Overview of climate modelling and approaches to downscaling

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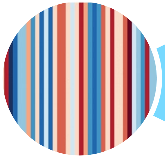
Spatial and temporal climate change analysis using CORDEX regional climate models over South Asia

7 March 2022 | Online via Microsoft Teams

Outline

- Briefly explain how climate models work



- Introduce downscaling approaches and their key assumptions

- Outline an approach to regional climate model evaluation

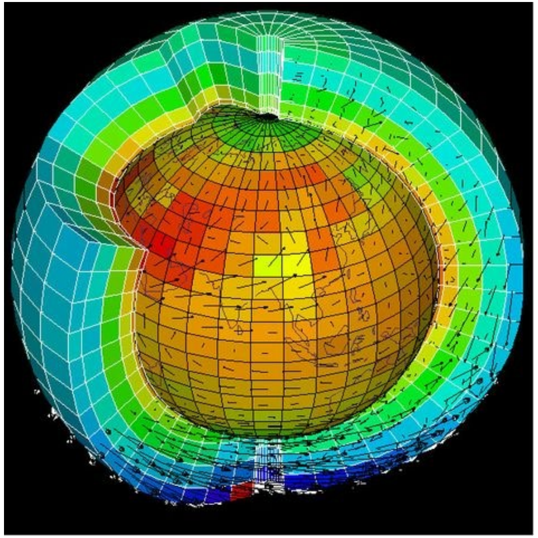
What is a climate model?

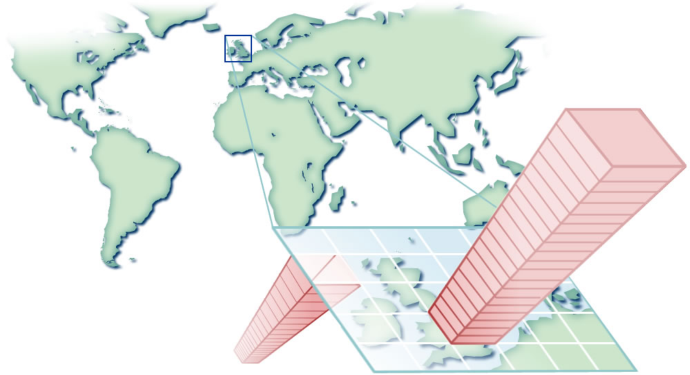
"A **numerical representation** of the **climate system** that is **based on the physical, chemical, and biological properties**" (IPCC AR5 2013)

