Tropical Indo-Pacific warming patterns and slowdown of the Walker circulation

Hiroki Tokinaga¹, Shang-Ping Xie¹, Clara Deser², Yu Kosaka¹ and Yuko M. Okumura³

1: IPRC/SOEST, Univ. of Hawaii
2: NCAR
3: The University of Texas at Austin
Long-term changes in
the Walker circulation & tropical Indo-Pacific SST
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• **Walker circulation has weakened** during the 20th century (e.g. Vecchi et al. 2006; Deser et al. 2010)
Long-term changes in the Walker circulation & tropical Indo-Pacific SST

- Walker circulation has weakened during the 20th century (e.g. Vecchi et al. 2006; Deser et al. 2010)
- Zonal SST gradient change is very uncertain in the tropics (e.g. Vecchi & Soden 2007; Deser et al. 2010; Tokinaga et al. 2012)
Long-term changes in the Walker circulation & tropical Indo-Pacific SST

- **Walker circulation has weakened** during the 20th century (e.g. Vecchi et al. 2006; Deser et al. 2010)

- SST trend pattern is reconstructed from **bucket SST & near-surface air temperature (MST)**

**Merged surface temperature (MST) trend (1950-2009)**

Reduced zonal SST gradient
AMIP experiments

• To test our hypothesis that a reduced zonal SST gradient plays an primary role in the Walker circulation slowdown
AMIP experiments

• NCAR CAM3 (T42L26), CAM4 (2.5°x1.9°L26), GFDL AM2.1 (2.5°x2°L24), MPI ECHAM5 (T42L19)
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- Forced by four different tropical SST trend patterns for 1950-2009
  - HadISST1, ERSST3b, MST, & spatially-uniform SST increase (SUSI)
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Tropics only

60 year change for 1950-2009
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• All SST experiments are also forced with increased GHGs
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• Each experiment was integrated for 41 years with the first year of integration discarded as a spin-up (40 year mean used)
**SUSI**: +0.5°C  
(Uniform warming)

**AGCM SLP**  
(SUSI-forced)

**OBS SLP**  
(HadSLP2)
**SUSI:** +0.5°C
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**AGCM SLP**
(SUSI-forced)

**AGCM SLP**
(MST-forced)
Changes in zonal SST and SLP gradients (East minus west)

East: 150-90°W, 5°S-5°N
West: 90-150°E, 5°S-5°N

r = -0.97
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\[ \nabla \text{SLP (hPa 60 yr}^{-1}) \]

\[ \nabla \text{SST (°C 60 yr}^{-1}) \]

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$\nabla SLP$ (hPa 60 yr$^{-1}$) vs $\nabla SST$ (°C 60 yr$^{-1}$)

- **Strengthening**
  - ERA40
  - NCEP/NCAR
  - HadISST1 forced
  - 20CR
  - ERSST3b forced
  - SUSI forced
  - HadSLP2
  - ICOADS SLP

- **Weakening**
  - CMIP3 20C3M (71 members)
  - MST forced

$r = -0.97$
Reanalysis SST & SLP trend

<table>
<thead>
<tr>
<th>SST</th>
<th>SLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCEP/NCAR</td>
<td>NCEP/NCAR SLP</td>
</tr>
<tr>
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<td>ERA40 SLP</td>
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<tr>
<td>20CRv2</td>
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</table>

Serious disagreement between reanalysis & observation...
Summary

• AGCM experiment forced with MST trend pattern can simulate the Walker circulation slowdown.

• The slowdown of the Walker circulation cannot be explained without a reduction in zonal SST gradient in the tropical Indo-Pacific.

