Probability distribution of tropical cyclone in large ensemble simulation by MRI-AGCM

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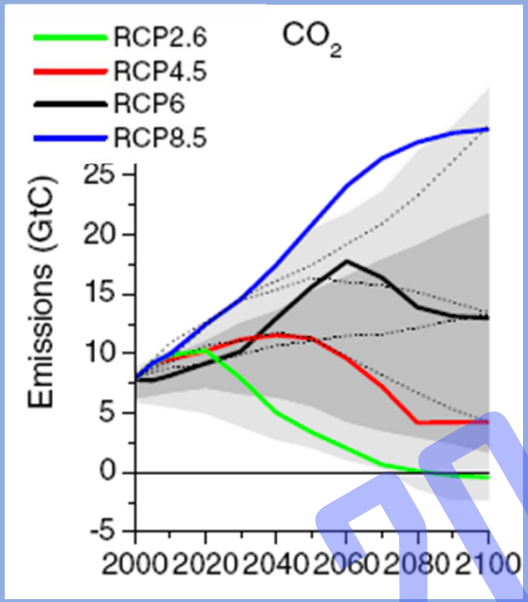
Outline

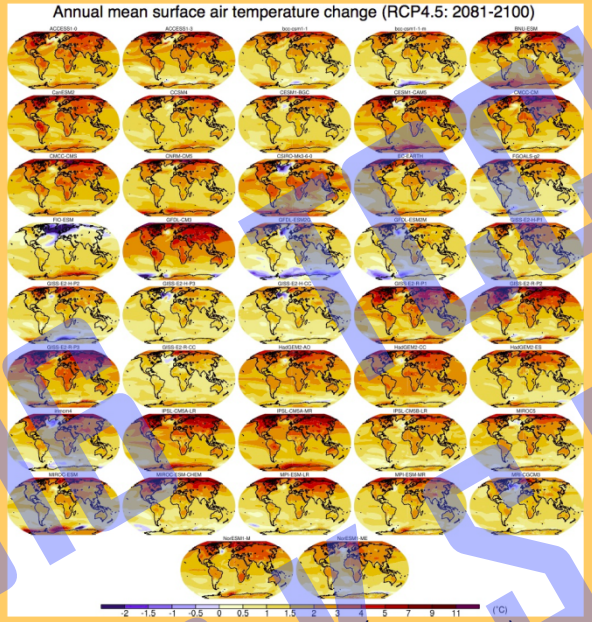
1. Huge ensemble simulation database “d4PDF”
2. TC genesis number
3. TC frequency
4. Major TC metrics
   (TC number, strong TC, surface wind, precipitation)
5. Bias correction for maximum surface wind

Uncertainty of global warming projection using climate models

Emission scenarios

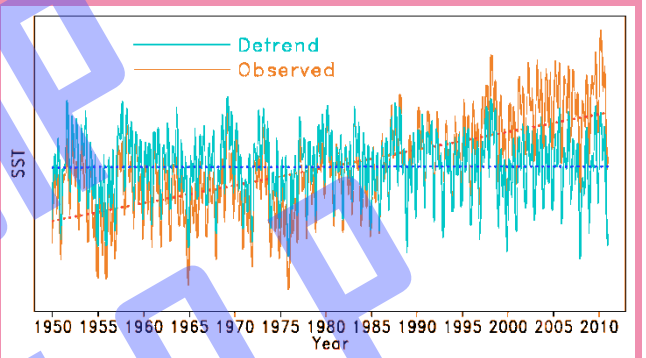


Climate models



(IPCC AR5)

Internal variability



Uncertainties of low frequency climate anomaly and extreme weather event are not assessed enough.

Low resolution, Ocean-coupled : CMIP5

High resolution, SST given : 20 and 60 km grid AGCMs and regional model in our projects

(e.g. SOUSEI program and KAKUSHIN program)

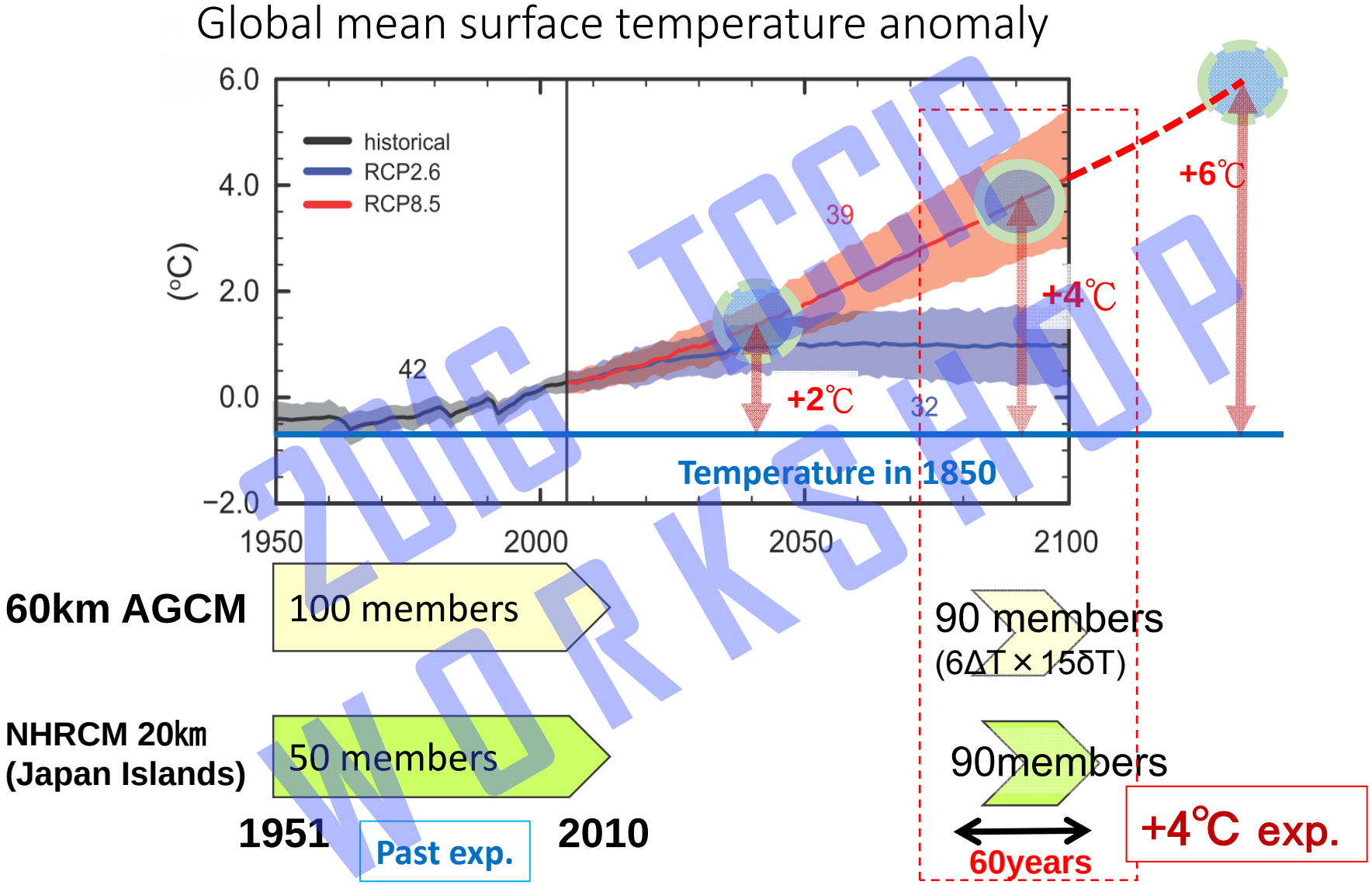
Statistical information by high-resolution and large ensemble = Main target

What is “d4PDF”?

To resolve these issues (uncertainties about low frequency climate anomaly and extreme weather event), we developed huge ensemble data set “Database for Probabilistic Description of Future Climate Change (d4PDF)” by 60 km grid MRI-AGCM3.2H and 20 km regional model NHRCM.

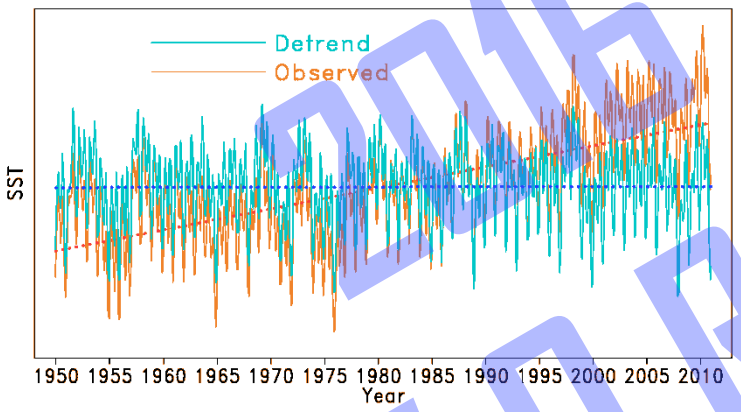
SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Design of d4PDF experiments (1)



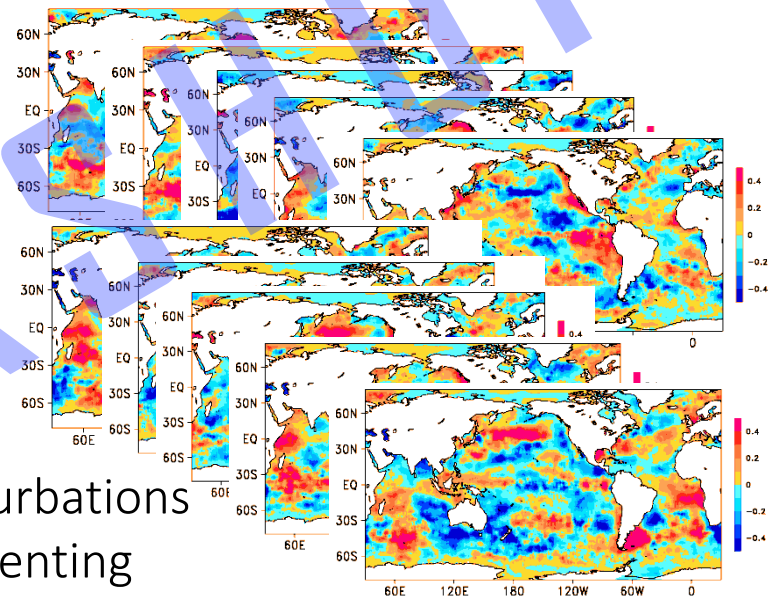
Design of d4PDF experiments (2)

- Past experiments: 1951-2010 (60 years), 100 ensemble members
  - COBE-SST2 including 100 observational perturbations
- No-global warming experiments: same as past exp. (ongoing)
  - Same SST as past exp. but for removing global warming trend



60 years past simulation including global warming trend (Orange; COBE-SST2)

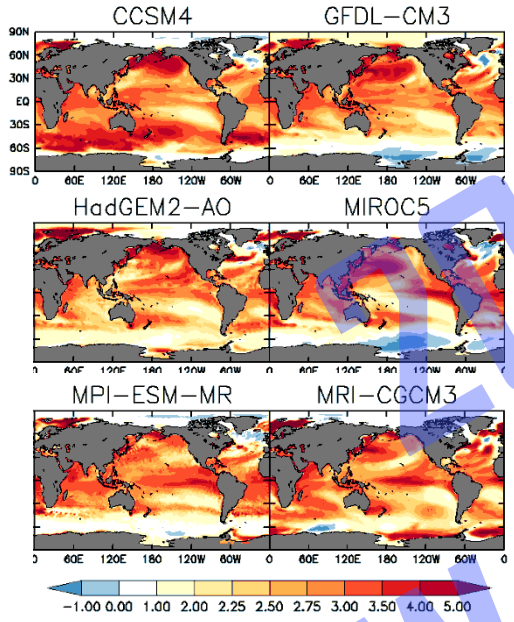
×



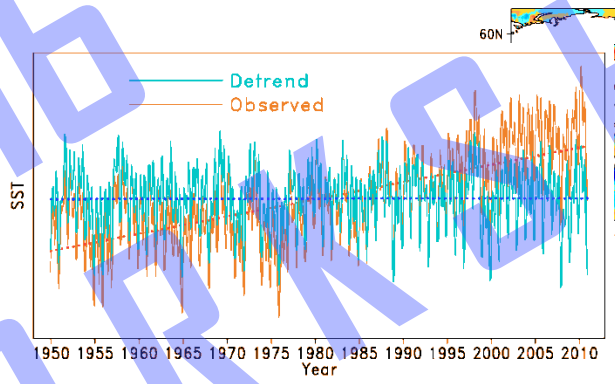
100 perturbations representing observational error(δT)

Design of d4PDF experiments (3)

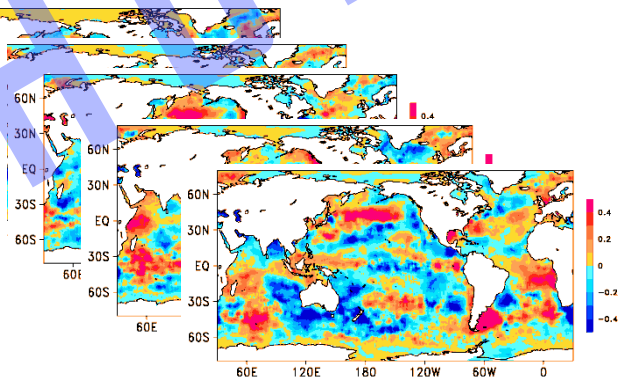
- Future (+4K) experiments: 60 years of 4 K warmer climate than pre-industrial climate, 6 (ΔSST) x 15 (perturbation) = 90 members
  - Future SST = detrended past SSTs + 6 SST warming patterns*
  *SST warming patterns are selected from 6 CMIP5 models in RCP8.5 scenario.
  - GHGs, ozone and aerosols: Values in 2090 following RCP8.5 scenario



6 types of SST warming pattern (CMIP5) (ΔT)

