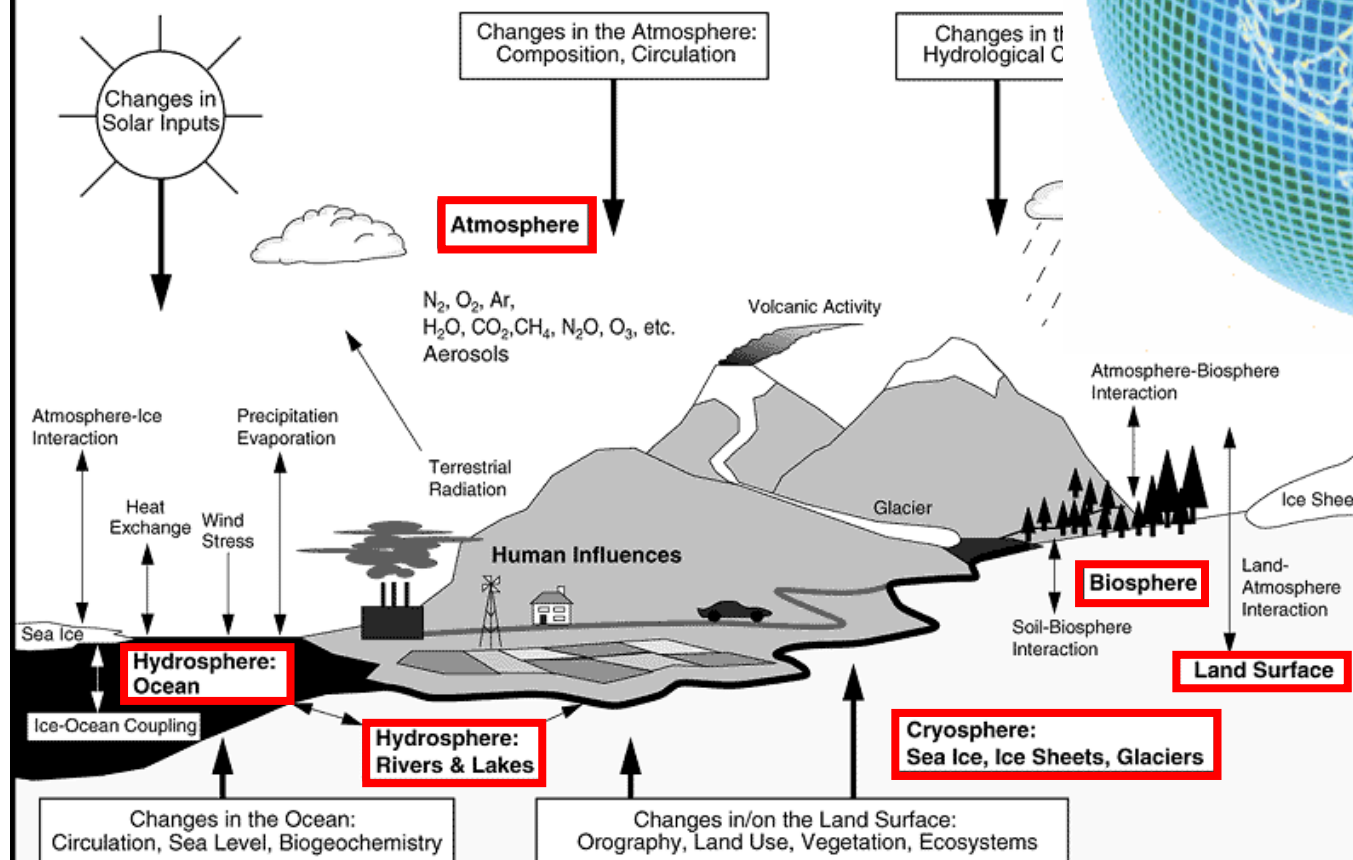
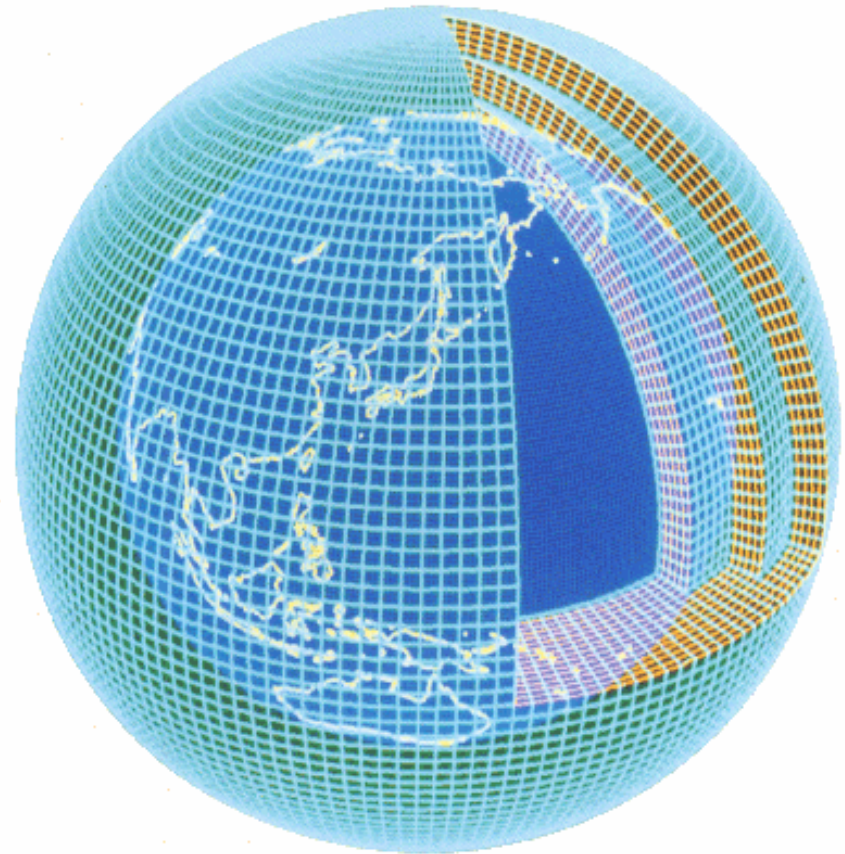


Climate Model and Prediction of Climate Change

Akira Noda
Meteorological Research Institute

- **Climate System of the Earth**
- **Governing Equations**
- **Projection of Global Warming**
 - **Mechanism of Global Warming**
 - **Experiments with the Earth Simulator**

Climate System and Modeling



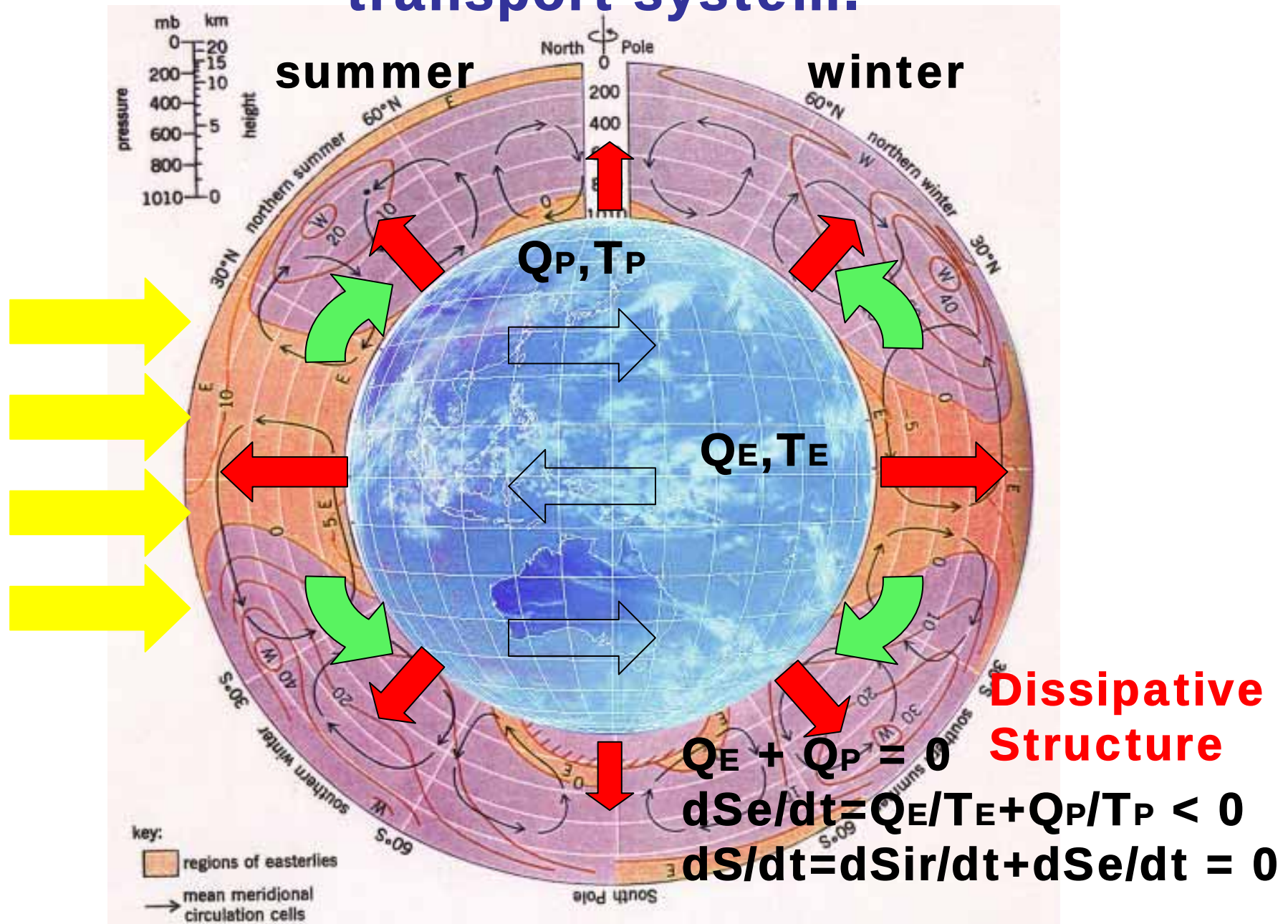
Governing Equations in Climate System Modeling

- **Horizontal equations of motion**
- **The hydrostatic equation**
- **Thermodynamic equation**
- **Continuity equation**
- **Equation of state**
- **Water vapor equation**

