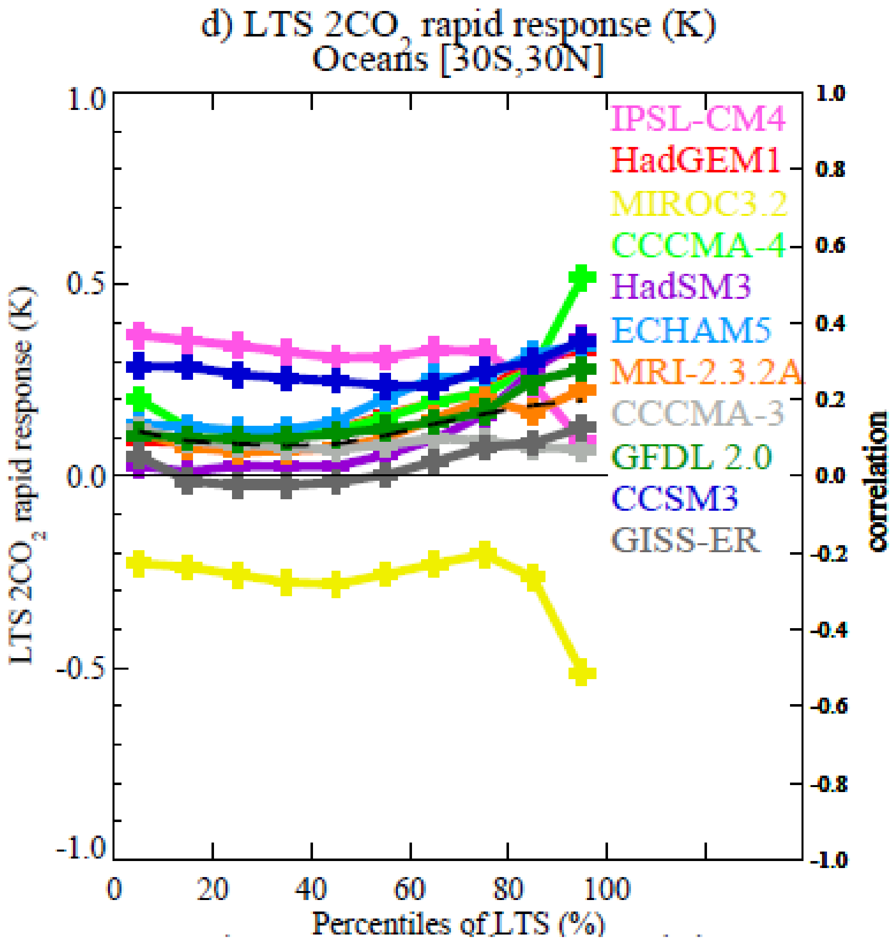
Importance of instantaneous radiative forcing to tropospheric adjustment

Tomoo Ogura[1], Mark Webb[2], Masahiro Watanabe[3], Hugo Lambert[4], and Yoko Tsushima[2]

1. National Institute for Environmental Studies
2. Met Office Hadley Centre
3. Atmosphere and Ocean Research Institute, The University of Tokyo
4. University of Exeter

2012/05/29 Joint EUCLIPSE-CFMIP meeting

Tropospheric adjustment of Lower Tropospheric Stability (LTS) to CO_2 doubling (CFMIP1/CMIP3 slab ocean experiments)



Webb et al. submitted to Climate Dynamics

Negative response of MIROC3.2 leads to large inter-model difference.

Understanding the difference in LTS adjustment

Additional experiments with 3 GCMs

- **MIROC3.2**(T42L20) compared with **HadGEM2-A**(N96L38) and **MIROC5.0**(T85L40).

  CMIP3 *CMIP5*

Experimental design

- Trop. adjustment evaluated by **"4xCO_2 AMIP" minus "AMIP"**, 1979-2008.
  ; difference in 30 years average between the two experiments. (Hansen et al. 2005)

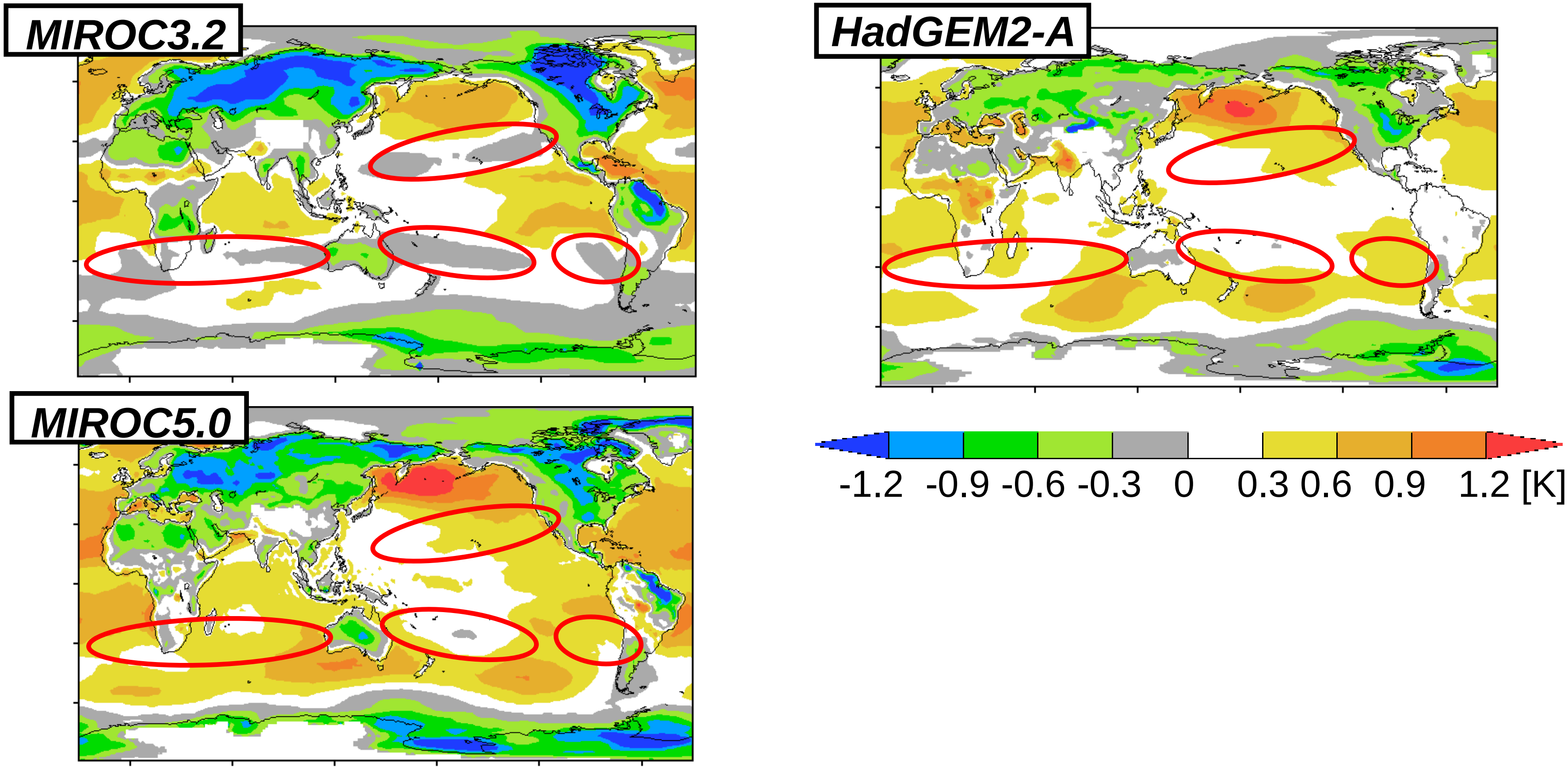
- The above approach chosen to confirm the result of regression method.
  (Gregory et al. 2004)

