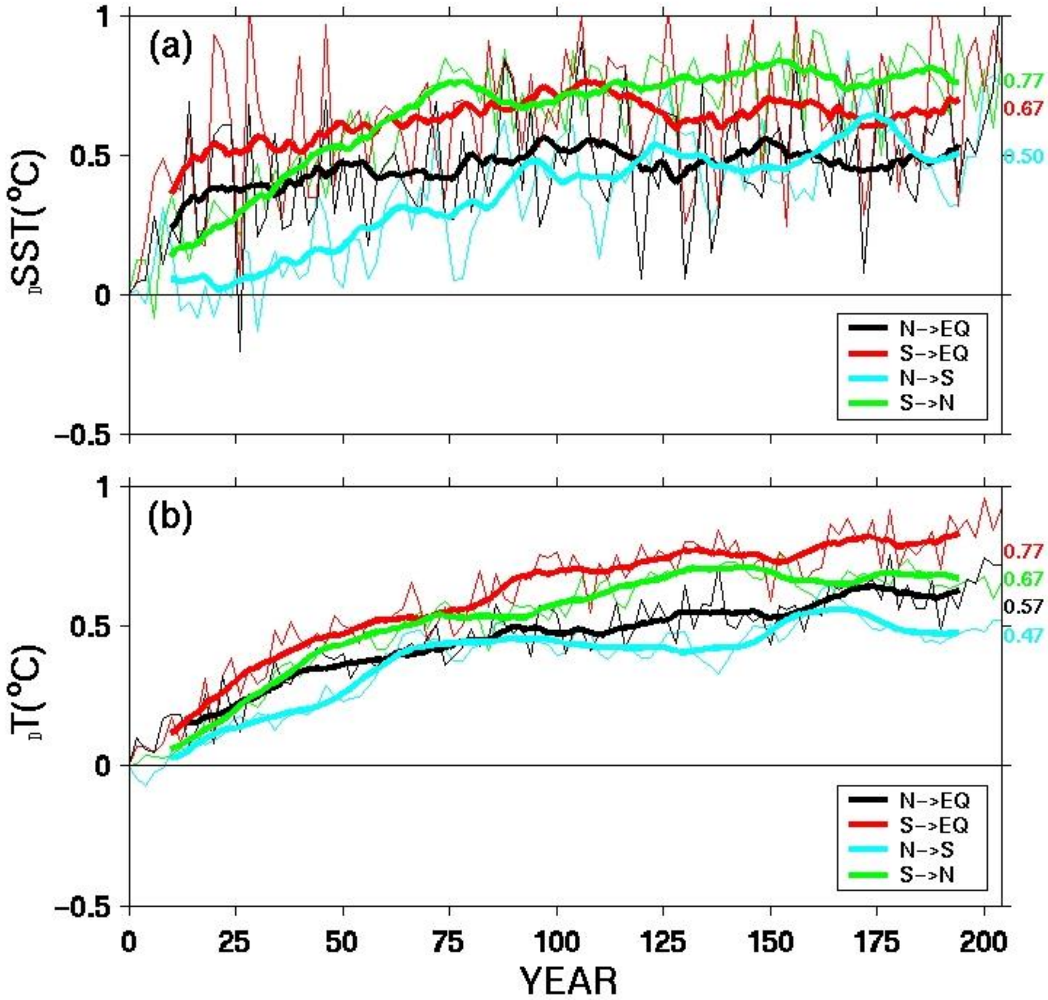
Atmos. Bridge Only:

EQ-SST ↑ ⇒ ∇SST ↑ ⇒ HC ↑ ⇒ Cloud ↓ ⇒ SW ↑
⇒ Ex-SST ↑↑ ⇐ Sea ice – albedo feedback

SH ⇔ NH

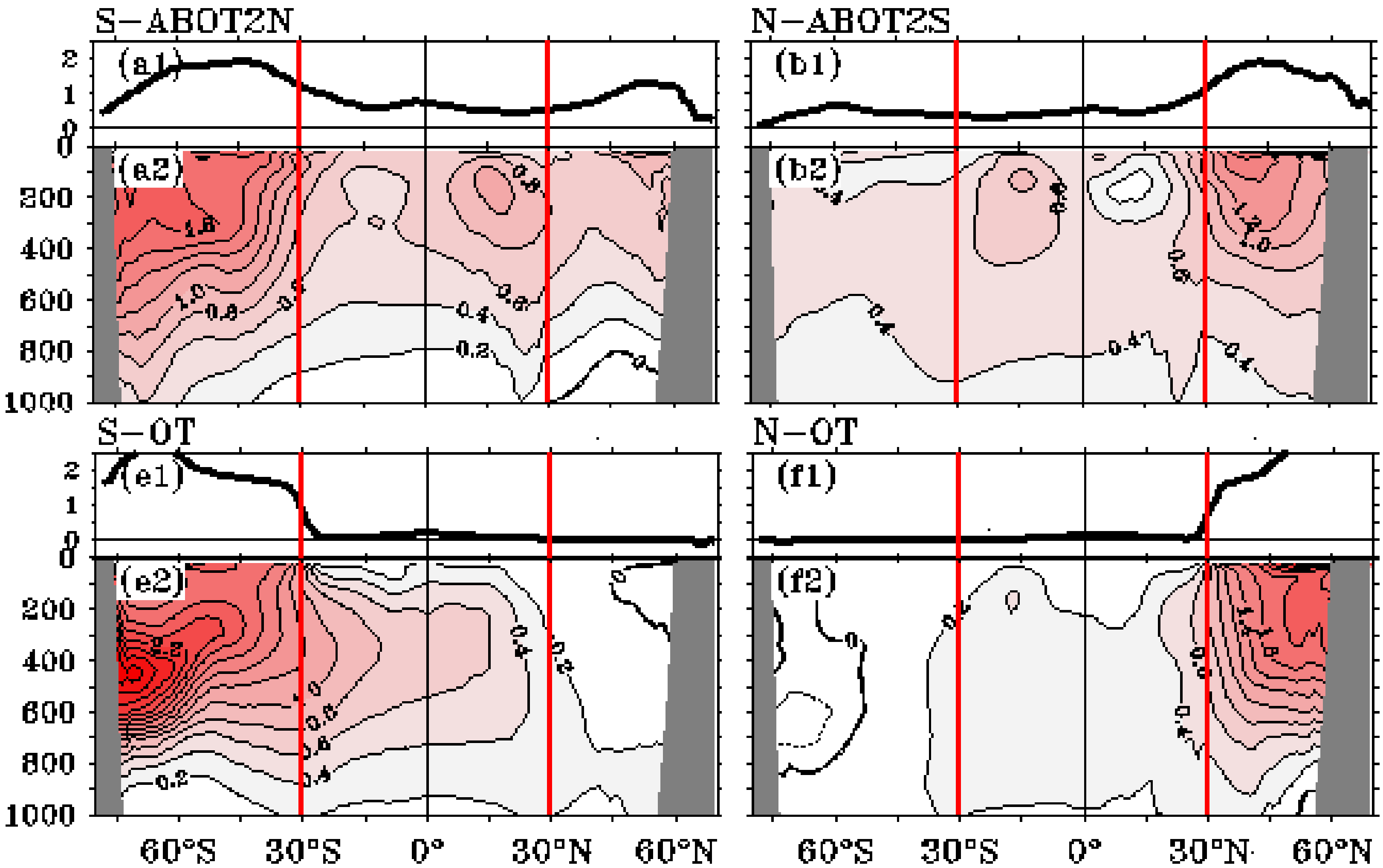
Yang, H., H. Jiang, and B. Tan, 2005: Asymmetric impact of the North and South Pacific on the Equator in a coupled climate model. *Geophys. Res. Lett.*, **32**(5), L05604, doi: 10.1029/2004GL021925.

SH ⇔ EQ ⇔ NH

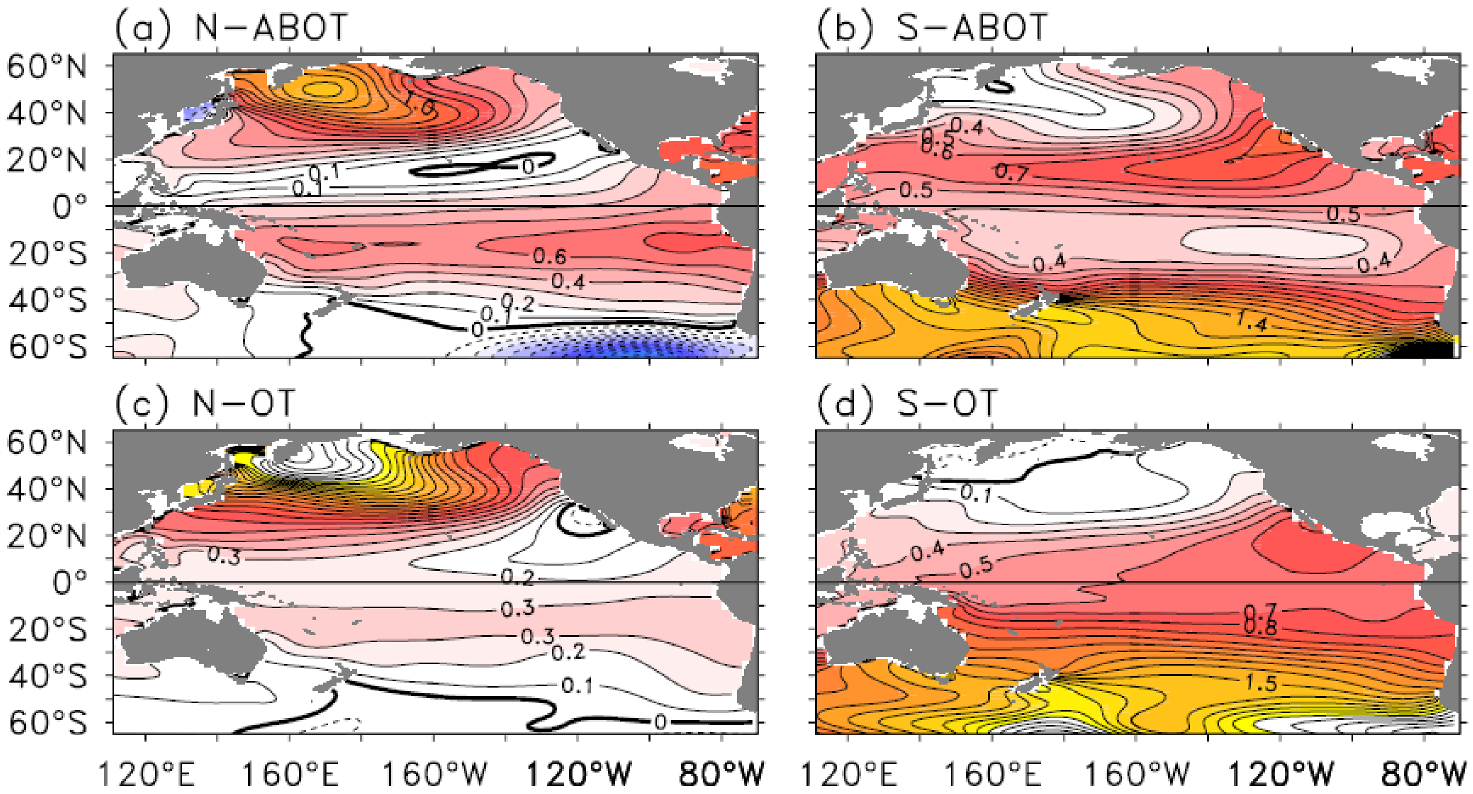


(a)
SST(°C)
1
0.5
0
−0.5
0.77
0.67
0.50
N−>EQ
S−>EQ
N−>S
S−>N
(b)
T(°C)
0.77
0.67
0.57
0.47
N−>EQ
S−>EQ
N−>S
S−>N
0
25
50
75
100
125
150
175
200
YEAR