Peculiarity of climate system modeling

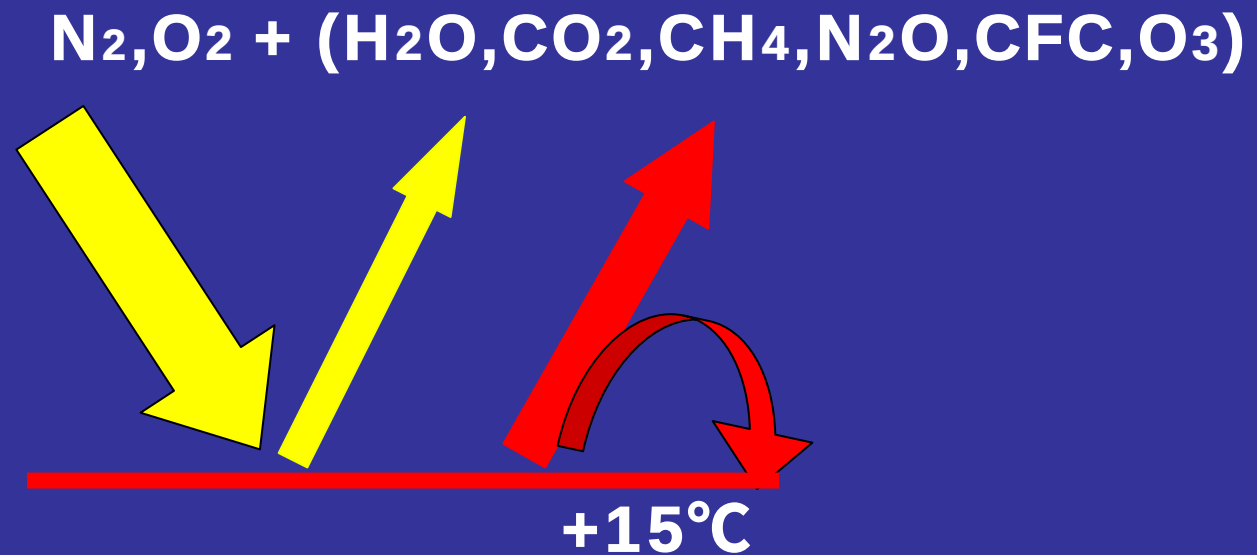
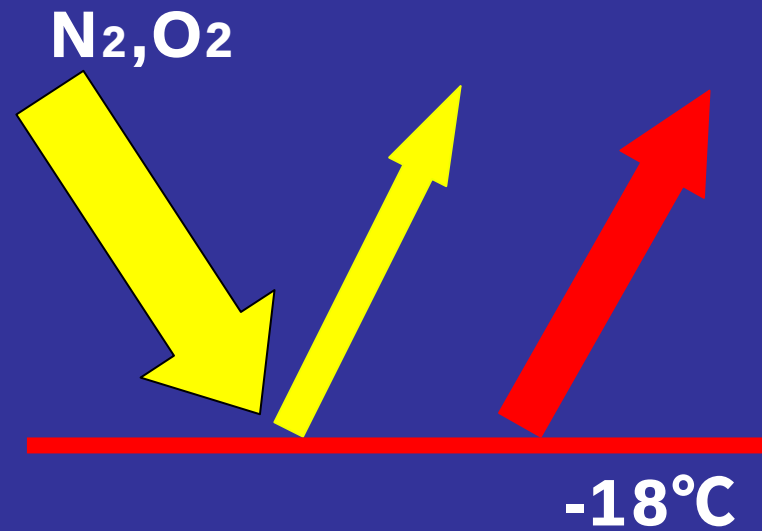
- **Rotating Earth**
 - **Spherical coordinates,**
Coriolis force
- **Strong inhomogeneity**
 - **parameterization of subgrid-scale phenomena**
(>> molecular viscosity, heat conduction)
- **Multi-scales in space and time**
 - **Nesting method**
 - **Time-Slice method**
 - **Computer resources of CPUs and storage**

The Earth's climate system is a heat transport system.



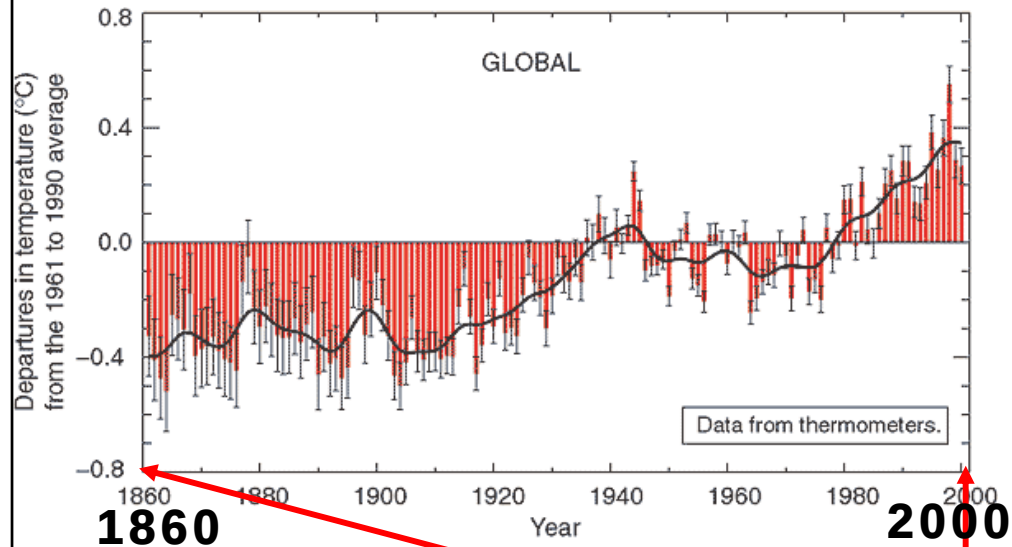
Issue of Global Warming

Mechanism of Greenhouse Effect

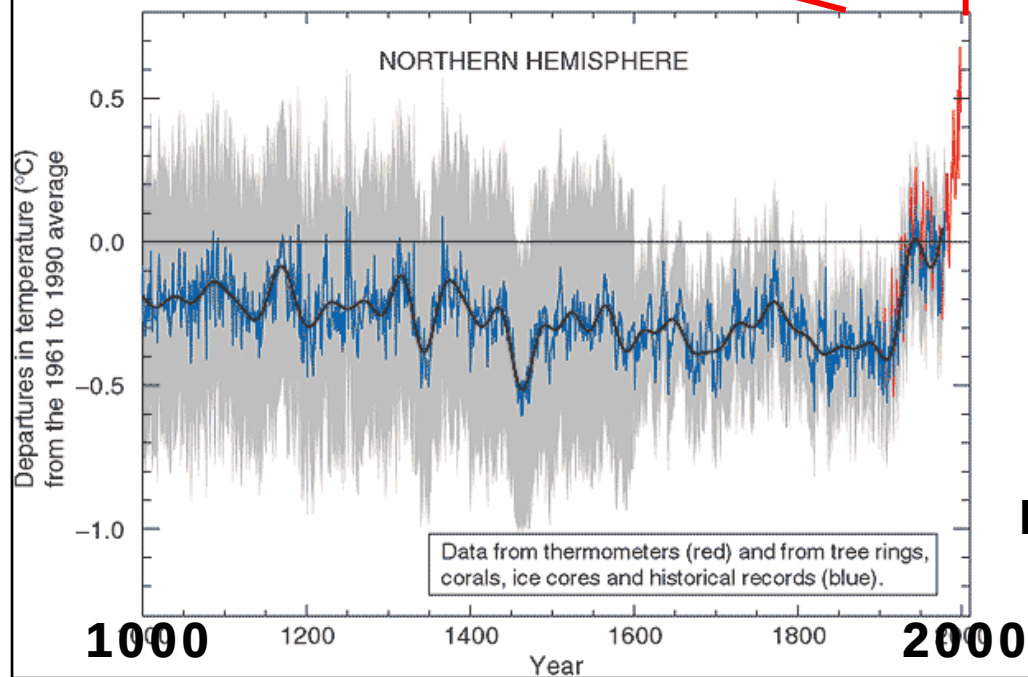


Variations of the Earth's surface temperature for:

