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

～Advantages of a high resolution model～

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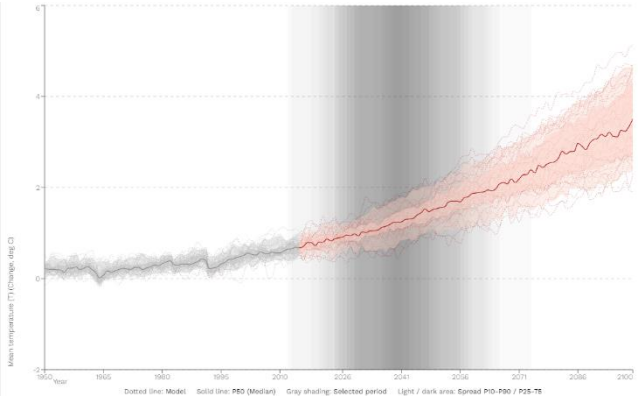
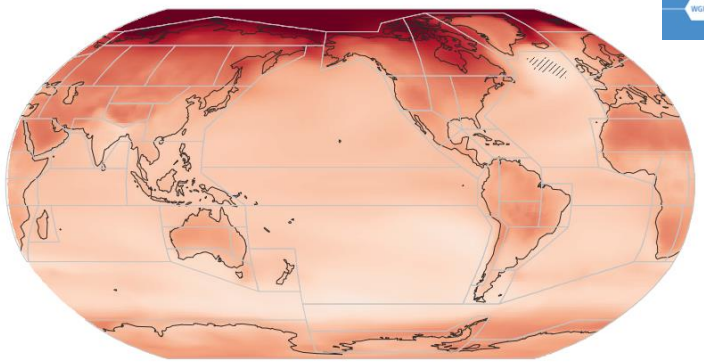
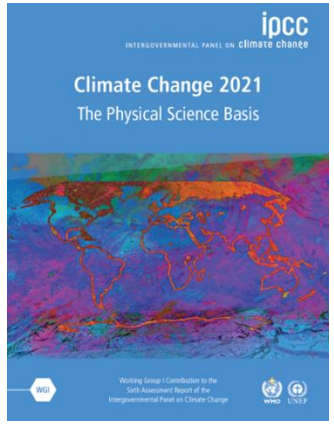
advanced studies of climate change projection

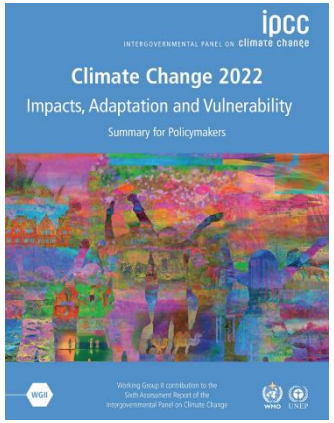
How is a future climate projected?