- Using MIROC3.2, four members of initial value ensemble runs obtained for significance test (95%).

- For HadGEM-2 and MIROC5.0, one member analyzed for each.

Tropospheric adjustment of LTS estimated from AMIP-type runs

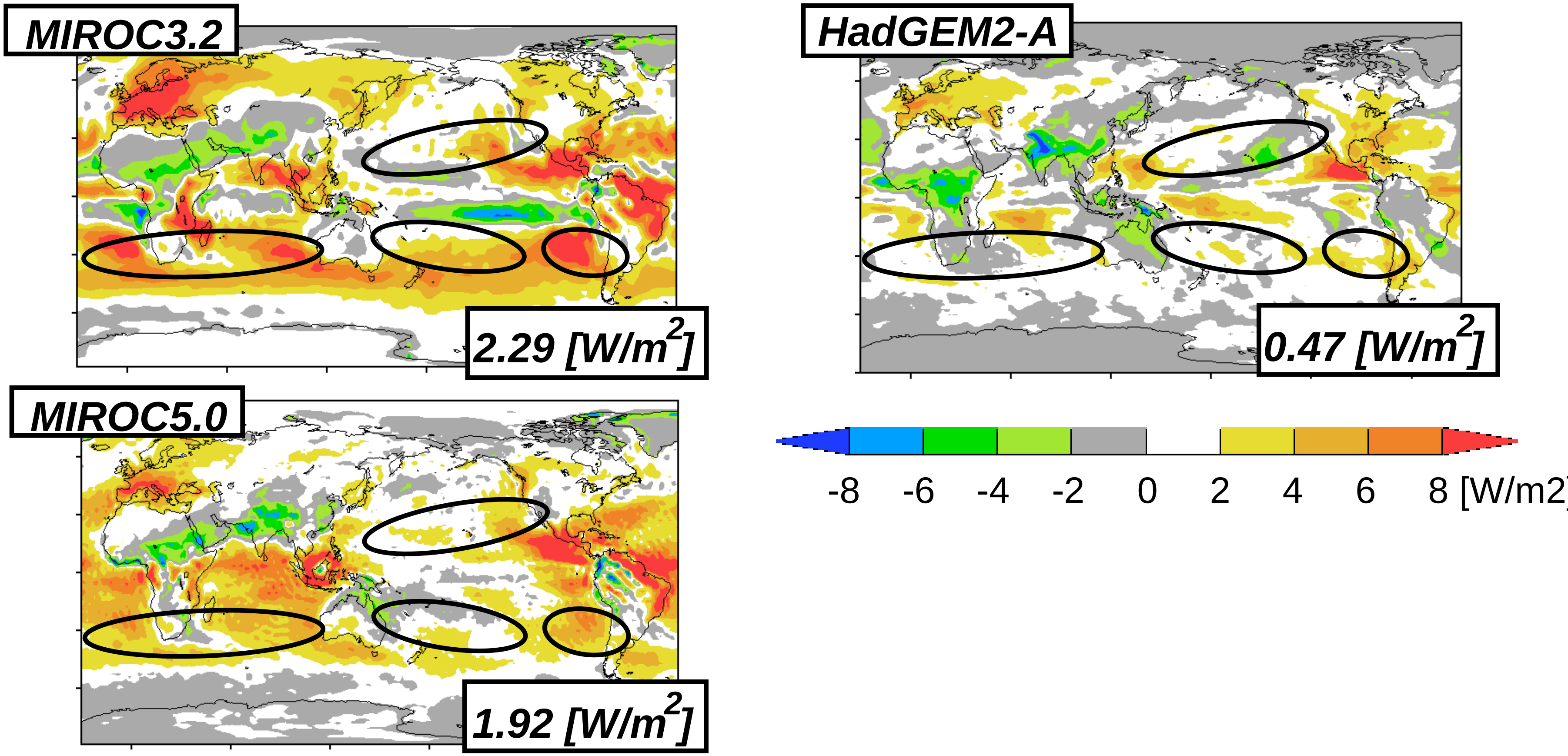
LTS response (4xCO2 AMIP *minus* AMIP, Annual mean)



Negative adjustment found in MIROC3.2 (over subtropical ocean).

