Tropical Cyclone Simulation and Response to CO_2 Doubling in GFDL CM2.5 High-resolution Coupled Global Climate Model

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GFDL CM2.5

- Derived from CM2.1
- Fully coupled atmosphere, ocean, land and cryosphere model
- Resolution: ~50 km with 32 levels for atmosphere and ~25 km with 50 levels for ocean
- Compared to CM2.1, CM2.5 shows marked improvement in simulating ITCZ, ENSO, regional rainfall features and Indian monsoon, etc. (Delworth et al. 2012, Doi et al. 2012)

Experiments

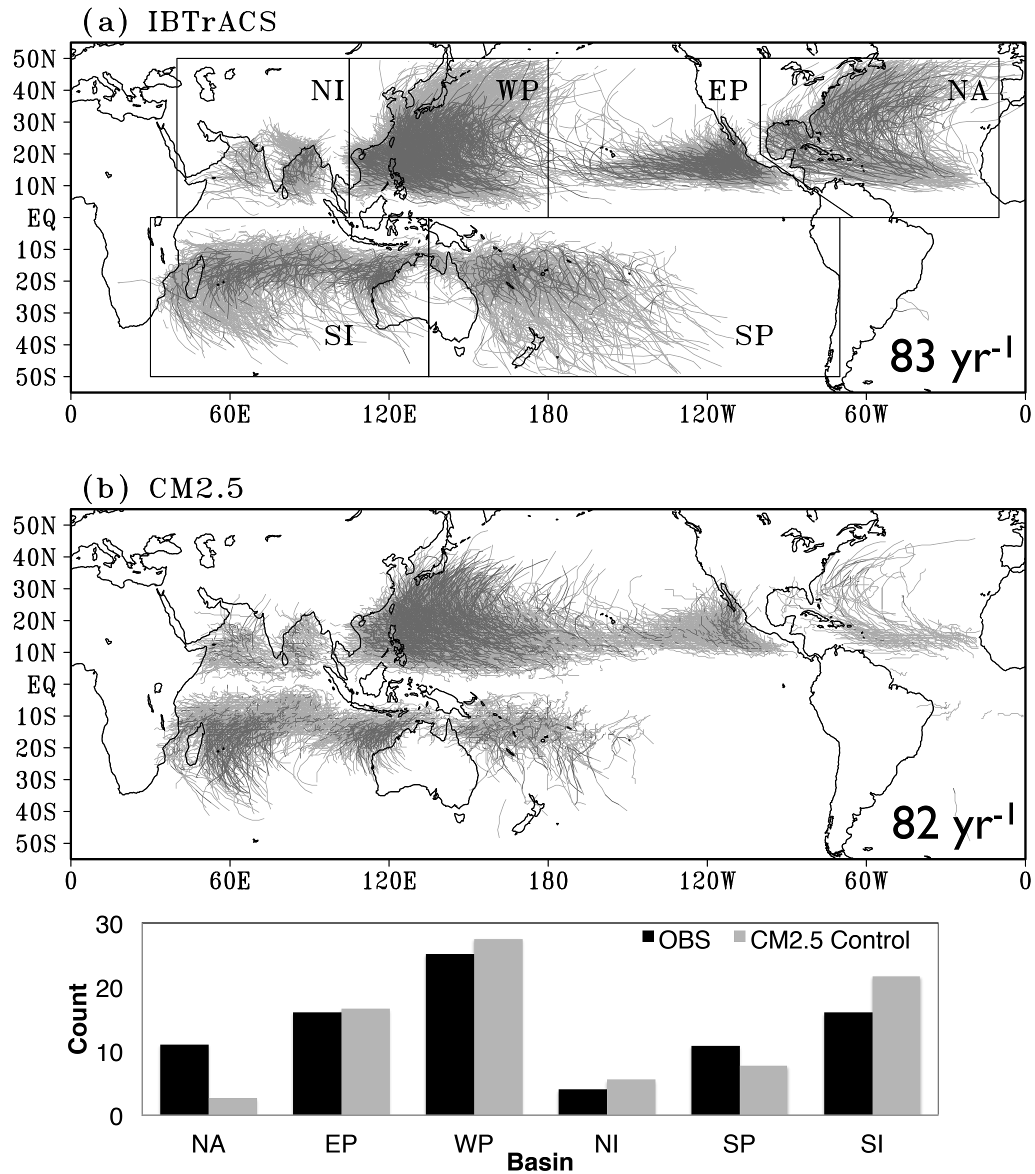
- Control : 280 year simulation with the atmospheric composition and external forcing fixed at 1990 levels.
- CO_2 Doubling : 140 year simulation with atmospheric CO_2 increases at 1% per year until doubling after 70 year.

- We analyze 91-140 years for both experiments to focus on the approximately steady state response to CO_2 doubling .

Detection of Tropical Cyclone

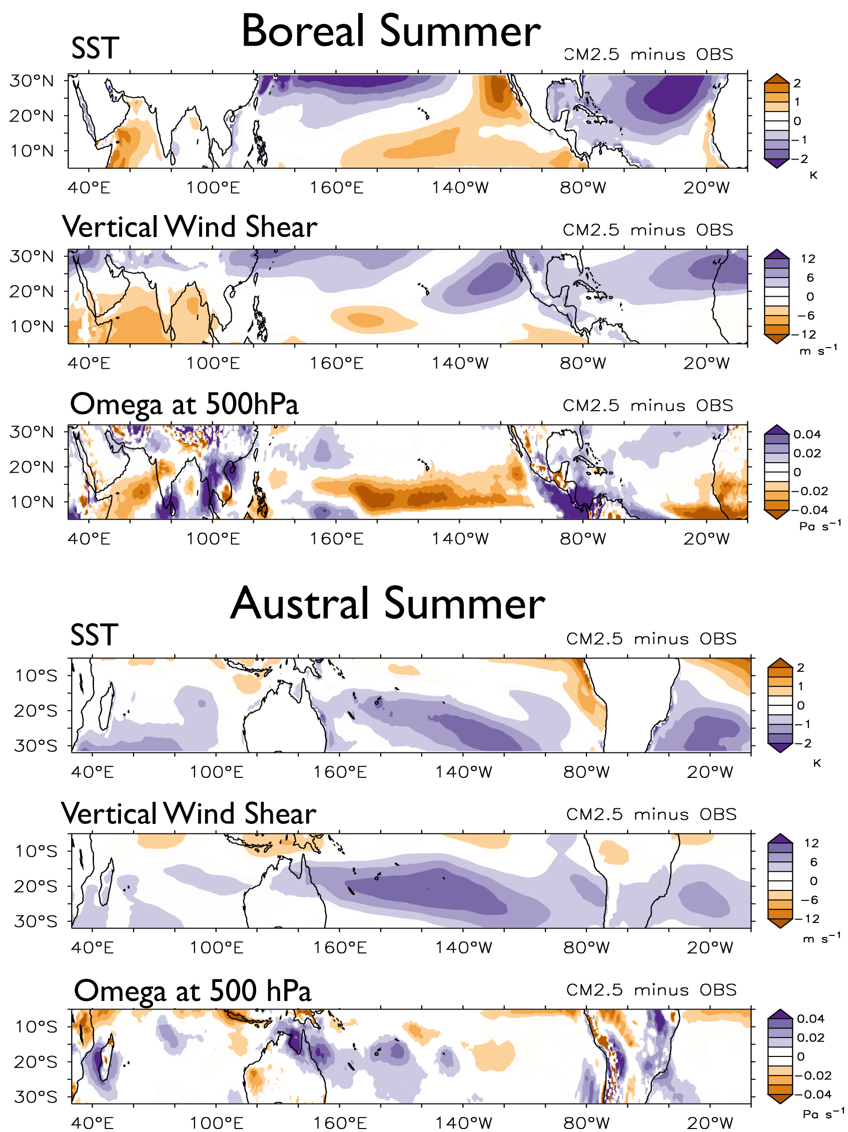
- Tropical cyclone detection and tracking algorithm is adopted from Zhao et al. (2009, JC)
- This algorithm selects warm-core vortices that satisfy the certain criteria in the 6-hourly model outputs and connects them into individual TC tracks. The criteria are as follows.
  - 850-hPa relative vorticity > $3.5\times10^{-5}\ s^{-1}$
  - warm core > 1 K
  - distance between two "connected" vortex locations < 400 km in 6 hours.
  - 3 days with maximum winds exceeding 17 m/s (not necessarily consecutive) .

