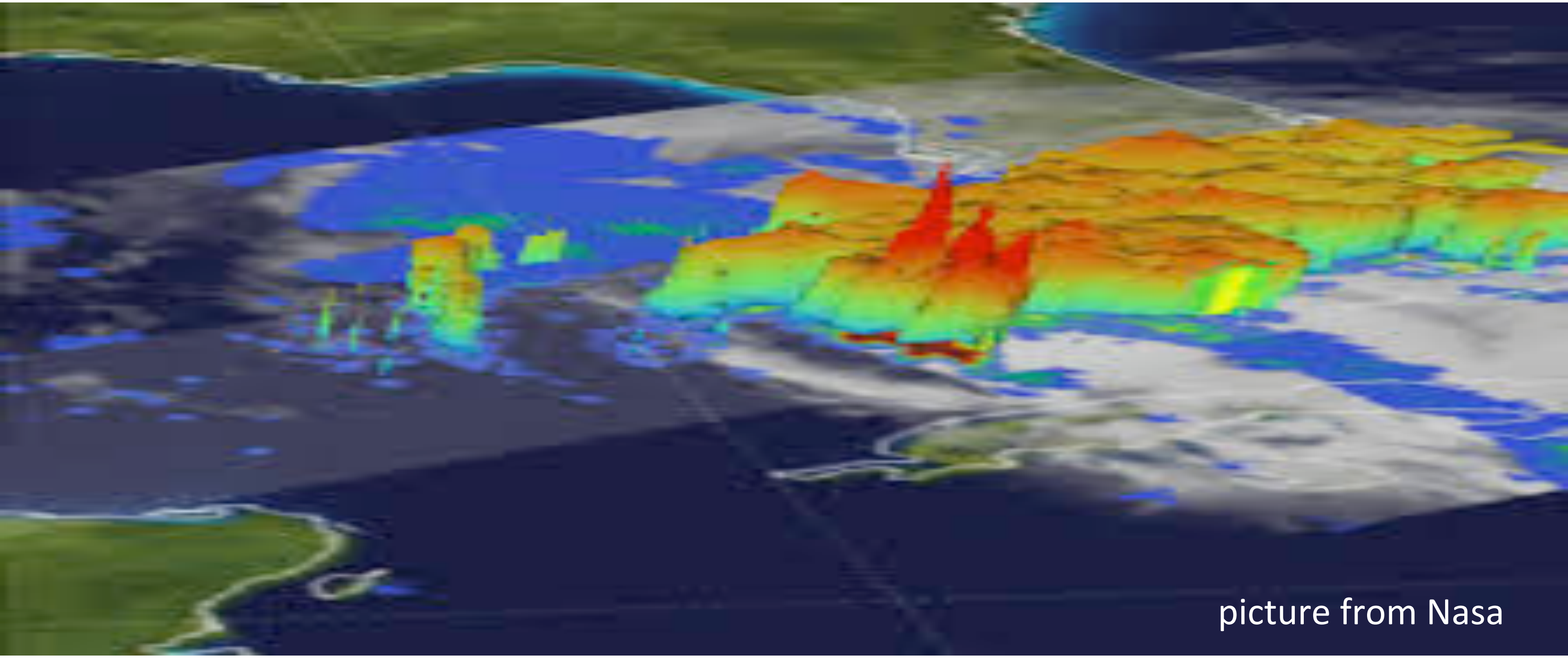
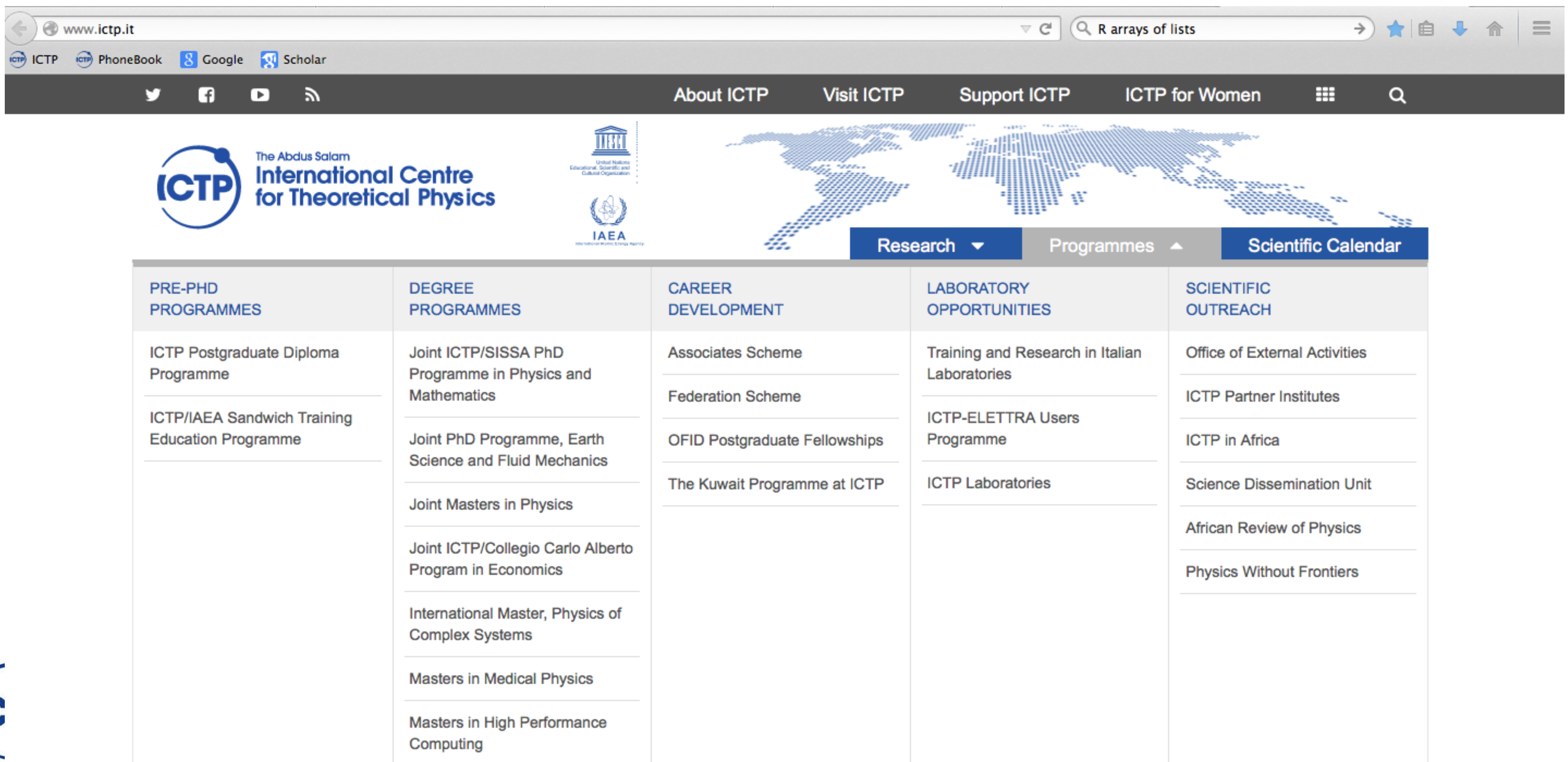
NWP and climate model uncertainty

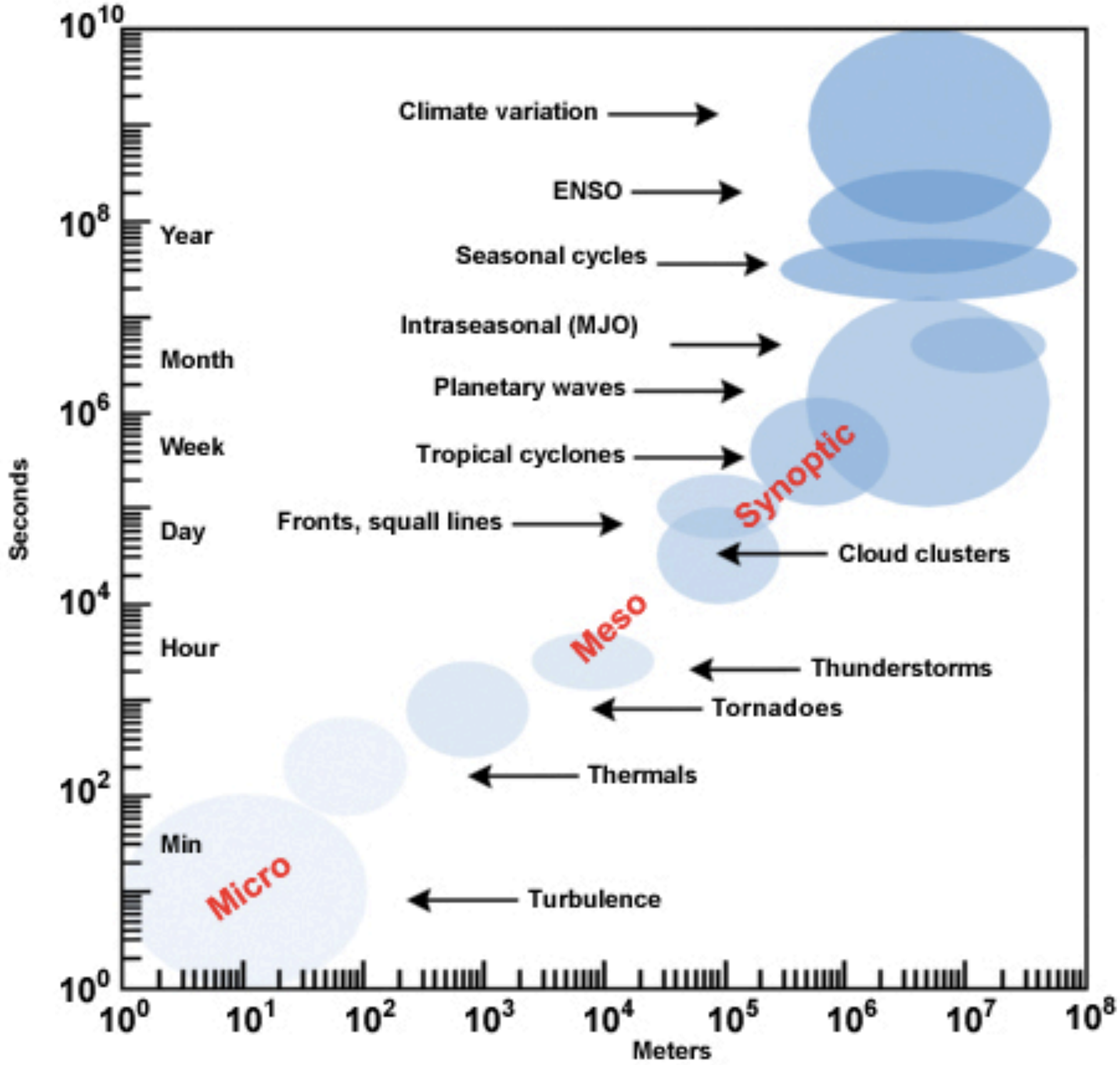
Adrian M Tompkins, ICTP
Tompkins@ictp.it



- ICTP Diploma – one year fully masters-like programme in earth system sciences.
- STEP – sandwich PhD programme. joint supervisors, 6 months visit each year
- Associate programme – junior to senior, 3 visits in 6 years.

- Oceangraphy
- Regional climate modelling
- Aerosols (REGCM)
- Teleconnections (Speedy)
- Health Applications (VECTRI)
- Hydrology (CHYM)
- Solid earth geophysics
- Computing





