Response of global tropical cyclone activity to a doubling of CO2 and uniform SST warming: A multi-model inter-comparison

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Motivation

Separate the effect of CO2 increase and SST warming on global TC activity

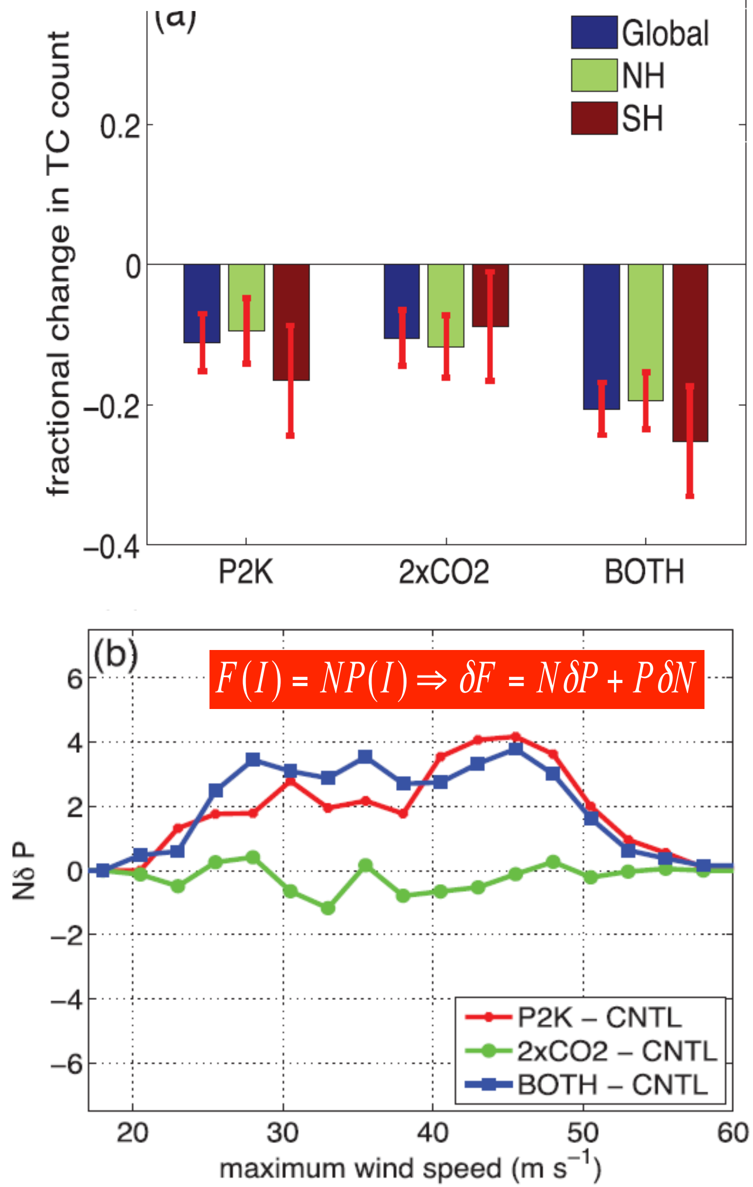
HIRAM produces ~20% reduction in global TC frequency. Nearly half of the response comes from the CO2 increase with the other half from SST warming.

Intensity response is also different: SST warming tend to increase storm intensity while CO2 increase has no significant impact.

To what extent are these results robust across models? If robust, what are the fundamental mechanisms, if not, what are possible sources of uncertainty?

This separation has implications to transient climate response and geo-engineering.

Held and Zhao 2011



Use a common TC tracking algorithm to minimize differences

Threshold values used in GFDL tracking algorithm:

vorticity: 3.5e-5 1/s; warm core: 1 ^{o}C; duration: 2 day

1.GFDL HIRAM: max wind speed=17m/s

2.GFDL C180AM2: max wind speed=17m/s (additional model)

3.CMCC ECHAM5: max wind speed=12m/s

4.NCEP GFS: max wind speed=12m/s

5.GSFC GEOS5: max wind speed=12m/s (effective, averaged wind

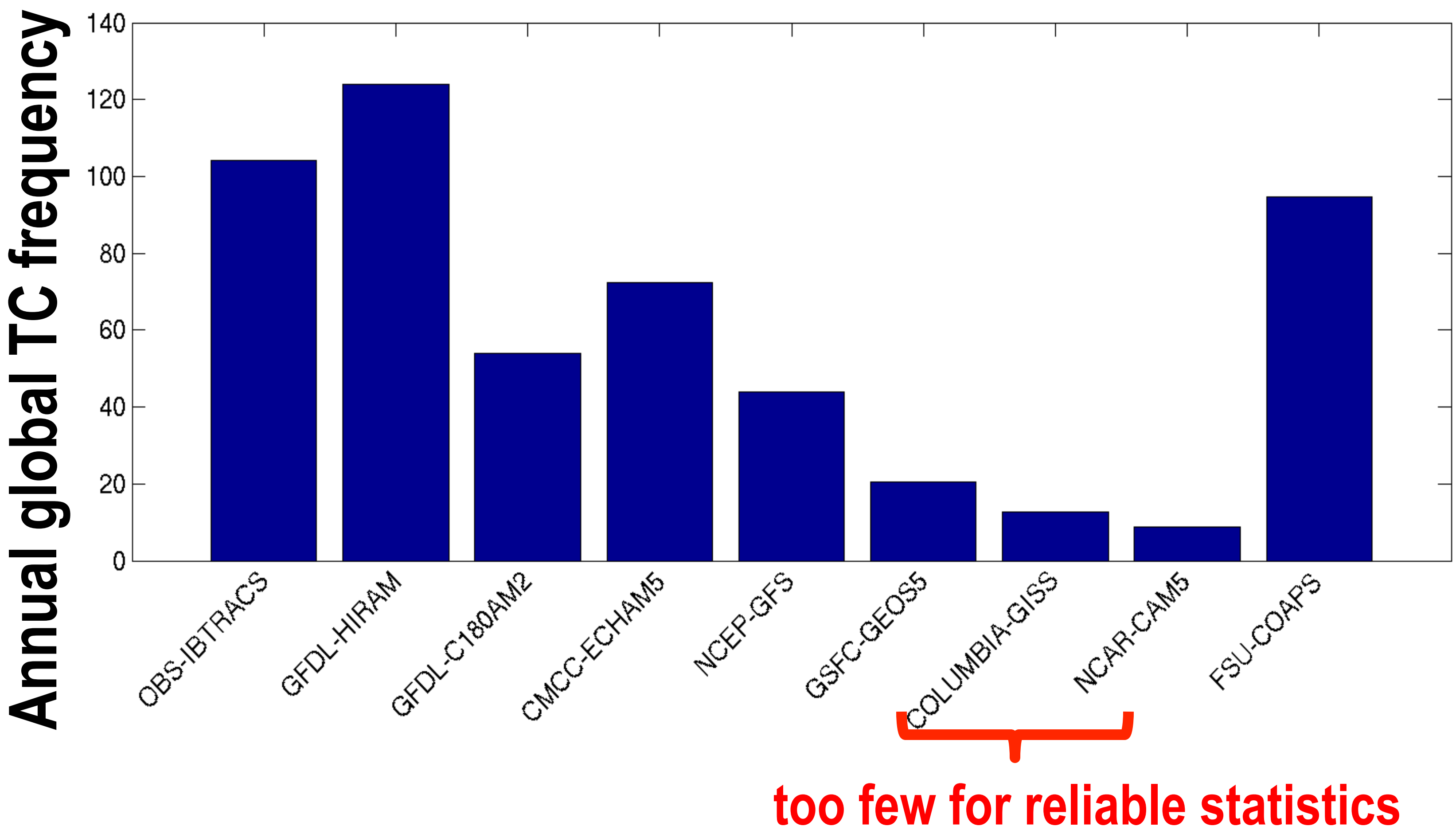
6.Columbia GISS: max wind speed=12m/s (SST might be different?)

7.NCAR CAM5: original track files used

8.FSU COAPS: original track files used

Analysis focused only on genesis locations between 30S-30N (>95%)

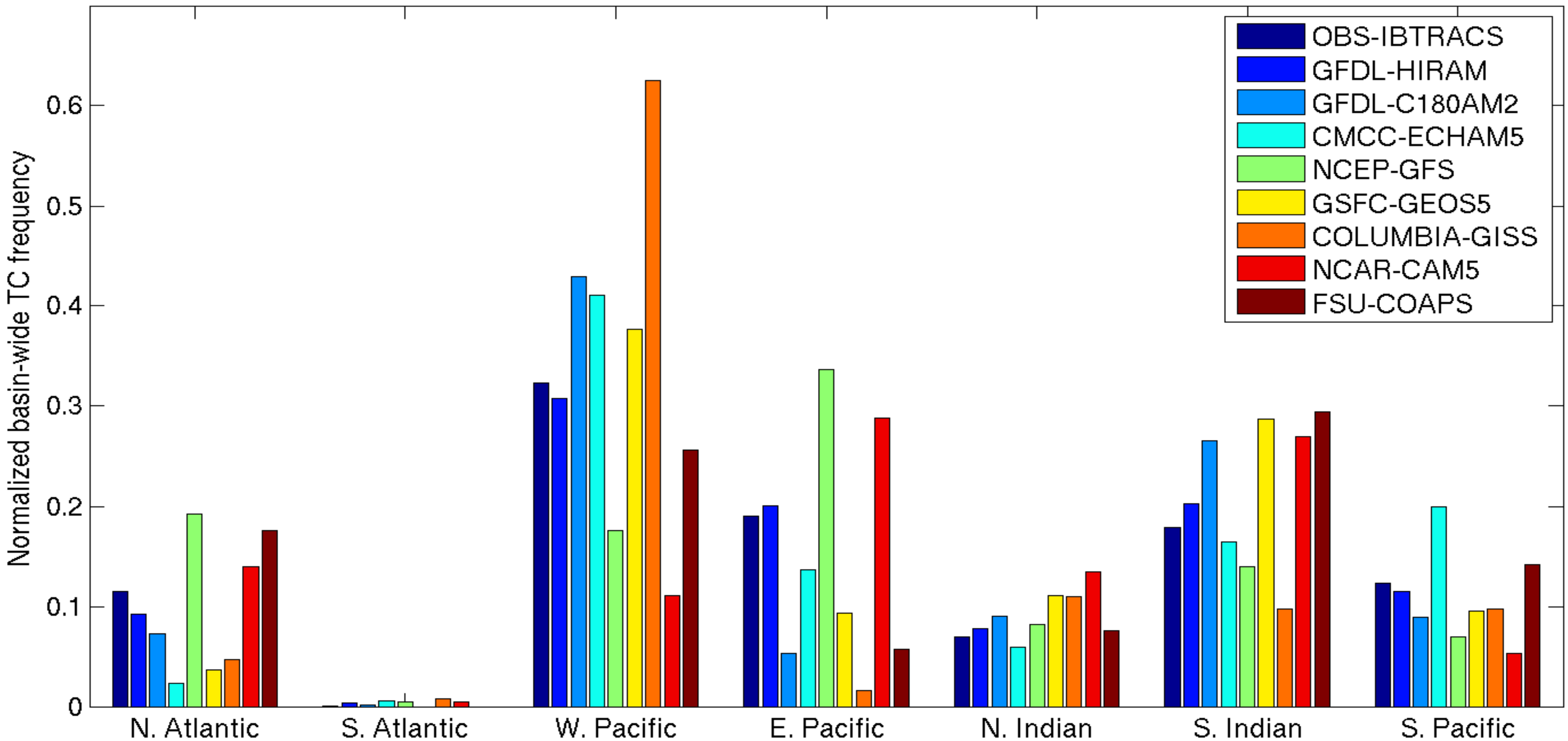
Global TC frequency from each control simulation forced by the present-day climatological SST and CO2 concentration



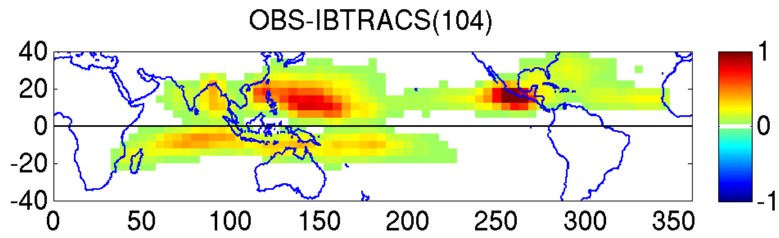
Basin-wide TC frequency normalized by the global frequency for each model

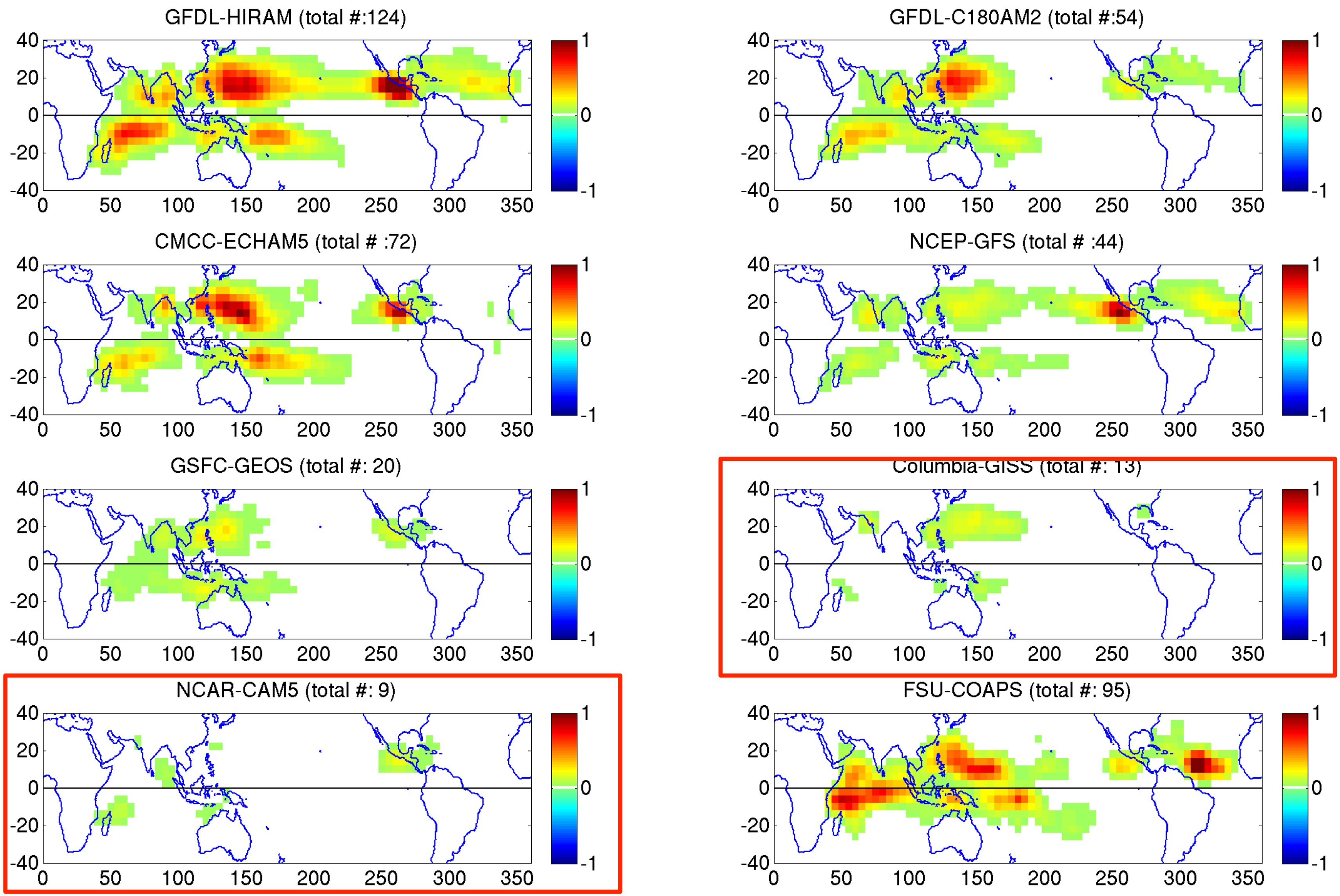
GISS, C180AM2, ECHAM5, GEOS5: excessive WP to EP and NA TC ratio

