The seasonal to decadal climate prediction system FIO-CPS v2.0

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Who am I

- Name
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  – BSc and MSc in Meteorology
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  – Climate Prediction
  – Air-sea Interaction in Monsoon Region
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Lecture series

- **Lecture 1 (14:00pm to 14:40pm)**

  Introduction of climate system and climate model

- **Lecture 2 (14:50pm to 15:30pm)**

  Seasonal to decadal prediction ability of climate prediction system

Main aims and objectives

Answer two questions:

- What’s the climate prediction system?
- How well do the climate models to predict on seasonal to decadal time scale?

Lecture 1

Introduction of climate system and climate model

- What is the earth's climate system?
- Why we need to make climate prediction?
- What is the current progress in climate model development?

The Earth's Climate System

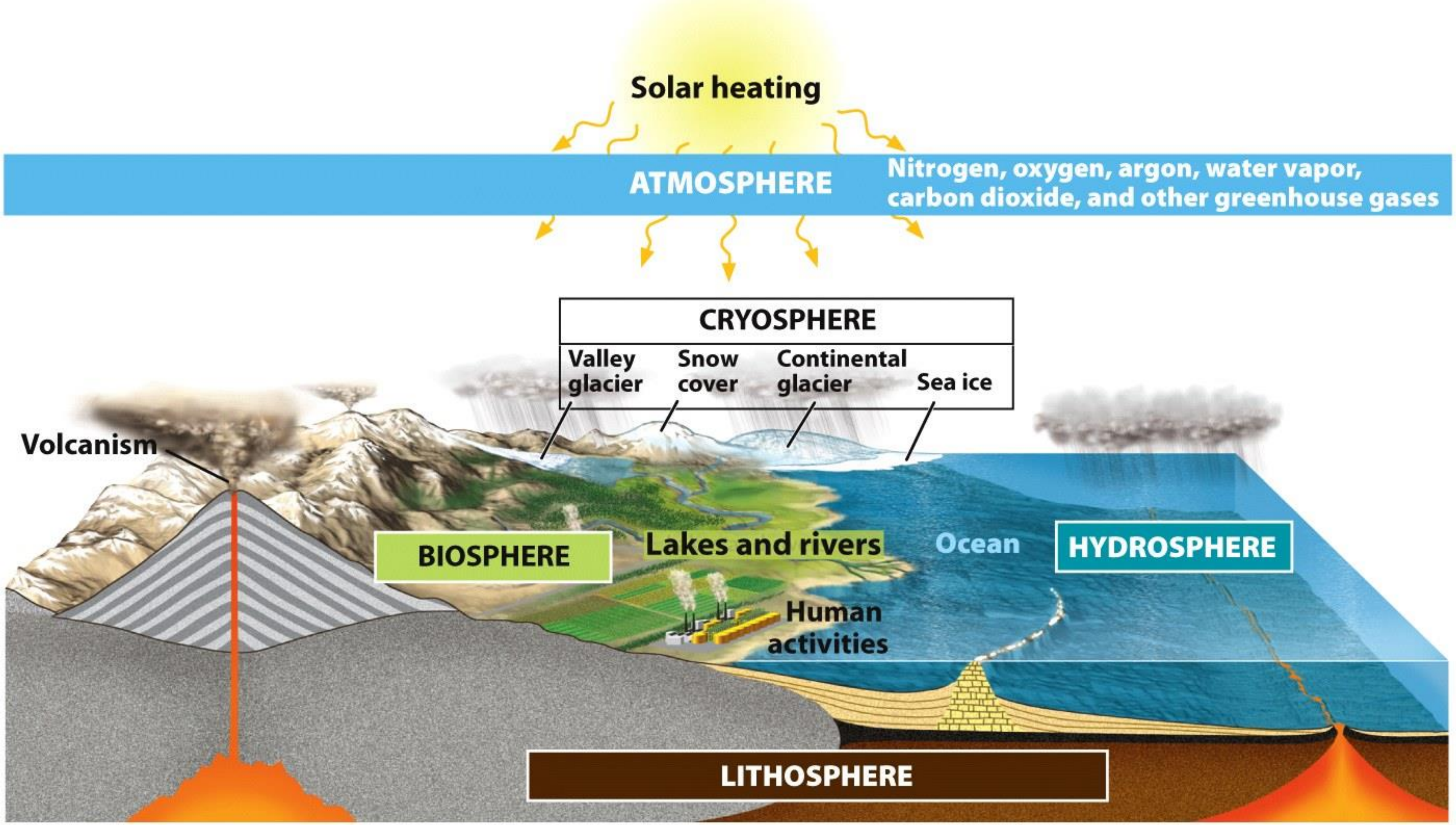


Figure 15.1
***Understanding Earth*, Sixth Edition**

Climate System Components

Atmosphere

- Fastest changing and most responsive component
- Previously considered the only "changing" component

Ocean

- The other fluid component covering ~70% of the surface
- Plays a central role through its motions and heat capacity
- Interacts with the atmosphere on days to thousands of years

Cryosphere

- Includes land snow, sea ice, ice sheets, and mountain glaciers
- High reflectivity and low thermal conductivity
- Largest reservoir of fresh water

Land and its biomass

- Slowly changing extent and position of continents
- Faster changing characteristics of lakes, streams, soil moisture and vegetation

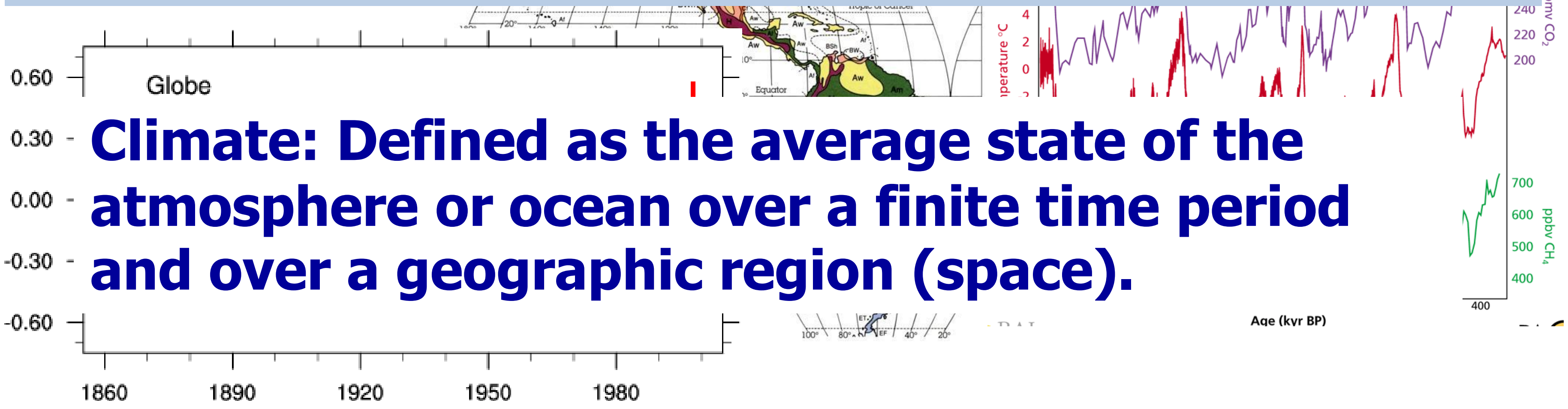
Human interaction

- agriculture, urbanization, industry, pollution, etc.

Climate and Weather

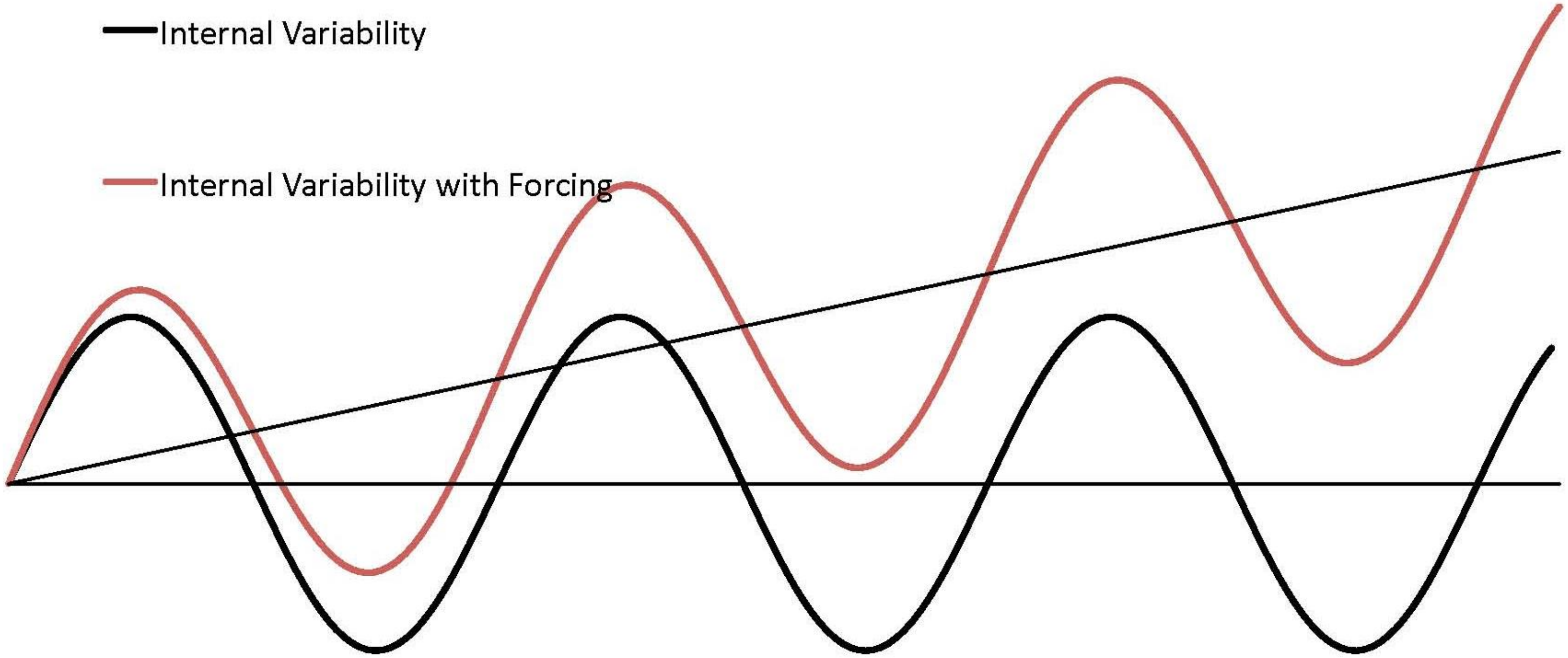
Weather: The condition of atmosphere <u>at a given time and place</u>

Weather versus Climate:
Climate tells what clothes to buy, but weather tells you what clothes to wear.

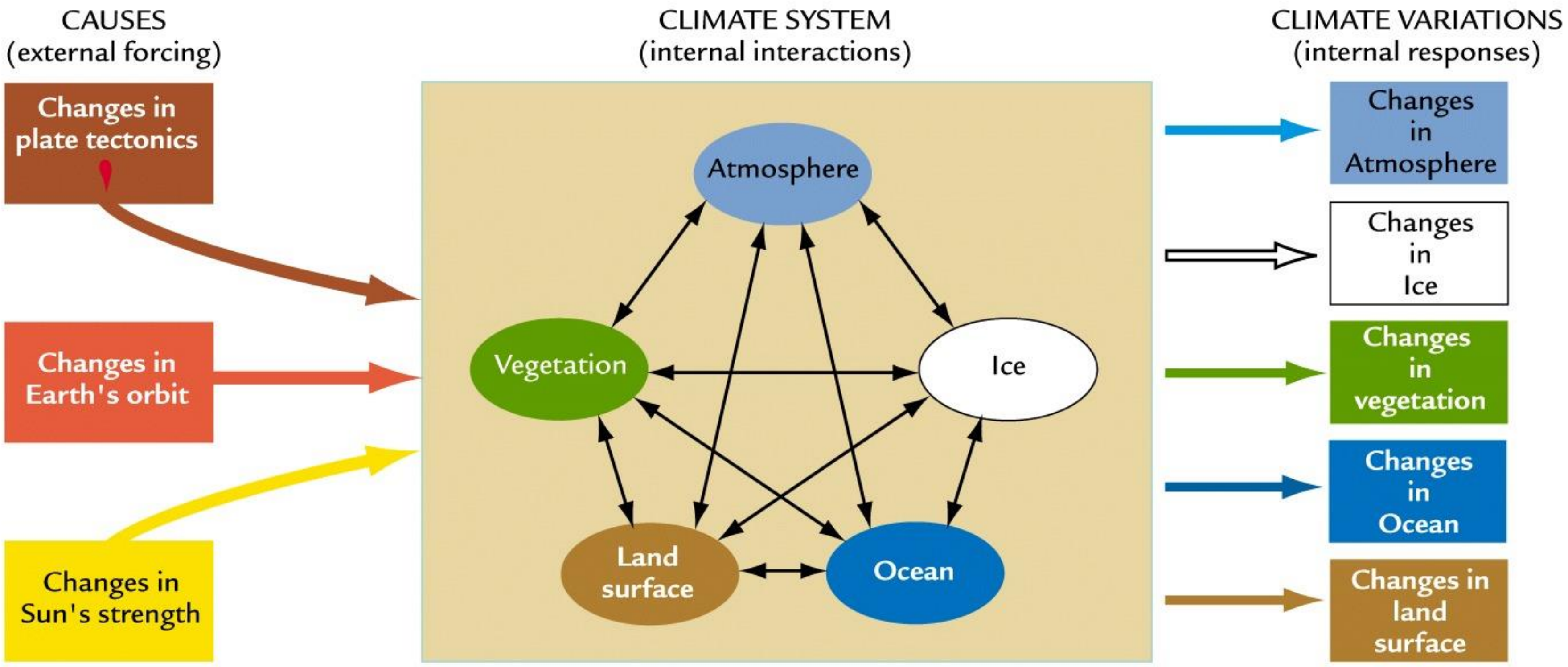


Climate: Defined as the average state of the atmosphere or ocean over a finite time period and over a geographic region (space).

