



LUND  
UNIVERSITY

# Climate Models

MOA SPORRE

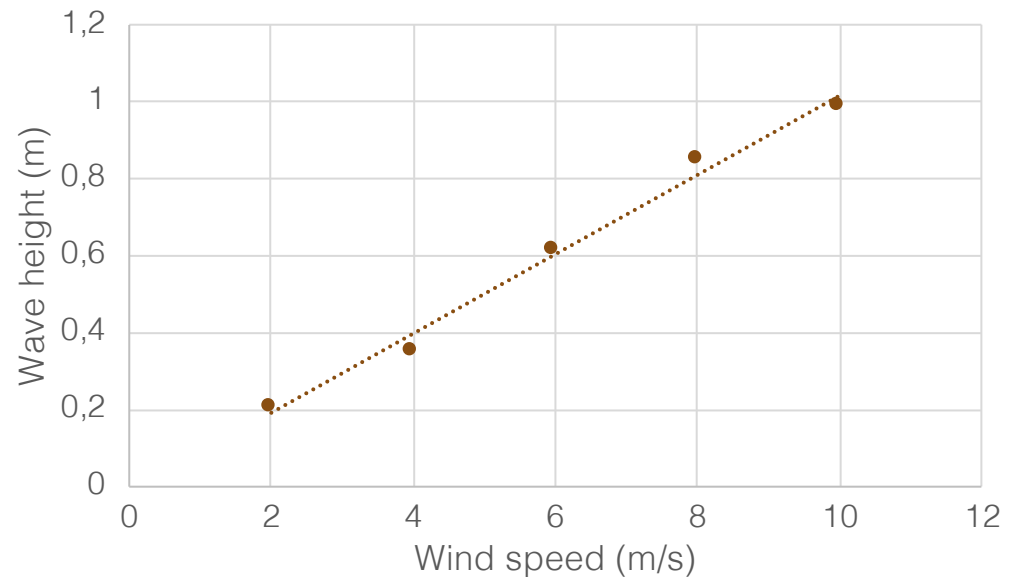


# How do we predict the future climate on Earth?

- Very complex task
- Based on science
- IPCC
- CMIP
- RCP (SSP)

# What is a model?

- Mathematical representation of a real feature
- $E = mc^2$



# Why do we need models?

- We can observe what is happening currently and what has happened before
- In order to estimate what will happen in the future we need models.

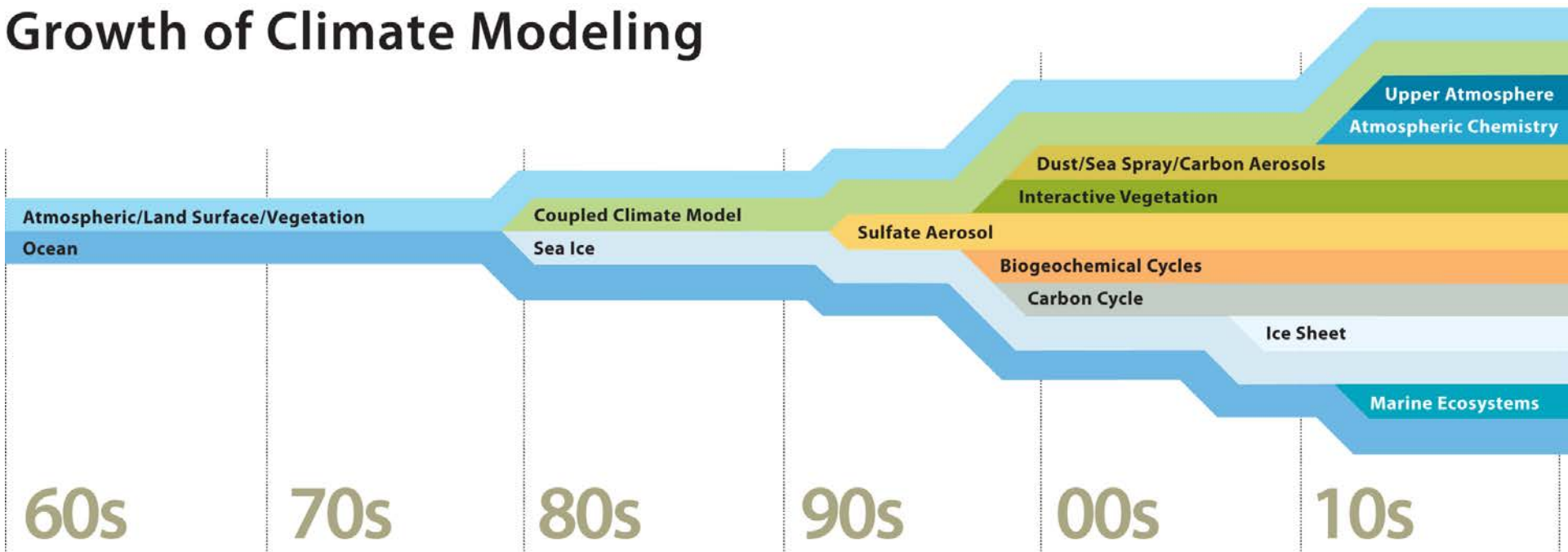


# History of climate modelling

- 1859 - Svante Arrhenius calculated on the radiative effects of CO<sub>2</sub>
- 1922 - First attempt at predicting the weather numerically
- 1940 - 1950 weather models start being run on powerful computers
- 1950 – Start to develop general circulation models (GCM)
- 1950 - 1960 A lot of development of these models, including radiation
- 1970 satellites observing the Earth starts being used to validate the models
- 1970 the first reports of CO<sub>2</sub> impact on climate reach politicians



# Growth of Climate Modeling

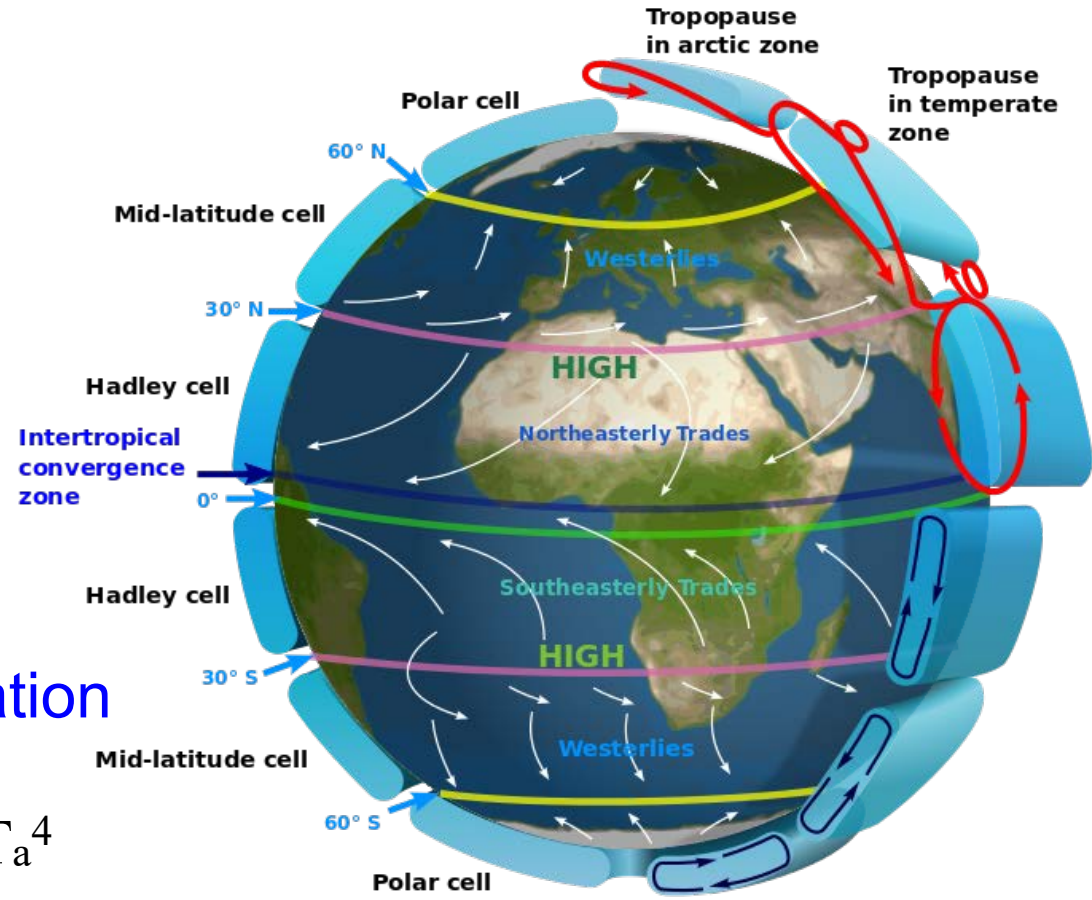
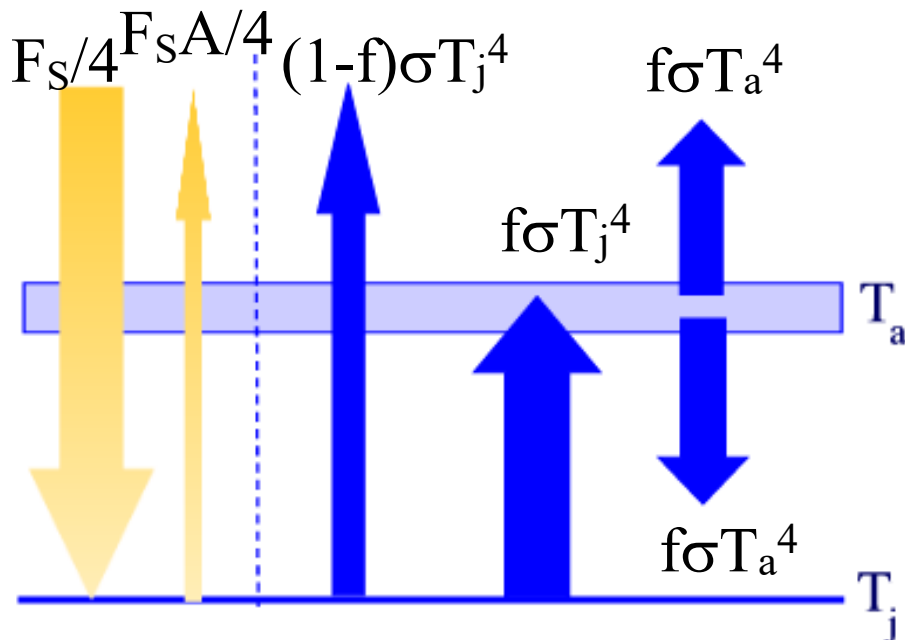


# First models

- Circulation
- Radiation

Solar radiation

Terrestrial radiation



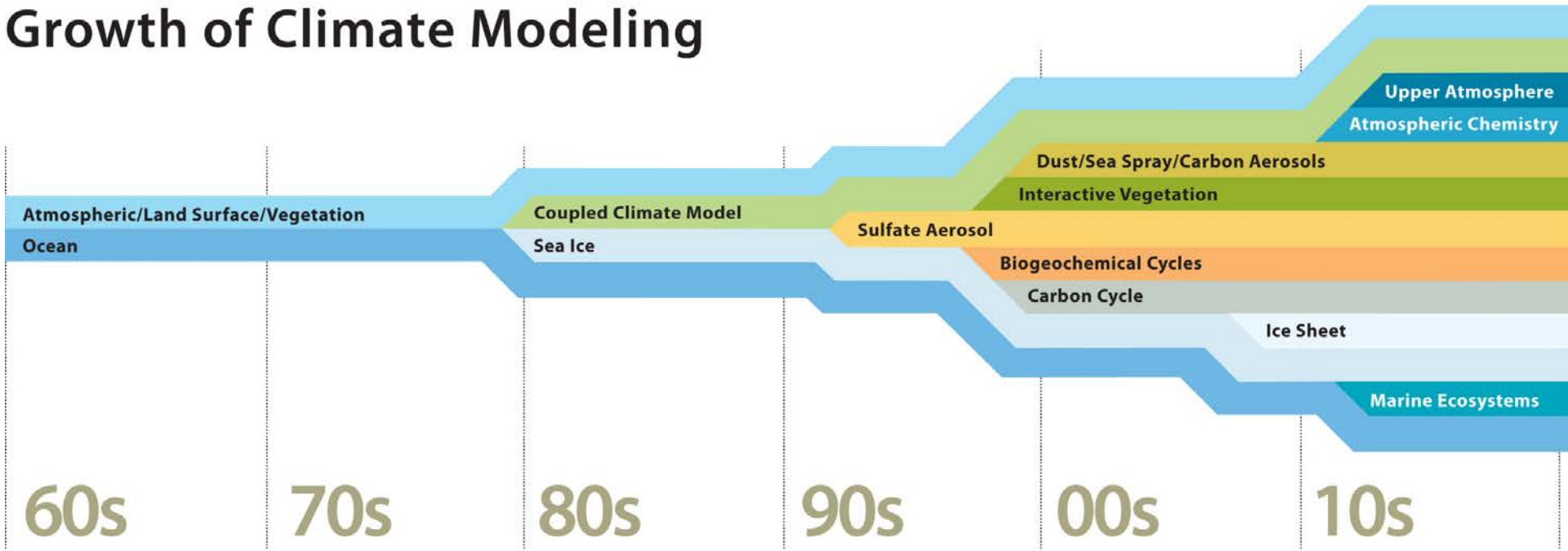
# Climate model basics

- Governing equations:
  1. Equation of motion (**conservation** of **momentum**; Newton's 2<sup>nd</sup> law)
  2. Continuity equation (**conservation** of **mass**)
  3. Thermodynamic energy equation (**conservation** of **energy**; 1<sup>st</sup> law of thermodynamics)
  4. Equation of state ( $p = \rho RT$ )
  5. Continuity equation for water in various forms (**conservation** of **water** mass)
  6. Chemical transformation equations for trace gases and aerosols

