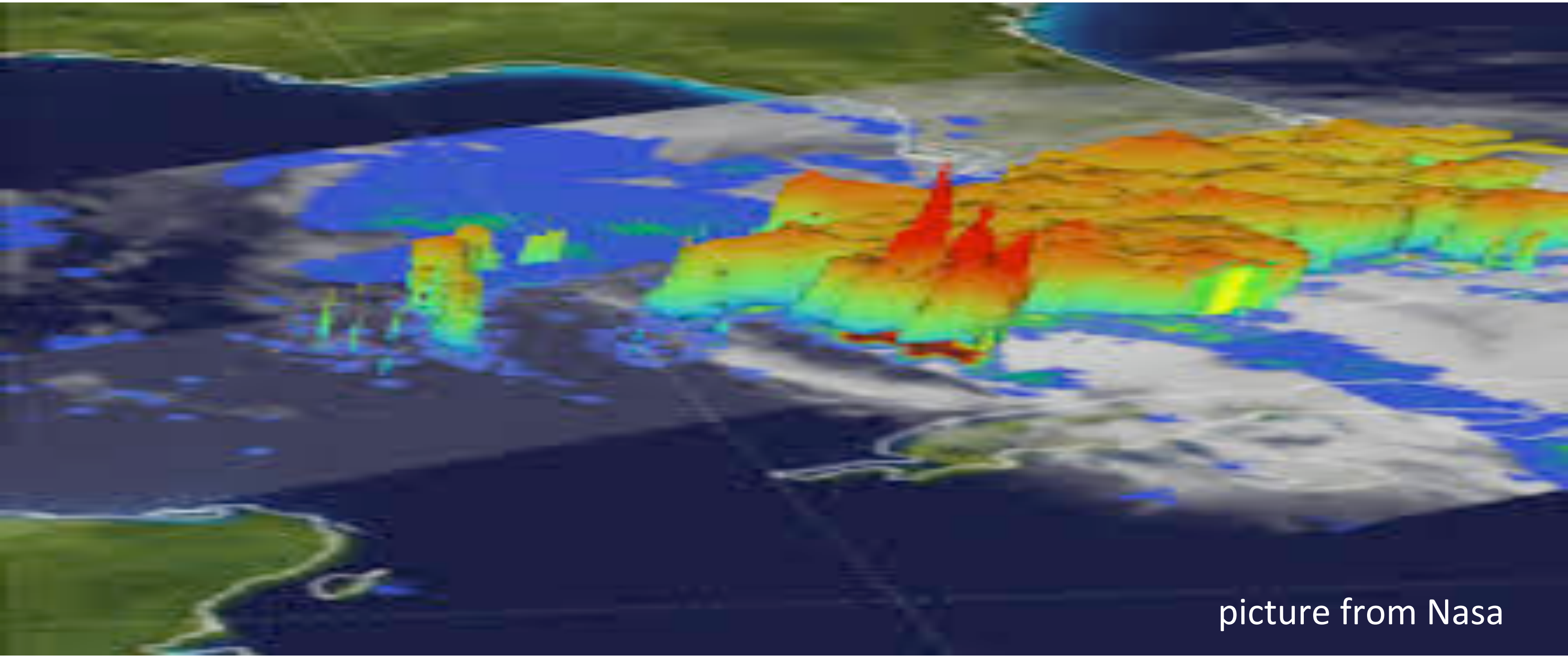
2. NWP and climate model uncertainty

Adrian M Tompkins, ICTP

Tompkins@ictp.it



Many hazards to health have climate drivers

- Precipitation:
  - Water-borne disease such as cholera,
  - Vector-borne diseases e.g. malaria, dengue, LF, schisto...
- Temperature:
  - heatstress, extremes, accidents
  - vector-borne diseases,
  - communicable diseases (behaviour)
- Humidity
  - Vector-borne disease
  - Virus transmission
- Wind
  - Meningitus
  - malaria (vector tracking)
  - transport of pathogens

Predicting the Future

- Days – Medium range weather forecasts

  Sensitivity to model error and atmospheric initial conditions

- Weeks – months – Ensemble seasonal forecasting

  Sensitivity to model error and ocean/land surface initial conditions

- Years to decades – Ensemble of climate models

  Sensitivity to model errors, ocean initial conditions and boundary forcing error

Climate and numerical weather prediction models are constructed using 5 fundamental set of equations

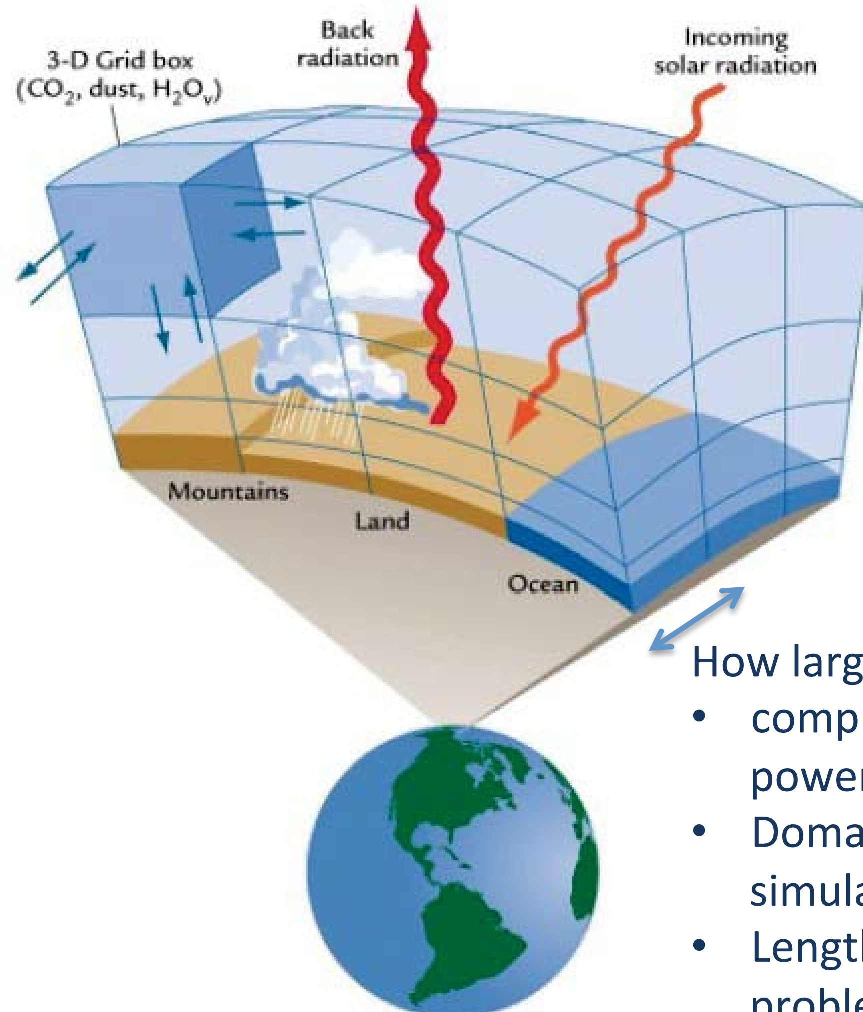
climate model equation set

- equations of motion
- equations of state
- thermodynamic equation
- mass balance equation
- water balance equation

It is important to realize that for a continuous medium consisting of an ideal gas, (or mixture of ideal gases) these equations are derived from first principles and are certain.

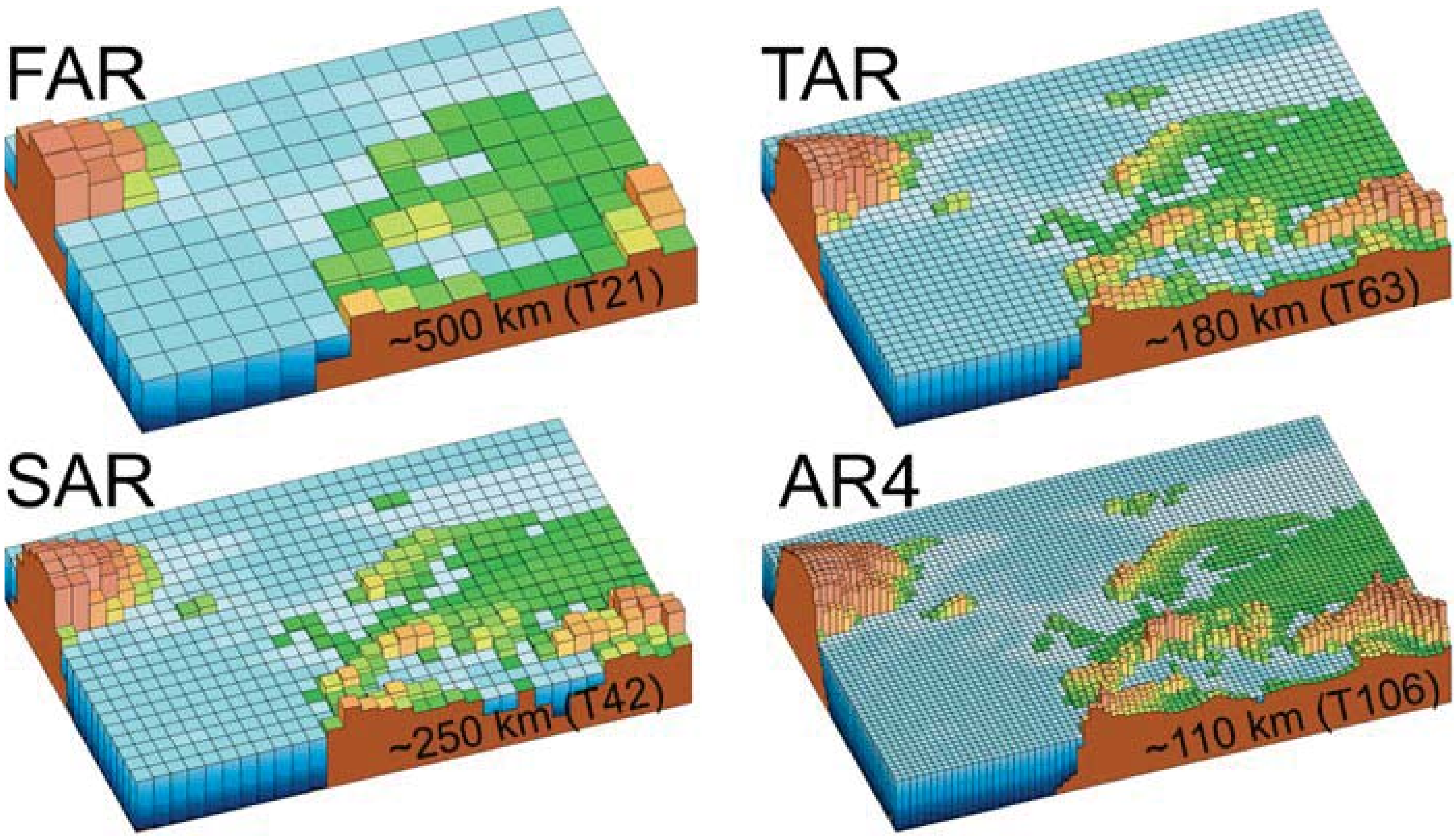
The continium hypothesis

- Dividing the atmosphere into grid boxes
- Properties are considered uniform in each box
- Equations are integrated numerically forward in time



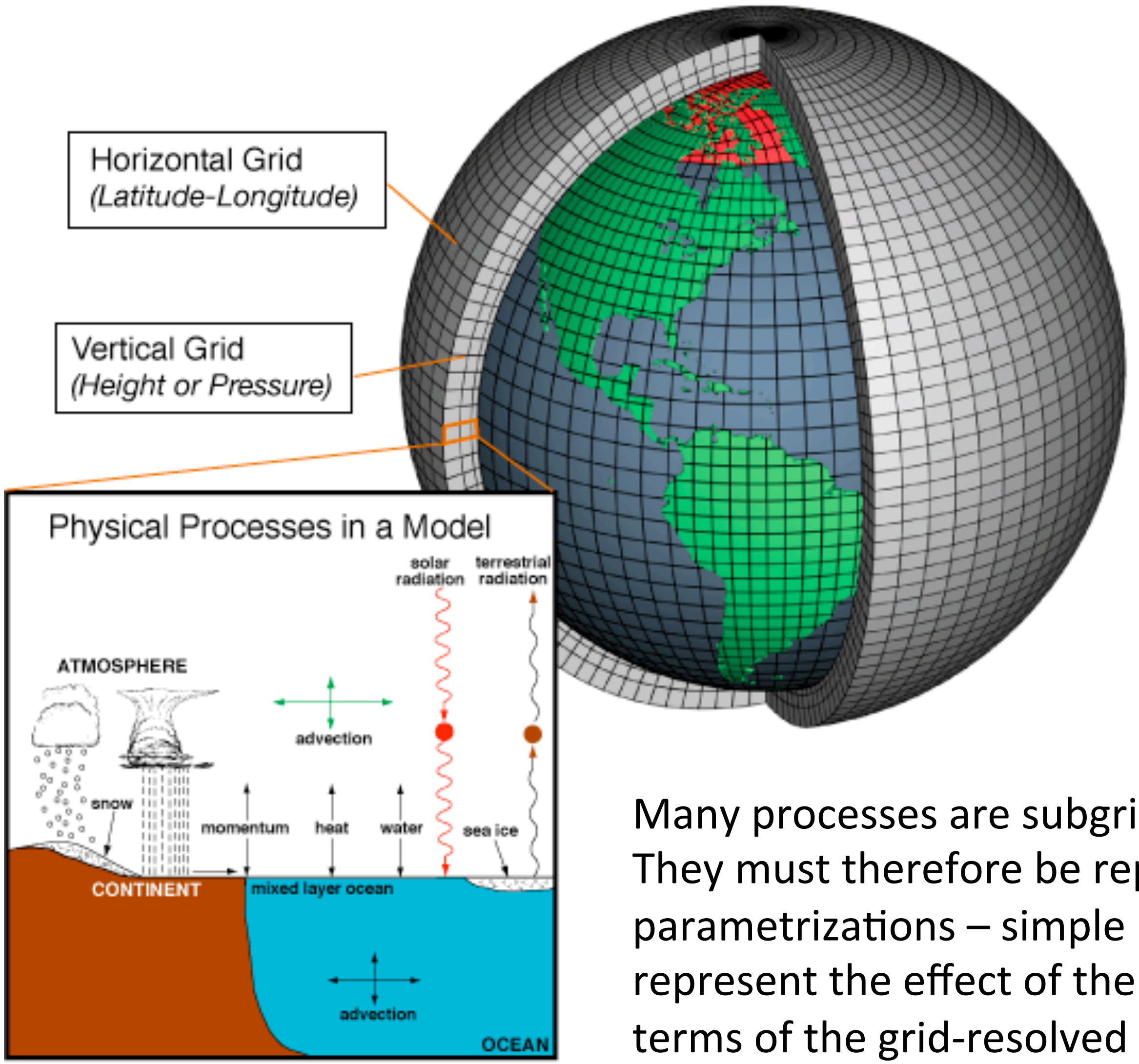
How large?

- computing power
- Domain of simulation?
- Length of problem (5 days forecast of 100 year climate projection?)



