Use of long-term MSU/AMSU data to examine the weakening of Walker Circulation in CMIP5 climate simulations

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Current problems: Climate model simulations and theoretical assessment suggest that Walker circulation **should** be weakened under the global warming conditions. In contrast observations at least over the past three decades indicate the strengthening.

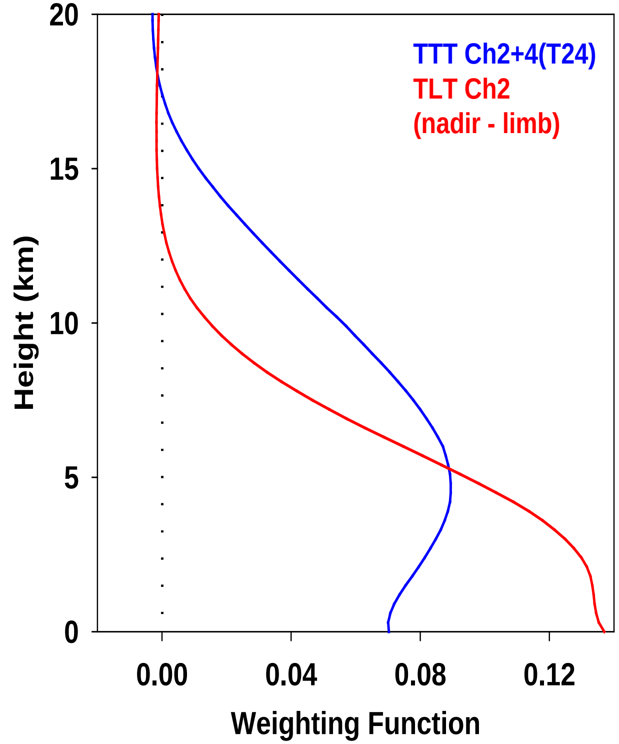
Mail goal: to diagnose the relative importance of diabatic heating vs dry static stability for the Walker circulation variability & trend.

Method: The first-order thermodynamic energy balance of large-scale tropical circulation (at any time and location) is between diabatic heating & adiabatic cooling,

$$\boldsymbol{Q} \approx -\boldsymbol{\omega} \times \left(-\frac{\boldsymbol{T}}{\boldsymbol{\theta}}\frac{\partial\boldsymbol{\theta}}{\partial\boldsymbol{p}}\right) \approx -\boldsymbol{\omega} \times (\boldsymbol{S_p})$$

where Q is the diabatic heating; $S_p = -(T/\theta)(\partial\theta/\partial p)$, the static stability parameter, and $\omega = dp/dt$.

MSU data: To obtain the stability parameter, satellite-derived temperatures are needed at least two layers. Of course we need a long-term data set to have an idea of climate change. MSU data may satisfy such conditions.



TLT: MSU channel 2 (nadir − limb)

T24: (= a TMT – b TLS; a=1.1, b=0.1)

TLS: MSU Channel 4

TMT: MSU Channel 2

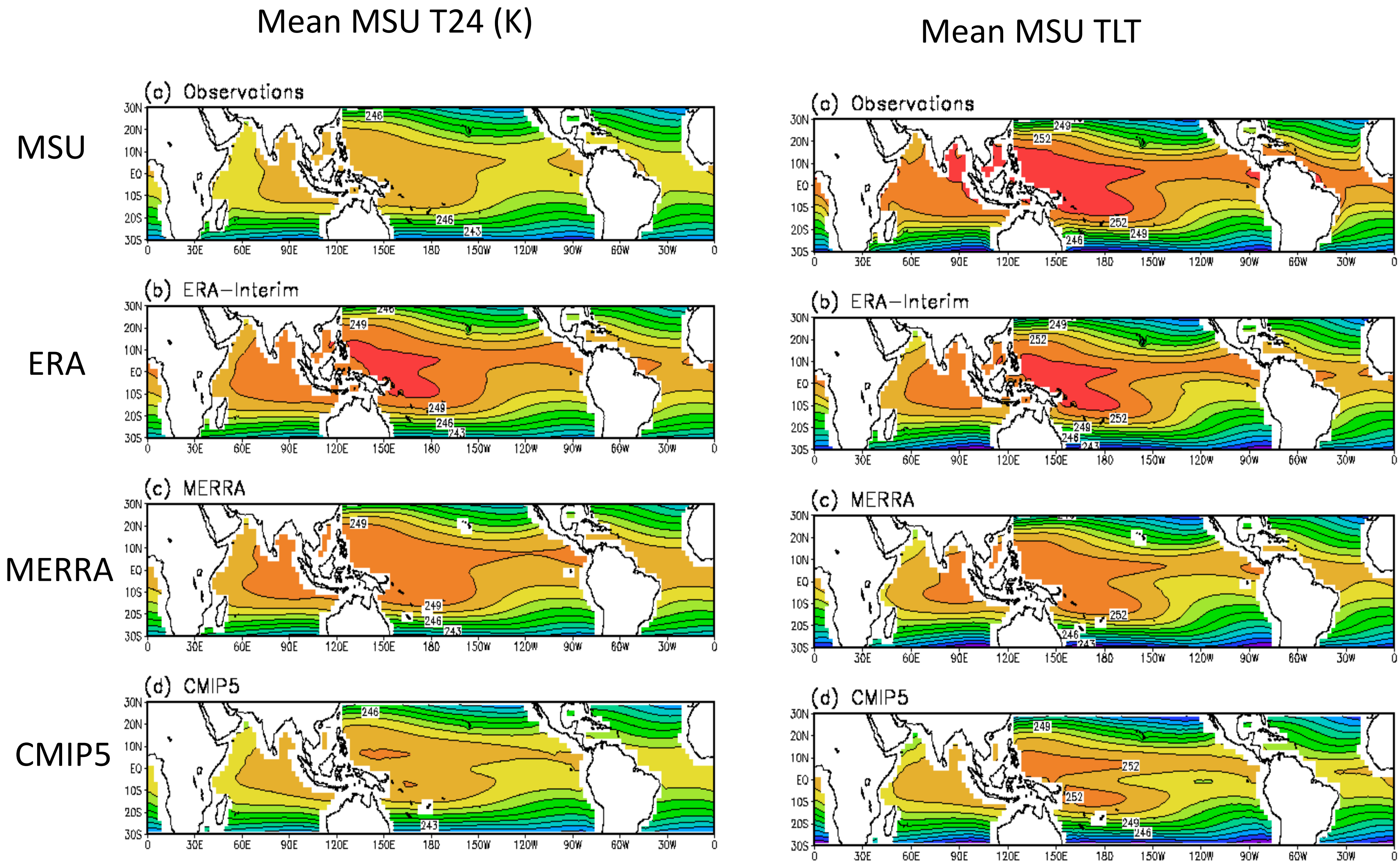
$$T_B\left(\bar{\nu}\right) = \varepsilon_{\tilde{\nu}} T_s \Im_{\tilde{\nu}}\left(p_s\right) + \left(1-\varepsilon_{\tilde{\nu}}\right)\Im_{\tilde{\nu}}\left(p_s\right)\int_0^{p_s} -T\left(p\right)\left[\frac{\Im_{\bar{\nu}}\left(p_s\right)}{\Im_{\bar{\nu}}\left(p\right)^2}\right]\cdot\frac{\partial \Im_{\bar{\nu}}\left(p\right)}{\partial p}dp + \int_{p_s}^{0} T\left(p\right)\frac{\partial \Im_{\bar{\nu}}\left(p\right)}{\partial p}dp$$