Simulated TCs

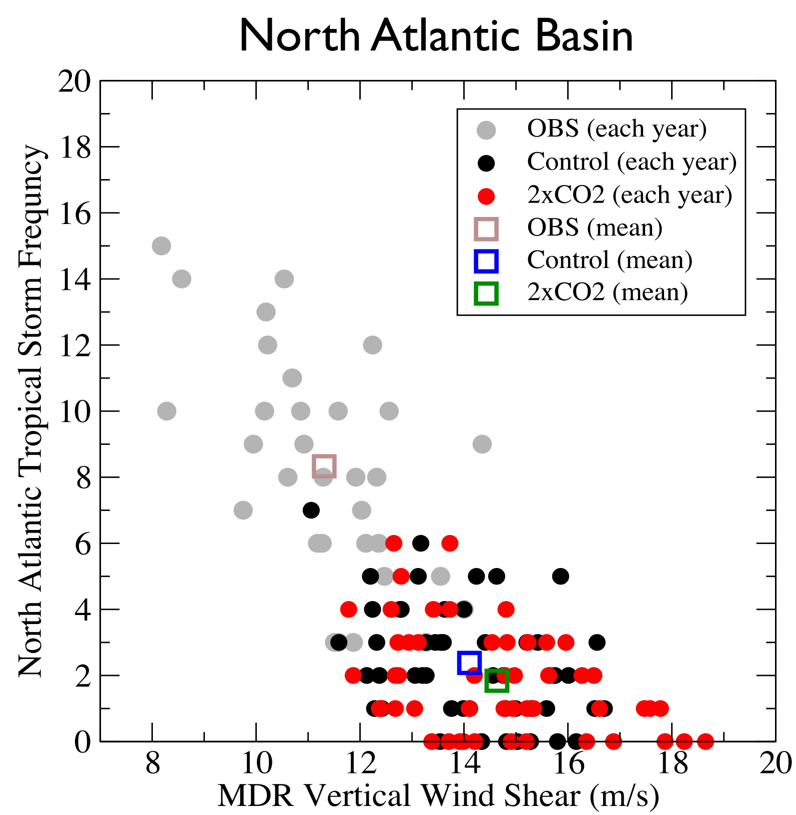


Bias in Large-scale Environments Simulated by CM2.5

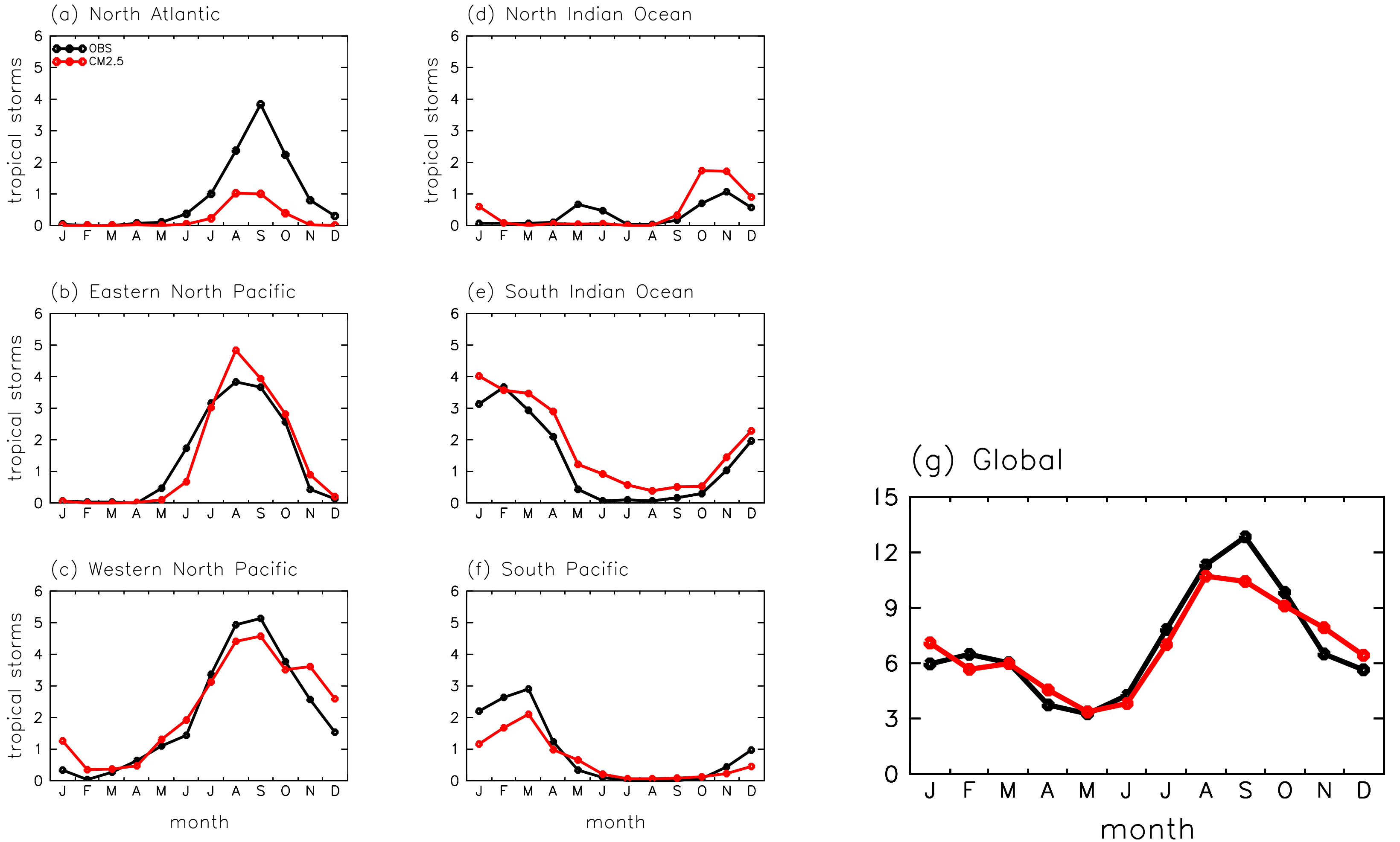
CM2.5 minus OBS



Warm color : favorable for TC activity
Cold color : unfavorable for TC activity

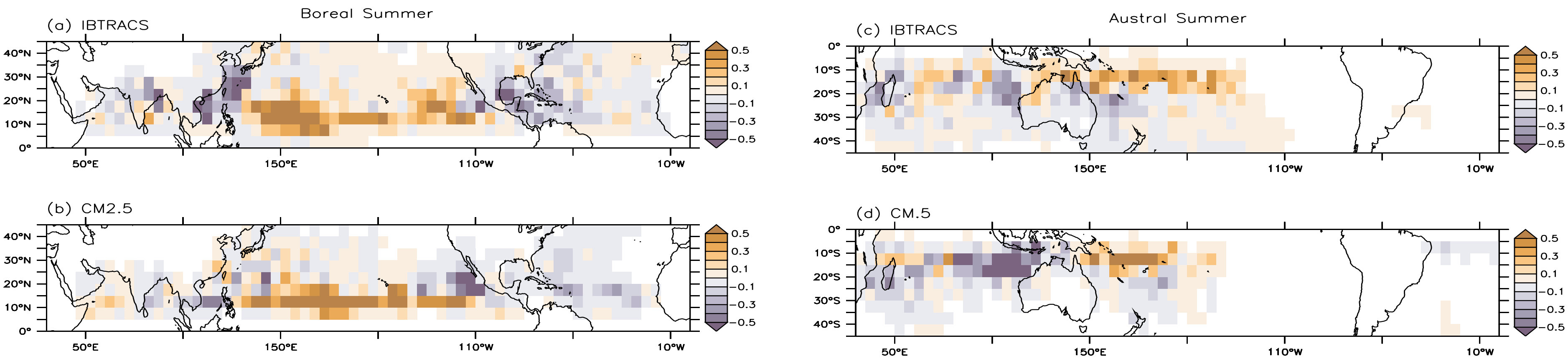


TC Seasonal Cycle (OBS vs. CM2.5)

