How are future climates projected under a global warming in a computer?

～Advantages of a high-resolution model～

Tosiyuki NAKAEGAWA

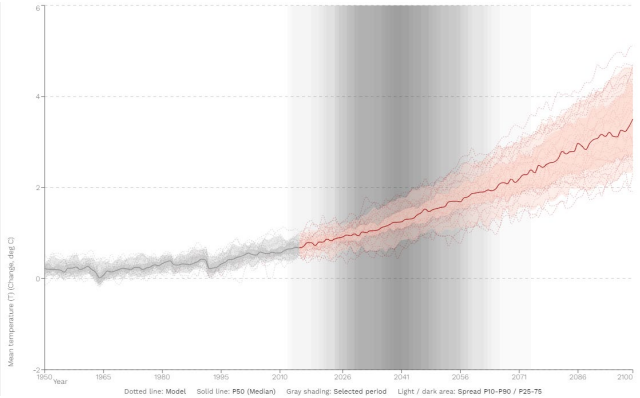
Japan Meteorological Business Support Center

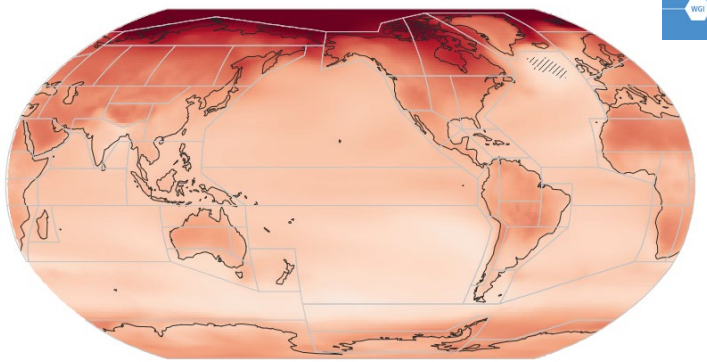
Meteorological Research Institute, Tsukuba, Japan

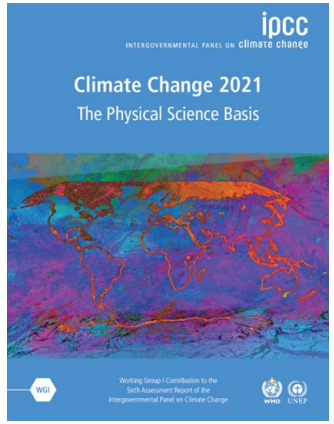
Advanced studies of climate change projection

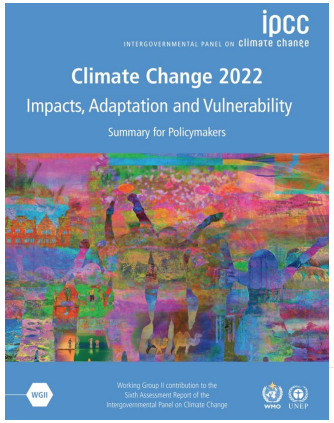
How is a future climate projected?

IPCC AR6 WGI Interactive Atlas

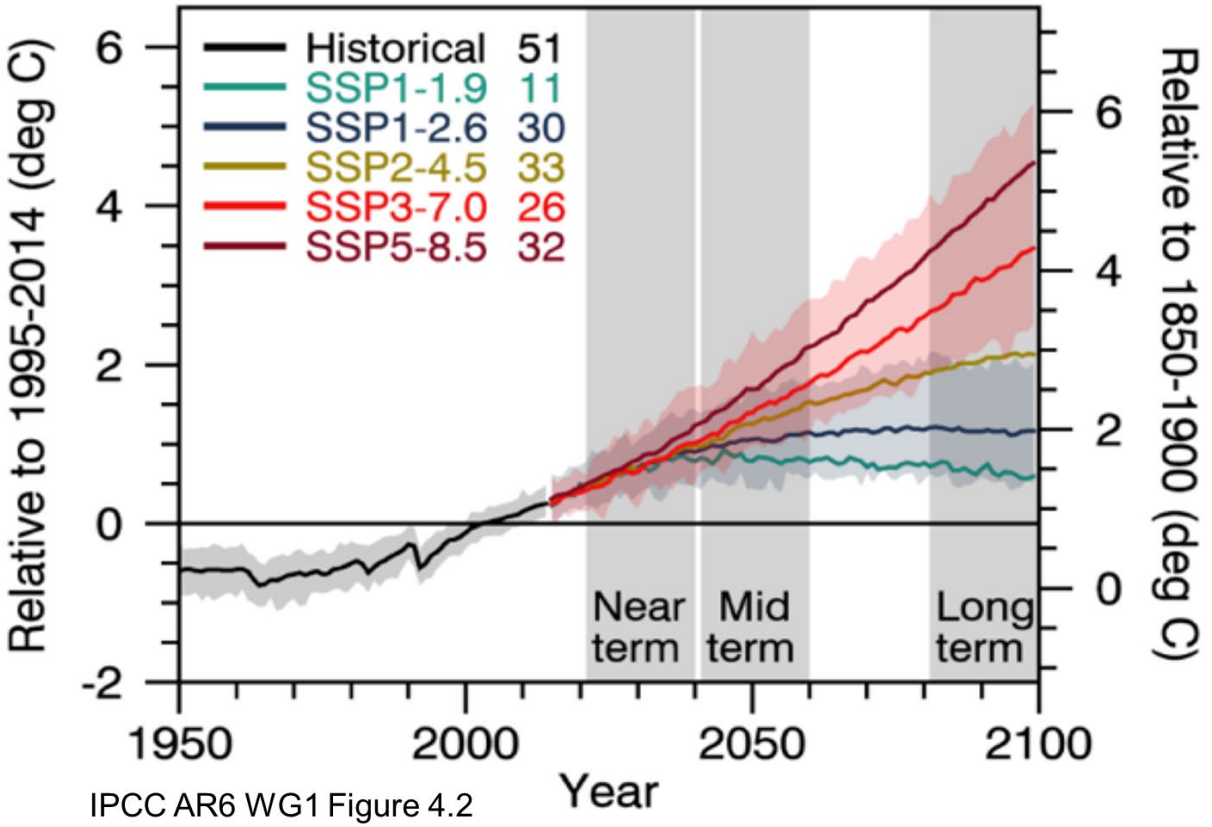








IPCC AR6 WGI Report

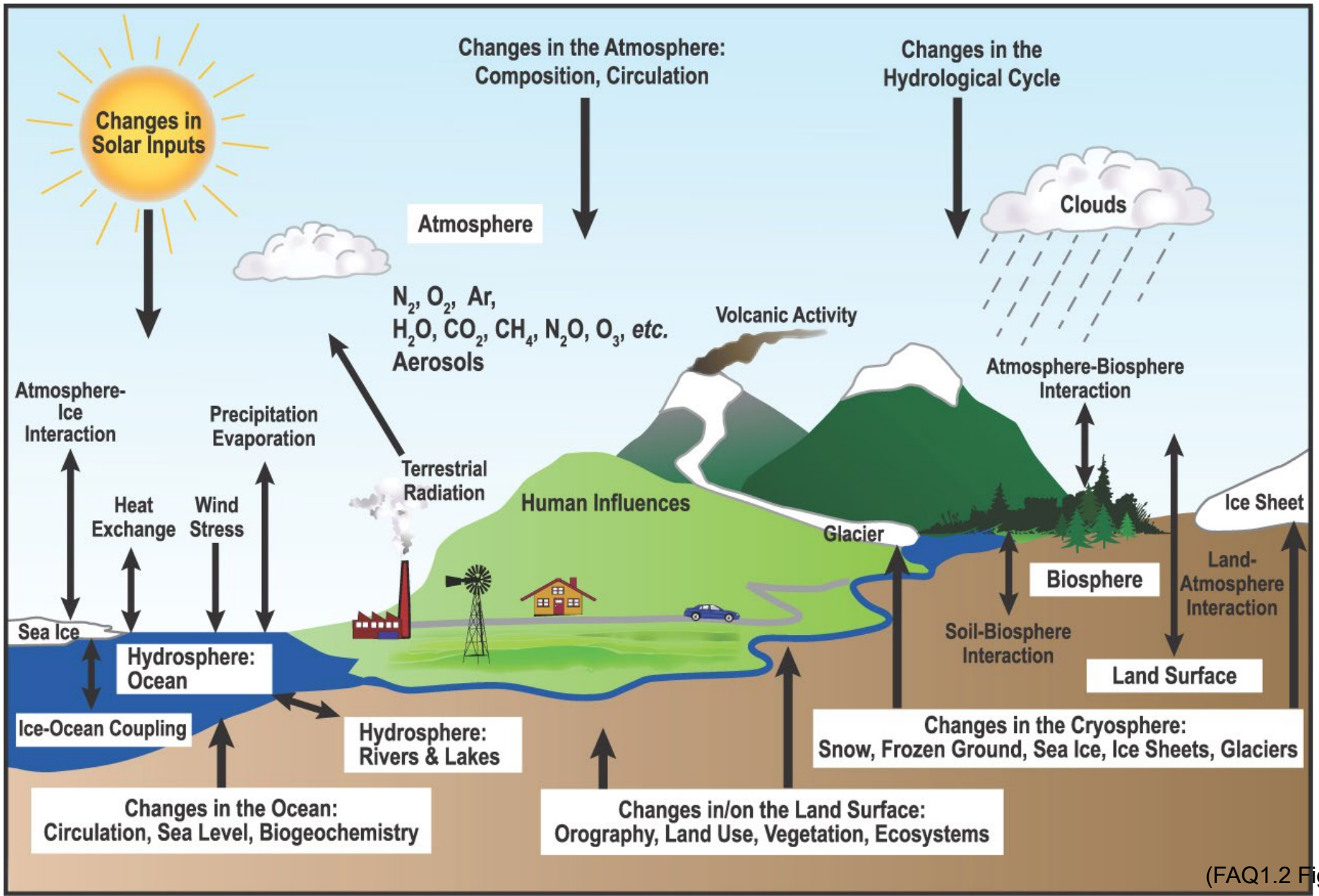


IPCC AR6 WG1 Figure 4.2

Today's contents

- Basics of future climate projections in a computer
- Advantages of a model with a higher horizontal resolution

