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

～Advantages of a high resolution model～

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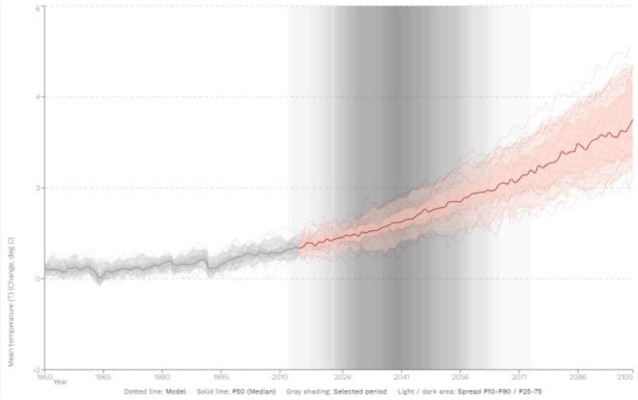
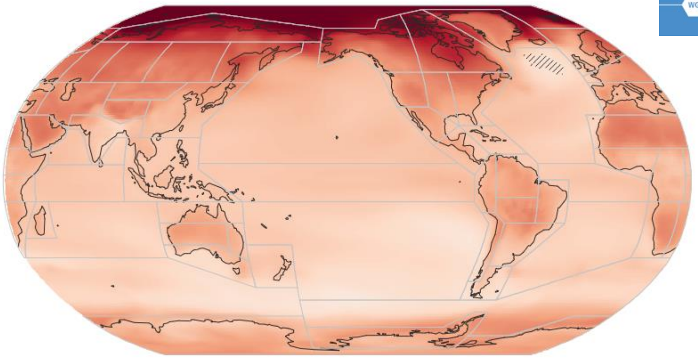
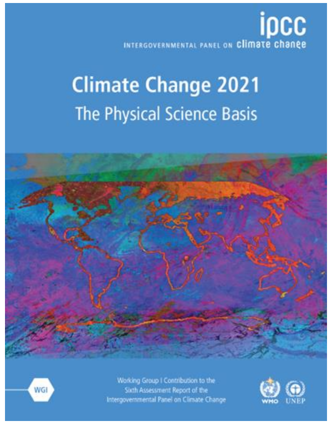
advanced studies of climate change projection

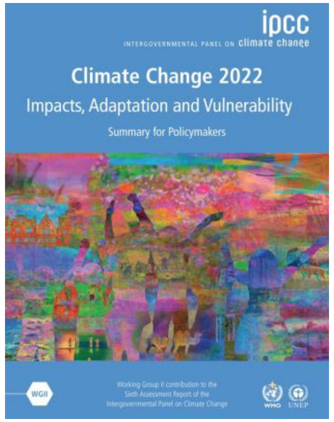
How is a future climate projected?