IPCC use of Internal Variability



Earth's Climate: Forcing and Response



Input **Machine** **Output**

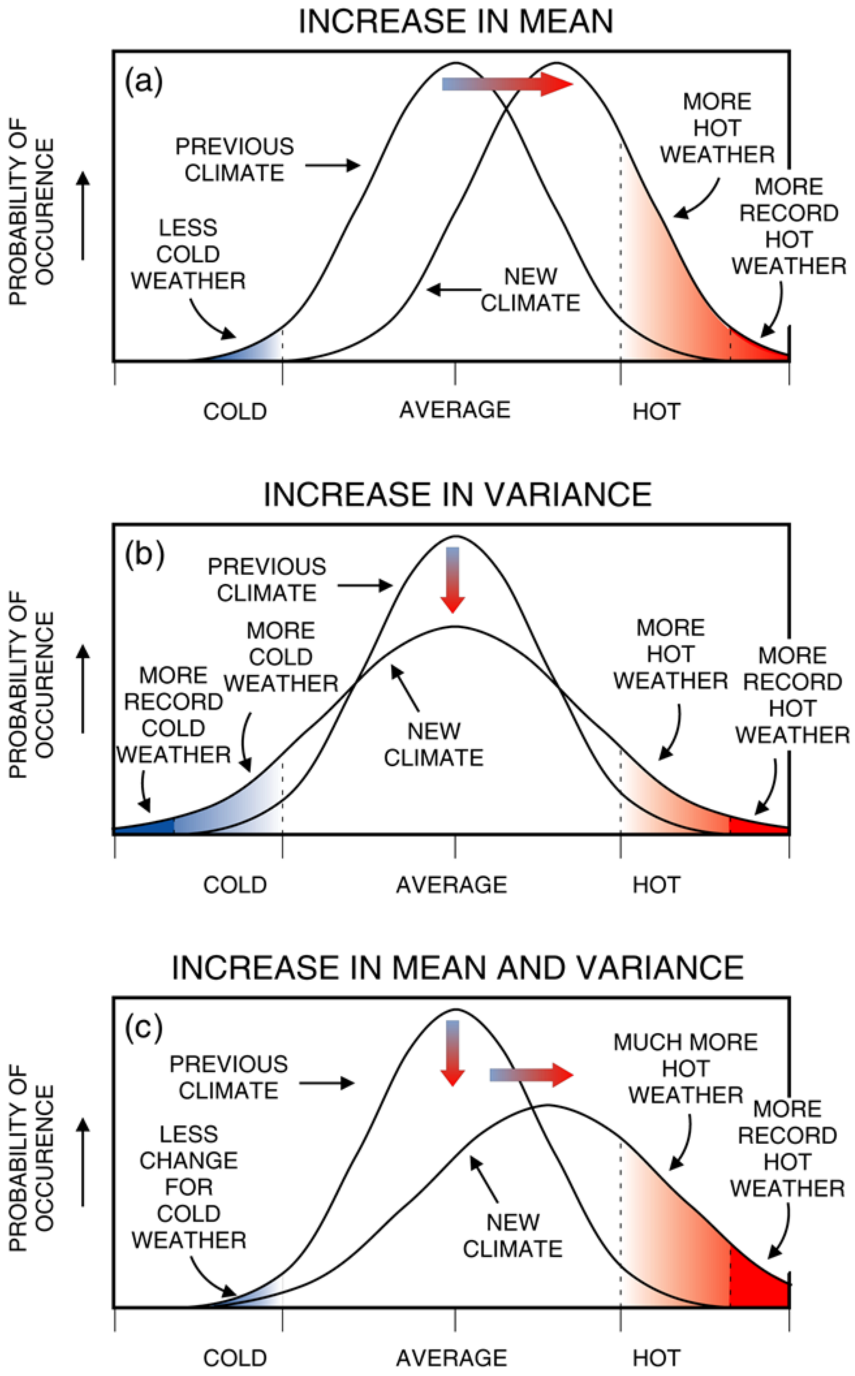
Response Times of Various Climate System Components

TABLE 1.1 Response Times of Various Climate System Components

Component	Response time (range)	Example
	Fast responses	
Atmosphere	Hours to weeks	Daily heating and cooling Gradual buildup of heat wave
Land surface	Hours to months	Daily heating of upper ground surface Midwinter freezing and thawing
Ocean surface	Days to months	Afternoon heating of upper few feet Warmest beach temperatures late in summer
Vegetation	Hours to decades/centuries	Sudden leaf kill by frost Slow growth of trees to maturity
Sea ice	Weeks to years	Late-winter maximum extent Historical changes near Iceland
	Slow responses	
Mountain glaciers	10–100 years	Widespread glacier retreat in 20th century
Deep ocean	100–1500 years	Time to replace world's deep water
Ice sheets	100–10,000 years	Advances/retreats of ice sheet margins Growth/decay of entire ice sheet

Climate change

- Climate change can occur on global, regional, and local scales.
- It refers to a significant change in the climatic state as evidenced by the modification of the mean value or variability of one or more weather measures persisting over several decades or longer.



Climate variability

- Variation about the mean state and other statistic (such as standard deviations, statistics of extremes) of the climate on all time and space scales beyond that of individual weather events (defined by WMO）

- It’ s often used to describe deviations in climate statistics over a period of time (e.g., month, season, year) compared to the long-term climate statistics for the same time period.

Climate variability

Some examples

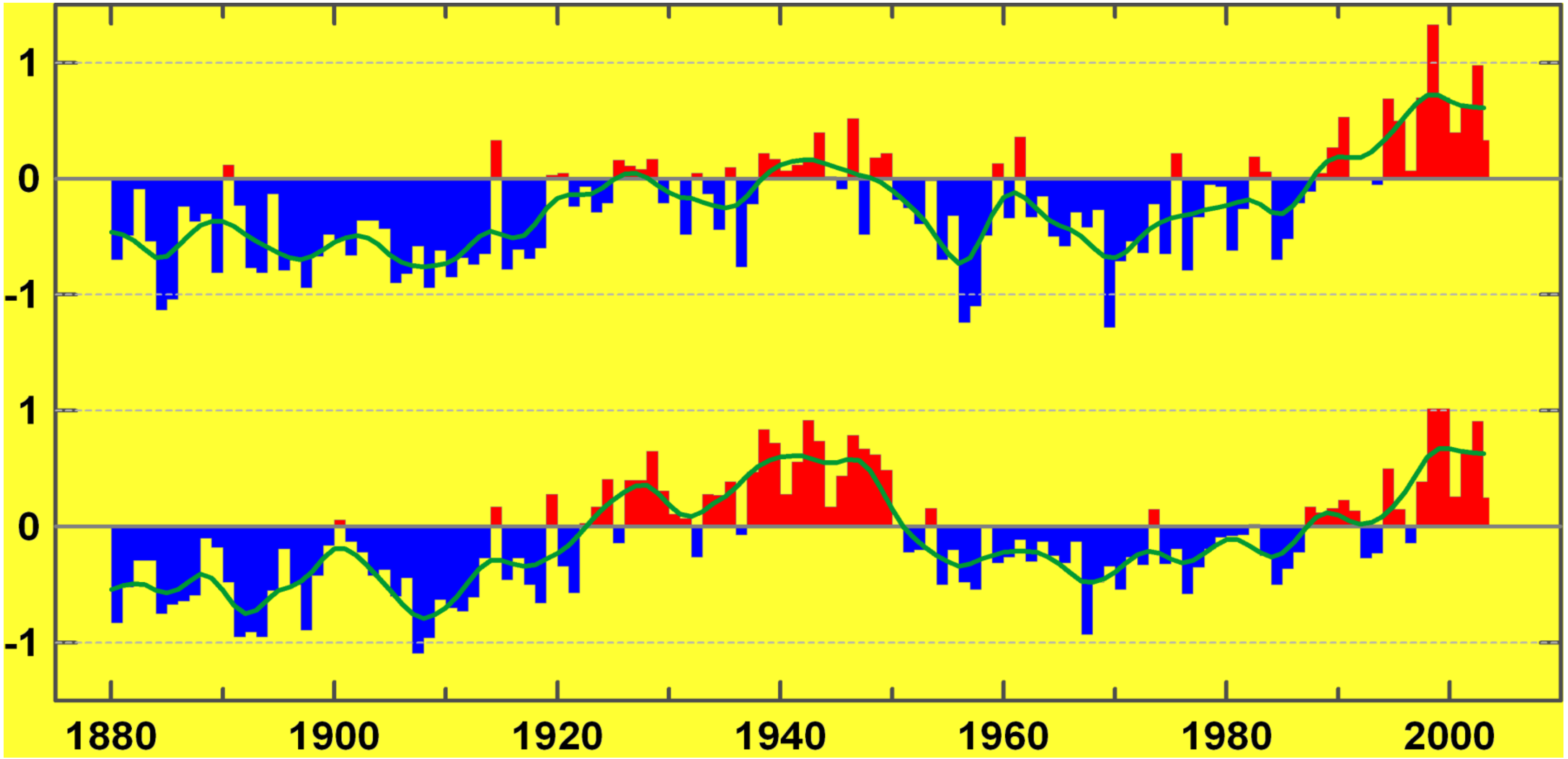
- Diurnal and Seasonal cycles
- MJO(intraseasonal, 20-80d)
- ENSO (interannual, 2-7a)
- PDO\AMO…(decadal/interdecadal)
- Volcanic activity (decades to millennia)
- Changes in surface properties
- Evolution of the sun
- Changes in atmospheric composition