Tropospheric adjustment of Cloud Radiative Effect (CRE) from AMIP-type runs

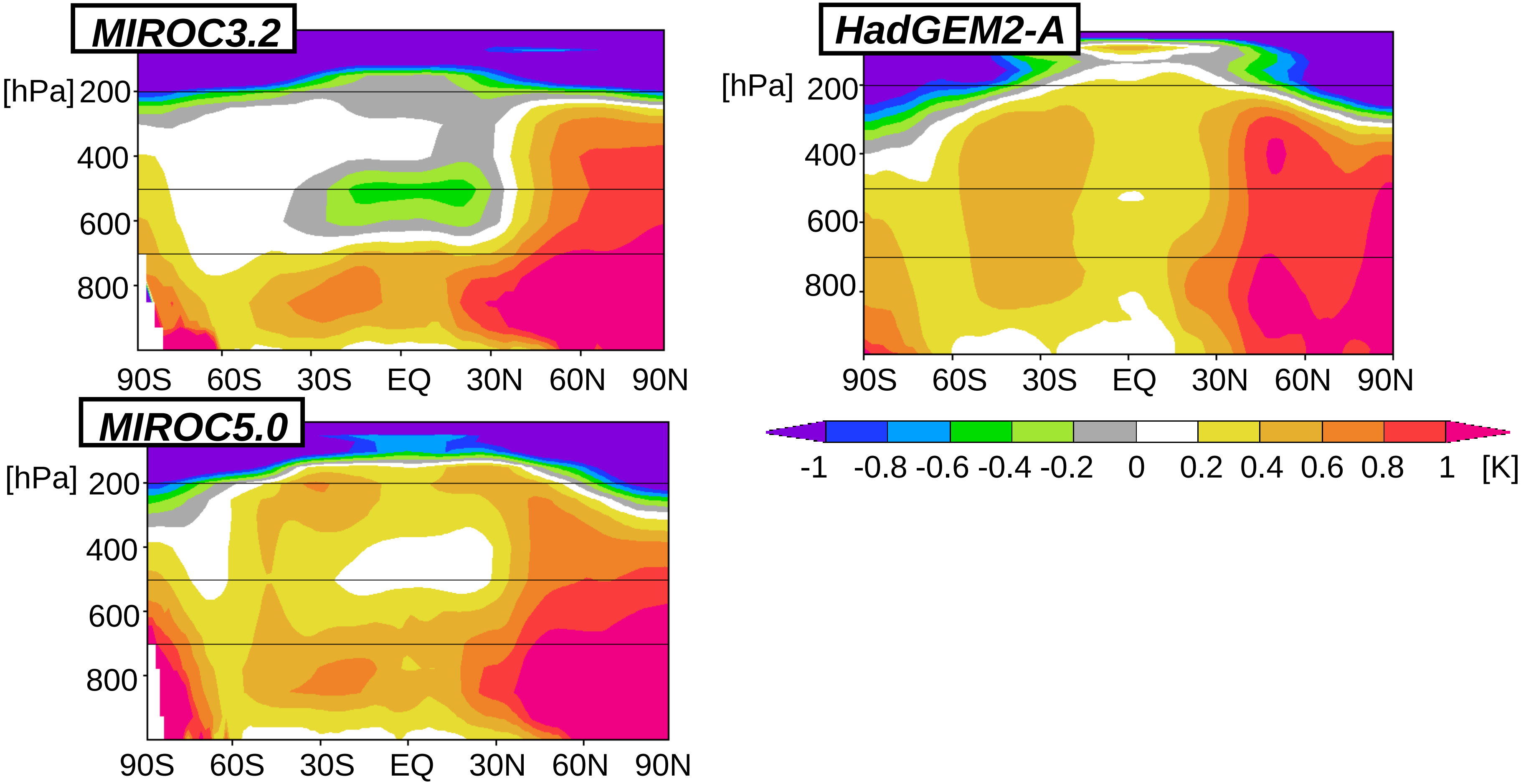
Shortwave CRE Response (4xCO_2 AMIP *minus* AMIP, Annual mean)



Positive adjustment in MIROC3.2, consistent with the LTS adjustment.

Tropospheric adjustment of temperature profile from AMIP-type runs

Temperature response (4xCO2 AMIP *minus* AMIP, Zonal Annual mean)



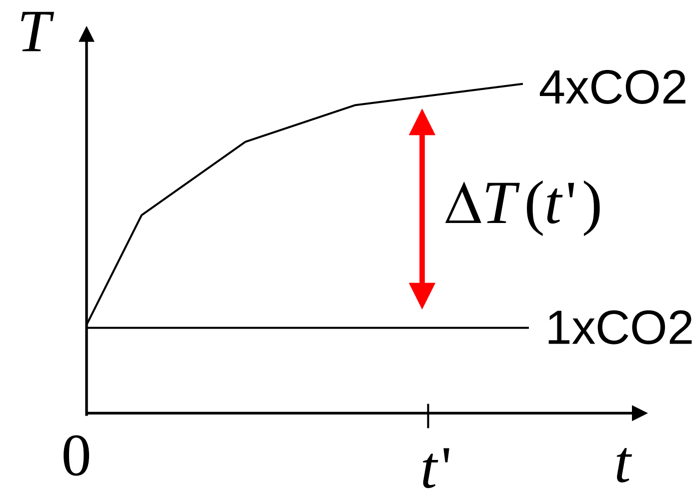
What causes the negative adjustment in mid-troposphere in MIROC3.2 ?

Analysis of temperature tendency terms

$$\frac{\partial T}{\partial t} = \text{Convective Cloud} + \text{Non-Convective Cloud} + \text{Longwave Heating} + \text{Shortwave Heating} + \text{Diffusion} + \text{Dynamics} + \text{Residual}$$

$$\equiv \sum_{i=1}^{7} \dot{T}i$$

Integrating from t=0 to t=t’, and taking the difference between 4xCO2 and 1xCO2 by Δ,