IPCC AR6 WGI Interactive Atlas

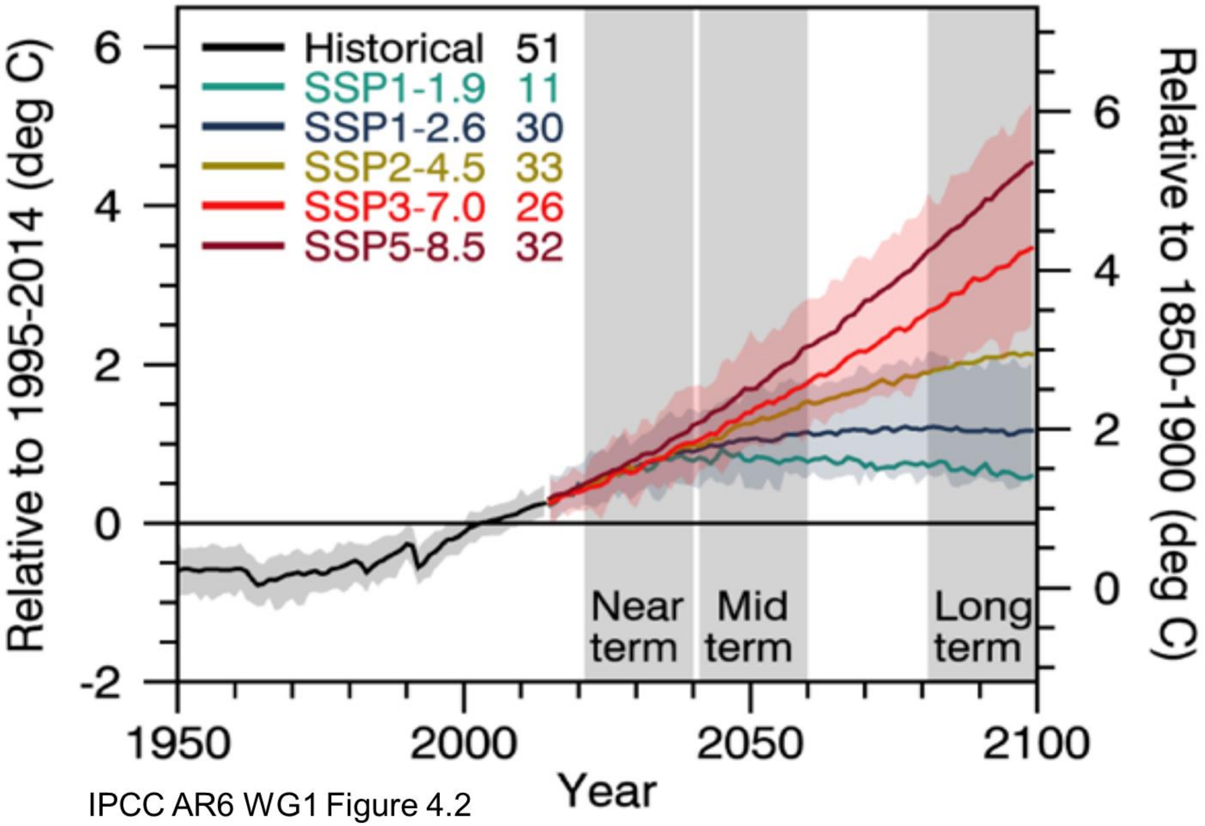








IPCC AR6 WGI Report

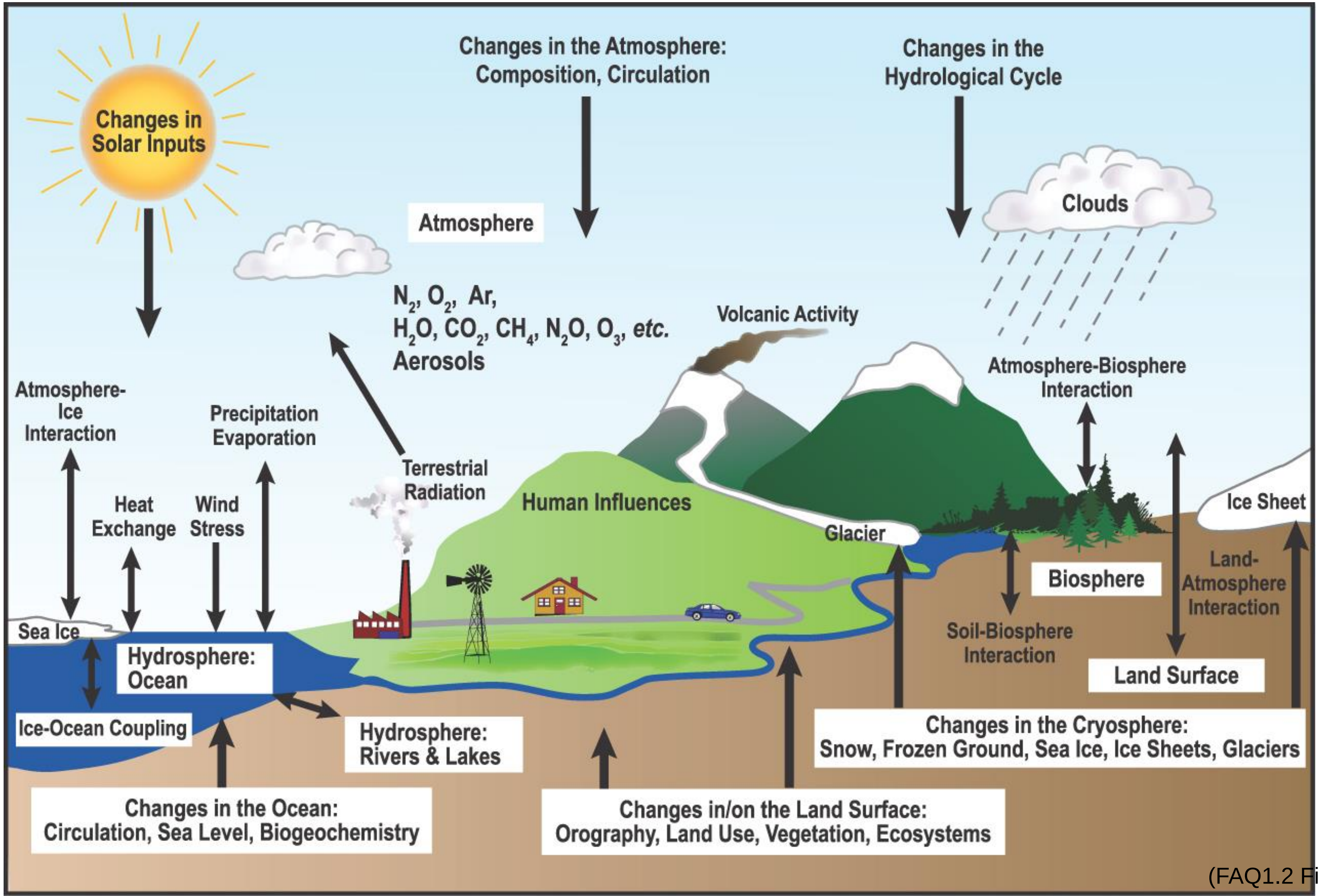


IPCC AR6 WG1 Figure 4.2

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



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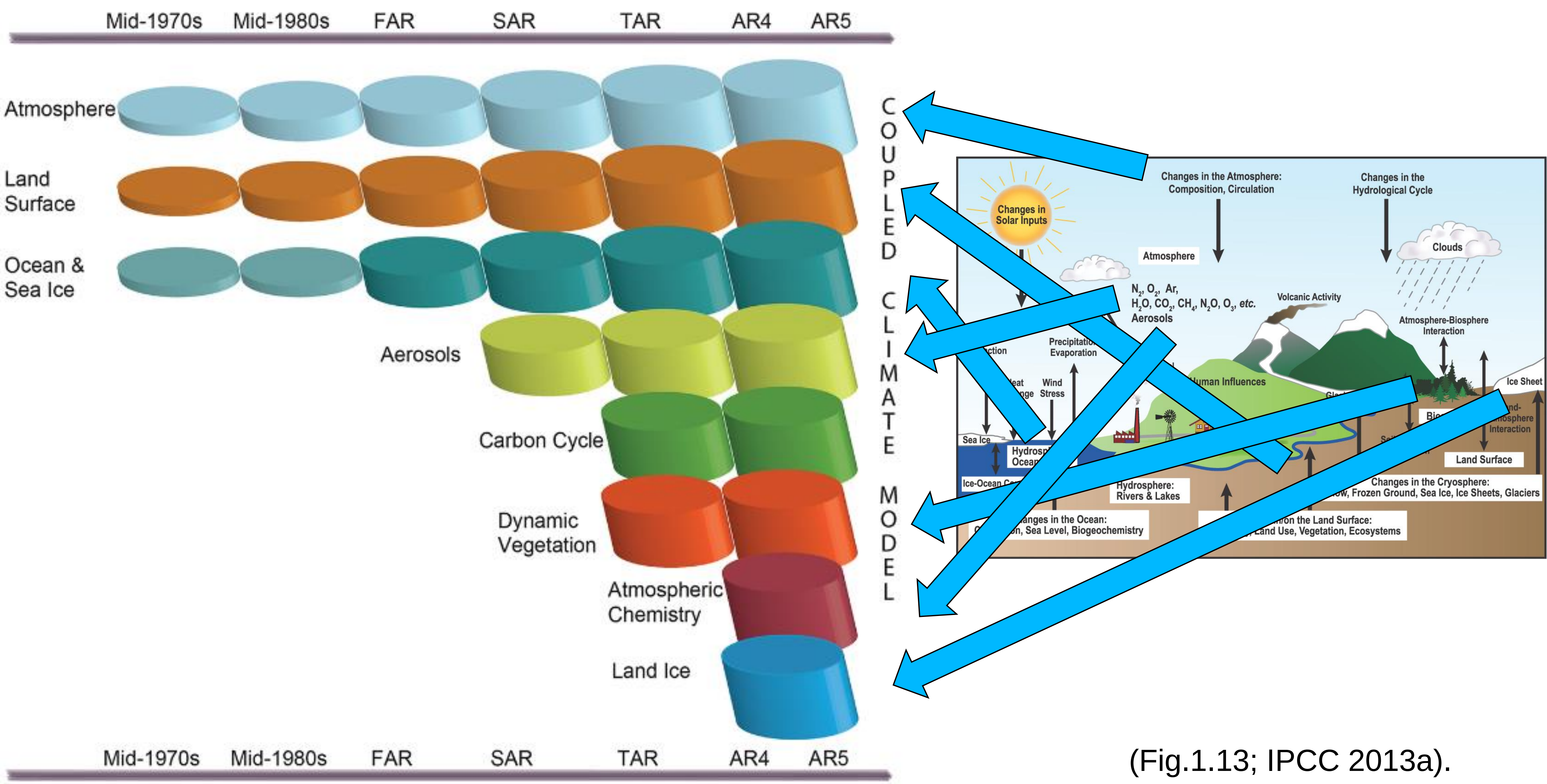
(FAQ1.2 Fig. 1: IPCC AR4 WGI 2007)

Development of CGCMs



(Fig.1.13; IPCC 2013a).