Long-term climate variability

Surface air temperature

Eastern China

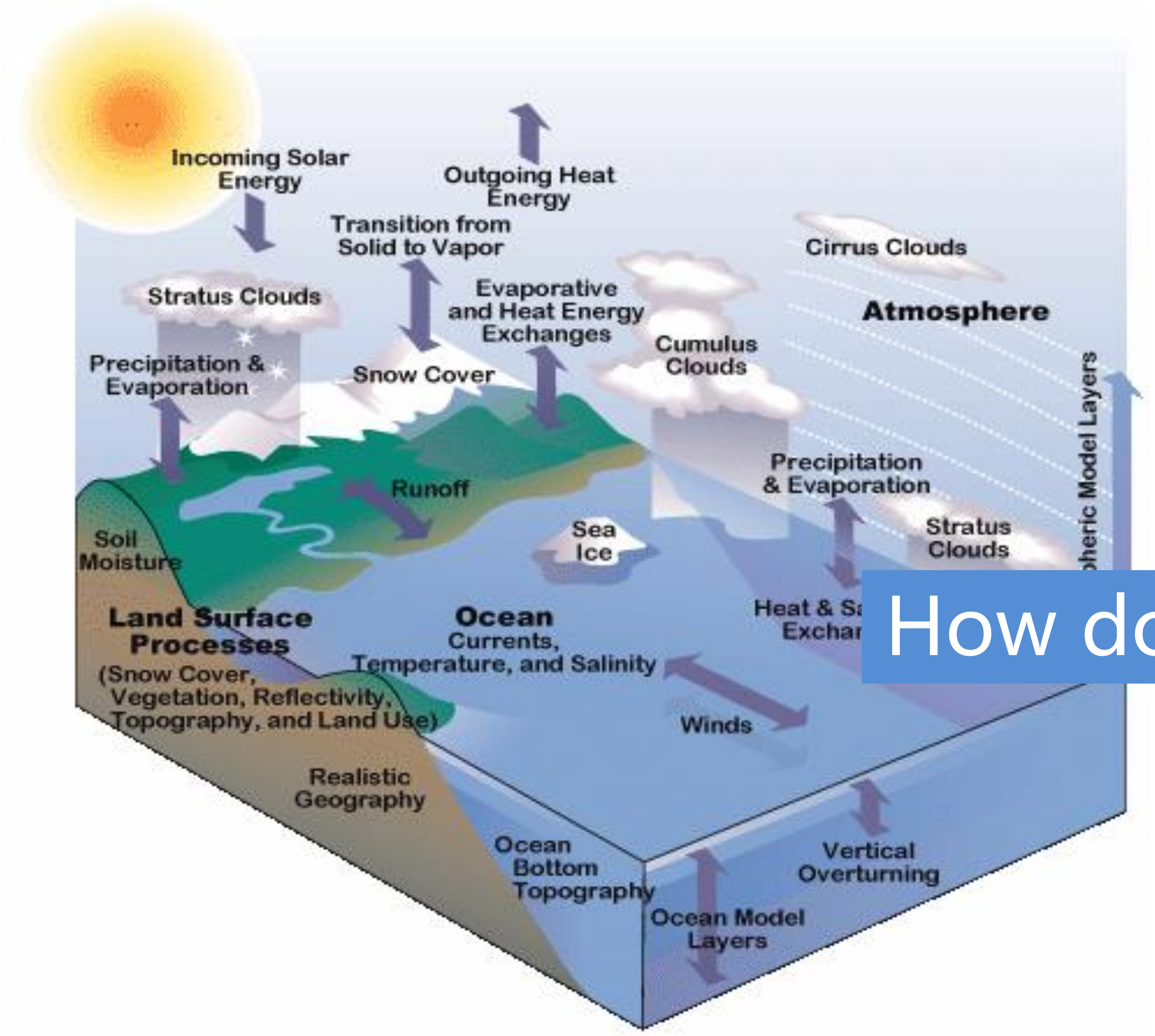
Western China



（Wang et al., 1998）

Interannual variability ⟷ interdecadal variability

General circulation models



Processes to include

How do we simulate this?

What is a climate model?

- A mathematical representation of the many processes that make up our climate.
- Requires:
  - Knowledge of the physical laws that govern climate
  - Mathematical expressions for those laws
  - Numerical methods to solve the mathematical expressions on a computer
  - A computer of adequate size to carry out the calculations

Why Model Climate?

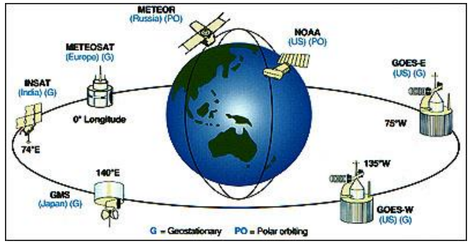
Understanding and Prediction

Climate theory/understanding

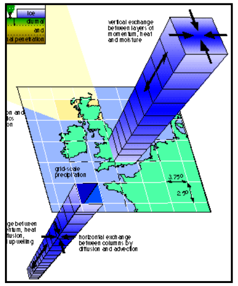
Test understanding

Model-data agreement?

Climate observations and monitoring



Climate modelling

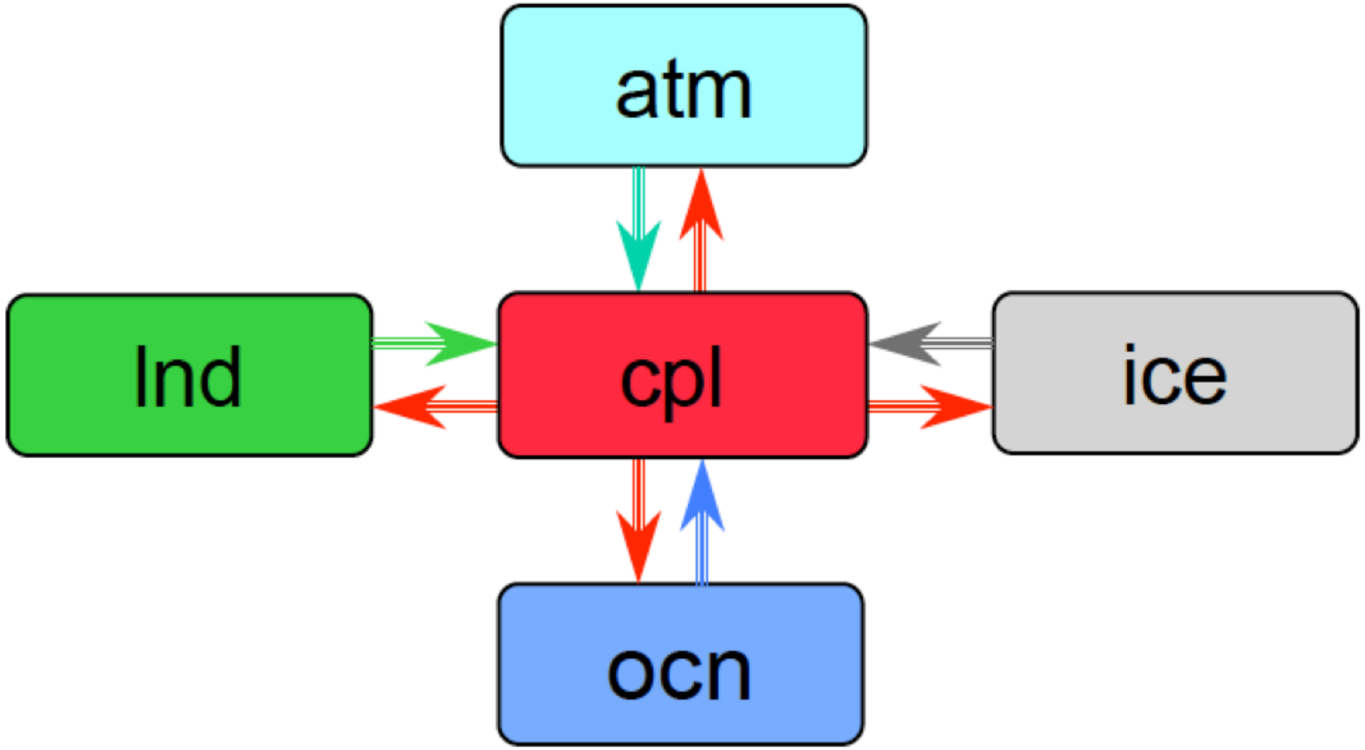


Application to prediction of climate change, mitigation etc.

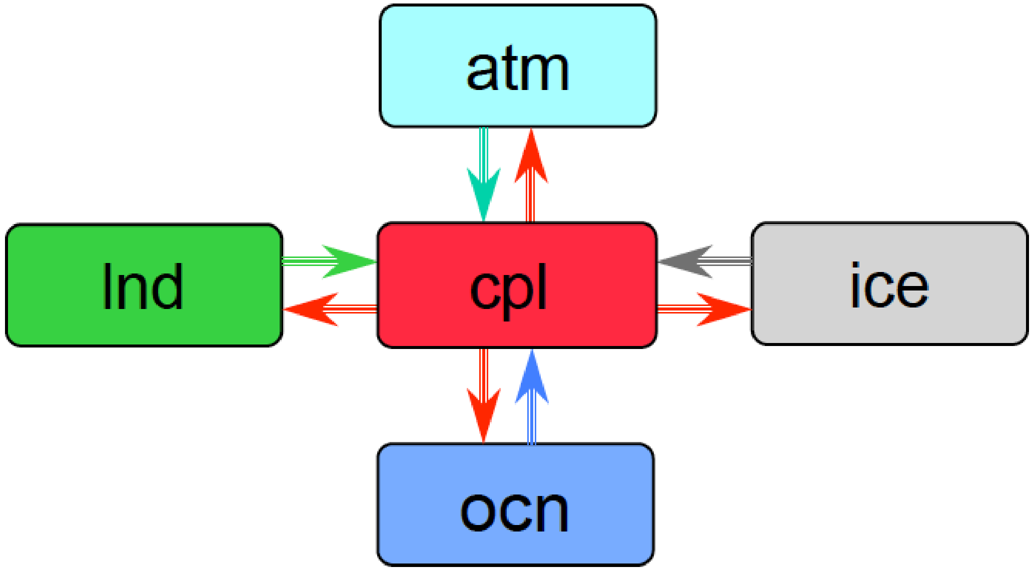
Important climate model components

- Radiation
  - as it drives the system each climate model needs some description of the exchange of shortwave and longwave radiation
- Dynamics
  - the movement of energy in the system both in the horizontal and vertical (winds, ocean currents, convection, bottom water formation)
- Surface processes
  - the exchange of energy and water at the ocean, sea-ice and land surface, including albedo, emissivity, etc.
- Chemistry
  - chemical composition of the atmosphere, land and oceans as well as exchanges between them (e.g., carbon exchanges)

Coupling framework of the climate model



The role of coupler



Function

- Control the system
  – start, stop, restart, write file, when and what communicate between each component
- Exchange data
- Interpolation (mapping)
- Calculate flux

- Minimum modification to component model
- Easy to upgrade
- High parallel efficiency

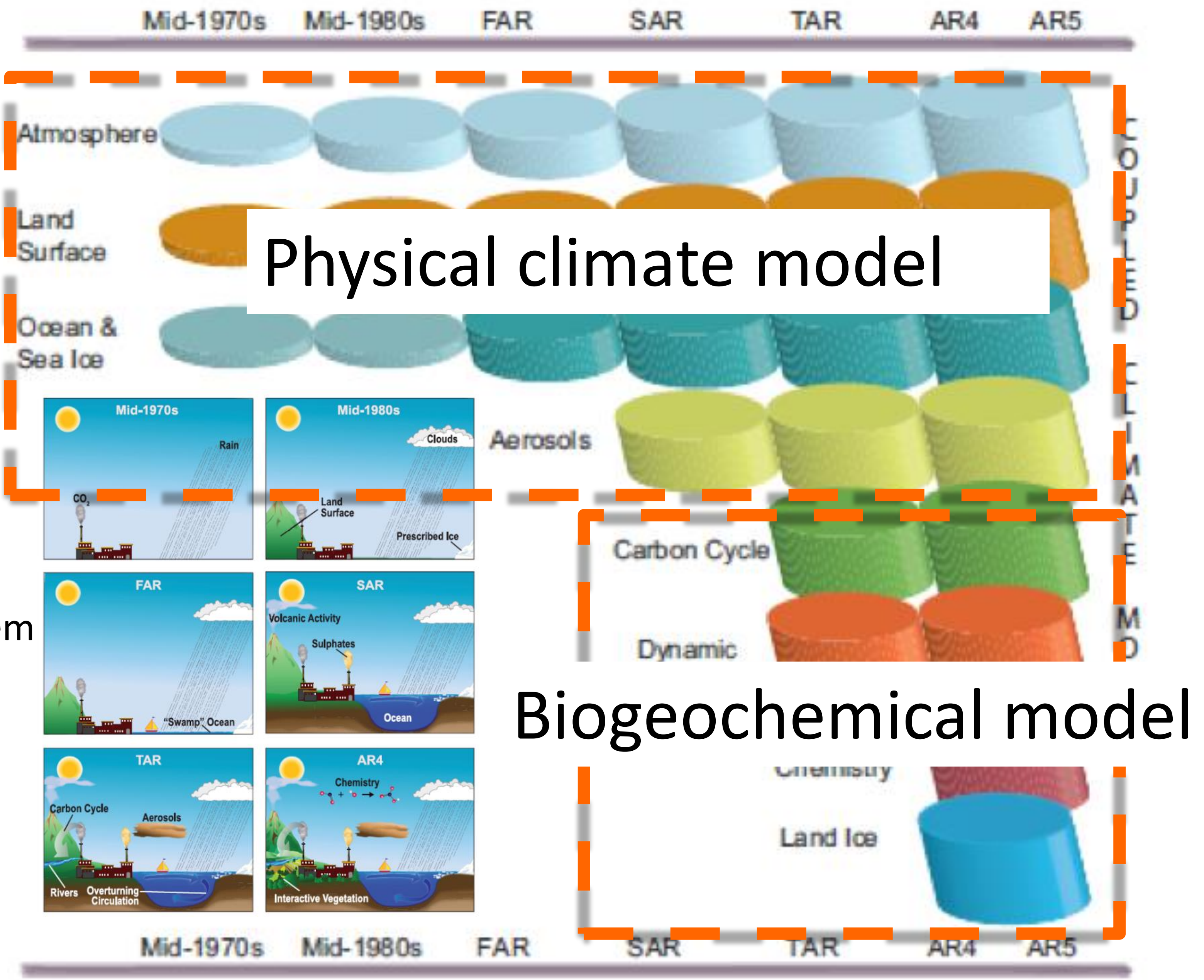
US: CPL、ESMF、MCT
Europe: OASIS
China: C-Coupler

