Future climate projections and HPC in meteorology

Tosiyuki Nakaegawa

Meteorological Research Institute, Japan Meteorological Agency

Self-introduction

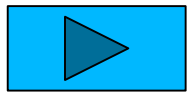
- Member, Iinternational Commission on Climate, IAMAS, IUGG
- Board member, Meteorological Society of Japan
- Vice Editor-in-Chief, SOLA
- Co-leader, Expert team on Sector-specific Indices, WMO
- Member, Expert team for Impact of Climate Change on Tropical Cyclone, ESCAP/WMO

World Meteorological Organisation

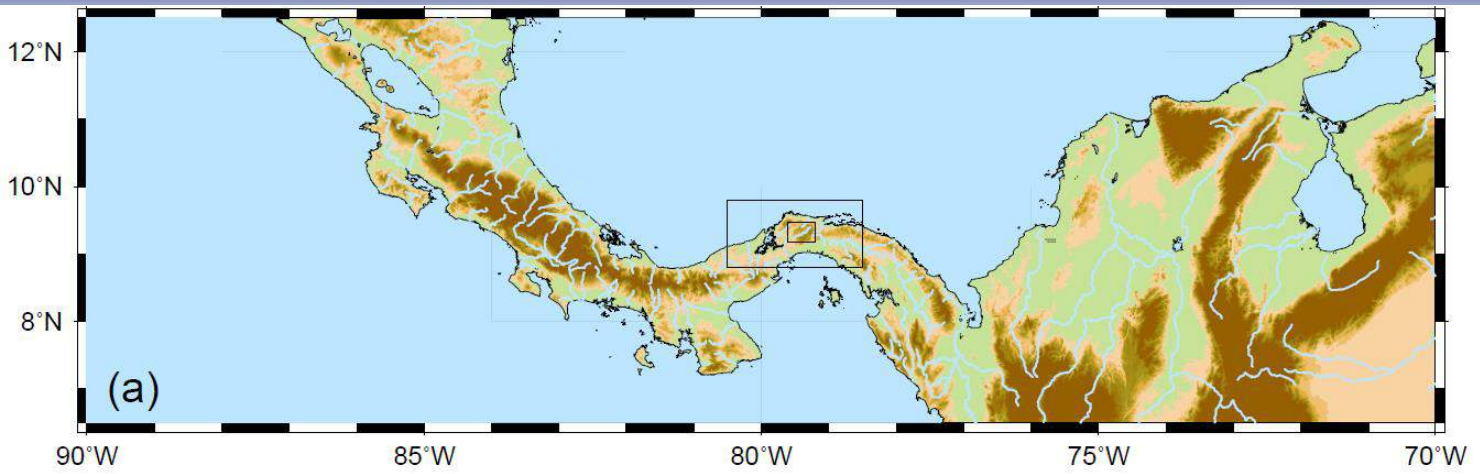
ESCAP/WMO Typhoon Committee

Meteorological Research Institute

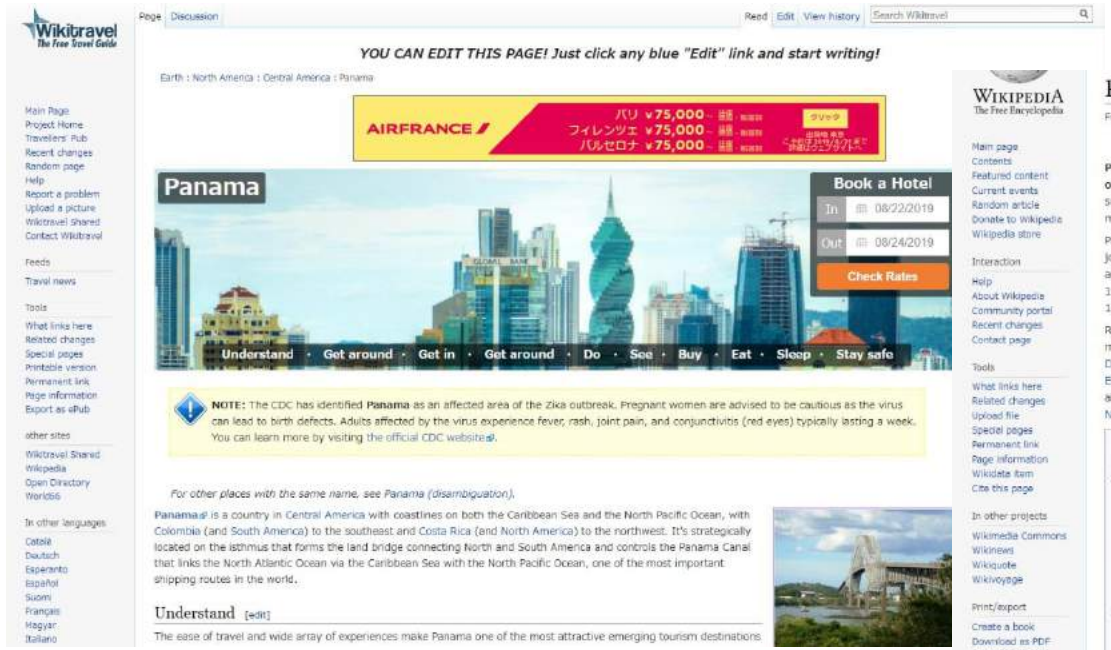
Contents of my talks

- Climates in Panama 
- Introduction of the JMA's models and their products
- Global Warming Projection ~Concept~
- Overview of future climate projections using global climate prediction over Central America

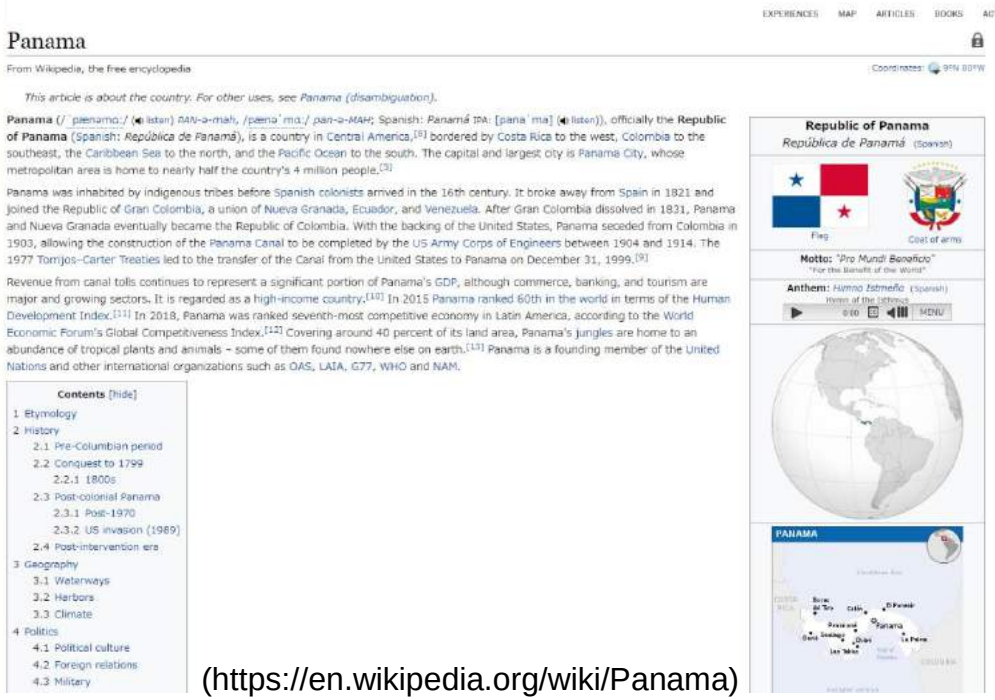
Welcome to Panama



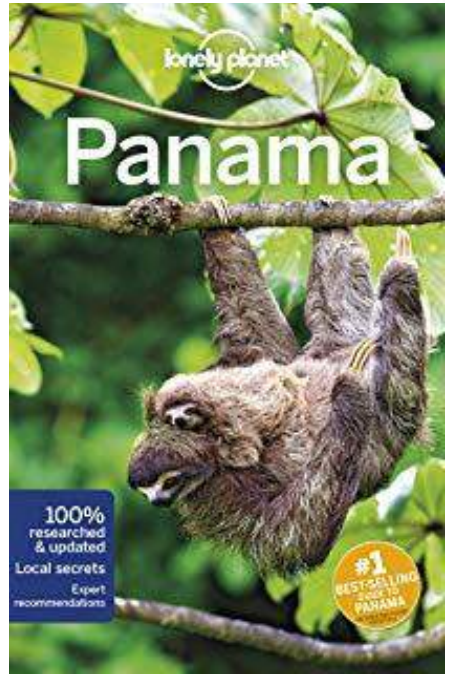
(https://www.lonelyplanet.com/panama)



(https://en.wikitravel.org/en/wiki/Panama)

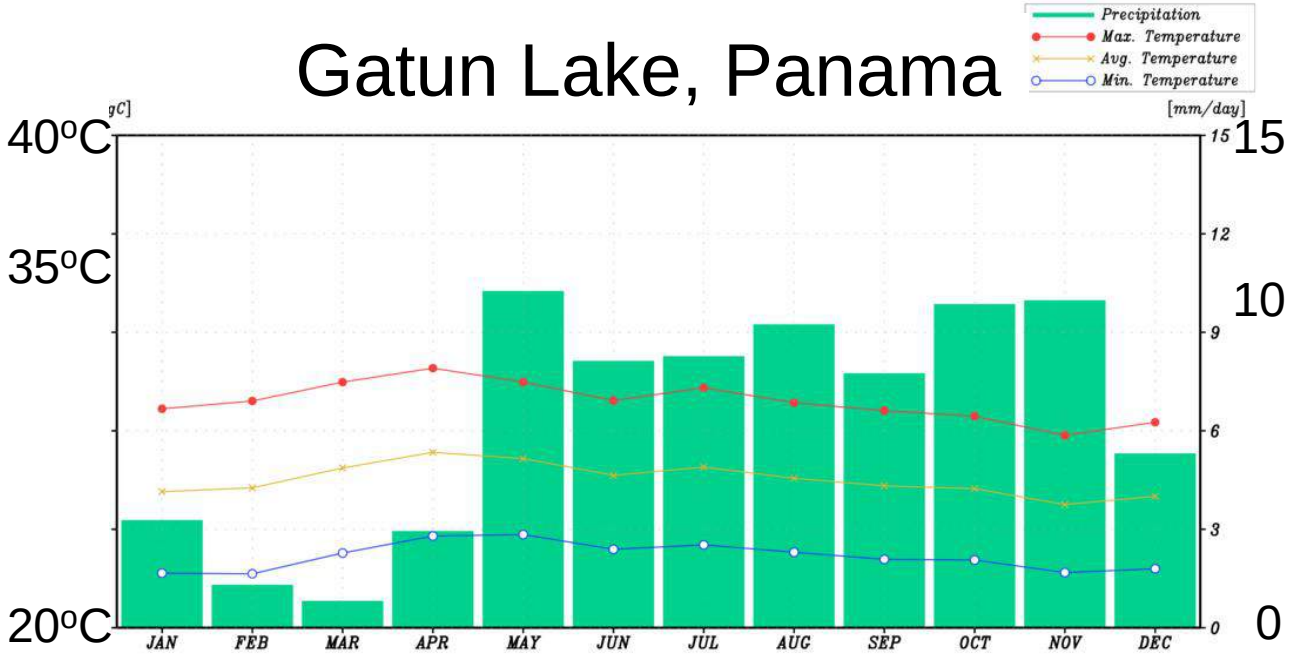


(https://en.wikipedia.org/wiki/Panama)

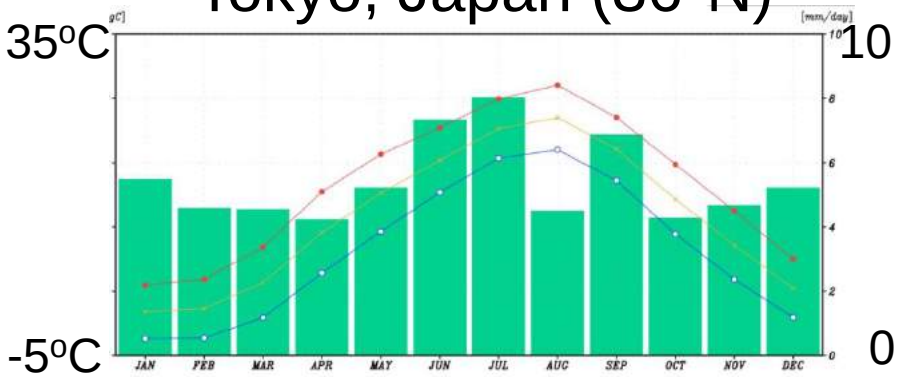


Climates of Panama

Gatun Lake, Panama



Tokyo, Japan (36°N)

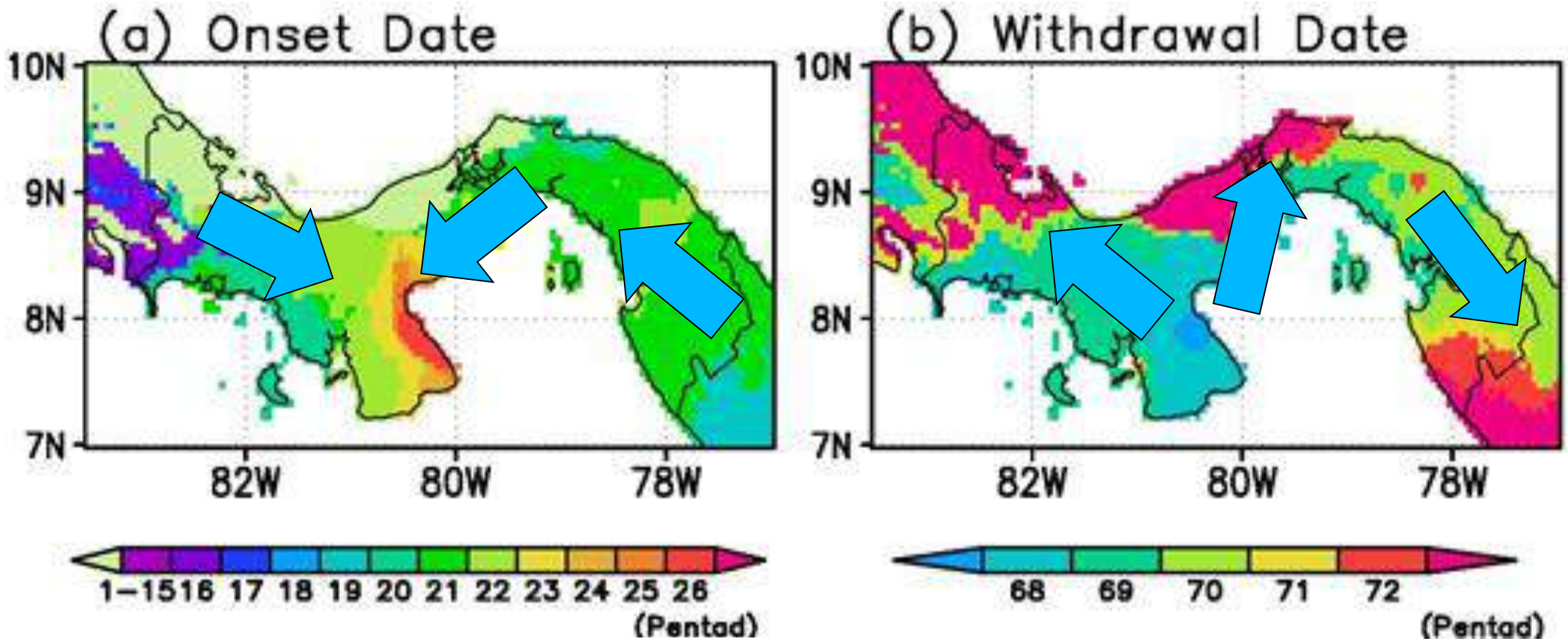


(Nakaegawa et al., 2015, HRL)

Rainy season

May to June

October to December

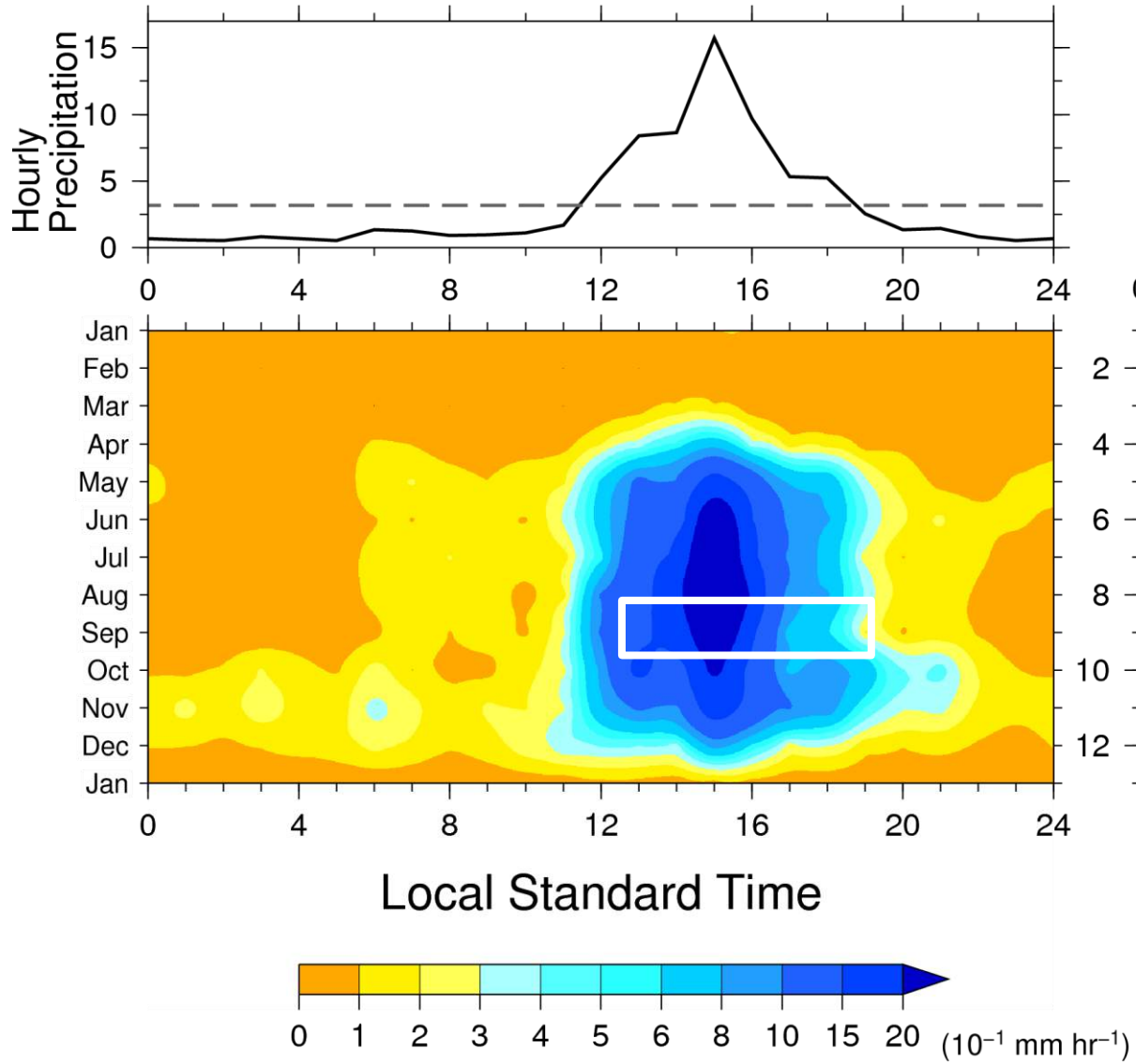


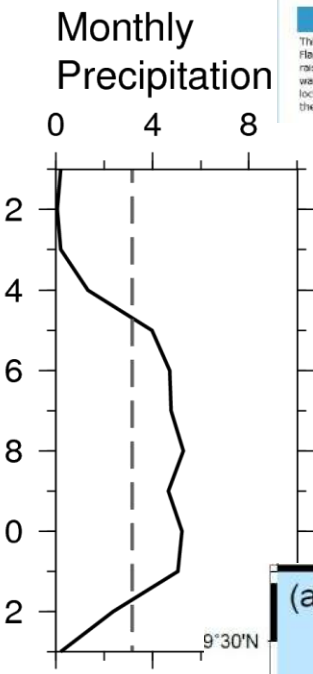
Geographical distributions of the (a) onset and (b) withdrawal dates of the rainy season in Panama. The onset and withdrawal dates have been defined with the uniform threshold value method and a threshold value of 3 mm day^{-1}.

