Mechanisms Setting the Scale of the ITCZ

Sarah Kang
Columbia University

Collaborators: Isaac Held (Princeton Univ./GFDL), Shang-Ping Xie (IPRC)
Tropical Response to
Zonally Asymmetric Thermal Forcing

Sarah Kang
Columbia University

Collaborators: Isaac Held (Princeton Univ./GFDL),
Shang-Ping Xie (IPRC)
What Can Cause ITCZ Shifts?

**Differential Radiative Forcings**

- Reflecting or absorbing aerosols
  (e.g. Rotstayn et al. 2000, Roberts and Jones 2004, Yoshimori and Broccoli, 2008)

- High latitude sea ice cover (Chiang and Bitz, 2005)

- Atlantic Meridional Overturning Circulation (AMOC) strength
  (Zhang and Delworth, 2005)

\[
\Delta \text{SST} \quad (\text{K}) \quad \Delta \text{Precipitation} \quad (\text{mm day}^{-1})
\]

Zhang and Delworth, 2005

Sarah Kang

Miami

Mar. 24th, 2011
Global Teleconnection in response to AMOC shutdown

1. **Tropical Atlantic Pathway**  (Zhang and Delworth 2005; Xie et al. 2008)
   - via the Central American Isthmus

2. **Wind-Evaporation-SST (WES) fingerprinting from the North Pacific**  (Wu et al. 2008)
Outline

1. Zonally Symmetric Forcing
   - ITCZ location and atmospheric energy budget

2. Zonally Asymmetric Forcing
### Experiment Design

**The Model - GFDL AM2.0**
- Lower boundary: Aquaplanet slab mixed layer ocean (2.4 m)
- No seasonal cycle
- Modify the extent to which convection is inhibited (Tokioka et al. 1988).

**Impose Forcing, \( H = -\nabla \cdot F_0 \)**

![Graphs showing \( H \) and \( F_0 \)](image_url)
Hadley Circulation

\[ C = \frac{dF_A}{F_0} \]

**Control**

**Perturbed**

**Anomaly**

- **WARM**
- **COOL**

energy transport

implied ocean transport

Sarah Kang

Miami

Mar. 24th, 2011
Sensitivity to a Convection Scheme Parameter

Precipitation

Control

Perturbed

Increasing convection
Less ITCZ shift
Decreasing C

WARM

COOL
Inhibiting convection
ITCZ and Compensation

Inhibiting convection

Kang et al. (J. Climate, 2008)
ITCZ and Compensation

ITCZ

Compensation (%)

Inhibiting convection

Kang et al. (J. Climate, 2008)
Zonally Asymmetric Thermal Forcing

(a) HIGH

(b) TROP

(c) SINE

(d) $F_O$ (PW)

Sarah Kang
Princeton Univ.
Apr. 2nd, 2009

Miami
Mar. 24th, 2011
Zonally Averaged Responses

\[
\delta\text{SST (K)} \quad \quad \quad \quad \delta\text{Precip (mm day}^{-1}\text{)}
\]

Zonal mean responses vary little as the width of the forcing is changed.

Sarah Kang (Princeton Univ.)

Miami

Mar. 24th, 2011
Tropical Responses

δSST (K)

δPrecip (mm day$^{-1}$)

HIGH

TROP

SINE

Latitude

Longitude

Latitude

Longitude

Latitude

Longitude

δSST

δPrecip

Color bars: 0 to 20

Color bars: -10 to 10

Color bars: 0 to 20

Color bars: -20 to 20

Sarah Kang

Miami

Mar. 24th, 2011

Saturday, April 9, 2011
Transient Responses

1~3 months

4~6 months

10~12 months

Shading: \( \delta T \) at 700mb

Contour: \( \delta \text{Precip} \)
Shading: $\delta$CRF
Contour: $\delta$Precip

AM2

AM2 with prescribed water vapor

AM2 with prescribed clouds
The magnitude of the tropical precipitation response is proportional to cross-equatorial atmospheric energy transport.