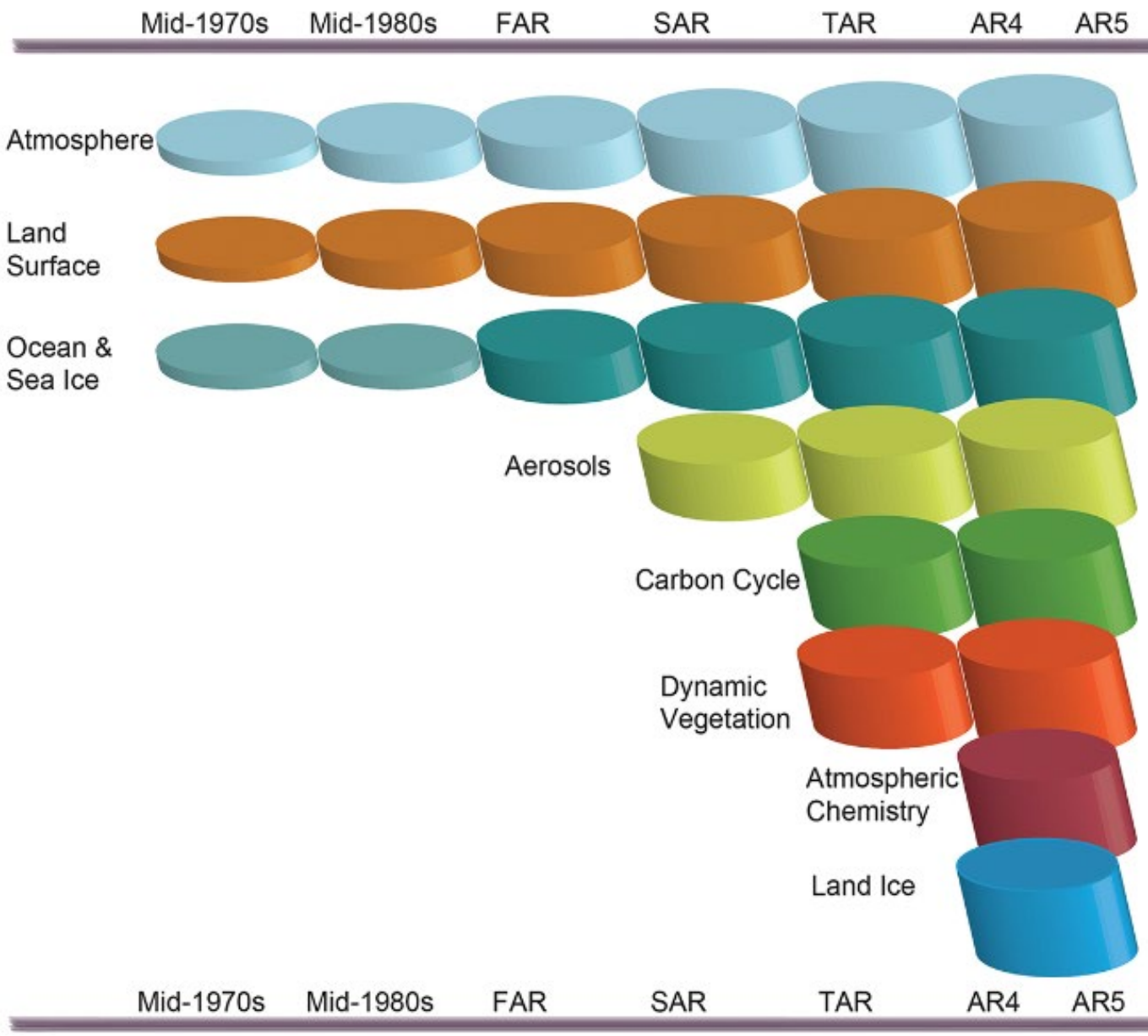
Processes in the Earth System

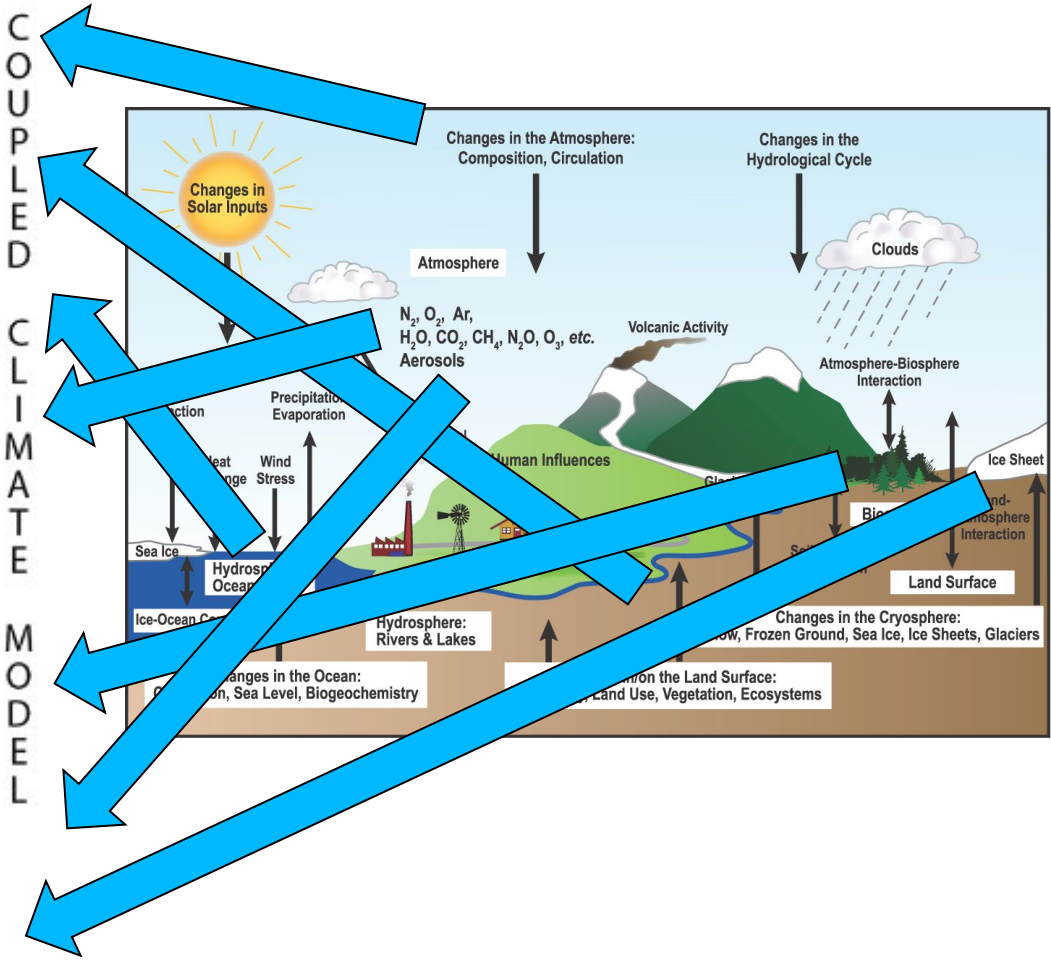


(FAQ1.2 Fig. 1: IPCC AR4 WGI 2007)

Meteorological Research Institute

Development of CGCMs





(Fig.1.13; IPCC 2013a).

Configuration of a GCM for future climate projections

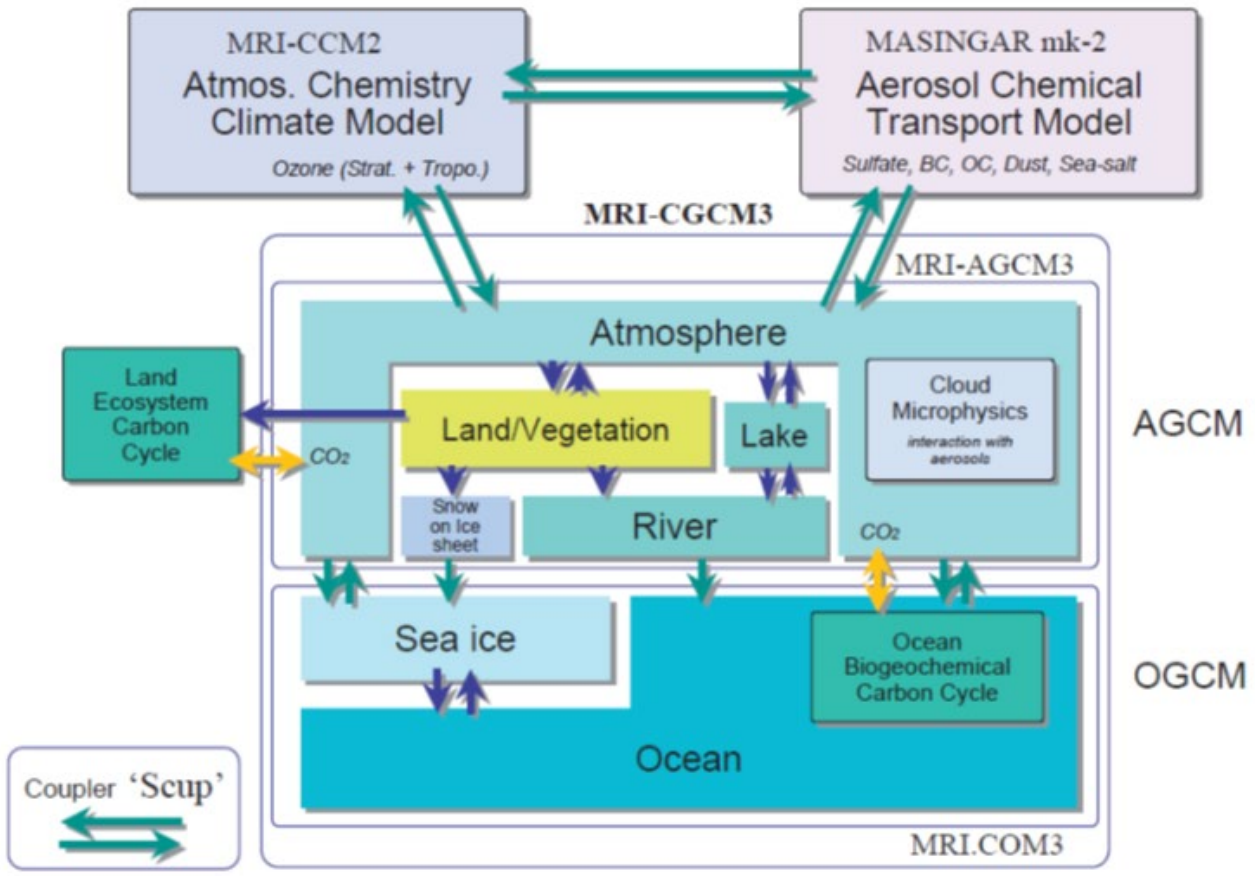


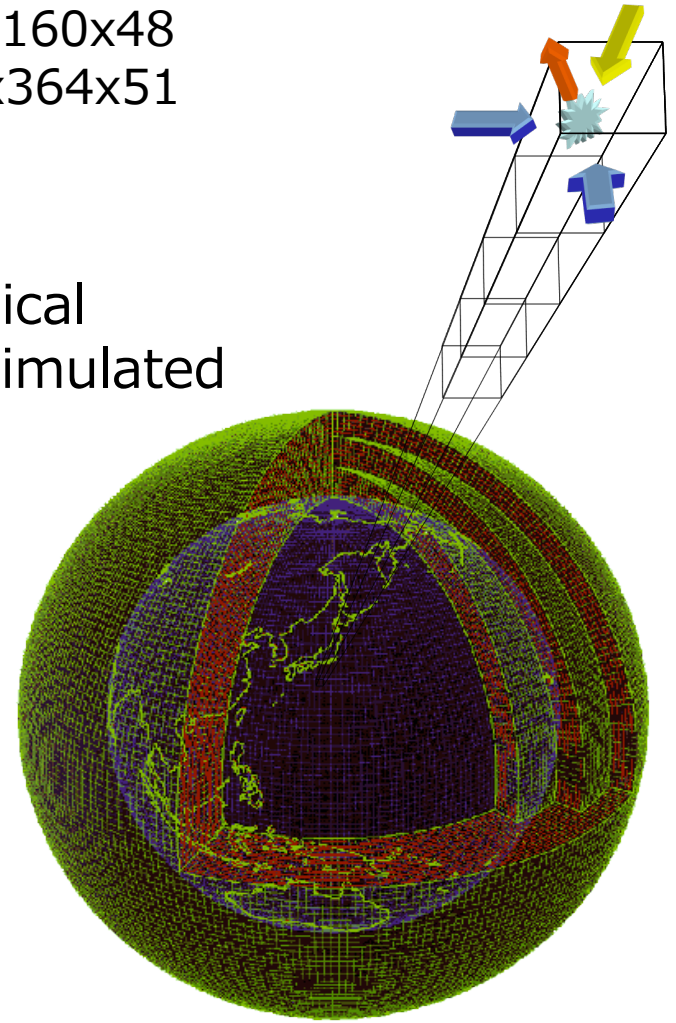
Figure 1 Configuration of the component models in MRI-ESM1. Green arrows denote data exchange with using Scup between the component models.

