Introduction to Global Warming Projection

- by High Resolution Models to assess Regional Impacts –

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Contents

- Climate Prediction & Weather Forecast
- Global Warming Projection by Climate or Earth System Models
- Assessment of Regional Climate Change by High-resolution AGCMs

- Method
- Ensemble
- Tropical Cyclones
- Downscaling
- Experiments based on CMIP5 SST

Global Warming Projection

One of Climate Predictions

Climate and Climate System

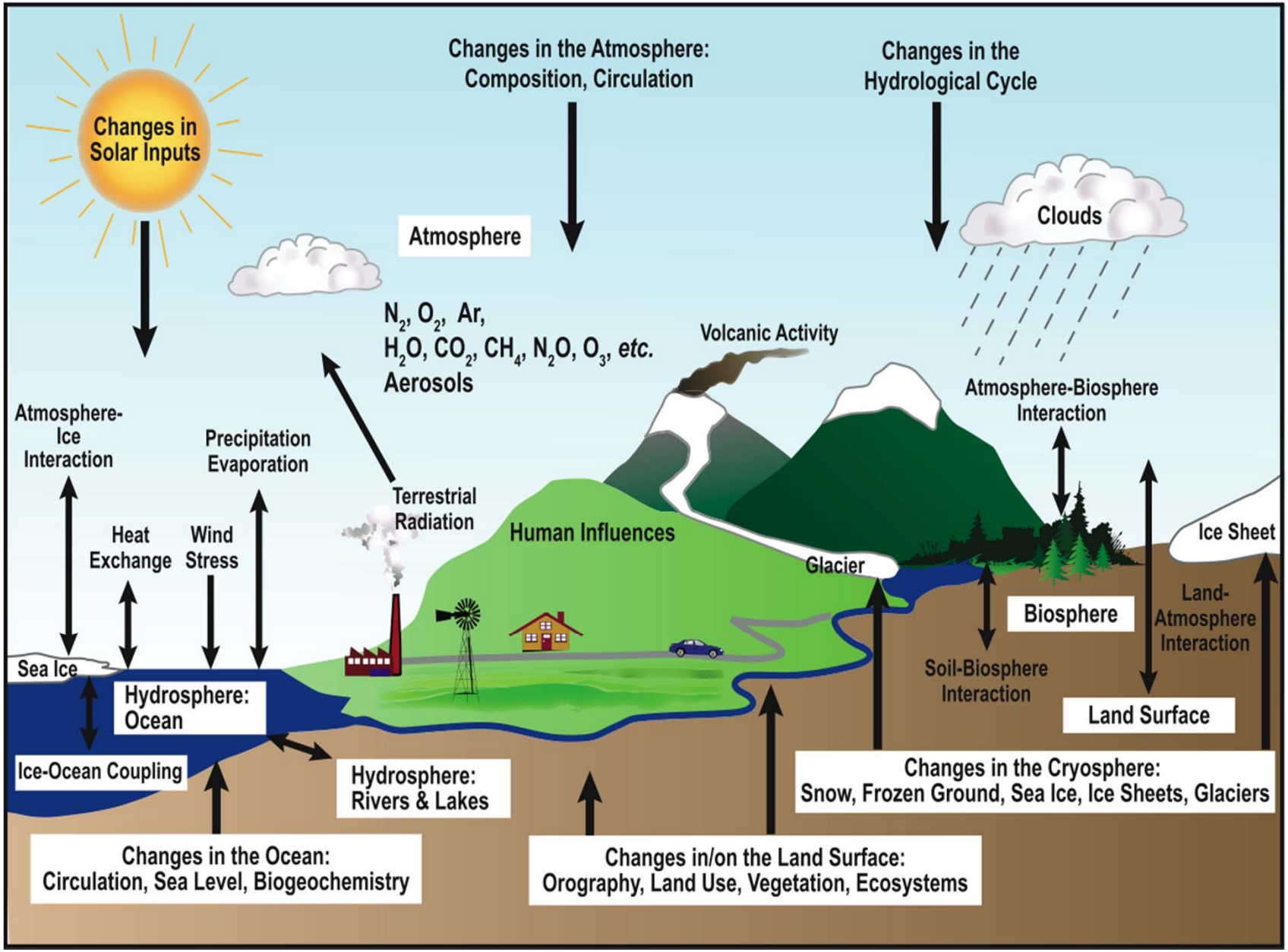
"Weather is what is happening to the atmosphere at any given time.

Climate in a narrow sense is the "average weather," the statistical description over a period of time."

Climate is formed in the interactions in climate system, consisting of atmosphere including composition and circulation, the ocean, hydrosphere, land surface, biosphere, snow and ice, solar and volcanic activities in its spatial and temporal variability.

Climate System

http://ipcc-wg1.ucar.edu/wg1/FAQ/wg1_faq-1.2.html



Schematic view of the components of the climate system, their processes and interactions.

What is the target to predict?

Weather Forecast

- Atmosphere at any given time

For example,

- Surface Air Temperature at 00Z on Jan 26, 2015
- Precipitation during 00Z-12Z on Jan 26, 2015

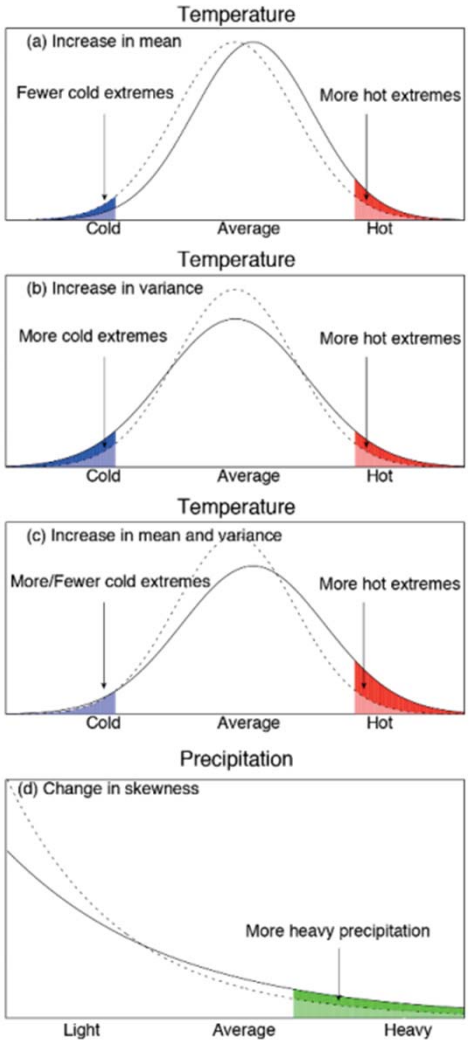
Climate Prediction

- Statistics of Weathers

For example,

- 30year Average of Jan mean Surface Air Temperature and Precipitation during 1981-2010
- Frequency Distribution of Jan Daily Mean Air Temperature during 1981-2010

How climate (<u>the statistics or distribution of weathers</u>) change ?



Change in mean

Change in variance

Change in mean and variance

Change in skewness

(From 5th IPCC 2013)

Methods

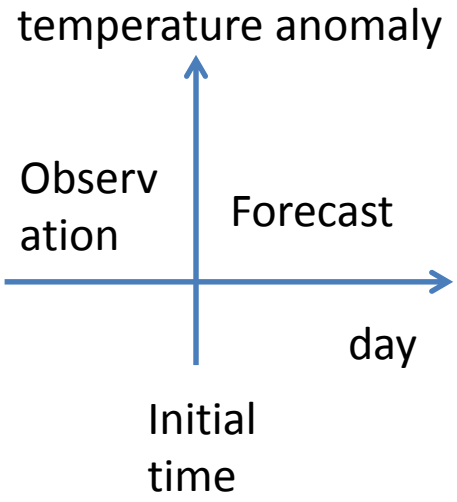
■ Weather Forecast

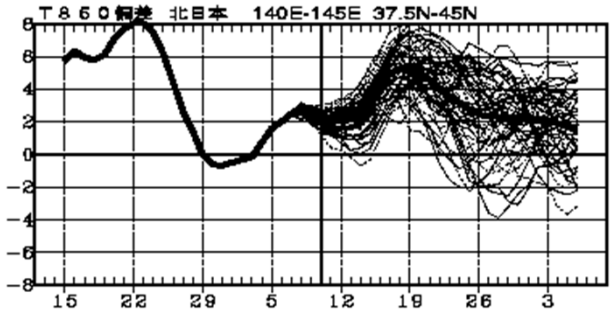
- Dynamical Evolution of the atmosphere with time
- From an initial state of the atmosphere
- By High-resolution Atmosphere Models
- Limited Predictability by Chaos feature of the atmosphere (~a few weeks)

■ Global Warming Projection

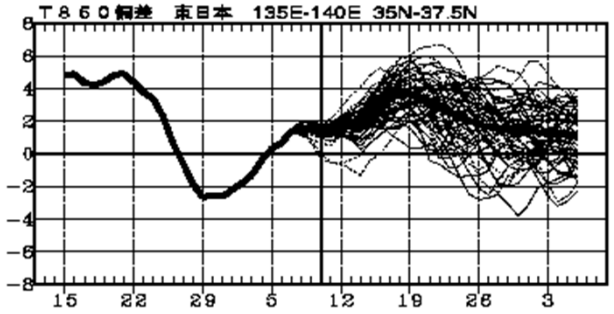
- Change in long-term Equilibrium of the atmosphere
- Due to Change in External Forcing
- By Earth or Climate System Models representing the Energy and Water Balance of the Earth
- Limited Predictability by finite samples for statistics (~30 year period statistics)

Ensemble Weather Forecast members diverge within the first 2 weeks then go around the climatology

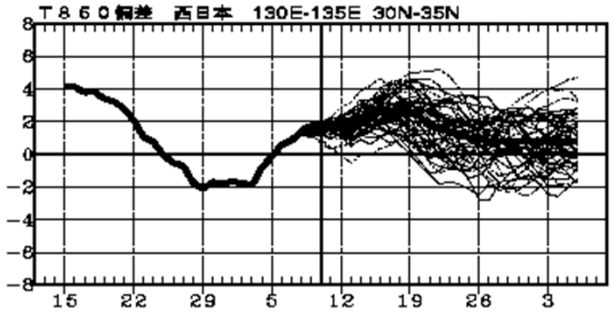




A JMA one month Forecast of 850hPa temperature for Northern Japan



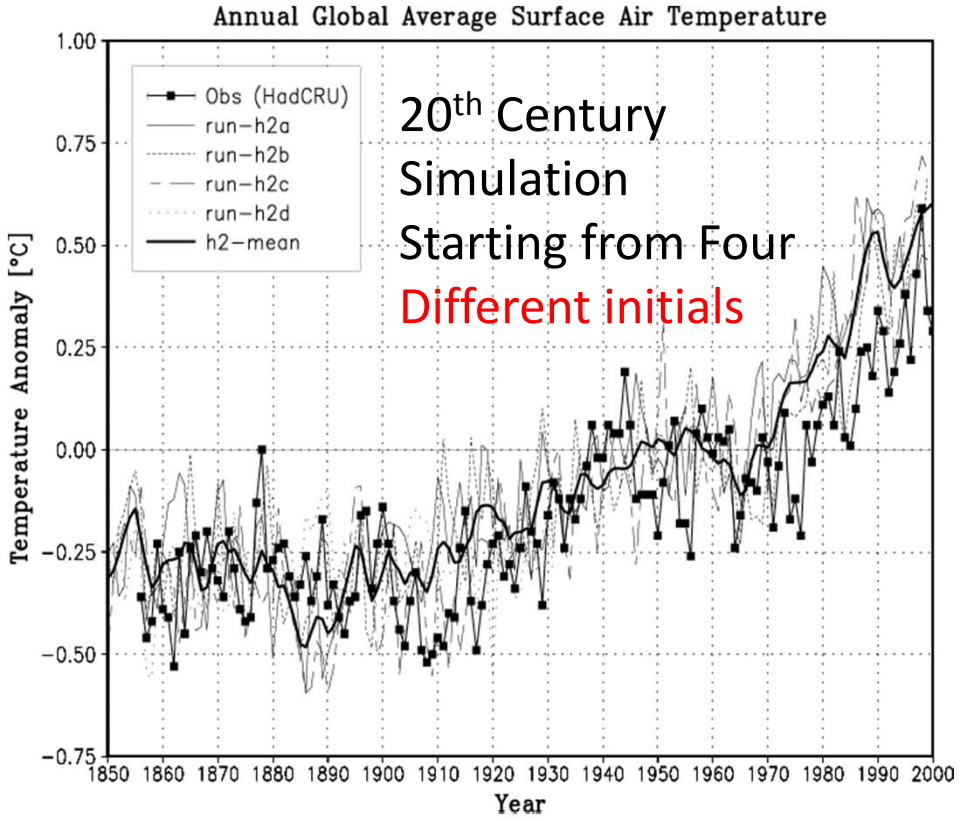
Eastern Japan



Western Japan

Based on JMA Forecast

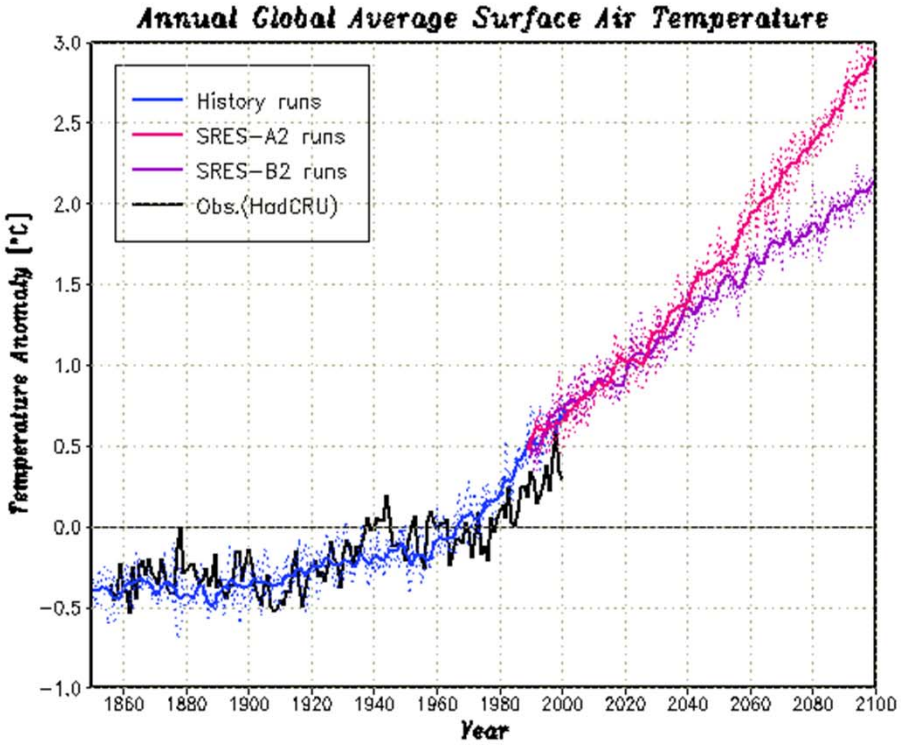
Annual Global Mean Temperature Simulations by MRI-CGCM2



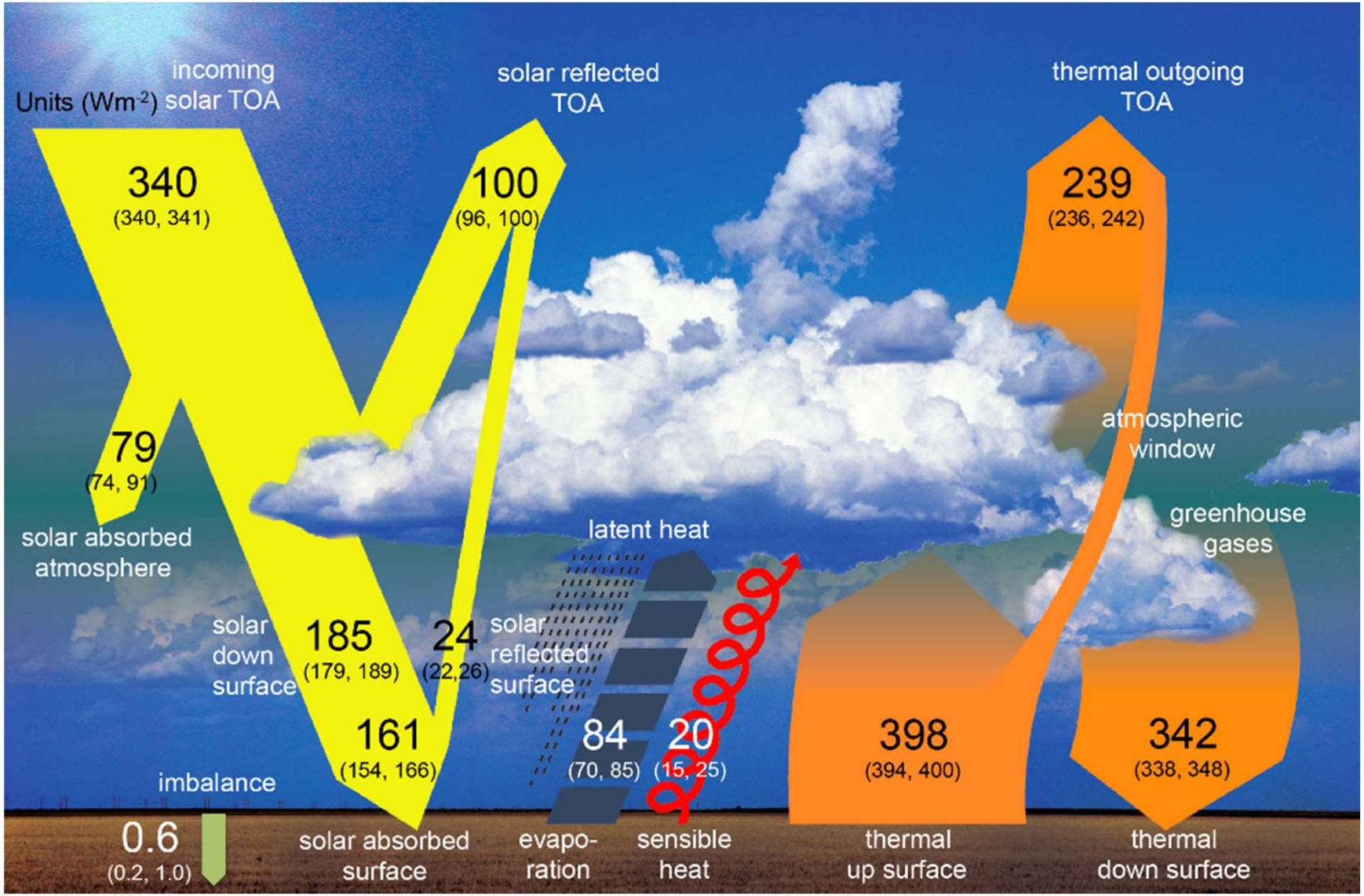
20th Century Simulation Starting from Four Different initials

- 0.75 C increase at 1990s
- Rapid warming starts 1970s, 10 years earlier than observation
- Model reproduced temperature trend and interdecadal change

21st Century Projection Depends on Emission Scenarios



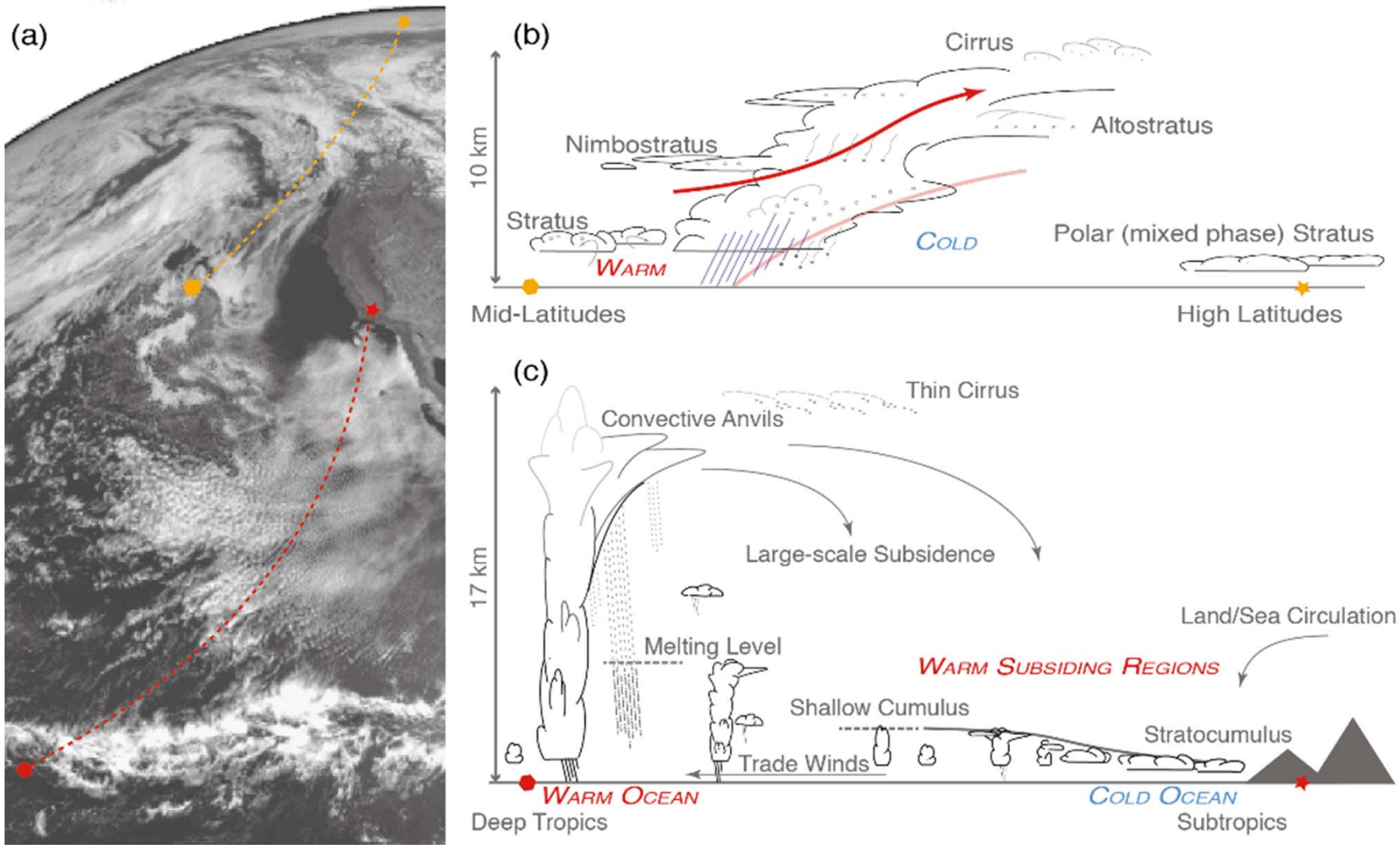
Increasing Greenhouse Effect makes Imbalance in Earth Energy budget



Global mean energy budget (IPCC 2013)

