Change in Ocean Subsurface Environment to Suppress Tropical Cyclone Intensification Under Global Warming

Presented by
Kerry Emanuel (MIT, USA)

Ping Huang (Chinese Academy of Science, CAS, China)
I-I Lin* (Dept. of Atm. Sci., National Taiwan University, Taiwan)
late Chia Chou (Academia Sinica, Taiwan), Rong Hui Huang (CAS)

Motivation

It is well known that not only SST, but also upper ocean subsurface thermal stratification is important for TC intensification. Ocean stratification (slope of the upper ocean profile below mixed layer) affects the TC-induced ocean cooling effect (OCE) during intensification. The sharper the slope, the stronger the OCE, the less enthalpy flux is supplied from the ocean for intensification (Emanuel 1999; Bender and Ginis 2000…).

A curious question:

Recently oceanographers (e.g., Capotondi,et al. 2012) suggest a general increase in stratification (slope sharpening) under global warming. Will this sharpening occur over the TC Main Development Regions (MDRs) and affect TC intensification?

[This question was asked also in Knutson et al. 2001.]

Content

Present and discuss 2 recent papers on the subject, with updated results.

Huang et al. Nat. Comm. 2015 (H15)

Study Areas: North Atlantic (NA) & North West Pacific (WNP)

&

Emanuel JC 2015 (E15)

Study area: North West Pacific

ACCESS1-0	HadGEM2-AO (-ES in Emanuel 2015)
ACCESS1-3	IPSL-CM5A-LR
BCC-CSM1-1	IPSL-CM5A-MR
CCSM4	IPSL-CM5B-LR
CMCC-CESM	MIROC-ESM-CHEM
CMCC-CM	MIROC-ESM
CMCC-CMS	MIROC5
CNRM-CM5	MPI-ESM-LR
CSIRO-Mk3-6-0	MPI-ESM-MR
FGOALS-g2	MRI-CGCM3
GFDL-CM3	NorESM1-M

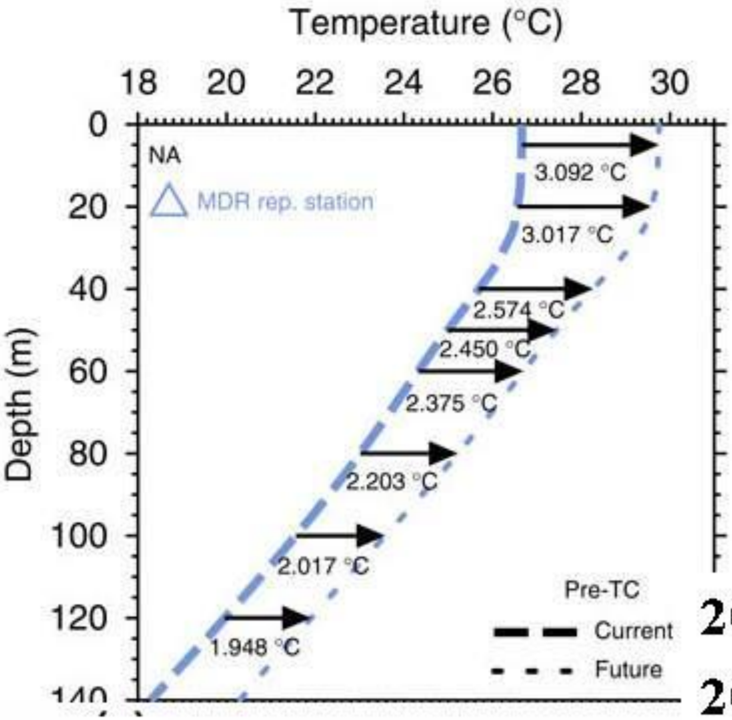
22 CMIP5 models in H15.

Red: the 7 overlapped models in H15 and E15.

TABLE 1. Models used in this study. (Expansions of acronyms are available at http://www.ametsoc.org/PubsAcronymList.)

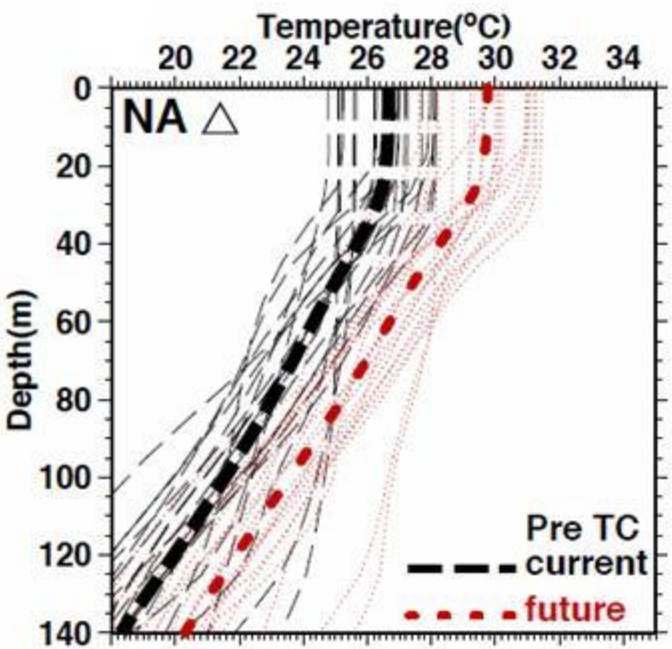
Modeling center	Institute identifier	Model name	Avg horizontal resolution (lon × lat)
NOAA/Geophysical Fluid Dynamics Laboratory	GFDL	GFDL CM3	2.5° × 2.0°
Met Office Hadley Centre	HadGEM	HadGEM2-ES	1.875° × 1.25°
L'Institut Pierre-Simon Laplace	IPSL	IPSL-CM5A-LR	3.75° × 1.89°
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC	MIROC5	1.4° × 1.4°
Max Planck Institute for Meteorology	MPI	MPI-ESM-MR	1.88° × 1.86°
Meteorological Research Institute	MRI	MRI-CGCM3	1.12° × 1.12°
National Center for Atmospheric Research–Center for Ocean–Land–Atmosphere Studies	NCAR–COLA	SP-CCSM4	1.25° × 0.94°