IPCC AR6 WGI Interactive Atlas

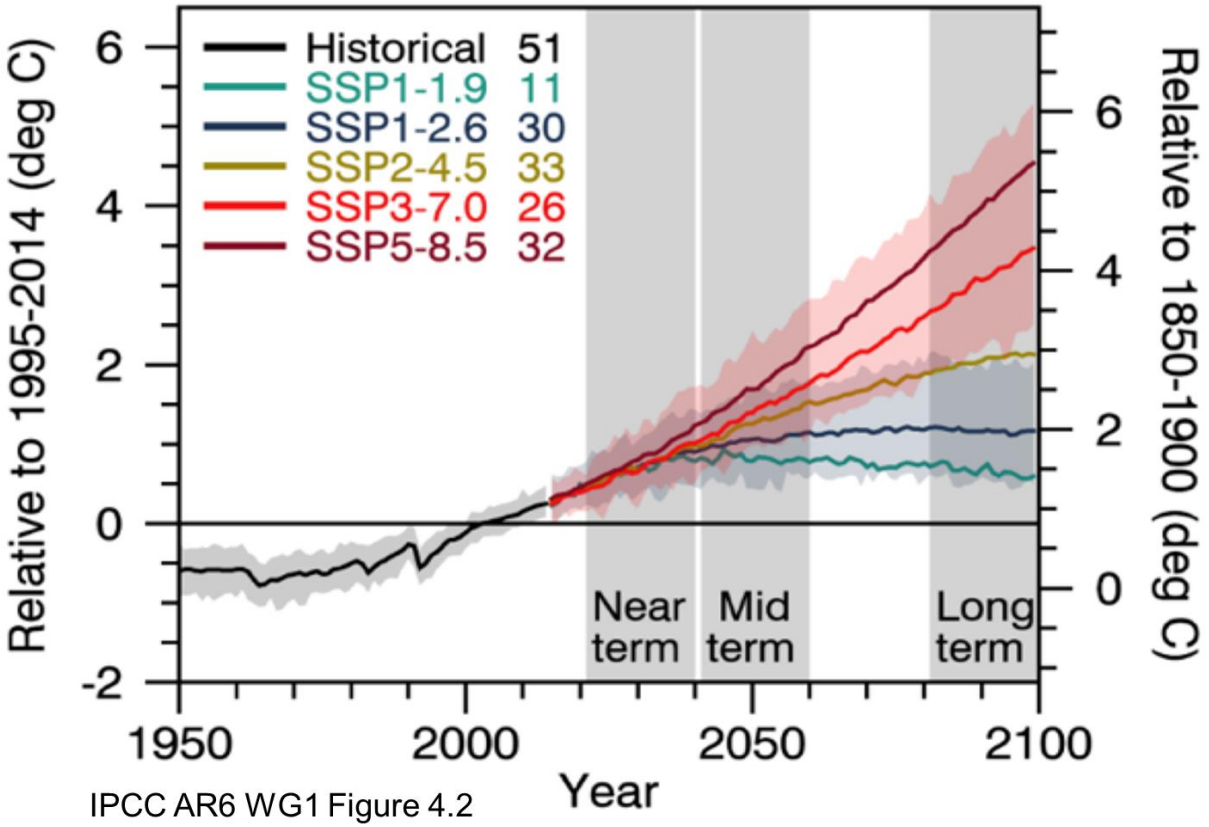








IPCC AR6 WGI Report

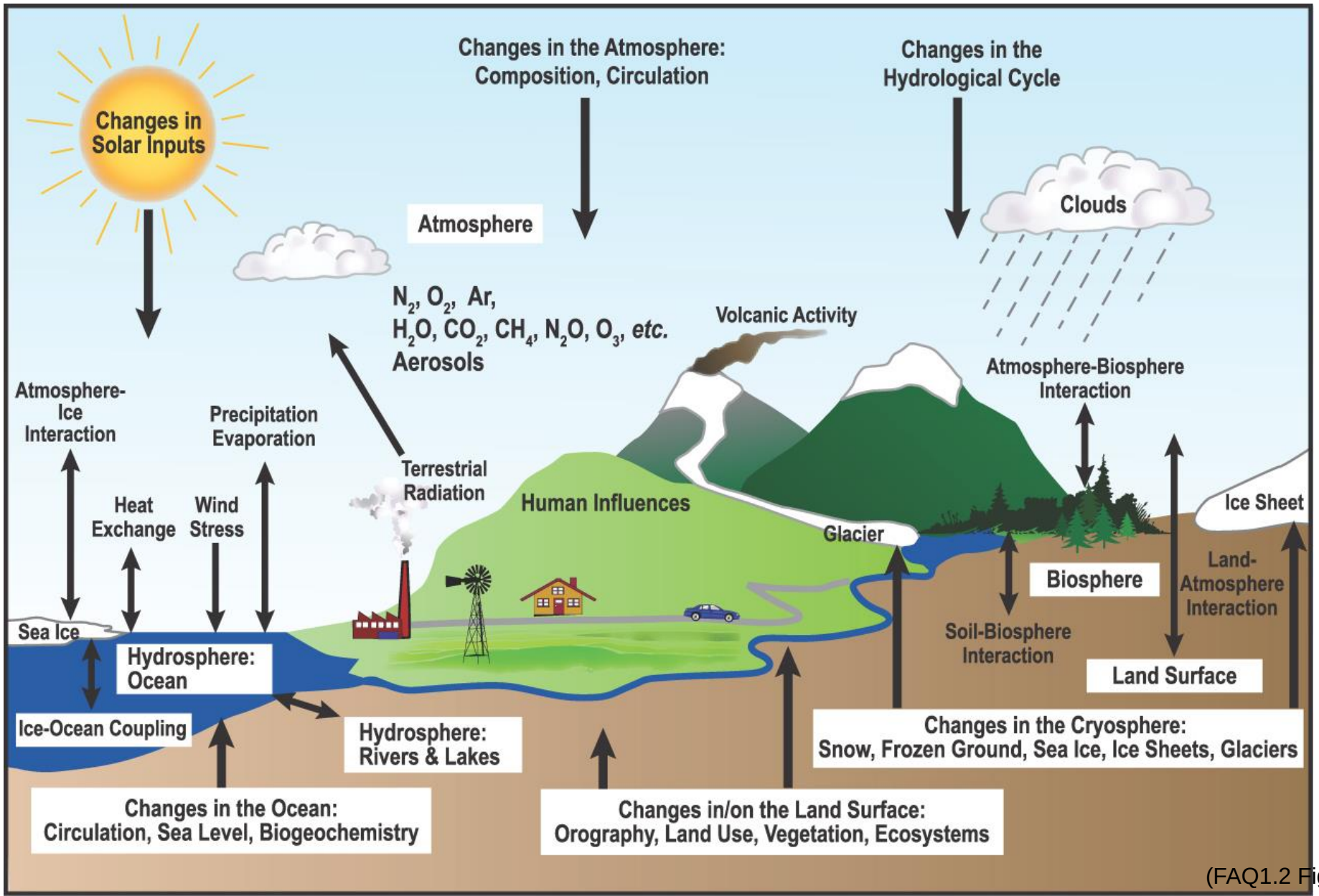


IPCC AR6 WG1 Figure 4.2

Today's contents

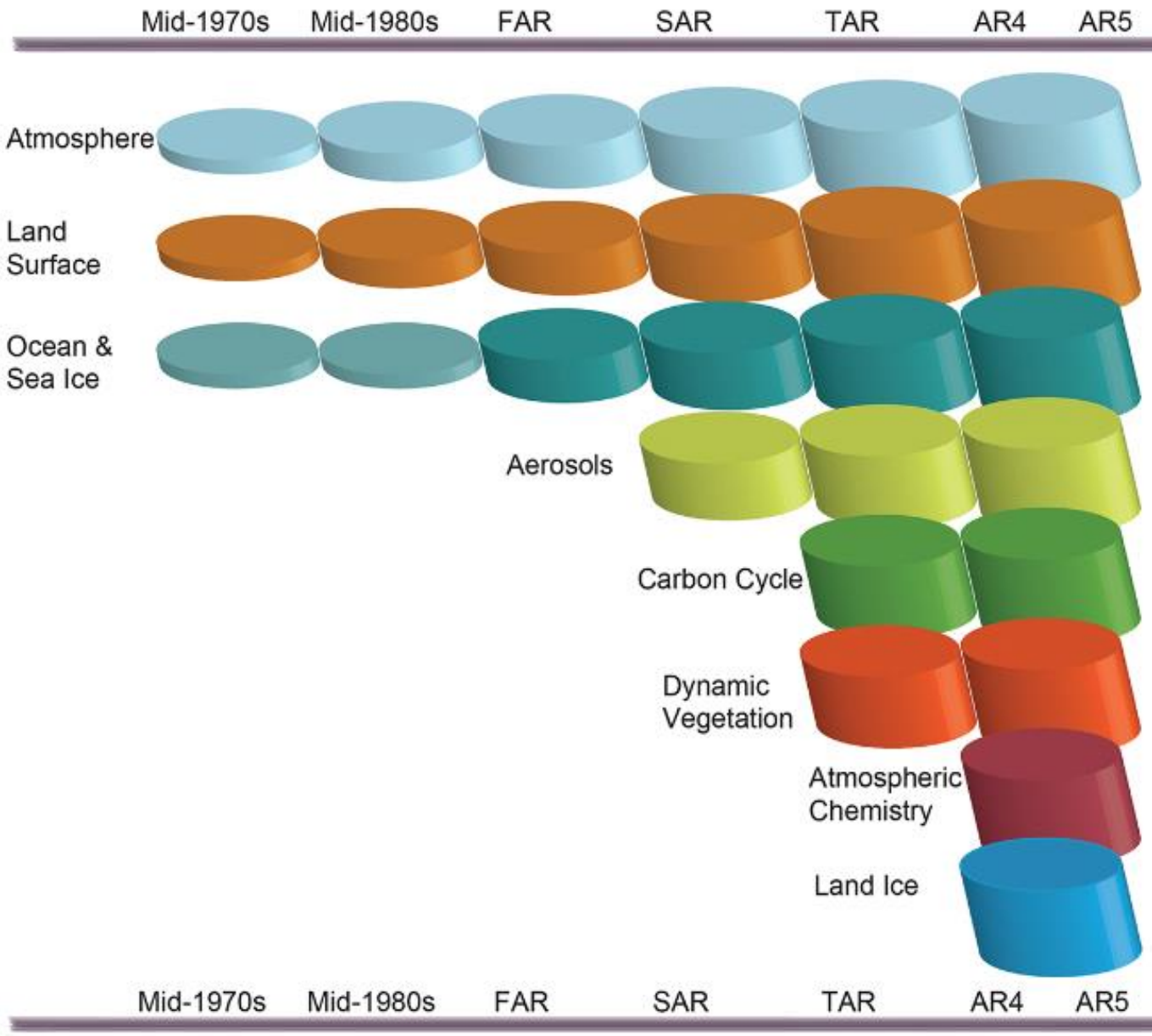
- Basics of future climate projections in a computer
- Advantages of a model with a higher horizontal resolution

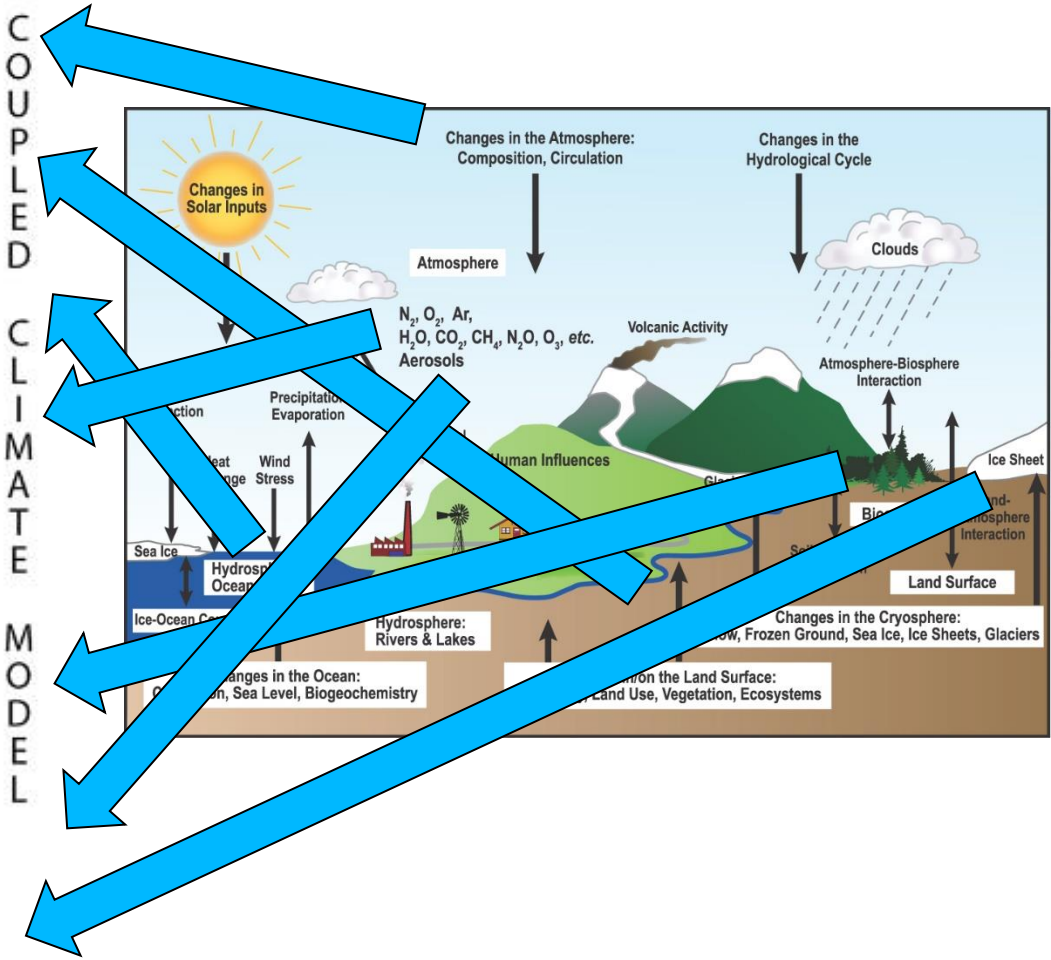
Processes in the Earth System



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

Development of CGCMs





(Fig.1.13; IPCC 2013a).