Configuration of a GCM for future climate projections

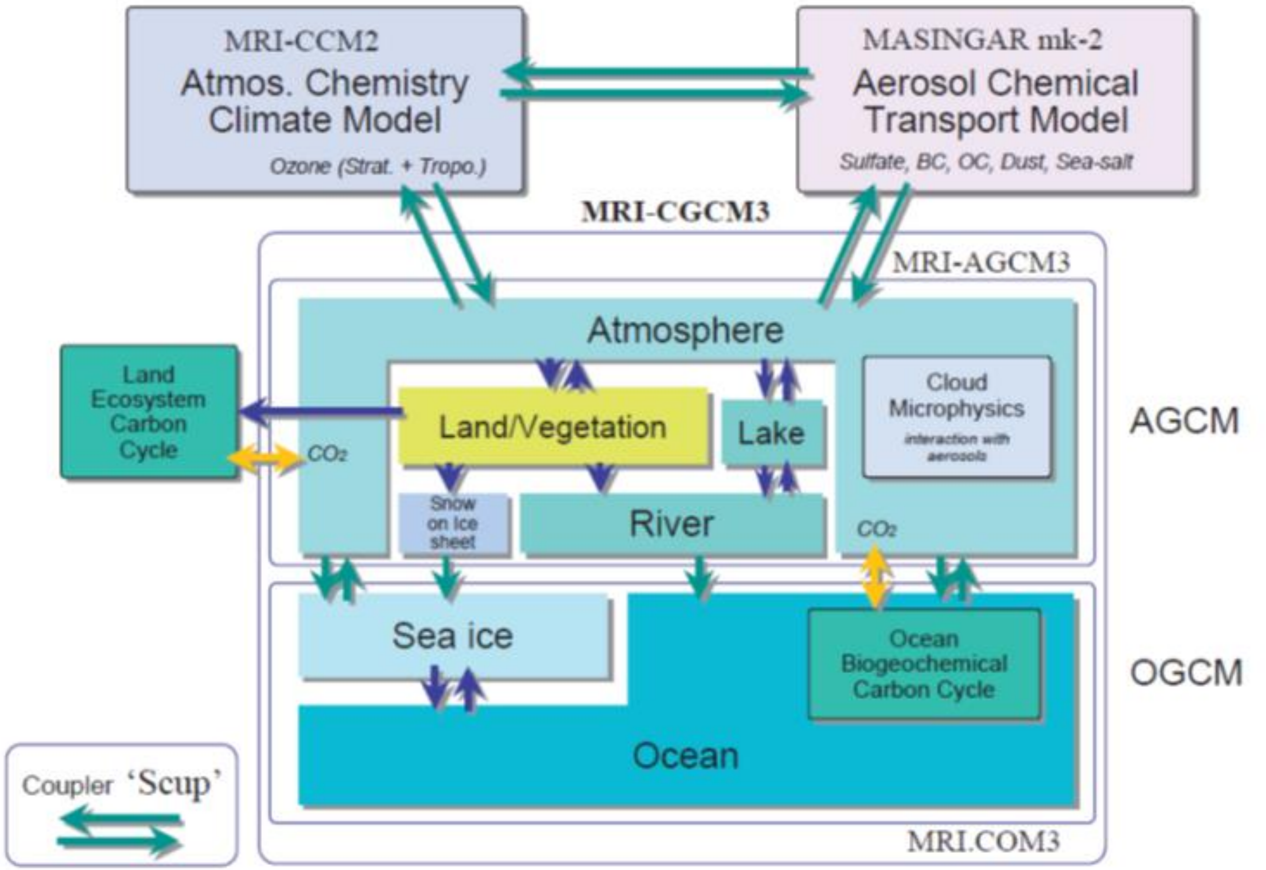


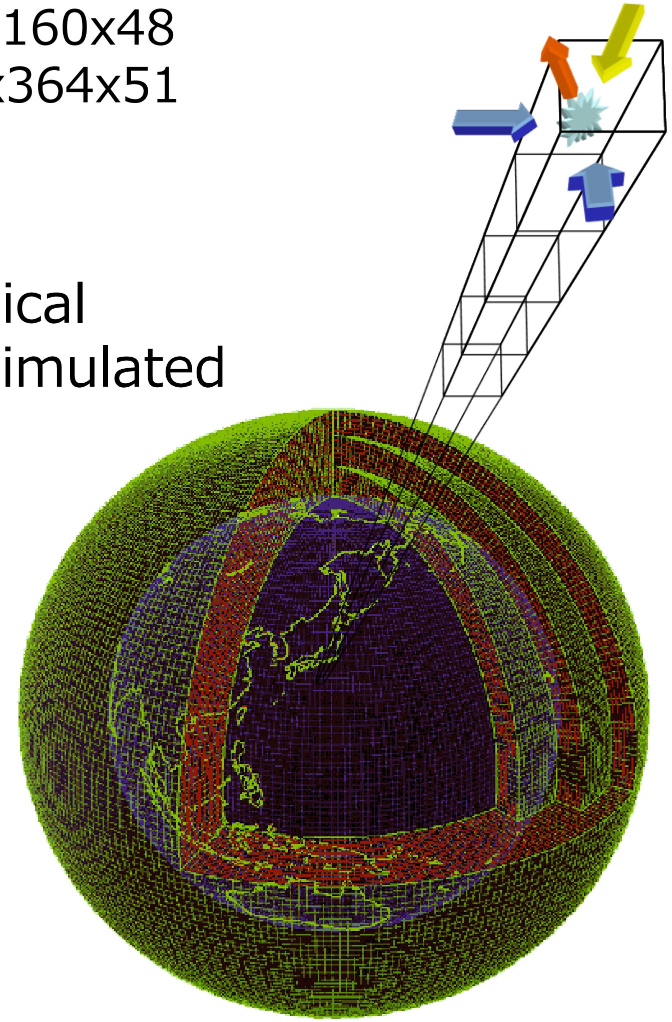
Figure 1 Configuration of the component models in MRI-ESM1. Green arrows denote data exchange with using Scup between the component models.

Atmosphere, land, and ocean are discretized:

Atmospher: 320x160x48

Ocean: 360x364x51

Flows and physical processes are simulated for each grid



- (Yukimoto et al. 2011)

(Courtesy of Yukimoto@MRI)

How these processes are implemented in a computer?

Navier-Stokes equation

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

Discretization of the equations above

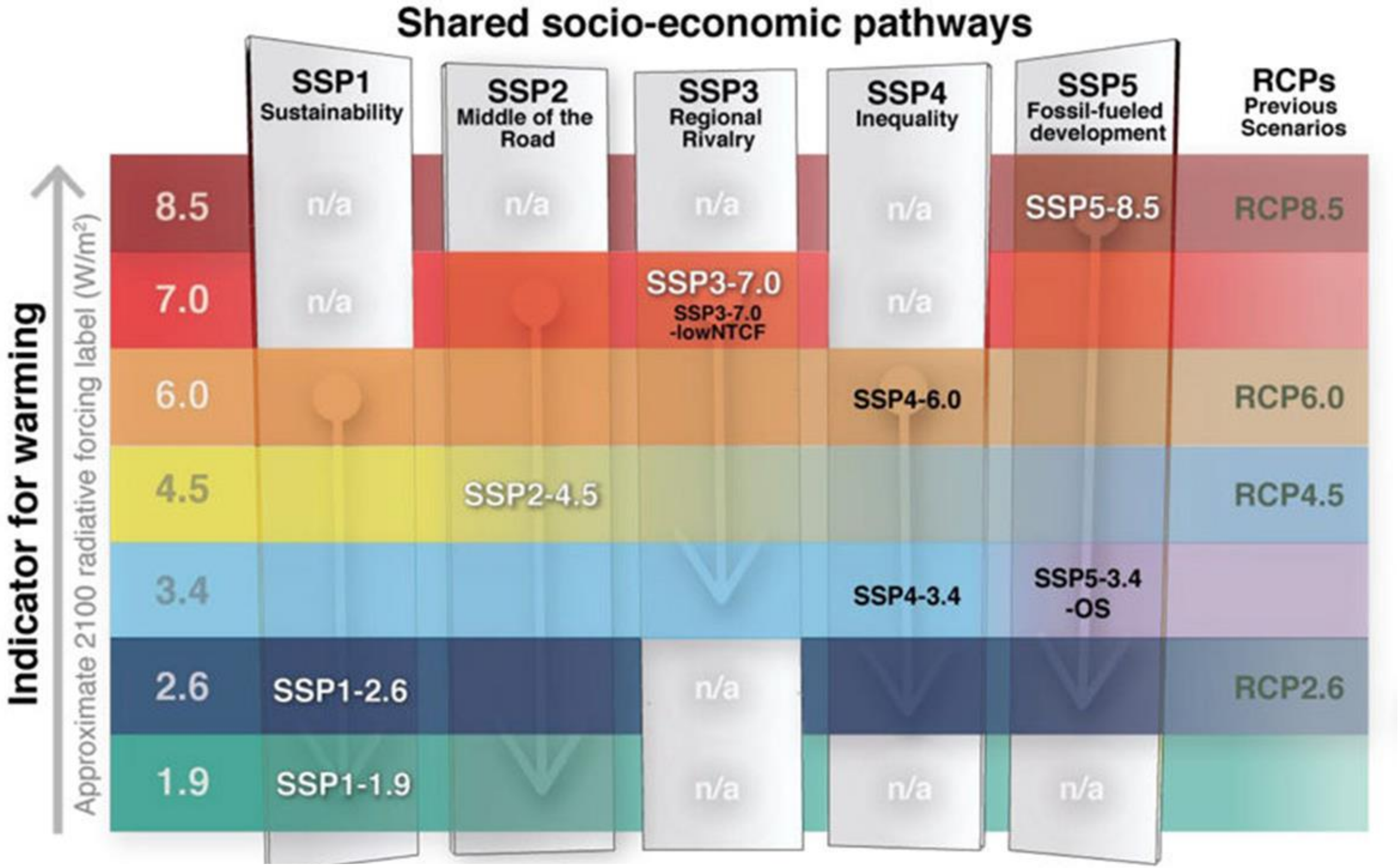
$$\frac{\partial u}{\partial t} \rightarrow \frac{u_j^{n+1} - u_j^n}{\Delta t}$$