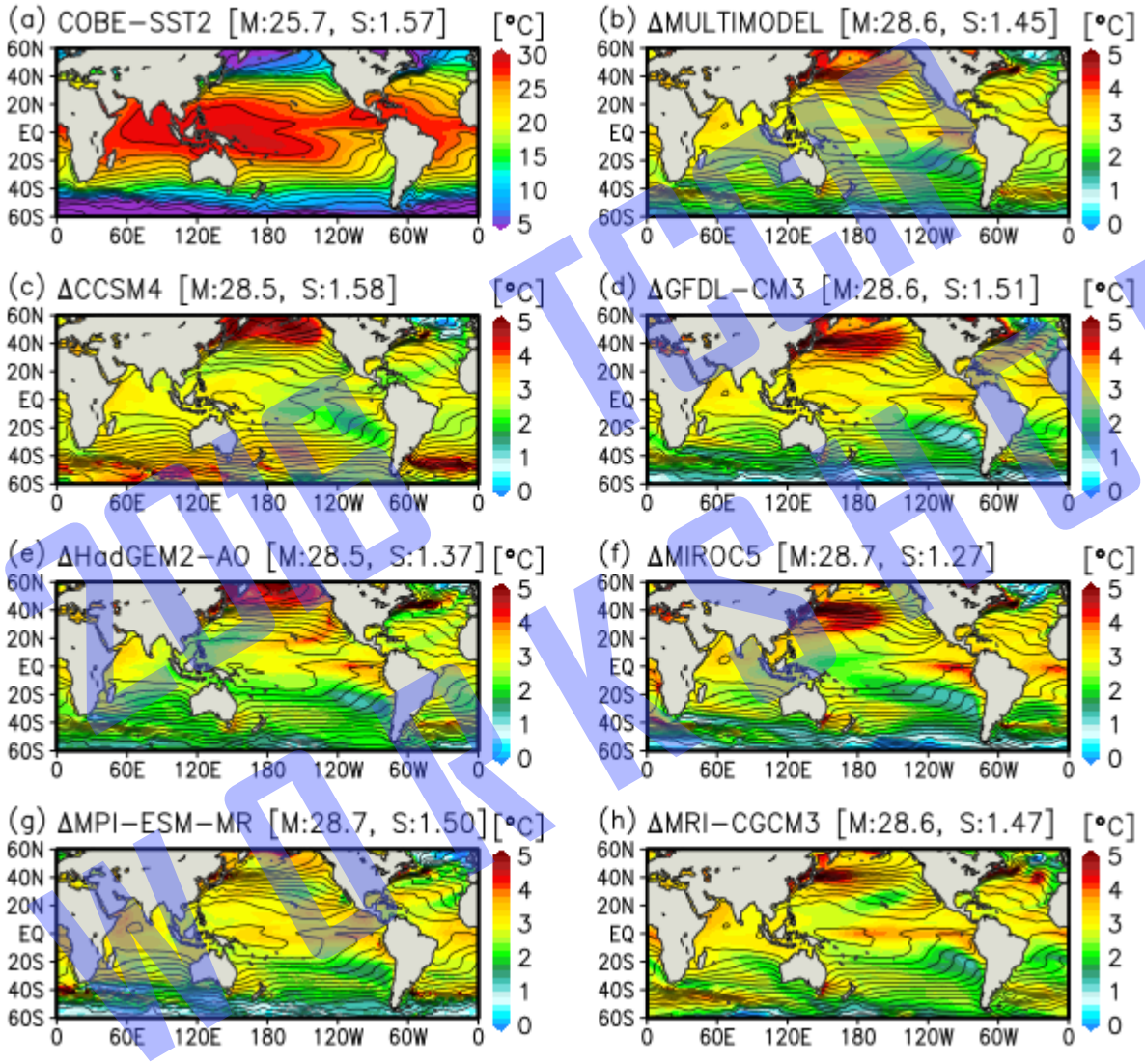


60 years of detrended SST in past exp. (Blue; detrended COBE-SST2)



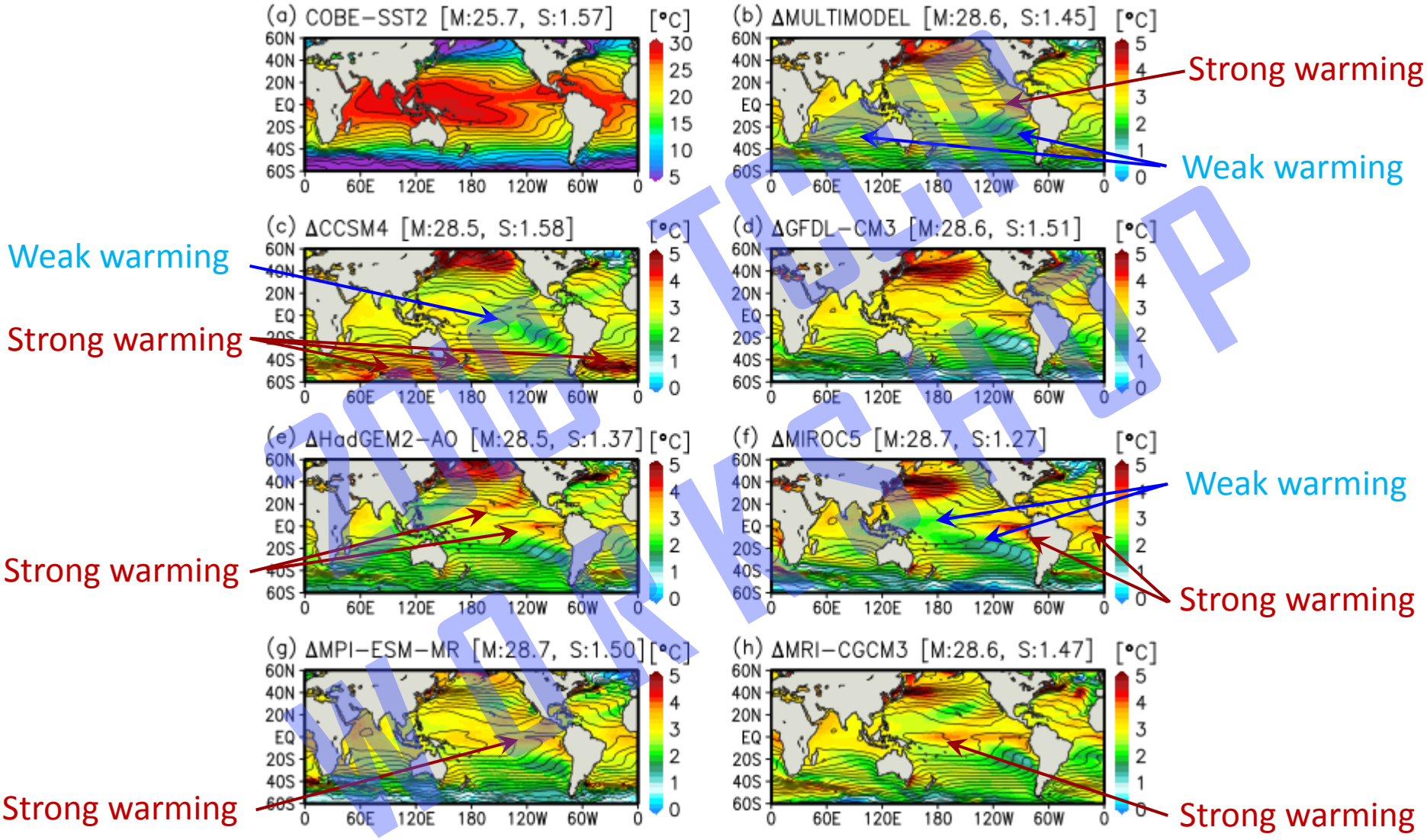
15 perturbations representing observational error (δT)

Climatology in sea surface temperature



Climatology in sea surface temperature

Uncertainty of future SST changes are well expressed.



Download

We can download the dataset from huge data server “DIAS”.

Global model:
http://dias-dss.tkl.iis.u-tokyo.ac.jp/ddc/viewer?ds=d4PDF_GCM&lang=en

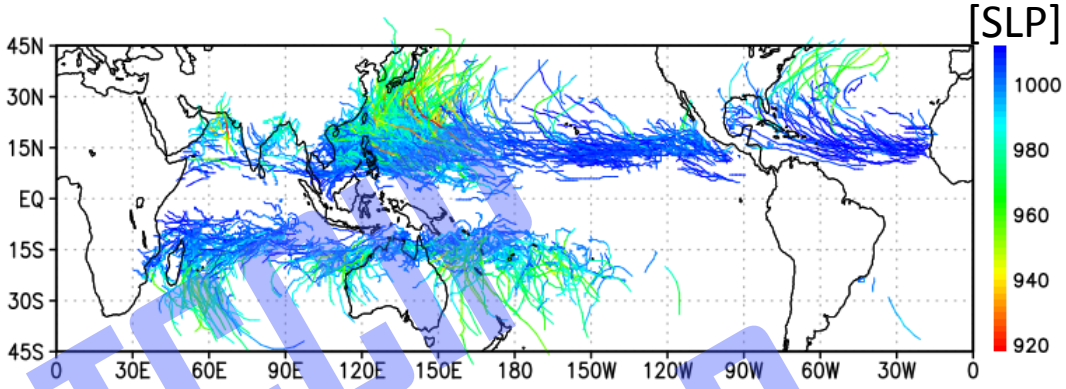
Regional model (around Japan):
http://dias-dss.tkl.iis.u-tokyo.ac.jp/ddc/viewer?ds=d4PDF_RCM&lang=en

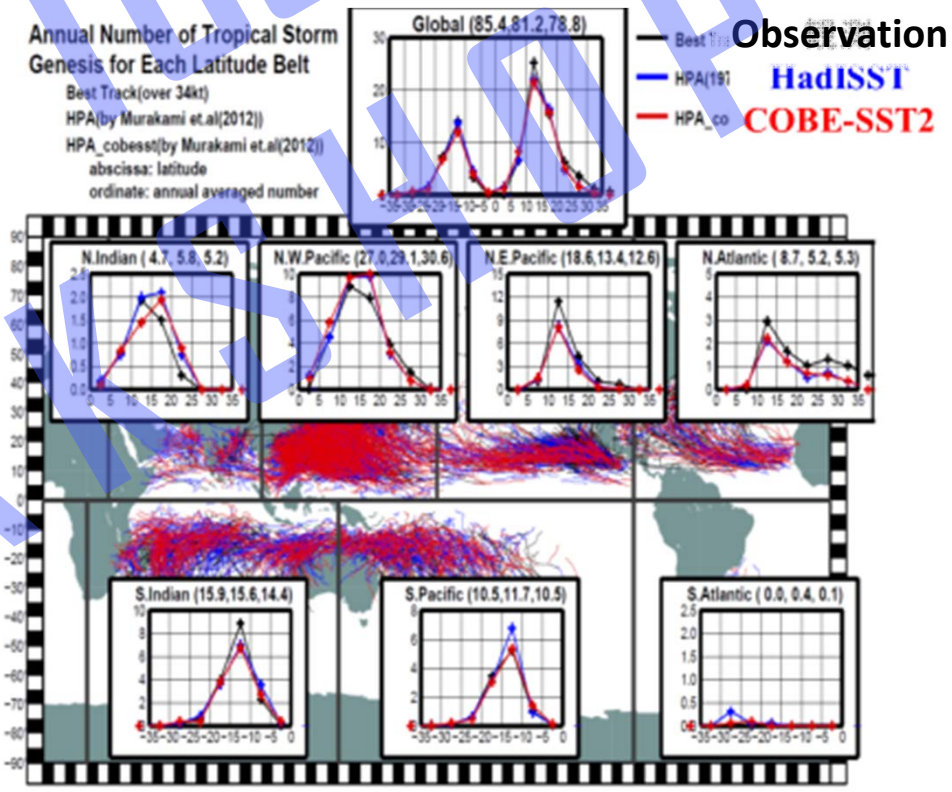
Total size of this dataset is 2 PB (= 2,000,000 GB)!

TC tracking method

- Murakami et al. (2012, *Clim. Dyn.*)
  - Suitable for 60km MRI-AGCM3.2H
- 850 hPa relative vorticity: 8.0×10^{-5}/s
- 850 hPa maximum wind: 13.0 m/s
- Temperature anomaly averaged between 300, 500 and 700 hPa: 0.8 K
- 36 hours duration