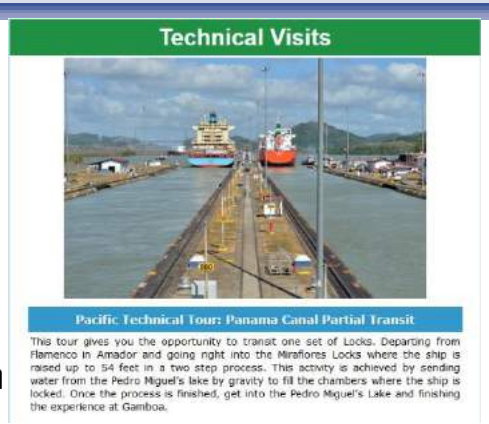
(Nakaegawa et al., 2015, J. Clim)

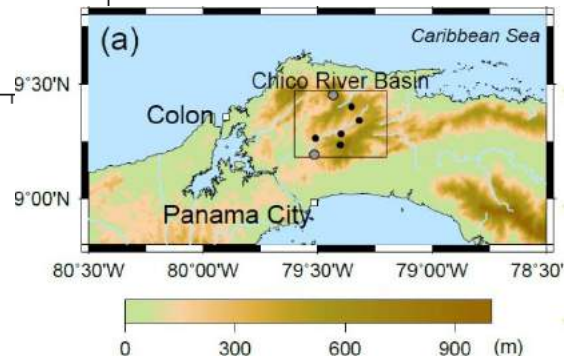
You had better bring an umbrella when …

Diurnal cycle of rainfall







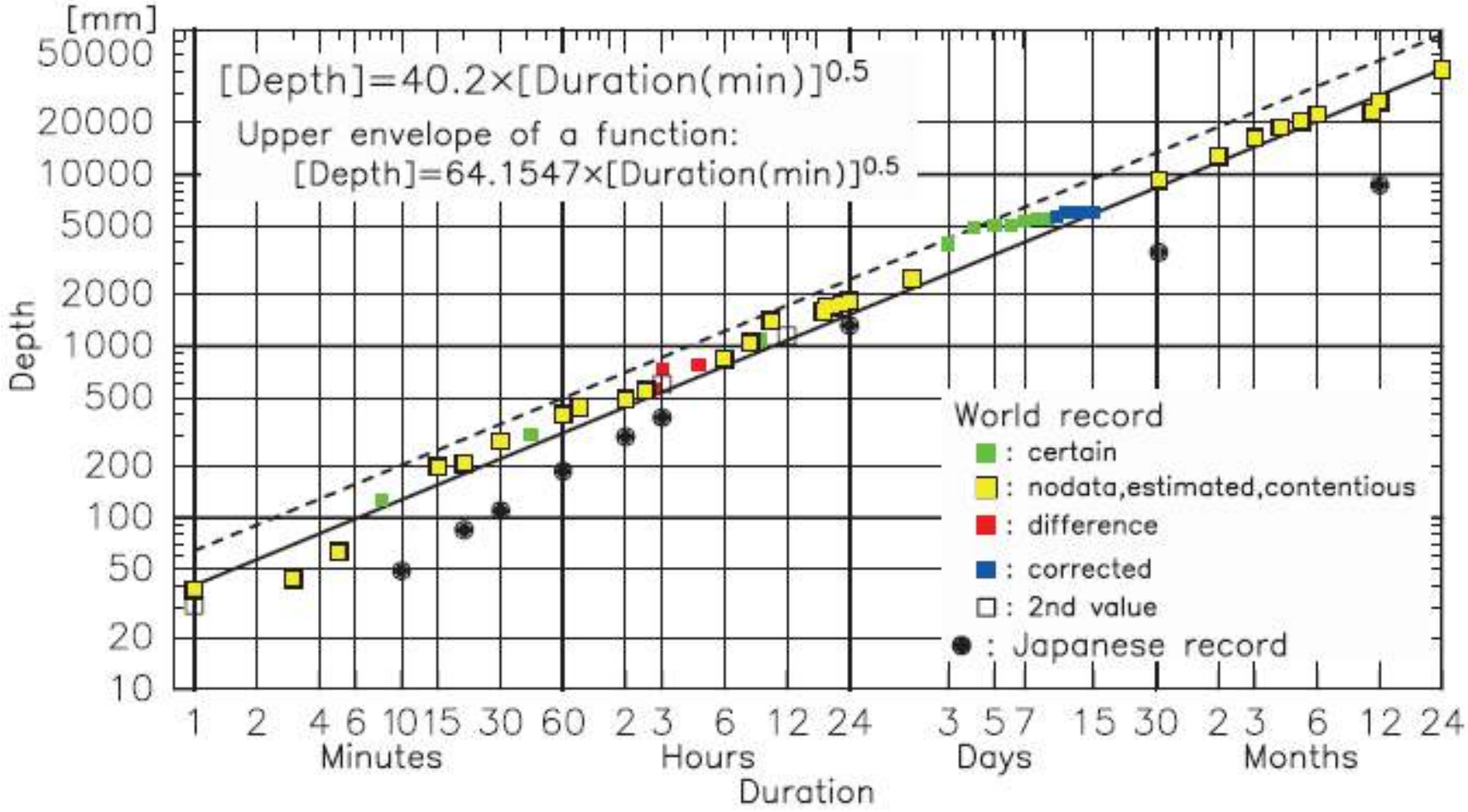


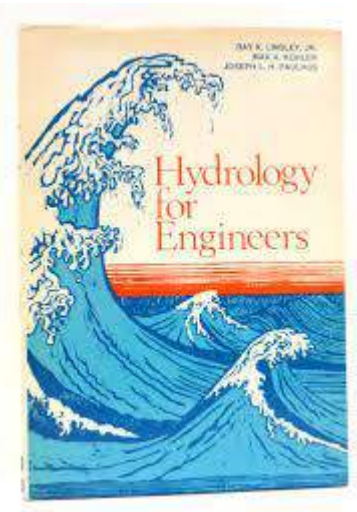
3, 2019

(Nakaegawa et al. in review)

Extreme rainfall events

Cross section of depth and duration of world-record rainfall extremes

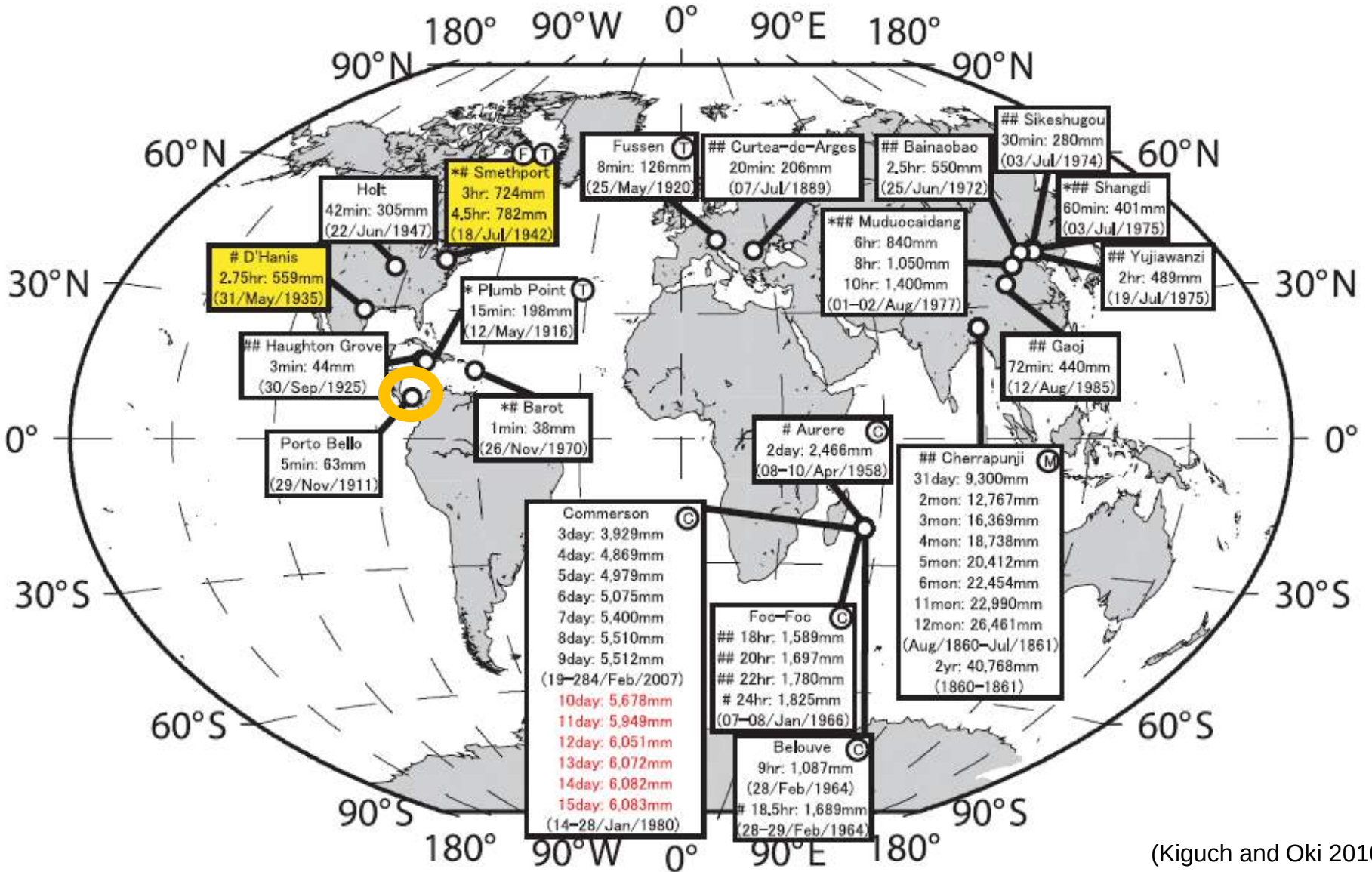




(Kiguch and Oki 2010, JSHWR)

Extreme rainfall events

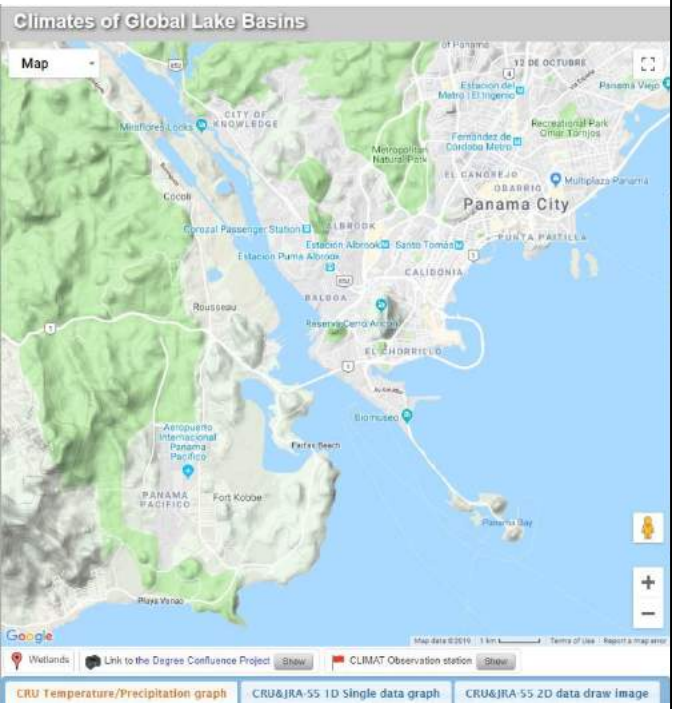
World record point of extreme rainfall



(Kiguch and Oki 2010)

World record point of extreme rainfall

Pacific Ocean



May,1919

PANAMA RAINFALL.

By H. G. CORNTHWAITE, Chief Hydrographer.

[Dated: Balboa Heights, C. Z., Jan. 31, 1919.]

SYNOPSIS.—The writer sketches the geographical distribution of the rainfall in Panama, and follows with an account, with tables and figures, of monthly and hourly precipitation, local showers, and excessive rainfall. Whatever rain occurs on the Isthmus must be attributed to local convection currents in conjunction with the deflective effects of hills and mountains on such winds as there are.

The rainfall on the north side exceeds that on the south side of the Isthmus, and is greatest on the north coast and locally on the higher portions of the Caribbean slope. The mean annual rainfall at Colon is 129.04 inches; at Porto Bello 169.15 inches, and at Balboa, 91.61 inches.

An excessive downpour in a brief period, probably 2.48 inches in 5 minutes at Porto Bello, May 1, 1910, seems to have been the most intense rainfall ever recorded.—H. L.

"(3) Cyclonic circulation."

Since the Isthmus of Panama is in that section of the globe where the influence of convection is very great and where cyclonic disturbances are almost unknown, it follows that the greater part of the Isthmian rainfall must be attributed to the first two processes mentioned above.

Panama is situated in the Torrid Zone, where tropical weather conditions prevail. The year is divided into two seasons, a dry season of approximately four months duration, January to April, inclusive, and a rainy

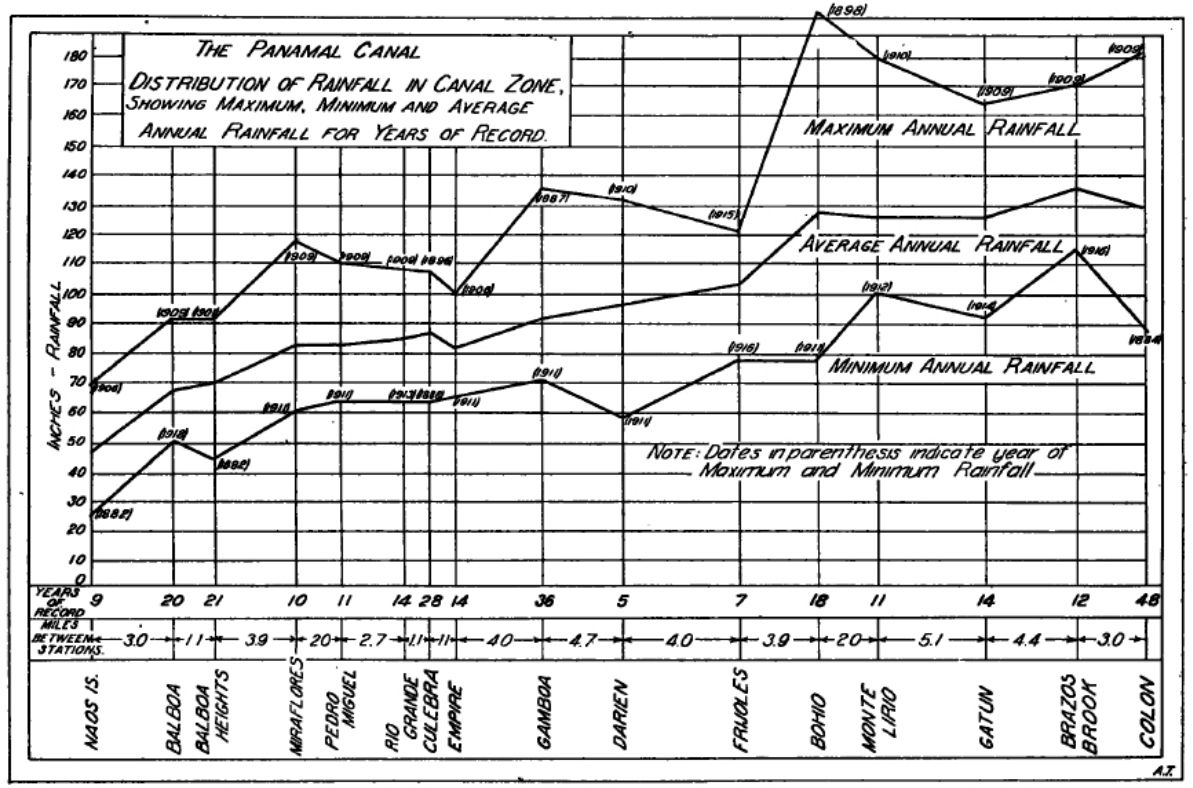
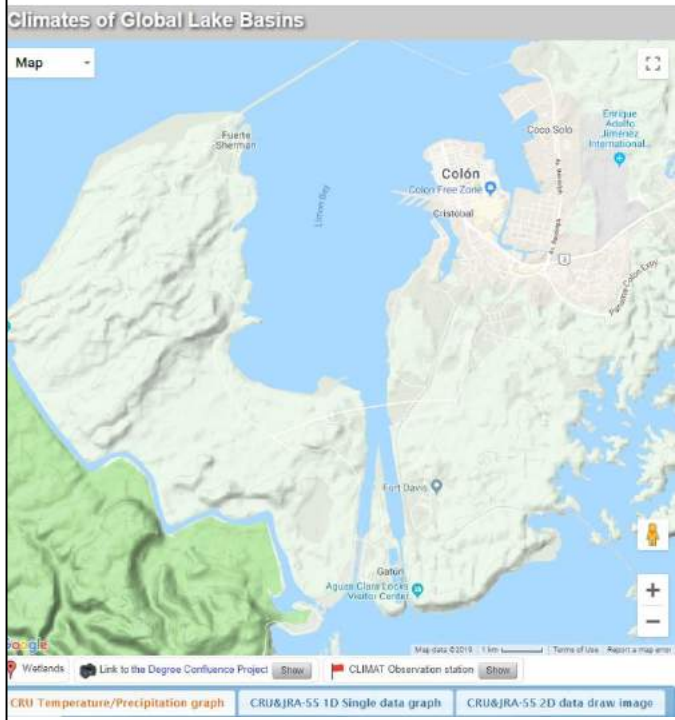


FIG. 1.

Caribbean Sea



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5-min rainfall record at Porto Bello

TABLE 1.—*Maximum rainfall in Canal Zone October, 1905, to January, 1919.*

Stations.	Maximum rainfall.					
	5 minutes.		1 hour.		24 hours.[1]	
	Inch.	Date.	Inch.	Date.	Inch.	Date.
Balboa (June 10, 1906).	.90	May 12, 1912	5.86	June 2, 1906	7.57	Nov. 16–17, 1906.
Balboa Heights (Oct. 1, 1905).	.64	Aug. 7, 1908	3.98	Oct. 9, 1911	7.23	May 12–13, 1912.
Miraflores (June 19, 1914).	.50	Sept. 6, 1917	4.09	Sept. 6, 1917	4.75	Sept. 6, 1917.
Pedro Miguel (Jan. 1, 1908).	.60	Nov. 11, 1908	3.46	Sept. 6, 1917	5.45	Nov. 19–20, 1917.
Rio Grande (Dec. 29, 1905).	.75	July 24, 1908	4.14	Nov. 20, 1917	8.24	Nov. 19–20, 1917.
Empire (July 18, 1906).	.60	July 25, 1906	4.19	Oct. 21, 1908	6.15	Dec. 3, 1906.[2]
Gamboa (Nov. 18, 1905).	.59	July 27, 1908	3.32	May 11, 1911	6.56	Dec. 2–3, 1906.
Alhajuela (Mar. 31, 1907).	.60	July 20, 1909	4.19	July 8, 1915	8.19	Dec. 2–3, 1906.[2]
Gatun (Oct. 1, 1905)	.62	{Aug. 3, 1912 Aug. 12, 1914	4.72	Aug. 12, 1914	10.48	Dec. 3, 1906.[2]
Bohio (Oct. 1, 1905)	.67	June 16, 1909	4.51	Aug. 7, 1908	8.85	Aug. 7–8, 1908.
Colon (Oct. 1, 1905).	.64	Aug. 25, 1909	4.90	Oct. 8, 1909	8.53	Dec. 2–3, 1906.
Porto Bello (May 1, 1908).[3]	[4] 2.48	Nov. 29, 1911	4.53	Nov. 29, 1911	10.86	Dec. 28–29, 1909.

[1] Maximum rainfall in 24 consecutive hours.
[2] No automatic record on this date, total for 24 hours ending at noon.
[3] Station closed in August, 1914, and reopened in December, 1918.
[4] Approximate, automatic record indistinct due to unusually excessive rate of rainfall. [This rate exceeds that of 205 mm. (8.07 in.) in 20 minutes at Curtea-de-Arges, Roumania, July 7, 1889, heretofore considered the greatest on record.—ED.]
Dates in parenthesis refer to the installation of automatic raingages.

World Heritage Site


(Lombana, Wikipedia)


(Tedder, Wikipedia)

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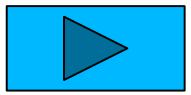
- Climates in Panama 
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- Global Warming Projection ~Concept~
- Overview of future climate projections using global climate prediction over Central America

Introduction of the JMA's models and their products

Contents are available from the following site:
https://www.restec.or.jp/geoss_ap11/pdf/tg1/tg1-5-1.pdf

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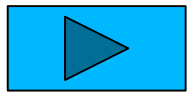
- Climates in Panama 
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Global Warming Projection

Shoji KUSUNOKI

Meteorological Research Institute

Climate Research Department

JAPAN

E-mail: skusunok@mri-jma.go.jp

This material is first presented in Climate change studies using dynamical downscaling applications: Panama case, 18-29 September 2017, Panama City, Panama

Projection

Word	Meaning	Field
Forecast Prediction	to say what you think will happen in the future based on information that you have now	Sort-range weather forecast, Seasonal forecast
Projection	Same as 'forecast' with some uncertainty	Future climate change

What is IPCC?