https://www.youtube.com/watch?v=Pn3ZKB1XLiQ&feature=emb_title

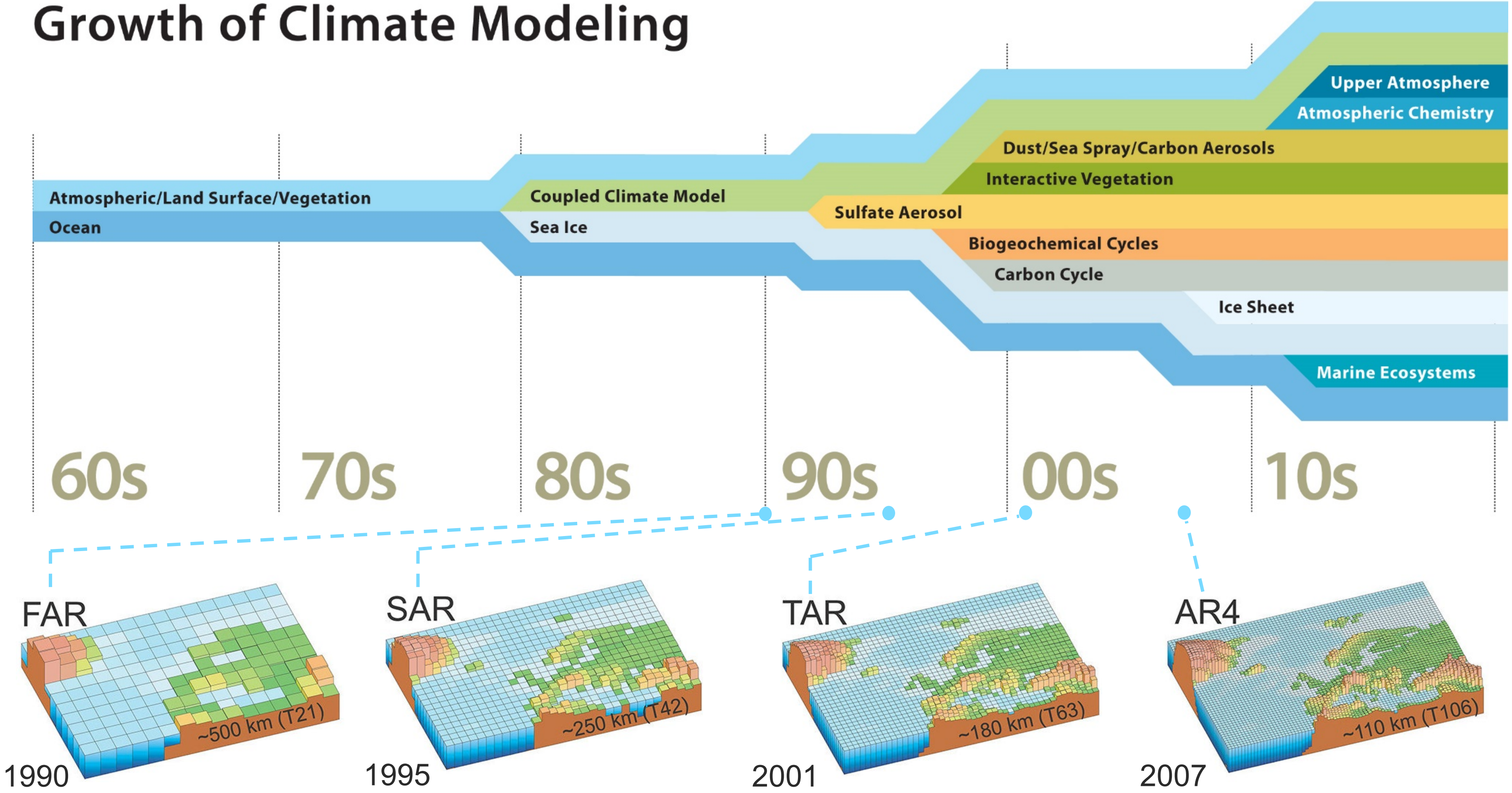
GCMs

- Global Climate or General Circulation Models
- Have resolutions typically 100-300km
- Many different GCMs are run by modelling centres all over the world
- These are compared during the different stages of the Coupled Model Intercomparison Project (CMIP) to support national and international climate change assessments



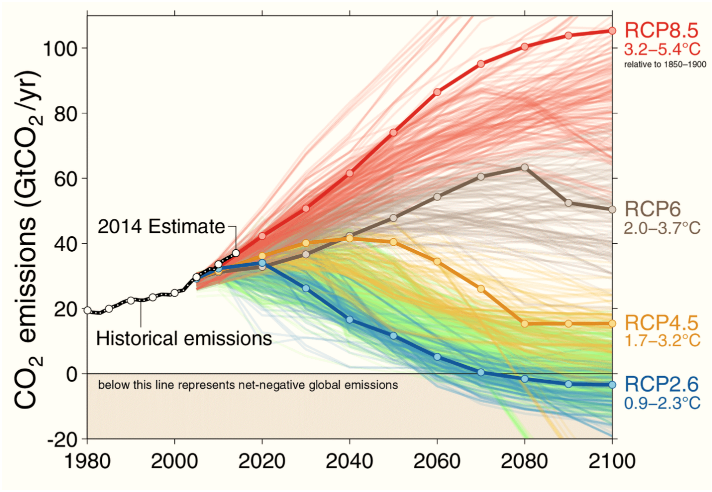


Growth of Climate Modeling

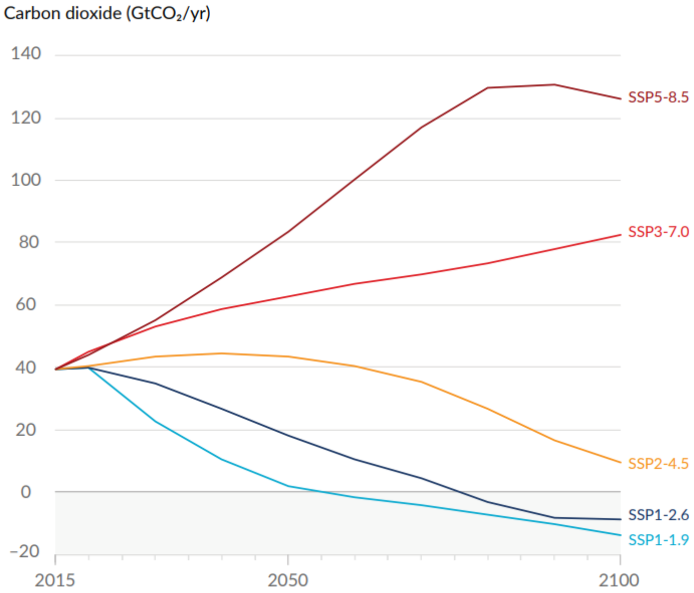


Future socio-economic pathways

IPCC AR5



IPCC AR6



RCPs (Representative Concentration Pathways) provide the end of century net **climate forcing**.