$$= \varepsilon_{\tilde{\nu}} T_s \Im_{\tilde{\nu}}\left(p_s\right) + \int_{p_s}^{0} J_{\tilde{\nu}}\left(p\right)\frac{\partial \Im_{\tilde{\nu}}\left(p\right)}{\partial p}dp$$

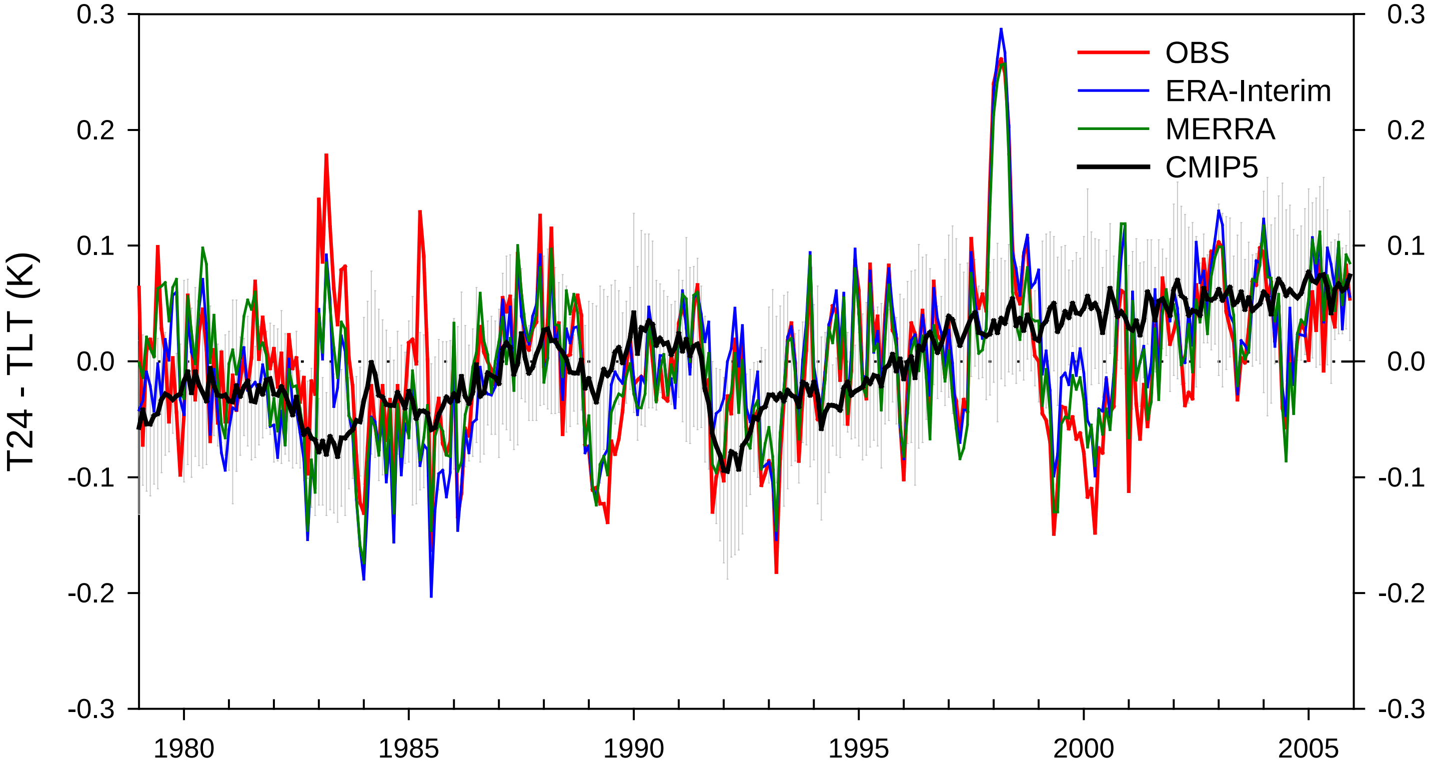
MSU channel TB - TS term = $\int_{p_s}^{0} J_{\tilde{\nu}}\left(p\right)\frac{\partial \Im_{\tilde{\nu}}\left(p\right)}{\partial p}dp$