(a) the past 140 years

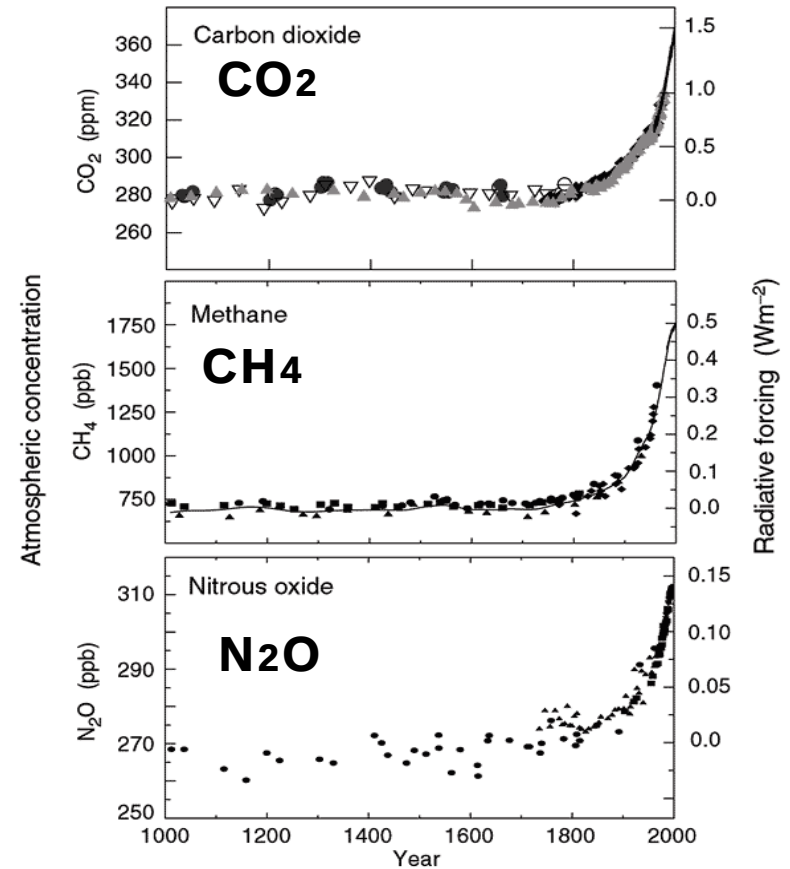


(b) the past 1,000 years

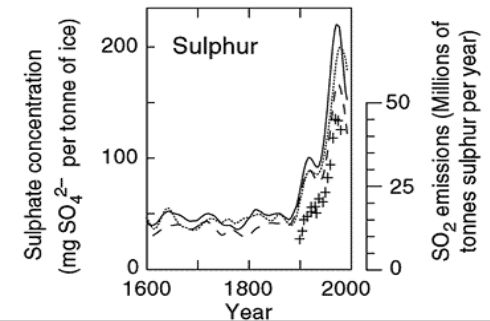


Indicators of the human influence on the atmosphere during the Industrial Era

(a) Global atmospheric concentrations of three well mixed greenhouse gases



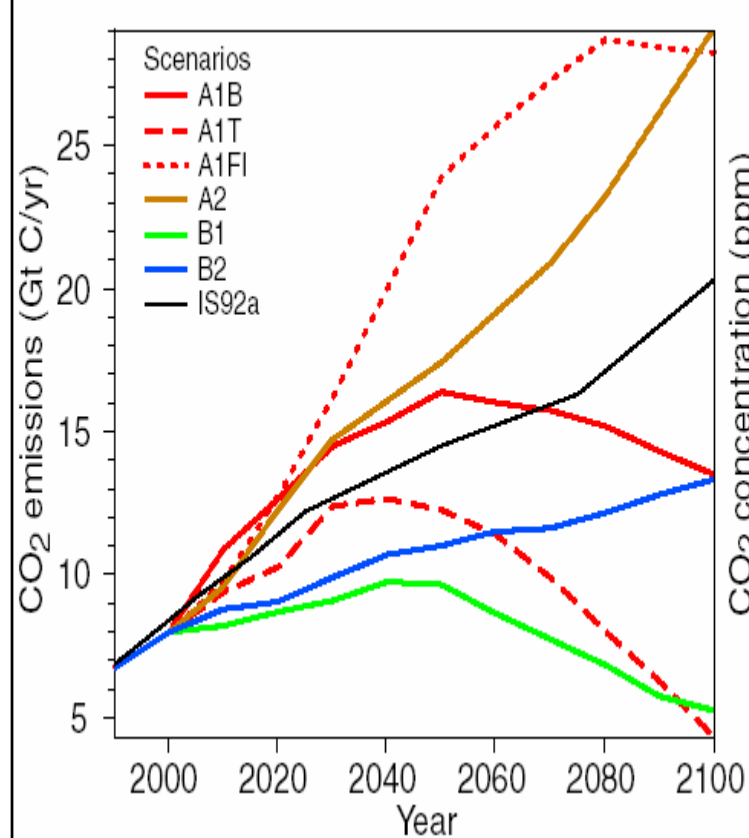
(b) Sulphate aerosols deposited in Greenland ice



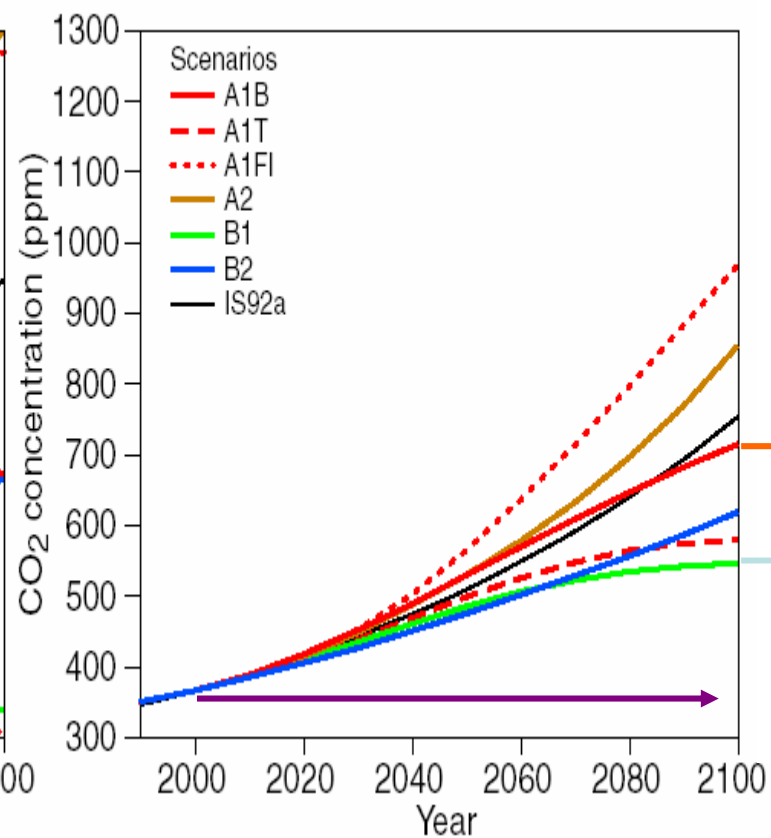
IPCC(2001)