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

A code for a computer

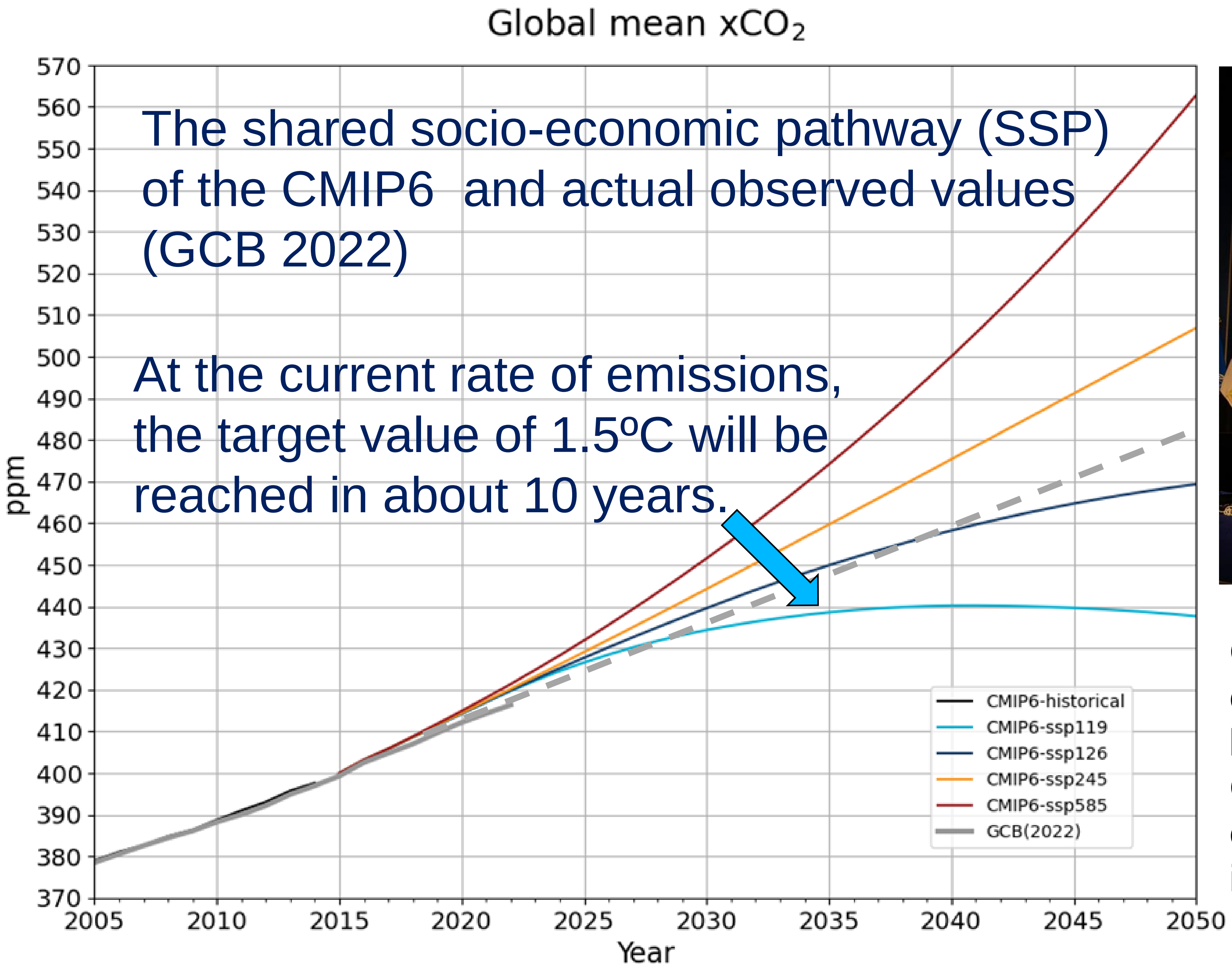
```
do j=1,latg2_
        do i=1,lonf2_
          ftsea(i,j)=ftsea(i,j)+tsea(i,j)*weight(ifstep)
          fsheleg(i,j)=fsheleg(i,j)+sheleg(i,j)*weight(ifste
          ftg3(i,j)=ftg3(i,j)+tg3(i,j)*weight(ifstep)
          fzorl(i,j)=fzorl(i,j)+zorl(i,j)*weight(ifstep)
          fplantr(i,j)=fplantr(i,j)+plantr(i,j)*weight(ifstep)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

Photo:Johann Olivier

