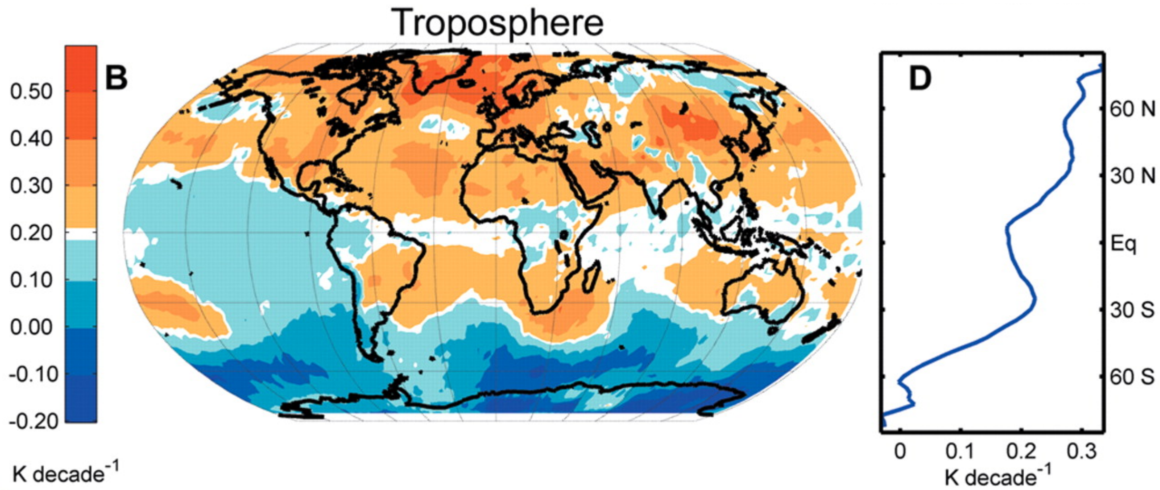
Tropical expansion driven by poleward advancing subtropical front

Hu Yang[1], Gerrit Lohmann[1], Jian Lu[2], Evan J. Gowan[1], Xiaoxu Shi[1], Jiping Liu[3], Qiang Wang[1]

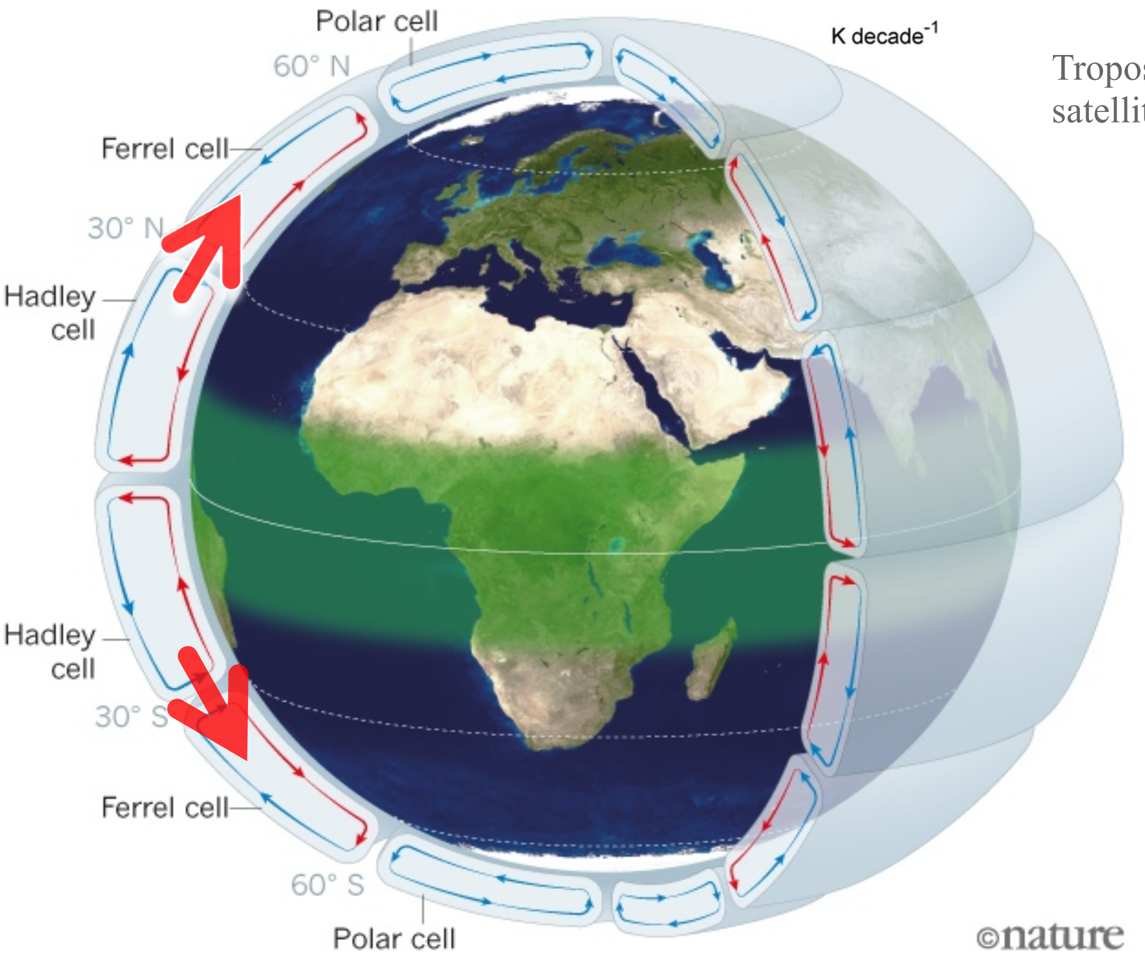
1. Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
2. Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, Washington, USA
3. Department of Atmospheric and Environmental Sciences University at Albany, State University of New York, Washington, USA

07.May.2020

EGU General Assembly 2020



Tropospheric temperature trends for 1979 to 2005 based on satellite-borne MSU observations. Fu. et al. (2006)

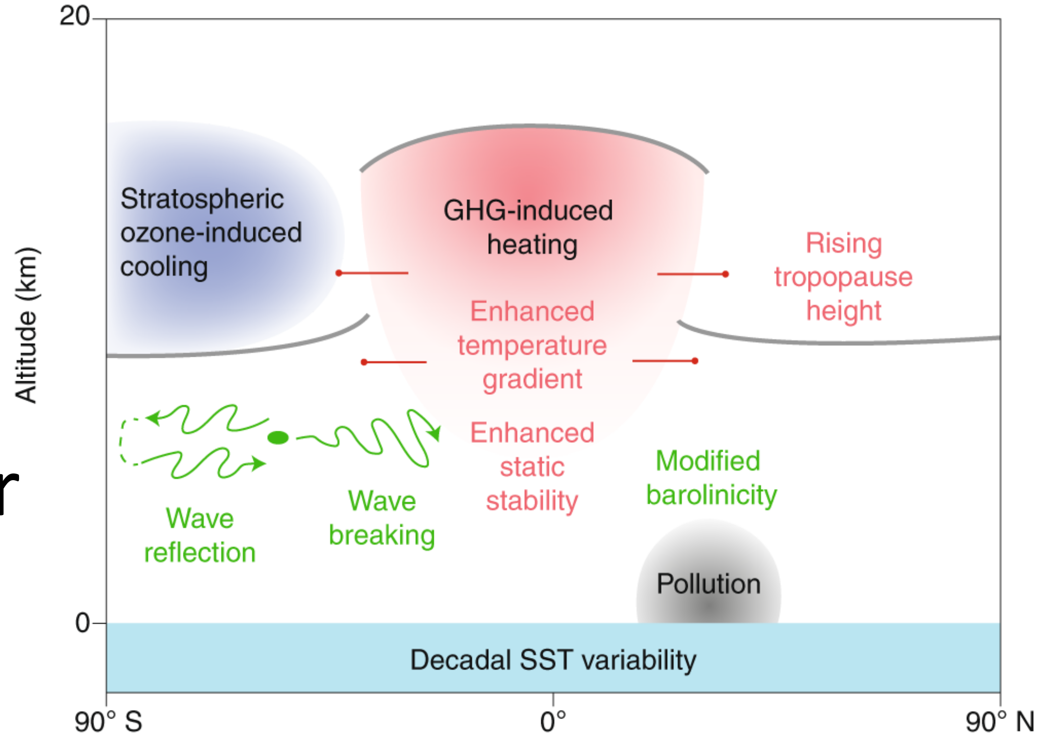


https://www.joboneforhumanity.org/the_mystery_of_the_expanding_tropics

- Storm tracks Yin, (2005)
- Jet Streams Archer and Caldeira, (2008)
- Westerly winds Chen et al, (2008)
- Precipitation pattern Scheff and Frierson, (2012)
- Could Norris et al, (2016)
- Large-scale ocean gyres Yang et al, (2020)