7 CMIP5 models in E15.



2006–2014

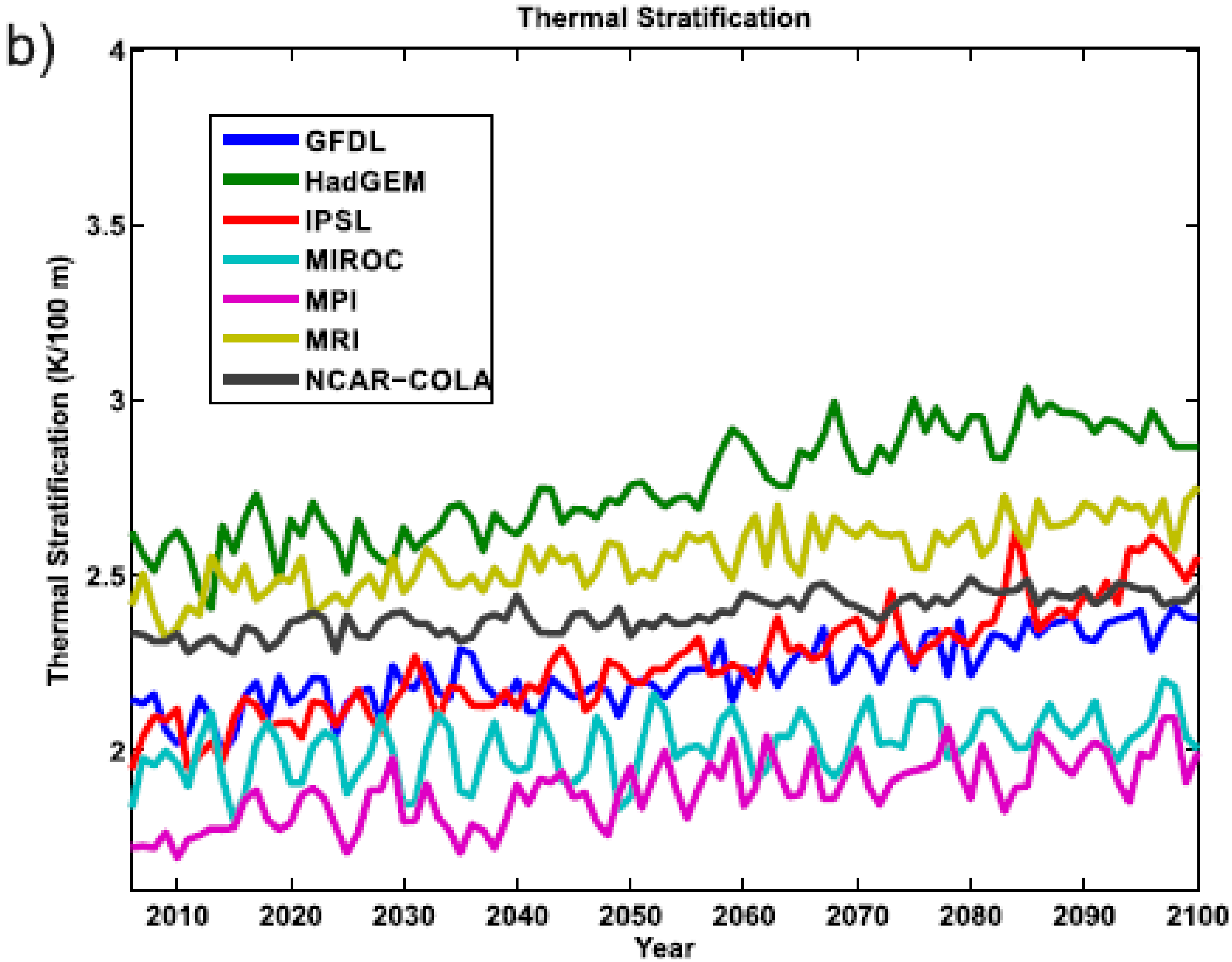
2092-2100



Multi-Model Ensemble (RCP 8.5 of 22 models) over NA MDR shows increase in stratification (slope sharpening) under global warming, because SST warms faster than subsurface ocean.