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)

How these processes are implemented in a computer?

Navier-Stokes equation

$$\begin{cases} \rho\dfrac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u}\cdot\nabla)\boldsymbol{u} - \nabla\cdot\boldsymbol{\sigma}(\boldsymbol{u},p) = \boldsymbol{f} & \text{in } \Omega\times(0,T) \\ \nabla\cdot\boldsymbol{u} = 0 & \text{in } \Omega\times(0,T) \\ \boldsymbol{u} = \boldsymbol{g} & \text{on } \Gamma_D\times(0,T) \\ \boldsymbol{\sigma}(\boldsymbol{u},p)\hat{\boldsymbol{n}} = \boldsymbol{h} & \text{on } \Gamma_N\times(0,T) \\ \boldsymbol{u}(0) = \boldsymbol{u}_0 & \text{in } \Omega\times\{0\} \end{cases}$$

Discretization of the equations above

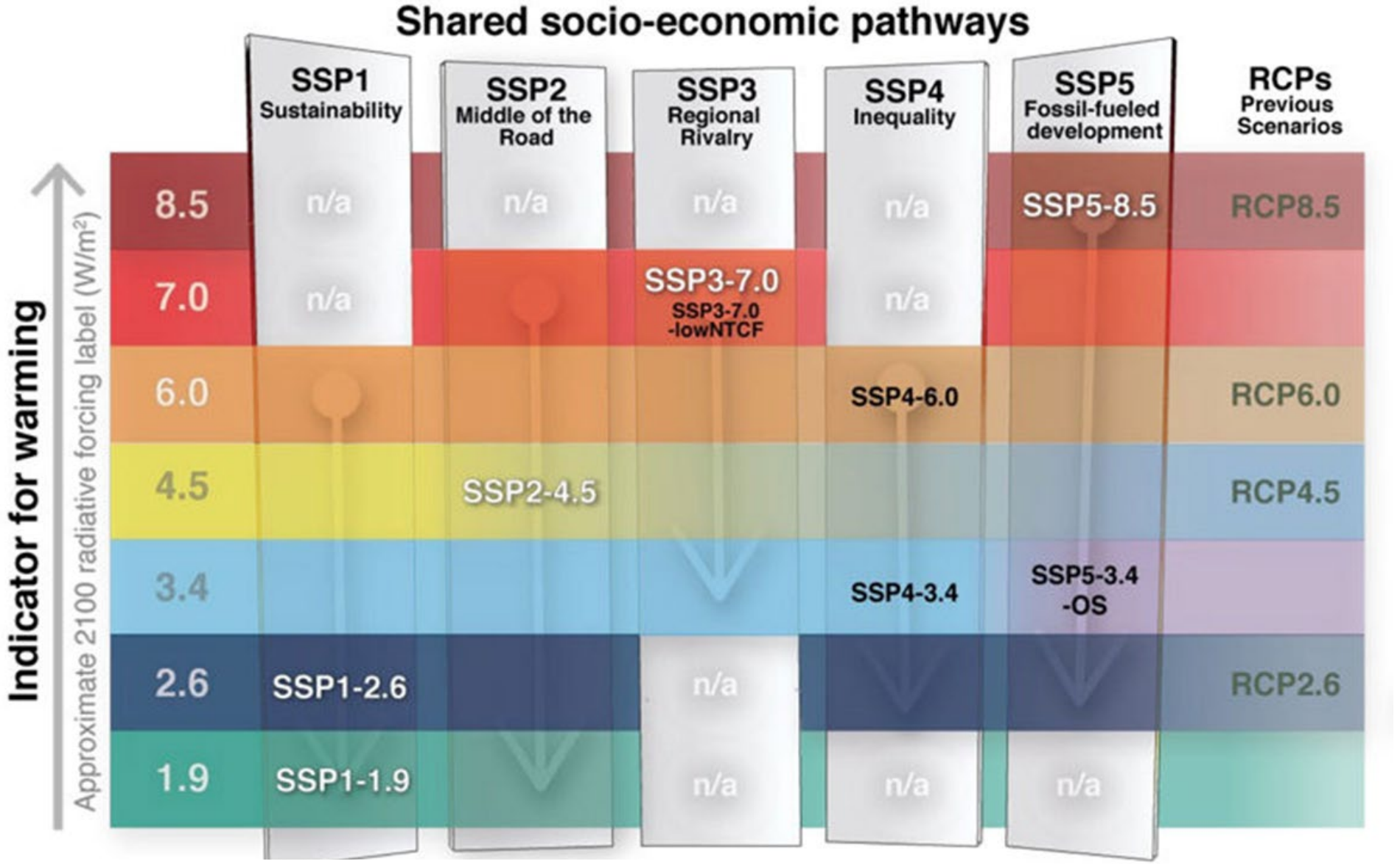
$$\frac{\partial u}{\partial t} \rightarrow \frac{u_j^{n+1} - u_j^n}{\Delta t}$$

$$\frac{\partial^2 u}{\partial x^2} = \frac{u_{j+1}^n - 2u_j^n + u_{j-1}^n}{\Delta x^2}$$

A code for a computer

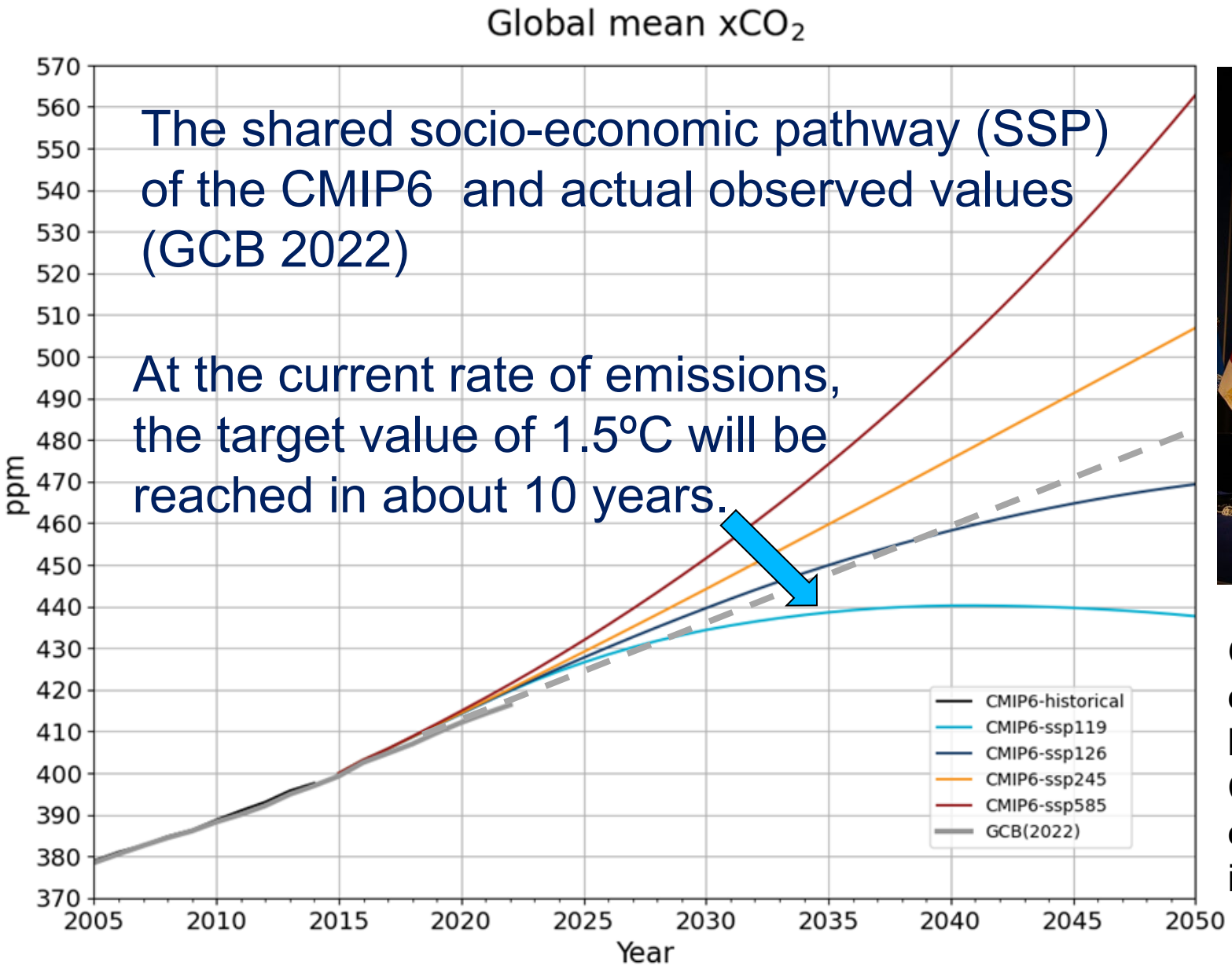
```
do j=1,latg2_
      do i=1,lonf2_
        ftsea(i,j)=ftsea(i,j)+tsea(i,j)*weight(ifstep)
        fsheleg(i,j)=fsheleg(i,j)+sheleg(i,j)*weight(ifste
        ftg3(i,j)=ftg3(i,j)+tg3(i,j)*weight(ifstep)
        fzorl(i,j)=fzorl(i,j)+zorl(i,j)*weight(ifstep)
        fplantr(i,j)=fplantr(i,j)+plantr(i,j)*weight(ifstep)
        fcv(i,j)=fcv(i,j)+cv(i,j)*weight(ifstep)
        do il = 1, 4

falbedo(i,j,il)=falbedo(i,j,il)+albedo(i,j,il)*weight(ifstep
        enddo
        ff10m(i,j)=ff10m(i,j)+f10m(i,j)*weight(ifstep)
        fcanopy(i,j)=fcanopy(i,j)+canopy(i,j)*weight(ifs
        isl=nint(slmsk(i,j))+1
        islmsk(i,j,isl)=islmsk(i,j,isl)+1
        if(cvb(i,j).ne.cvb0) then
          fcvb(i,j)=fcvb(i,j)+cvb(i,j)*weight(ifstep)
          wcvb(i,j)=wcvb(i,j)+weight(ifstep)
        endif
```

Emission scenario SSP



IPCC (2021) Cross Chapter Box 1.4, Figure 1.

