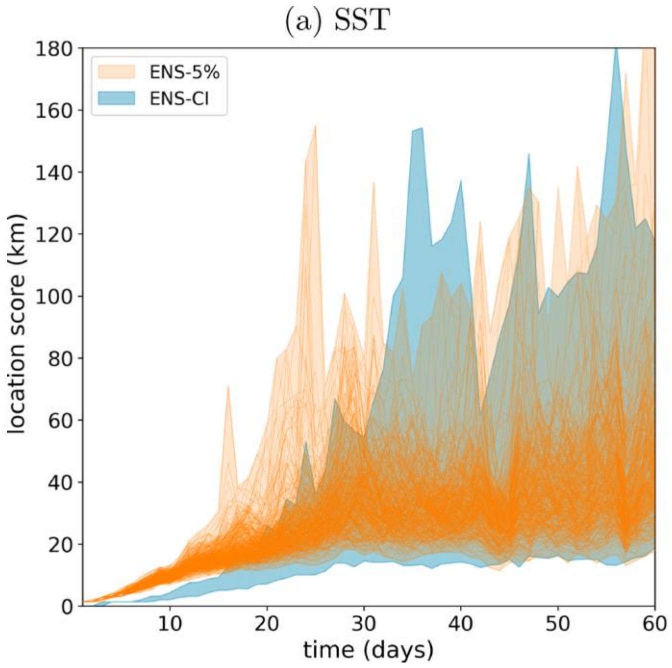
Climate Modeling: Global and Regional

Prediction vs Projections

- Prediction: Driven by initial condition
- Projection: No impacts of initial condition
- Spin-up: to forget initial condition



Climate Models

Energy balance models (EBMs): models considers radiation process, may predict the variation of surface temperature with latitude.

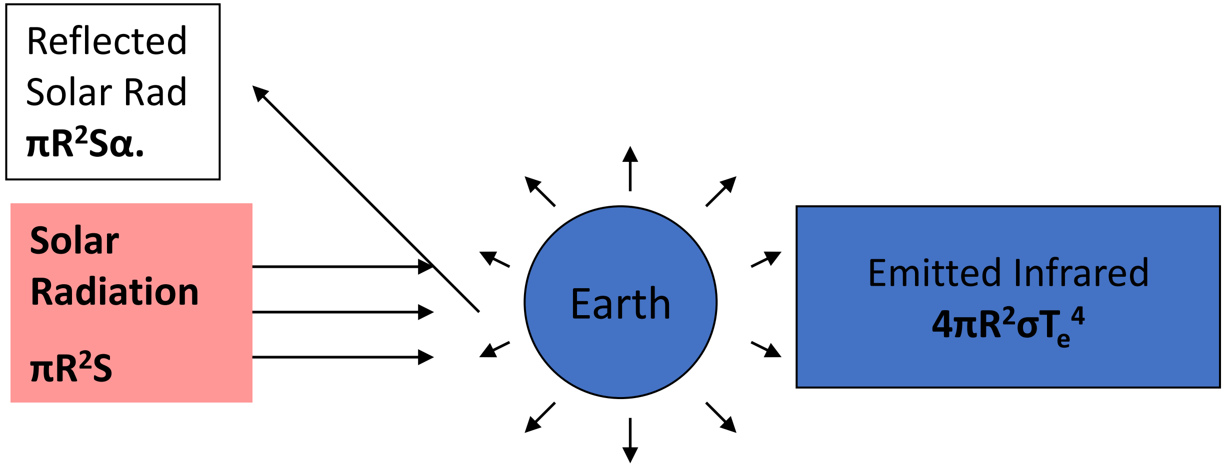
One-dimensional Radiative-Convective models (RCs): computes the vertical temperature profile by explicit modelling of the radiative processes with convective-adjustment.

Two-dimensional Statistical dynamical models (2D-SDs): they deal with surface processes and dynamics in a zonally averaged framework and have a vertically resolved atmosphere

General Circulation Models (GCMs): these are three dimensional nature models of atmosphere/ocean with all the physics and dynamics included

Energy Balance Models (EBMs)

Zero-dimensional EBM



S = solar "constant" =
1370 W/m² /K⁴
α = albedo
σ = 5.67 x 10^{-8} W/m² K⁴
(Stefan-Boltzman
Constant)
T_e = Earth's temperature
in Kelvin
Results in T_e=255K
Green house = +33 K
Total = 288 K

The energy balance equation: $\pi R^2 S - \pi R^2 S\alpha = 4\pi R^2 \sigma T_e^4$

$$(1-\alpha)S = 4\sigma T_e^4$$

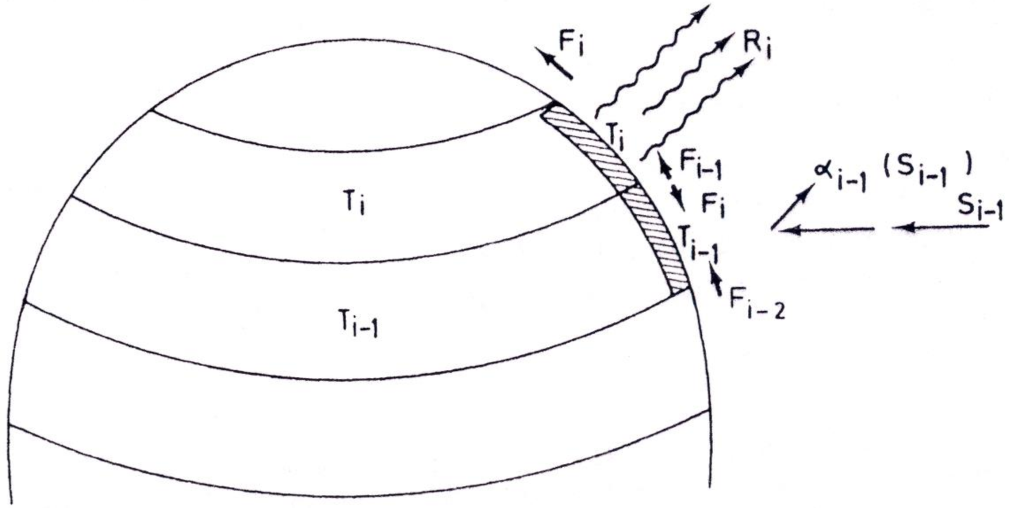
Incorporating greenhouse effect the equation can be modified to:

$(1-\alpha)S = 4\varepsilon\sigma T_e^4$ where, ε=Factor accounting for greenhouse effect

EBMs (contd..)

- One-dimensional EBM
  - Zonal (based on latitude) averaged energy balance model
  - Governing Equation:

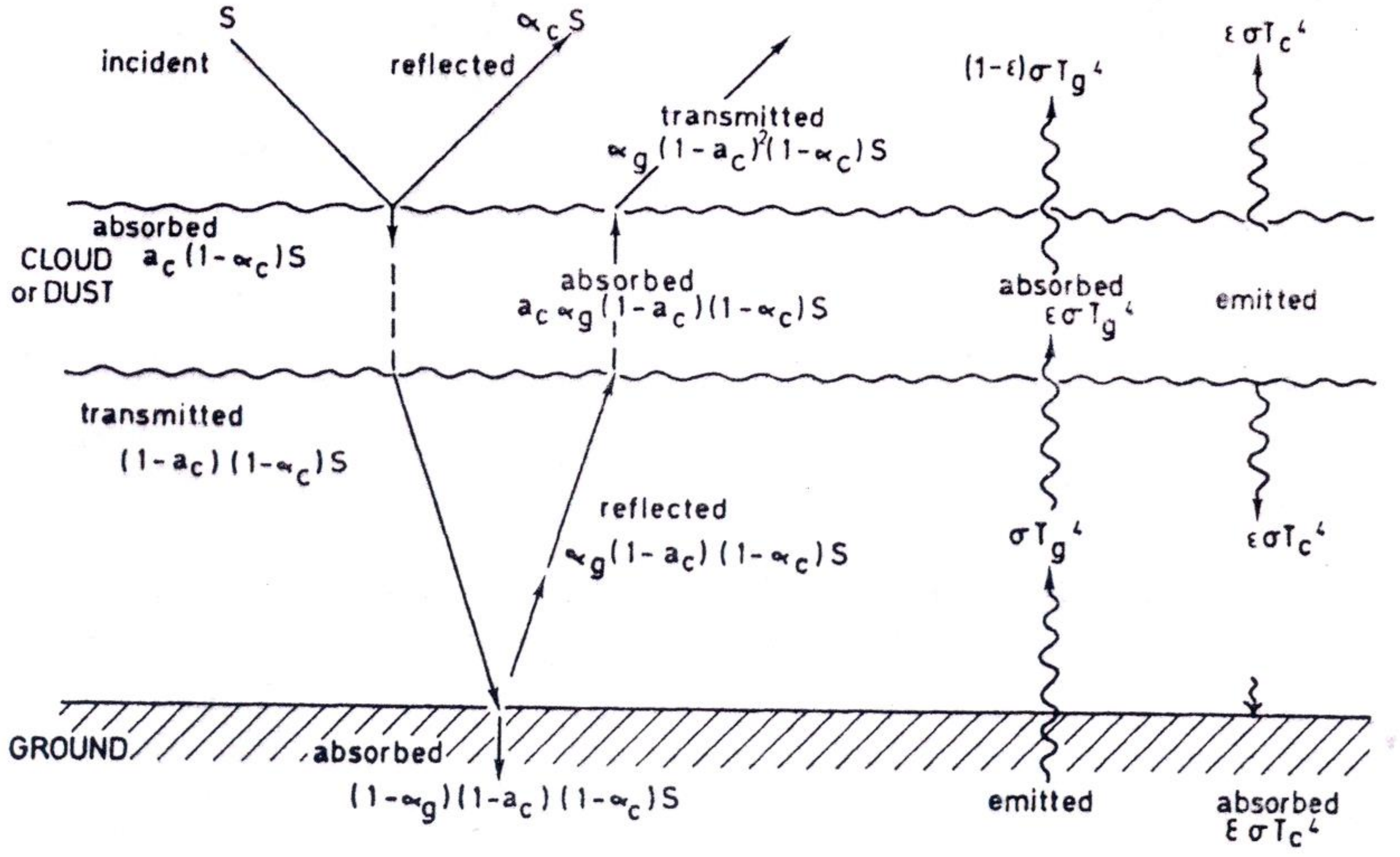
$$S_i(1-\alpha_i) = R_i \uparrow + F_i$$



1-D Radiative Convective Model

- Dimension is vertical

Radiative Modeling



$$S = \alpha_c S + \alpha_g (1 - a_c)^2 (1 - \alpha_c) S + \varepsilon \sigma T_c^4 + (1 - \varepsilon) \sigma T_g^4$$

$$a_c (1 - \alpha_c) S + a_c \alpha_g (1 - a_c)(1 - \alpha_c) S + \varepsilon \sigma T_g^4 = 2 \varepsilon \sigma T_c^4$$

$$(1 - \alpha_g)(1 - a_c)(1 - \alpha_c) S + \varepsilon \sigma T_c^4 = \sigma T_g^4$$

$$\sigma T_g^4 = \frac{S(1 - \alpha_c)}{(2 - \varepsilon)} (2 - a_c)$$

$S=S/4=343\ Wm^{-2}$

1-D Radiative Convective Model (contd..)