Previous mechanisms

- Increasing GHG
- Decreasing ozone over Antarctic
- Increasing aerosol over Northern Hemisphere
- Natural variations (PDO)



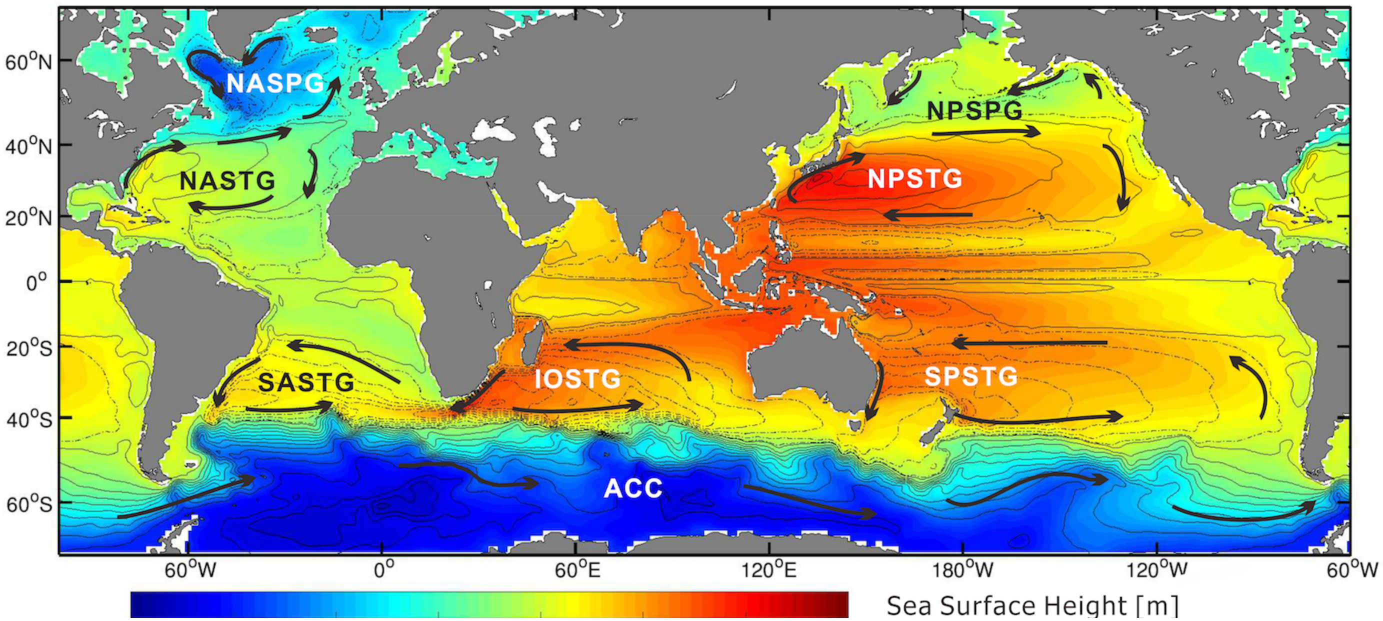
Staten et al., 2018

Major Gaps

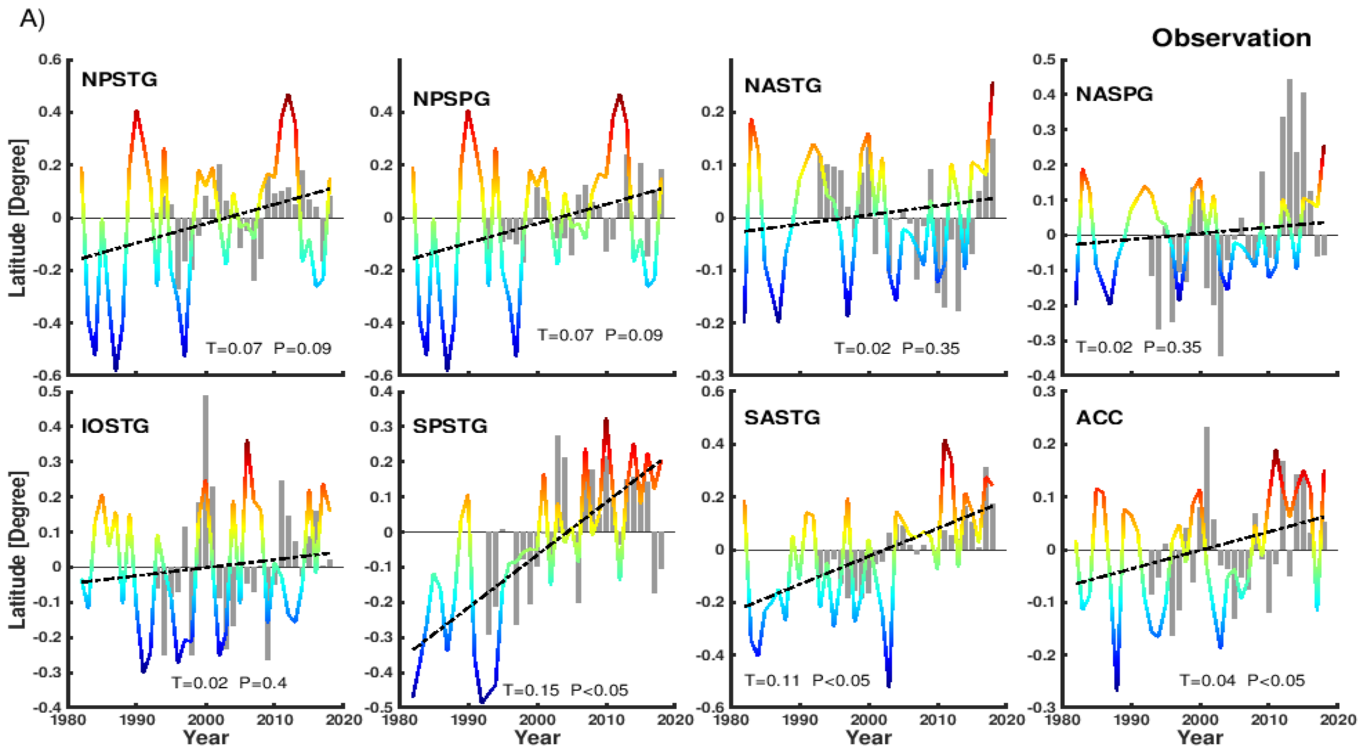
- No observational support showing that GHG, ozone, aerosol correlate with the variations of tropical width (Allen & Kovilakam, 2017).

- The subtropical climate zone shifted during past glacial-interglacial cycles, without evidence of changes in ozone or aerosol (Gersonde et al., 2005; Toggweiler & Russell, 2008; Bard & Rickaby, 2009; Benz et al., 2016)

- GHG alone (without contribution from SST) plays a minor role in widening tropics (Grise & Polvani, 2014)



Poleward shift of the major ocean gyres detected in a warming climate



Whether ocean play a crucial role in expanding tropics?

Yang et al, (2020)

Data and Method

- Observations (ERA5, HadISST, NOAA-OISST)

- CMIP5 multi-model (24) simulations (piControl, 1pctCO2).