Data: ERA-Interim, MERRA reanalysis data
20 CMIP5 model simulations

Analysis period: 1979 - 2005

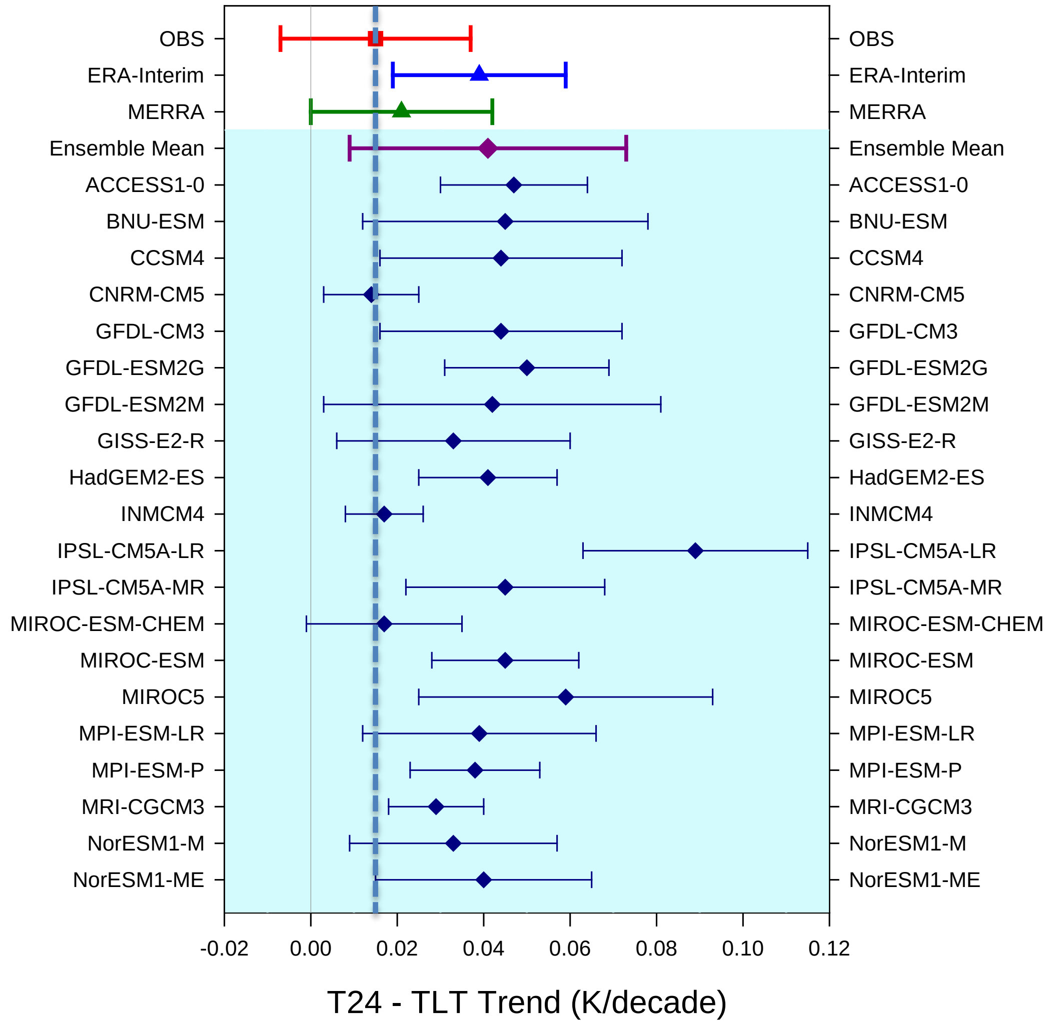


Mean MSU T24 (K)
Mean MSU TLT
MSU
ERA
MERRA
CMIP5
(a) Observations
(b) ERA-Interim
(c) MERRA
(d) CMIP5
30N
20N
10N
EQ
10S
20S
30S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0



T24 – TLT Anomaly Timeseries over the Tropics (20N-20S) for the Period 1979-2005

Error bars in grey: ±1 intermodel standard deviation



T24 – TLT Trend over the Tropics (20N-20S) for the Period 1979-2005
Horizontal error bars: ±2 standard error of the linear trend except for multi-model ensemble mean (±2 intermodel standard deviation)