Historical and future global mean CO_2



November 6-18, 2022 in Sharm el-Sheikh, Egypt

Given the current emissions rate and global efforts to reduce emissions, it is not very likely that SSP2-4.5 will be exceeded. COP27 reported an increase of 2.5ºC by the end of the century. COP27 reported an increase of 2.5ºC at the end of the century.

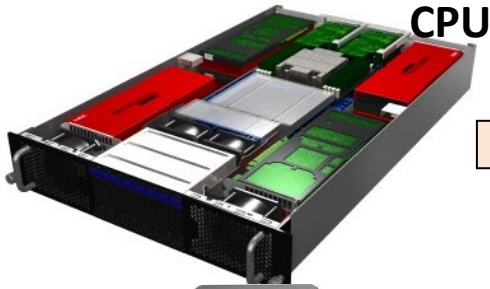
Supercomputer is essential for climate projections

Multi-architecture supercomputer based on AMD EPYC CPUs, combined with accelerators, Earth Simulator 4

- Cores: total 136,960 processor cores of AMD EPYC 7742 (Zen2)
- GPUs: 64 of Nvidia A100
- Memory: total 556.5 TB
- Performance: 19.5 PFLOPS
- Interconnection: 200 Gb/s
- Release: 2021

TOP 500 The List.

Rank #95 (#29



Operational in Deutscher Wetterdienst since 2019 as well

https://www.r-ccs.riken.jp/en/fugaku/

Needs for high-resolution models

In order to make a progress in adaptation planning, we need

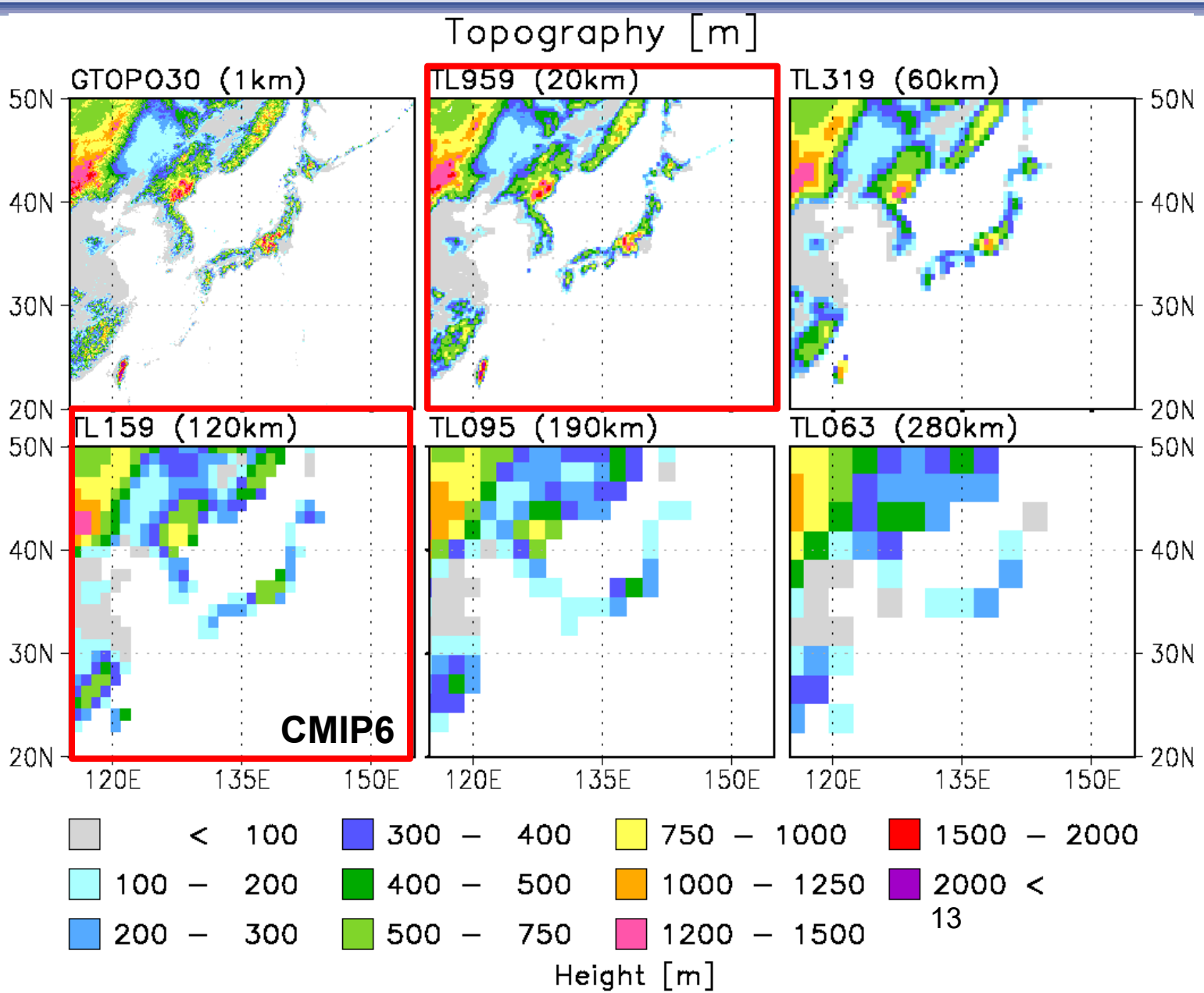
1. to project future weather extremes such as typhoon and heavy rainfall triggering natural disasters, and
2. to assess their impact on our lives.

・representation of topography depends on resolution

・low resolution models often fail to reproduce precipitation systems such as tropical cyclones, stationary front systems, and blocking