- Convective adjustment
  - Temperature reduces with height.
  - Generated convective heat transfer.
  - Should be coupled with radiative model.
  - Such coupling or adjustment is known as convective adjustment

Two-Dimensional Statistical Dynamical Models

- General circulation in this case is assumed to be composed mainly of flow between latitudes which is characterized by using empirical and theoretical formulations

- a set of statistics summarizes wind speed and direction

- an eddy diffusion coefficient is used which govern EBM transport.

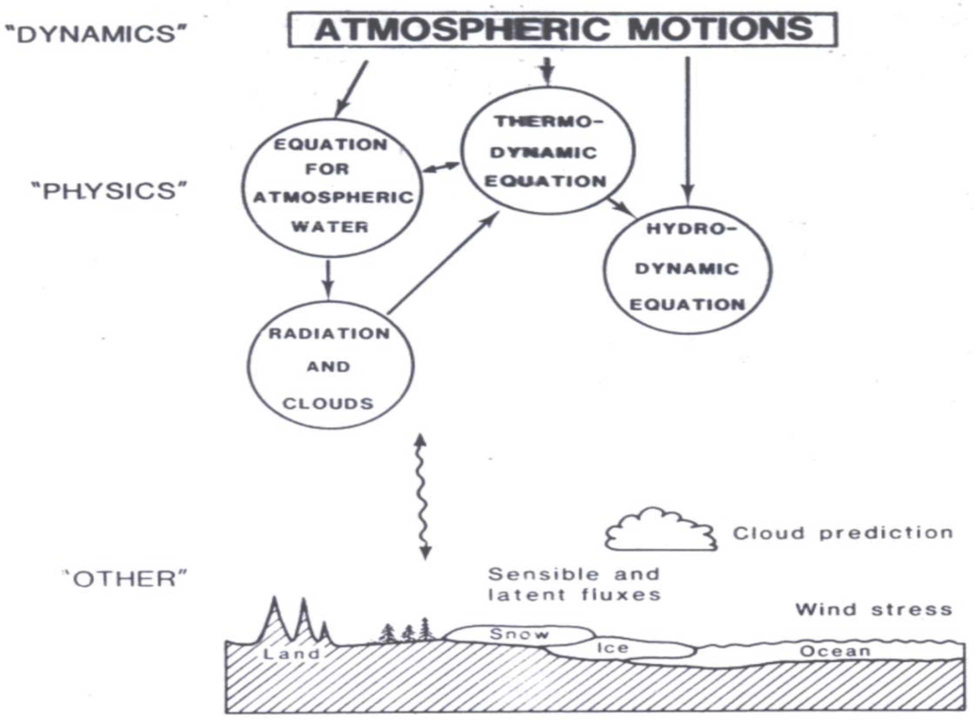
General Circulation Model (GCM)

3-D modeling considers all geophysical laws and dynamics.

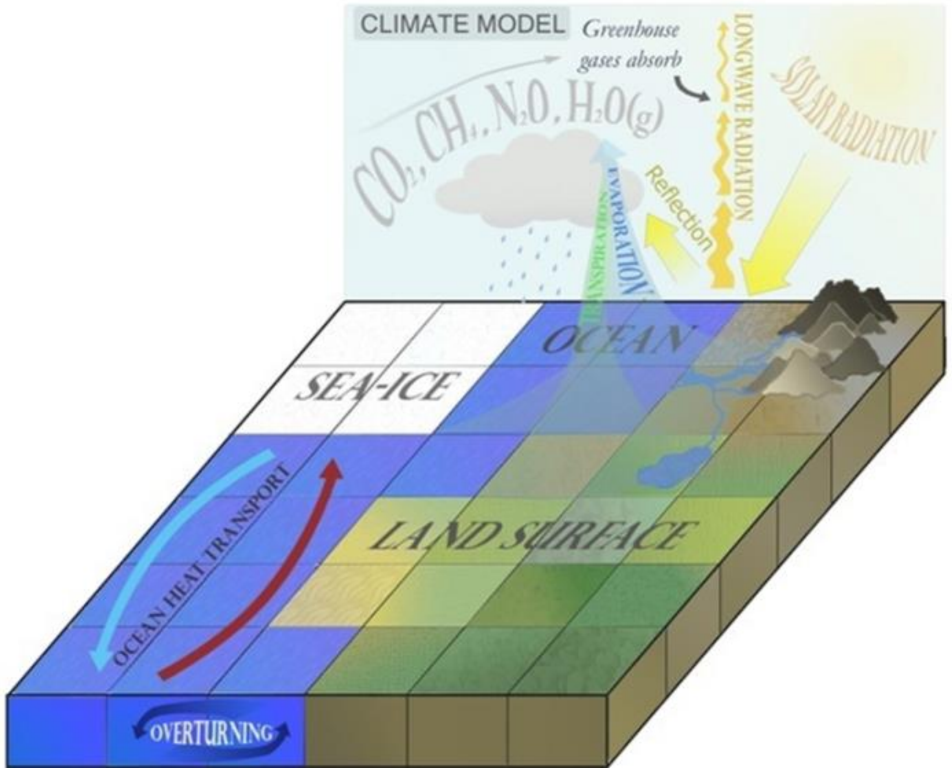
Considered as ‘complete model’.

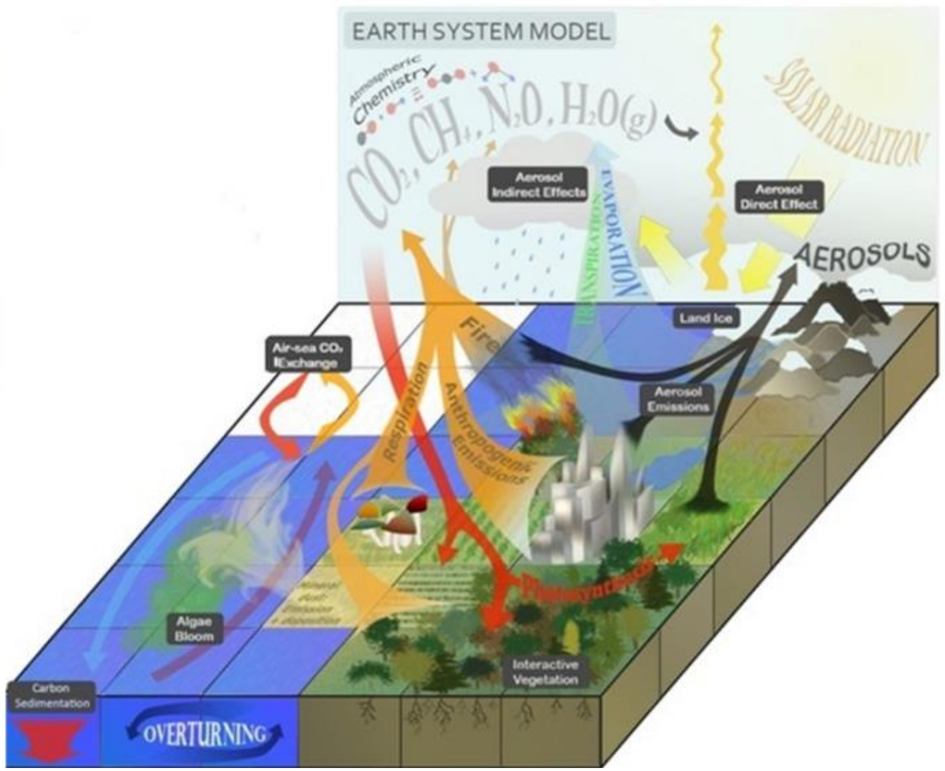
Sets of equations considered in GCM

- Conservation of mass
- Conservation of momentum
- Conservation of energy
- Conservation of water vapor
- Equation of state
- Ideal Gas Law



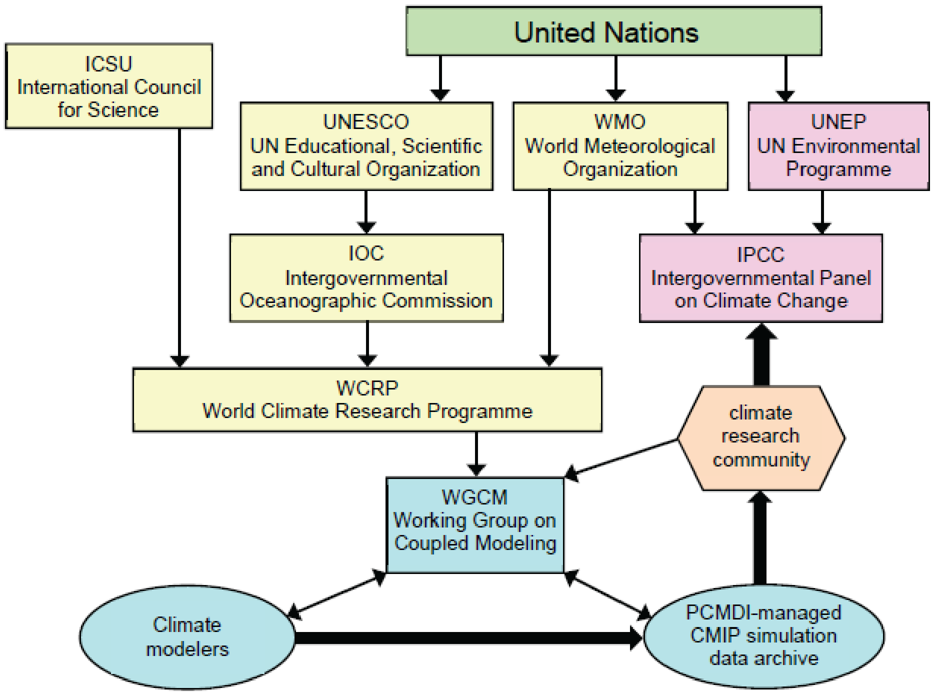
Earth System Model: New Generation Model





What is “CMIP”?