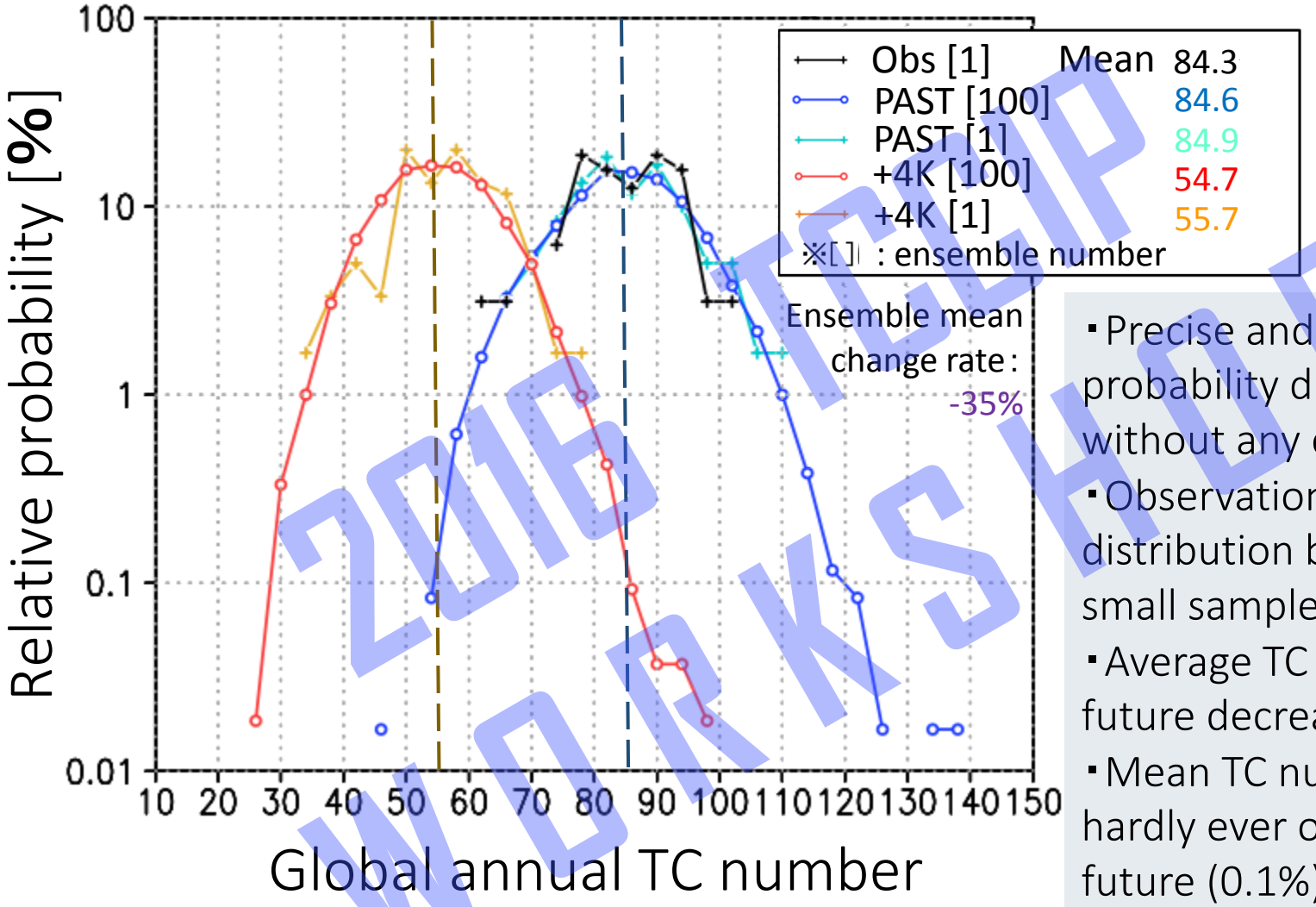
- Extracted from 6-hourly snapshot data





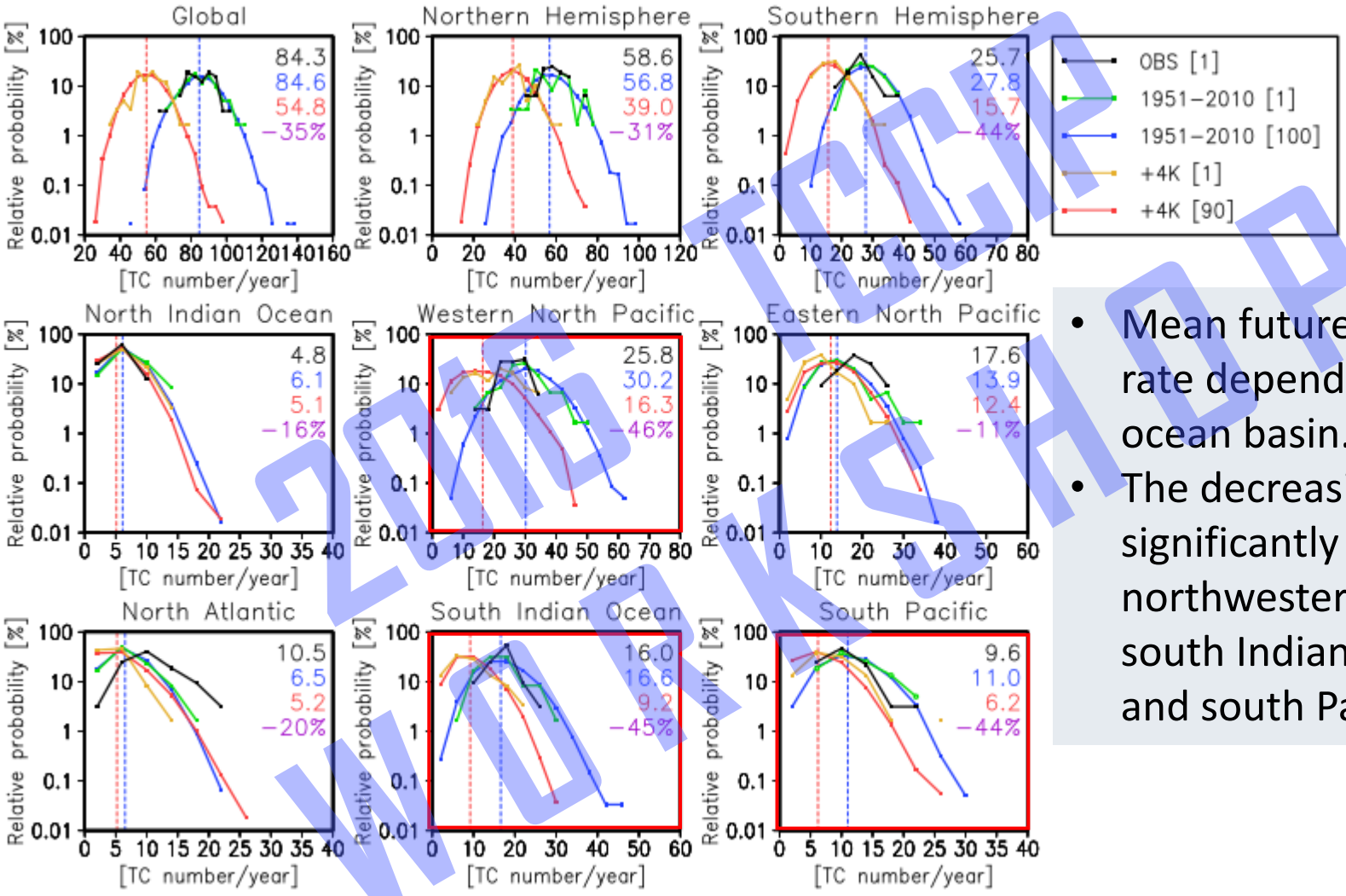
1. Huge ensemble simulation database “d4PDF”
2. TC genesis number
3. TC frequency
4. Major TC metrics
   (TC number, strong TC, surface wind, precipitation)
5. Bias correction for maximum surface wind

Annual tropical cyclone genesis number



- Precise and smooth probability distributions without any estimation
- Observation has coarse distribution because of small sample.
- Average TC number in future decreases by 35%.
- Mean TC number in past hardly ever occurs in future (0.1%).

Annual TC number in each ocean basin



- Mean future change rate depends on ocean basin.
- The decreasing rate is significantly large in northwestern Pacific, south Indian Ocean, and south Pacific.

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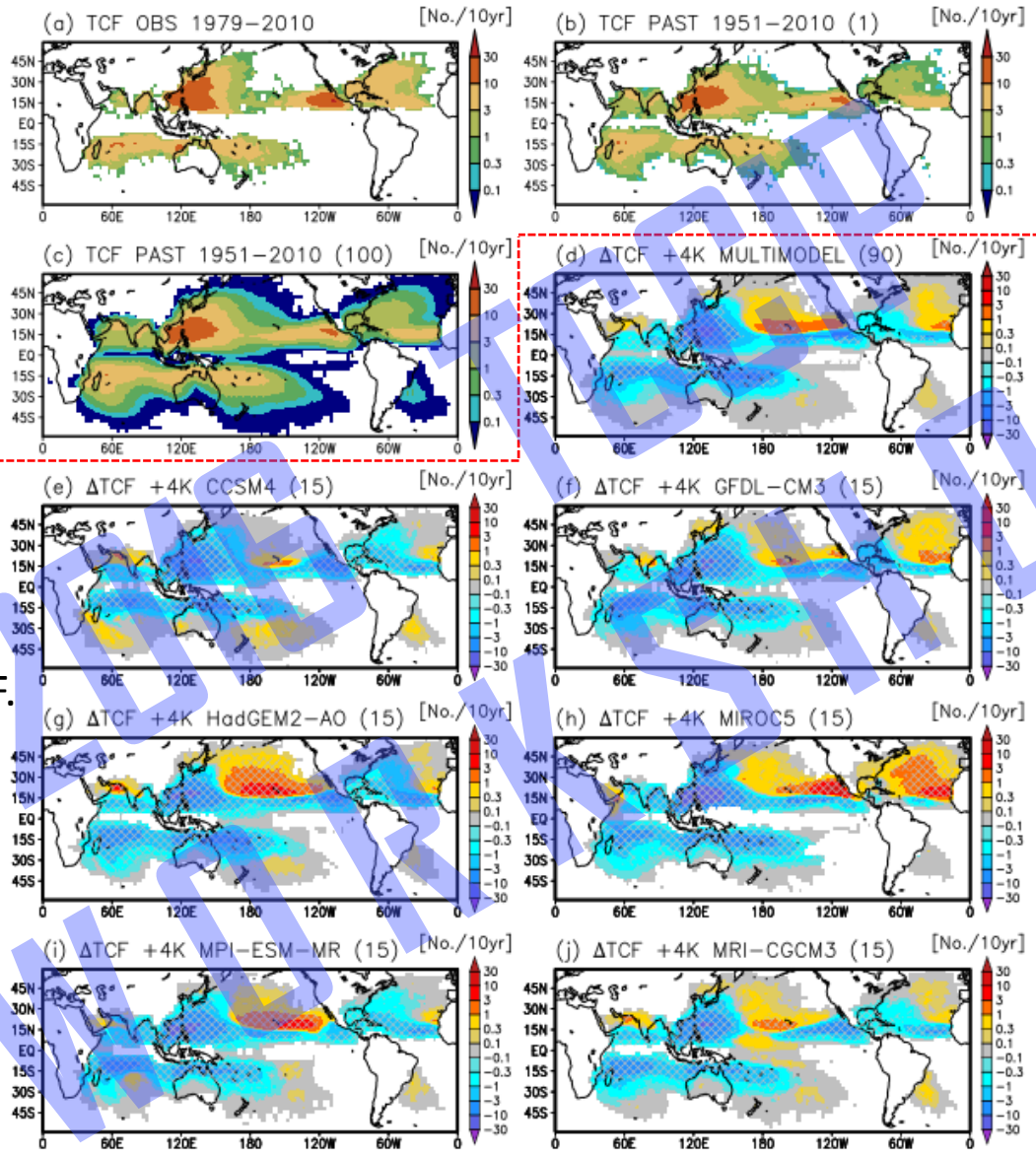
Spatial distribution in TC frequency (TCF)

MRI-AGCM3.2H well expresses TC frequency (TCF) behavior.

100-member ensemble shows very smooth and accurate TCF distribution.

Difference in SST warming affects future changes in TCF.

Difference in TCF occurs especially in North Pacific and North Atlantic.



Decrease: whole tropics and WNP

Increase: subtropical ENP and NAT

Spatial distribution in TC frequency (TCF)

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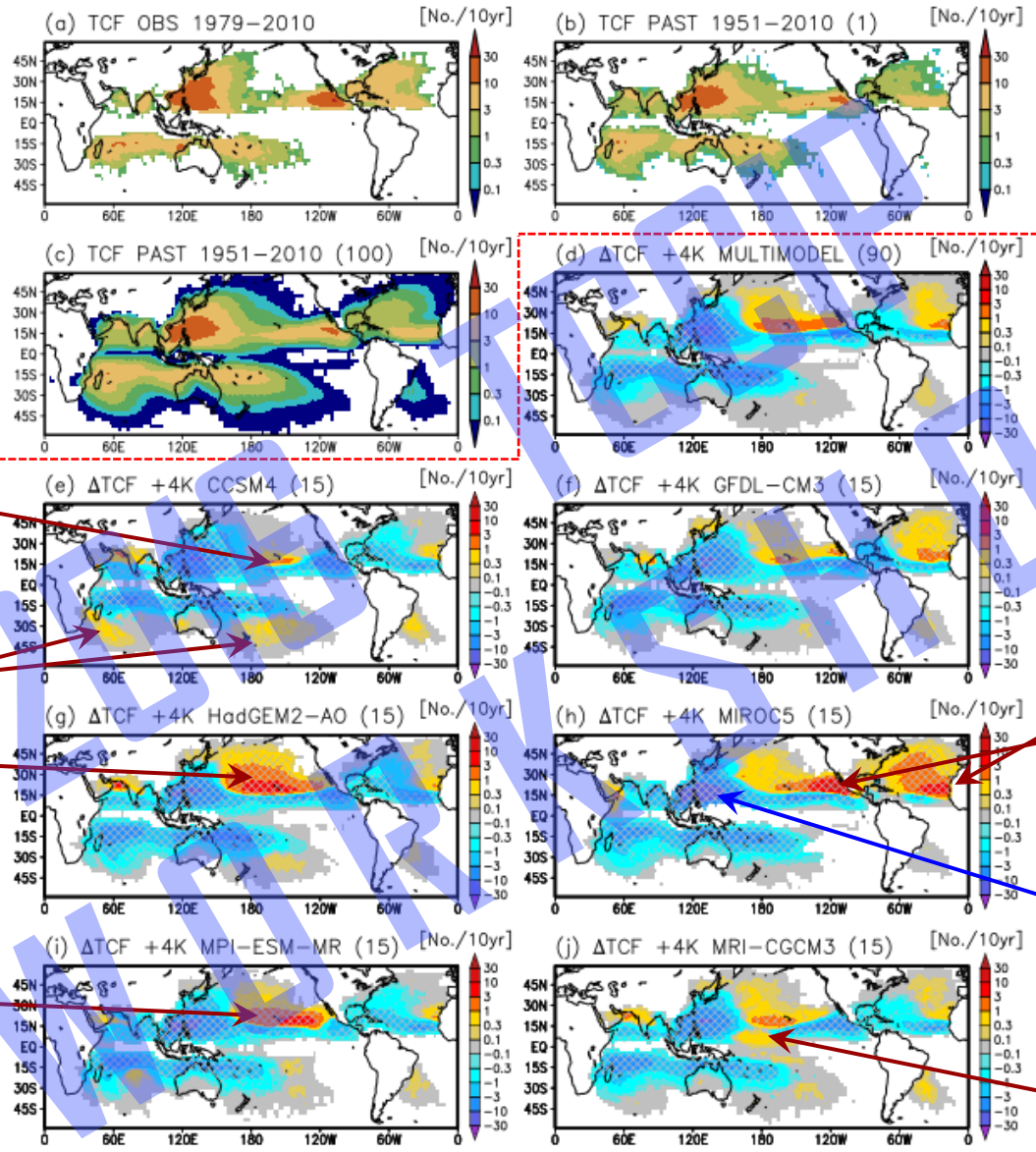


Decrease: whole tropics and WNP
Increase: subtropical ENP and NAT

Weak increase

Increase

Strong increase

Strong increase

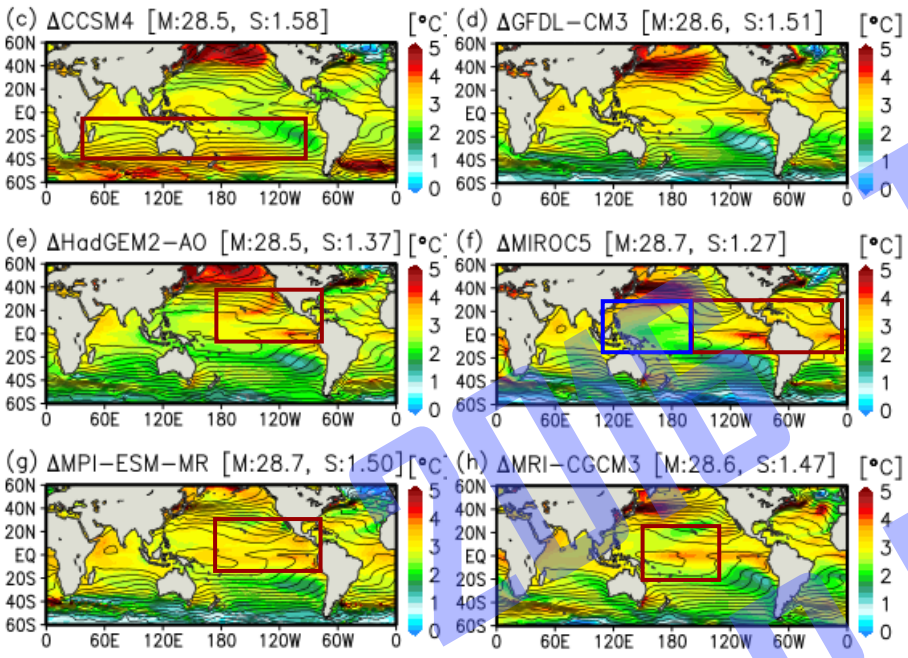
Strong decrease

Strong increase

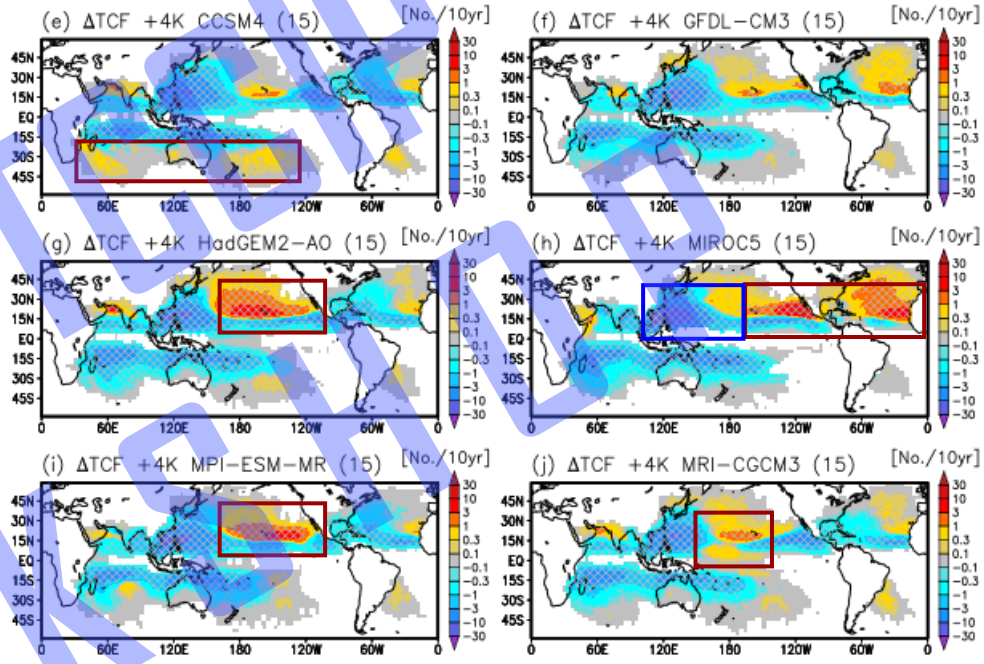
Increase

SST change vs TC frequency change

Future changes in SST climatology



Future changes in TC frequency



- TC frequency changes are largely corresponding to relative SST change.
- Relative SSTs are difficult to explain uniform TC frequency decreasing.