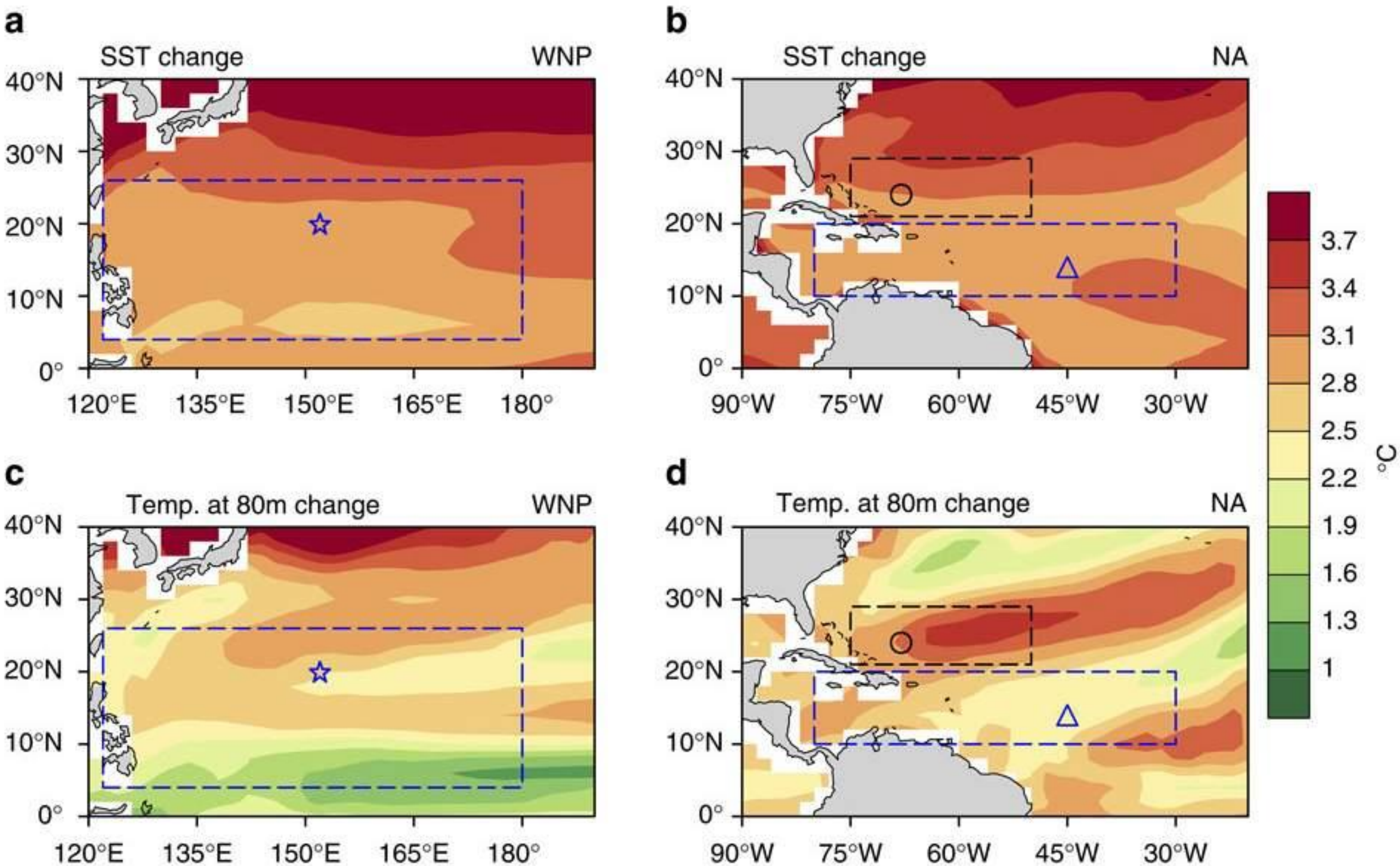
21/22 ensemble members shows sharpening in representative station

Consistent results is found in WNP MDR

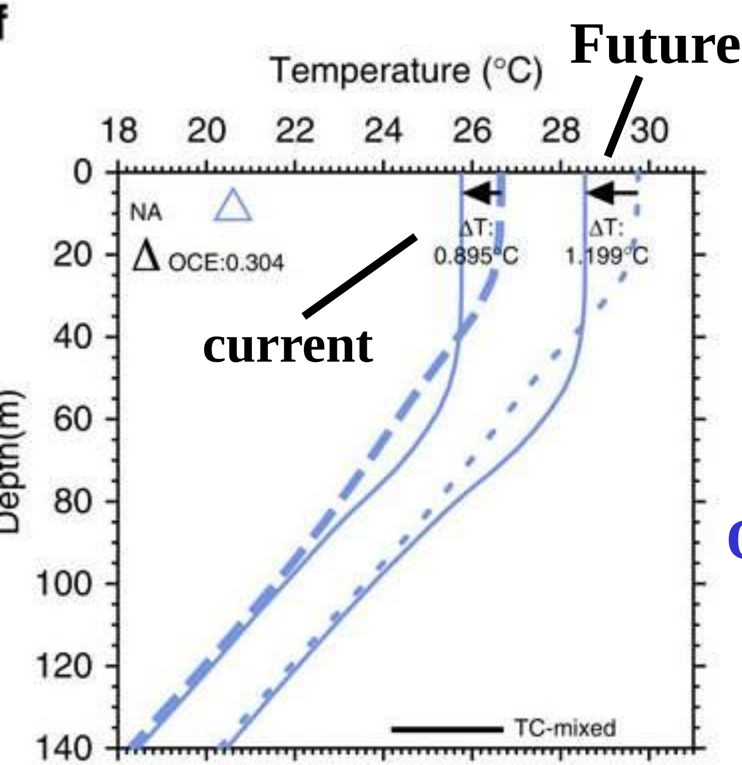


Increase in stratification over WNP is also found in the 7 models from E15.