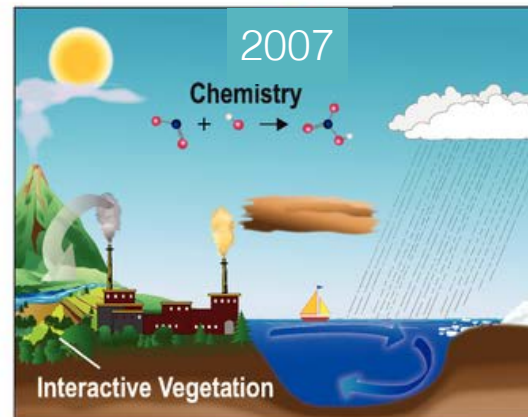
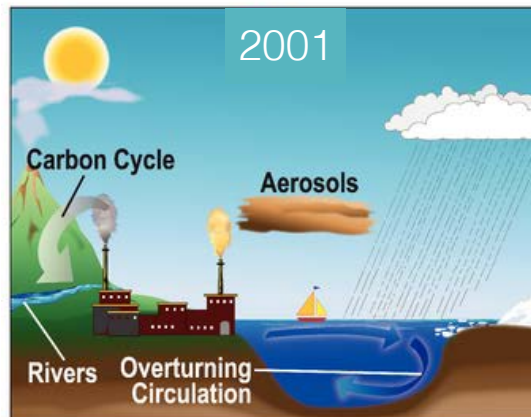
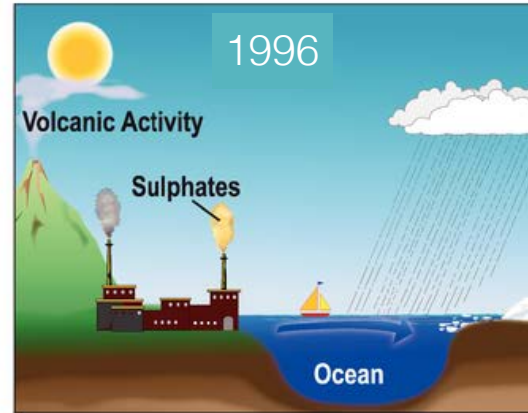
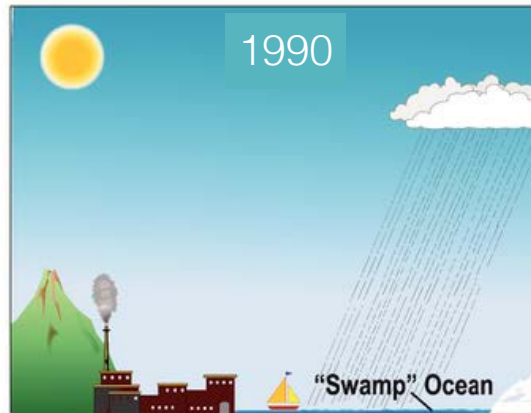
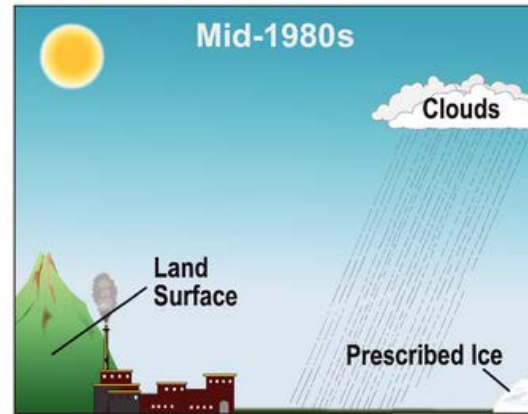
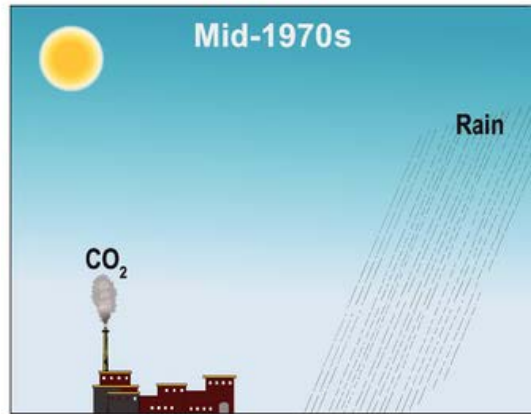


# Earth System Models

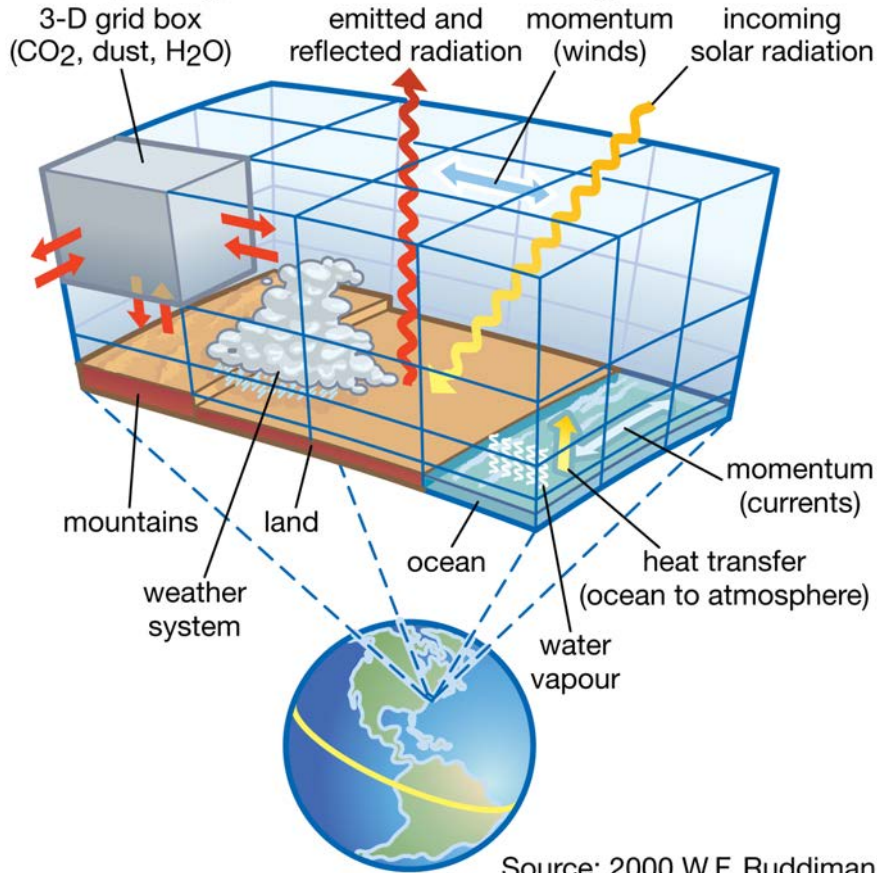
## Growth of Climate Modeling



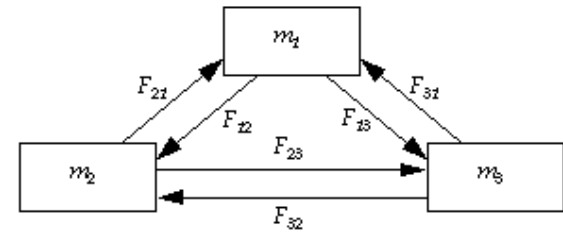
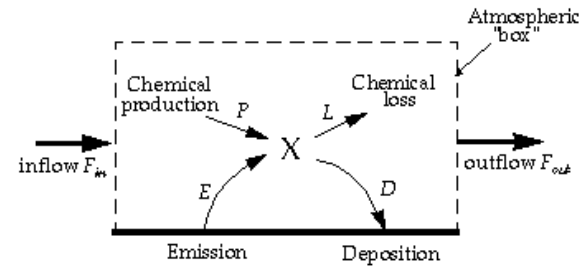
# The World in Global Climate Models