Climate variation
ENSO
Seasonal cycles
Intraseasonal (MJO)
Planetary waves
Tropical cyclones
Fronts, squall lines
Cloud clusters
Thunderstorms
Tornadoes
Thermals
Turbulence
Synoptic
Meso
Micro
Year
Month
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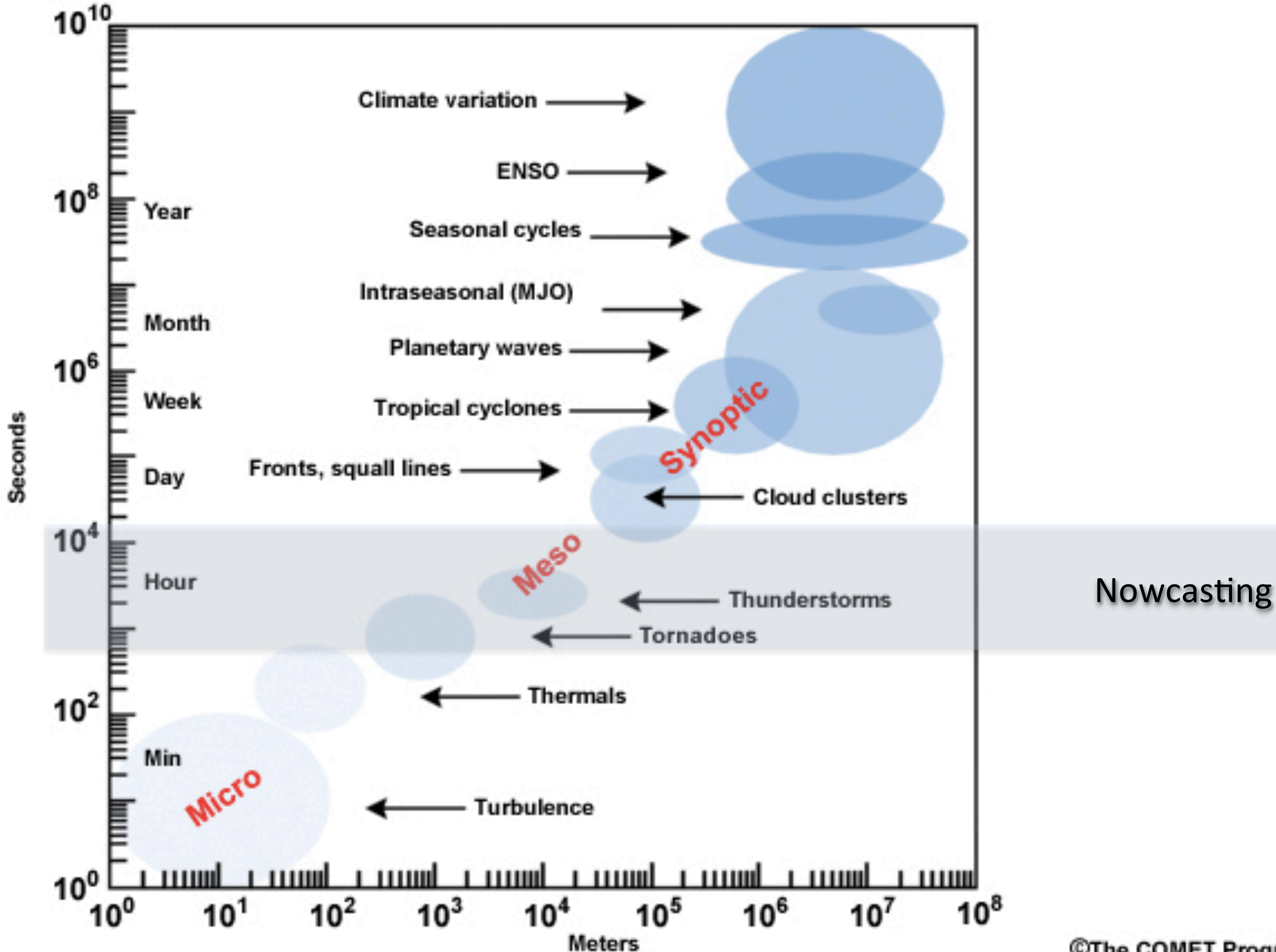

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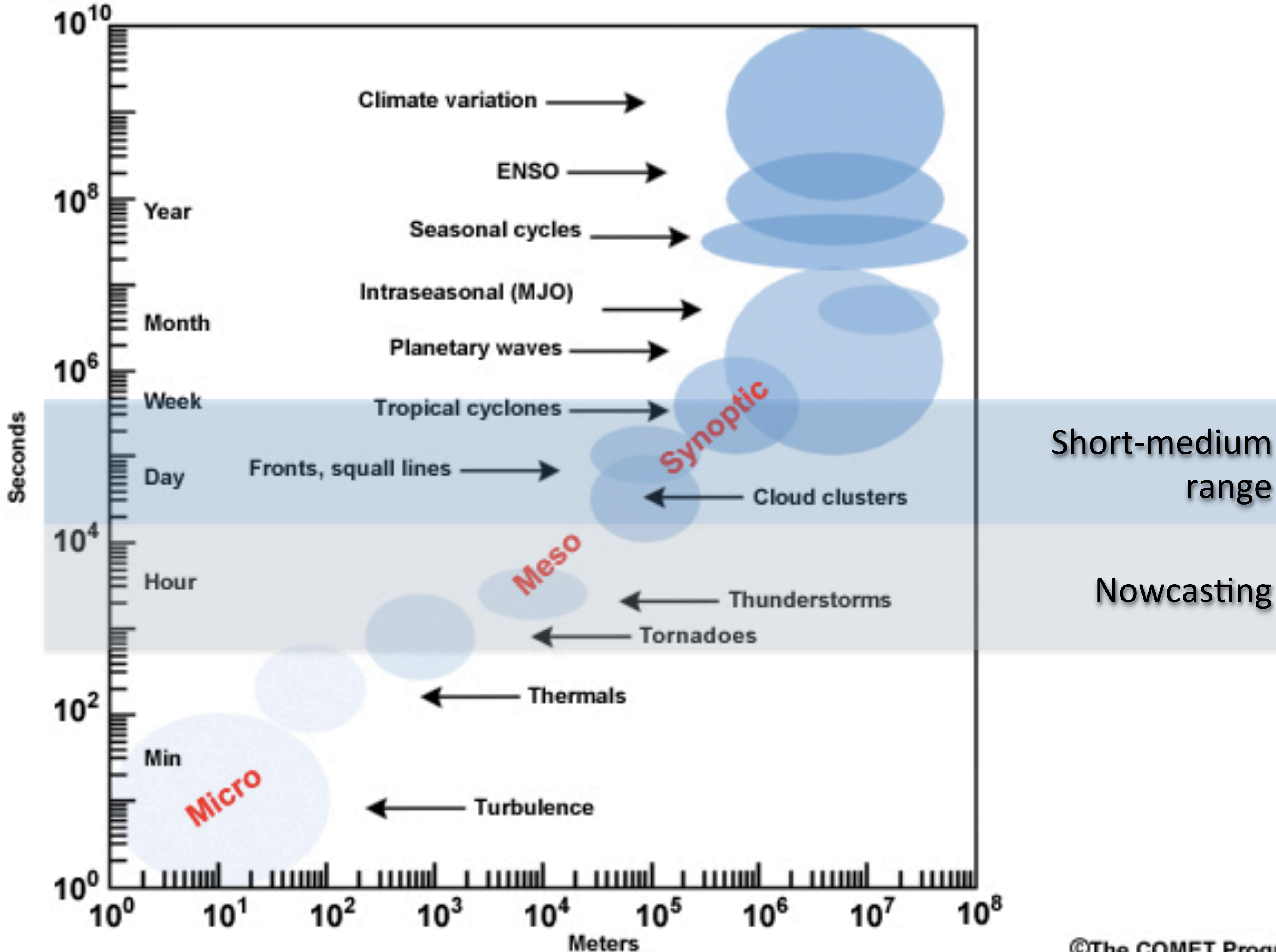
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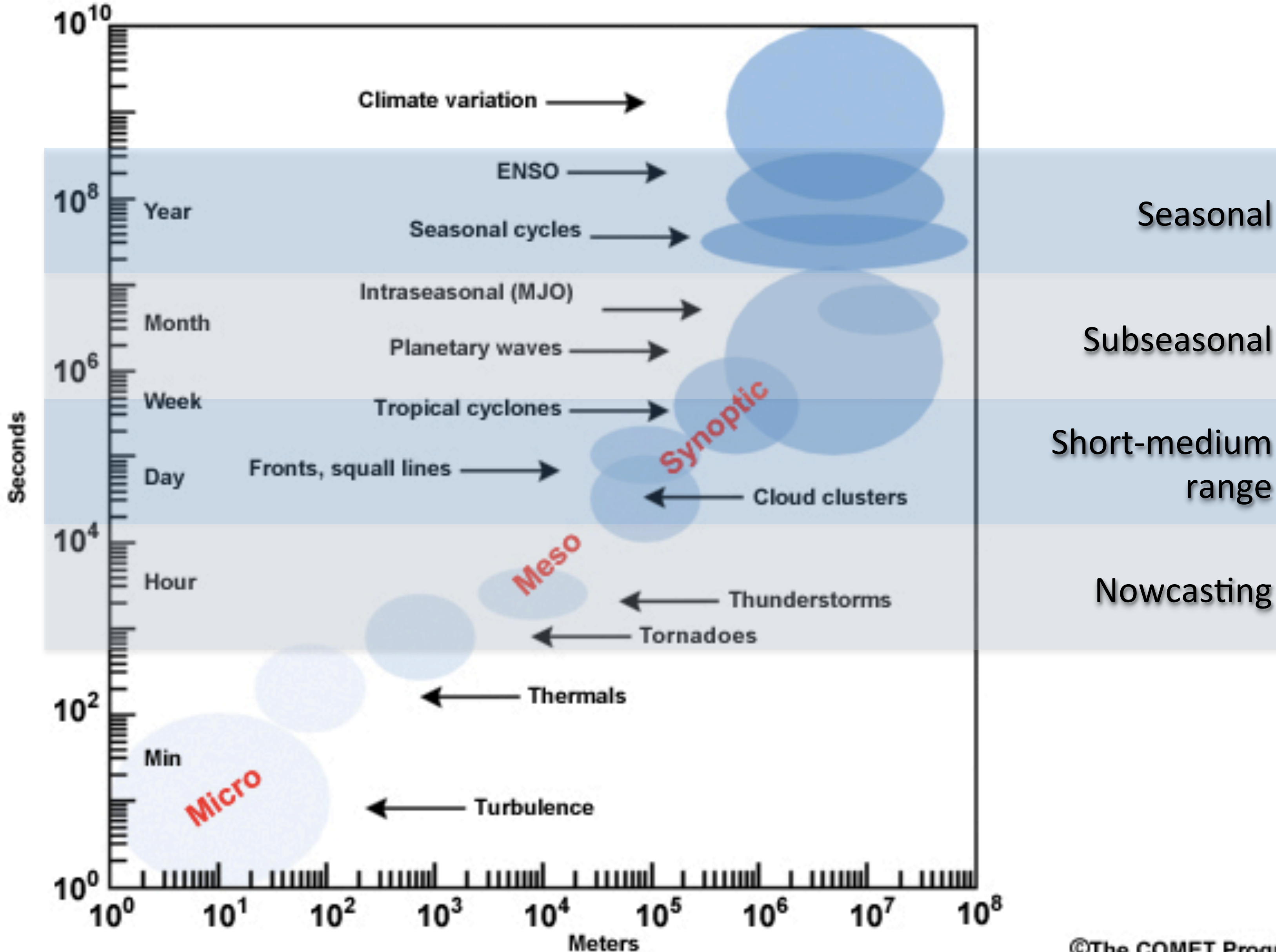
Short-medium range
Nowcasting



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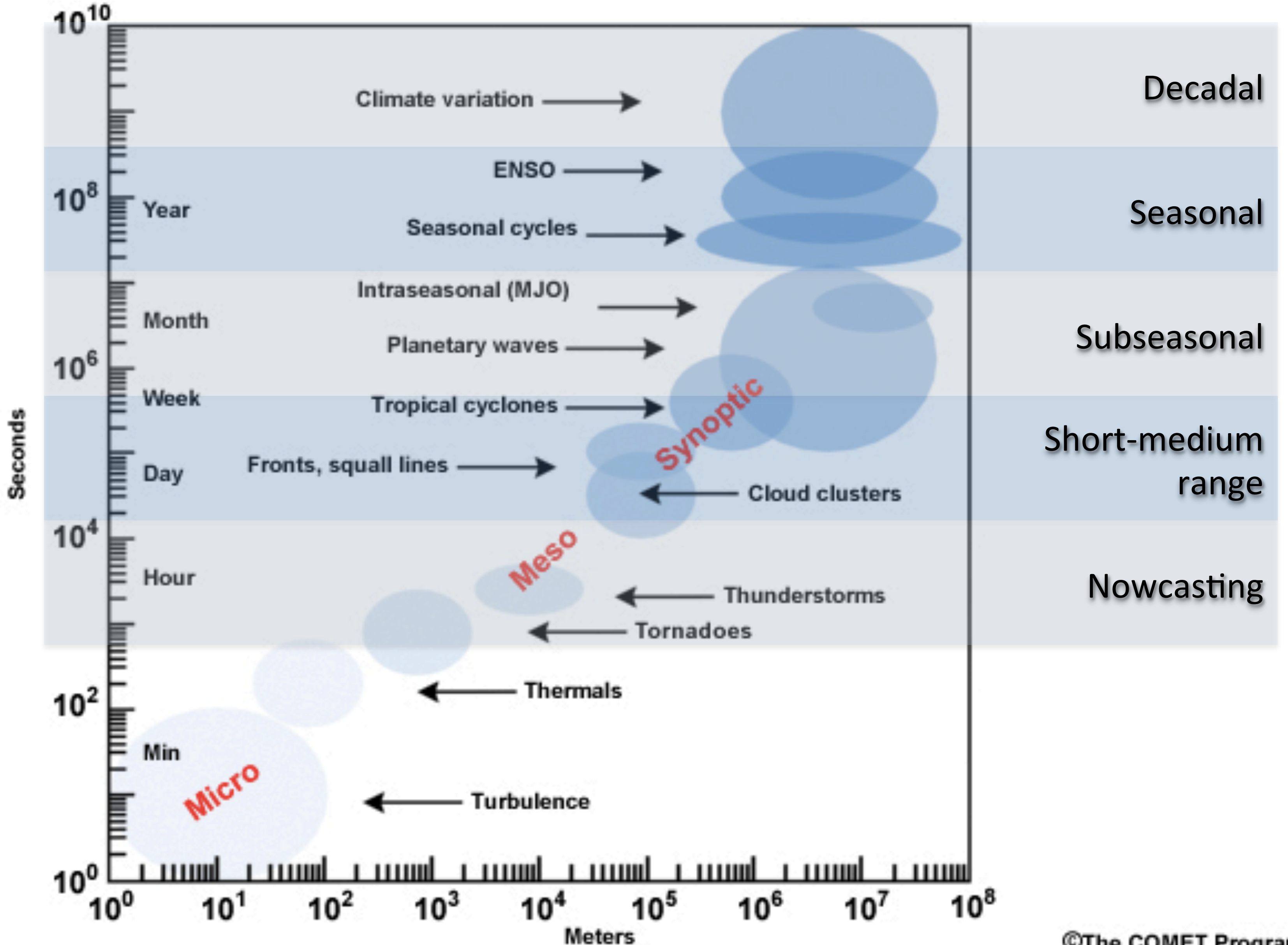
Meters
Seasonal
Subseasonal
Short-medium range
Nowcasting