One of organization of United Nations: Network of scientists

Most reliable information on climate change

Policymakers

Policy

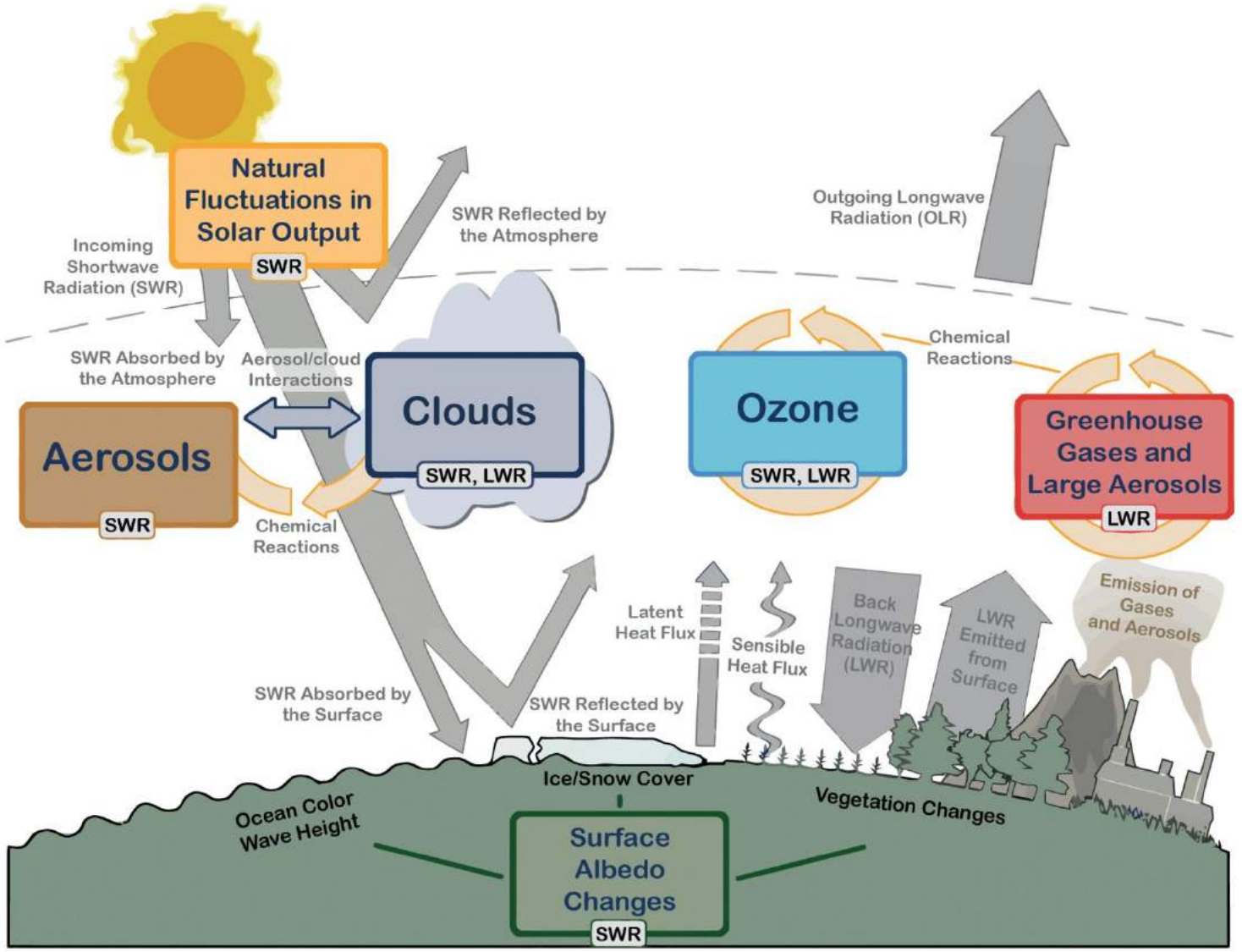
Save the earth

IPCC Reports

Report number	Name	Year
1	First Assessment Report (FAR)	1990
2	Second Assessment Report (SAR)	1996
3	Third Assessment Report (TAR)	2001
4	AR4 (Fourth Assessment Report)	2007
5	AR5 (Fifth Assessment Report)	2013

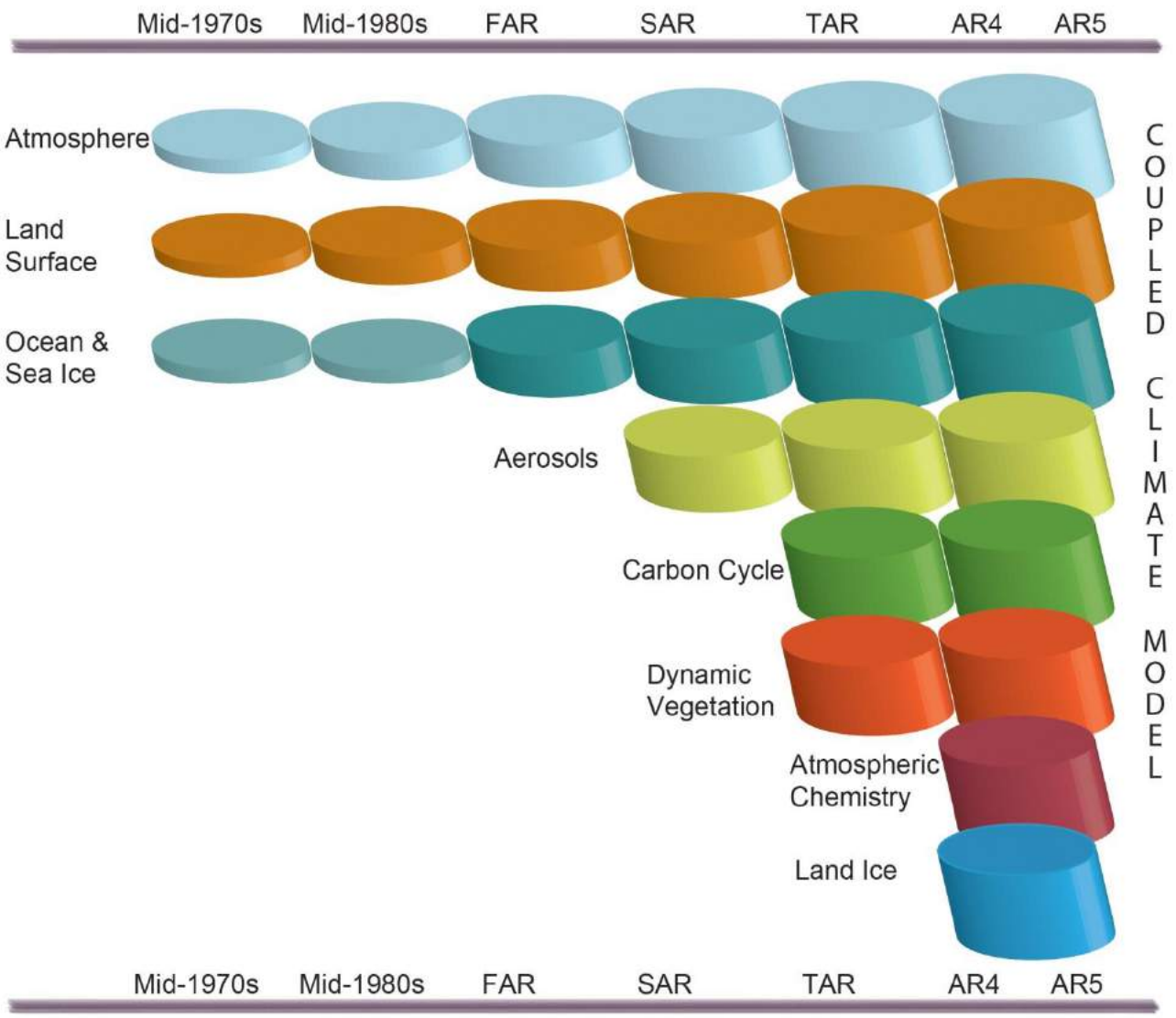
Climate models

Drivers of climate change



IPCC AR5 WG1 (2013) Fig. 1.1

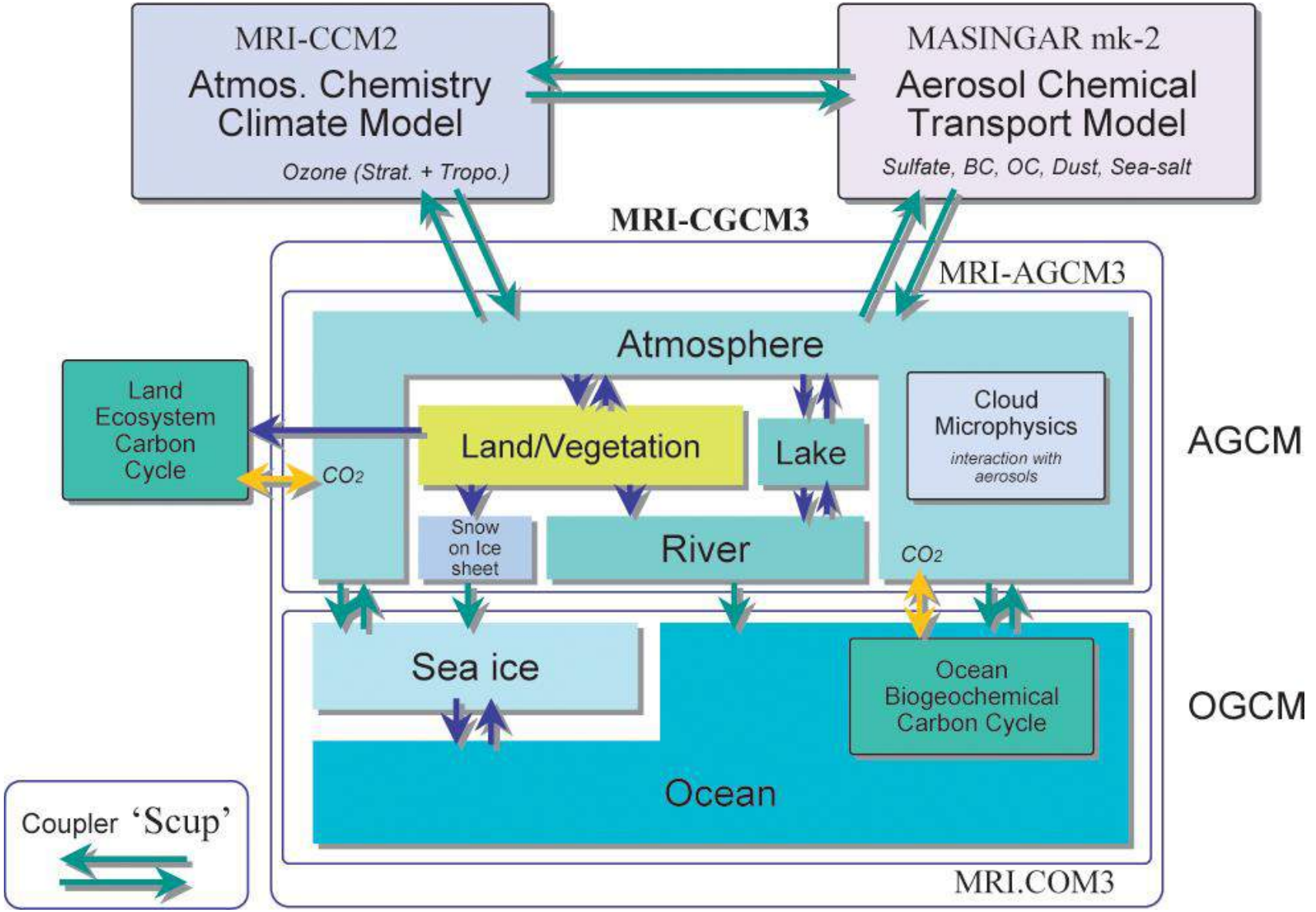
Development of climate models



IPCC AR5 WG1 (2013) Fig. 1.13

MRI-ESM1

Earth System Model (ESM)



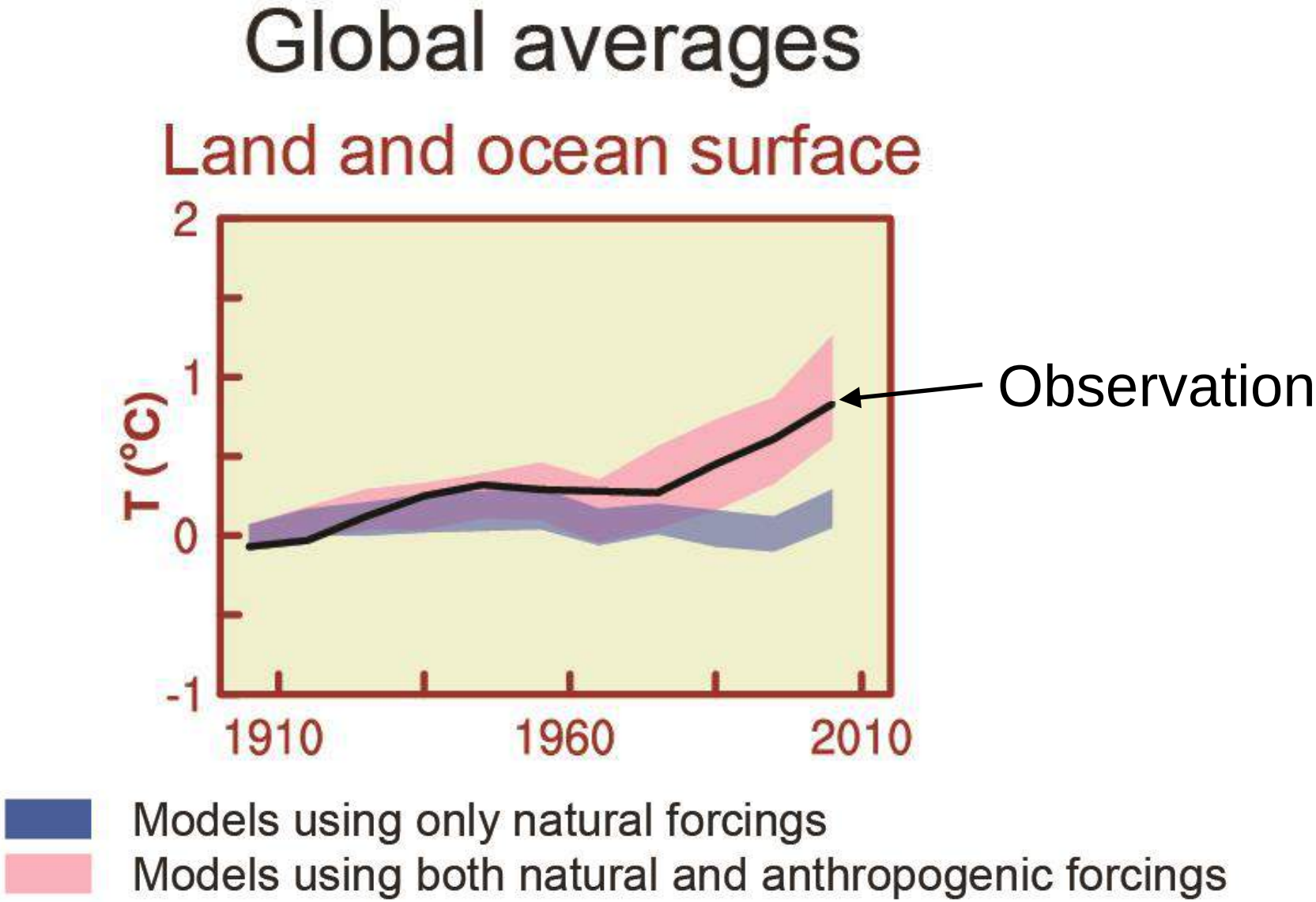
Yukimoto et al. (2011)

Models for IPCC AR5 / CMIP5

Coupled Model Intercomparison Project 5: CMIP5

Model	Official Name	Complexity	Purpose
Earth System Model (ESM)	MRI-ESM1	Large	Evaluate feedback and interaction between sub-models
Atmosphere -Ocean General Circulation Model (AOGCM)	MRI-CGCM3	Medium	Standard projection
High Resolution Atmospheric General Circulation Model (AGCM) 20km mesh	MRI-AGCM3.1 MRI-AGCM3.2	Small	Extreme events projection

Detection and attribution of climate change



IPCC AR5 WG1 (2013) SPM.6

How to project future climate?

Emission scenario

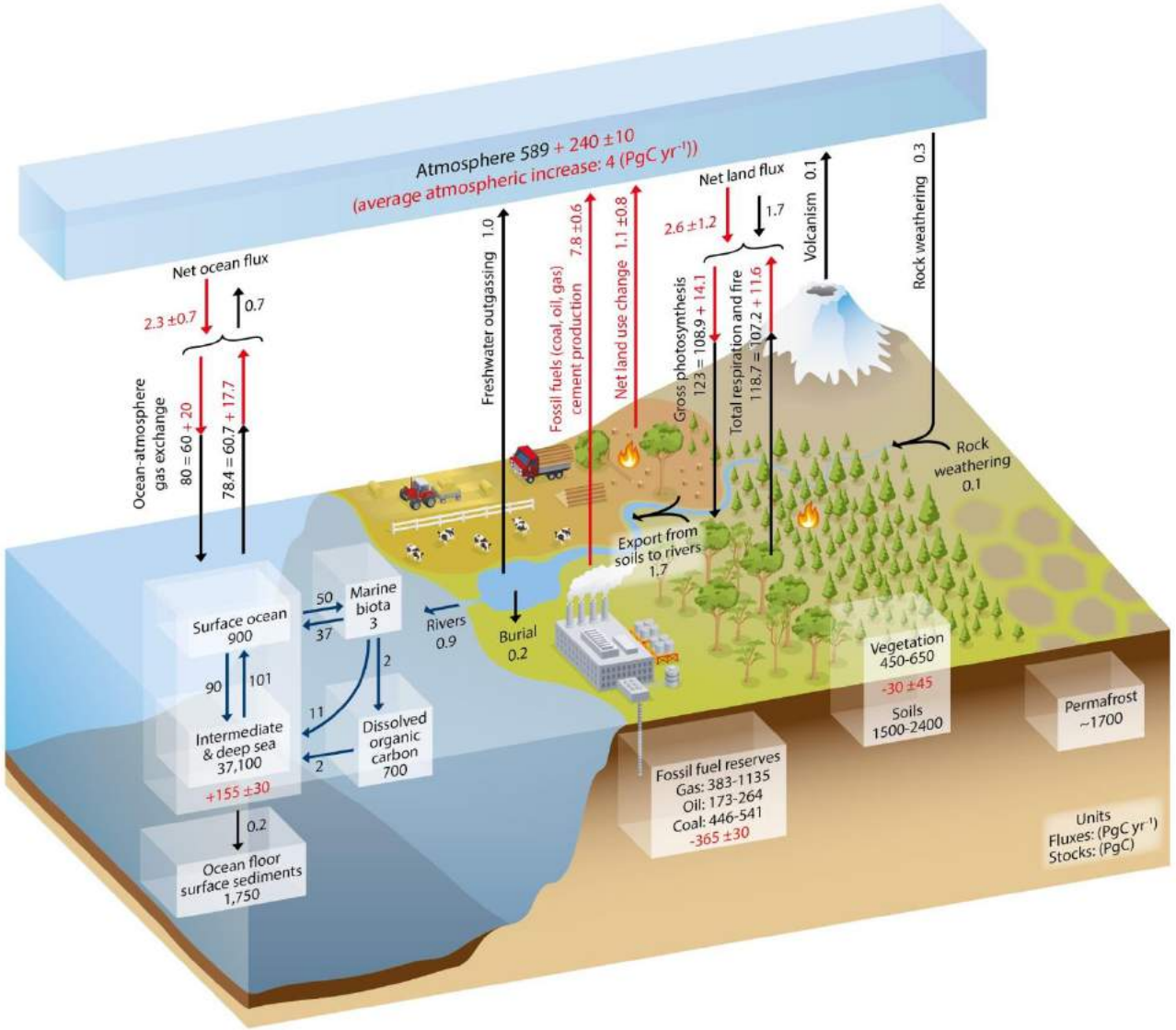
Simple Carbon (CO_2) cycle model

Greenhouse gas (CO_2) concentration

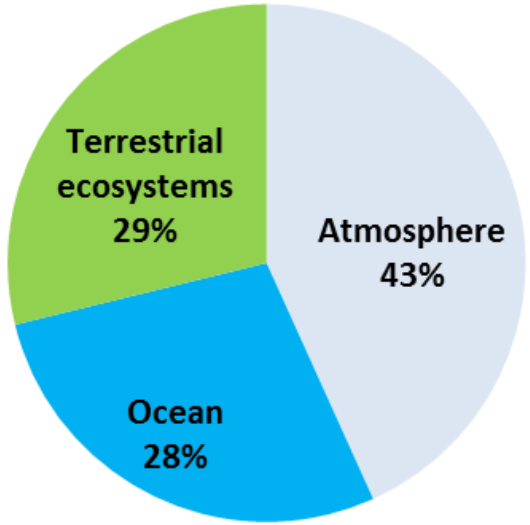
Atmosphere-Ocean General Circulation Model (AOGCM)