Configuration of a GCM for future climate projections

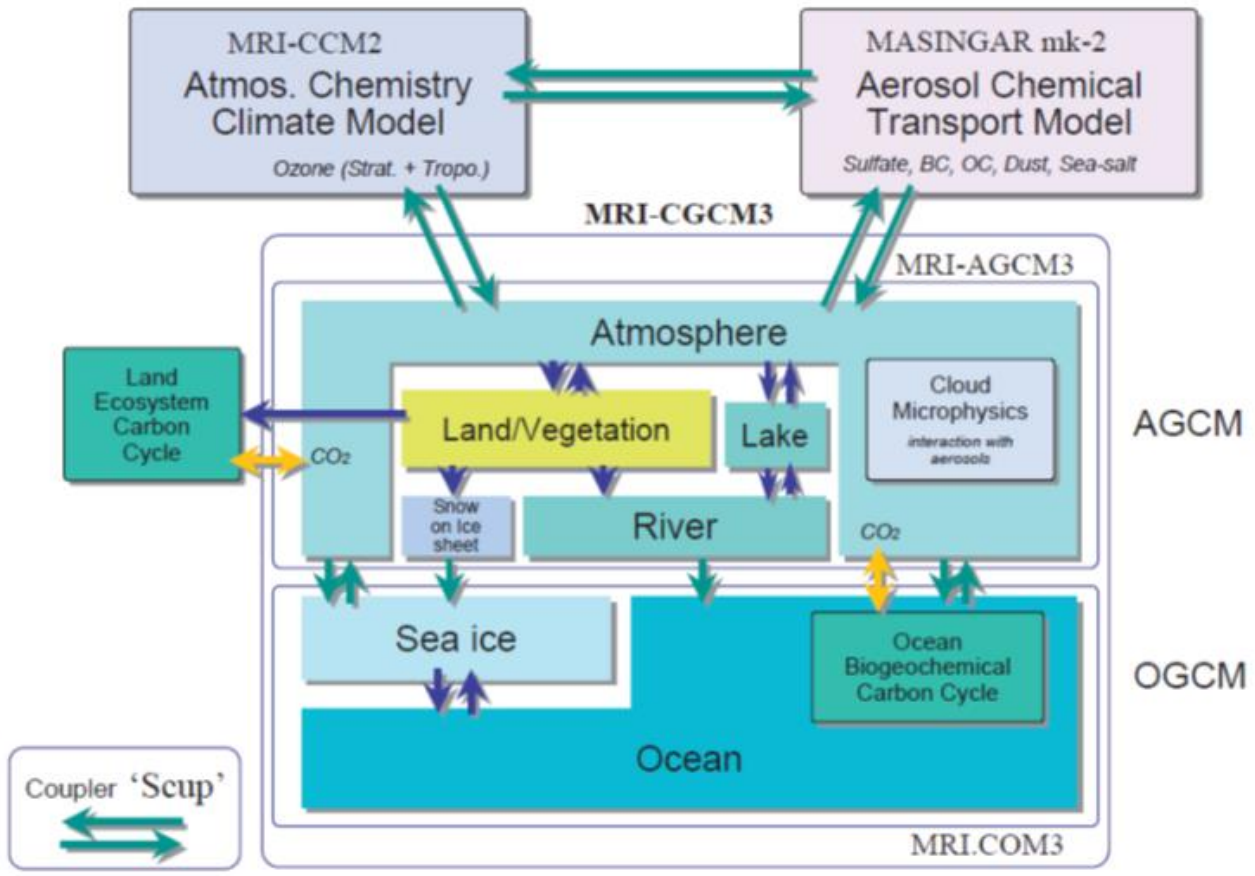


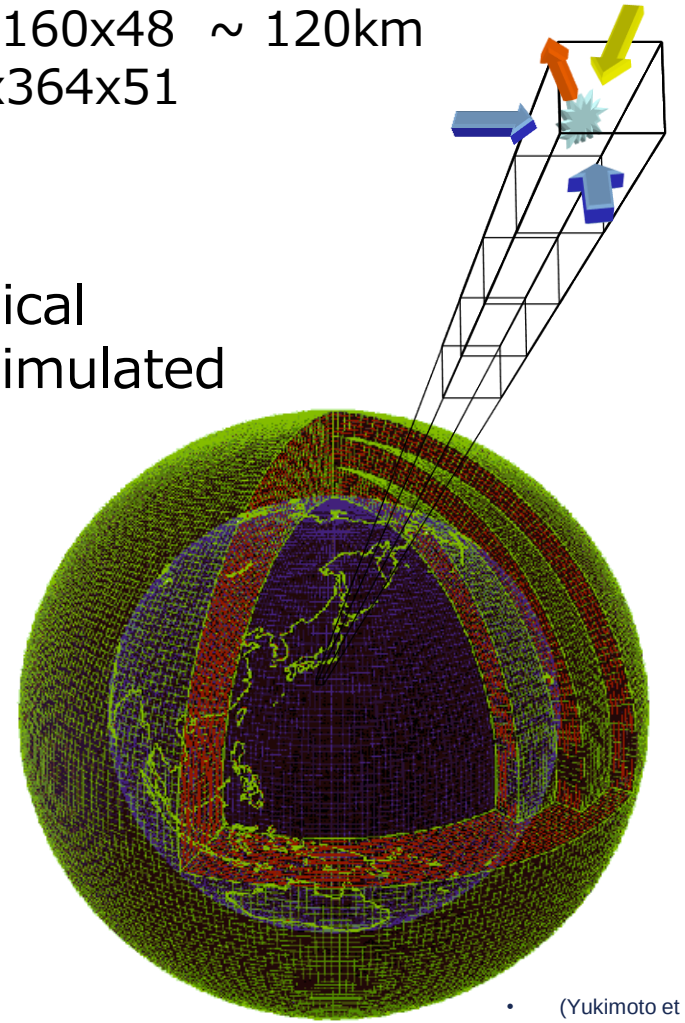
Figure 1 Configuration of the component models in MRI-ESM1. Green arrows denote data exchange with using Scup between the component models.

Atmosphere, land, and ocean are discretized:

Atmospher: 320x160x48 ~ 120km

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

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

Discretization of the equations above

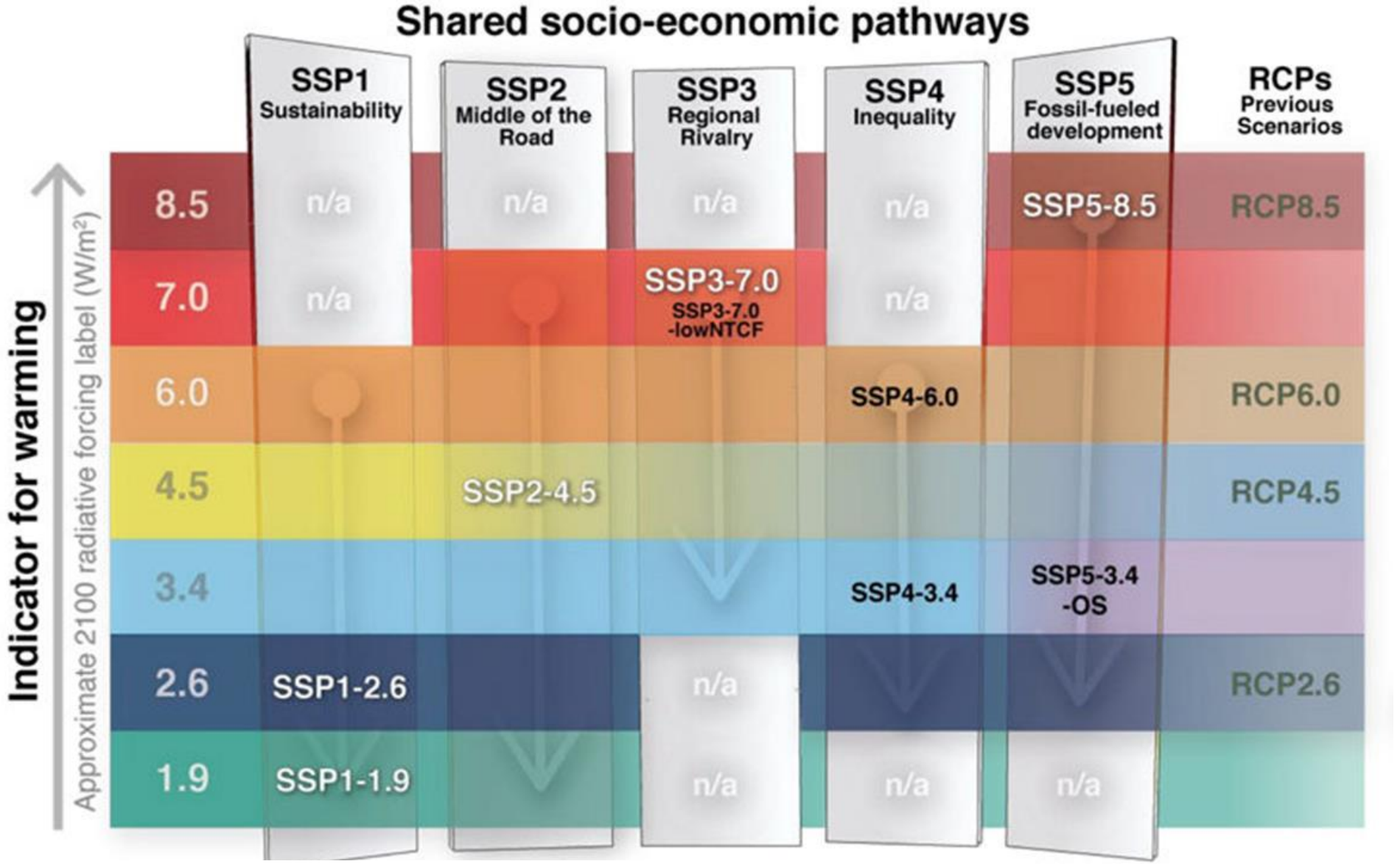
$$\frac{\partial u}{\partial t} \rightarrow \frac{u_j^{n+1} - u_j^n}{\Delta t}$$