Decadal
Seasonal
Subseasonal
Short-medium range
Nowcasting
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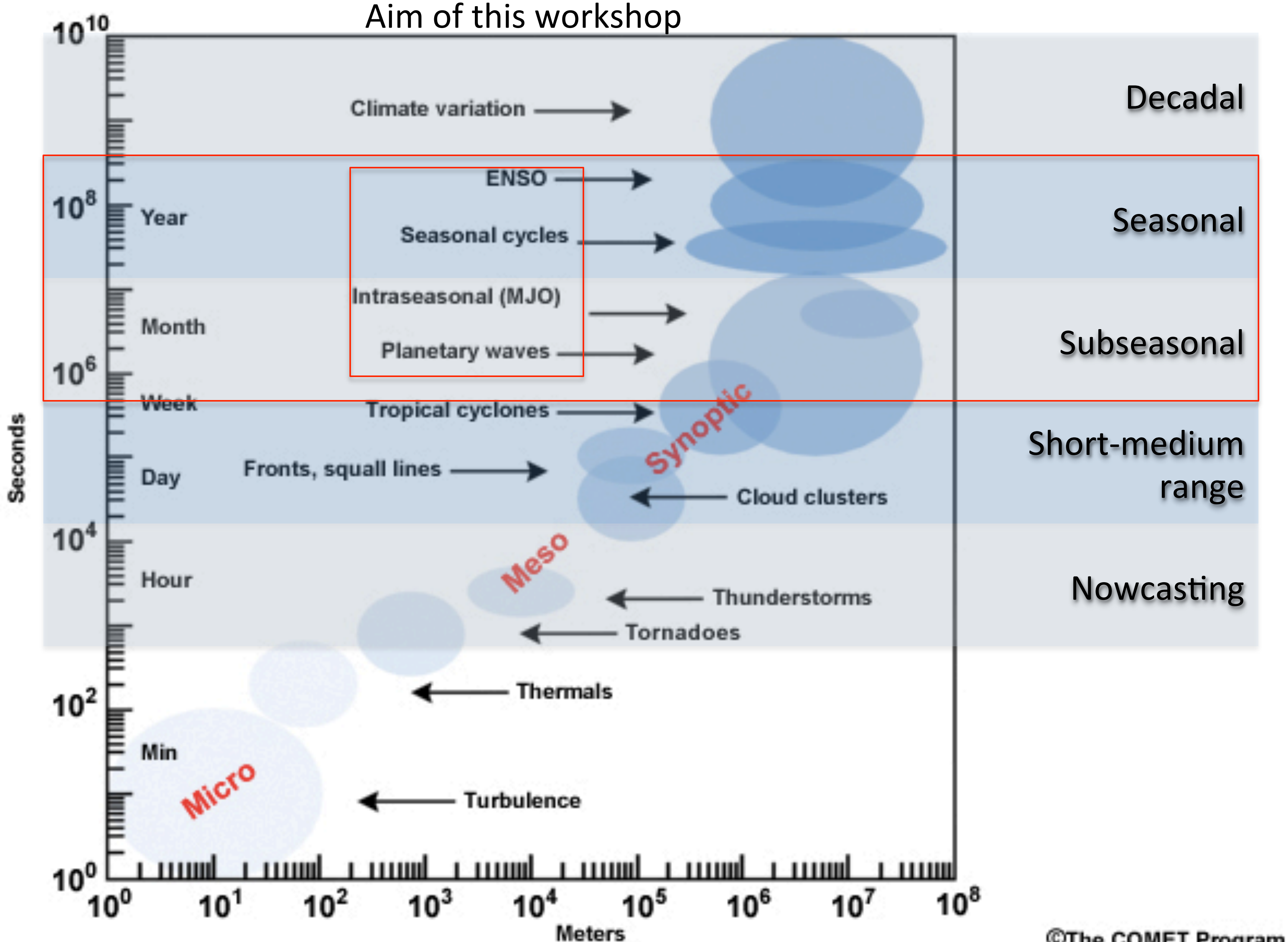
Aim of this workshop



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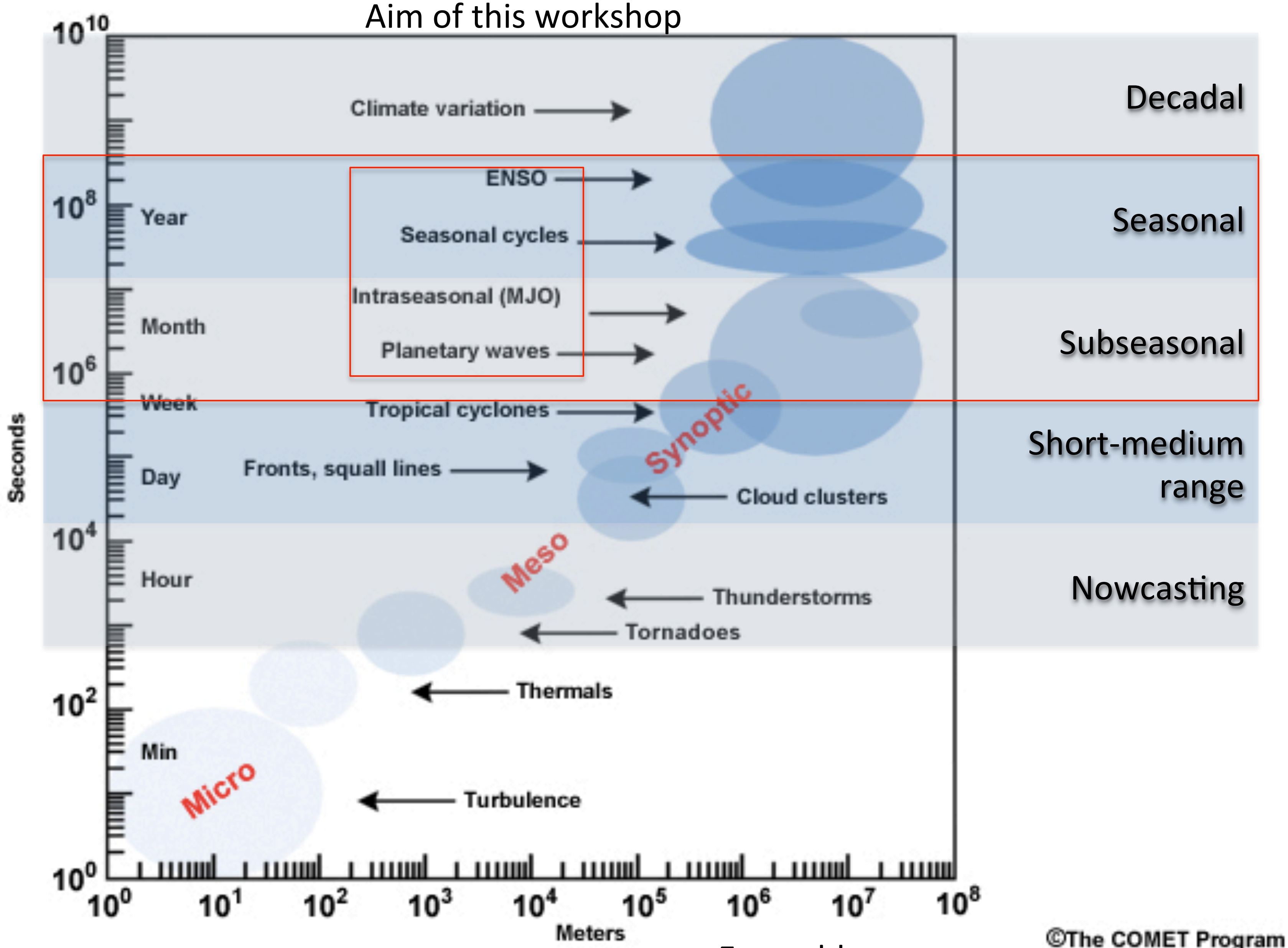


Need to consider:

- Ensembles
- Initialization
- Hindcasts

Aim of the School

- Introduce subseasonal phenomena that can lead to predictability (e.g. MJO, planetary waves)
- Give an overview of NWP systems
- Introduce the new S2S database at ECMWF
  - Explain the web interface
  - Show how to retrieve S2S datasets using python scripts
- Introduce observation databases (IRI) and the reanalysis dataset for evaluation
- Show examples of S2S applications in drought and flood forecasting
- Give you a chance to have hands-on experience at manipulating the S2S datasets in a series of lab classes
- Now: Uncertainty in forecasting systems, simple introduction to the way S2S and seasonal forecasting systems are set up... uncertainty