Future - Current

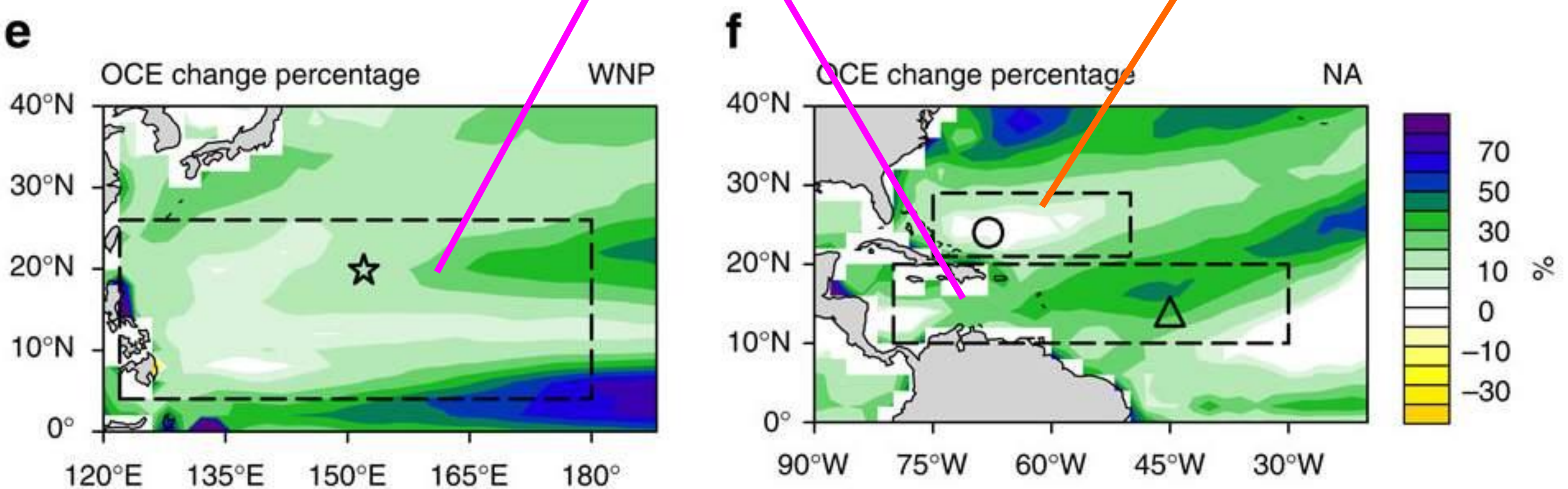


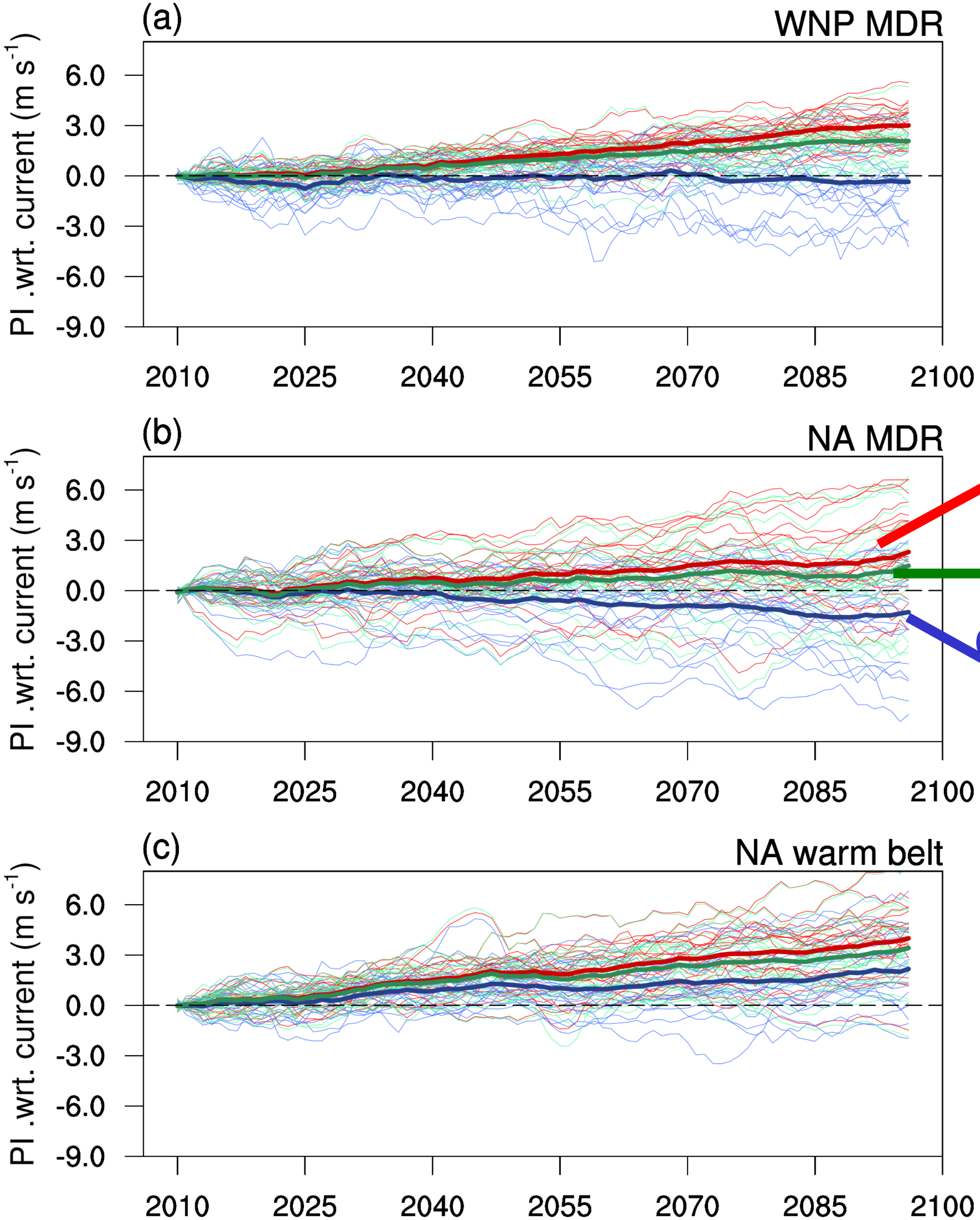
In global warming, the increasing downward heat flux from CO_2 heat surface (top maps) first and then subsurface (bottom), ocean subsurface thus warms less than SST and profile gradient sharpens.



Gradient sharpening increases Ocean Cooling Effect (OCE). Here OCE is estimated under category 3 intensity and 5m/s translation speed for both current and future, using Price et al. 1994 model.

Over most of WNP and NA, OCE increases by ~ 5-30% under global warming. However, in some local regions, e.g. NA Warm Belt, OCE does not increase.