GFS, CAM5: produce the opposite

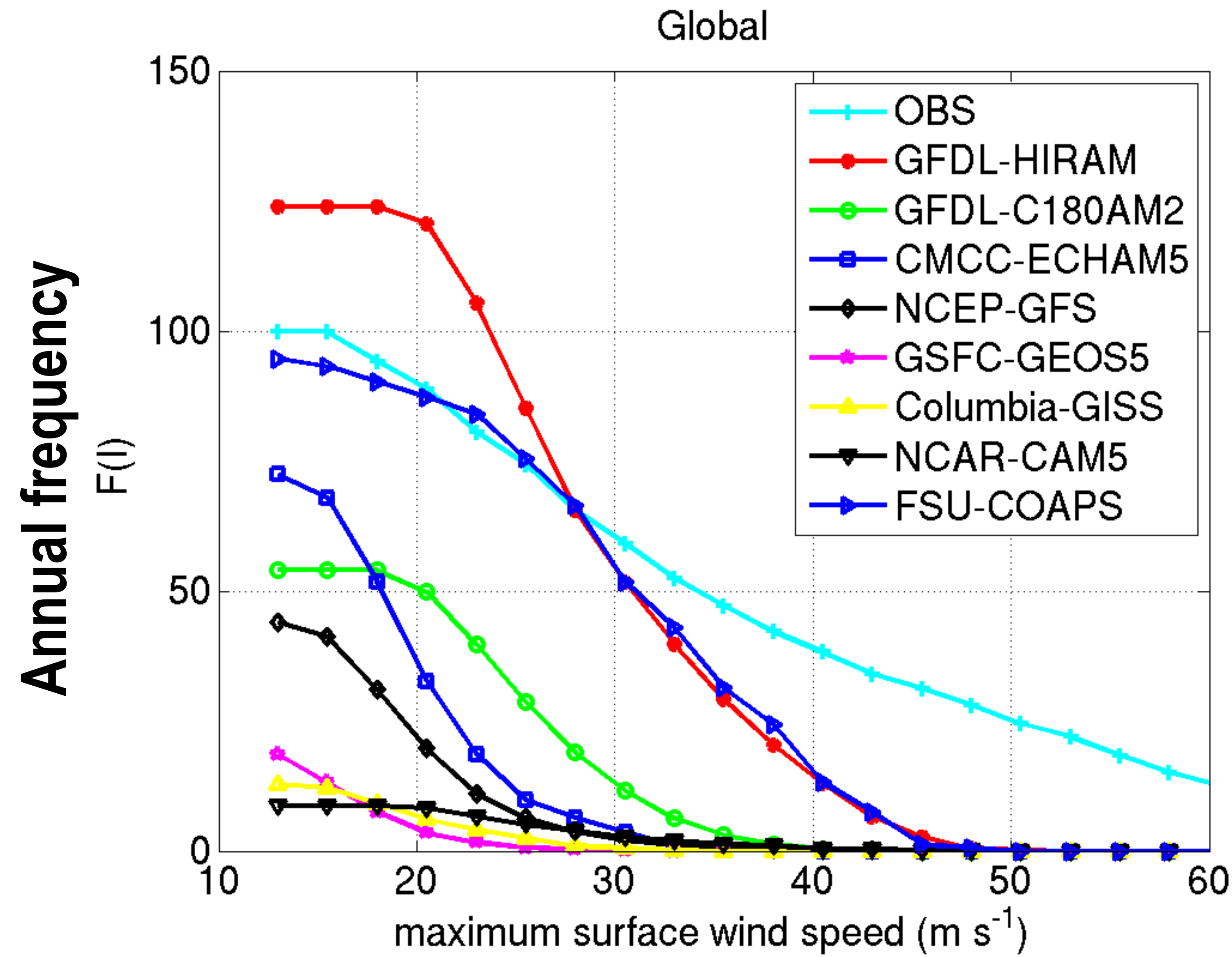


TC genesis frequency distribution from the control simulations

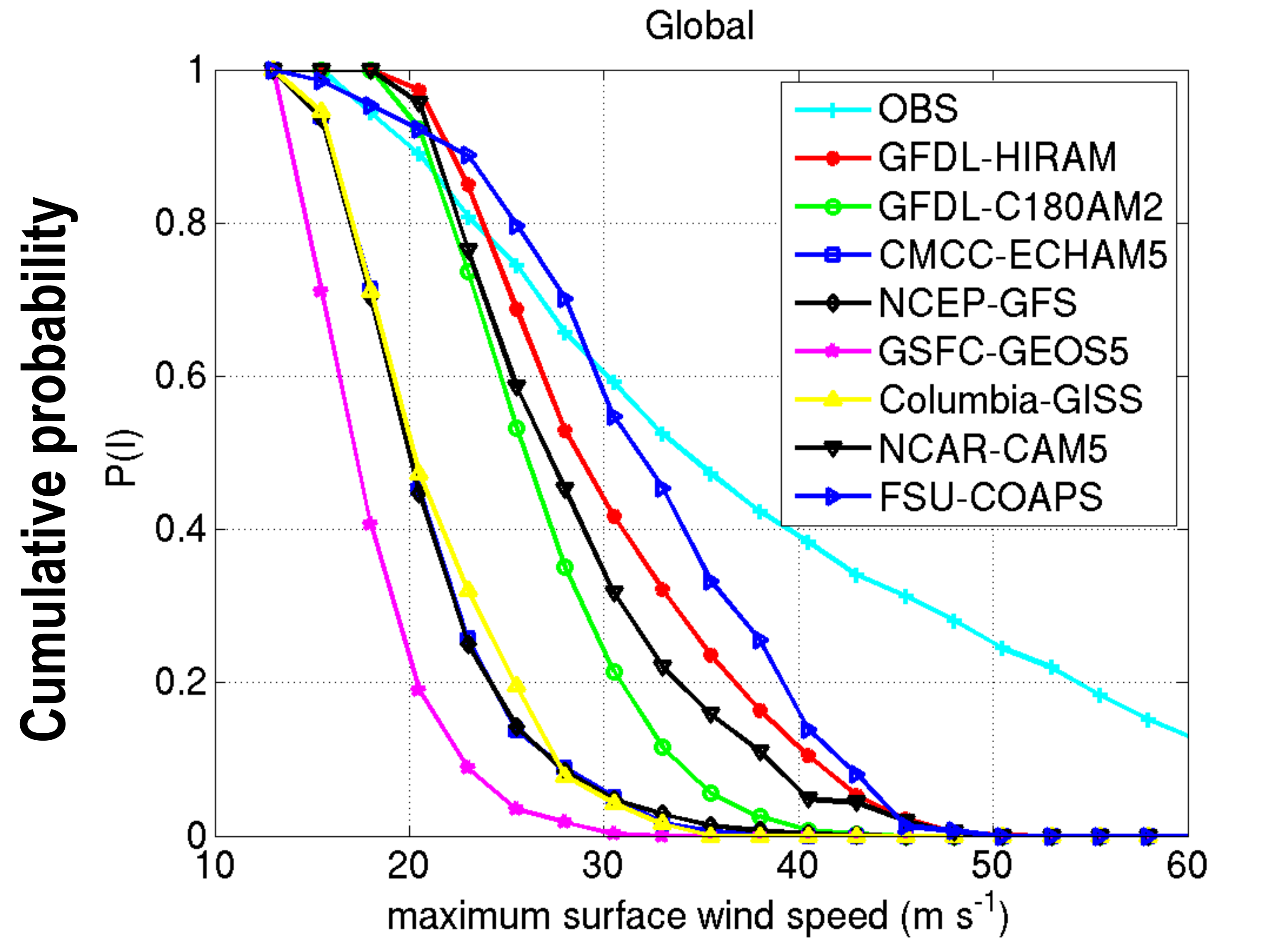




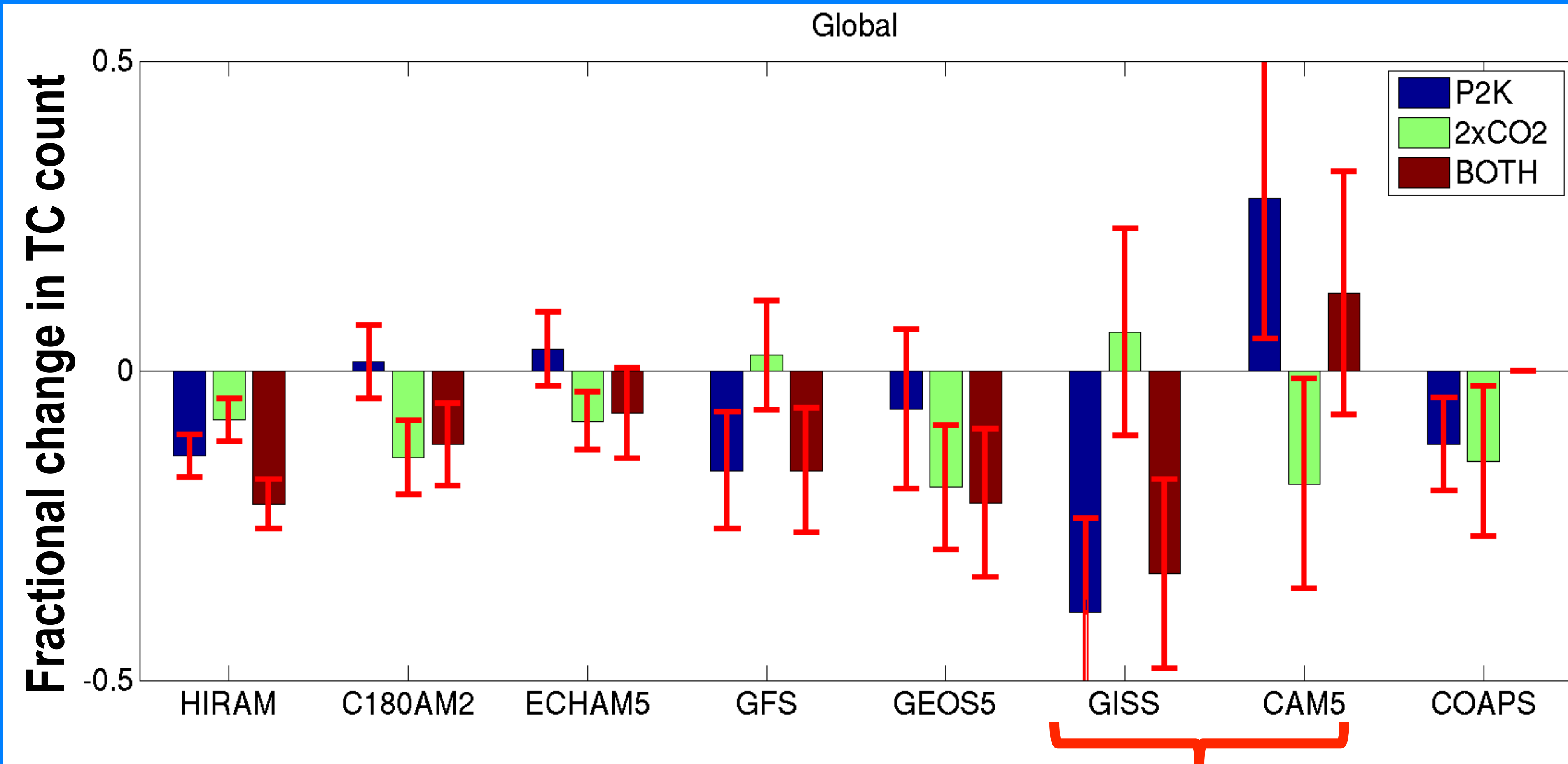
Cumulative frequency distribution of global TC intensity



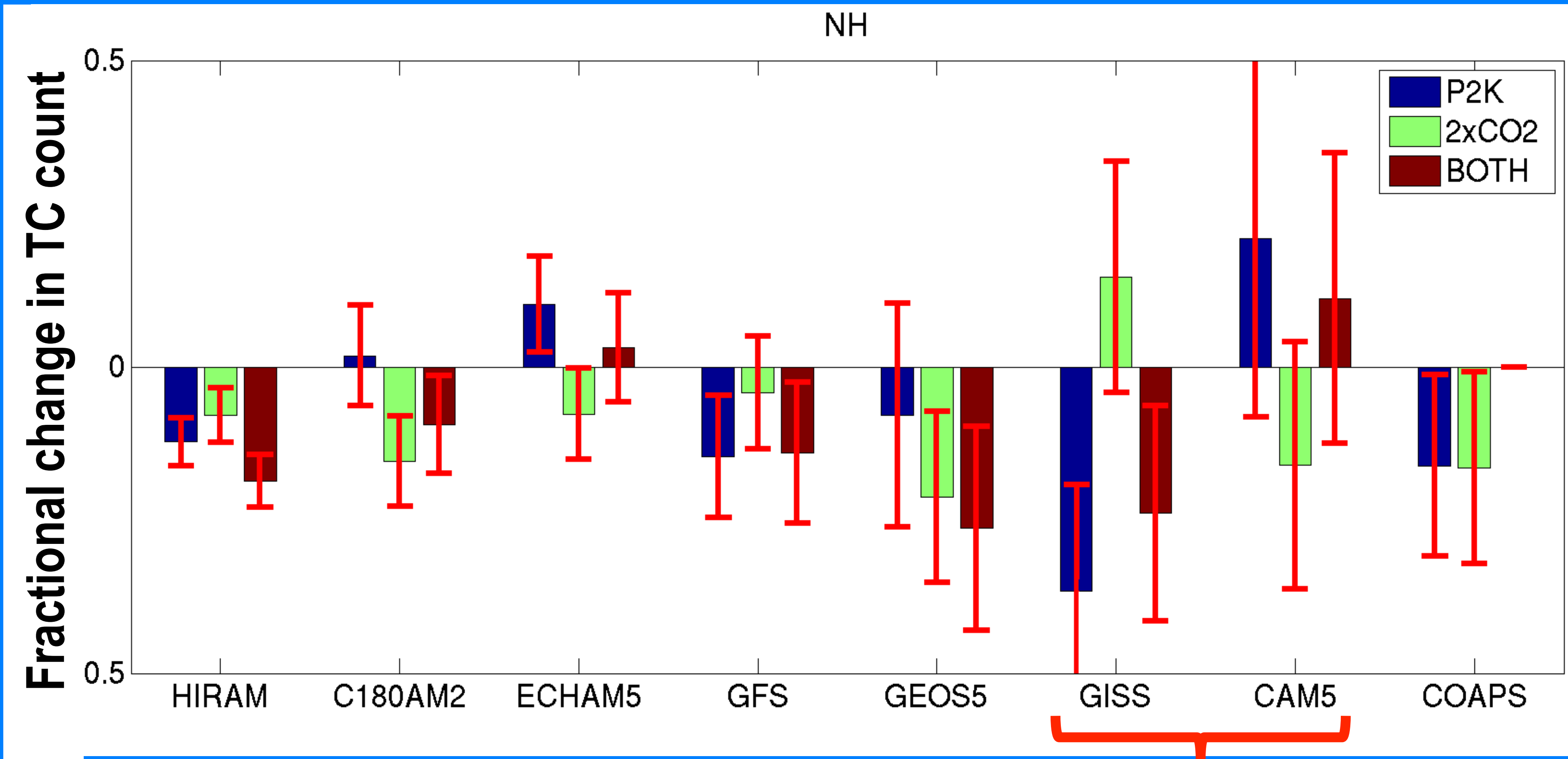
Cumulative probability distribution of global TC intensity