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

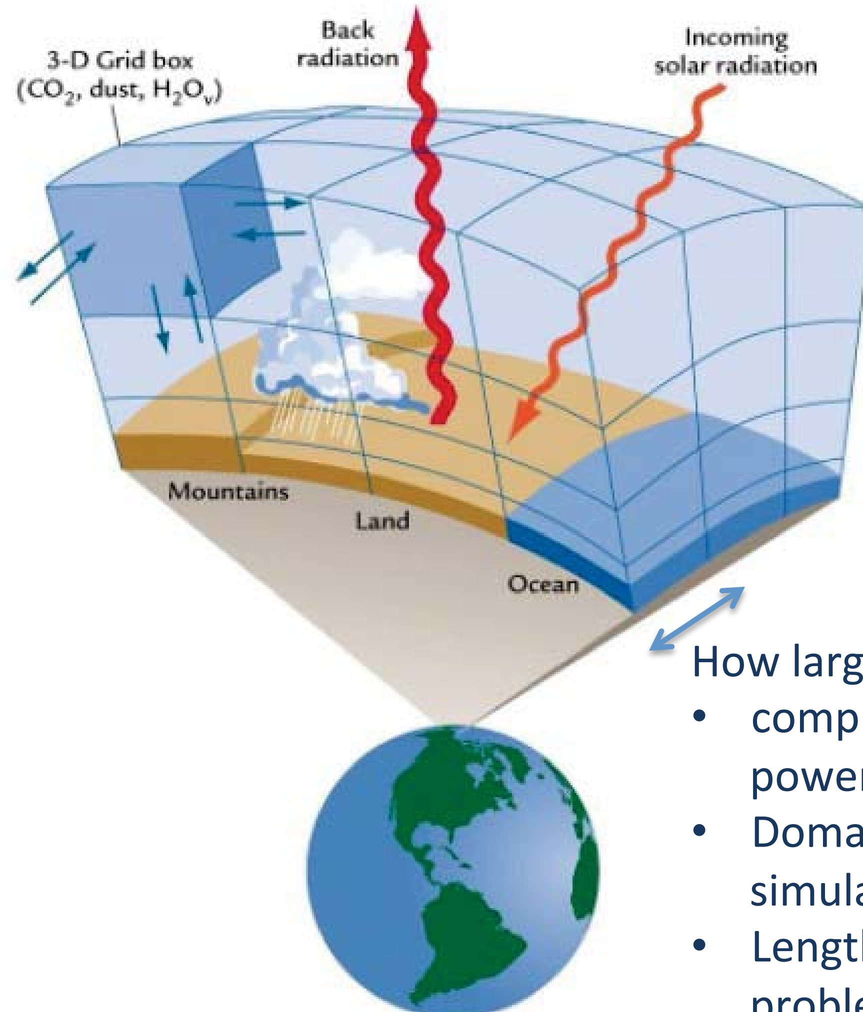
climate model equation set

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

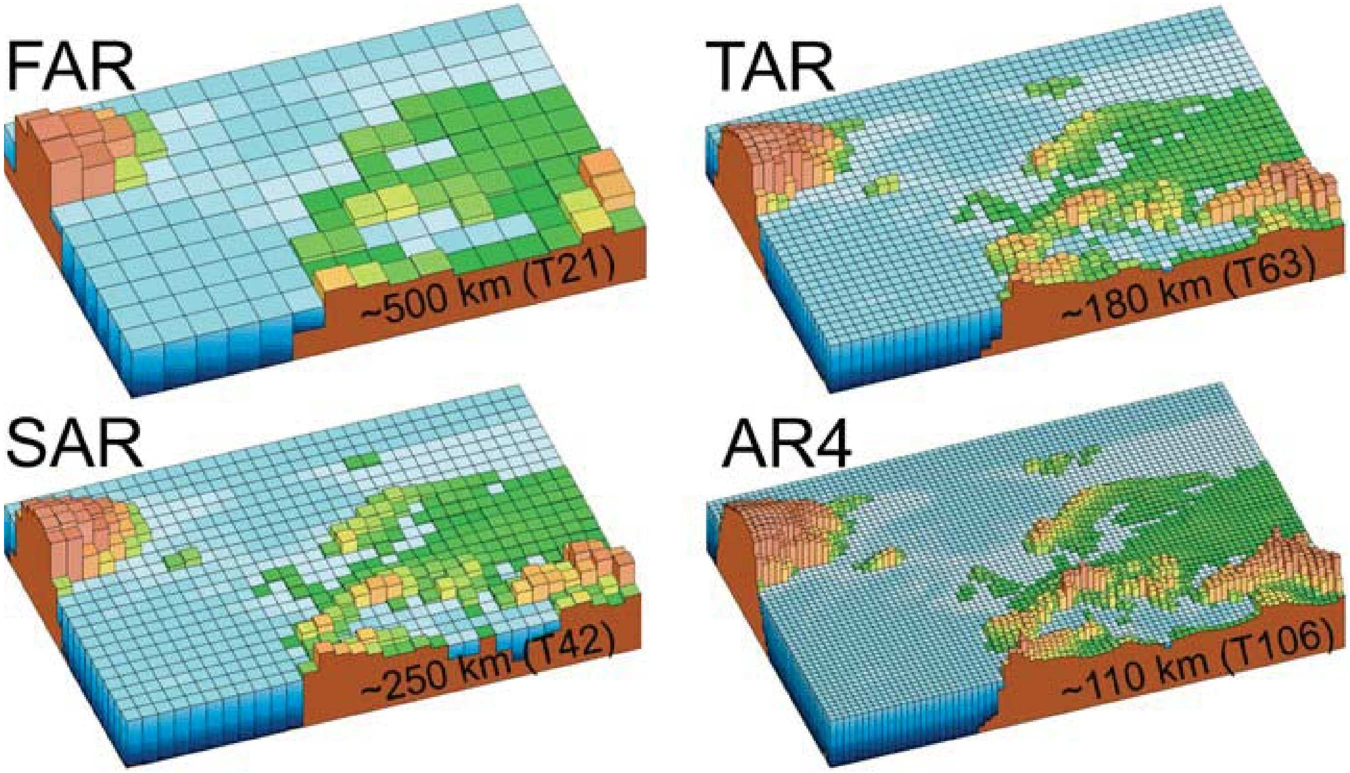
It is important to realize that for a continuous medium consisting of an ideal gas, (or mixture of ideal gases) these equations are derived from first principles and are certain.

The continium hypothesis

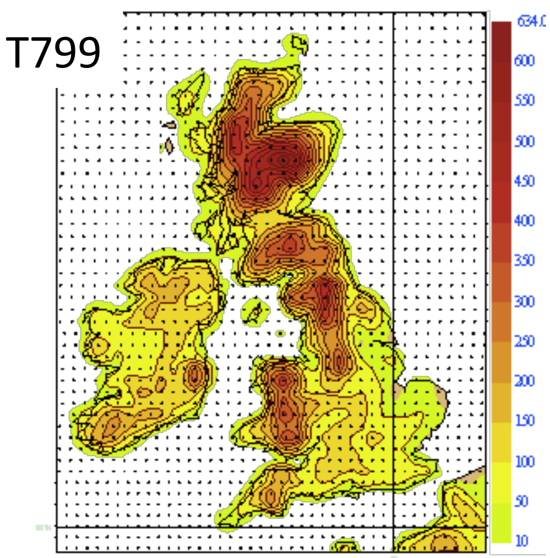
- Dividing the atmosphere into grid boxes
- Properties are considered uniform in each box
- Equations are integrated numerically forward in time

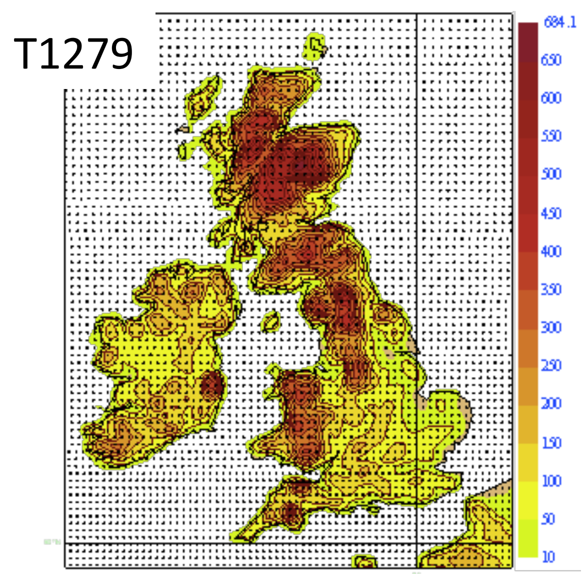


How large?
- computing power
- Domain of simulation?
- Length of problem (5 days forecast of 100 year climate projection?)



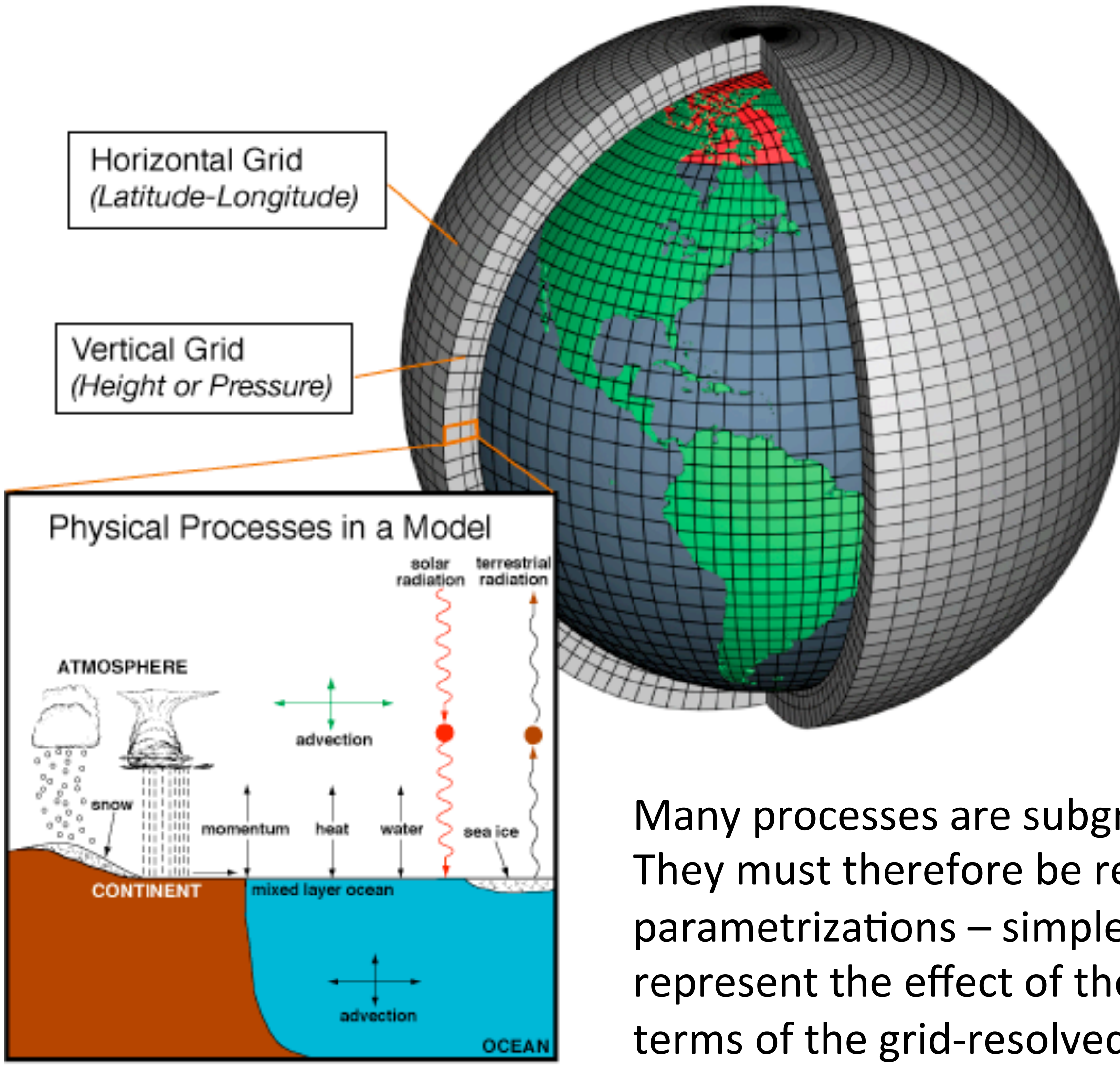
From climate model resolutions



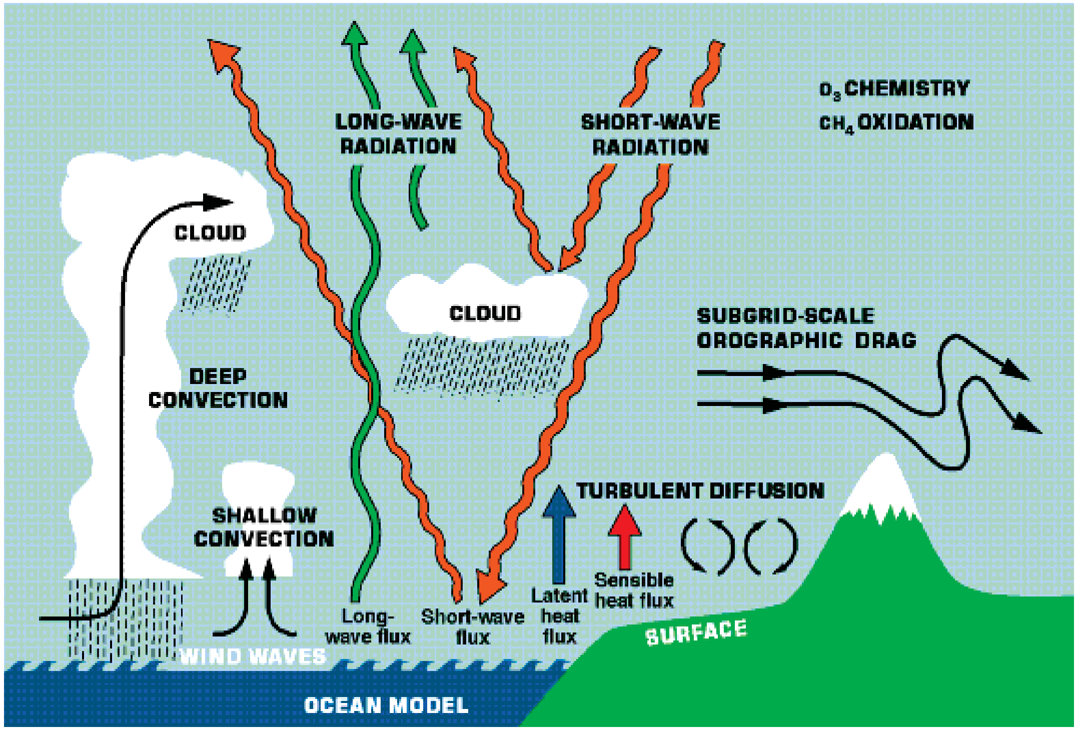


To medium range NWP

What is the issue concerning finite grid scales?

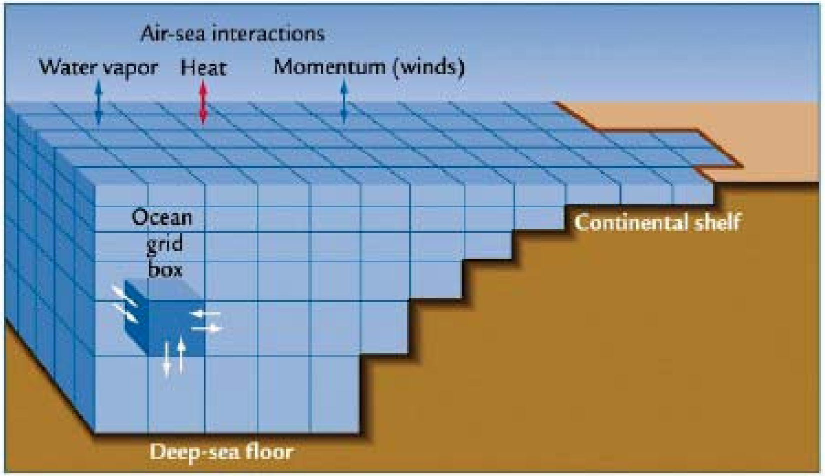


Many processes are subgrid-scale!
They must therefore be represented by parametrizations – simple models that represent the effect of the small scales in terms of the grid-resolved variables.