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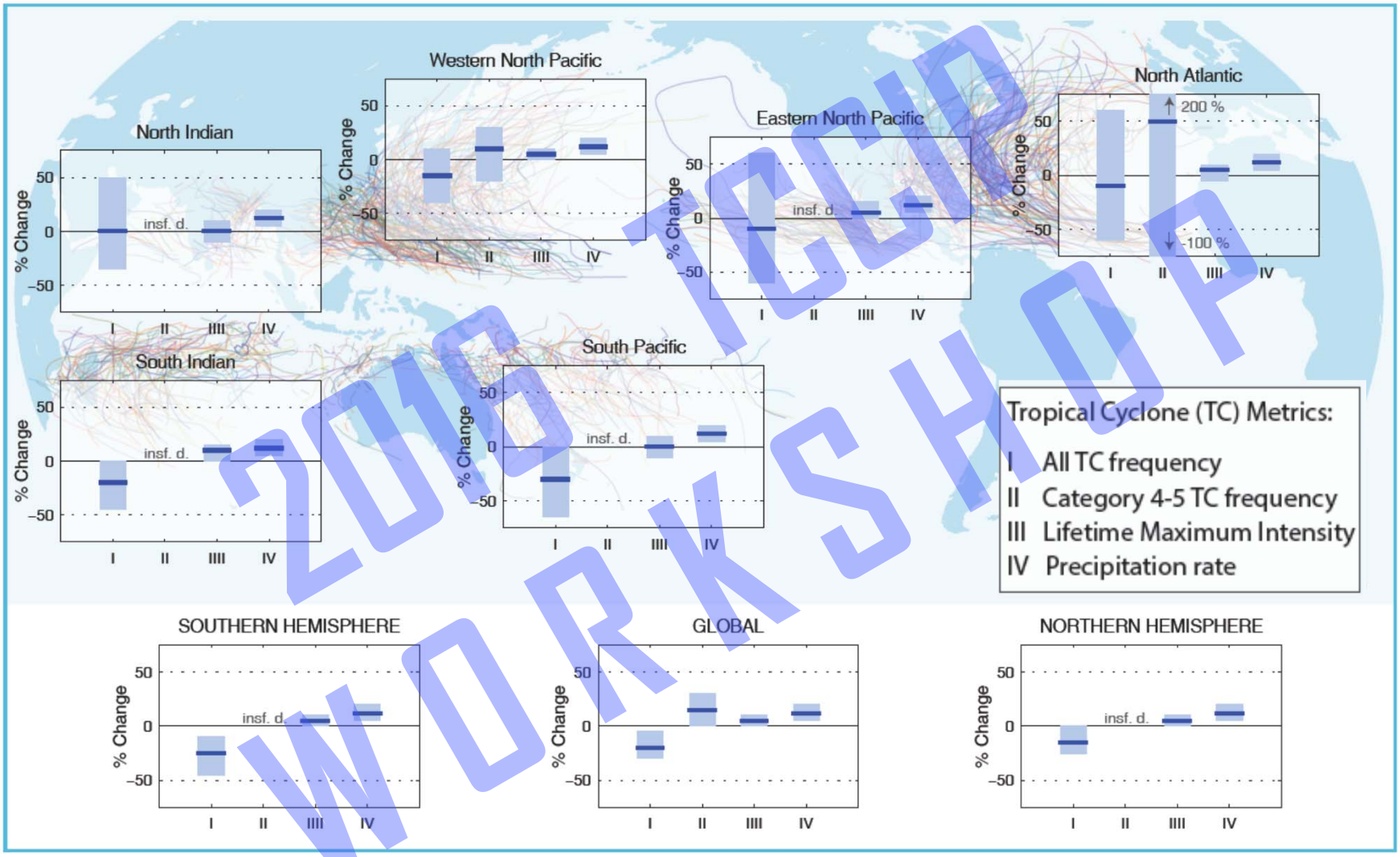
Major TC metrics - IPCC -

IPCC (2013)



Major TC metrics - future changes in climatology of d4PDF -

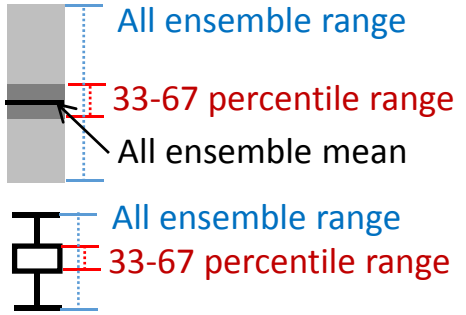
Global
All TC freq: -35%
Strong TC: +26%
LMI: +11%
Precip.: +29%

TC metrics change has same tendency as global case but depend on SST warming pattern especially in ENP and NAT.
Strong TC ratio decreases only in SPA.

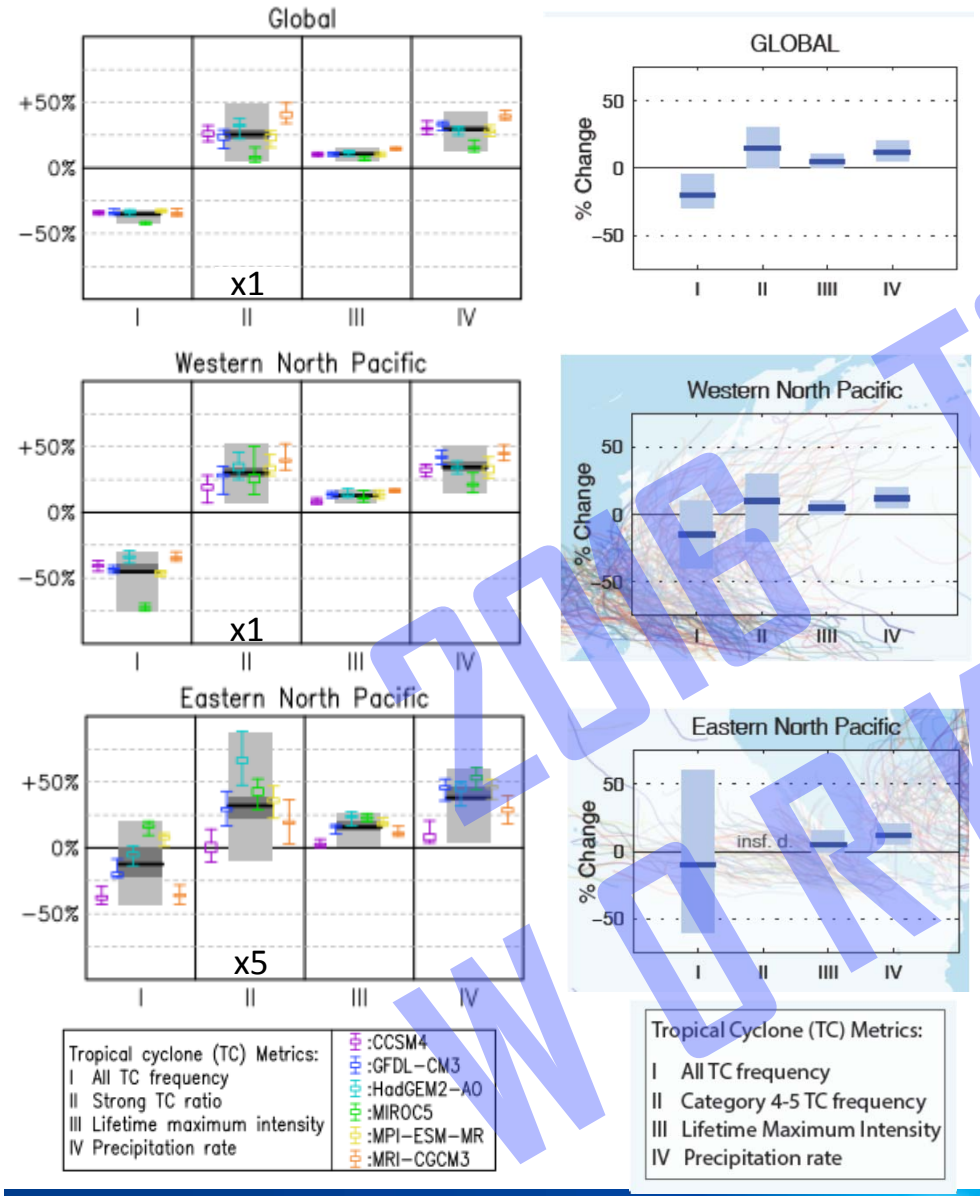
I: All TC frequency III: Lifetime maximum intensity
II: Strong TC ratio* IV: Precipitation rate

*37 m/s is criteria for strong TC

:CCSM4
:GFDL−CM3
:HadGEM2−AO
:MIROC5
:MPI−ESM−MR
:MRI−CGCM3



Major TC metrics -comparison-

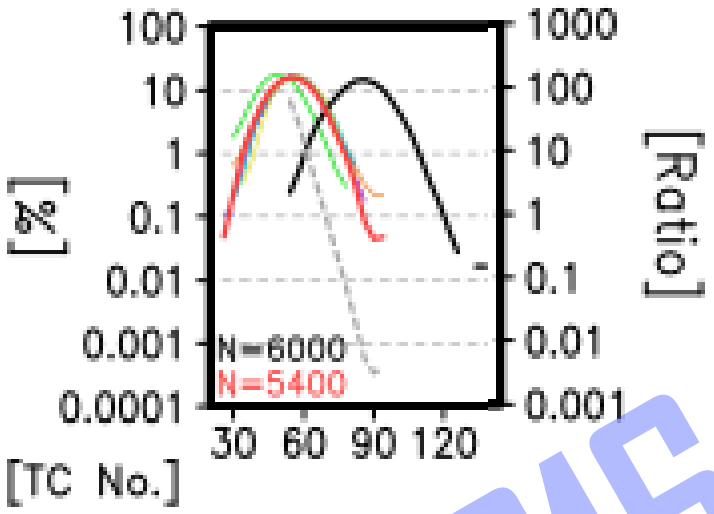


- Tendency of the future changes are similar between d4PDF and IPCC (2013).
- Due to difference in global warming level, future changes in d4PDF are larger than IPCC results.

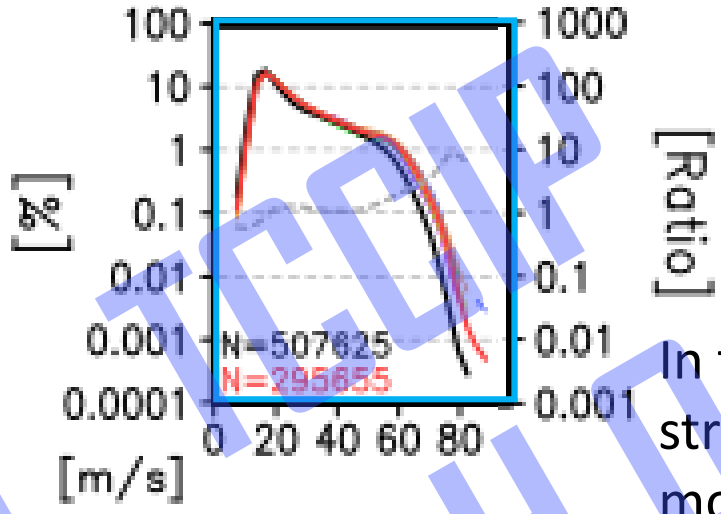
	Global	WNP	ENP
TC freq.:	-35%	-45%	-12%
Strong TC:	+26%	+30%	+160%
LMI:	+11%	+13%	+16%
Precip.:	+29%	+35%	+38%

PDF in major TC metrics for each year or TC event

TC number

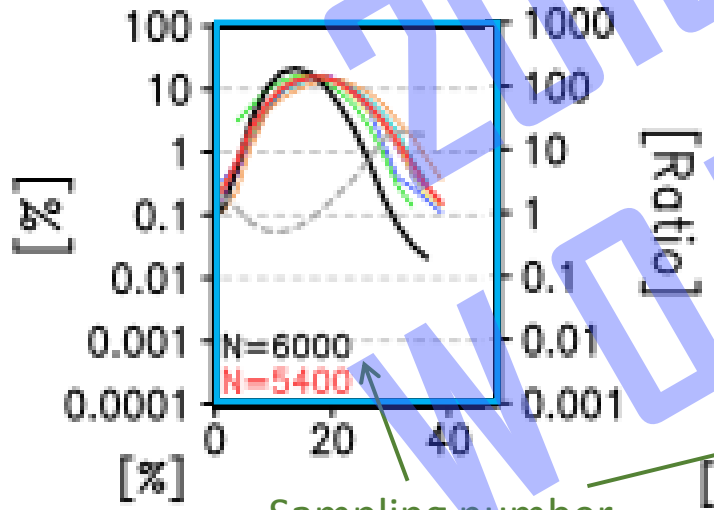


Lifetime Maximum Intensity

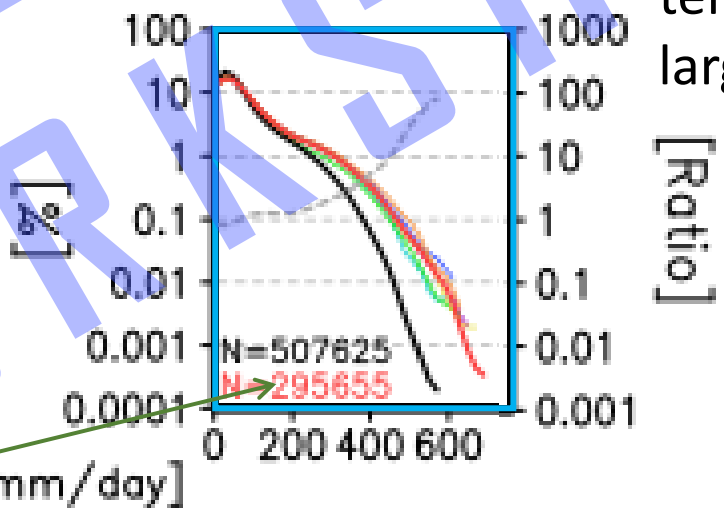


Past
+4K
Ratio of +4K to Past

Strong TC ratio



Precipitation



Sampling number

In the case of strength indices, more severe event tends to have larger amplification.