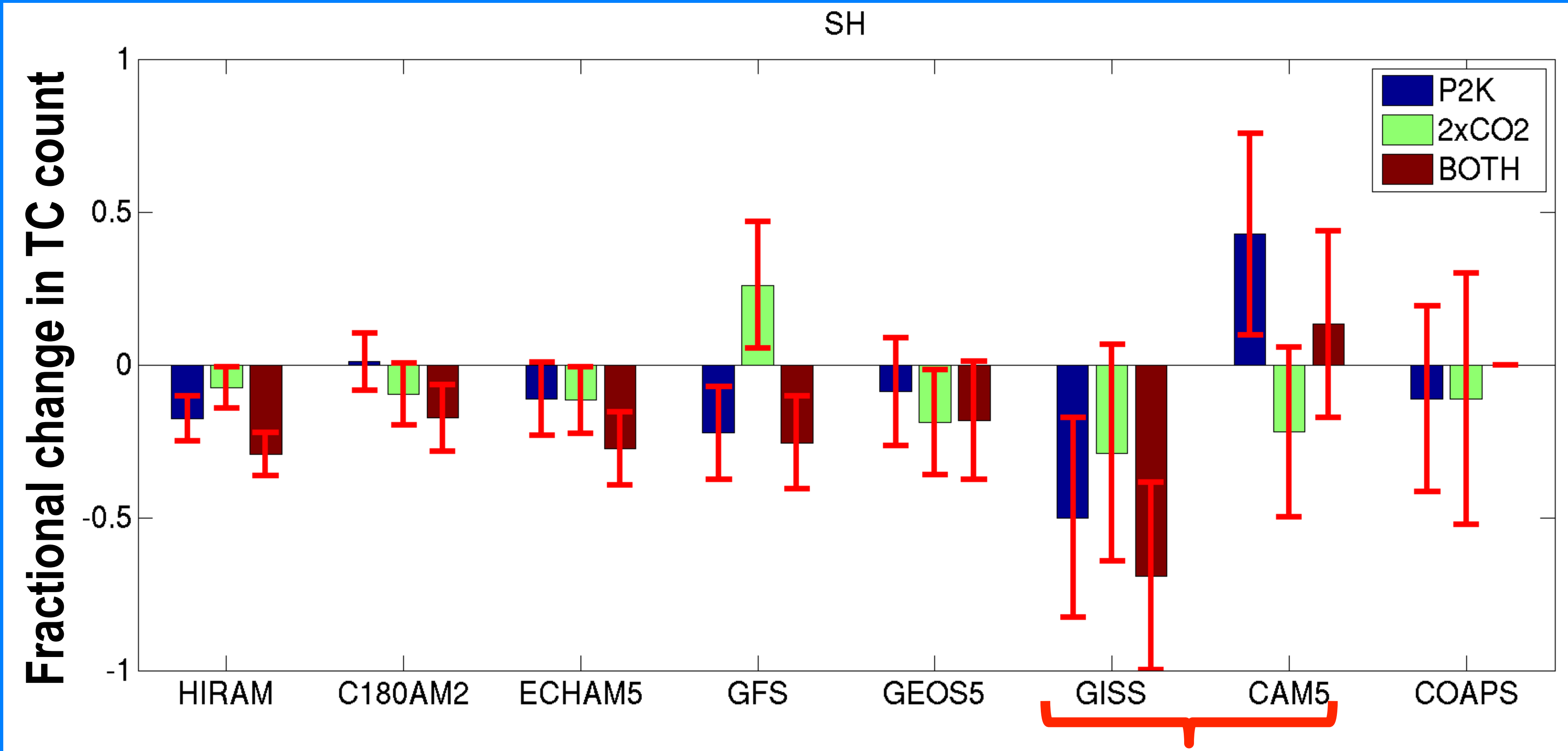
Response of global TC frequency



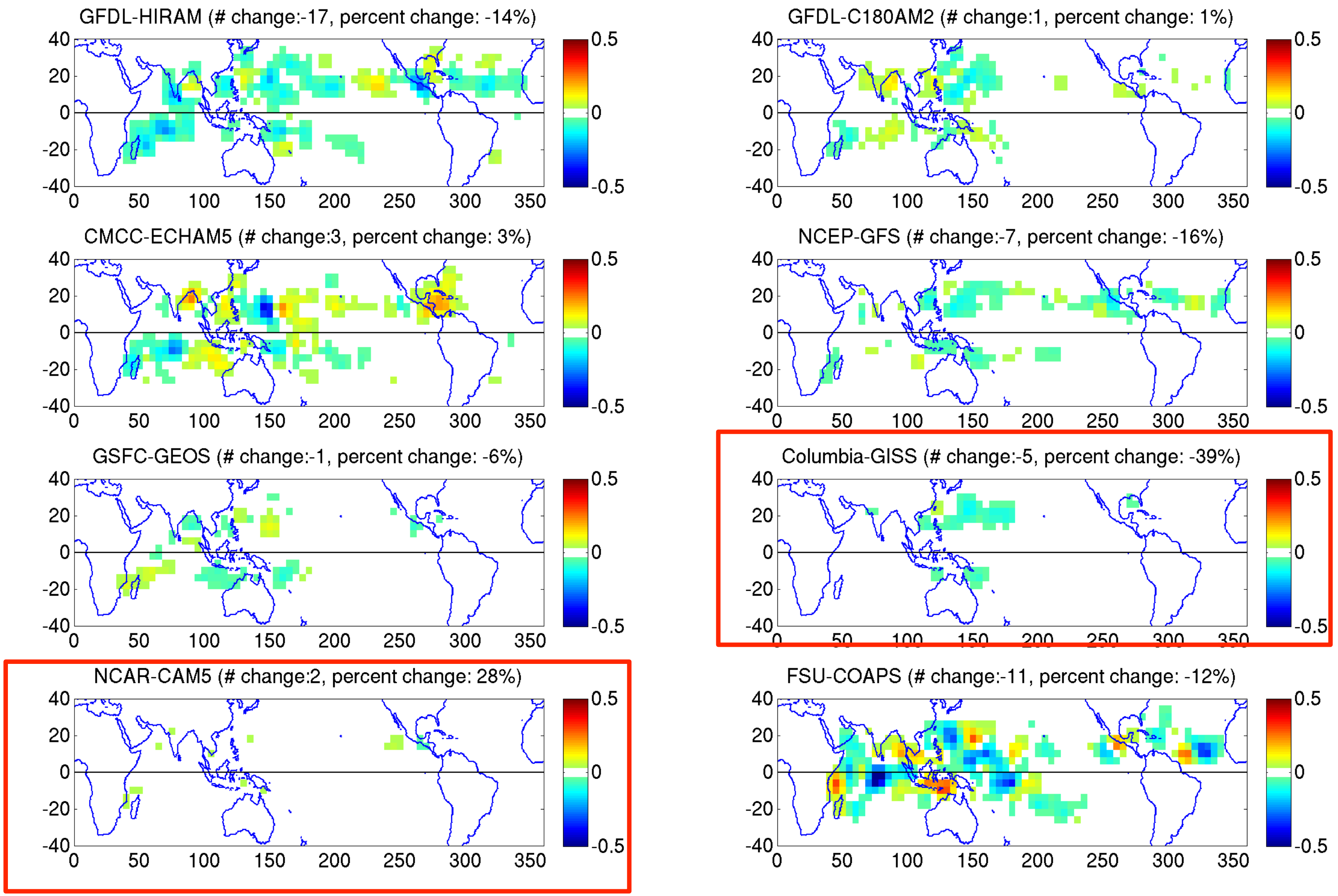
Response of N. Hemisphere TC frequency



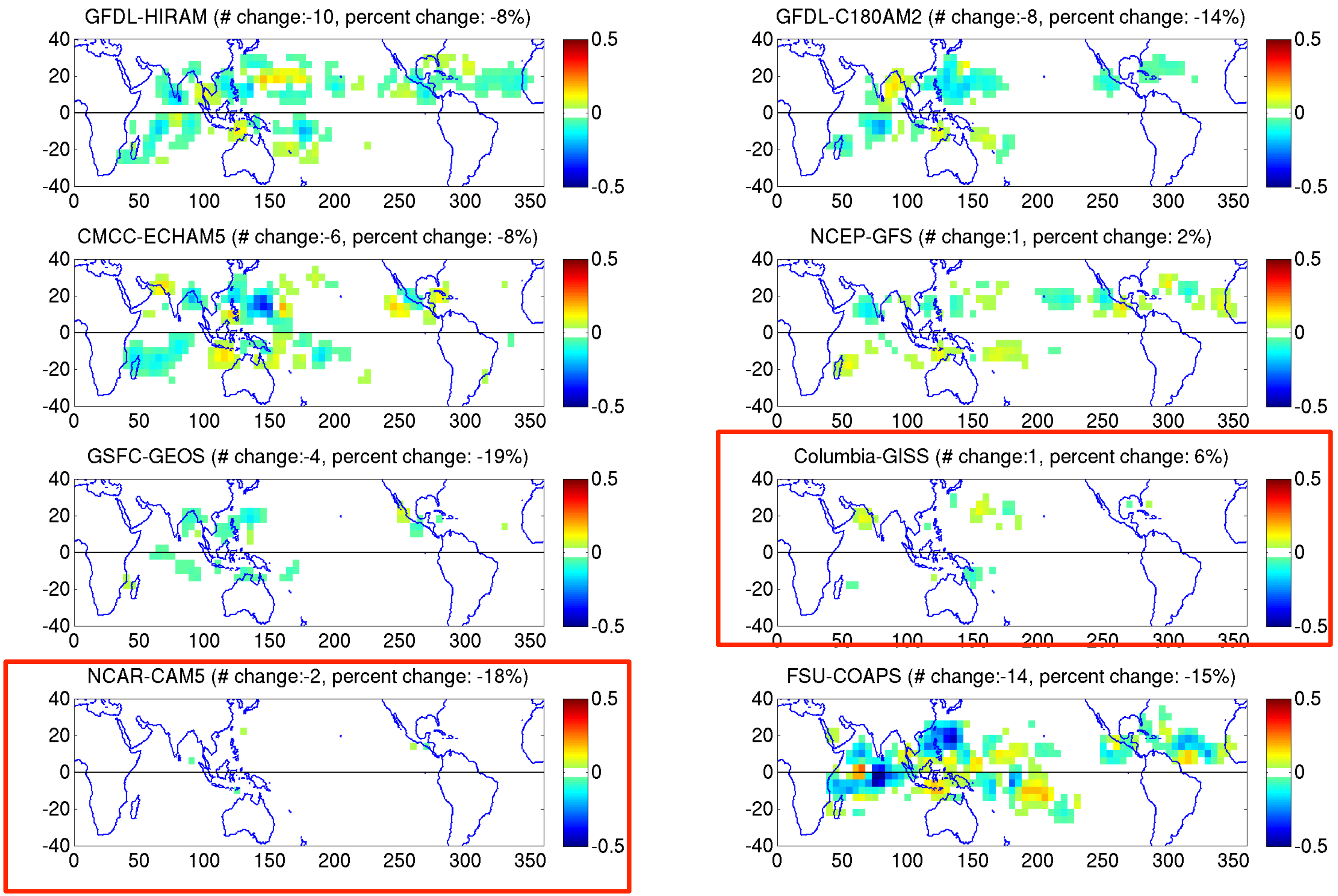
Response of S. Hemisphere TC frequency



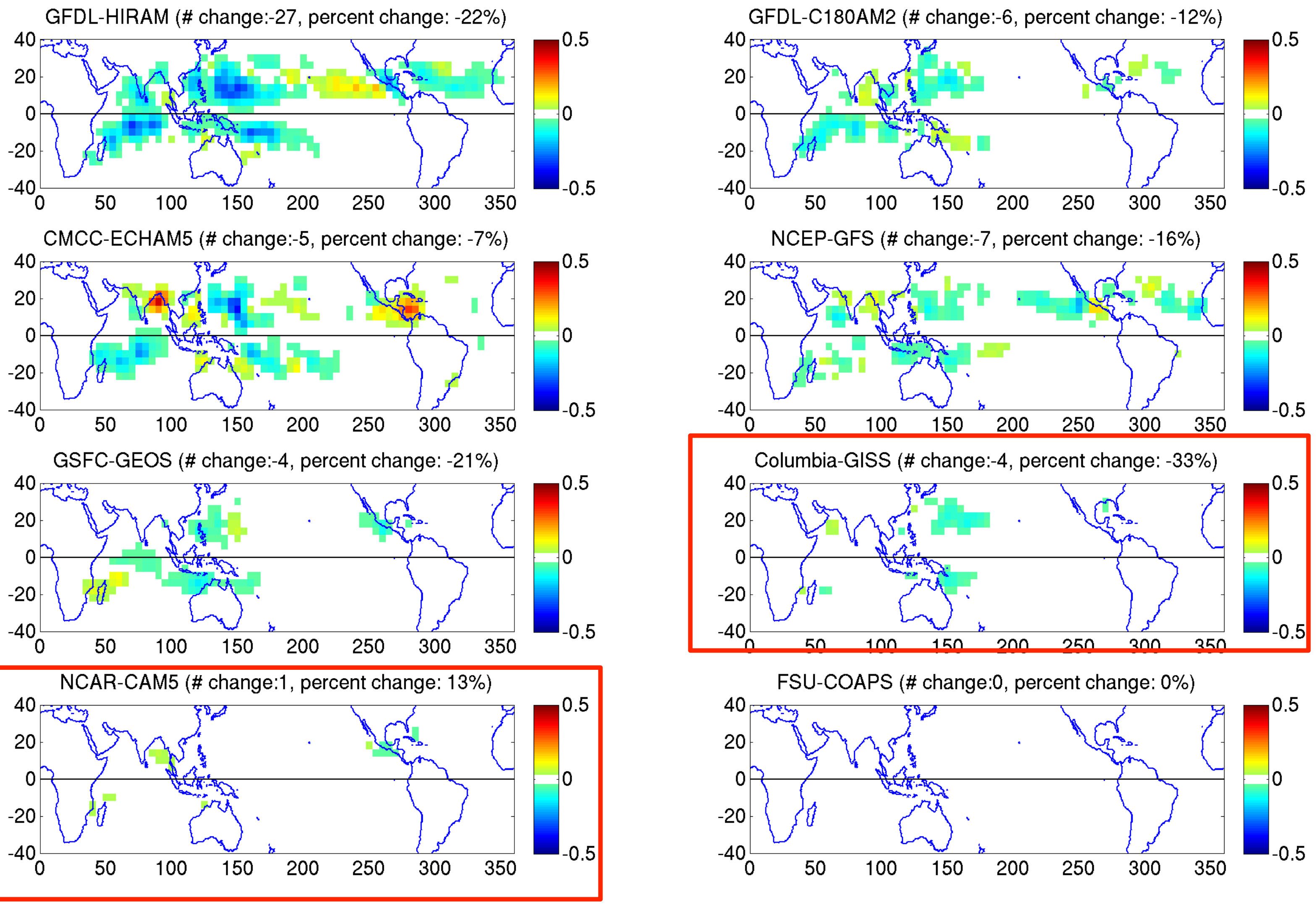
Response of geographic distribution of annual TC frequency to uniform 2K warming