Key physical processes to be parametrized in NWP

Seasonal forecast and climate models also require representation of the ocean

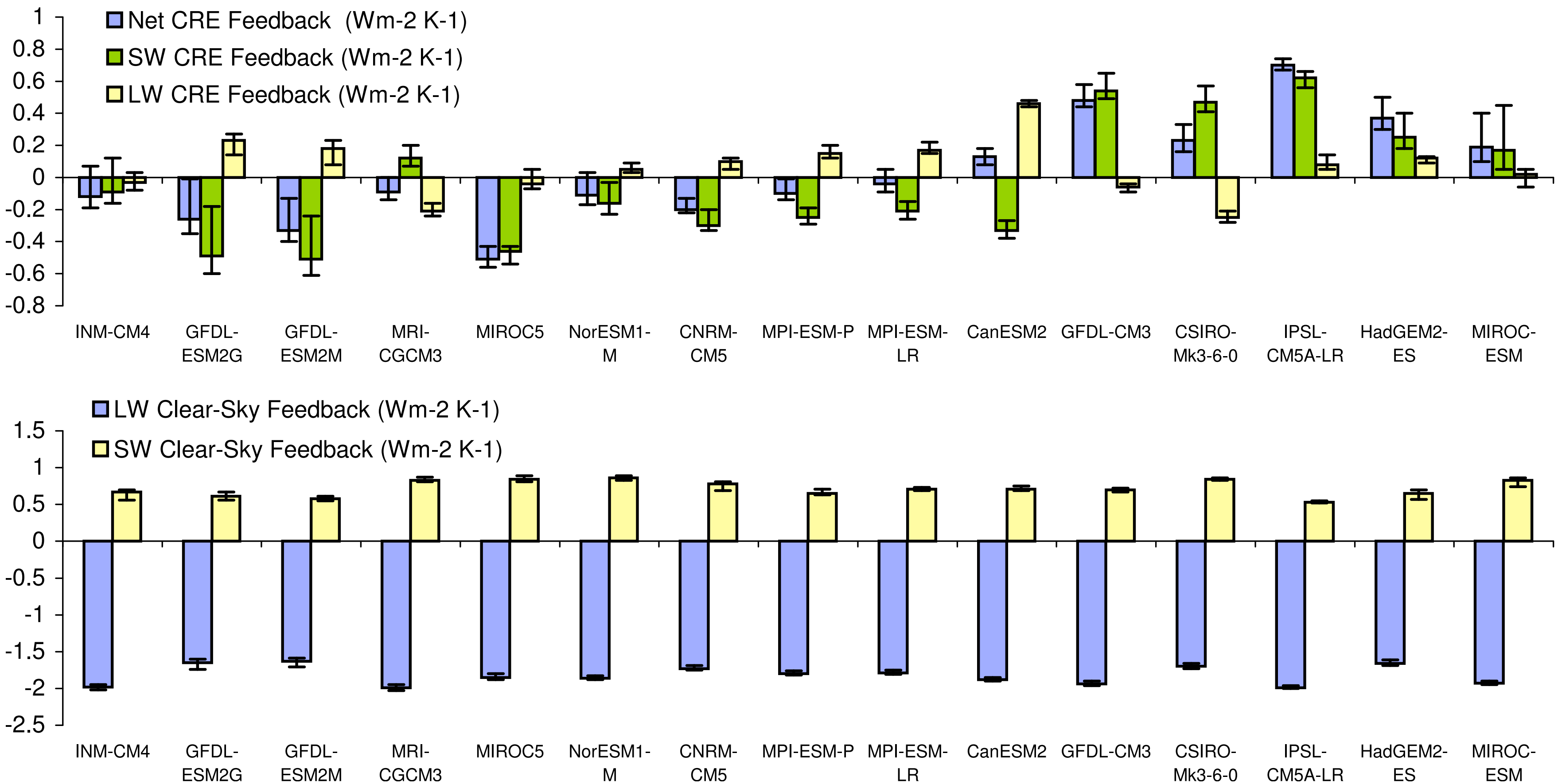


Again, in such models the effects of subgrid-scale and non-local turbulent transports need to be represented

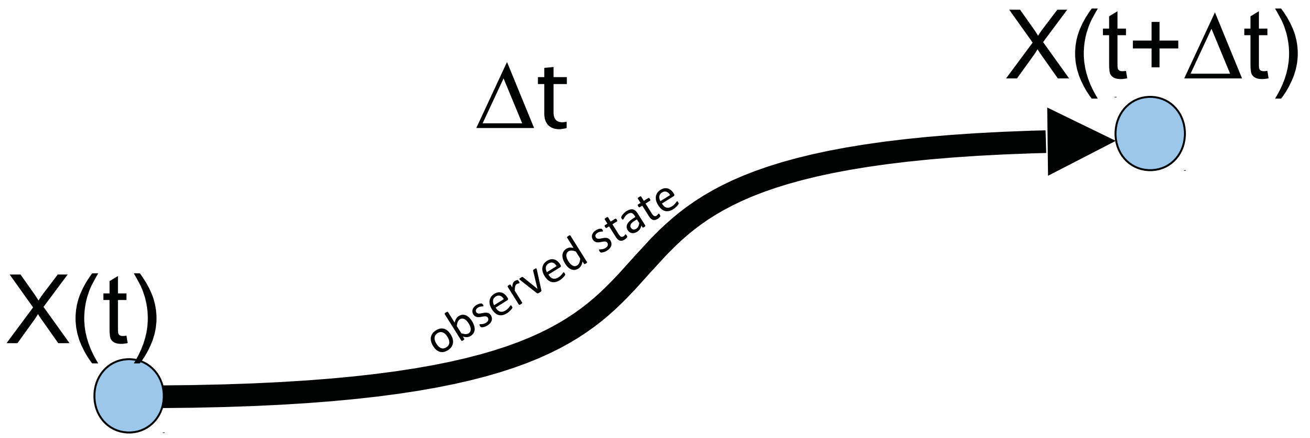
Parameterizations

- 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.

Example from Andrews et al. GRL (2012) shows the large differences between CMIP5 model cloud feedback relative to the clear-sky radiative feedbacks



This leads to uncertainty in forecasts due to an imperfect model



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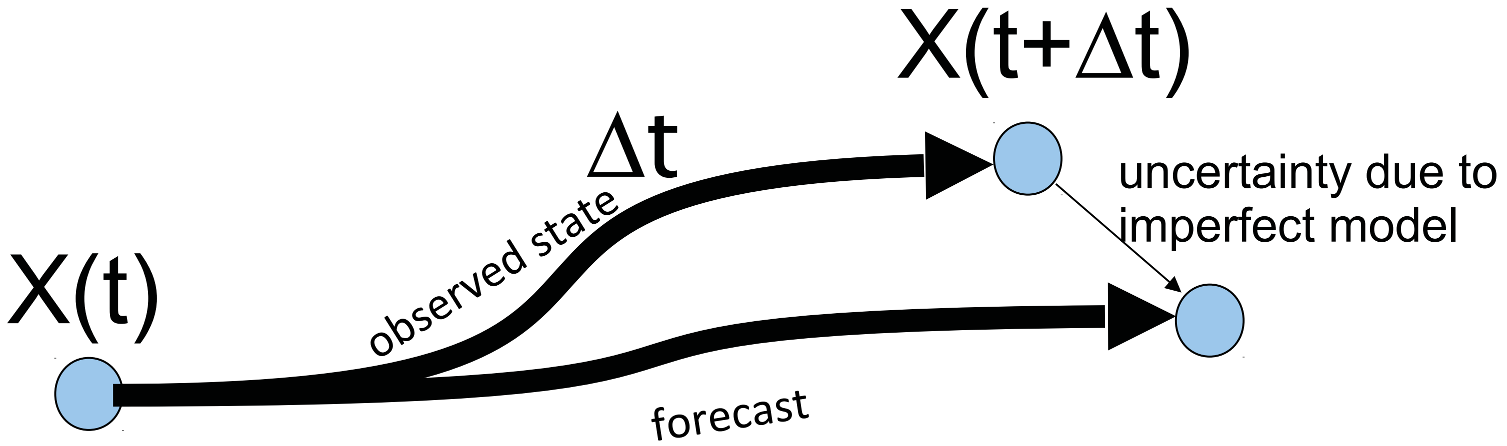
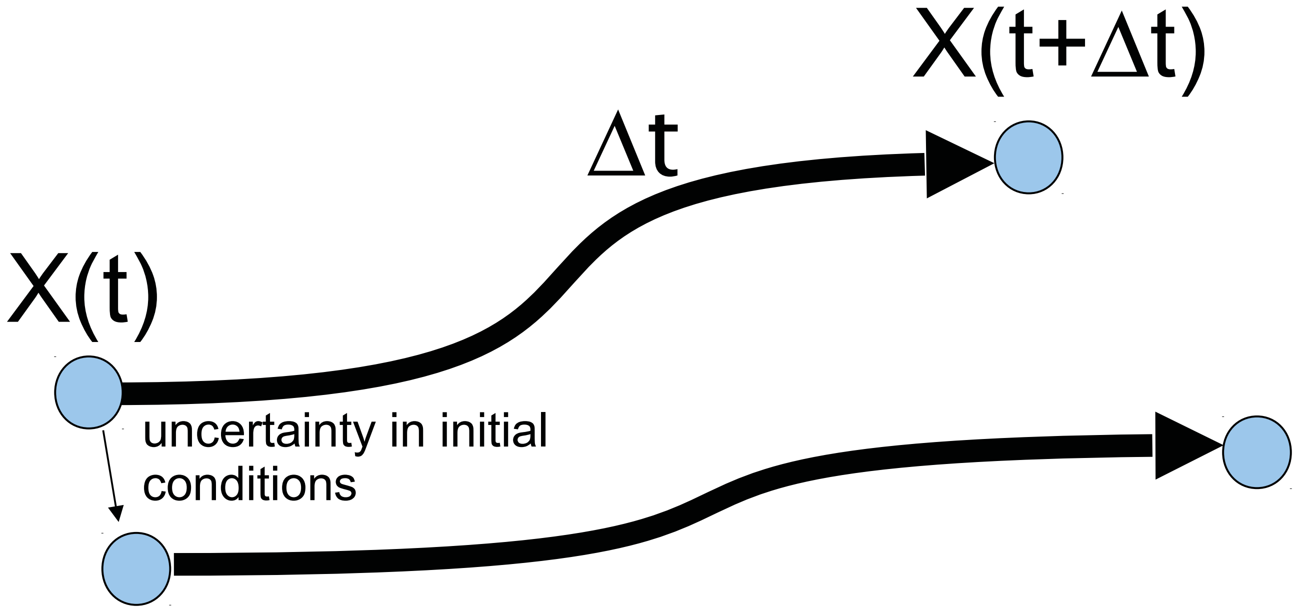
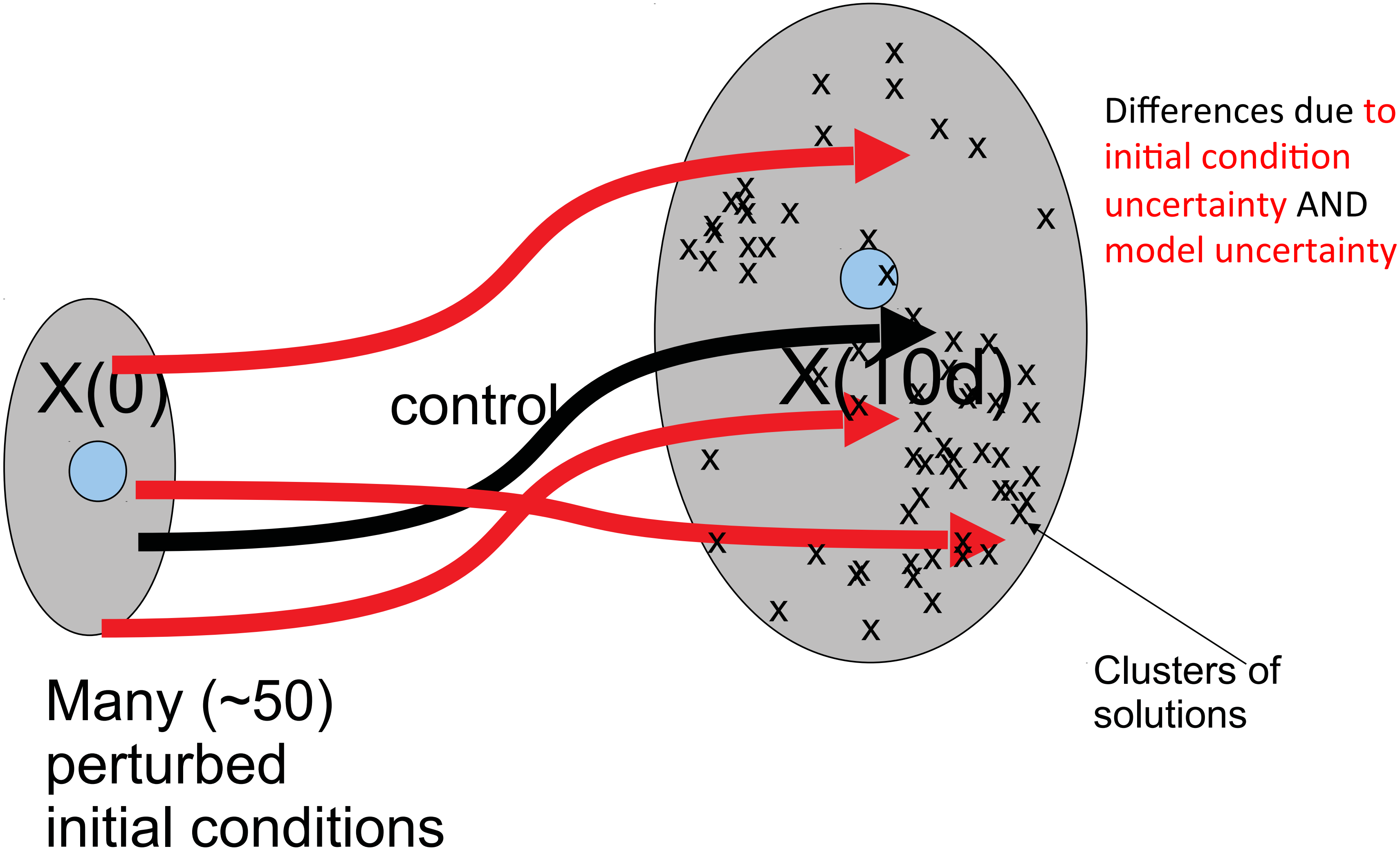