SSPs (Shared Socioeconomic Pathways) explore **socio-economic** changes (e.g. population, energy demand, etc)

each SSP is consistent with a range of RCPs

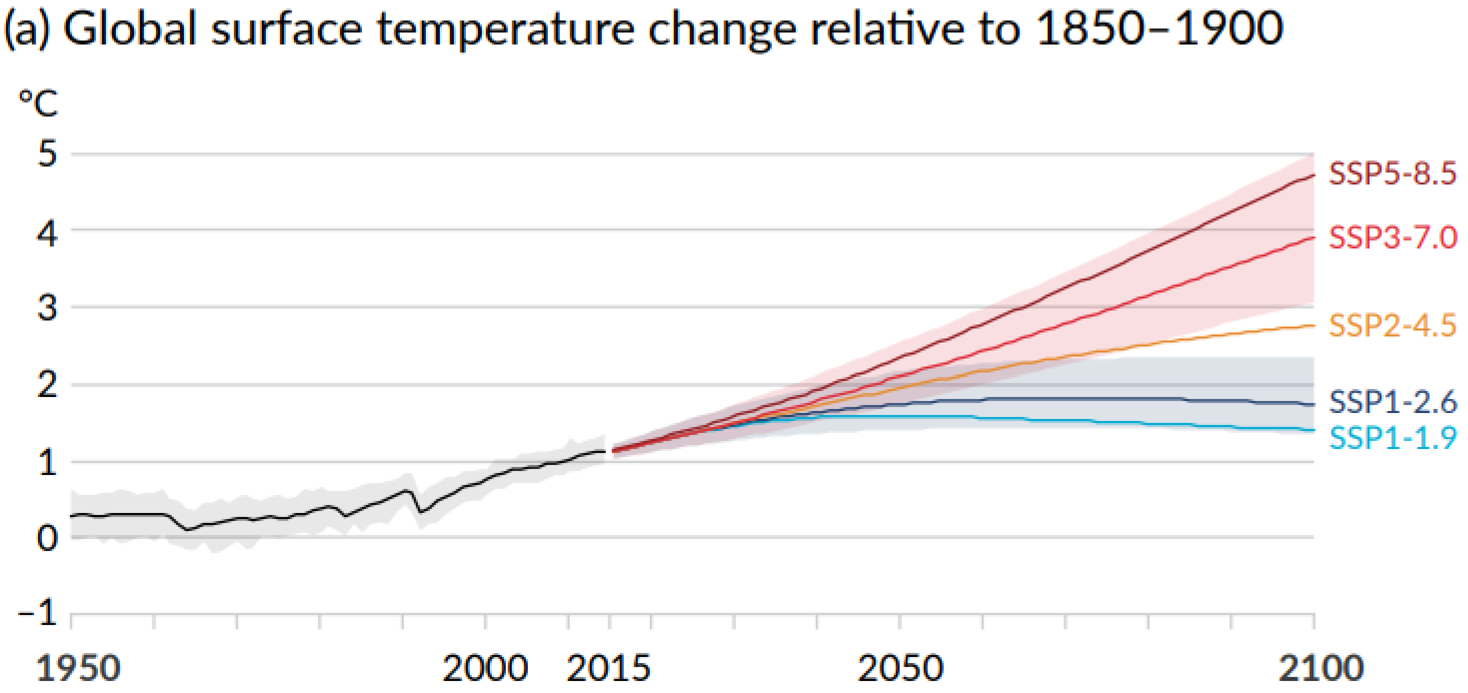


Figure SPM.8a – IPCC AR6

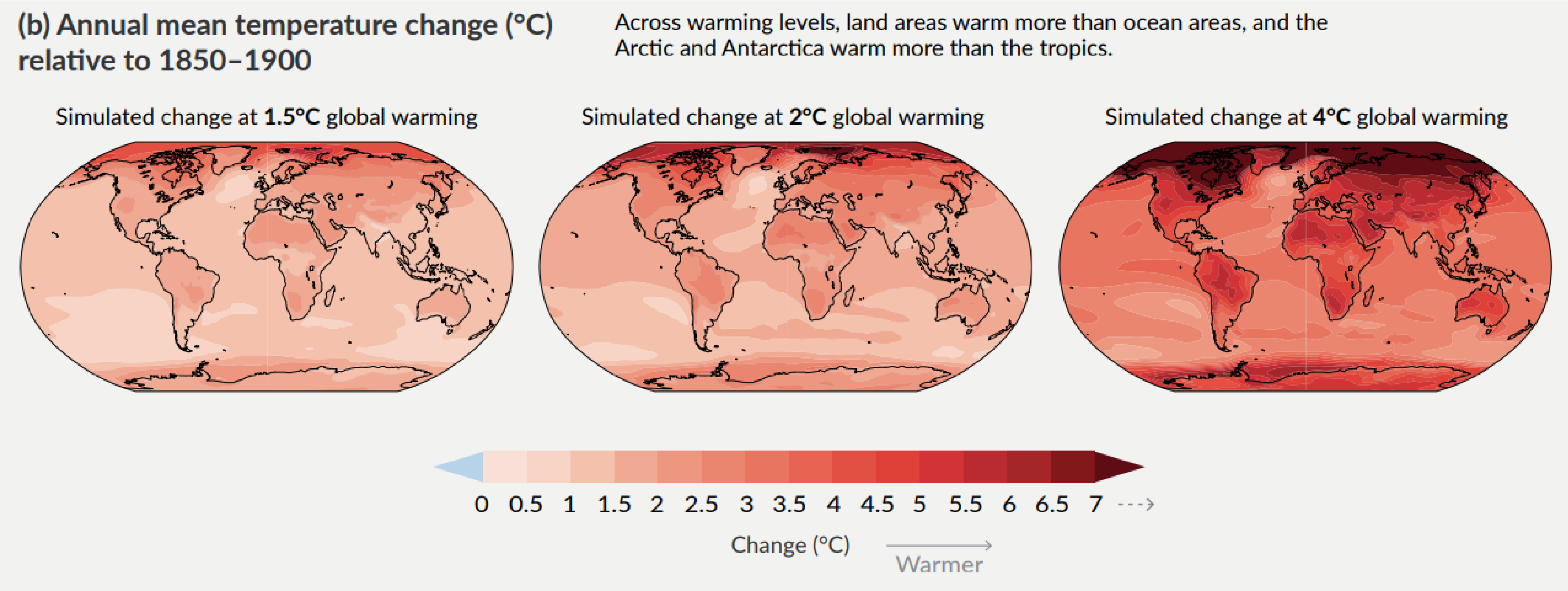


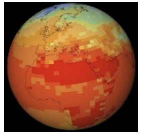
Figure SPM.5b – IPCC AR6

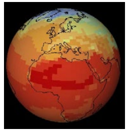
Sources and relative importance of uncertainties