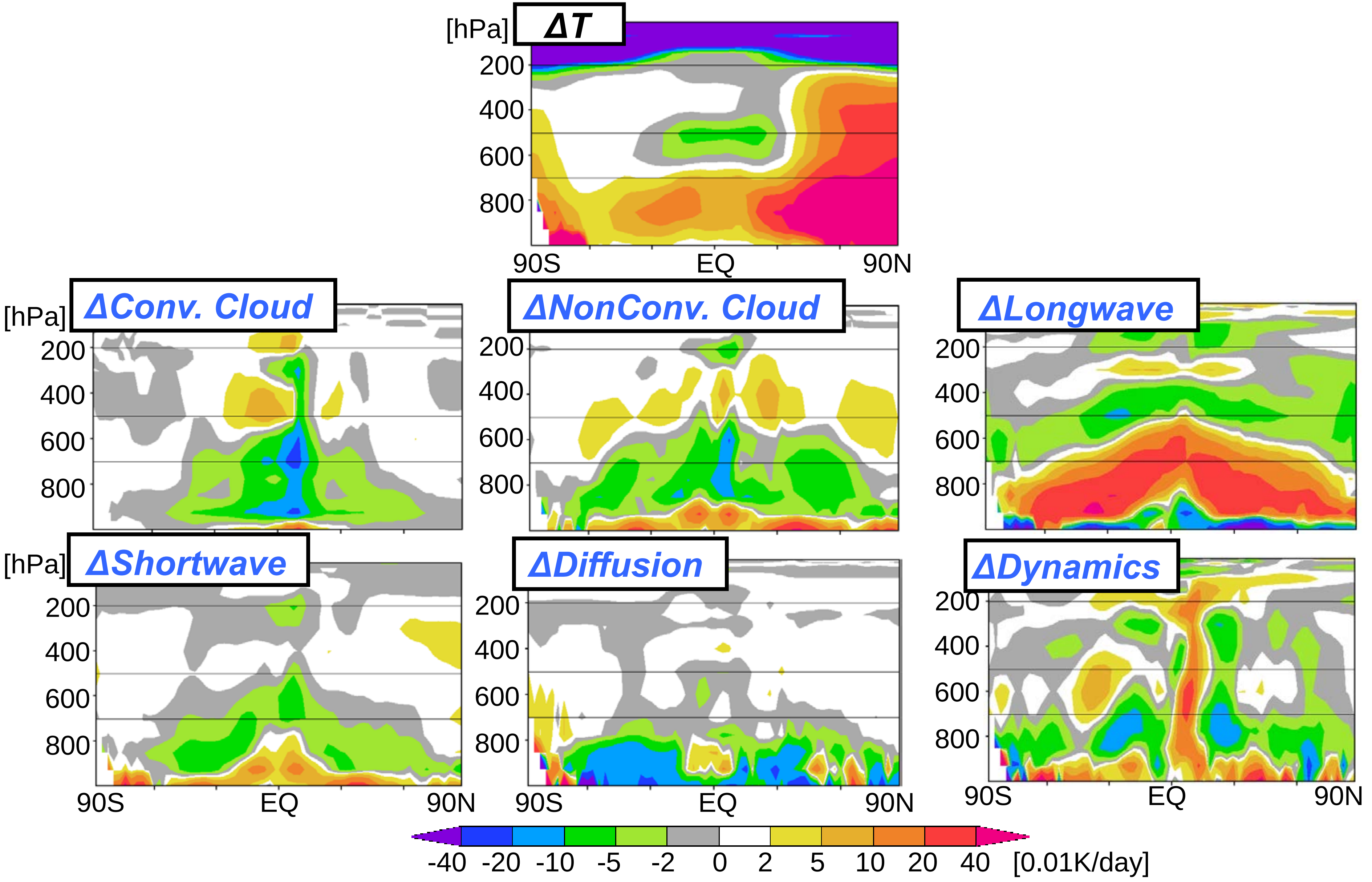


$$\Delta T(t') = \left(\sum_{i=1}^{7} \Delta \overline{\dot{T}i} \right) \times t'$$

Consistency checked between T response, $\Delta T(t')$

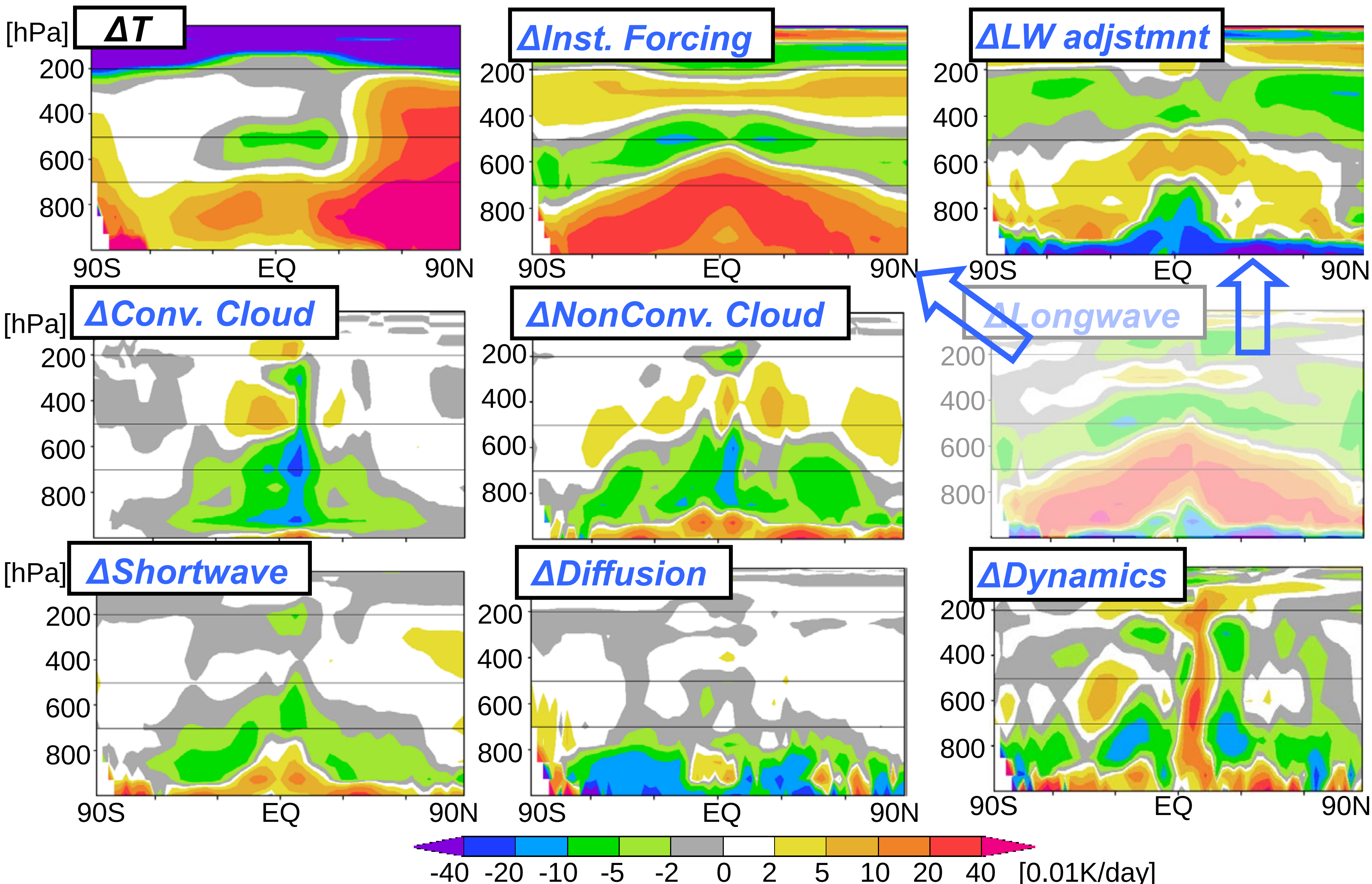
, and tendency terms response, $\Delta \overline{\dot{T}i}$.