Future climate change

Carbon (CO2) cycle



Breakdown of accumulation of anthropogenic emissions



IPCC AR5 WG1 (2013) Fig. 6.1

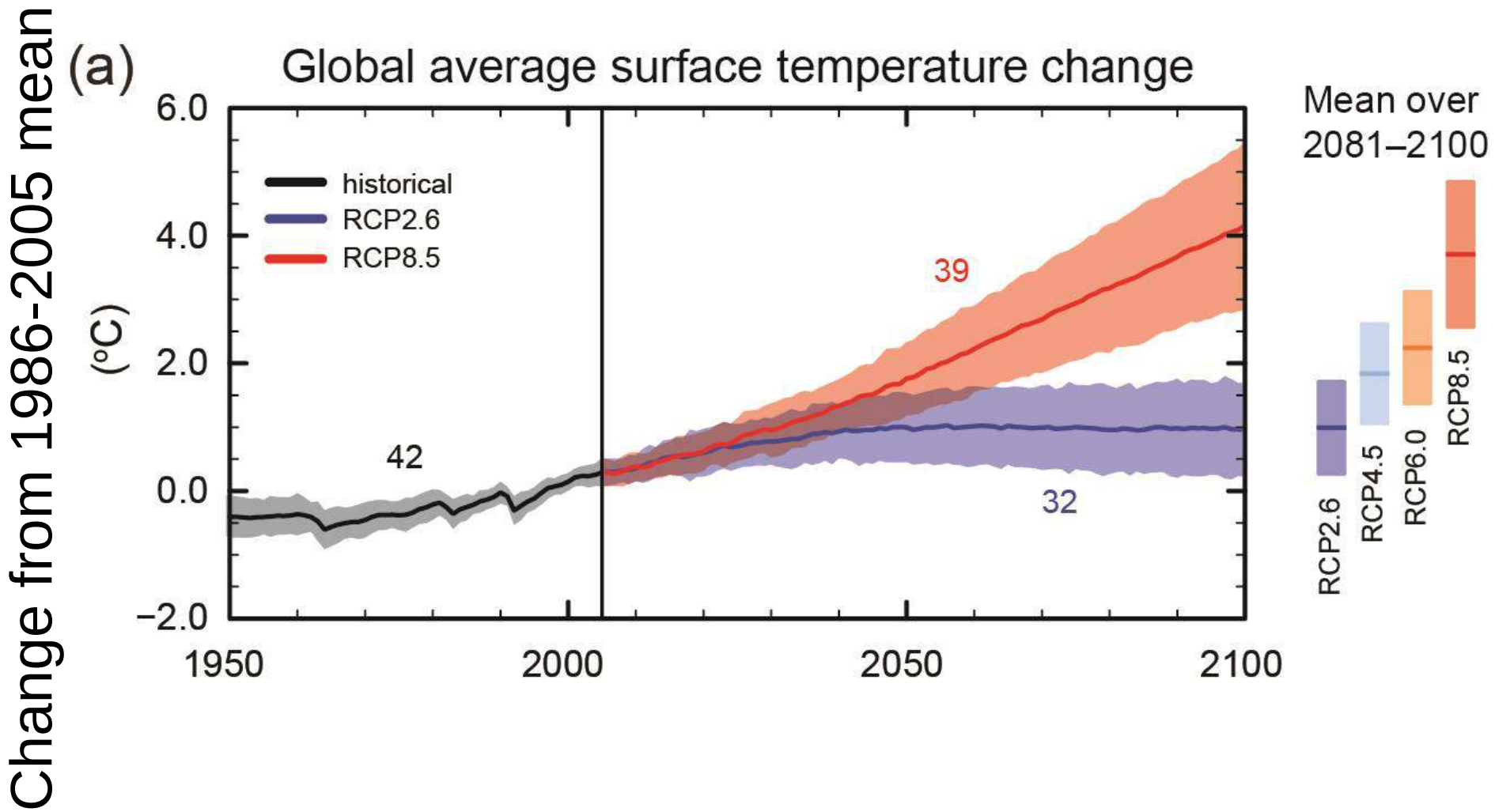
Emission scenario for AR5

Representative Concentration Pathway (RCP)

Major scenarios

Name	Amount of greenhouse gas emission	Warming
RCP2.6	Small	Small
RCP4.5	Medium	Medium
RCP8.5	Large	Large

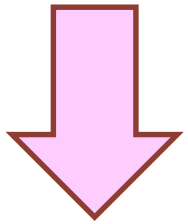
Global mean surface temperature



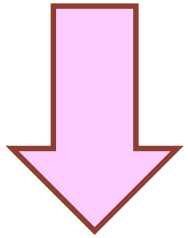
IPCC AR5 WG1 (2013) Fig. SPM.7

New method using ESM

Emission scenario



Earth System Model (ESM) coupled to carbon (CO2) cycle model

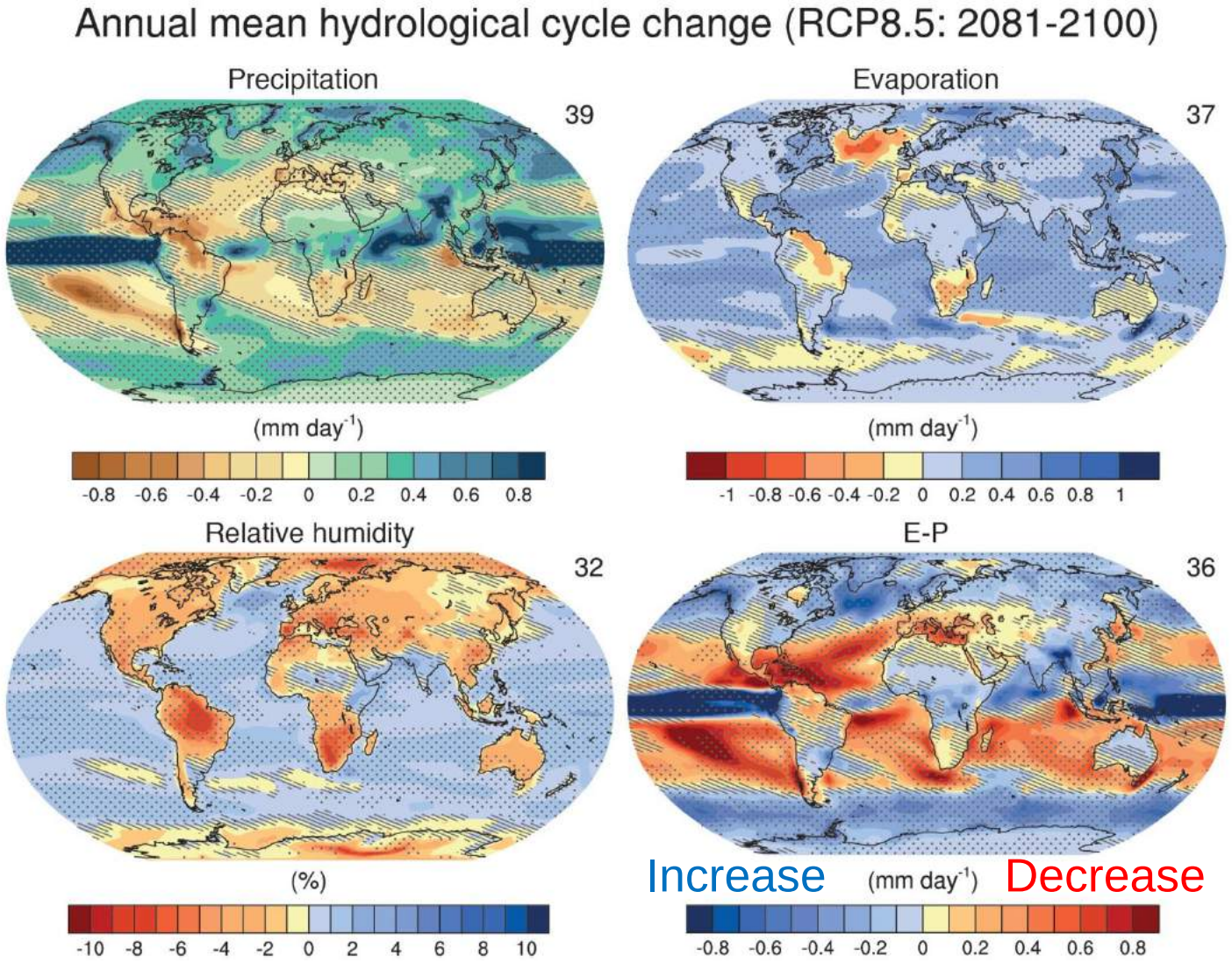


Future climate change

Two type of experiments for AR5

Method	Input	Model
Concentration driven	Greenhouse gas concentration	AOGCM
Emission driven	Greenhouse gas concentration	ESM with carbon cycle model

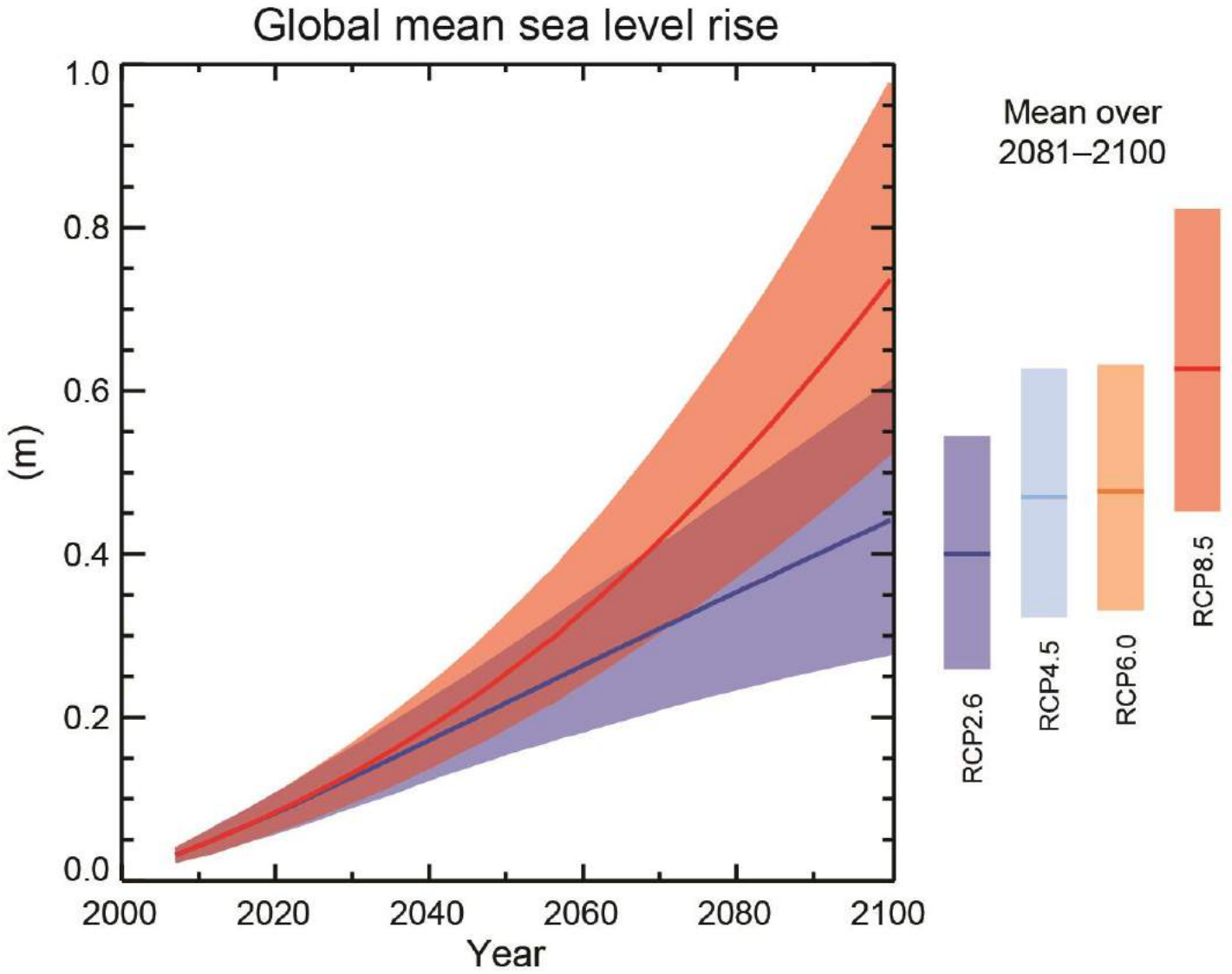
Hydrological cycle change



Available water resource

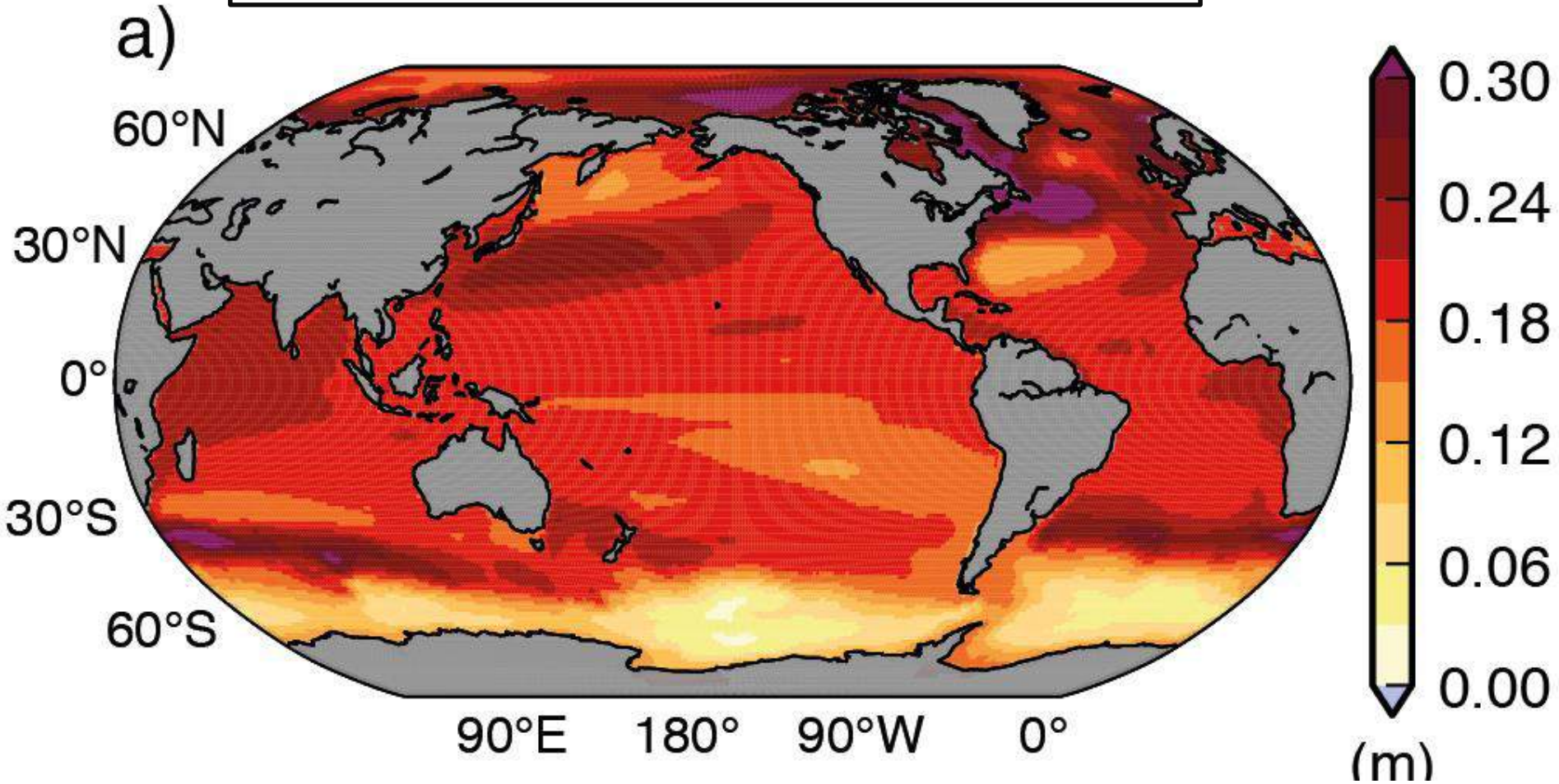
IPCC AR5 WG1 (2013) Fig. TS.TFE.1.3

Sea Level Rise



IPCC AR5 WG1 (2013) Fig. SPM.9

Sea Level Change



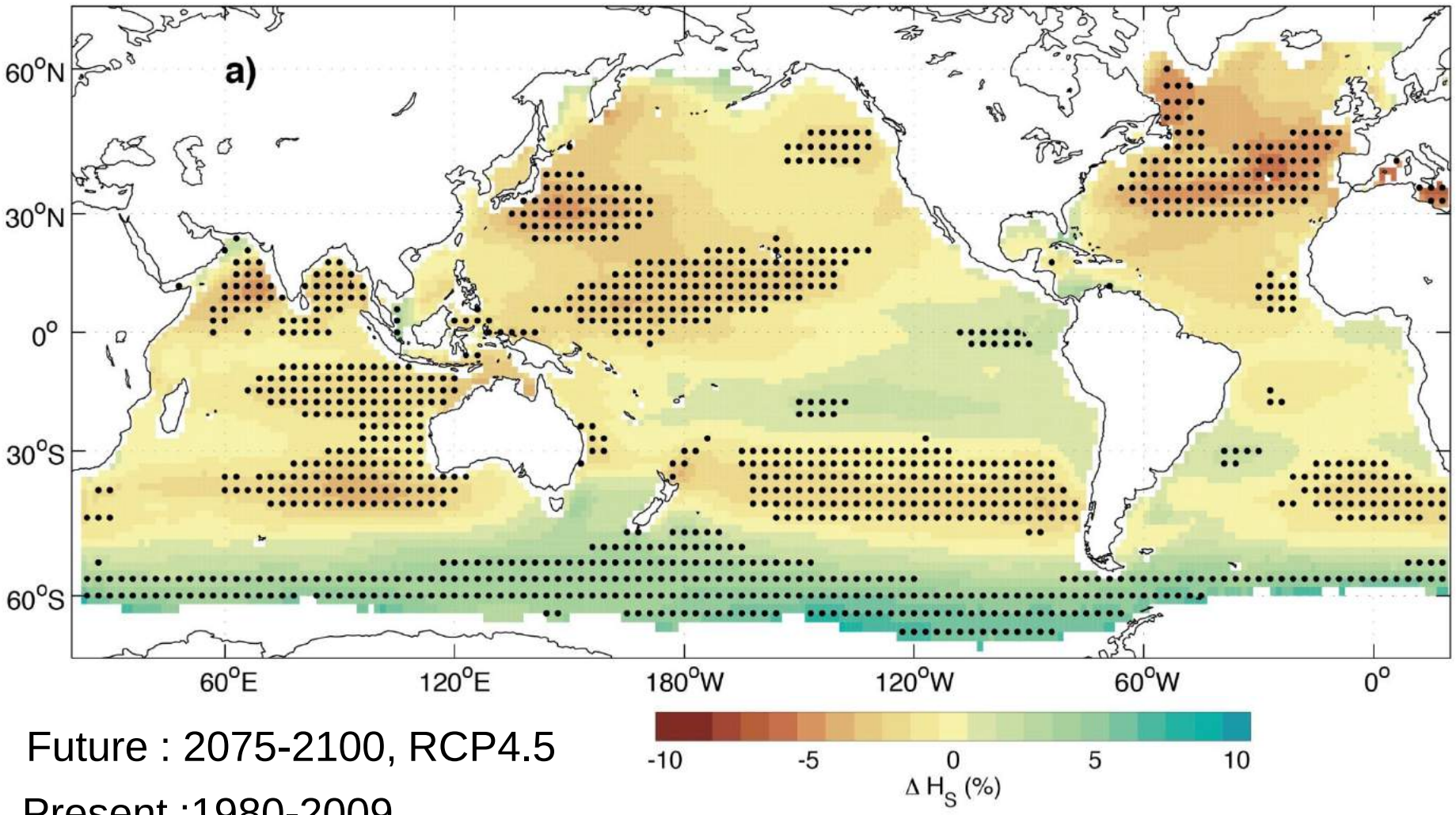
Future : 2081-2100, RCP4.5

Present :1986-2005

Thermal expansion only

IPCC AR5 WG1 (2013) Fig. 13.16

Wave height change



Future : 2075-2100, RCP4.5

Present :1980-2009

Annual mean significant wave height

IPCC AR5 WG1 (2013) Fig. 13.16

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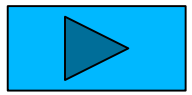
- Climates in Panama 
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Overview of future climate projections using global climate prediction over Central America