・high resolution models generally have better mean climate

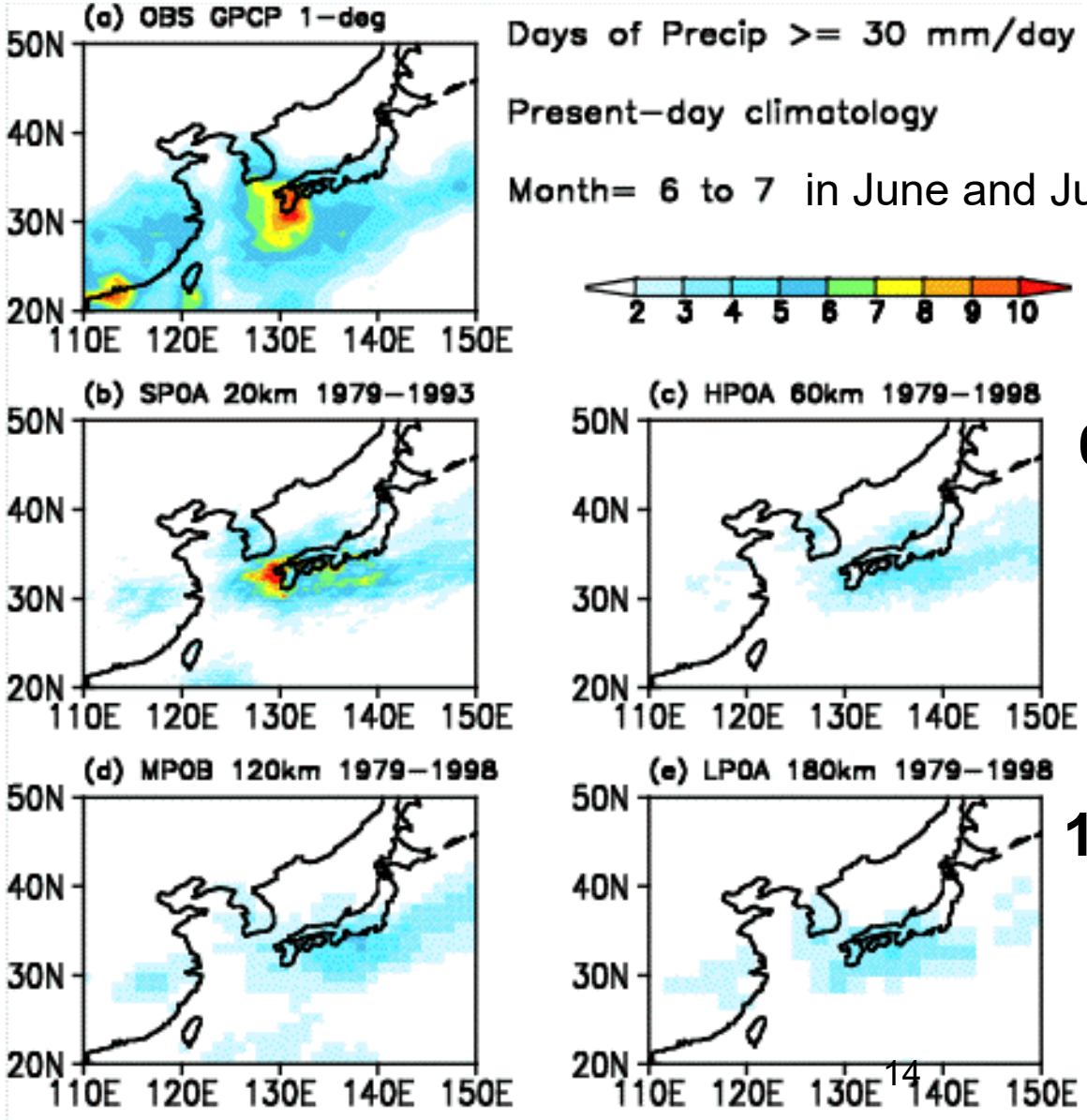
Topography dependent on resolutions



Meteorological Research Institute

Days of precipitation greater than 30mm/day between resolutions

Observation GPCP



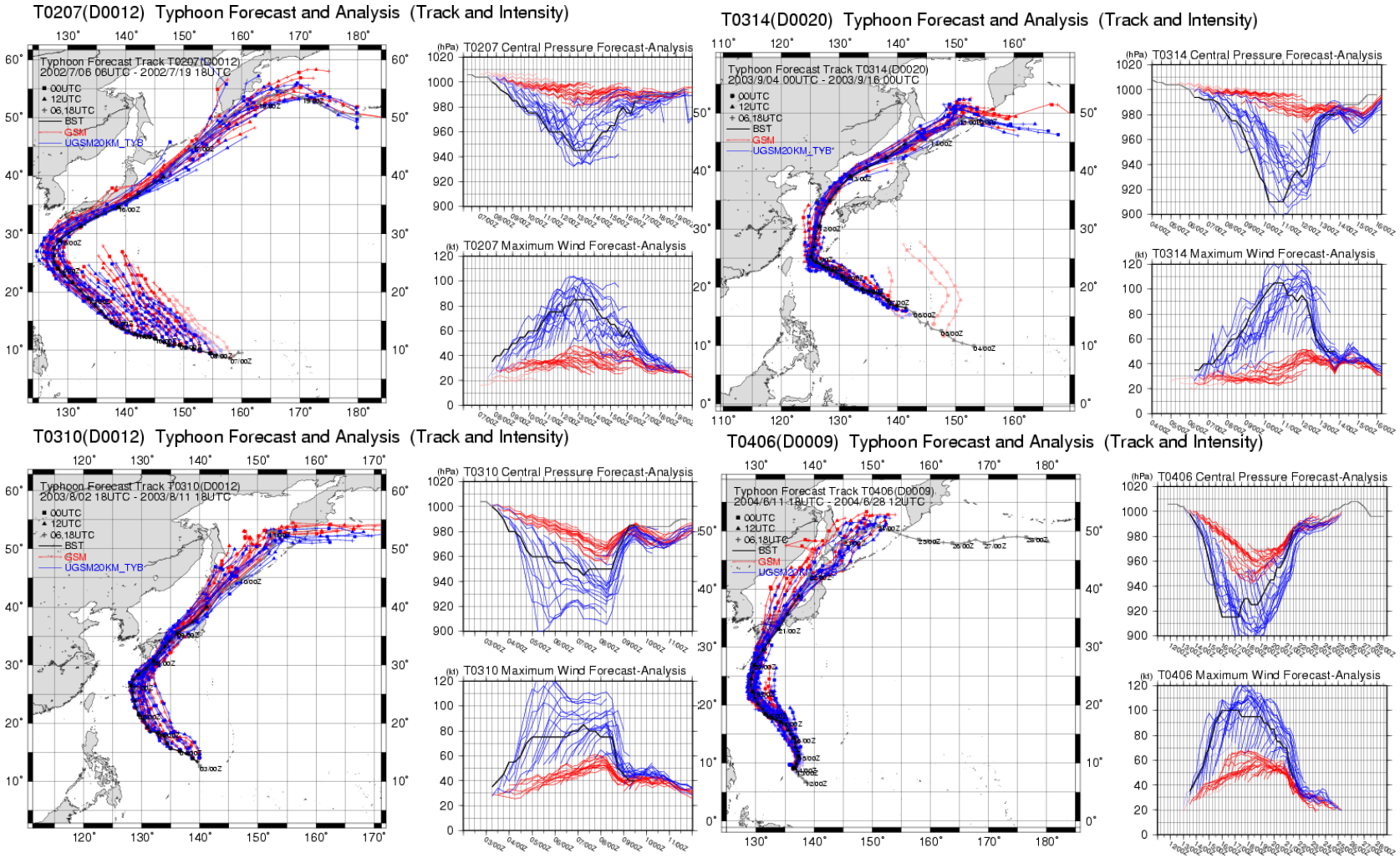
20km

60km

120km

180km

Typhoon prediction between 60km and 20km mesh models

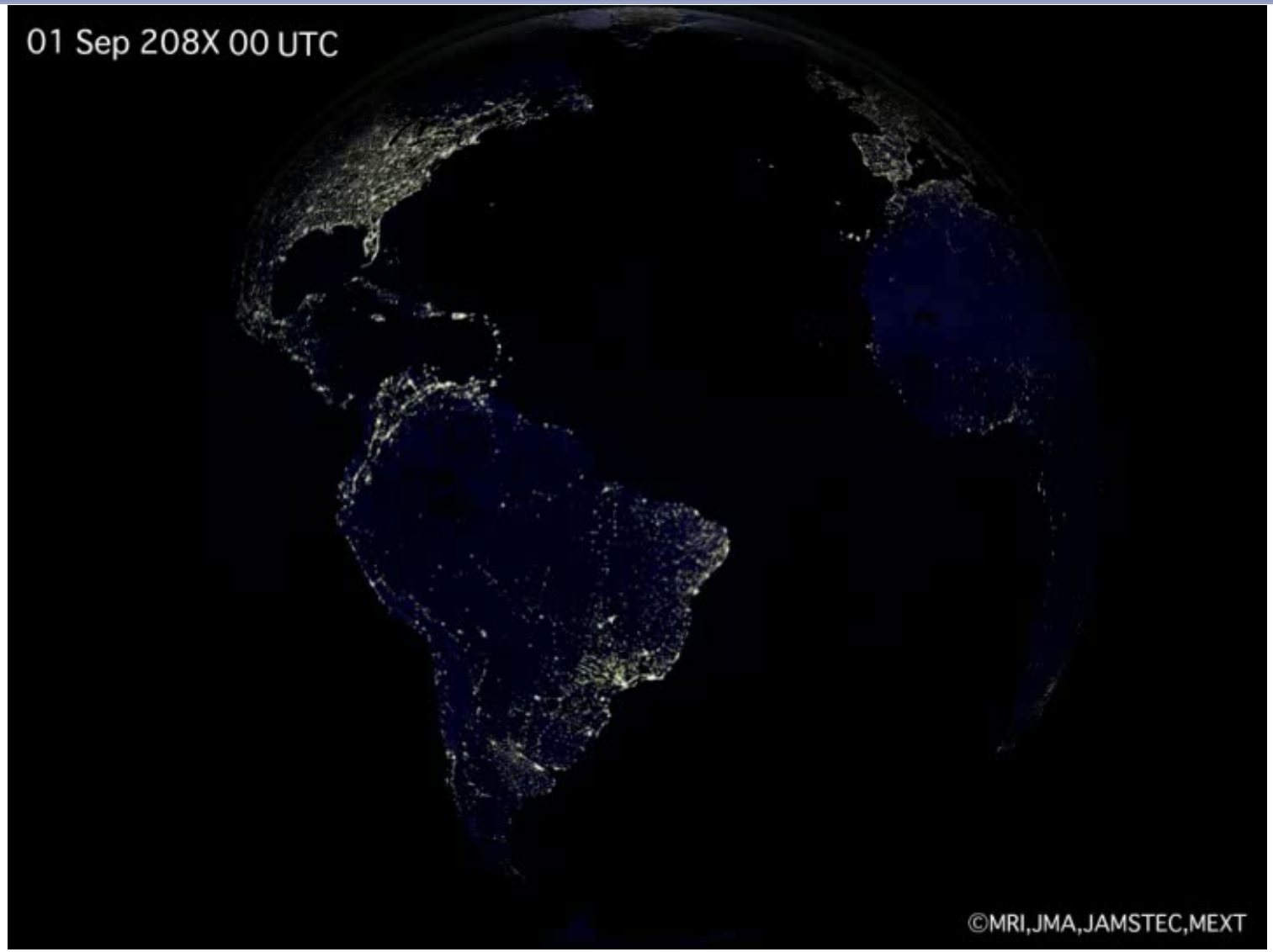


Weak central pressure and weak max. wind speed in the 60km mesh model. Reproducibility in the 20km mesh model is better.

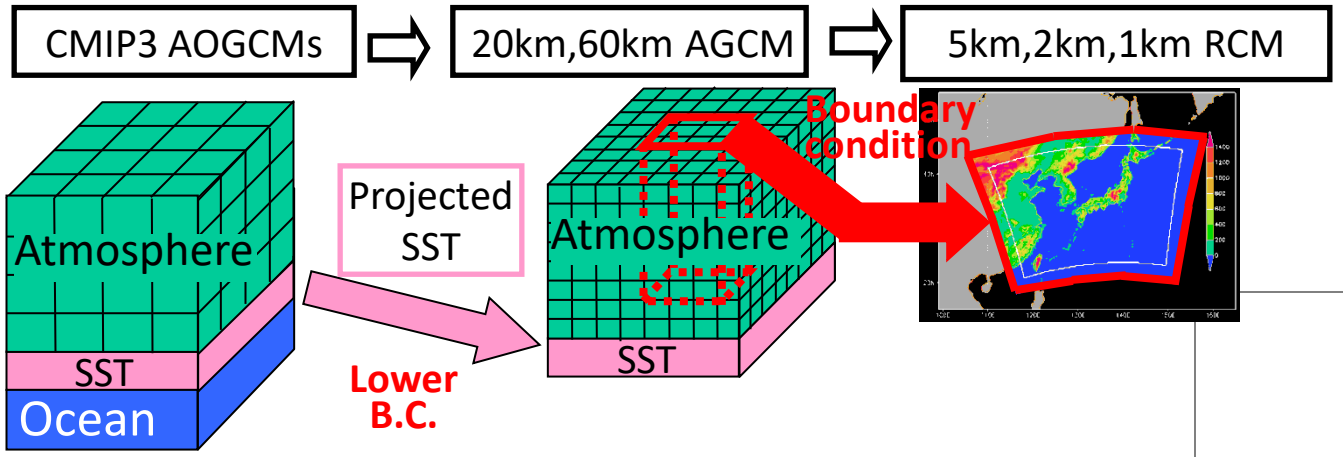
60km mesh model

20km mesh model

Tropical cyclones in the 20-km AGCM

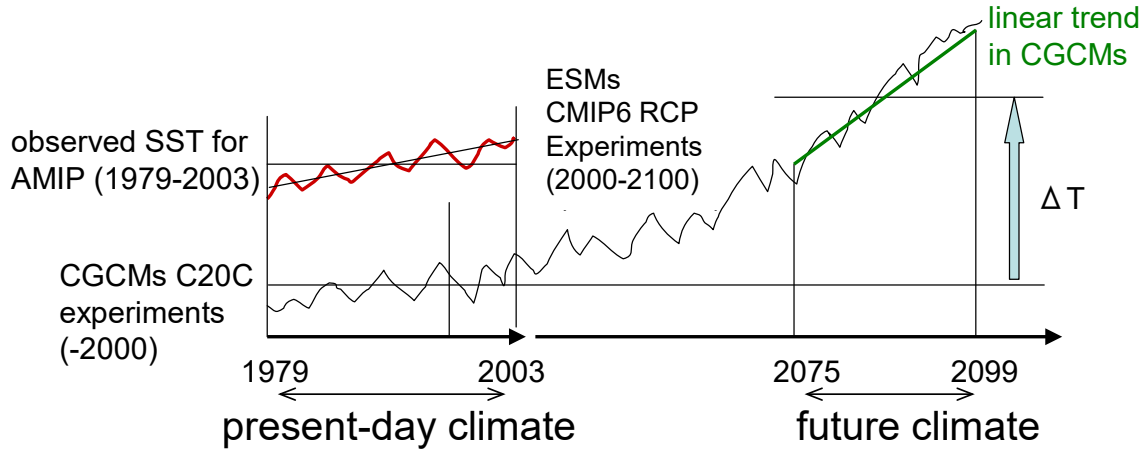


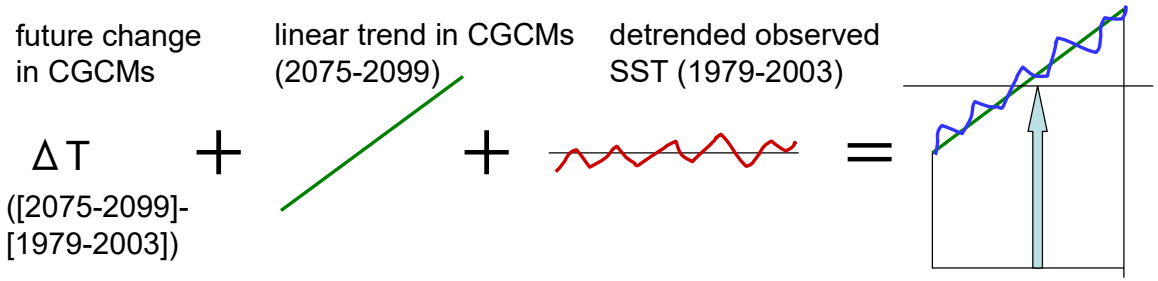
Time-Slice Experiments with high-horizontal resolution