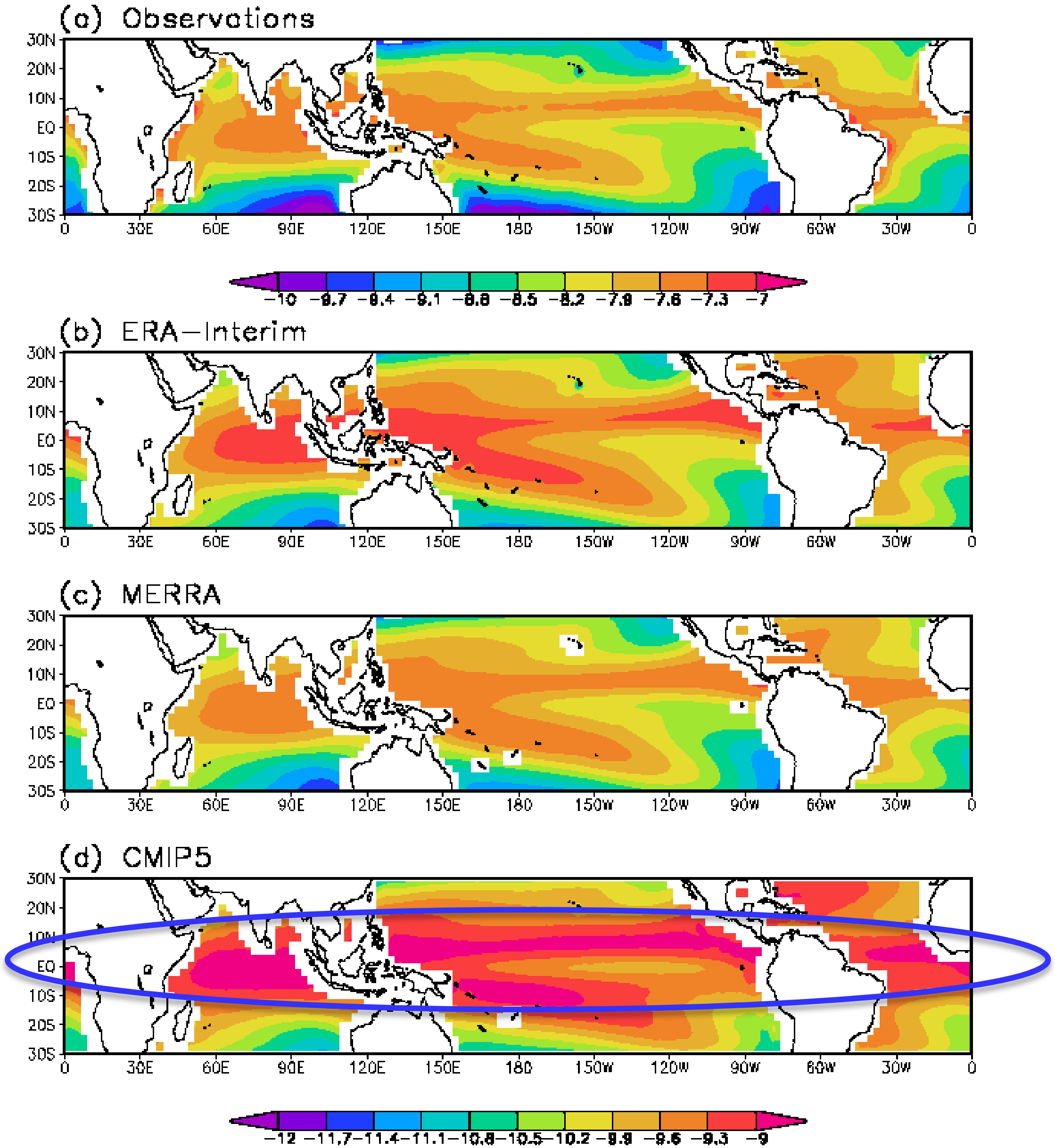
Mean $\frac{\partial \theta}{\partial p}$ (×100) estimated from T24 and TLT for 1979-2005