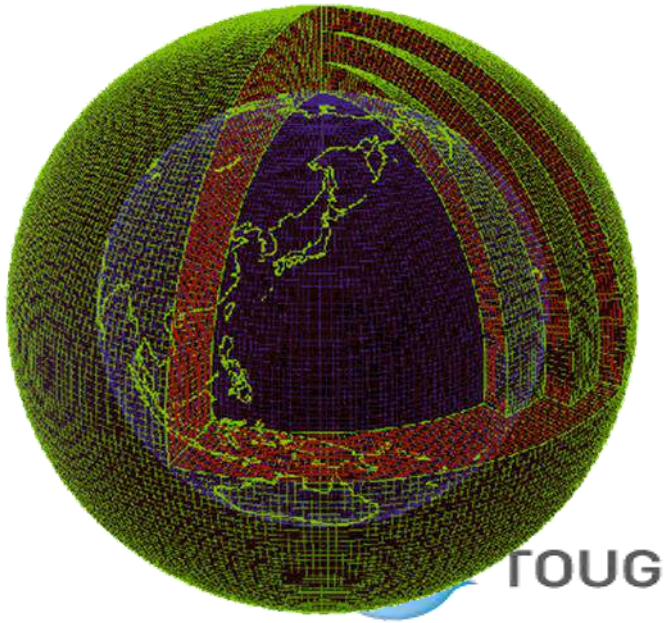
Tosiyuki Nakaegawa
Meteorological Research Institute and
Meteorological Business Support Center

September 12, 2019
UTP, Panama

Contents of my today's talk

- Collaborations between atmospheric scientists, impact assessment researchers, and stake holders

- Global dynamical downscaling of future climate projections with MRI-GCM with 20-km horizontal resolution

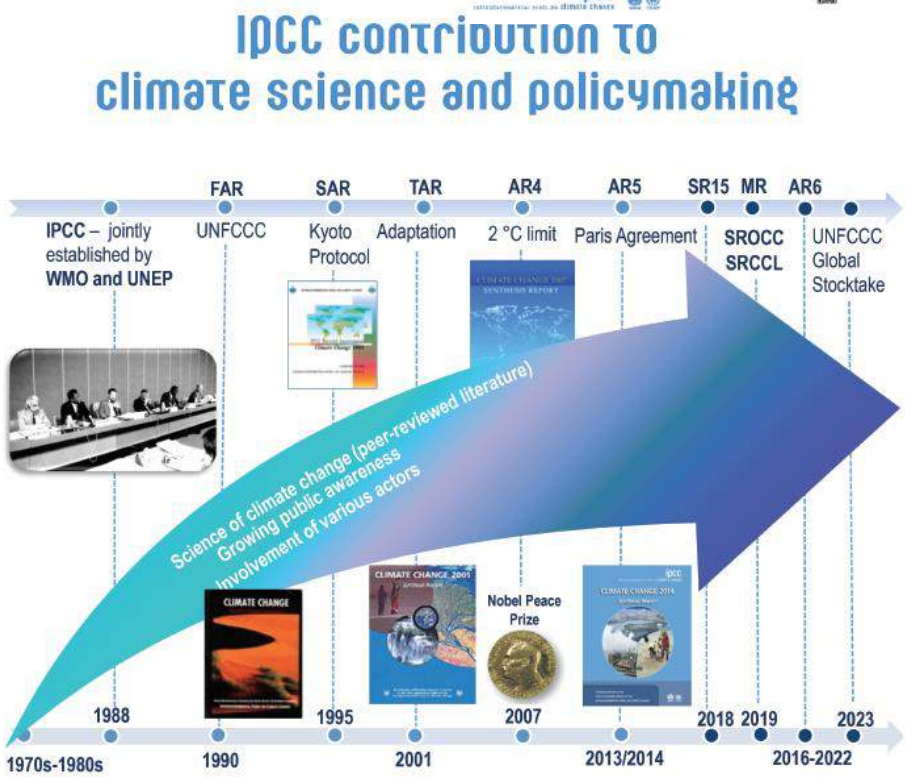


Collaboration between Providers and Users

- **IPCC AR6 is planned to be published in 2021**
- **Strong connection among WGs are recommended**

IPCC Expert meeting on assessing climate information for the regions (16-18/05/2018)

April 2021	Working Group I contribution The physical science basis
July 2021	Working Group III contribution Mitigation of climate change
October 2021	Working Group II contribution Impacts, adaptation and vulnerability
April 2022	Synthesis Report



History of collaboration in Japan

2002-2007 2007-2012

KAKUSHIN

2012-2017 2017-2022

SOUSEI

TOUGOU

Meteorological Research Institute

TOUGOU | Integrated Research Program for Advancing Climate Models

Research with Earth Simulator (ES) in Japan

March 2015 - Present

NEC SX-ACE

Peak performance :
1.3 Pflops
Main memory: 320 TB

Peak performance :
1.0 Pflops (half?)
0.25~ Pflops (double)
Total memory: 0.7 TB

History of Earth Simulator

ES1

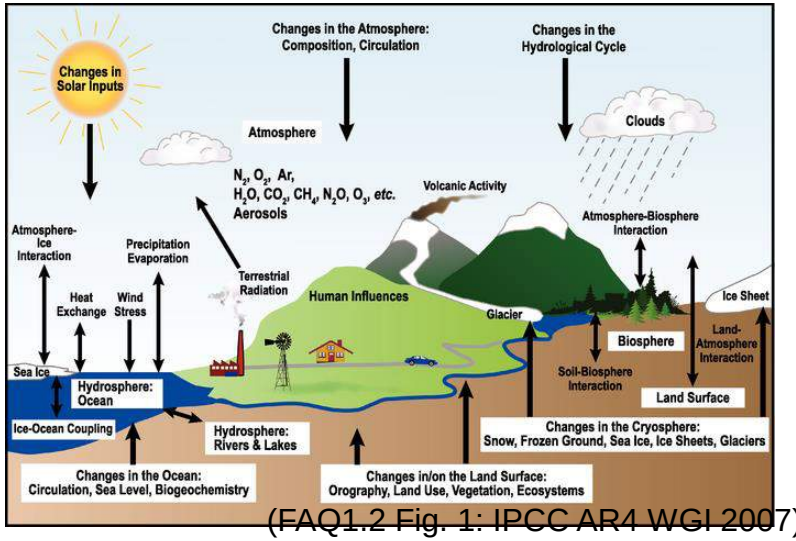
ES2

ES3

Year	Earth Simulator	IPCC Report	MRI-AGCM version
2002	ES1		
2003			
2004			3.0
2005			
2006			3.1
2007		4th	
2008			
2009	ES2		3.2
2010			
2011			
2012			
2013		5th	
2014			
2015	ES3		
2016			
2017			

IPCC = Intergovermental Panel on Climate Change

Configuration of a GCM for future climate projections



(FAQ1.2 Fig. 1: IPCC AR4 WGI 2007)

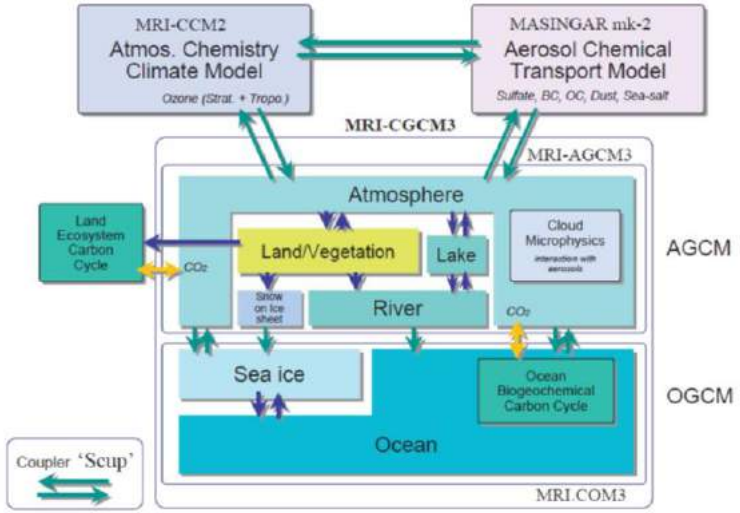


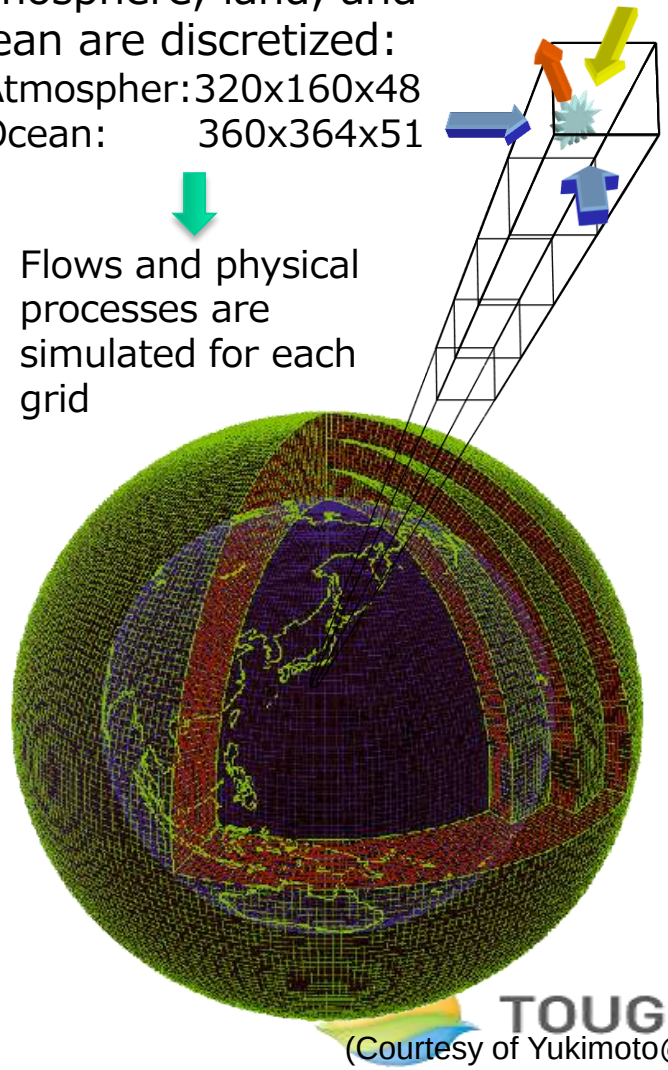
Figure 1 Configuration of the component models in MRI-ESM1. Green arrows denote data exchange with using Scup between the component models.

Atmosphere, land, and ocean are discretized:

Atmospher: 320x160x48

Ocean: 360x364x51

Flows and physical processes are simulated for each grid



(Courtesy of Yukimoto@MRI)

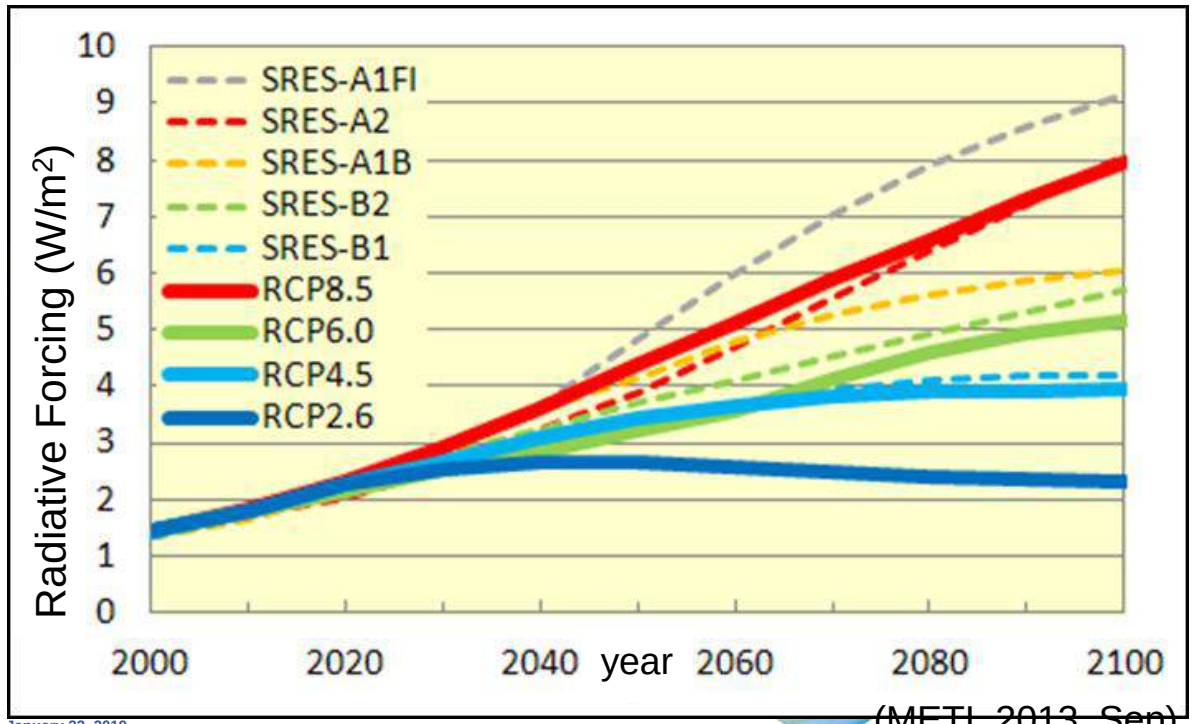
- (Yukimoto et al. 2011)

Emission scenario

We need a greenhouse gas emission scenario to project a future climate.

- Special Report on Emission Scenario: SRES until IPCC AR4
- Representative Concentration Pathway: RCP from IPCC AR5

	WG I	WG II
AR4 (2007)		
AR5 (2013,14)		



(METI, 2013, Sep)

Global Dynamical Downscaling

- Why we need a global dynamical downscaling with atmospheric GCM?
  - –RCM can produce poor regional outputs from poor global-scale lateral boundaries

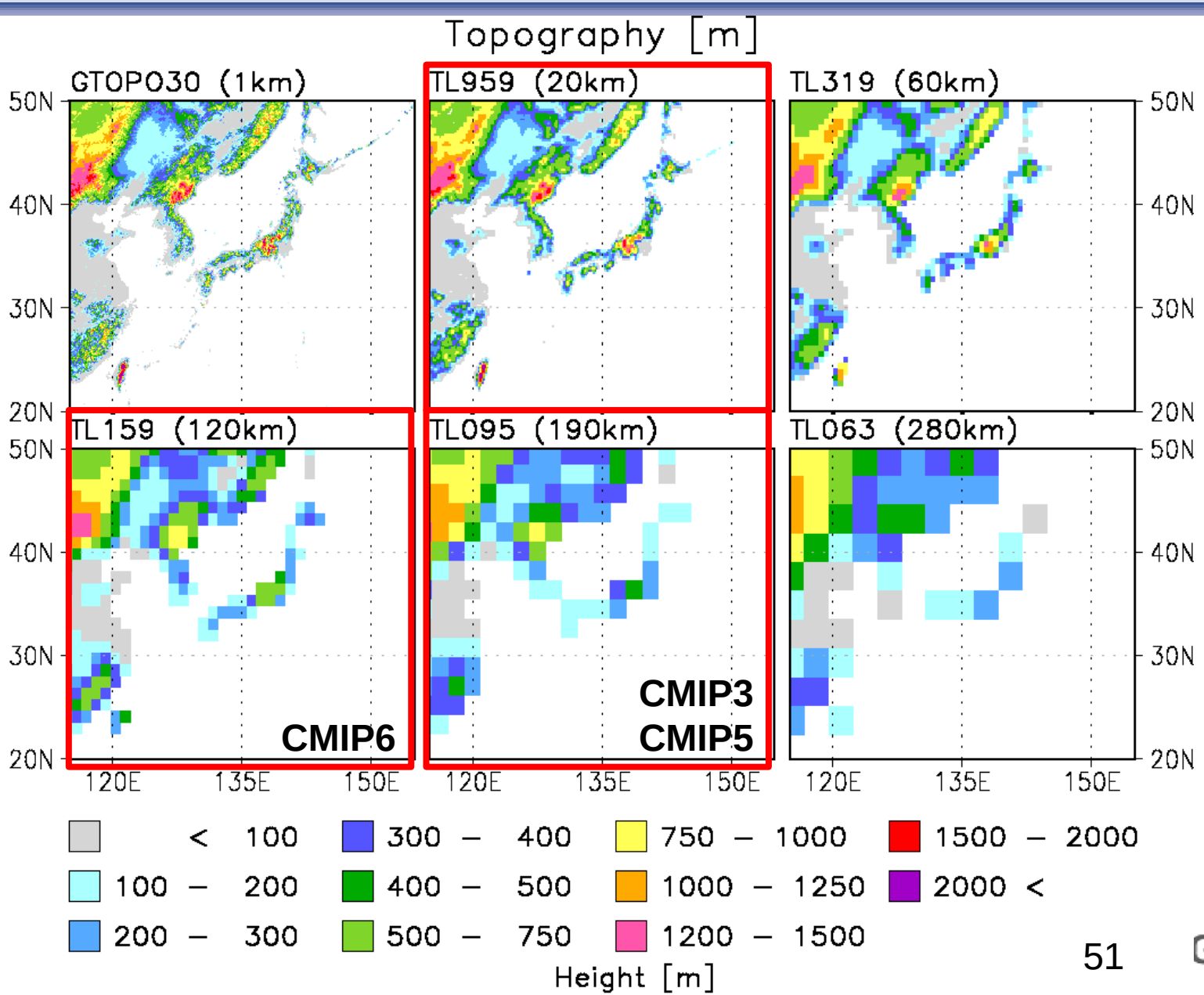
    garbage in, garbage out

    good in, good out

(http://benchmarksensory.com.au)

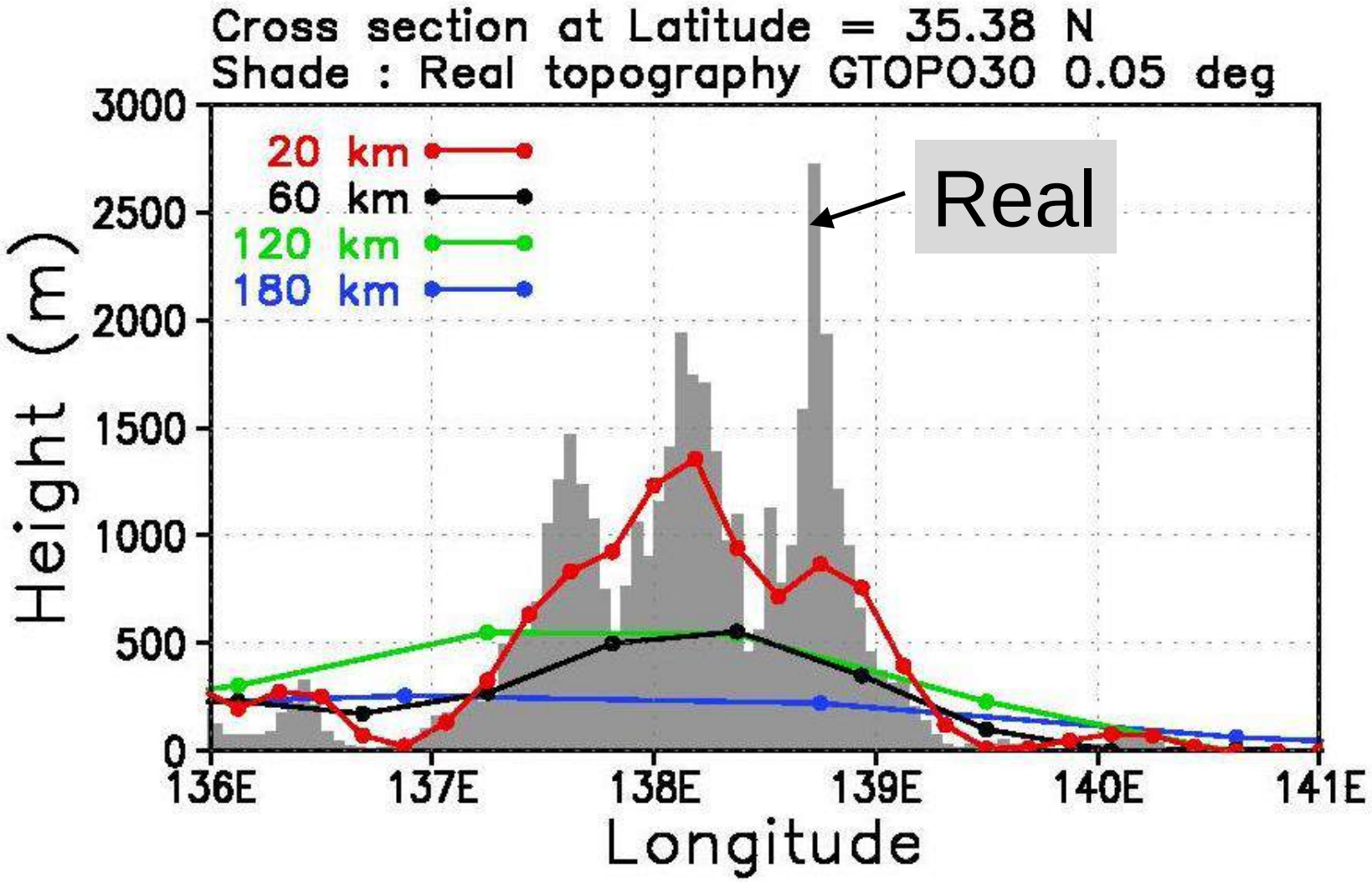
  - –We believe that highly accurate lateral boundaries are prerequisite for accurate dynamical downscaling.