# Concept diagram of climate modeling



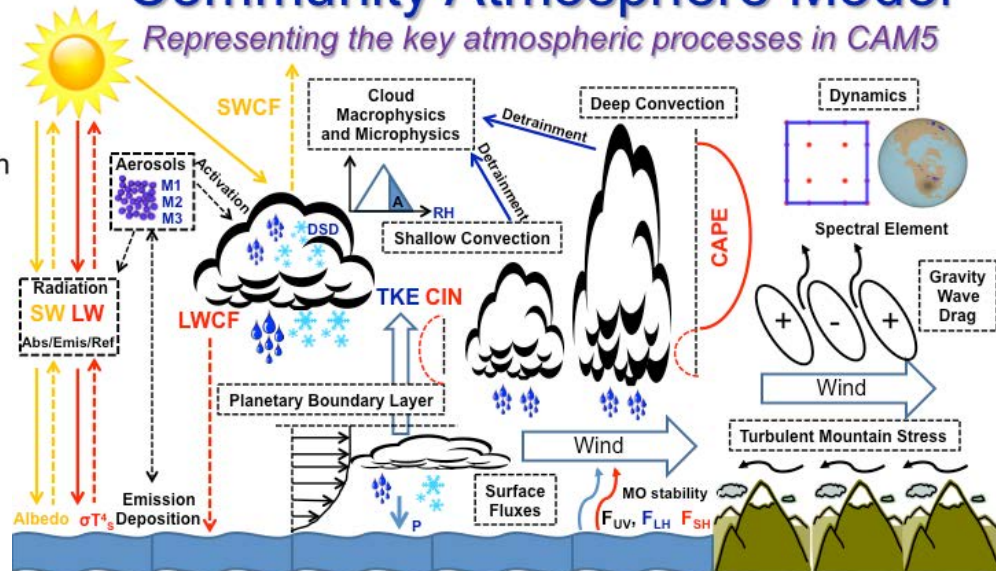
Source: 2000 W.F. Ruddiman



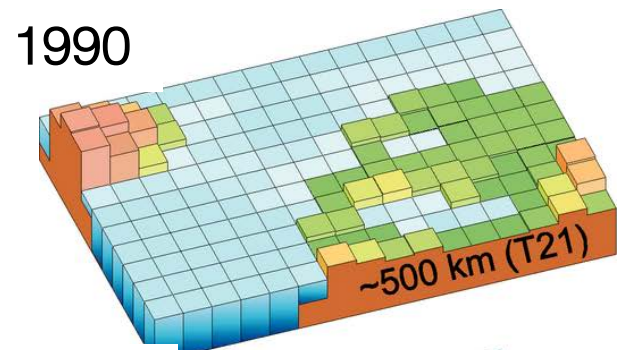
Community Earth System Model Tutorial

# Community Atmosphere Model

Representing the key atmospheric processes in CAM5



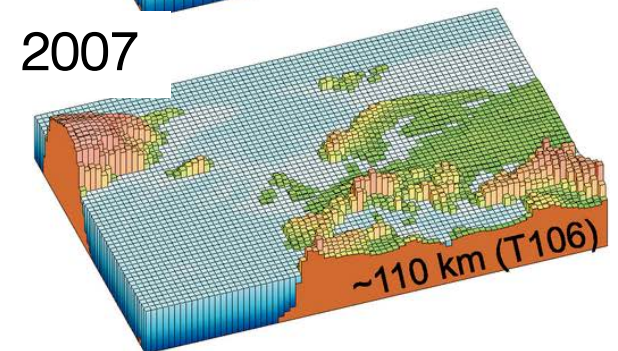
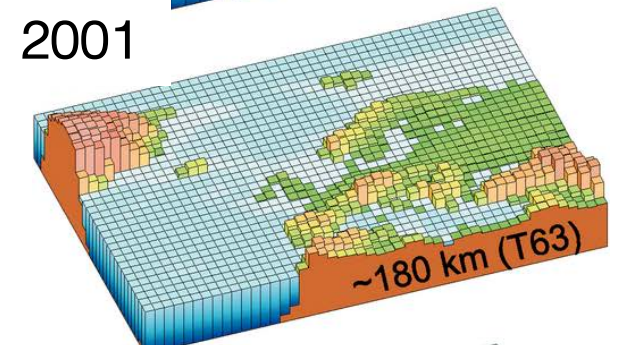
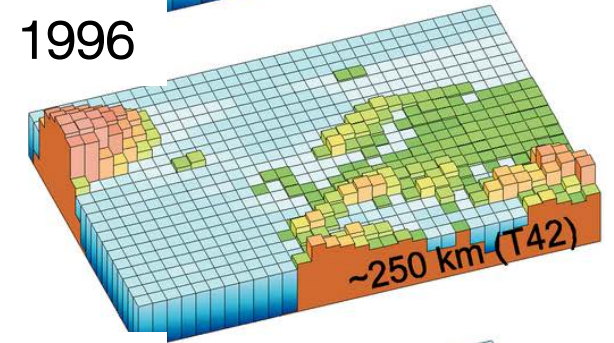
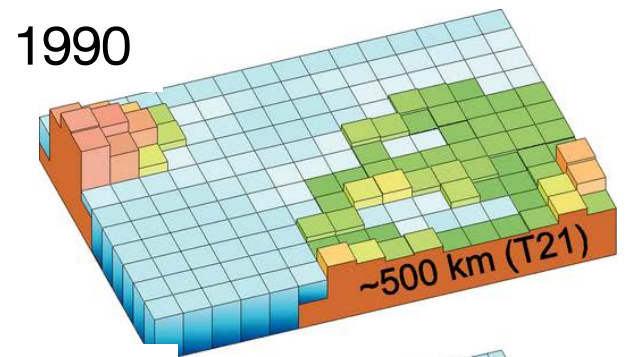
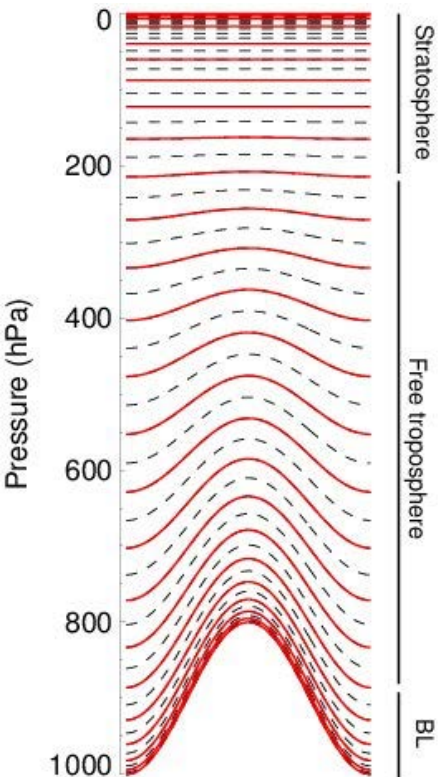
# Resolution



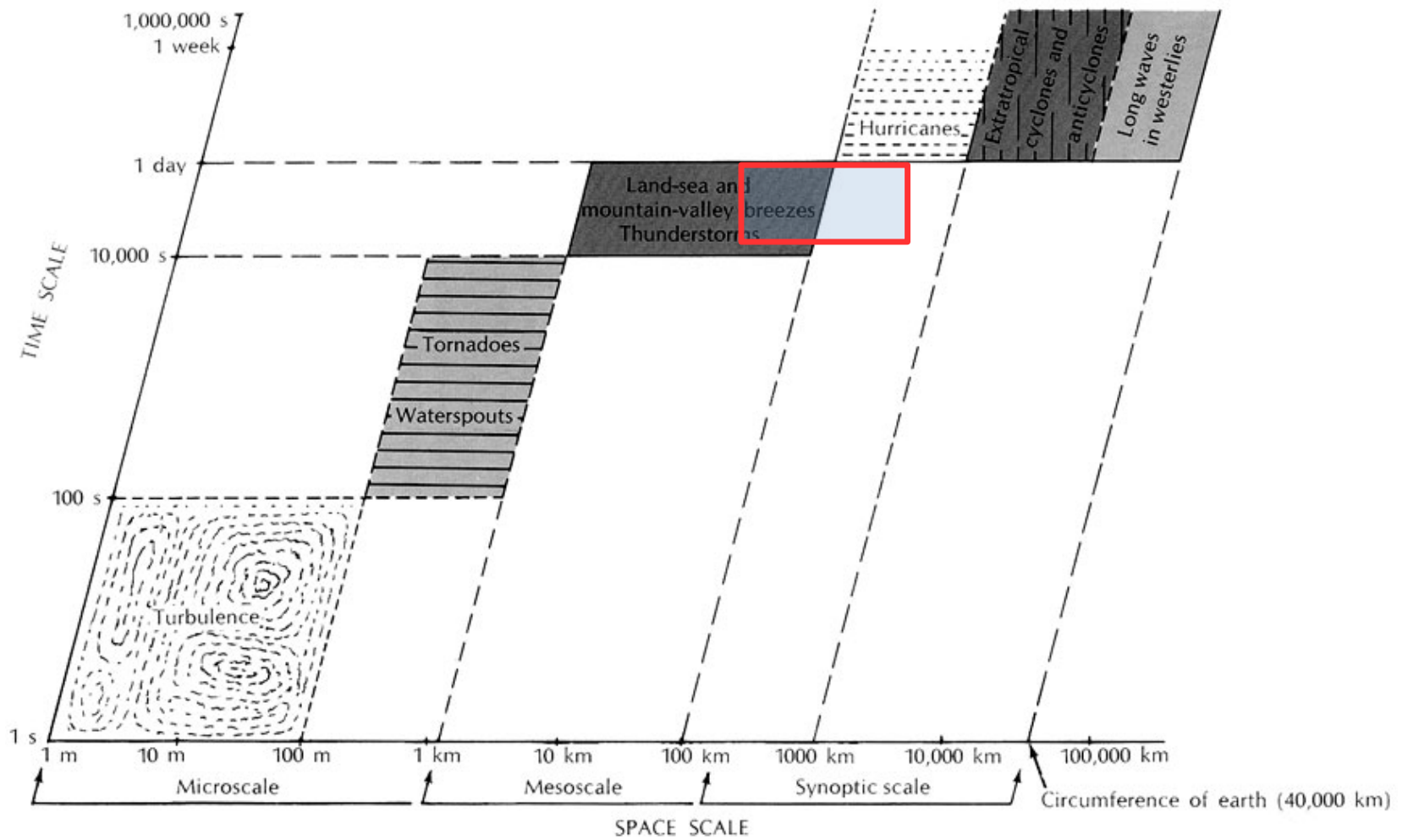


# Resolution

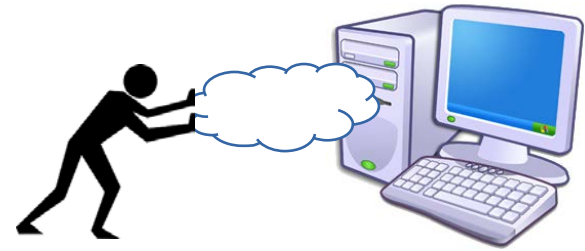
- Spatial resolution
  - Changing resolution substantially increases
    - run time of the model (10 times as much for a doubling of resolution)
    - output data size (4 times as large)
- Vertical resolution
  - 30 layers up to 40 km
  - More layers close to the surface
- Temporal resolution
  - 30 min
  - 1,753,152 time steps for 100 years



# Scales

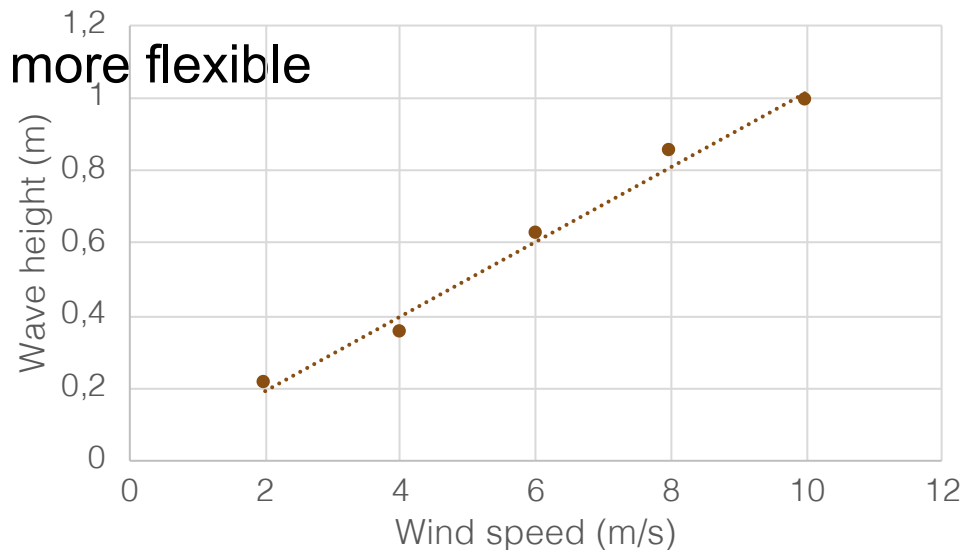


# How do we represent reality in climate models?



## Parameterizations

- What is a parameterization?
  - A mathematical representation of a feature
- Parameterizations can be based on:
  - Theory
    - Theoretical parameterizations more flexible
  - Measurements
    - Lab measurements
    - Field measurements



# Different types of variables in the model

- Prognostic variables – directly predicted by the model
- Diagnostic variables – variables calculated from prognostic variables

- Example:

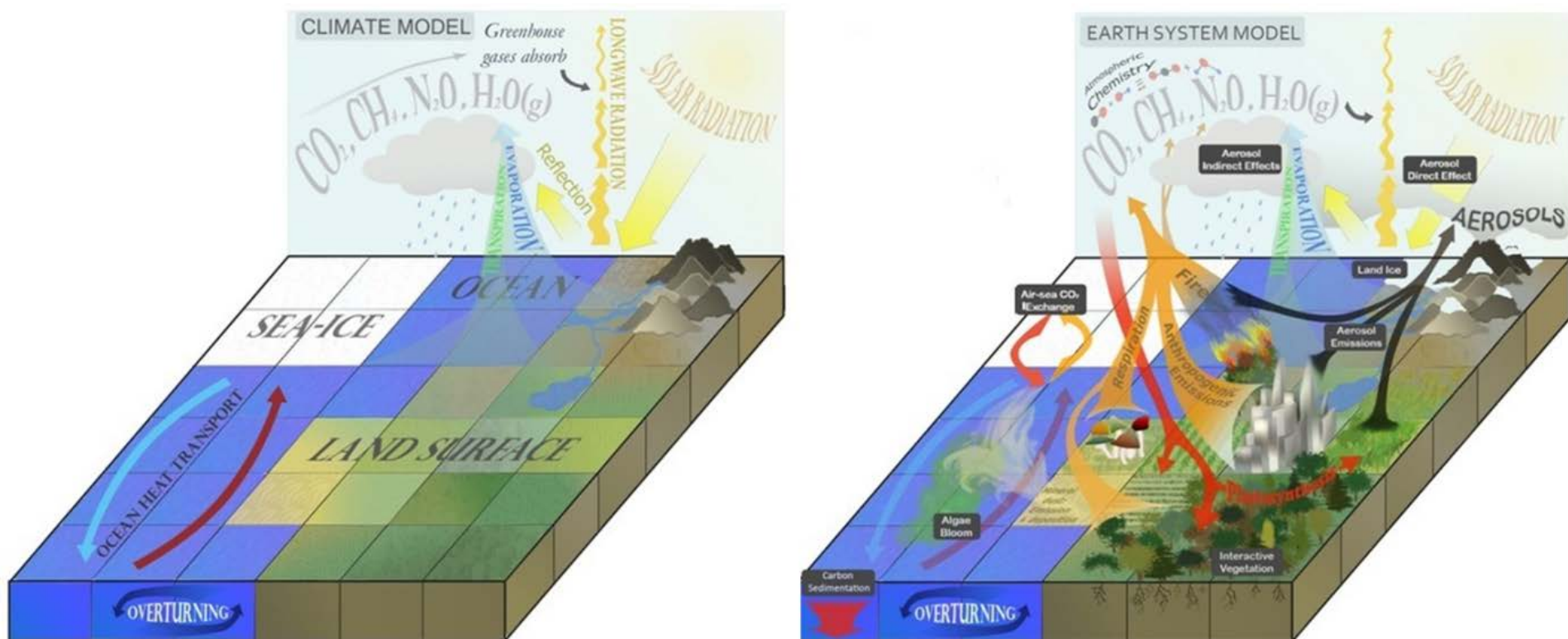
Temperature and specific humidity are prognostic