But uncertainty is also a result of inaccurate initial conditions

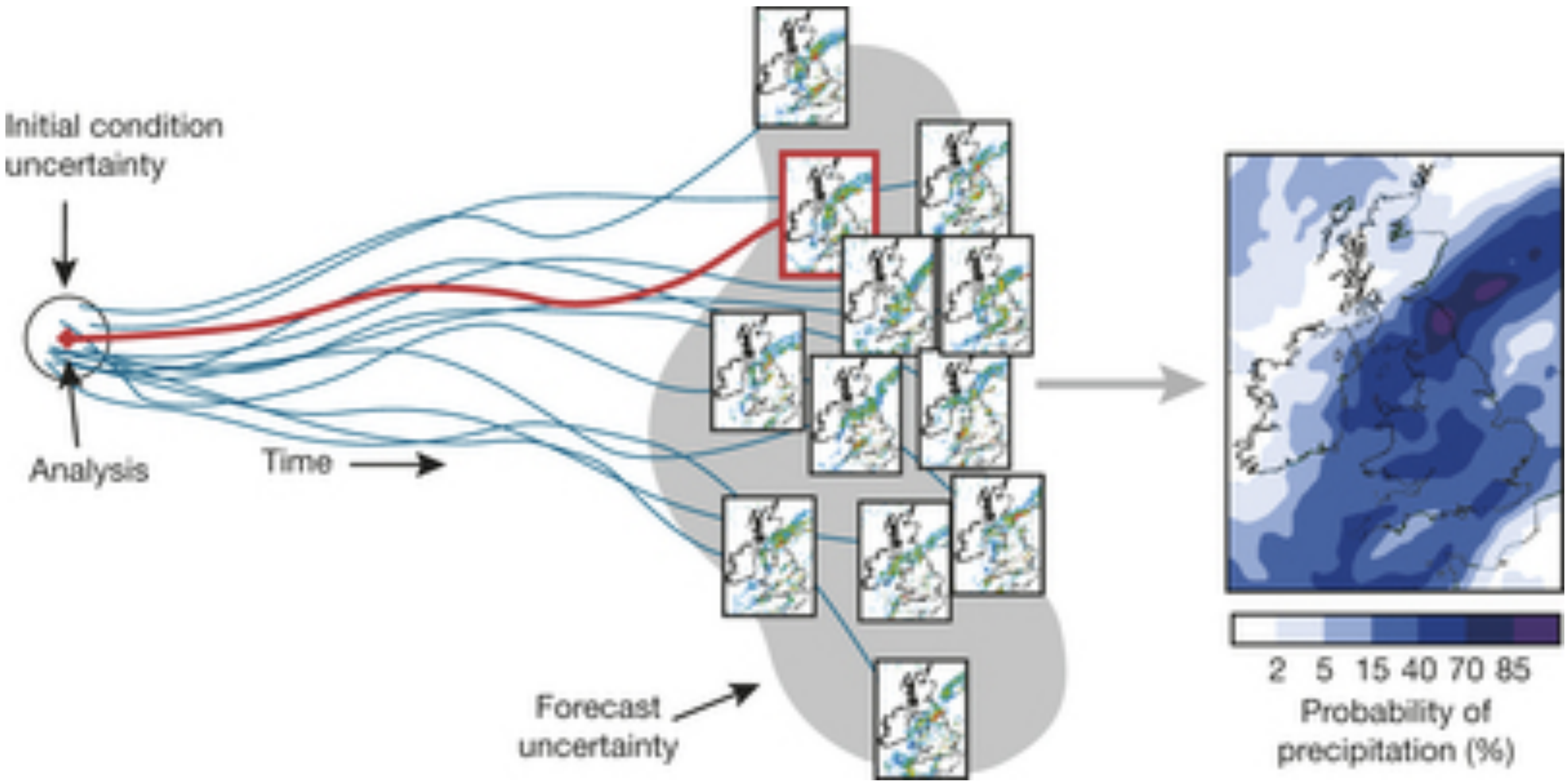


Question: how can we account for this uncertainty?

We run ensembles of forecasts...



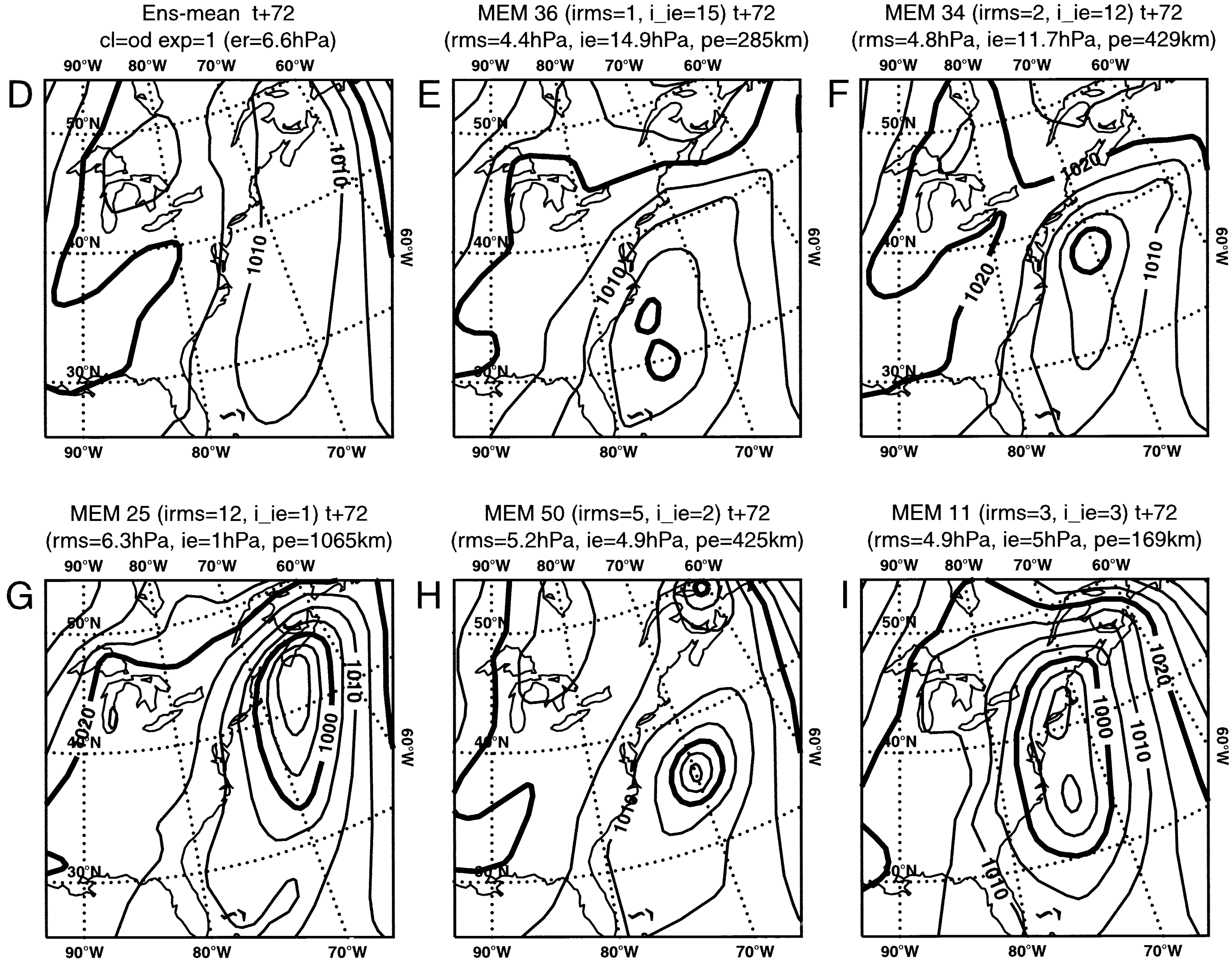
Example: Ensemble of rainfall predictions for UK



From Bauer et al. Nature 2015

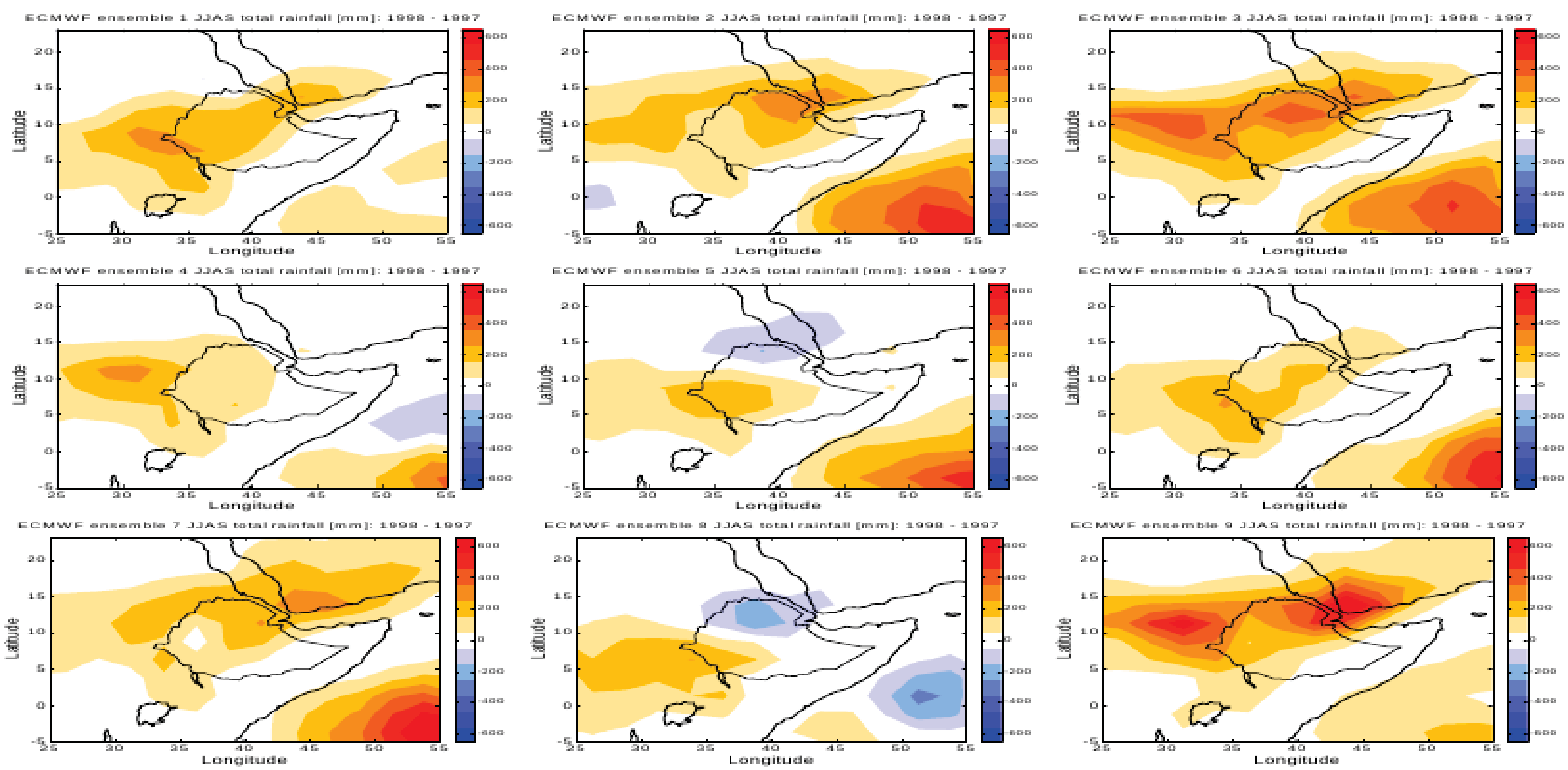
Example from short-range 3 day forecasts of the 2000 storms in USA