- CMIP: Coupled Model Intercomparison Project
- Established by Working Group on Coupled Modeling (WGCM) under World Climate Research Programme (WCRP)
- Provides community based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access.
- It is an effort and maintained by Program for Climate Model Diagnosis and Intercomparison (PCMDI)
- Funded by the Regional and Global Climate Modeling (RGCM) Program of the Climate and Environment Sciemce Division of the US Department of Energy.

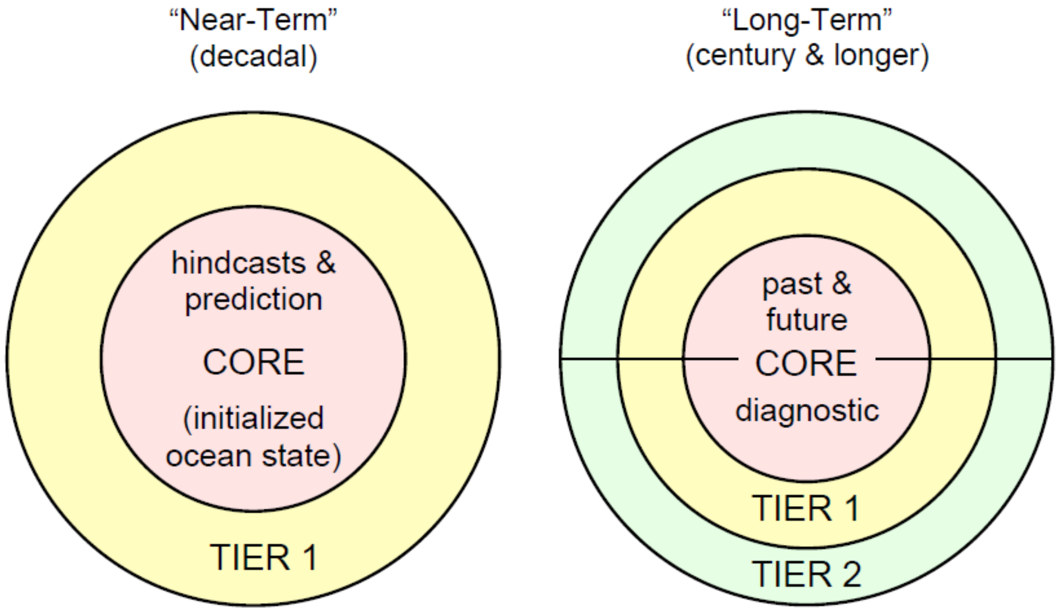


Source: Taylor et al. (2012), BAMS

CMIP5

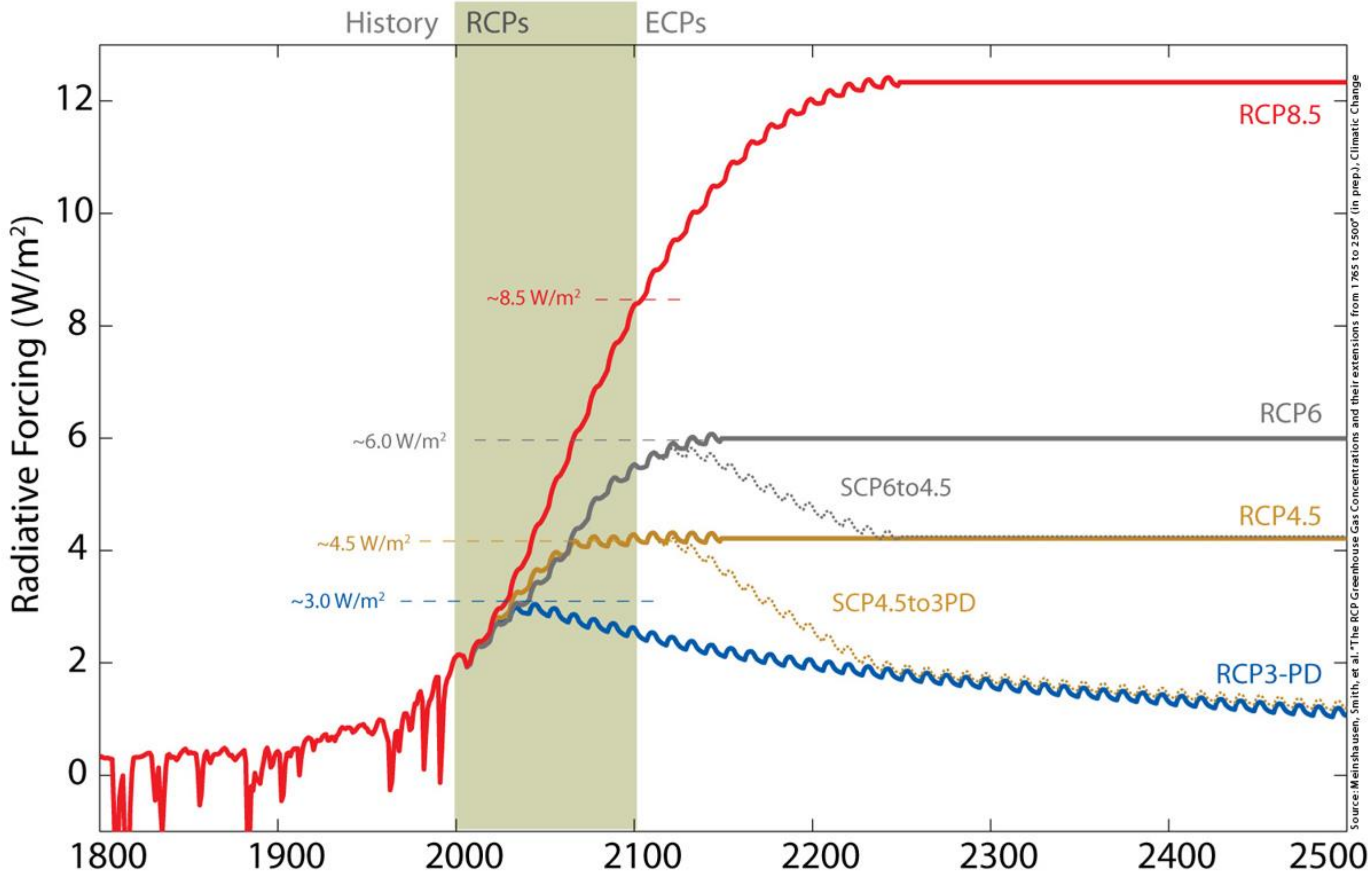
- Objectives
  - Evaluating how realistic the models are in simulating the recent past
  - Provide projections of future climate for near term (till 2035) and long term (2100 and beyond)
  - To understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks
- Projections
  - Decadal
  - Short term
  - Long term

Core, Tier I and Tier II



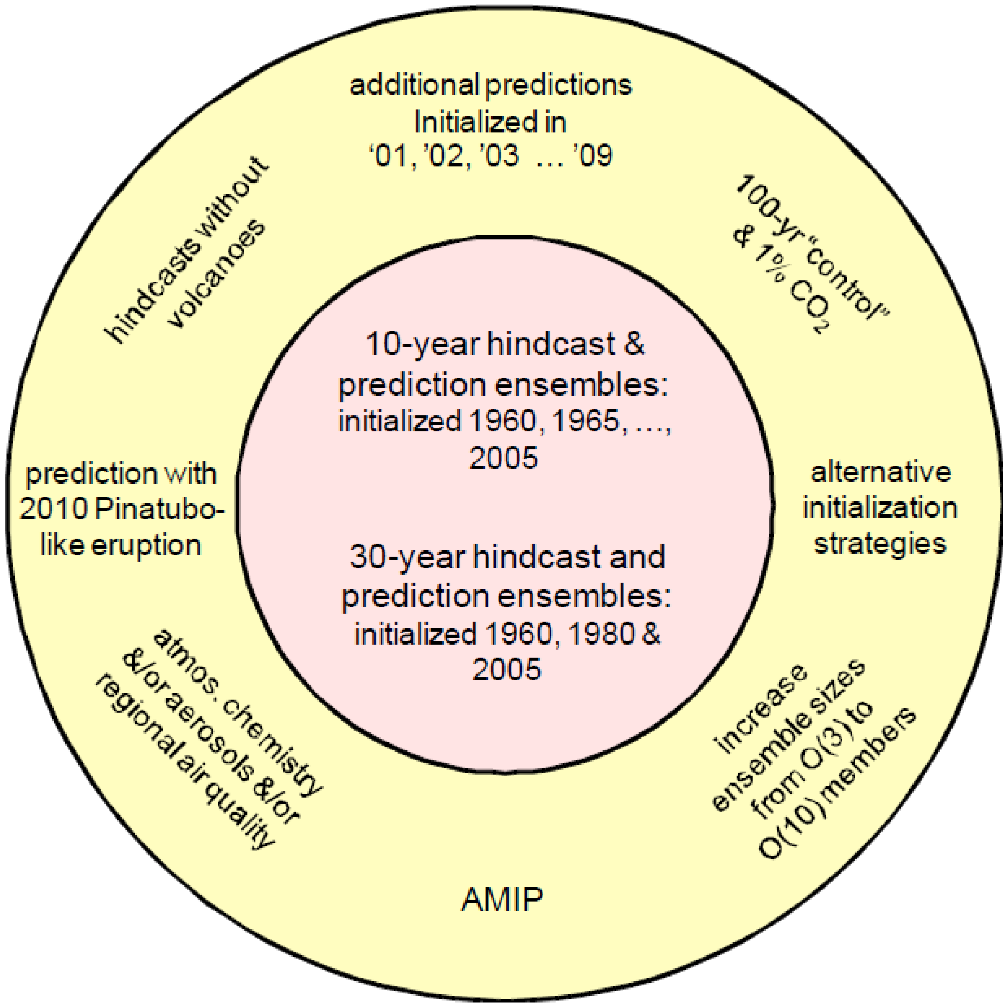
Core: Inter-comparison and producing data set
Tier I: Specific aspects of climate model forcing, response and processes
Tier II: Going deeper into these aspects

RCP and ECP scenarios



Decadal Run

- Initialized with observed oceanic states.
- Questions can be addressed:
    - Can we more accurately predict the actual trajectory of climate by initializing with observed state?
    - Dependence of future state on initial condition
- Runs
    - 10 years run initialized towards the end of 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005
    - 30 years run initialized at the end of 1960, 1980, 2005
- Minimum ensemble run: 3