From this the relative humidity can be calculated



# Terminology

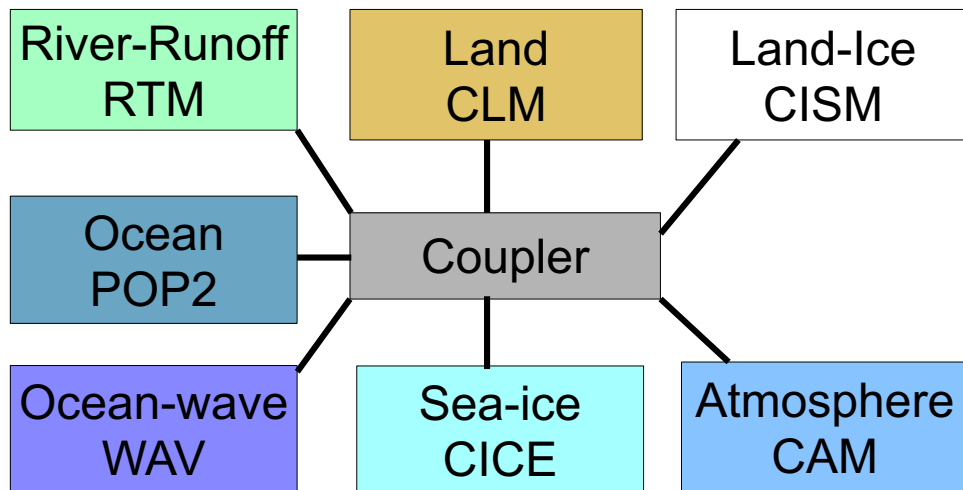
- GCM – Global Circulation Model
- GCM – Global Climate Model
- ESM – Earth System Models



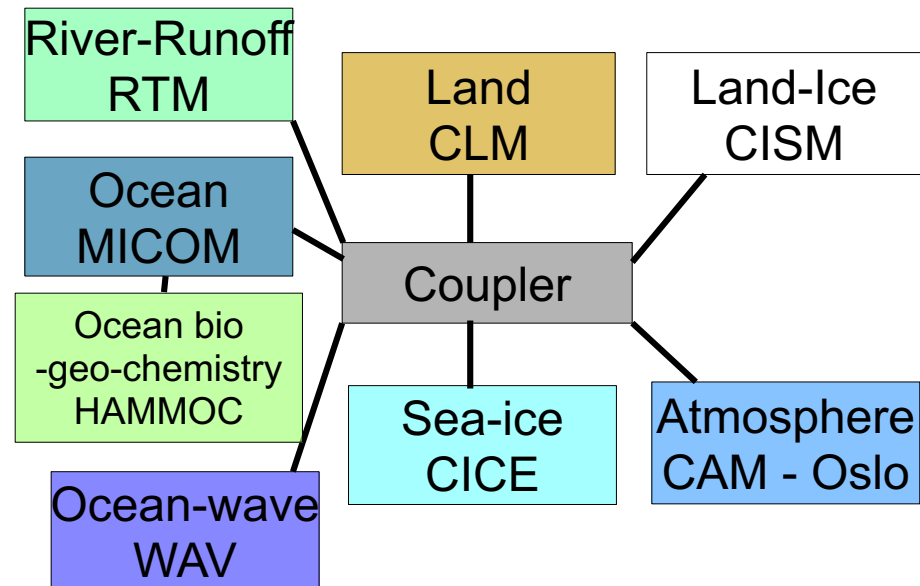
# How many climate models are there?

- About 25 “different” ESM in the world
- ESM build up of different models
- Coupler sends information between the models

## CESM



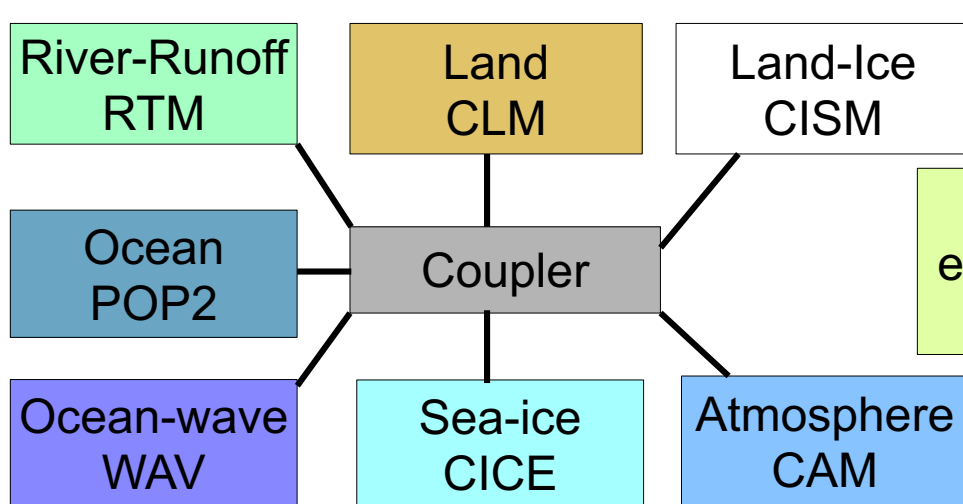
## NorESM



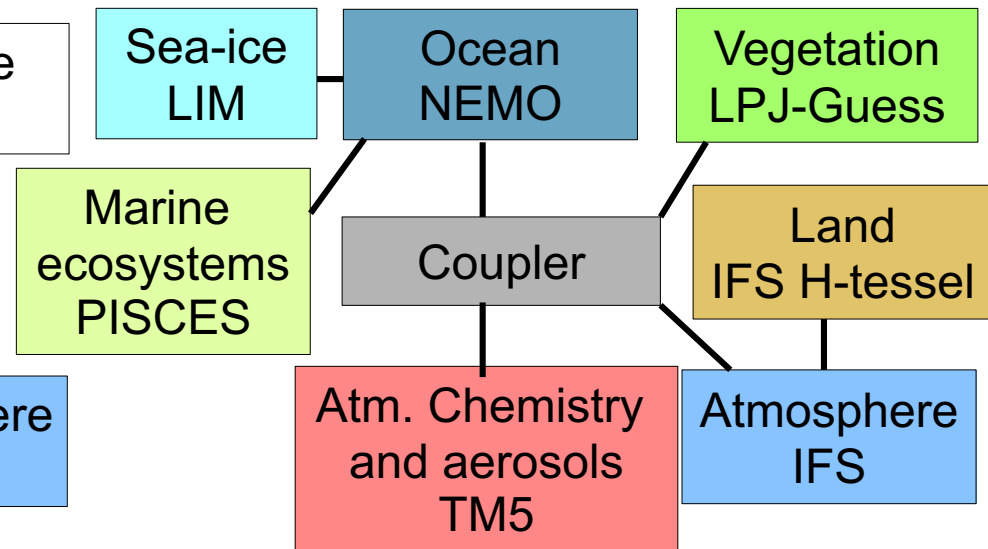
# Earth system models

- About 25 “different” ESM in the world
- ESM build up of different models
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## CESM

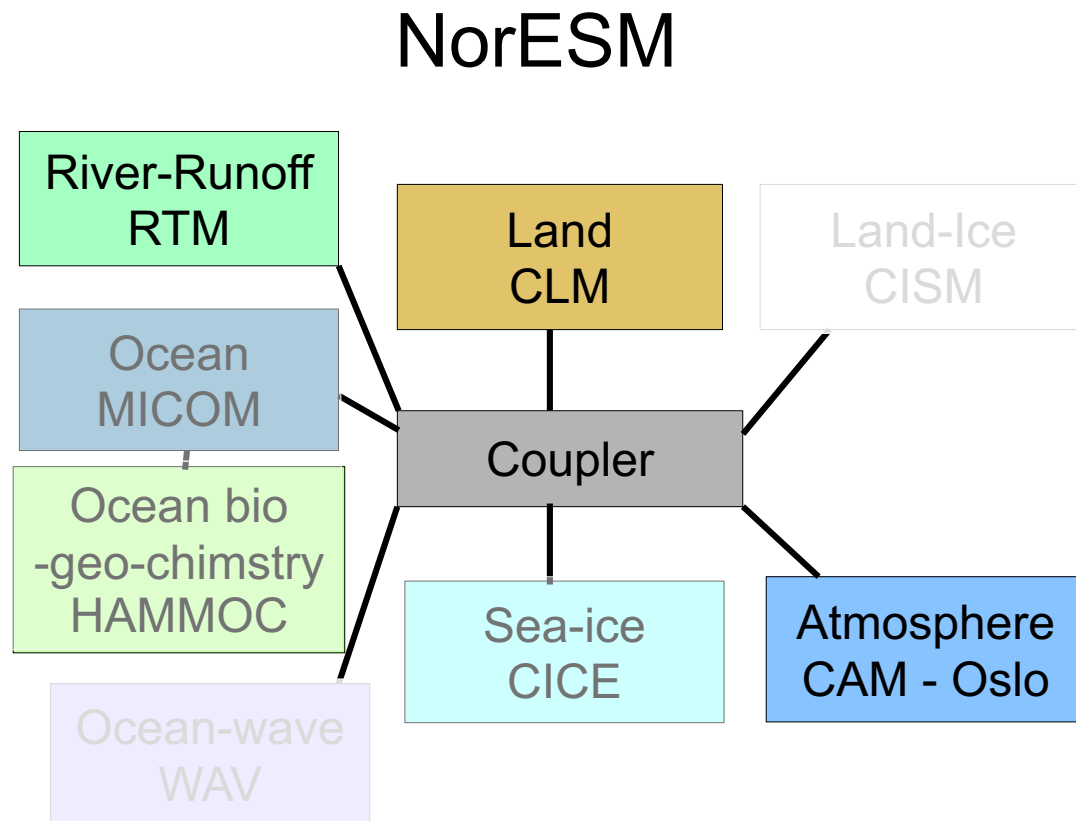


## EC-Earth



# Earth system models

- Models most often not run “fully coupled”





# Earth System Modelling

- Programming language - Fortran
- NorESM - Almost 2 million lines of code
- Run on hpc (high-performance computing) centers
- Atmosphere:
  - Resolution  $1.9 \times 2.5^\circ$ , 30 vertical levels (coarse)
  - 410 400 grid boxes



# What is the IPCC?



- Intergovernmental Panel on Climate Change
- Climate researchers summarize the current state of climate research
- Established in 1988 by UNEP and WMO
- Task is to assess the risks and impacts of climate change
  - Does not conduct research
  - Synthesise existing research
- Deliver assessment reports (AR)
  - AR5 released in 2013-2014
  - AR6 will be released in 2022 (already being written)
  - AR often contain CMIP (climate model intercomparison project)

## What is the IPCC?

- Reports are reviewed by both other scientists and governments
- Also produces special reports
- Many researchers (2500)
  - Work for free
  - Write on their field of expertise
  - Balance
    - Men and women
    - Junior and senior
    - Developed and developing countries

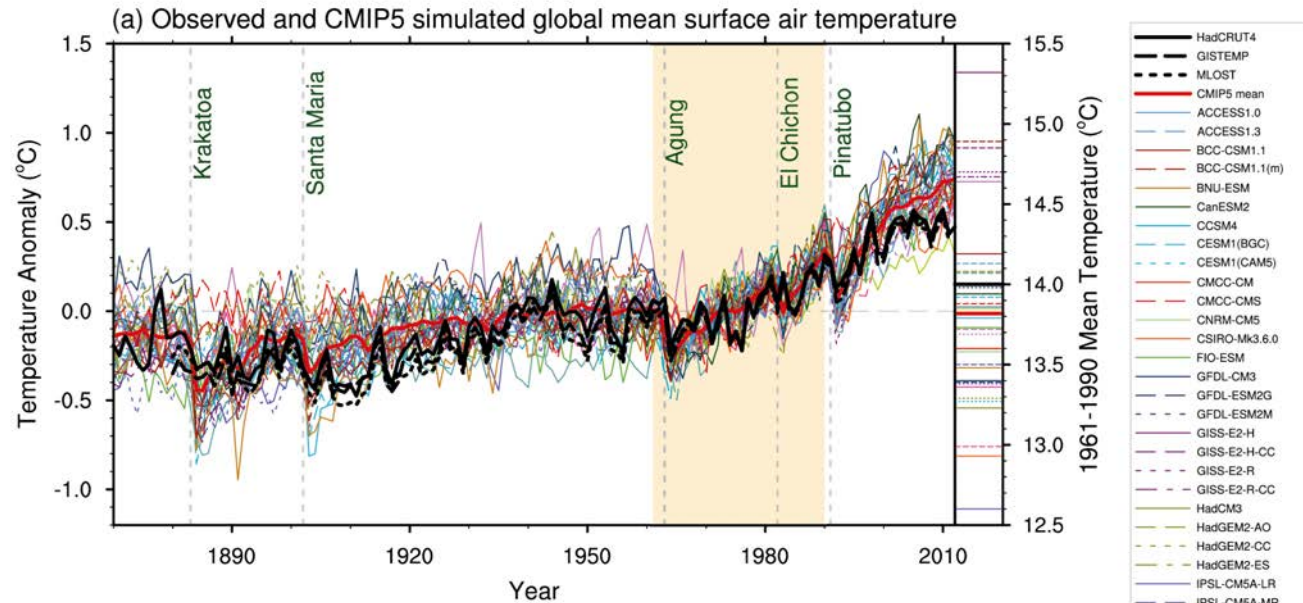


## What is CMIP?

- Coupled model intercomparison project
- Run the same climate experiments with all models (who wants to participate)
- Began in 1995
- Make the model data available to other scientists
- CMIP5 was included in AR5
- Nowadays more specialised MIPS: AMIP, VolMIP