AOGCM
(Atmosphere-
Ocean
General
Circulation
Model)

CGCM
(Coupled
General
Circulation
Model)

ESM
(Earth System
Model)

Model development



Starting Point: Fundamental Laws of Physics

1. Conservation of Mass

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot \left(\vec{V}\rho\right) - \frac{\partial (w\rho)}{\partial z}$$

2. First Law of Thermodynamics

$$\frac{\partial \rho\theta}{\partial t} = -\nabla \cdot \left(\vec{V}\rho\theta\right) - \frac{\partial w\rho\theta}{\partial z} + \frac{\rho}{C_p}\frac{T}{\theta}\dot{H}$$

3. Newton’s Second Law

$$\frac{d_a \vec{V}_{a,3}}{dt} = \sum (Forces/mass)$$

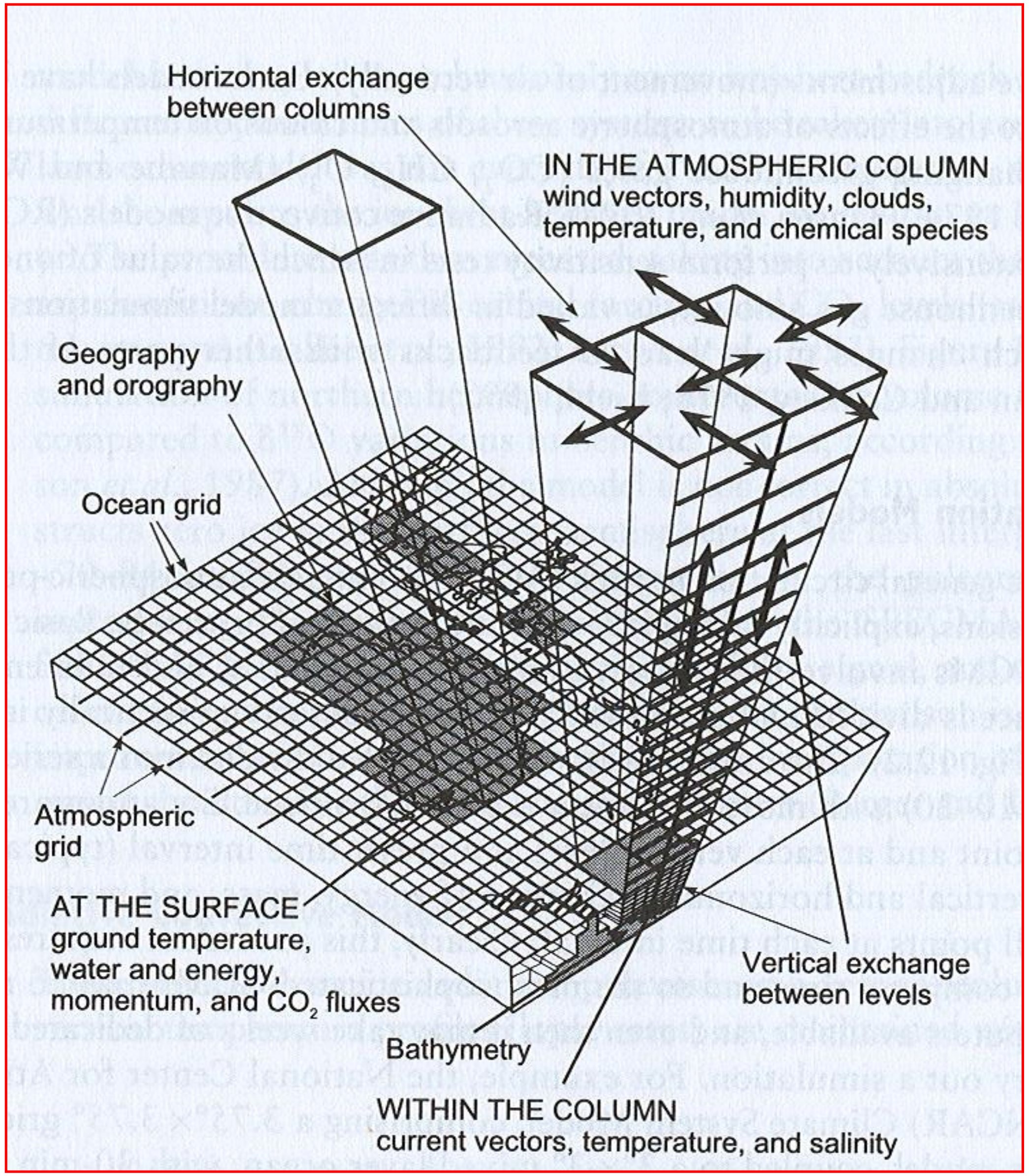
Plus conservation of water vapor, chemical species, …

But - these are complex differential equations!

How can we use them?

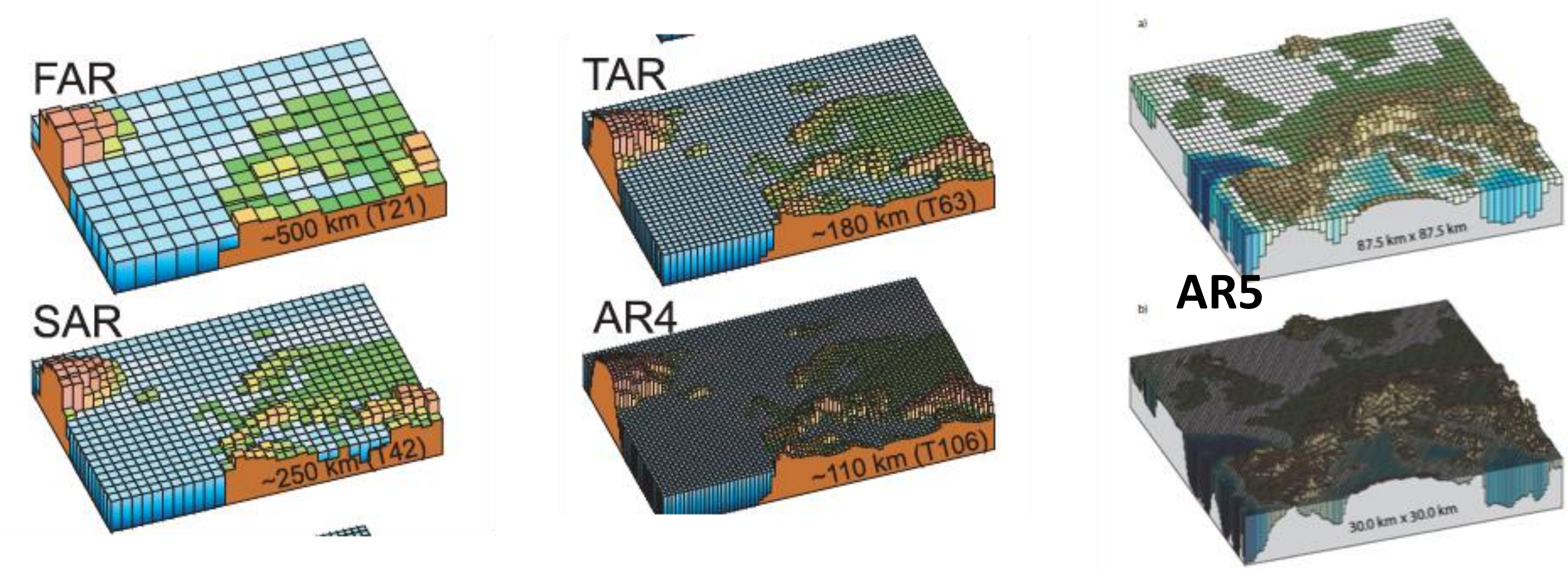
By solving them on a grid.

Climate Model: Structure



GCMs use a planet divided into small regions (grid boxes) and compute their equations for each grid box.