Short term run

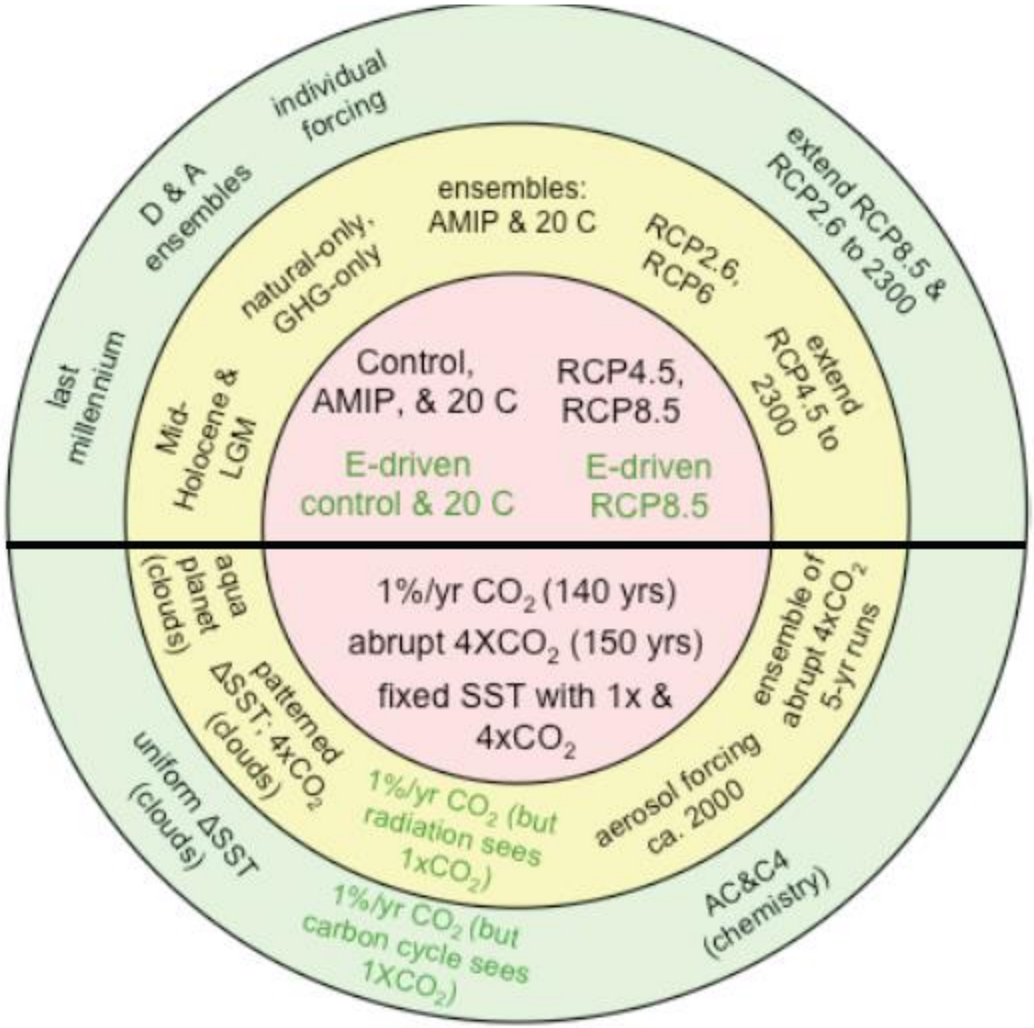
- This is for computationally demanding models (which are impossible to run for multiple centuries)
- Also known as time slice experiments
- Models are run with boundary conditions obtained from the scenarios generated by coupled model (less computationally demanding)
- Explored for
  - High resolution modeling
  - Regional effects of climate change
  - Air quality implications of climate change
  - Changes in extremes

Historical Run

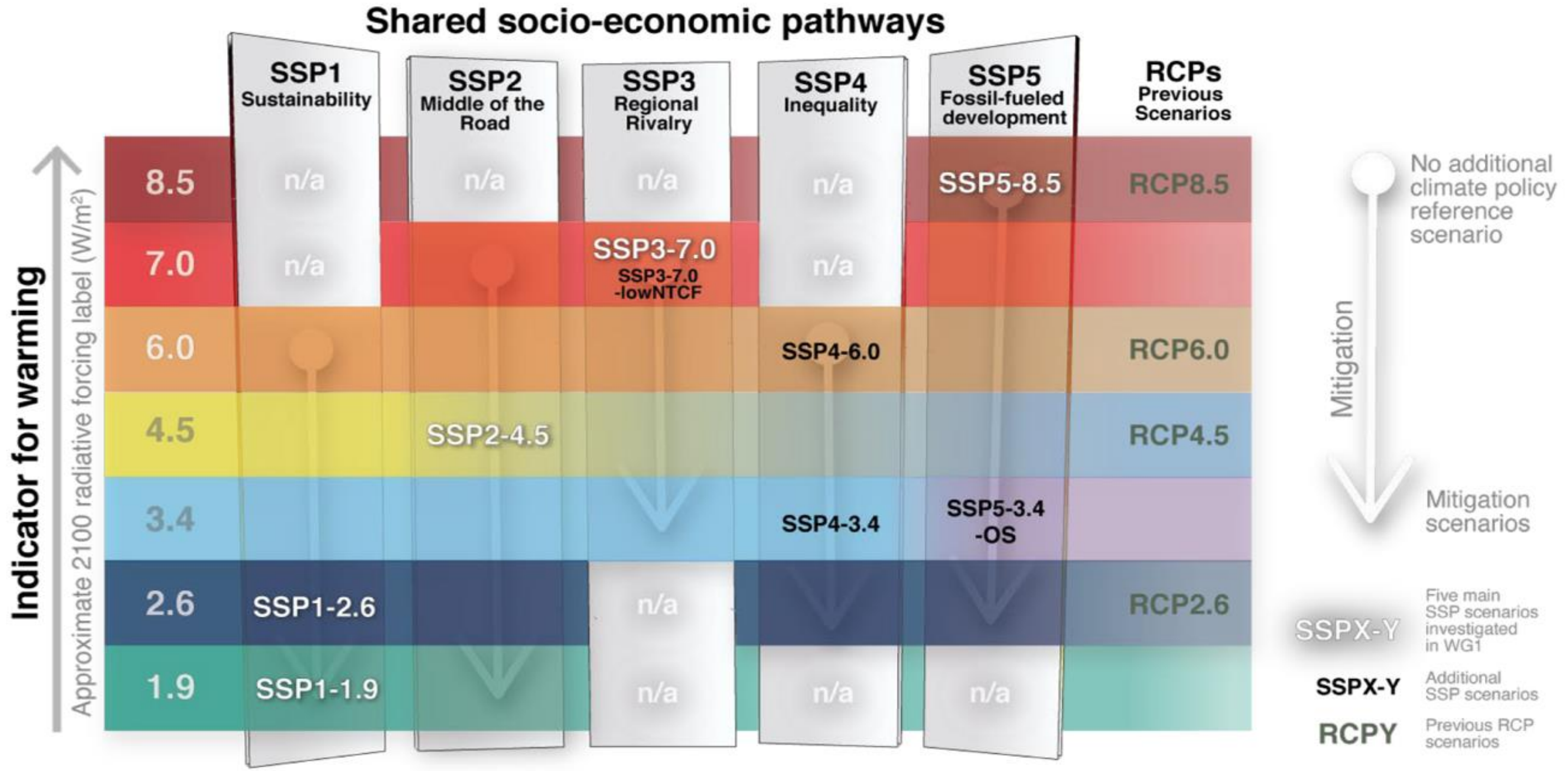
- Baseline simulations for model evaluation
- Duration: 1850-2005
- To evaluate model against present climate and observed climate change
- Provides initial conditions for future scenario experiments
- These runs need initial spin up runs (minimum of 450 years runs) → runs number depends on this
- Notation: rα iβ pγ → r denotes initial condition, i denotes the way initial condition is being posed, and p denotes the physics used; α, β and γ denote corresponding number respectively

Long term run

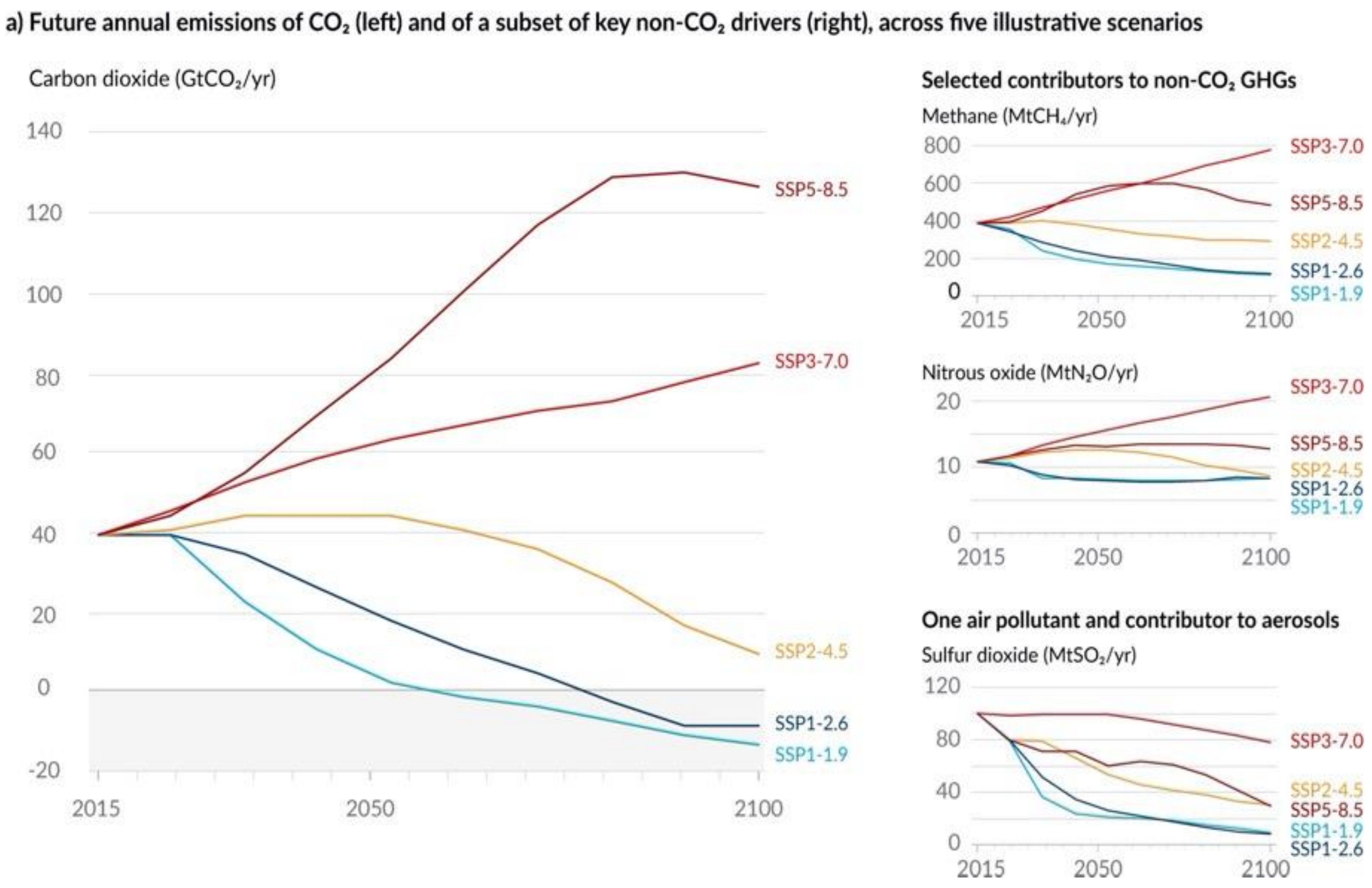
- Minimum duration
  2006-2100
- May be extended till 2300
- As per RCP scenarios