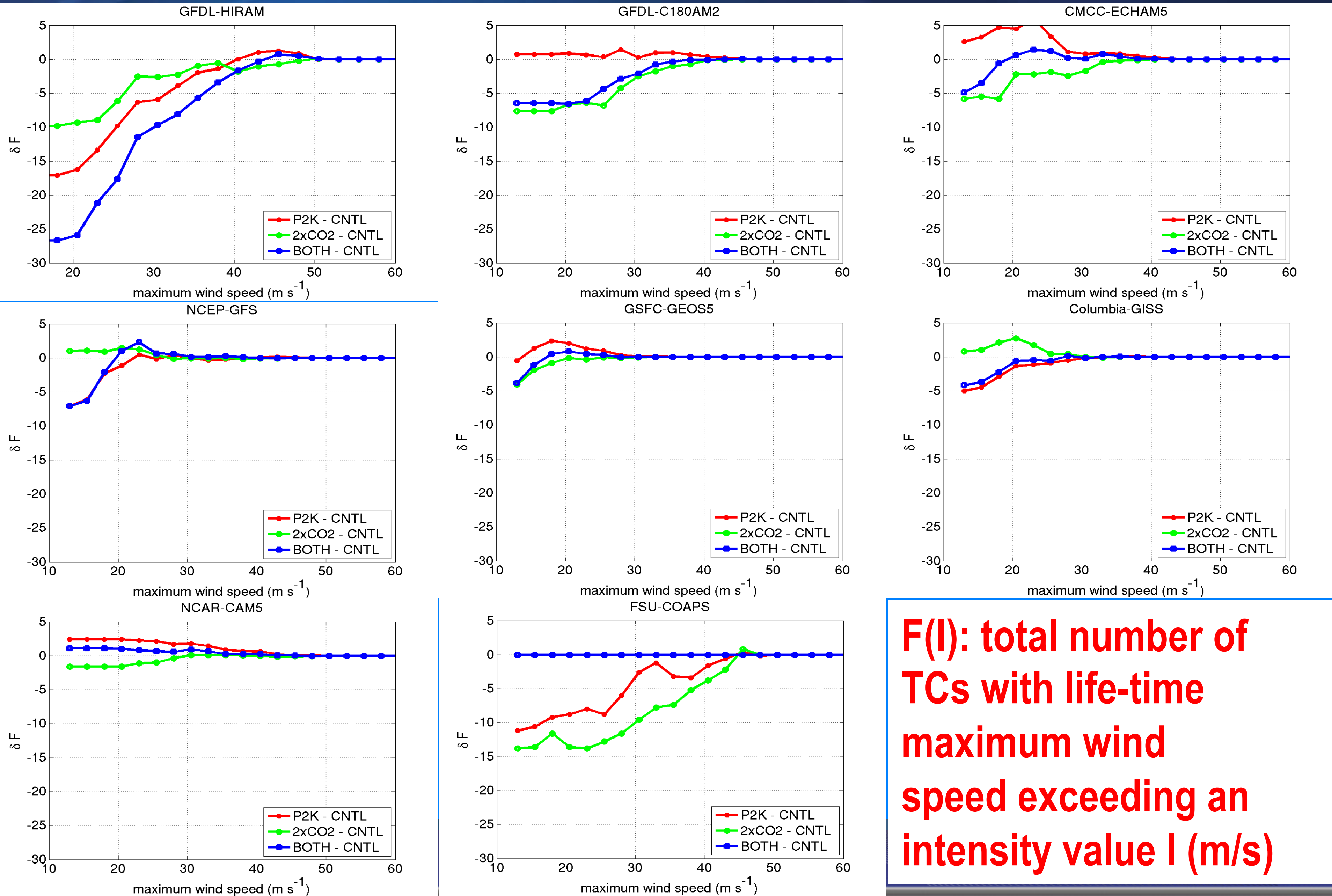
Response of geographic distribution of annual TC frequency to a doubling of atmospheric CO2 concentration



Response of annual TC frequency to both uniform 2K warming and a doubling of atmospheric CO2

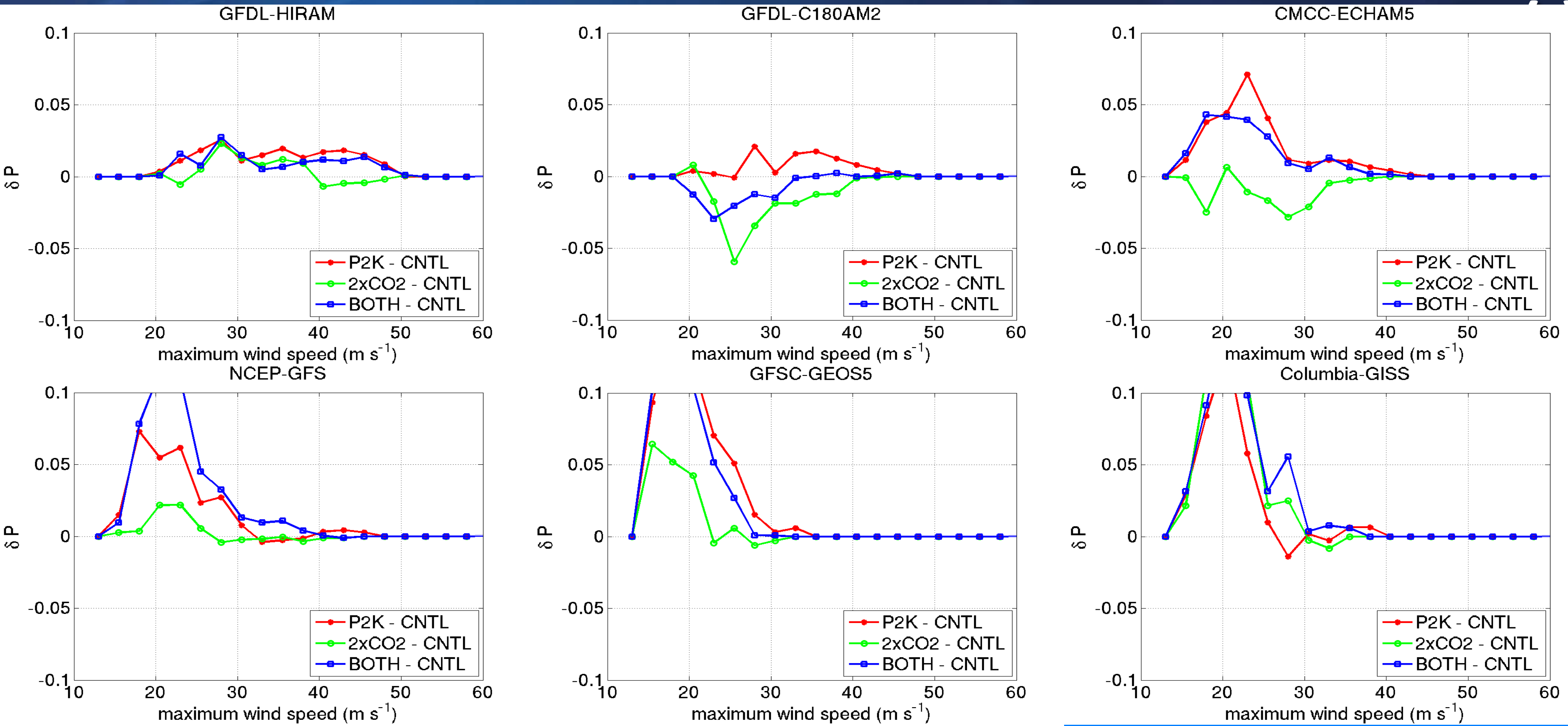


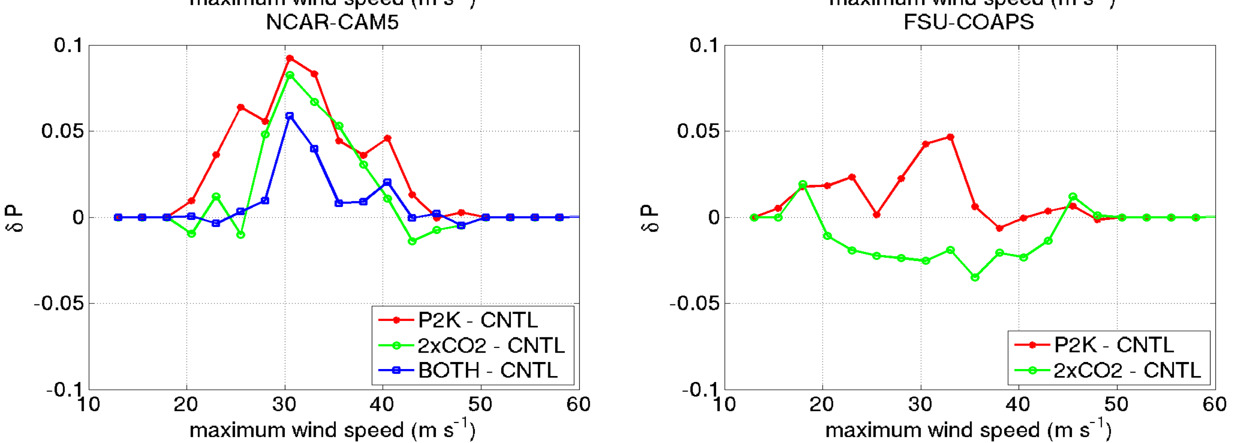
Changes in TC cumulative frequency distribution F(I)



F(I): total number of TCs with life-time maximum wind speed exceeding an intensity value I (m/s)