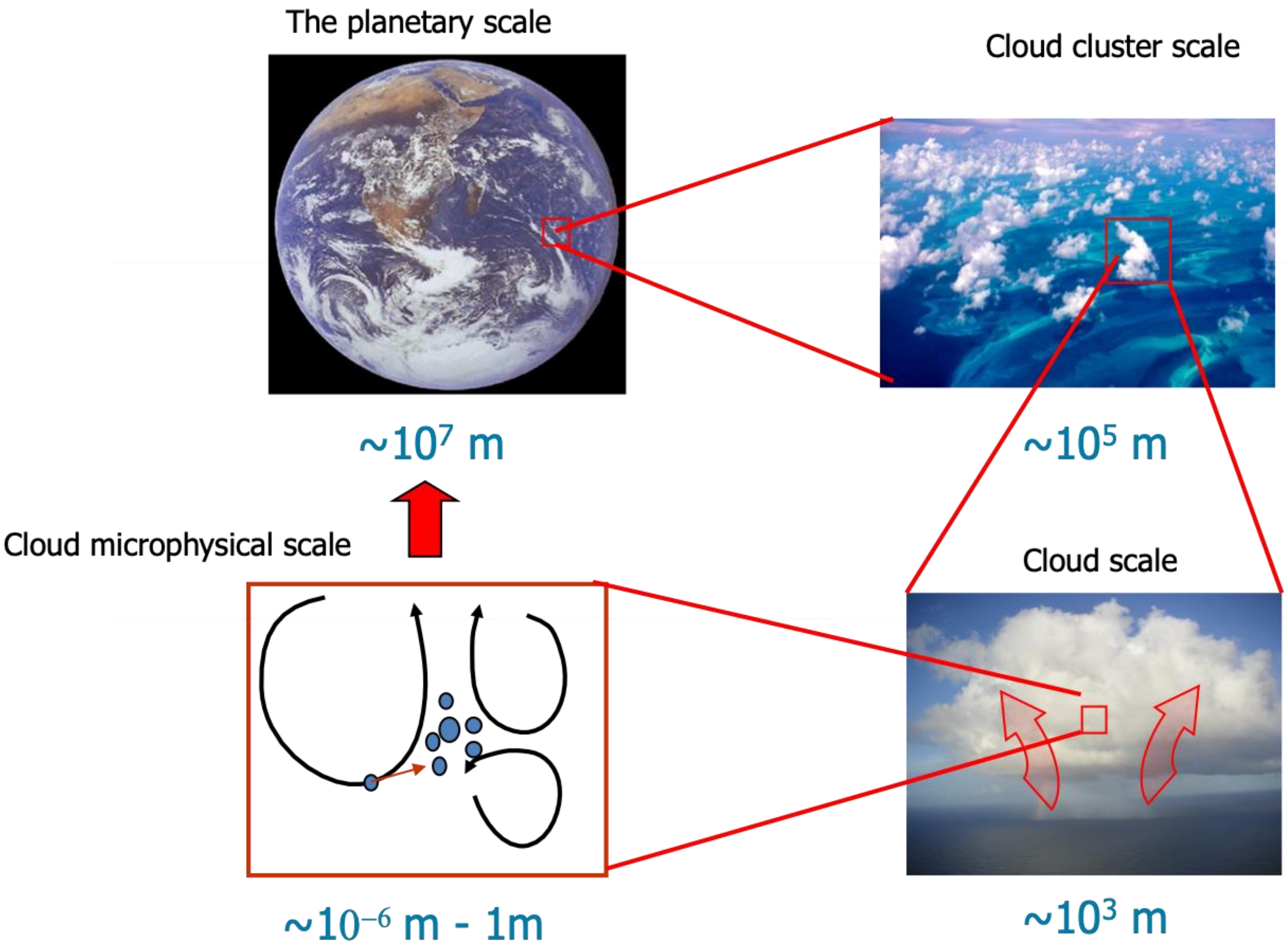
Resolution increases over time



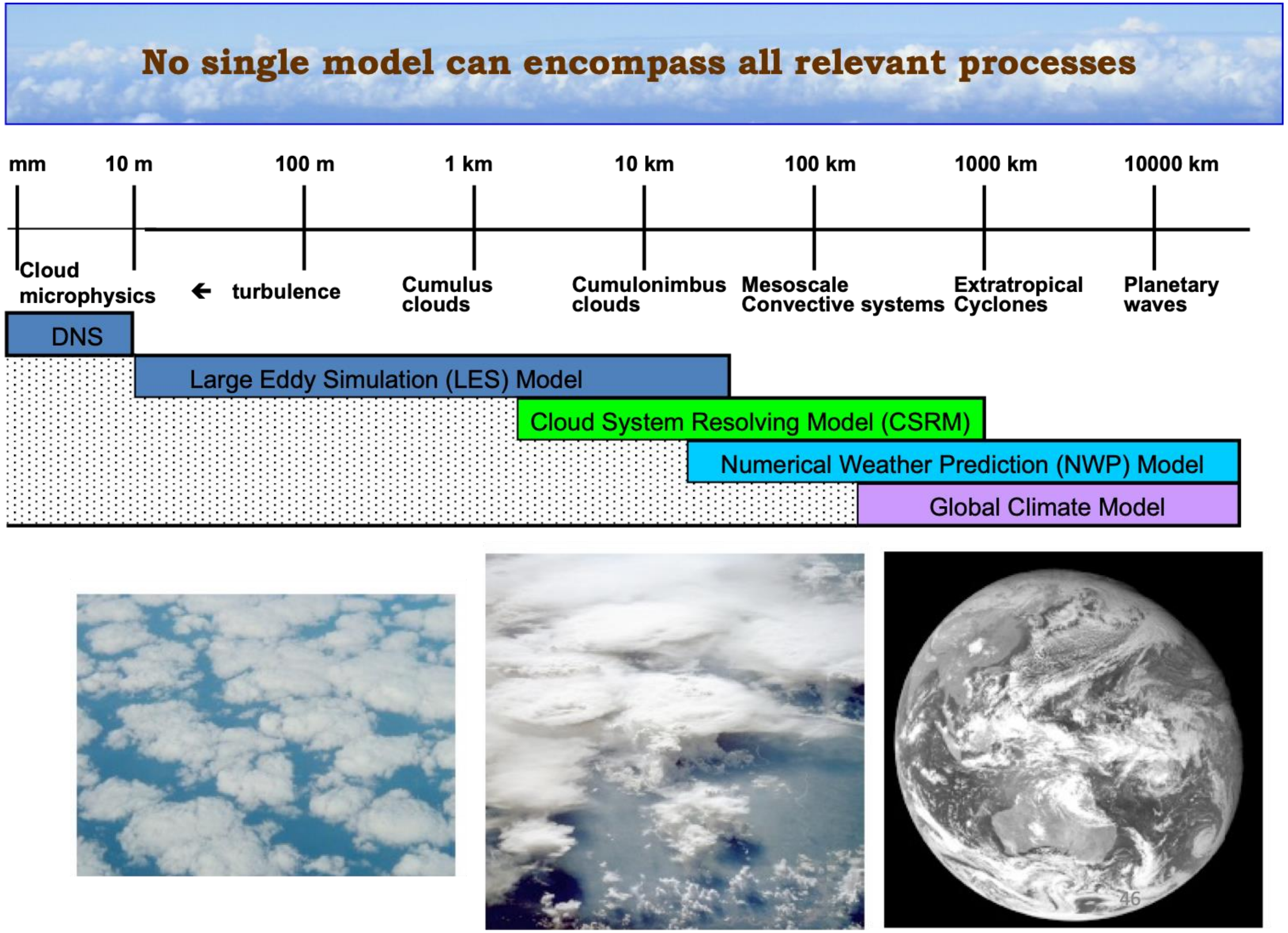
Computing demand increase inversely with *cube* of horizontal resolution

Demand for computing resources has increased dramatically.

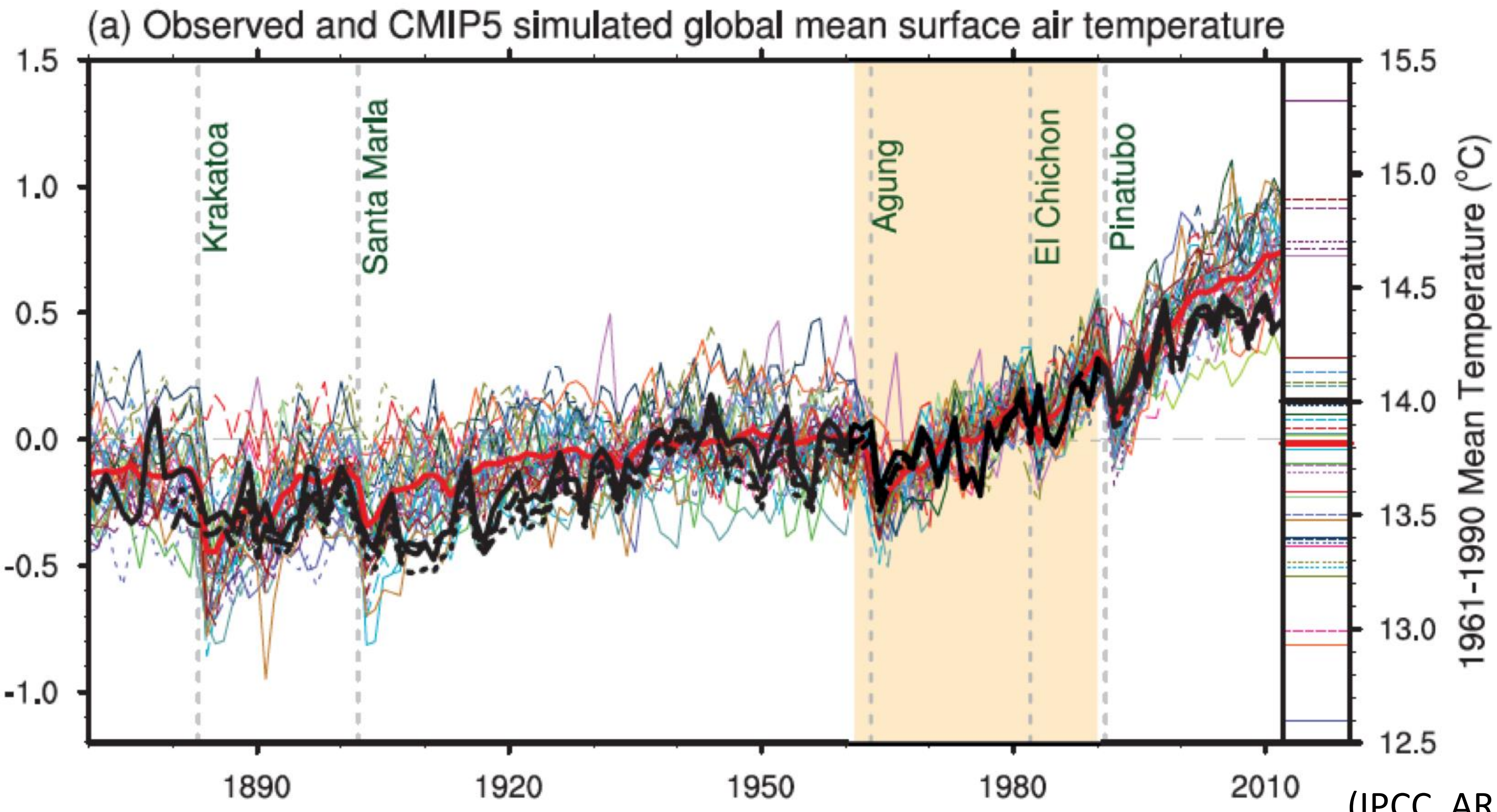
Physical parameterization



Physical parameterization



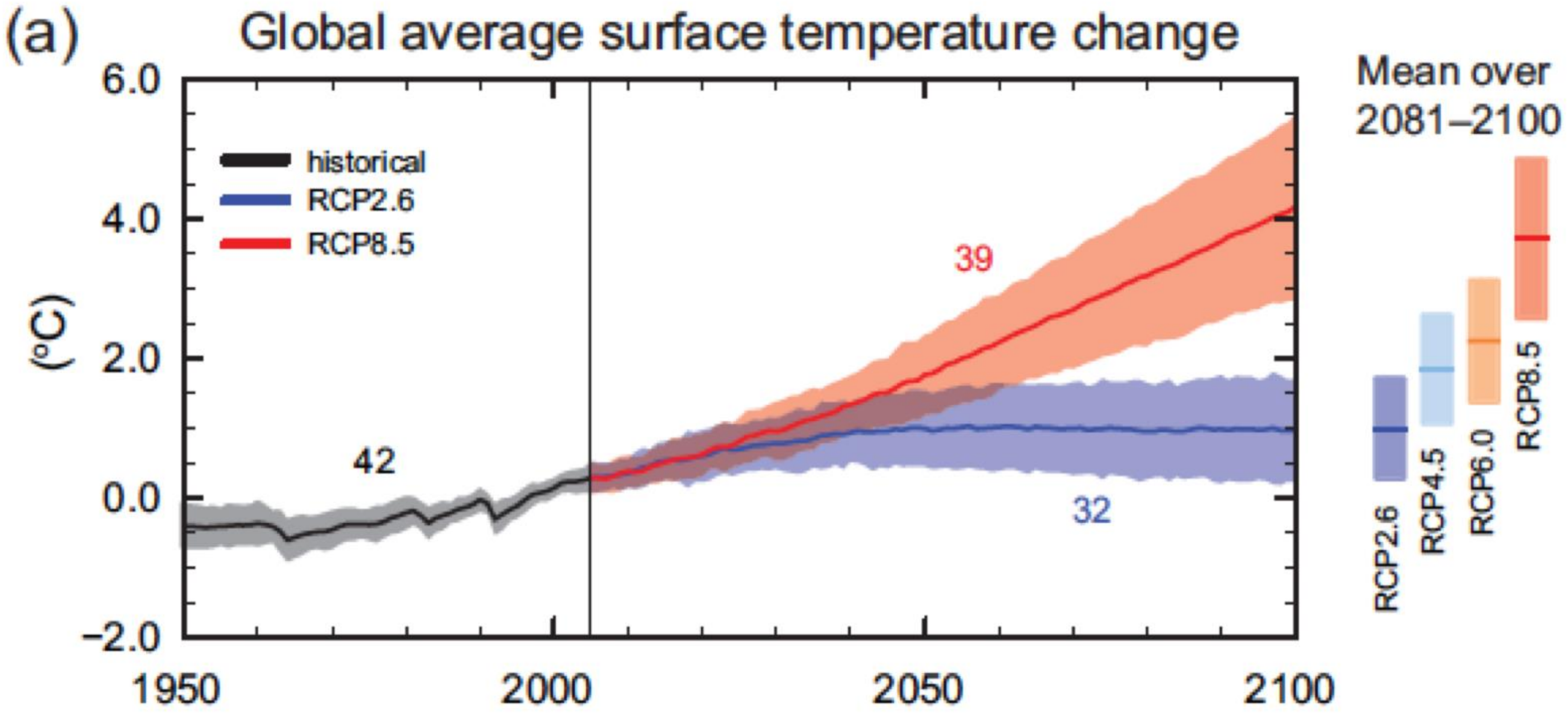
Uncertainty —— parameterization



(IPCC, AR5)

The description of physical processes are different in the climate models.