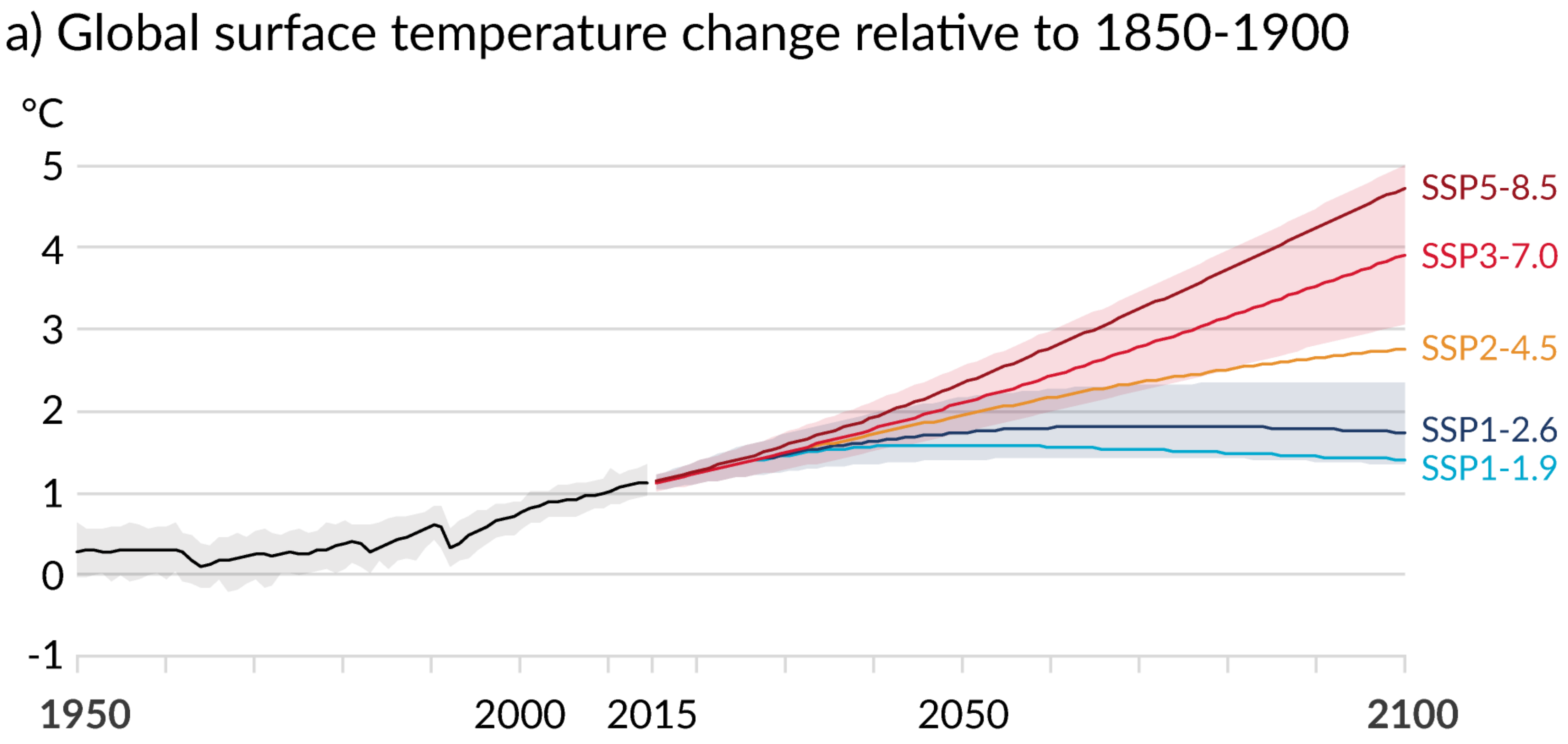
CMIP6: SSP (Shared Socioeconomic Pathways)