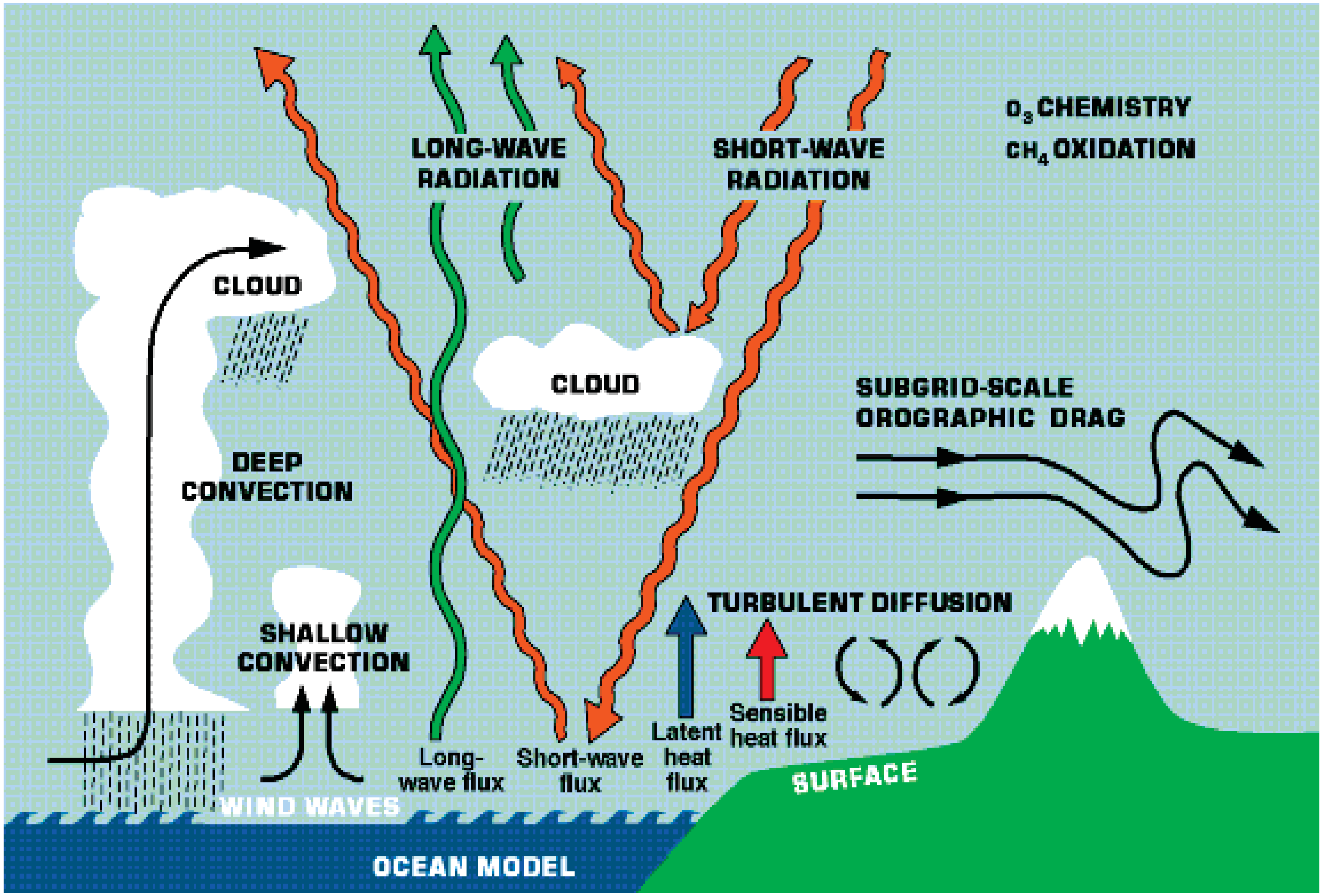
CMIP5/AR5 was not a great increase relative to AR4, due to increase in ensemble sizes

What is the issue concerning finite grid scales?



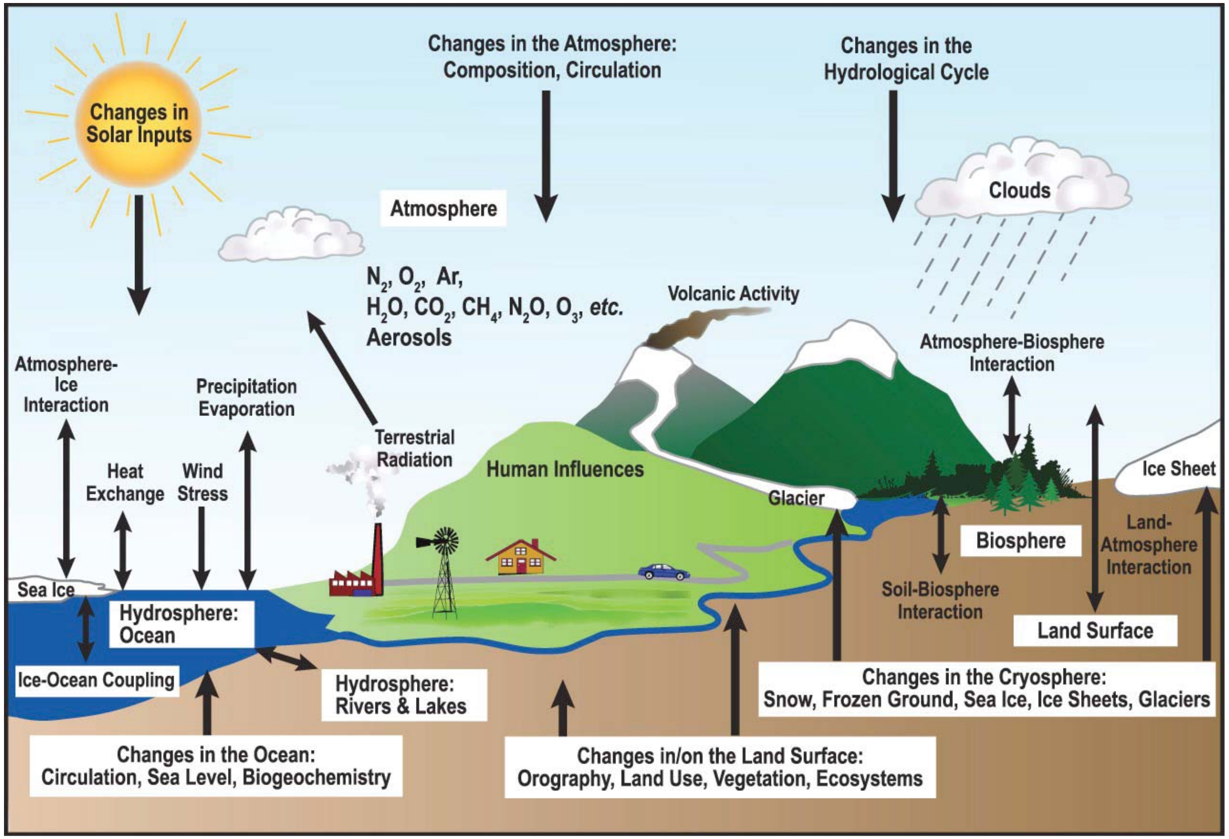
Many processes are subgrid-scale!
They must therefore be represented by parametrizations – simple models that represent the effect of the small scales in terms of the grid-resolved variables.

Key physical processes to be parametrized in NWP



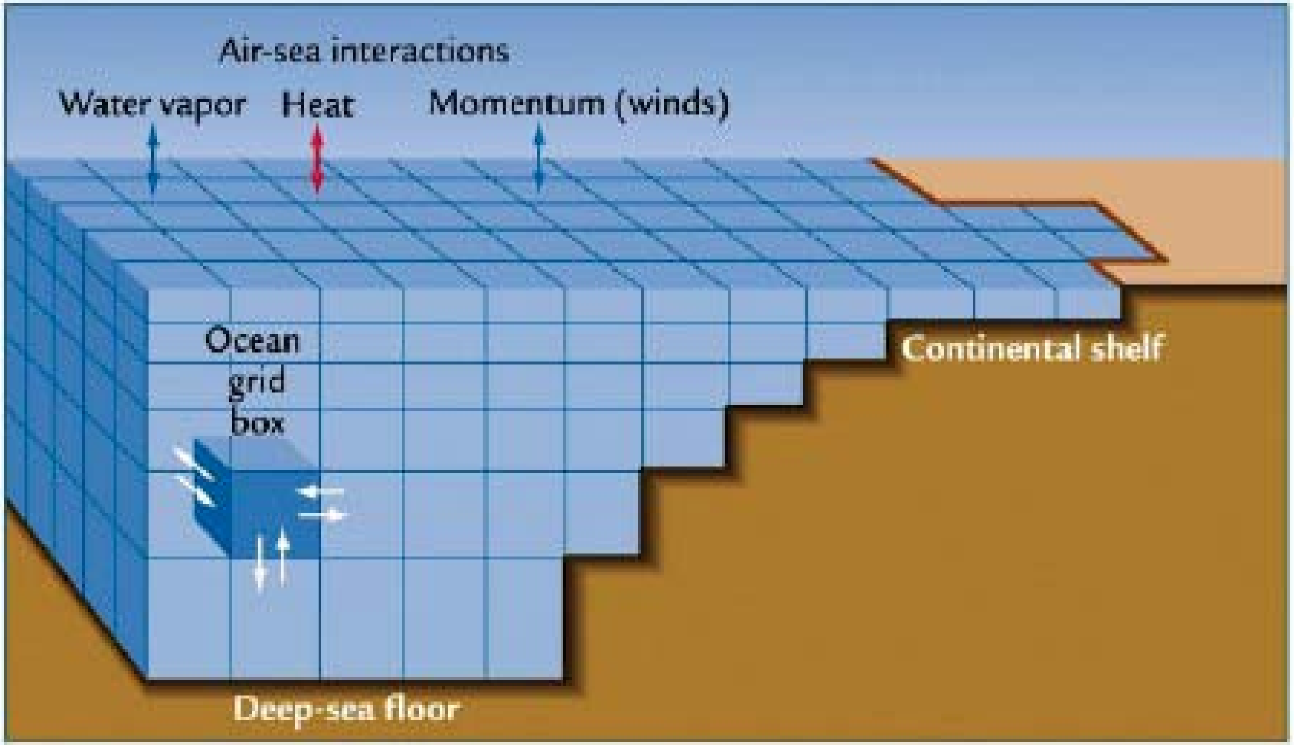
Climate models also must describe slower components of the climate system

- Sea ice
- Land cover and vegetation
- Land hydrological cycle
- Carbon cycles
- Biogeochemistry cycles



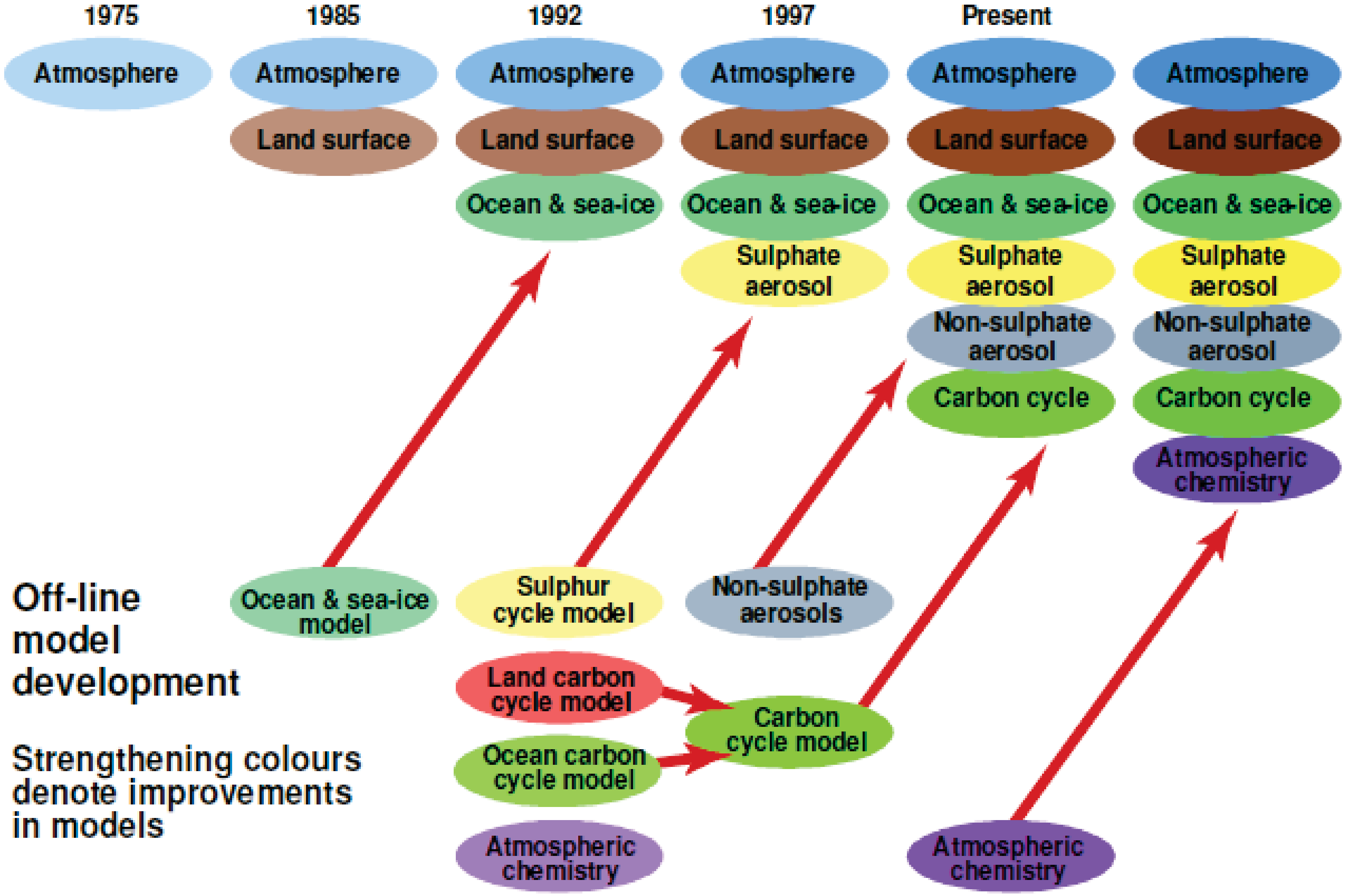
ICTP

Seasonal forecast and climate models also require representation of the ocean



Again, in such models the effects of subgrid-scale and non-local turbulent transports need to be represented