MSU

ERA-Interim

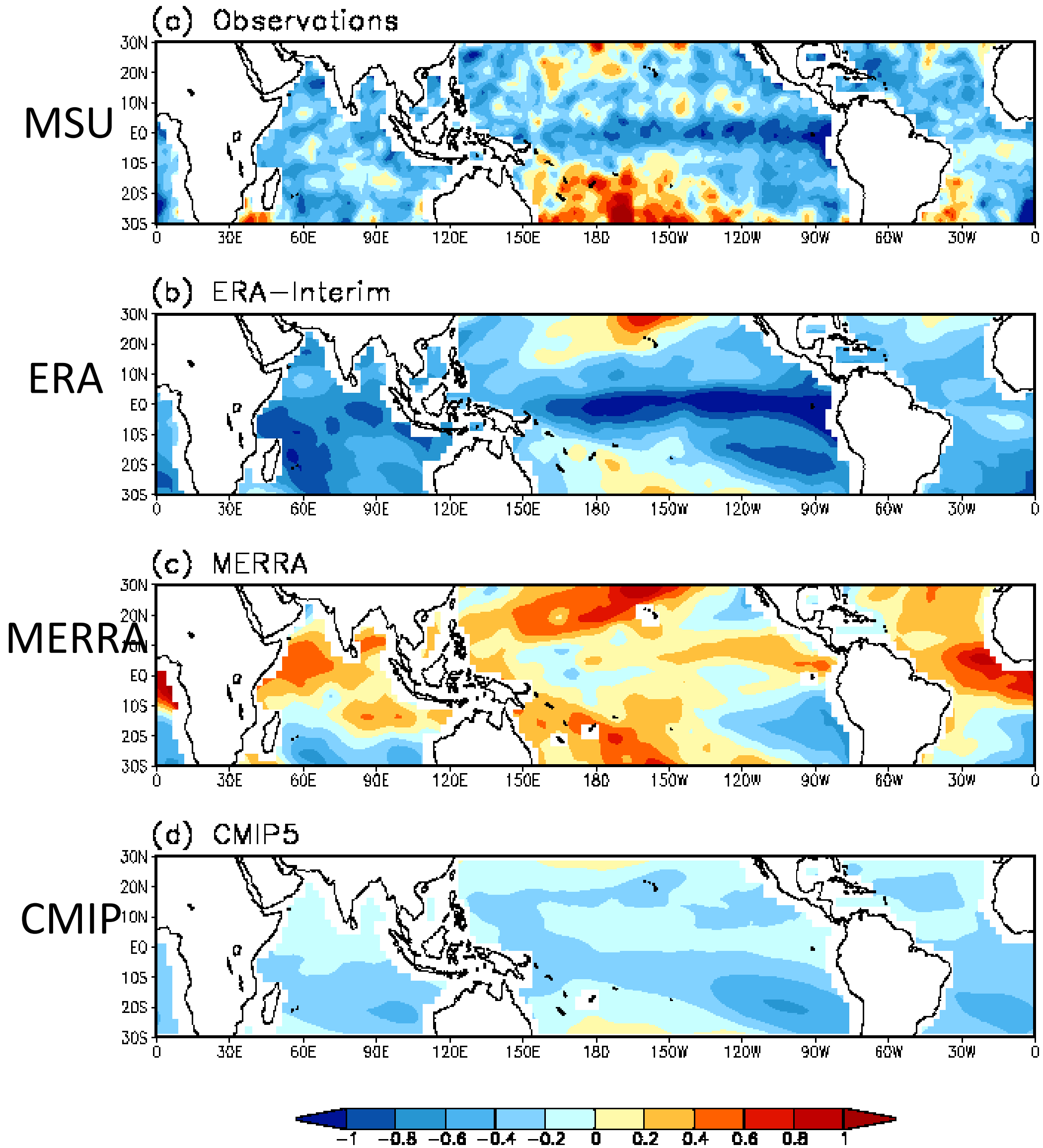
MERRA

CMIP5

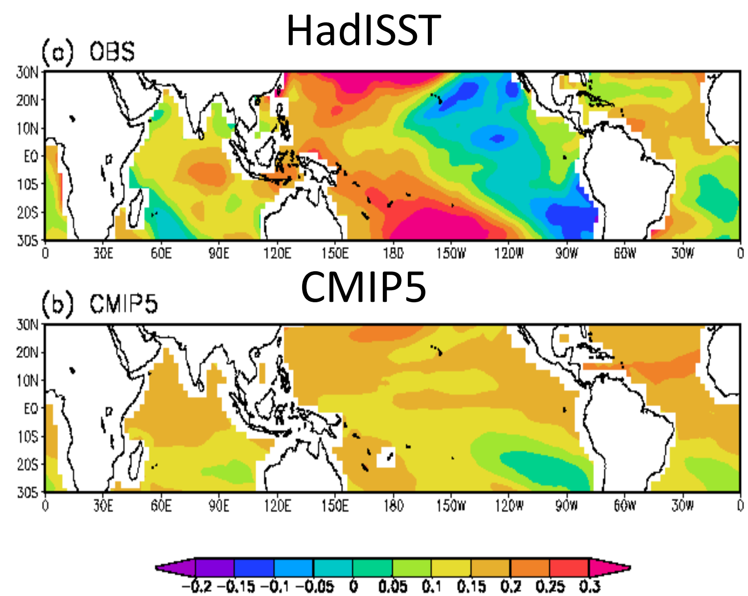


More unstable!

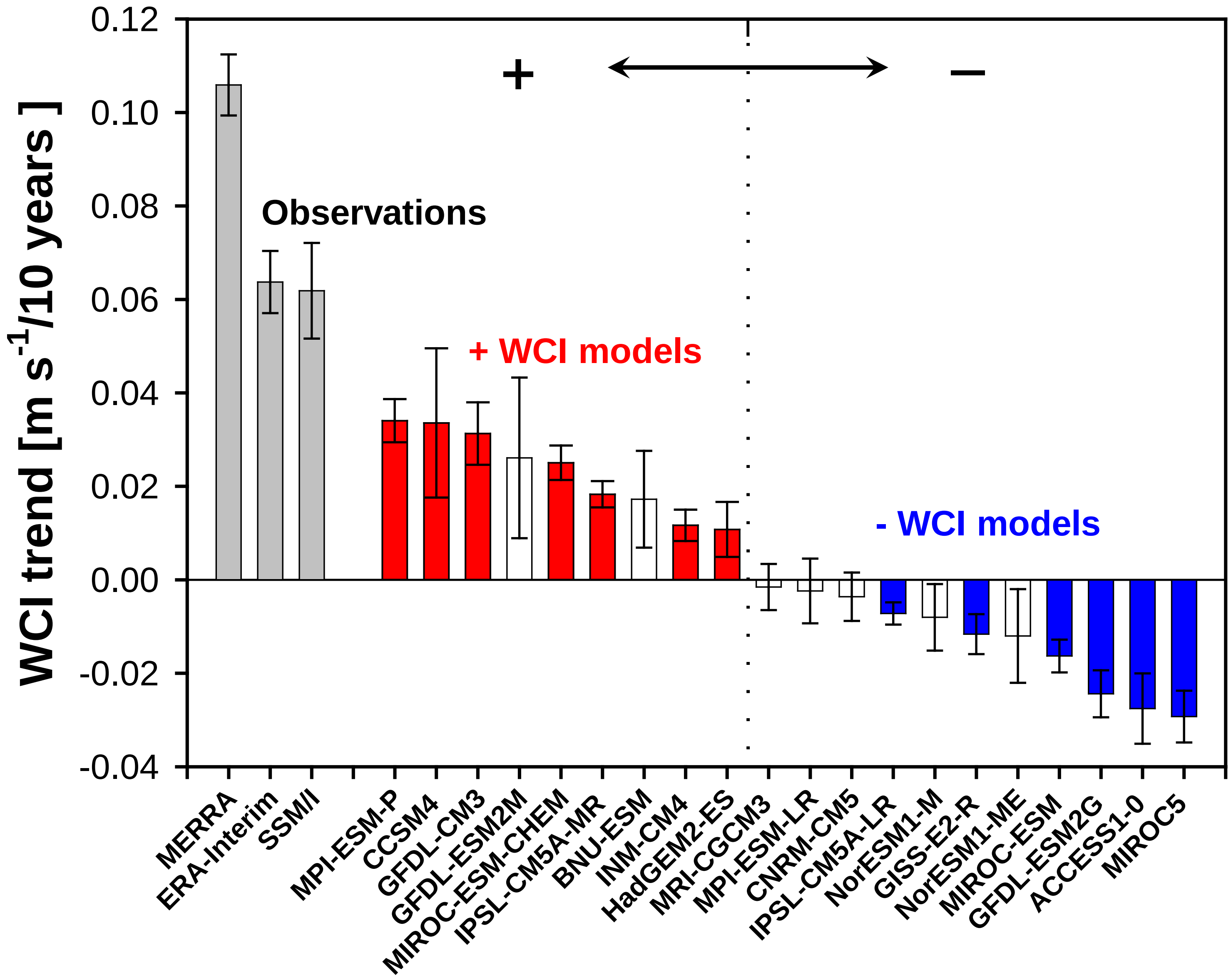
Decadal trend of $\frac{\partial \theta}{\partial p}$ (x 10^3 K/hPa/decade)