Changes in TC cumulative probability distribution



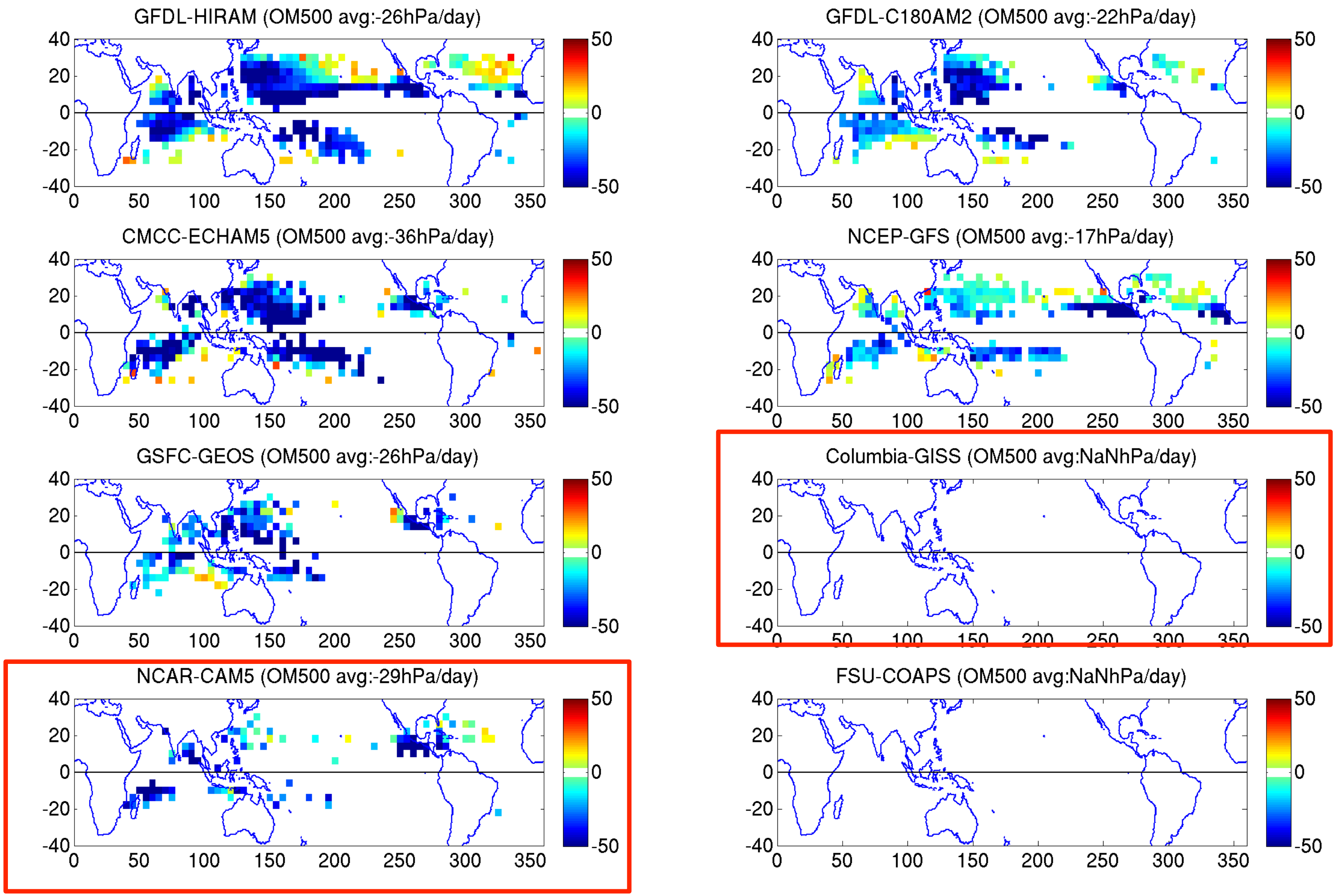


$$F(I) = NP(I)$$

$$\delta F = N\delta P + P\delta N$$

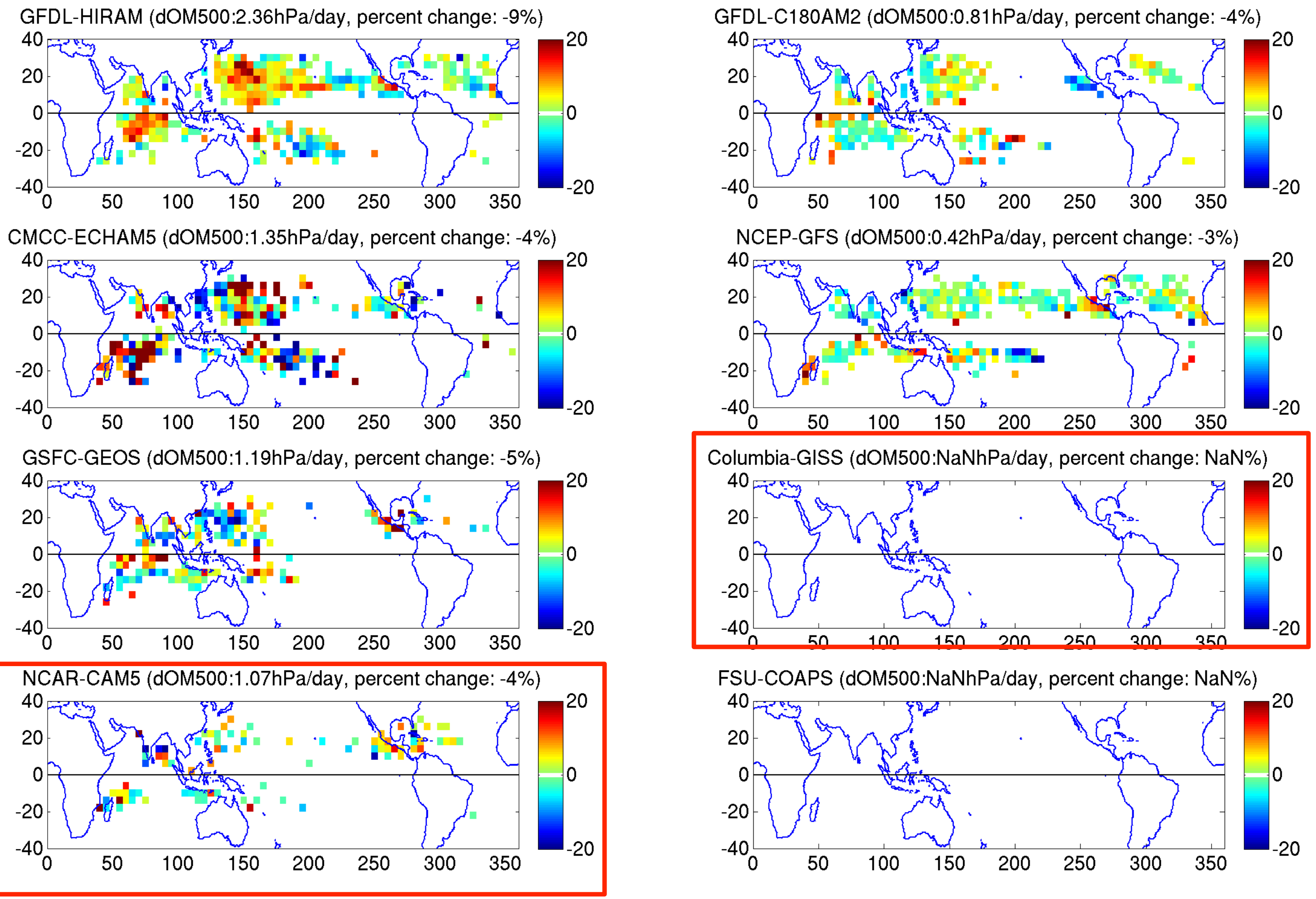
N: annual global TC count

Annual mean 500hPa omega weighted by monthly-mean climatological TC genesis frequency from each model



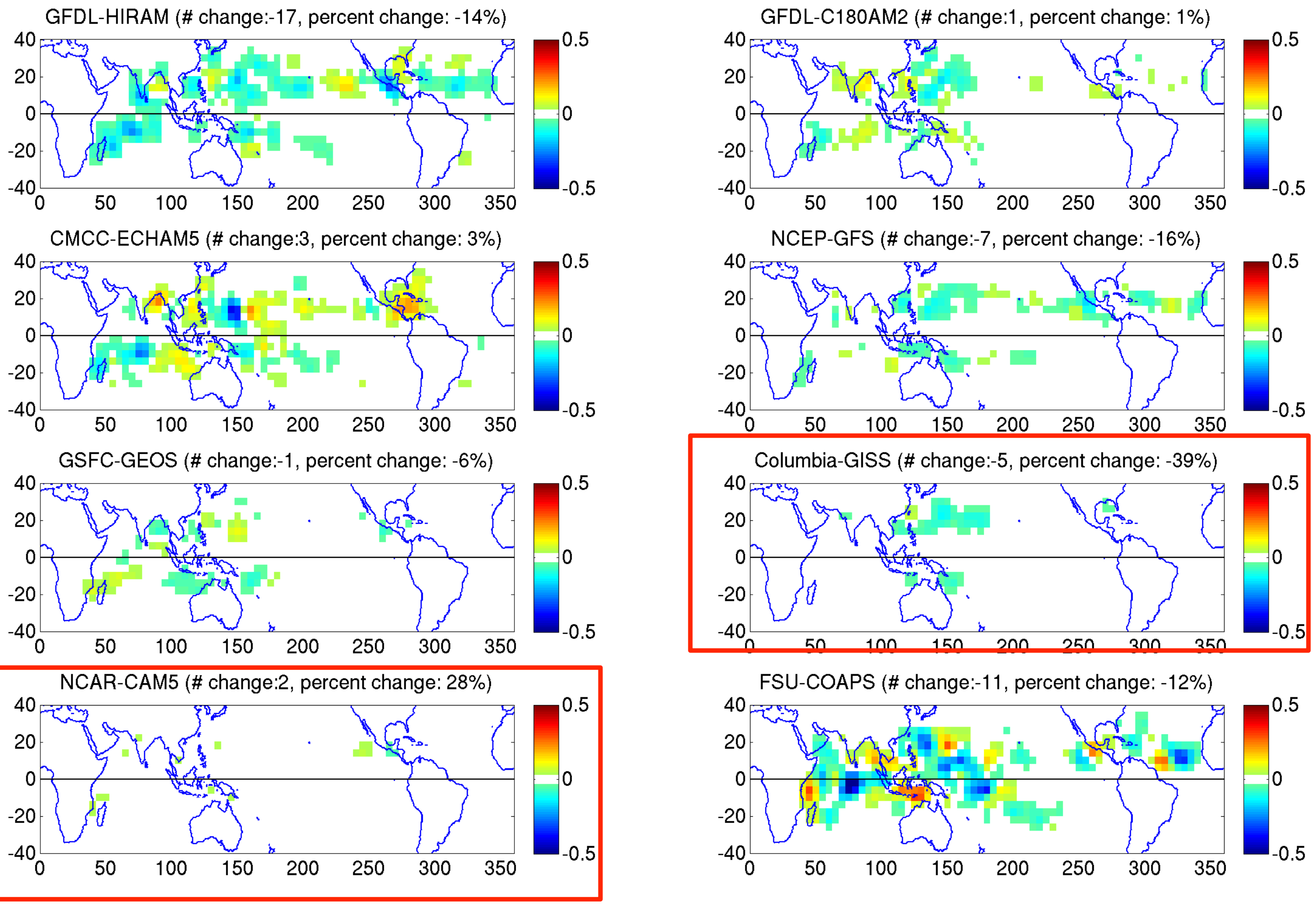
Negative value: regions of monthly ascent; positive value: regions of monthly decent

Response of the climatological TC genesis frequency weighted 500hPa omega to uniform 2K SST warming



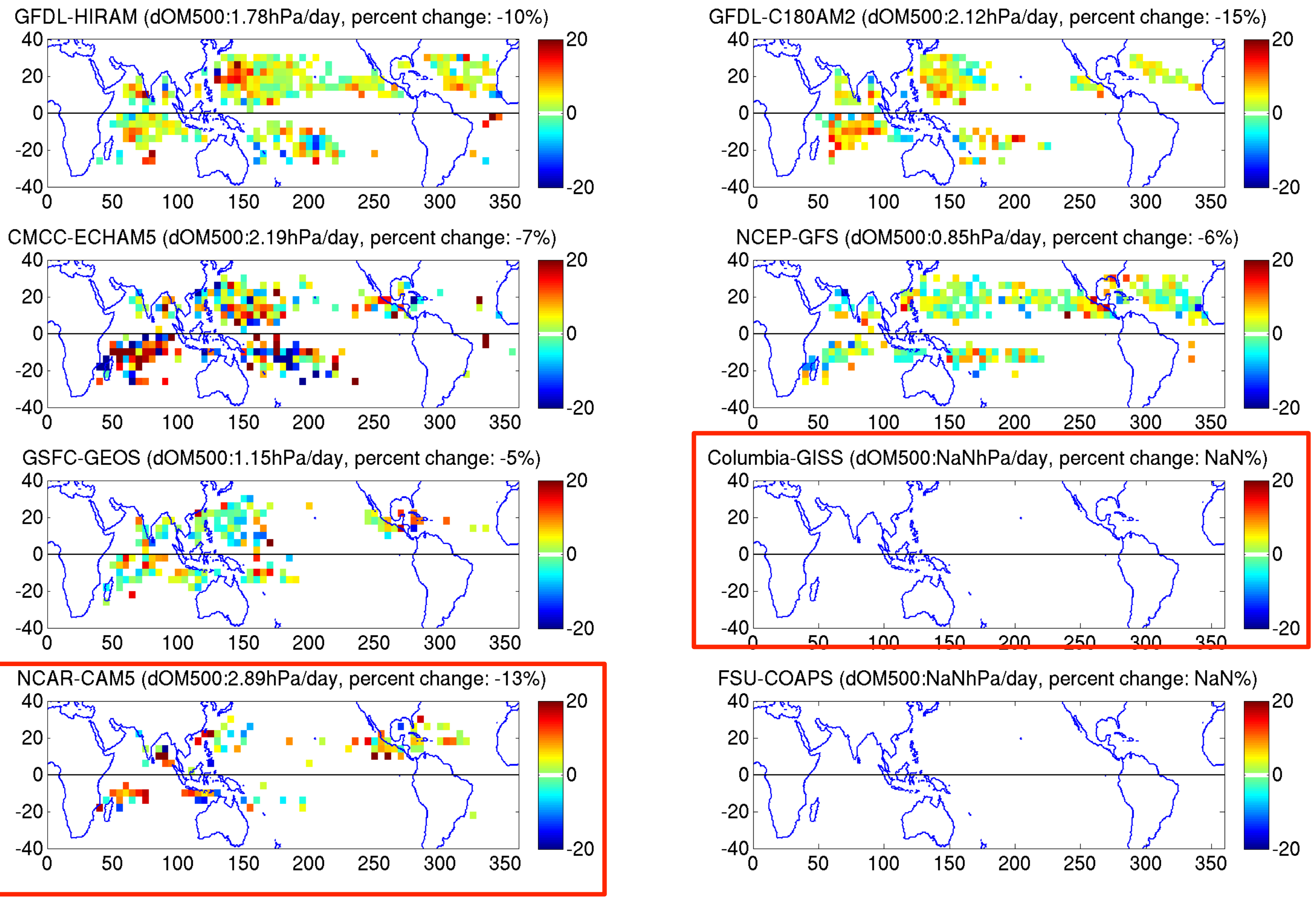
Positive value: reduction of ascent or increase of subsidence

Response of geographic distribution of annual TC genesis frequency to uniform 2K warming



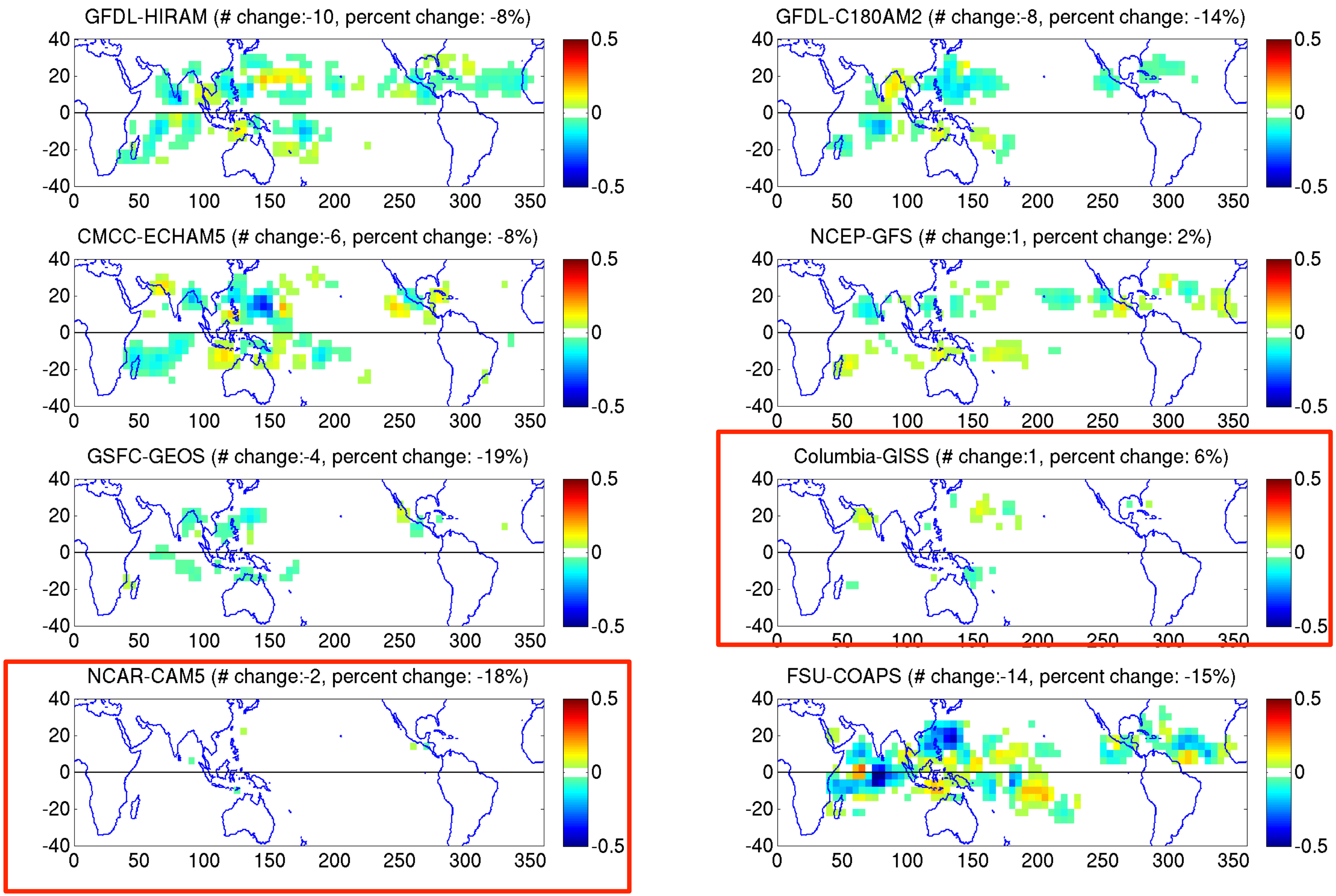
Positive: increase of TC genesis frequency; negative: reduction of TC genesis frequency