Land-Sea distribution and elevation



Height of mountain

Near Mt. Fuji



Comparison of days of precipitation greater than 30mm/day in June and July between resolutions

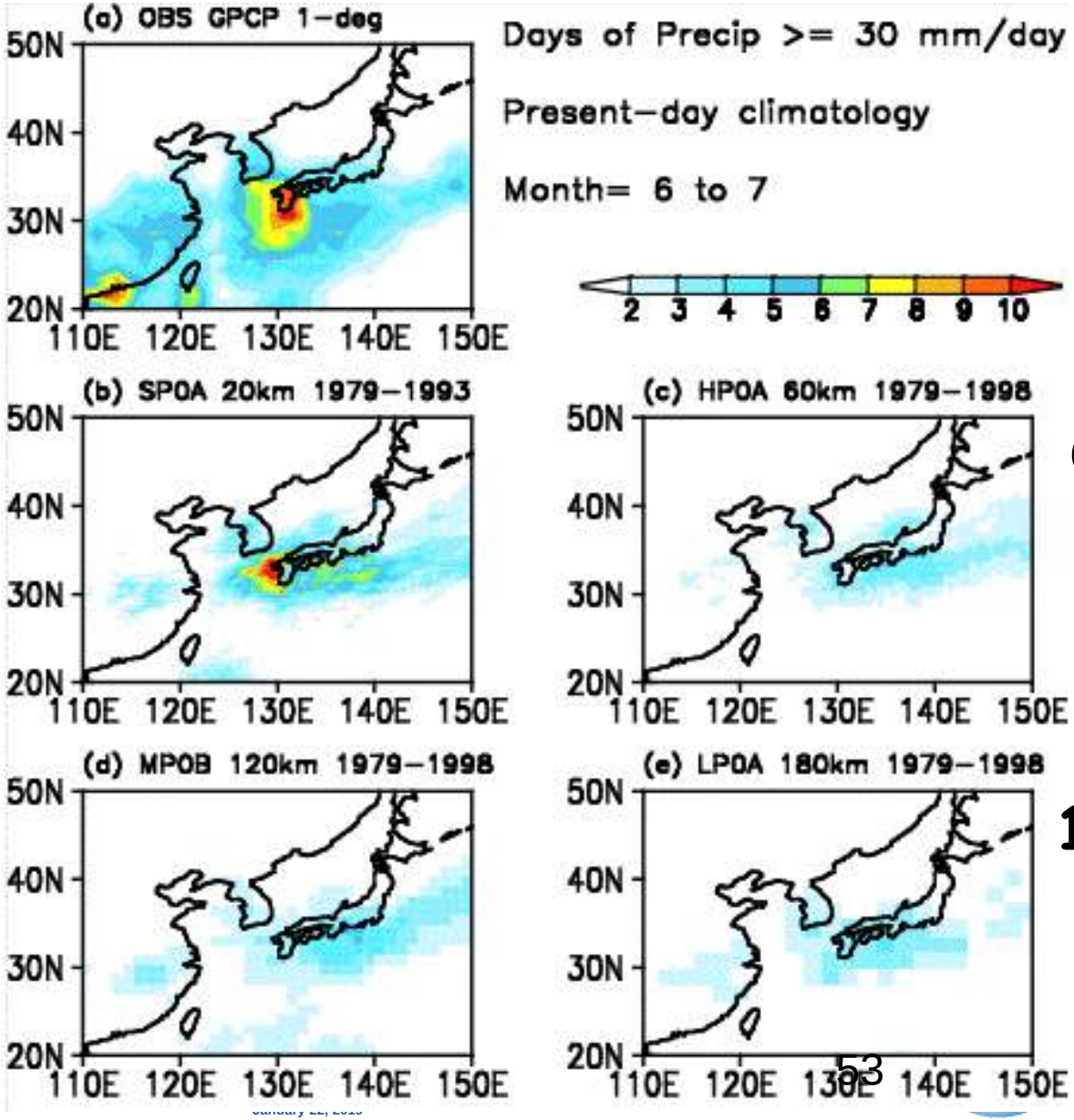
GPCP

20km

120km

60km

180km

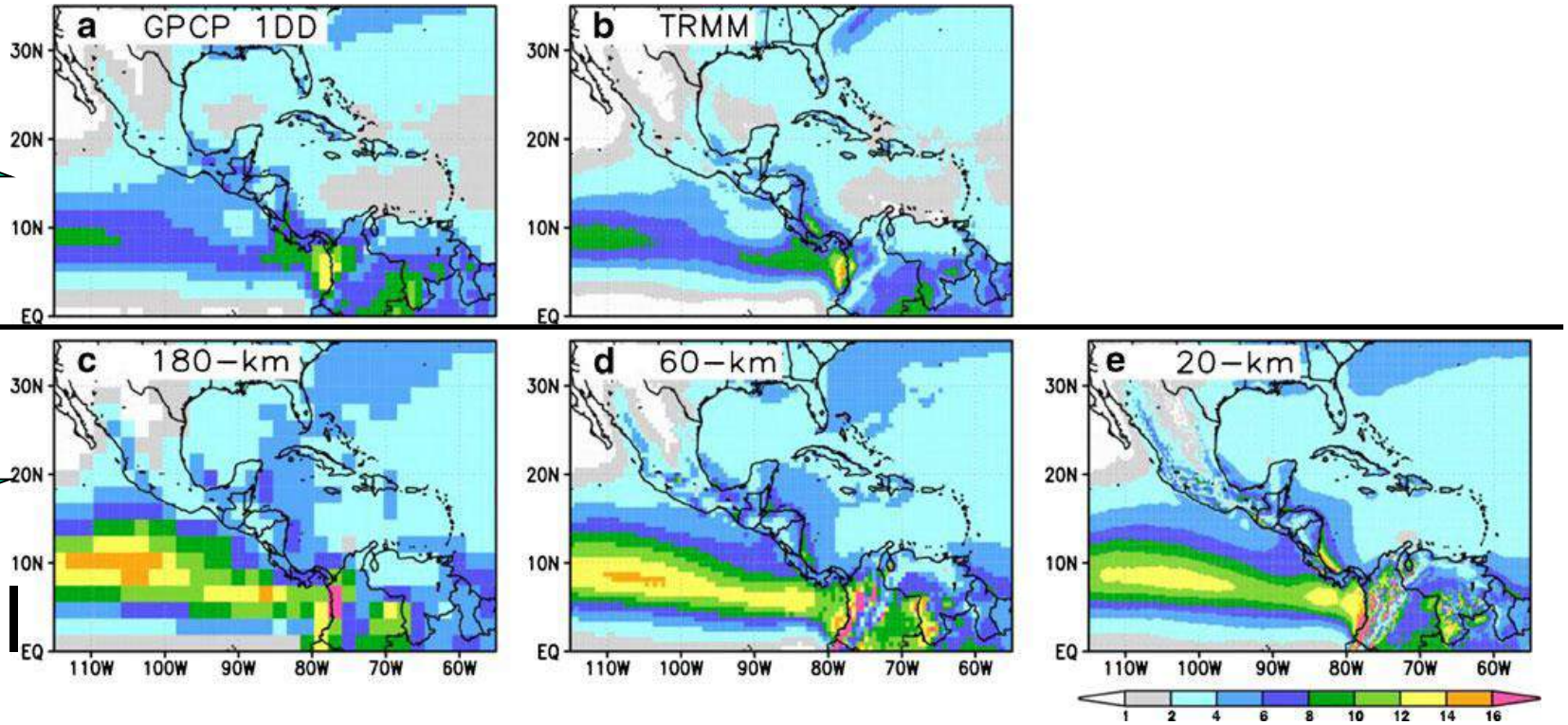


Central America: Annual mean

GPCP
1.0 deg

TRMM3B43
0.25 deg

OBS



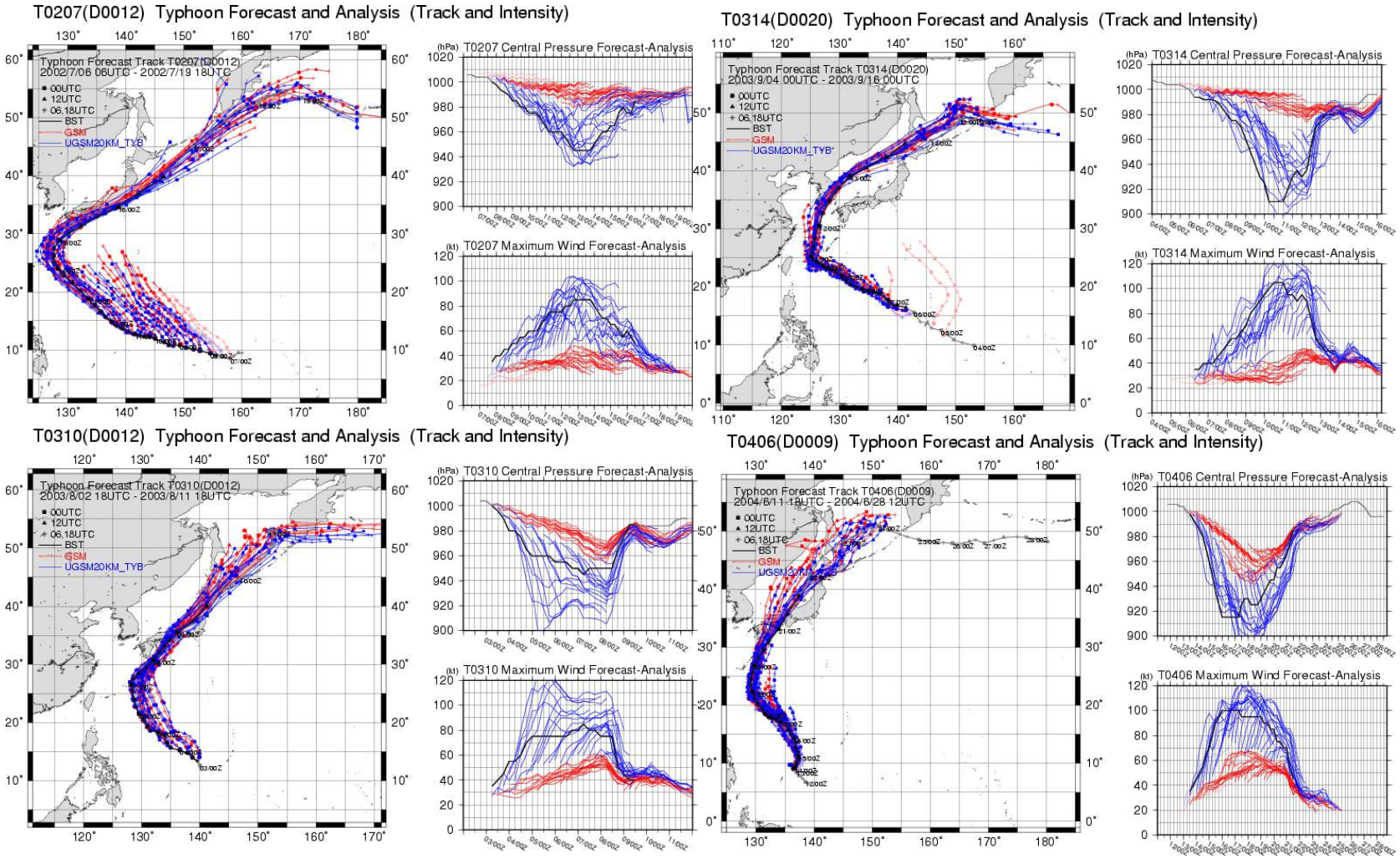
Model

180km

60km

20km

Comparison of typhoon prediction between 60km and 20km mesh models



weak central pressure and weak max. wind speed in the 60km mesh model. Reproducibility in the 20km mesh model is better.

60km mesh model

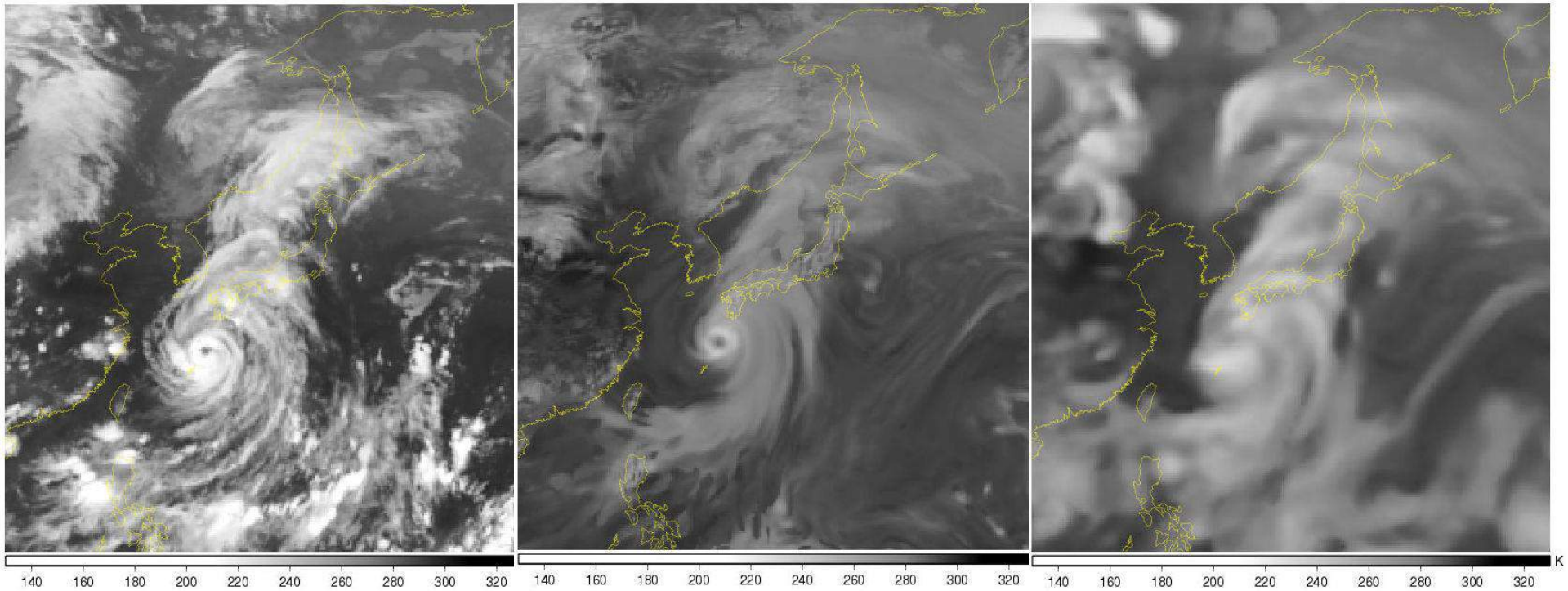
20km mesh model

Infrared brightness temperature:36 hour forecast

Satellite observation

20-km model

60-km model



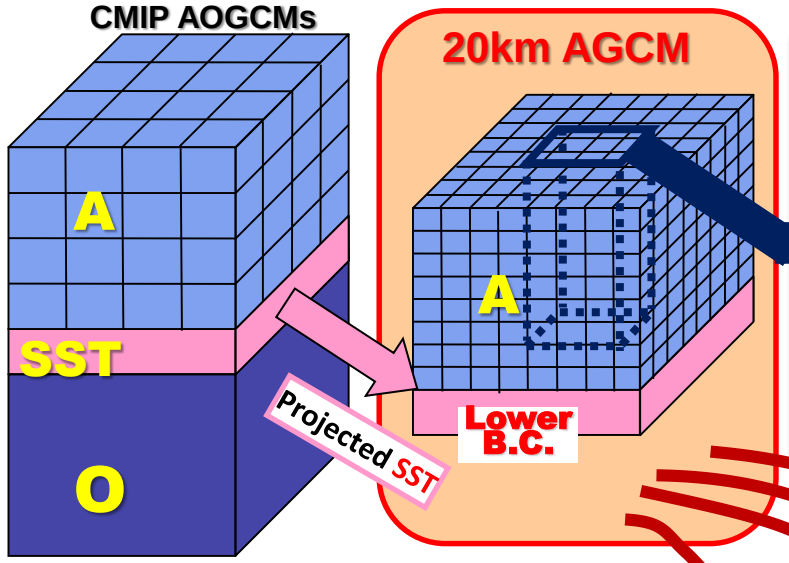
Typhoon 2003-10

Murakami, H. (2005)

Initial time:00UTC 6 Aug. 2003

Valid time:12UTC 7 Aug. 2003

Global Dynamical Downscaling

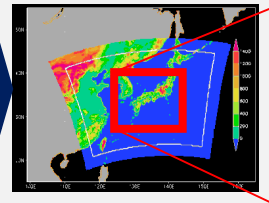


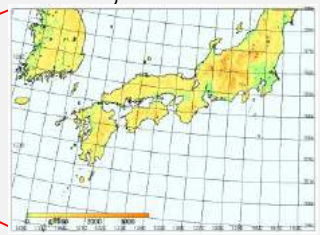
Regional Climate Model

Dynamical Downscaling by RCM

5km NHM

2km, 1km NHM





Nested in the 20km AGCM

Nested in the 5km NHM

Impact Assessments

- Disasters
- Agriculture
- Water Resources

Study of Future Change in Extreme Events

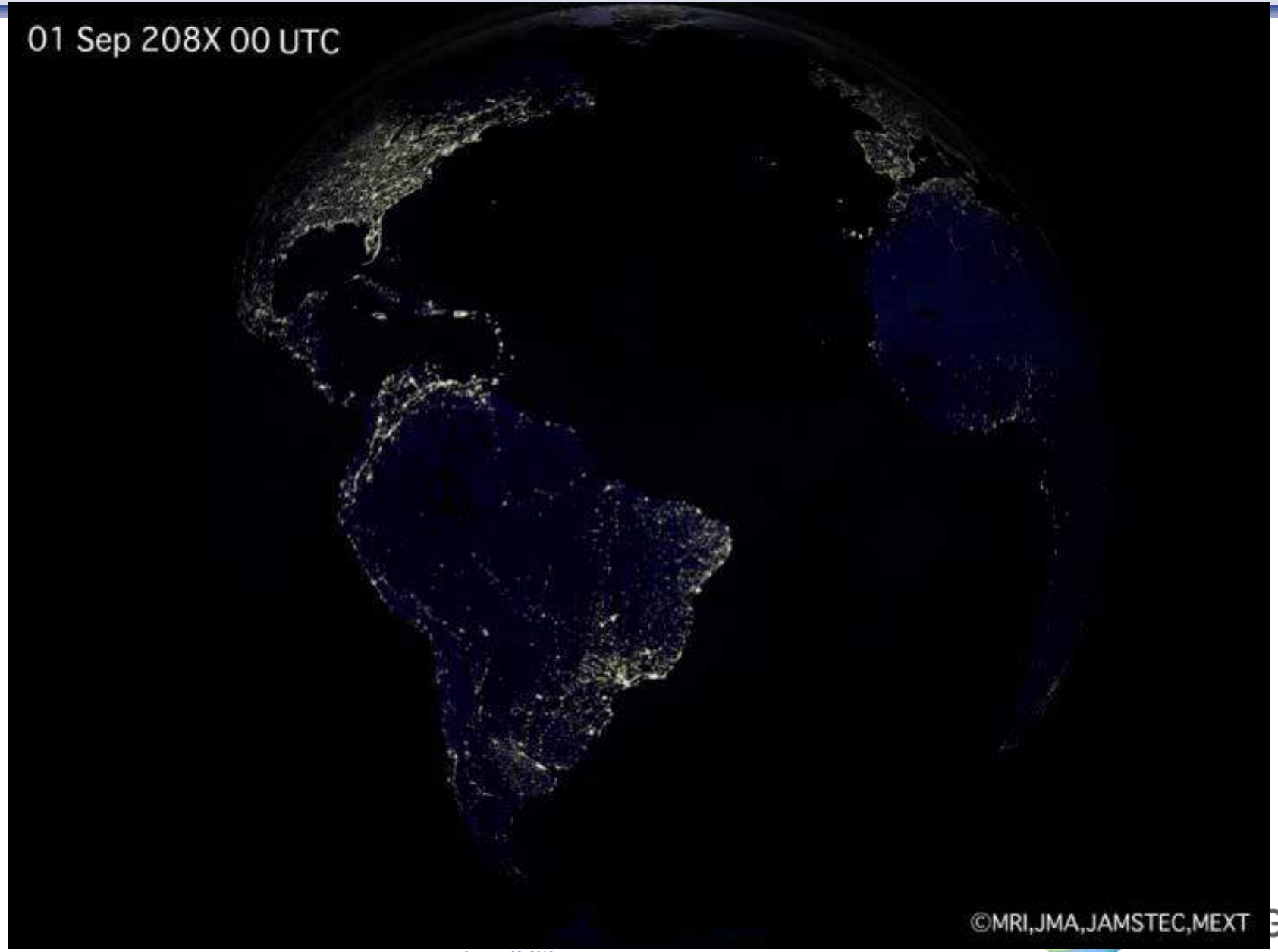
- Tropical Cyclones (e.g.Oouchi et al. 2006)
  →less number, more intense
- East Asia Monsoon (e.g.Kusunoki et al.2006)
  →seasonal migration delayed
- Extreme Rainfall (e.g.Kamiguchi et al. 2006)
  →more frequent
- Blockings (e.g.Matsueda et al. 2009)
  →less frequent
- Extratropical Cyclones(e.g.Mizuta et al.2011)

Regional Climate Change

Outputs provided to researchers of each region

(Korea, China, Taiwan, Philippines, Thailand, Indonesia, Viet Nam, Bangladesh, India, Israel, Saudi Arabia, Senegal, Spain, Netherland, UK, Ireland, Denmark, Switzerland, Germany, USA, Mexico, Columbia, Barbados, Belize, Bolivia, Peru, Ecuador, Brazil, Argentina, Australia, Papua New Guinea)

Tropical cyclones in the 20-km AGCM



Uncertainty in climate projections

- Merit of our approach:
  - –High horizontal resolution
  - –High reproducibility of current climate and extremes
- Demerit:
  - – Single model
    - ➢ Multiple projected SST changes
    - ➢ Multi-physics of convections
  - – Only two scenarios
    - ➢ Four scenarios but with low horizontal resolution (60 km) and 1950 to 2100.