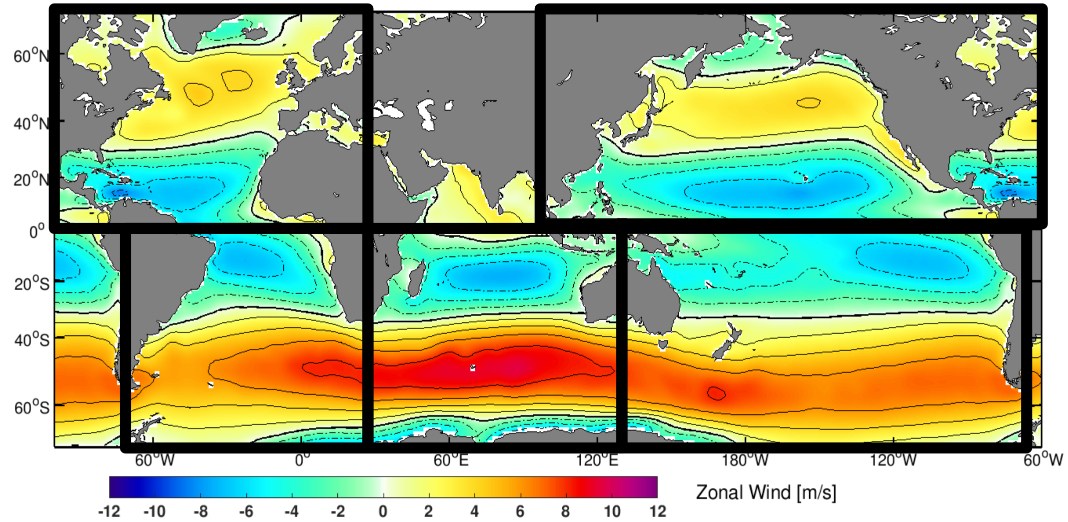
- Sensitivity simulation (FESOM, ECHAM6)

List of CMIP5 models used in our study

Model Name	Institution
ACCESS1.0	Centre for Australian Weather and Climate Research
ACCESS1.3	Centre for Australian Weather and Climate Research
CanESM2	Canadian Centre for Climate Modelling and Analysis
CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM/CERFACS)
CNRM-CM5.2	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM/CERFACS)
CSIRO Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
GFDL-CM3	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
GISS-E2-H	NASA Goddard Institute for Space Studies
GISS-E2-R	NASA Goddard Institute for Space Studies
HadGEM2-ES	Met Office Hadley Centre
INM-CM4	Institute for Numerical Mathematics
IPSL-CM5A-LR	Institut Pierre Simon Laplace
IPSL-CM5A-MR	Institut Pierre Simon Laplace
IPSL-CM5B-LR	Institut Pierre Simon Laplace
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MPI-ESM-LR	Max Planck Institute for Meteorology
MPI-ESM-MR	Max Planck Institute for Meteorology
MPI-ESM-P	Max Planck Institute for Meteorology
MRI-CGCM3	Meteorological Research Institute
NorESM1-M	Norwegian Climate Centre
NorESM1-ME	Norwegian Climate Centre

Edge of tropics: u-wind changes from easterly to westerly (USF)

Individually from five ocean basins



(a) NH

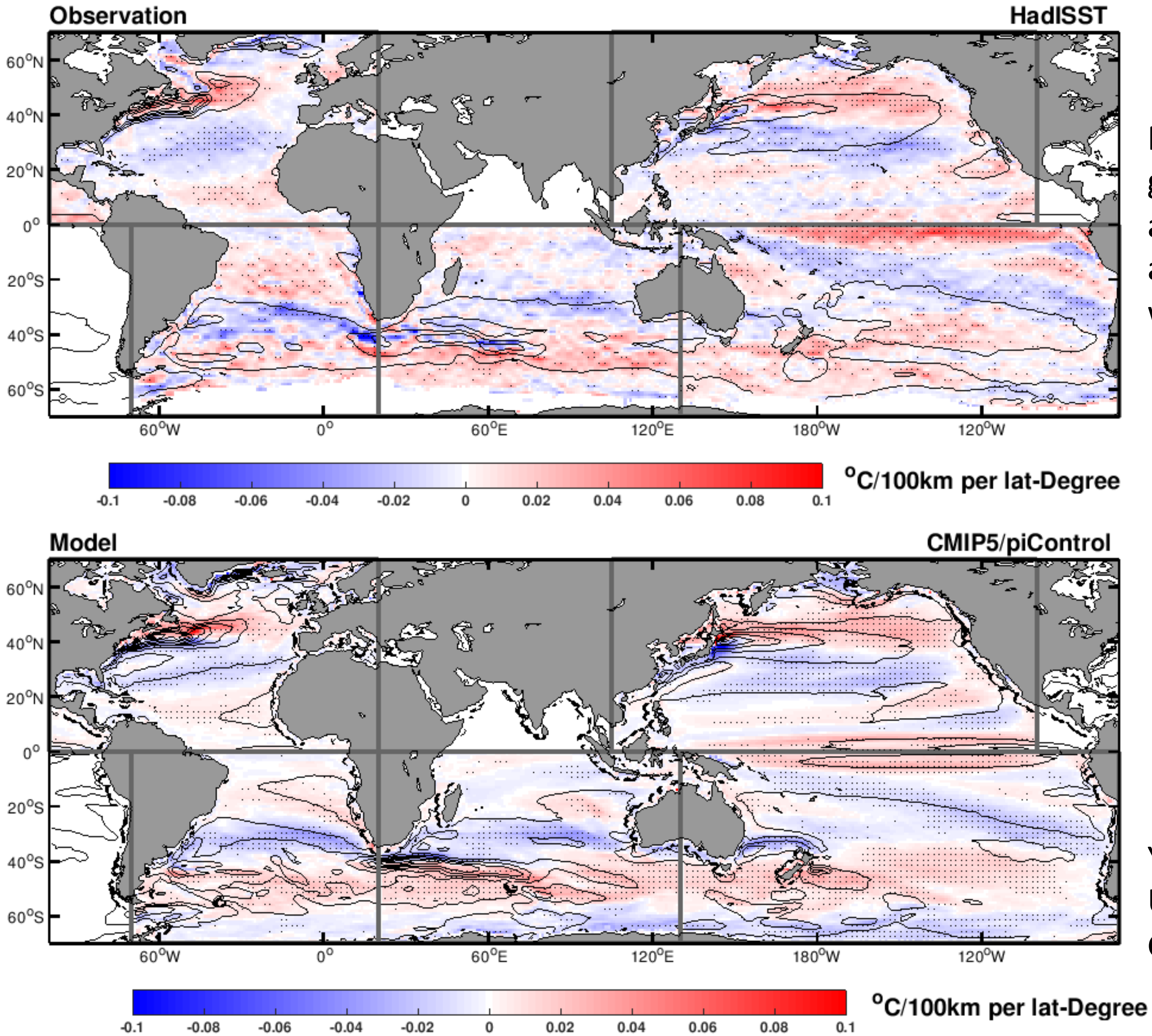
	EDJ	P-E	SLP	USF	STJ	TPB	OLR	ΔOLR
DJF	0.56* (0.08)	0.52* (0.11)	0.46* (0.20)	0.56* (0.11)	0.02 (0.11)	0.20 (0.11)	0.13 (0.16)	0.29* (0.13)
MAM	0.55* (0.11)	0.61* (0.10)	0.12 (0.39)	0.66* (0.10)	0.33* (0.15)	0.43* (0.15)	0.48* (0.16)	0.62* (0.09)
JJA	0.49* (0.13)	0.43* (0.28)	0.24 (0.32)	0.56* (0.19)	0.28* (0.15)	0.28* (0.13)	0.43* (0.18)	0.59* (0.13)
SON	0.53* (0.07)	0.57* (0.06)	0.48* (0.13)	0.56* (0.08)	0.07 (0.11)	0.13 (0.11)	0.14 (0.23)	0.35* (0.16)
Ann	0.61* (0.07)	0.65* (0.08)	0.48* (0.21)	0.68* (0.08)	0.28 (0.16)	0.34* (0.10)	0.46* (0.16)	0.68* (0.07)

(b) SH

	EDJ	P-E	SLP	USF	STJ	TPB	OLR	ΔOLR
DJF	0.72* (0.05)	0.76* (0.05)	0.83* (0.03)	0.83* (0.03)	0.05 (0.27)	0.20 (0.21)	0.65* (0.14)	0.77* (0.14)
MAM	0.46* (0.14)	0.66* (0.06)	0.76* (0.05)	0.75* (0.06)	0.10 (0.18)	0.16 (0.13)	0.18 (0.28)	0.48* (0.18)
JJA	0.26 (0.17)	0.54* (0.13)	0.56* (0.11)	0.55* (0.11)	0.13 (0.16)	0.22* (0.14)	0.22* (0.15)	0.21 (0.11)
SON	0.42* (0.20)	0.57* (0.10)	0.68* (0.11)	0.69* (0.10)	-0.03 (0.18)	.006 (0.15)	0.16 (0.18)	0.32* (0.17)
Ann	0.53* (0.14)	0.64* (0.08)	0.73* (0.07)	0.73* (0.07)	0.06 (0.20)	0.10 (0.17)	0.20 (0.24)	0.54* (0.13)