Tropospheric adjustment of temperature tendency terms in MIROC3.2



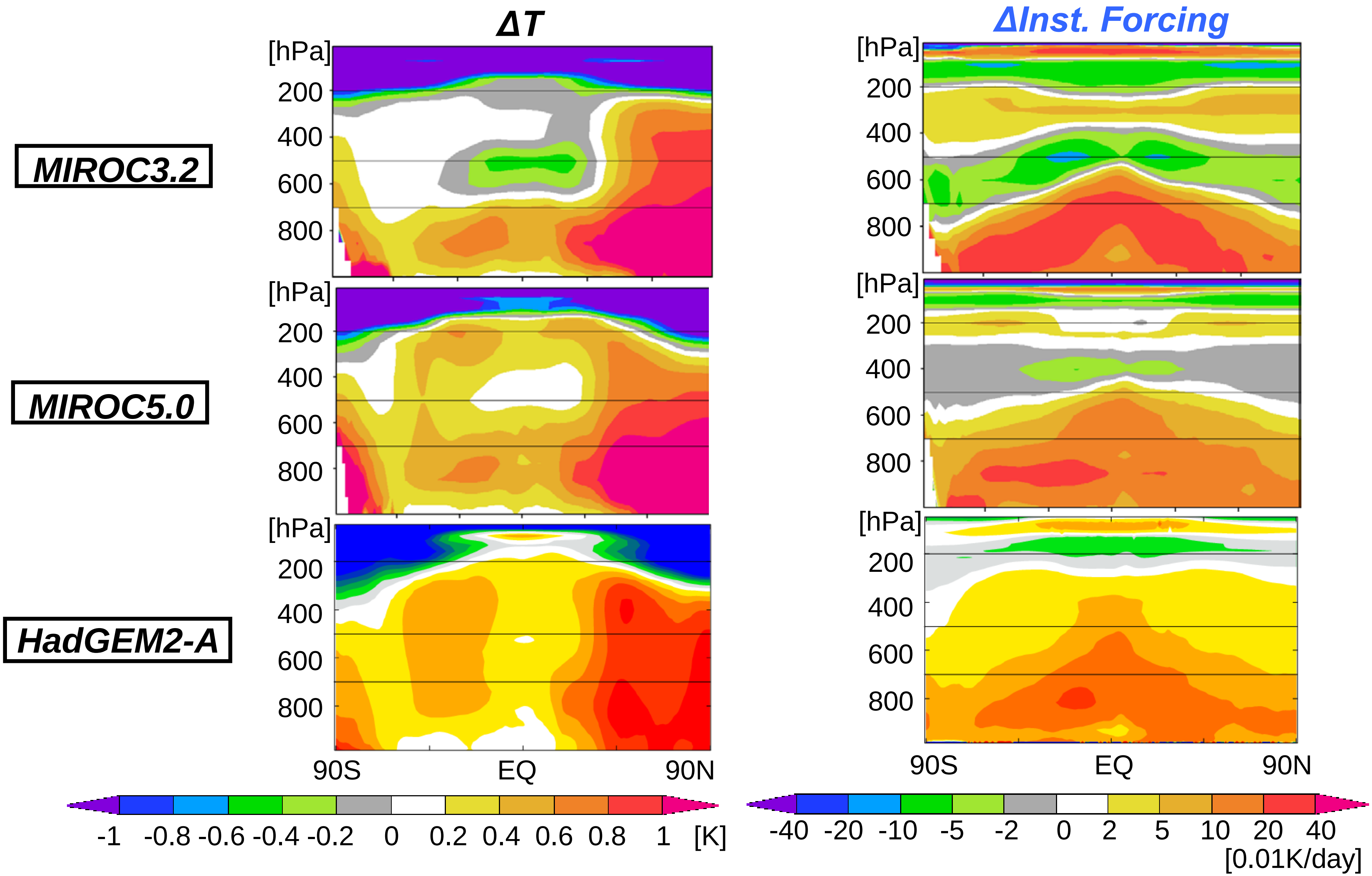
Contribution from multiple terms to the negative ΔT in mid-troposphere.

Tropospheric adjustment of temperature tendency terms in MIROC3.2



Contribution of ΔInst. Forcing appears important to the negative ΔT.

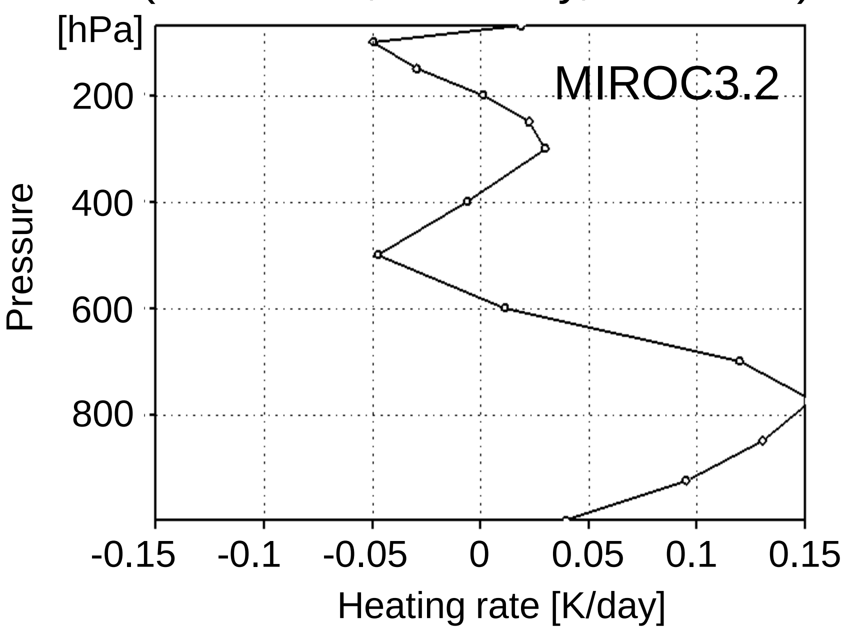
Inter-model difference of ΔInst. Forcing; is it consistent with ΔT ?



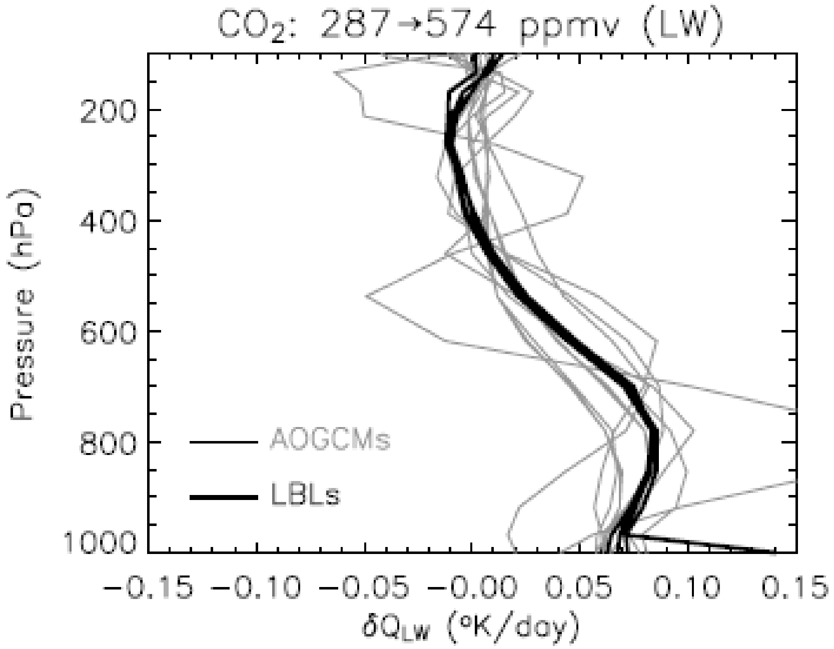
Inter-model difference of ΔInst. Forcing appears consistent with ΔT.