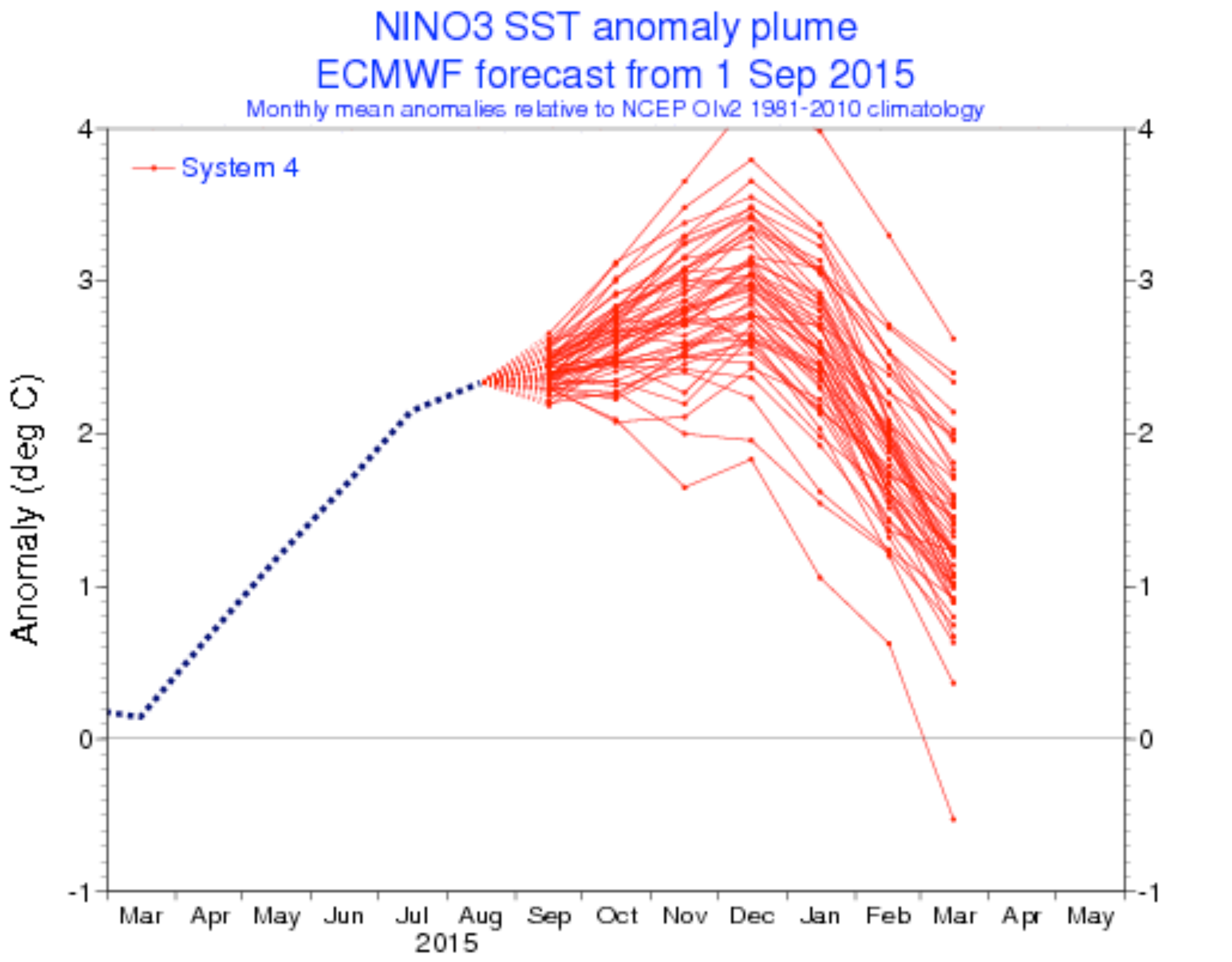
from Buizza and Chessa, 2002, MWR



Example from seasonal-range
Seasonal forecasts of rainfall over Ethiopia

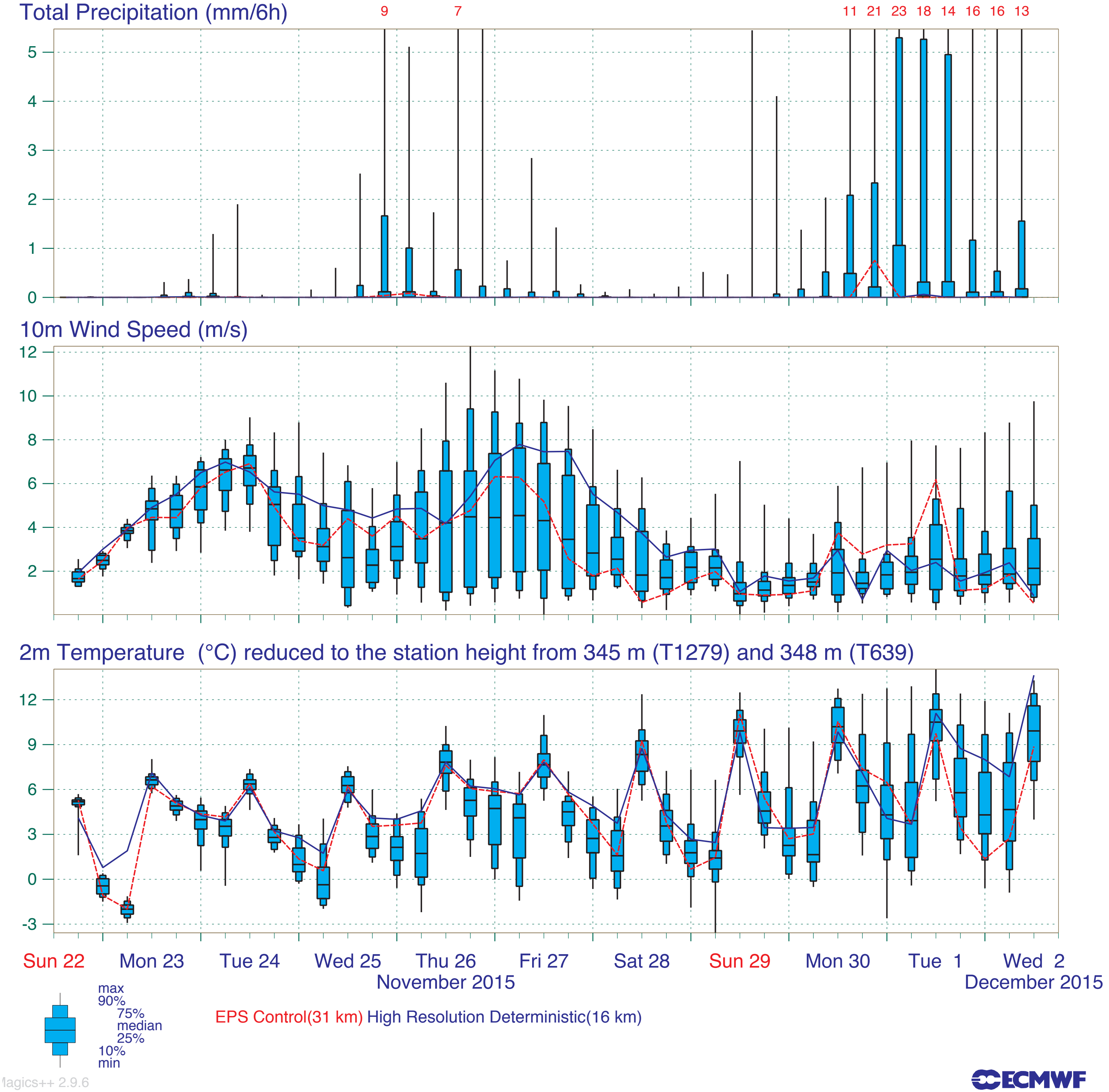
9 member regional model rainfall seasonal forecasts for East Africa (Diro et al. JGR 2012)





NINO3 SST anomaly plume
ECMWF forecast from 1 Sep 2015
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology
System 4
Anomaly (deg C)
4
3
2
1
0
-1
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
2015
ECMWF

Forecast for Trieste

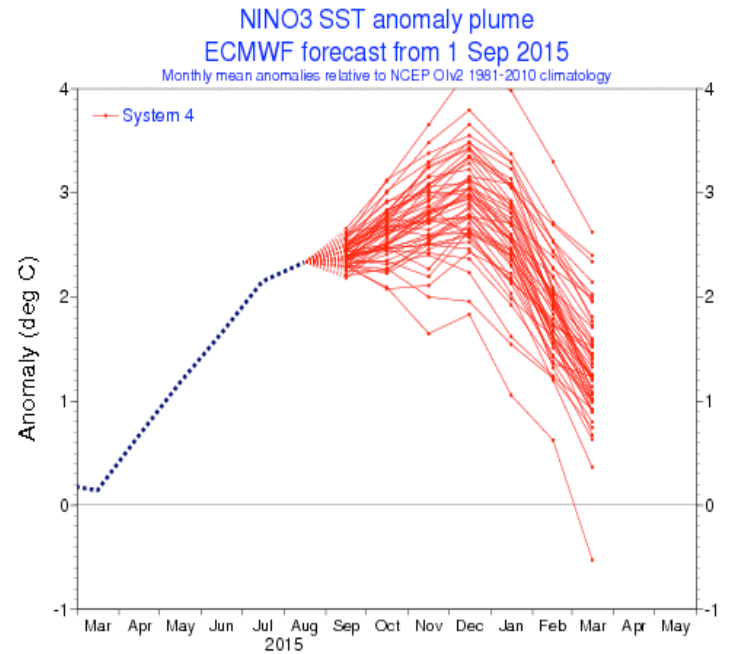


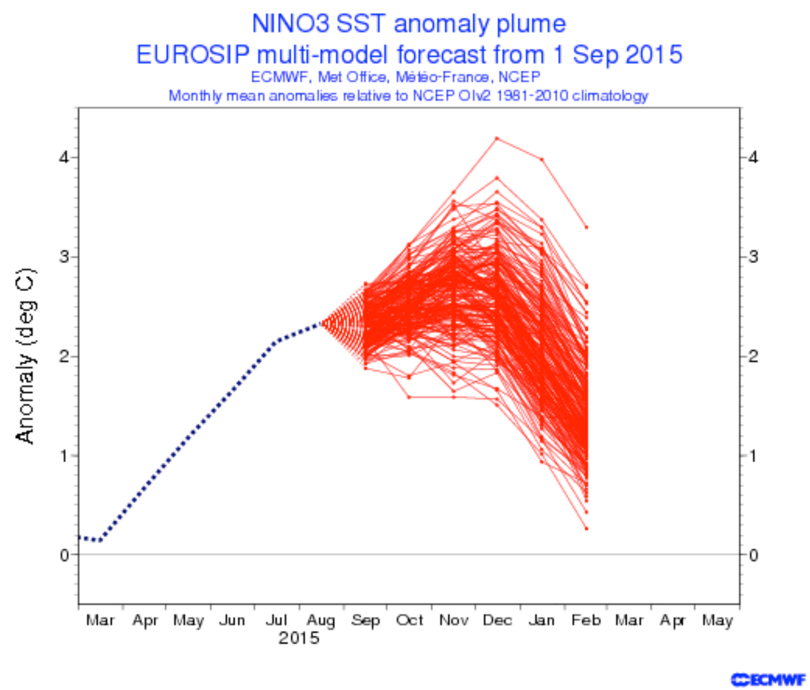
Initial conditions and model uncertainty

- Perturbations to initial conditions
  - Random perturbations (size, location)
  - Targeted perturbations (Breeding, singular vector techniques)
  - Ensemble data assimilation
- Perturbations to model physics
  - Parameter settings or parametrization choices
  - Stochastic physics
- Combination of both the above: Multimodel Systems!

Uncertainties in model physics and initialization: Multimodel systems

- Seasonal forecasts:
  - Eurosip (ECMWF, MeteoFrance, NCEP, Met Office)
  - North American Multi Model Ensemble NMME
  - CHFP database of hindcast suites
- Subseasonal Forecasts:
  - S2S database at ECMWF
  - Planned for 2016: NMME S2S systems
- Medium Range
  - TIGGE database at ECMWF





NMME ENSO Example

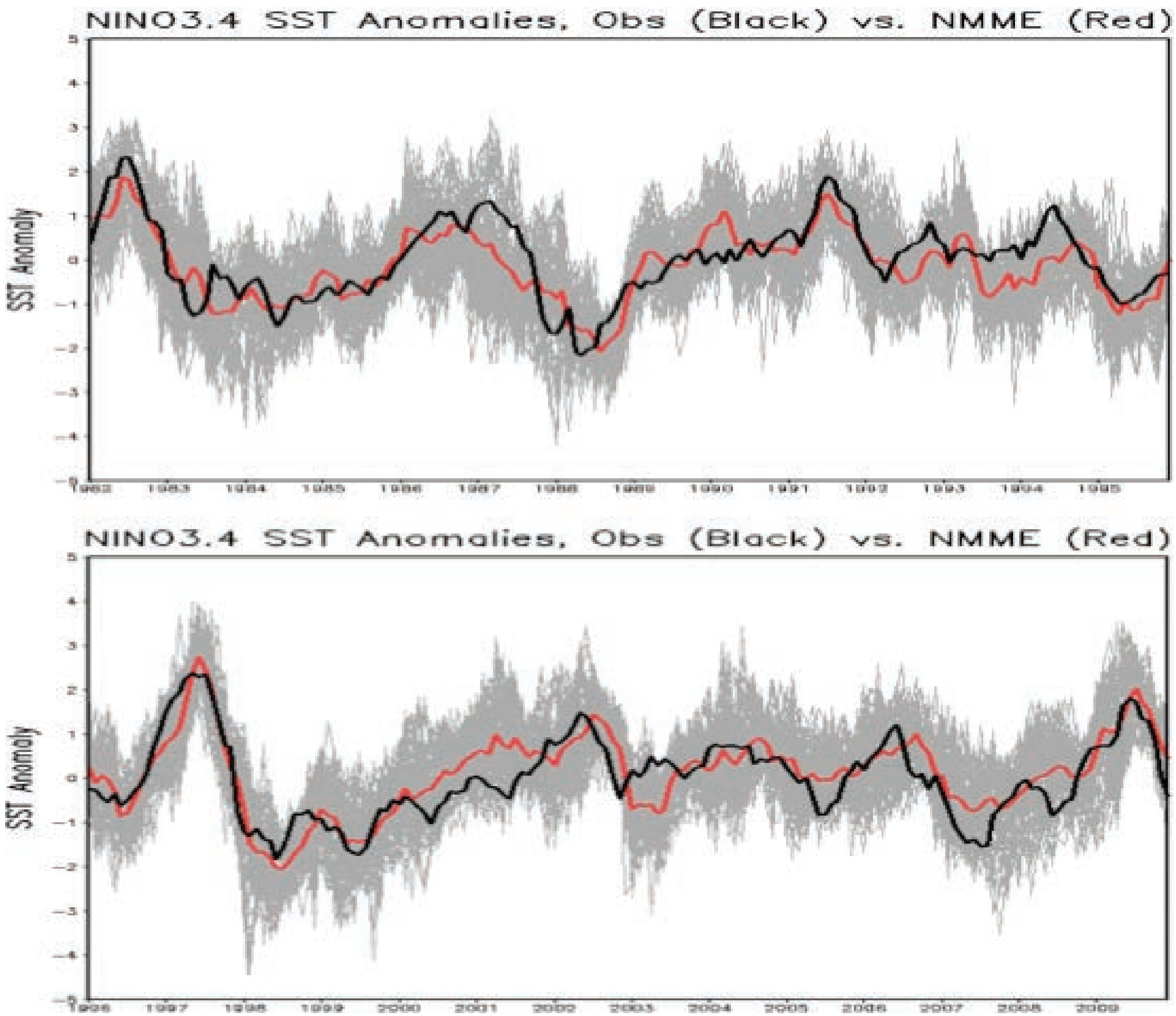


Fig. 2. As in Fig. 1, but for 6.5-month lead.