# How are the models run for CMIP?

- Spin-up
  - Make sure the model is in balance
  - Create a climate in the model
  - Run with pre-industrial emissions
  - Hundreds of years



- Deck simulations (Diagnostic, Evaluation and Characterization of Klima)
  - Pre-industrial Control (min 500 years)
  - 4xCO2 concentration (min 150 years)
  - CO2 increase at 1 % per year (min 150 years)
  - AMIP (atmospheric model intercomparison project)
    - Simulate 1979 – 2014
    - Fixed sea surface temperature and sea ice
    - CO2 prescribed

- CMIP6 historical simulations
  - 1850 – 2014
  - One with CO2 concentrations from measurements
  - One with CO2 emissions from measurements



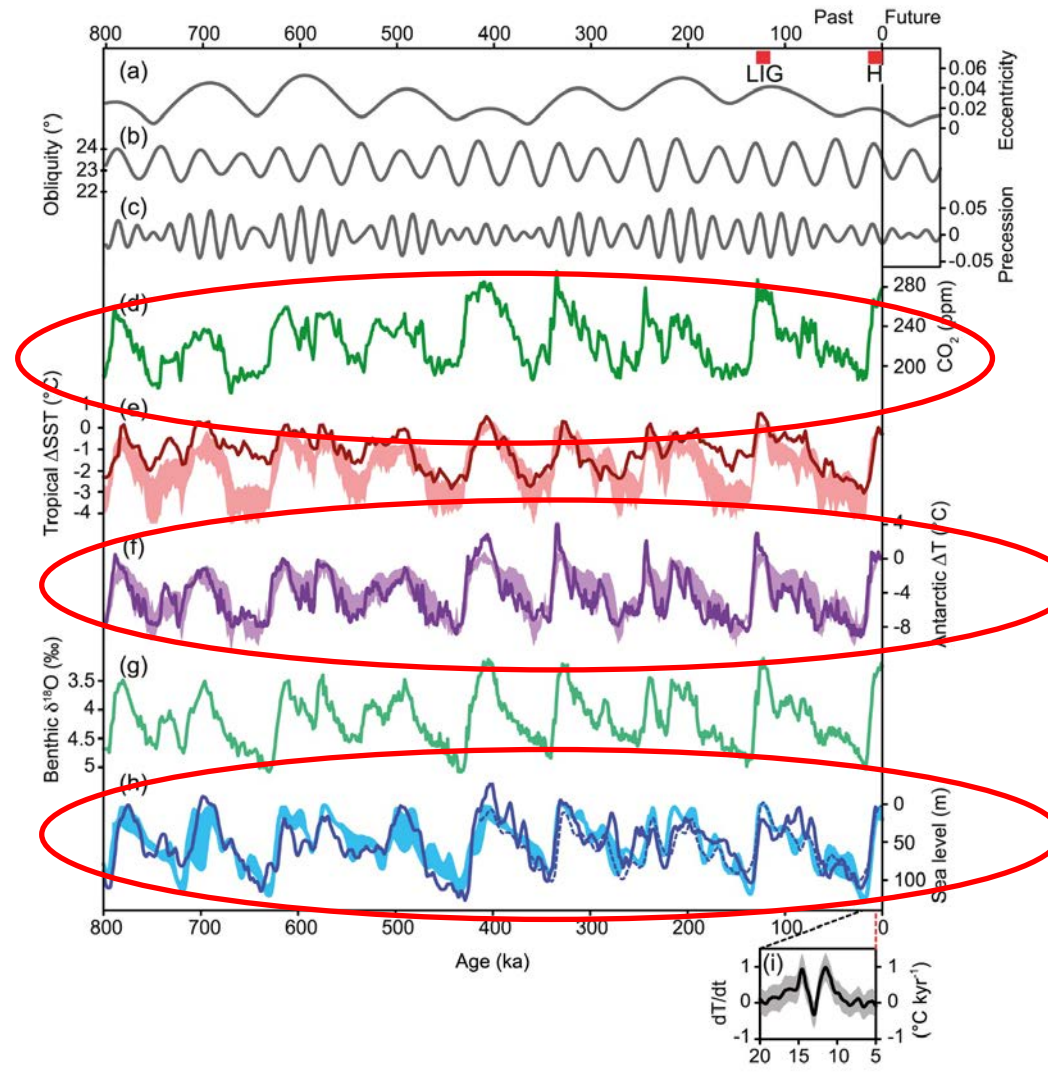
# Causes of climate change

- Solar output
- Plate tectonics
- Orbital variability
- Ocean variability
- Volcanism
- Human influences

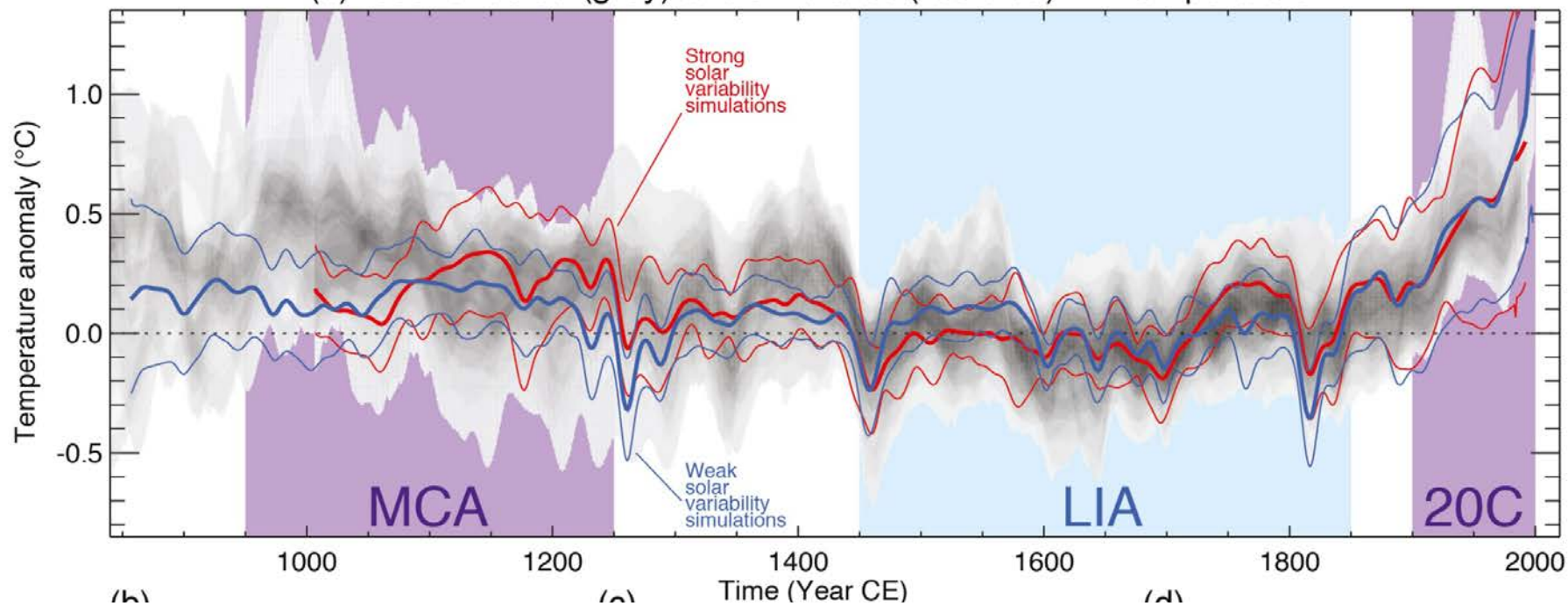
# Signs of climate change

- Temperature Increase/decrease
- Glaciers and sea ice loss/Gain
- Vegetation changes
- Sea level changes
- Changed precipitation patterns

- Variation due to changes in Earth's orbit around the sun (Milankovitch cycles)