Latitude - Depth Section



Interhemispheric Interaction



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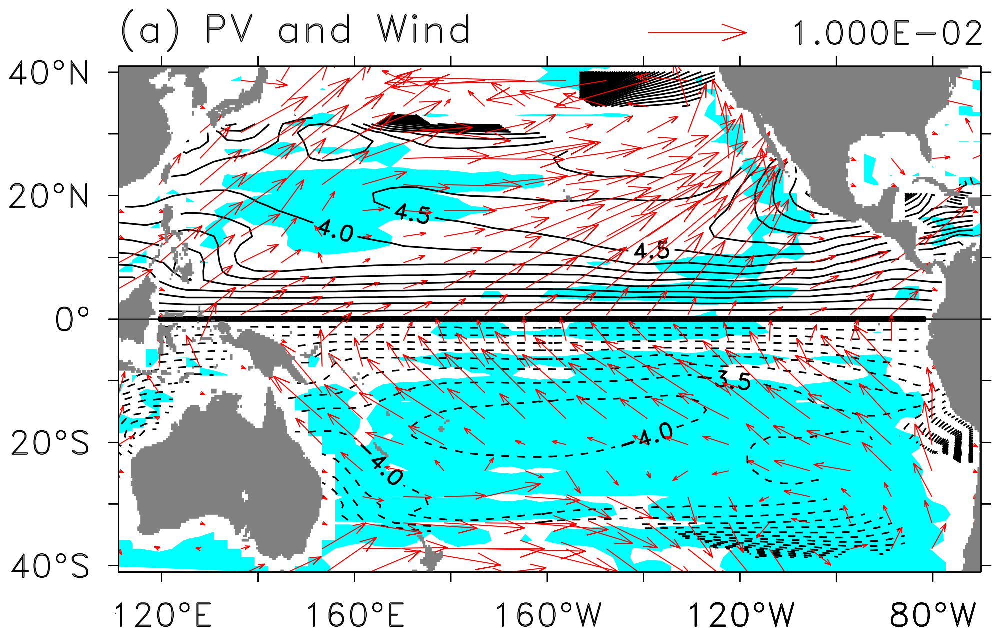
Mechanism: Potential Vorticity



PV at 24-26 σ_t , Surface wind and Ekman pumping

Yang, H., H. Jiang, and B. Tan, 2005: Asymmetric impact of the North and South Pacific on the Equator in a coupled climate model. *Geophys. Res. Lett.*, 32(5), L05604

Conclusions

- Equal impact: Tropics ⇔ Extratropics
- Extratropics → Tropics

Atmos. Bridge: 70%; Ocean Tunnel: 30%

- Tropics → Extratropics

Atmos. Bridge: 100%

- SH → EQ 30% more than NH → EQ
- SH → NH 60% more than NH → SH
- SH dominates in global climate change

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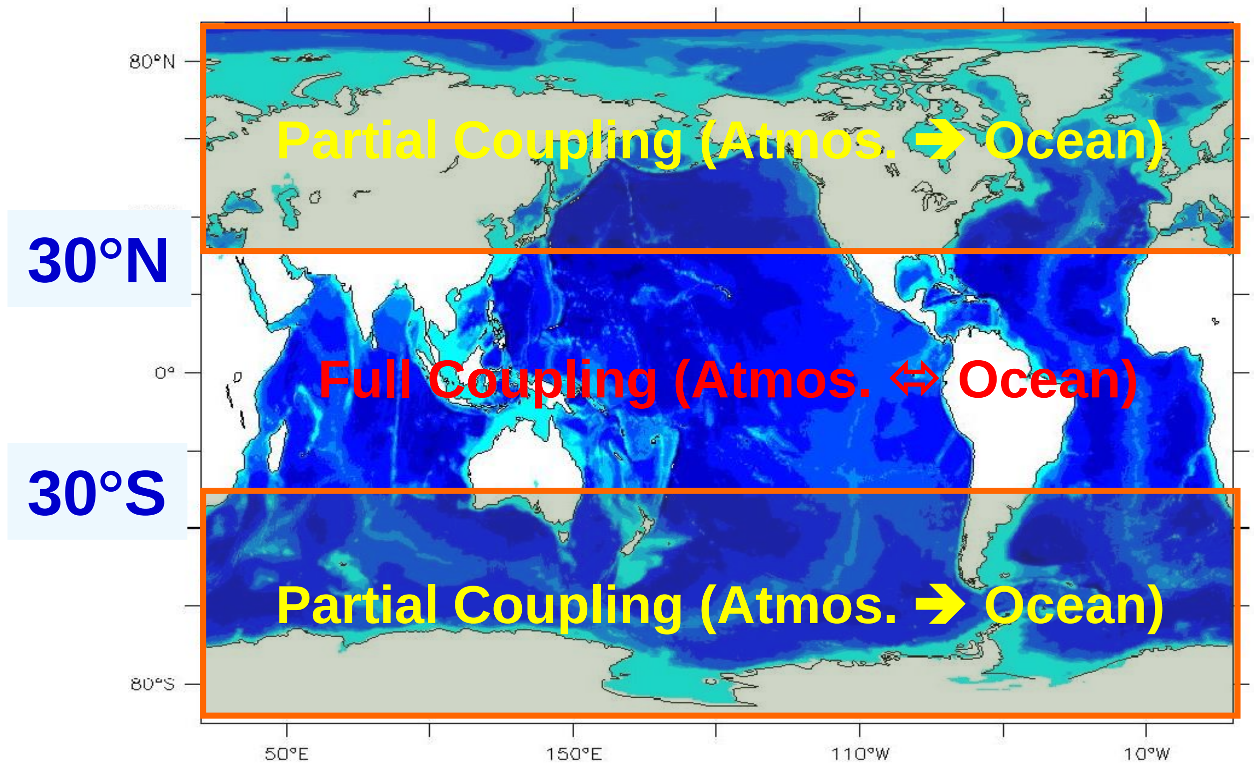
Pacific *vs.* Atlantic

Yang, H., and L. Wang, 2011: Tropical oceanic response to extratropical thermal forcing in a coupled climate model: A comparison between the Atlantic and Pacific Oceans. *J. Climate*, 24, 3850-3866.

Yang, H., and L. Wang, 2008: Estimating the nonlinear response of tropical ocean to extratropical forcing in a coupled climate model. *Geophys. Res. Lett.*, 35, L15705, doi: 10.1029/2008GL034256.

Experiments

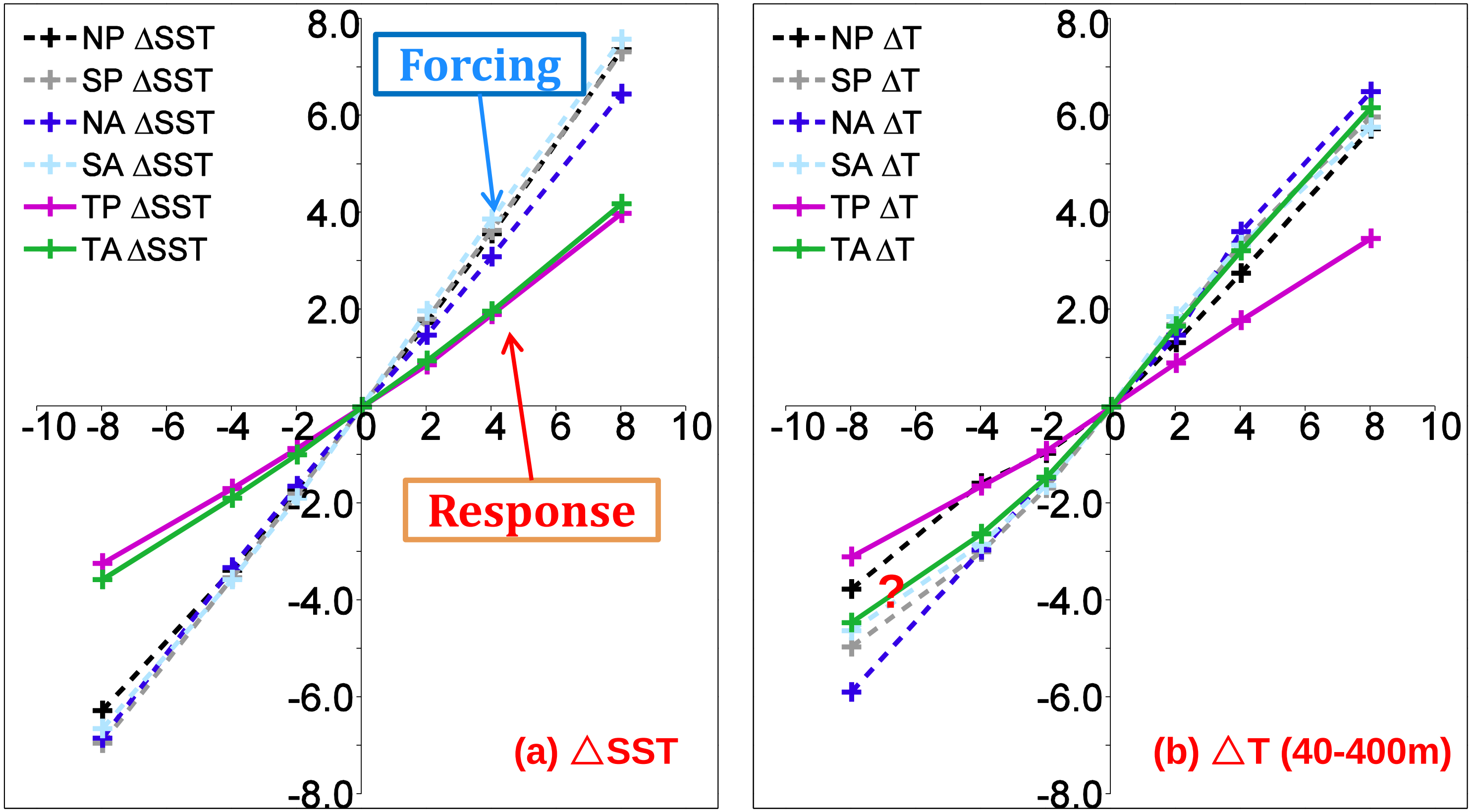


- PC: Clim. + SSTA
- SSTA: ±2℃, ±4℃, ±8℃; 200 years
- P – Warming exp; M – Cooling exp.

Summaries

- Tropical SST
  - Same magnitude in Atlantic and Pacific
- Tropical thermocline
  - Much stronger in Atlantic than in Pacific
- Atlantic STC (wind-driven)
  - Asymmetric change and critical role

Tropical Atlantic vs. Pacific



SST: Atlantic ~ Pacific;
Tropics ~ ½ * Extra.
Anti-symmetric

Subsurface: Atlantic >> Pacific;
Atlantic: Tro. ~ Extra.; Nonlinear
Pacific: Tro ~ ½ * Extra