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

A code for a computer

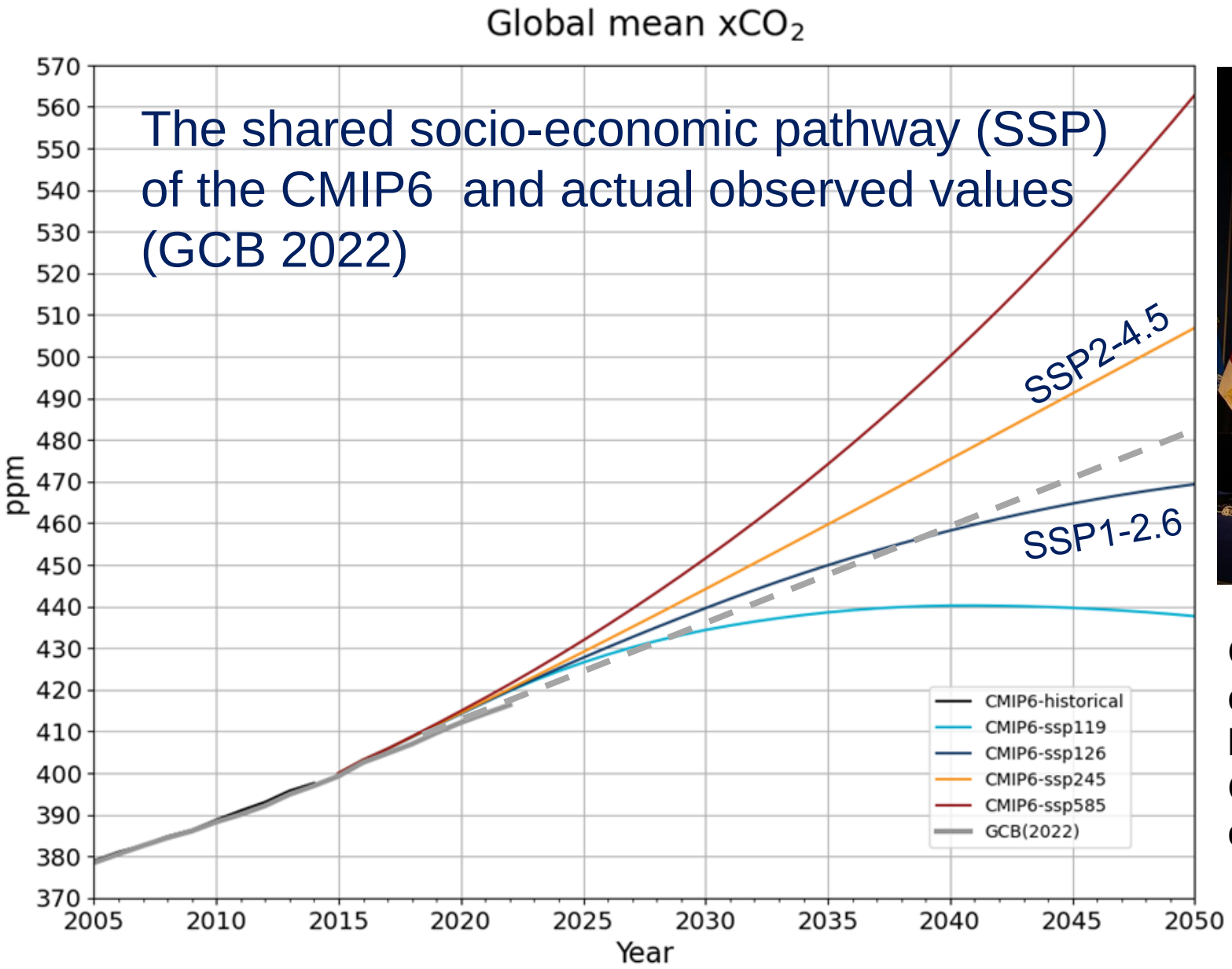
```
do j=1,latg2_
      do i=1,lonf2_
        ftsea(i,j)=ftsea(i,j)+tsea(i,j)*weight(ifstep)
        fsheleg(i,j)=fsheleg(i,j)+sheleg(i,j)*weight(ifste
        ftg3(i,j)=ftg3(i,j)+tg3(i,j)*weight(ifstep)
        fzorl(i,j)=fzorl(i,j)+zorl(i,j)*weight(ifstep)
        fplantr(i,j)=fplantr(i,j)+plantr(i,j)*weight(ifstep)
        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 2.5^{o}C by the end of the century.

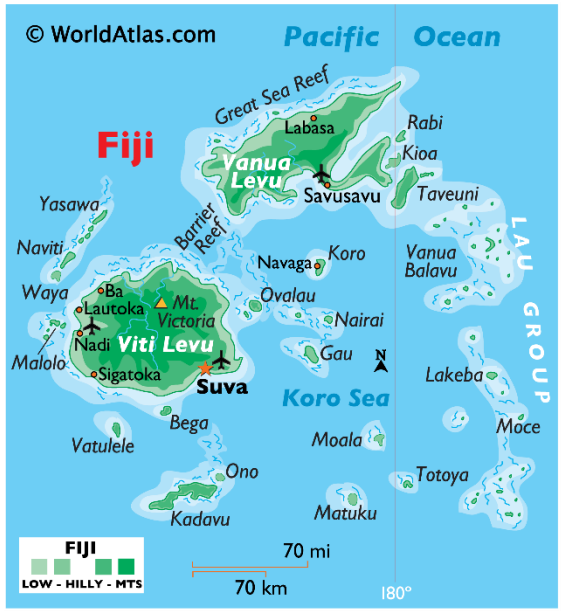
Needs for high-resolution models

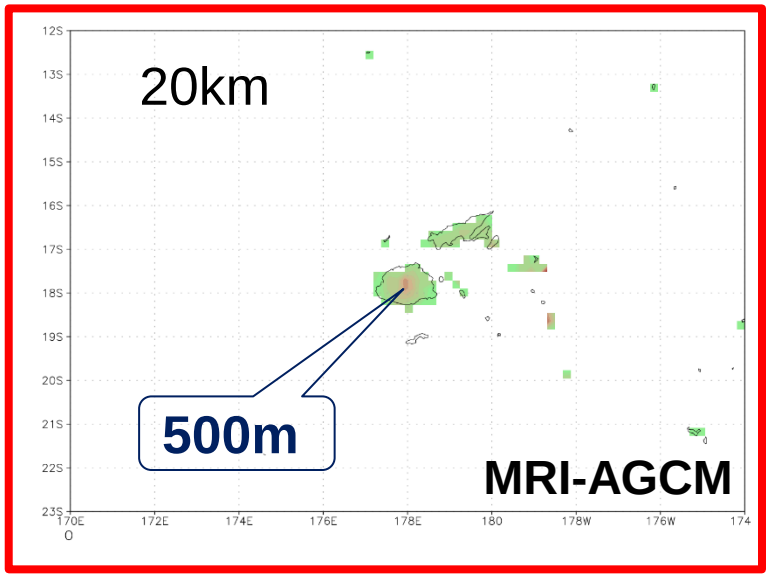