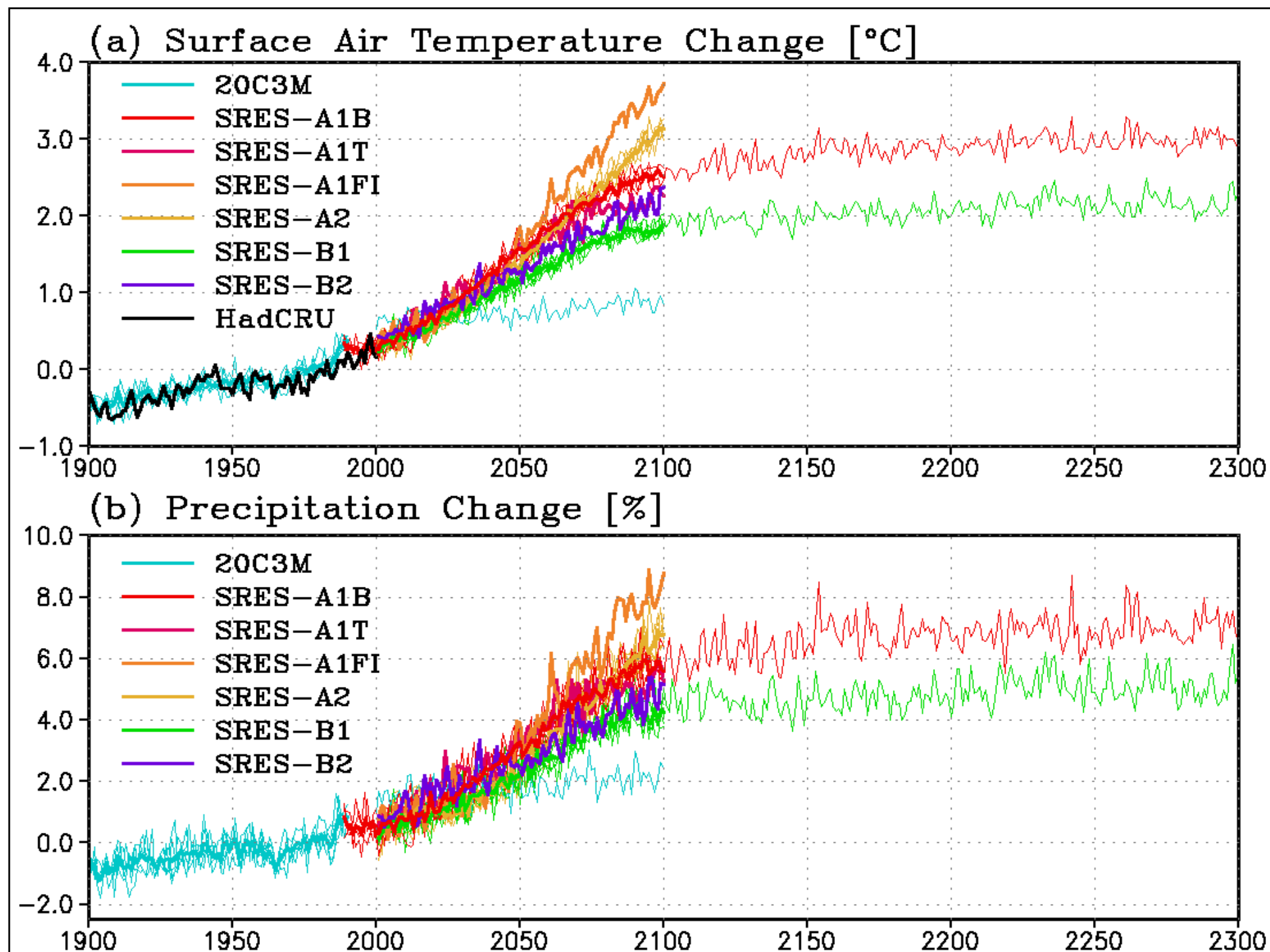
IPCC SRES and Stabilization Scenarios

(a) CO₂ emissions

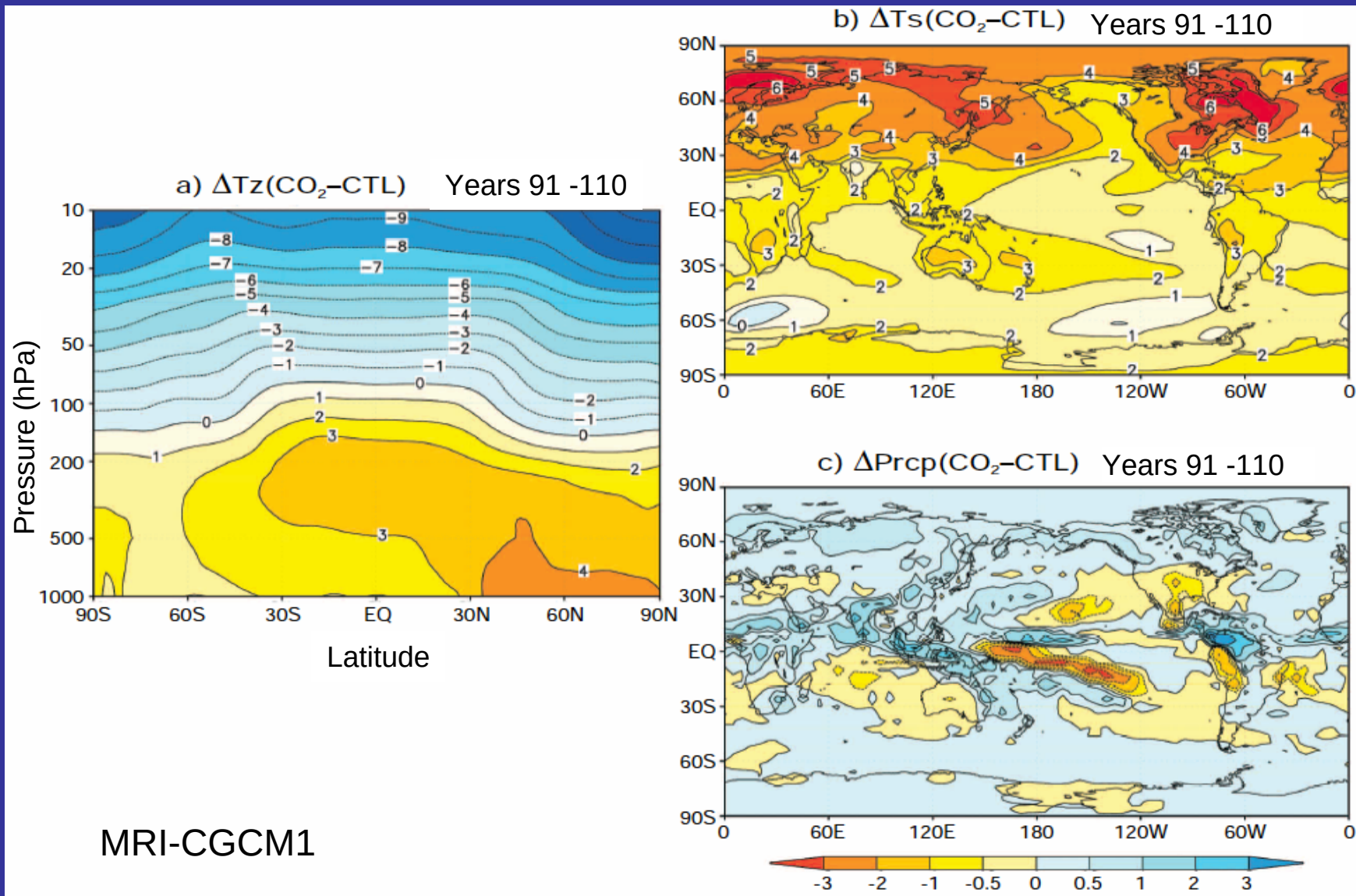


(b) CO₂ concentrations

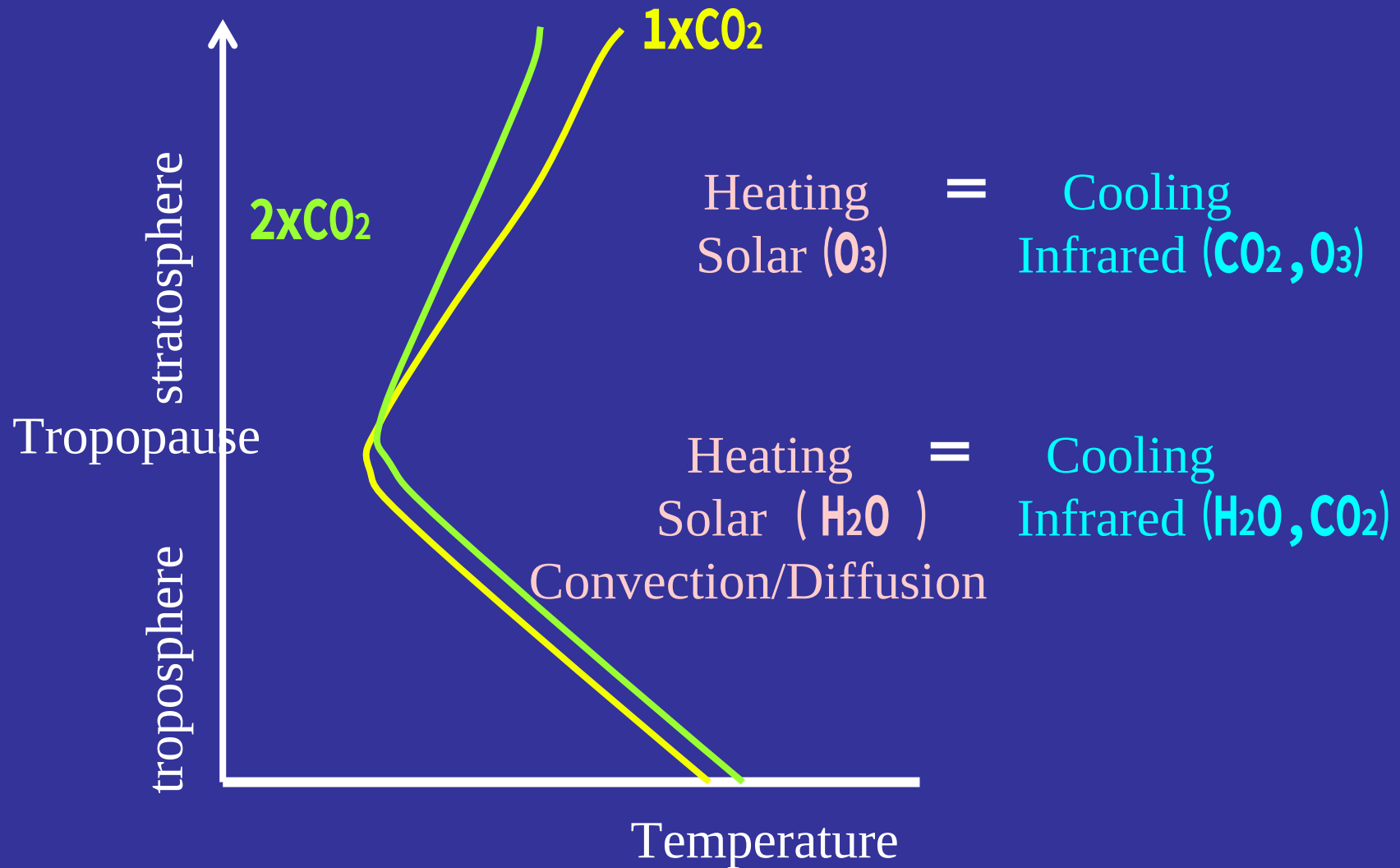




Typical Change patterns due to Global Warming

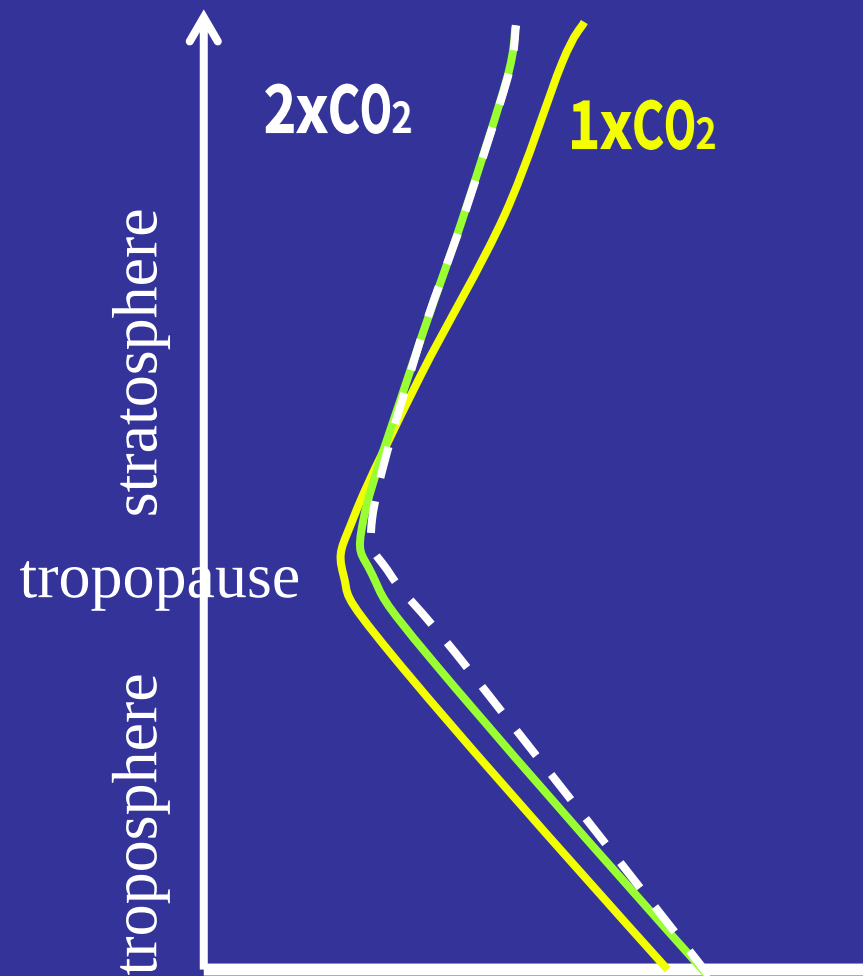
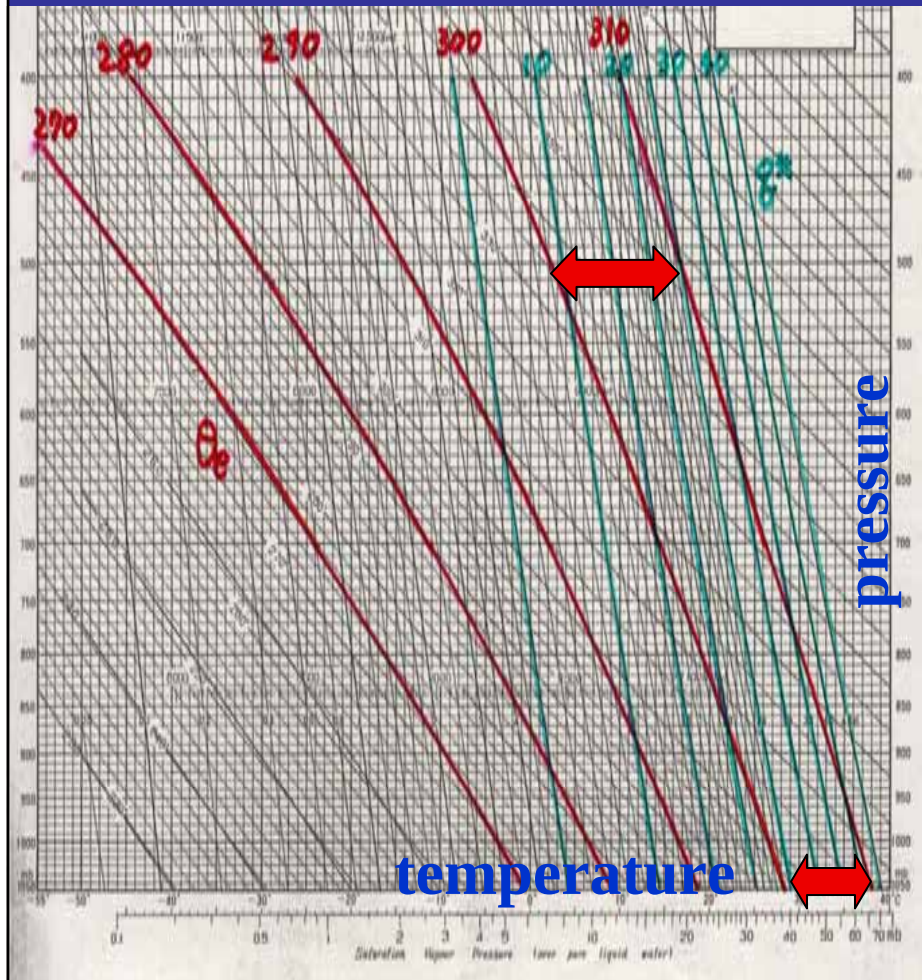