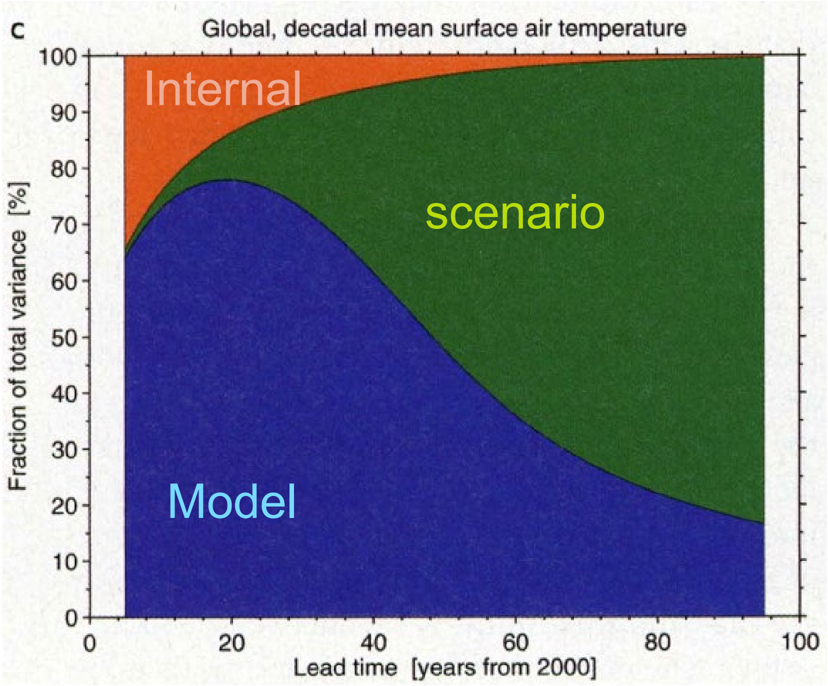
Internal climate variability

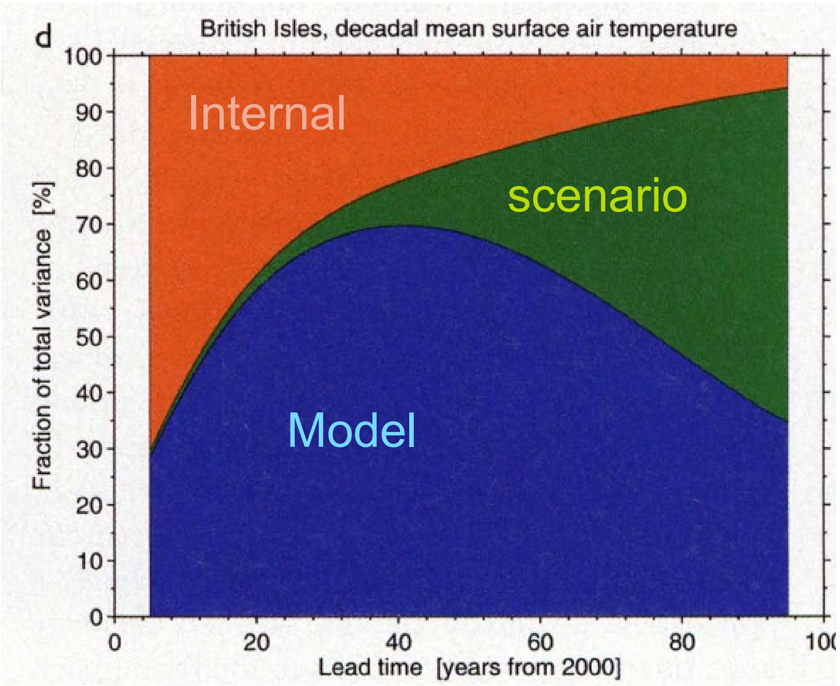
Greenhouse gas scenarios

Model spread









Hawkins and Sutton, 2009

Climate model downscaling

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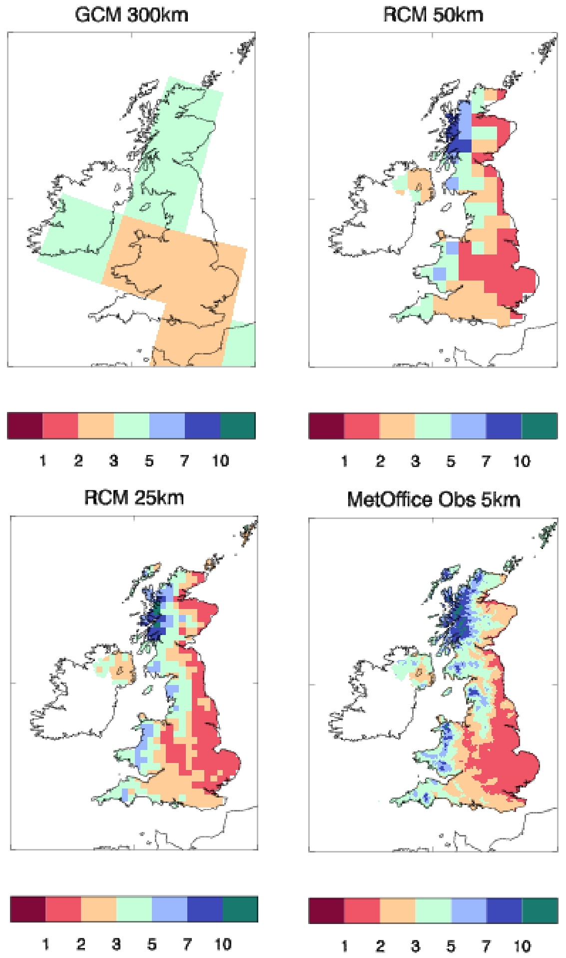
Why downscale?

High-resolution global scale simulations are expensive to run. Downscaling over a region enables:

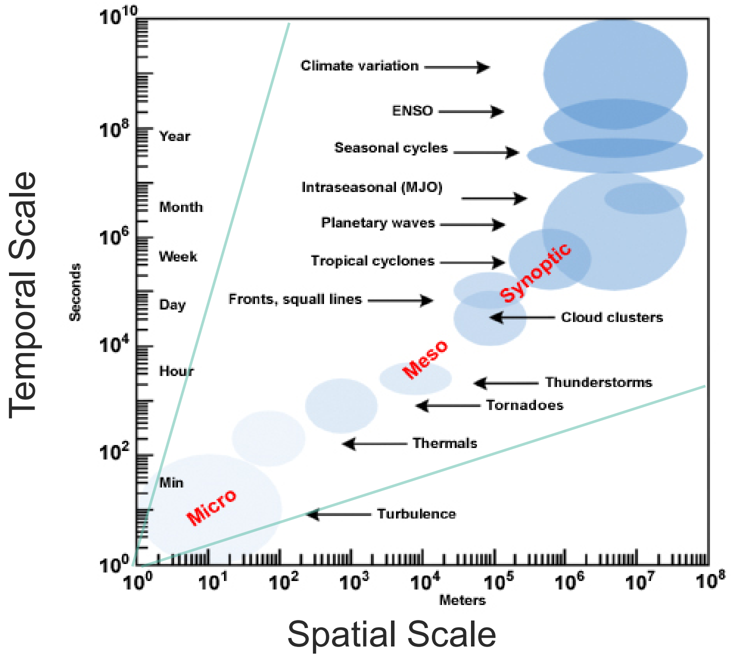
1. More spatial detail to resolve smaller scale climate processes and physical factors (e.g., mountains) and better represent local scale climate conditions

2. More spatial detail to inform understanding of climate change impacts at regional and local scale for use in climate change adaptation planning and policy



Coarse spatial resolution is not the only problem

- At typical resolutions, GCMs can skilfully resolve large weather systems – systems at the synoptic scale.
- These systems have a lifetime of several days.
- Shorter time scales and details of these systems requires higher horizontal resolutions – systems at the meso scale.



Downscaling techniques

100-300km

Coarse atmospheric data (T, Q, winds, pressure etc)

Statistical

Statistical relationship between large- and local- scale. Derived from present / historical climate.

$$fine\ scale\ value = \emptyset(large\ scale\ variable)$$

Dynamical

Numerical models at fine resolution over region of interest.

Feeds in output from GCM into a Regional Climate Model (RCM).

OR

Stretch-grid global models, with higher resolution over area of interest

50km-1km

Local surface data (T, rainfall, winds, Q etc)

Regional climate modelling

What is an RCM?