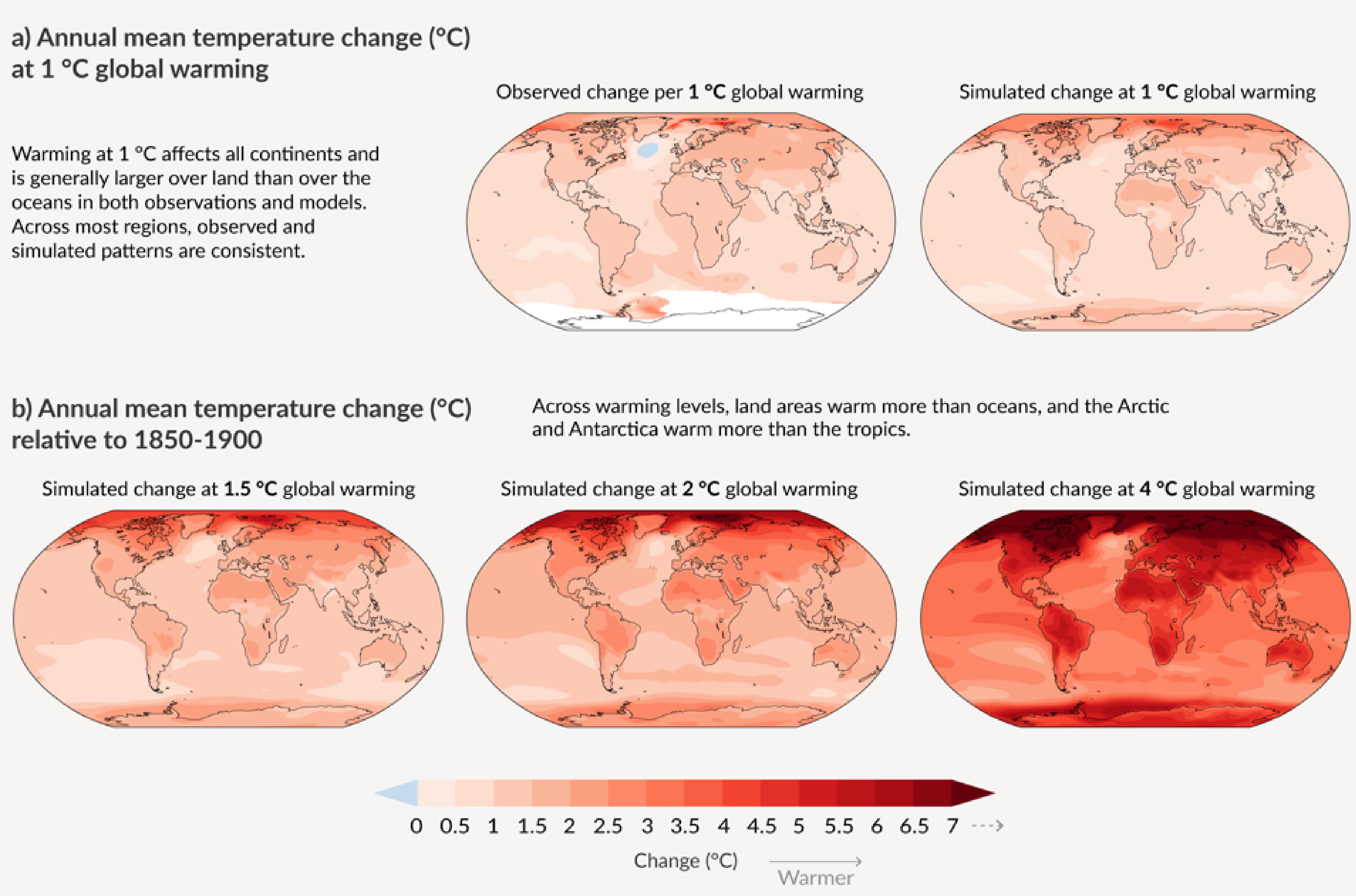
Emissions for Different Scenarios



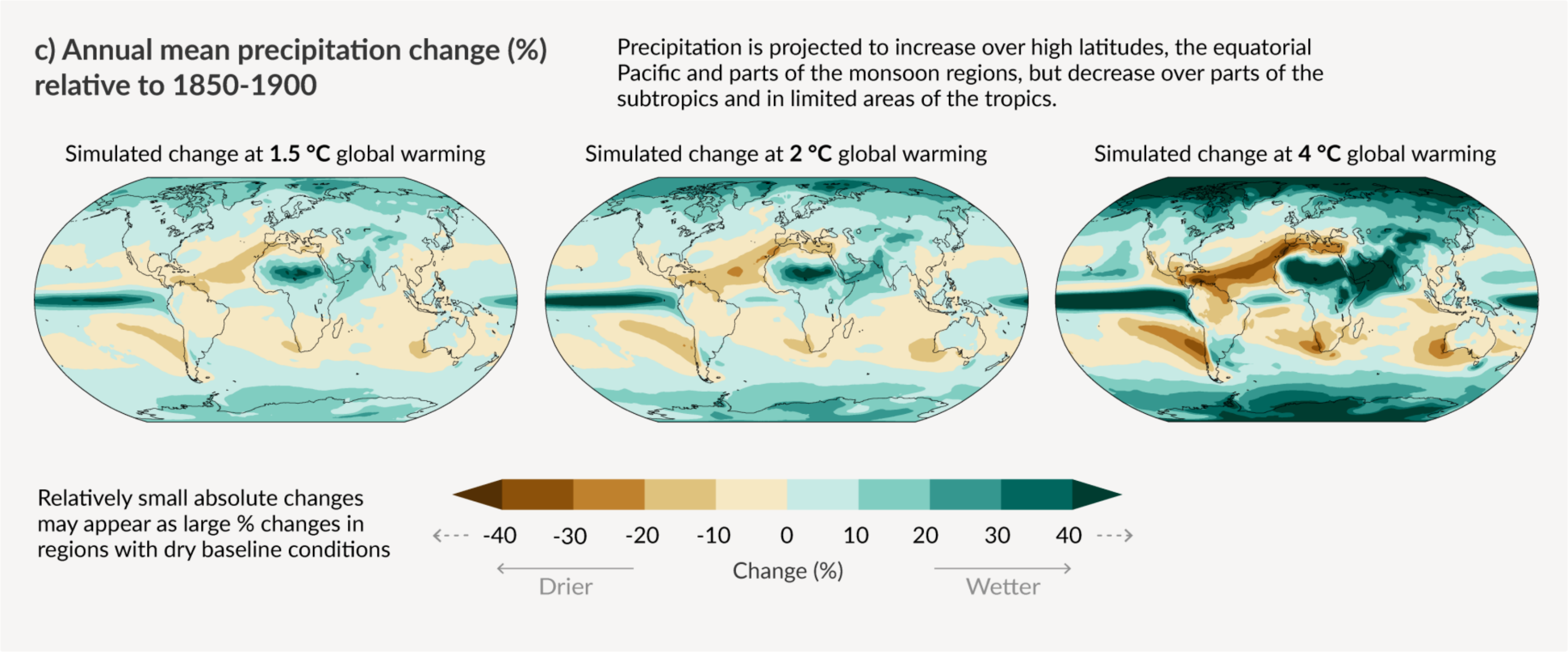
Projected Warming



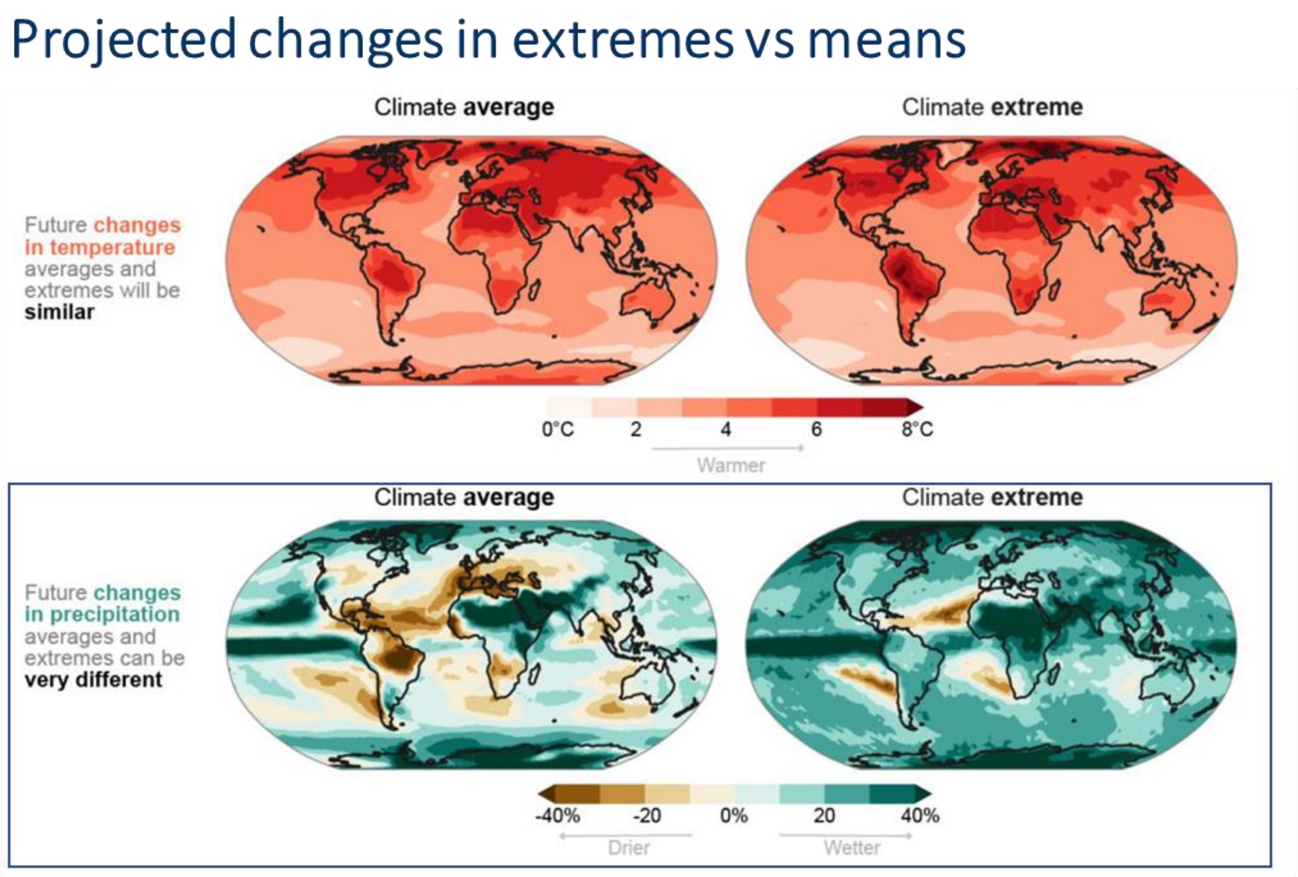
Changes in Regional Temperature



Changes in Regional Precipitation



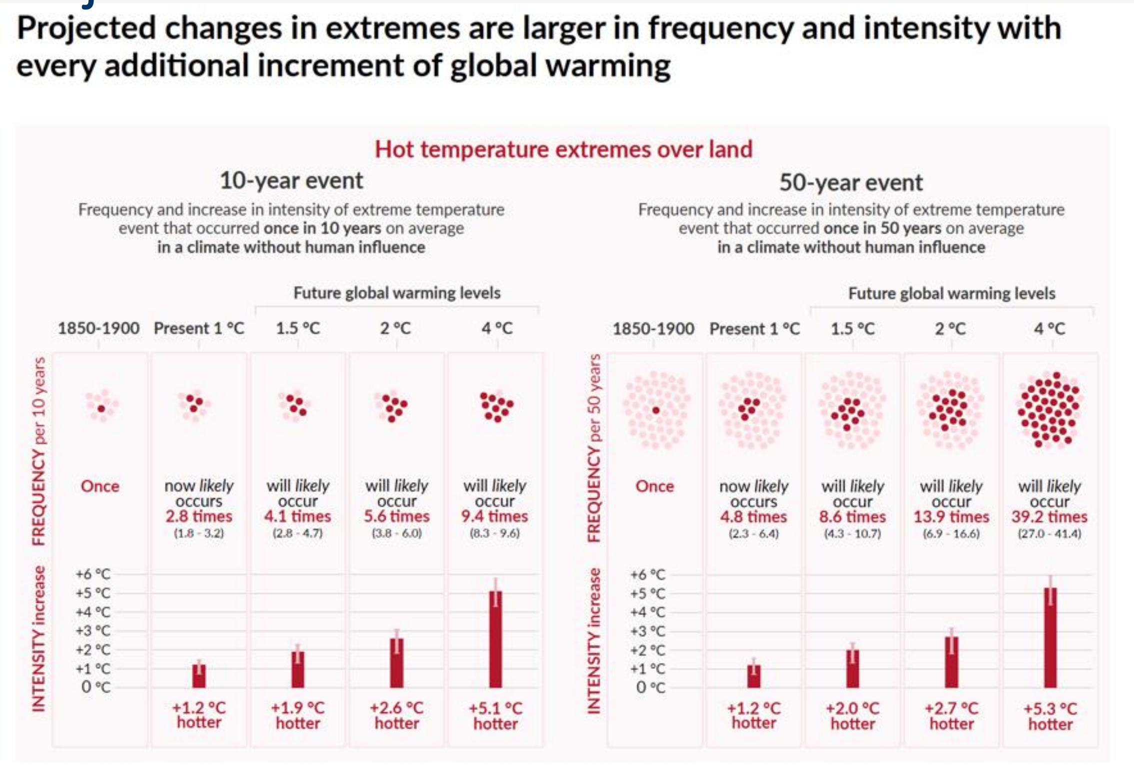
Mean vs Extremes



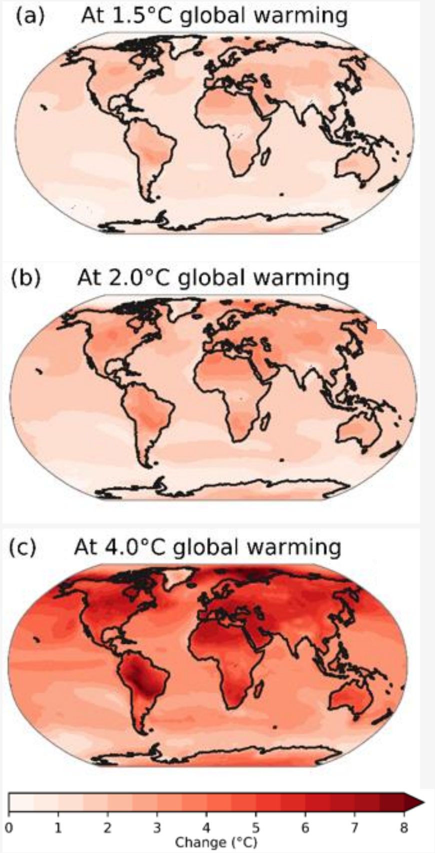
FAQ 11.1 Fig. 1

IPCC AR6

Projected Hot Extremes



Annual maximum temperature



Cross-Chapter Box 11.1 Fig. 3

Every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (*very likely*)