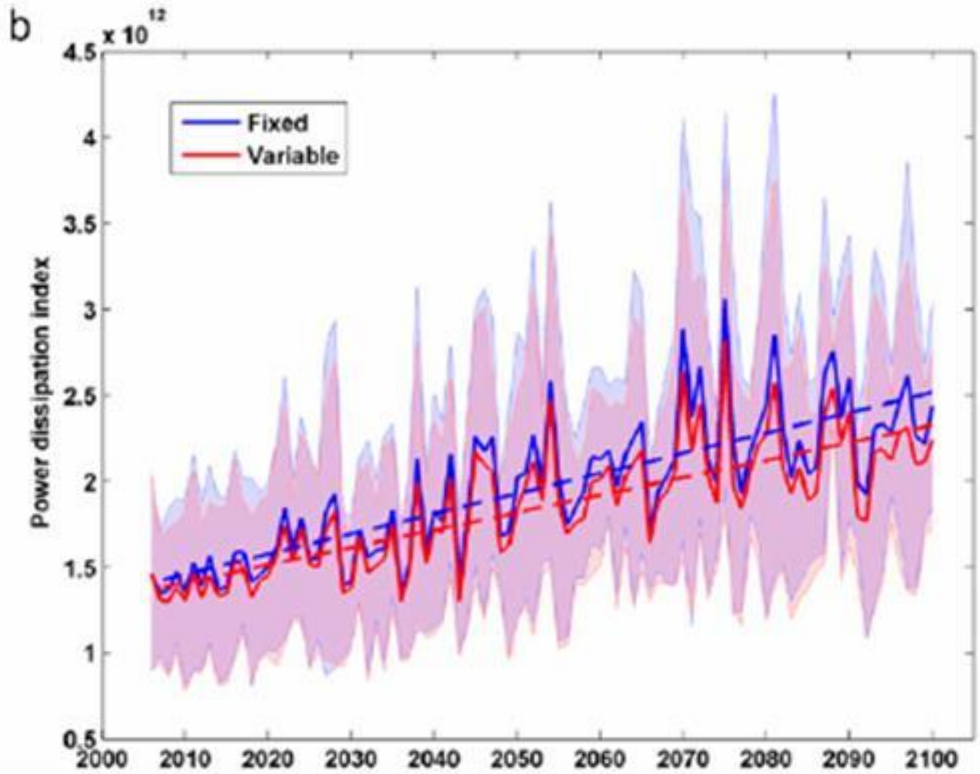
Impact to TC, based on Potential Intensity (PI, Bister and Emanuel 1998). OCE is included in a revised PI index (Lin et al. 2013)

Uncoupled scenario (no OCE effect)

OCE fixed as current

OCE allow to increase due to future stratification increase

In WNP and NA MDRs, OCE increase has a non-negligible impact to future TC PI. Over NA Warm belt (bottom), the impact is weak, because this local region has little OCE increase and stratification increase.