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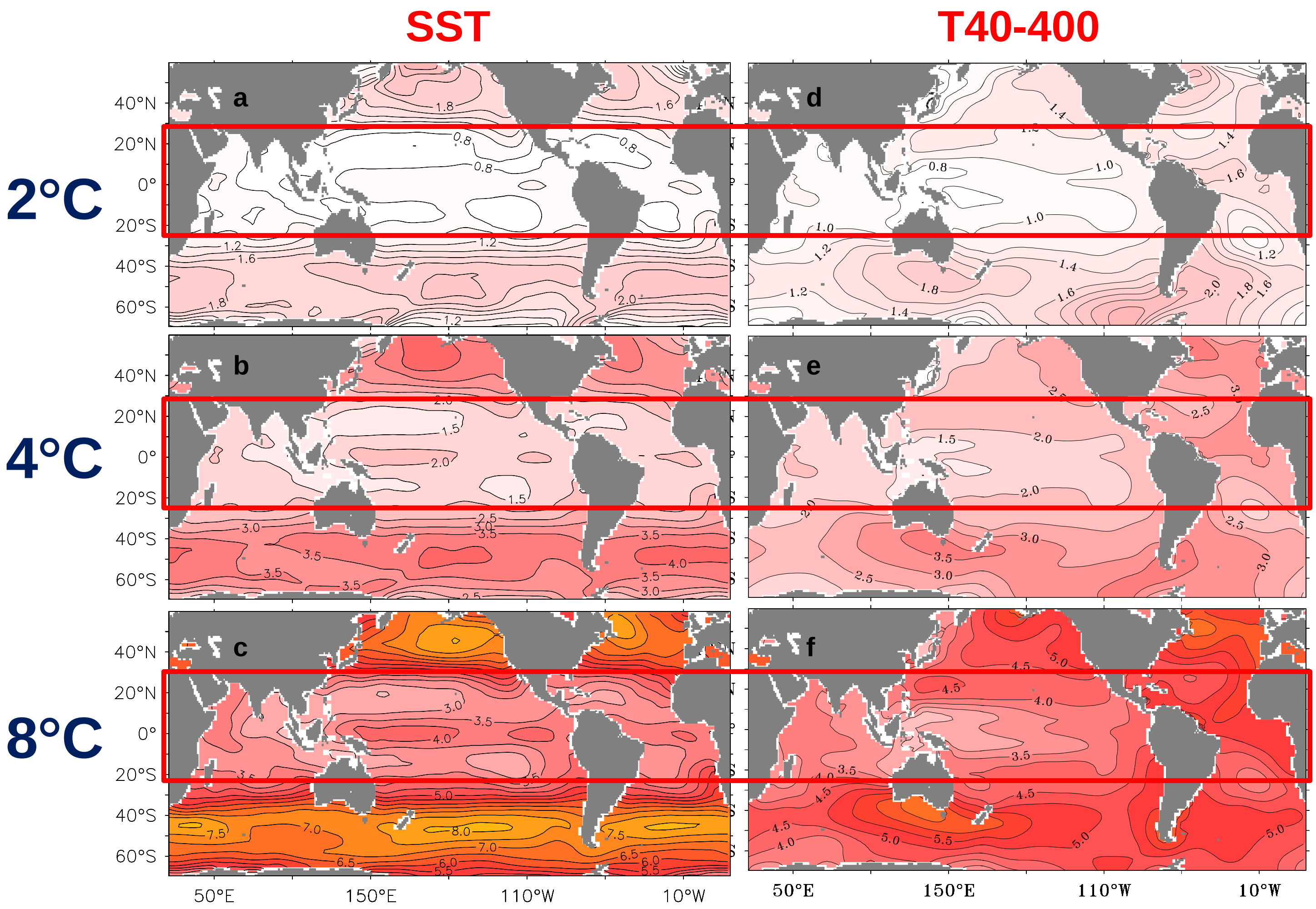
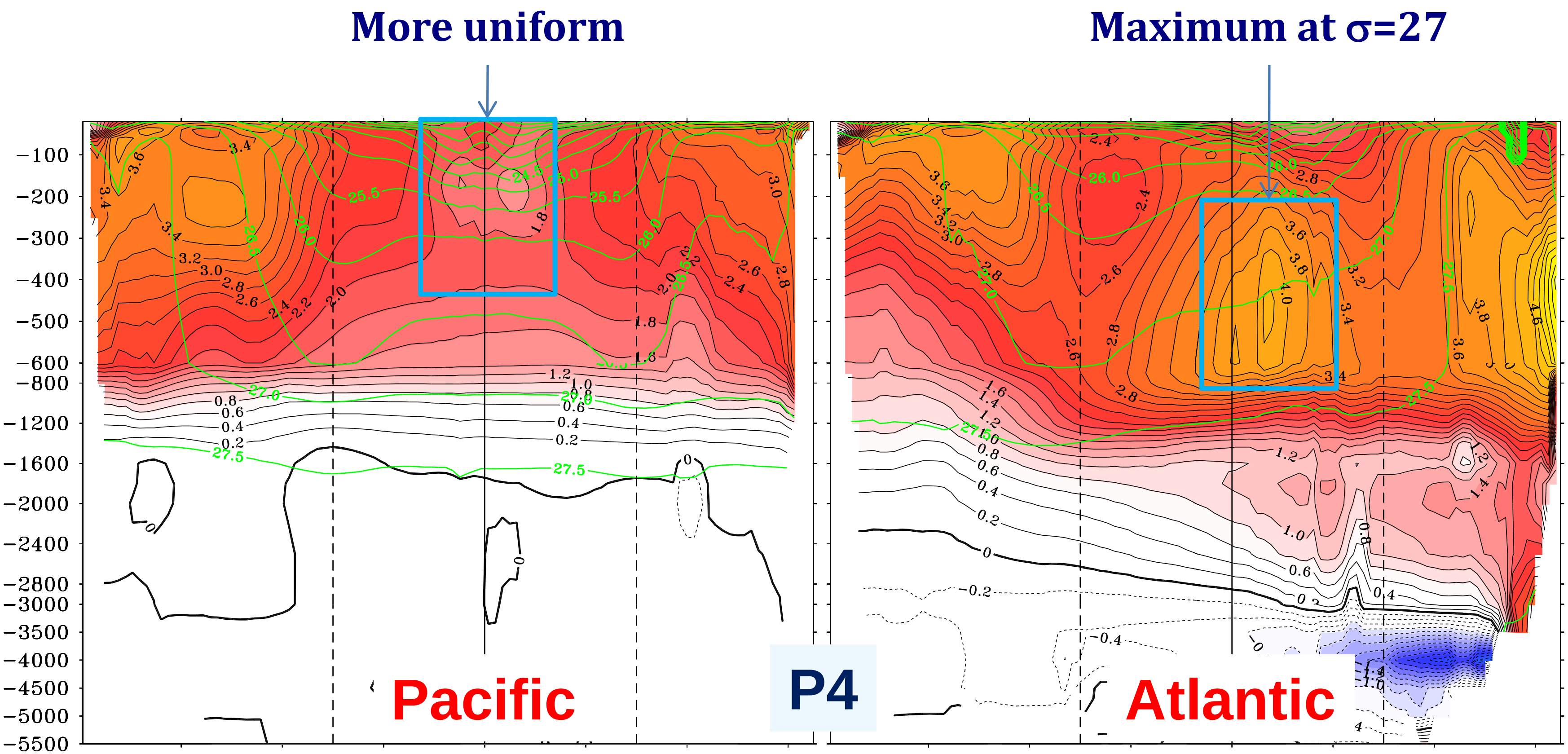
SST and Thermocline Changes



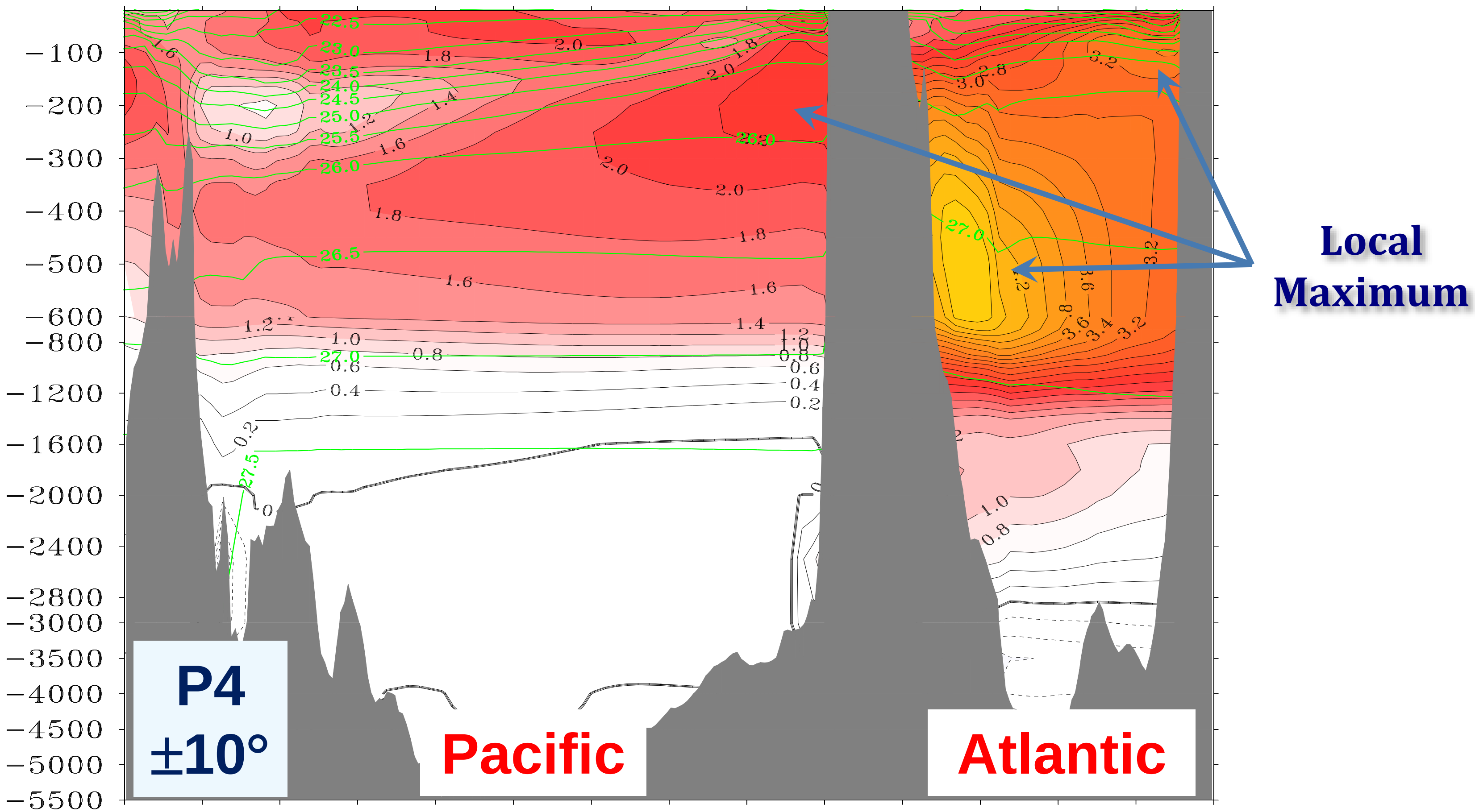
Meridional Section of Temperature Changes