-0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0. 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
correlation coefficient

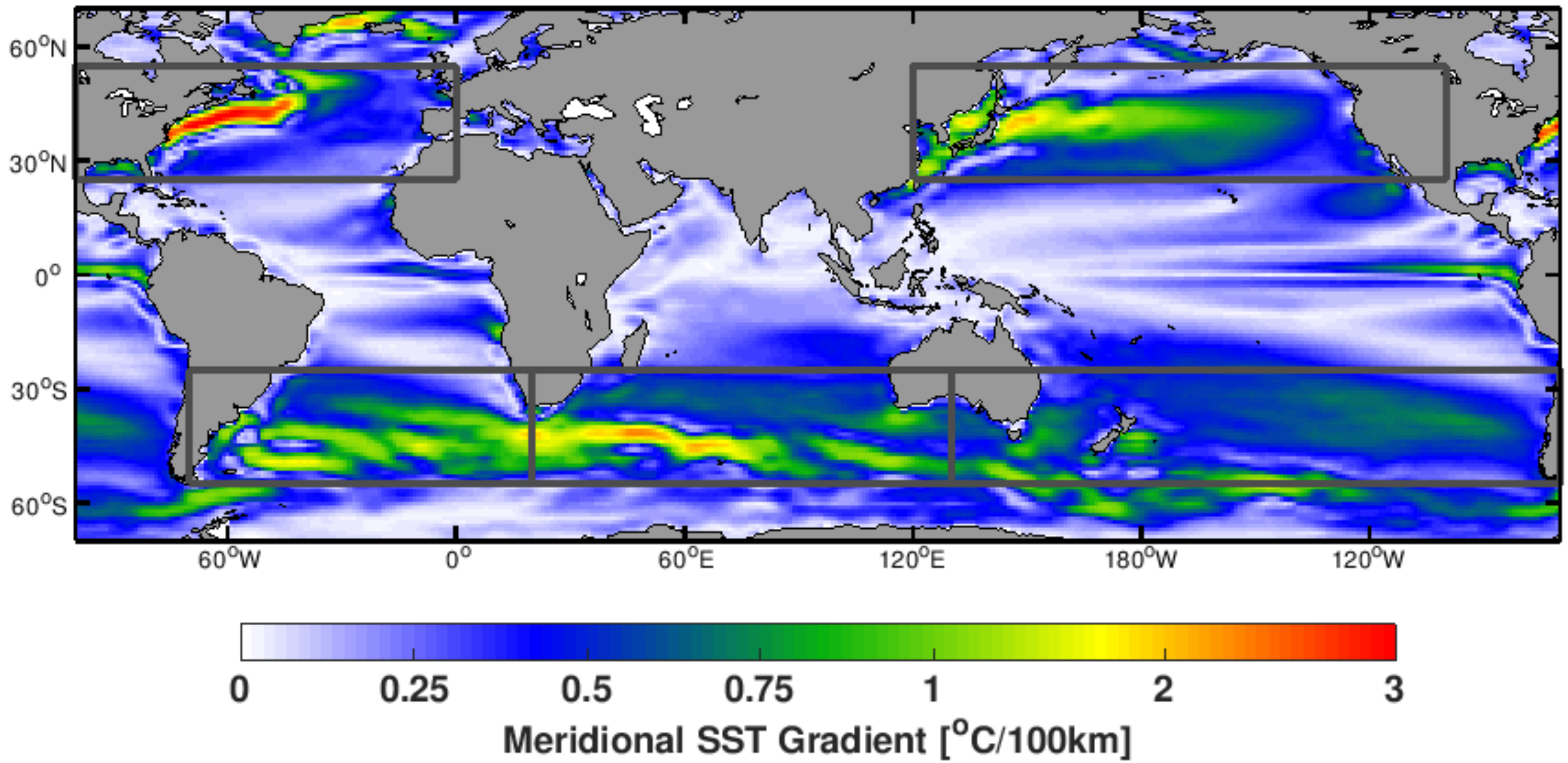
Waugh et al., 2018



Meridional SST gradient anomalies associated with wider tropics.

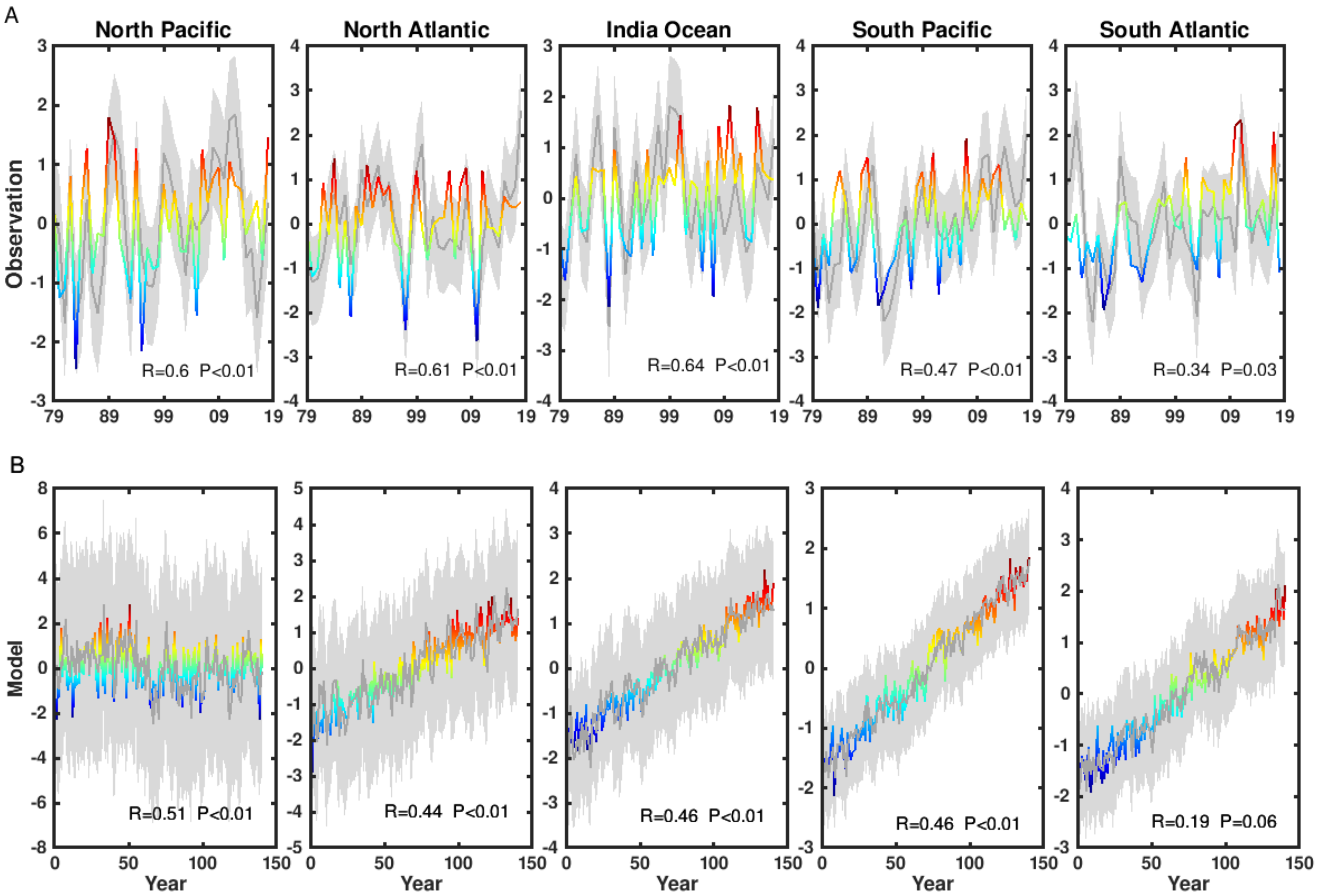
Yang et al, (2020) Under review on GRL.