AGCM/RCM is a climate model version of the JMA operational NWP models

- Present-day climate experiment (1979-2003)
  - the observed sea surface temperature (SST) and sea-ice concentration
- Future climate experiment (2075-2099)
  - the warming in the SST for the CMIP5/6 multi-model ensemble mean is added to the observed SST





Mizuta et al. (2008)

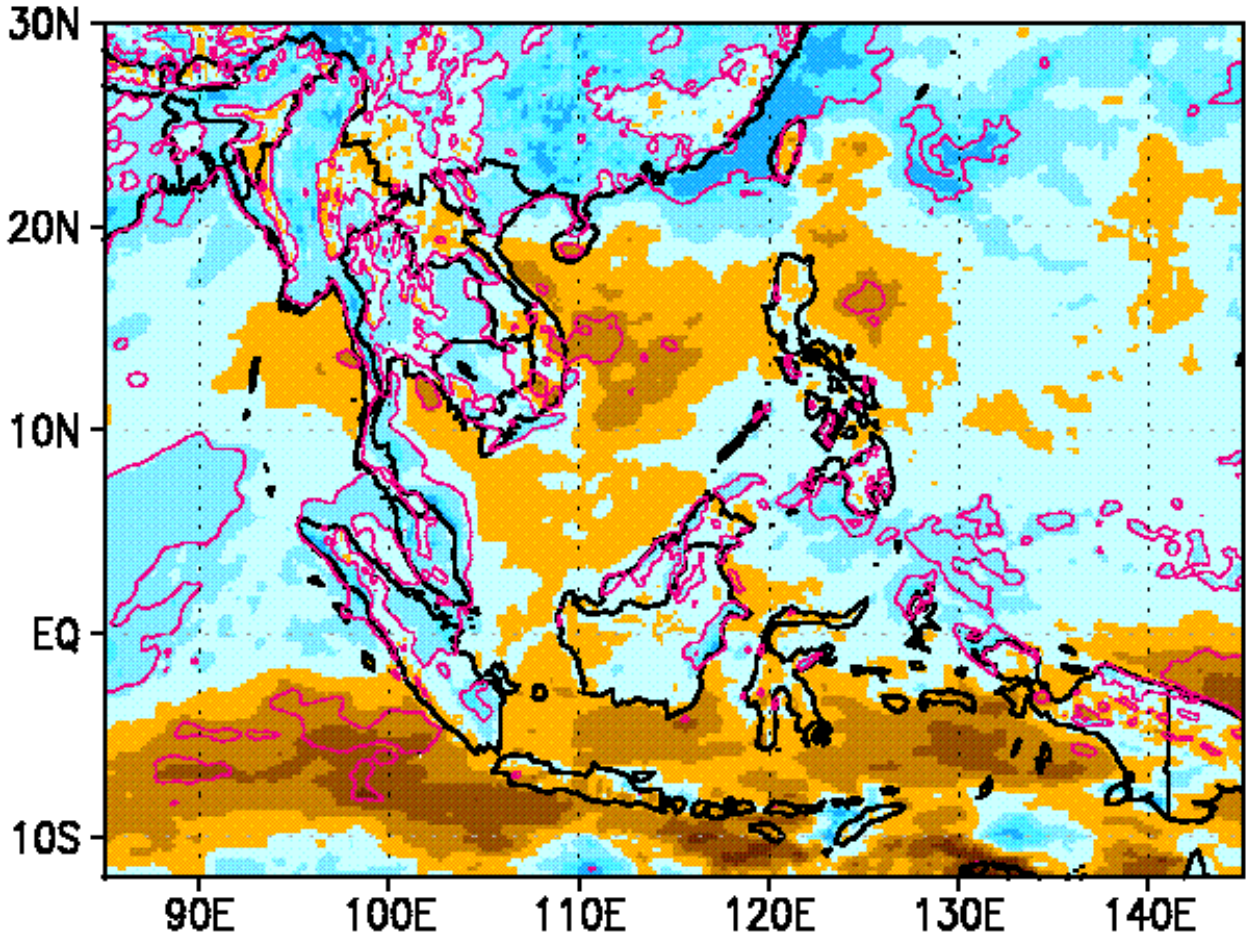
Future climate projections

June-Aug Precipitation in a future climate

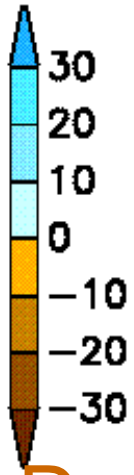
Dr. Kusunoki

Precipitation Change ratio (%) Month=6 to 8
Present SP0A: 1979–2003
Future SF0A: 2075–2099
Contour: 95% significant

Future: 2075-2099



Increase



Change
=(F-P)/P (%)

Decrease

Malaysia

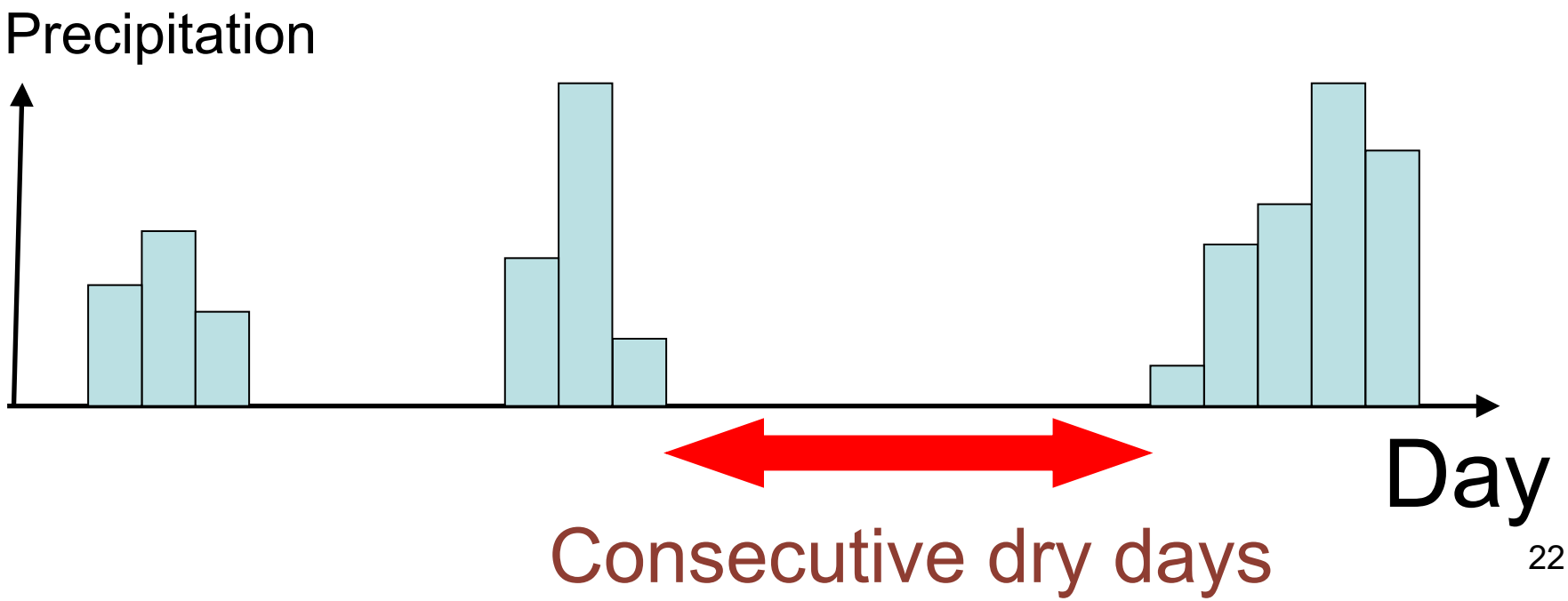
Meteorolo
Research
Institute

A drought index

Dr. Kusunoki

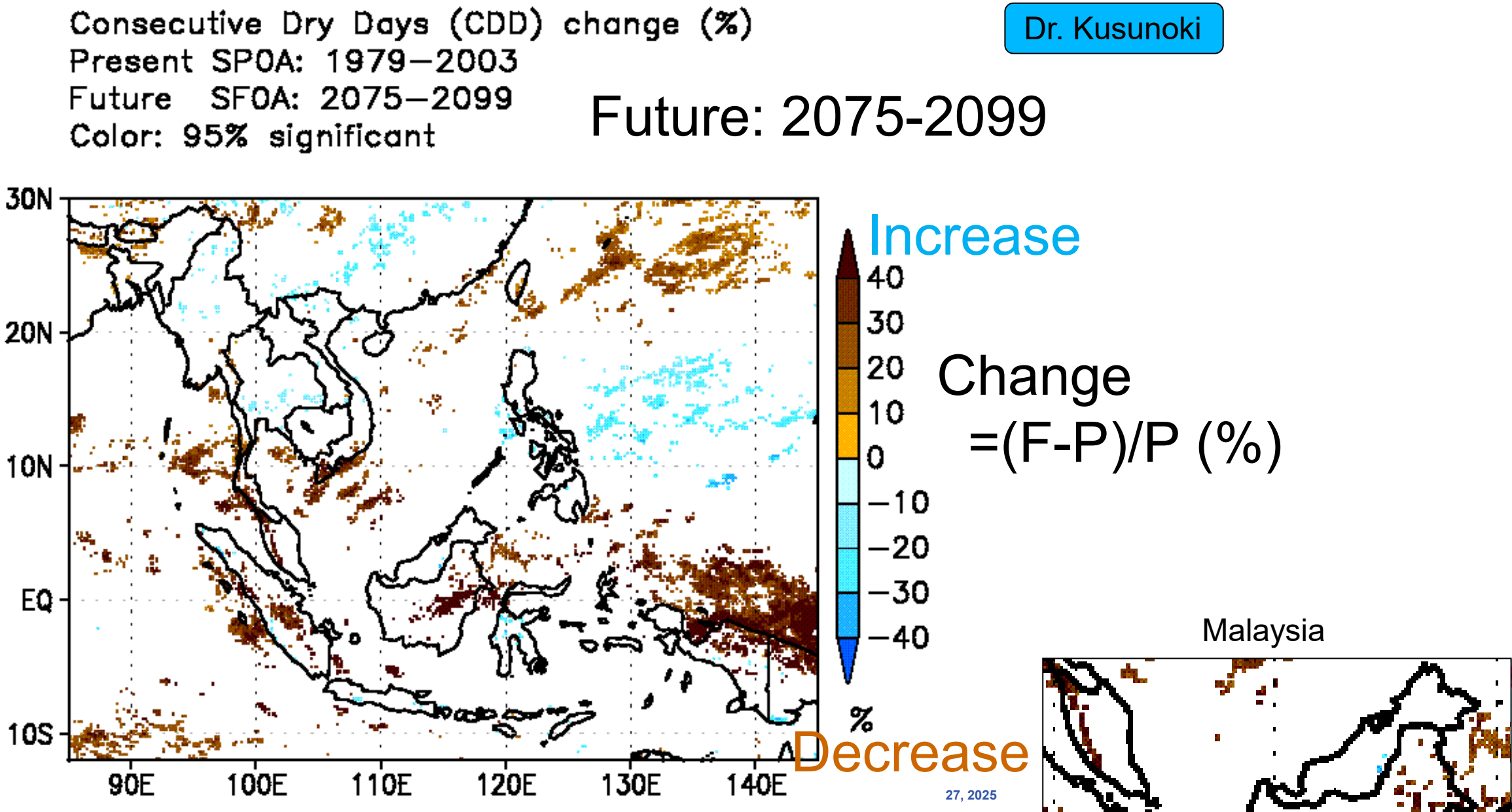
Maximum number of consecutive dry days (CDD)

where "dry day": day of precipitation < 1 mm/day



Change in consecutive dry days in a future climate

Dr. Kusunoki



Simple daily precipitation intensity index (SDII)