Evaluation of ΔInst. Forcing with Line-By-Line (LBL) calculations.

Instantaneous 4xCO2 Heating rate x 0.5
(JJA mean, clear sky, 30N-60N)



Longwave heating rate perturbation



Adapted from Collins et al. (2006), JGR, Fig.10

Radiative Transfer Model Intercomparison Project (RTMIP), AR4 models including MIROC3, compared with LBLs.

The negative ΔInst. Forcing in mid-troposphere may be questionable.

Tropospheric adjustment of Lower Tropospheric Stability (LTS) to 2xCO2

(CFMIP1/CMIP3 slab ocean experiments)

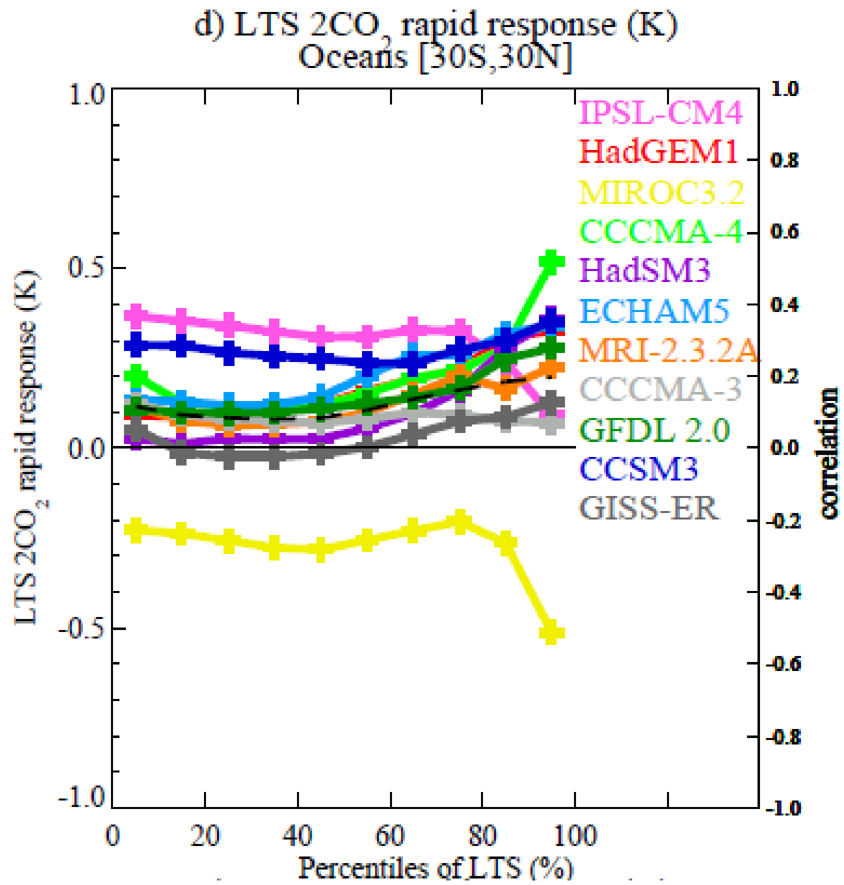


Fig. 9 Lower Tropospheric Stability (LTS) composites of net, shortwave and longwave CRE components of forcing over the low latitude oceans (30N/S) in the AR4 ensemble, and rapid responses of LTS, Estimated Inversion Strength (EIS) and pressure velocity at 500 hPa.

Webb et al. submitted to Climate Dynamics

Negative response of MIROC3.2 leads to large inter-model difference.

Summary

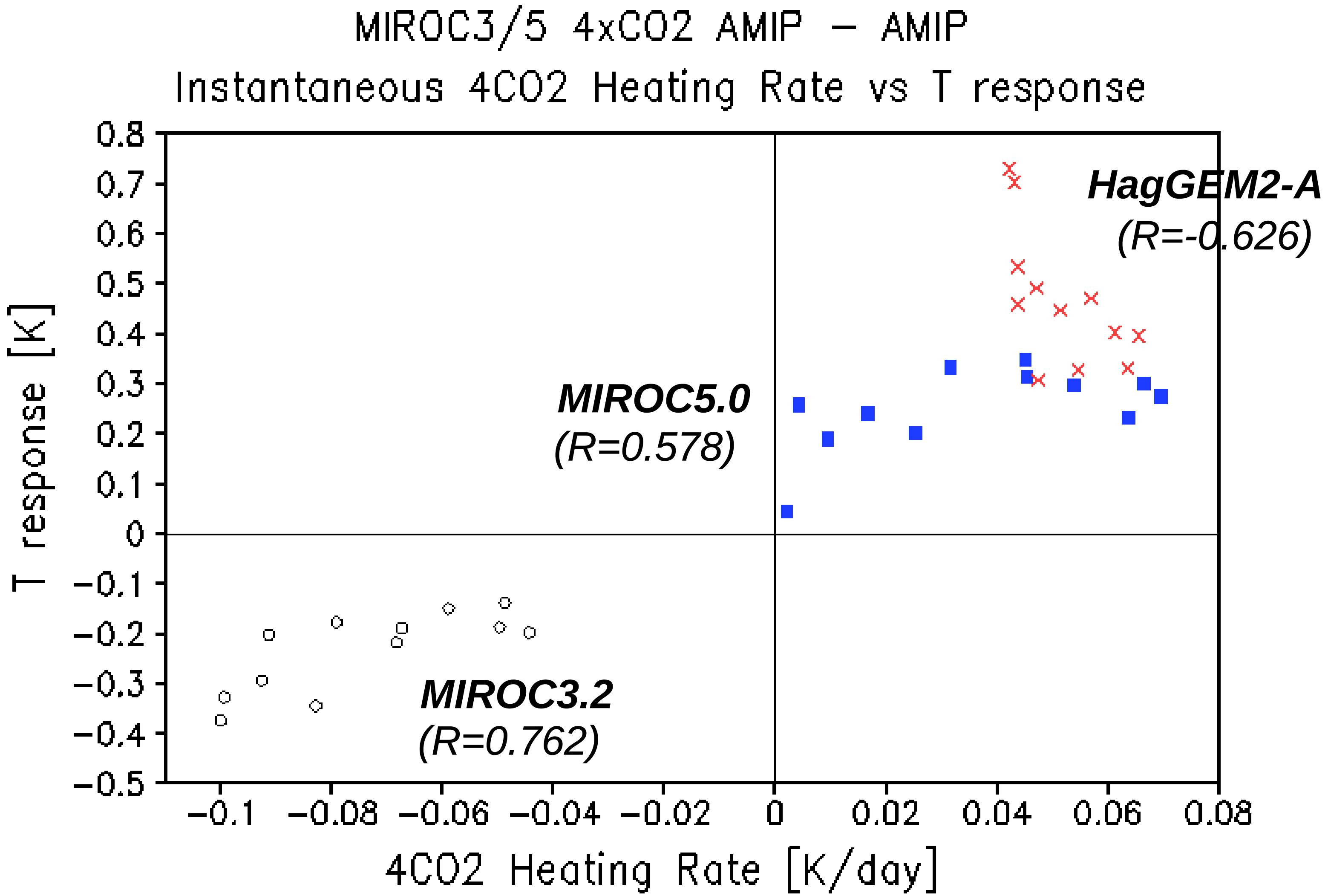
An example of model inter-comparison study on LTS adjustment presented.