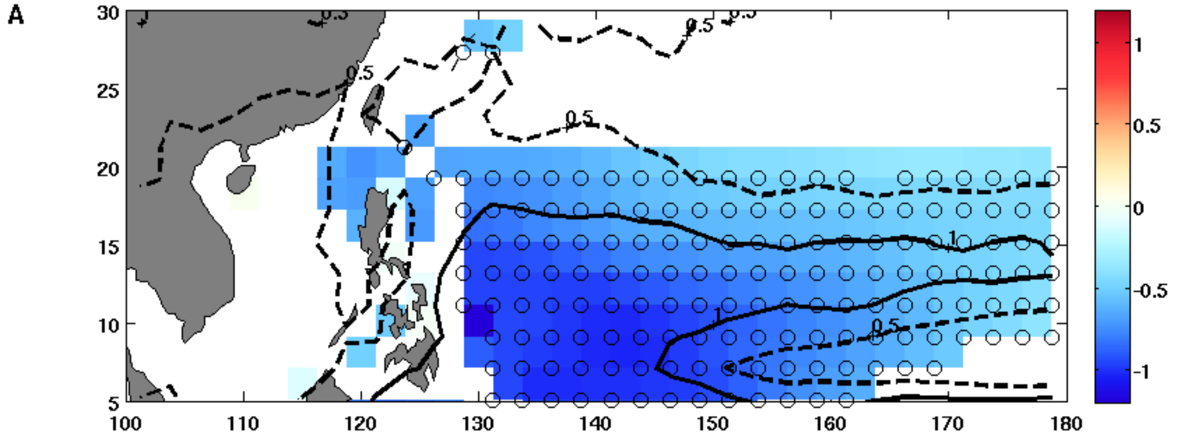


Further quantifications from E15 shows

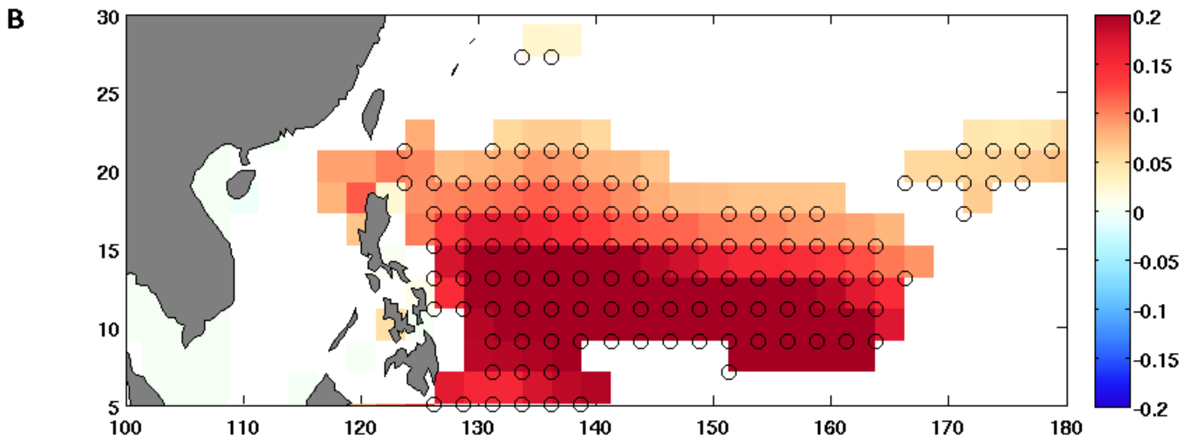
13% decrease in PDI and 15% decrease in category-5 TC frequency in the future, due to future stratification increase

TABLE 3. Percentage change in the difference of linear trends of western North Pacific tropical cyclone metrics from 2006 to 2100 between Fixed and Variable simulations for the models denoted by institution identifier in Table 1. The P values are shown in parentheses if they are greater than 0.01.

	GFDL	HadGEM	IPSL	MIROC	MPI	MRI	NCAR–COLA	Multimodel mean
Overall frequency	−2 (0.19)	0 (0.60)	0 (0.96)	−2 (0.03)	1 (0.82)	−2 (0.79)	0	−1 (0.14)
Frequency of hurricanes	−2 (0.31)	0 (0.91)	−4 (0.21)	−5	1 (0.80)	−1 (0.56)	0 (0.67)	−2 (0.02)
Frequency of category 1	5 (0.65)	2 (0.55)	7 (0.73)	6 (0.42)	9 (0.35)	9 (0.41)	1 (0.87)	3 (0.02)
Frequency of category 2	46 (0.07)	27 (0.06)	94 (0.25)	3 (0.83)	−33 (0.30)	−114	−1 (0.94)	34
Frequency of category 3	20 (0.42)	−1 (0.92)	14 (0.67)	13 (0.43)	106 (0.36)	14 (0.47)	9 (0.59)	11 (0.19)
Frequency of category 4	7 (0.56)	17 (0.04)	−3 (0.84)	−17 (0.13)	21 (0.39)	−5 (0.74)	10 (0.12)	4 (0.40)
Frequency of category 5	−19	−16	−24	−22	−8 (0.13)	−15	−6 (0.05)	−15
Power dissipation	−22	−10	−13	−14	−14 (0.07)	−24	−2 (0.05)	−13