Dr. Kusunoki

$$\text{SDII} = \frac{\text{Annual total precipitation}}{\text{Number of rain day}}$$

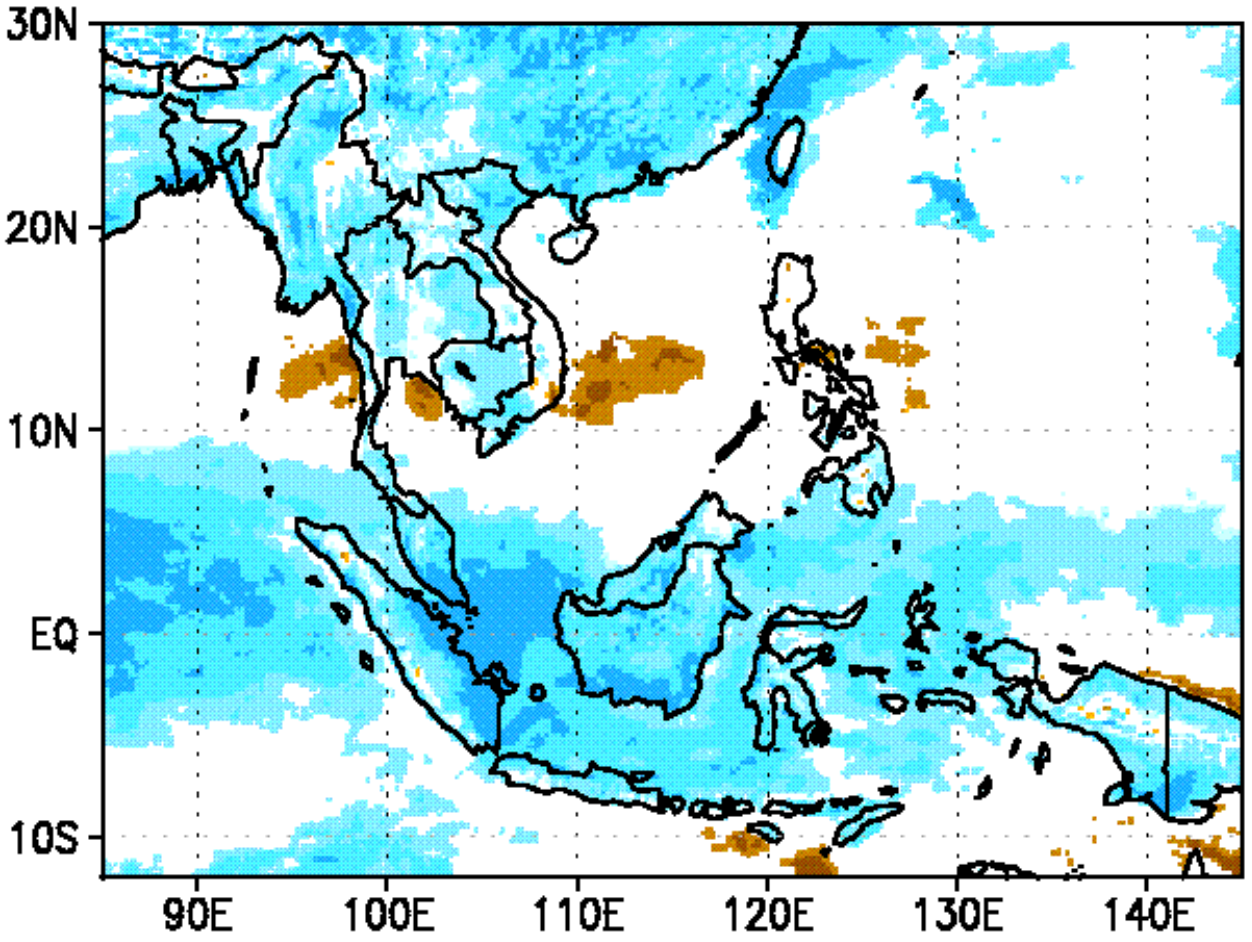
where “rain day”: day of precipitation ≧ 1 mm/day

Change in precipitation intensity in a future climate

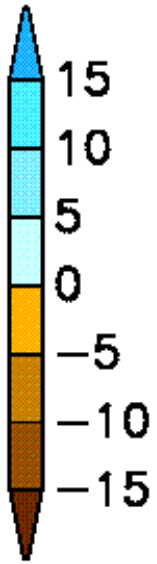
Dr. Kusunoki

Simple Daily precip Int Index (SDII) change (%)
Present SP0A: 1979–2003
Future SF0A: 2075–2099
Color: 95% significant

: 2075-2099



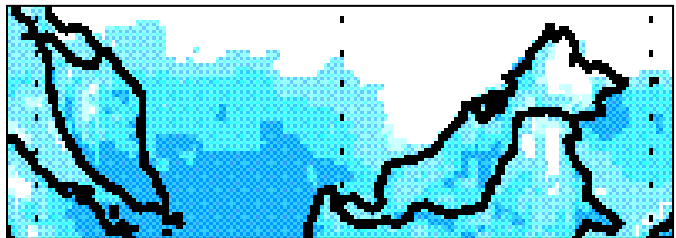
Increase



Change
=(F-P)/P (%)