Trop. Atlantic ≈ 2 x Pacific, different depth

Green line – Mean Density; Color – Temperature change

Zonal Section of Temperature Changes



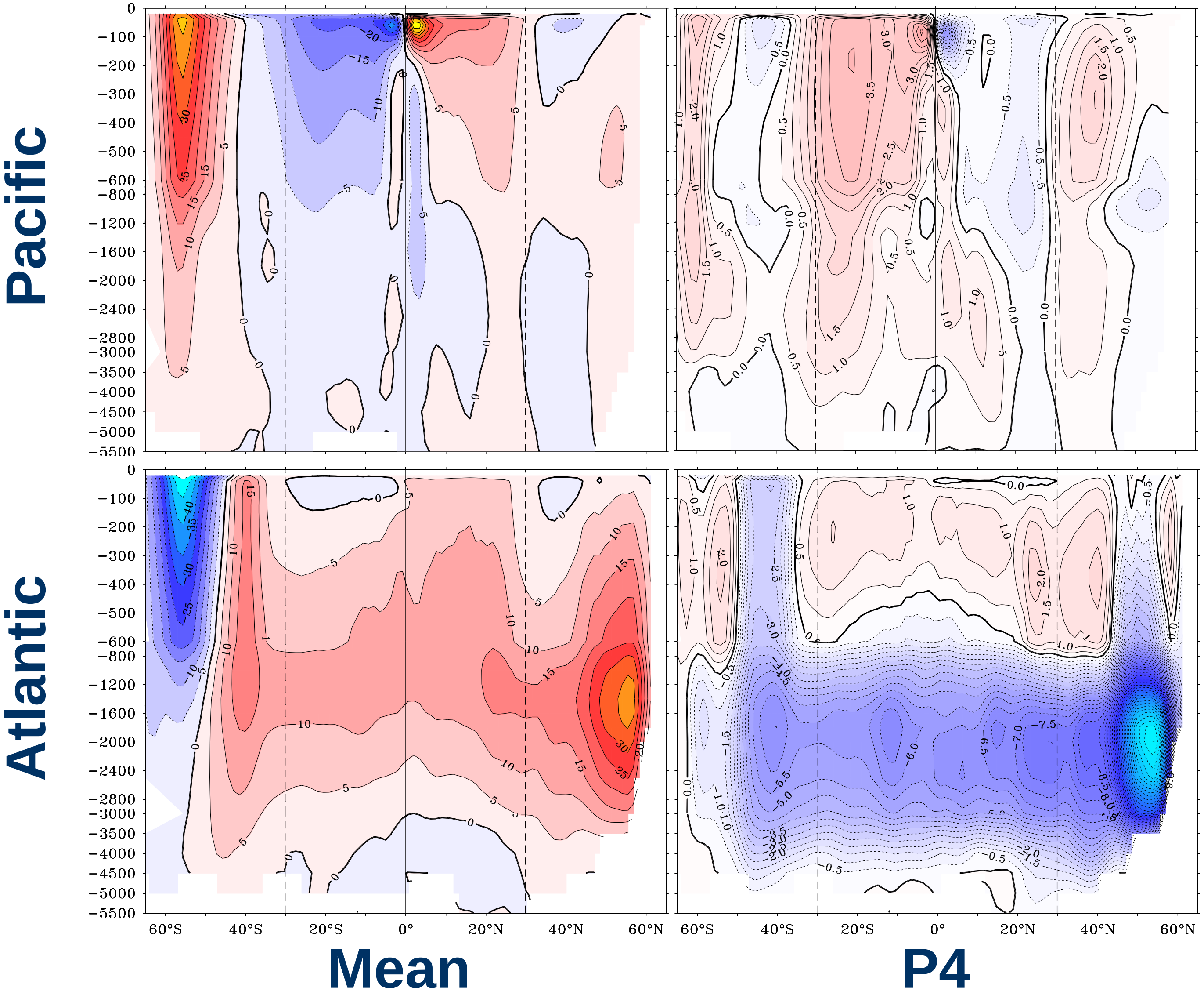
Trop. Atlantic ≈ 2 x Pacific, different depth

Green line – Mean Density; Color – Temperature change

Similarity and Difference: An Impression

- Similarities
  - SST: Same magnitude, nearly linear and antisymmetric
- Differences (subsurface)
  - Much stronger in Atlantic
  - Deeper in Atlantic
  - Western Atlantic VS. Eastern Pacific

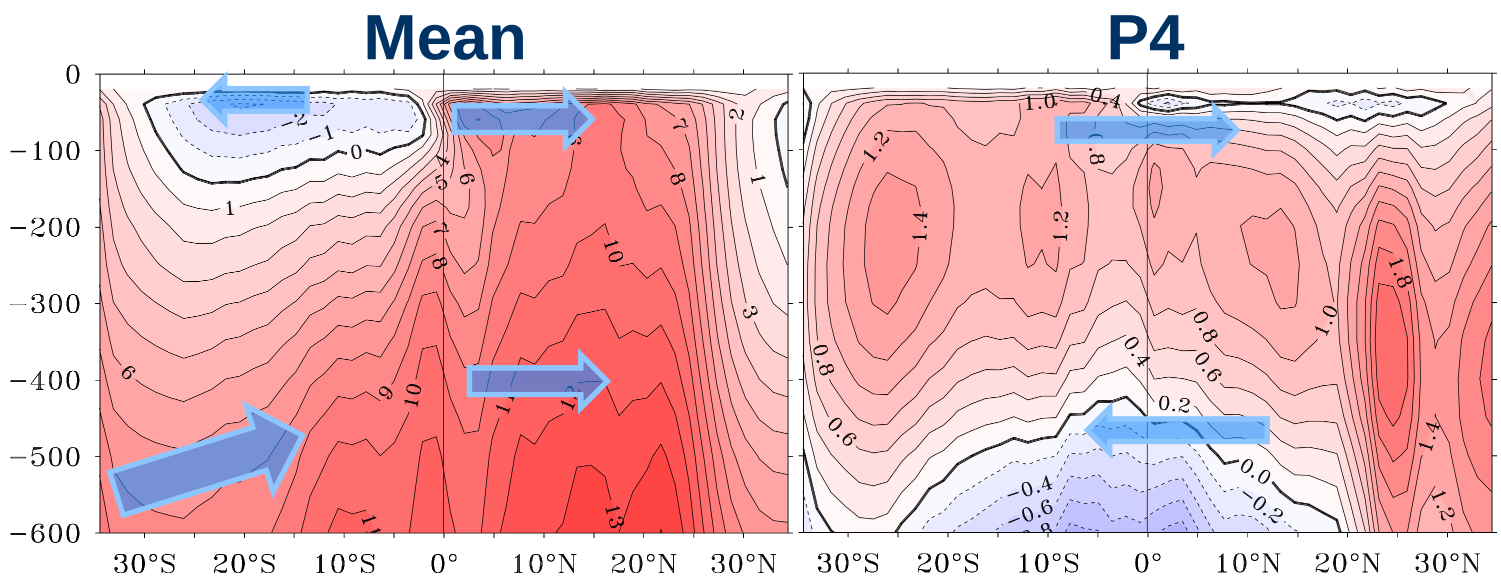
Overturning Circulations in the Pacific and Atlantic



Symmetric Change

Asymmetric Change

A Close Look at the Atlantic MOC



- MOC: thermohaline, weakened in P4
- STC: thermocline, wind-driven
  - Weakened in the southern branch
  - Strengthened in the northern branch

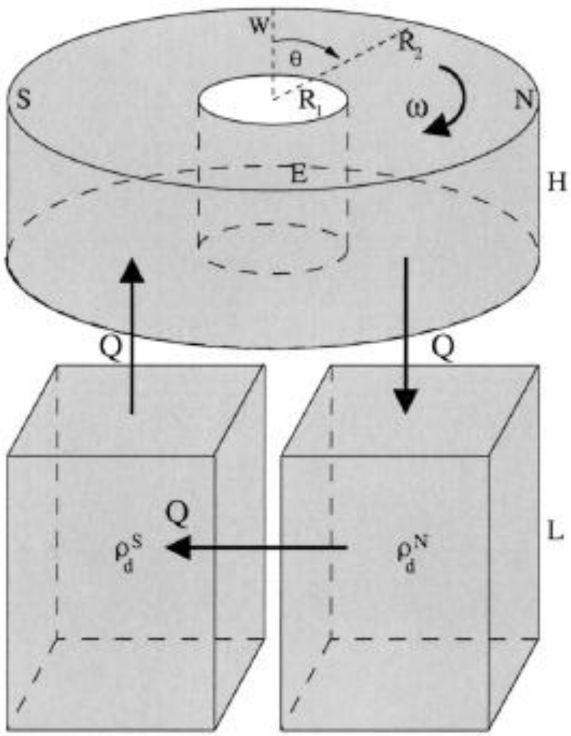
Interaction between STC and MOC in Atlantic

MOC ➔ STC:

- MOC → Atmosphere → STC
- MOC suppress the Northern STC (Zhang et al., 2003; Hazeleger and Drijfhout, 2006):

STC ➔ MOC:

- STC advects S & T anomalies which may reach the area of deep water formation and enhance or shut off the MOC (Delworth et al., 1993; Yin and Sarachik, 1995)



Pasquero and Tziperman (2004), JPO

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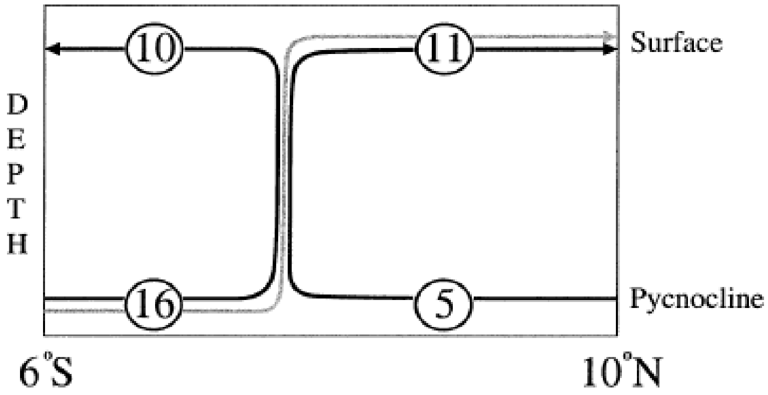
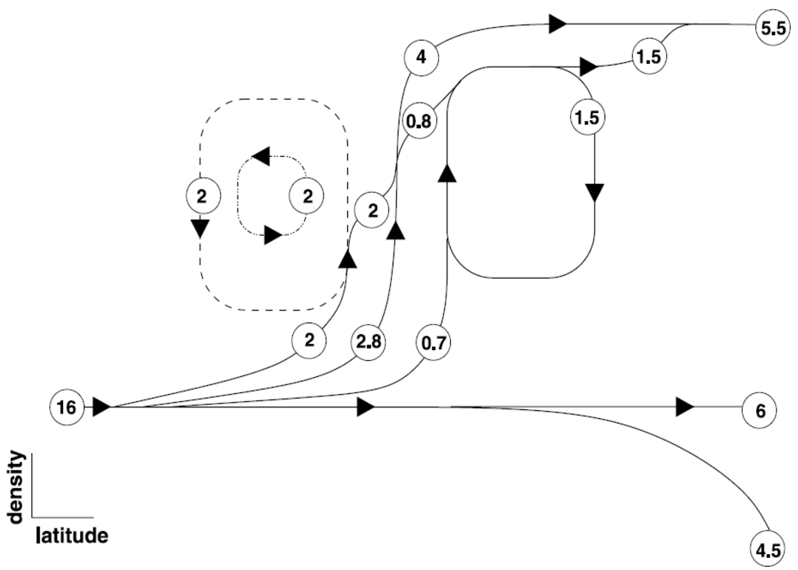
Interaction between STC and MOC in Atlantic



- Hazeleger and Drijfhout, J. G. R. (2006): STC in the NH ~ 1.5 Sv, confined to western boundary.
- MOC prevents much of the subsurface branch of the North Atlantic STC from reaching the equator. (High-res. ocean model)
- The weakness of northern STC is of course a consequence of the MOC

- Zhang et al., J. Climate (2003): THC reduce the supply of thermocline water to the equator from the North Atlantic and increase the supply from the South Atlantic. (DATA)



- Schott and McCreary (2004): Shallow overturning circulations of the tropical-subtropical oceans. Earth Climate: the Ocean-Atmosphere Interaction Geophysical Monograph Series

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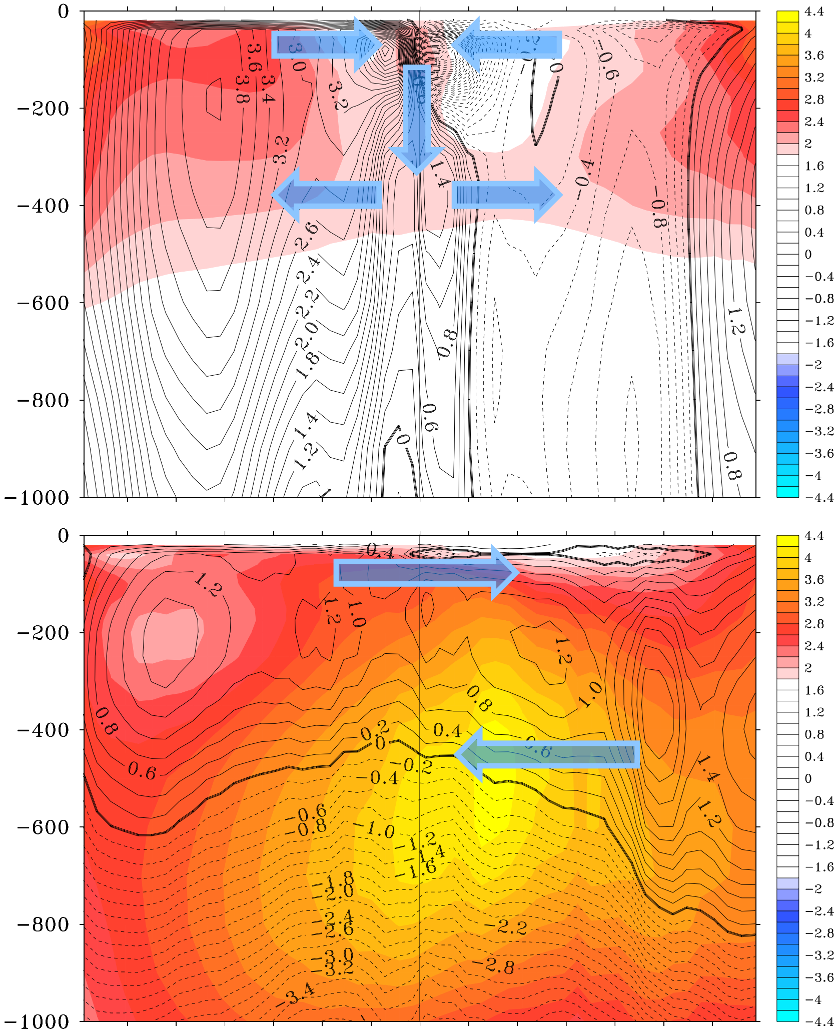
Changes in STC and Temperature