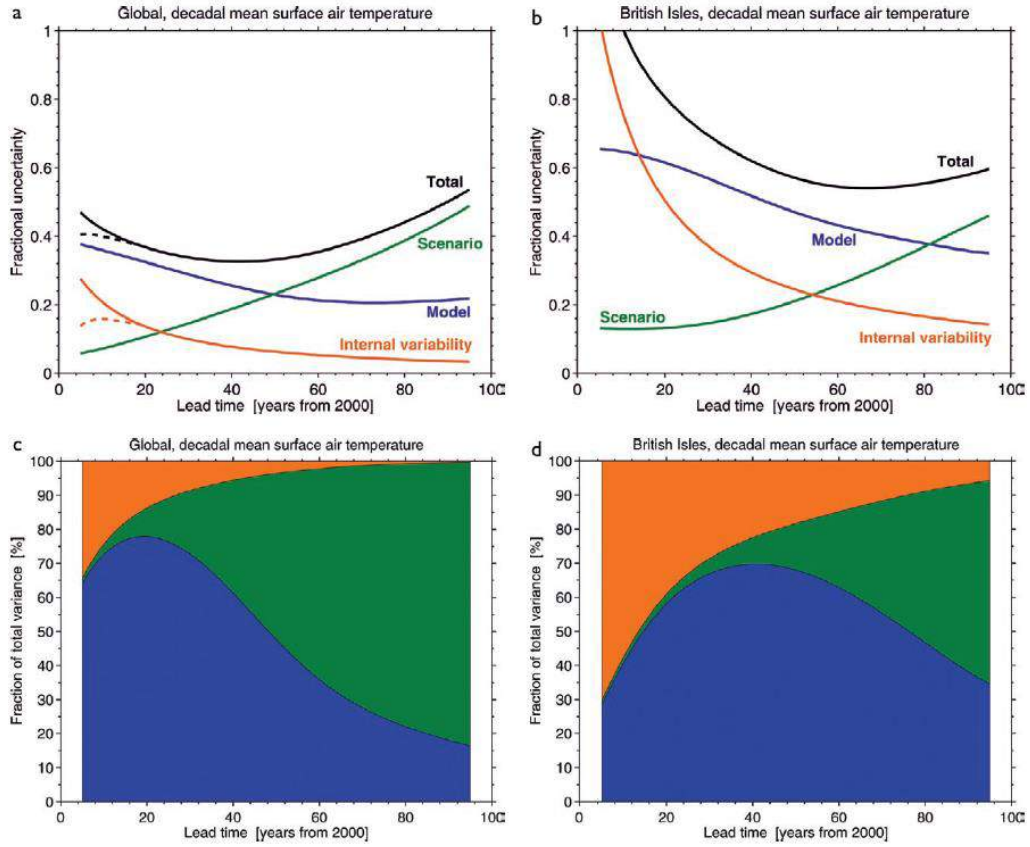
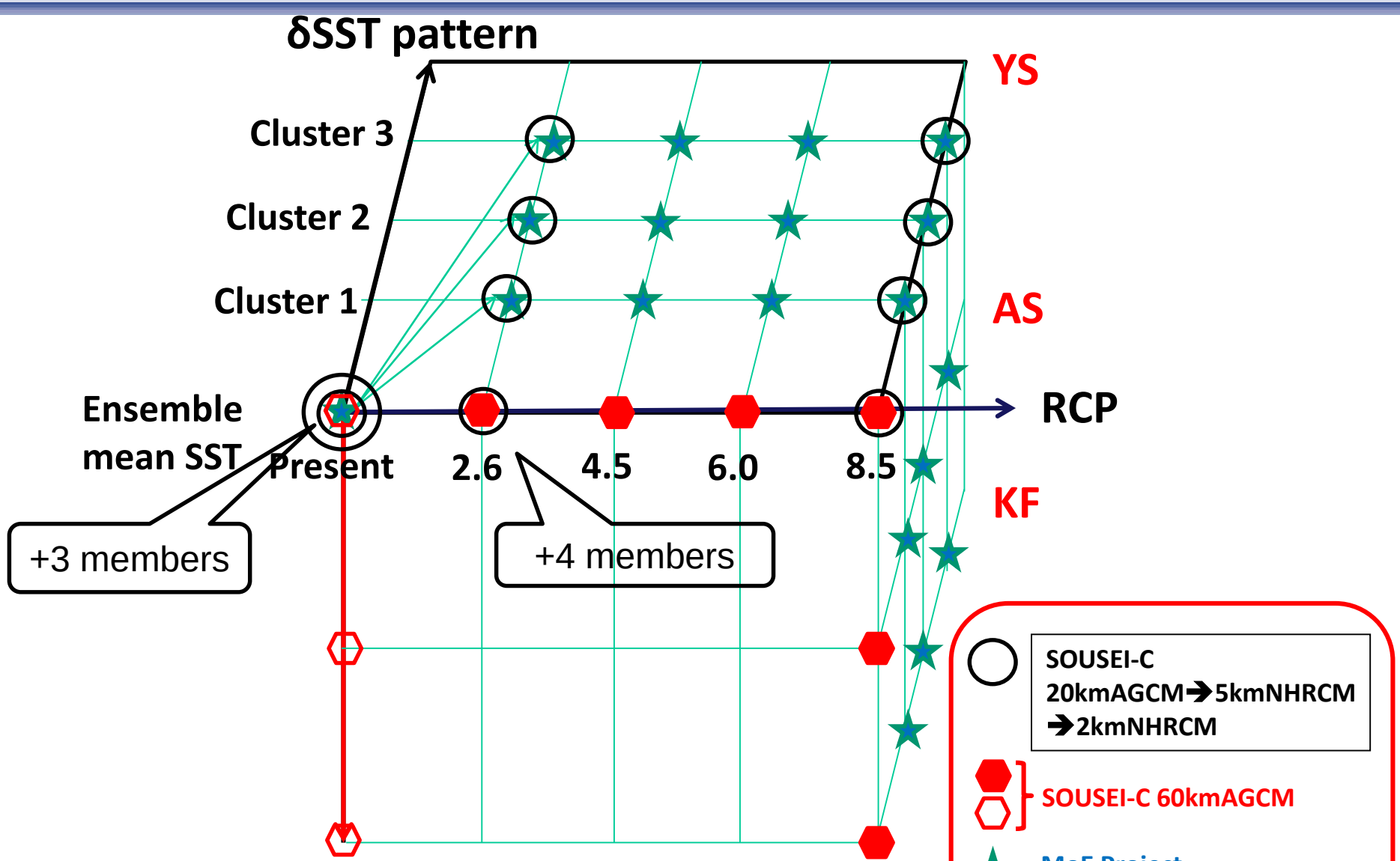


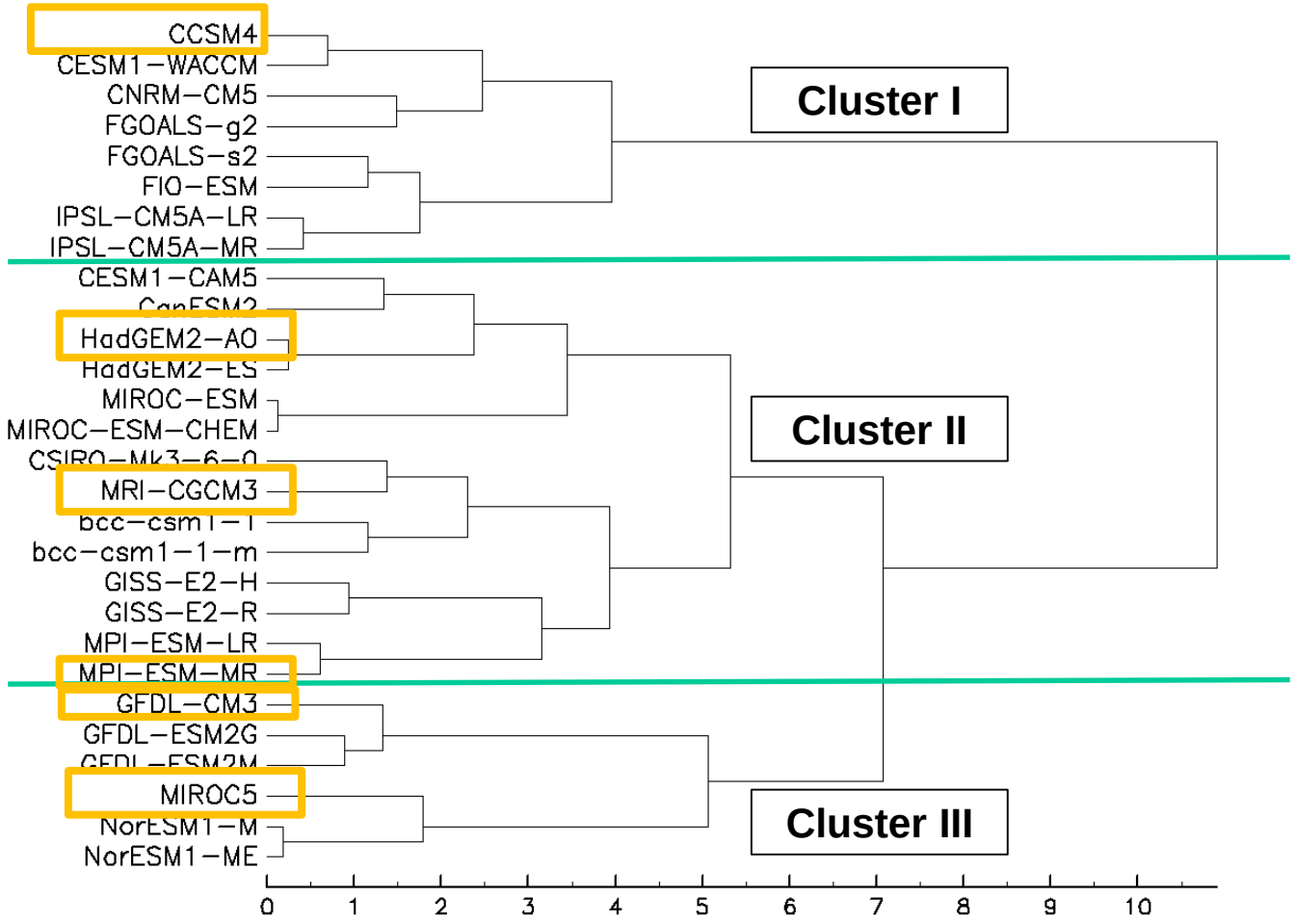
FIG. 4. The relative importance of each source of uncertainty in decadal mean surface temperature projections is shown by the fractional uncertainty (the 90% confidence level divided by the mean prediction) for (a)

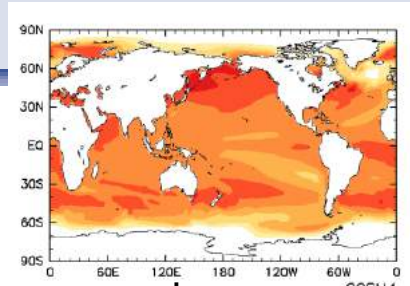
Hawkins and Sutton (2009, BAMS)

Matrix of ensemble experiments under RCPs

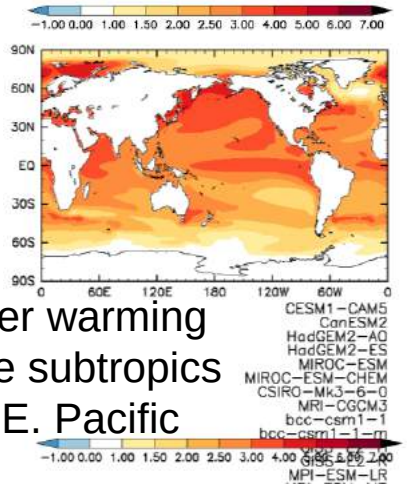


Cluster analysis results

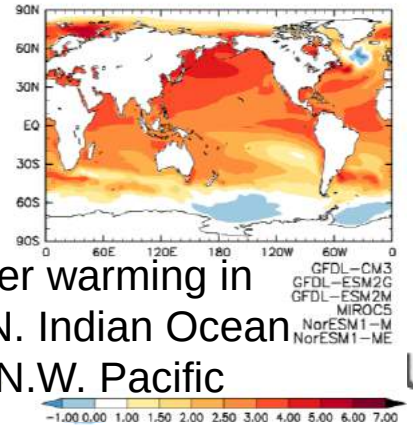




Uniform warming in the tropics



Larger warming in the subtropics of N.E. Pacific



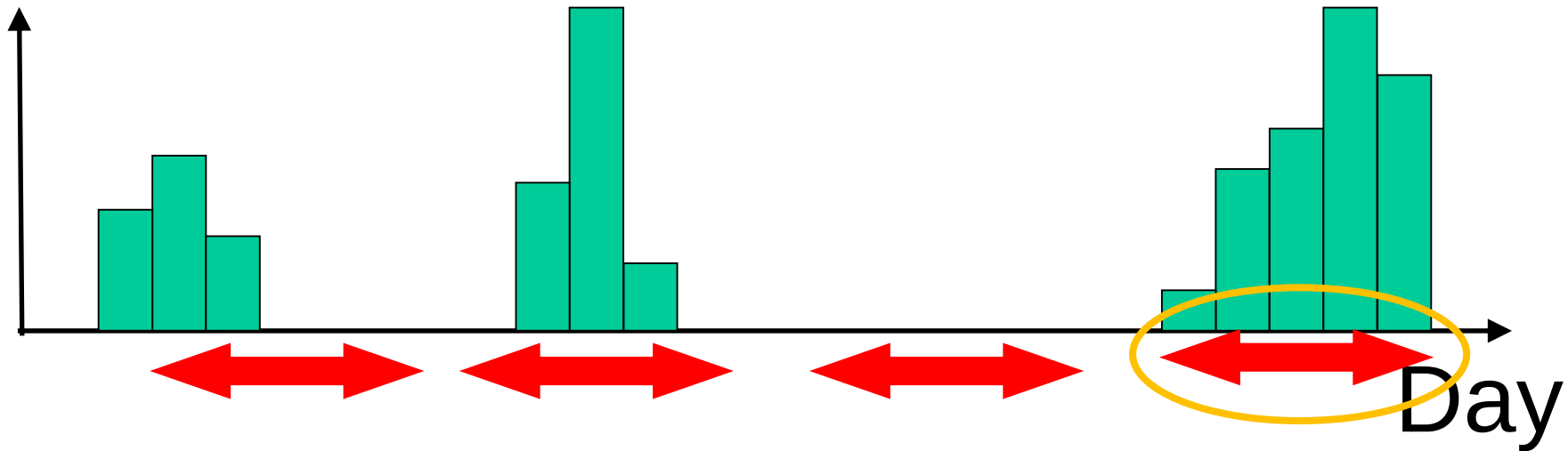
Larger warming in the N. Indian Ocean and N.W. Pacific

by courtesy of Mizuta (2014, JpGU)

Rainfall index

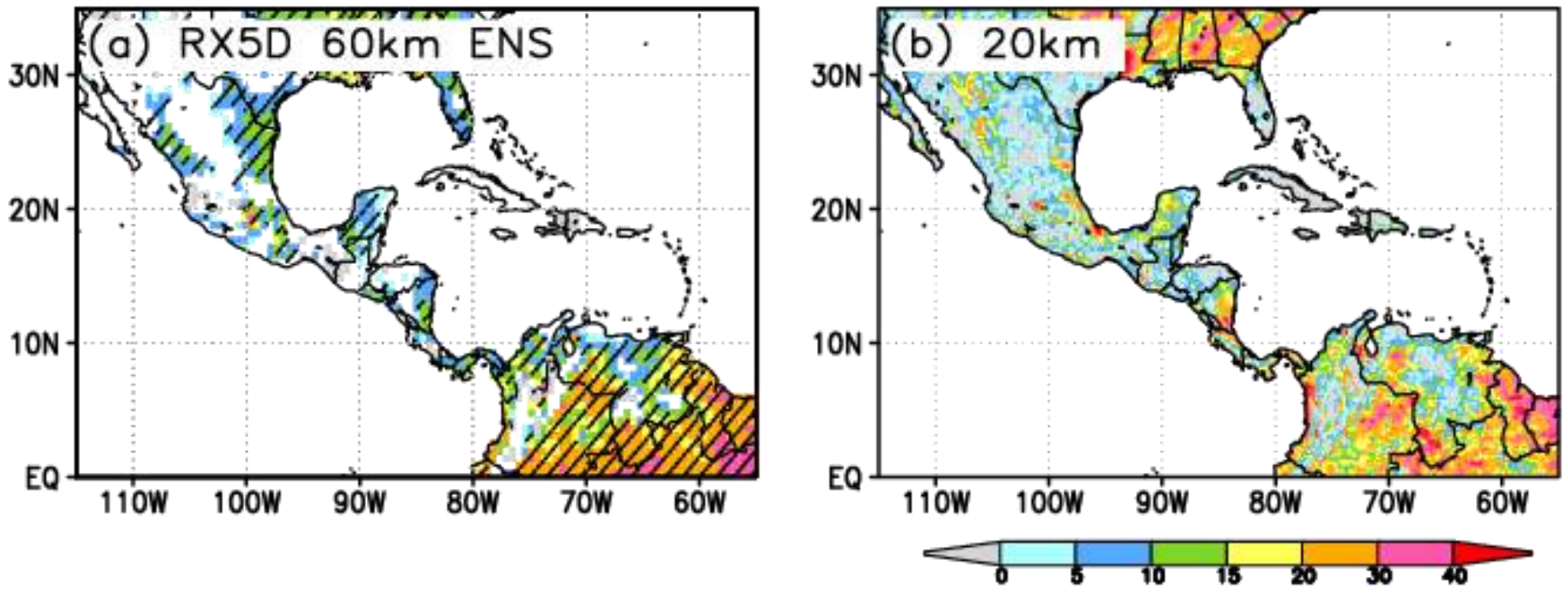
Maximum of 5-day rainfall total (**RX5D**) for a year

soil erosion,
flood, and water
excess supply



Consecutive 5 days

Change in 5-day rainfall total



MRI-AGCM3.2S 20-km grid spacing

Period: 2075-2099

Scenario: SRES A1B

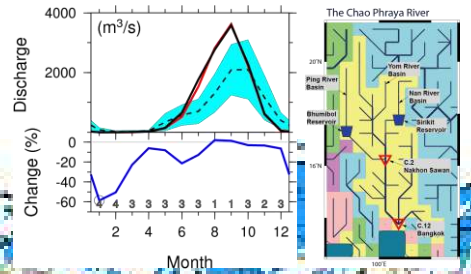
SST: 4 different SSTs projected by CMIP3 models

Meteorological Research Institute

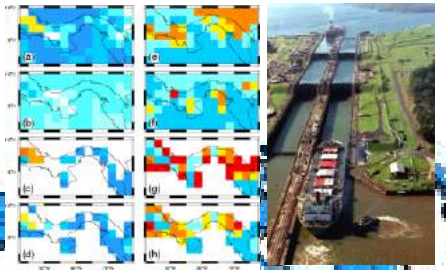
(Nakaegawa et al. 2014, TAC; cited in IPCC AR5 WGII)

International cooperation

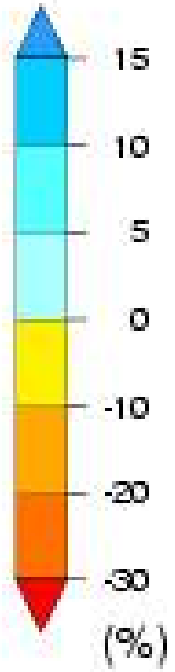
Chao Phraya River (Champathong et al. 2013; HRL)

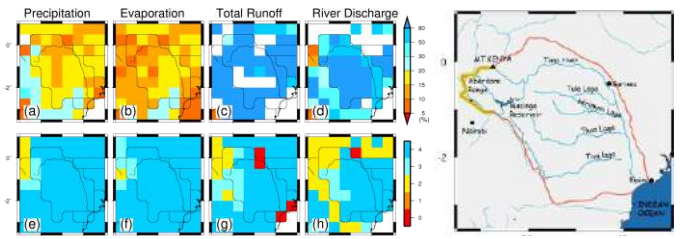


Panama (Fabrega et al. 2013; HRL)

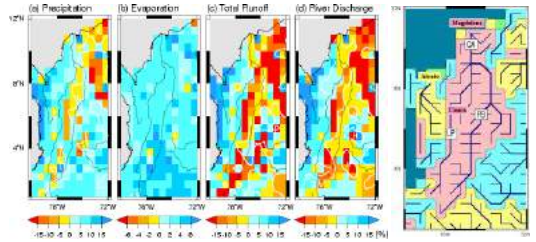


Our articles has been cited in it!