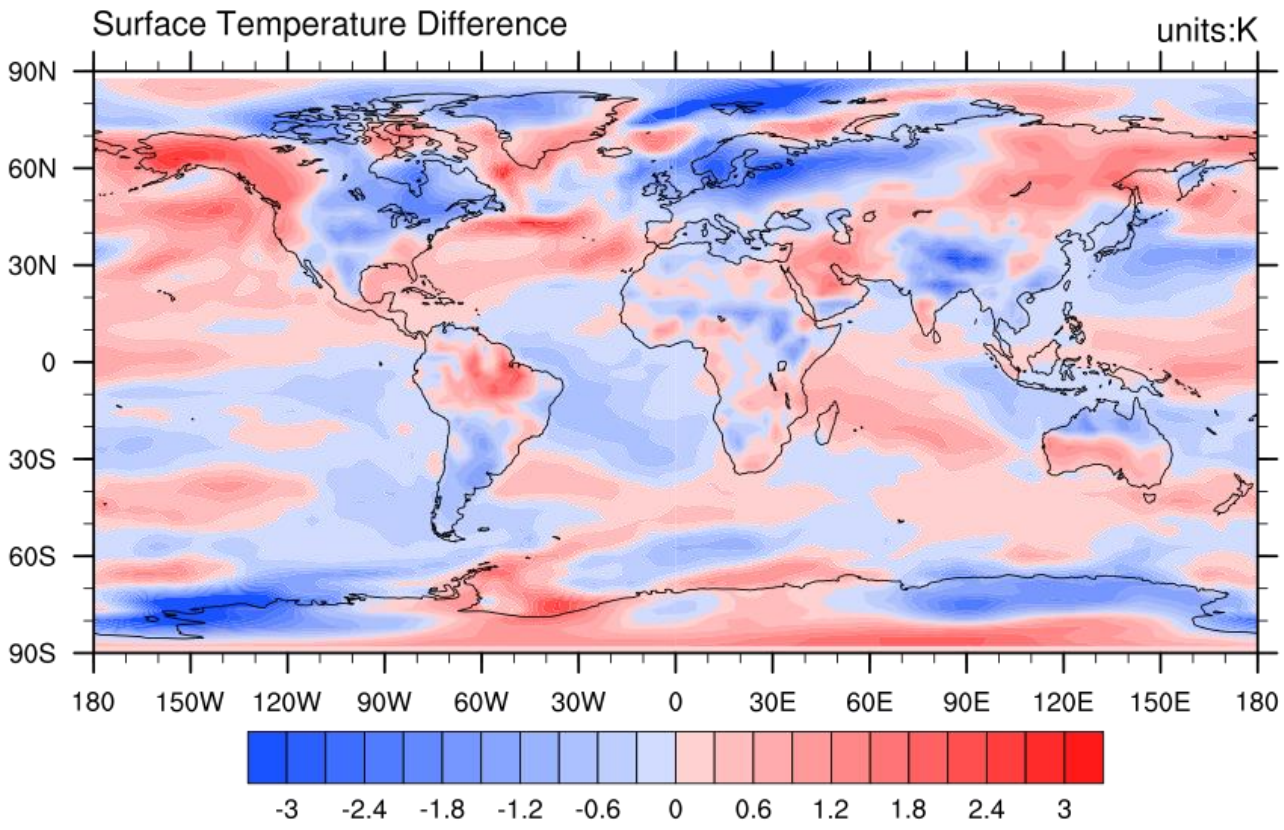
Uncertainty —— different forcing



The different model response to the aerosol and greenhouse gases, as well as othre forcing also contributes to uncertainties.

(IPCC, AR5)

Uncertainty —— computational accuracy

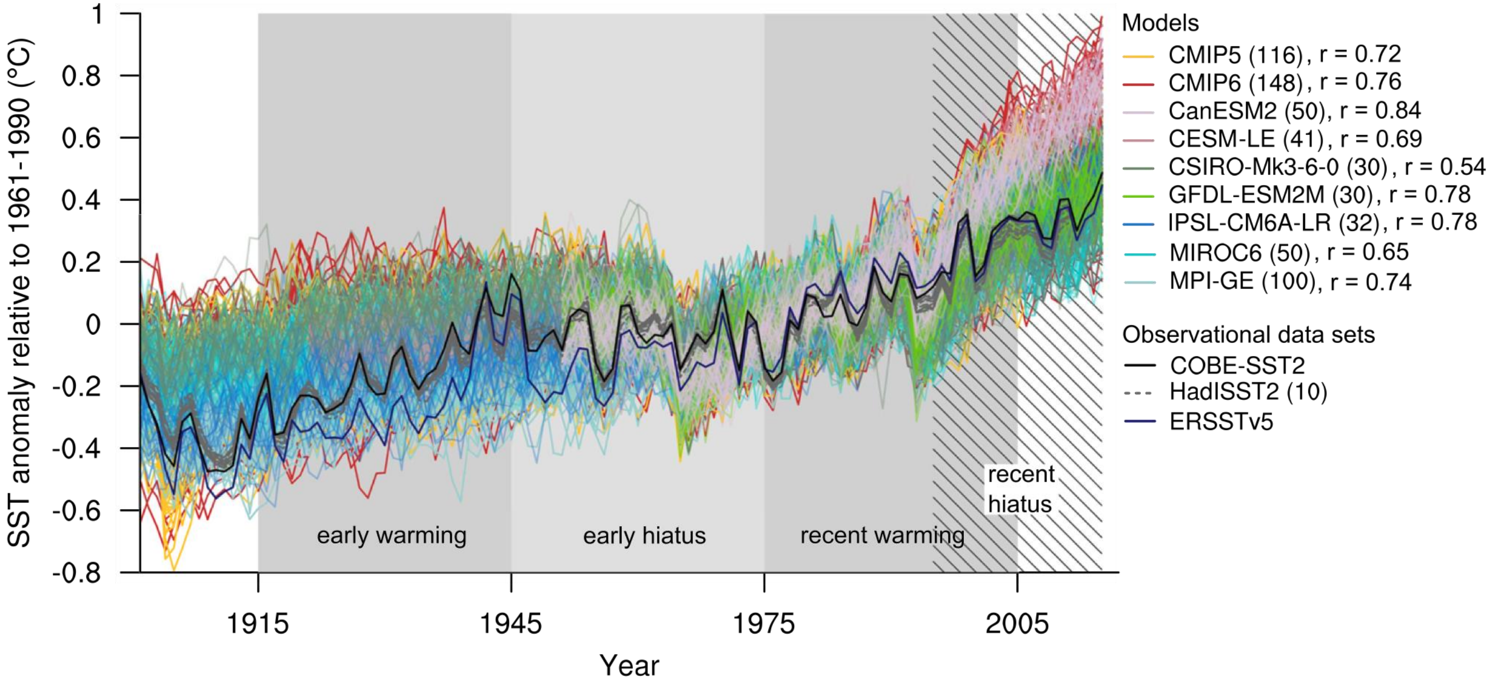


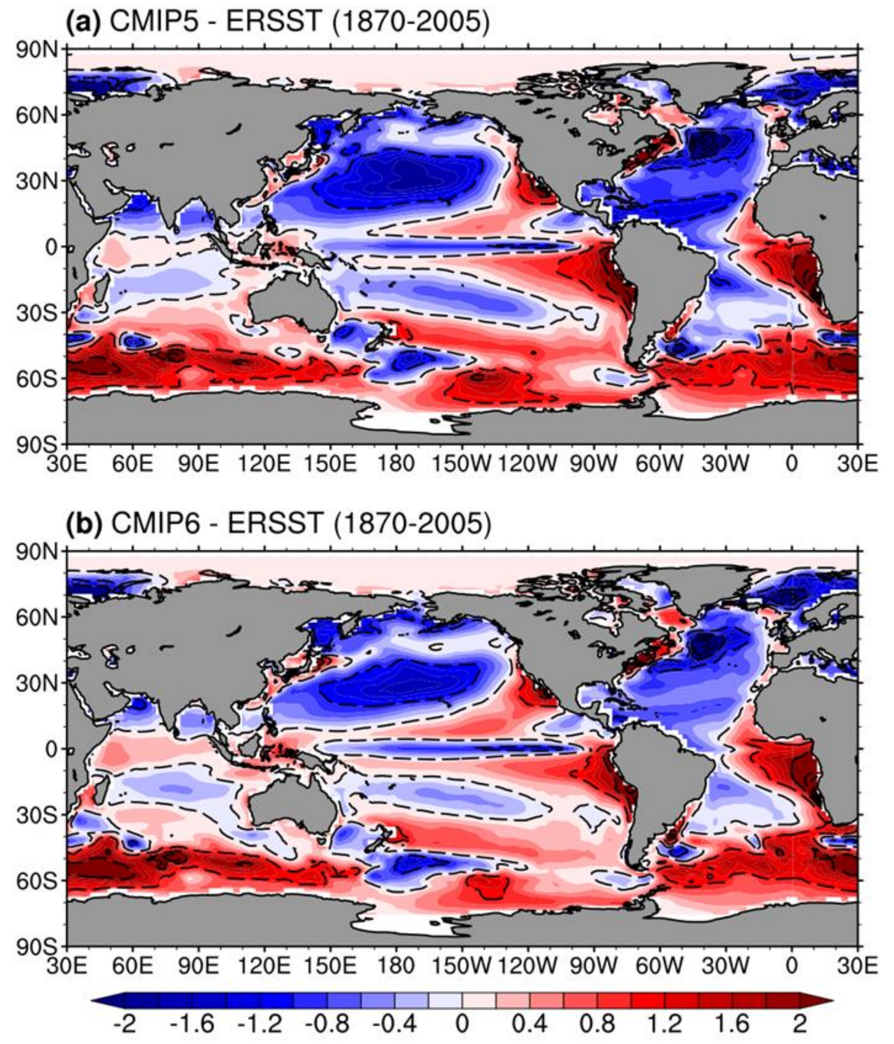
more than 3 degrees

Truncation error also cause uncertainty in climate modeling

- different CPU number, system configuration……
- infinite computing is replaced by a finite computing

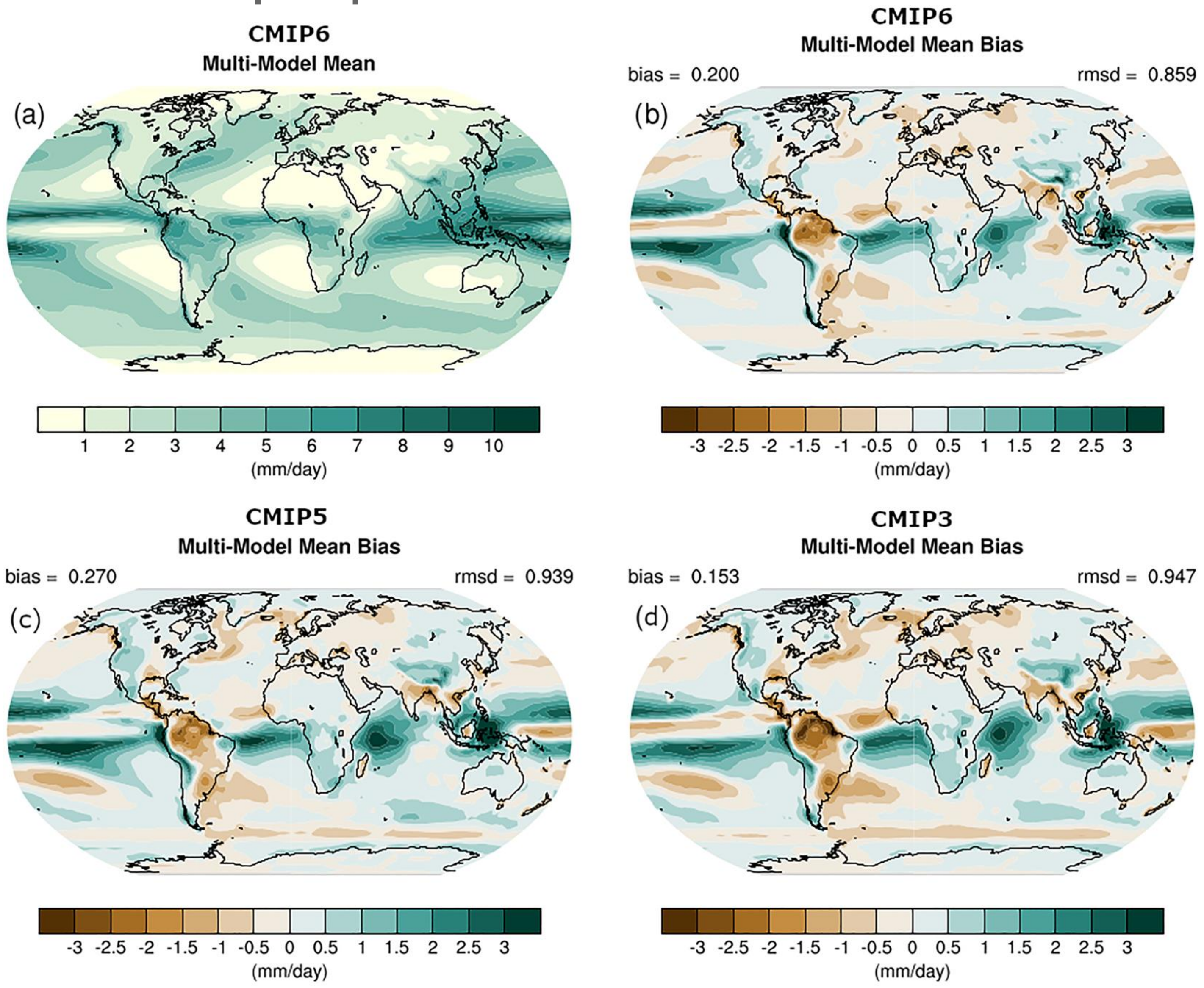
Simulated bias of sea surface temperature