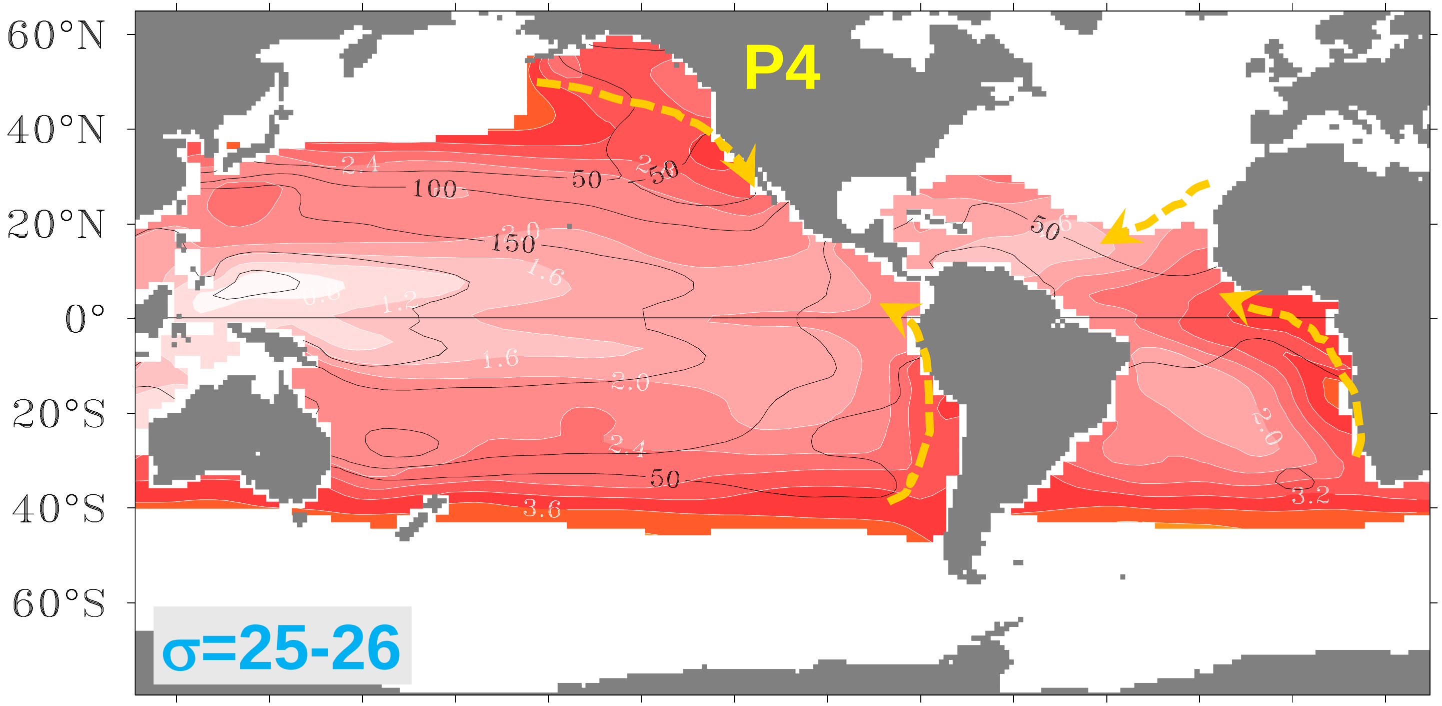
Pacific:

- Tropical temperature change ⇔ STCs change in both hemisphere, ***V*** & ***W***

Atlantic:

- Tropical subsurface maximum ⇔ Northern STC change, only ***V***

Temperature Changes on Isopycnal Level



- Shallow subduction
- Pacific: Eastern boundary pathway from the SH
- Atlantic: Eastern boundary pathway from the SH

  Interior pathway from the NH

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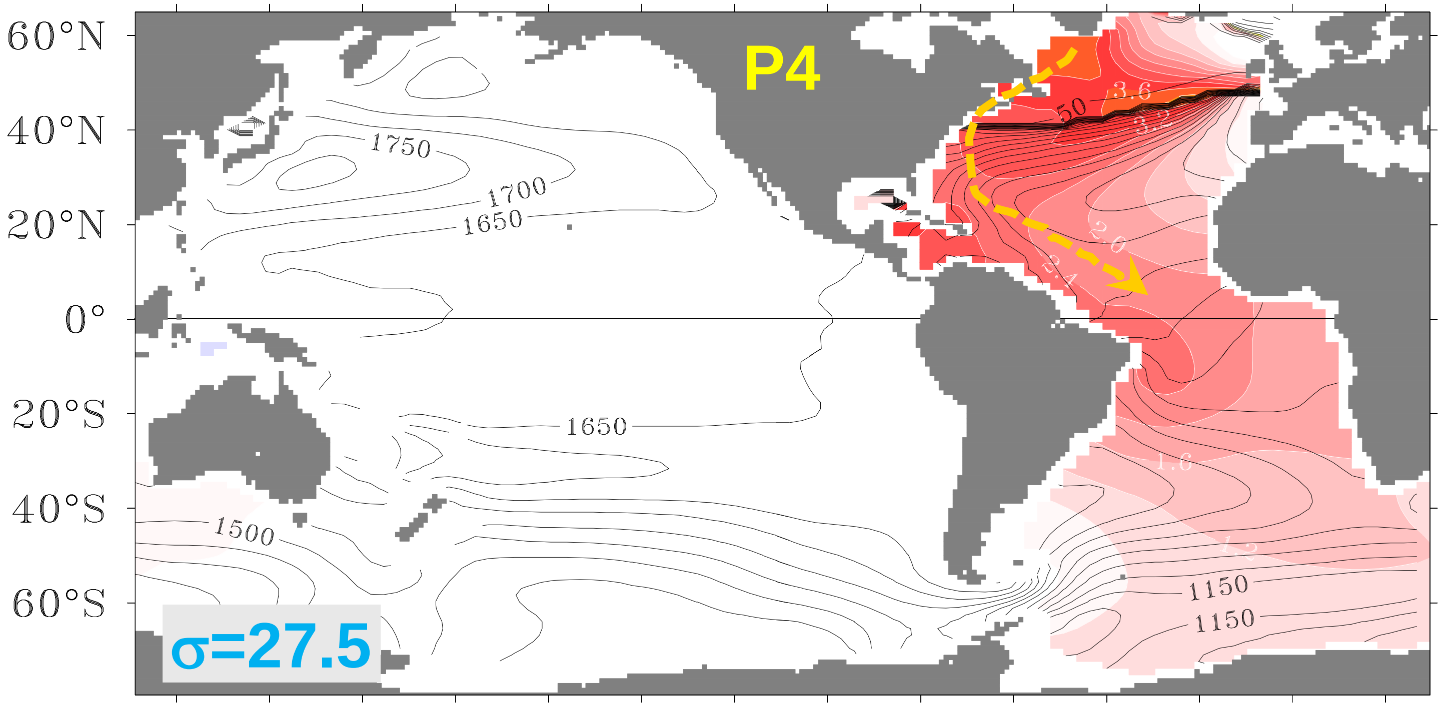
Temperature Changes on Isopycnal Level



- Intermediate water subduction
- Atlantic: Western boundary pathway from the NH

Black contour – depth of 27.5; color – T on 27.5

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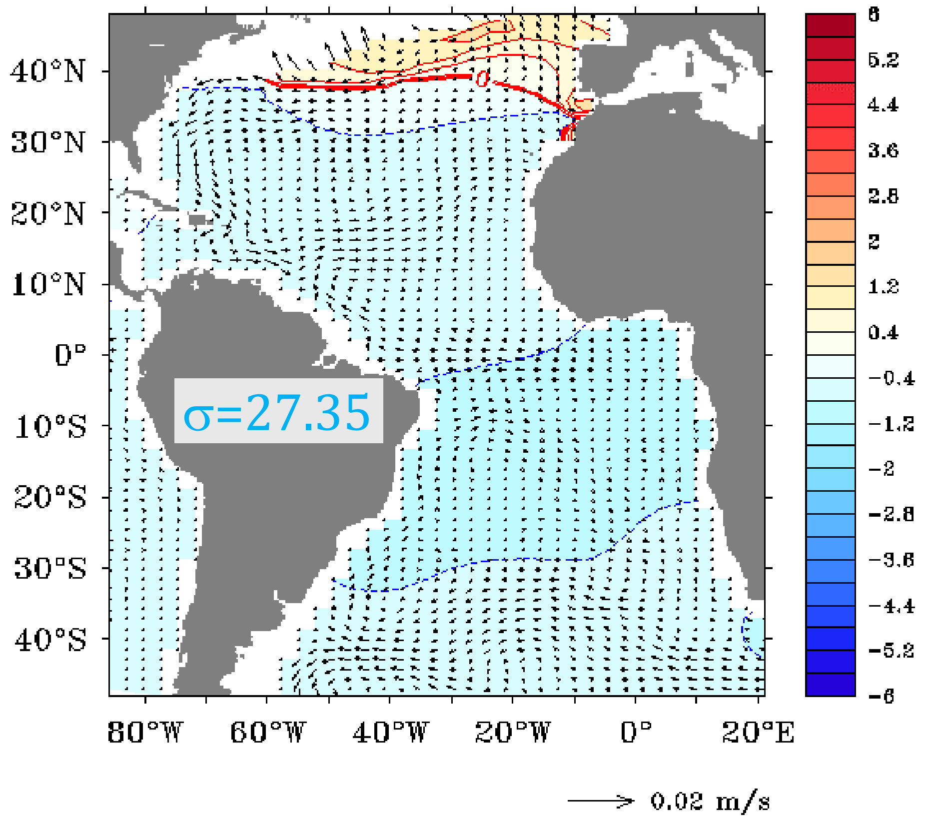
Basin Mode in CGCM