Decadal trend of SST(K/decade)
(1979–2005)



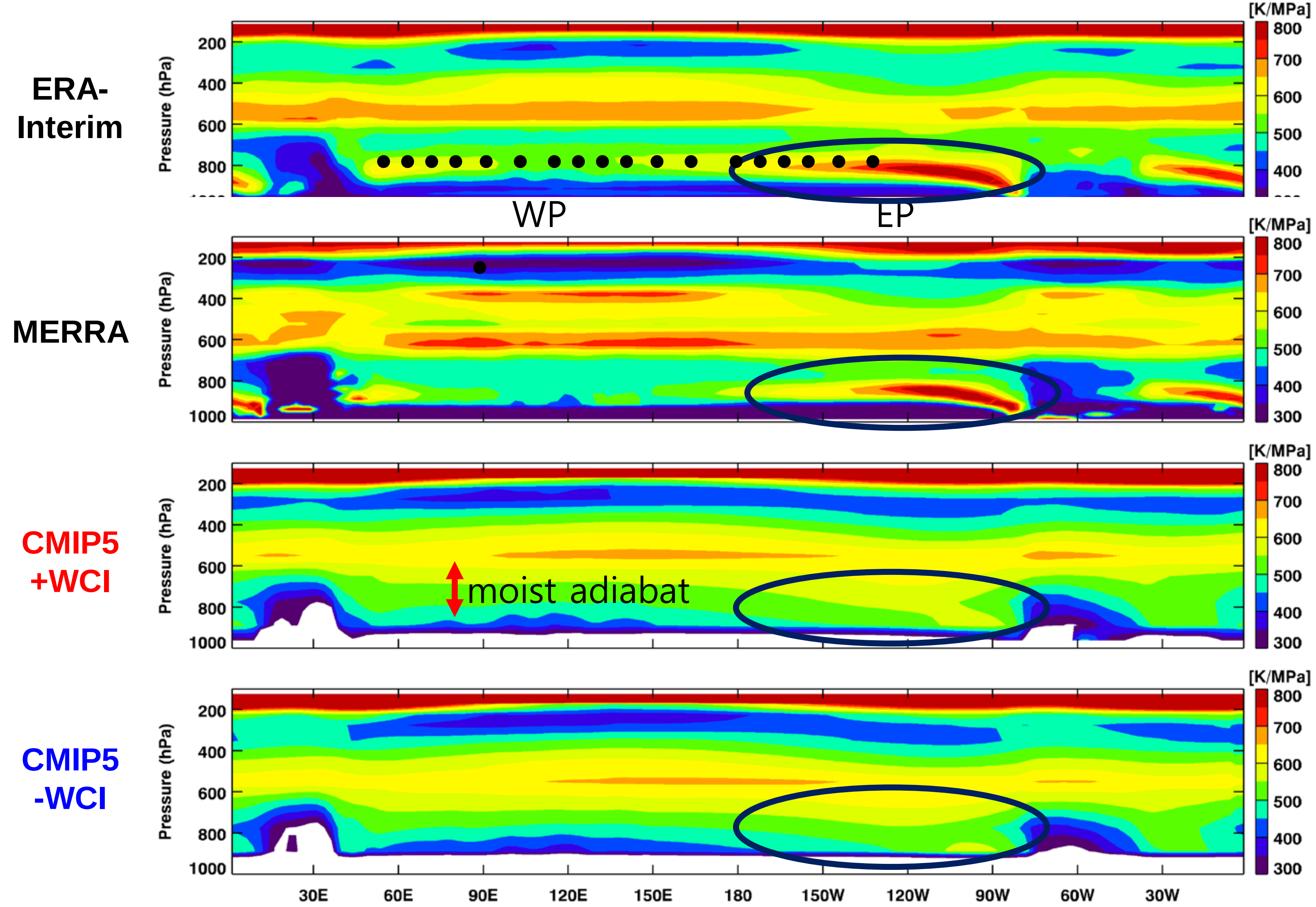
Walker Circulation trends (1979-2012)



❖ The WCI trends of CMIP5 models were highlighted with red/blue boxes if the t-test satisfies the 95 % confidence level.