Response of the climatological TC genesis frequency weighted 500hPa omega to a doubling of atmospheric CO2 concentration

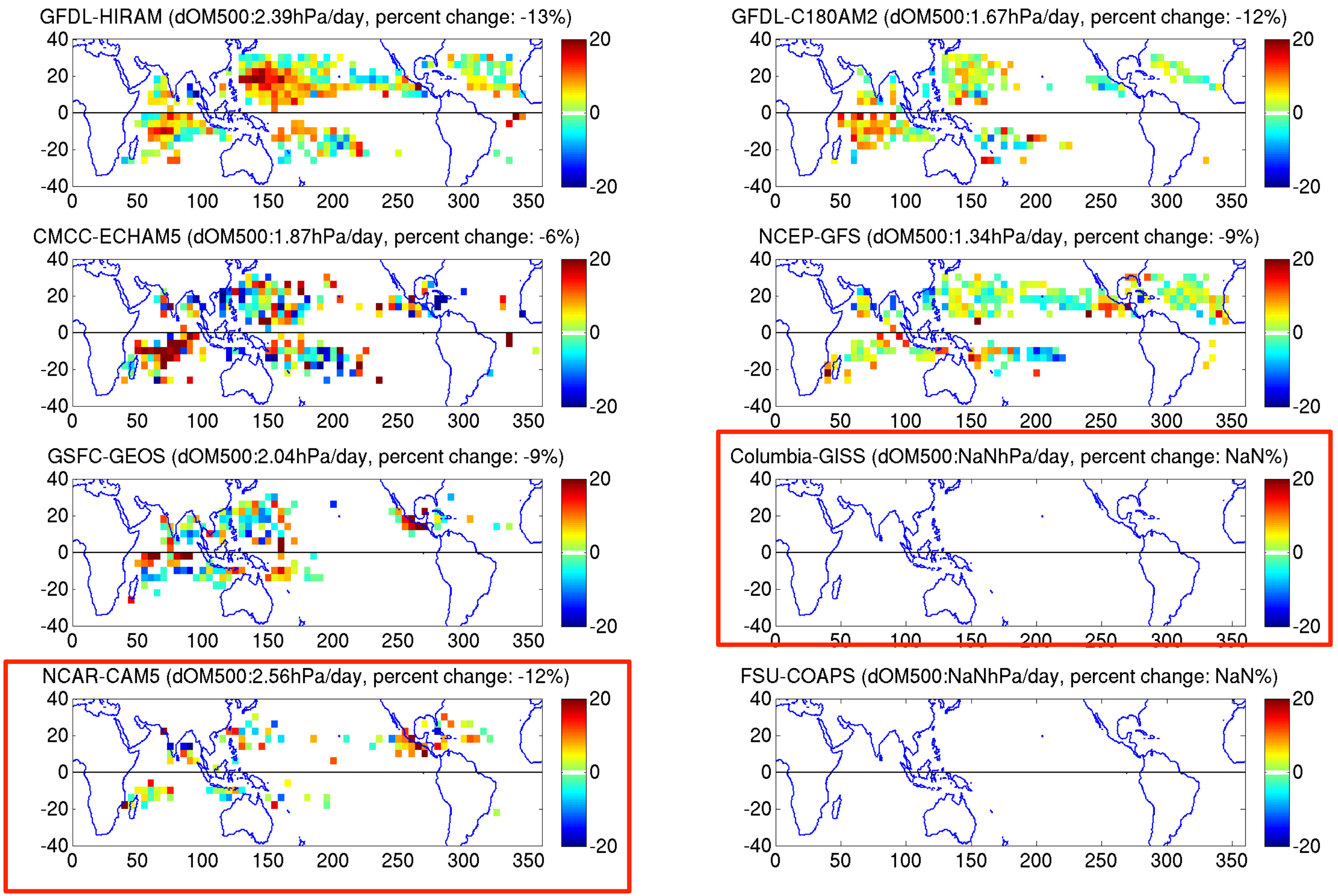


Positive value: reduction of ascent or increase of subsidence

Response of geographic distribution of annual TC frequency to a doubling of atmospheric CO2 concentration

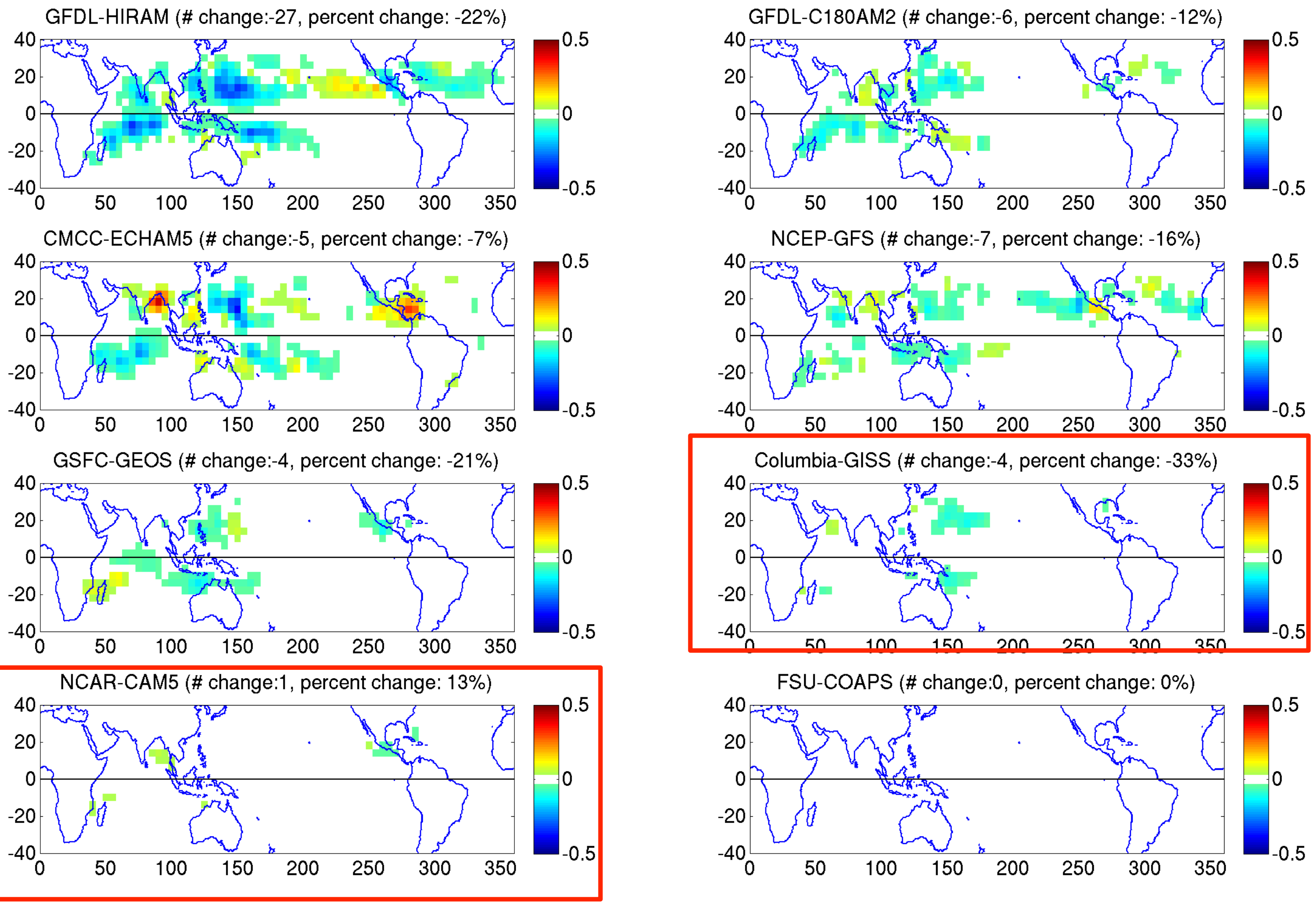


Response of TC genesis frequency weighted 500hPa omega to both uniform 2K warming and doubling of atmospheric CO_2



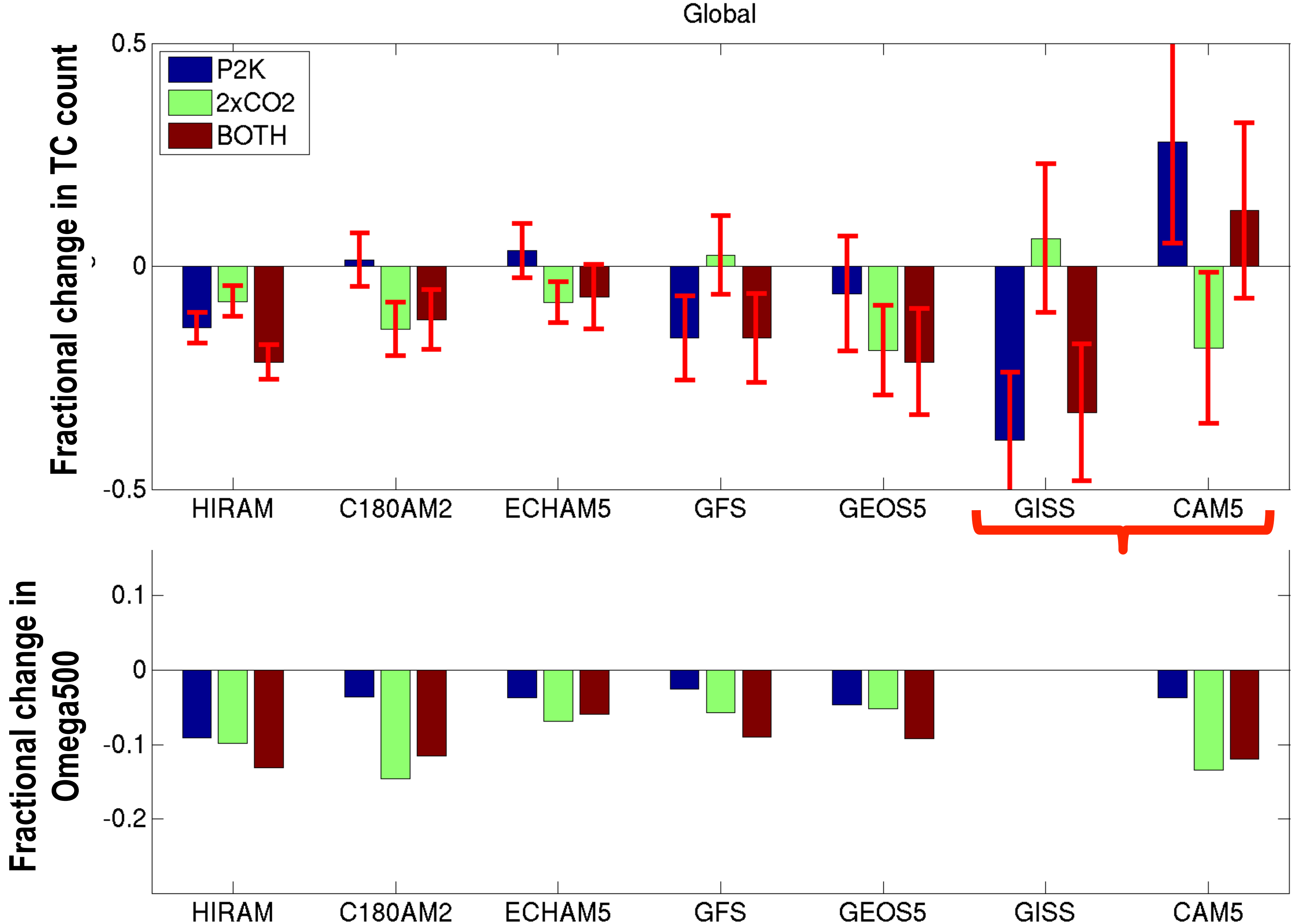
Positive value: reduction of ascent or increase of subsidence

Response of annual TC frequency to both uniform 2K warming and a doubling of atmospheric CO2

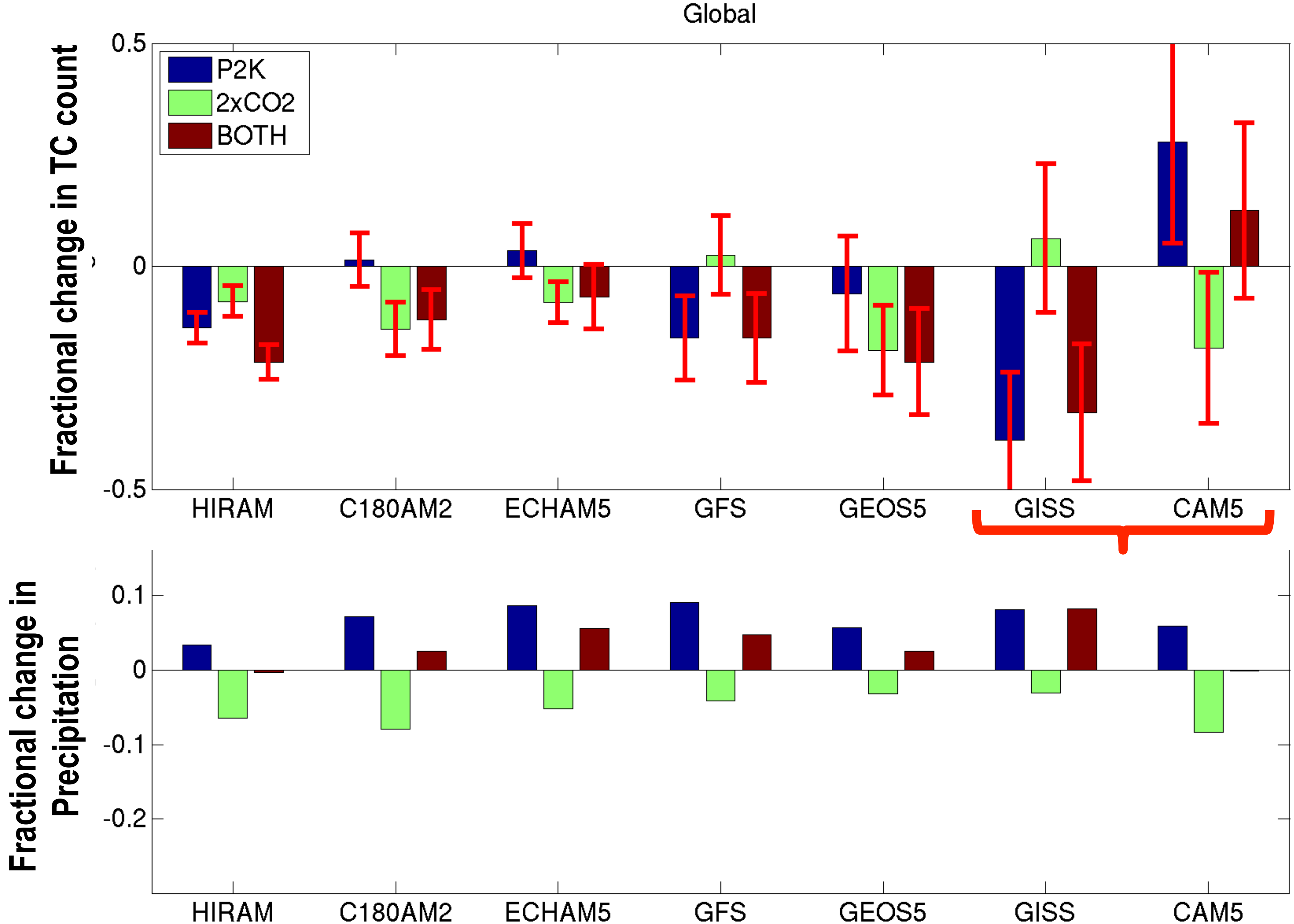


Positive: increase of TC genesis frequency; negative: reduction of TC genesis frequency