Multi-model projected change in mixed layer salinity, CMIP5 RCP 8.5



Multi-model change in temperature of super-typhoon cold wake temperature, between simulations with and without change in salinity

Karthik, B., G. R. Foltz, L R. Lueng, and K. A. Emanuel, *Nature*, submitted

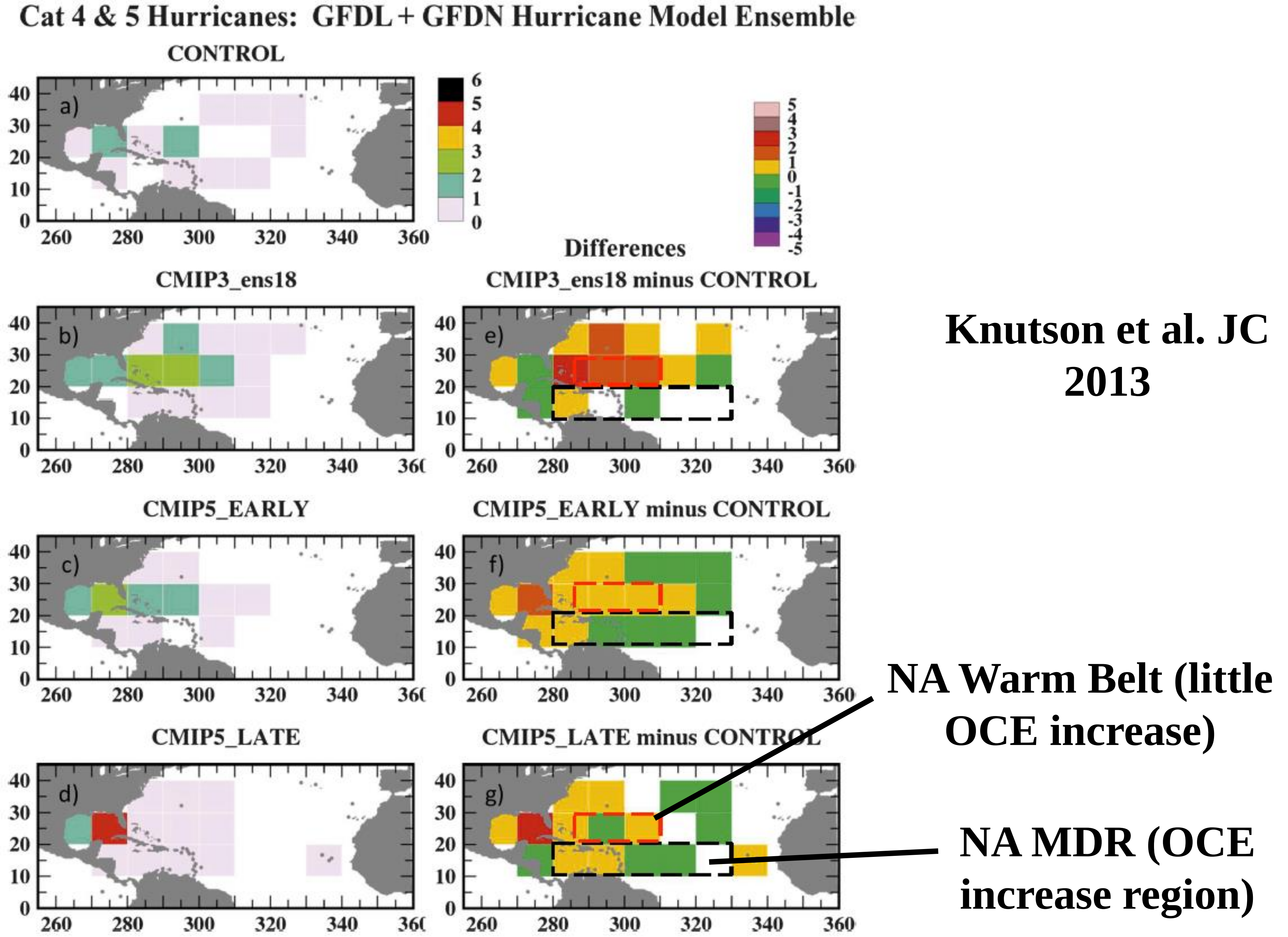
Summary

★ ***Under global warming, subsurface ocean warms SLOWER than surface ocean, ocean temperature gradient (stratification) sharpens, TC-induced ocean cooling effect (OCE) increases over WNP and NA MDRs.***

★ ***This effect appears to be non-negligible in affecting future TC intensification (H15). Recent quantification from E15 suggests that though it may not alter the increasing trend, it can effectively weaken (offset) the increase (PDI reduces by 13% and cat-5 TC increase reduces by 15%).***

★ ***Local variability exists, e.g. over NA Warm Belt region, there was little stratification sharpening (hence little OCE increase). Perhaps due to local ocean dynamic condition.***

Extra slides
(in case for questions)