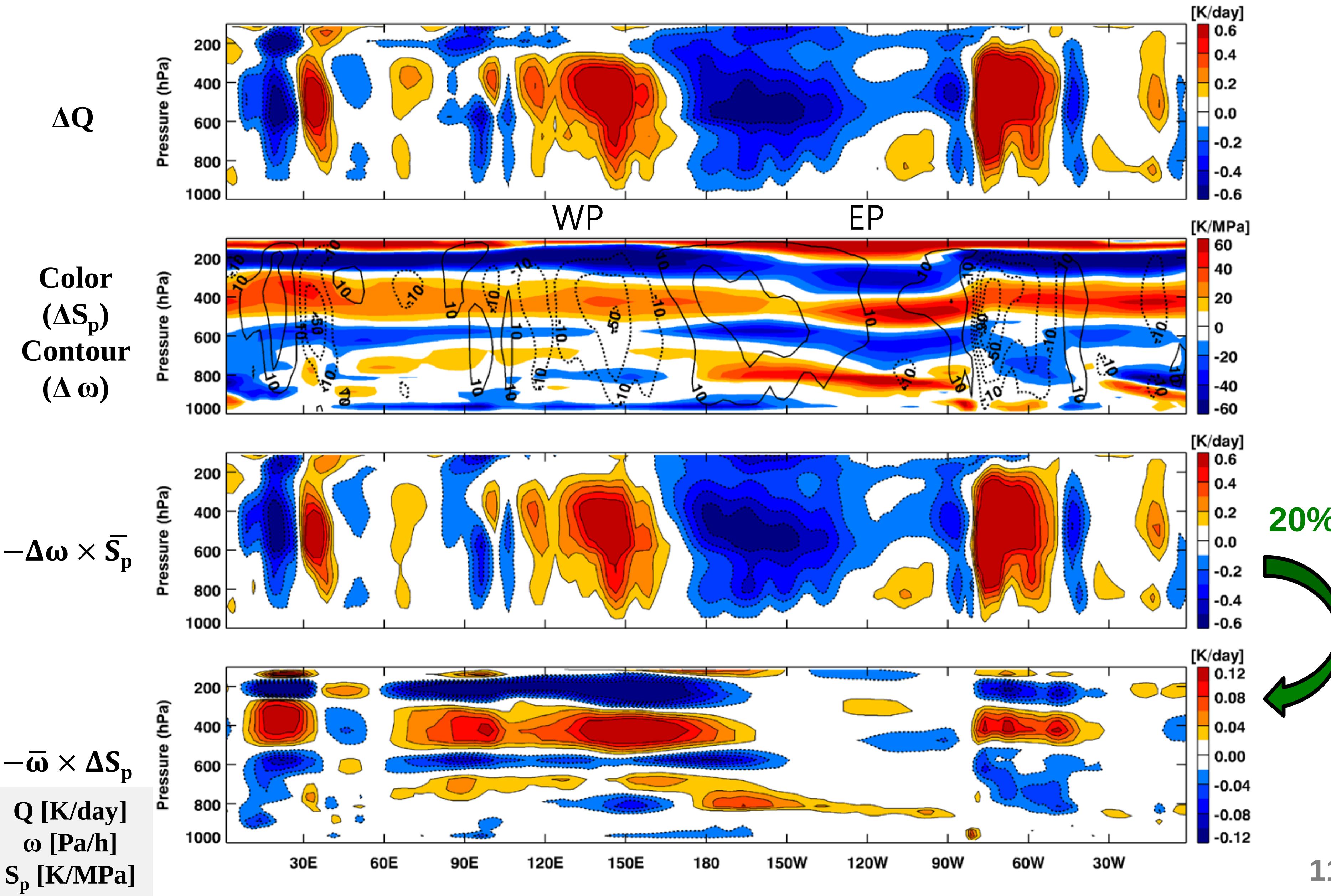
$-\frac{T}{\theta}\frac{\partial\theta}{\partial p}$

Mean S_p over 20N-20S (1979-2012)

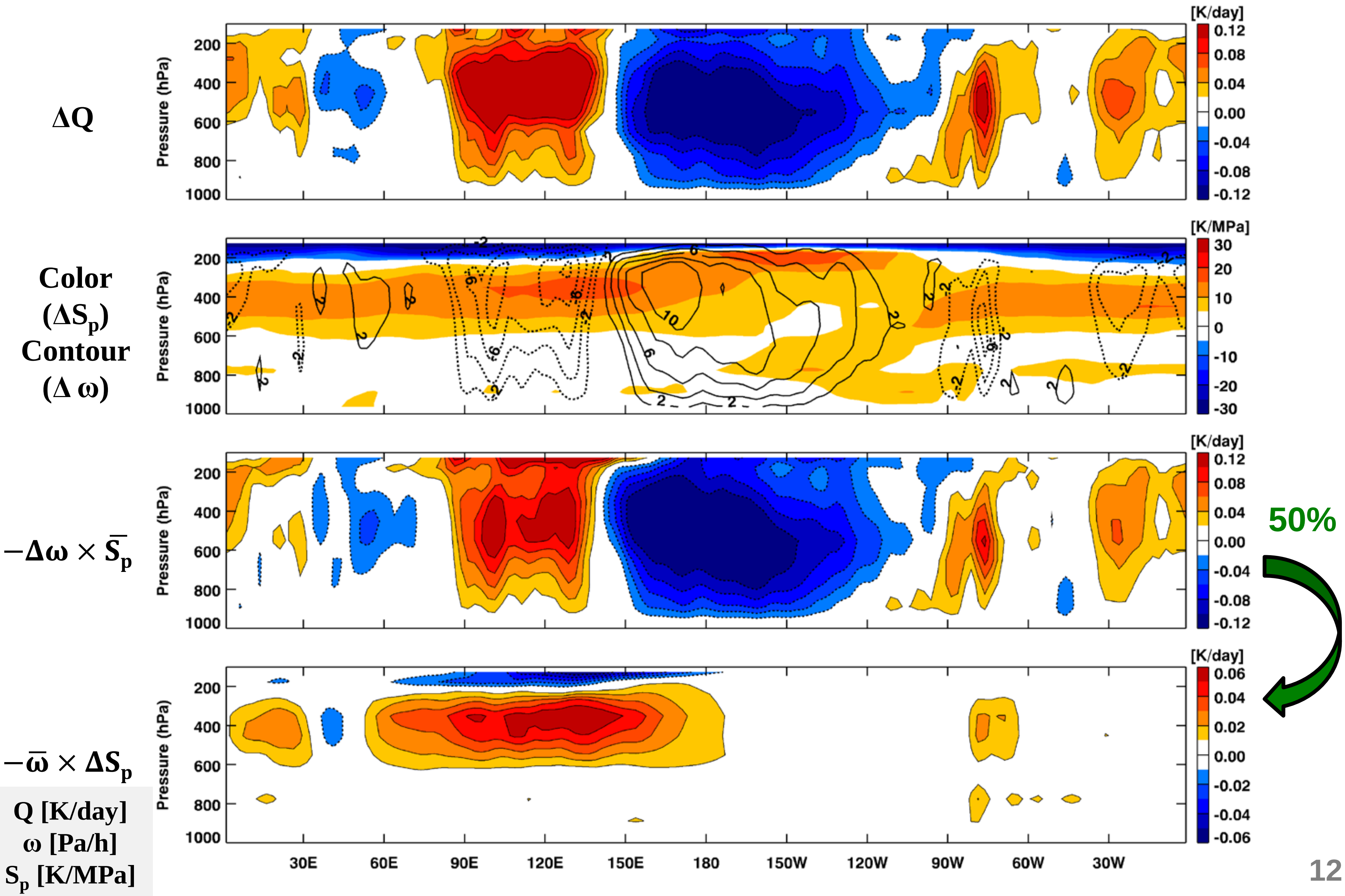


$Q \approx -\omega \times (S_p)$ → $\Delta Q \approx -\Delta\omega \times \overline{S_p} - \bar{\omega} \times \Delta S_p$