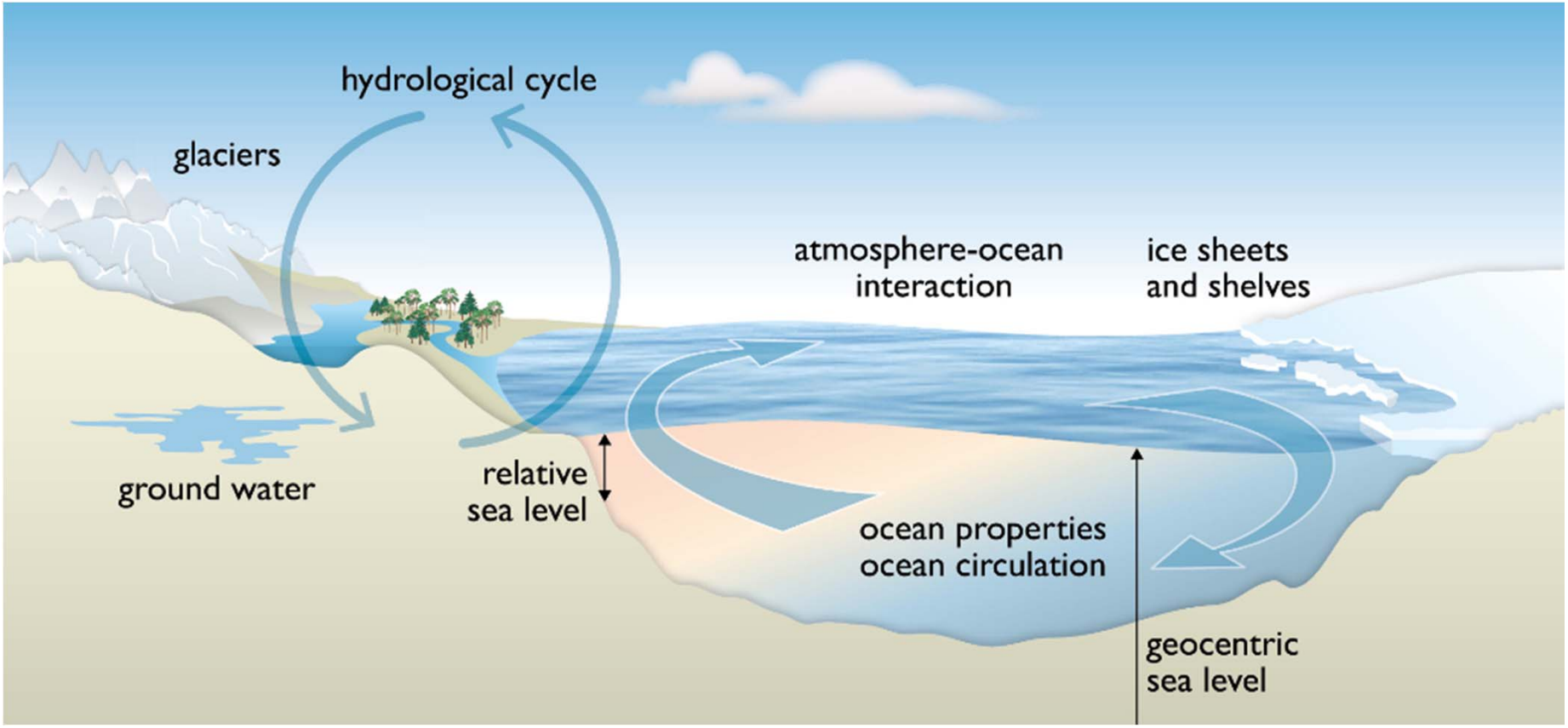
(IPCC 2013)

Solar Reflection by Clouds



(IPCC 2013)

Ice Melting and Ocean Heat Capacity



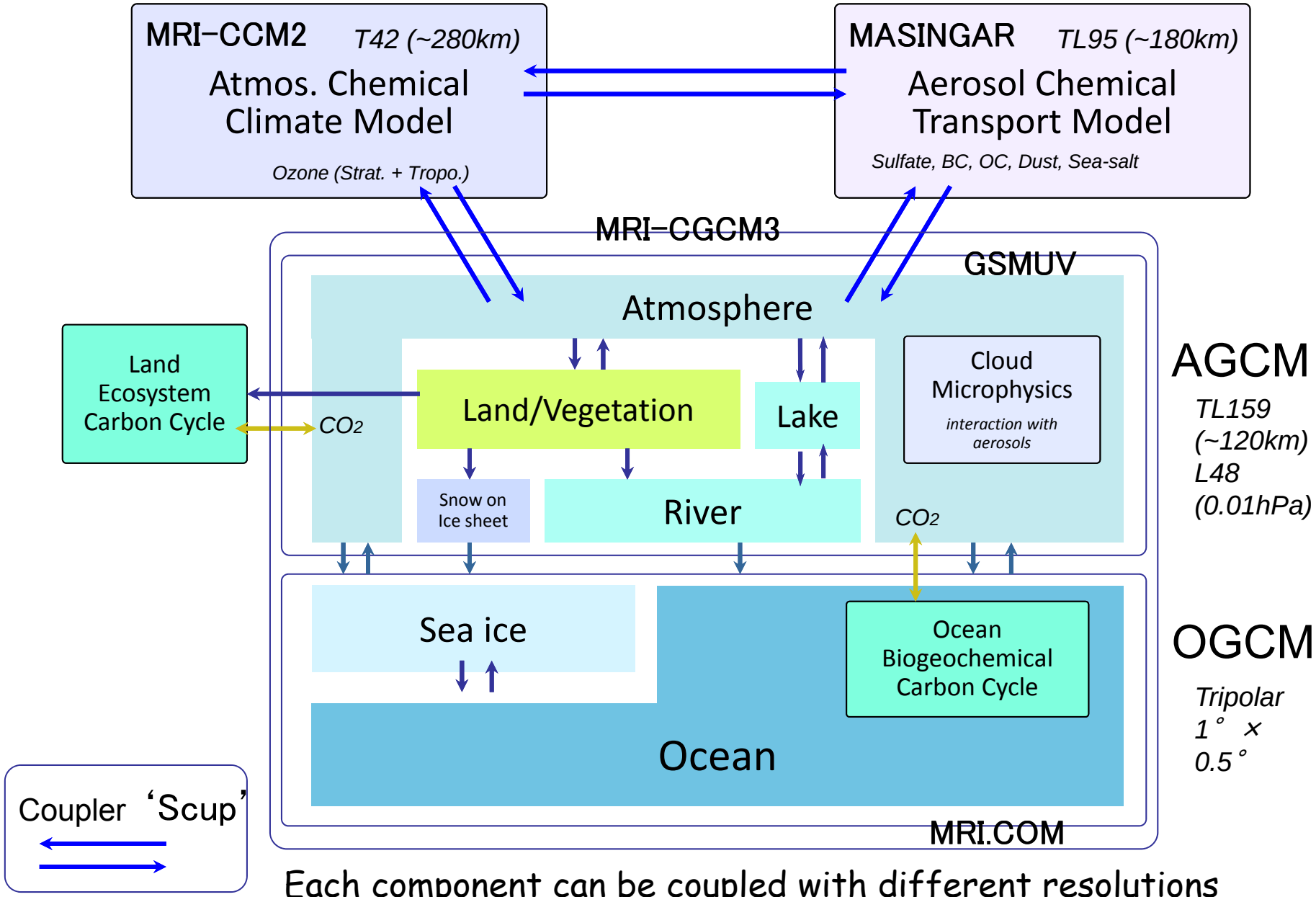
Earth System Models or Climate Models (CGCMs) are used

For

Global Warming Projection

MRI Earth System Model

(Yukimoto, 2012)



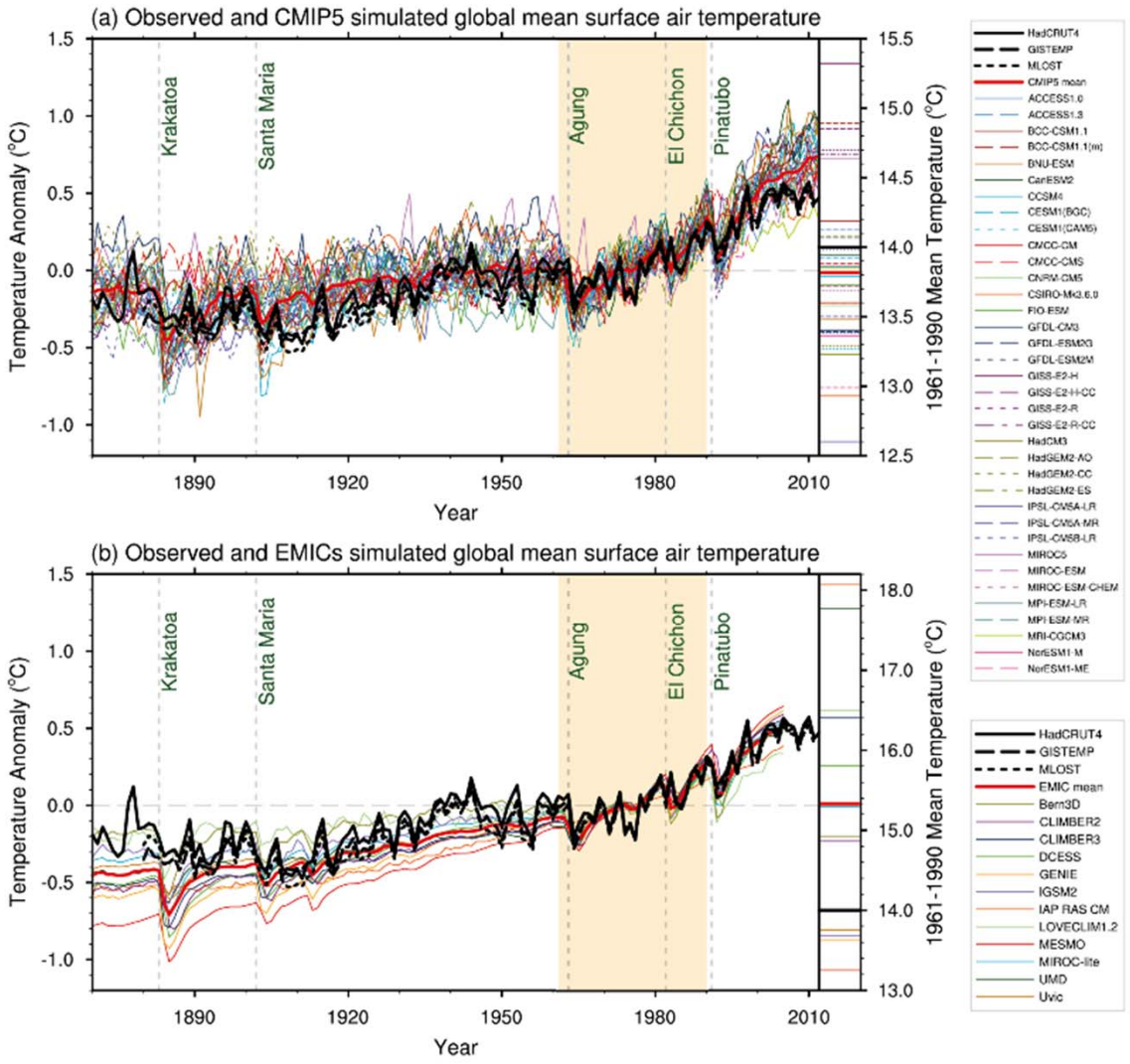
Each component can be coupled with different resolutions

Reliability of Global Warming Projection

1) **Reliability of Models**	2) **Reproducibility of the Past**
• Based on Physical Equations • Plus Micro Processes • Daily weather forecasts • Climatology Check • Model Sensitivity Test	• Past Climate Variability • Past Long-term Trend • Understanding Past Simulation and Future Projection

(IPCC 2013)

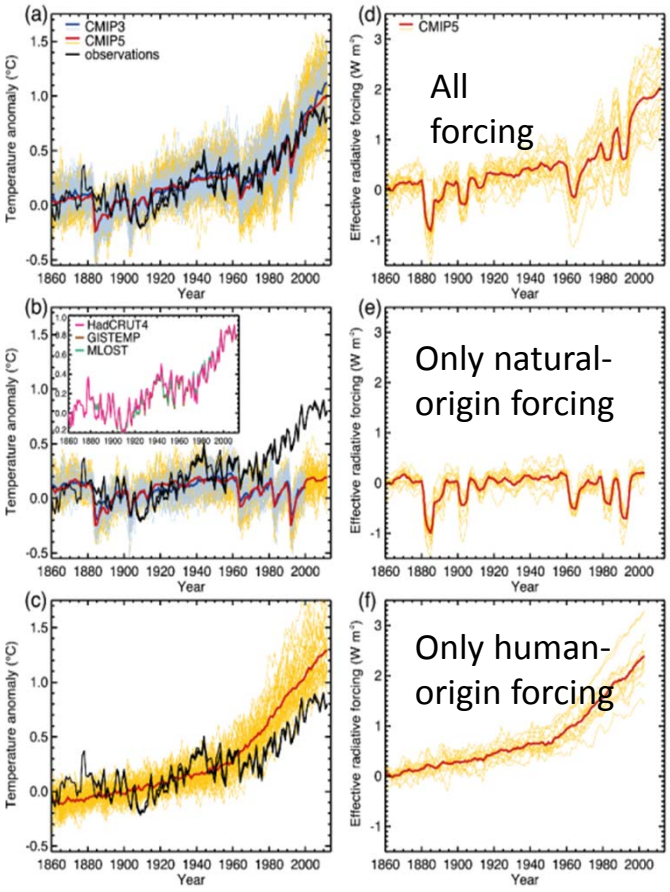
Historical Simulation and Model Sensitivity