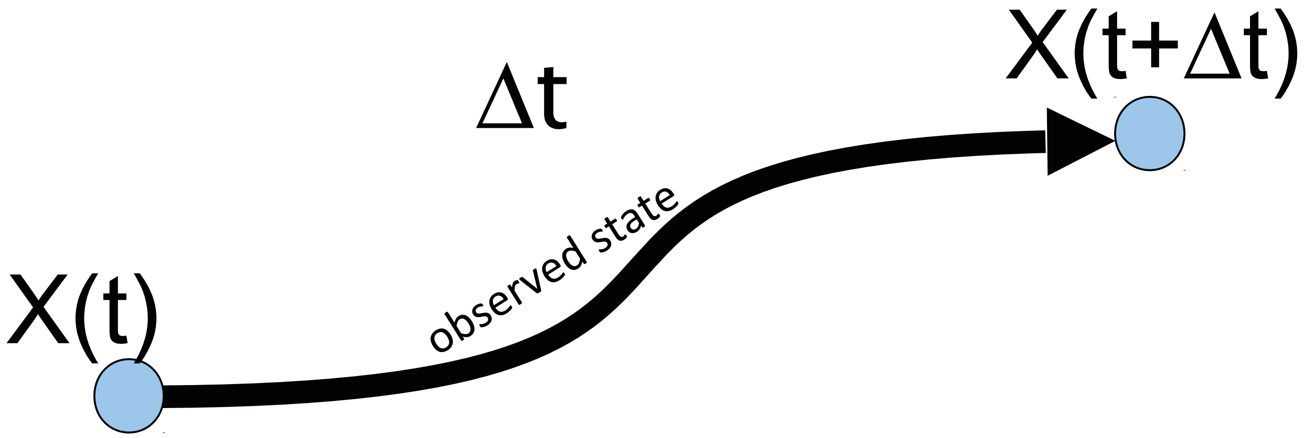
Towards Comprehensive Earth System Models
Past present and future



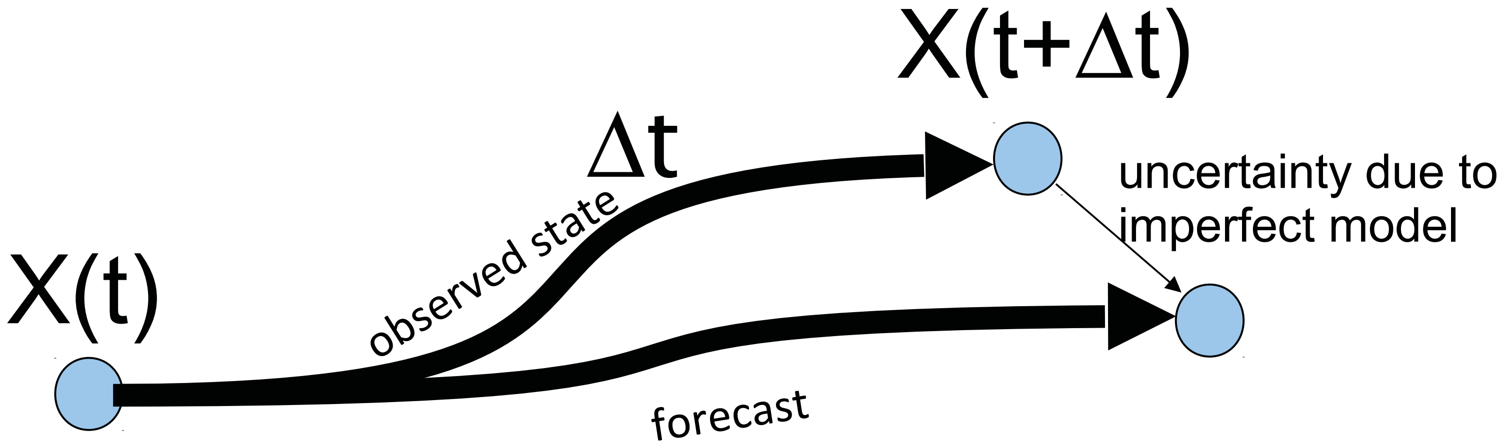
ICTP

- Why are we worried about parametrizations?
  - Not always derivable from theory
  - May contain ad-hoc assumptions, particularly to close the equation set.
  - May contain parameters that are difficult to measure from observations or derive from theory.
- Result: model uncertainty
- Example: in CMIP3/AR4 cloud parametrization schemes were the larges cause of differences in climate sensitivity between the models. This has not changed in CMIP5/AR5.

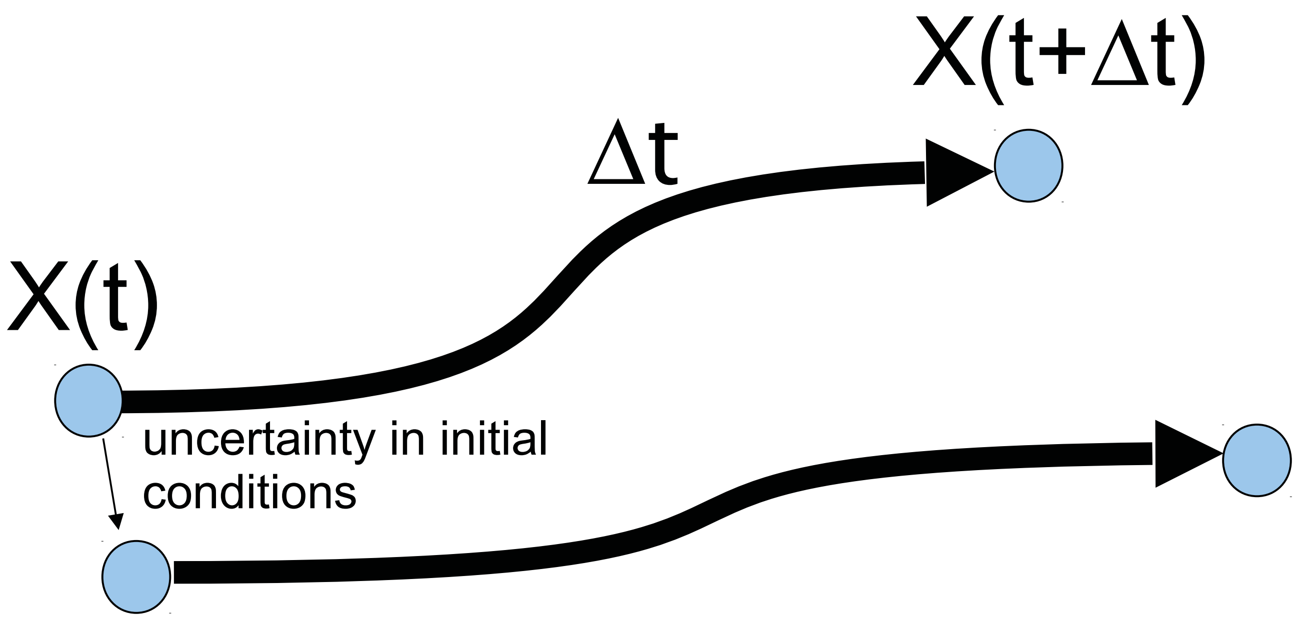
This leads to uncertainty in forecasts due to an imperfect model



This leads to uncertainty in forecasts due to an imperfect model

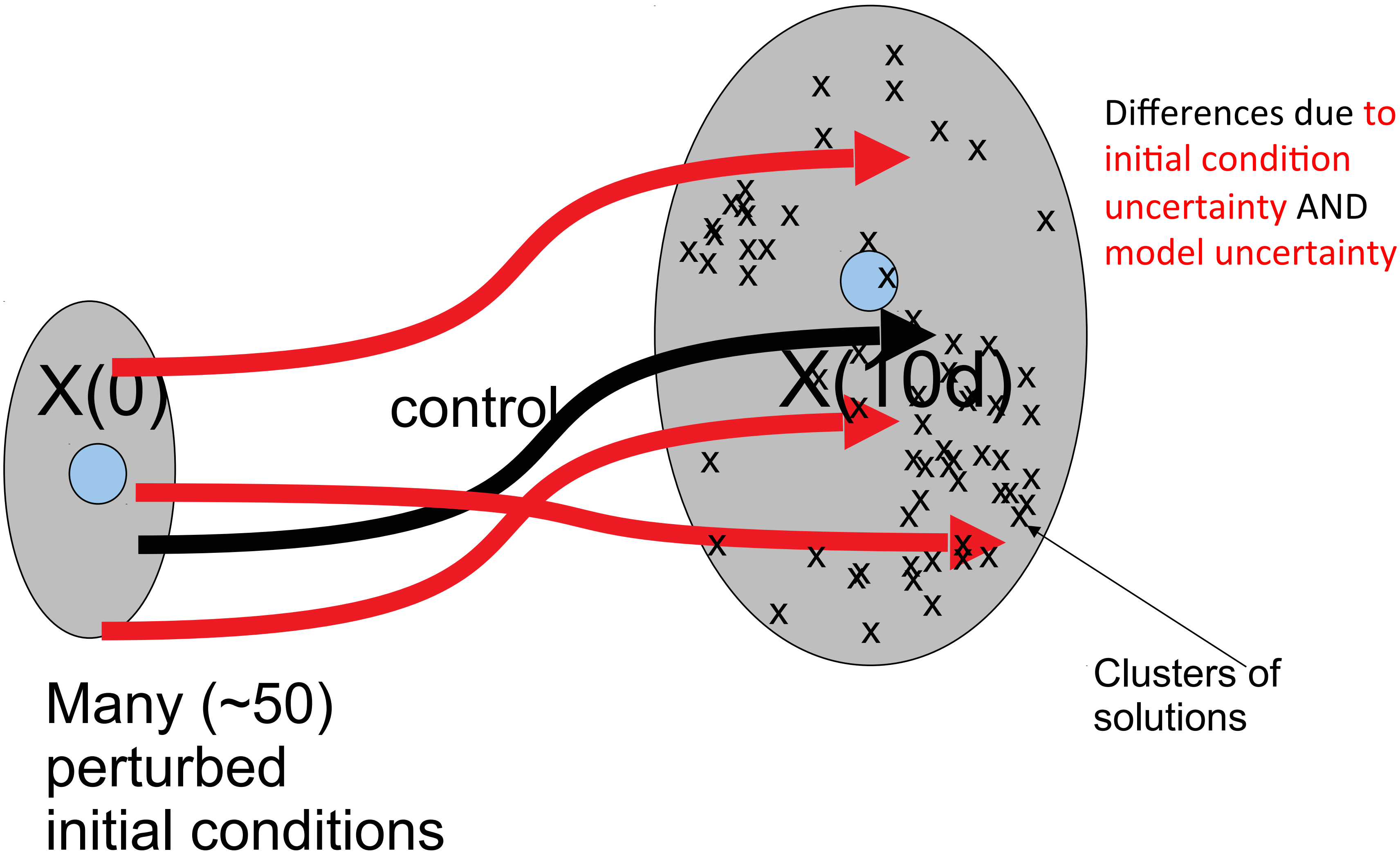


But uncertainty is also a result of inaccurate initial conditions



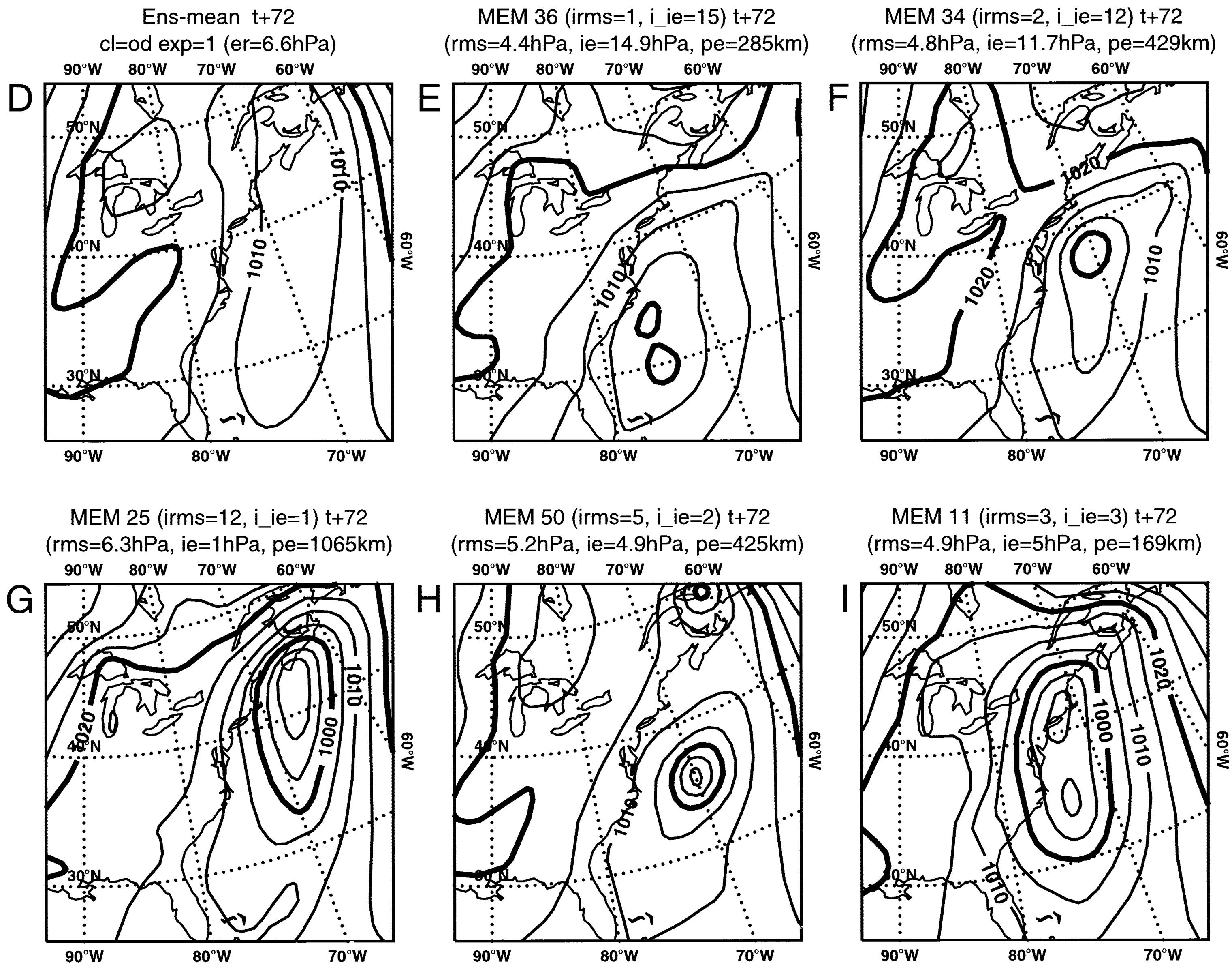
Question: how can we account for this uncertainty?

We run ensembles of forecasts...