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.

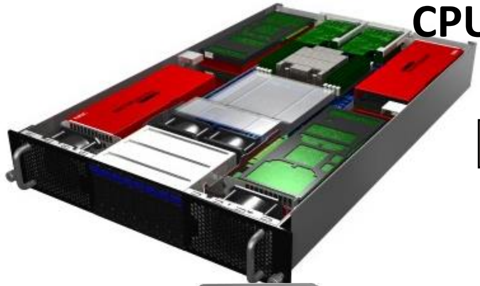
Supercomputer is essential for climate projections

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 #56
(#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

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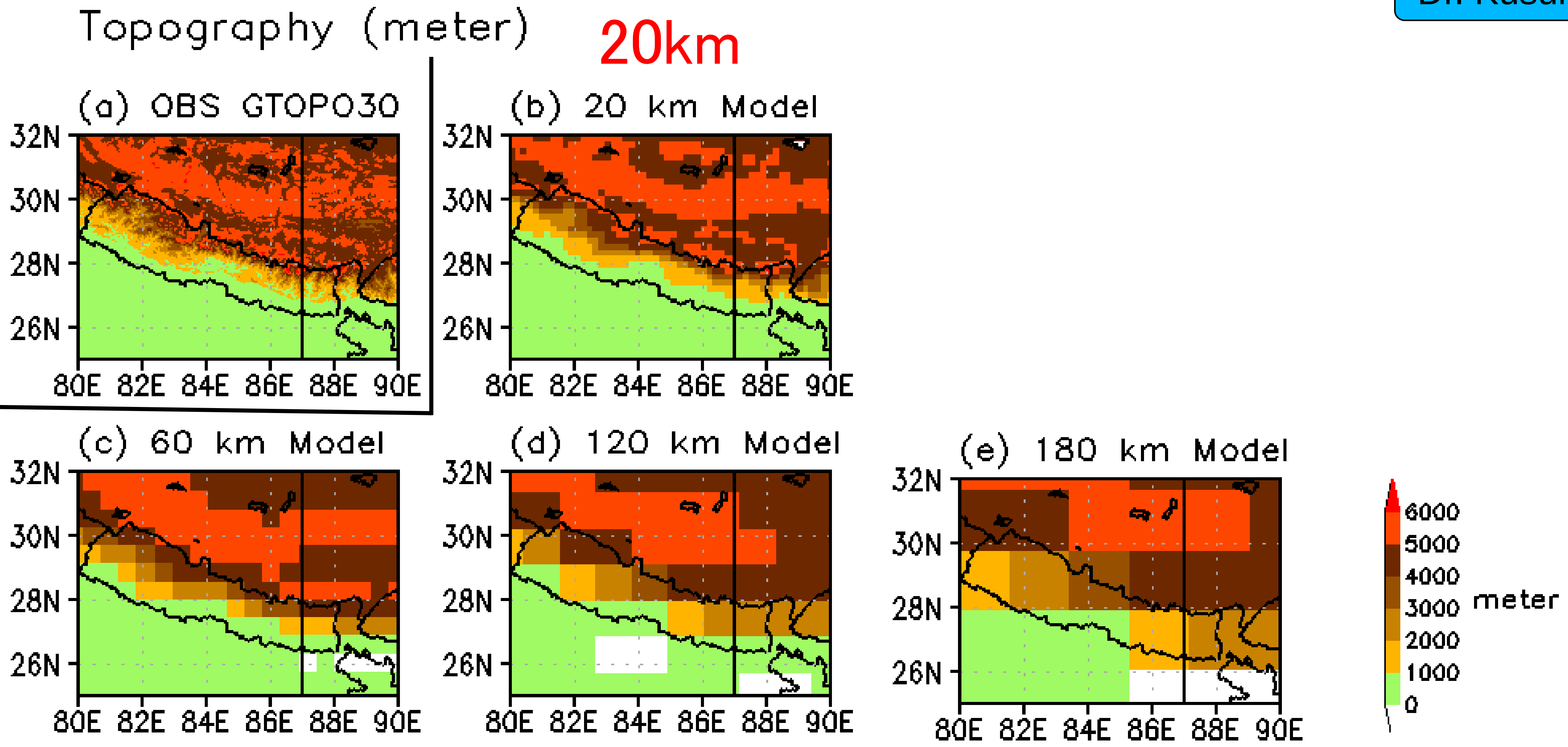
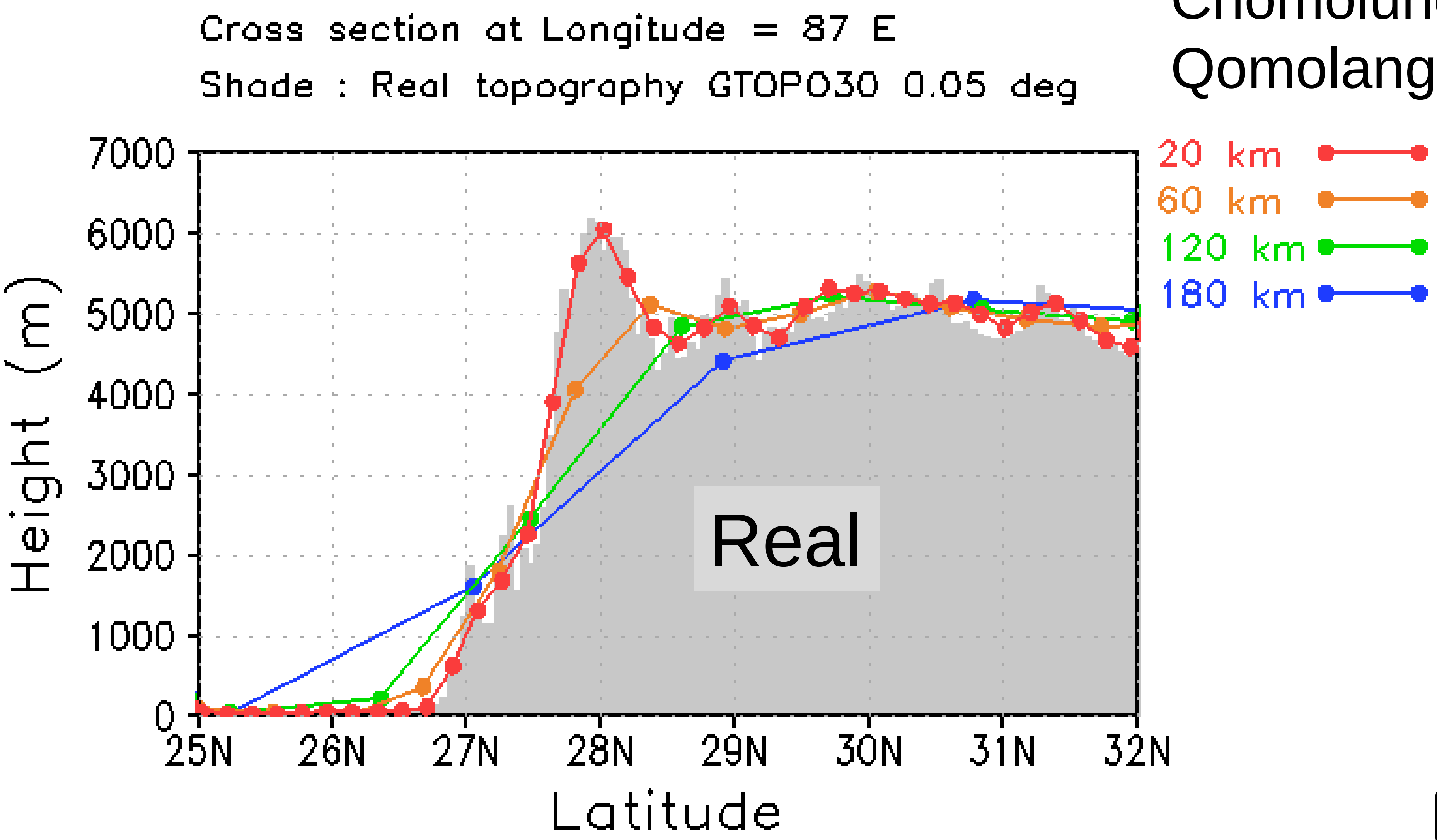


Real

60km 120km 180km

Cross section at 87E

Near Everest
Chomolungma or
Qomolangma or



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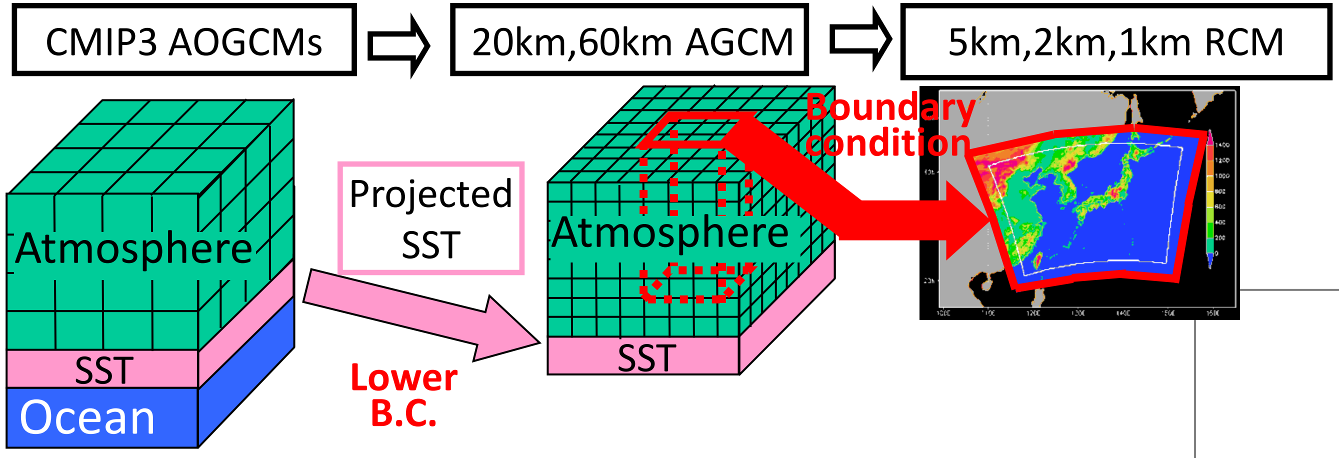