Historical Global Warming Experiments

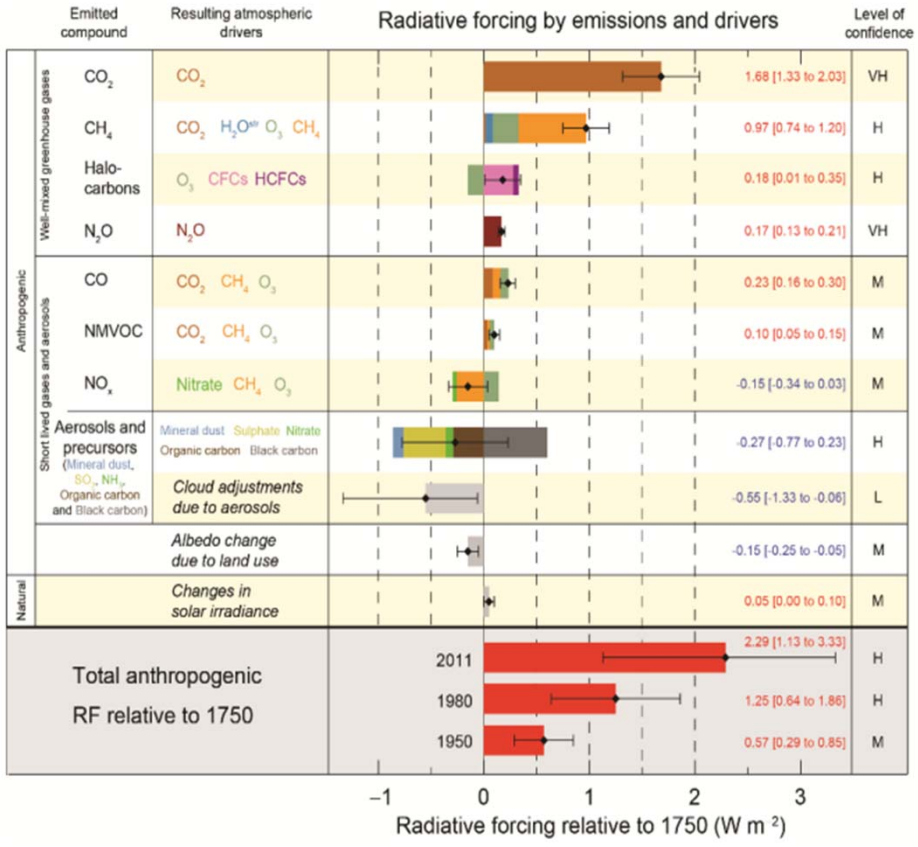
Model Experiments

WGI_AR5_Fig10-1



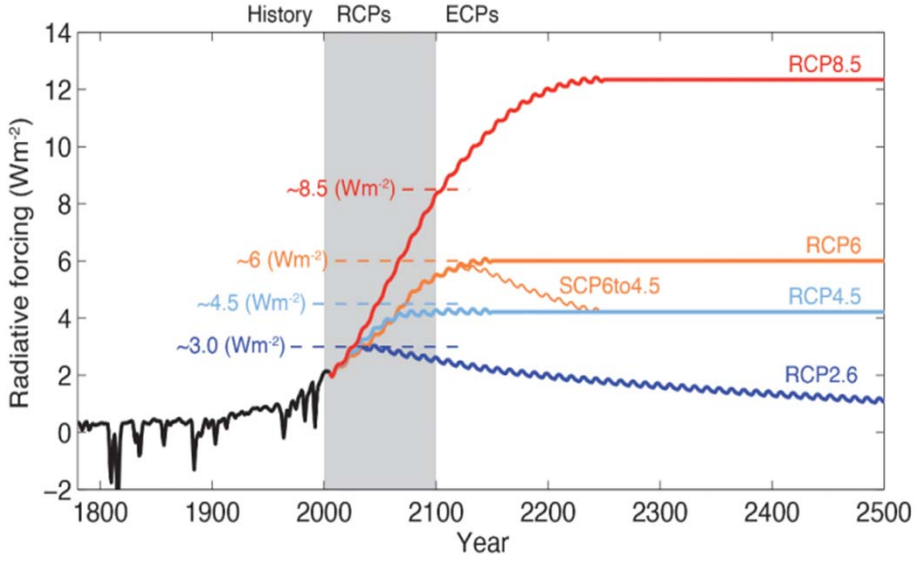
Radiative Forcing

WGI_AR5_FigSPM-5



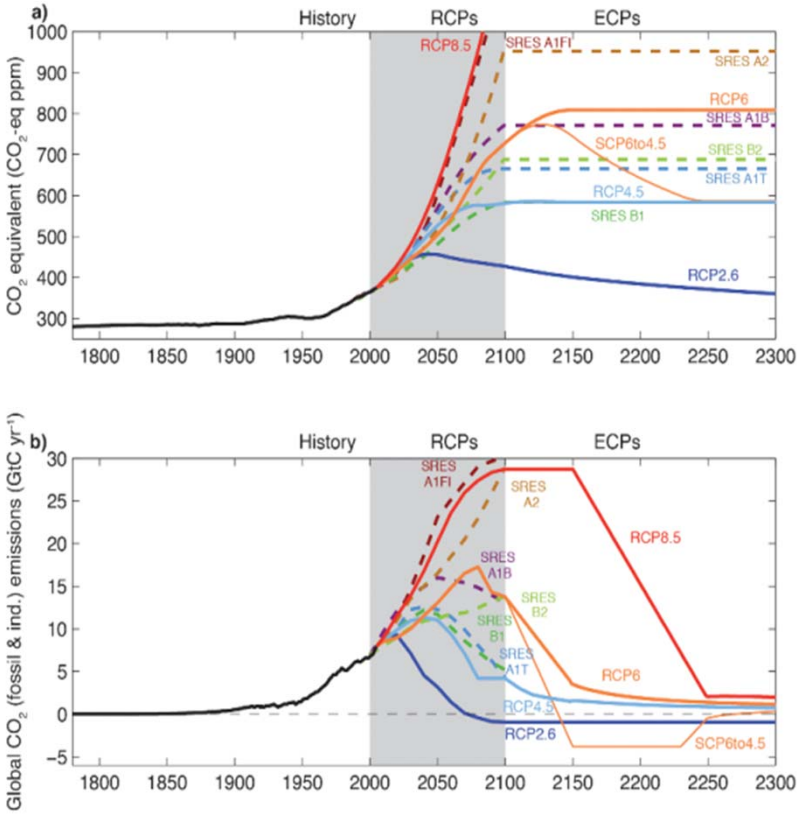
Future Scenarios

Radiative Forcing



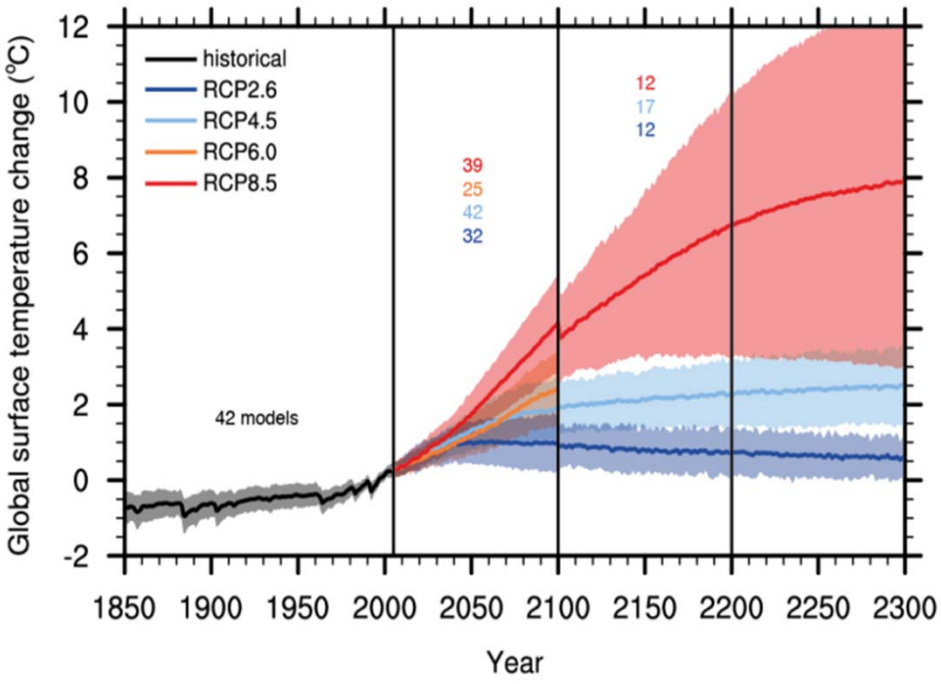
WGI_AR5_FigBox11-1

CO2 and Emisson

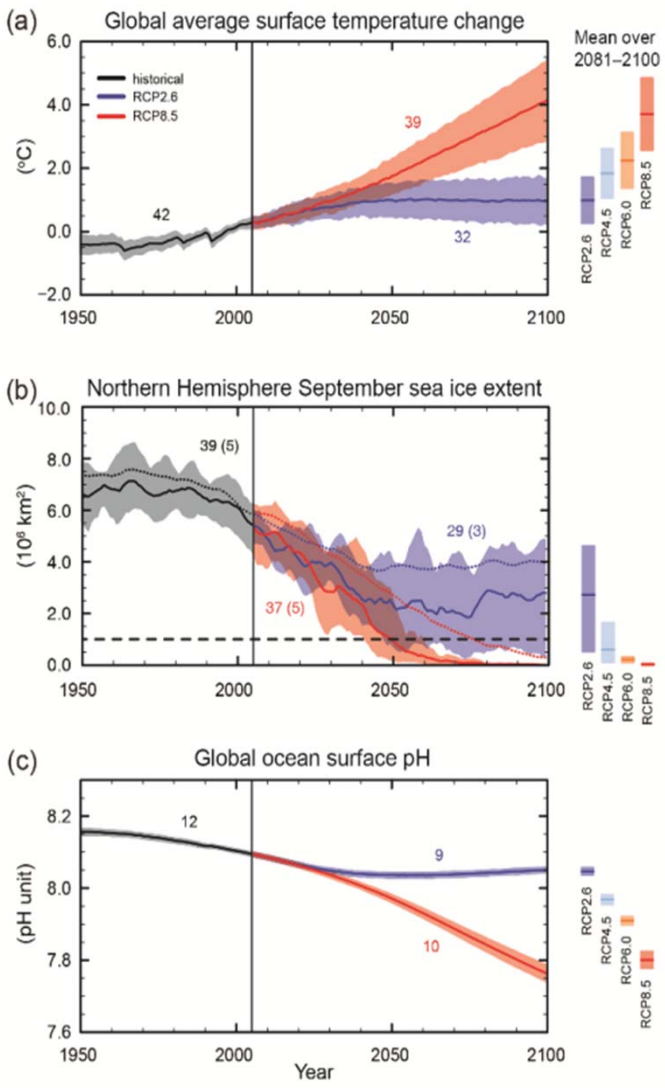


WGI_AR5_FigBox1_1-3

Future Projection

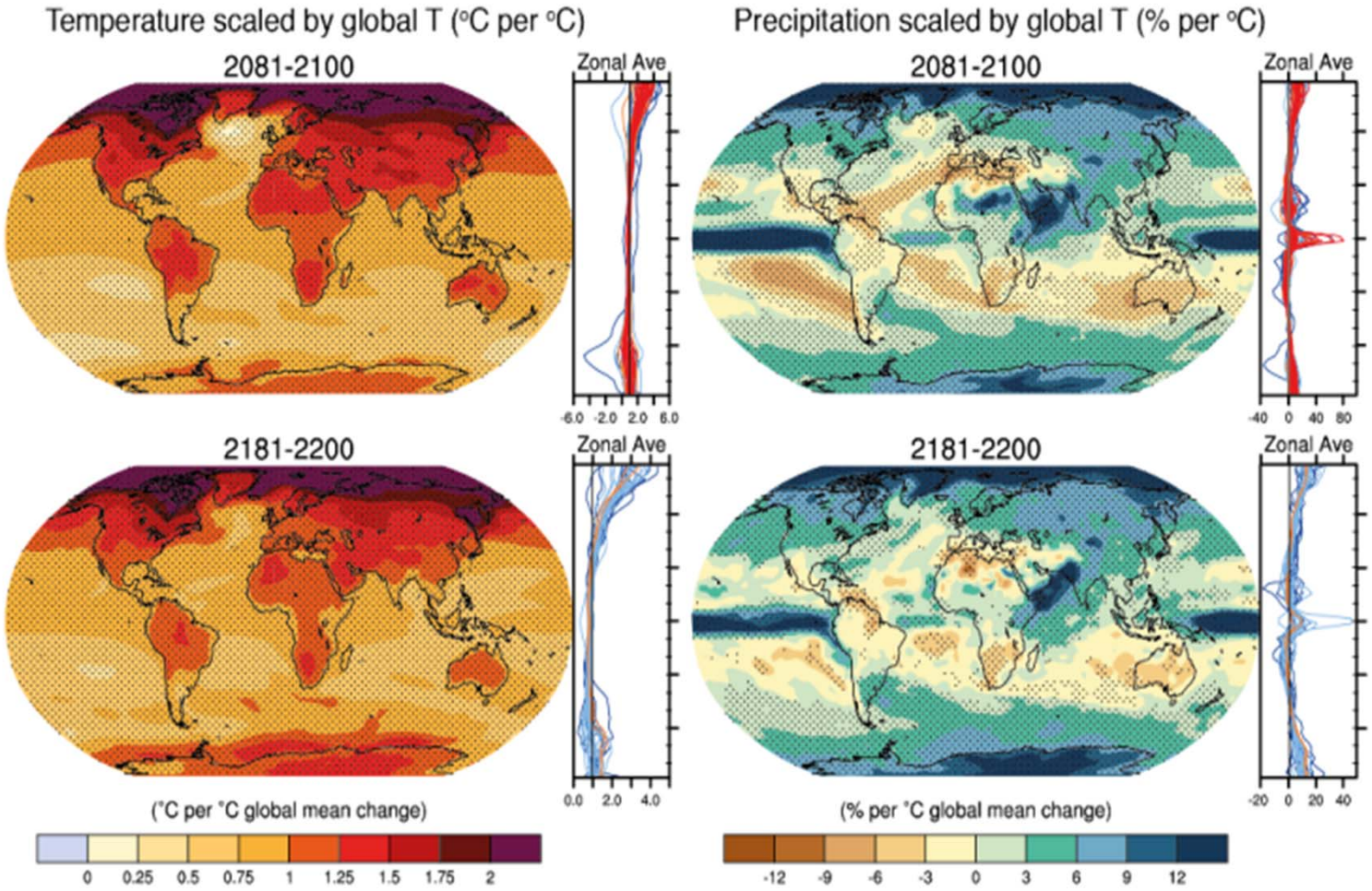


WGI_AR5_Fig12-5



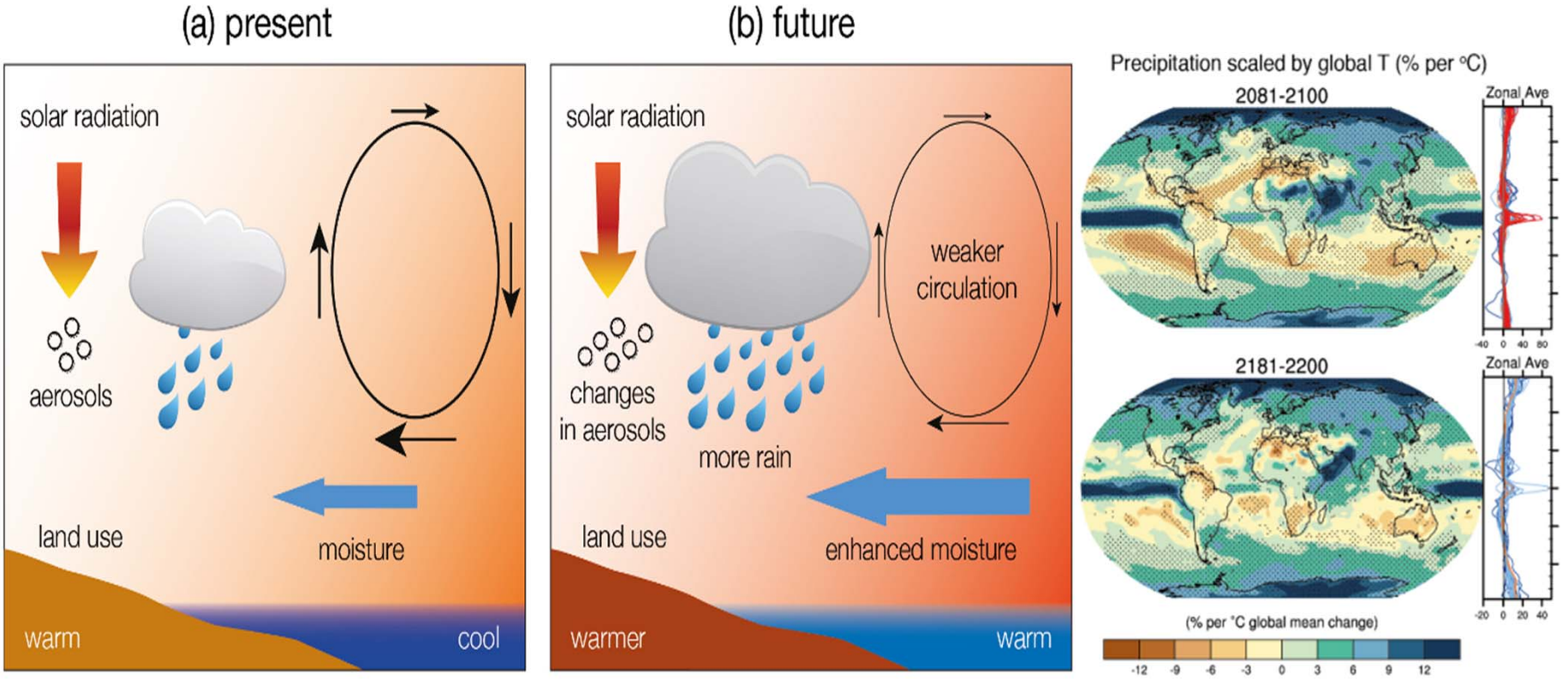
WGI_AR5_FigSPM-7

Distribution of Ts and Precipitation Changes



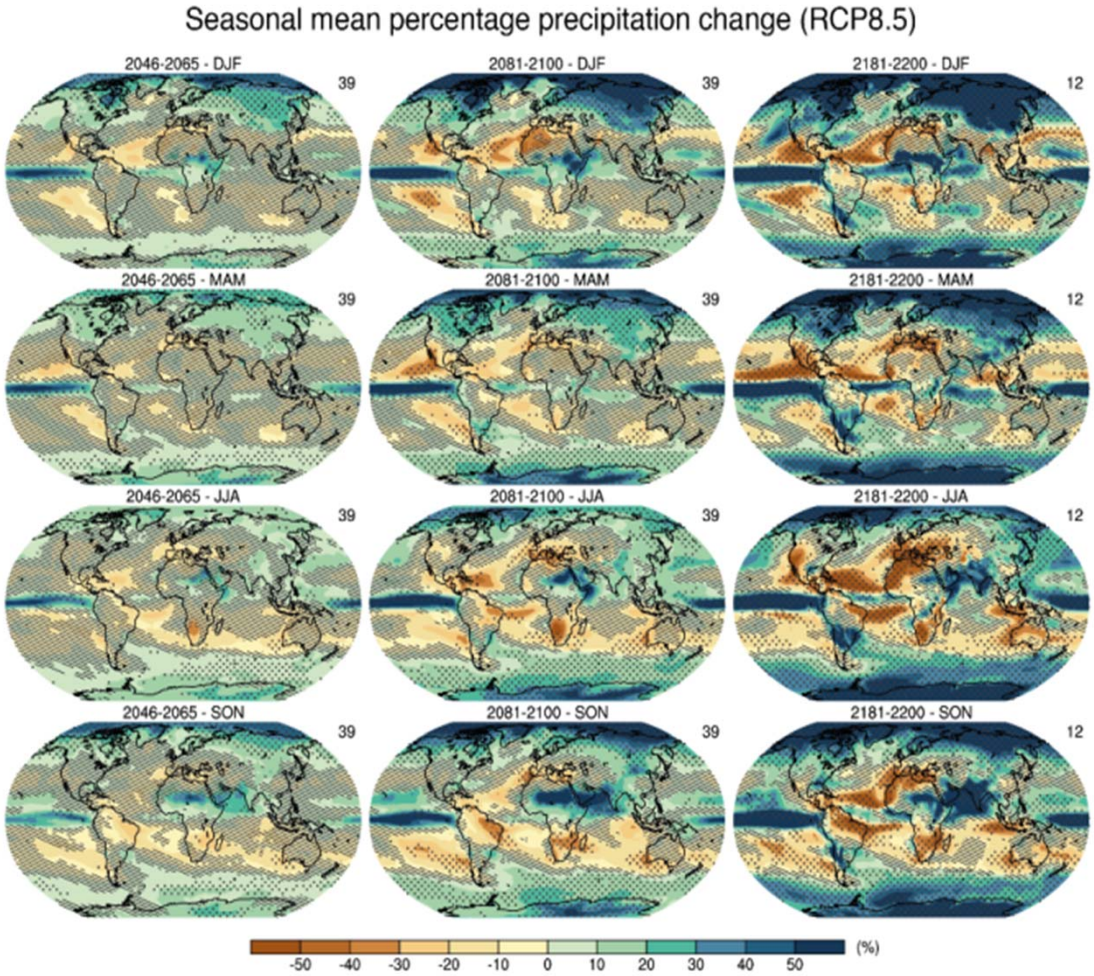
WGI_AR5_Fig12-41

Precipitation generally increase over wet regions and decrease over dry regions



(IPCC 2013)

Seasonal Dependence of Precipitation Change

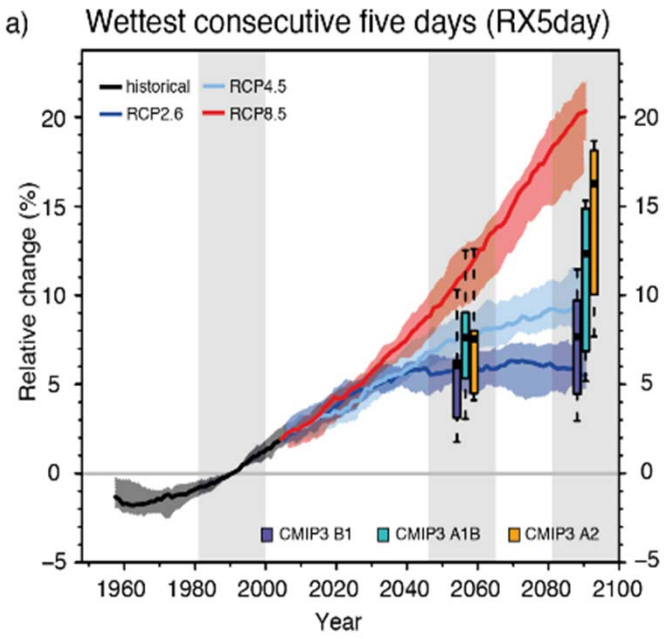


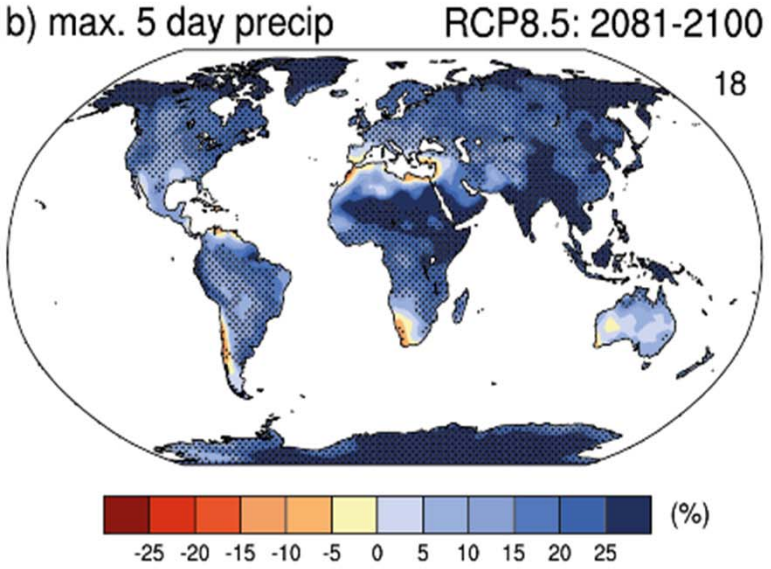
WGI_AR5_Fig12-22

Figure 12.22 | Multi-model CMIP5 average percentage change in seasonal mean precipitation relative to the reference period 1986–2005 averaged over the periods 2045–2065, 2081–2100 and 2181–2200 under the RCP8.5 forcing scenario. Hatching indicates regions where the multi-model mean change is less than one standard deviation of internal variability. Stippling indicates regions where the multi-model mean change is greater than two standard deviations of internal variability and where at least 90% of models agree on the sign of change (see Box 12.1).

Five-day Precipitation amount and Dry days

WGI_AR5_Fig12-26





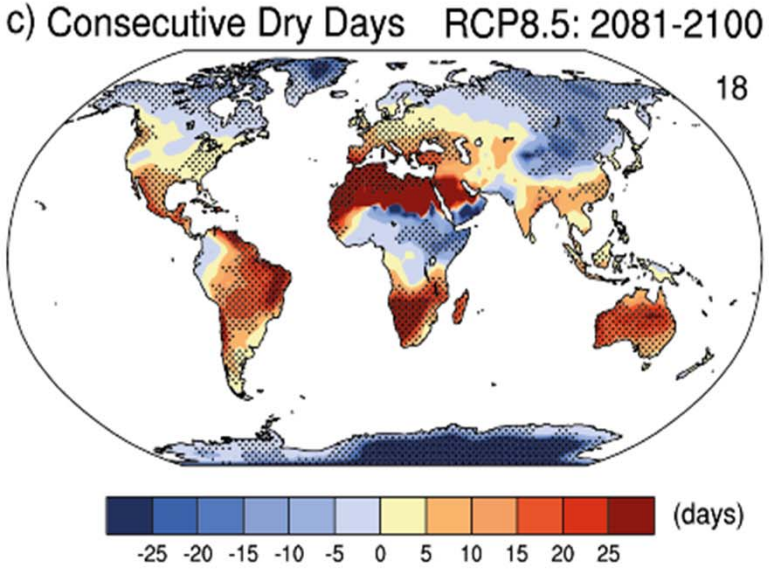


Figure 12.26 | (a, b) Projected percent changes (relative to the 1981–2000 reference period in common with CMIP3) from the CMIP5 models in RX5day, the annual maximum five-day precipitation accumulation. (a) Global average percent change over land regions for the RCP2.6, RCP4.5 and RCP8.5 scenarios. Shading in the time series represents the interquartile ensemble spread (25th and 75th quantiles). The box-and-whisker plots show the interquartile ensemble spread (box) and outliers (whiskers) for 11 CMIP3 model simulations of the SRES scenarios A2 (orange), A1B (cyan) and B1 (purple) globally averaged over the respective future time periods (2046–2065 and 2081–2100) as anomalies from the 1981–2000 reference period. (b) Percent change over the 2081–2100 period in the RCP8.5 scenario. (c) Projected change in annual CDD, the maximum number of consecutive dry days when precipitation is less than 1 mm, over the 2081–2100 period in the RCP8.5 scenario (relative to the 1981–2000 reference period) from the CMIP5 models. Stippling indicates gridpoints with changes that are significant at the 5% level using a Wilcoxon signed-ranked test. (Updated from Sillmann et al. (2013), excluding the FGOALS-s2 model.)

Observed Trend in Japan

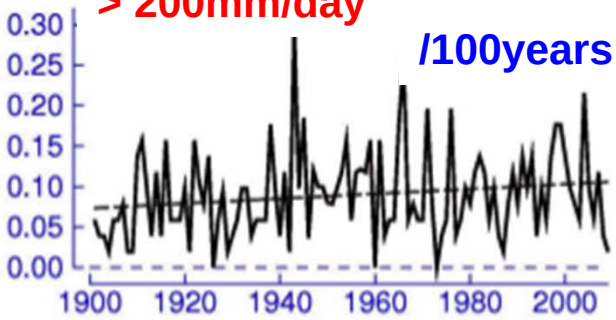
Frequency

(days/1year/ 1station)

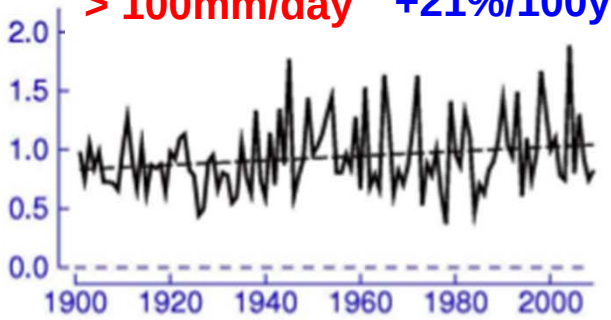
Long-term Trend of Precipition in Japanese 51 stations (1901-2009)

Heavy Precip

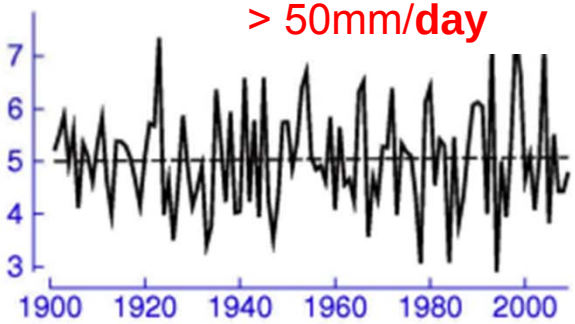
> 200mm/day **+33% /100years**



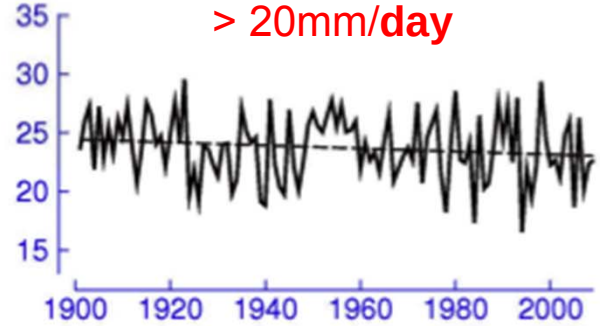
> 100mm/day **+21%/100years**



> 50mm/day

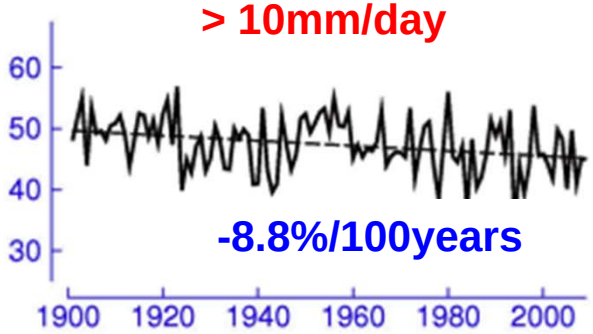


> 20mm/day



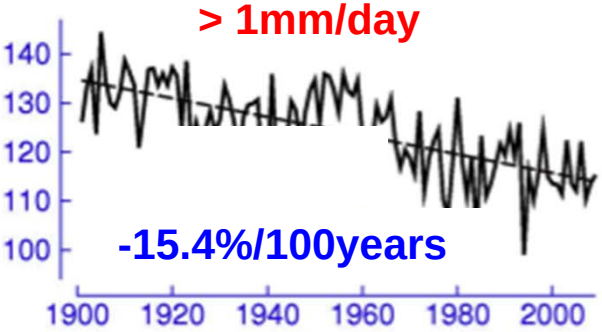
Light Precip

> 10mm/day



-8.8%/100years

> 1mm/day

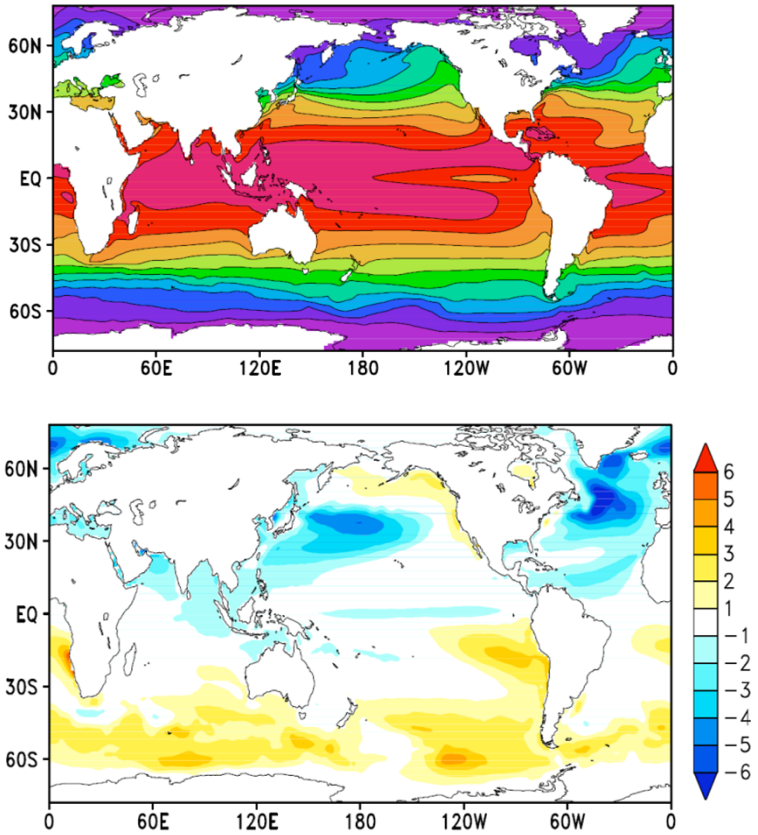


-15.4%/100years

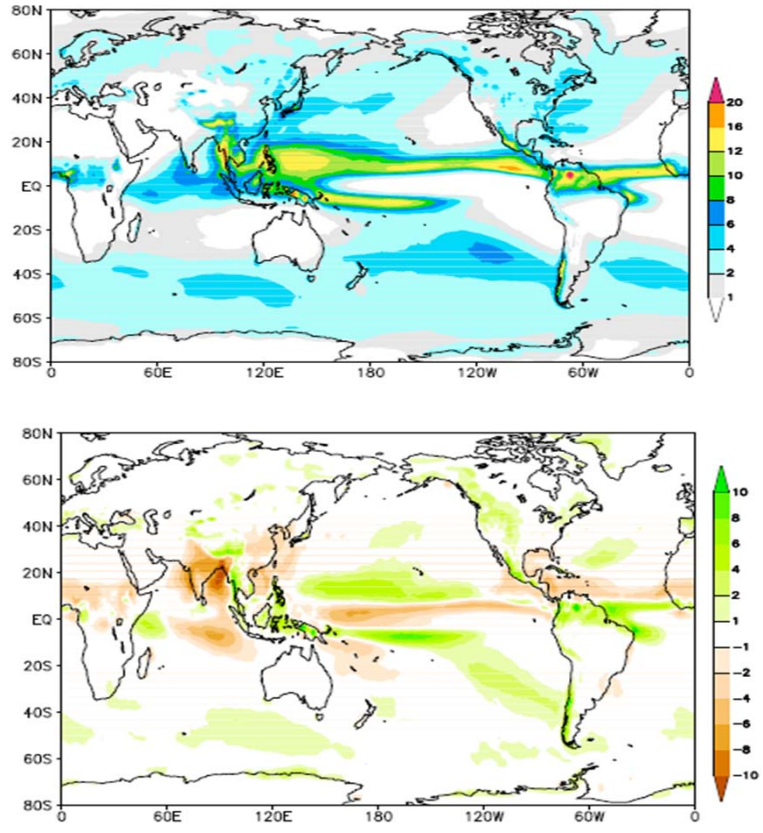
Fujibe (2011)