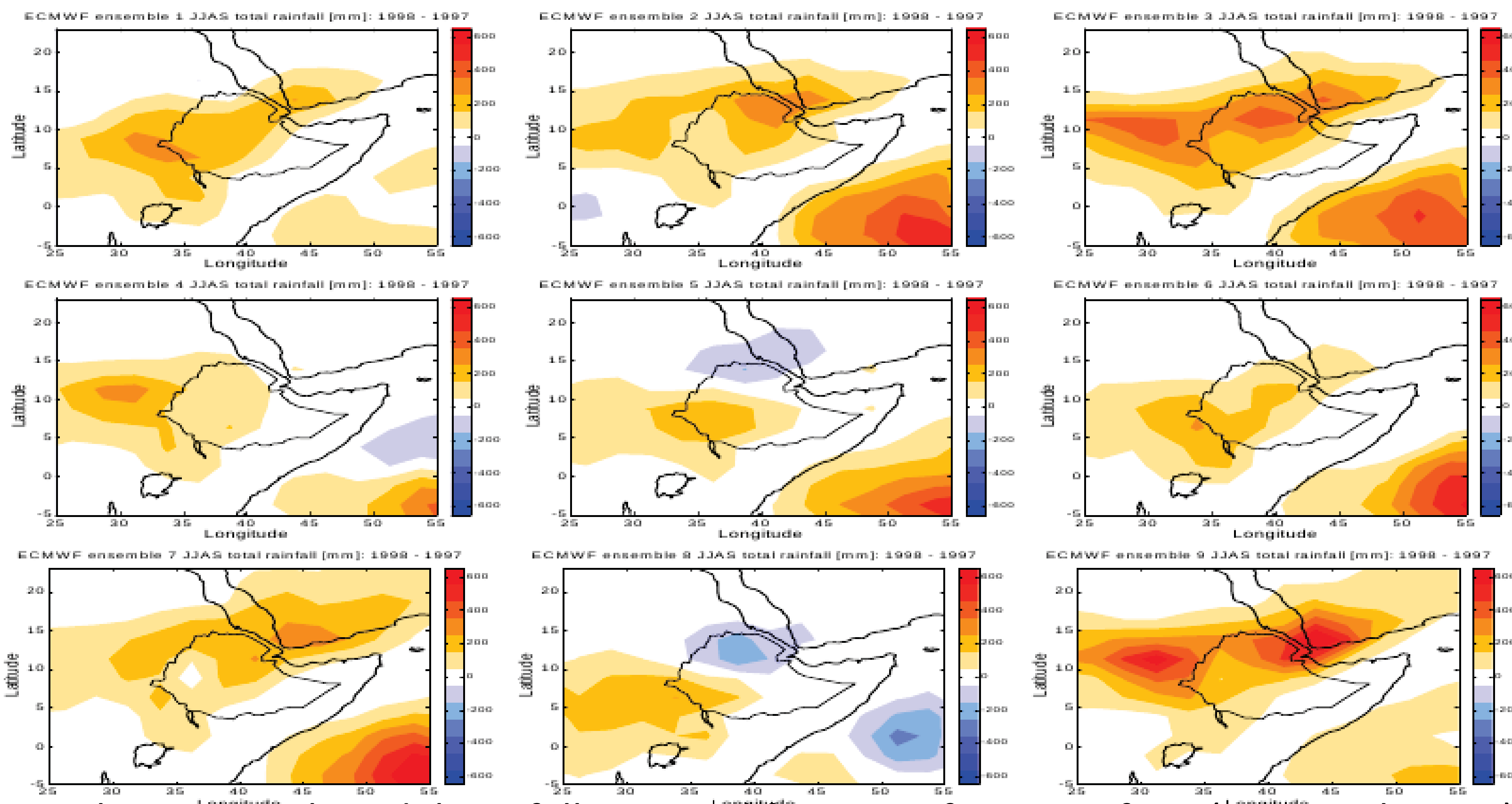
Example: 3 day forecasts of the 2000 storms in USA

from Buizza and Chessa, 2002, MWR

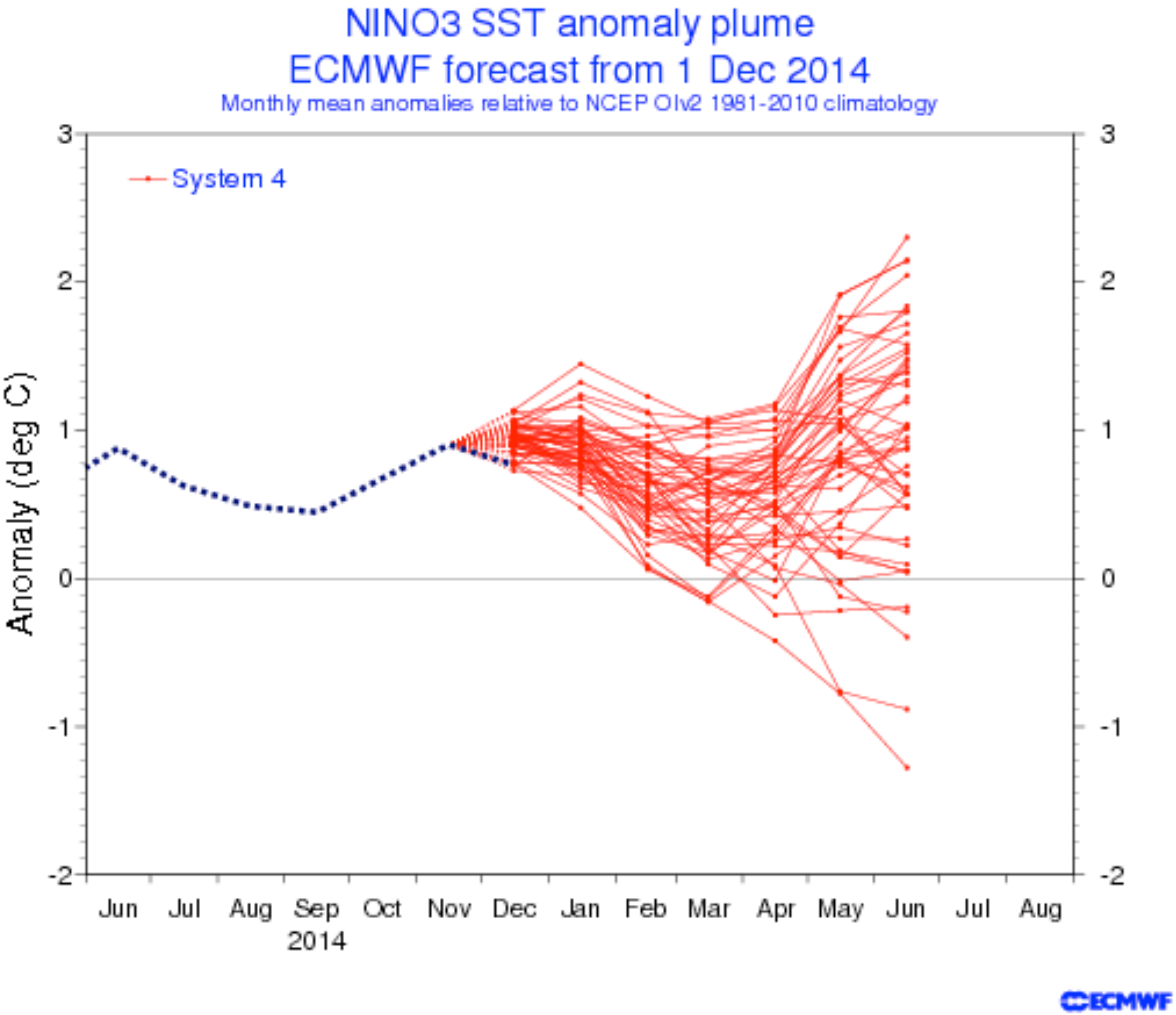


How?

- Perturbations to initial conditions
  - SV or breeding to determine fastest growing perturbations
- Perturbations to model physics
  - 1. parametrization choice
  - 2. stochastic physics
  - 3. Multi model ensemble



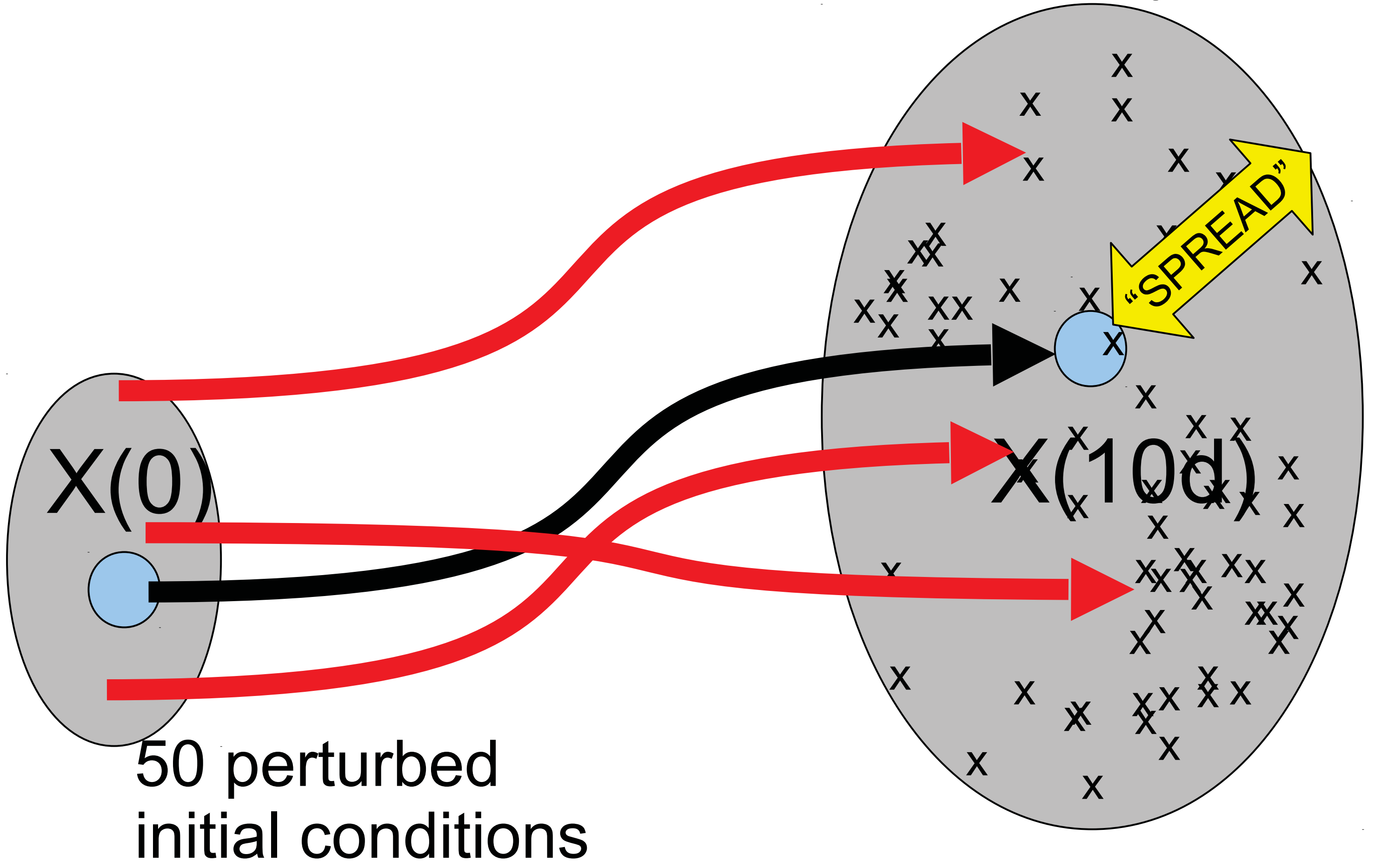
9 member regional model rainfall seasonal forecasts for East Africa (Diro et al. 2012)



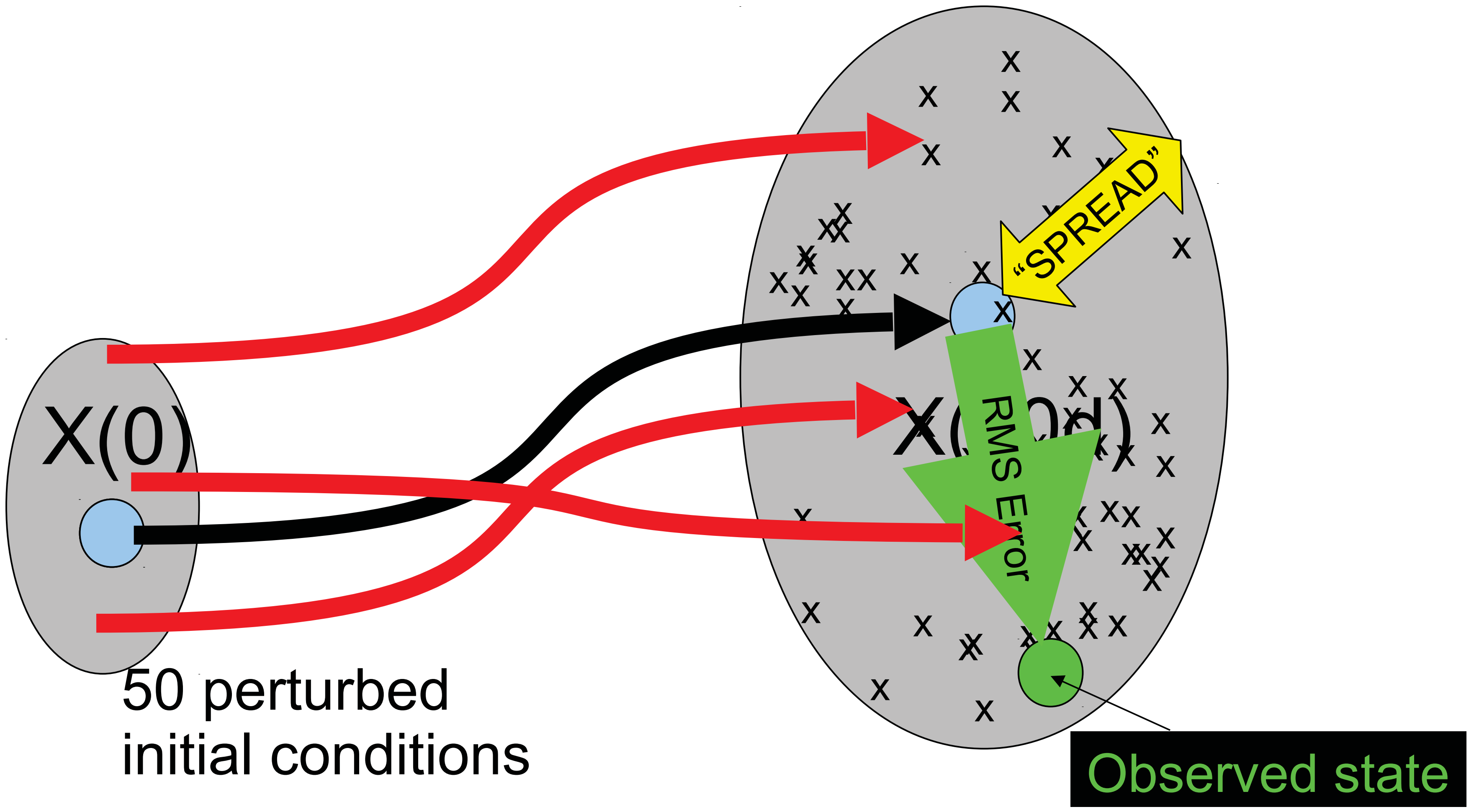
NINO3 SST anomaly plume
ECMWF forecast from 1 Dec 2014
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology
System 4
Anomaly (deg C)
3
2
1
0
-1
-2
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2014
ECMWF

ICTP

The standard deviation between the forecasts is referred to as the inter-ensemble “spread”