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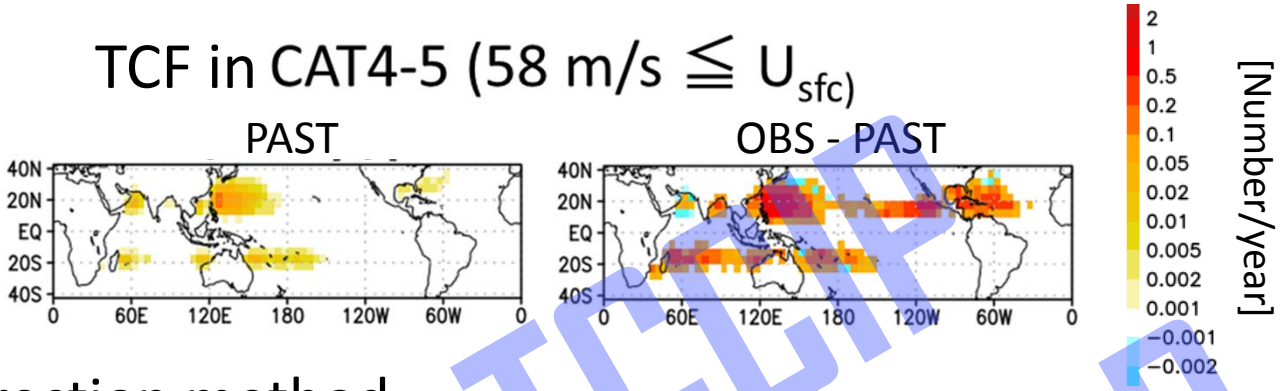
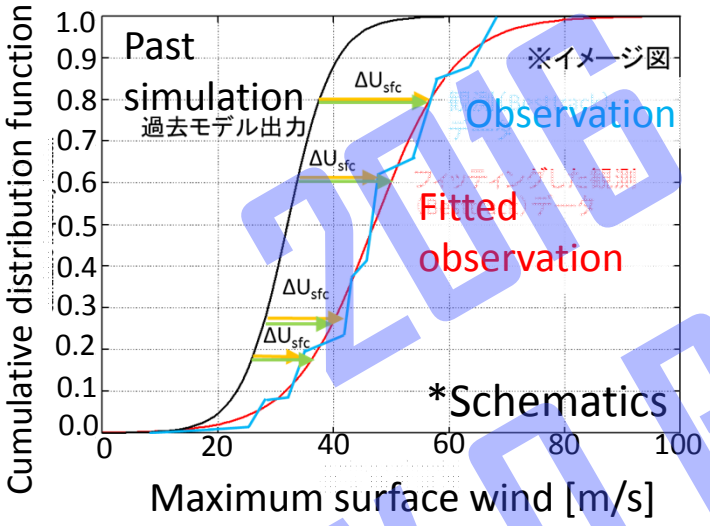
Bias correction for maximum surface wind

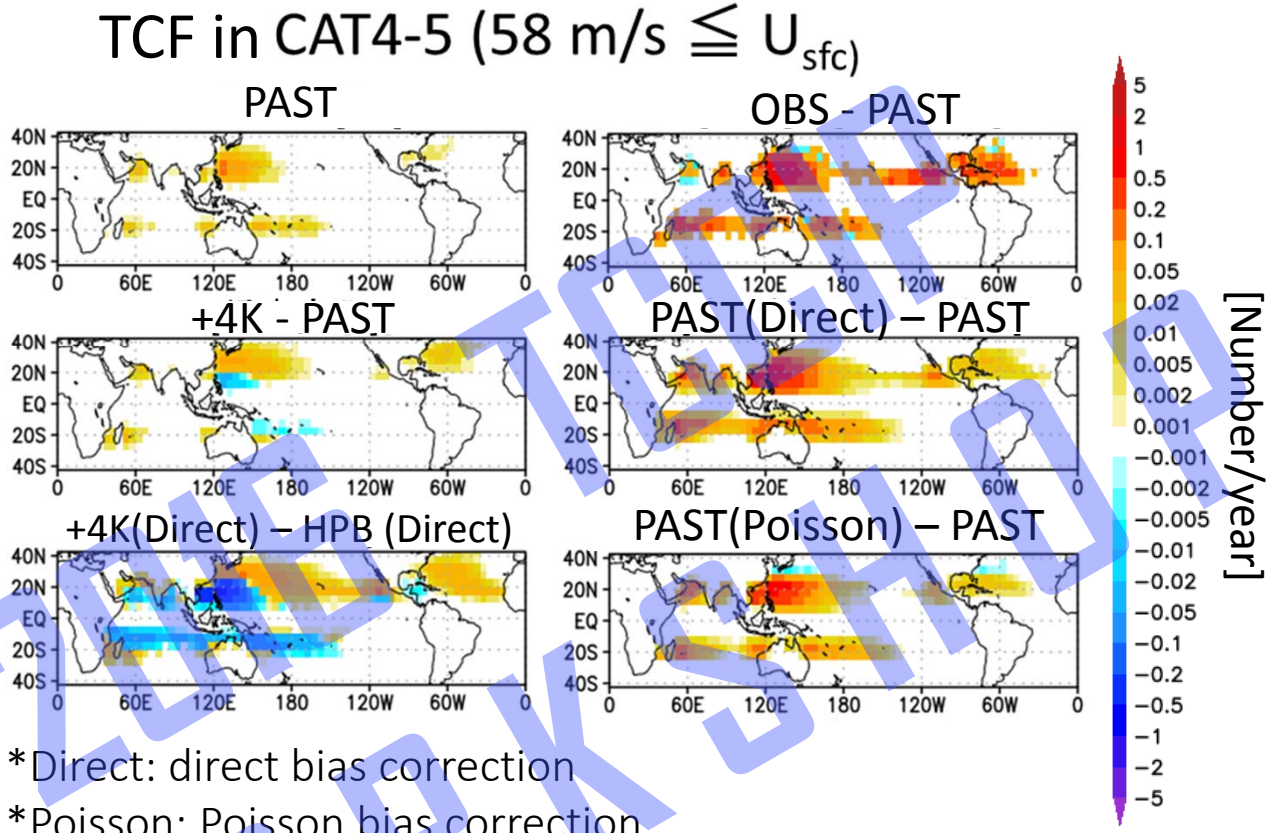


Bias correction method



- MRI-AGCM3.2H has weak surface wind bias.
- Bias correction is performed associated with cumulative distribution function (CDF) in each 5 deg latitudinal band (Direct correction).
- Between same values of CDF, bias correction is performed.
- Due to small sample size in observation, case of fitted observation PDF in Poisson distribution is also tried (Poisson correction).

TC frequency classified by Saffir-Simpson Hurricane Scale

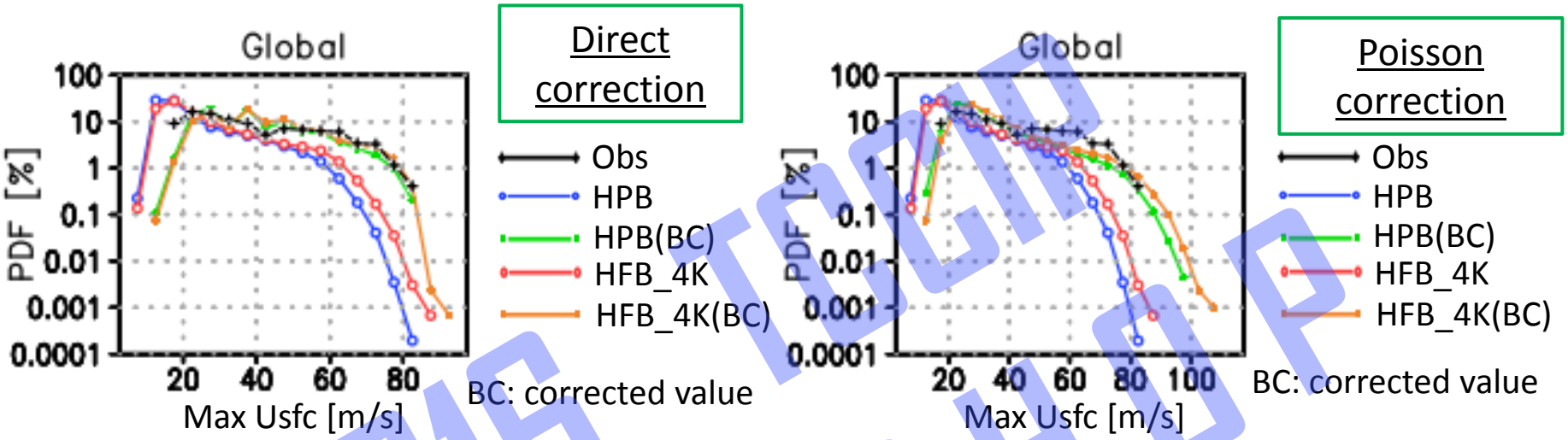


*Direct: direct bias correction

*Poisson: Poisson bias correction

- Very few frequency in CAT4-5 without bias correction
- TCF is improved by bias correction
- Difference in bias correction method is unclear

Lifetime maximum intensity



- Corrected value by direct method has similar PDF to observation but coarse PDF and inadequate correction in strong case.
- Corrected value by Poisson estimation has smooth PDF and good expression in strong case.

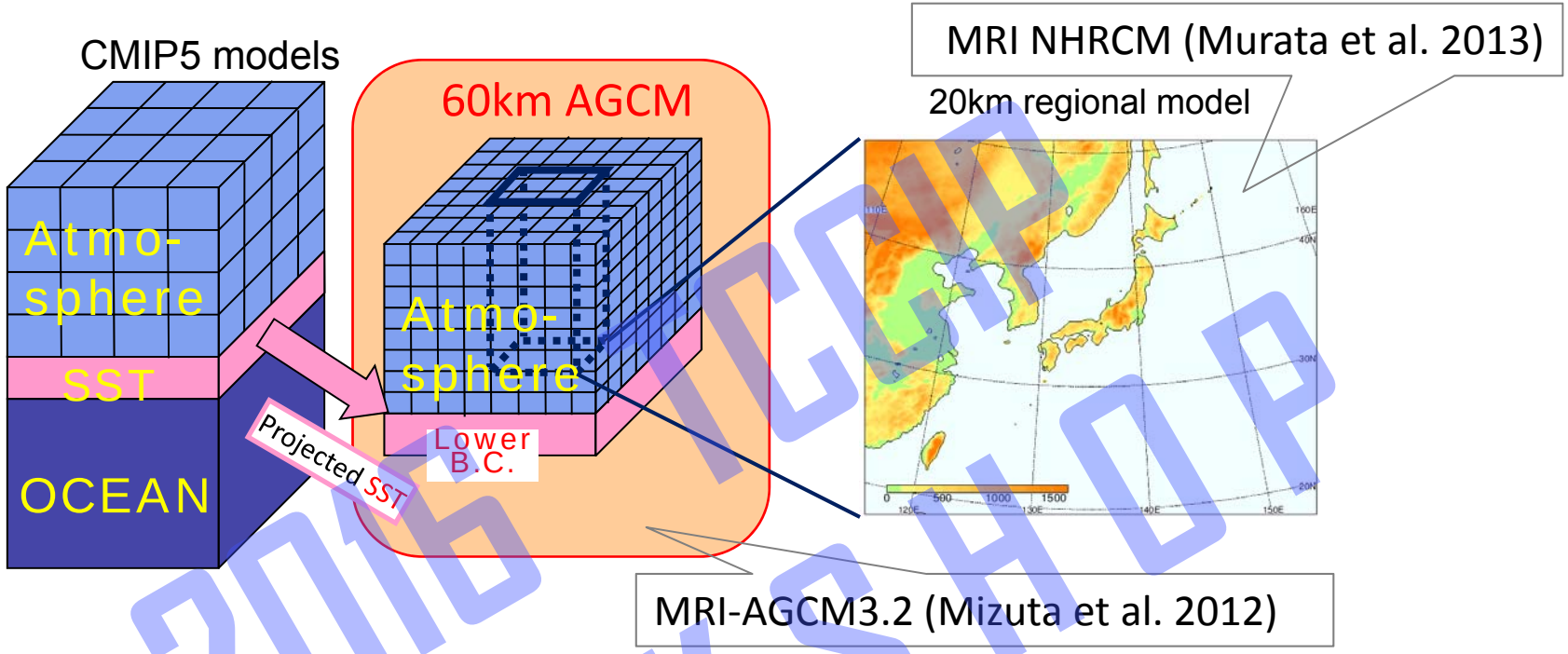
Summary

We developed large ensemble simulation dataset (d4PDF) for past and future (+4 K) climate and showed probabilistic behavior of tropical cyclone (TC).

- Very smooth and precise probabilistic TC behaviors (TC genesis number, TC frequency map, time variation, etc..) can be described by d4PDF.
- Major TC metrics have same tendency as IPCC (2013) results but degree of change is lager because of higher global warming level.
- In whole world, TC genesis number decreases by 35% , and strong TC ratio, lifetime maximum intensity, and precipitation rate increase by 26%, 11%, and 29%, respectively.
- In each ocean basin, although main features of future change are similar to global case, dependency of future SST uncertainty should be considered.
- Mean TC number in past corresponds to very unlike year in future climate (once in 1000 years; 0.1%).
- MRI-AGCM3.2H (60km grid) has weak surface wind bias, thus proper bias correction is necessary for hazard assessment.

Thank you !!