Climate (coupled) Models have been much improved, but still have some biases in Regional Climate Simulation

SST Bias (annual mean)



Precipitation Bias (JJA)

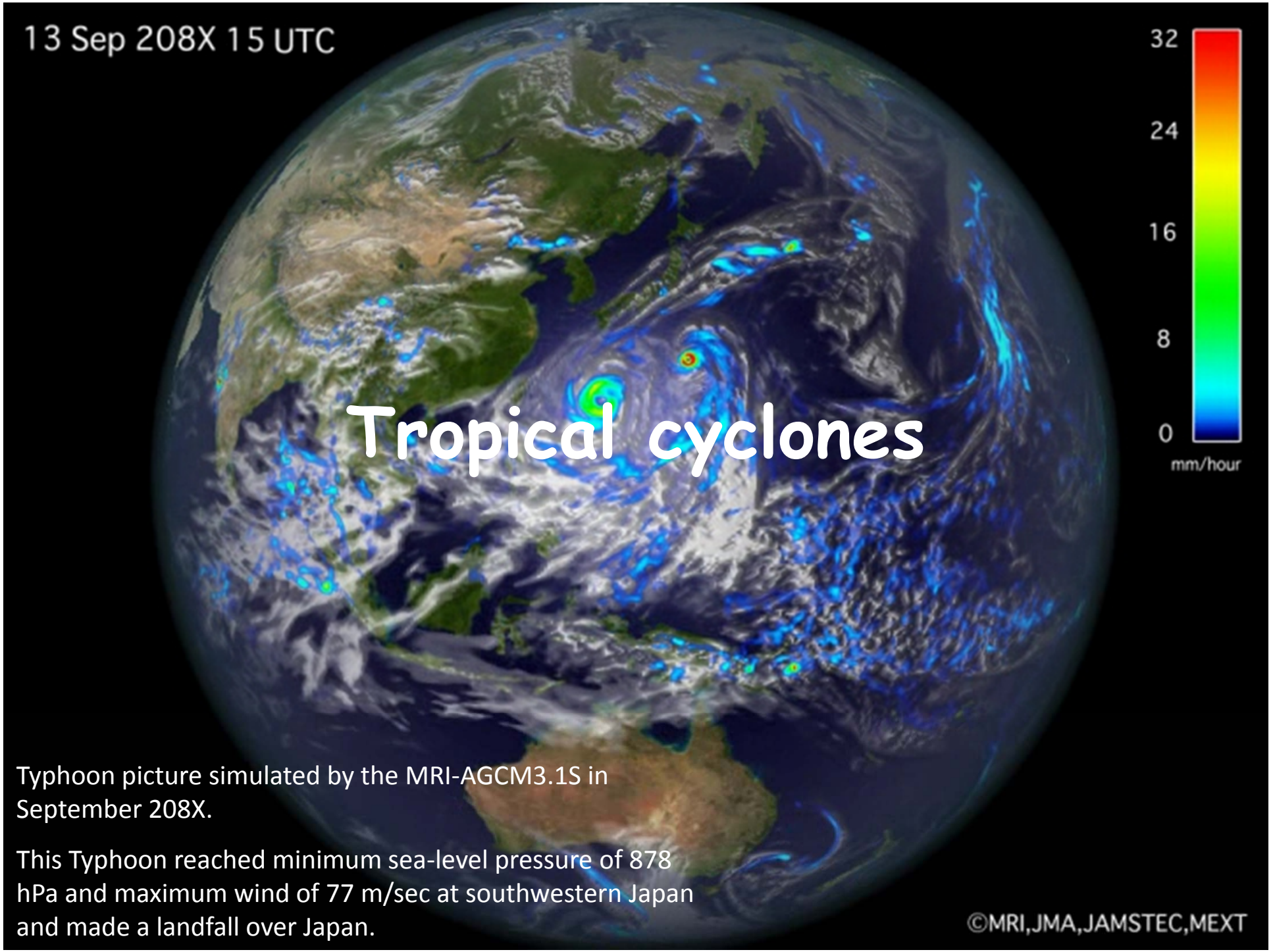


(Yukimoto, 2012)

High Resolution Atmospheric Models (AGCMs) are useful

for

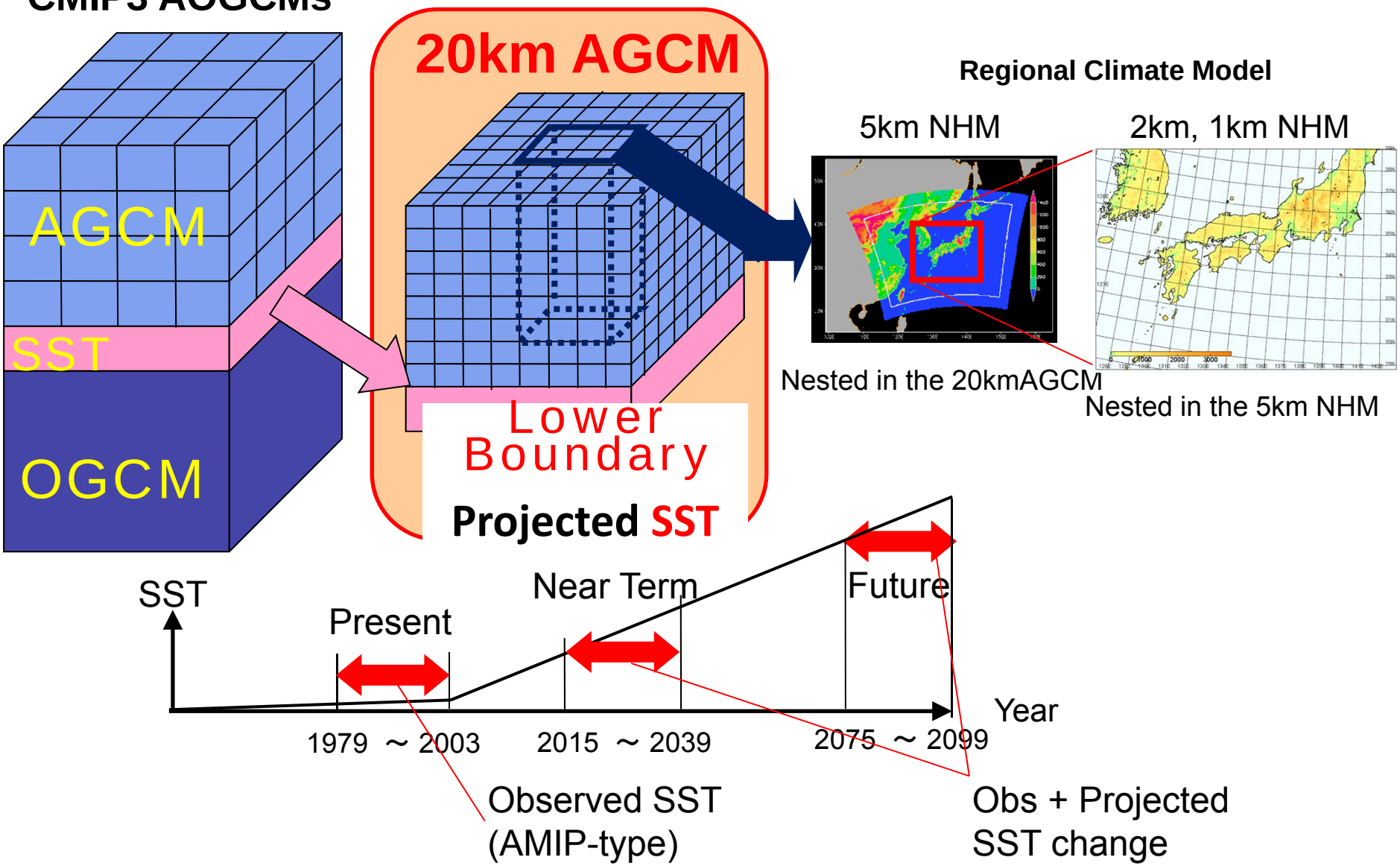
Assessments of Regional Climate Change


13 Sep 208X 15 UTC
32
24
16
8
0
mm/hour
Tropical cyclones
Typhoon picture simulated by the MRI-AGCM3.1S in September 208X.
This Typhoon reached minimum sea-level pressure of 878 hPa and maximum wind of 77 m/sec at southwestern Japan and made a landfall over Japan.
©MRI,JMA,JAMSTEC,MEXT

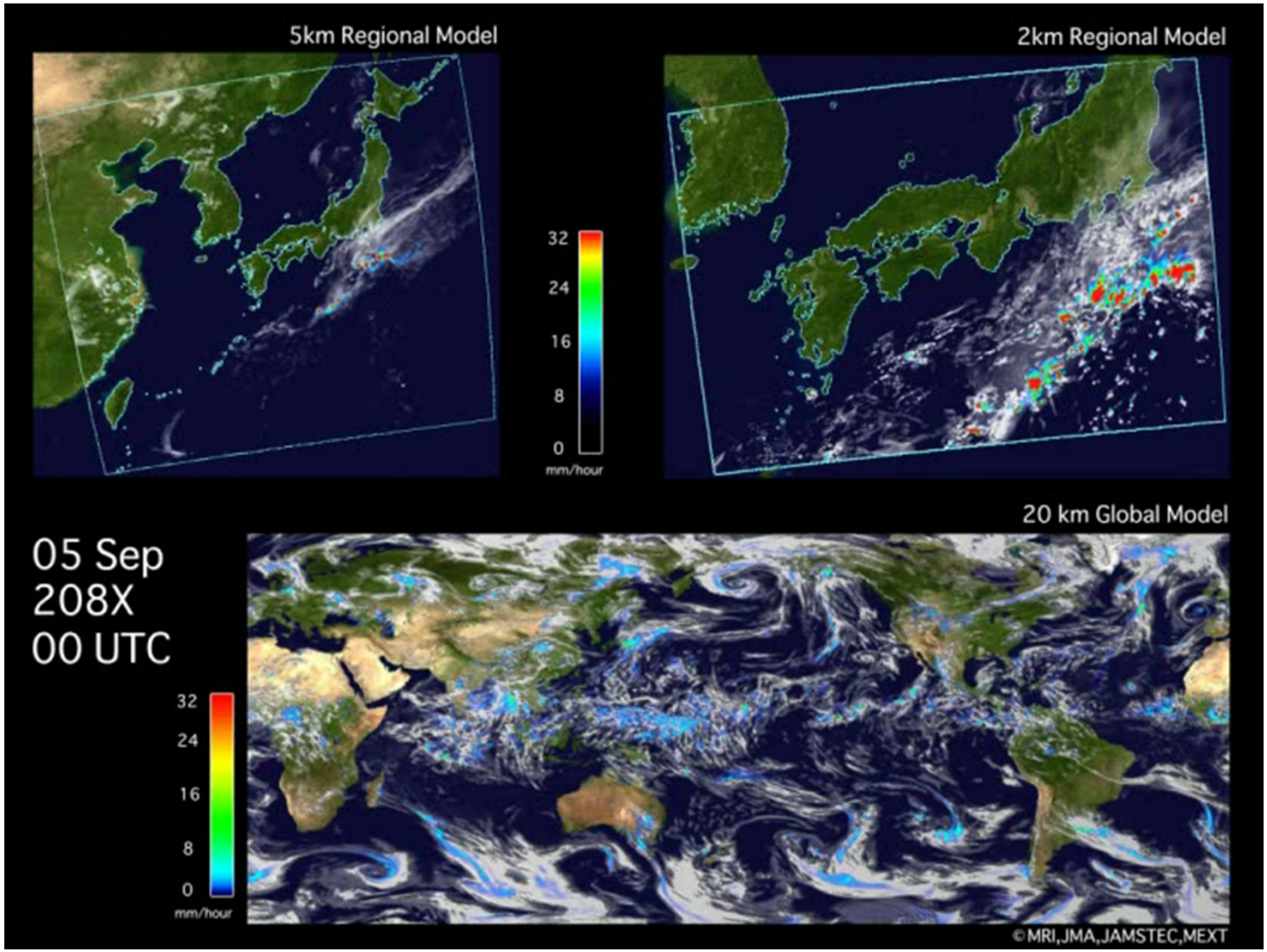
KAKUSHIN-3 Time-Slice Future Projection

(FY2007-FY2011)

(Kitoh et al. , 2009, HRL)



Dynamical Downscaling (over Japan)



Advantages of High Resolution AGCMs

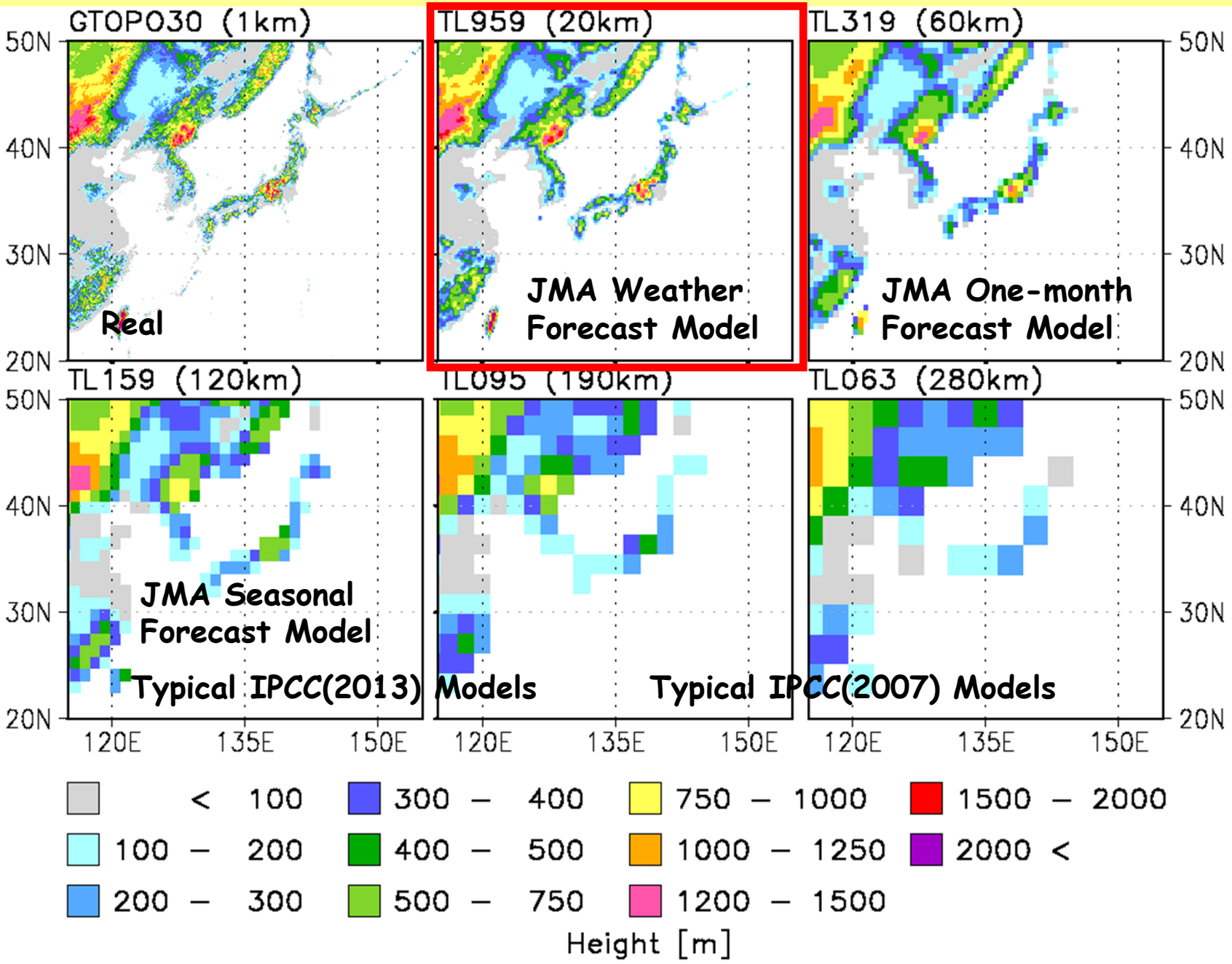
- **Realistic Present-day Climatology**

  （Because observed SST is specified）

- Fine geography
- **Realistic Extreme Events such as Typhoons**

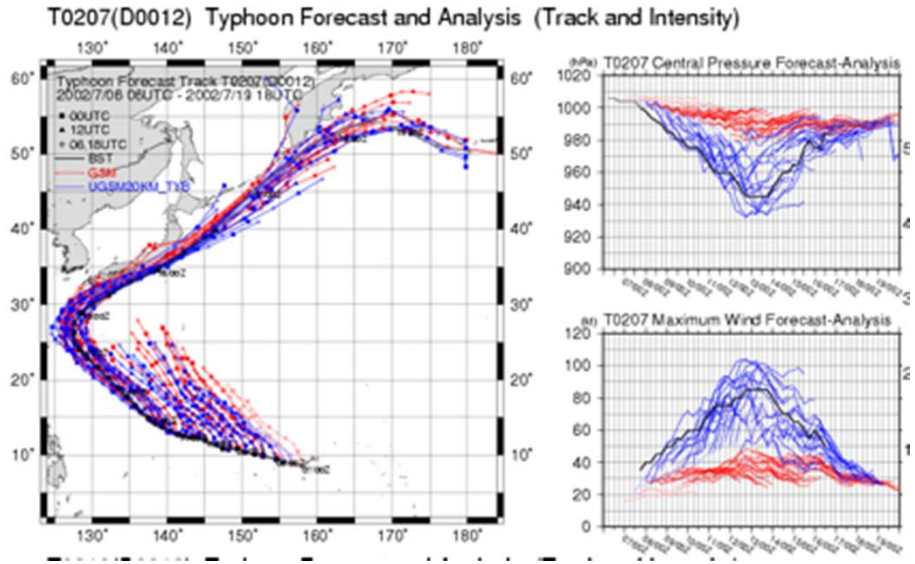
- Experiments can be controlled well.
- SST and Model Ensembles are easily made.

Fine Climatology <- Fine Topography in High Resolution Models



Typhoon Prediction（by 20km and 60km models）

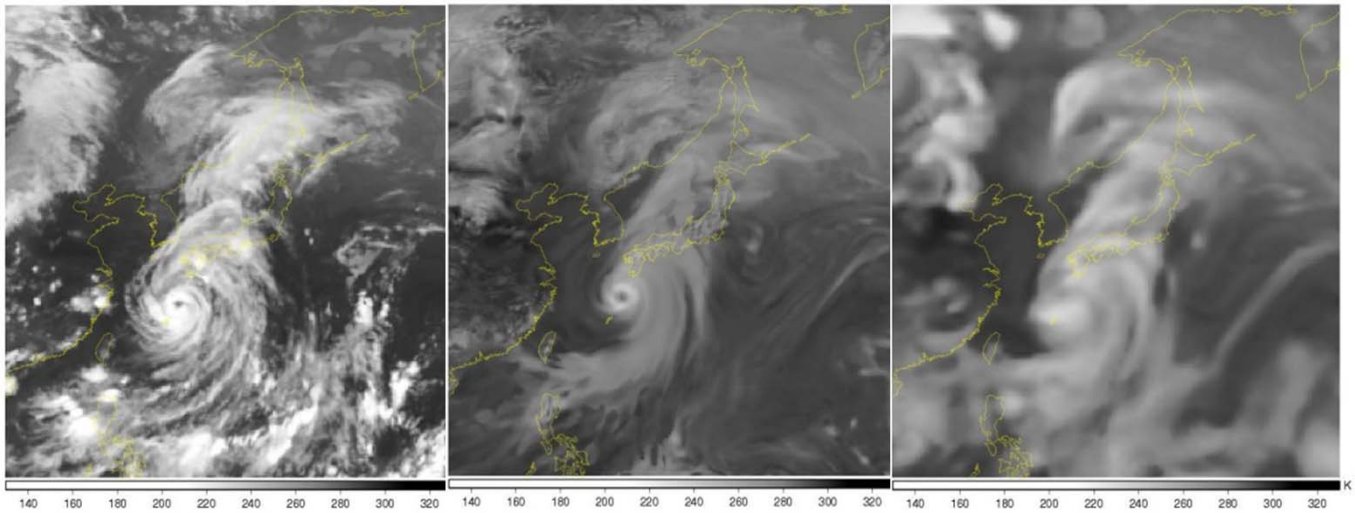
Track Prediction



Minimum Sea Level Pressure

Maximum Wind Speed

36-hour Prediction



(Murakami et al., 2008)

Model Improvement and Verification

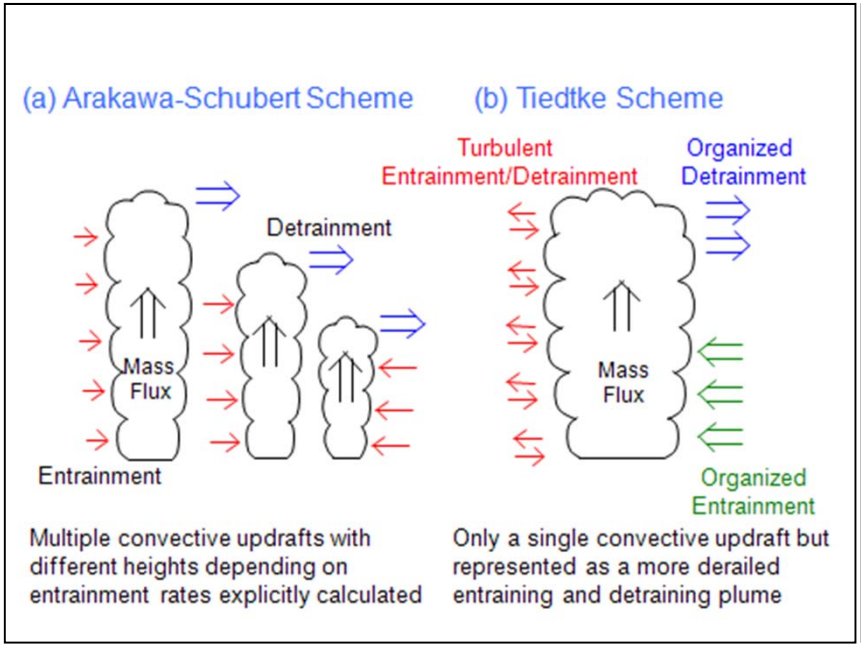
New 20km AGCM (MRI-AGCM3.2S) was developed
From Previous 20km AGCM (MRI-AGCM3.1S)
by Mizuta et al (2012)