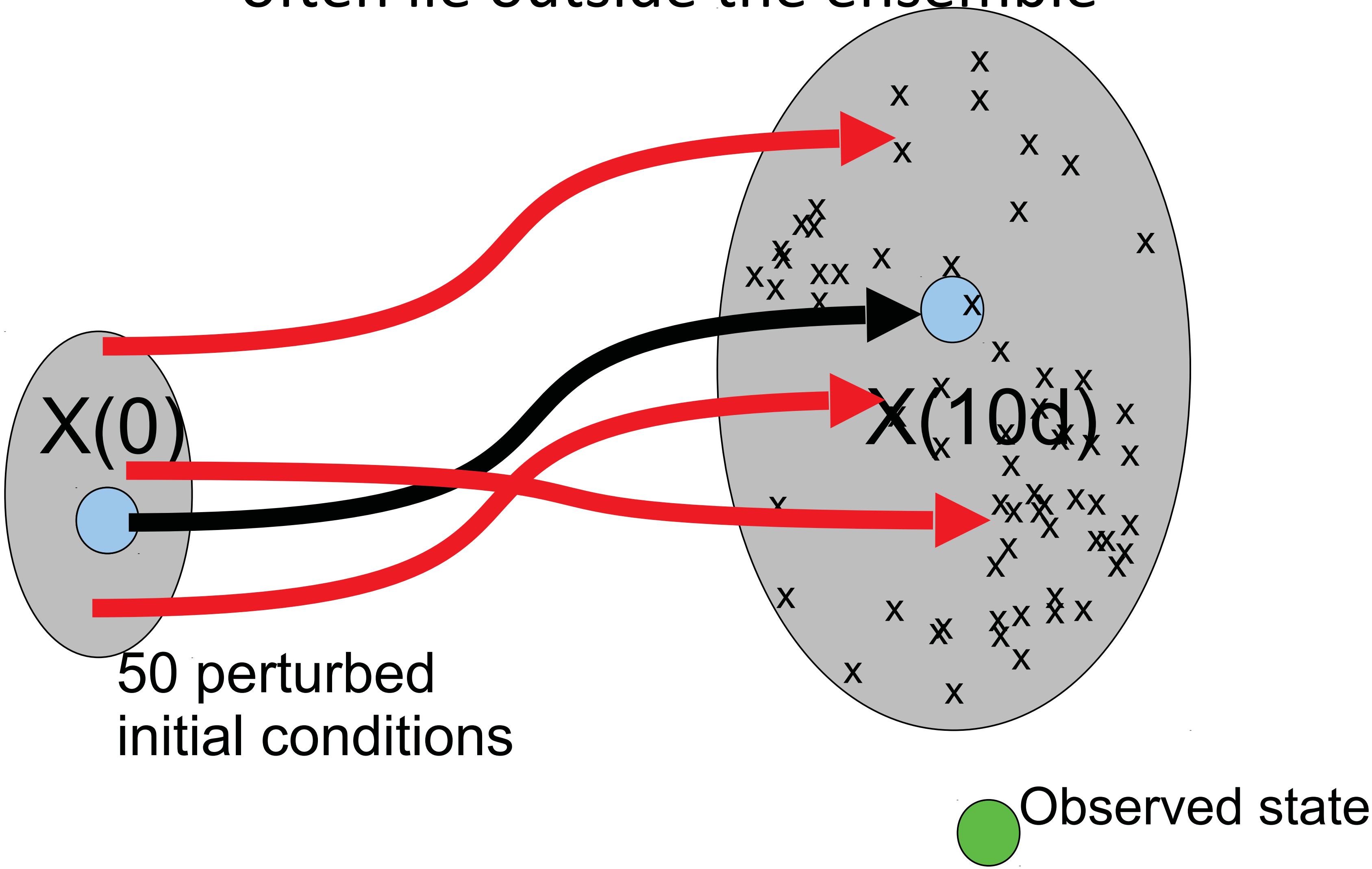


In general, for any given forecast lead time, we want the spread to be comparable to the RMS forecast error

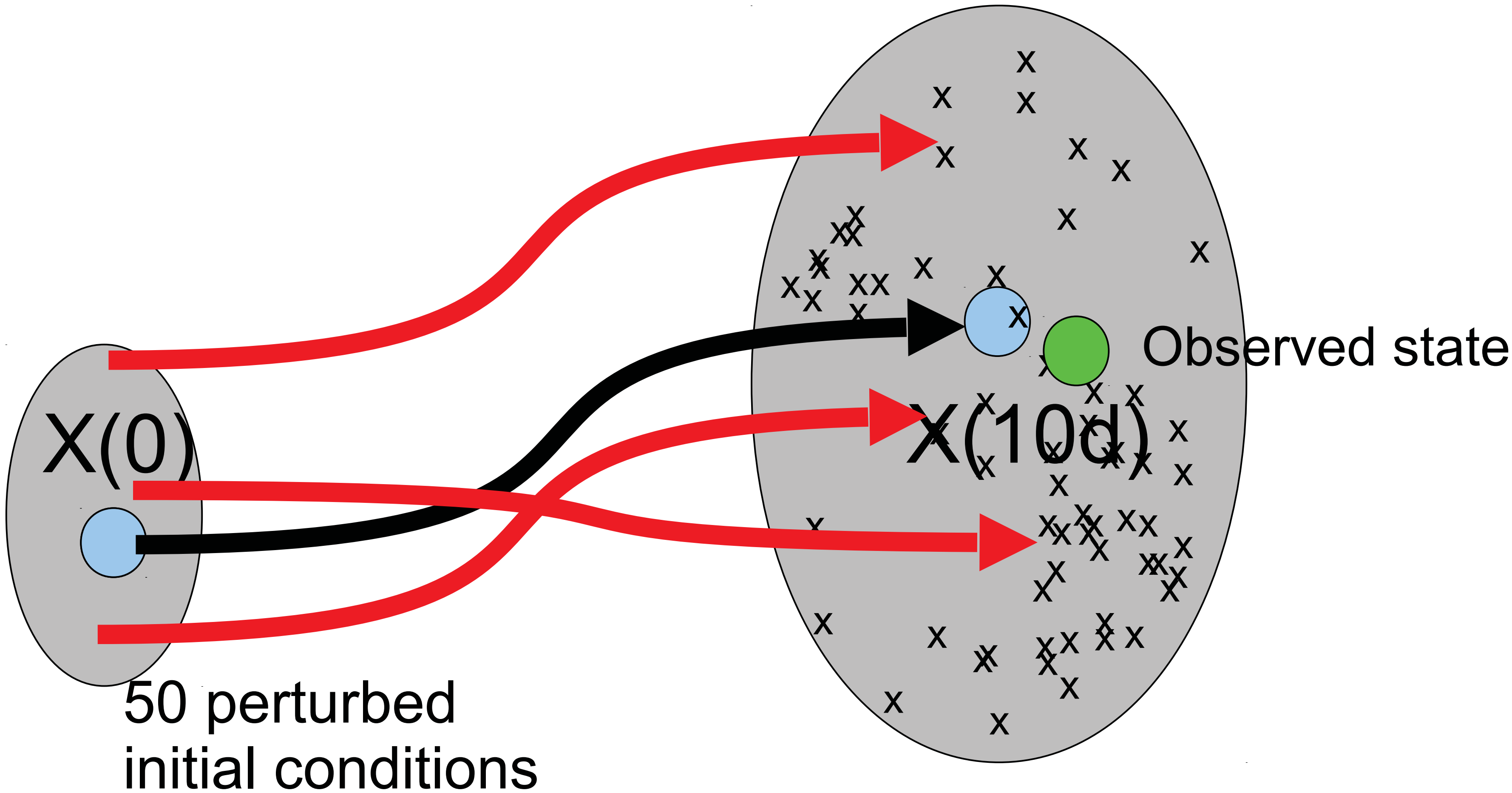


ICTP

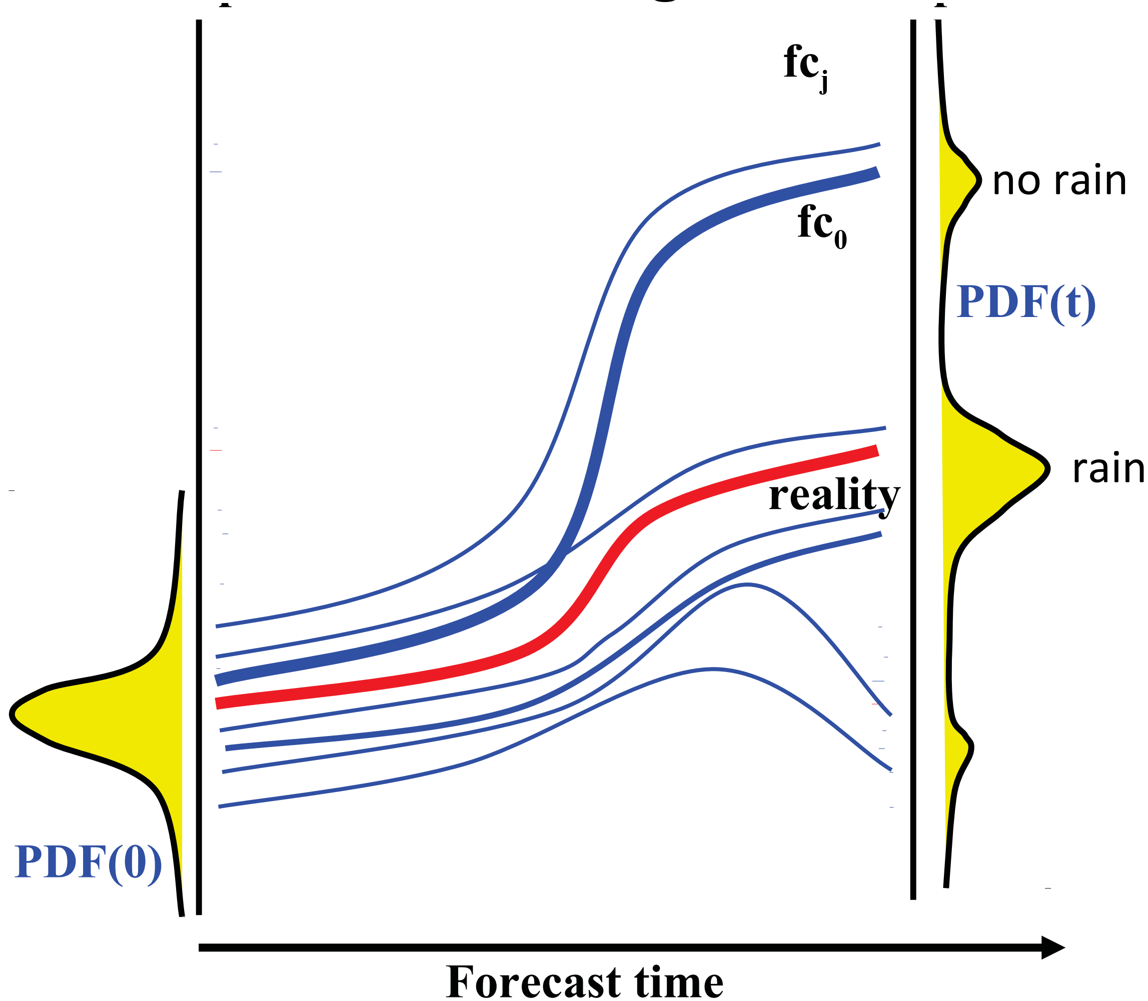
"Over-confident" forecasting system – observations often lie outside the ensemble



“Under-confident” system – perturbations are too strong and overestimate the system error



QUESTION: forecast states 70% chance of rain – and it rains – is this a good forecast?



Uncertainty in climate modelling

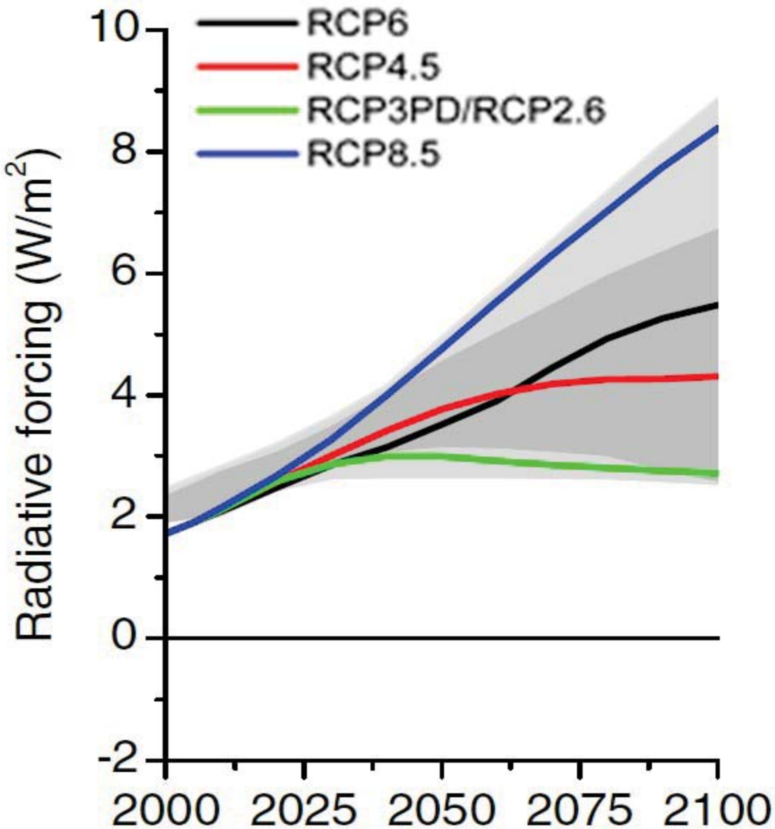
multiple forcing scenarios

↓

multiple climate models

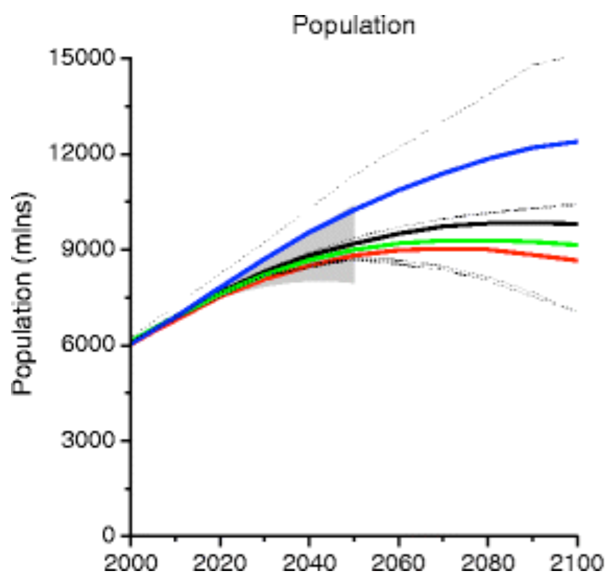
↓

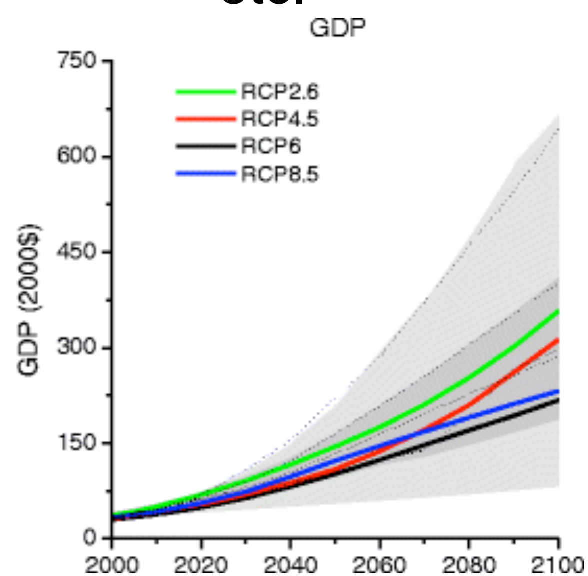
multiple integrations from different initial conditions