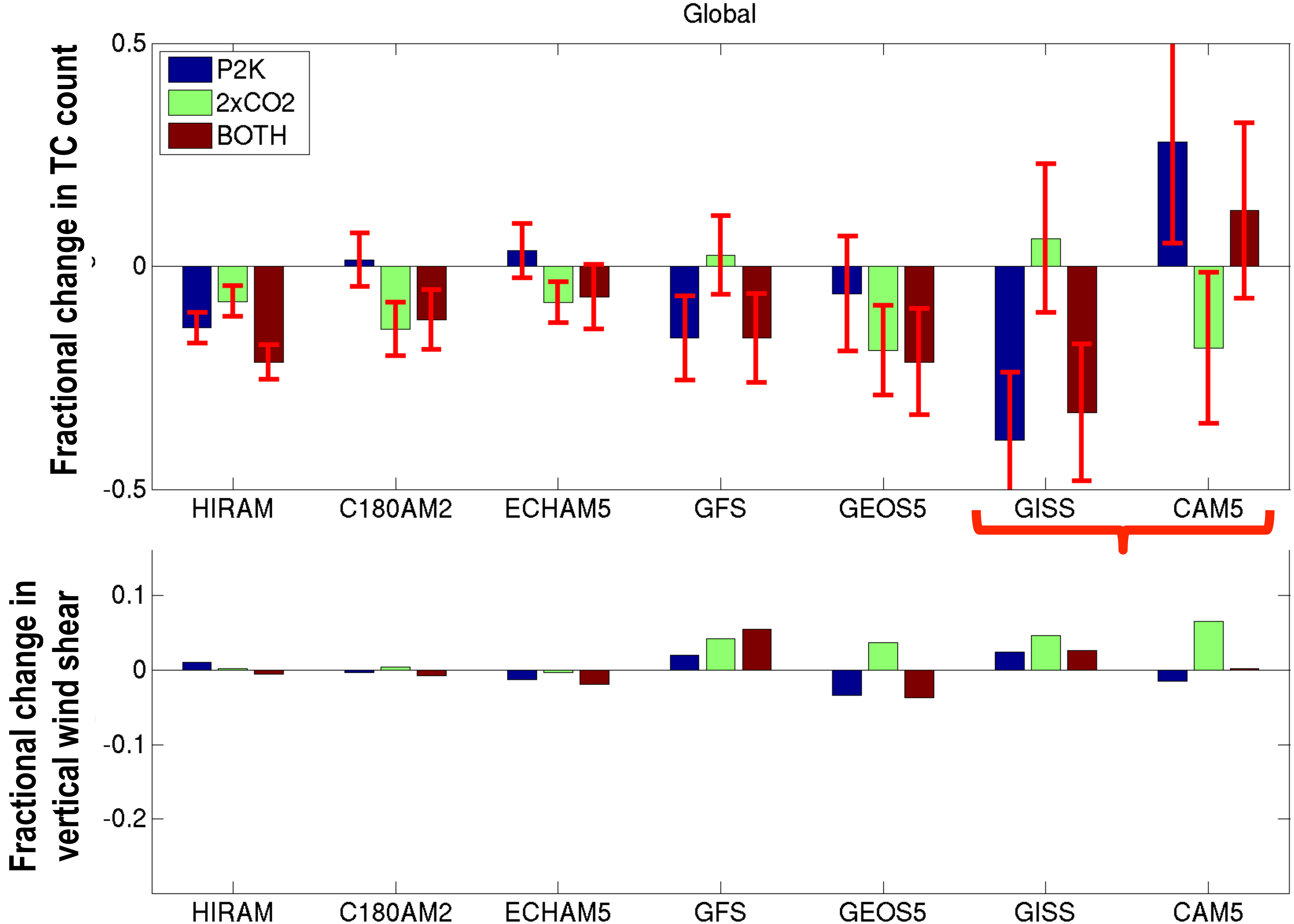
Response of global TC frequency versus TC genesis frequency weighted 500hPa omega



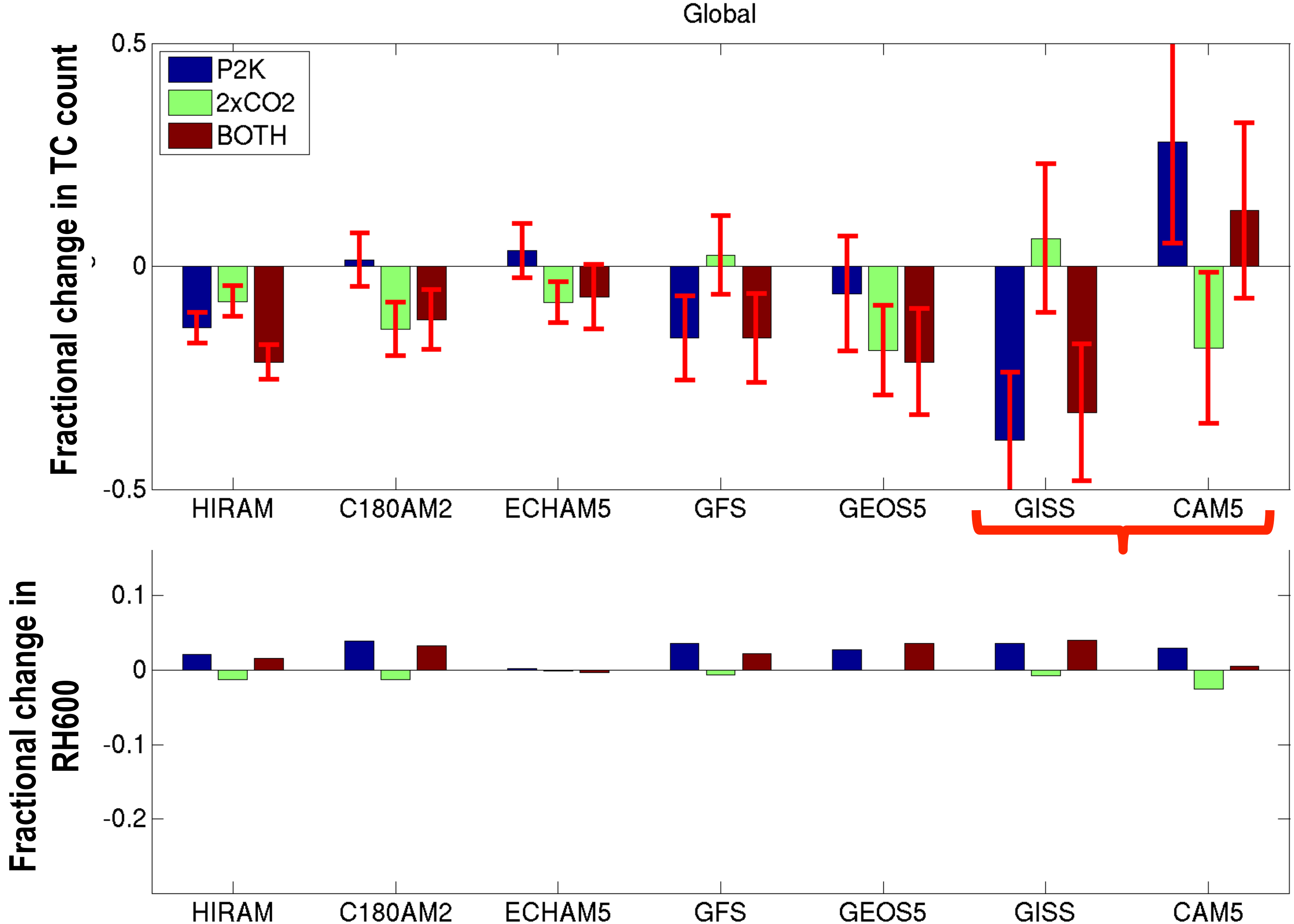
Response of global TC frequency versus TC genesis frequency weighted precipitation



Response of global TC frequency versus TC genesis frequency weighted vertical wind shear



Response of global TC frequency versus TC genesis frequency weighted 600hPa relative humidity



Summary

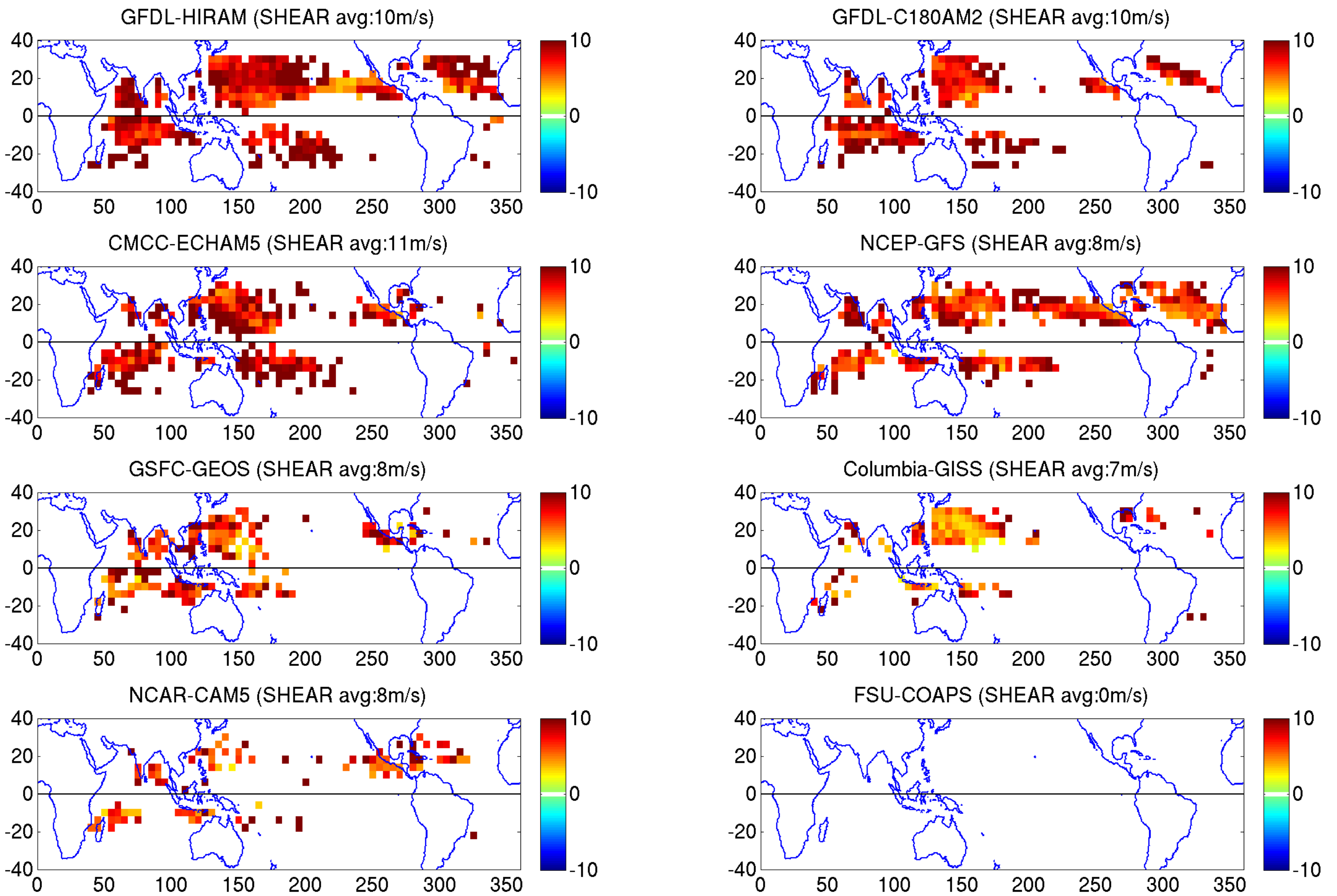
- Except CAM5, all models produce a significant reduction in global TC frequency for the case of both 2K warming and a doubling of CO_2.
- The partition of the total response to individual forcing is uncertain. In particular, 4 models show insignificant change to warming, while 2 models exhibit insignificant change to CO_2 doubling. No models generate a significant increase of global TC frequency to either forcing.
- Models producing less reduction to warming tend to produce more reduction to CO_2 doubling.
- 500hPa omega appears to be the best single variable index for explaining the models' responses although it does not explain all models.