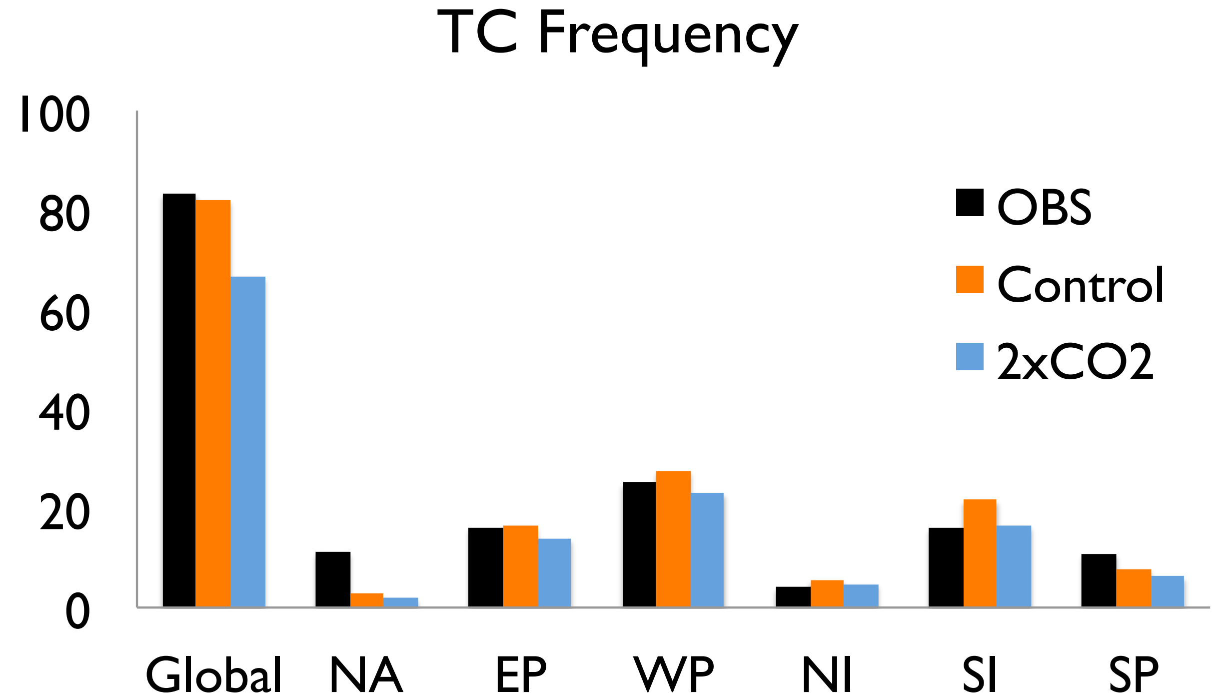


Relationship of TC Activity to ENSO

TC occurrences (5°x5°) Regressed on the NINO 3.4 Index

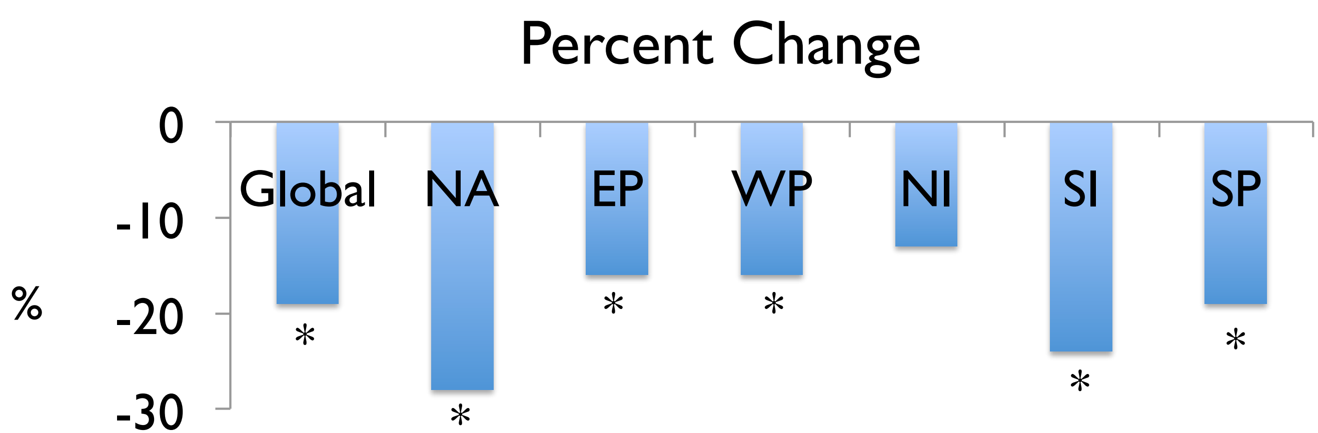


Response to CO_2 doubling: TC Frequency



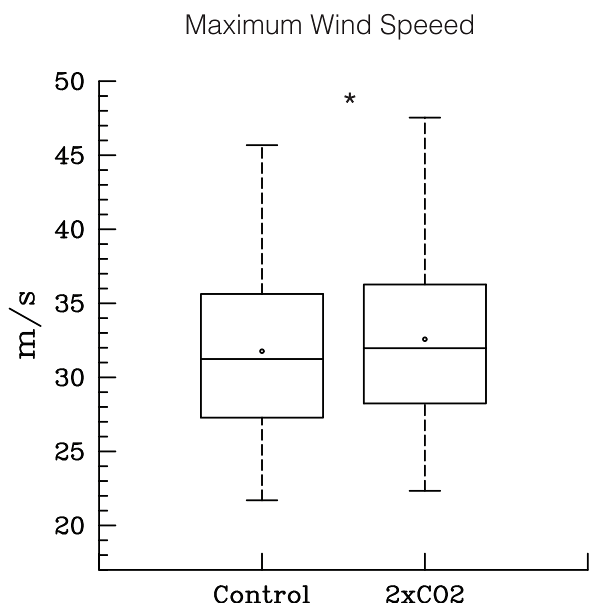
Tropical SST Response to $2xCO_2$: + 2.1 K