Projected Heavy Precipitation and Drought

Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming

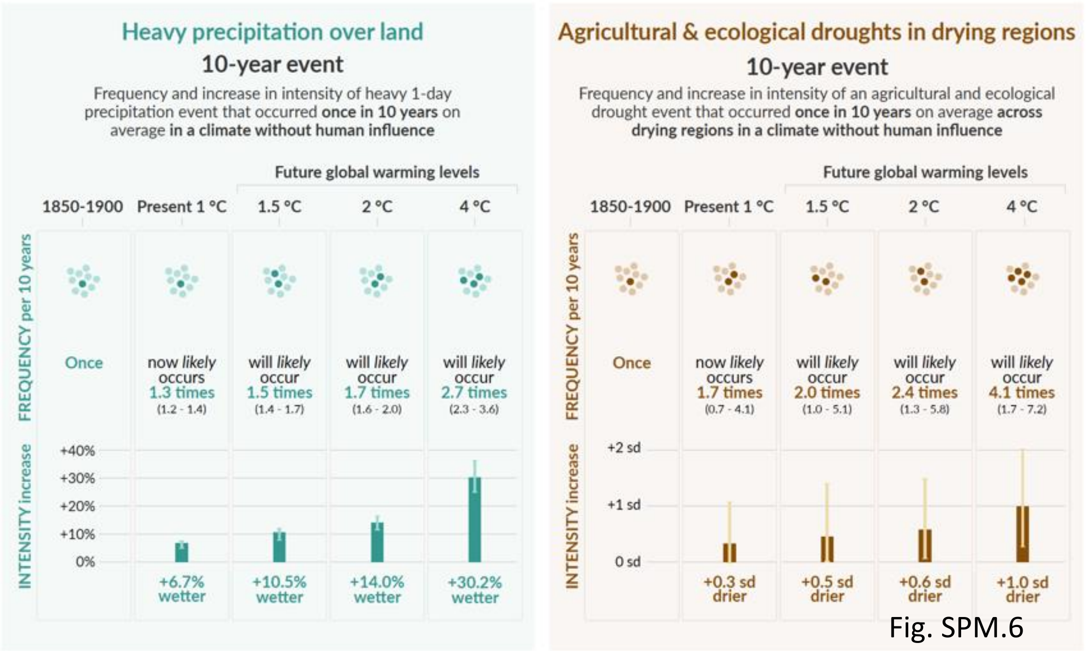
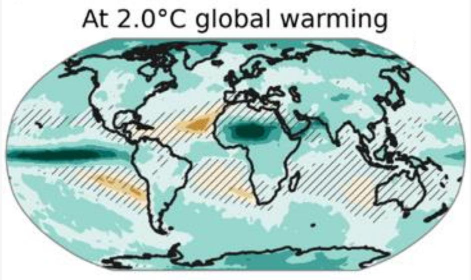
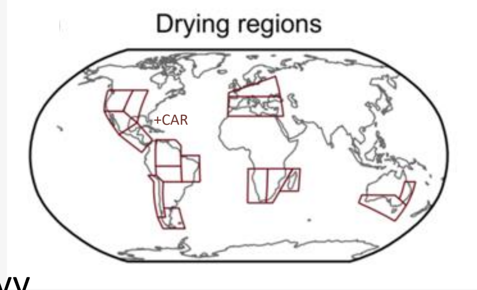


Fig. SPM.6

Annual maximum daily precipitation change (Rx1day)



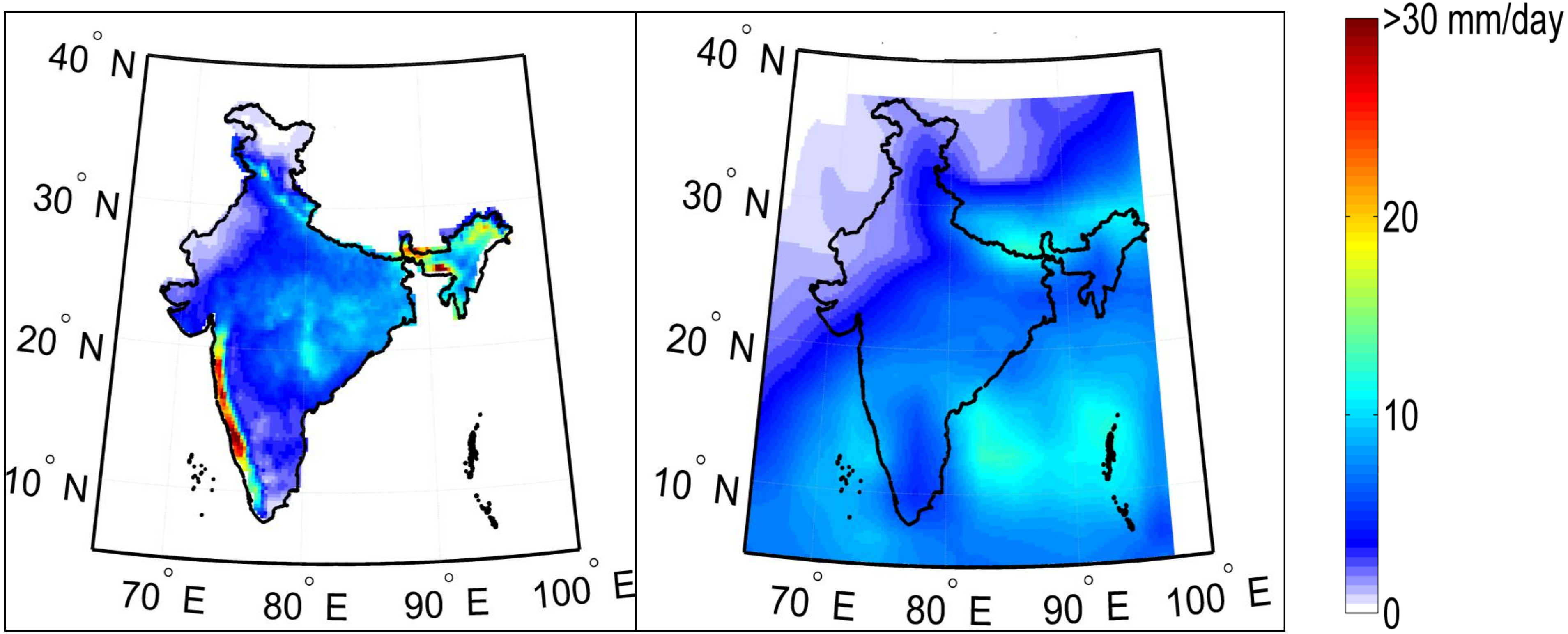
Regions with assessed drying at 2°C of global warming



Every additional 0.5°C of global warming causes clearly discernible increases in heavy precipitation (*high confidence)*, as well as agricultural and ecological droughts in some regions (*high confidence*).

Next: Regional Climate Modeling

GCM Simulations for Indian Monsoon Rainfall



Observed

Simulated

Downscaling

GCM Output

Large Scale Climate Variables

Regional Scale Hydro-meteorologic Variables, e.g., Rainfall in a city

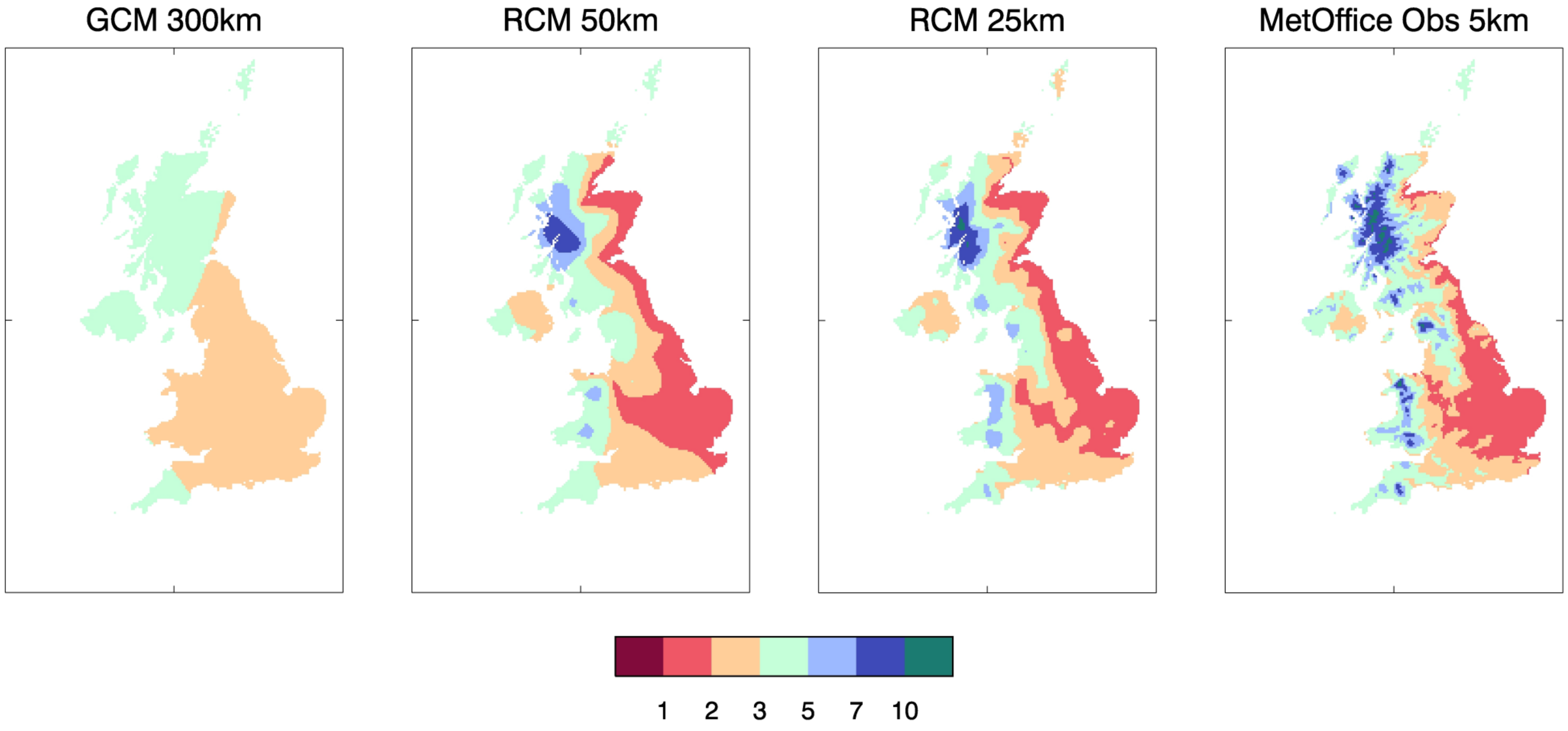
Impacts Assessment

- Drought Analysis
- Agricultural Management
- Water Demand Availability Analysis
- Water Resources Management
- Hydraulic Structure Design
- Ecological Impacts
- Risk and Vulnerability Assessment of Extreme Events