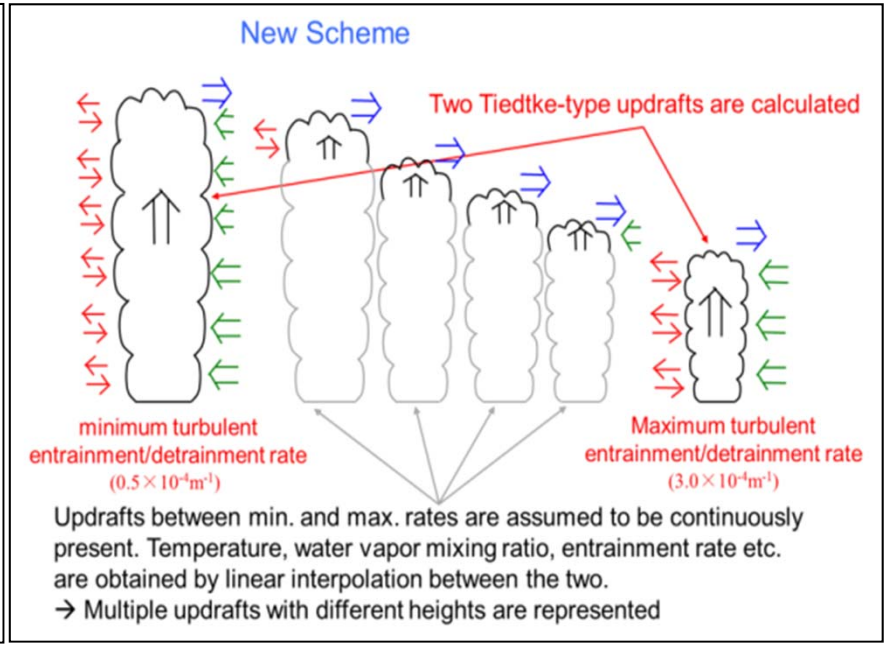
MRI-AGCM 3.1 vs 3.2

	Previous version (contributed to IPCC AR4)	New version (for IPCC AR5)
	MRI-AGCM 3.1 (Mizuta et al., 2006, *JMSJ*)	**MRI-AGCM 3.2** (Mizuta et al., 2012, *JMSJ*)
Horizontal resolution	TL959 (20km)	
Vertical resolution	60 levels (top at 0.1hPa)	64 levels (top at 0.01hPa)
Time integration	Semi-Lagrangian	
Time step	6minutes	10minutes
Cumulus convection	Prognostic Arakawa-Schubert	Yoshimura (Tiedtke-based)
Cloud	Smith (1990)	Tiedtke (1993)
Radiation	Shibata and Aoki (1989) Shibata and Uchiyama(1992)	JMA (2007)
GWD	Iwasaki et al. (1989)	
Land surface	SiB ver0109(Hirai et al.2007)	
Boundary layer	MellorYamada Level2	
Aerosol (direct)	Sulfate aerosol	5 species
Aerosol (indirect)	No	

Cumulus Scheme

In Previous AGCM → **In New AGCM**



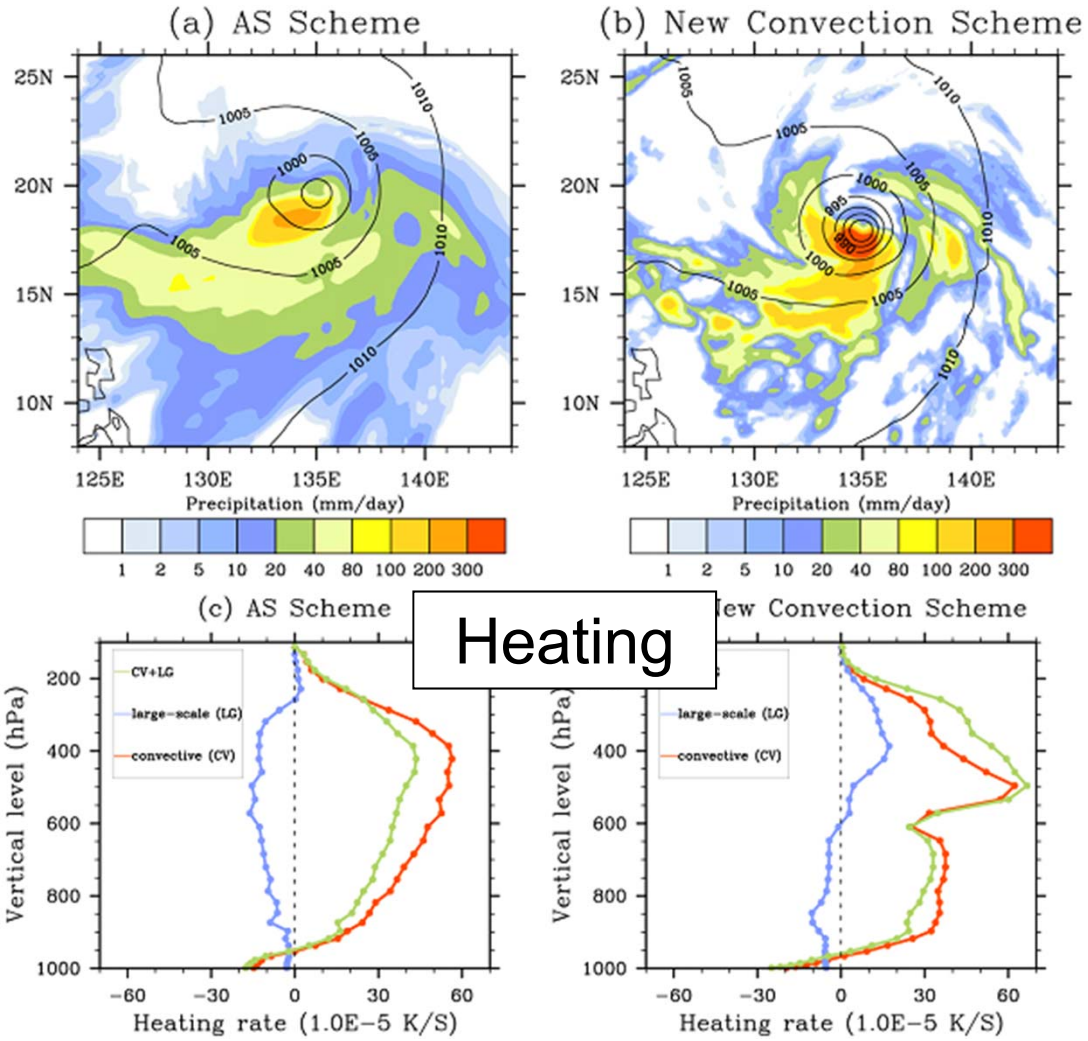


(Mizuta et al., 2012)

Precipitation by Tropical Cyclones

Previous AGCM

AS-type



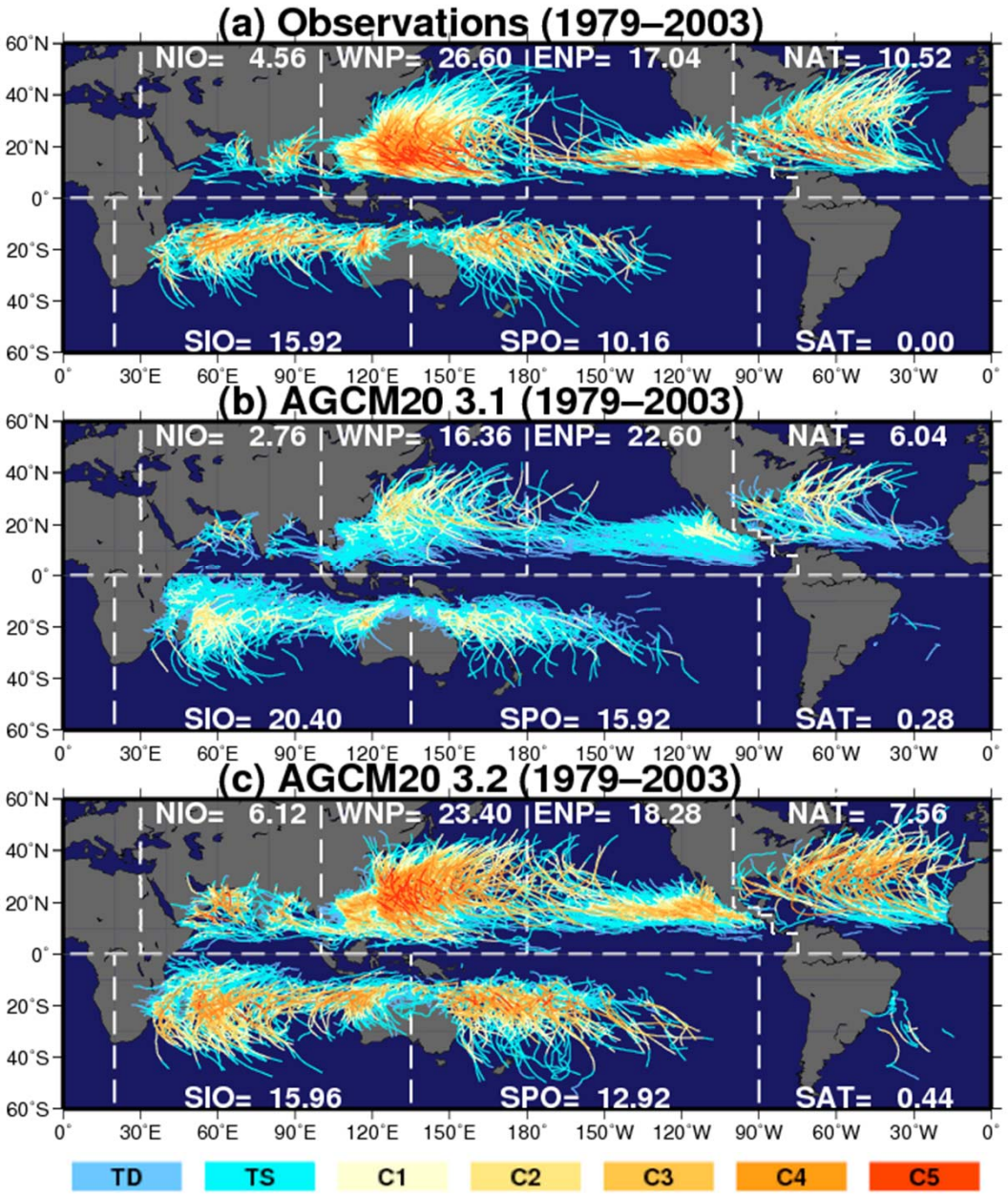
Heating

New AGCM

Yoshimura (2011)

Murakami et al., 2012, J.Climate

Tropical Cyclones (Weak -> Strong)



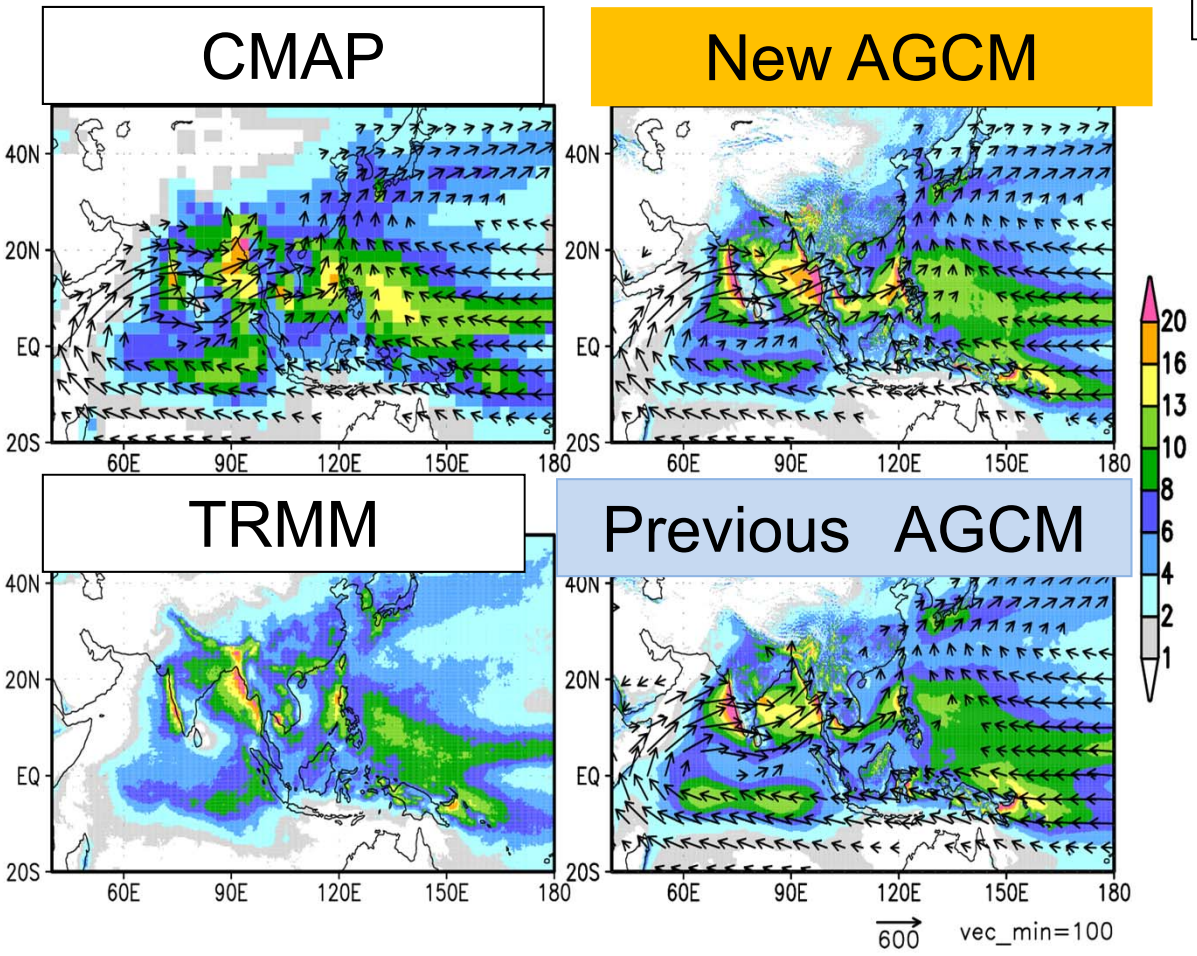
Observation

TL959L60
Previous AGCM

TL959L64
New AGCM

Murakami et al., 2012, J.Climate

Model Verification by Numerical Metrics

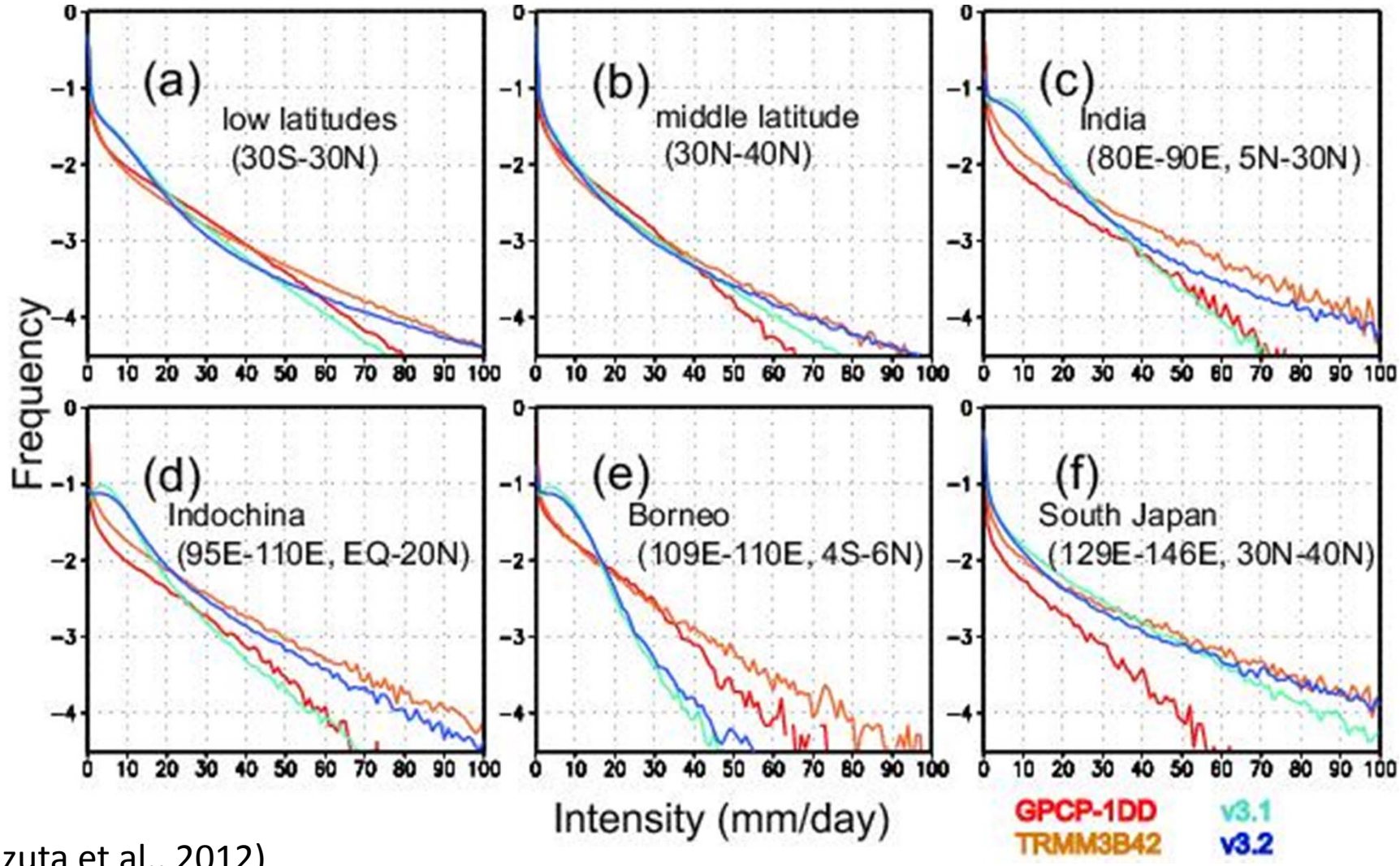


(Mizuta et al., 2012)

Metrics (60-150E,EQ-30N)
(New AGCM / Previous AGCM)
shows a higher value.

Element(July)	OBS	Previous	New
Precipitation	TRMM	0.3886	0.497
Precipitation	CMAP	0.4523	0.5616
Precipitation	GPCP	0.3441	0.4088
500hPa Height	JRA25	0.7266	0.7813
Sea Level Pressure	JRA25	0.7894	0.8836
850hPa Temperature	JRA25	0.9195	0.9776
850hPa Zonal Wind	JRA25	0.8395	0.8547
200hPa Zonal Wind	JRA25	0.8866	0.9641
200hPaMeridional Wind	JRA25	0.7945	0.7923
500hPa Height Wave	JRA25	0.8161	0.868
SLP Wave	JRA25	0.8185	0.902
850hPa T Wave	JRA25	0.8785	0.936
850hPaZonalWind Wave	JRA25	0.8393	0.8833
200hPaZonalWind Wave	JRA25	0.7995	0.9217

Frequency of Daily Precipitation Intensity



(Mizuta et al., 2012)

Ensemble Projection

to assess Uncertainty

Various Ensemble Methods

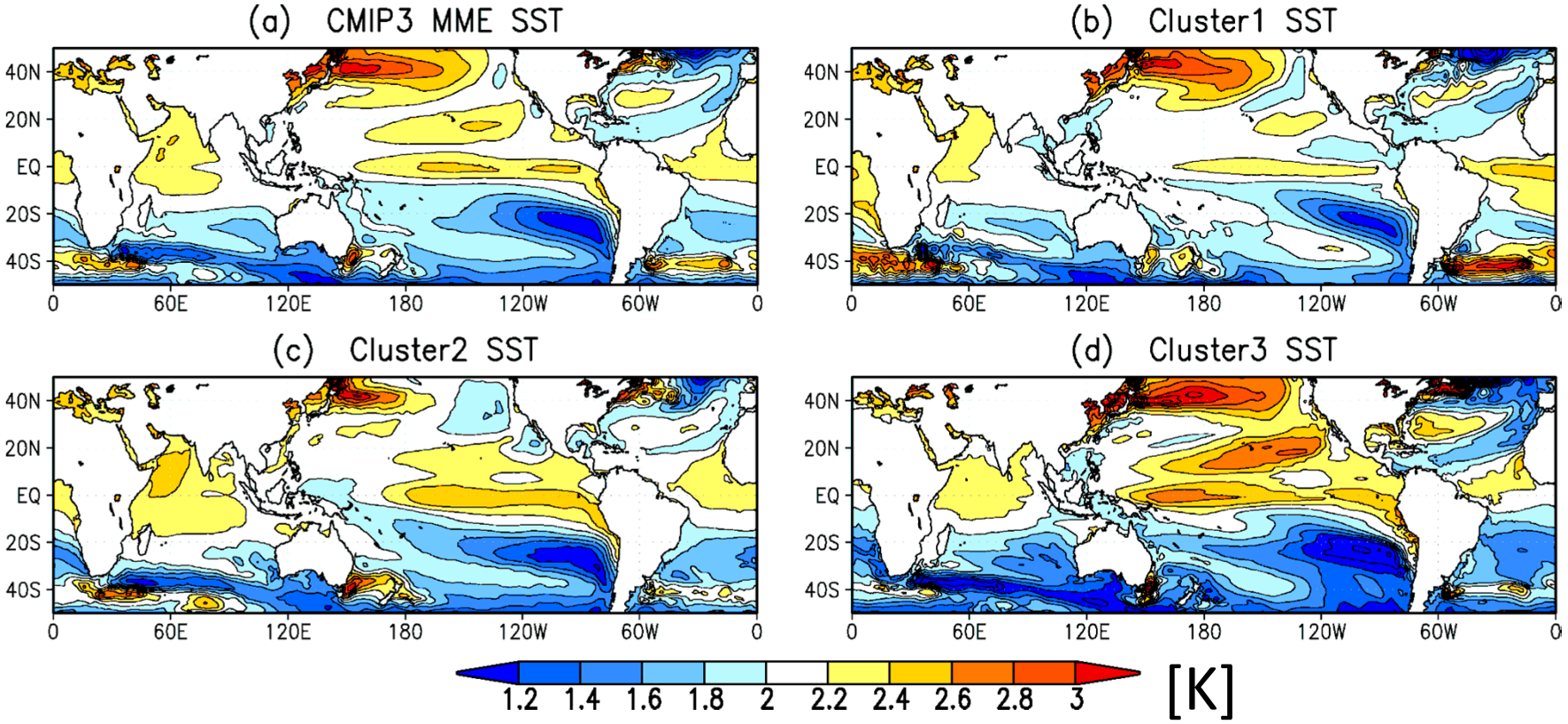
- Different Initials
- Different Forcing or Boundaries

  （Future SST, Global Warming Scenarios etc.）

- Different Physical Schemes
- Multi-models (such as CMIP3, CMIP5 models)

(Endo et al., 2012)

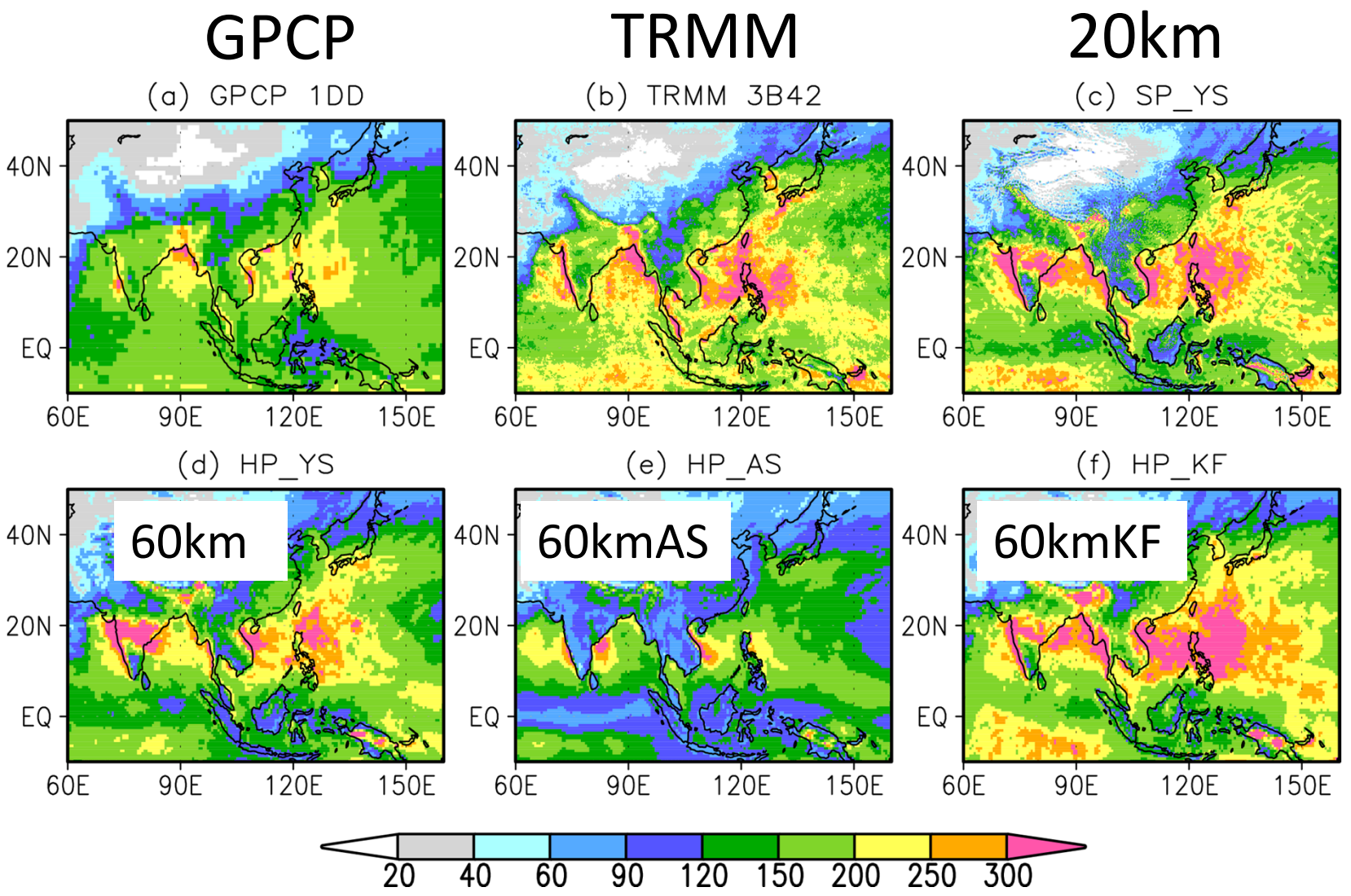
Four Patterns of Future SST Increase are adopted.