Vertical Structure of the Atmosphere and Global Warming

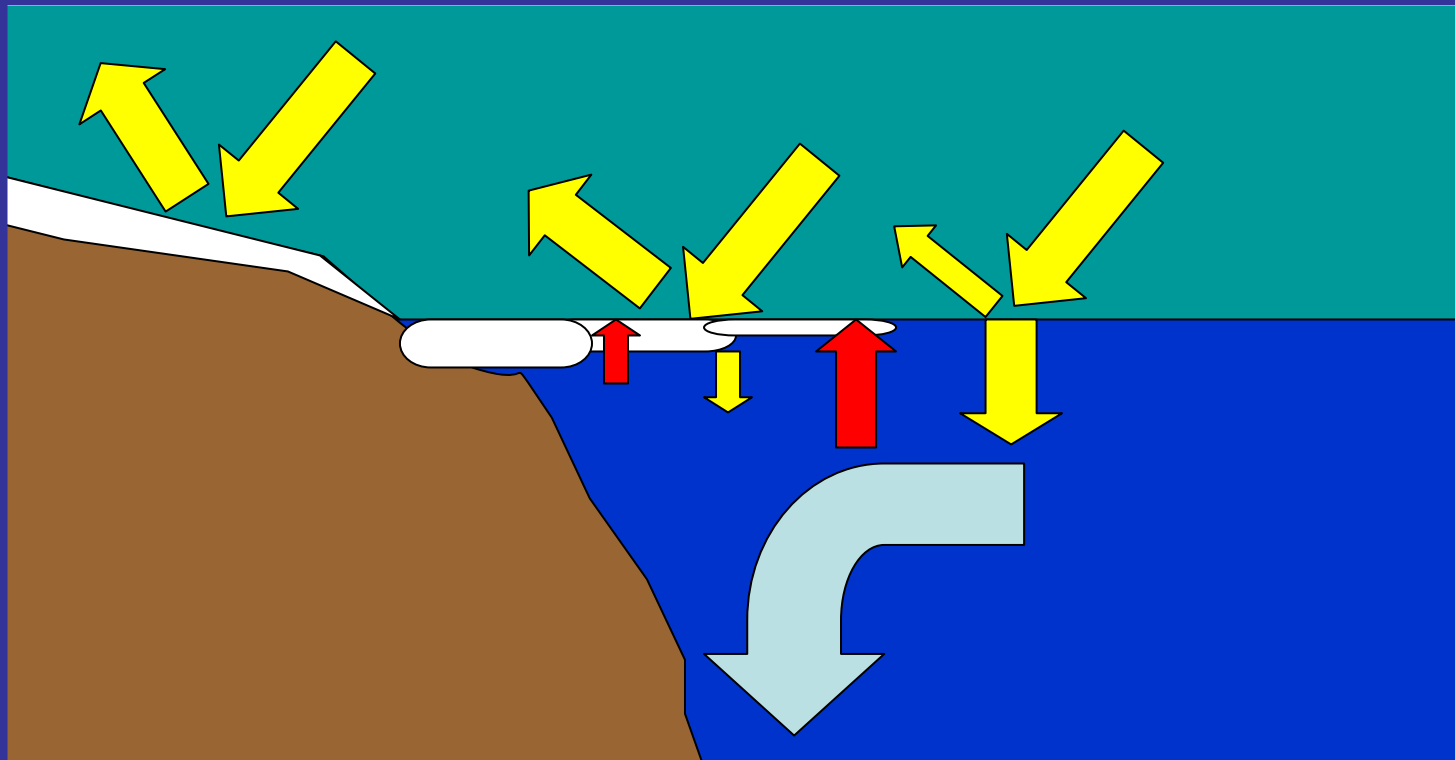


Feedback Effect of Water Vapor

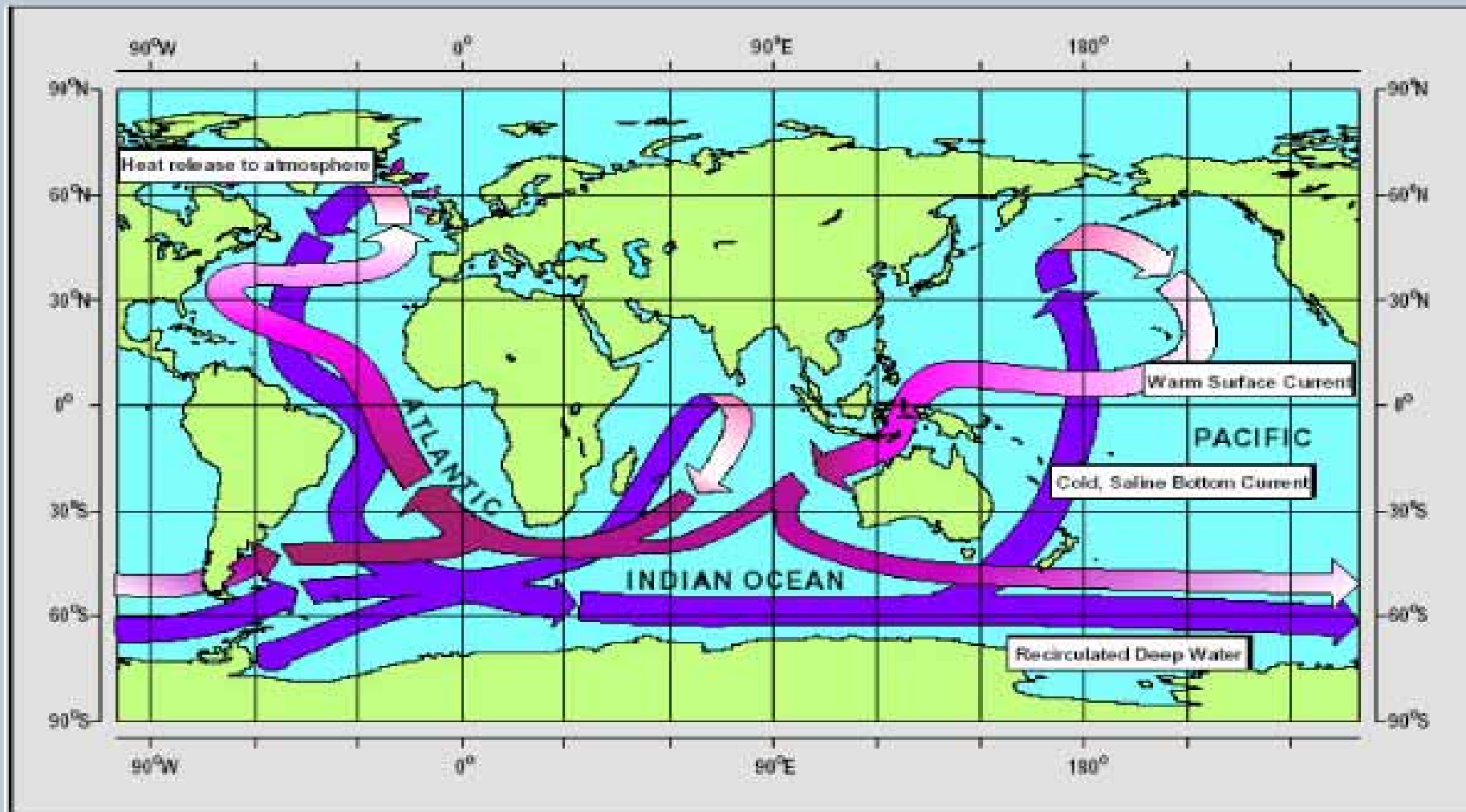
Emagram



Snow/Seaice/Albedo Feedback Effect and Deep Ocean Circulation

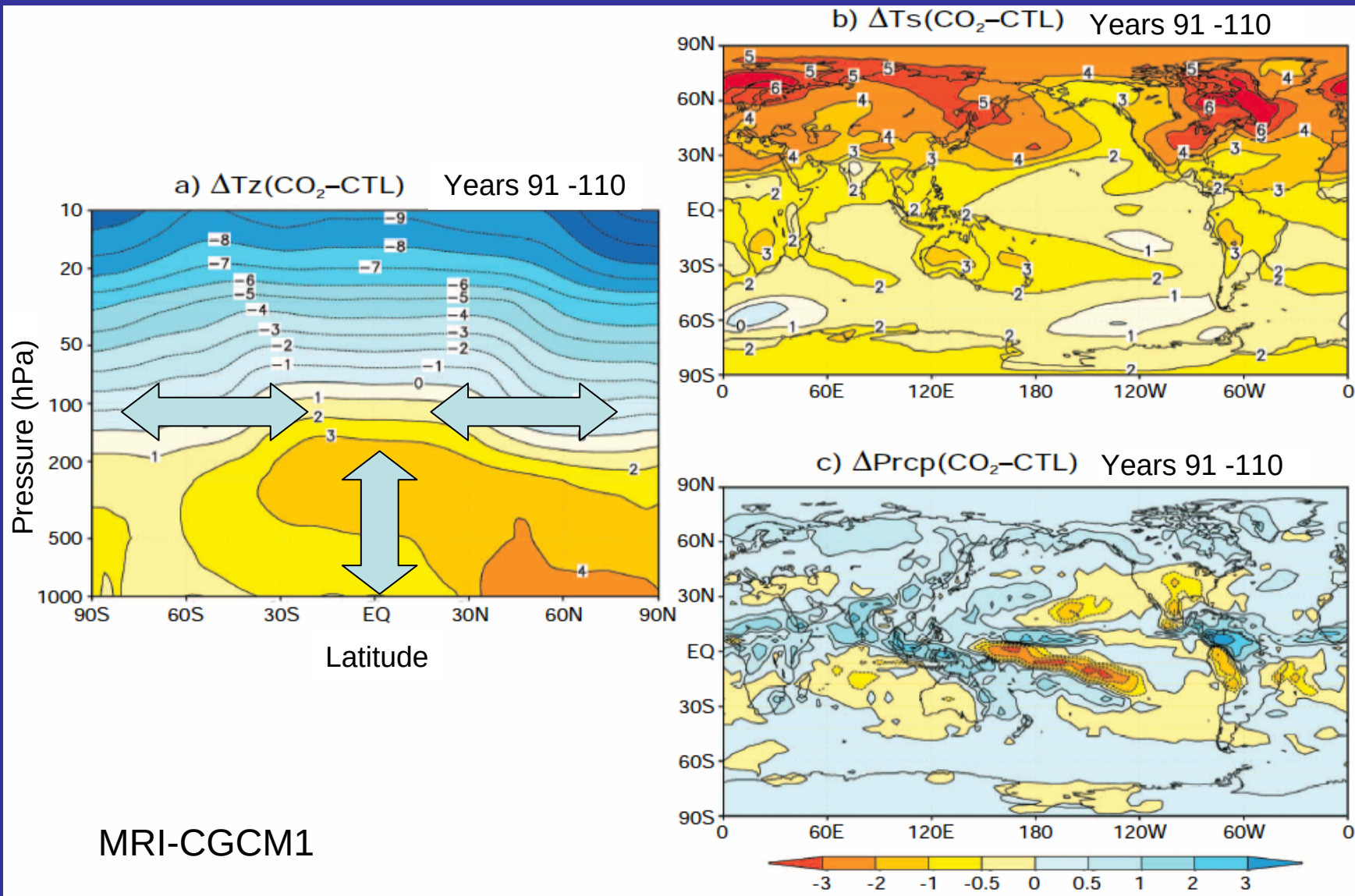


Global ocean circulation pathways (conveyer belt)