Significant reduction in TC frequency in response to 2xCO2 (-19%)

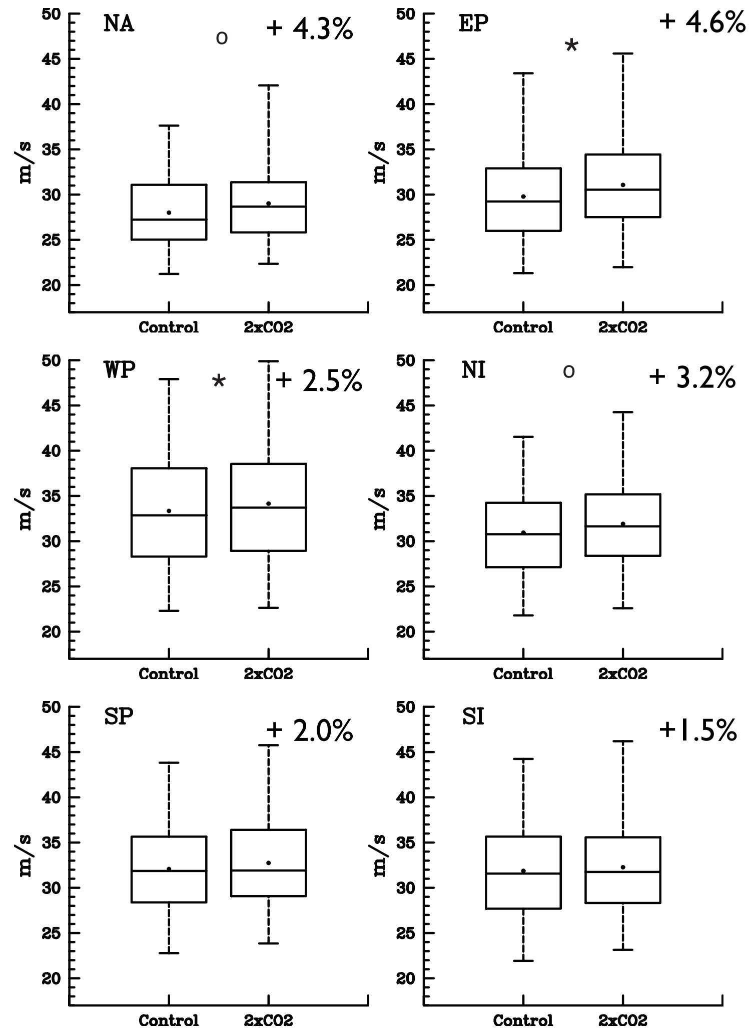


*: Significant at $p<0.05$

Response to CO_2 doubling: TC Maximum Wind Speed

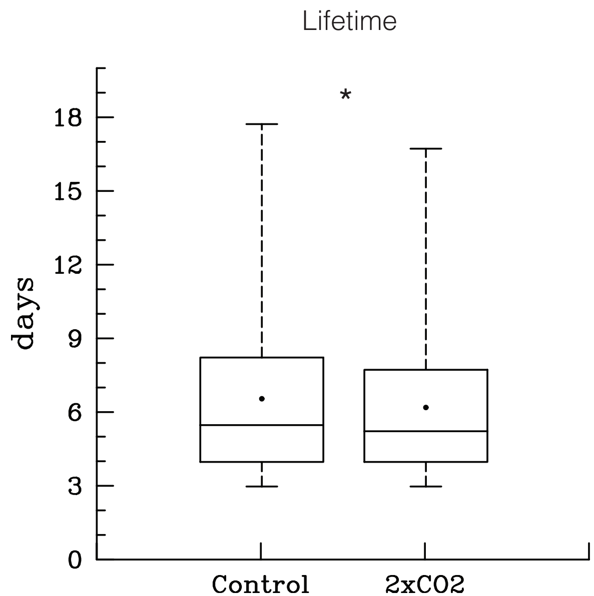


Increase by 2.7%



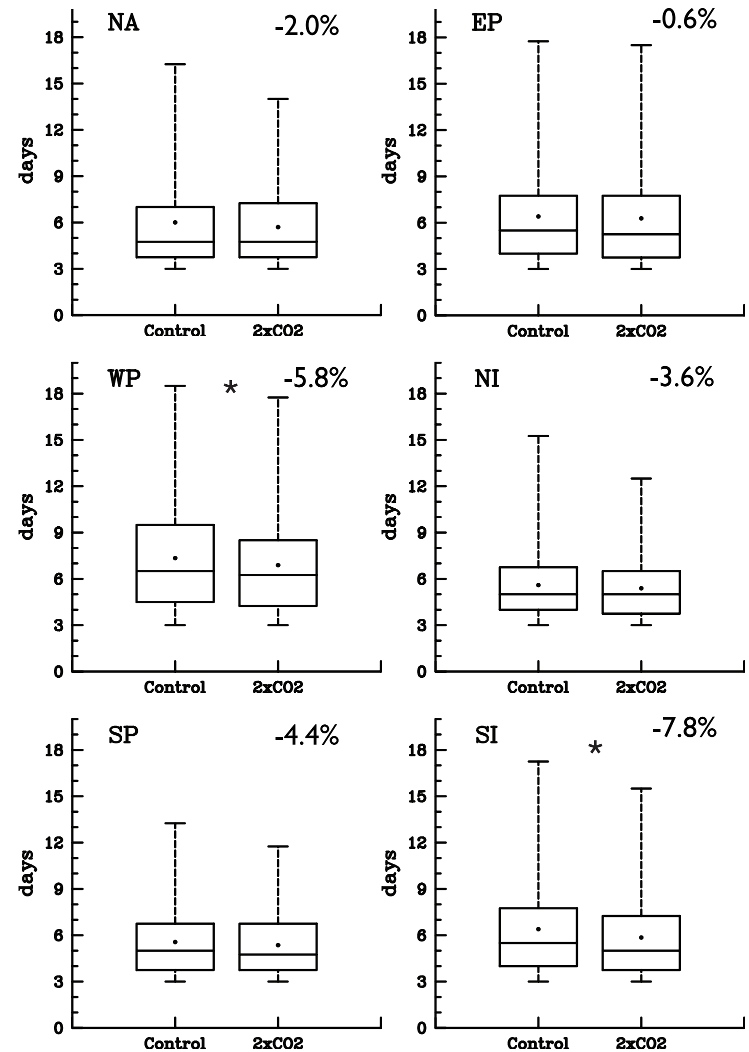
*: $p<0.01$, °: $p<0.05$

Response to CO_2 doubling: TC Lifetime



Decrease by - 4.6%

*: $p<0.01$, °: $p<0.05$

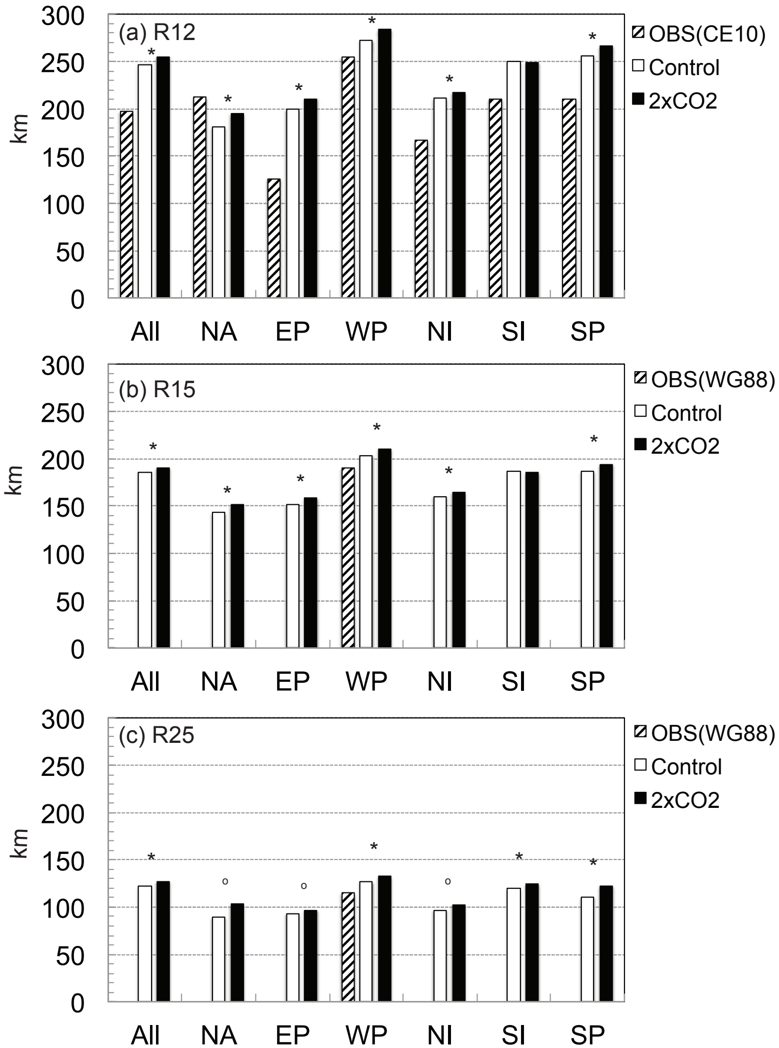


Response to CO_2 doubling: TC Size

+3,3%

+2.4%

+4.4%



R12, R15 and R25 are the distances from the storm center at which the azimuthal-averaged (around-the-storm-averaged) tangential wind speed reaches 12, 15 and 25 m/sec, respectively.

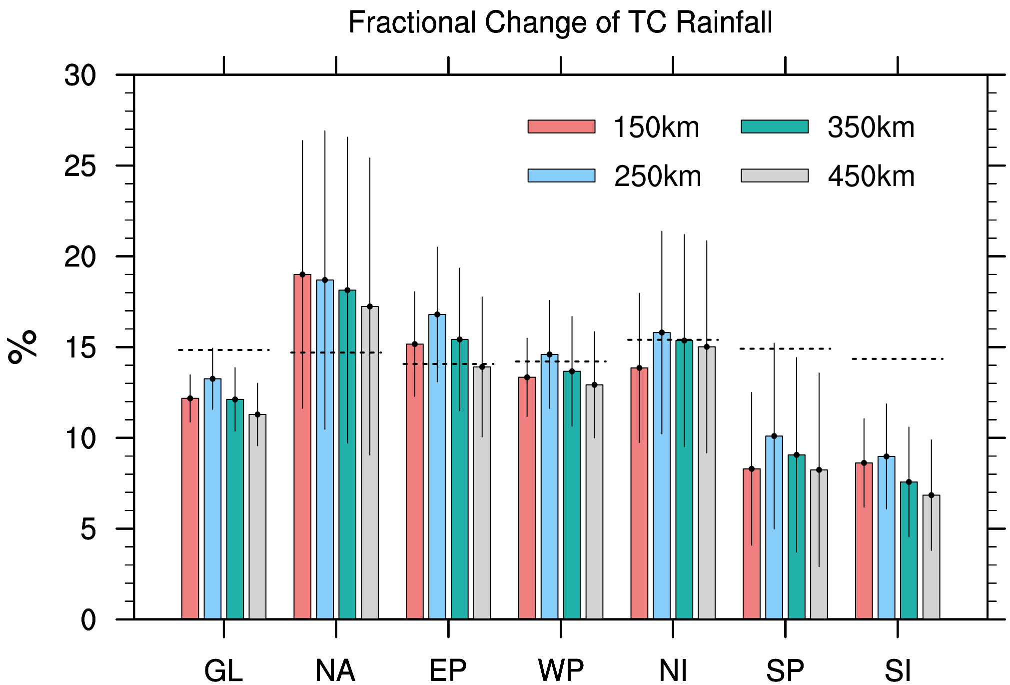
In terms of the interbasin differences in TC sizes, CM2.5 correctly simulates the largest TCs over WP, but the dramatically smaller average TCs over EP in observations is not well-captured in the model.

CE10: Chavas and Emanuel (2010, GRL)

WG88: Weatherford an Gray (1988, MWR)