The tropical responses to zonally asymmetric extratropical forcing is highly zonally symmetric.

The tropical responses to local tropical forcing is highly localized with some westward extension.
THANK YOU!
Over warmed hemisphere, the atmosphere is destabilized.

→ More deep convection → Less low clouds → More warming

Cloud forcing acts to amplify the implied oceanic fluxes.
Cloud Radiative Forcing = $R_{TOA} - R_{CLR}$

δCRF (Wm$^{-2}$)

Less inhibition of deep convection → More frequent deep convection

1) Impose warming → Larger increase in deep convection
   → Larger reduction of low clouds → Greater warming

2) Greater positive feedback from cloud responses

Sarah Kang
Univ. of Washington
Mar. 5th, 2010
Cloud Radiative Forcing ($W \text{ m}^{-2}$) = $R_{\text{TOA}} - R_{\text{CLR}}$

Control

Prescribed Clouds
Zonally Asymmetric Tropical Forcing

$H \, (W \, m^{-2})$

Latitude
Longitude

Sarah Kang  FPO  Apr. 20th, 2009

Saturday, April 9, 2011
Tropical Responses

δSST (K)

δPrecip (mm day\(^{-1}\))
Zonally Averaged Responses

\[
\delta \text{SST (K)}
\]

\[
\delta \text{Precip (mm day}^{-1}\text{)}
\]

Zonal mean responses are not well constrained.

Sarah Kang

FPO

Apr. 20th, 2009
Compensation is the key for the magnitude of the zonal mean response.
Simple Theory (Kang et al. 2009)

\[ \delta P \approx C \nabla \cdot \left( F_0 \frac{\Delta q_{ctl}}{\Delta m_{ctl}} \right) \]

Inhibiting convection

[AM2]

[Idealized GCM]
Larger tropical precipitation response with $R_{HSBM}$. 
Predict C from an 1D energy balance model given D.

\[ S - I = -D \nabla^2 m + \nabla \cdot F_0 \quad \text{where} \quad D \approx \left| -\left[ \frac{mv}{a \frac{\partial m}{\partial \theta}} \right] \right| \]
Model Description

**GFDL AM2**

- 24 vertical levels with horizontal resolution of 2°lat × 2.5°lon
- 2.4m slab mixed layer ocean
- A modified version of the Relaxed Arakawa-Schubert scheme
  - Convection is represented by a spectrum of entraining plumes.
  - Deep convection is prevented from occurring in updrafts with a lateral entrainment rate lower than a critical value \( \lambda_0 \) determined by the depth of the subcloud layer \( z_m \) (\( \lambda_0 = \alpha/z_m \); Tokioka et al. 1988).
  - Larger \( \lambda_0 \) → More entrainment → Harder for deep convection to occur.
  - Default value \( \alpha \) (Tokioka parameter) = 0.025 is multiplied by (0+, 2, 4, 10).
ITCZ and Compensation

Inhibiting convection

Latitude (°S)

Compensation (%)

Compensation (%)

Inhibiting convection

Sarah Kang (Princeton Univ.)
ICTP, Trieste
Nov. 19th, 2008
What Determines C?

Change in flux (PW)

Latitude

Total
Mean
Eddy

WARM
COOL

F₀

Saturday, April 9, 2011
This idealized model produces a low level of compensation of about 25% regardless of the convection scheme parameter $RH_{SBM}$, which can be predicted from the EBM.
In the tropics, 

\[ \nabla \cdot (\delta[v \bar{m}] + \delta[v'm']) = 0 \]

At the edge of the Hadley cell, 

\[ \nabla \cdot \delta[v \bar{m}] = 0 \]

\[ \nabla \cdot \delta[v'm'] \text{ in the tropics} \approx \nabla \cdot \delta[v'm'] \text{ at the edge} \]