In order to make a progress in adaptation planning, we need

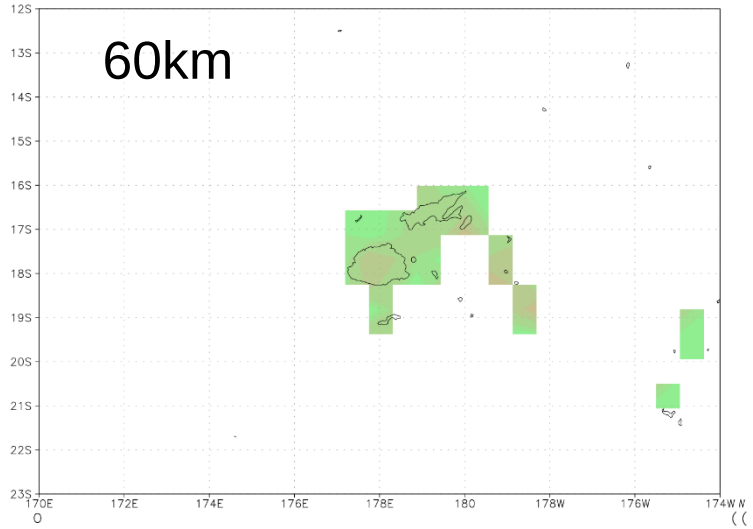
1. to project future weather extremes such as cyclones and heavy rainfall triggering natural disasters, and
2. to assess their impact on our lives.

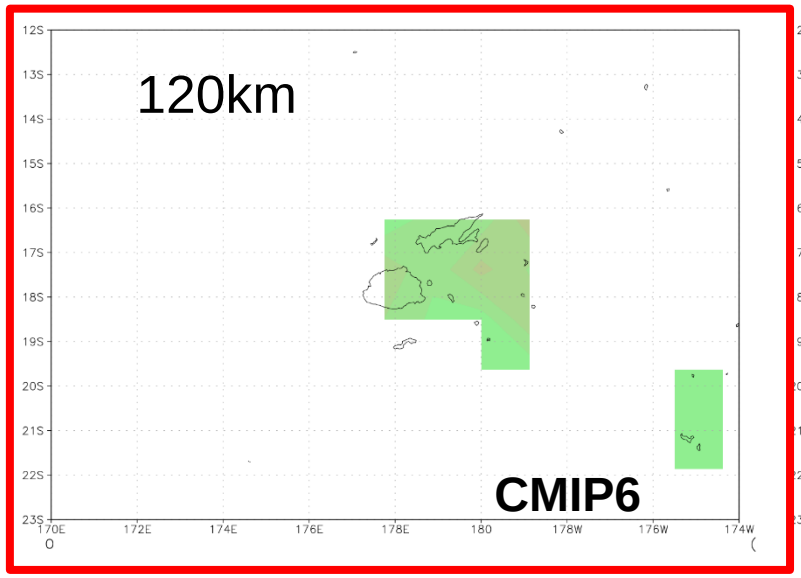
- representation of topography depends on resolution
- low resolution models often fail to reproduce precipitation systems such as tropical cyclones, organized convection systems, and MJO
- high resolution models generally have better mean climate

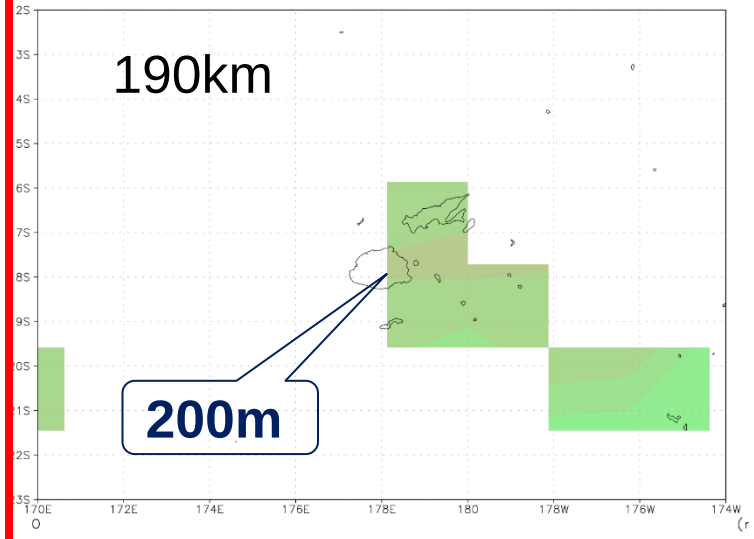
Topography dependent on resolutions