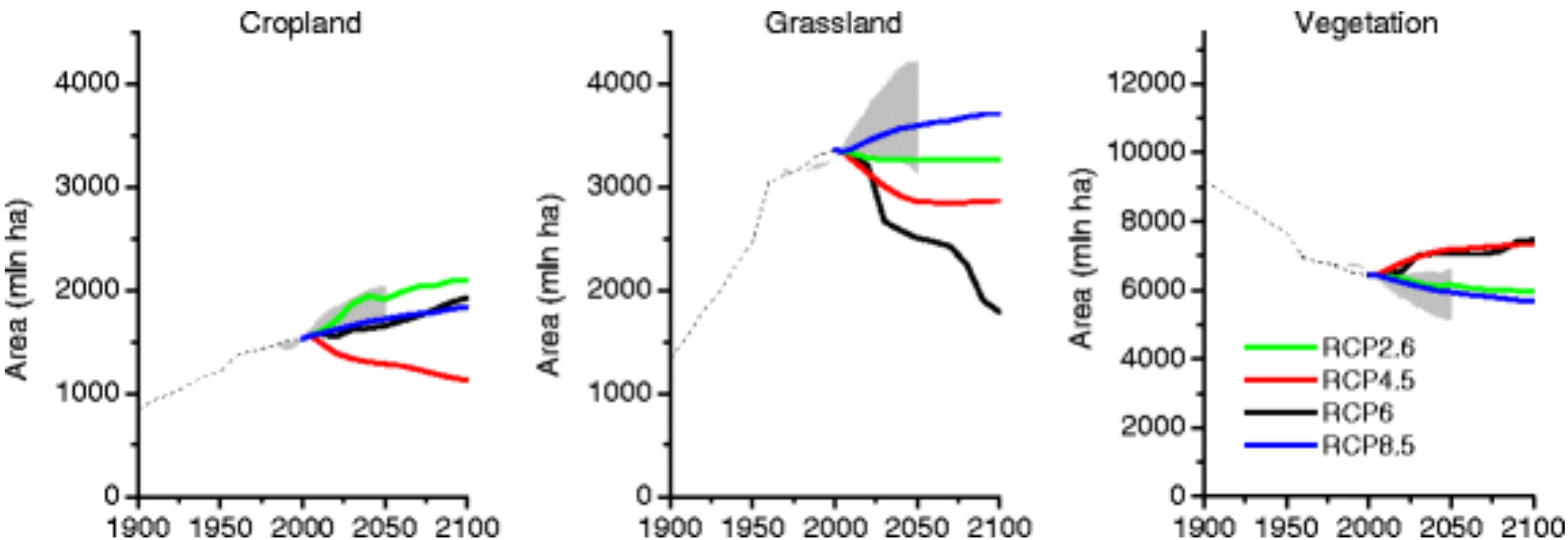
Emissions scenarios in CMIP5

- Each scenario known as a representative concentration pathway (RCP)
- Provided by a different impacts assessment model (IAM)
- Accounting for GDP, population, energy etc.





RCP2p6 is not all good news...

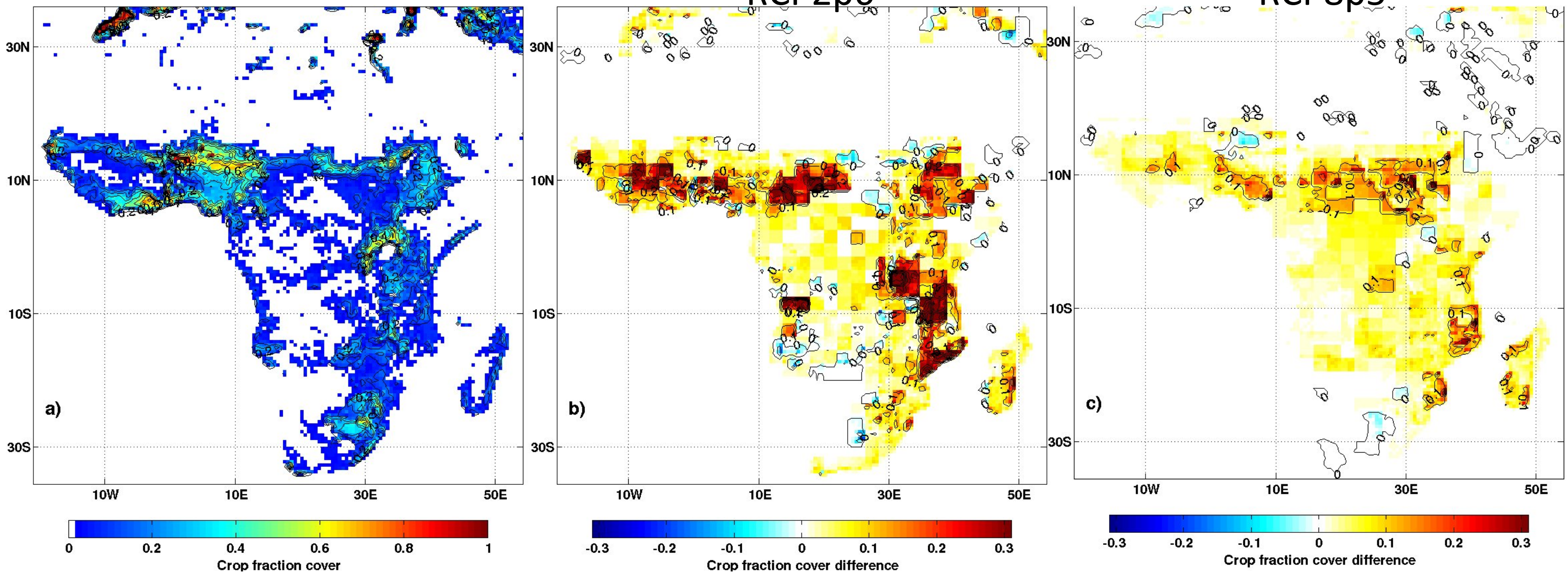


- RCP2p6 and 8p5 are surprisingly similar due to high use of biofuels needed to respect 2p6 Wm^{-2}

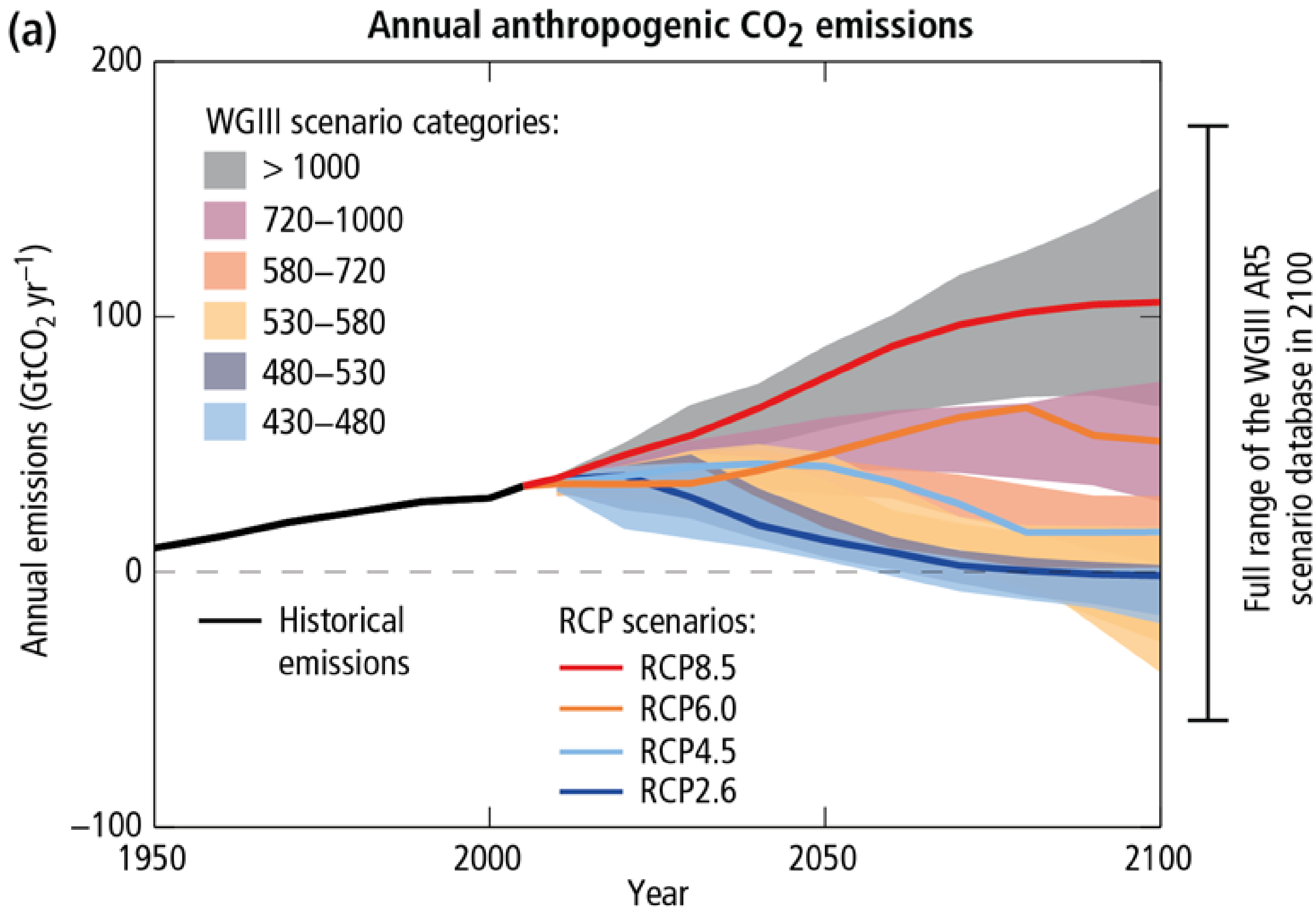
HYDE output example (using CLM)

RCP2p6 actually has one of the greatest conversation to cropland rates in Africa due to high use of biofuels.

RCP2p6 RCP8p5



Leads to emissions scenarios for major greenhouse gases



Question: Are these 4 scenarios all equally likely? Which one is the most likely?

Uncertainty in climate modelling

multiple forcing scenarios

↓

multiple climate models

↓

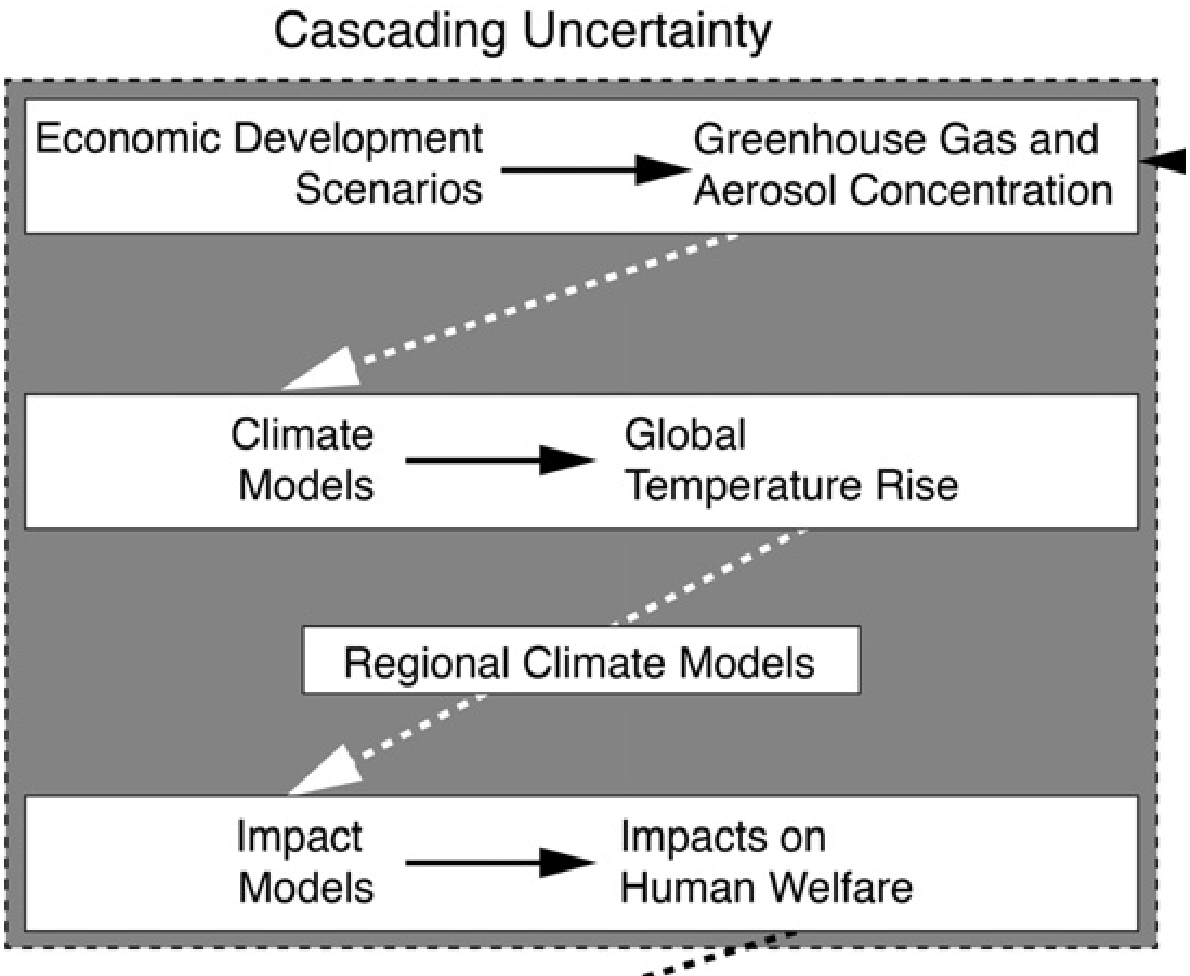
multiple integrations from different initial conditions