Downscaling

- Statistical Downscaling
- Dynamic Downscaling

Typical Example (UK Winter Precipitation) [Maraun et al., 2010]

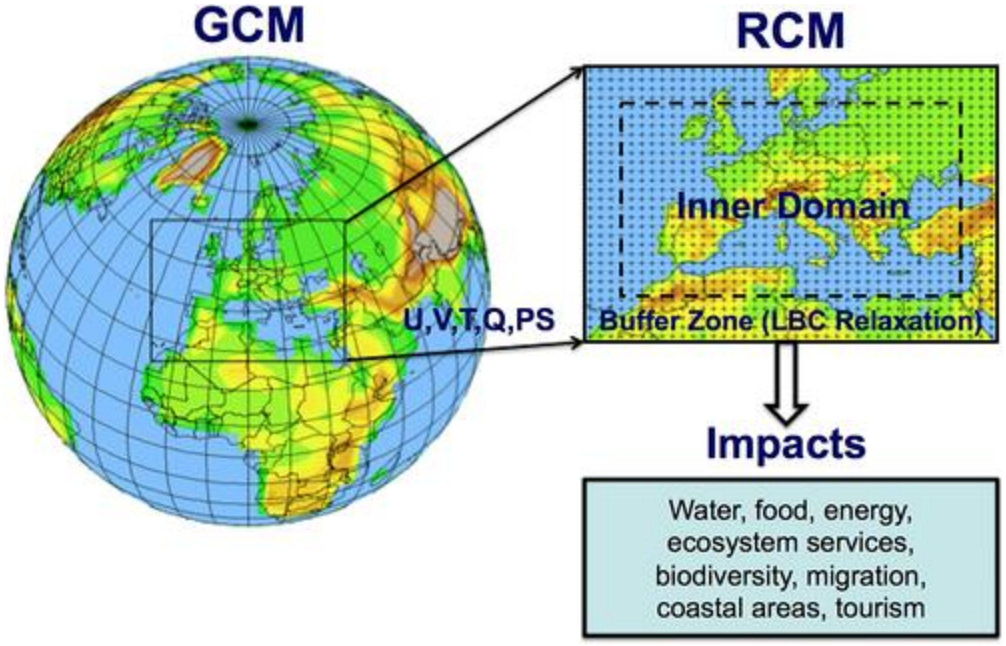


Classification of Downscaling

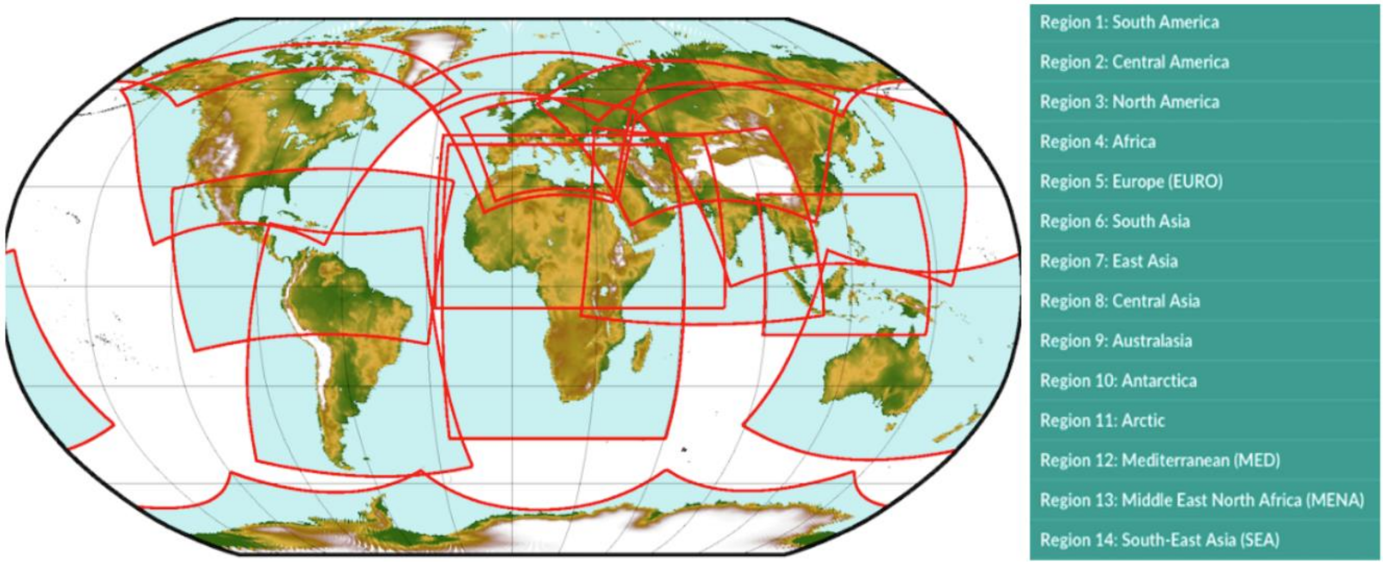
- Dynamic Downscaling
- Statistical Downscaling

Dynamic Downscaling

- Nested Gridding
- GCM outputs work as boundary condition
- Uses physics based equation
- Computationally expensive
- Models used:
  - WRF
  - RegCM



CORDEX



Statistical Downscaling

- Data Driven Approach
- Computationally in-expensive
- Based on relationship between large scale climate variables and local scale desired variables
- Basic Assumption: this statistical relationship will not change in altered condition

Statistical Downscaling

- Philosophy:
  - GCMs can not simulate rainfall very well as rainfall is a regional scale phenomena
  - But GCMs simulate well some of the large scale variables, which affects rainfall.
  - Those large scale variables: Predictor
  - Rainfall: Predictand
  - Derive and apply the relationship between predictor and predictand

Steps in Statistical Downscaling

- Deriving relationship between predictor and predictand
- Apply the relationship to the GCM simulated predictors to project predictand

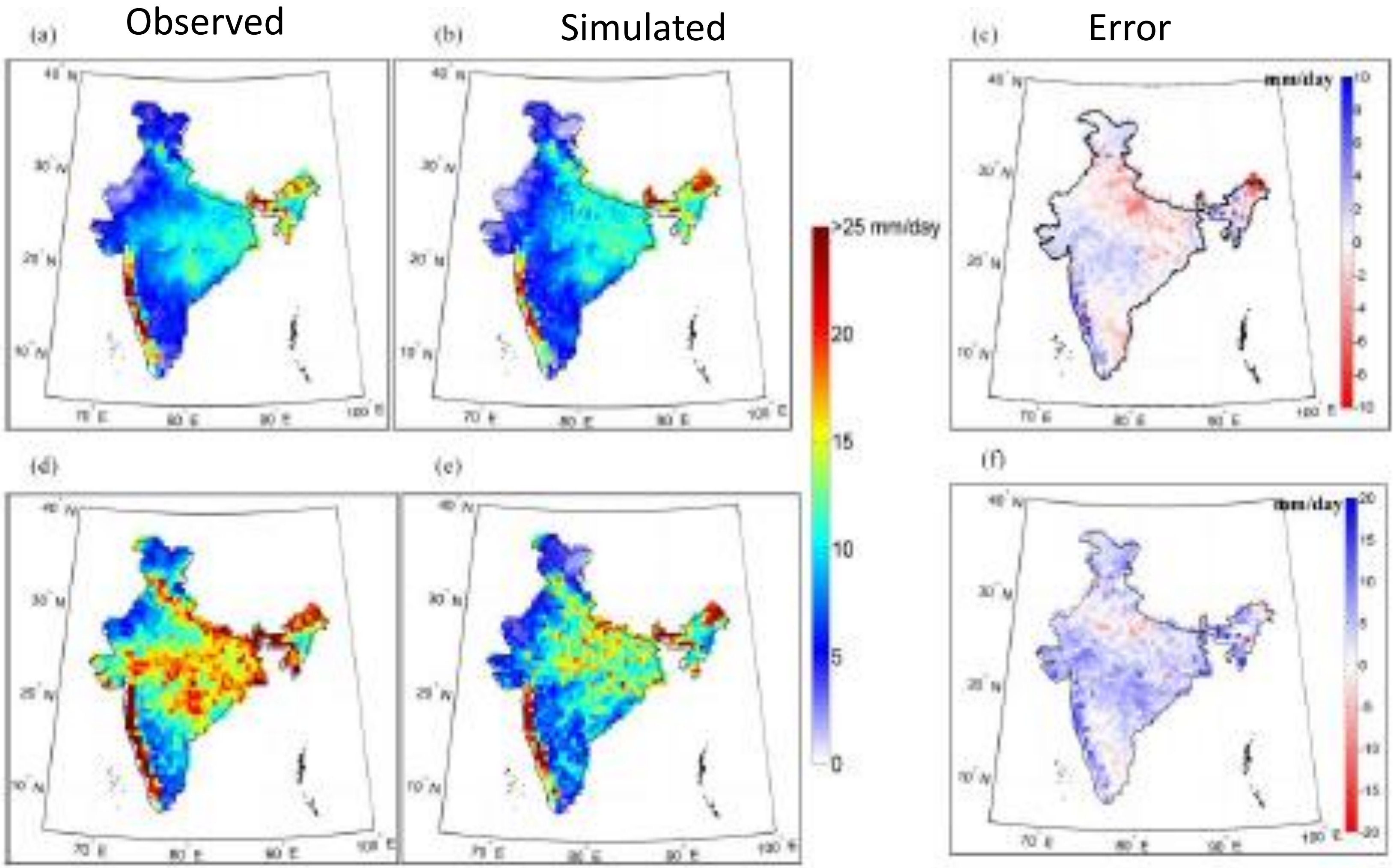
Deriving Statistical Relationship

- Data needed: Observed predictors and predictand
- Observed large scale climate variables: mostly not available
- Proxy data: NCEP/ NCAR reanalysis data OR ERA-40 reanalysis data

Applying to GCM outputs

- Grids of GCM outputs → not same as reanalysis grids
- Re-gridding : may be with interpolation
- GCM outputs: systematic difference with respect to observed/ reanalysis data
- Bias: systematic difference
- Bias needs to be removed: Standardization OR Quantile tranformation

Mean and Standard deviation of simulated data



Thank You