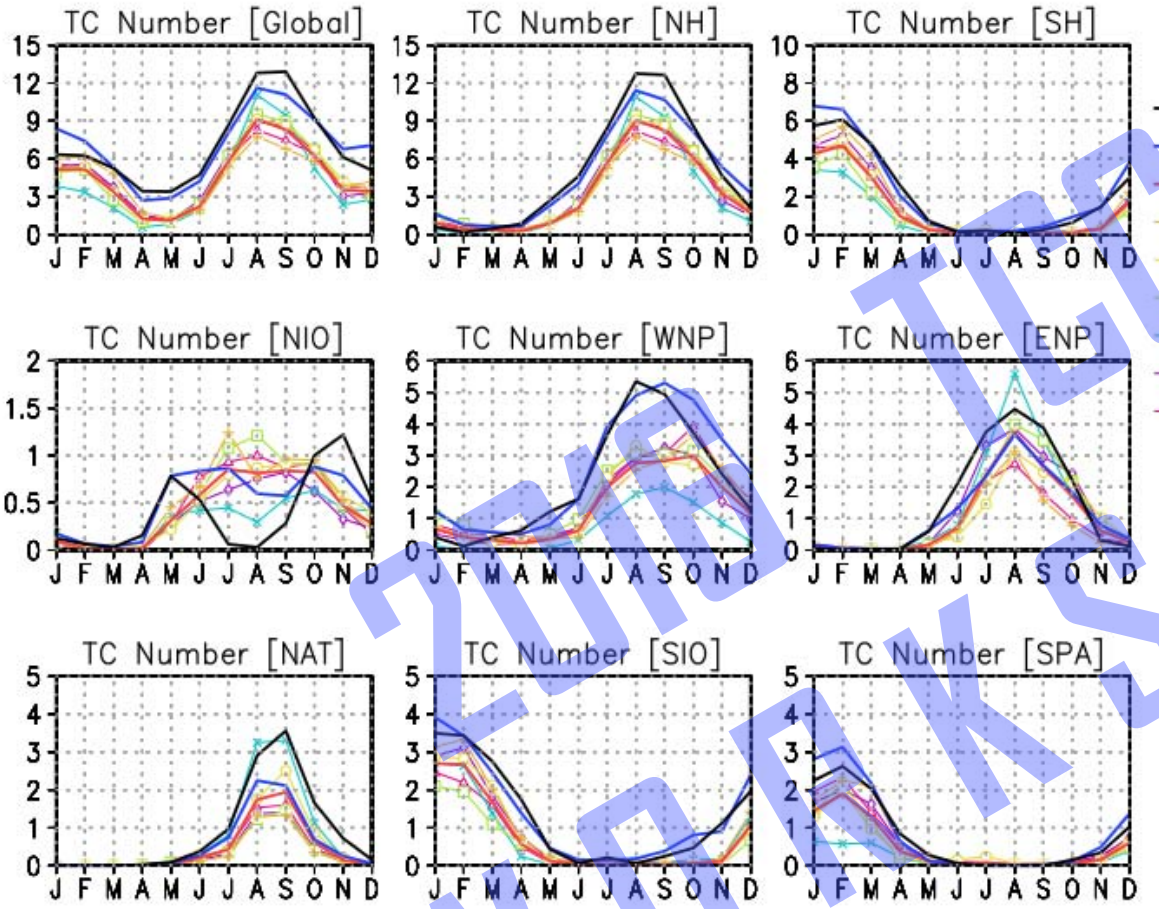
Models



- MRI-AGCM3.2 60km grid
  - High-resolution model to resolve realistic tropical cyclone
  - Proper computational resource for large ensemble
- Achievement of this model
  - Dynamical downscale for SRES-A1B scenario* (KAKUSHIN program)
  - Same but for RCP2.6, RCP4.5, RCP6.0, and RCP8.5* (e.g. SOUSEI program)

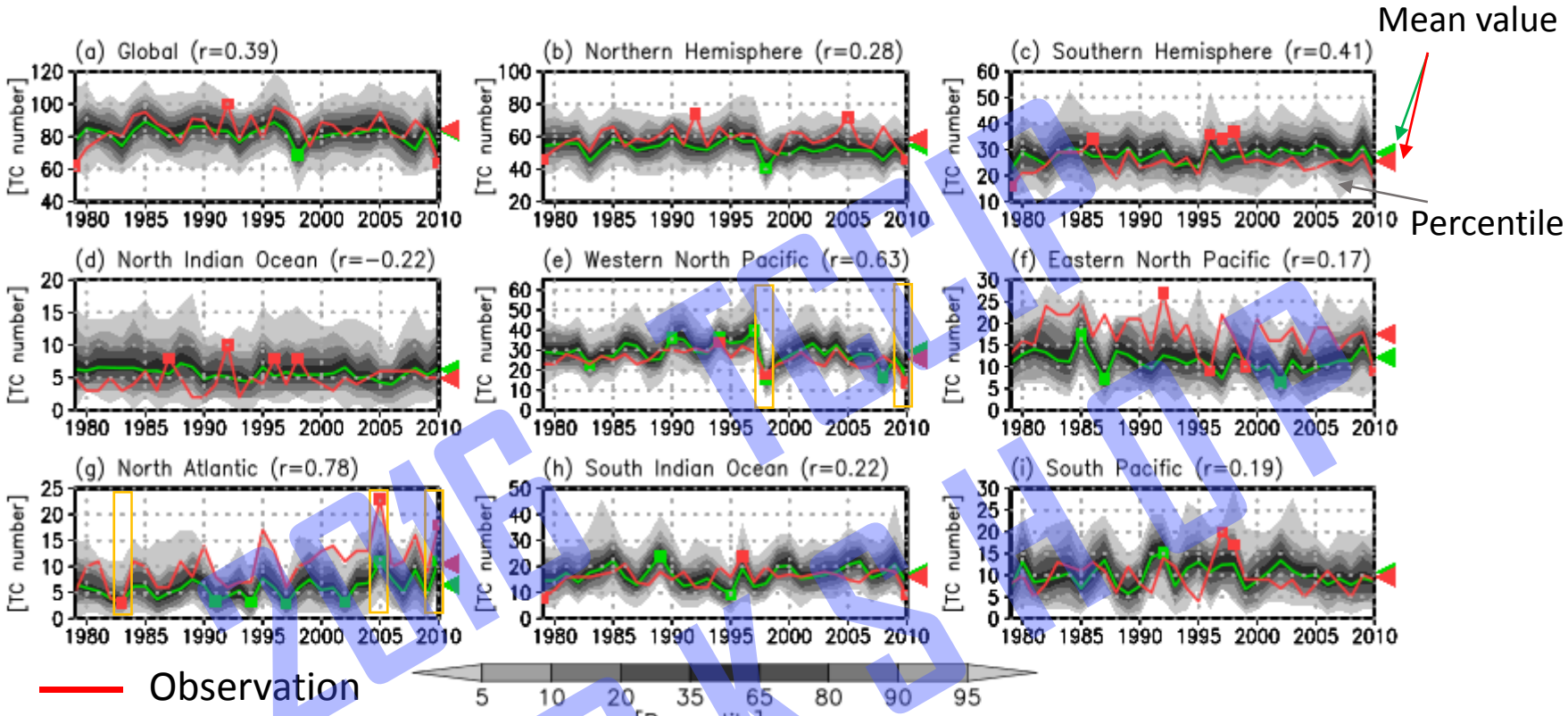
*Cumulus convection scheme ensemble was included above.

Seasonal variation in TC number



- Past simulation has realistic seasonal variation in TC number.
- In future experiment, TC number decreases uniformly, but SST pattern dependency appears.

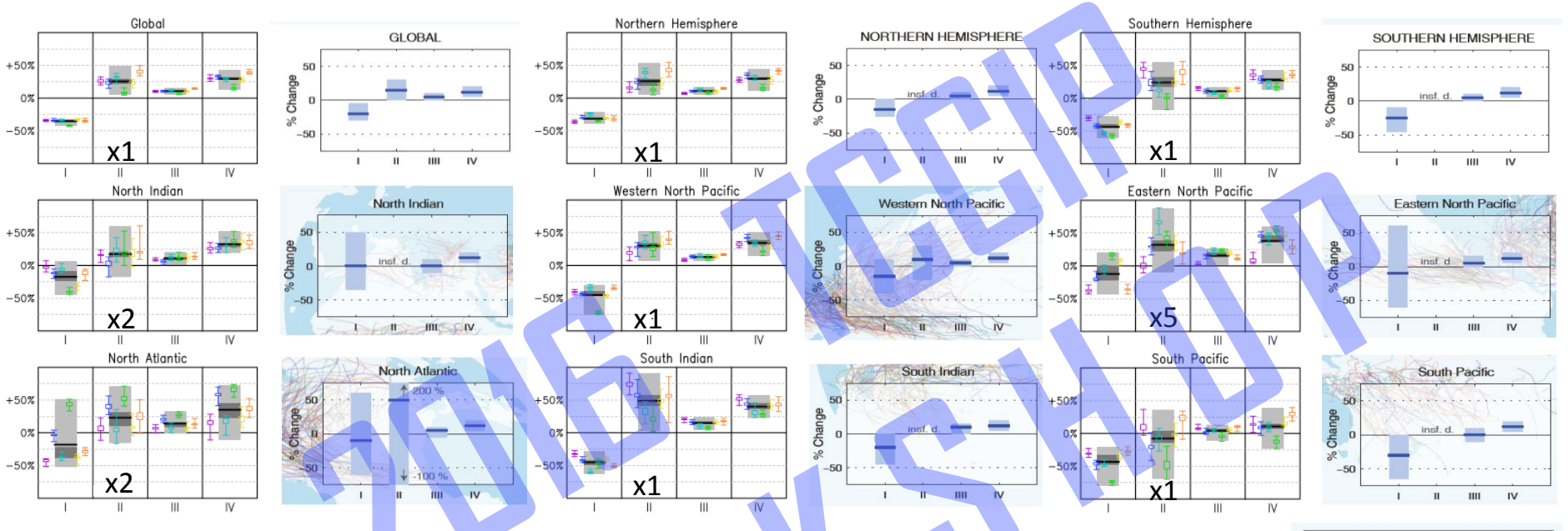
Year-to-year variation and predictability



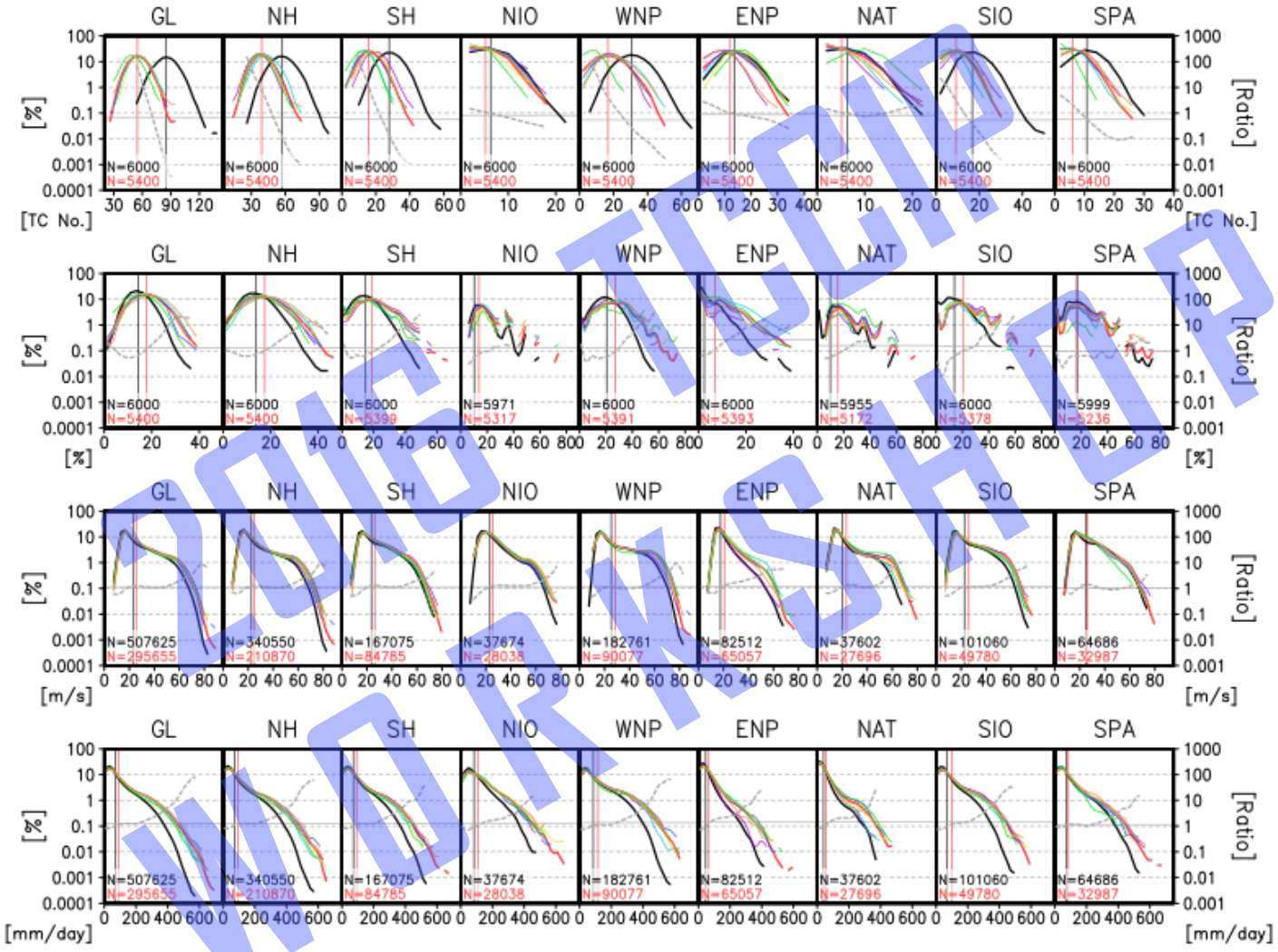
r: correlation between obs and all ensemble mean

- Observation is well explained by all ensemble mean in WNP and NAT.
- Ocean basin which has low S/N ratio (e.g. NIO) does not have predictability.
- Showing potential TC genesis number explicitly is an advantage of d4PDF.

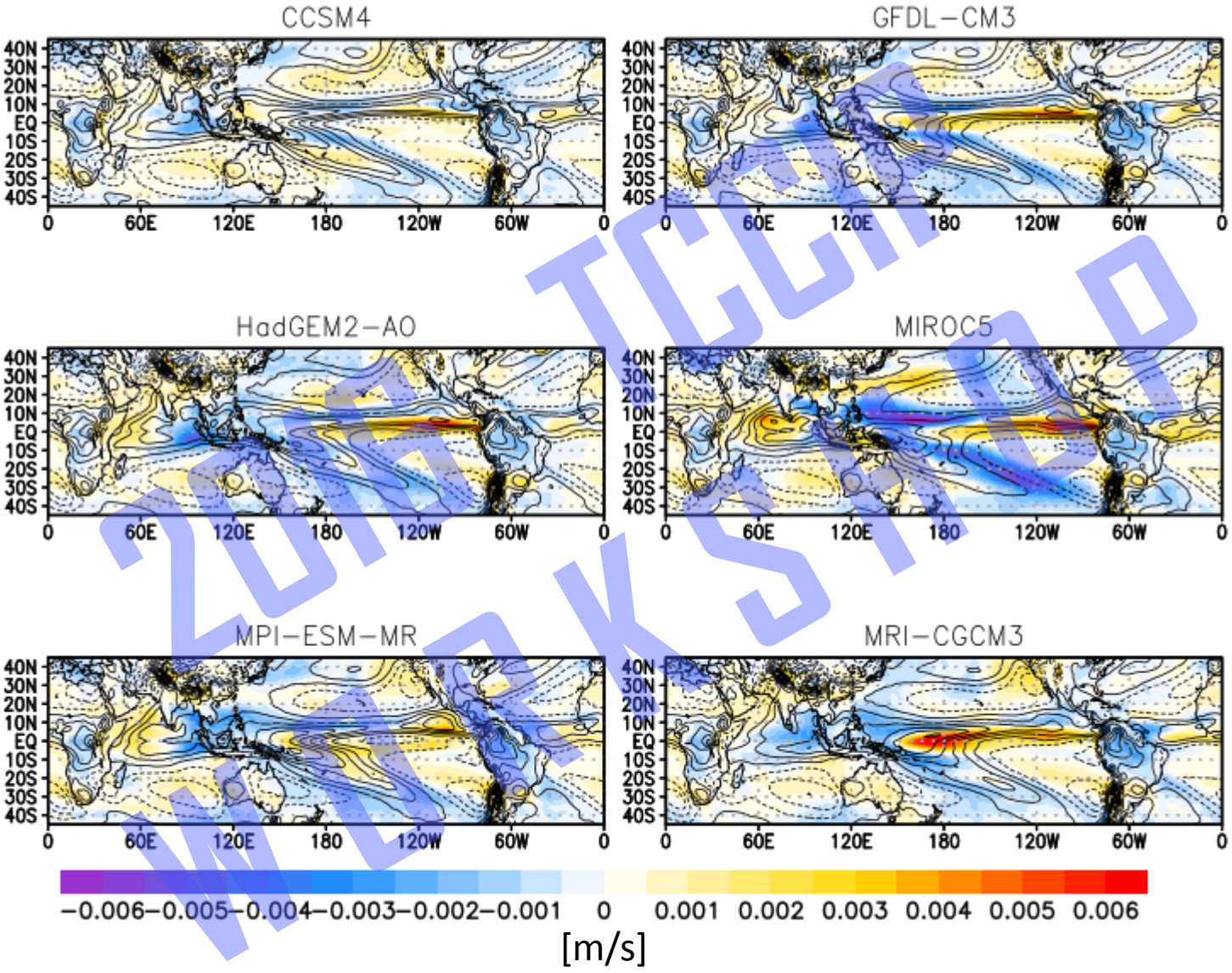
Major TC metrics –comparison-



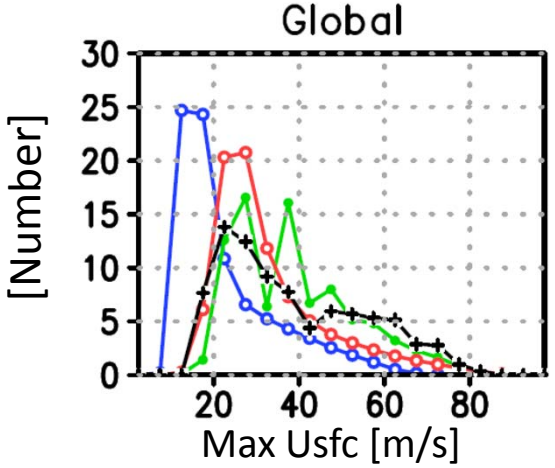
- Tendency of the future changes are similar between d4PDF and IPCC.
- Due to difference in global warming level, future changes in d4PDF are larger than IPCC results.