*: $p<0.01$, °: $p<0.05$

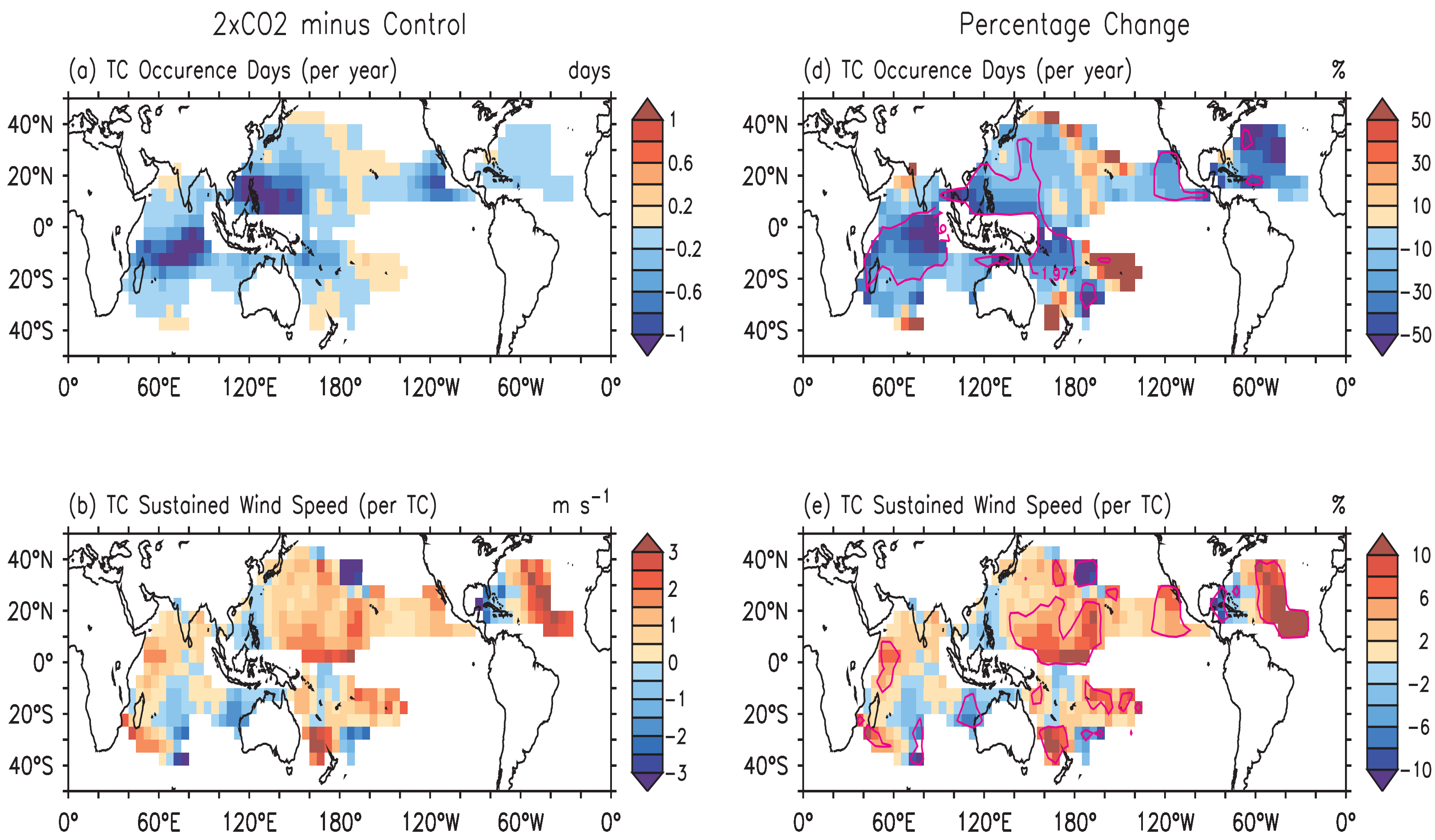
Response to CO_2 doubling: TC Rainfall



The fractional change of rainfall rate averaged within 150km, 250km, 350km and 450km of the TC center for the globe and each basin.

The dotted lines represent the approximate changes of the water holding capacity for each basin (estimated as 7% per degree C increase of basin-averaged SST).