Cat 4 & 5 Hurricanes: GFDL + GFDN Hurricane Model Ensemble
CONTROL
a)
Differences
CMIP3_ens18
b)
CMIP3_ens18 minus CONTROL
e)
CMIP5_EARLY
c)
CMIP5_EARLY minus CONTROL
f)
CMIP5_LATE
d)
CMIP5_LATE minus CONTROL
g)
Knutson et al. JC 2013
NA Warm Belt (little OCE increase)
NA MDR (OCE increase region)

References

Emanuel Nature 2005: uncoupled

Vecchi and Soden Nature 2007: uncoupled

Murakami et al. JC 2012; Sugi et al. GRL 2015: Uncoupled

Emanuel et al. PNAS 2013: coupled but without updating ocean subsurface field

Knutson et al. JC 2001: Coupled, CMIP2

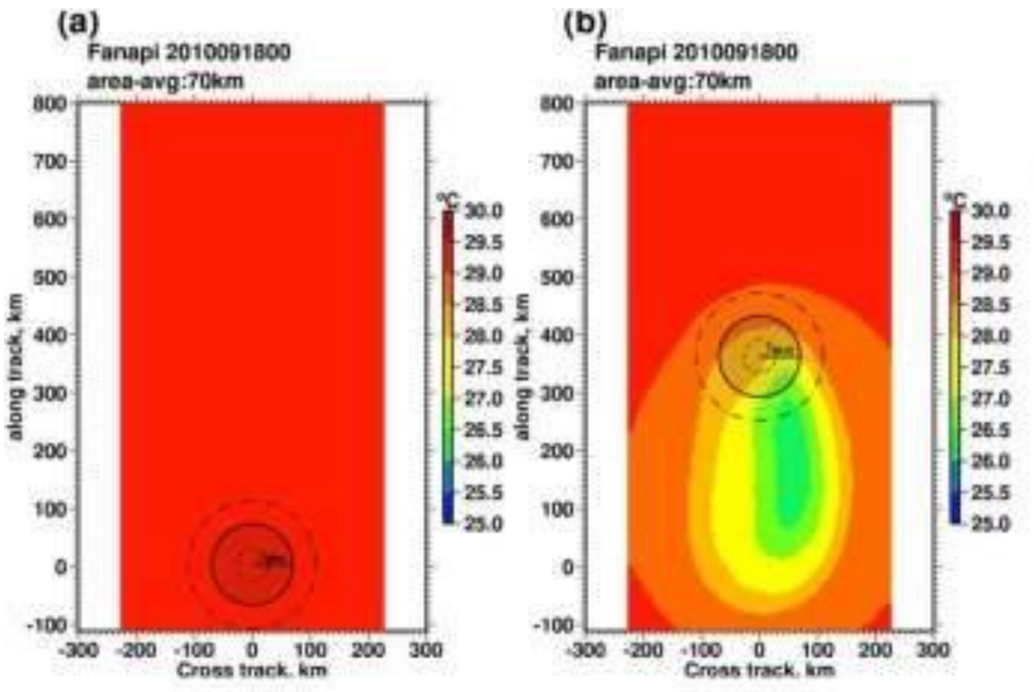
Bender et al. Science 2010: Coupled, CMIP3 mean profile, no ensemble spread,

Knutson et al. JC 2015: Coupled, fixed future ocean mixed layer

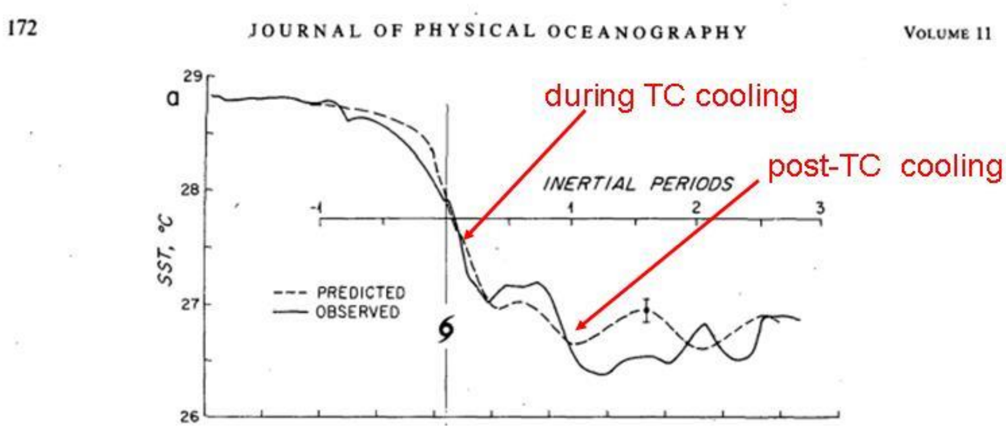
Huang et al. 2015: Coupled, CMIP5, 22 ensemble members with spread

Emanuel JC 2015: Coupled, CMIP5, 7 ensemble members with spread

Uncoupled .vs. coupled



Bender and Ginis 2000; Shay et al. 2000; Emanuel et al. 2004; Lin et al. 2005; 2013; 2014; Moon et al. 2007; 2008; Wada and Usui 2007; Wu et al. 2007; Goni et al. 2009; Balaguru et al. 2012; D'Asaro et al. 2014…..



Price 1981