- Besides one CMIP3-MME SST increase, three patterns of SST increase are obtained by cluster analysis.
- Tropical averages are the same as that of the MME SST increase.

(Endo et al., 2012)

Annual Max 5-day Precipitation (GPCP, TRMM, Three schemes)



- New 20km AGCM is comparable with TRMM Observation

(Endo et al., 2012)

Ensemble Projection by 60km AGCMs

● Present Day : 25 years of 1979-2003

SST ＼Cumulus	YS-scheme	AS-scheme	KF-scheme
Observed	HP_YS	HP_AS	HP_KF

● End of the 21st Century Under A1B Scenario

ΔSST ＼Cumulus	YS-scheme	AS-scheme	KF-scheme
CMIP3-MME	HF_YS	HF_AS	HF_KF
Cluster-1	HF_YSc1	HF_ASc1	HF_KFc1
Cluster-2	HF_YSc2	HF_ASc2	HF_KFc2
Cluster-3	HF_YSc3	HF_ASc3	HF_KFc3

YS: Yoshimura (Yukimoto et al. 2011)
AS: Arakawa and Schubert (1974); Randall and Pan (1993)
KF (Kain and Fritsch 1990, 1993)

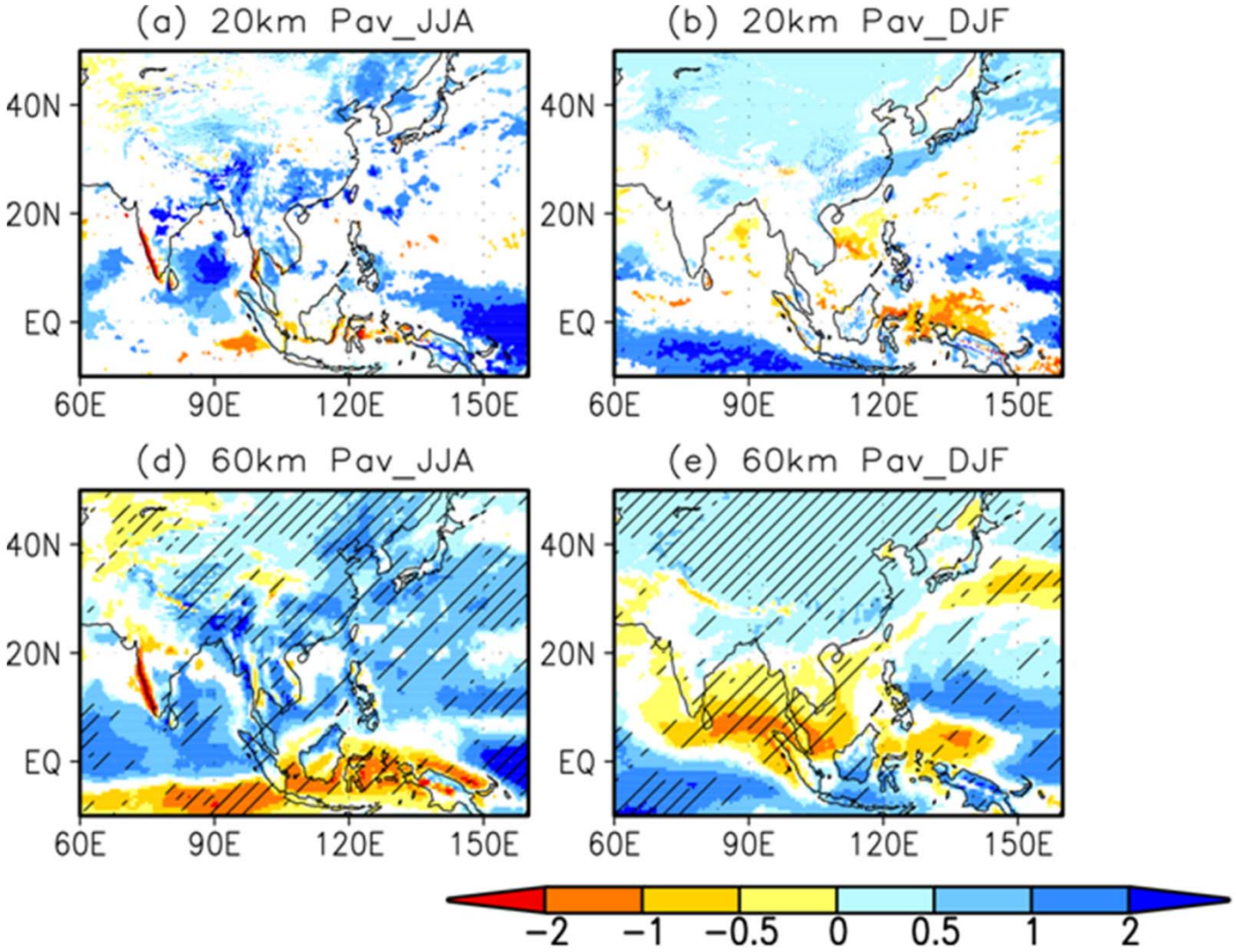
(Endo et al., 2012)

Future Change in Precipitation

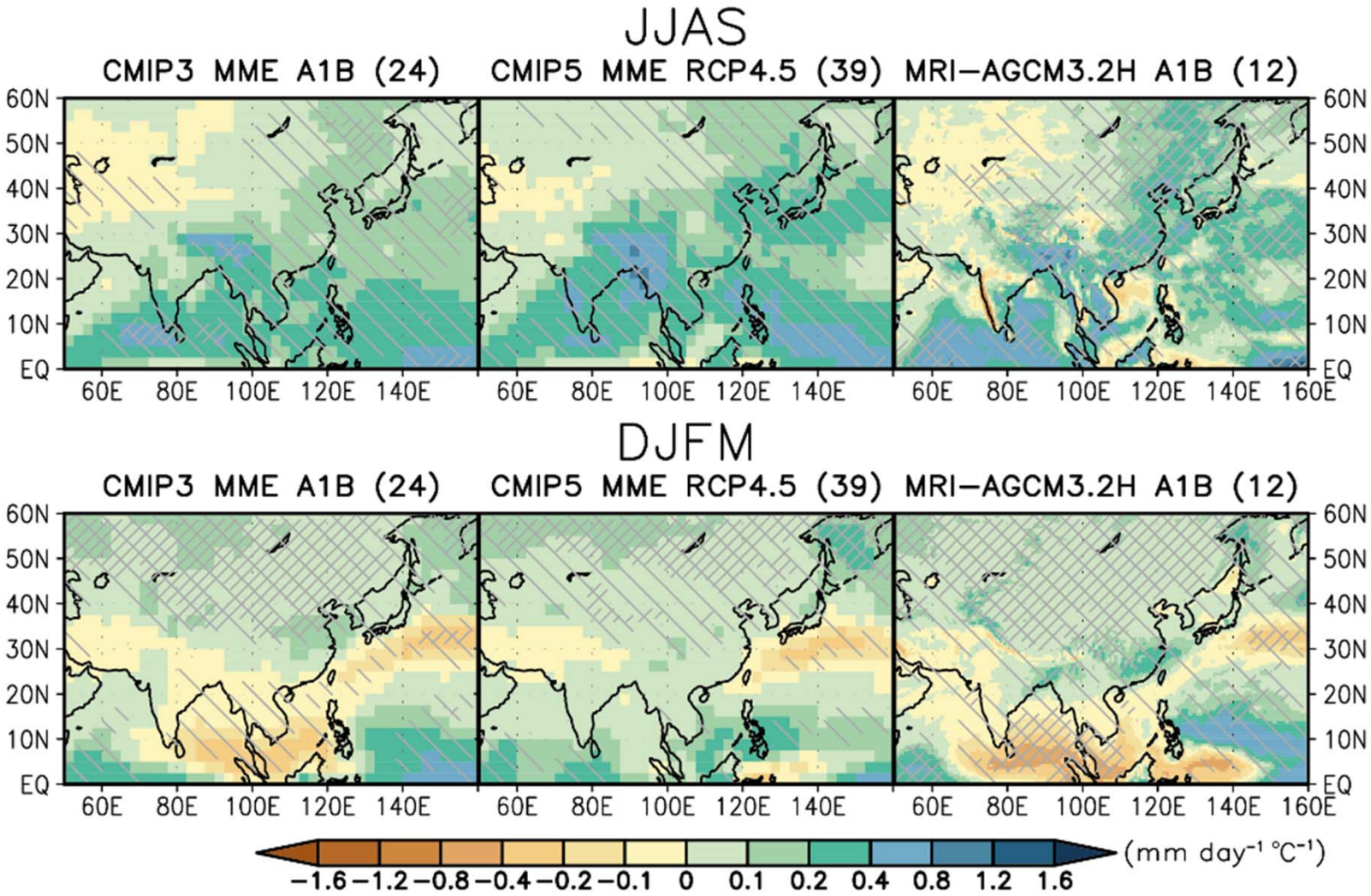
Narrow(wide)-interval shades indicate the same (+ or -) among all (more than 9) experiments

20km AGCM

60km AGCM



Comparison with CMIP3 and CMIP5 Multi-Model Ensemble

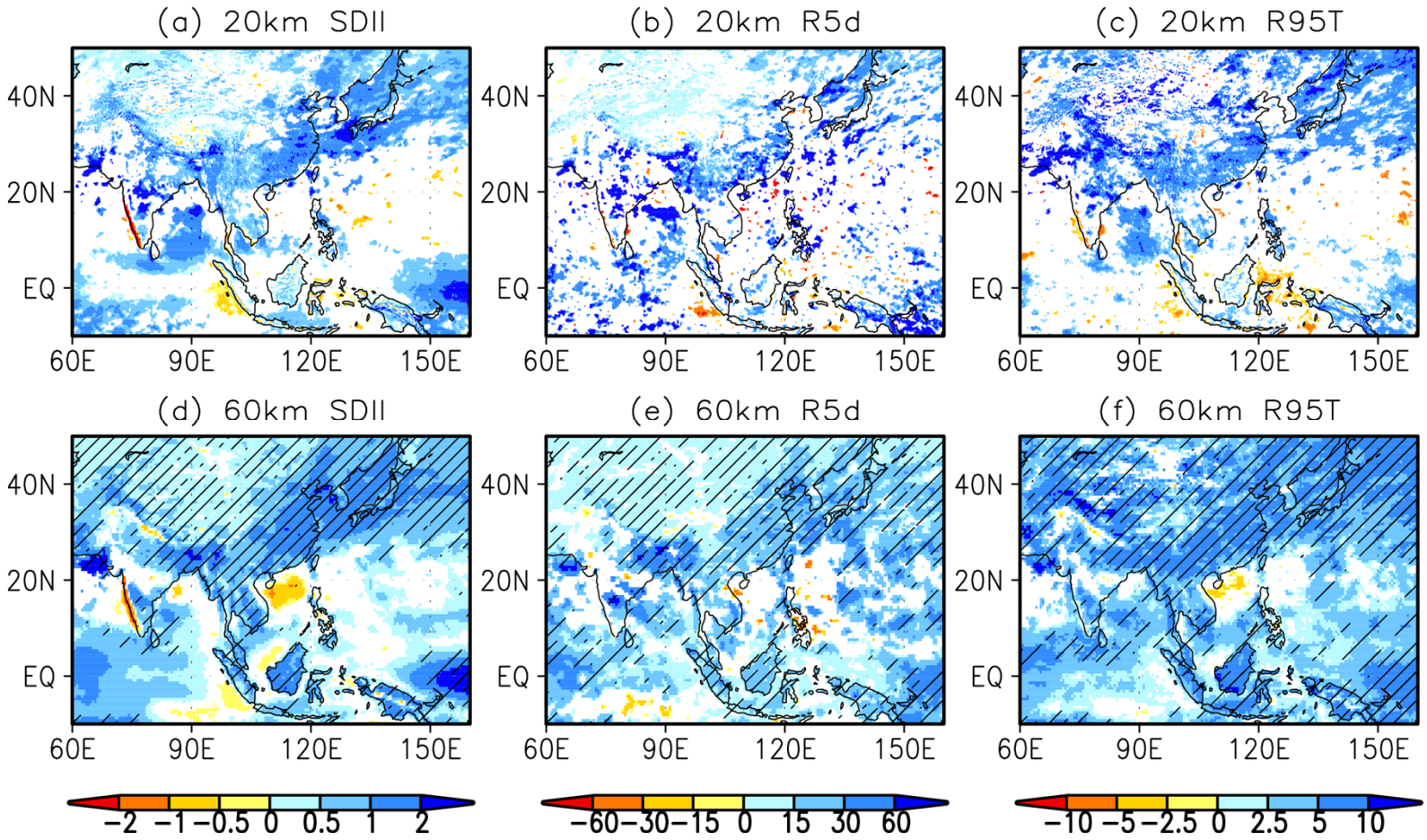


(Endo et al., 2012)

Future Change in Precipitation Extremes

Narrow(wide)-interval shades indicate the same (+ or -) among all (more than 9) experiments

	Precipitation Intensity (mm/rain day >1mm/day)	Annual 5-day Precipitation Maximum	95% tile of daily precipitation
20km AGCM	(a) 20km SDII	(b) 20km R5d	(c) 20km R95T
60km AGCM	(d) 60km SDII	(e) 60km R5d	(f) 60km R95T

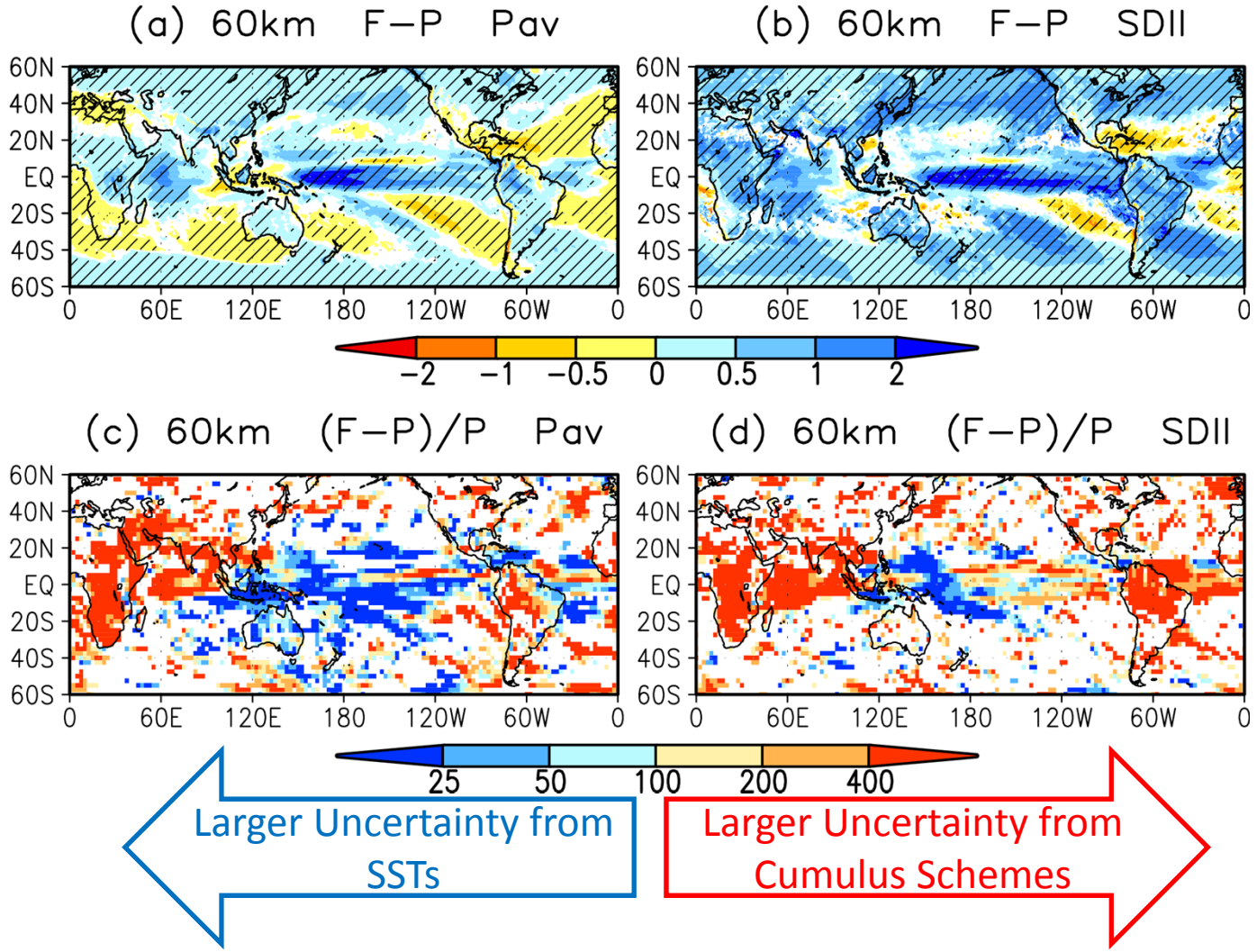


(Endo et al., 2012)

Projection Uncertainty comes from SSTs ? or Cumulus Schemes ?

Annual Precipitation (Pav)

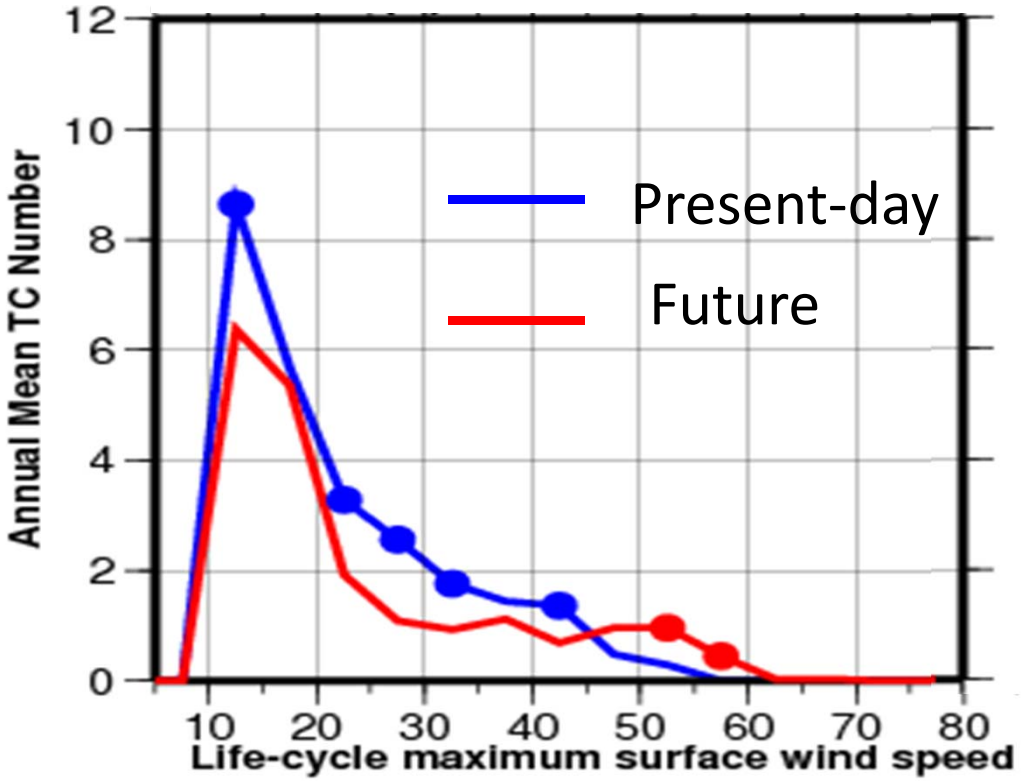
Precipitation Intensity (SDII)



Projection of Tropical Cyclones

Increase in Strong Tropical Cyclones and Decrease in Weak Ones

Murakami et al., 2012, J.Climate

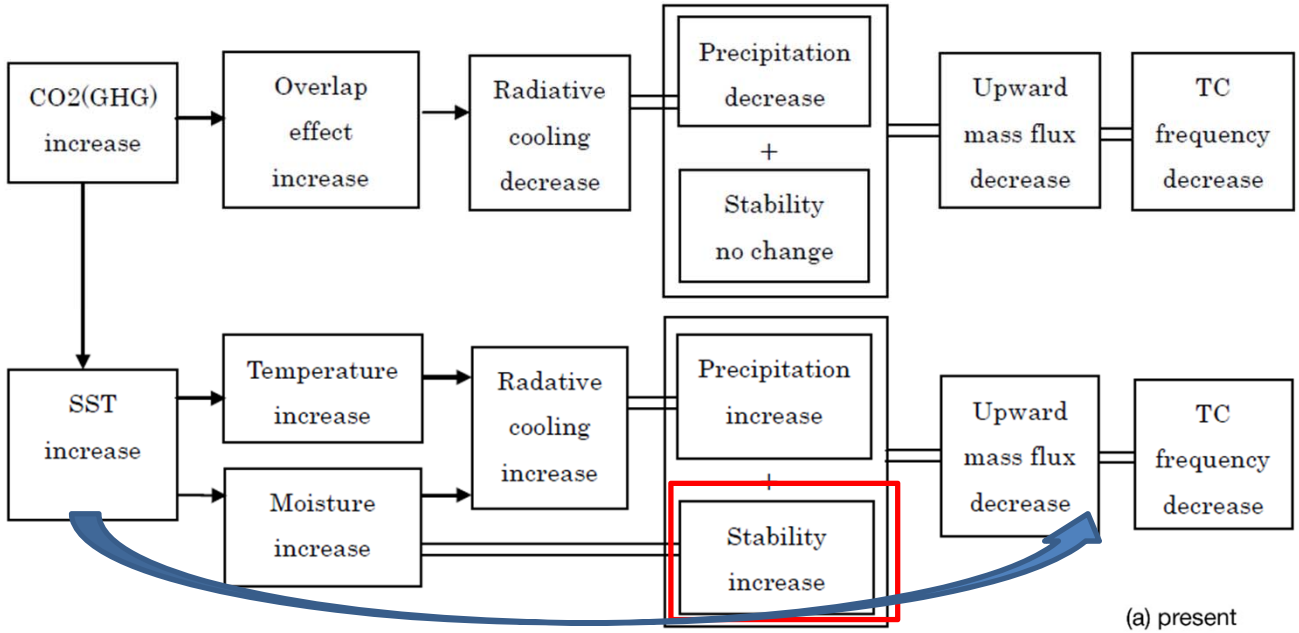


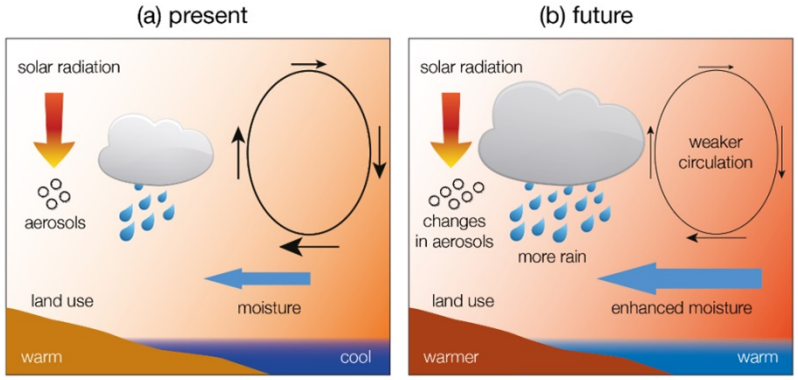
Increase significantly
Decrease significantly

Occurrence number of tropical cyclones increases in future, however, the chance to be strong cyclones increases because of warmer SST and more moisture in air.