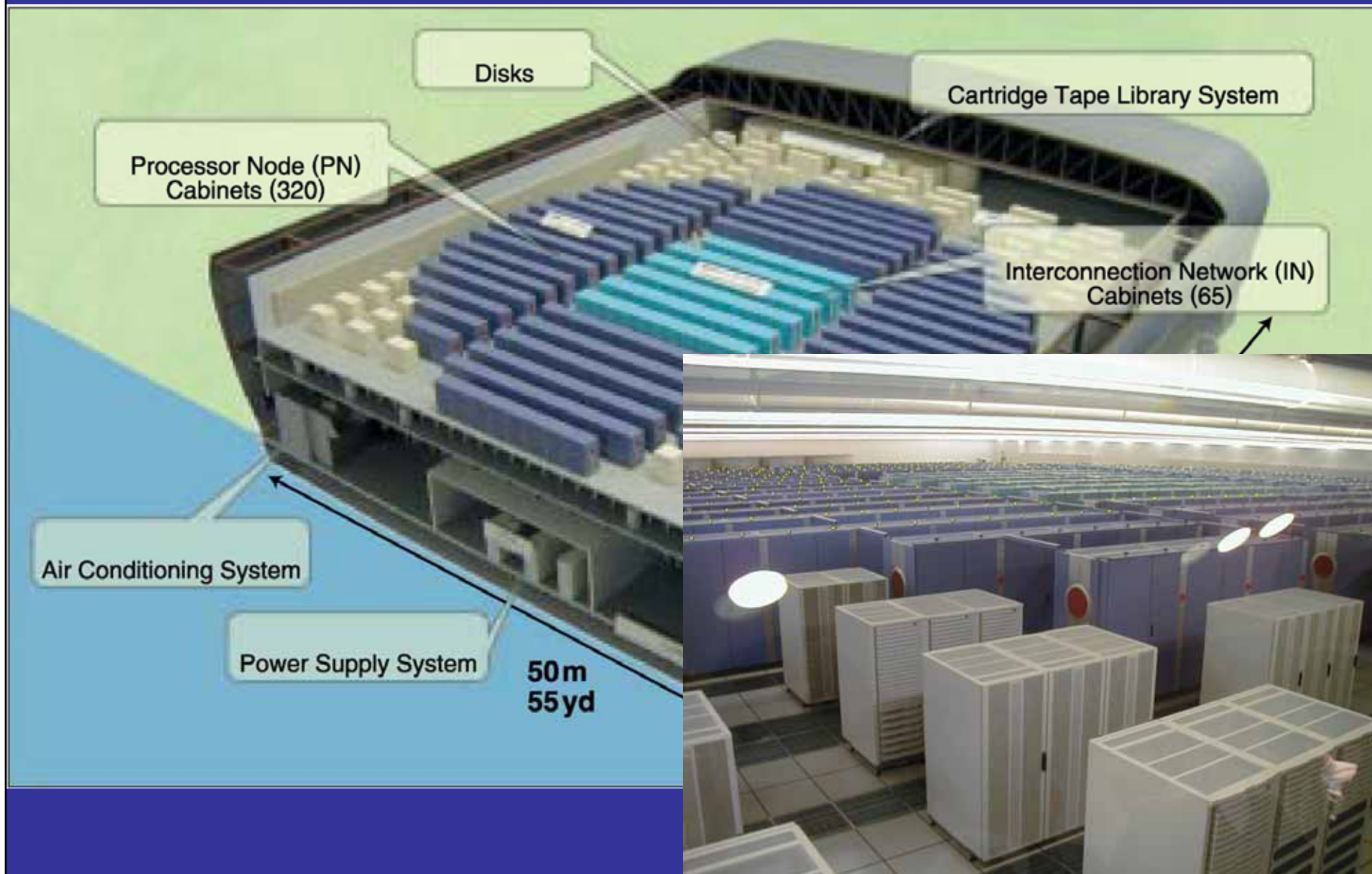


Schematic diagram of the global ocean circulation pathways, the 'conveyer' belt (after W. Broecker, modified by E. Mäler-Reimer).

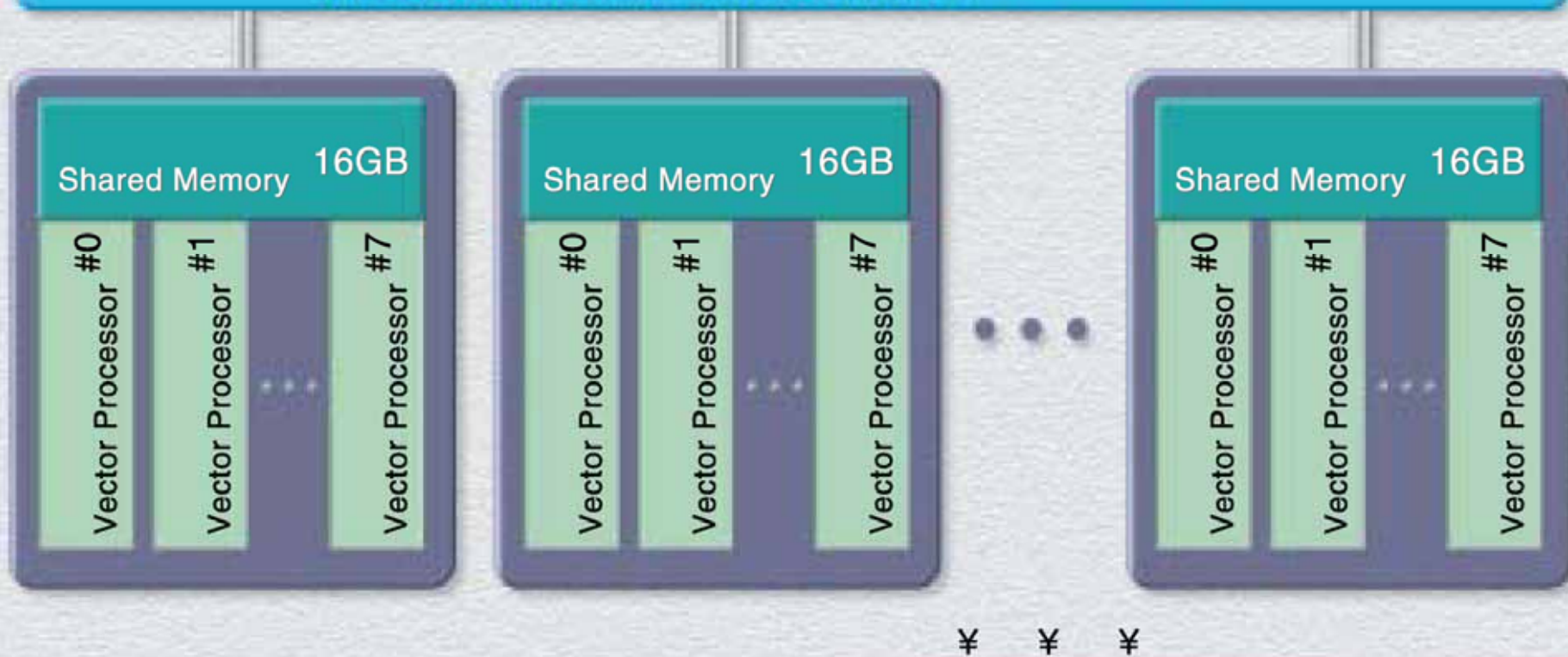
Typical Change patterns due to Global Warming



The Earth Simulator



結合ネットワーク Interconnection Network (IN) (16GB/s×2)



Specifications

Peak performance/processor	8 GFLOPS
Peak performance/node	64 GFLOPS
Shared memory	16 GB

Total number of processors	5,120
Total number of nodes	640
Total peak performance	40 TFLOPS
Total main memory	10 TB