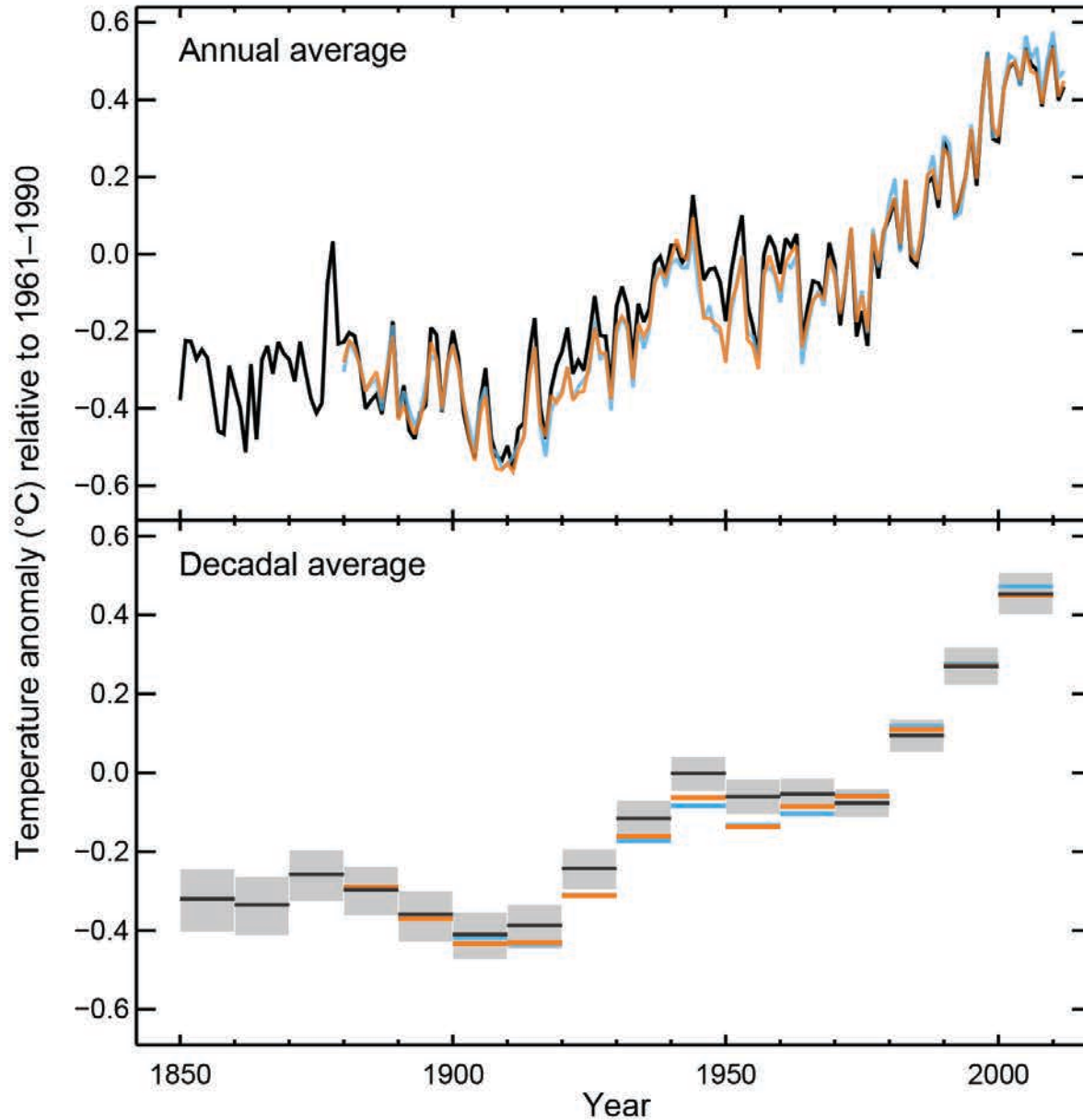


(a) reconstructed (grey) and simulated (red/blue) NH temperature

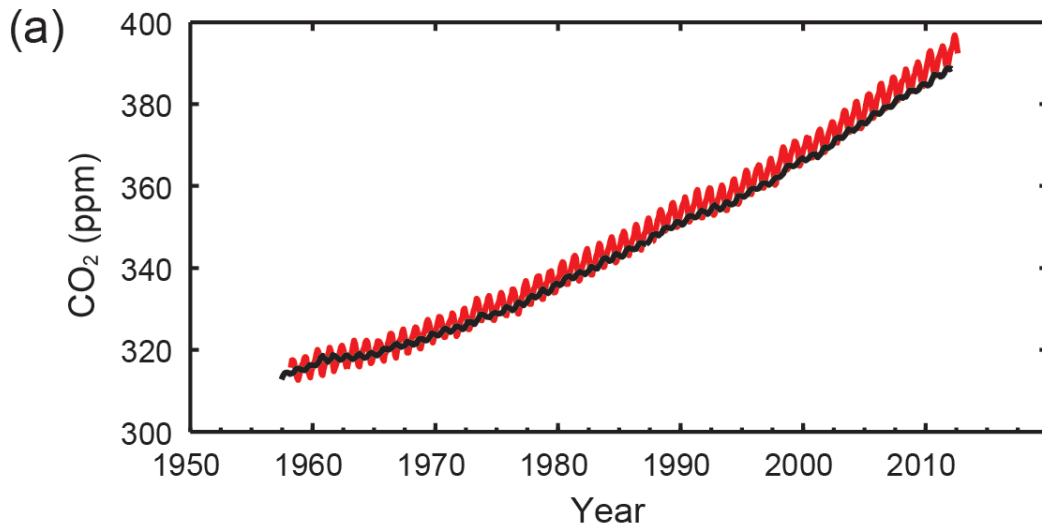


Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012

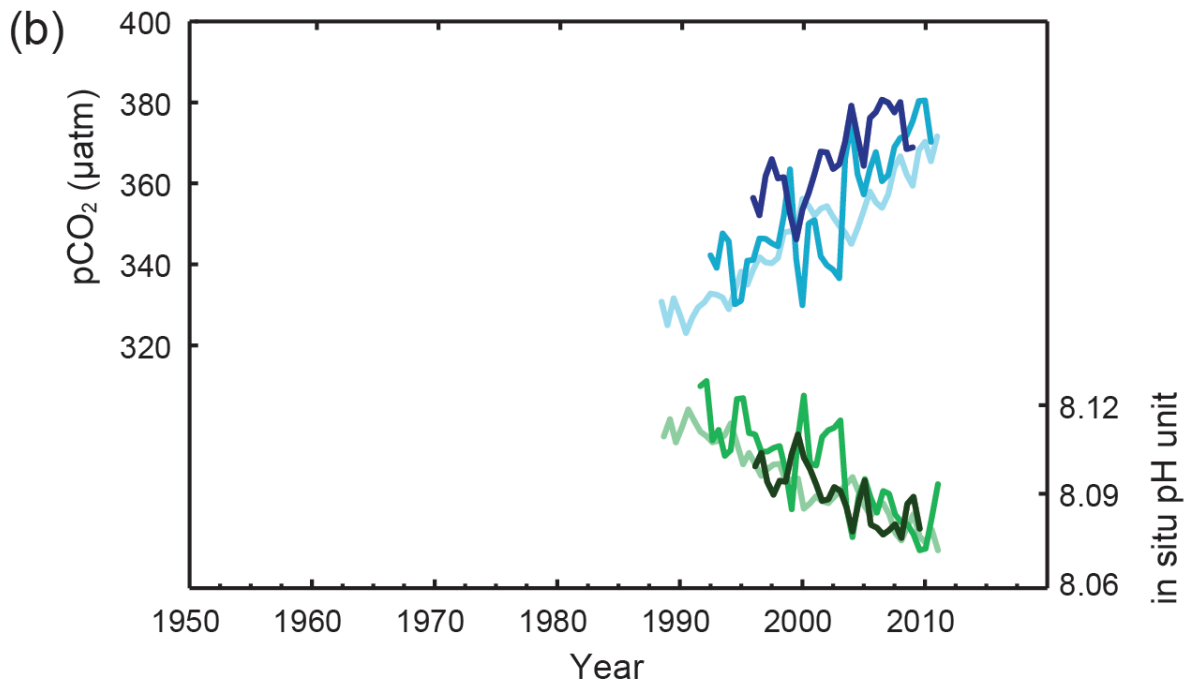
(a)