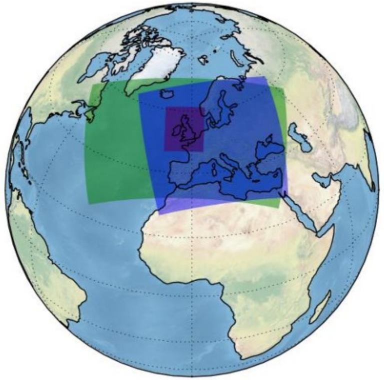
- An RCM is:

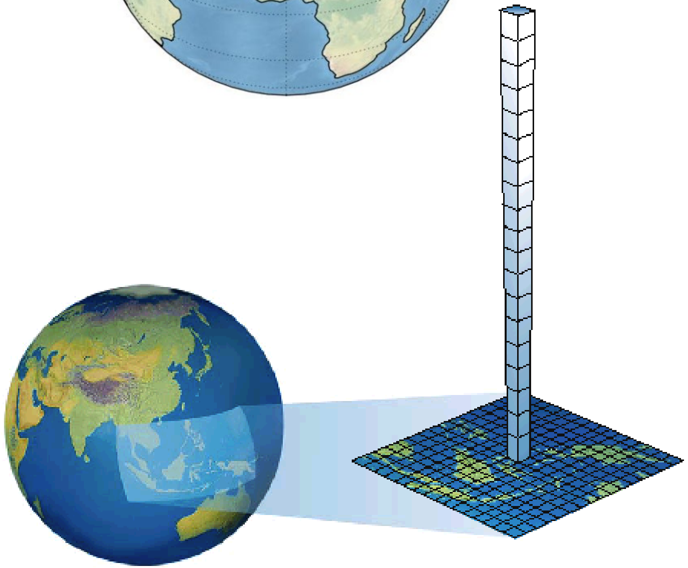
  - a **Limited Area Model (LAM)** similar to those used in Numerical Weather Prediction (NWP) i.e. short-term weather forecasting

  - a physically-based high resolution model
    - Includes atmosphere and land surface components
    - Contains representation of important processes

  - one-way nested: driven at boundaries by GCM or observed data

  - highly dependent on boundary conditions



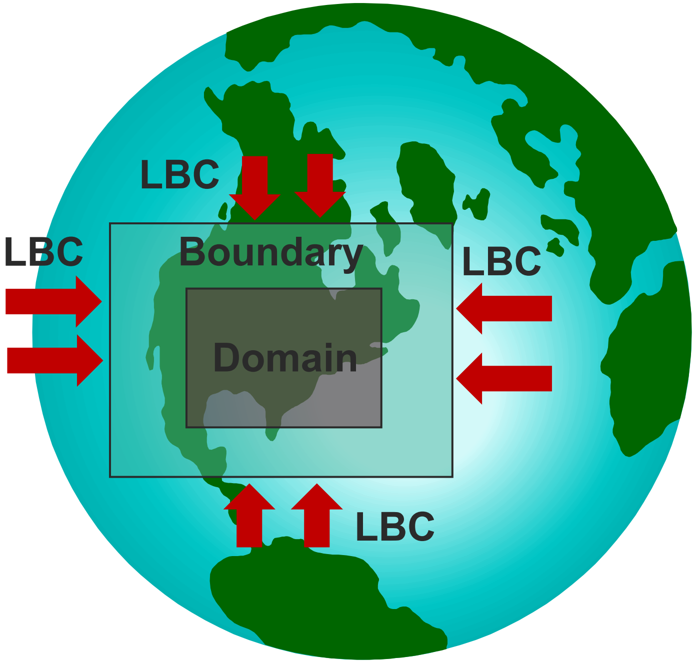


Lateral Boundary Conditions (LBCs)

What are LBCs?
- Meteorological boundary conditions at the lateral (side) boundaries of the RCM domain (time dependent large scale data)
- E.g. Wind, Temperature, Water, Pressure, Aerosols

Why are LBCs important?
- Constrain the RCM throughout the simulations
- Provide the information the RCM needs from outside the domain

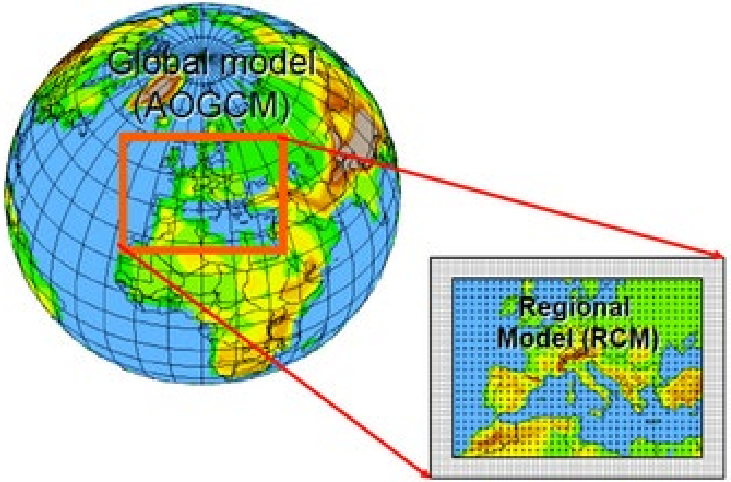
Where to LBCs come from?
- GCMs
- reanalysis