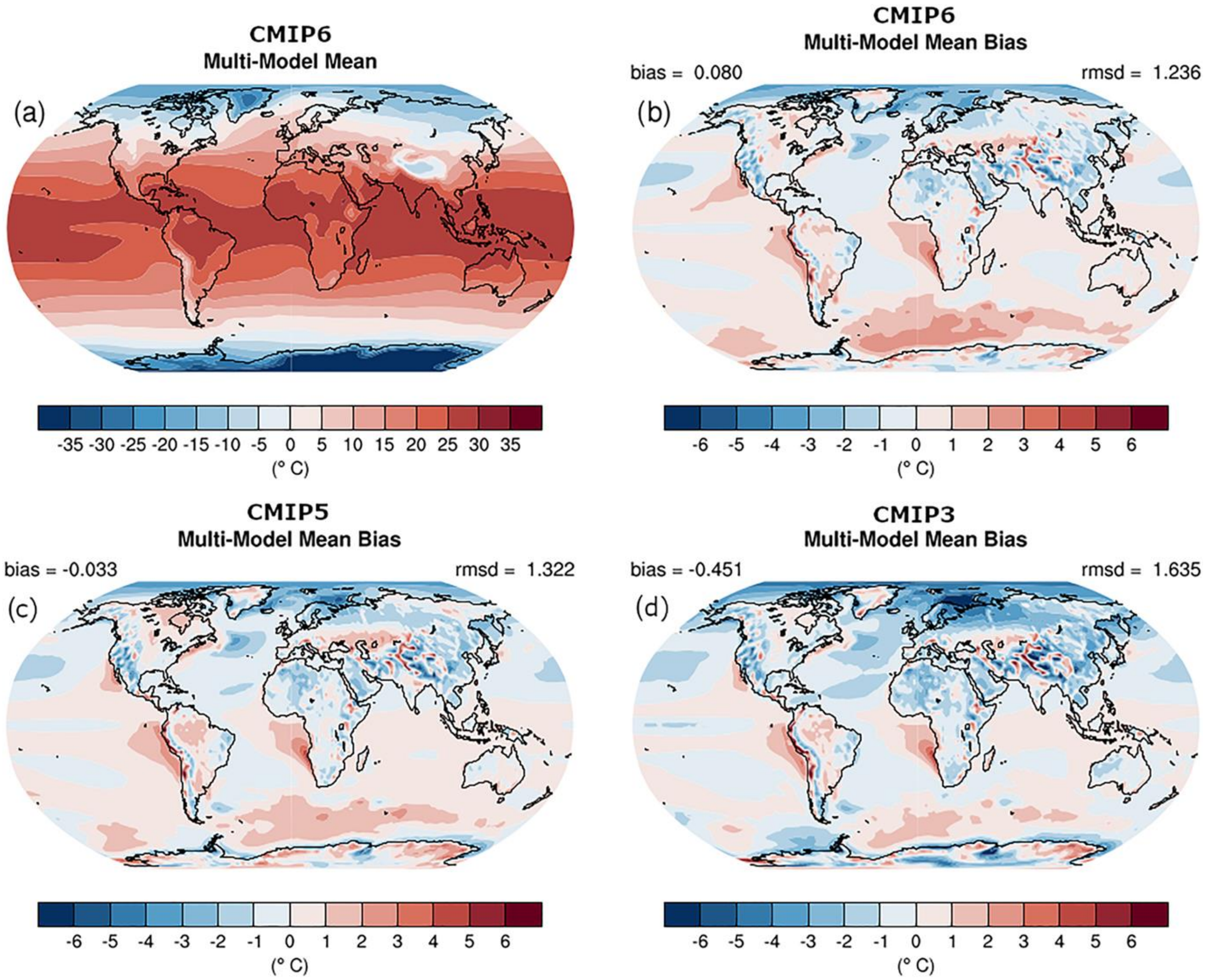
(Olonscheck et al., 2020)

Simulated bias of annual mean precipitation



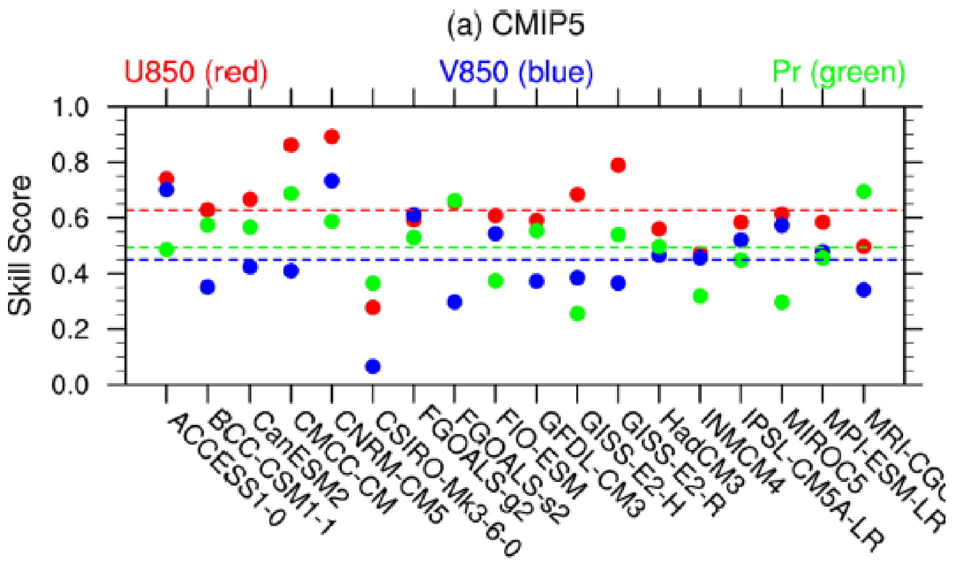
(Bock et al.,2020)

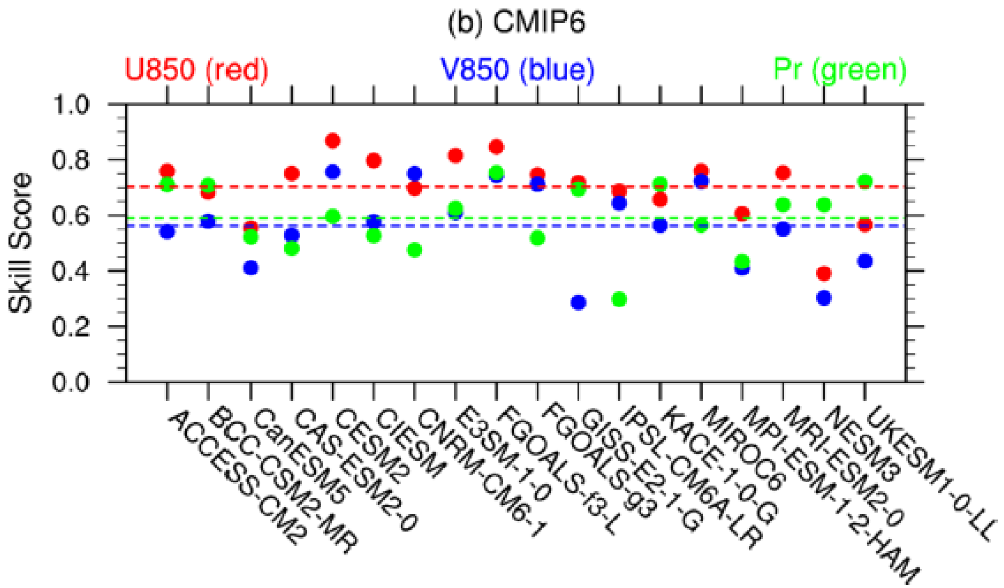
Simulated bias in surface air temperature



Bock, et al, 2020,
JGR:Atmosphere

Simulated skill in summer monsoon circulation





- CMIP6 models tend to reproduce more reasonably climatological atmospheric circulation over East Asia, with smaller inter-model spreads compared with the CMIP5 models.
- The multi-model ensemble mean of CMIP6 is more skillful than CMIP5 in both the summertime climatological wind

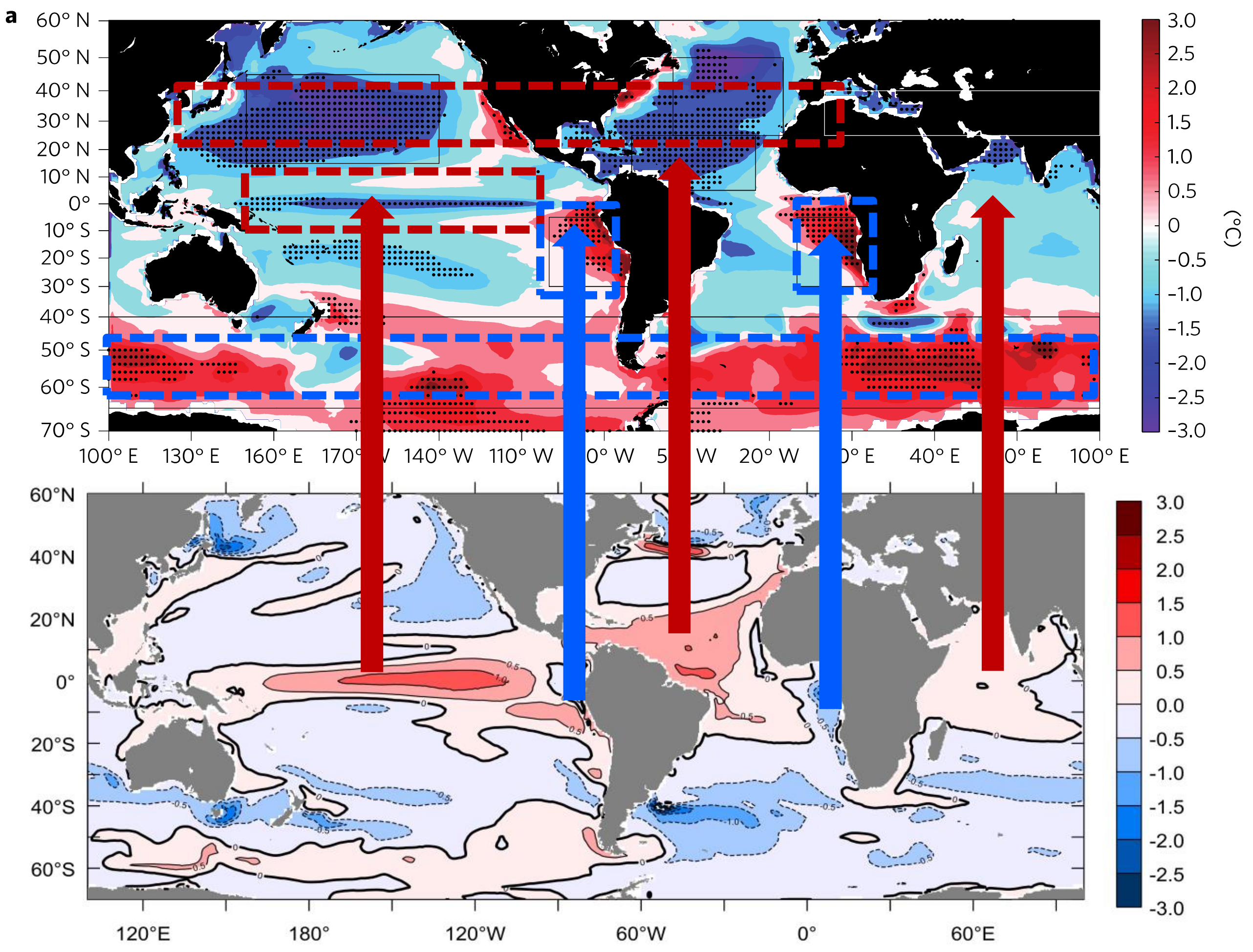
Yu et al. 2022

Wave effect can improve the tropical SST bias

Cold biases in the equatorial Pacific

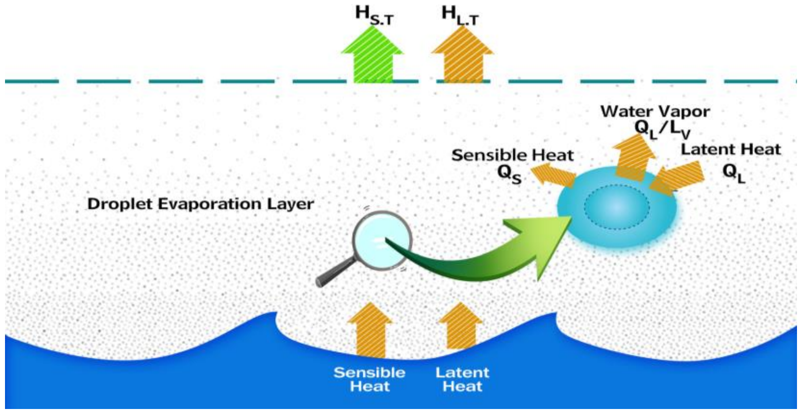
Warm biases in the eastern Pacific and Atlantic