### Atmospheric CO<sub>2</sub>

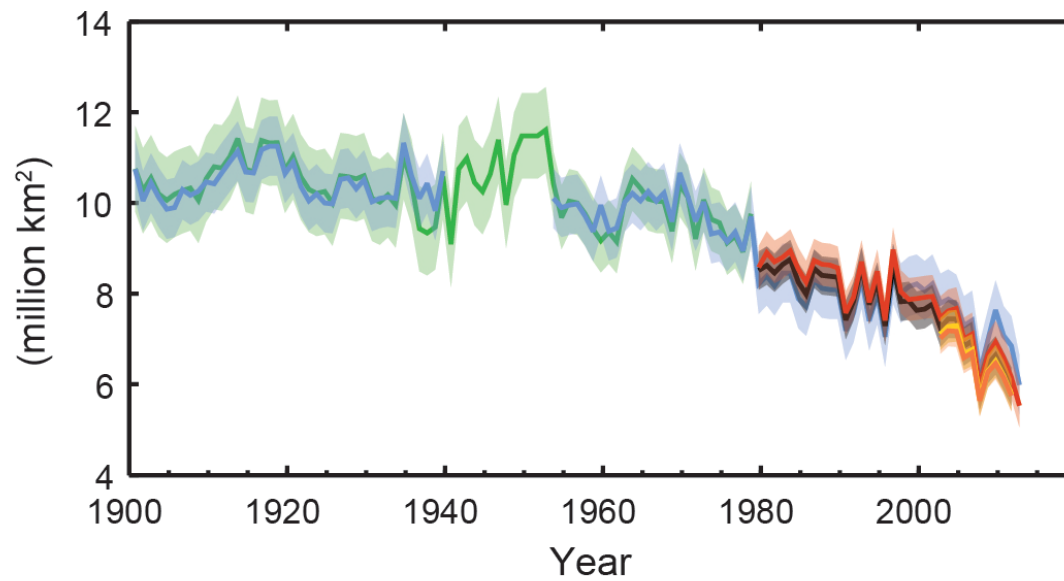


### Surface ocean CO<sub>2</sub> and pH

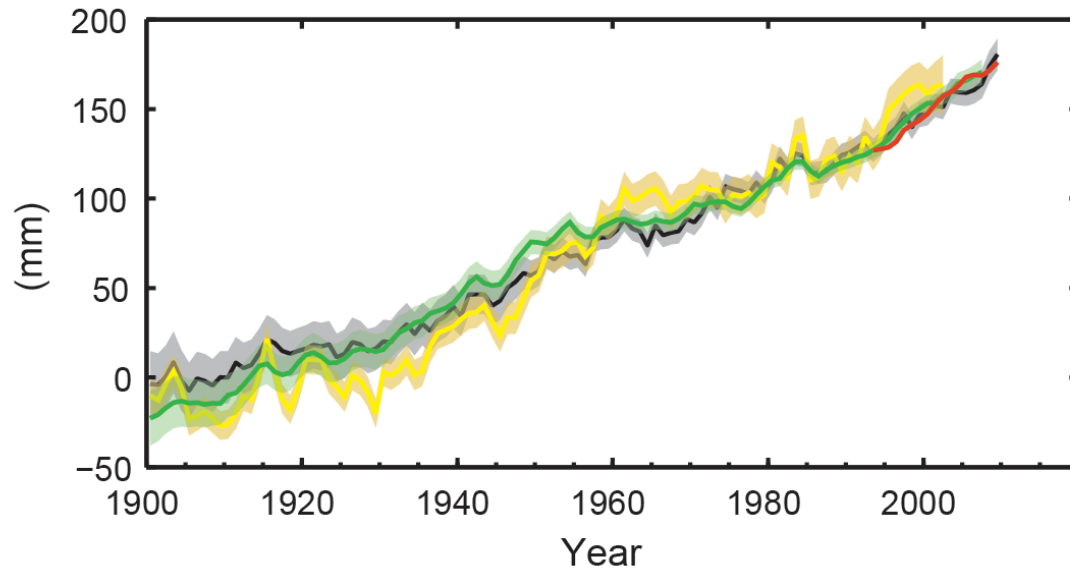




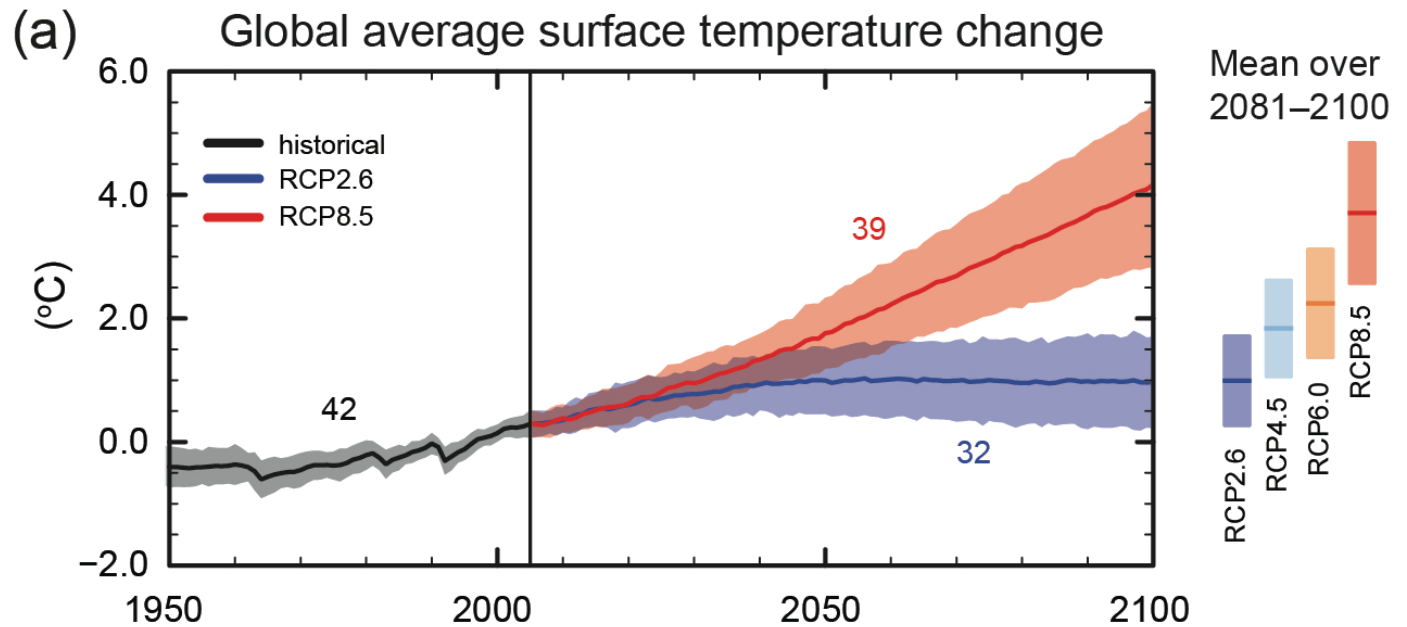
(b) Arctic summer sea ice extent



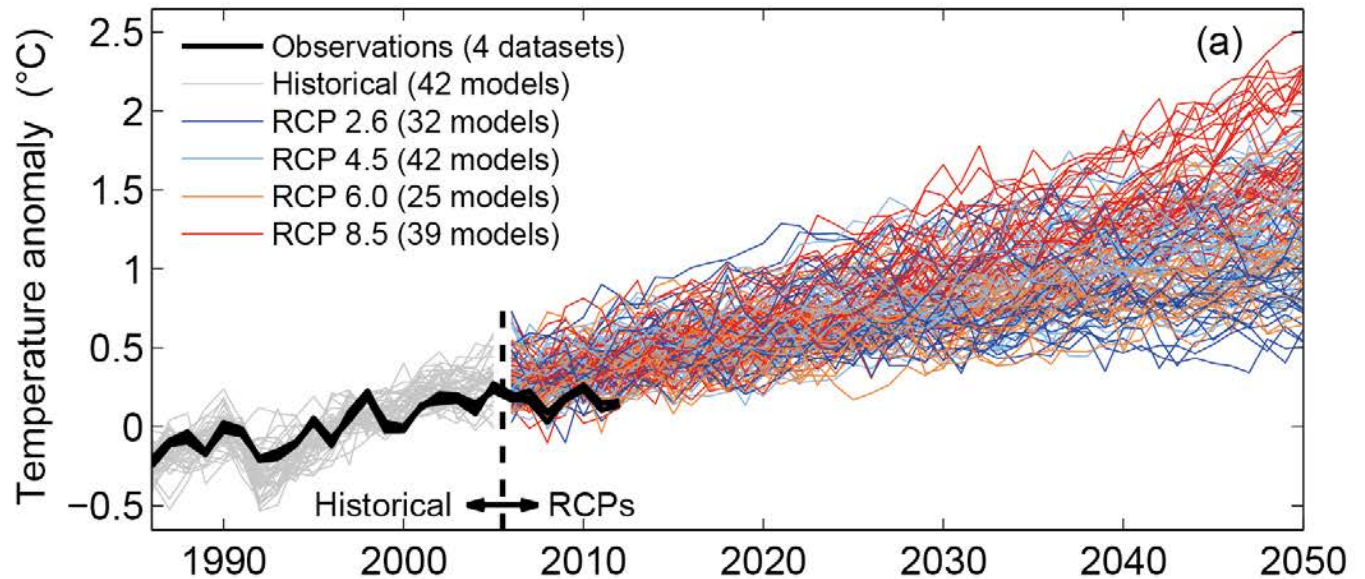
(d) Global average sea level change



# The future

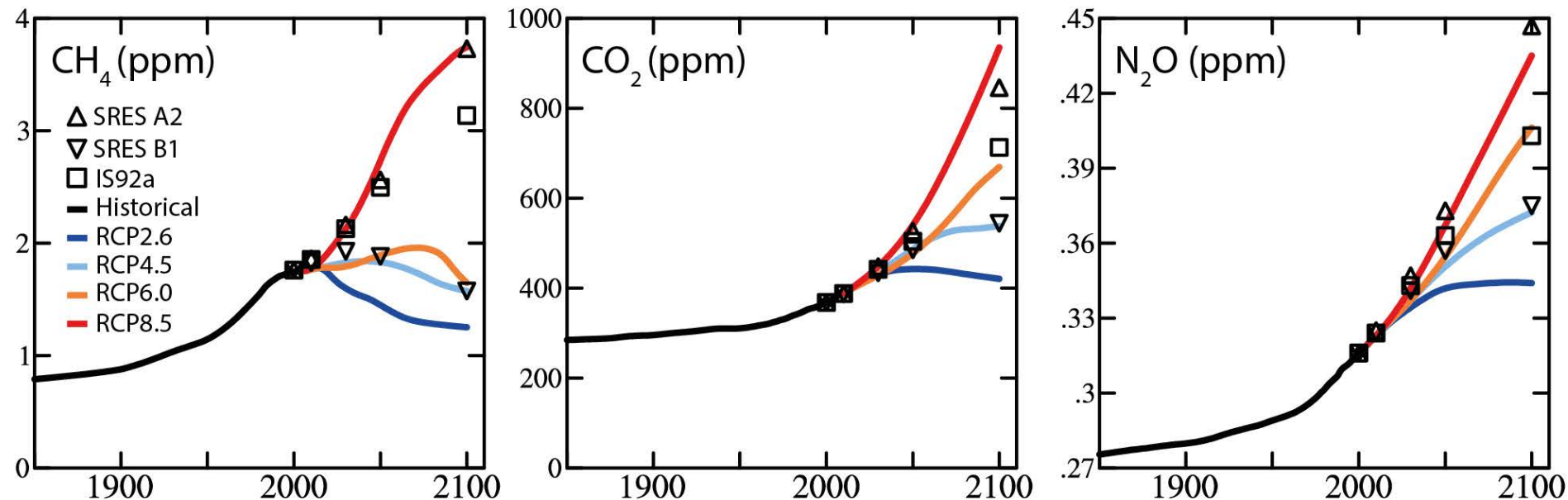


Global mean temperature near-term projections relative to 1986–2005

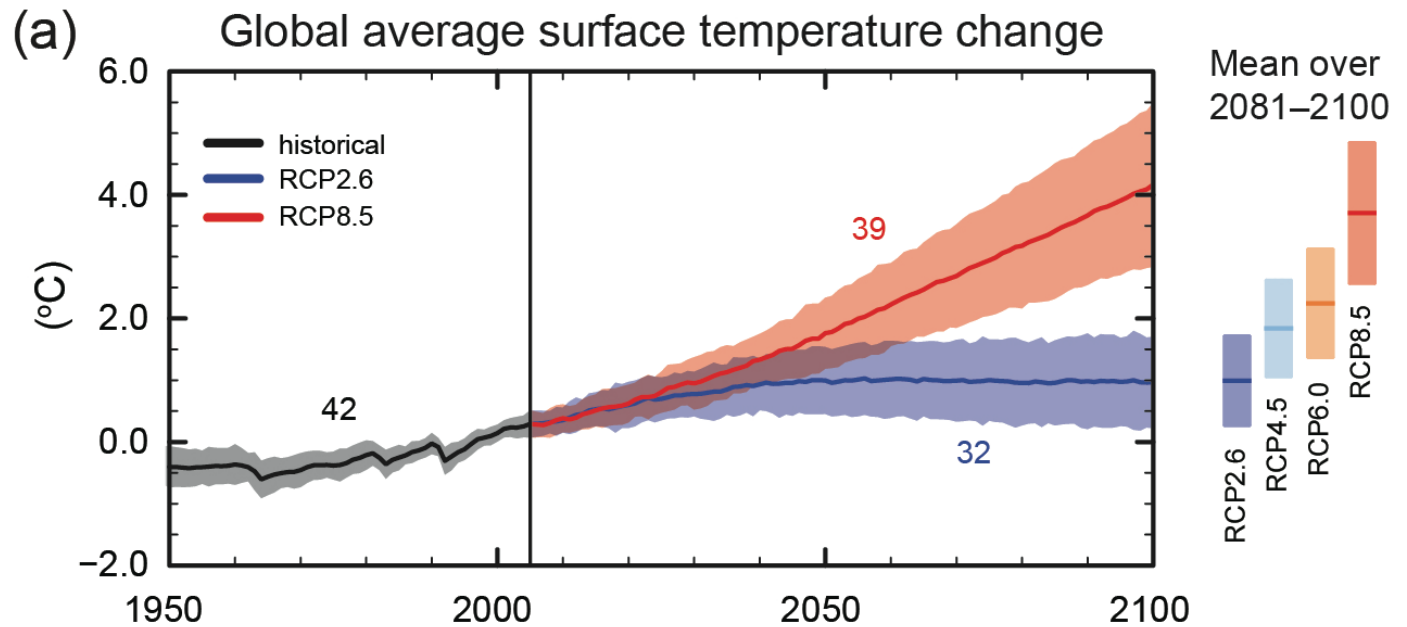


# What is RCP?

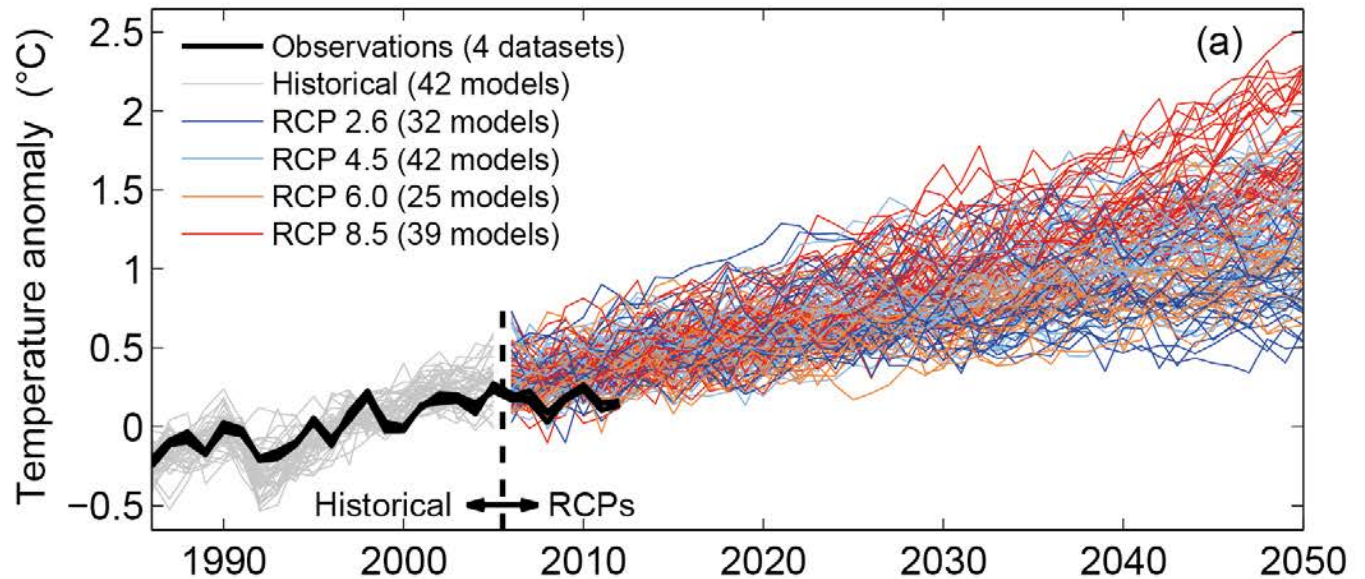
- RCP – representative concentration pathway
- Is calculated using economic models
- Model future socioeconomic pathways
  - RCP2.6 global effort to reduce emissions
  - RCP8.5 business as usual
- There will be new scenarios in CMIP6
  - SSP (Shared socio-economic pathways)
  - At least 5 different scenarios