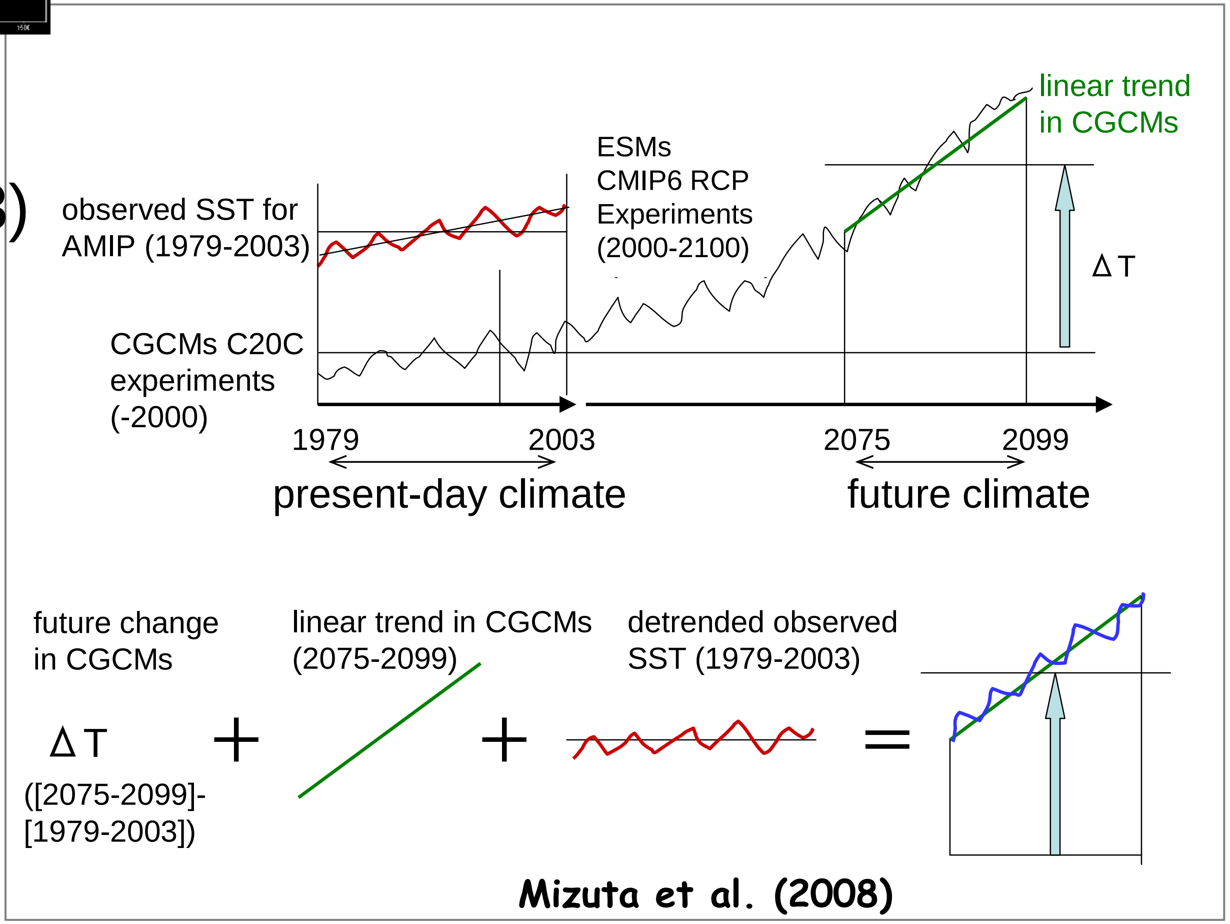
Time-Slice Experiments with high-horizontal resolution



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



Comparison of reproducibility between horizontal resolutions

Precipitation dependent on resolutions

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Rain
July

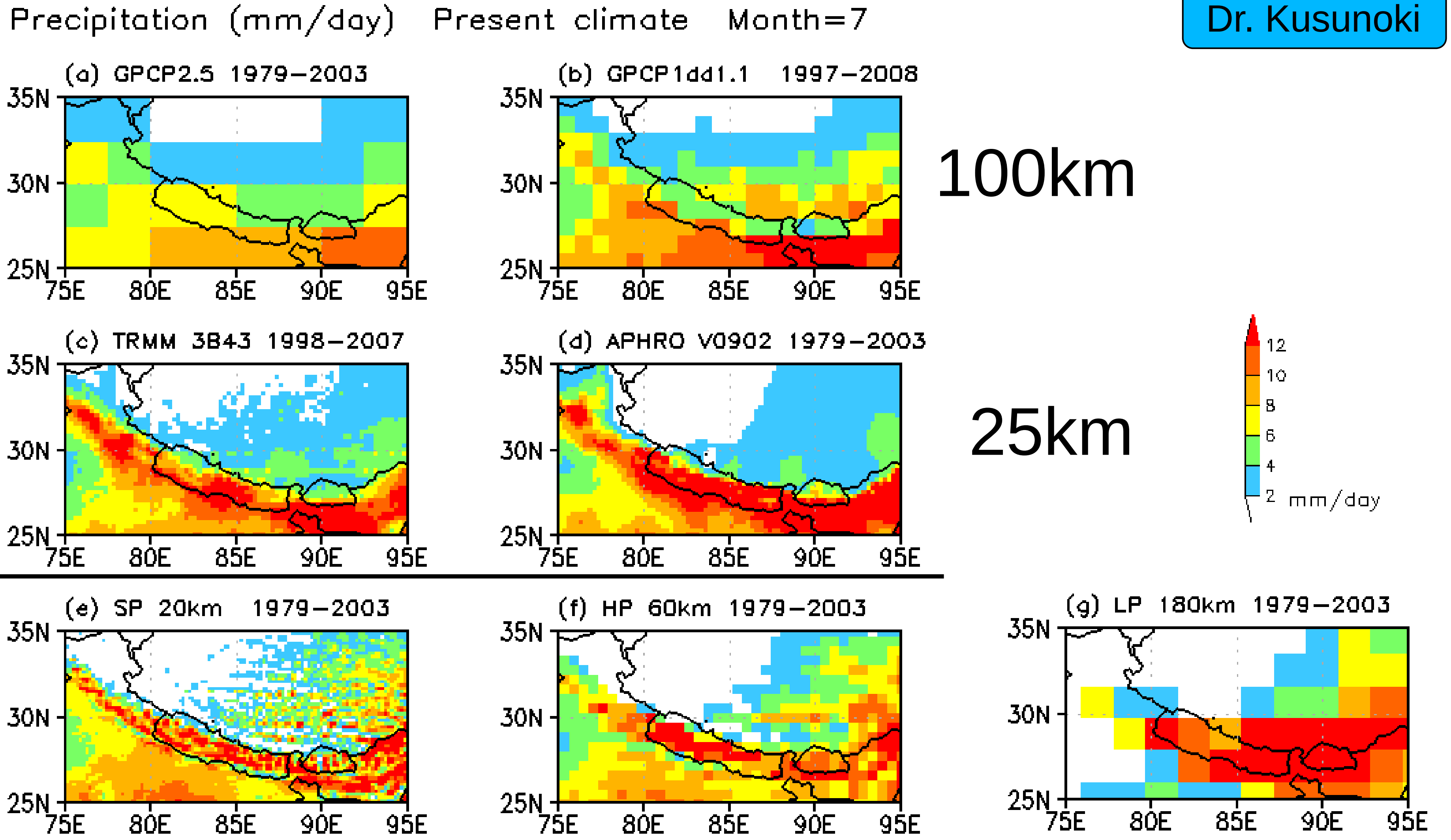
Observation

250km

25km

100km

25km



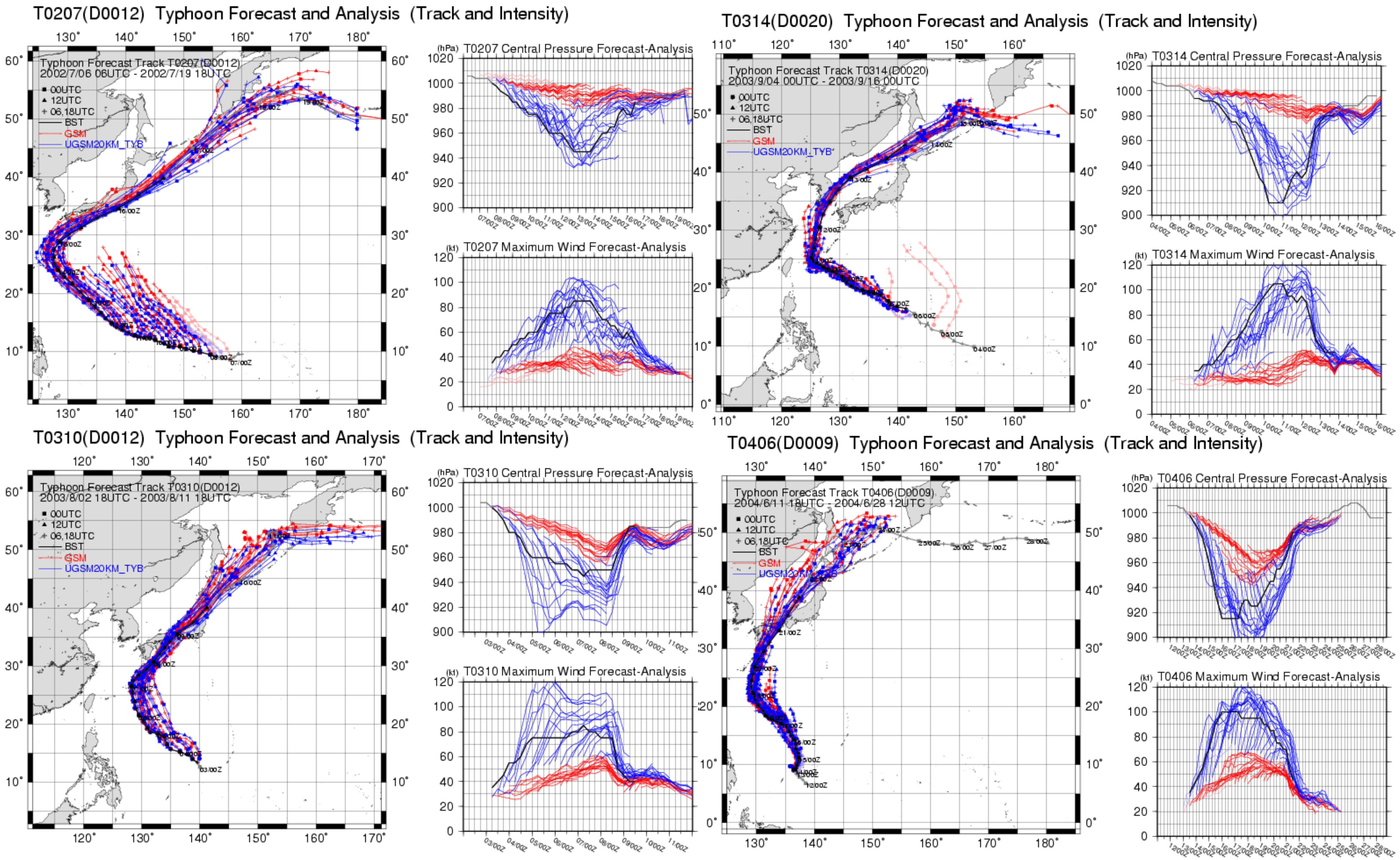
Model

20km

60km

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