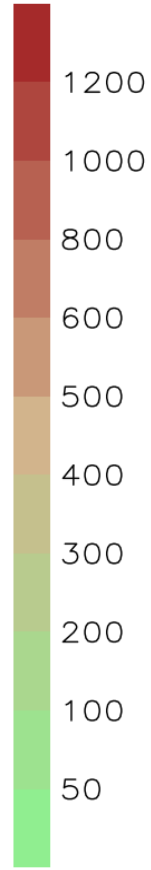




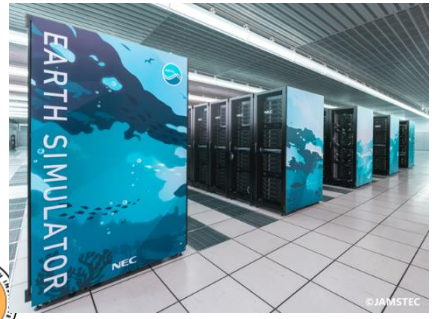




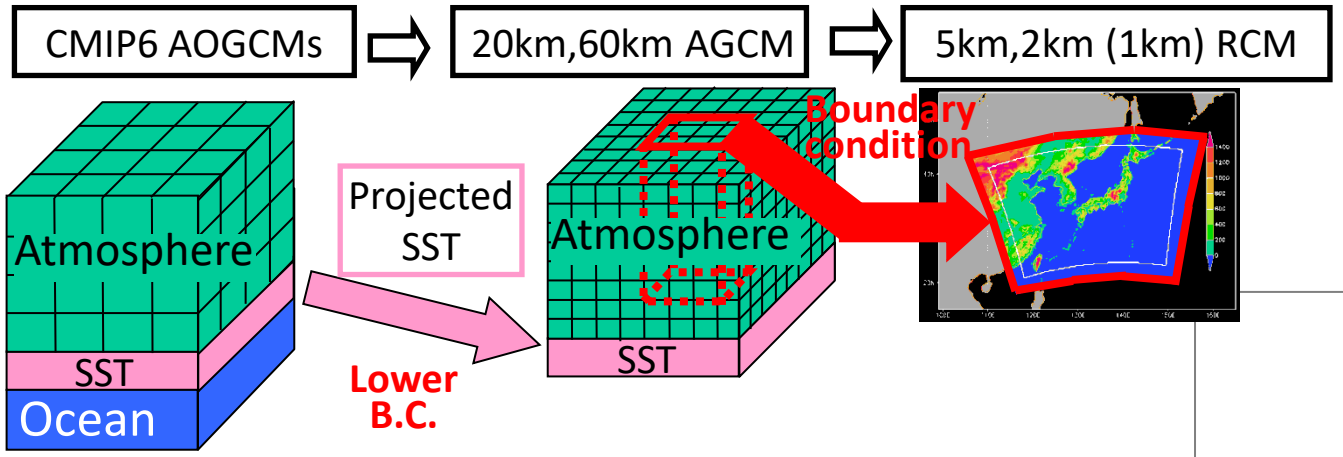




Computer resources
(120km/20km)^3=216 times

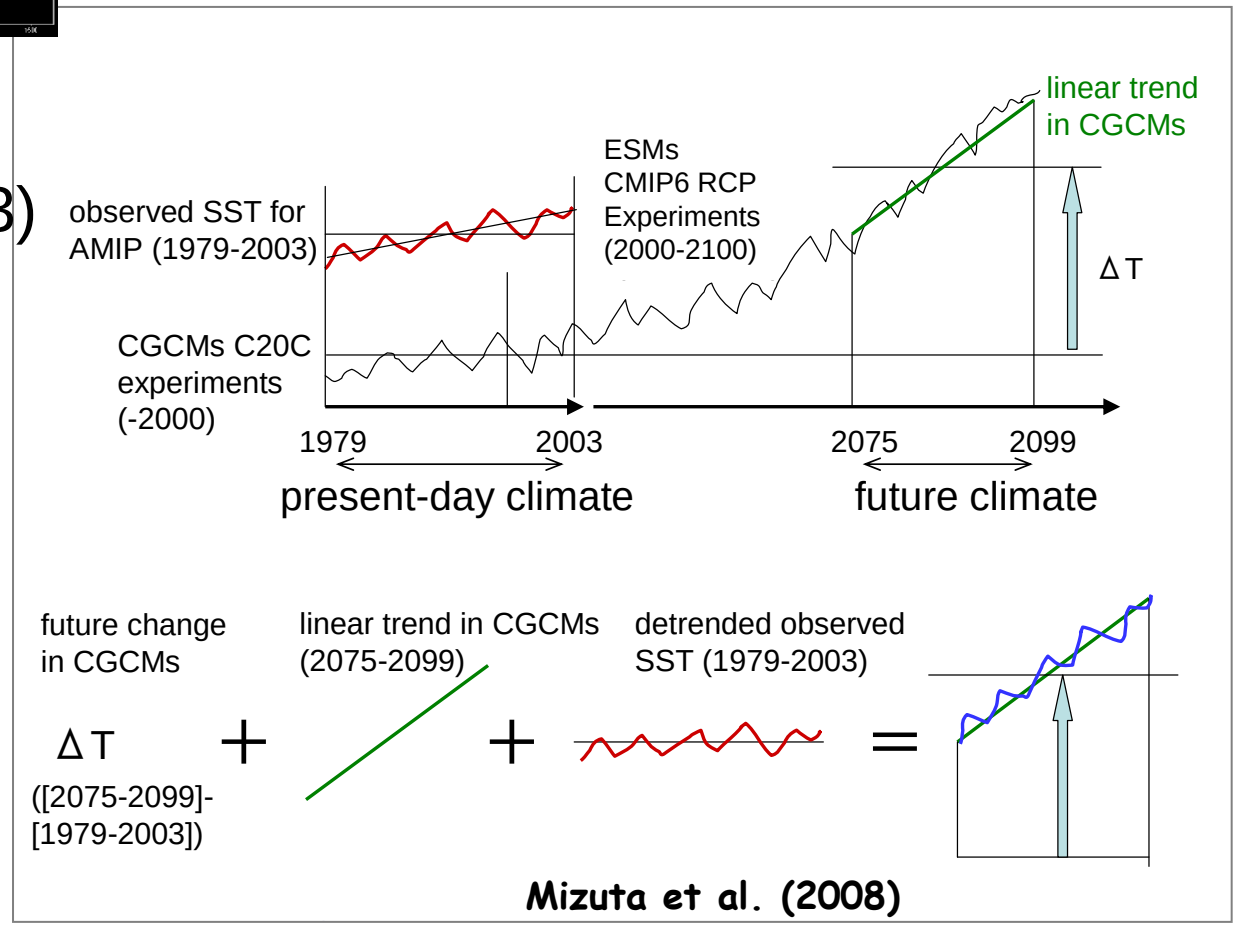


Time-Slice Experiments with high-horizontal resolution



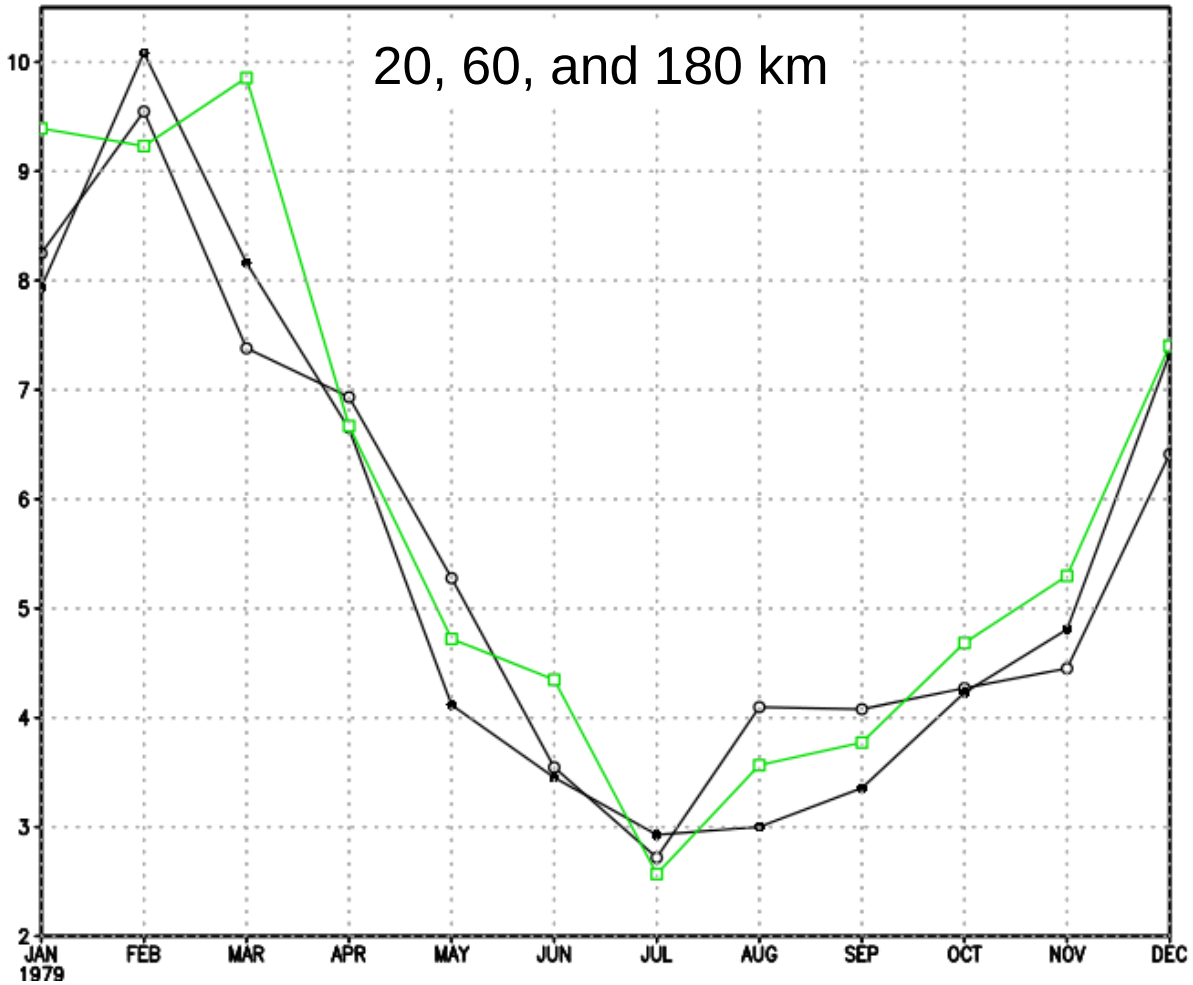
AGCM/RCM is a climate model version of the JMA operational NWP models

- 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



Precipitation dependent on resolutions

Climatological monthly mean precipitation in Fiji

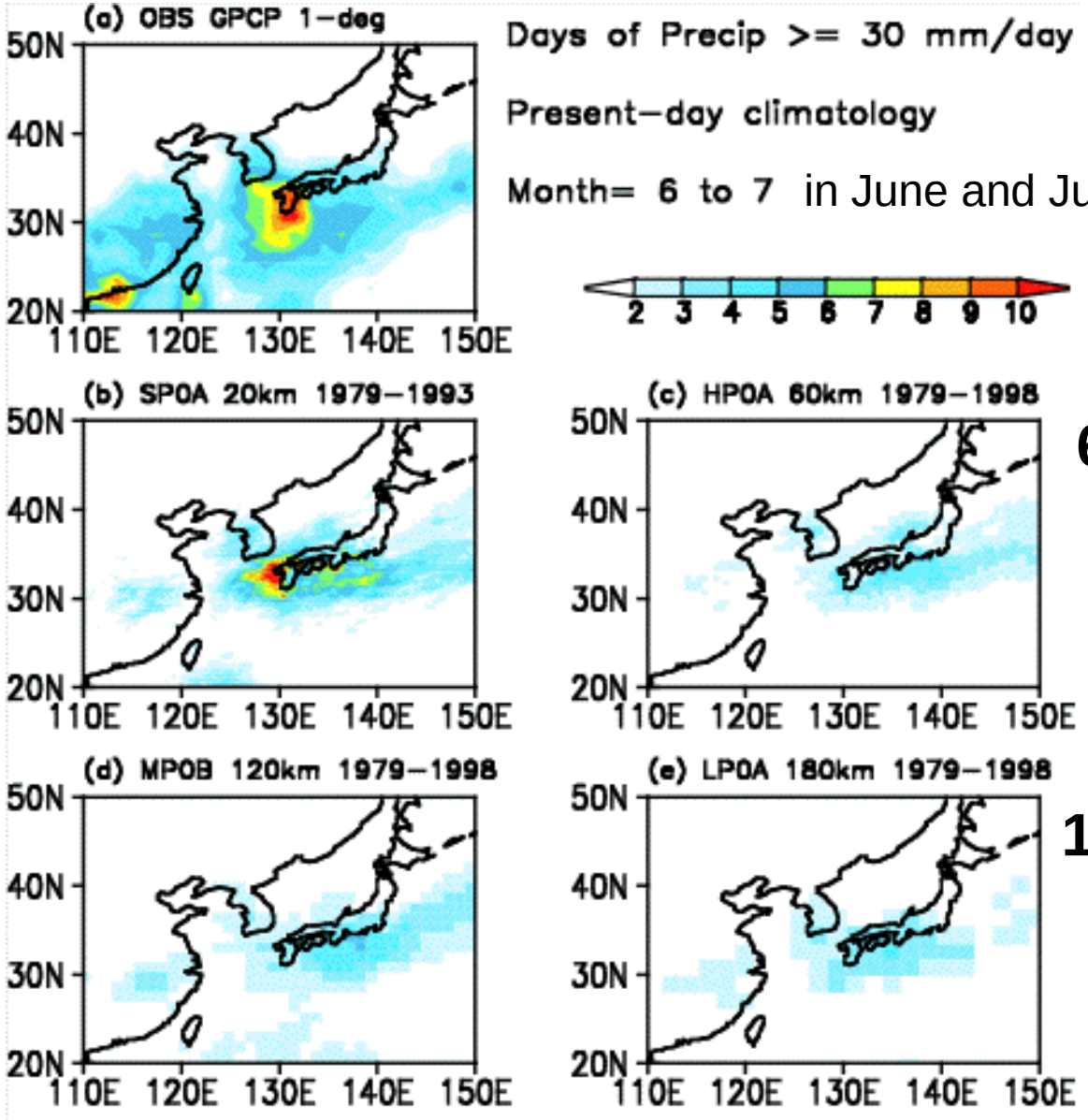


Future changes in precipitation in Central America

Country	Statistics	P