Climatology meridional SST gradients



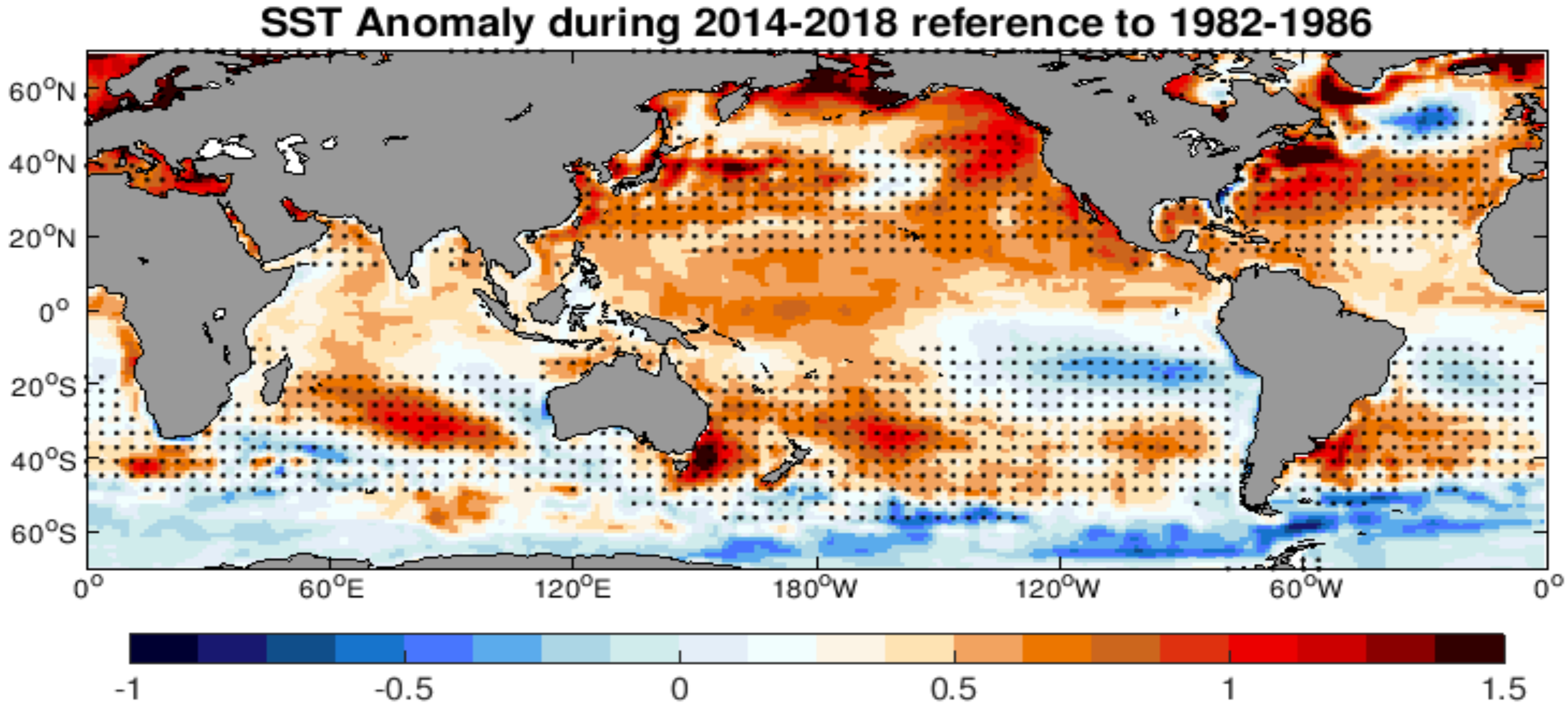
$$P = \left(\int_{25^\circ}^{55^\circ} G_{sst}(y) \cdot y dy\right) / \left(\int_{25^\circ}^{55^\circ} G_{sst}(y) dy\right)$$

Definition of of meridional position of subtropical fronts

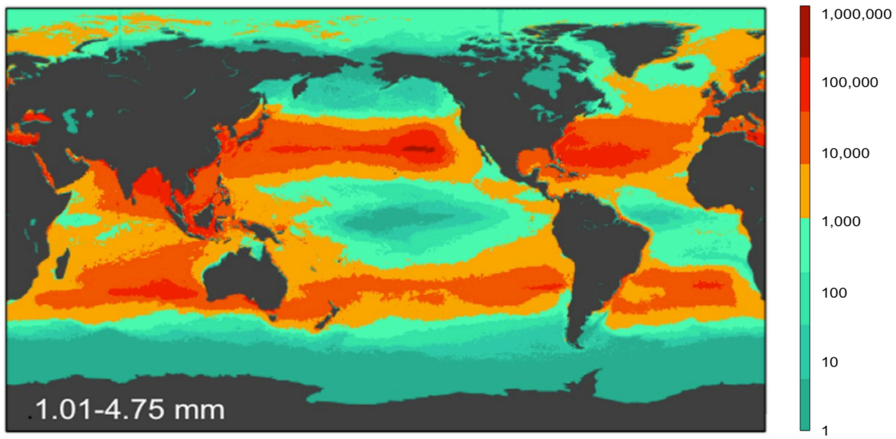


Grey line: meridional position of subtropical front, Coloured line: edge of tropics. Positive values indicate poleward shift, vice versa.