Future work

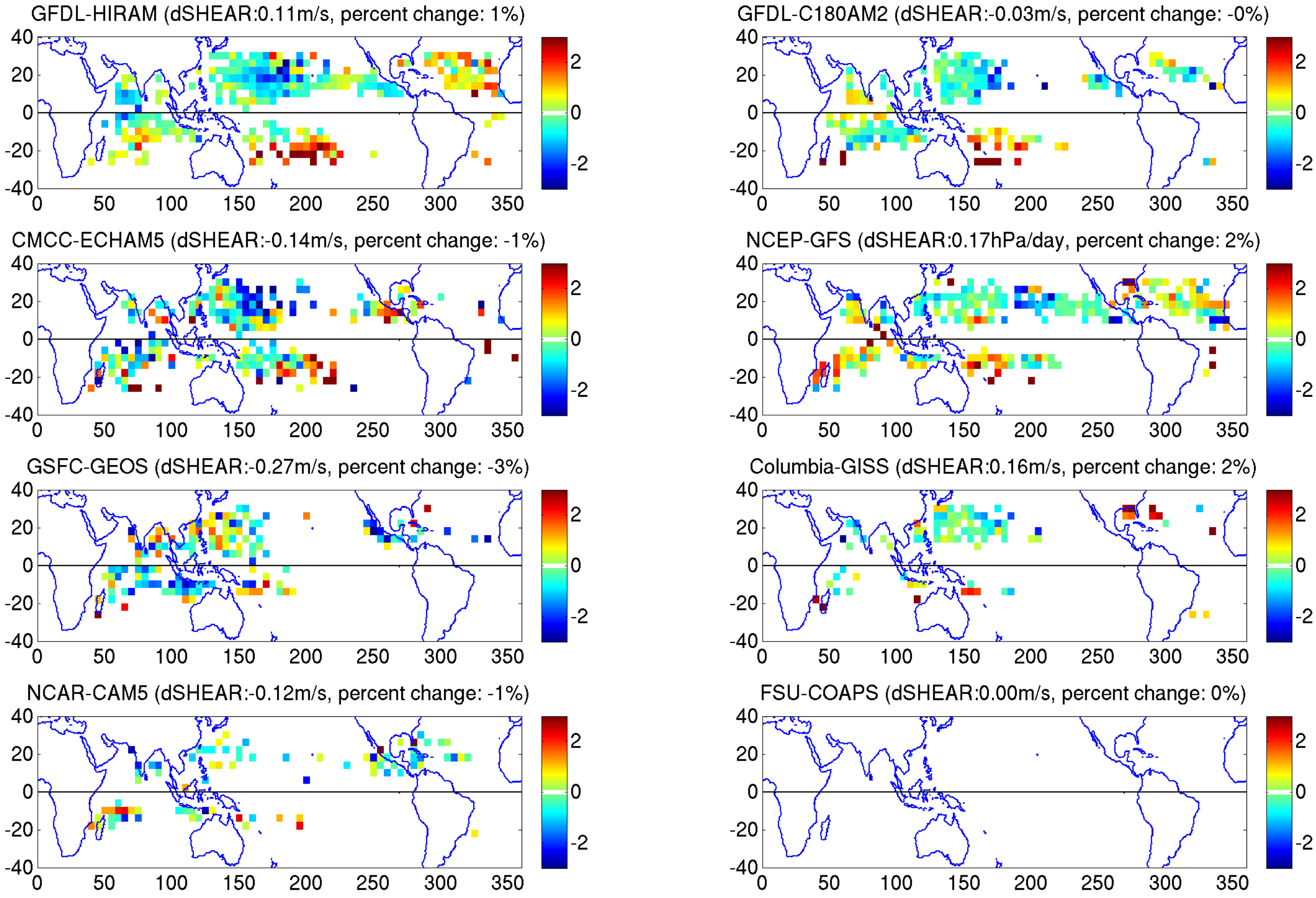
- Why some models produce insignificant change in global TC frequency while others produce a reduction? What are the sources of uncertainties?
  - In the case of uniform SST warming, uncertainty associated with the response of parameterized convection to warming may be the key.
  - In the case of CO_2 doubling, uncertainty associated with the response of monsoonal circulation may be the key.

End

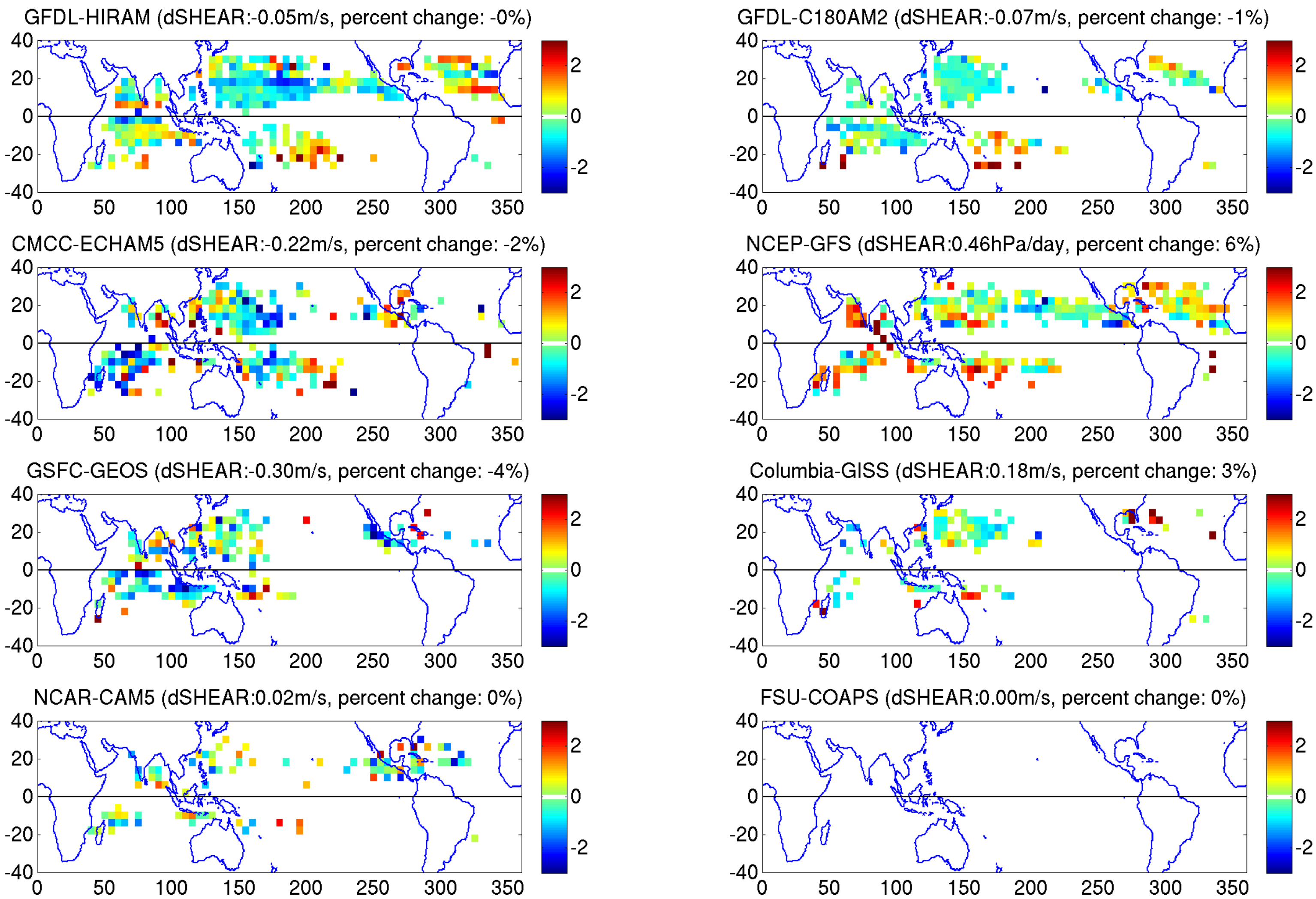
Annual mean 200-850 hPa vertical wind shear weighted by control climatological monthly-mean TC genesis frequency



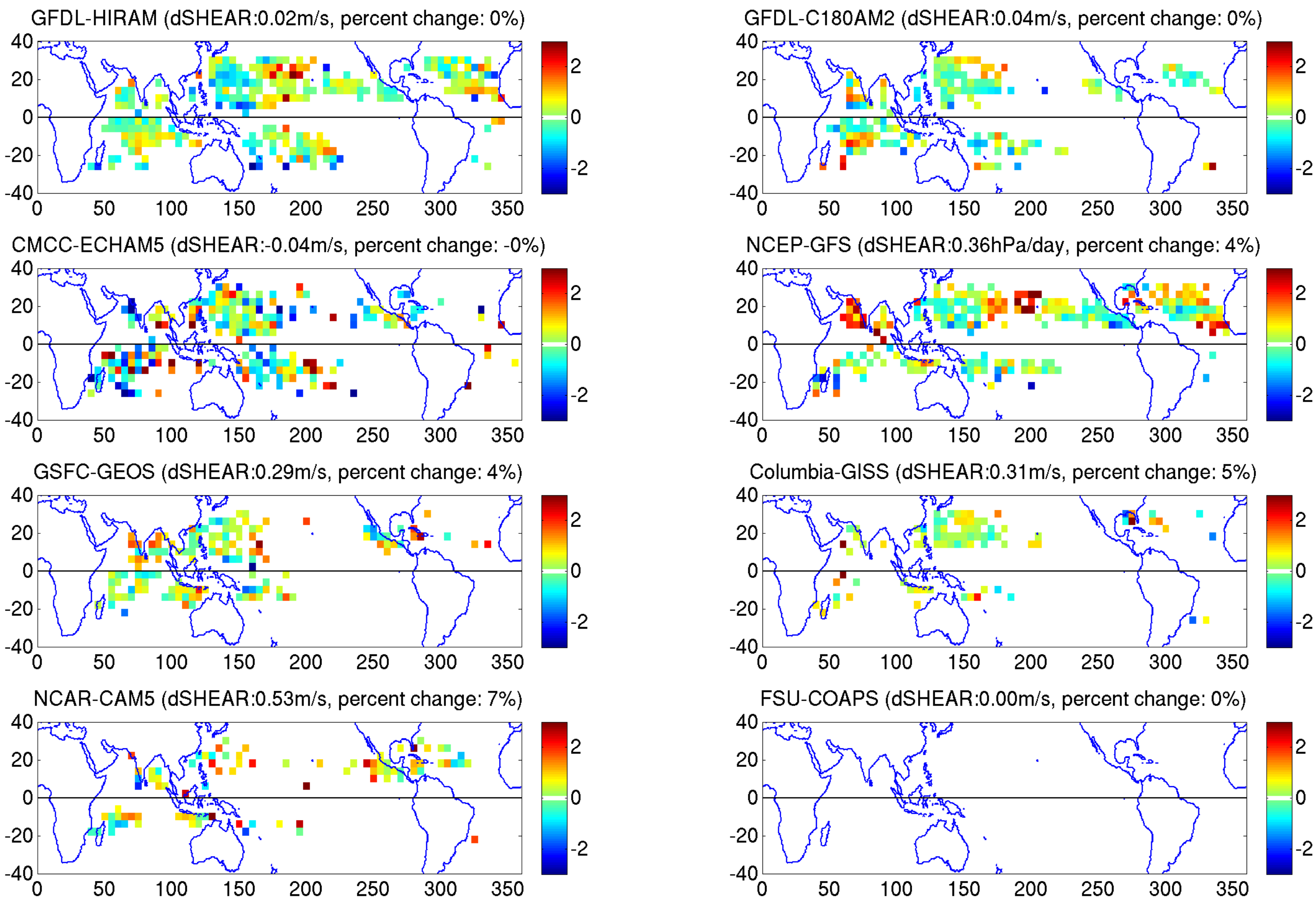
Changes in climatological TC genesis frequency weighted vertical wind shear between uniform warming and control simulation

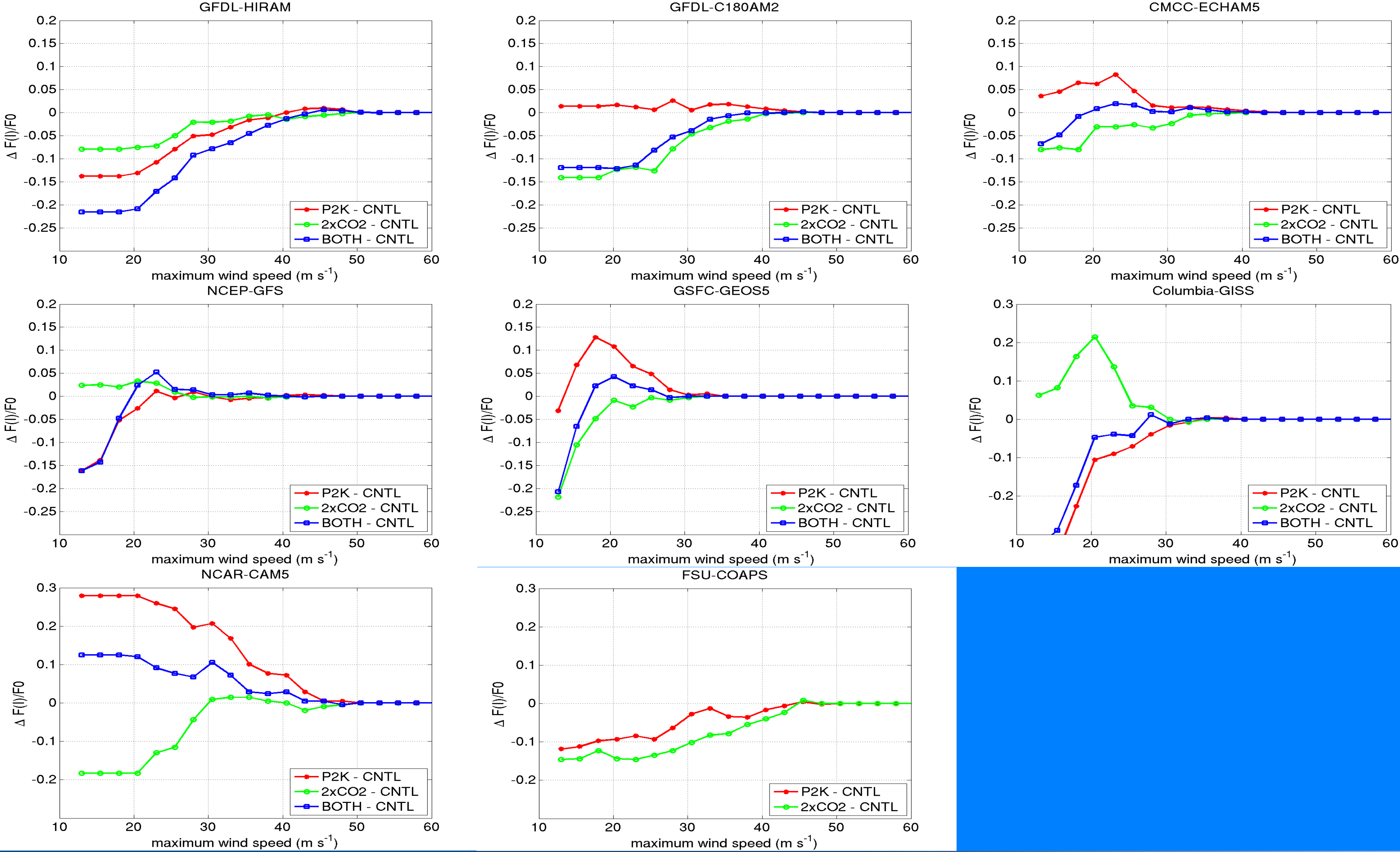


Changes in climatological TC genesis frequency weighted vertical wind shear between double CO2 and control simulation



Changes in climatological TC genesis frequency weighted vertical wind shear between uniform 2K plus double CO2 and control simulation




GFDL-HIRAM
GFDL-C180AM2
CMCC-ECHAM5
NCEP-GFS
GSFC-GEOS5
Columbia-GISS
NCAR-CAM5
FSU-COAPS
Δ F(I)/F0
maximum wind speed (m s-1)
P2K - CNTL
2xCO2 - CNTL
BOTH - CNTL