The Geographical Journal, 2013, doi: 10.1111/j.1475-4959.2012.00494.x

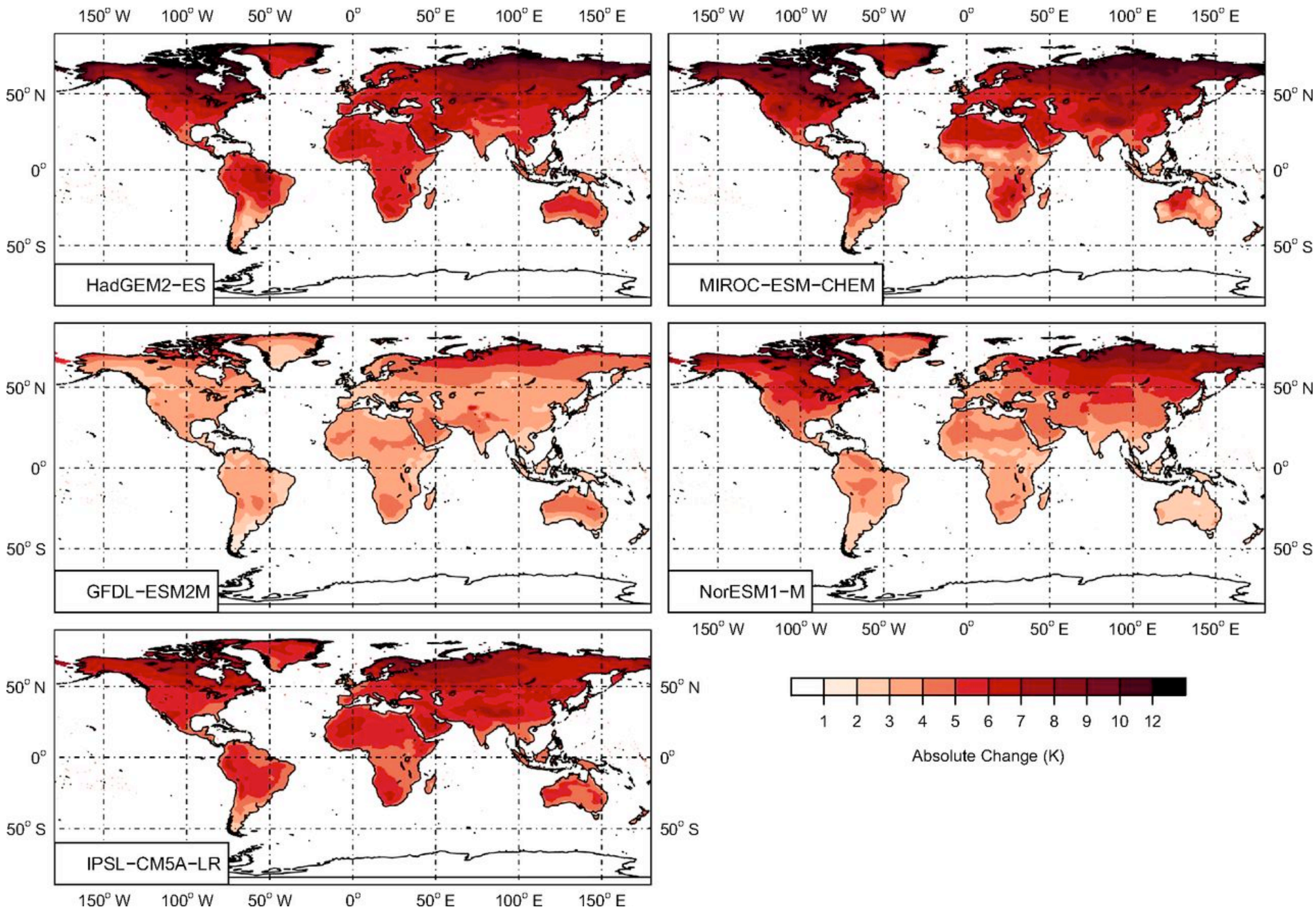
Commentary

Cascading uncertainty in climate change models and its implications for policy

MARK MASLIN

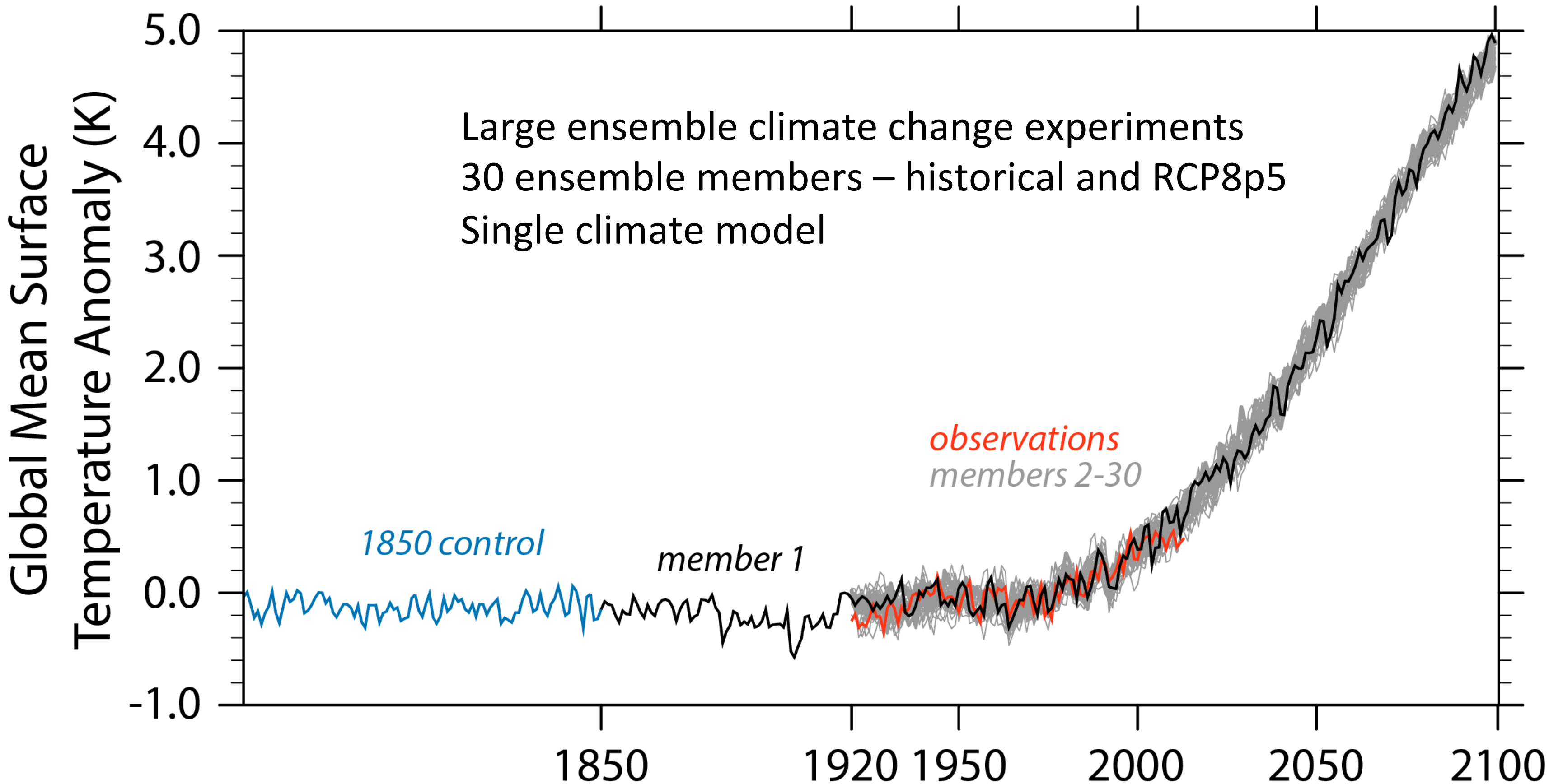


ISIMIP – PNAS special issues 2014 investigated multisectoral impacts of climate change using one member of 5 climate models



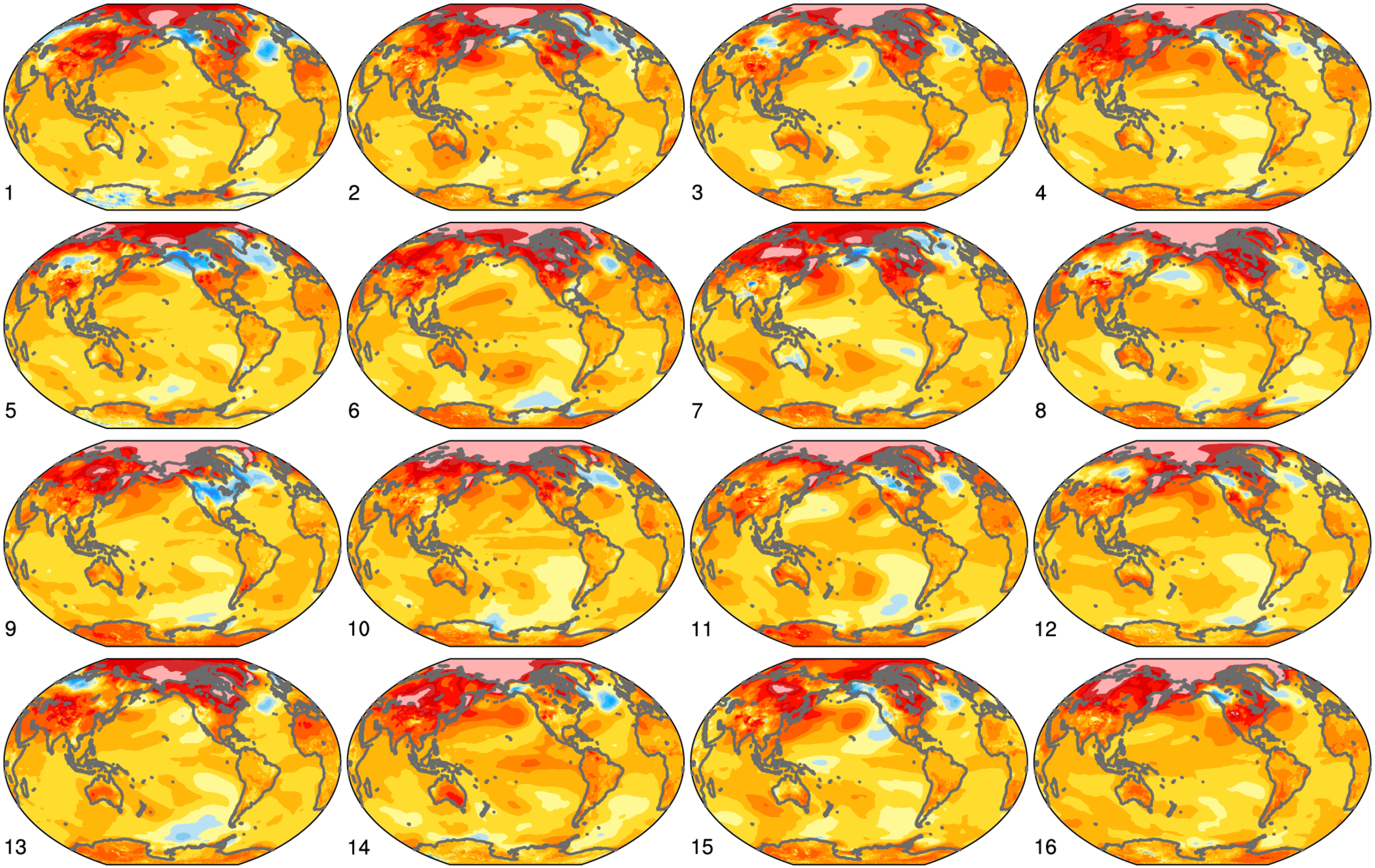
- Ensembles techniques less well developed
- Season/decadal - Initial condition error:
  - Atmosphere (relatively) unimportant > seasonal
  - Perturbations to Sea Surface Temperature are key
  - However, the way to do this effectively is unknown:
    - Surface wind perturbations in ocean analysis system
    - Direct perturbations to SST to account for observation error (but not to maximize growth)
    - Lagged start dates
- Seasonal to climate - Model error:
  - Multiple models used (IPCC, EUROSIP)
  - Stochastic Physics schemes
  - Perturbations to physics tuning parameters (not IPCC AR4)

However, model error and initial condition "sampling" error are often confused.



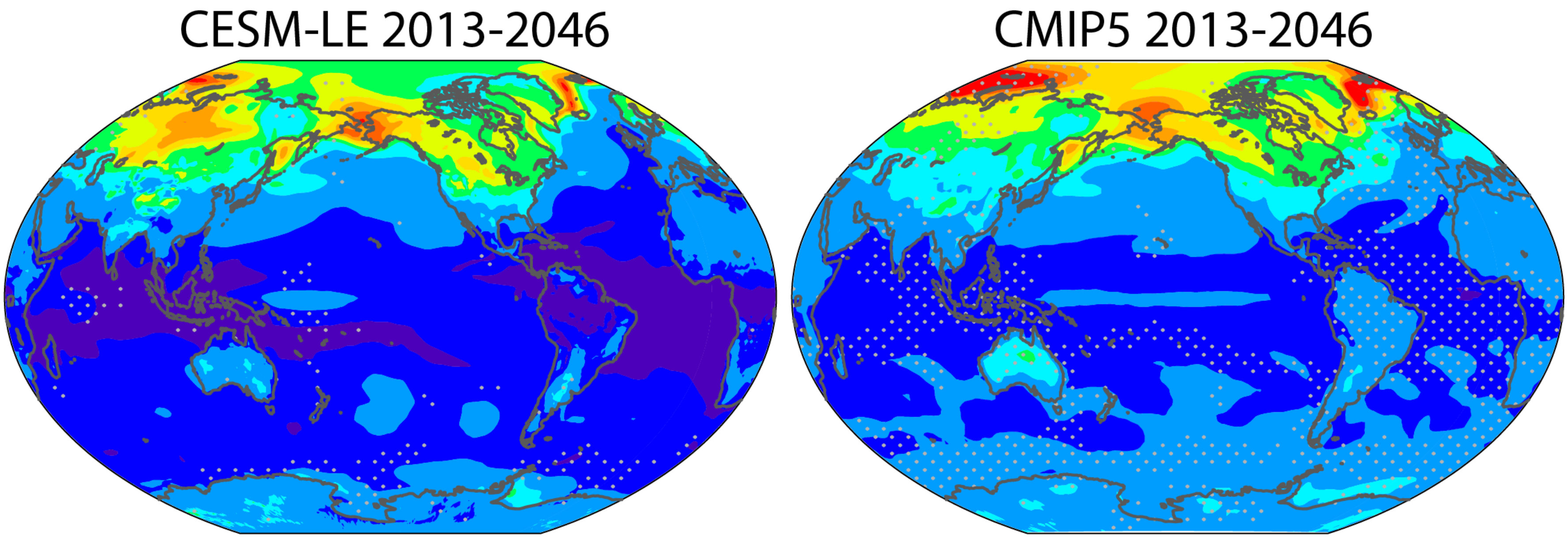
Key et al. BAMS to appear 2015: http://dx.doi.org/10.1175/BAMS-D-13-00255.1