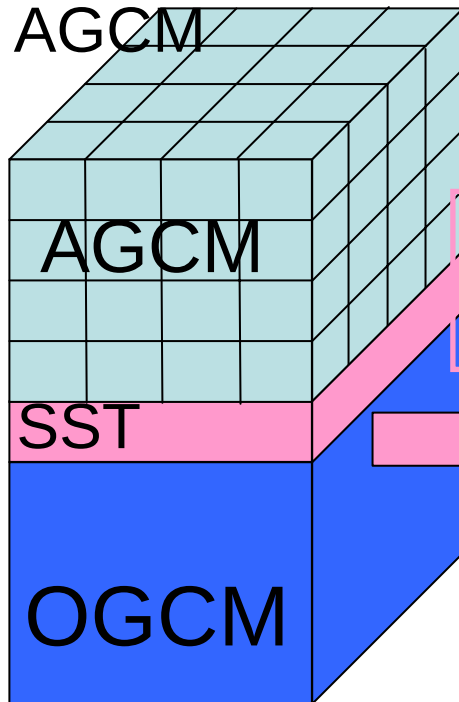
Time-Slice Global Warming Experiment

Global Warming
Experiment with
CGCM

Time-Slice
Experiment with
AGCM

Nesting Time-
Slice Experiment
with RCM

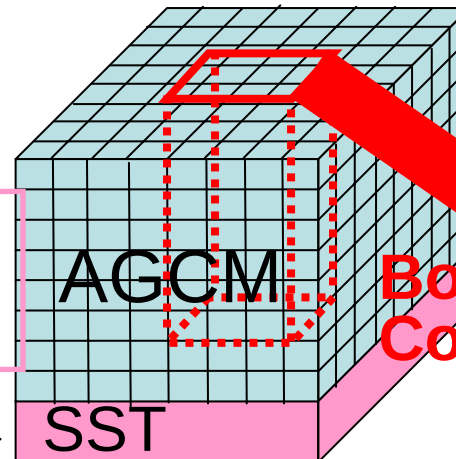
300km-mesh
AGCM



Predicted
SST

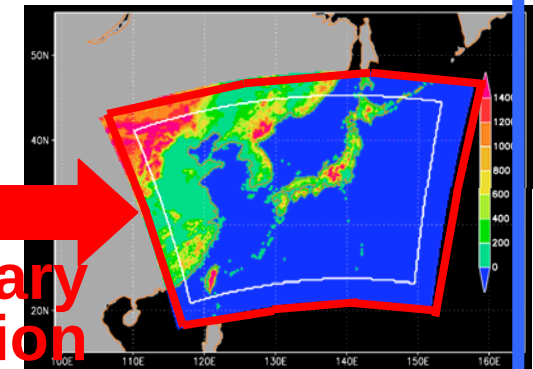
Boundary
Condition

20km-mesh AGCM

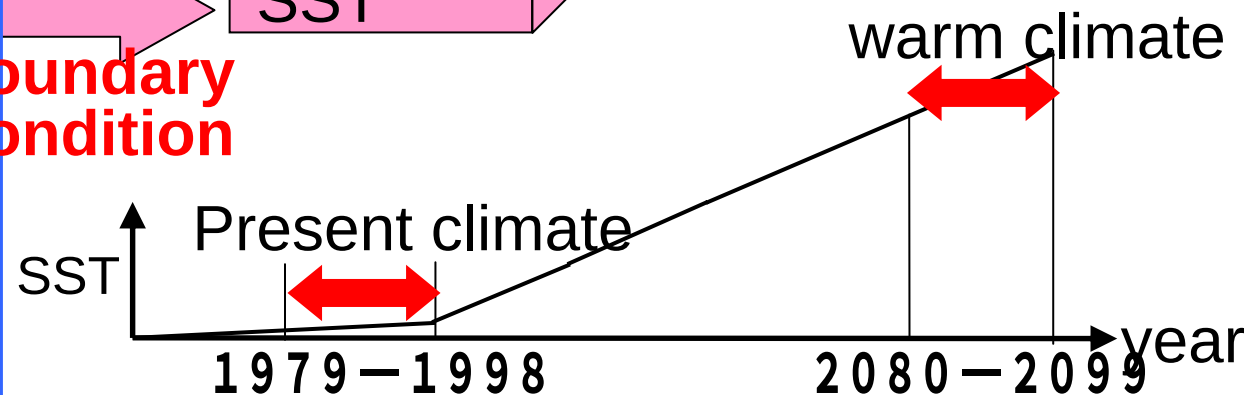


Boundary
Condition

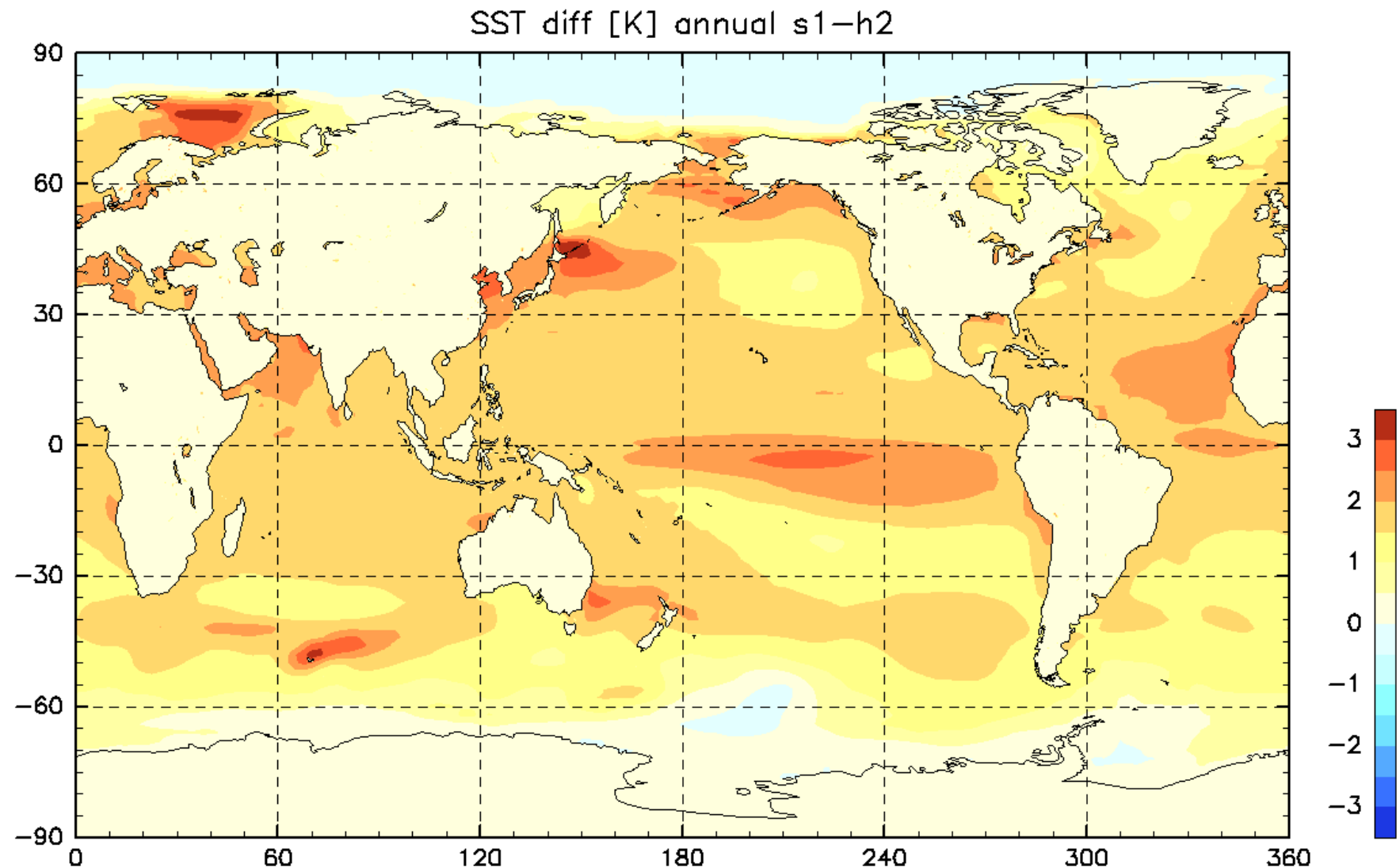
5km-mesh cloud
resolving RCM



200-50km
OGCM



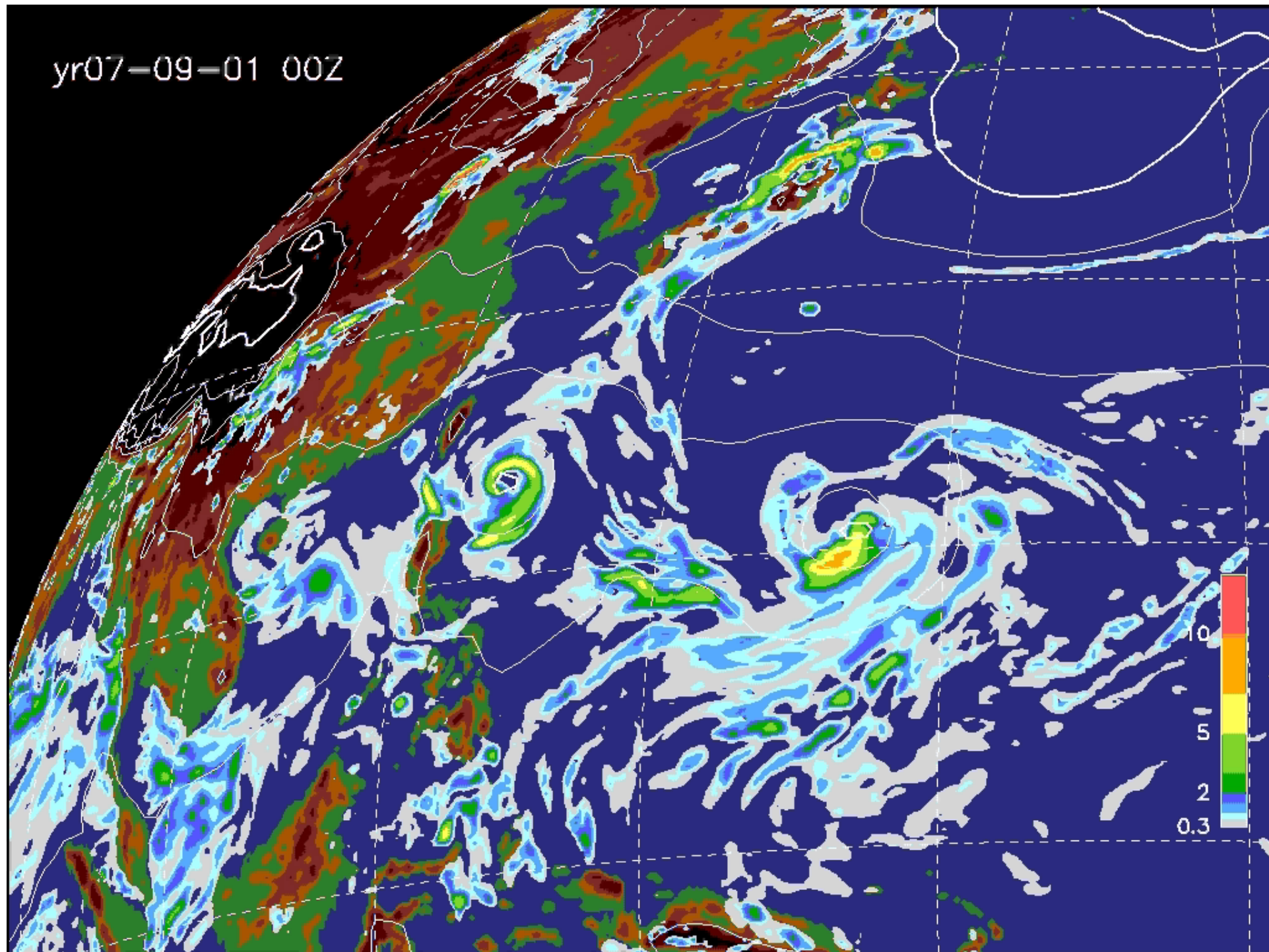
CGCM $\Delta SST = \text{Future} - \text{Present}$