• Atmospheric reanalyses might be significantly improved if right patterns of tropical SST trend are provided.
MST

AGCM cloud & surface wind (MST-forced)

OBS cloud & surface wind (ICOADS & WASWind)
Reconstruction of SST data set

Changes in measurements

- Satellite
- Buoy
- Engine intake
- Bucket

Timeline:
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
Reconstruction of SST data set

Changes in measurements

Bucket

Surface air temperature

Engine intake

Satellite

Buoy


Changes in measurements
Reconstruction of SST data set

Changes in measurements

Engine intake

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Surface air temperature

Merged surface temperature (MST) trend

-0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 °C 60yr⁻¹
Zonal SST gradient change

• Reduced zonal SST gradient acts to weaken the Walker circulation at the Pacific climate shifts (e.g. Deser et al. 2006)
• Highly uncertain in the twentieth century (Deser et al. 2010)
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HadSST3

- HadSST3 provides 100 bias-corrected realizations
- Estimate of **uncertainty in SST trend pattern**

**EOF-1 for 100 SST trend patterns (83.6%)**

**Large uncertainty over the equatorial Indo-western Pacific**
HadSST3 zonal gradient change

Extreme cases: Realization #34, #01, and #12

All realizations show a reduction in zonal SST gradient
HadSST3-forced experiments
(only ECHAM5)

Walker circulation slows down
Walker circulation change
Walker circulation change

• **Slowdown** under global warming
  (Held and Soden 2006; Vecchi et al. 2006; Vecchi and Soden 2007)
Walker circulation change

- **Slowdown** under global warming (Held and Soden 2006; Vecchi et al. 2006; Vecchi and Soden 2007)
- **Decrease in convective mass flux** under global warming that balances a **slower increase in global-mean precipitation** than **atmospheric water vapor** (Held and Soden 2006)
Walker circulation change

• **Slowdown** under global warming  
  (Held and Soden 2006; Vecchi et al. 2006; Vecchi and Soden 2007)

• **Decrease in convective mass flux** under global warming that balances a **slower increase in global-mean precipitation** than atmospheric water vapor  
  (Held and Soden 2006)

Observed & simulated SLP trend

Vecchi et al. (2006, *Nature*)
Walker circulation change

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  (Held and Soden 2006; Vecchi et al. 2006; Vecchi and Soden 2007)

• **Decrease in convective mass flux** under global warming that balances a **slower increase in global-mean precipitation** than **atmospheric water vapor**  
  (Held and Soden 2006)

**How** does the **tropical SST trend pattern** play a role in the **observed slowdown** of the **Walker circulation**?
Patterns of observed SST & SLP trend (1950-2009)
Patterns of observed SST & SLP trend (1950-2009)

Changes in SST measurements

Satellite

Buoy

Engine intake

Bucket

Bucket
Trend patterns of bucket SST & surface air temperature
Changes in zonal SST and SLP gradients
Changes in zonal SST and SLP gradients

\[ \nabla SLP \ (\text{hPa} \ 60\text{yr}^{-1}) \]

\[ \nabla SST \ (^\circ\text{C} \ 60\text{yr}^{-1}) \]

MST forced
Changes in zonal SST and SLP gradients

\[ \nabla SLP \text{ (hPa 60yr}^{-1}) \]

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- Strengthening
- Weakening

- CMIP3 20C3M (71 members)
- MST forced
- SUSI forced
- HadSLP2
- ICOADS SLP
Changes in zonal SST and SLP gradients

Changes in zonal SST and SLP gradients are illustrated in the scatter plot. The plot shows the relationship between changes in sea surface temperature (SST) gradients (\(\nabla SST\)) and changes in sea level pressure (SLP) gradients (\(\nabla SLP\)).

The diagram includes data from various models and experiments:
- **ERSST3b forced**
- **SUSI forced**
- **HadSLP2**
- **ICOADS SLP**
- **MST forced**

The data points are color-coded and labeled accordingly. The plot also indicates the strengthening and weakening of gradients, with different symbols representing different models and experiments.
Changes in zonal SST and SLP gradients
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\Delta \text{SLP} \quad (\text{hPa 60yr}^{-1})
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\Delta \text{SST} \quad (^{\circ} \text{C 60yr}^{-1})
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- HadISST1 forced
- ERSST3b forced
- SUSI forced
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CMIP3 20C3M (71 members)
Changes in zonal SST and SLP gradients

![Diagram showing changes in zonal SST and SLP gradients with various forcing scenarios and models.](image)