Warm biases in the tropical Indian Ocean



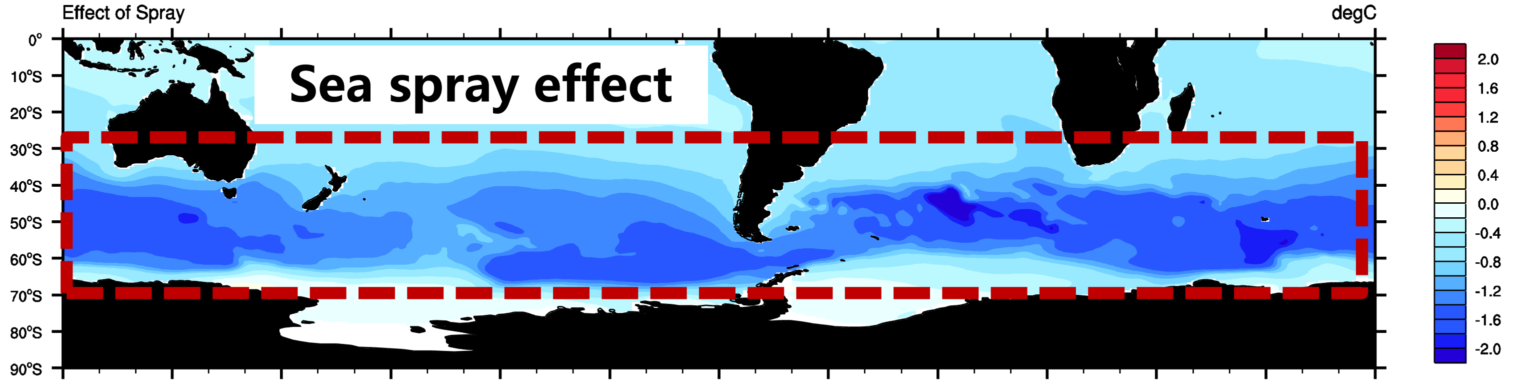
- FGCM-0： Song et al., 2007, 2012; Huang et al., 2008
- CCSM3： Song et al., 2011; 2012
- BCC-CSM2： Wu et al., 2016

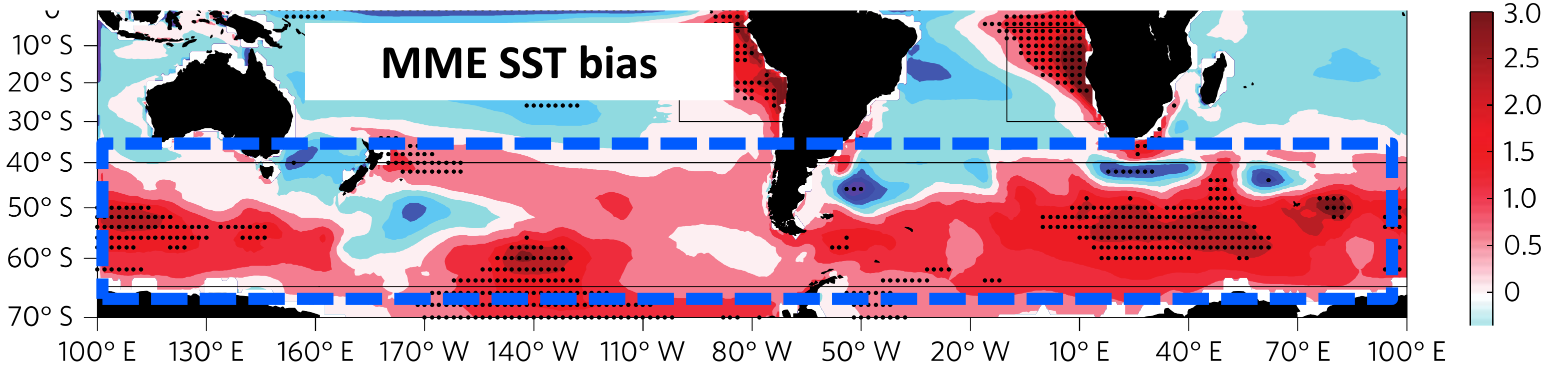
Wave effect can improve the tropical SST bias



$$H_{S,sp} = \beta\overline{Q_S} - (\alpha-\gamma)\overline{Q_L} = \rho_s c_{ps}\left(T_s - T_{eq,100}\right)V_S\left(u_*\right)$$

$$H_{L,sp} = \alpha\overline{Q_L} = \rho_s L_v\left\{1 - \left[\frac{r\left(\tau_{f,50}\right)}{50\mu\mathrm{m}}\right]^3\right\}V_L\left(u_*\right)$$

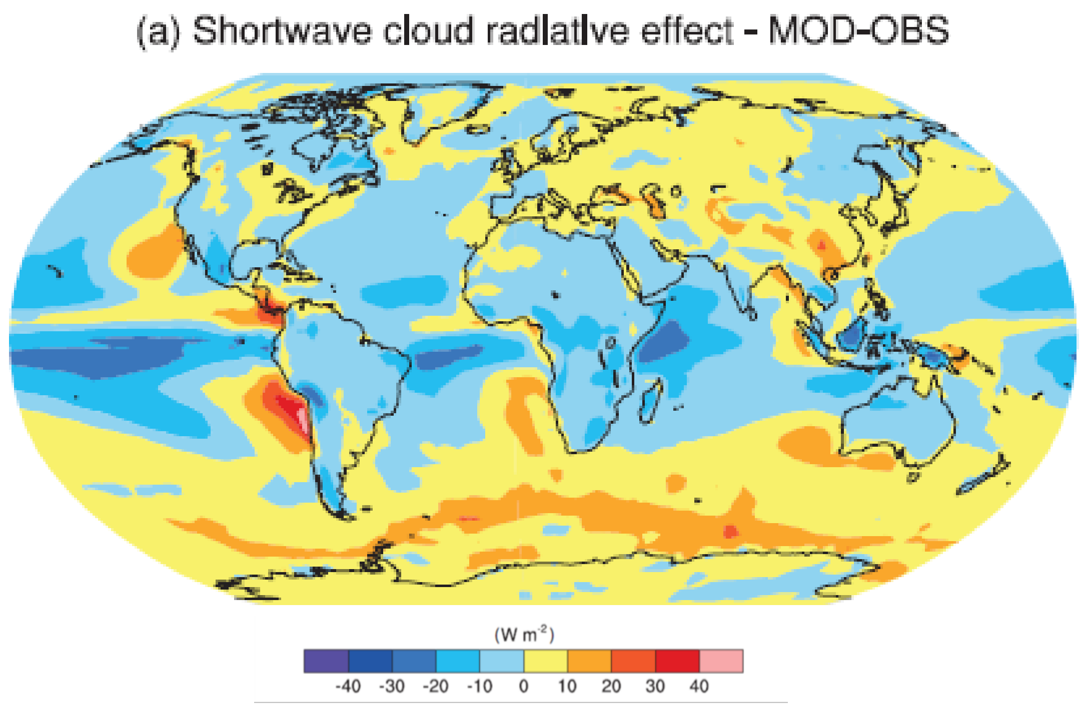


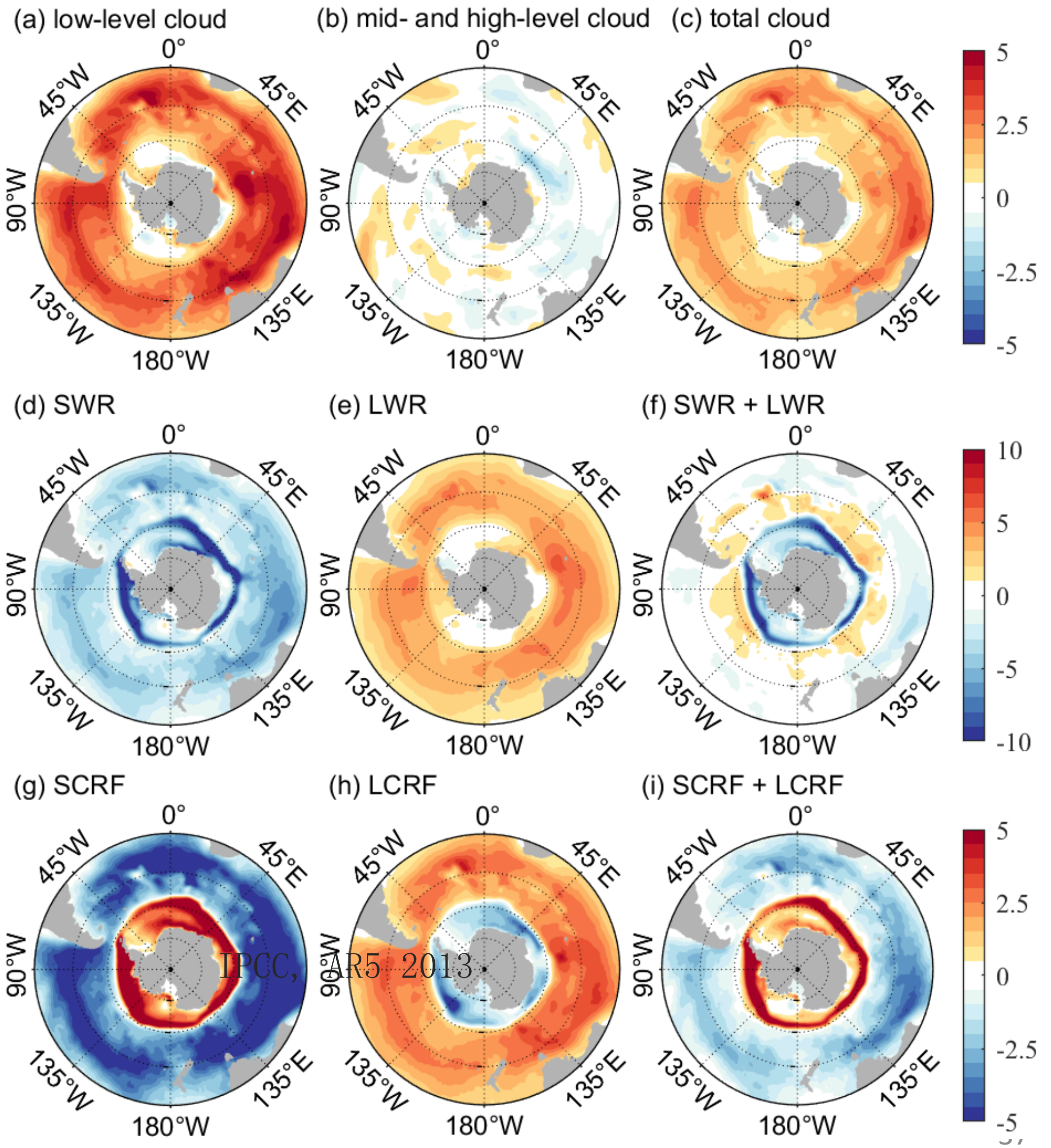


Sea spray can reduce 32% SST bias over the Southern Ocean

Song et al., 2022

Wave effect can improve the cloud simulation





IPCC, AR5 2013

- Bias: more shortwave radiation received by Southern Ocean
- Strong shortwave cloud radiation effect
- All these biases are improved by including sea spray effect

Interim Summary 1

What’s the earth system climate

The ESC includes atmosphere, hydrosphere, cryosphere, biosphere, geosphere, and all the interactions in space and time.

What’s the climate change and climate variability

- Climate change is a long-term continuous change (increase or decrease) to average weather conditions
- Climate variability is defined as variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events.

What is a climate model? and How They Work

- Climate models are based on well-documented physical processes to simulate the transfer of energy and materials through the climate system
- Climate models help scientists to test their understanding of our climate system, and to predict future changes to our climate.

Thank you for your attention