ERA (1999-2012) minus (1979-1998)



CMIP5 +WCI (1999-2012) – (1979-1998)



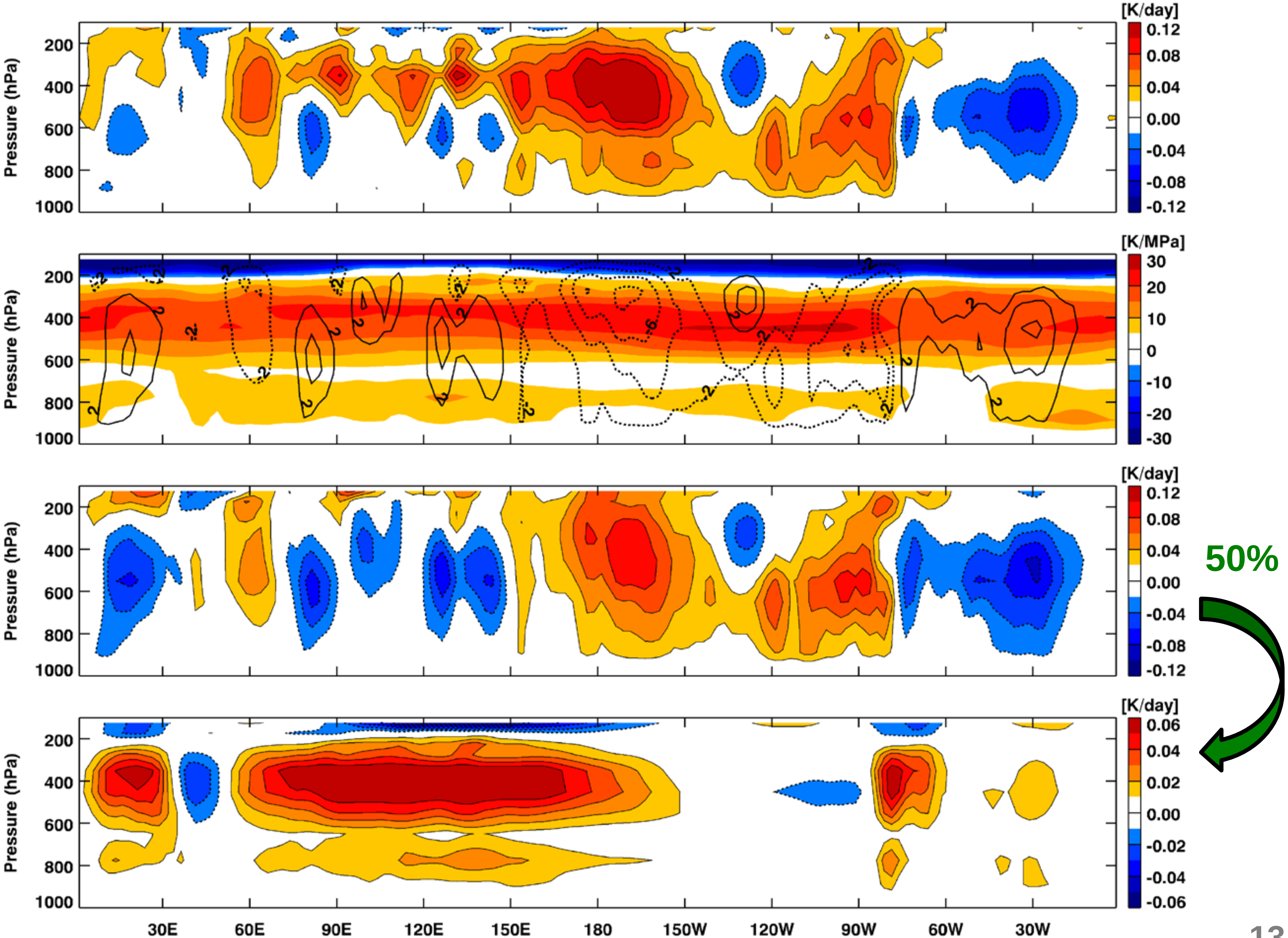
CMIP5 –WCI (1999-2012) – (1979-1998)

ΔQ

Color (ΔS_p) Contour ($\Delta\,\omega$)

$-\Delta\omega \times \bar{S}_p$

$-\bar{\omega} \times \Delta S_p$



Q [K/day]
ω [Pa/h]
S_p [K/MPa]

Conclusions

In contrast to MSU and reanalysis data CMIP5 models suggest:
(1) overall more unstable atmosphere over the tropics
(2) Lacks the 800-hPa local maximum, and appears to closely resemble the Sp profile of the moist adiabatic lapse rate
(3) Lacks the stable layer below 800 hPa in the eastern Pacific.
(4) Smaller vertical variations in Sp than in the reanalysis
(5) The models appear to closely follow the moisture adiabatic profile
(6) Stability trend closely resembles SST trend.

Changes in diabatic heating should be the main element of inducing weakening/strengthening of Walker circulation.

Stabilities in CMIP models looks simpler, but the contributions to the circulation intensity looks far higher than shown in analysis data.

CMIP models seems to follow moist adiabatic lapse rate (which is supposed to be more stable -- explaining weakening of the circulation), but in contrast CMIP models are overall more unstable (inducing El Nino-like climate).