中纬度大西洋影响热带的

路径

强度

时间尺度

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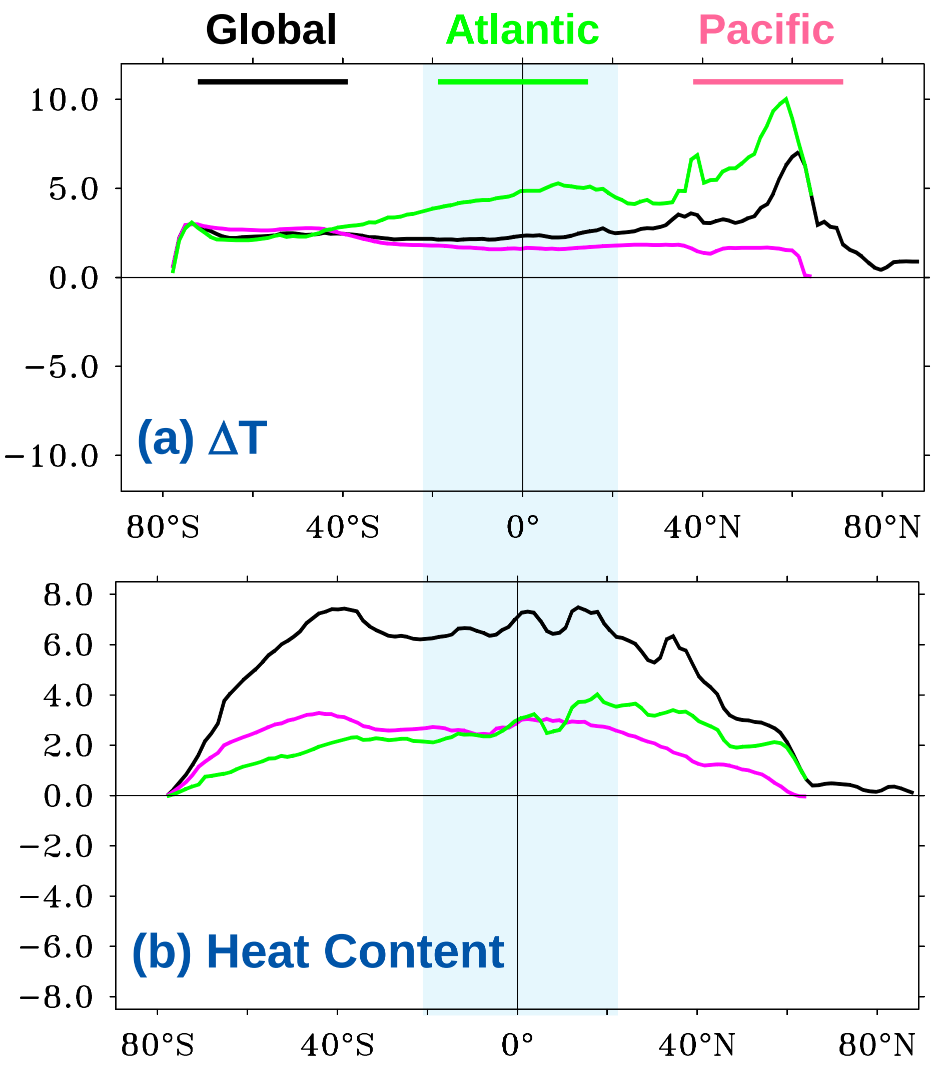
Atlantic VS Pacific: Relative Role



Zonal and vertical average (ΔT):

- Atlantic >> Pacific

Zonal and vertical integral (Heat content):

- Atlantic ≈ Pacific

Comparable weighting in global ocean

Summaries

- Stronger and deeper temperature response in Atlantic due to enhanced northern STC
- For tropical Atlantic, should focus more on the STC instead of MOC
- Same weighting in global ocean.
  - Pacific – bigger area;
  - Atlantic – bigger temperature change

Implications

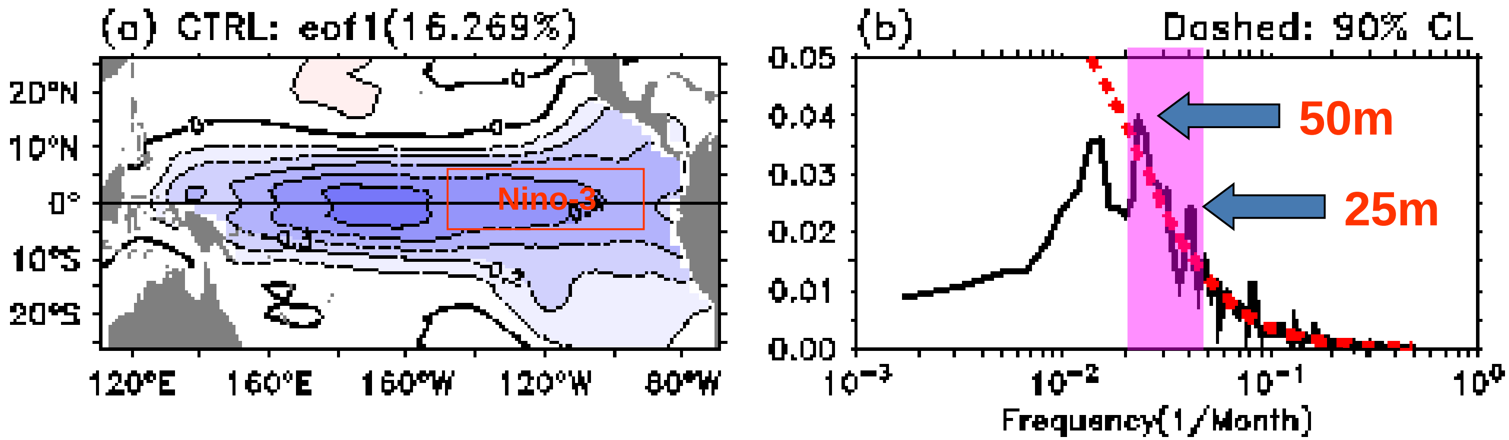
- Critical region in global climate change
- Regional contribution to global warming
- PDO: direct and indirect connection
- SH crucial for long-term climate prediction

Extratropics → ENSO

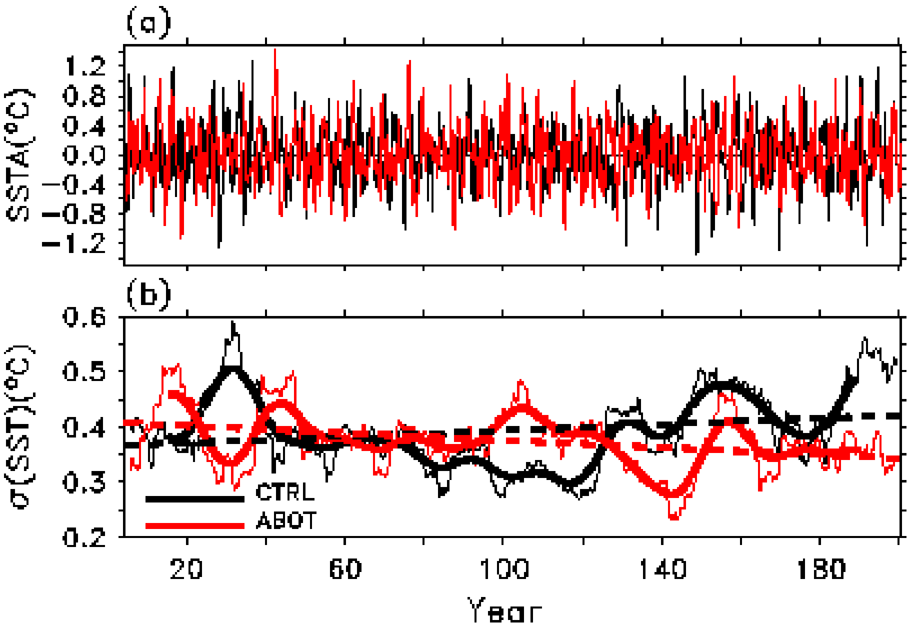
Zhang, Q., H. Yang, Y. Zhong, and D. Wang, 2005: An idealized study of the impact of extratropical climate change on ENSO. *Climate Dynamics*, 25, 869-880, doi: 10.1007 /s00382-005-0062-z.

Yang, H., Q. Zhang, Y. Zhong, S. Vavrus, and Z. Liu, 2005: How does extratropical warming affect ENSO? *Geophys. Res. Lett.*, 32(1), L01702, doi: 10.1029/2004GL021624.

ENSO: 1st EOF mode



ENSO Variability: Nino-3 SST



Nino-3: 150W-90W, 5N-5S

Remove:

- Mean annual cycle
- Secular linear trend
- 5-85 months band-pass filter

Standard Deviation:

- 10-year sliding window

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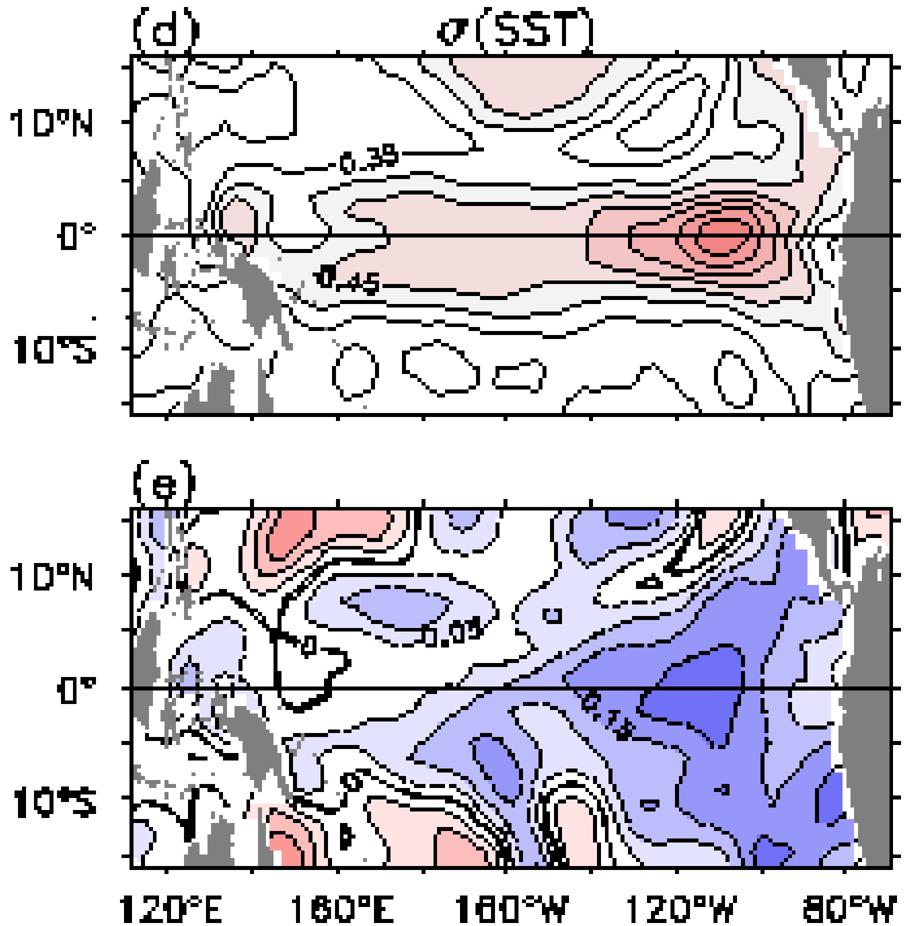
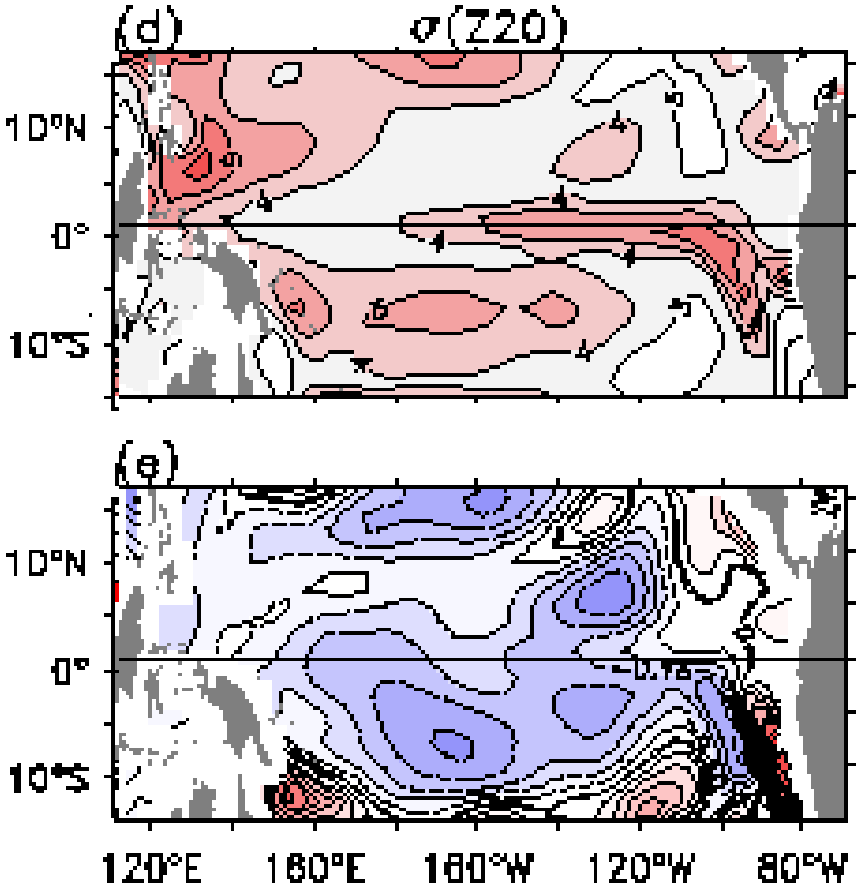
ENSO variability: σ(SST)