Yang et al, (2020) Under review on GRL

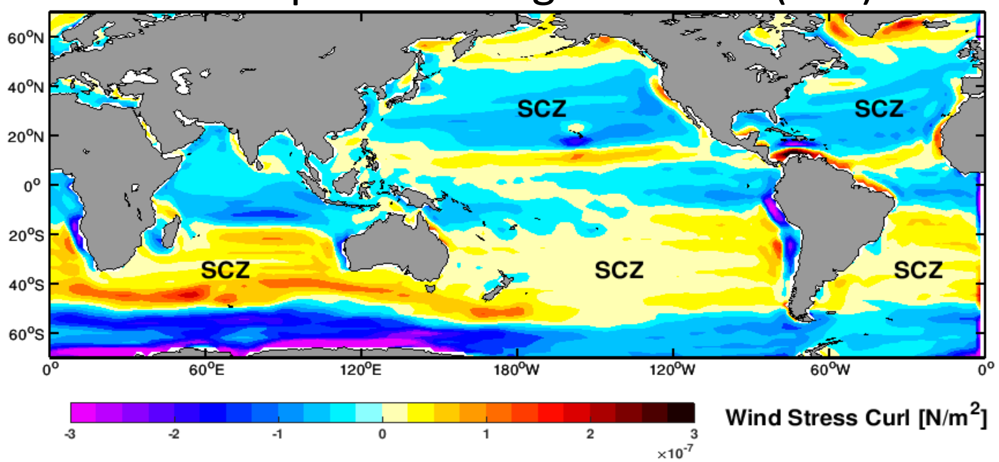


Regions with heavy plastic accumulation

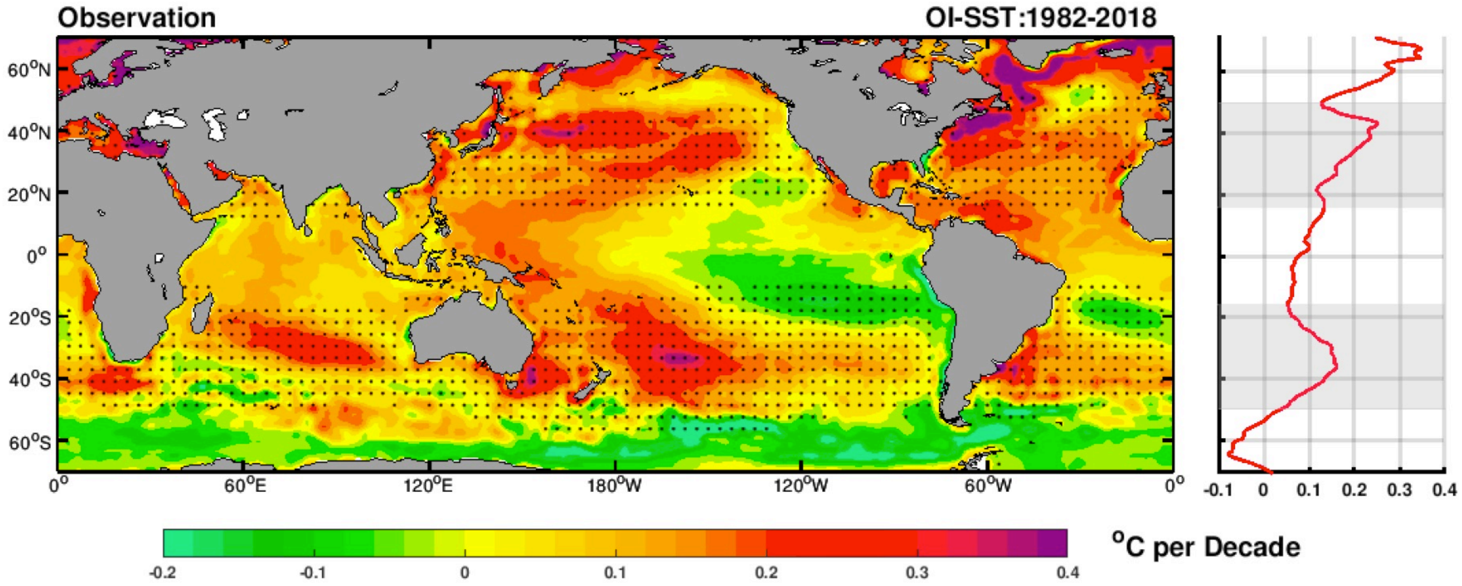


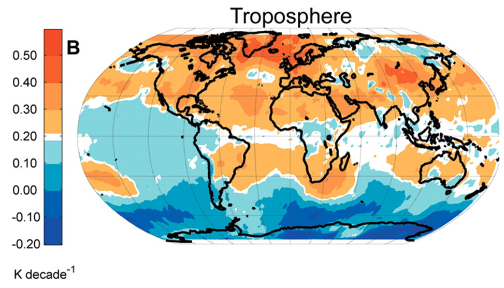
Eriksen et al., 2014

Subtropical convergence zone (SCZ)

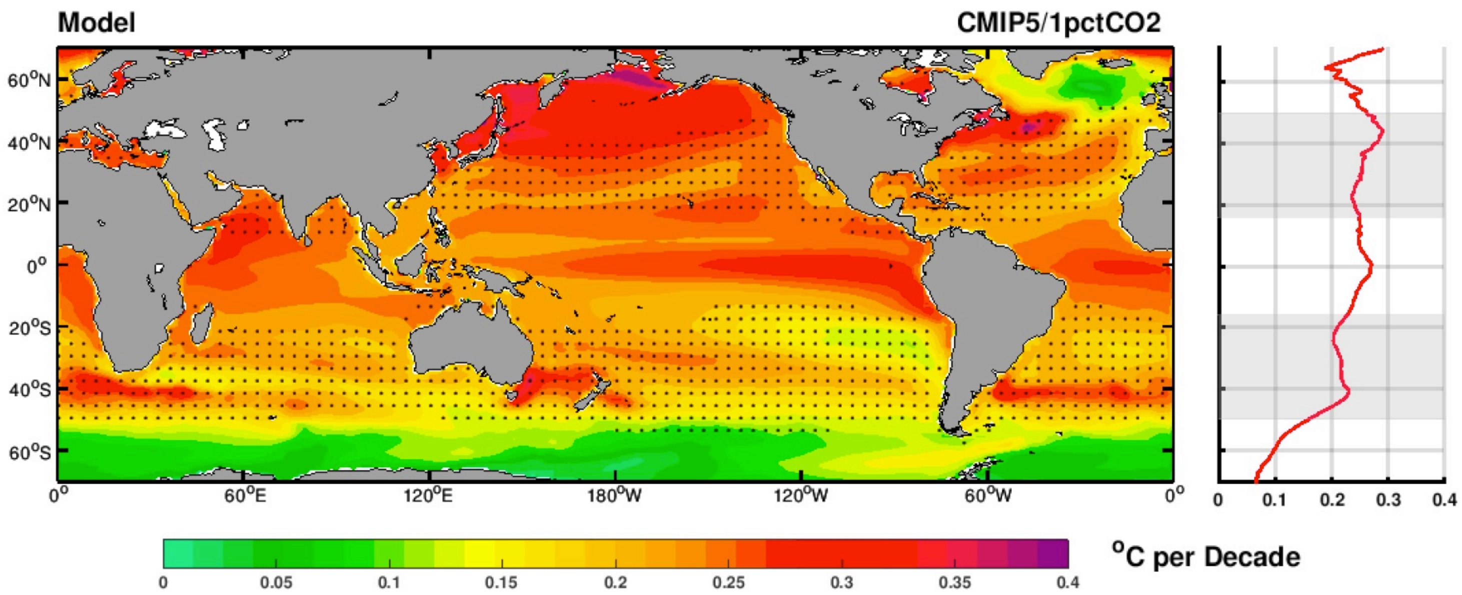


Yang et al, (2020) Under review on GRL.



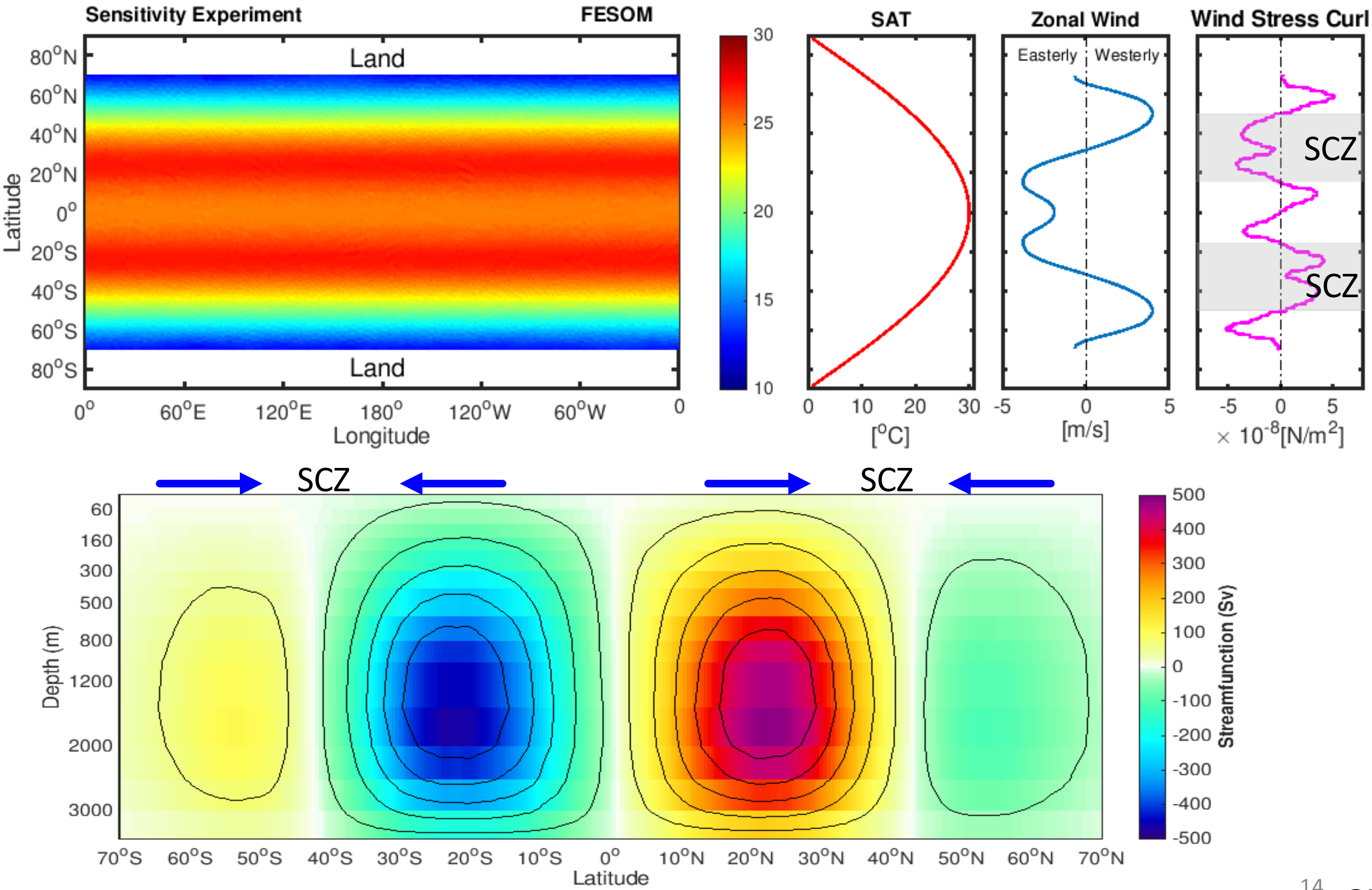


Fu. et al. (2006)