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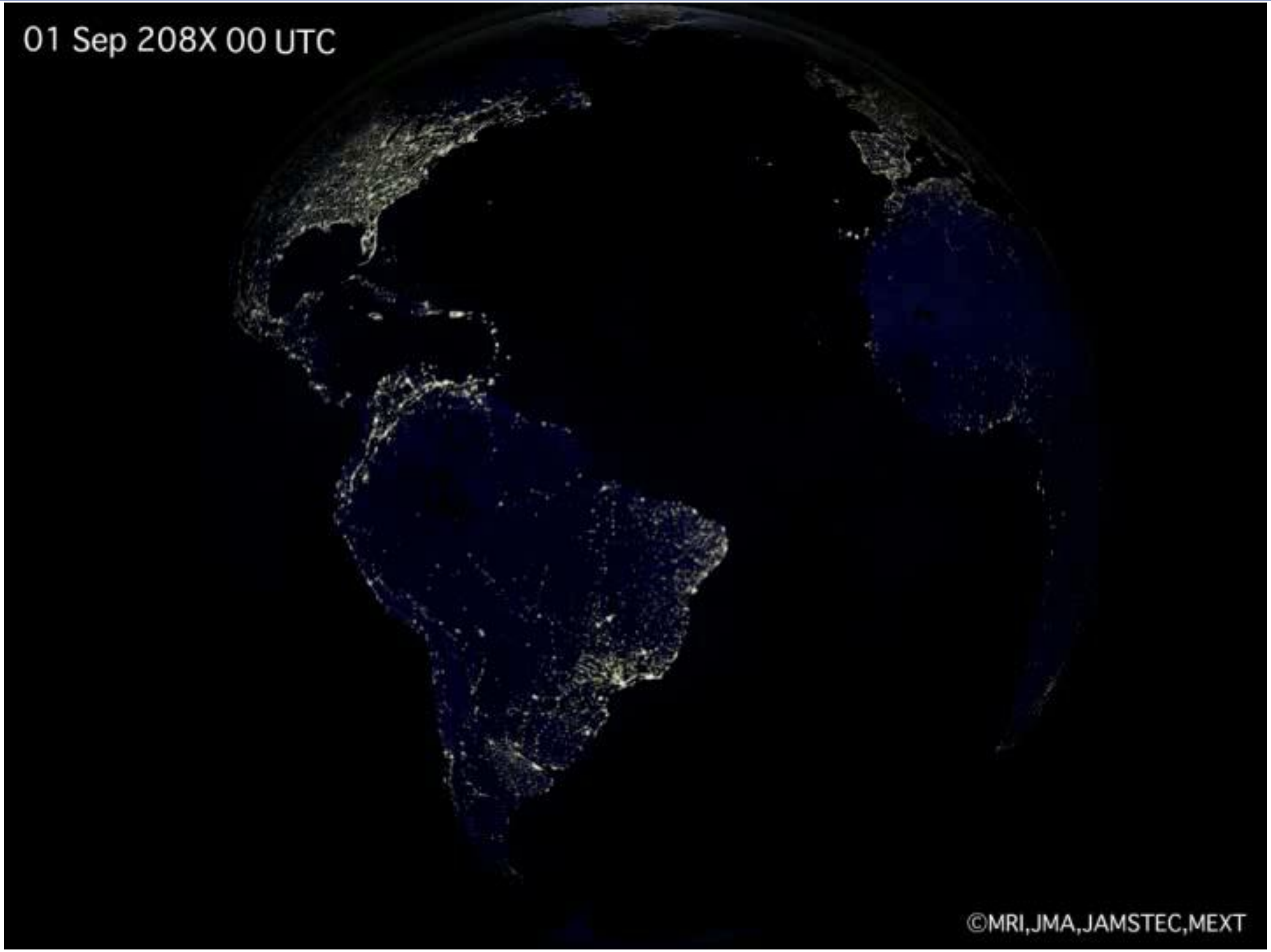
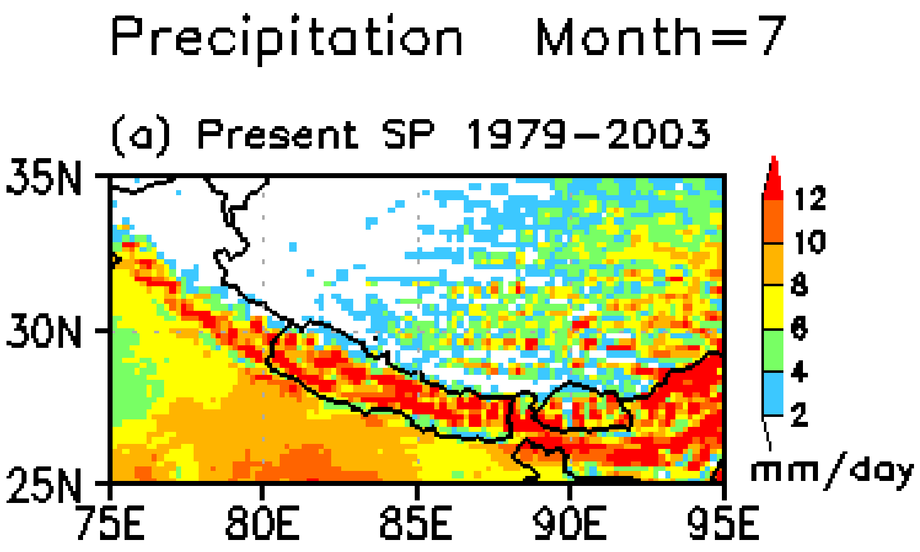
Tropical cyclones in the 20-km AGCM



Future climate projections

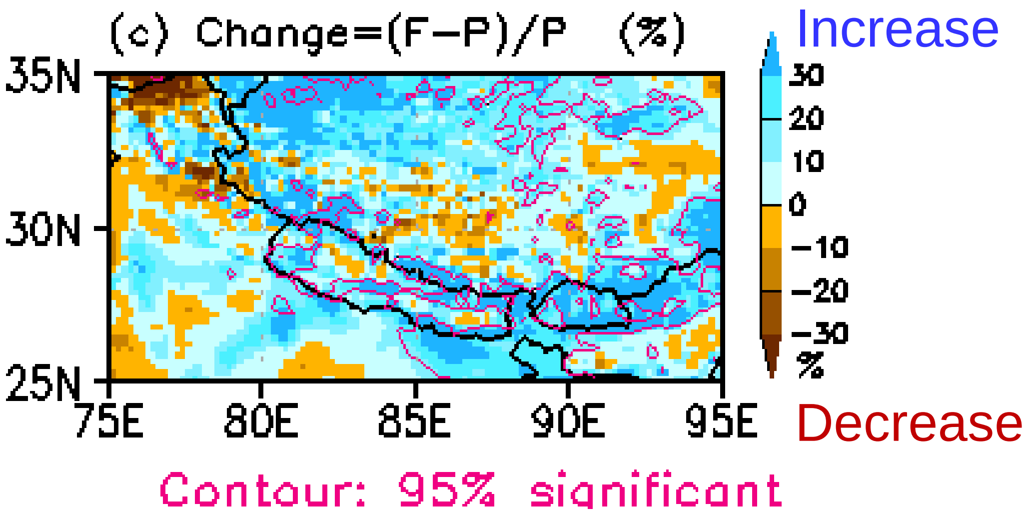
July Precipitation in a future climate

Present-day
1979-2003



Future
2075-2099

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



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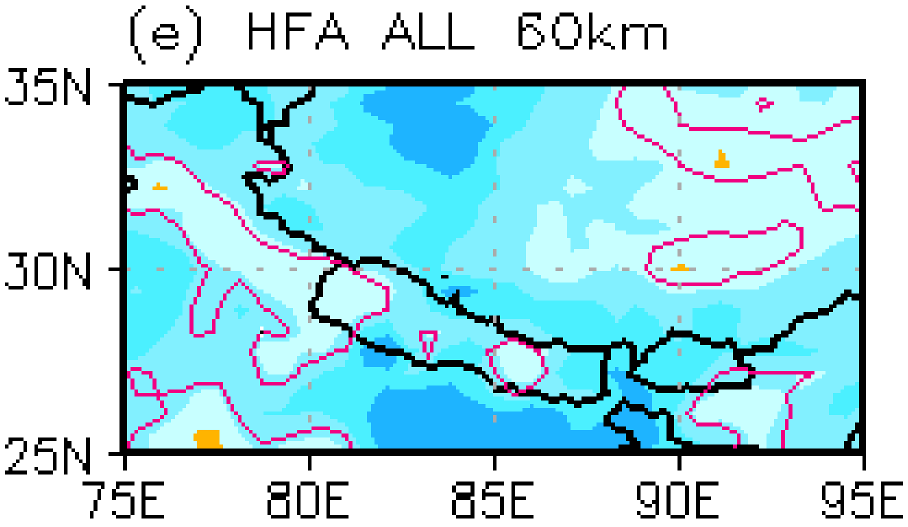
Maximum 5 day precipitation in a future climate