Why the number of tropical cyclones decreases?

(Sugi et al., 2012_JMSJ)

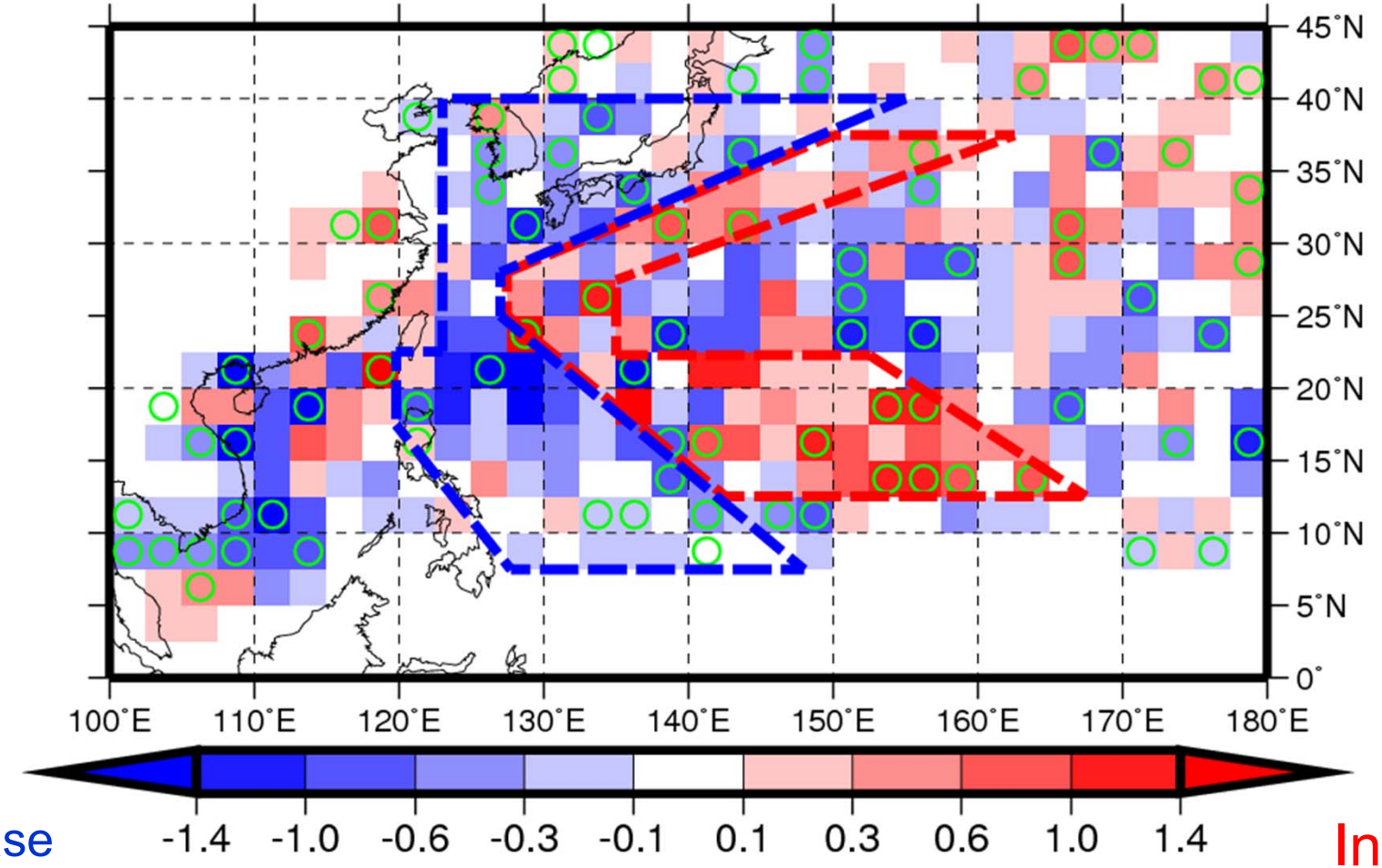




Typhoon paths shift eastward

Murakami et al. (2011) *J. Climate*

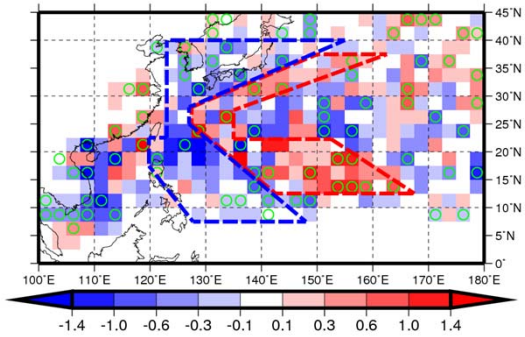
Difference between Future (2075-2099) and Present-day (1979-2003)
of the number of tropical cyclones In 2.5degree by 2.5 degree areas in July-Oct



Decrease

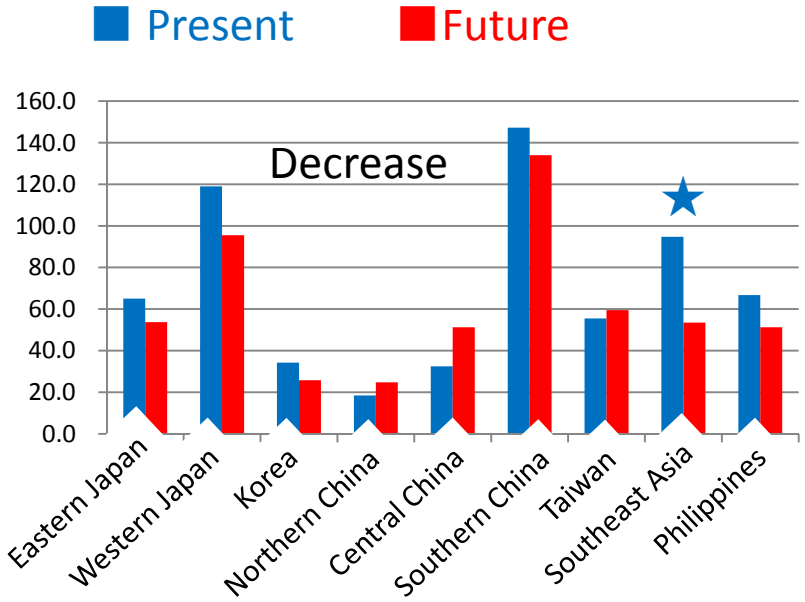
Increase

Future Change of Tropical Cyclones near Coasts

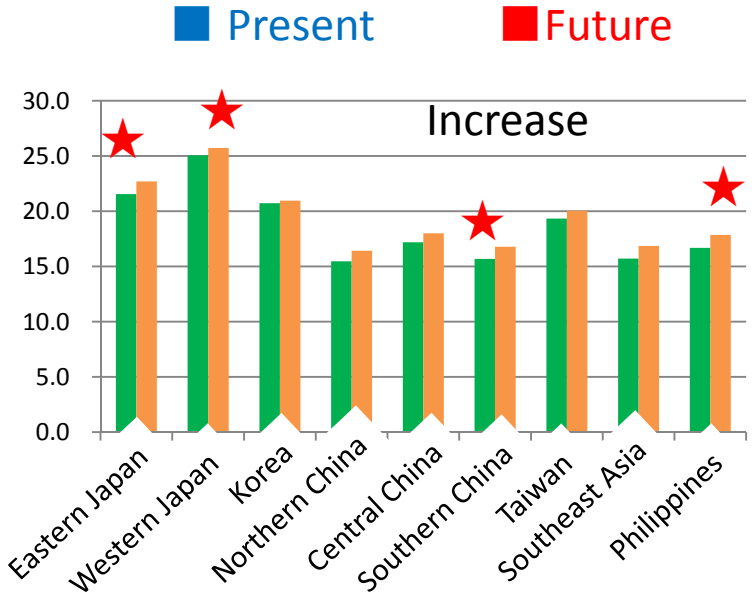


Murakami et al., 2011, J.Climate

TC Frequency near Coasts



TC MaxWind mean near Coasts

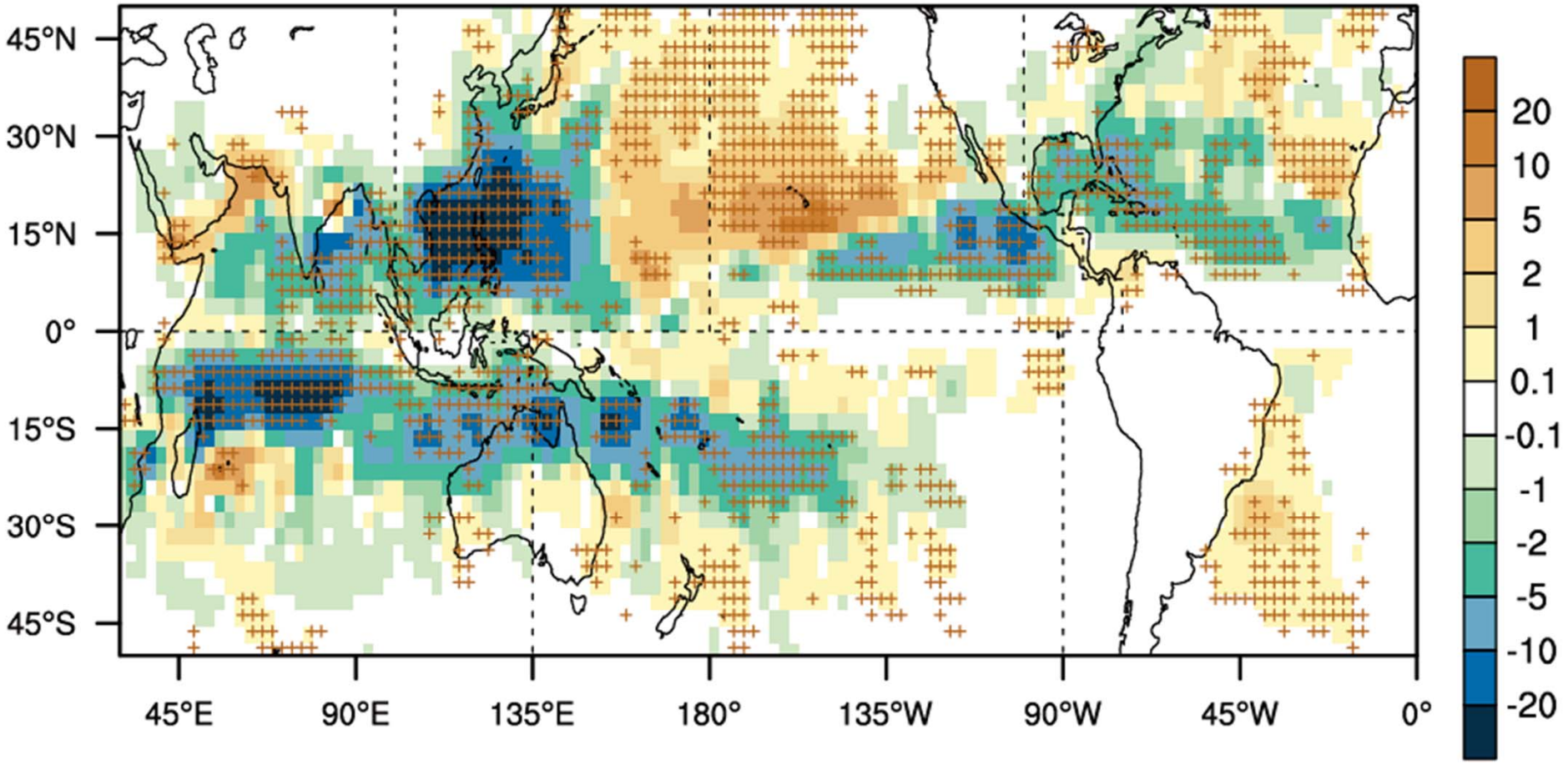


★ 95% Significance

H. Murakami et al., 2012

Ensemble Projection of Tropical Cyclone Occurrence

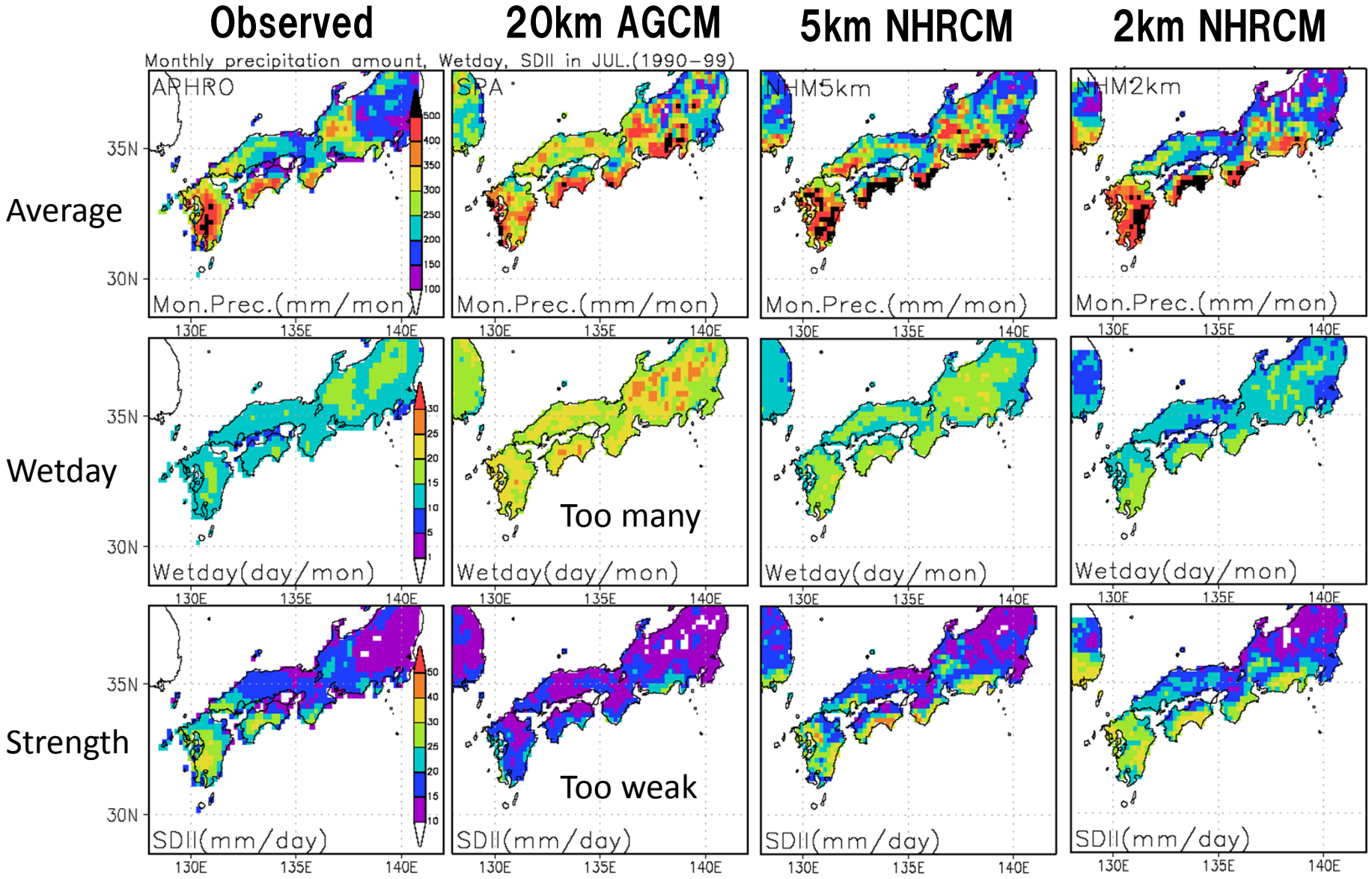
Ensemble Difference in occurrence number between 2075-2099 and 1979-2003
(+) indicate the same direction of the change among over 10 of 12 experiments



Dynamical Downscaling

Details of Regional Climate Change

Precipitation Details (AGCM and NHRCM)



∗ All values are interpolated at 20km mesh grids

(Kanada et al. 2010)

Precipitation Change (JUNE)

Present Day

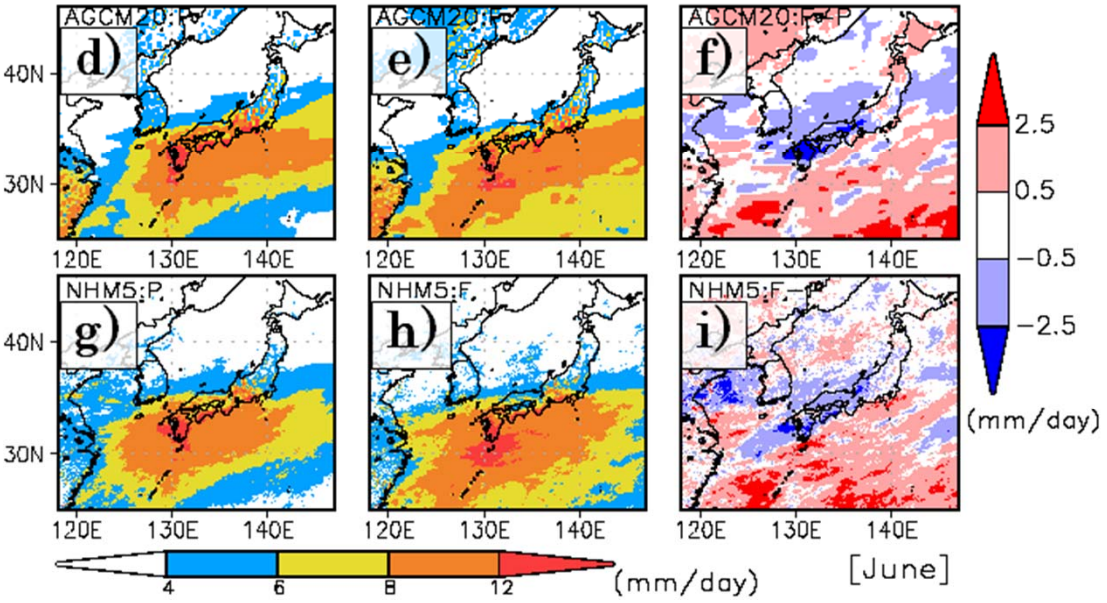
Future

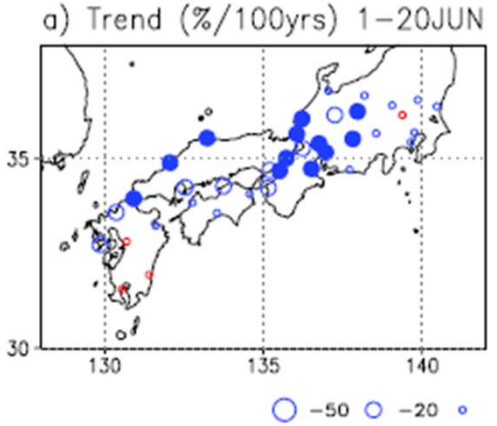
Change

Observed Trend (Endo, 2011, SOLA)

Global 20km

Regional 5km





Kanada et al., 2012, JMSJ

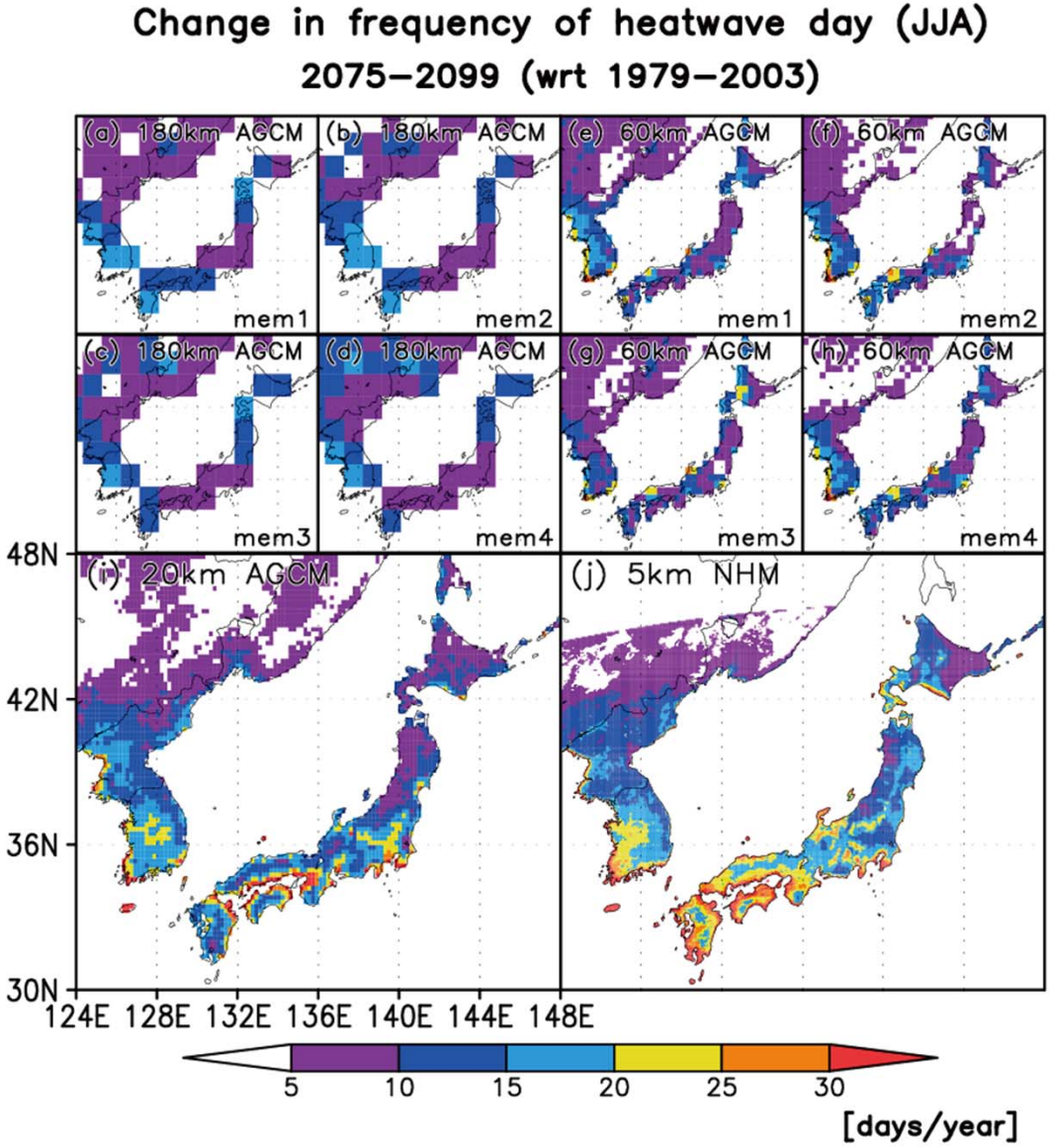
Projection of Heat wave day

180km AGCM

60km AGCM

20km AGCM

5km NHM



Summary

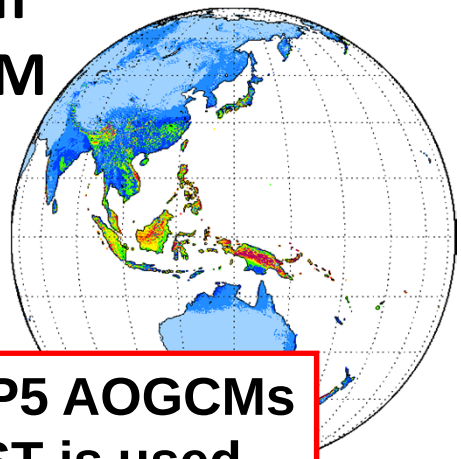
- Use of Climate Models based on Numerical Weather Prediction Models
- Physical and Quantitative Projection of global, regional climates and extreme weathers
- Physically understandable Future projection
- Consistency with observed long-term trends leads to high reliability.
- Further detailed projections are being tried with cloud-resolving models.