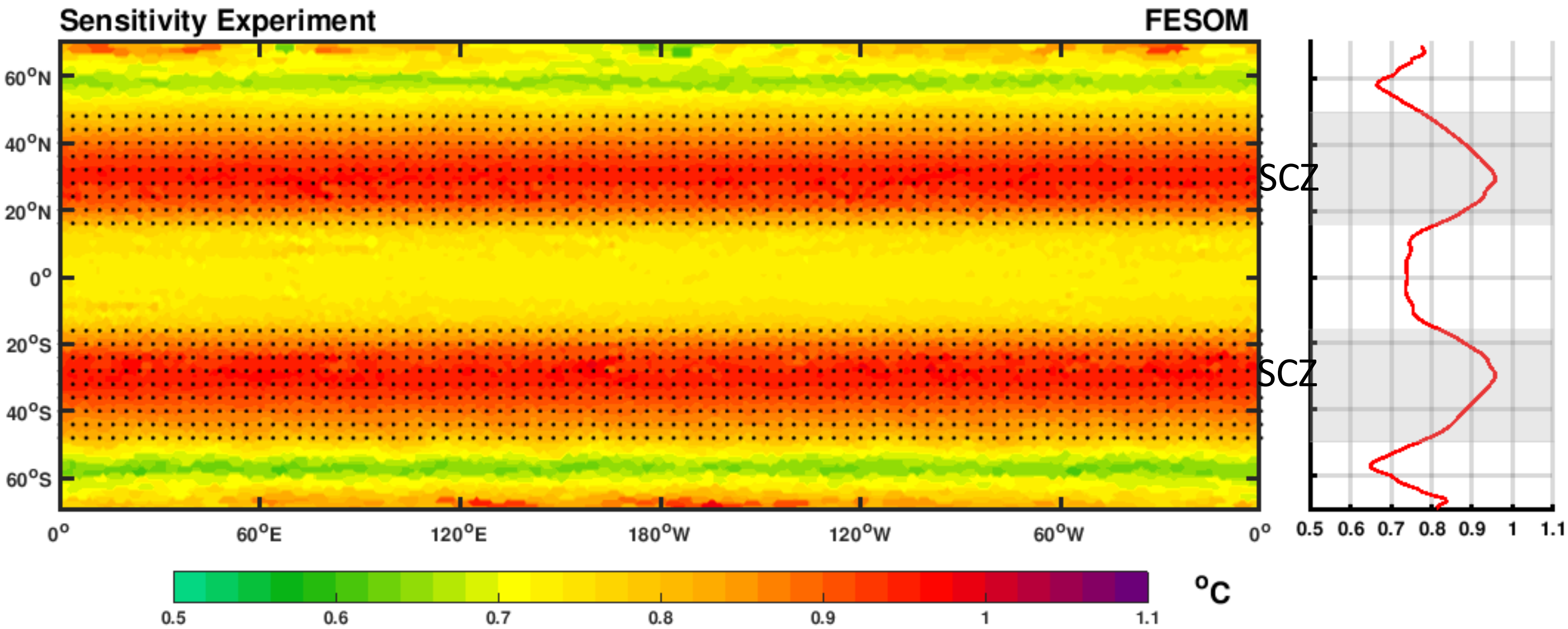
Yang et al, (2020) Under review on GRL.

Aqua-Planet FESOM



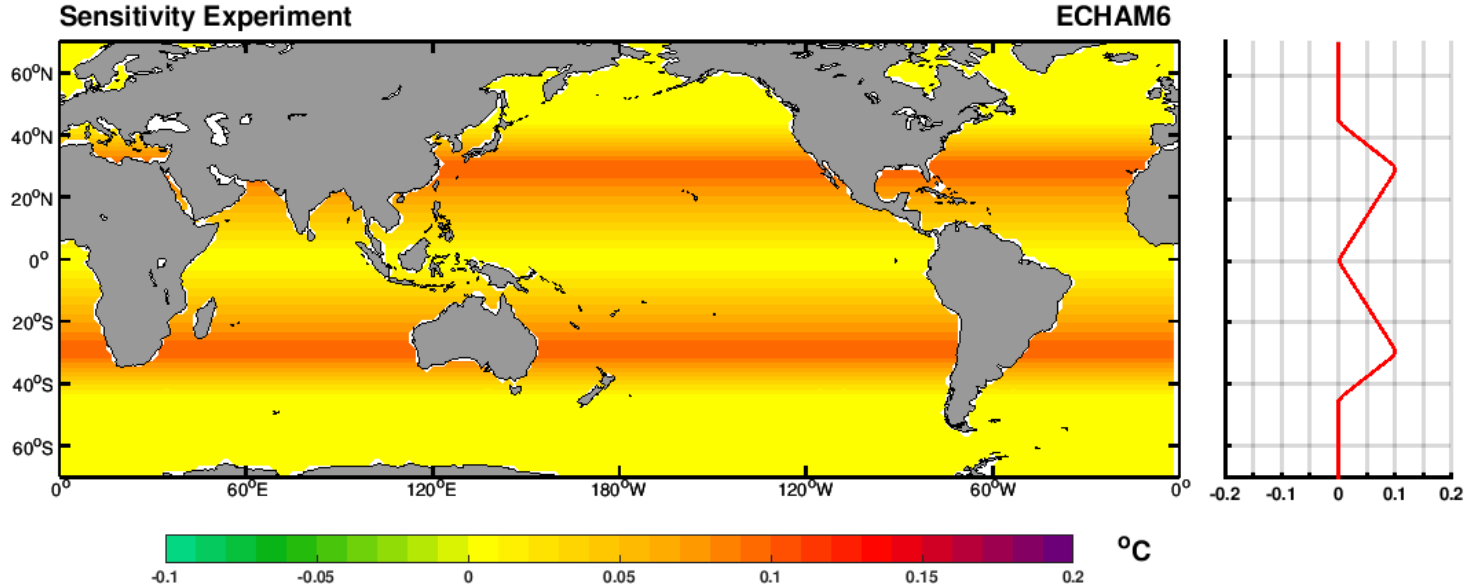
Yang et al, (2020) Under review on GRL.

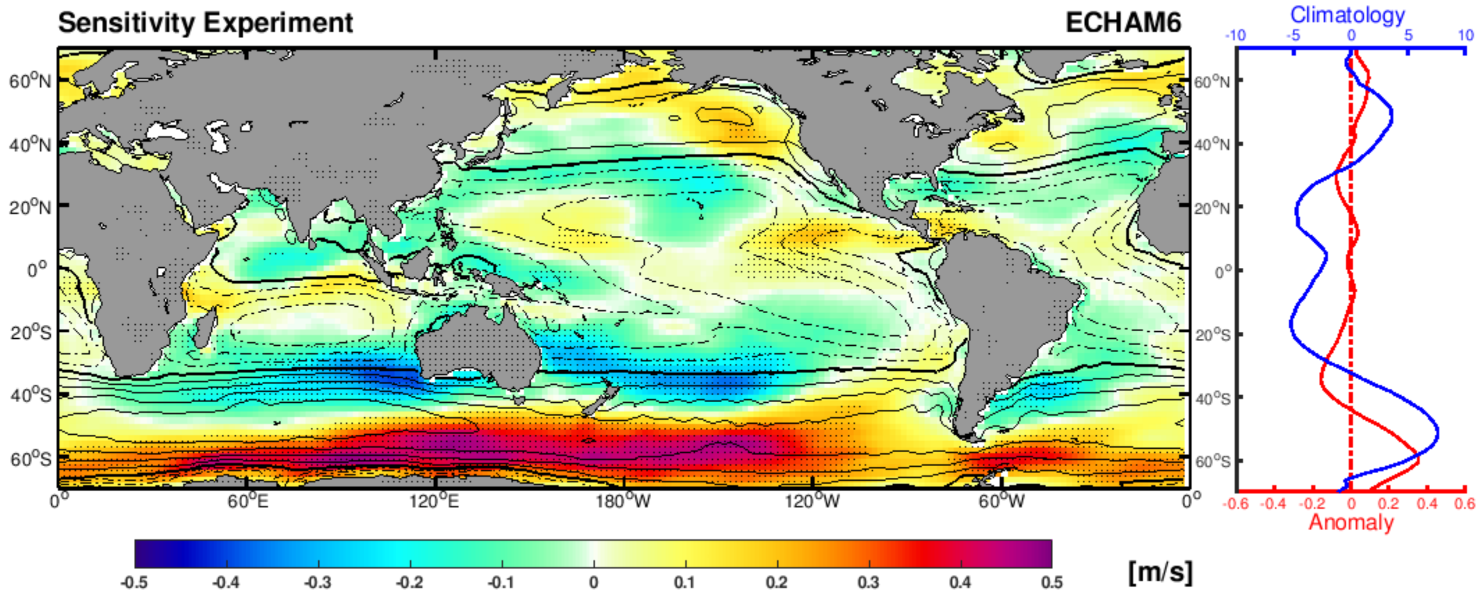
SST warming pattern under uniform 1 degree warmer SAT forcing