Choice of domain and simulation length

Optimum domains:

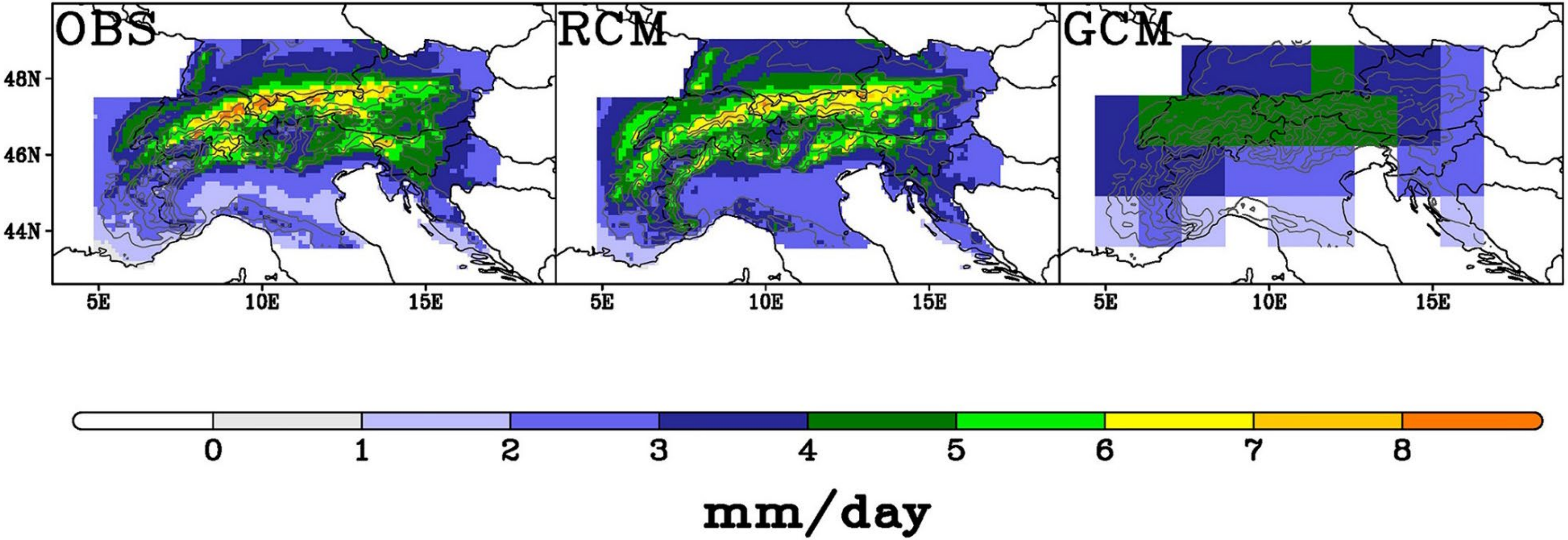
- Not too large or small.
  - Continental scale (5000km x 5000km)
  - Smaller domains: no mesoscale features
  - Larger domains: lose consistency with large scale atmospheric flow
- Will complete in a reasonable amount of time
- Typically have the area of interest in the domain centre
- Encompass important climatological influences



Optimum simulation length:

- Longer periods are better
- 30 years or more to study higher order statistics, climate variability, extremes, etc
- Multi-annual mode of variability (e.g ENSO) should also be considered

Added value of RCMs



Simulation of summer precipitation over the Alpine region in the study of Torma et al. (2015). (left) Observations (Isotta et al., 2014); (middle) RCM ensemble (~ 12-km grid spacing); (right) GCM ensemble (~ 150-km grid spacing). Simulation period is 1975–2004. The figure is adapted from the data of Torma et al. (2015). Reproduced from Giorgi 2019.

Model Evaluation

What is a model evaluation?

An assessment of **how well** the model is able to **simulate the “present day**” climate

For a climate model, it is difficult to define an overall skill score for long-term projections. Each model tends to simulate some aspects of the climate system well and others not so well, and each model has its own set of strengths and weaknesses.

We do not need a perfect model, just one that serves the purpose

Why is it important?

- It enables you to gain **familiarity** with the model characteristics
- It indicates **which aspects** of the model simulation **are most credible**
- …and therefore indicates how to make the best, most credible**, use of the data** to answer relevant questions

The model evaluation process:

Stages of model evaluation:

1) Identify target and purpose
2) Obtain multiple sources of observed data
3) Assess errors and biases in the GCM
4) Evaluate RCM

1) Identify the target and **purpose of the evaluation**

2) **Obtain multiple sources of observed data** to evaluate model performance

3) **Assess the errors and biases in the GCMs** that provide the LBCs for the RCM

4) **Evaluate the RCM** acknowledging the multiple sources of uncertainty

   (splits into 3 types of RCM evaluation)

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Stages of model evaluation:

1) Identify target and purpose

2) Obtain multiple sources of observed data

3) Assess errors and biases in the GCM

4) Evaluate RCM

Which aspects of the climate system are of most interest?