# The future

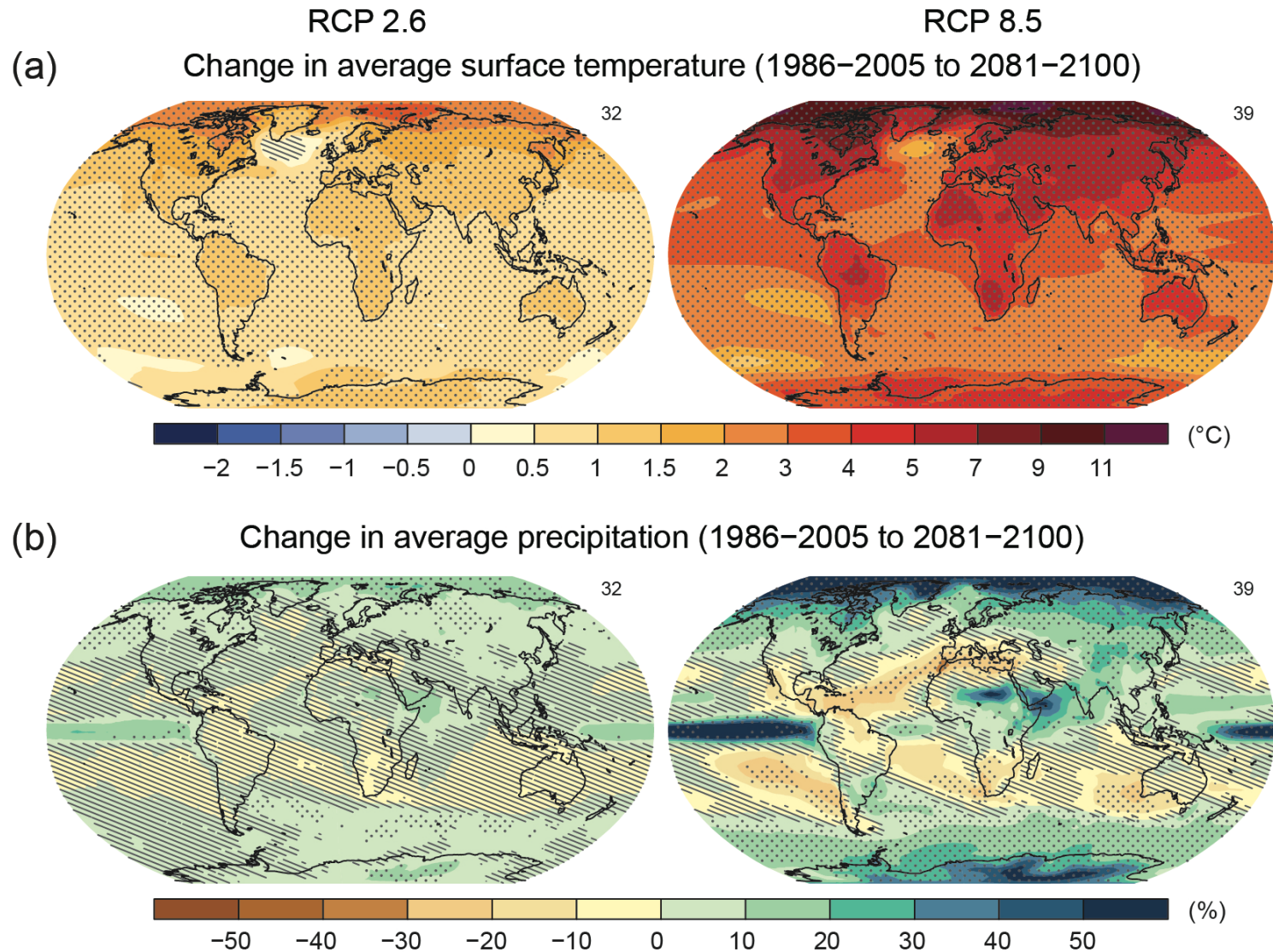


Global mean temperature near-term projections relative to 1986–2005





# Temperature and Precipitation





# The future

2081–2100

RCP2.6



RCP6.0



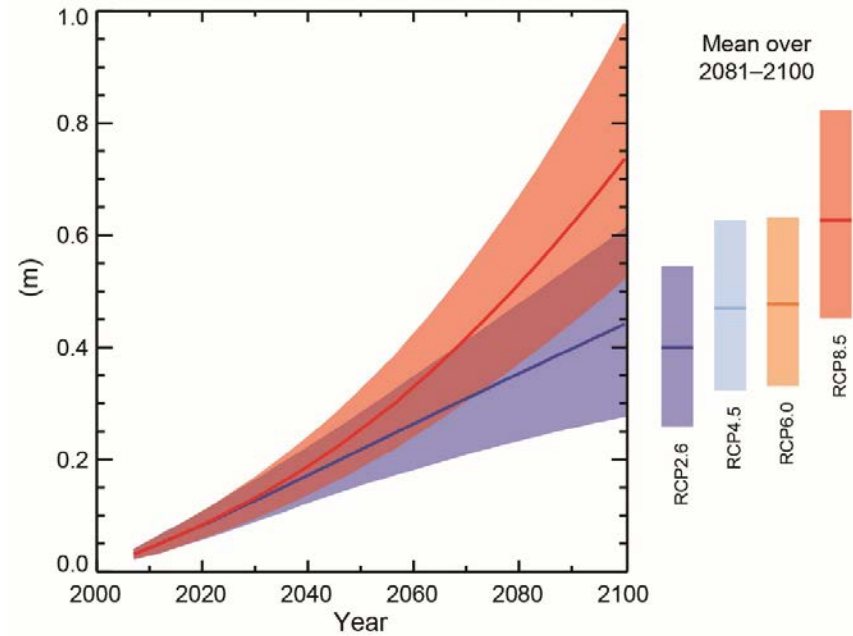
RCP4.5



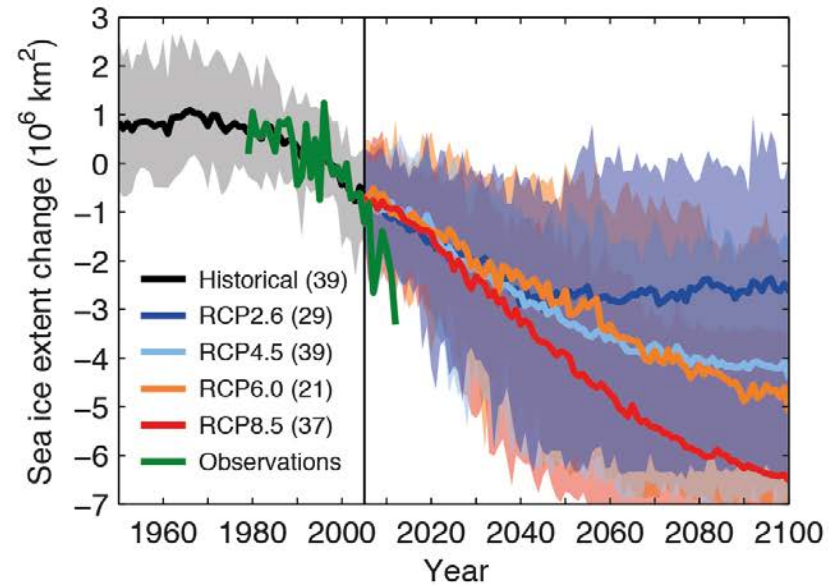
RCP8.5



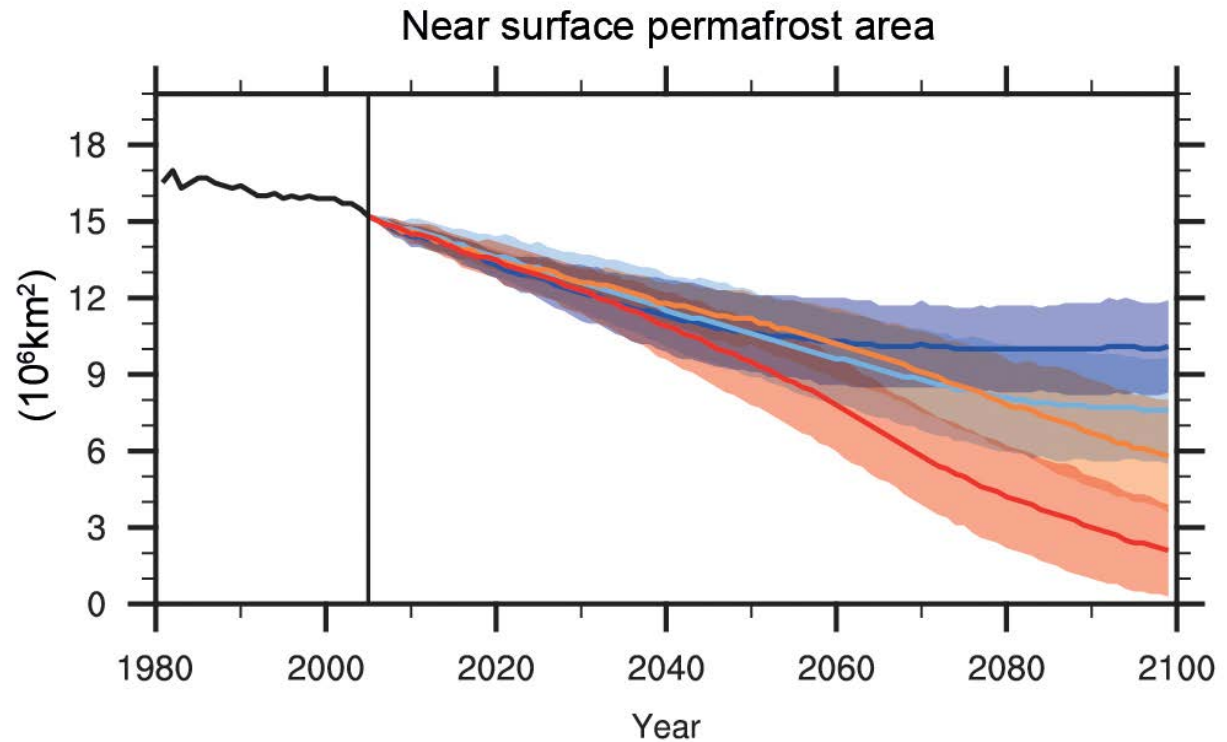
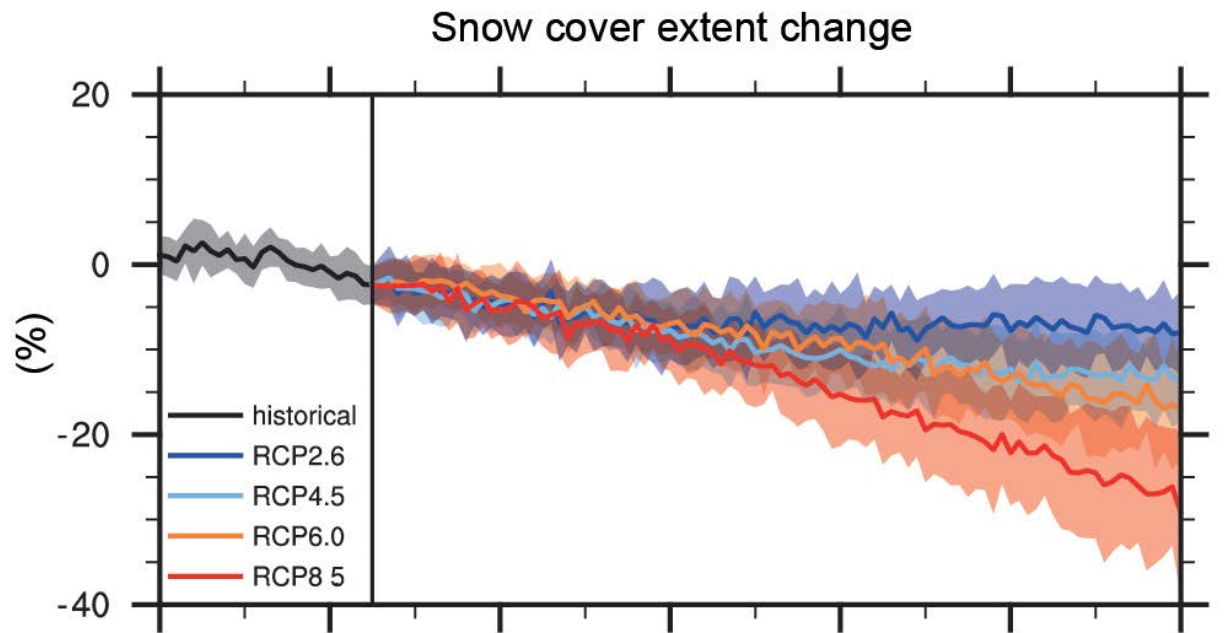
Global mean sea level rise



b) Northern Hemisphere September  
Satellite obs. 1986–2005 avg:  $7.1 \times 10^6 \text{ km}^2$   
CMIP5 historical 1986–2005 avg:  $6.6 \times 10^6 \text{ km}^2$

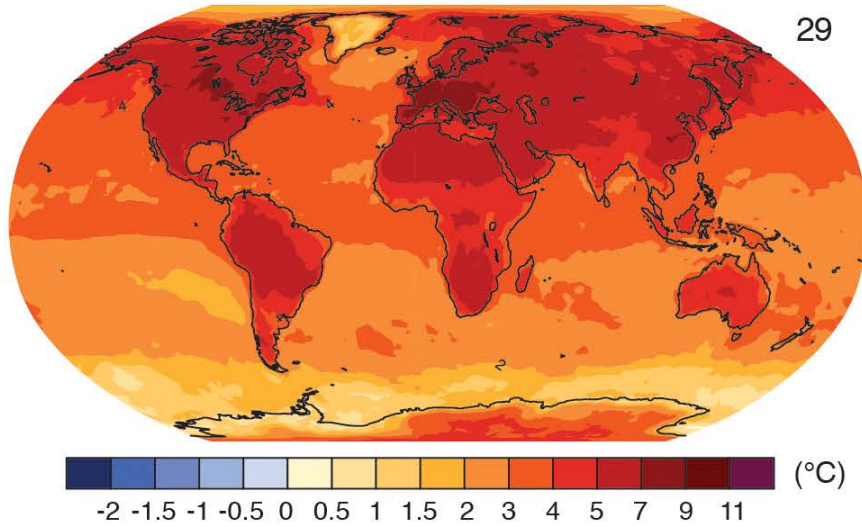


# The future

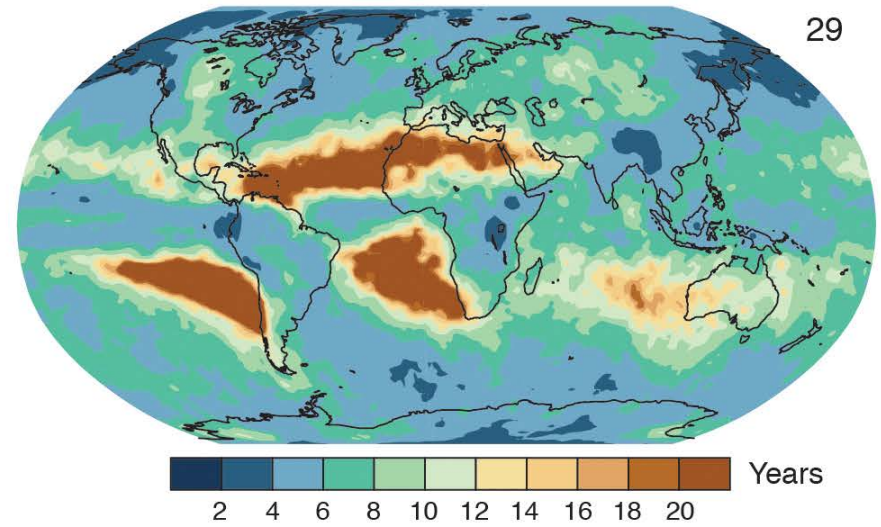


# The future

(e) Future change in 20yr RV of warmest daily Tmax (TXx)



(f) Future RP for present day 20yr RV of wettest day (RX1day)







# SUSTAINABLE DEVELOPMENT GOALS

**1** NO POVERTY

**2** ZERO HUNGER

**3** GOOD HEALTH AND WELL-BEING

**4** QUALITY EDUCATION

**5** GENDER EQUALITY

**6** CLEAN WATER AND SANITATION

**7** AFFORDABLE AND CLEAN ENERGY

**8** DECENT WORK AND ECONOMIC GROWTH

**9** INDUSTRY, INNOVATION AND INFRASTRUCTURE

**10** REDUCED INEQUALITIES

**11** SUSTAINABLE CITIES AND COMMUNITIES

**12** RESPONSIBLE CONSUMPTION AND PRODUCTION

**13** CLIMATE ACTION

**14** LIFE BELOW WATER

**15** LIFE ON LAND

**16** PEACE, JUSTICE AND STRONG INSTITUTIONS

**17** PARTNERSHIPS FOR THE GOALS

SUSTAINABLE DEVELOPMENT GOALS

Thank you!



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