Future changes in W500

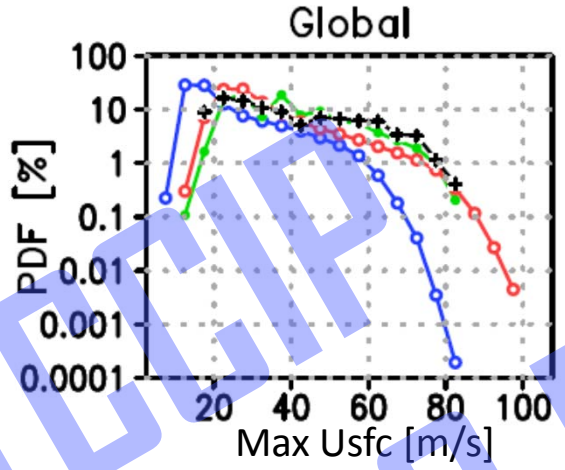


Lifetime maximum intensity



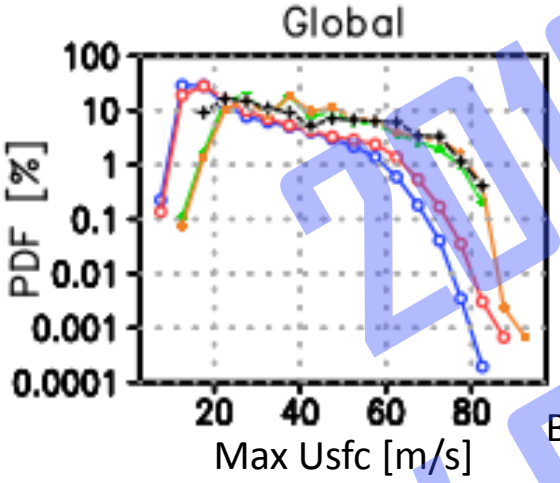
Comparison in past

Obs
HPB
Direct
Poisson



Comparison in past

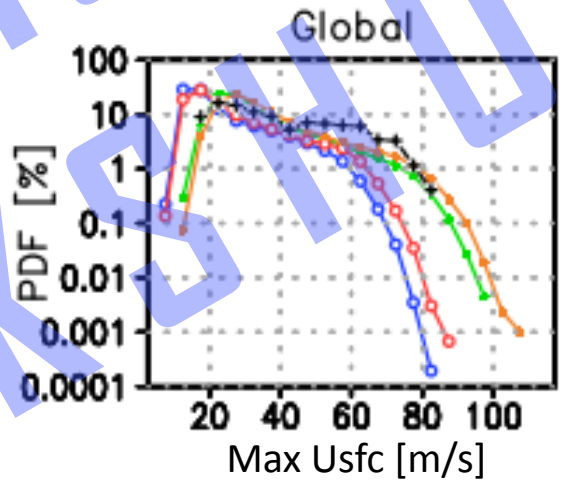
Obs
HPB
Direct
Poisson



Direct correction

Obs
HPB
HPB(BC)
HFB_4K
HFB_4K(BC)

BC: corrected value



Poisson correction

Obs
HPB
HPB(BC)
HFB_4K
HFB_4K(BC)

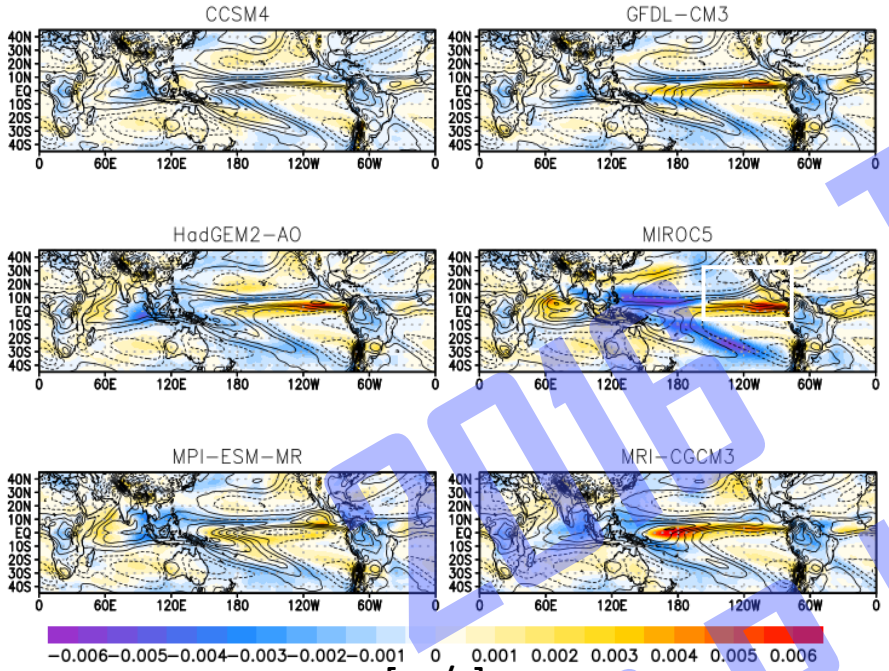
BC: corrected value

Corrected value has coarse PDF and bad expression in strong case.

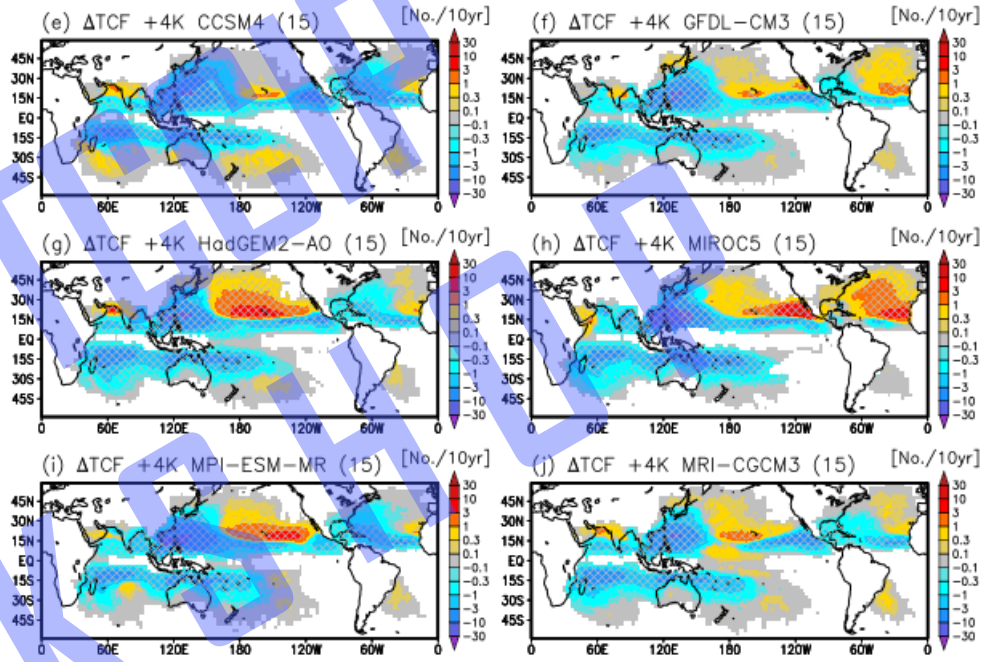
Corrected value has smooth PDF and good expression in strong case.

TC frequency

Δw500 [m/s]



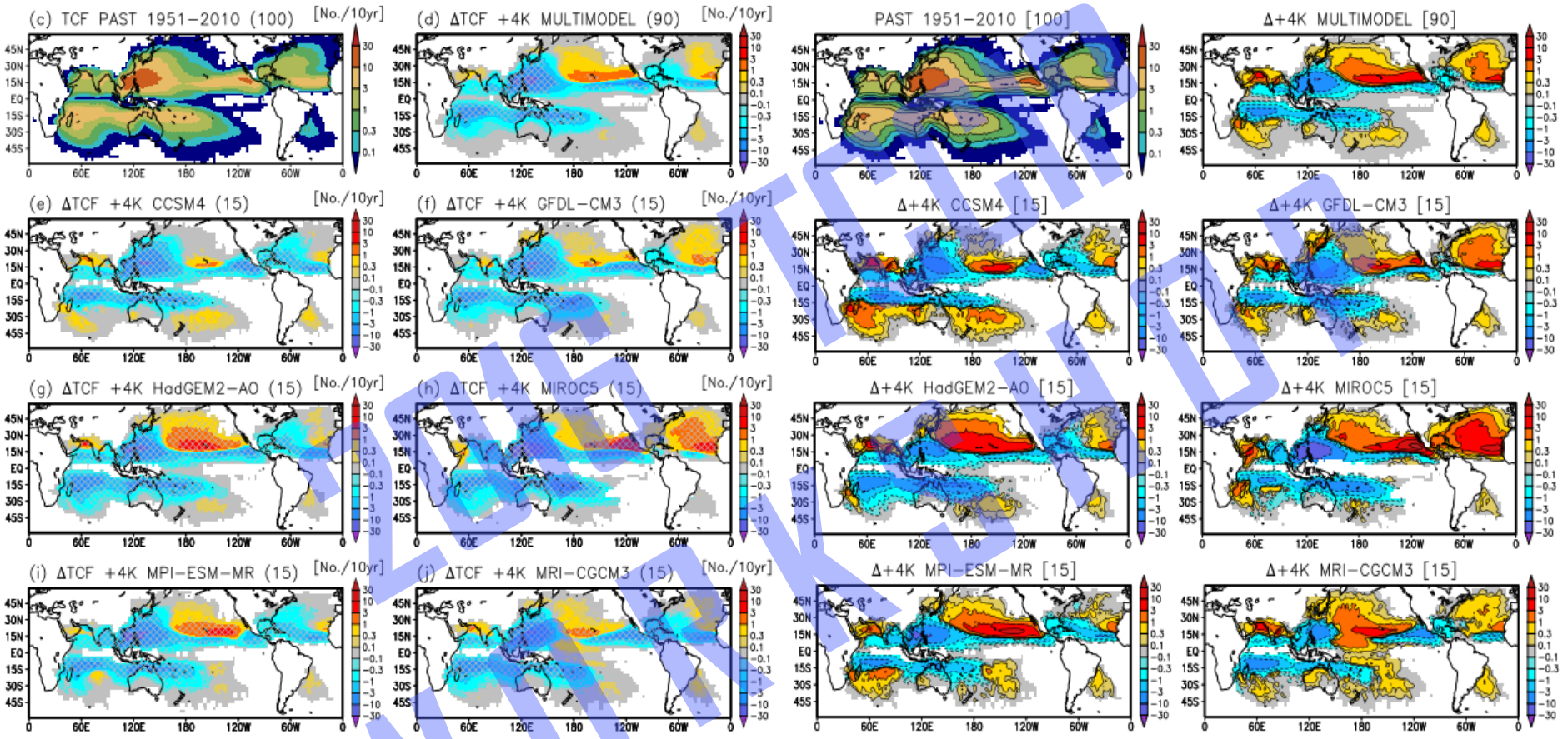
ΔTC frequency [No./10yr]