CTRL

ABOT

ENSO variability: σ(Z20)



CTRL

ABOT

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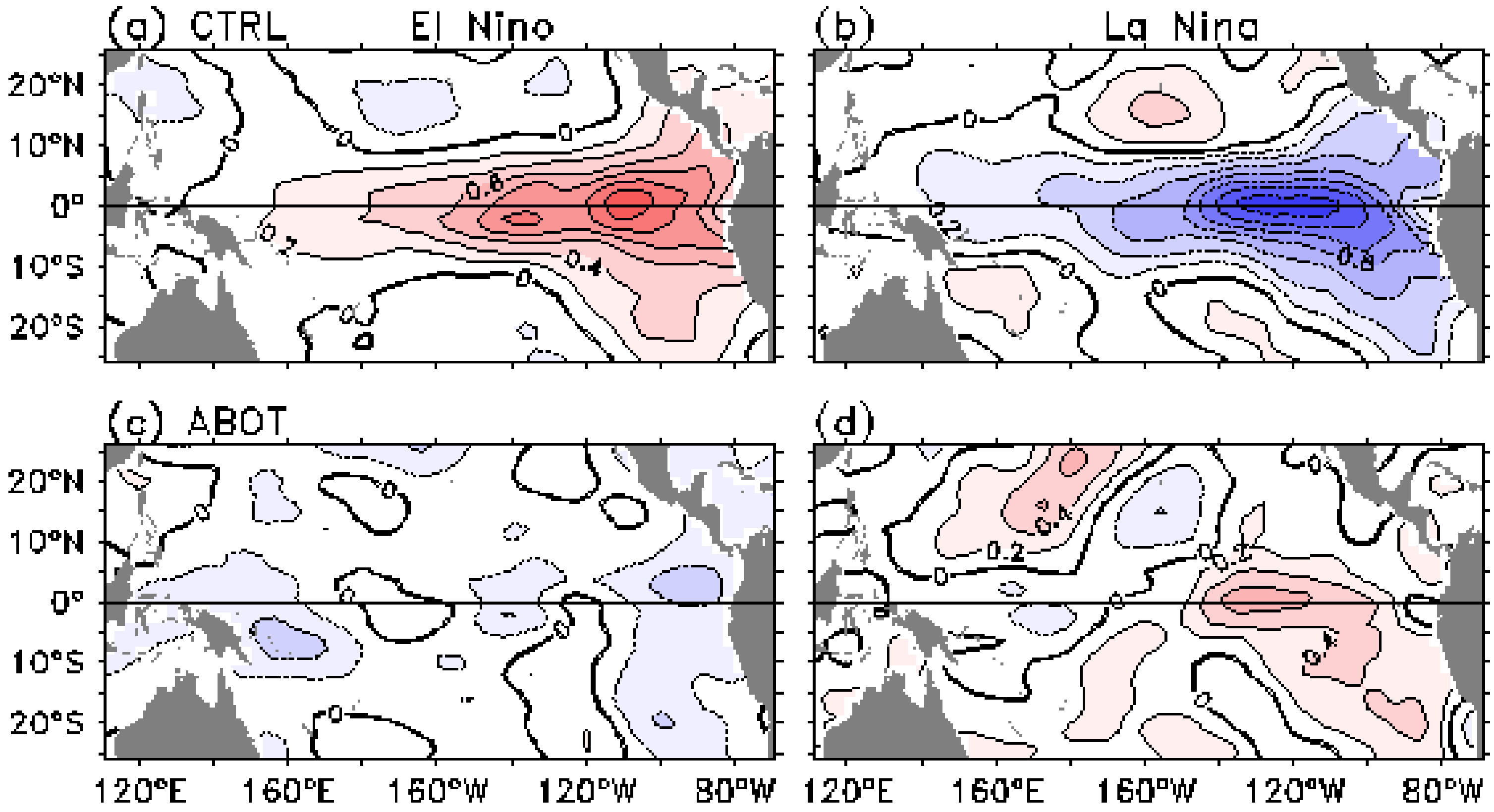
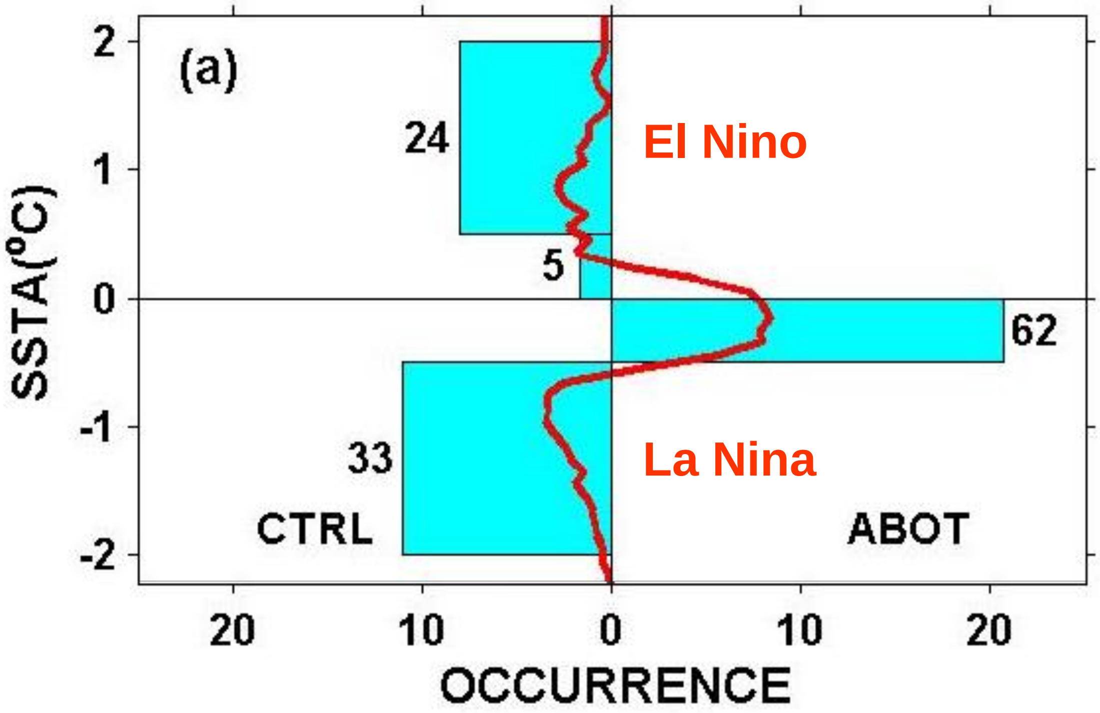
Skewed ENSO: El Nino vs. La Nina