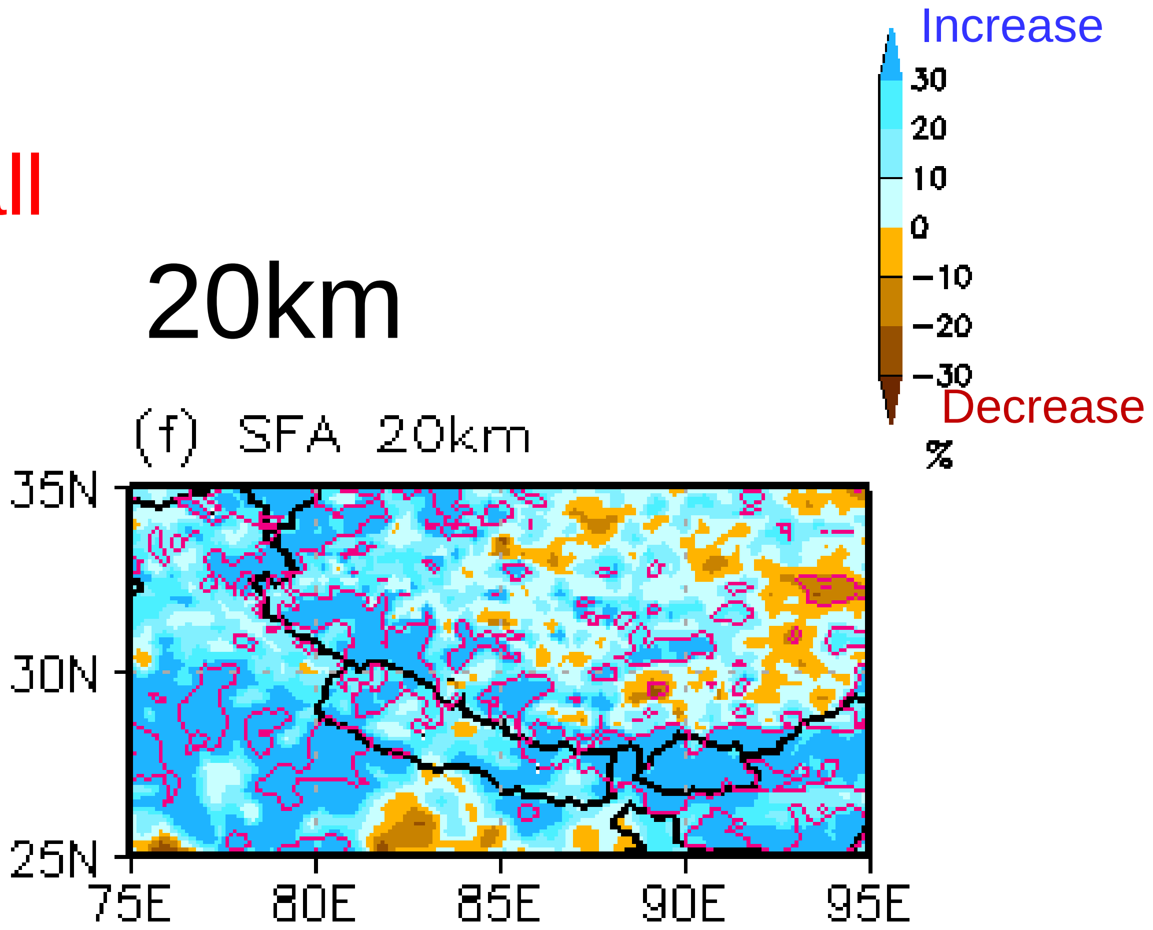
Annual statistics **Heavy rainfall**

60km



Average of 16 experiments

20km



One experiment

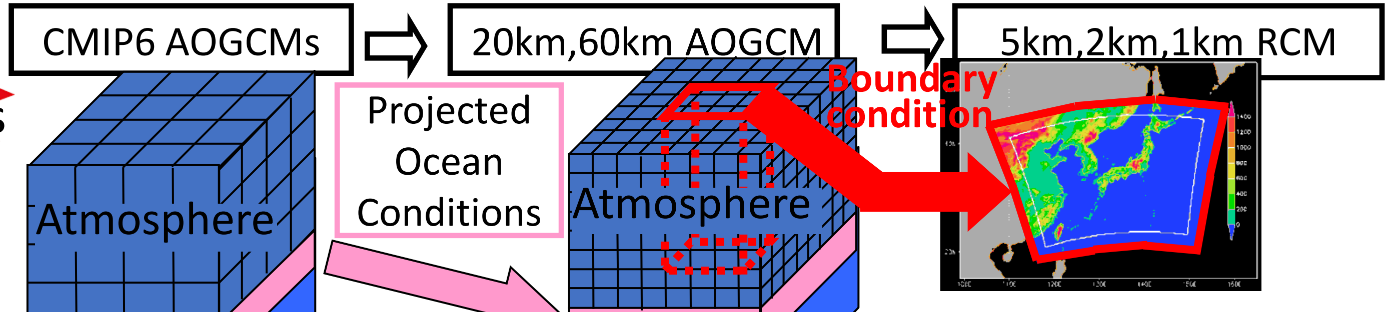
SENTAN Theme-3: future climate projections in Japan

NEW!

Time-sequential experiments

AOGCM

- (1950-2100)

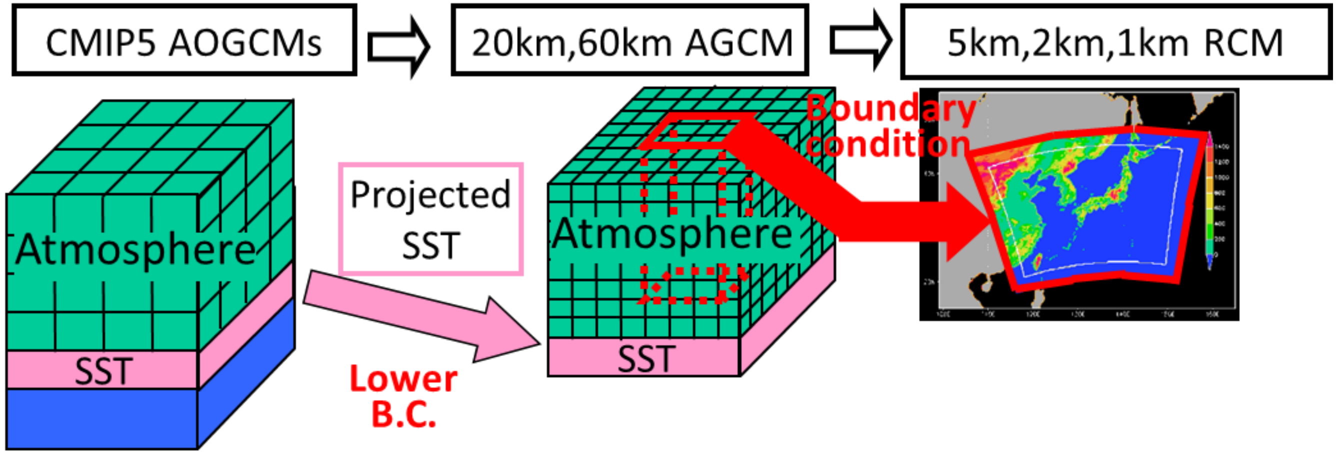


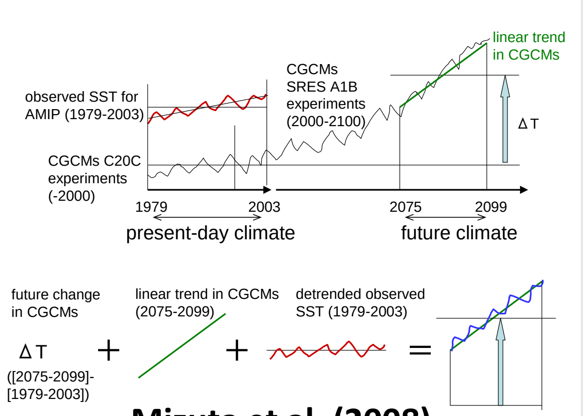
AGCM/RCM is a climate model version of the JMA operational NWP models

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!

Thank you for your attention