Mexico	20km	−2.7
	60km	0.3
	CV	3.6
Nicaragua	20	1.1
	60	−4.5
	CV	9.7
Panama	20	8.4
	60	−3.3
	CV	4.4
Saint Kitts and Nevis	20	2.2
	60	3.1
	CV	6.4

Days of precipitation greater than 30mm/day between resolutions

Observation GPCP



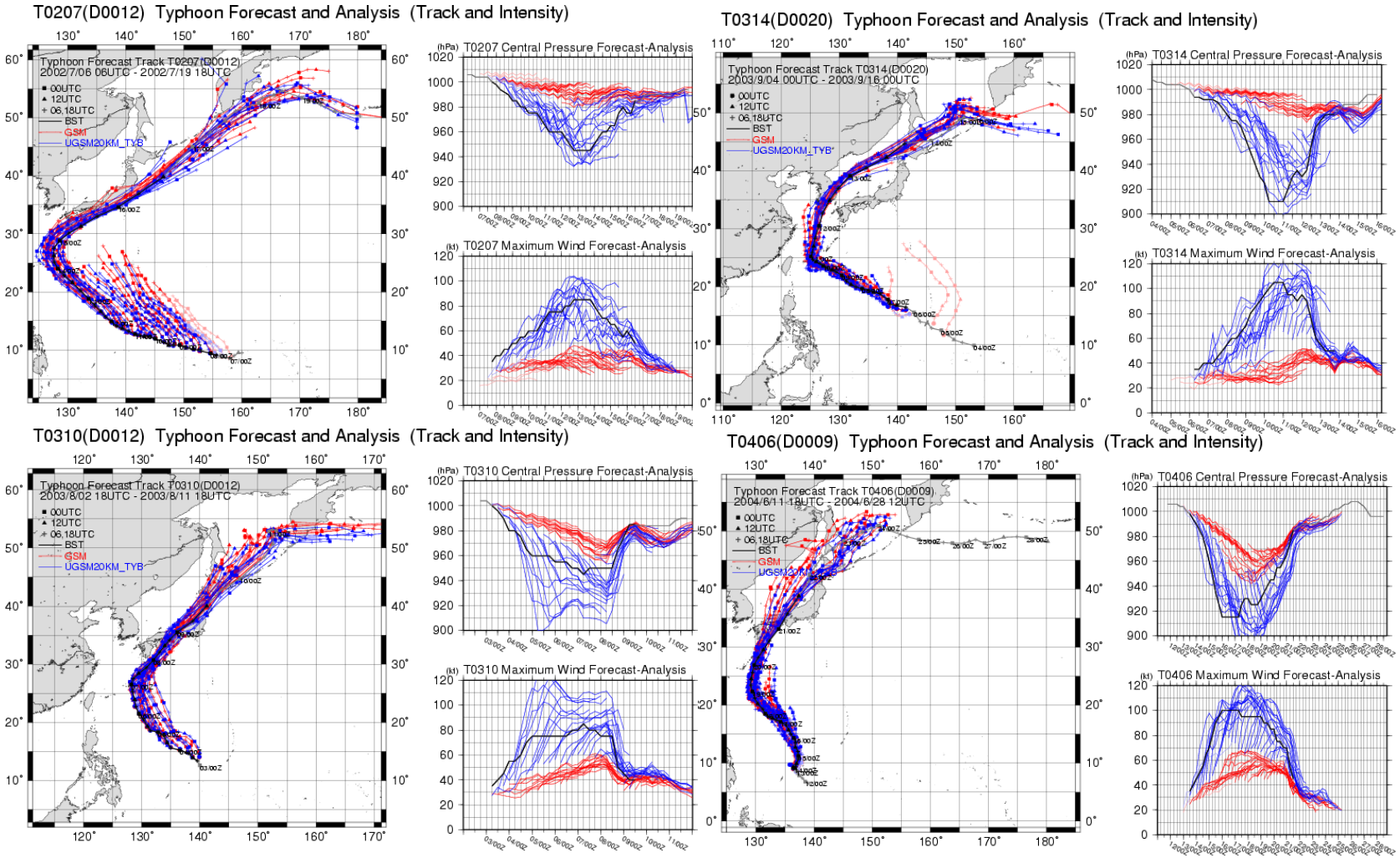
20km

60km

120km

180km

Cyclon prediction between 60km and 20km mesh models

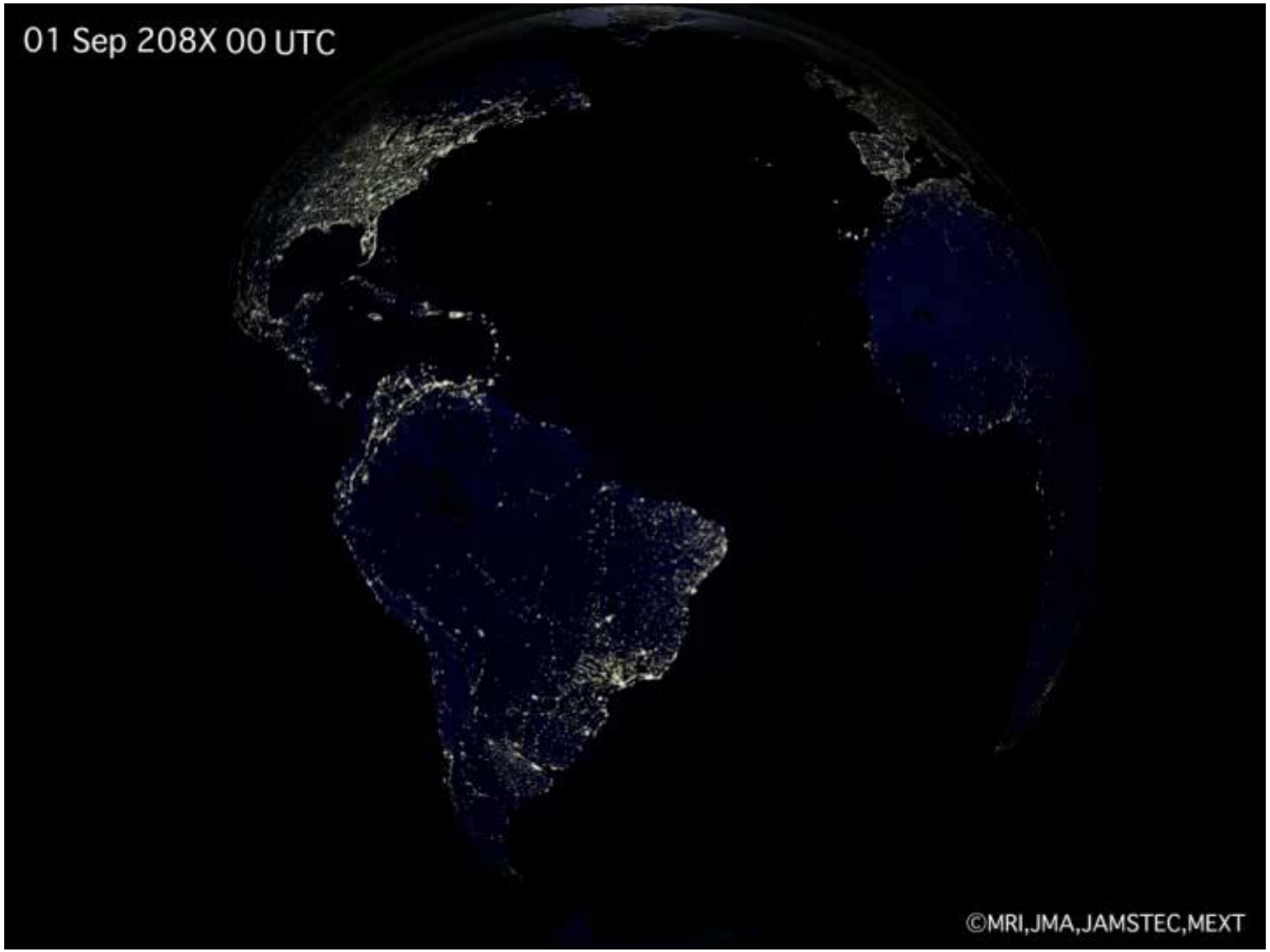


Weak central pressure and weak max. wind speed in the 60km mesh model. Reproducibility in the 20km mesh model is better.

60km mesh model

20km mesh model

Tropical cyclones in the 20-km AGCM

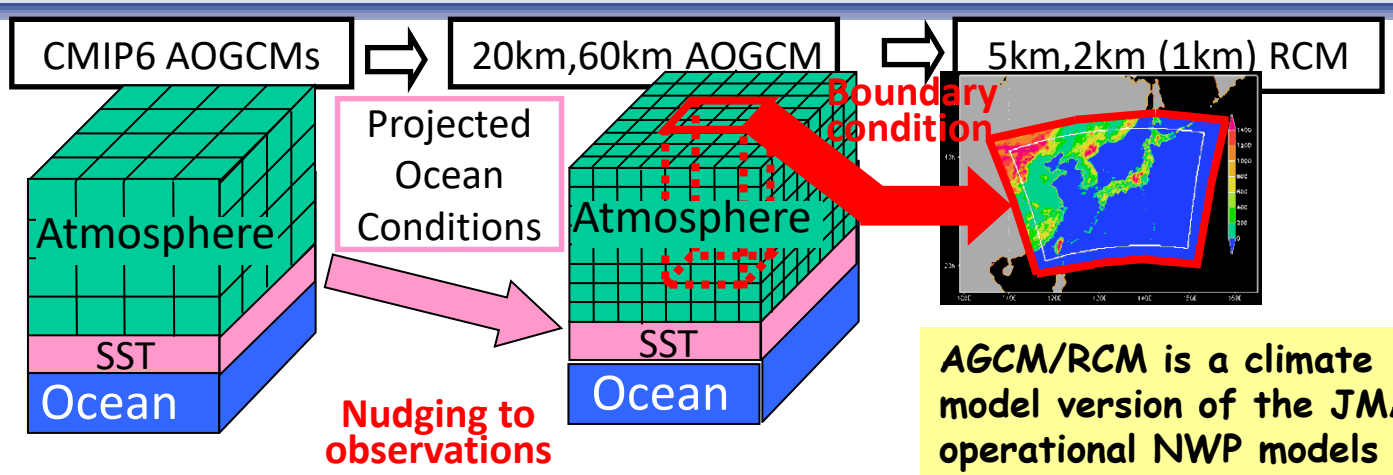