New Japanese Program (SOUSEI-C) (2012-2016)
Development of Basic Technology
for Risk Information on Climate Change

by Izuru Takayabu (MRI/JMA)
supported by the Ministry of Education, Culture, Sports, Science, and Technology

(ii) Producing a standard climate scenario of Future projection by using super high resolution models

20km AGCM



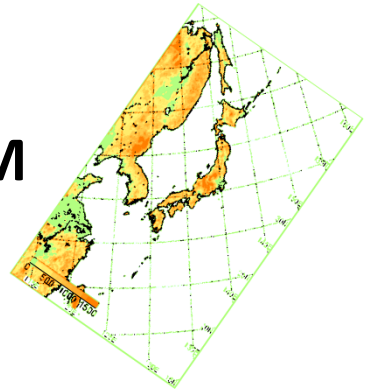
CMIP5 AOGCMs SST is used

Projection Output

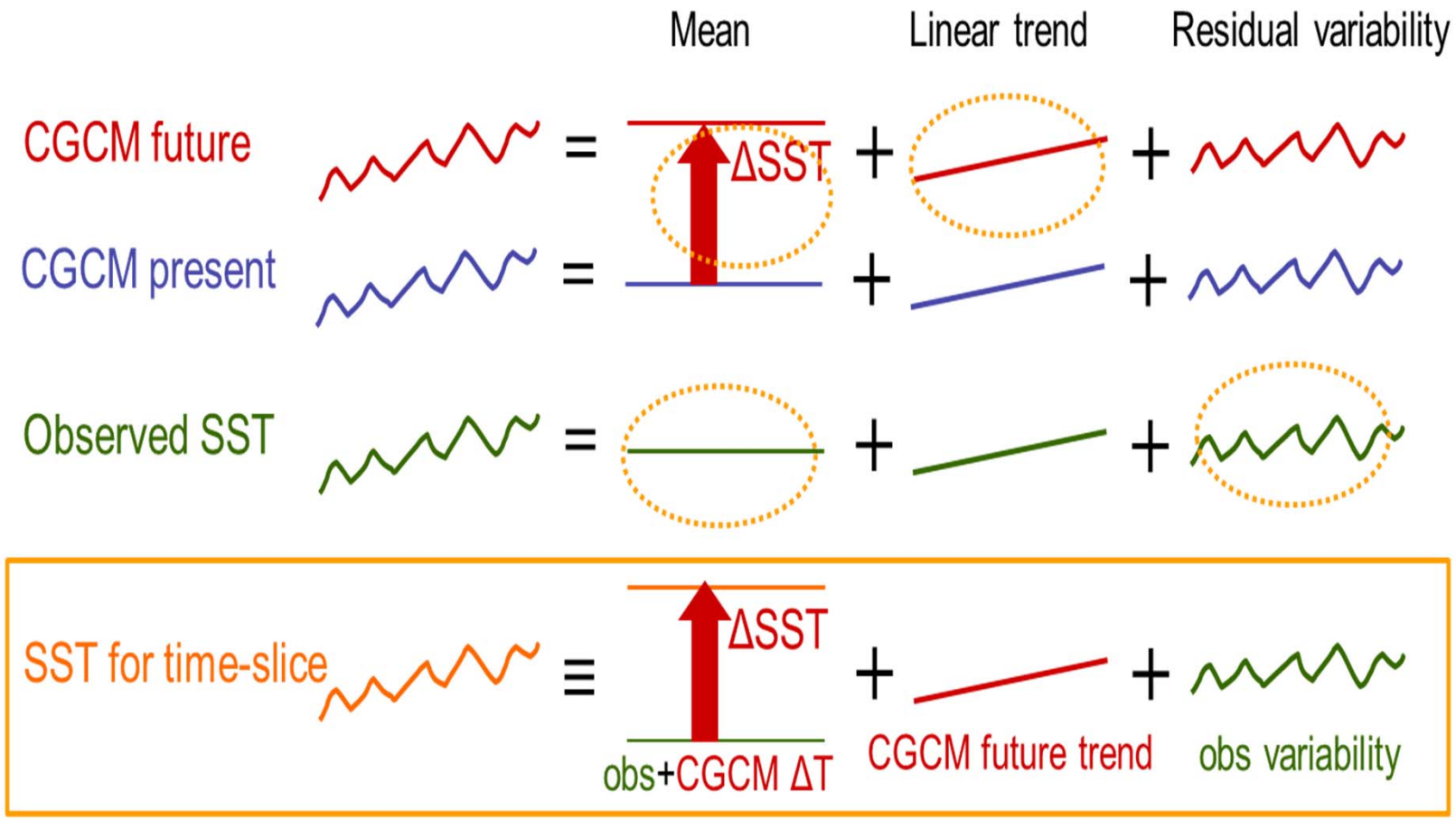
Boundary data for downscaling over any regions in the world

downscaling over Japan

5~2km NHRCM

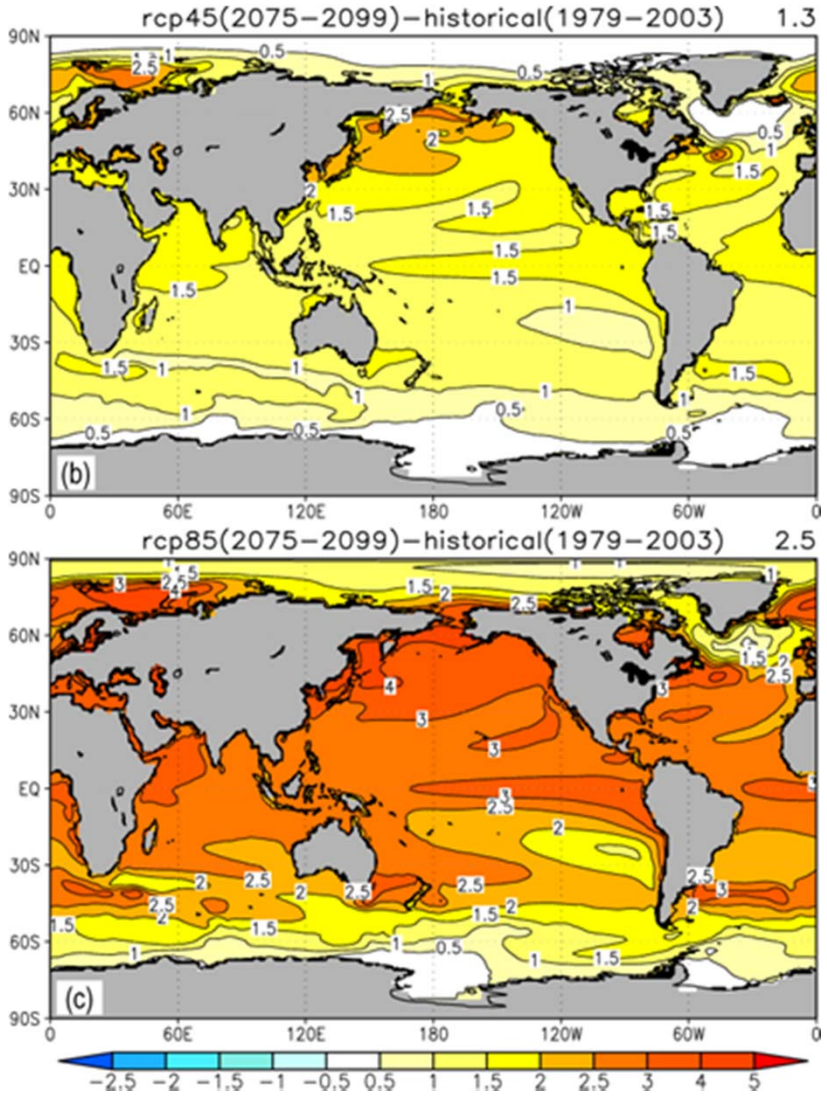


Future SST is designed in the same way as the Kakushin Project

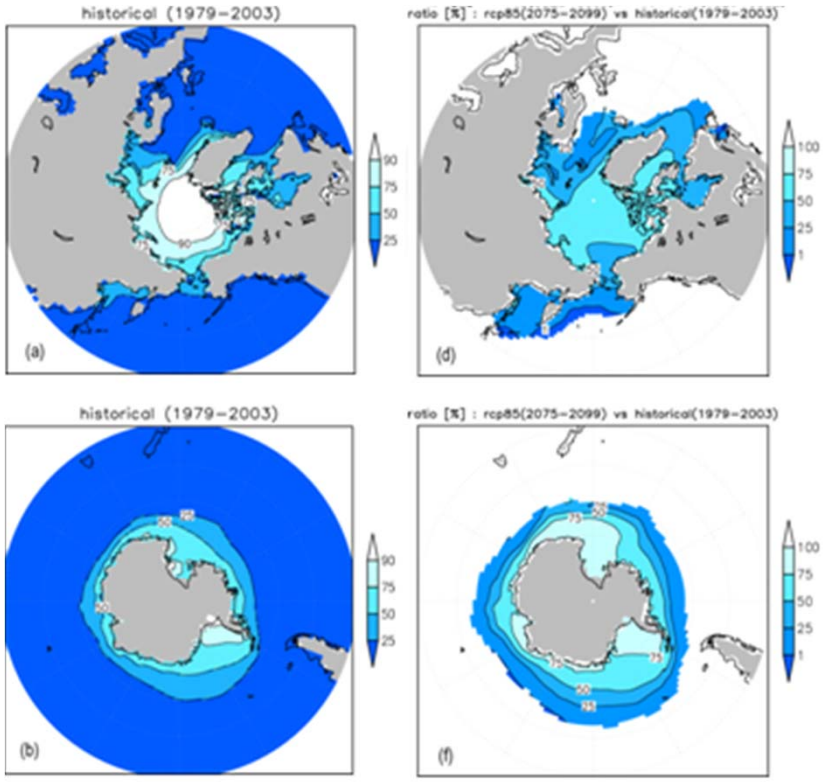


CMIP5-MME SST Increase and Sea-Ice Shrink

Future Change in SST (K)



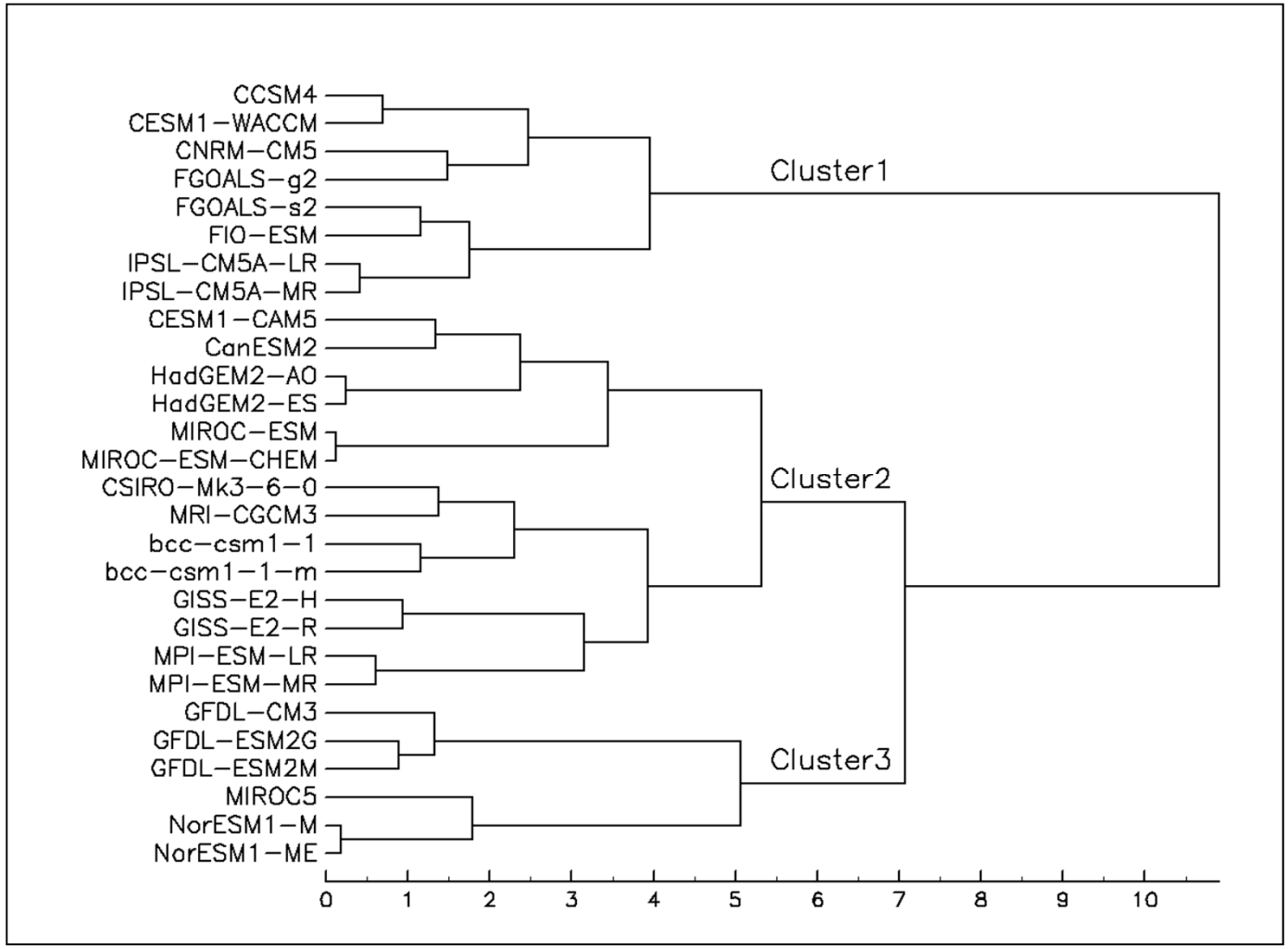
Future Change in Sea-Ice (%)



(Arakawa, O., 2014)

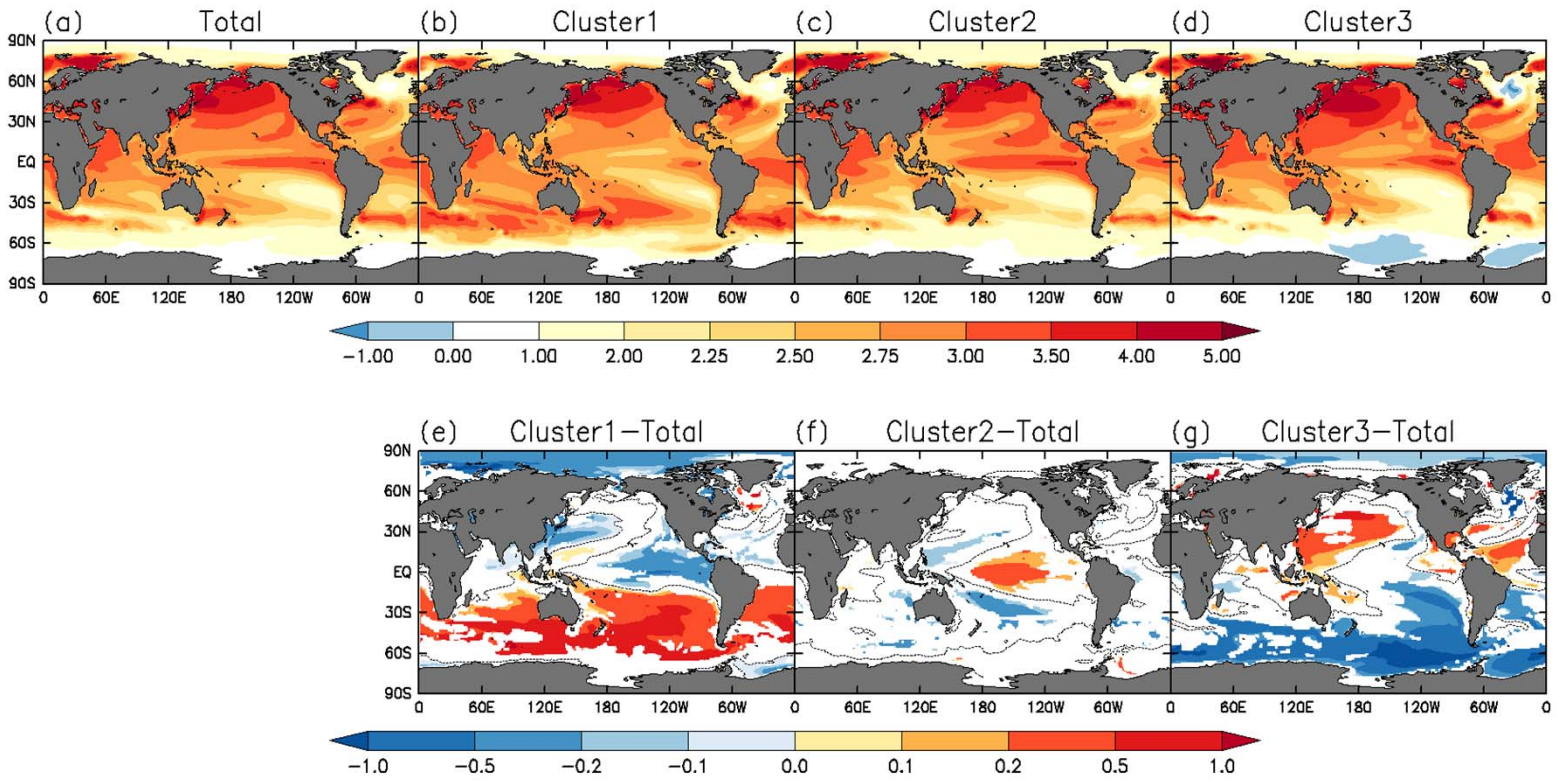
Three Patterns of SST Increase are obtained by Cluster Analysis of Tropical (30N-30S) SST Change in CMIP5 models

CMIP5 Models



SST Change Ensemble for Future Projection

Based on Cluster Analysis of CMIP5-RCP8.5 Scenario Projections



NCAR-Type	HadGEM2-Type	GFDL-Type
Warm SH Ocean	Warm Eastern Pacific	Warm Western Pacific Atlantic Ocean

（Mizuta et al. 2014）

Ensemble Projection by 20km AGCMs in SOUSEI-C

● Present Day : 25 years of 1979-2003

SST ＼Cumulus	YS-scheme	*AS-scheme (Plan)*	*KF-scheme (Plan)*
Observed	SP_YS	*SP_AS*	*SP_KF*

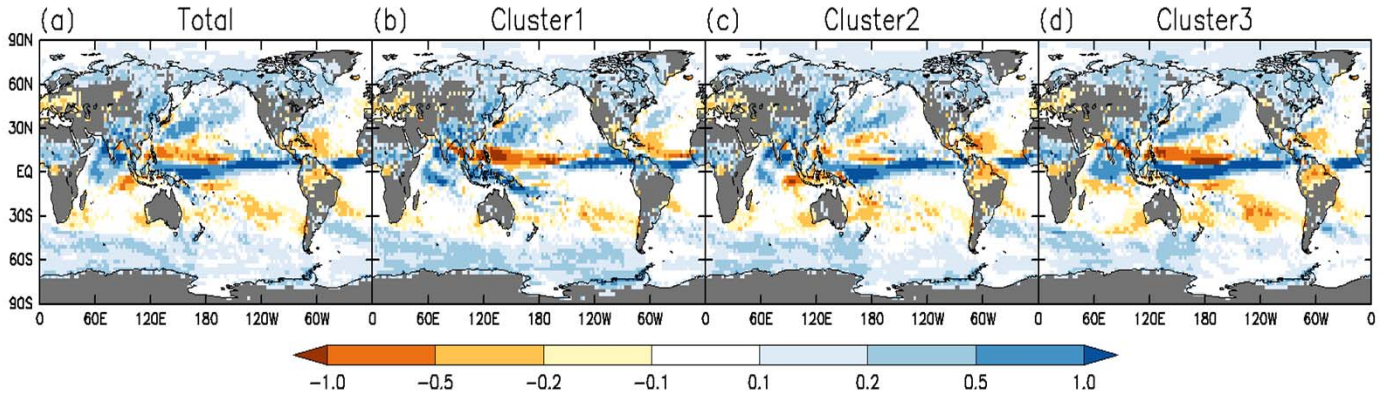
● End of the 21st Century

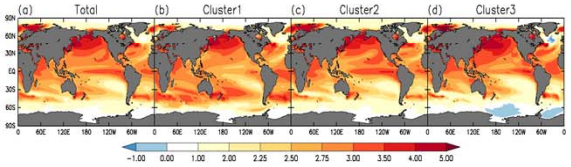
Under RCP8.5 Scenario

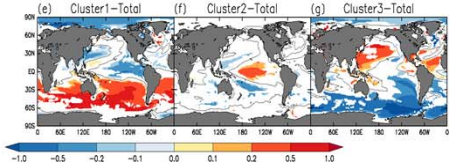
ΔSST ＼Cumulus	YS-scheme	*AS-scheme (Plan)*	*KF-scheme (Plan)*
CMIP5-MME	SF_YS	*SF_AS*	*SF_KF*
Cluster-1	SF_YSc1	*SF_ASc1*	*SF_KFc1*
Cluster-2	SF_YSc2	*SF_ASc2*	*SF_KFc2*
Cluster-3	SF_YSc3	*SF_ASc3*	*SF_KFc3*

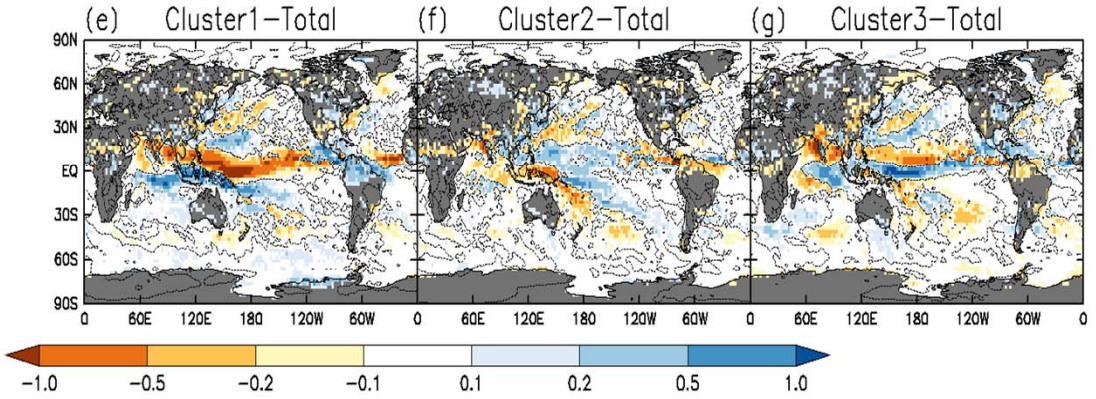
YS: Yoshimura (Yukimoto et al. 2011)
AS: Arakawa and Schubert (1974); Randall and Pan (1993)
KF (Kain and Fritsch 1990, 1993)

Future Ensemble Projection of JJA Precipitation in SOUSEI-C









(SOUSEI-C Report, 2015)

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