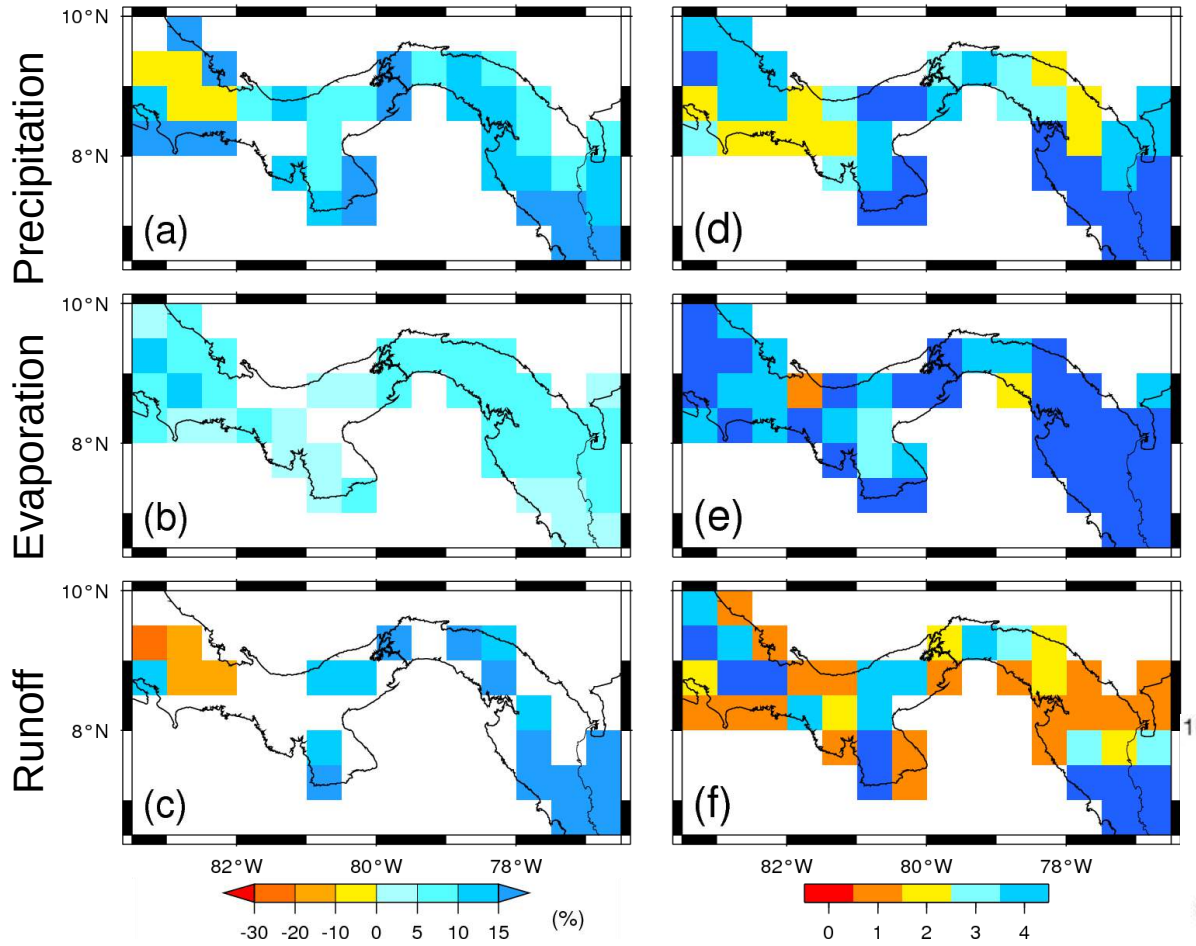
Tana River (Nakaegawa and Wachana 2012; HRL)



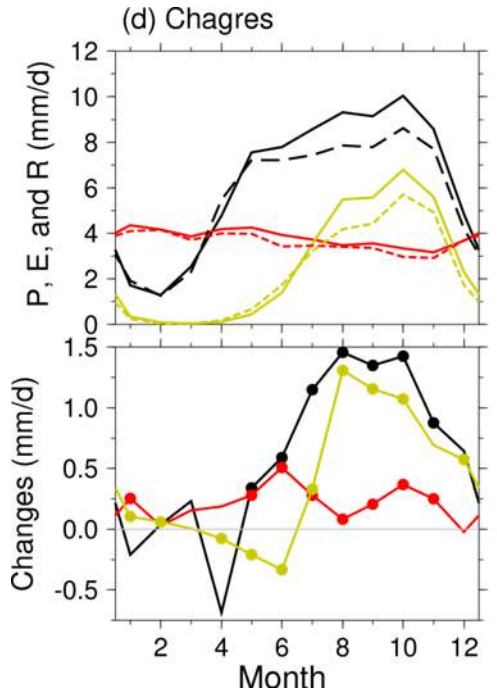
Magdalena River (Nakaegawa and Vergara 2010; HRL)

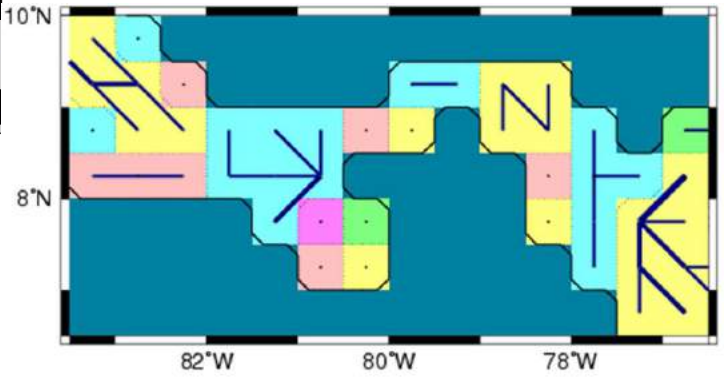
Chao Phraya River Basin in a future

Future changes Consistent changes in sign



Seasonal variation in Chargres



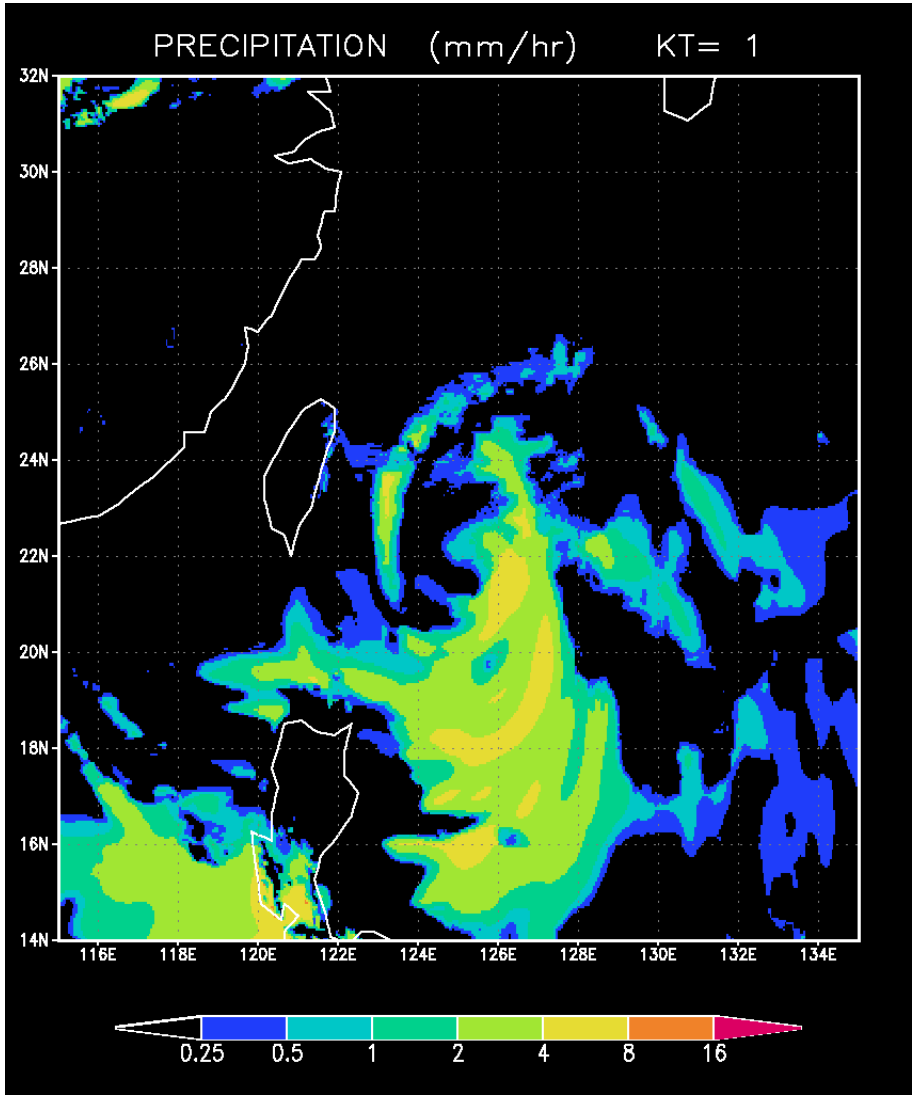


(Fabrega et al. 2013)

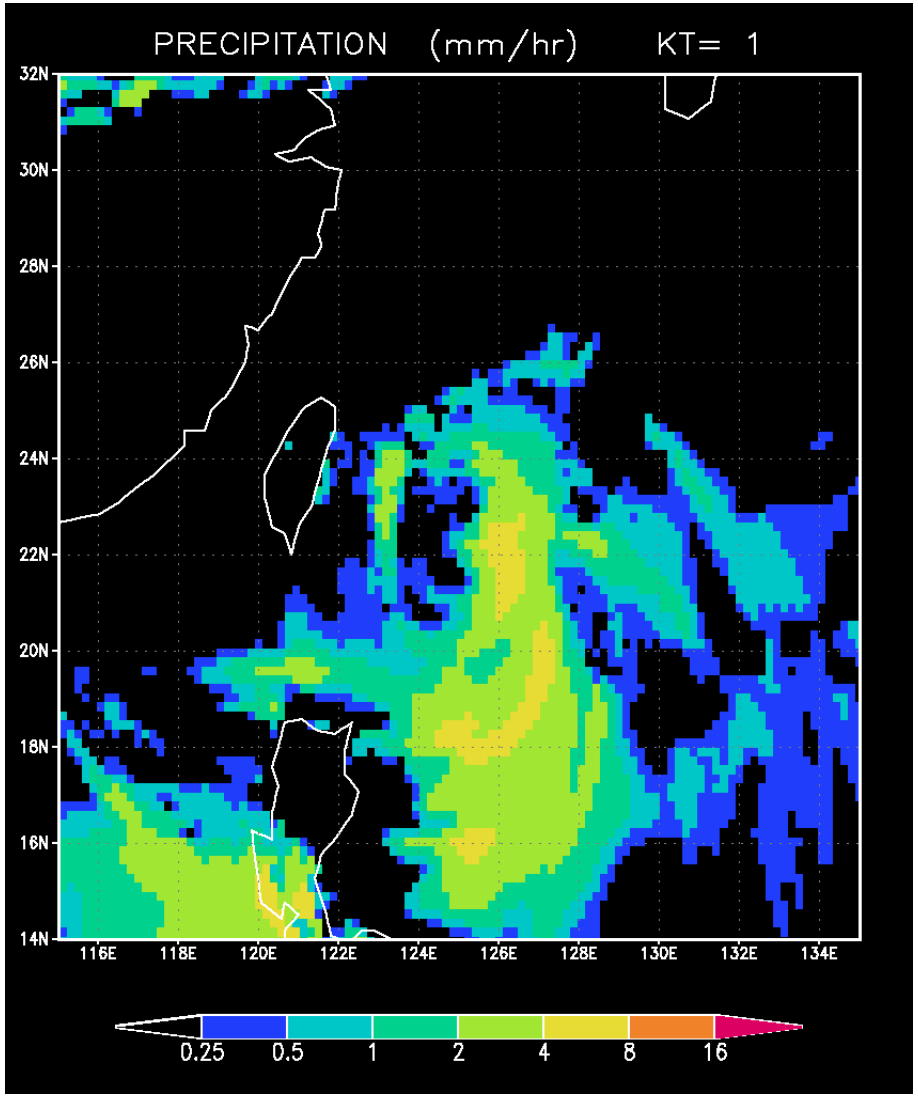
Meteorological Research Institute

Simulated precipitation of a TC (mm/hr)

TL3839L60 (horizontal 5km)



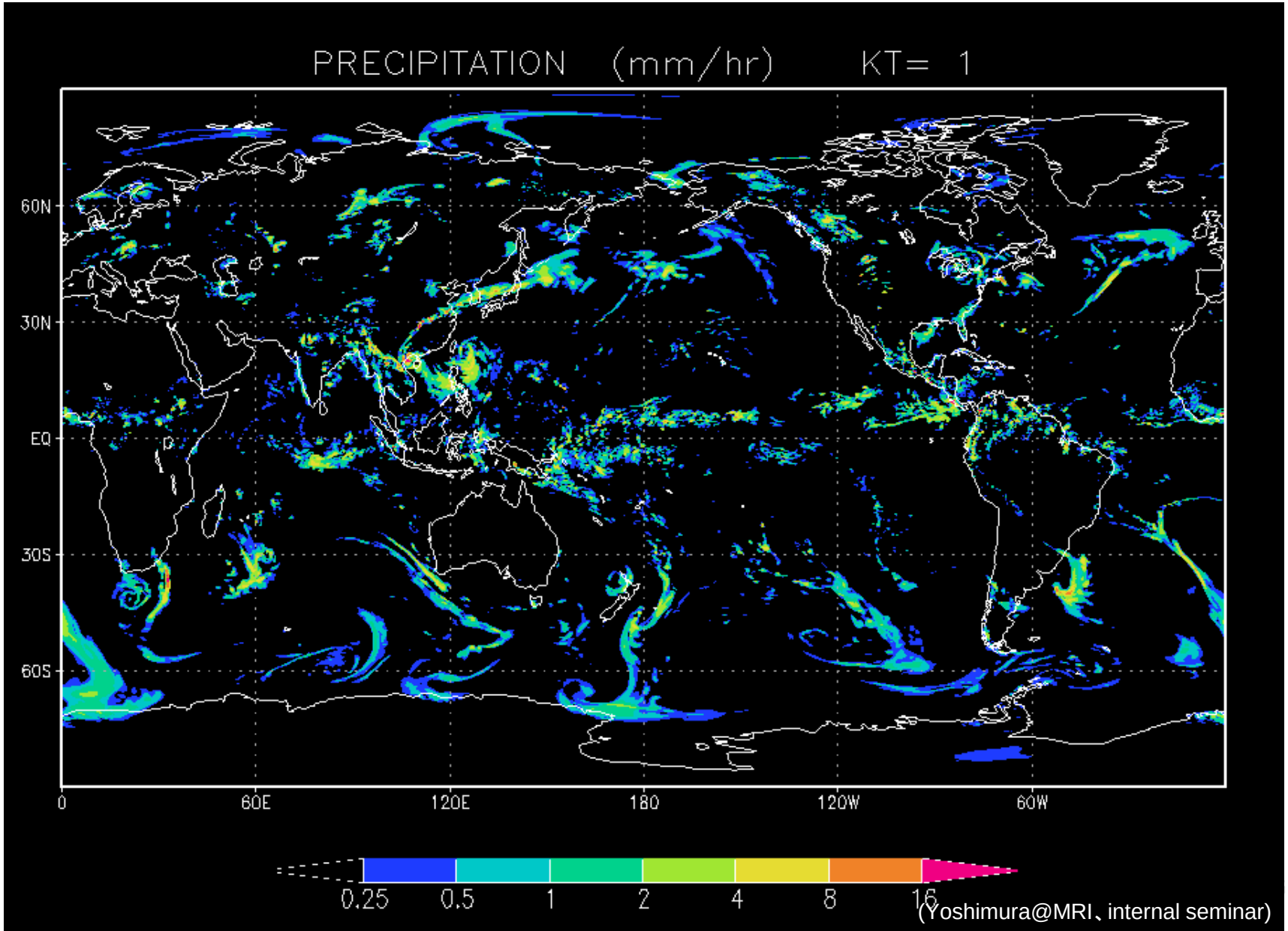
TL959L60 (horizontal 20km)



Arakawa-Shubert convection scheme and Smith cloud scheme

5-km Global simulation

TL3839L60 (horizontal 5km)
East-west 7680 grid,
north-south 3840 grid



(Yoshimura@MRI、internal seminar)

Concluding summary

- Dialogues between atmospheric scientists and impact assessment researchers are essential for better scientific outcomes
- Global dynamical downscaling with an atmospheric GCM can provide better lateral boundary conditions.
  - –Better representations of topography
  - –Better reproducilibities of topography-induced precipitation and extreme events such as typhoons
  - –Global-scale impact assessments can be carried out from the outputs of the global dynamical downscaling.

Comparison of UTP Supercomputer with MRI one

MRI: Fujitsu (SPARC)

2015-2019

1.1PF

$4milion /year

UTP: Nvidia DGX-1 (Tesla V100)

2019-

1.0PF (DL) – 0.056PF(DP)

$1thouthad

Japanese top supercomputer @ RIKEN

RIKEN: Fujitsu (SPARC)

2012-2019

10.51PF

$1.1billion

(August 30, 2019RIKEN, https://tech.nikkeibp.co.jp/atcl/nxt/news/18/05832/?ST=nnm)

RIKEN: Fujitsu (SPARC)

2021-202X?

~1.0EF

$1thouthad

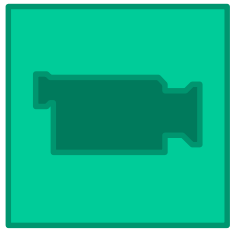
(May 23, 2019RIKEN, https://mainichi.jp/articles/20190523/k00/00m/040/149000c)

Target: GENESIS

Supplement

Building a GPU-enabled and Performance-portable Global Cloud-resolving Atmospheric Model

- Xeon Broadwell: Intex CPU Xeon 12XXv4, September 2014
- Xeon phi KNL: Intel Coprocessor Xeon phi 72XX, Q4, 2016
- NVIDIA Tesla P100: NVIDIA GPU Tesla Pascal 100, April 2016



RichReport on youtube: https://www.youtube.com/watch?v=XXV5TIcSZUI

Thank you for your attention!

TOUGOU | Integrated Research Program for Advancing Climate Models