First 16 members: 2013-2046 temperature trend

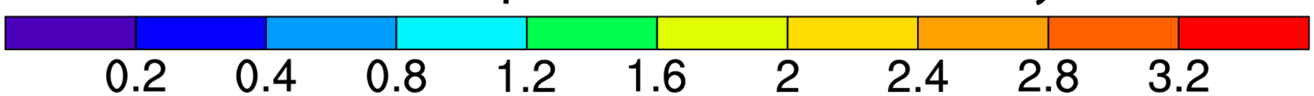


http://dx.doi.org/10.1175/BAMS-D-13-00255.1

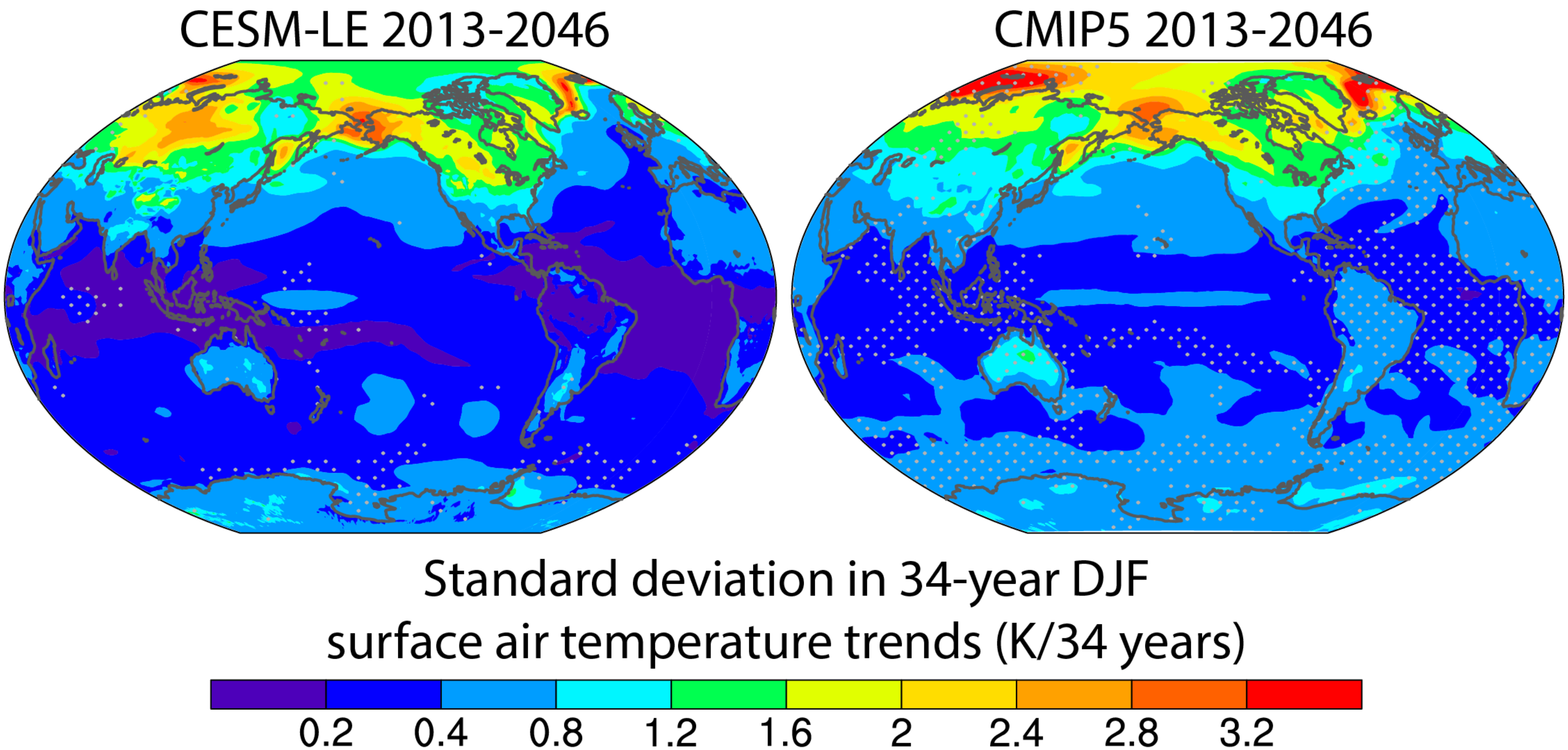
Inter-ensemble temperature “spread” – what is the difference between the left and right?



Standard deviation in 34-year DJF
surface air temperature trends (K/34 years)

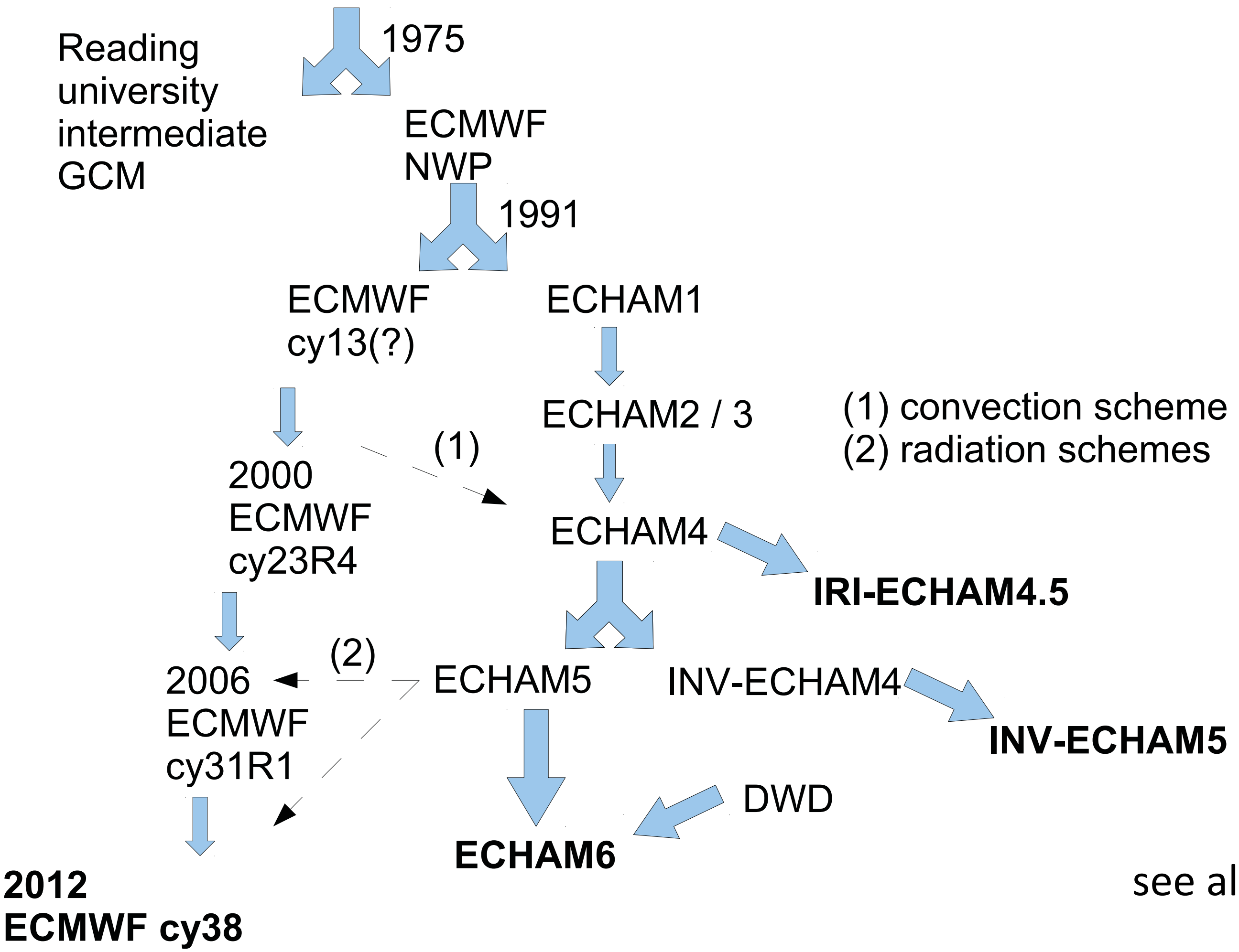


Left: 30 members single model = sampling uncertainty
Right: 38 CMIP5 models, one member per model



Are the differences on the right due to model uncertainty or initial condition sampling? And why is this important?

Small ensembles may lead to overestimate of uncertainty due to model error, but… …are models “genetically” diverse enough?

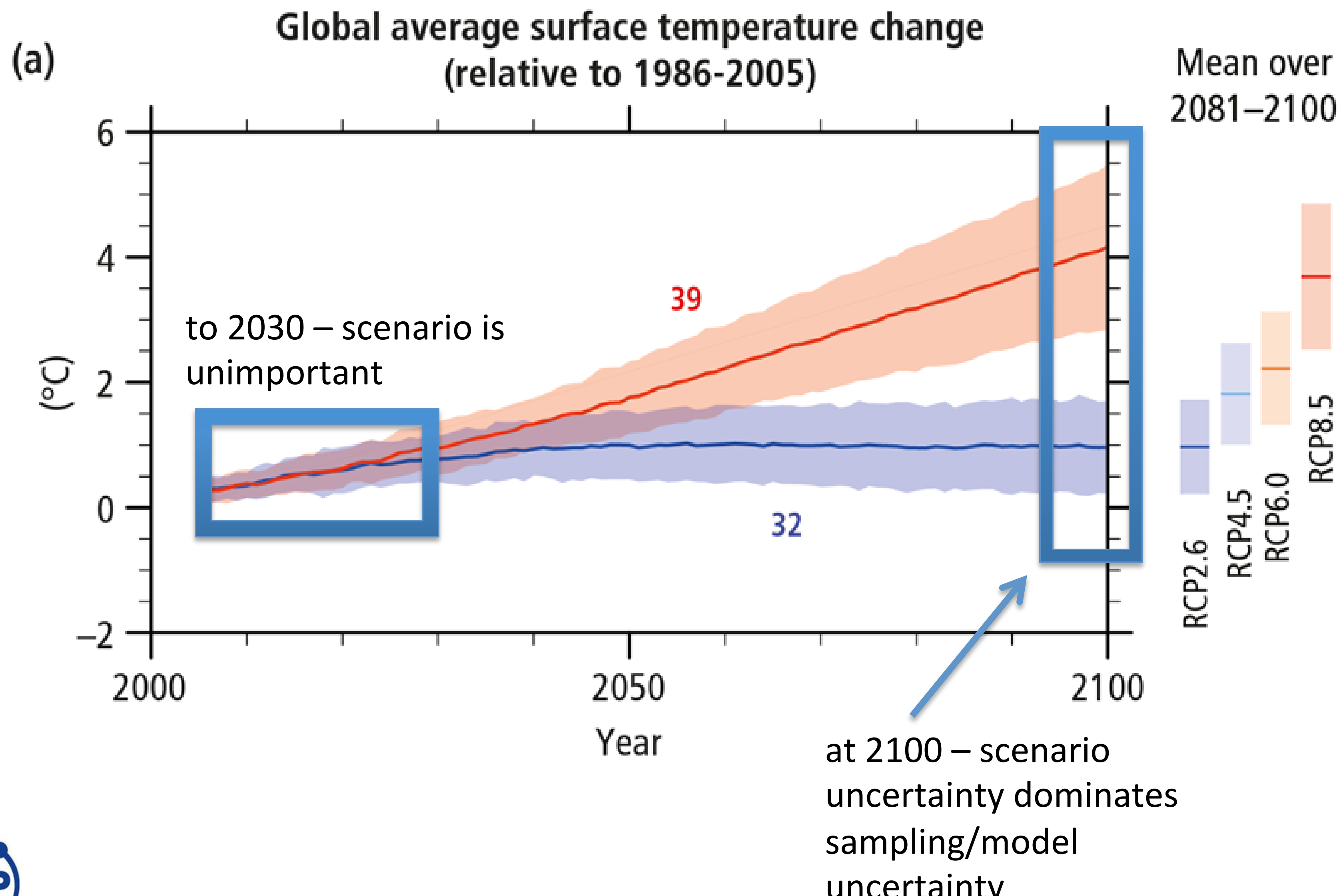


see also in GRL (2013):

Climate model genealogy: Generation CMIP5 and how we got there

Reto Knutti,[1] David Masson,[2] and Andrew Gettelman[1,3]

Temperature projections to 2100



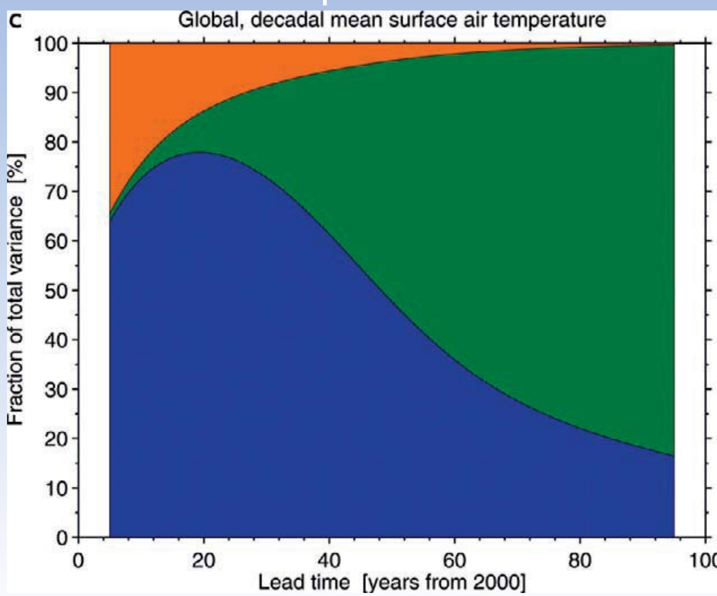
The source of uncertainty depends how far ahead you look...

Fraction of uncertainty explained by different sources as a function of lead time

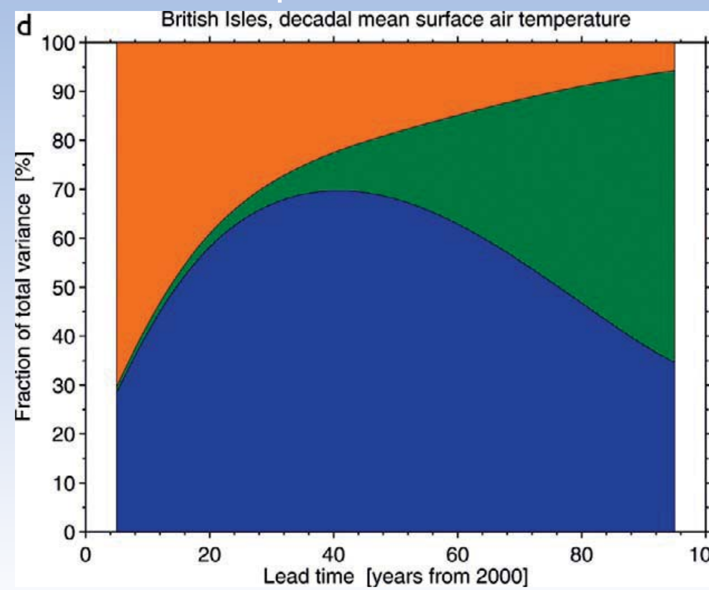
Internal variability
Scenario uncertainty
Model configuration uncertainty

Hawkins and Sutton 2009

Decadal temperature - Global



Decadal temperature – British Isles



Note: small ensembles in CMIP5 may leading overestimation of model component of uncertainty

Take home messages

- Forecast and climate models are based on fundamental physics equations, which are solved numerically on a set of grid boxes
- Processes that occur on smaller scales can not be explicitly modelled, and thus are parametrized – an uncertain process.
- Climate models and weather prediction models share the same “core” features, but climate models must add slower evolving components

And Uncertainty...

- Due to:
  - Natural variability, initial conditions
  - Model uncertainty
  - Forcing (emissions) uncertainties
- Large ensembles are required in an attempt to understand sources of uncertainty in predictions and projections