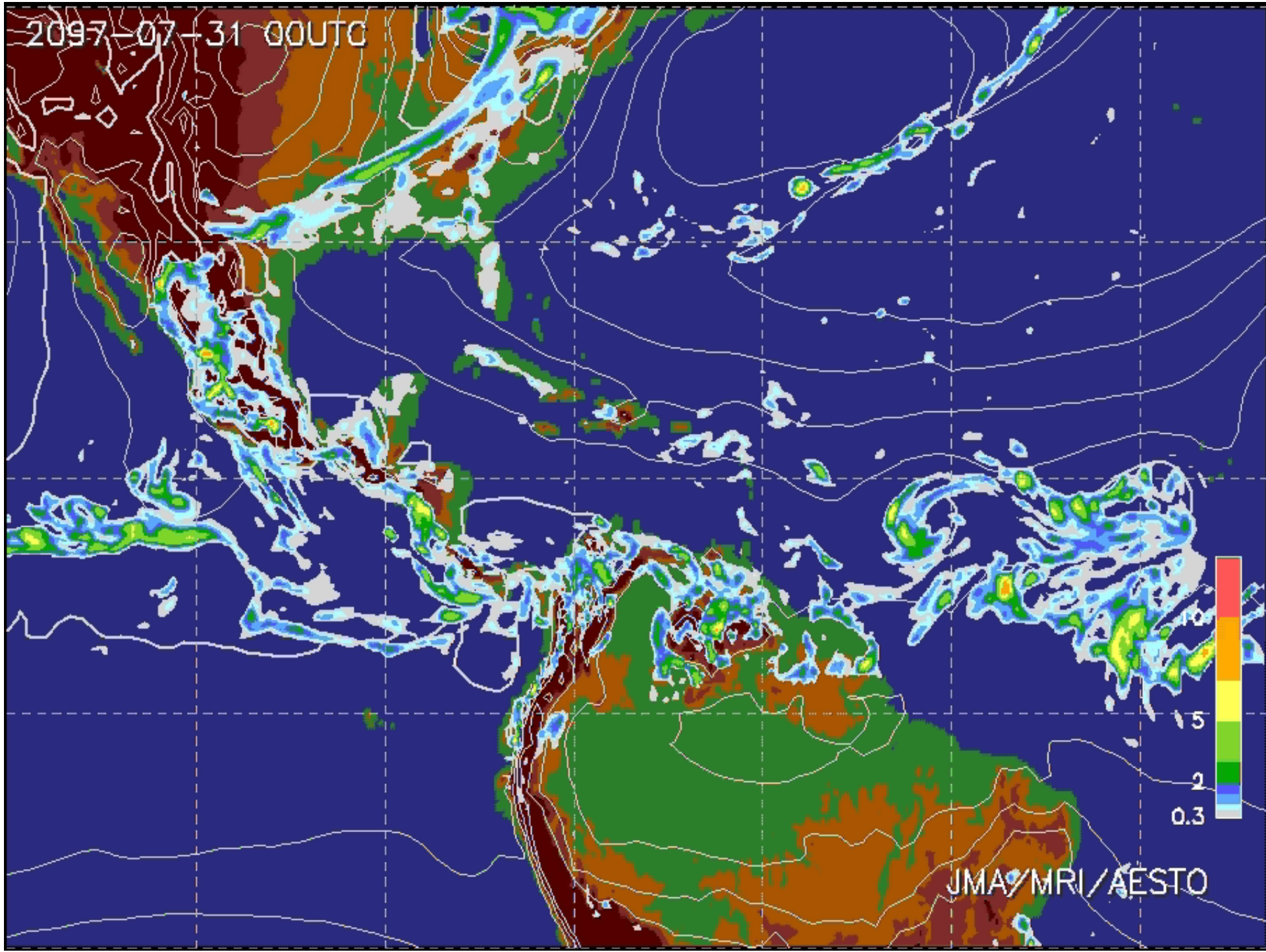


Future:2080-2099, 20 yrs Present:1979-1998, 20 yrs

Tropical Cyclones

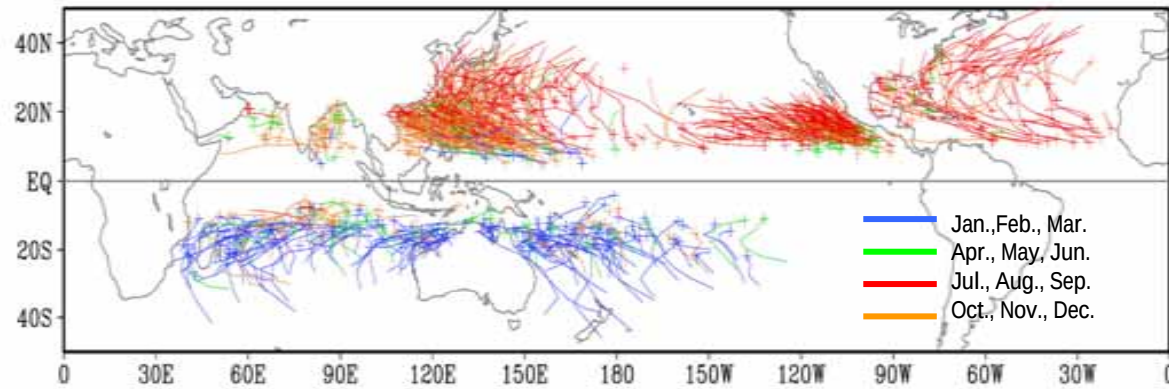
yr07-09-01 00Z





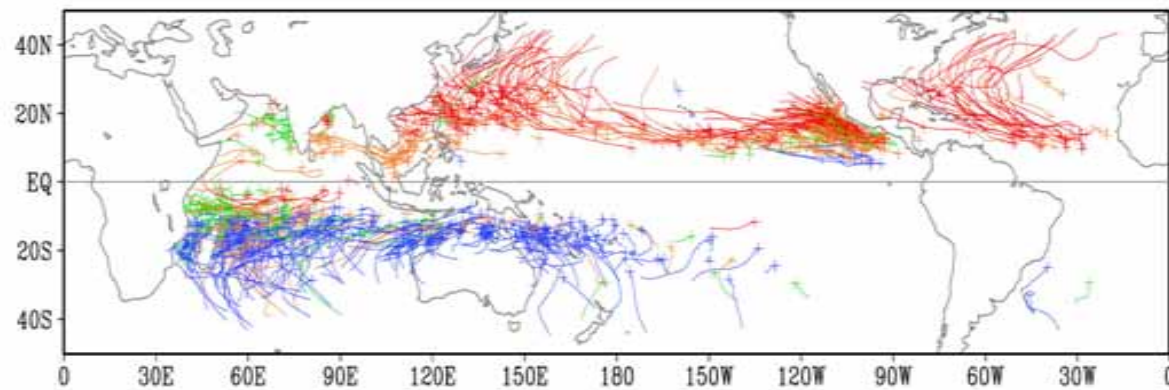
Observation 1979–1988

10 years



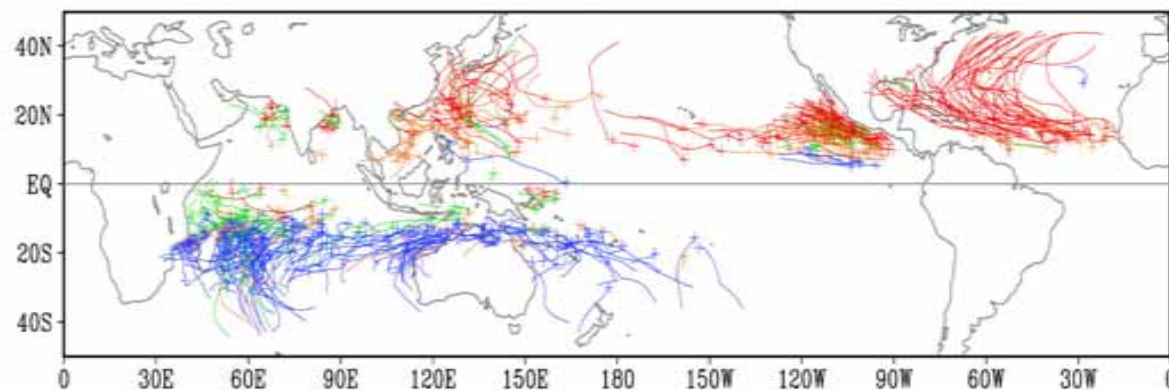
Present-day expt.

10 years



Future expt.

10 years



(Oouchi et al., 2005)

Change in Tropical Cyclones

Occurrence Frequency

Regions	Lat	Lon	Observation 20 years	Present 10 years	Future 10 years
Global	45S-45N	ALL	83.7 (10.0)	78.3 (8.4)	54.8 (8.4) **
N Hemisphere	0 -45N	ALL	58.0 (7.1)	42.9 (7.0)	30.8 (5.8) **
S Hemisphere	0 -45S	ALL	25.7 (5.6)	35.4 (3.8)	24.0 (6.1) **
N Indian Ocean	0 -45N	30E-100E	4.6 (2.4)	4.4 (2.5)	2.1 (1.7) **
WN Pacific Ocean	0 -45N	100E-180	26.7 (4.2)	12.4 (3.7)	7.7 (2.6) **
EN Pacific Ocean	0 -45N	180 - 90W	18.1 (4.8)	20.5 (3.4)	13.5 (5.7) *
N Atlantic Ocean	0 -45N	90W- 0	8.6 (3.6)	5.6 (2.7)	7.5 (1.8) #
S Indian Ocean	0 -45S	20E-135E	15.4 (3.8)	25.8 (3.0)	18.6 (5.1) **
S Pacific Ocean	0 -45S	135E- 90W	10.4 (4.0)	9.4 (3.3)	5.4 (1.9) **

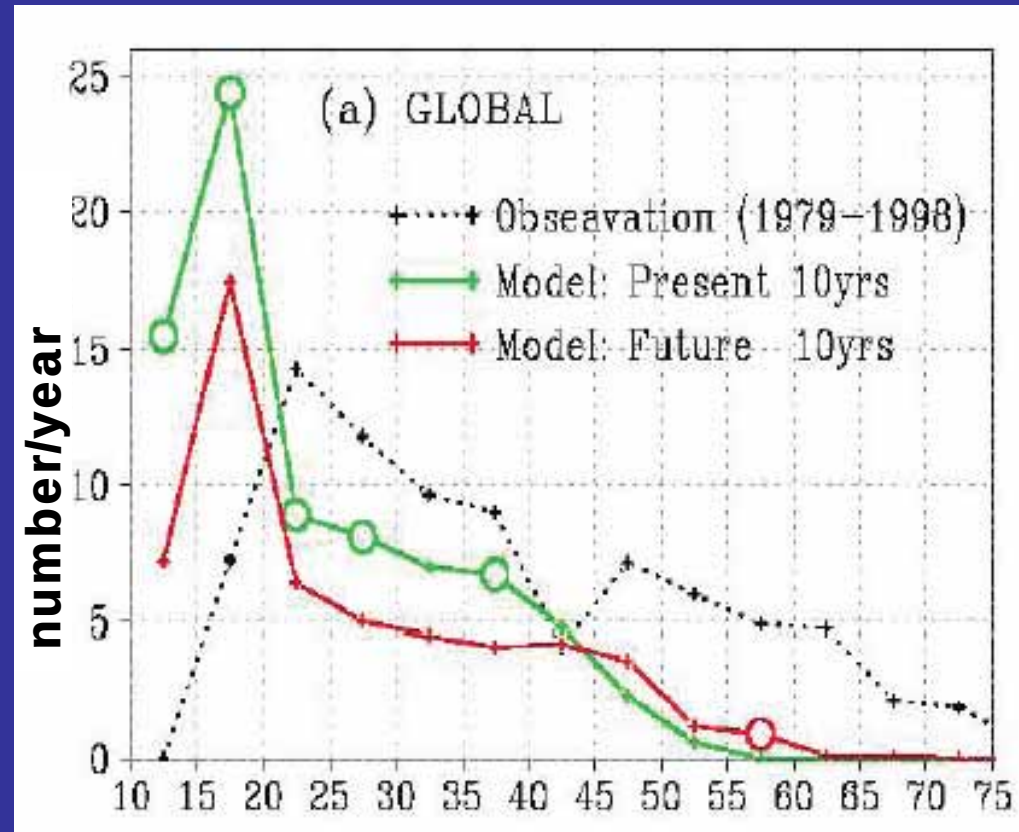
**** Statistically significant decrease at 99 % confidence level.**

*** Statistically significant decrease at 95 % confidence level.**

Statistically significant increase at 95 % confidence level.

Change in Tropical Cyclones

Max wind speed distribution



Oouchi et al., 2005

Summary

- The main function of the climate system of the earth is to transport heat from surface to upper atmosphere, and tropics to polar regions.
- **Global warming projection has been done by many models after evaluating their performance by simulating 20 century climate change.**
- Main response patterns in a warmer climate are determined by several basic climate processes.
- **A time-slice experiment on the Earth Simulator shows that the number of tropical cyclones decreases globally (except for North Atlantic) but intensity increases in a warmer climate.**