Response to CO_2 doubling: TC Regional Activity



Response to CO_2 doubling: Large-Scale Environments

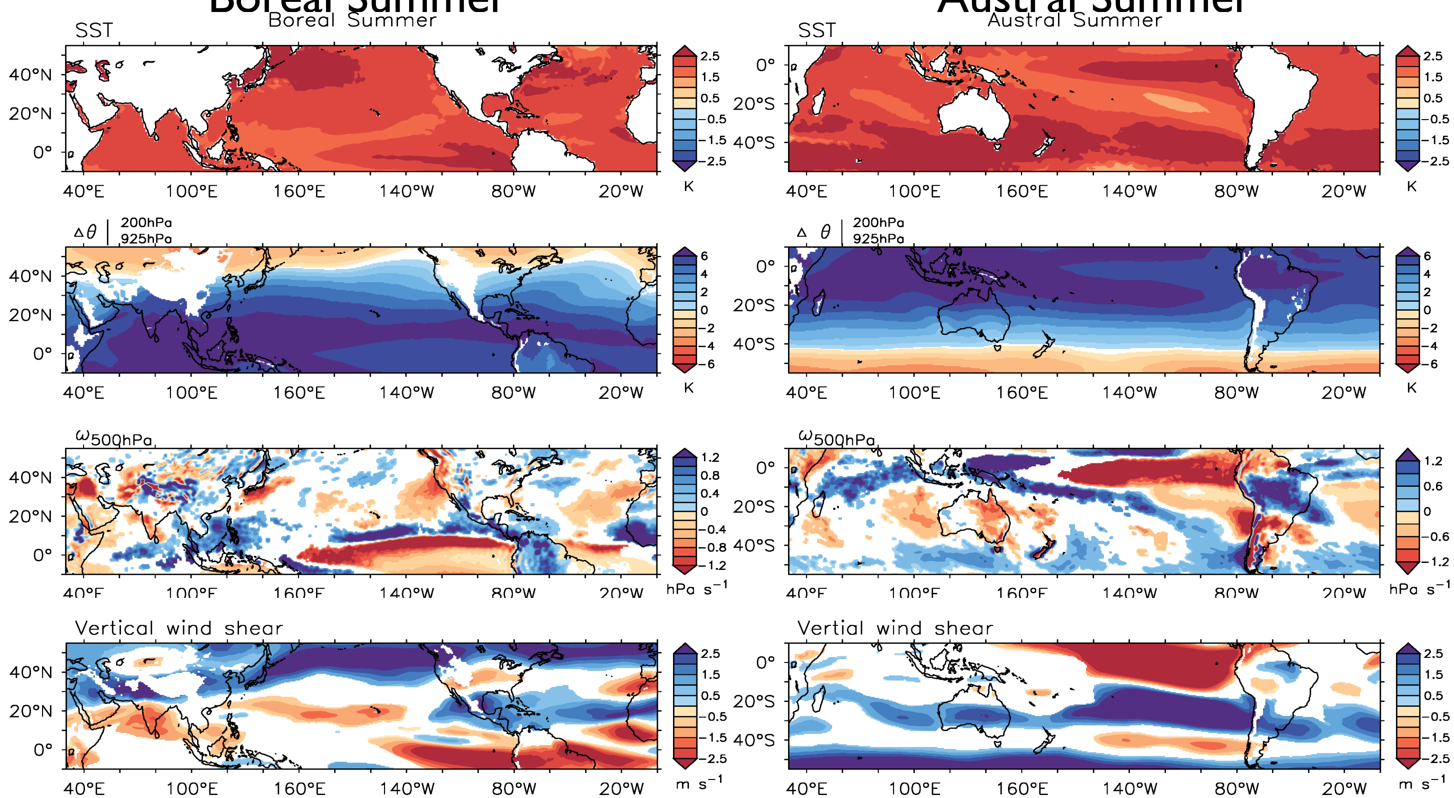
Boreal Summer | Austral Summer

SST

Dry Static Stability

Vertical Pressure Velocity at 500hPa

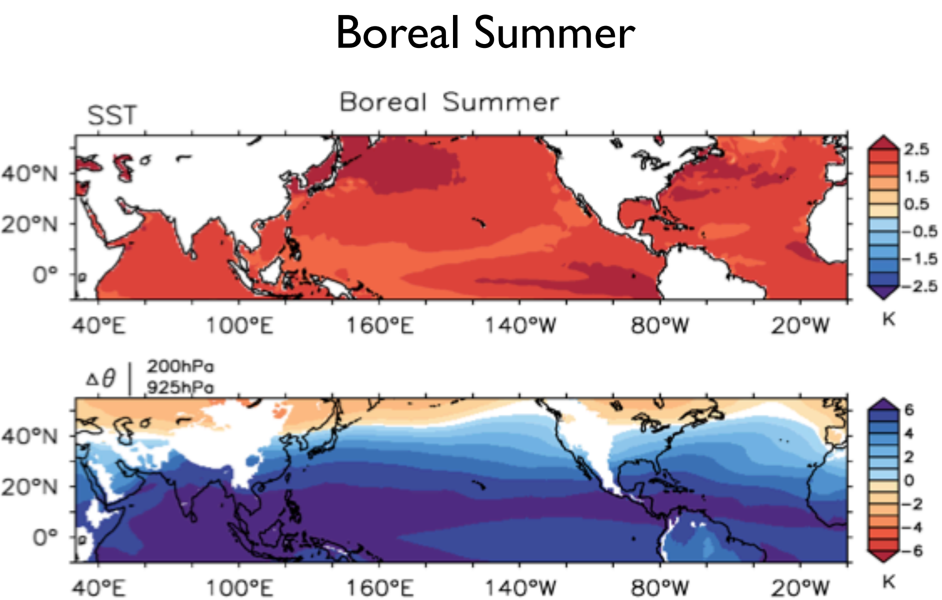
Vertical Wind Shear

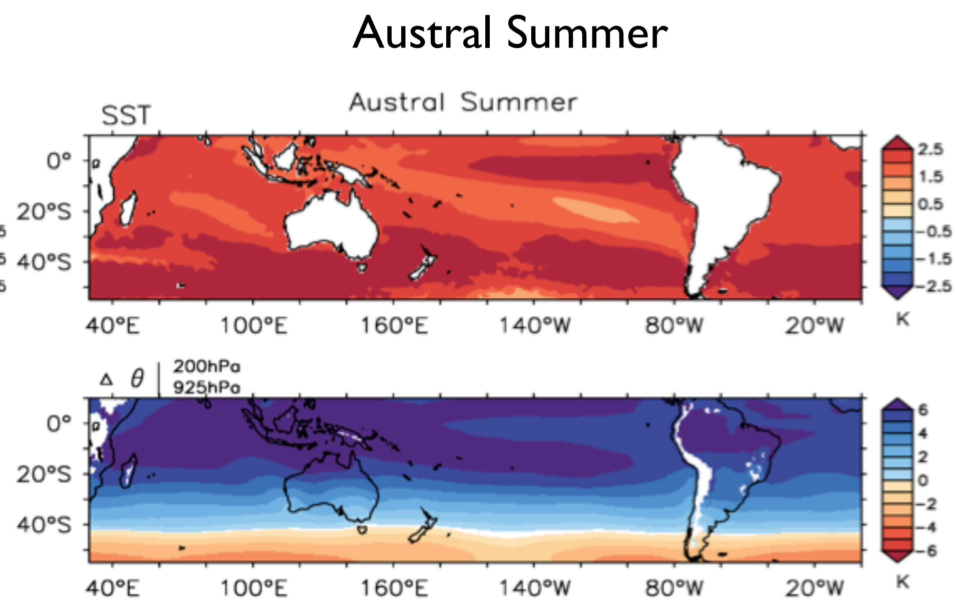


Warm color : favorable for TCs

Cold color : unfavorable for TCs

Response to CO_2 doubling: Large-Scale Environments





Warm color : favorable for TCs

Cold color : unfavorable for TCs

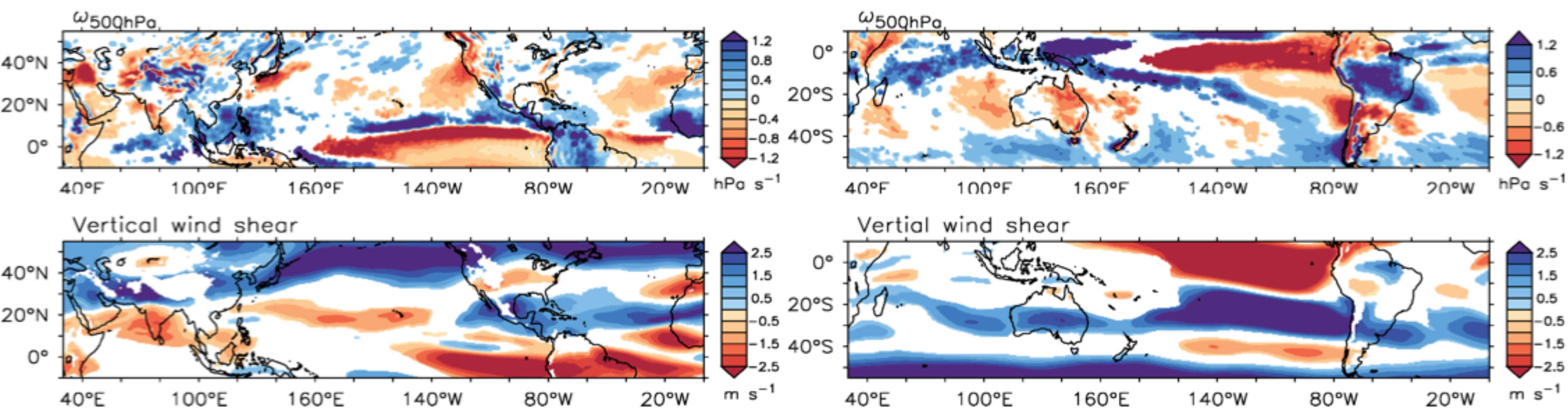
SST increase over the globe. (+ 2.1 K)