- LTS reduction in MIROC3.2 reflects cooling in mid-troposphere , which can be explained by multiple factors, especially instantaneous radiative forcing.

- Comparison with LBL calculation suggests that the negative forcing in mid-troposphere is questionable.

- Inter-model difference in LTS adjustment is expected to decrease with the above constraint (at least in CMIP3).

Seasonal variation of ΔInst. Forcing; is it related to ΔT ?



Seasonal variation of ΔInst. Forcing correlated with ΔT only in MIROCs.

Forcing, feedback and tropospheric adjustment

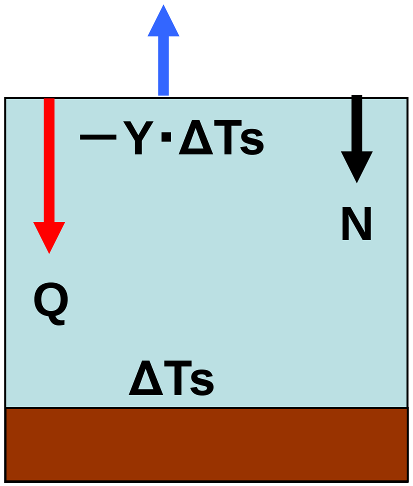
N = Q − Y・ΔTs Gregory et al. (2004)

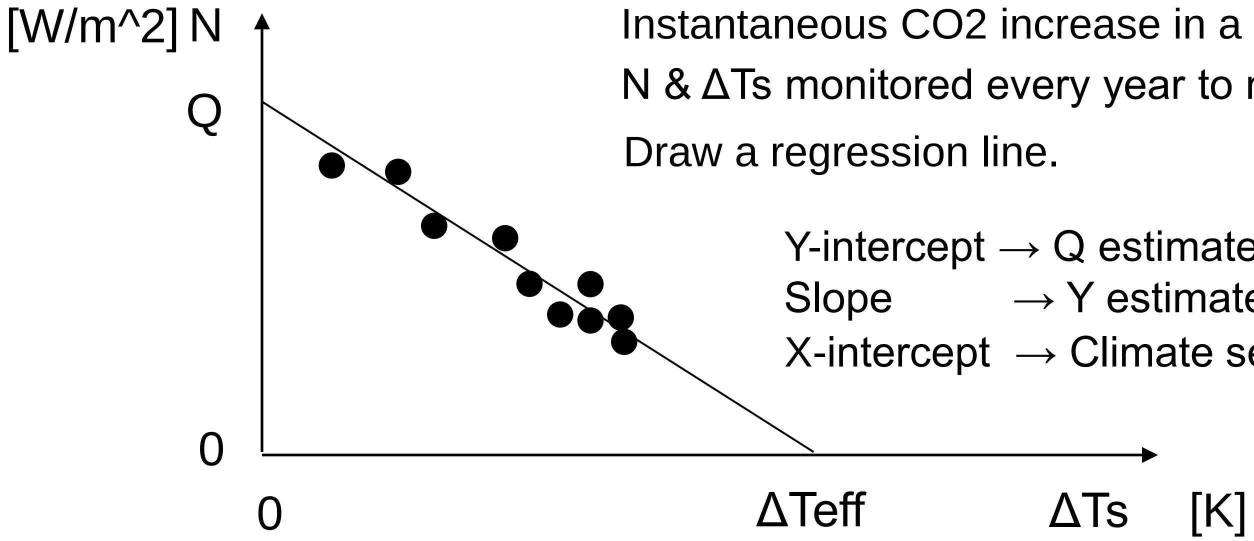
N: radiative imbalance at TOA (positive down, W/m2)

Q: radiative forcing

Y: climate feedback (W/m2/K)

ΔTs: global annual mean surface T change





Instantaneous CO_2 increase in a GCM.

N & ΔTs monitored every year to make a scatter plot.

Draw a regression line.

Y-intercept → Q estimated **(adjustment included)**
Slope → Y estimated.
X-intercept → Climate sensitivity estimated.

Diversity in ΔTeff between GCMs results from diversity in Y and Q (including adjustment)

Lower Tropospheric static Stability (LTS)

Δθ=θ(p=700mb) −θ(p=sea level pressure, T=surface air temperature)

Klein and Hartmann (1993)

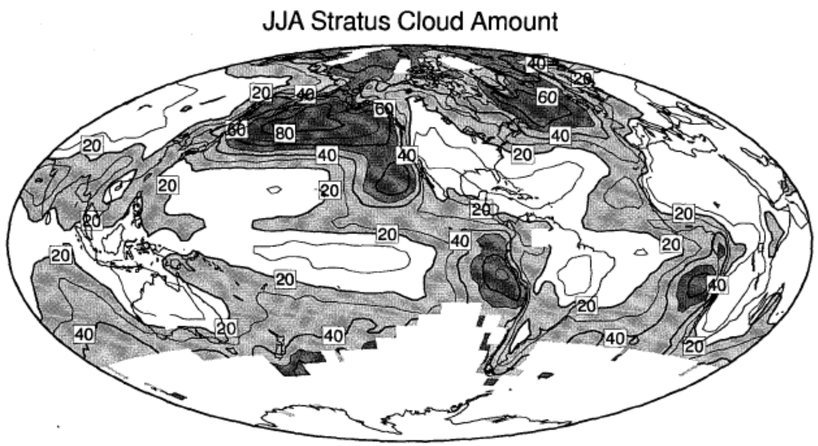


FIG. 2. The average stratus, stratocumulus, and sky-obscuring fog cloud amount in percent as seen by surface-based observers (a) annually; (b) for June, July, and August; and (c) for December, January, and February. Missing data indicates regions where fewer than 100 observations