TC frequency

TCF

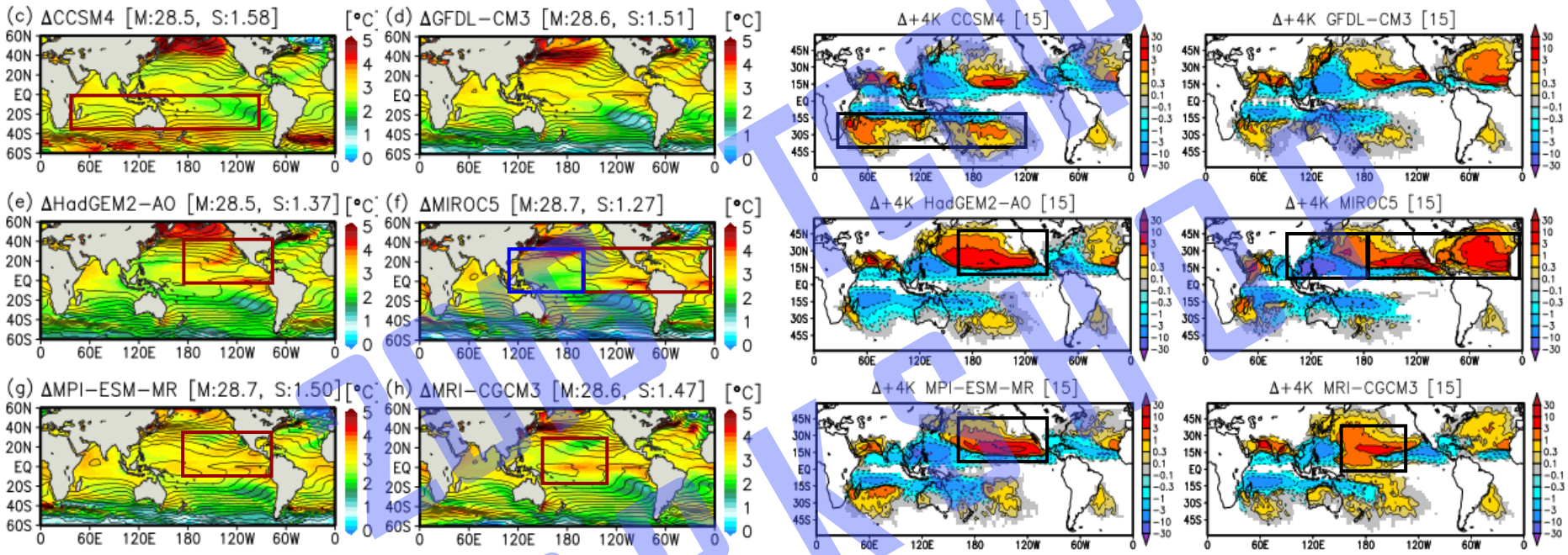
Normalized TCF



Normalized TC frequency change

Future changes in SST climatology

Future changes in normalized TC frequency

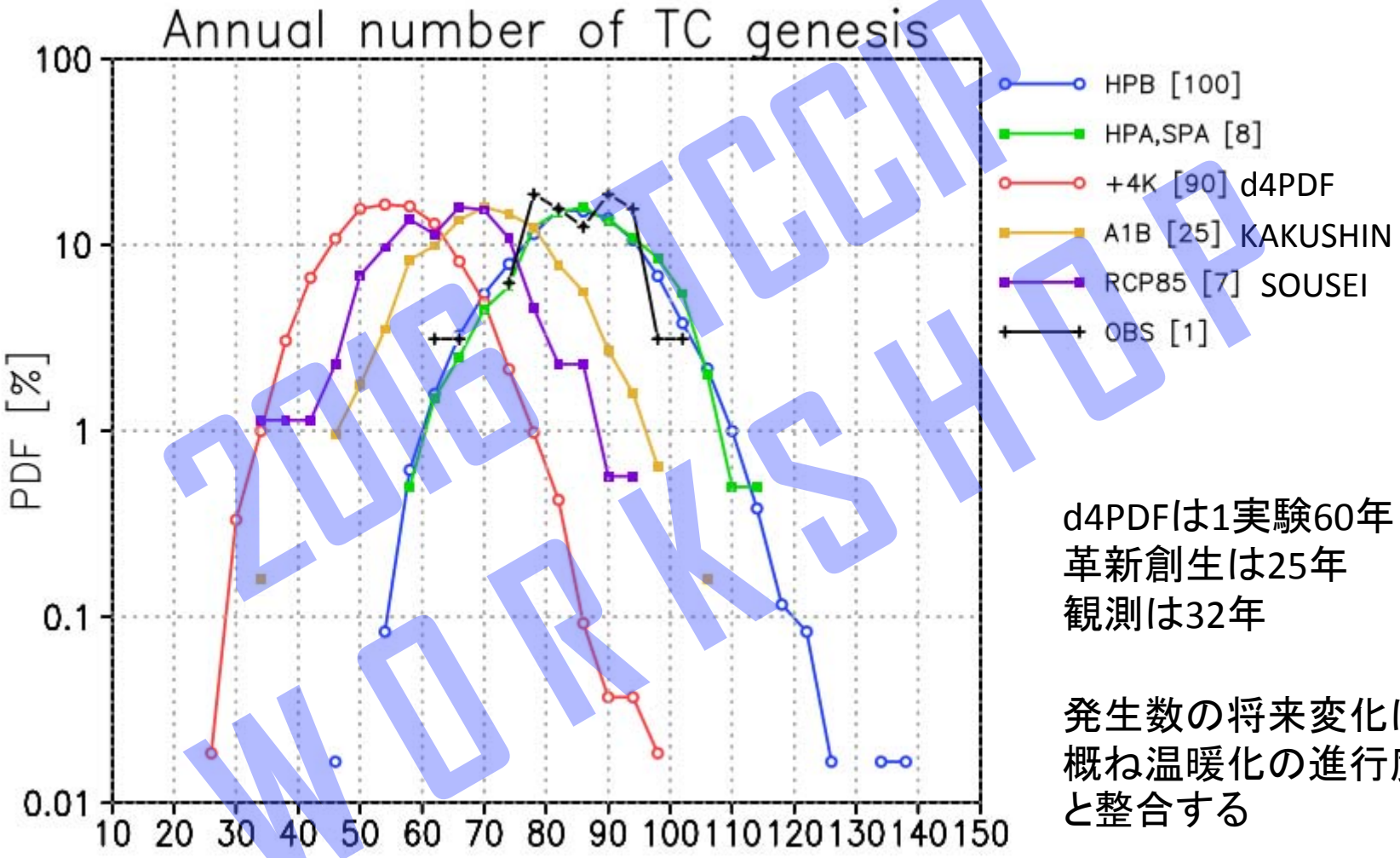


- Relative SSTs are slightly difficult to explain uniform TC frequency change.
- Normalized TC frequency changes are well consistent with relative SST change.

Relationships with KAKUSHI and SOUSEI program

List of experiments

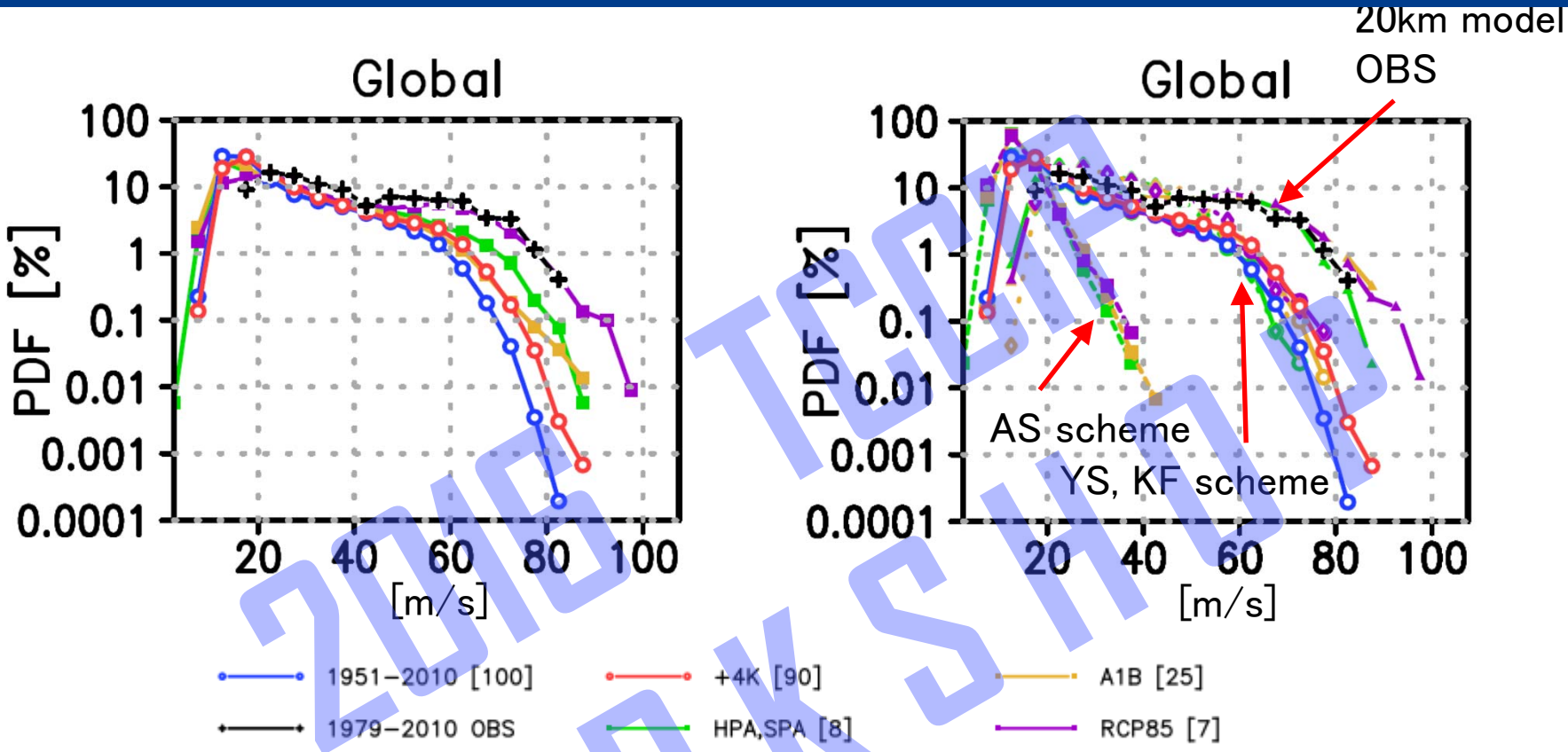
PAST（1979-2003年）: [2]	20km Yoshimura scheme(YS)
	60km YS scheme[2]
	AS scheme [2]
	KF scheme [2]
SRES-A1B（2075-2099年）:	20km YS scheme [1]
	60km YS scheme [8]
	AS scheme [8]
	KF scheme [8]
RCP8.5（2075-2099年）:	20km YS scheme [4]
	60km YS scheme [1]
	AS scheme [1]
	KF sceheme [1]



d4PDFは1実験60年
革新創生は25年
観測は32年

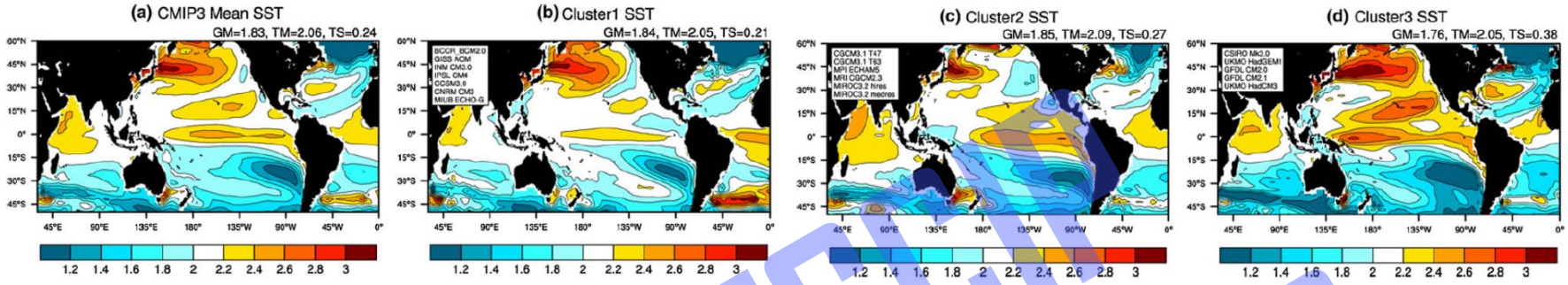
発生数の将来変化は
概ね温暖化の進行度
と整合する

Lifetime maximum intensity

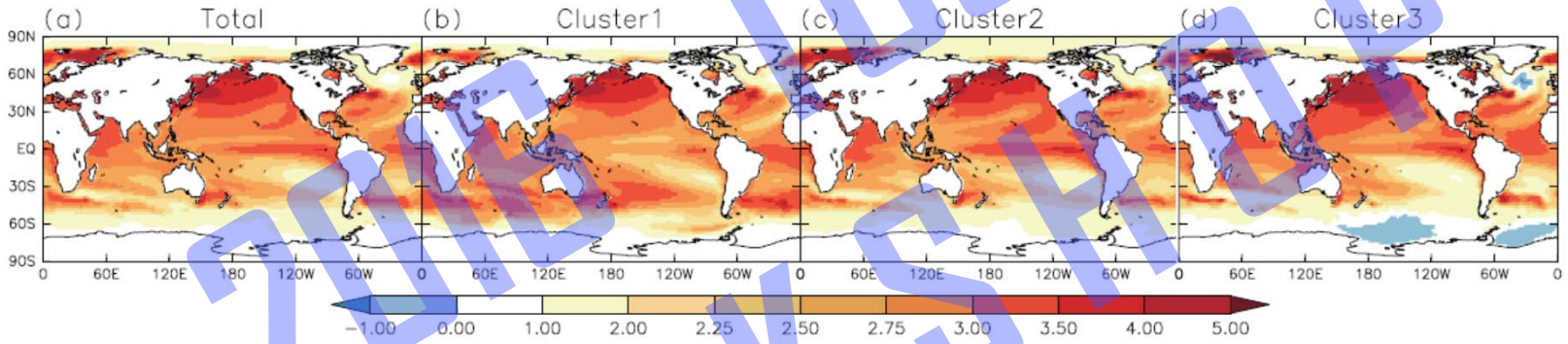


・20kmモデルを含んでいる革新後期、創生のデータはd4PDFより最大地表風速が大きい傾向があり、モデル不確実性を反映している
・RCP8.5は20kmモデルの結果を多く含むので最も観測に近い
・d4PDFの方が低頻度事象を描写することに優れている

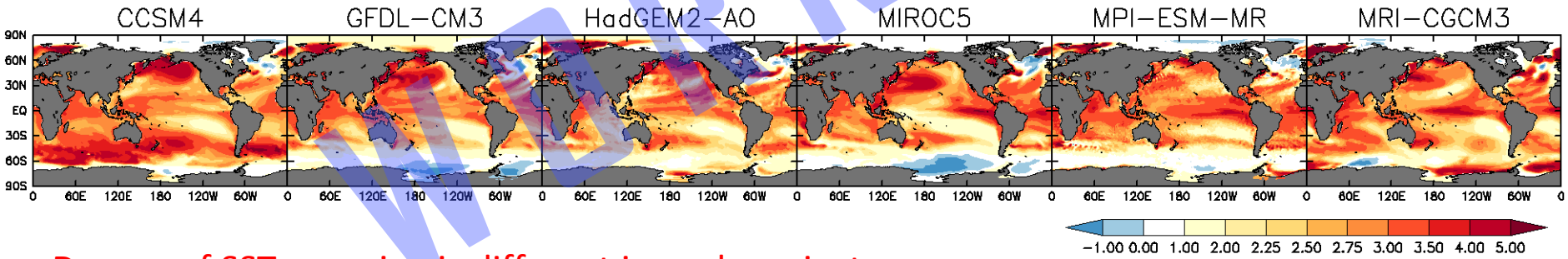
KAKUSHIN [Murakami et al., 2012] SRES A1B +2.1 K in tropics



SOUSEI [Mizuta et al., 2014] RCP8.5 +2.7 K in tropics



d4PDF [courtesy of Mizuta] RCP8.5 +2.9 K in tropics



Degree of SST warming is different in each project.

4 major TC metrics

PAST	GL	NH	SH	NIO	WNP	ENP	NAT	SIO	SPA
TC No.	84.6	56.8	27.8	6.3	30.5	13.8	6.3	16.8	10.8
Strong TC ratio	14.2%	13.8%	15.0%	10.2%	20.5%	2.5%	9.9%	13.9%	16.9%
LMI	23.0	22.7	23.5	23.4	25.4	17.7	19.9	22.7	24.8
Precipi. rate	71.3	71.0	72.0	84.3	85.9	46.2	39.6	70.8	74.5
+4K change rate	**GL**	**NH**	**SH**	**NIO**	**WNP**	**ENP**	**NAT**	**SIO**	**SPA**
TC No.	-35%	-31%	-44%	-17%	-45%	-12%	-18%	-45%	-43%
Strong TC ratio	+26%	+26%	+24%	+34%	+30%	+160%	+46%	+49%	-8%
LMI	+11%	+11%	+11%	+11%	+13%	+16%	+14%	+15%	+4%
Precipi. rate	+29%	+30%	+28%	+32%	+35%	+38%	+35%	+40%	+11%