The simulated tropical atmospheric warming is larger in the upper troposphere than near surface, resulting in increased static stability over the tropical regions.

These two factors apparently cannot sufficiently explain the regional differences in TC response

Response to CO_2 doubling: Large-Scale Environments

Boreal Summer | Austral Summer



Warm color : favorable for TCs
Cold color : unfavorable for TCs

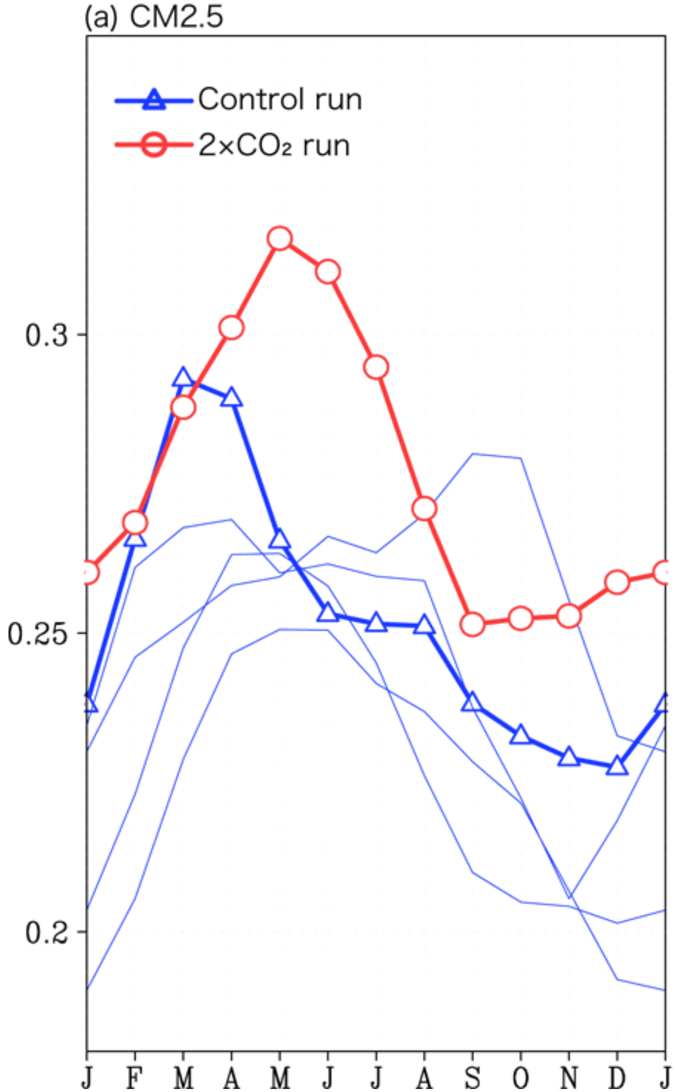
(Only significant change regions are shaded)

The areas of significant increases of ω_{500hPa} are well matched with the region of significant reduction of TC occurrence.