- Which processes are key to understanding climate variability/change in the focus region?
- Which variables are of most interest?

Which time and space scales are of most interest?

- Extreme or rare events, or multi-year averages?
- Does the model need to provide accurate data at a specific spatial scale?

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Choice of observed data

Stages of model evaluation:

1) Identify target and purpose
2) Obtain multiple sources of observed data
3) Assess errors and biases in the GCM
4) Evaluate RCM

- Use as many relevant observed datasets as possible.
- Ensure you're comparing 'like for like' data.

Gridded datasets

- Observed datasets – e.g. CRU (land surface), TRMM (satellite rainfall), GPCP (merged rain gauge and satellite rainfall)
- Reanalysis data – e.g. ERA-5

Station data

- It can be useful to compare directly to model output but be aware of differences in spatial scales; ultimately one would not expect the data to match.

Assess the GCM data that provides the LBCs

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Stages of model evaluation:

1) Identify target and purpose
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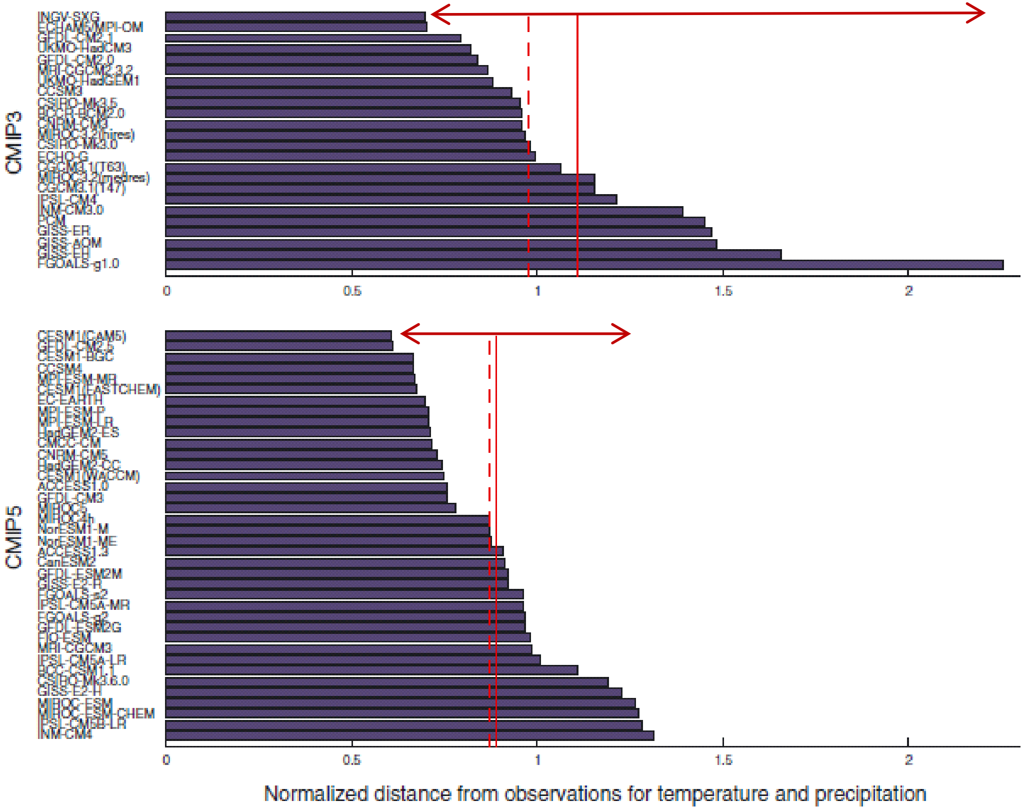

There is a general improvement in GCM/observations comparison over time

Three potential RCM comparisons:

Stages of model evaluation:

1) Identify target and purpose
2) Obtain multiple sources of observed data
3) Assess errors and biases in the GCM
4) Evaluate RCM

1) RCM (driven by reanalysis) versus Observations

2) RCM (driven by GCM) versus Observations

3) RCM (driven by GCM) versus GCM

Having evaluated the RCM output…

- Is it appropriate to use the simulated future climate output?
- For what scales, variables and types of questions is the model output able to provide “useful” information?

Giorgi 2019 “Thirty Years of Regional Climate Modeling: Where Are We and Where Are We Going next?” JGR Atmospheres

Future directions in RCM research include:

1. Transition to convection-permitting modeling systems
2. Further development of Regional Earth System Models including the human component
3. Next phase of the Coordinated Regional Climate Downscaling Experiment project
4. Use of RCMs in the distillation of actionable information for climate services

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Summary

Global climate models (GCMs) can be downscaled to obtain fine-scale climate information

- Statistical or dynamical downscaling
- RCMs can add more information relevant to studying climate impacts

RCM evaluation is important because:

- It enables familiarisation with the model and its projected output;
- An evaluation provides a baseline for assessing the credibility of future projections from RCMs, which has implications for how the output can and should be used.

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Thank you for listening.