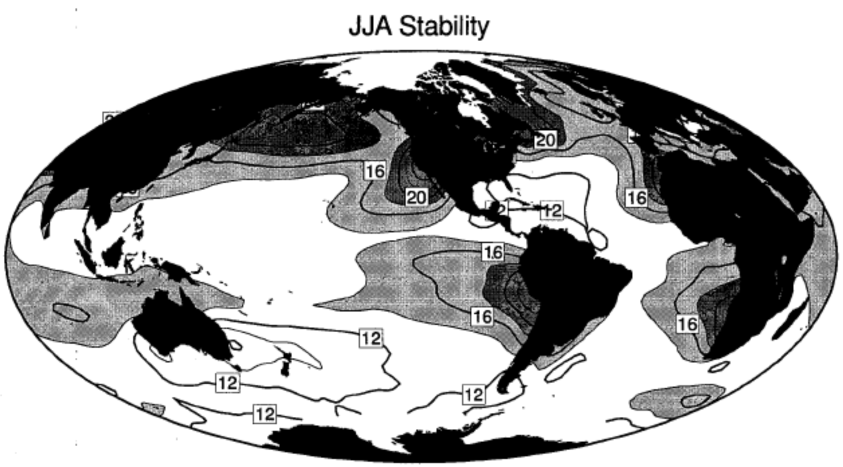


FIG. 14. Climatological values of lower-tropospheric static stability for the June, July, and August season in degrees Celsius. Contour interval is 2°C.

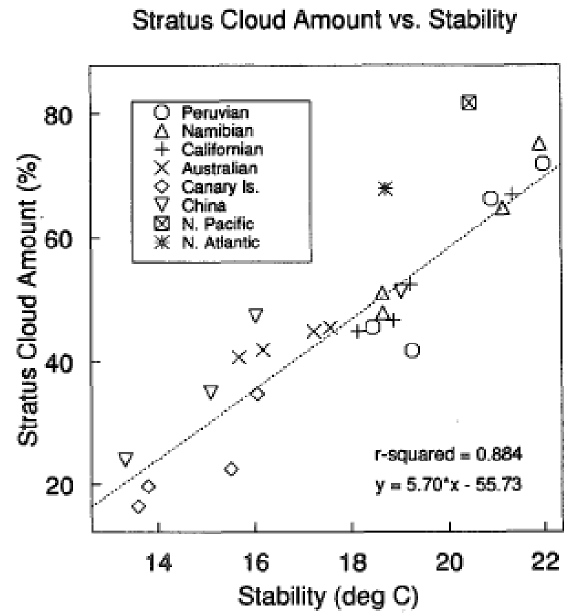
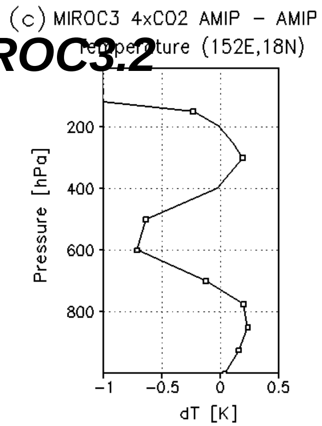
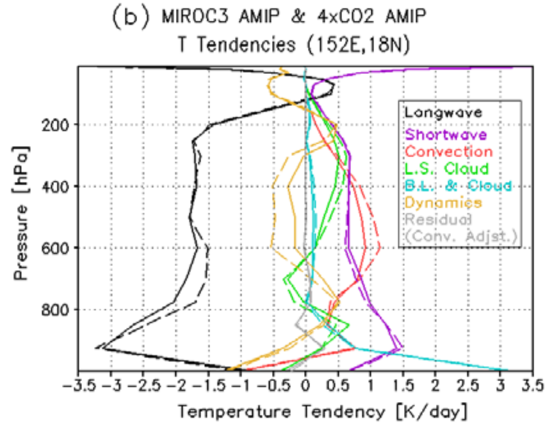
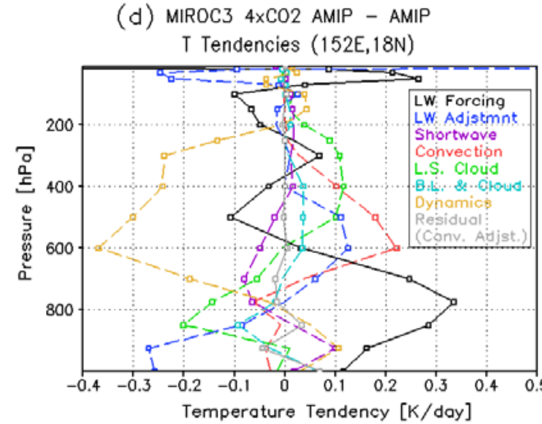


FIG. 13. Scatterplot of seasonally averaged stratocumulus cloud amount with seasonally averaged lower-tropospheric stability for the five subtropical oceanic regions and the Chinese stratus region. In addition, the June, July, and August seasonally averaged quantities are plotted for the North Pacific and North Atlantic but are not included in the regression.

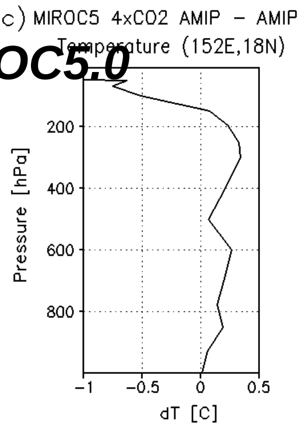
MIROC3.2

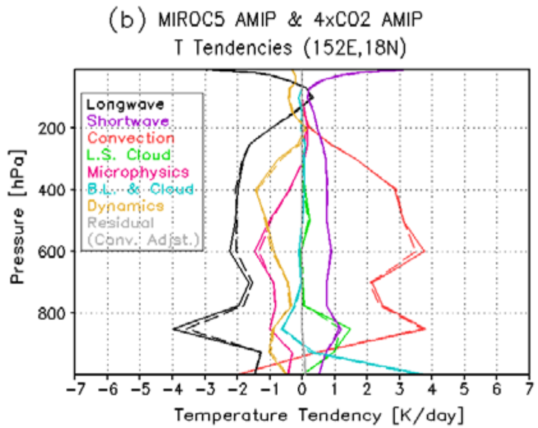


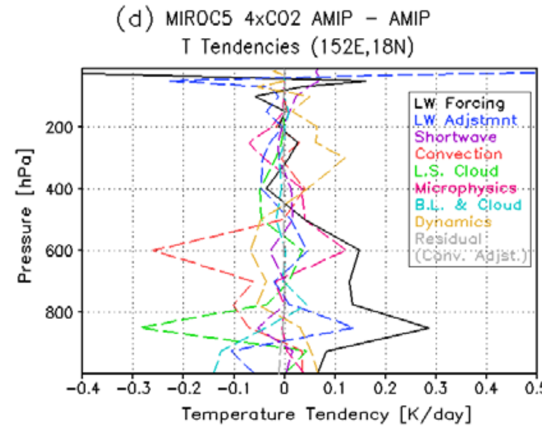




MIROC5.0







HadGEM2