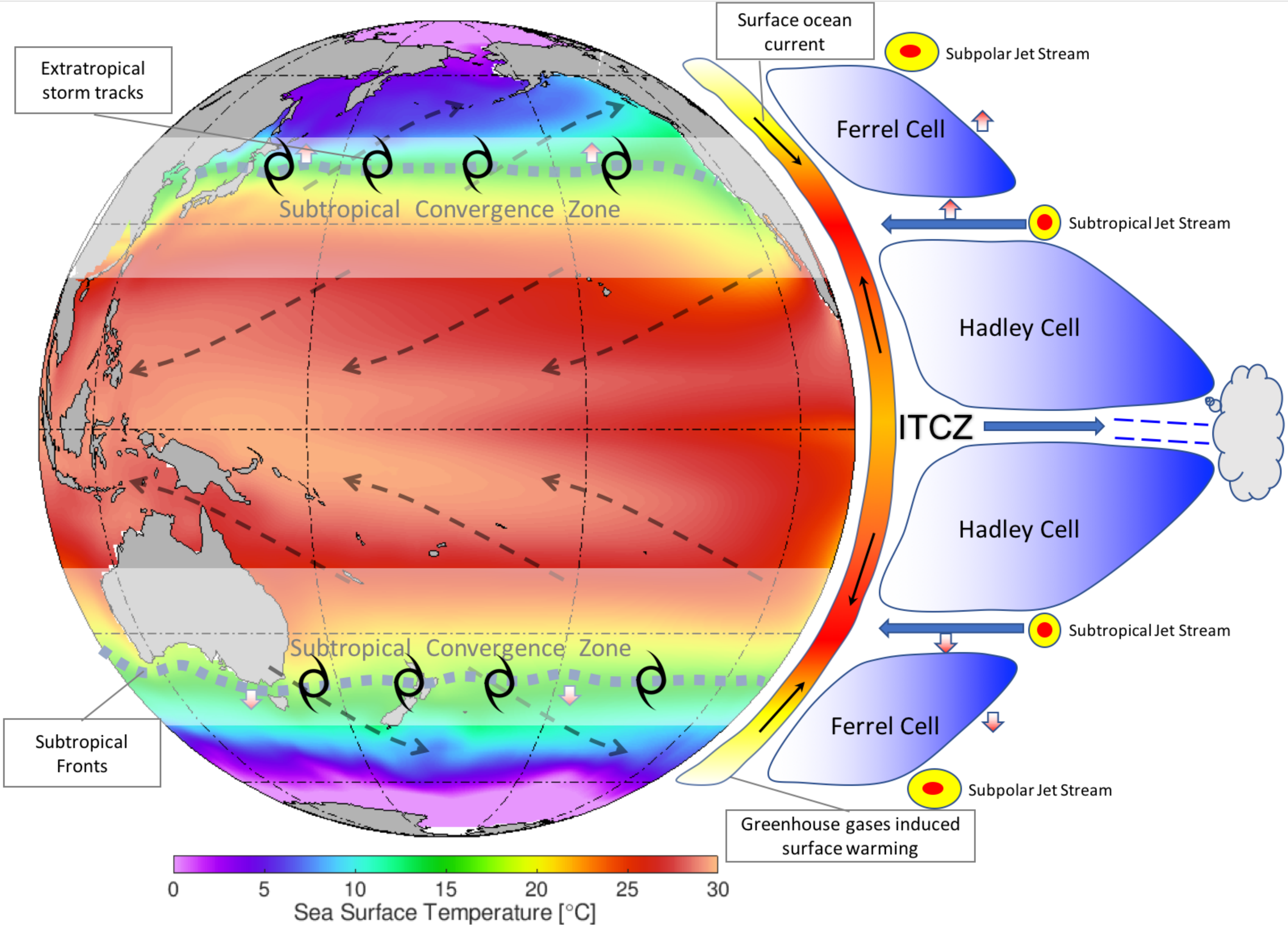
Yang et al, (2020) Under review on GRL.

Warmer subtropical ocean (poleward shift of subtropical front) drives wider tropics





Yang et al, (2020) Under review on GRL.



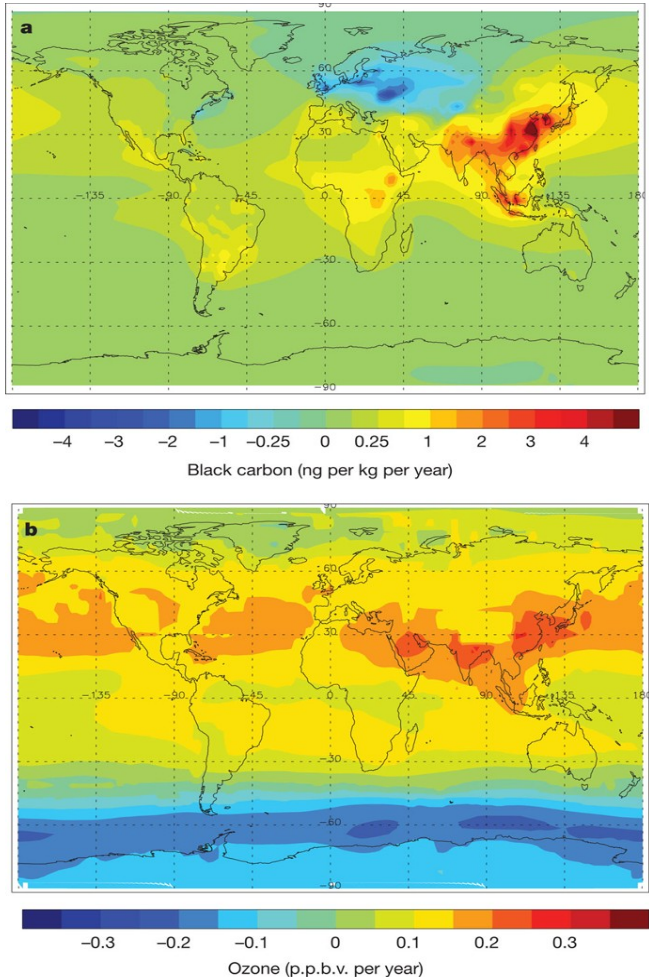
Yang et al, (2020) Under review on GRL.

Answers to the previous questions

- ✓ The aerosol, especially for black carbon, contribute to warming over the mid-latitudes (Allen et al., 2012), which has the potential to sustain a poleward shift of atmospheric subtropical front.

- ✓ The ozone hole over the Antarctic cools the Antarctic (Randel & Wu, 1999; Thompson et al., 2011; Orr et al., 2012) contributing to the migration of the mid-latitude temperature gradients.

- ✓ The tropics are narrower during glacial period (Son et al., 2018), because high-latitude cold water expands towards lower latitudes (Annan & Hargreaves, 2013), causing an equatorward contraction of the temperature gradients.



(Allen et al., 2012)

Conclusions

- Both observations and climate simulations indicate that the width of the tropics follows the meridional variations of subtropical fronts.
- Under global warming, the subtropical fronts advance towards poles due to enhanced warming over the subtropical ocean.
- Poleward advancing of the subtropical fronts shifts the edges of the tropics, westerlies, jet streams and storm tracks towards poles.