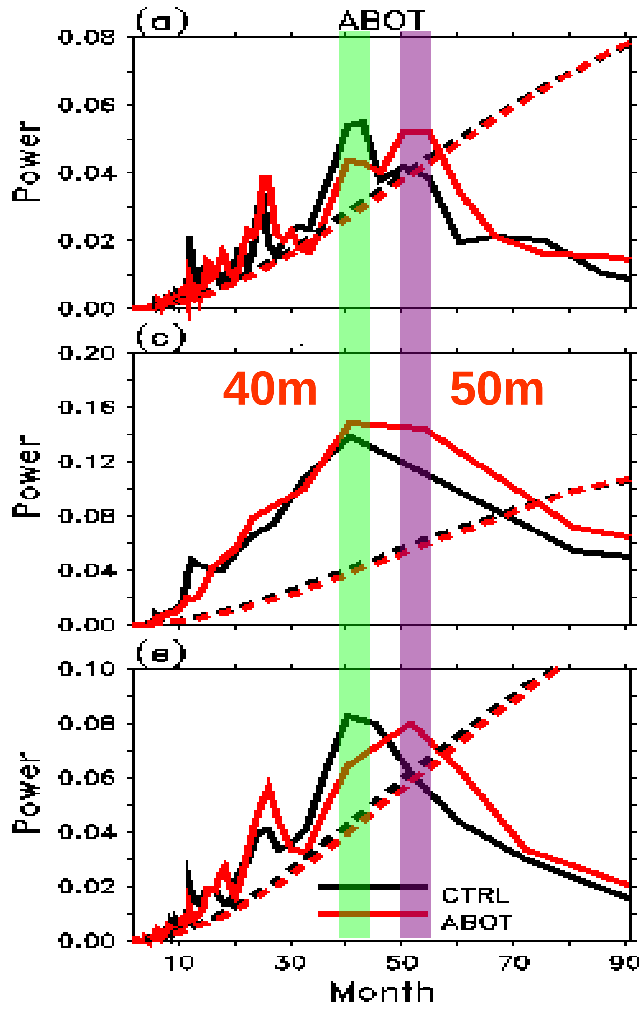


Skewed ENSO: Occurrence



Slowed ENSO

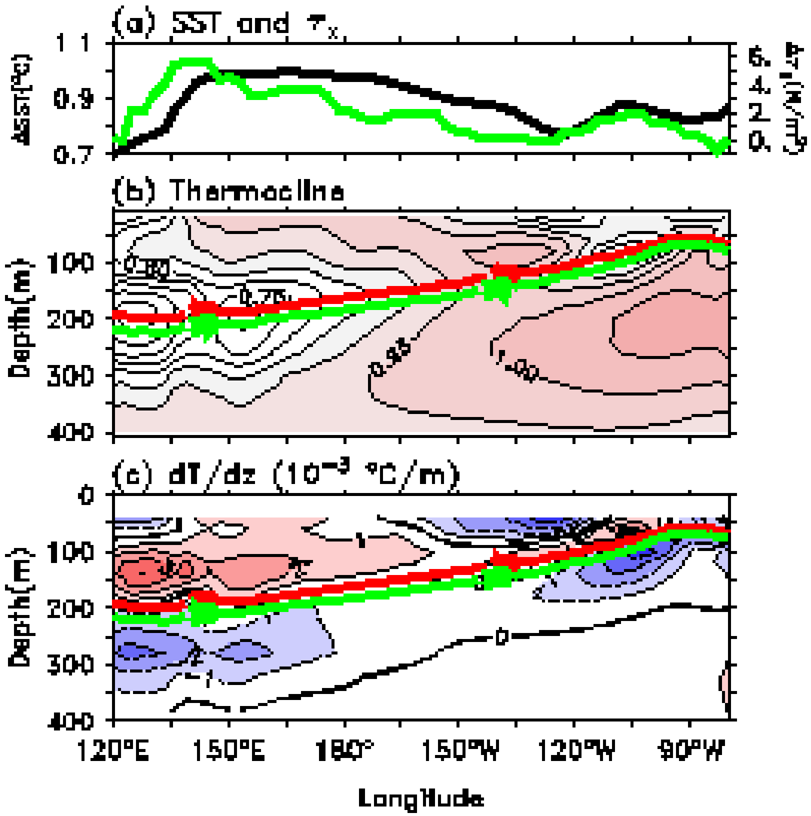
ABOT

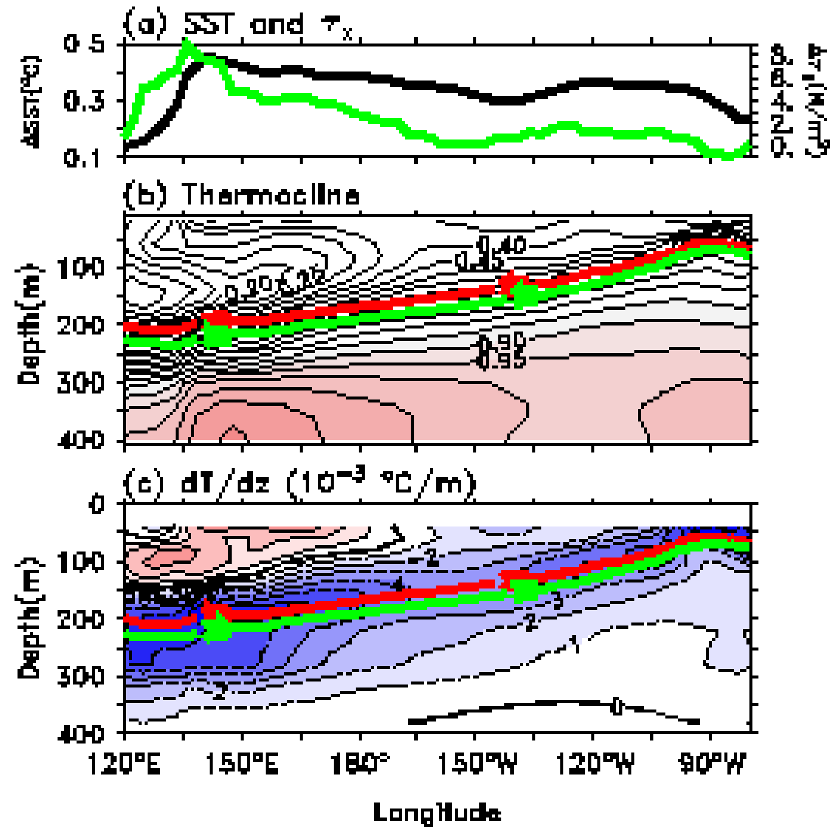


Extensive Change in ENSO!

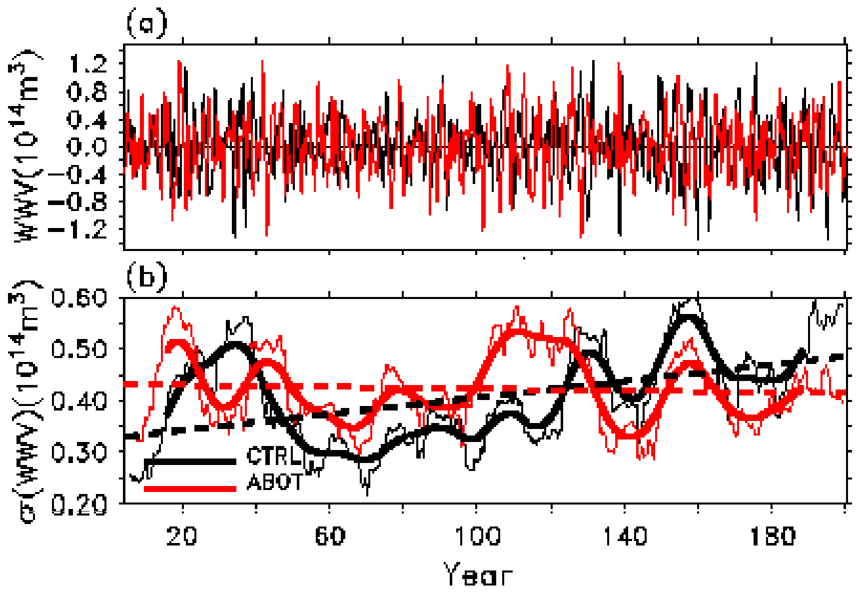
- Intensity
- Pattern
- Frequency

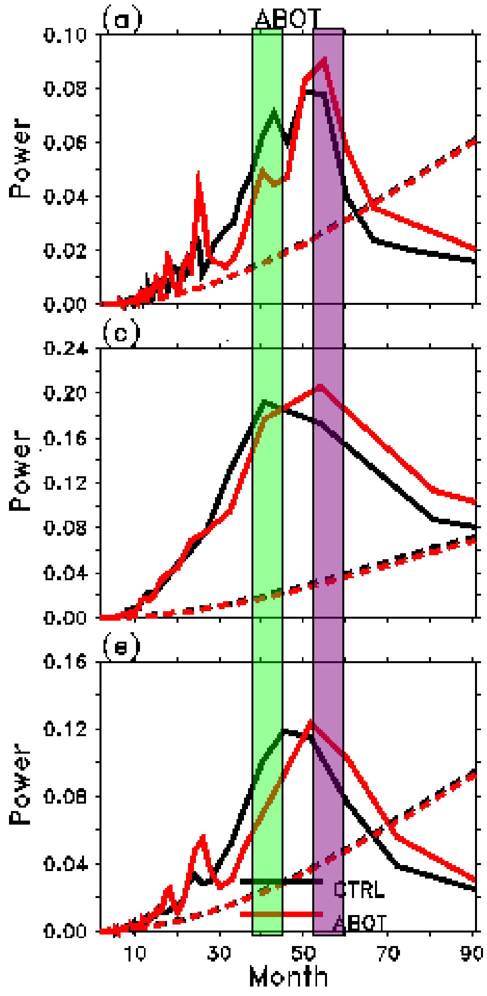
ENSO Background: A Weaker Gradient



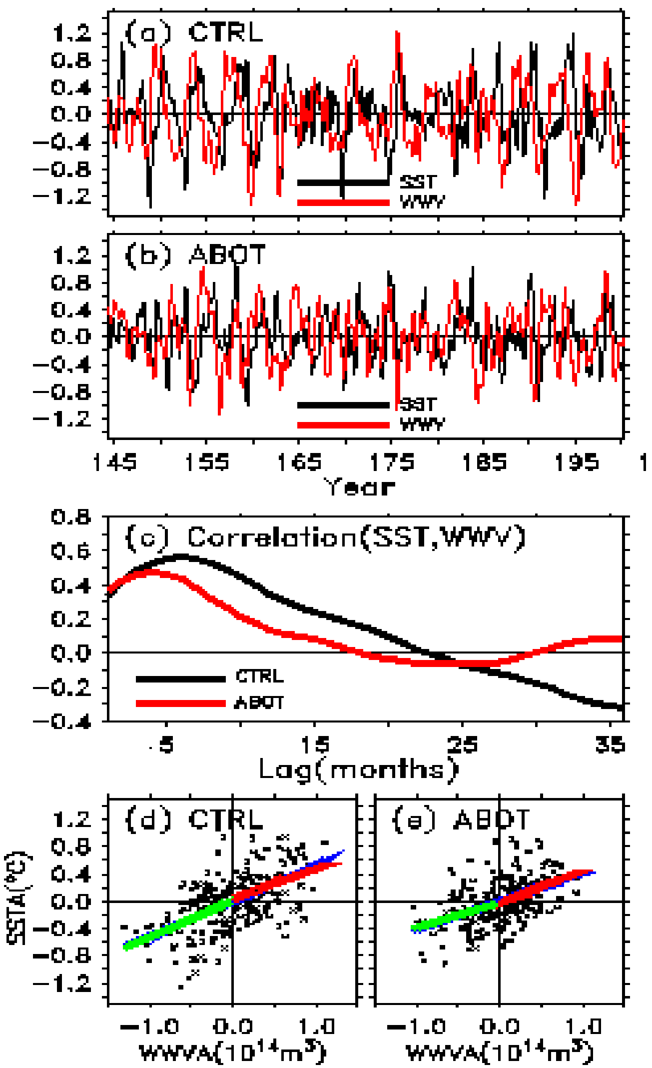


Warm Water Volume

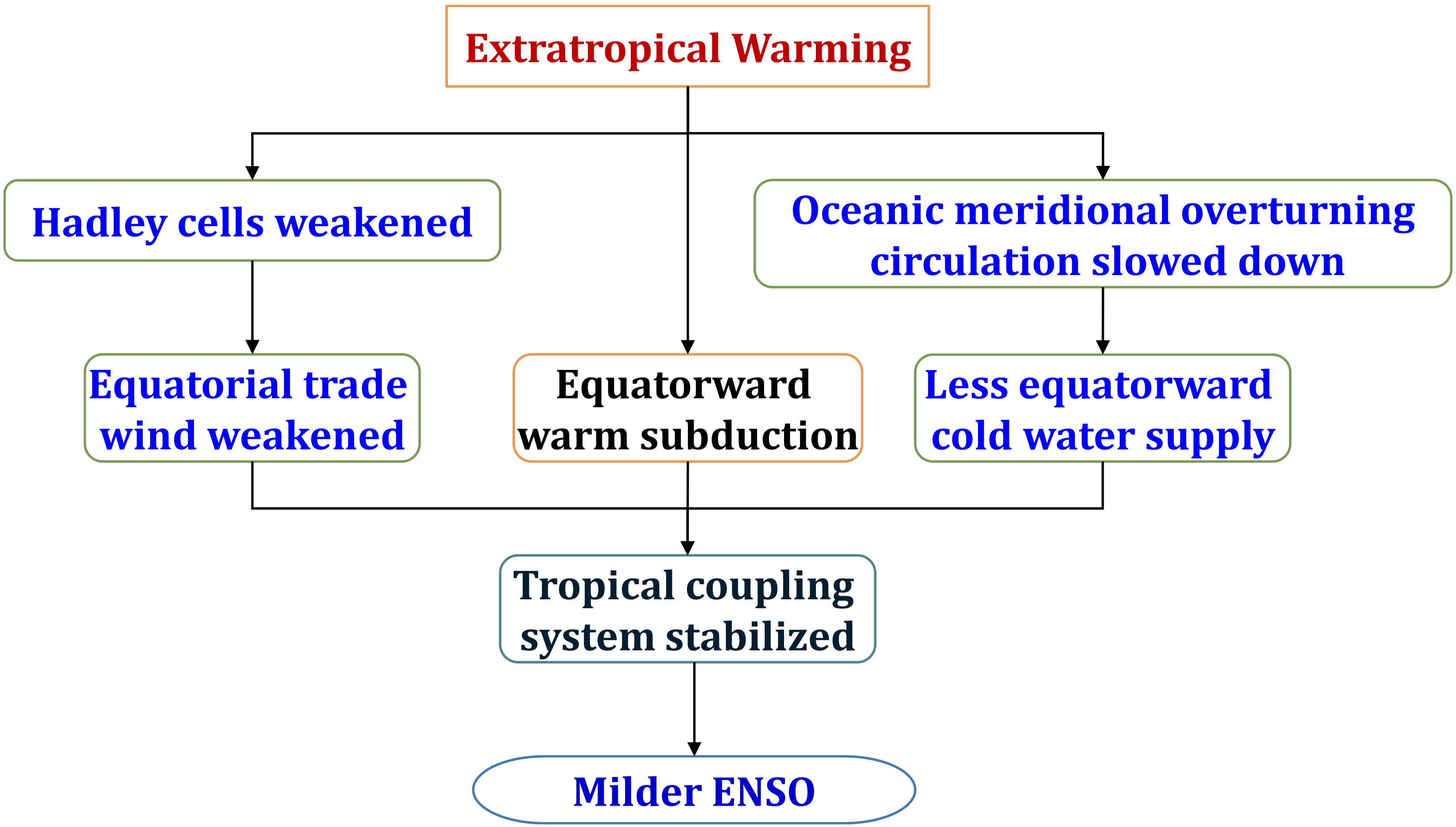




A Slackened Recharge/Discharge



Conclusion Diagram



Summary and Discussion

- Extratropics → Tropics
  - SST: Atmosphere bridge
  - Thermocline: Ocean dynamics
  - STC and MOC
- Tropics → Extratropics
  - Atmosphere bridge
  - Hadley Cell
- SH ⇔ NH
  - SH more important
- *Atlantic* vs *Pacific*: same important

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Thanks

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