Decrease

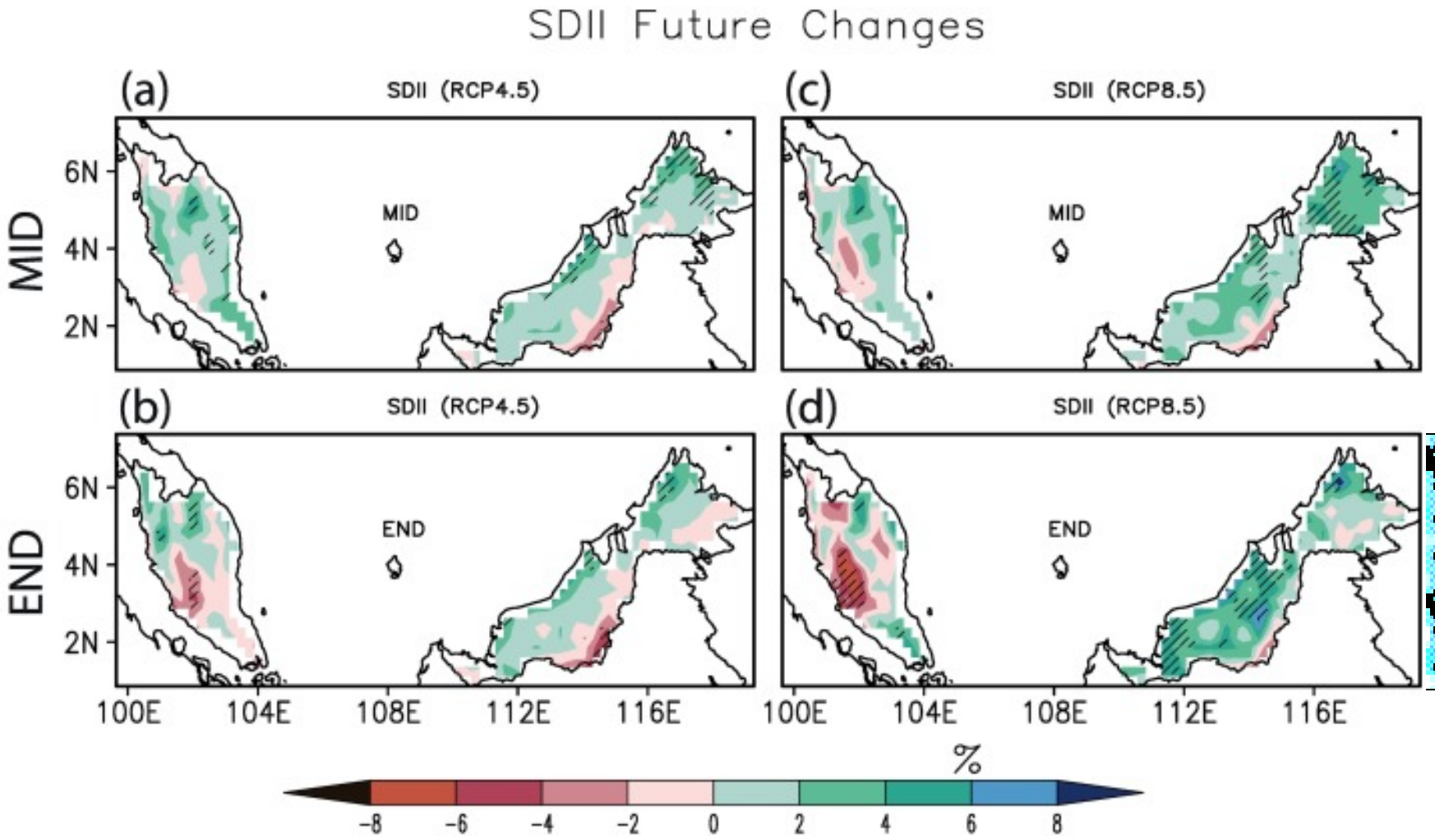
Malaysia

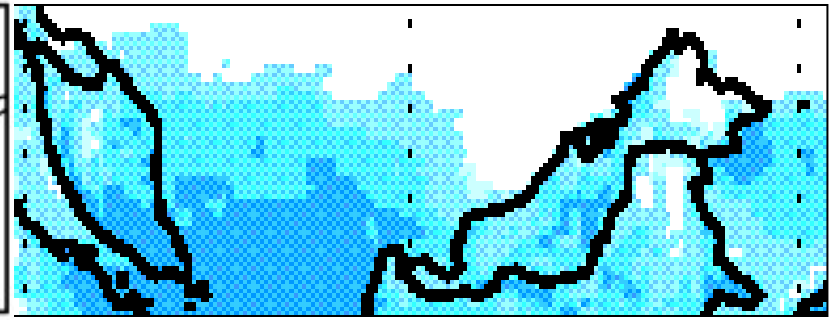


Meteorolo
Research
Institute

ruary 27, 2025

Changes in precipitation with multi-model ensemble





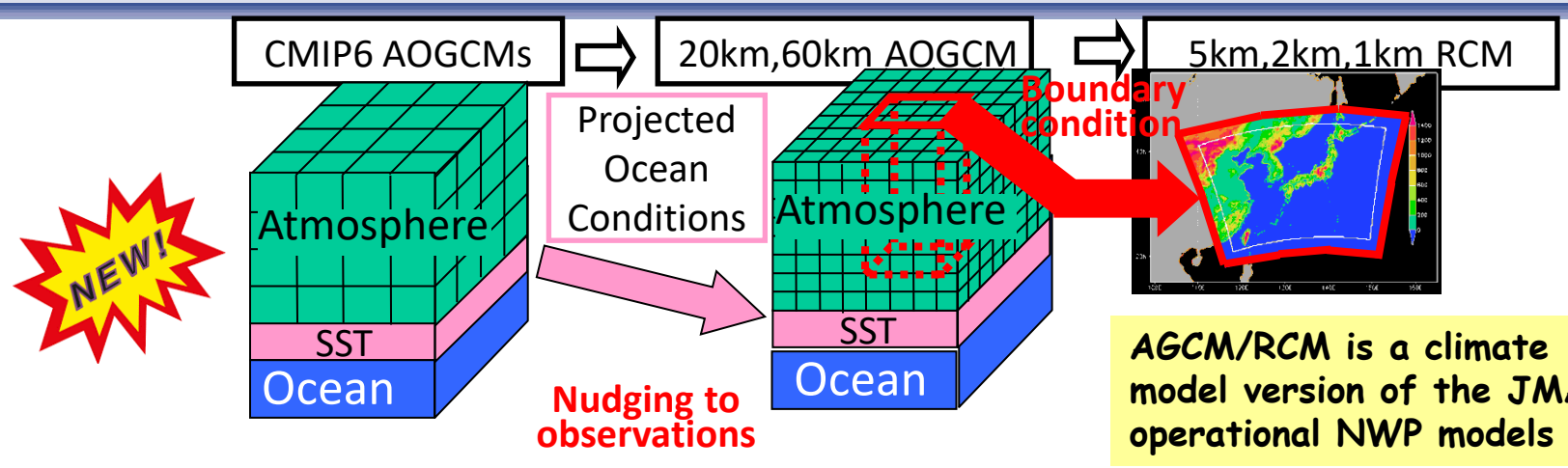
(Ngai et al., 2020)

SENTAN Theme-3: future climate projections in Japan

Time-sequential experiments

AOGCM

- (1950-2100)

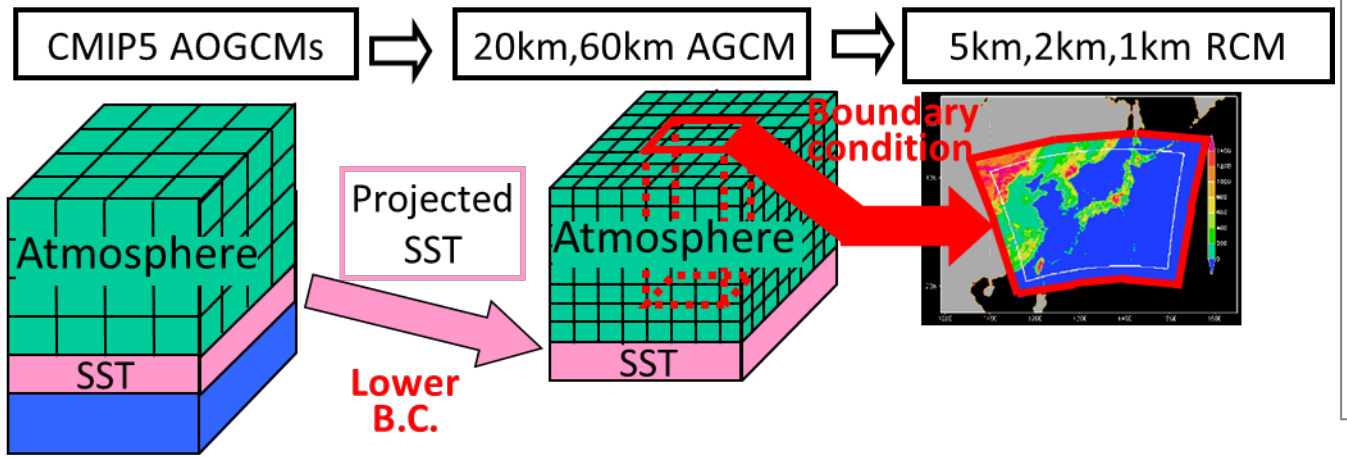


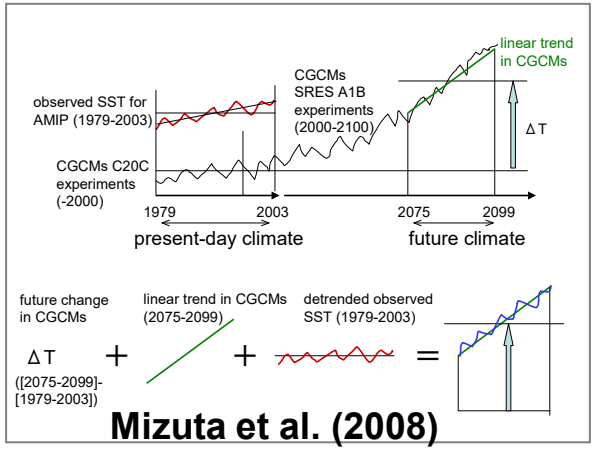
AGCM/RCM is a climate model version of the JMA operational NWP models

Time-sliced experiments

AGCM

- Present-day climate (1979-2003)
- Future climate (2075-2099)



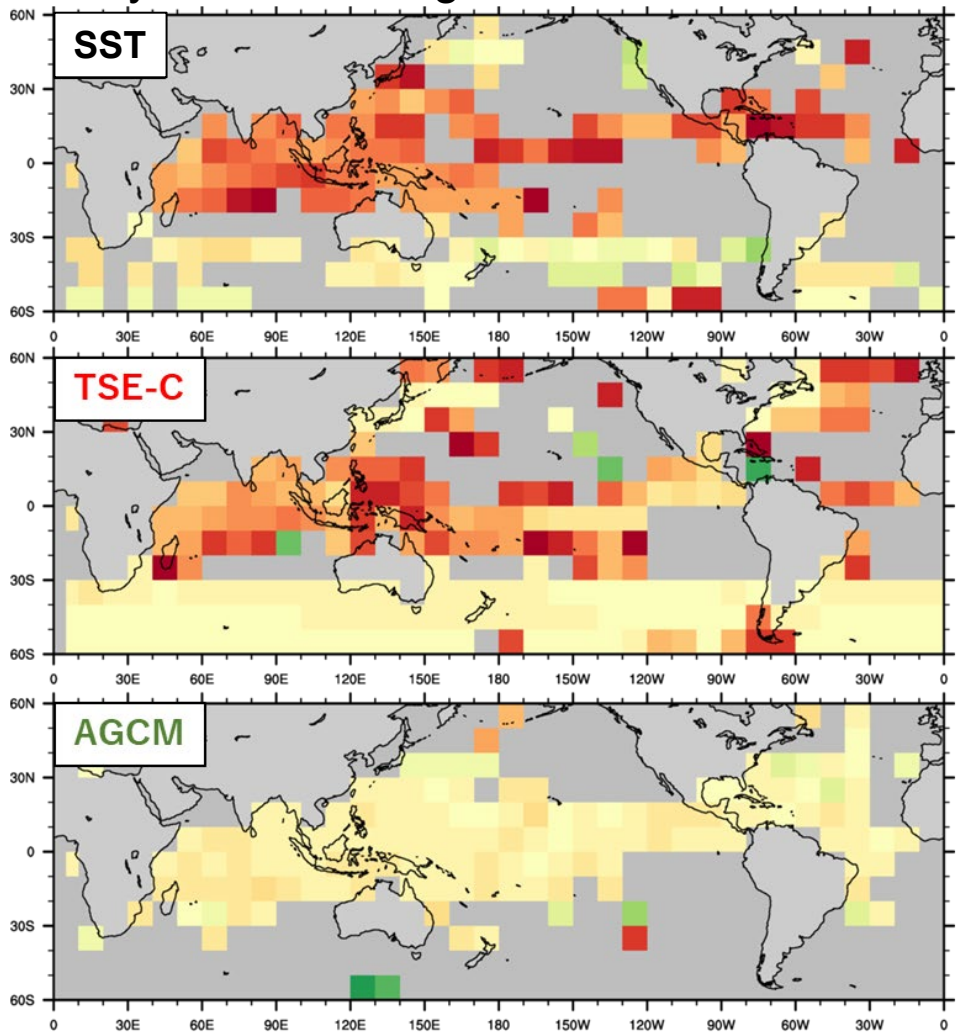


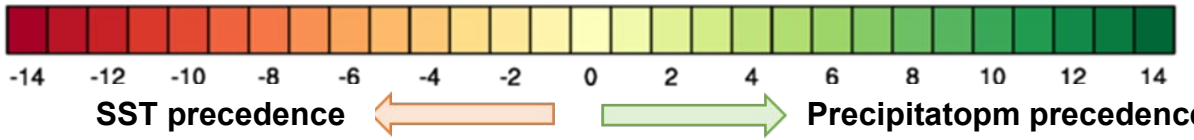
Mizuta et al. (2008)

DDS under the CMIP6 conditions can be performed now!

Improvement in interactions btw atmosphere and oceans

Number of days when the lag correlation reaches the maximum





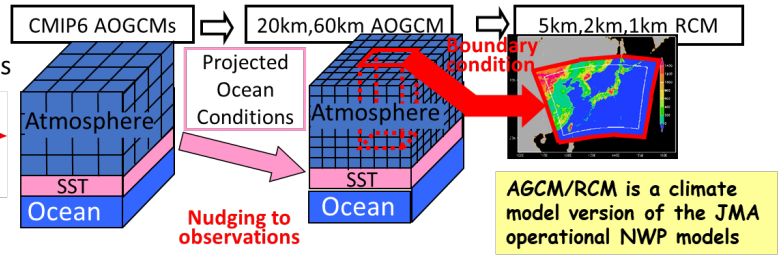
advanced studies of climate change projection

Time-sequential experiments

AOGCM

- (1950-2100)

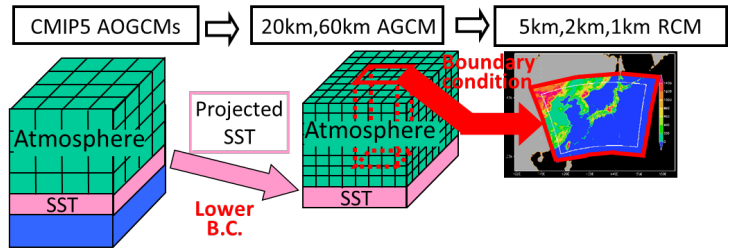
NEW!



Time-sliced experiments

AGCM

- Present-day climate (1979-2003)
- Future climate (2075-2099)



DDS under the CMIP6 conditions can be performed now!

Please contact me if you are interested in analyzing future climate in Malaysia.

Thank you for your attention