SENTAN Theme-3: future climate projections in Japan

Time-sequential experiments: **TSE-C**

AOGCM

- (1950-2100)



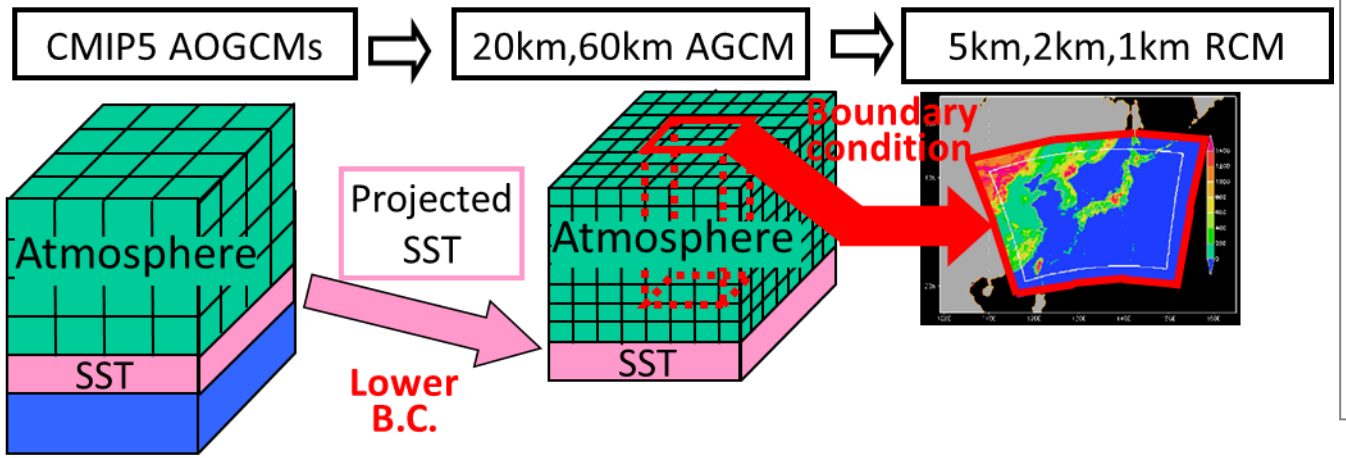
NEW!

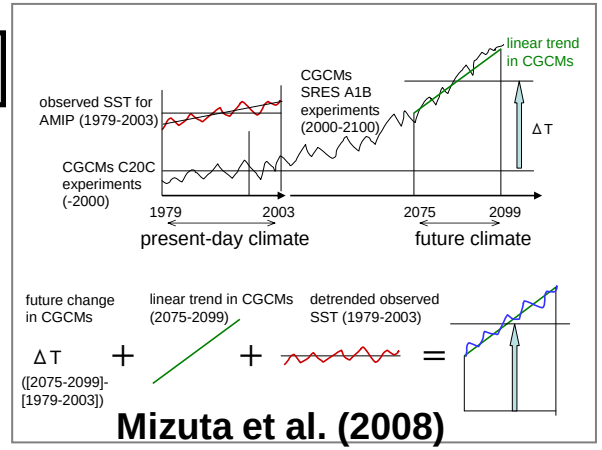
AGCM/RCM is a climate model version of the JMA operational NWP models

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!

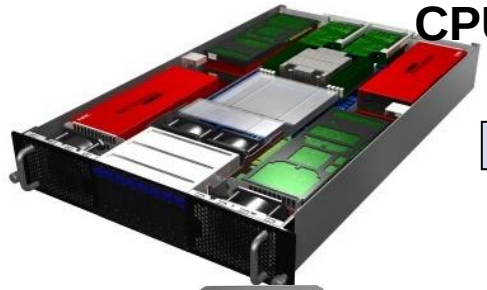
Supercomputer is essential for climate projections

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

TOP500 The List.

Rank #56 (#29



Operational in Deutscher Wetterdienst since 2019 as well

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

Thank you for your attention