The vertical wind shear during northern summer decreases over much of the tropics and subtopics in the North Pacific whereas it increases over the North Atlantic.

An increase in the vertical wind shear is simulated over mid-latitude in Northern Hemisphere and extra-tropics in the southern hemisphere. Because these regions tend to be located in the vicinity of the end of TC tracks, the increasing vertical wind shear in these areas possibly contributes to the reduced TC lifetimes and track lengths in the 2xCO2 simulation.

Monthly standard deviation of the interannual variation of the SST_{MDR} for the Control and the $2xCO_2$ (°C).



Doi et al. 2013, JC

Despite of reduction in frequency from $2xCO_2$, the warmed climate exhibits increased interannual hurricane frequency variability so that the simulated Atlantic TC activity is enhanced more during unusually warm years in the CO_2-warmed climate relative to that in unusually warm years in the control climate.

(a)	Mean TC count for all years (A)	Anomalous TC count for warm SST_{MDR} years (B)	Percentage change (B/Ax100)
Control	2.7	0.7	26.1
$2xCO_2$	1.9	1.0	50.0
2xCO2 minus Control	-0.8 (-28.3%)	0.3 (+37.1%)	

(b)	Mean PDI for all years (C)	Anomalous PDI for warm SST_{MDR} years (D)	Percentage change (D/Cx100)
Control	22.7	2.4	10.4
$2xCO_2$	20.3	9.4	46.4
2xCO2 minus Control	-2.4 (-10.7%)	7.1 (+289.1%)	

PDI unit is 10^3 m^{-3} s^{-3}

Summary (1)

- GFDL CM2.5 shows fairly realistic global TC frequency, TC seasonal cycle, and geographical distribution in the various basins.
- The model has some notable biases in regional TC activity, including simulating too few TCs in the North Atlantic basin.
- Despite these biases, the model simulates the large-scale variations of TC activity induced by El Nino/Southern Oscillation fairly realistically.
- The regional biases in TC activity are associated with simulation biases in the large-scale environments. This suggests that the simulation skill for TC activity in the model could be improved if the model biases in the environments were reduced.

Summary (II)

- $2xCO_2$ response has reduced TC frequency (-19%) increased intensity (+2.7%), shorten lifetime (-4.6%), increased size (+3%) and increased TC rainfall rates (+12%).
- The most of results are in agreement with the consensus of other climate models (Knutson et al. 2010, Nature Geoscience).
- Our analysis suggests that regional changes in several large-scale environmental factors influence the various TC characteristics at the regional scale.
- Although there is an overall reduction in frequency in the Atlantic from CO_2 doubling, the warmed climate exhibits increased interannual variability so that the simulated Atlantic TC activity is enhanced more during unusually warm years in the CO_2-warmed climate relative to that in unusually warm years in the control climate.

Thank you !

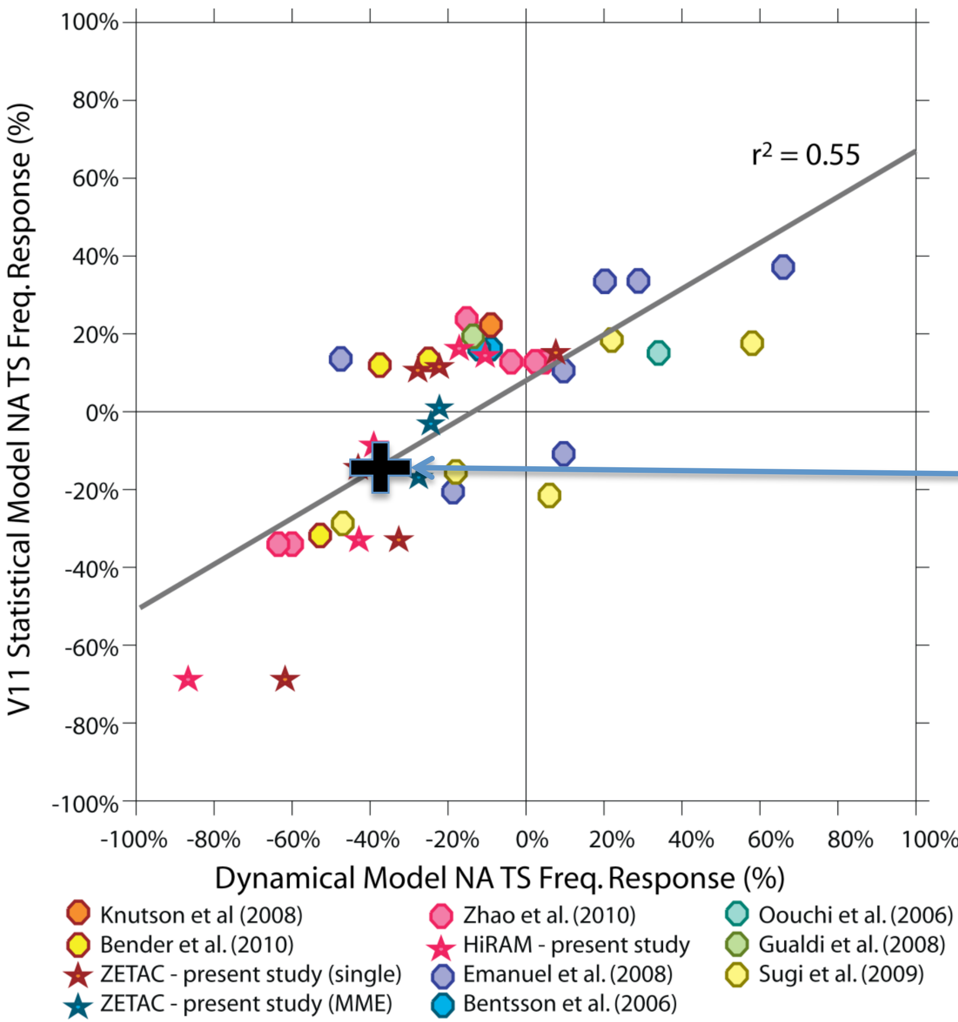
Response to CO_2 doubling: TC Frequency

Tropical SST Response to $2xCO_2$: + 2.1 K

Bold : significant change at $p<0.05$

	> Tropical Storms (v_{max} >17 m/s) (A)			> Hurricanes (v_{max} >33 m/s) (B)			Ratio (B/Ax100)	
	Control (yr^{-1})	2xCO2 (yr^{-1})	Percent Change (%)	Control (yr^{-1})	2xCO2 (yr^{-1})	Percent Change (%)	Control (%)	2xCO2 (%)
Global	82.0	66.6	**-19**	31.6	28.7	**-9**	39	43
NA	2.7	1.9	**-28**	0.4	0.3	-11	13	17
EP	16.6	13.9	**-16**	4.0	4.5	12	24	32
WP	27.5	23.1	**-16**	13.4	12.5	-6	49	54
NI	5.5	4.8	-13	2.0	2.0	3	36	42
SI	21.7	16.5	**-24**	8.7	6.7	**-22**	40	41
SP	7.8	6.3	**-19**	3.2	2.6	-17	41	42

Response to CO_2 doubling: North Atlantic Basin



Knutson et al. 2013

V11 Statistical Model is based on the relative SST changes over Atlantic basin (Villarini et al. 2011)

CM2.5 response to 2xCO2

Dynamic Model: -28%
Statistical Model: -10%