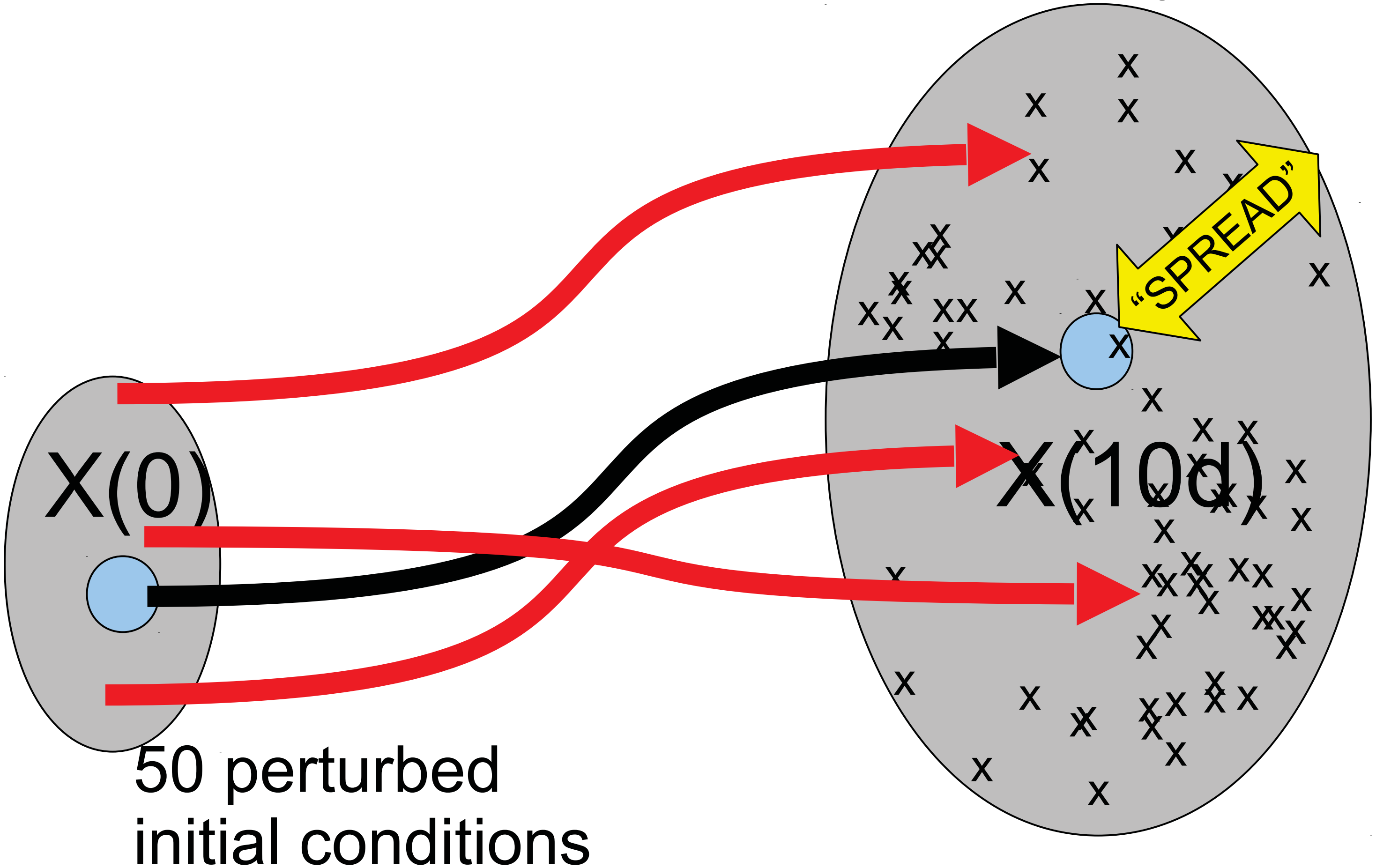
Table 1. NMME partne

Model
CFSv1
CFSv2
GFDL Climate Model, version 2.2 (GFDL CM2.2)
IRI-ECHAM4f*
IRI-ECHAM4a*
CCSM3
Goddard Earth Observing System, version 5 (GEOS5)
Third Generation Canadian Coupled Global Climate Model (CMC1-CanCM3)
Fourth Generation Canadian Coupled Global Climate Model (CMC2-CanCM4)

*=deceased

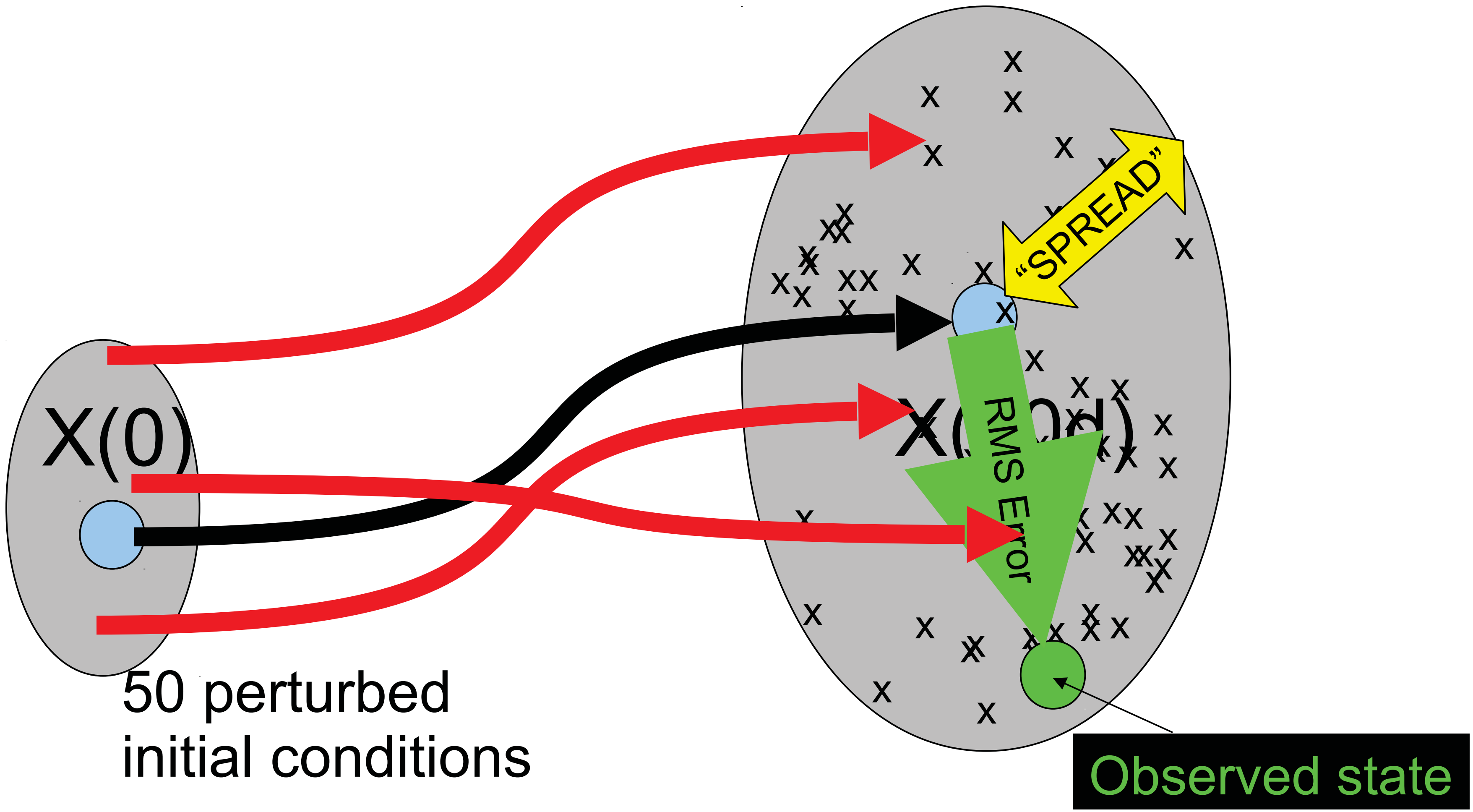
From Kirtmann et al. BAMS 2014

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

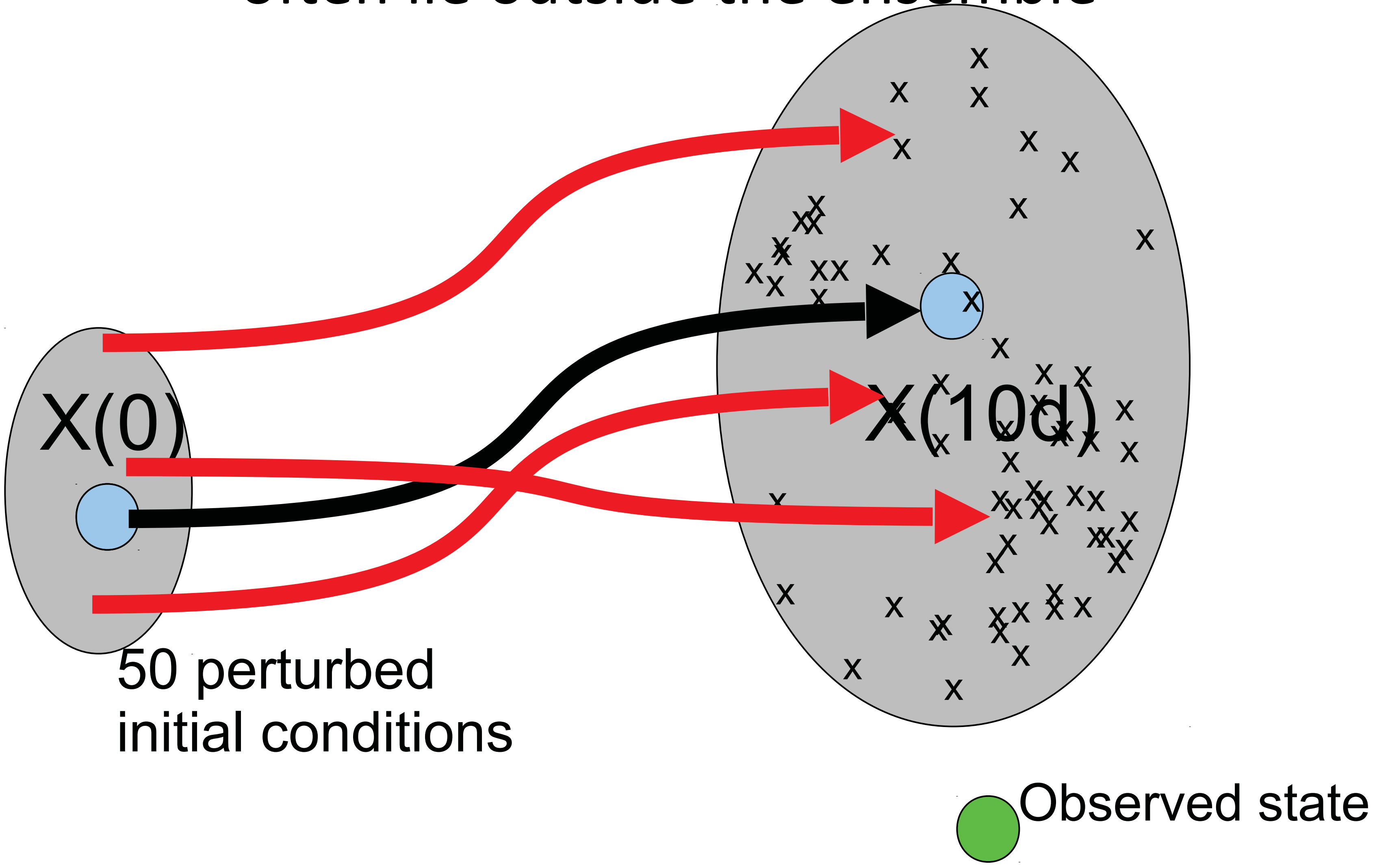


QUESTION: How large should the spread be?

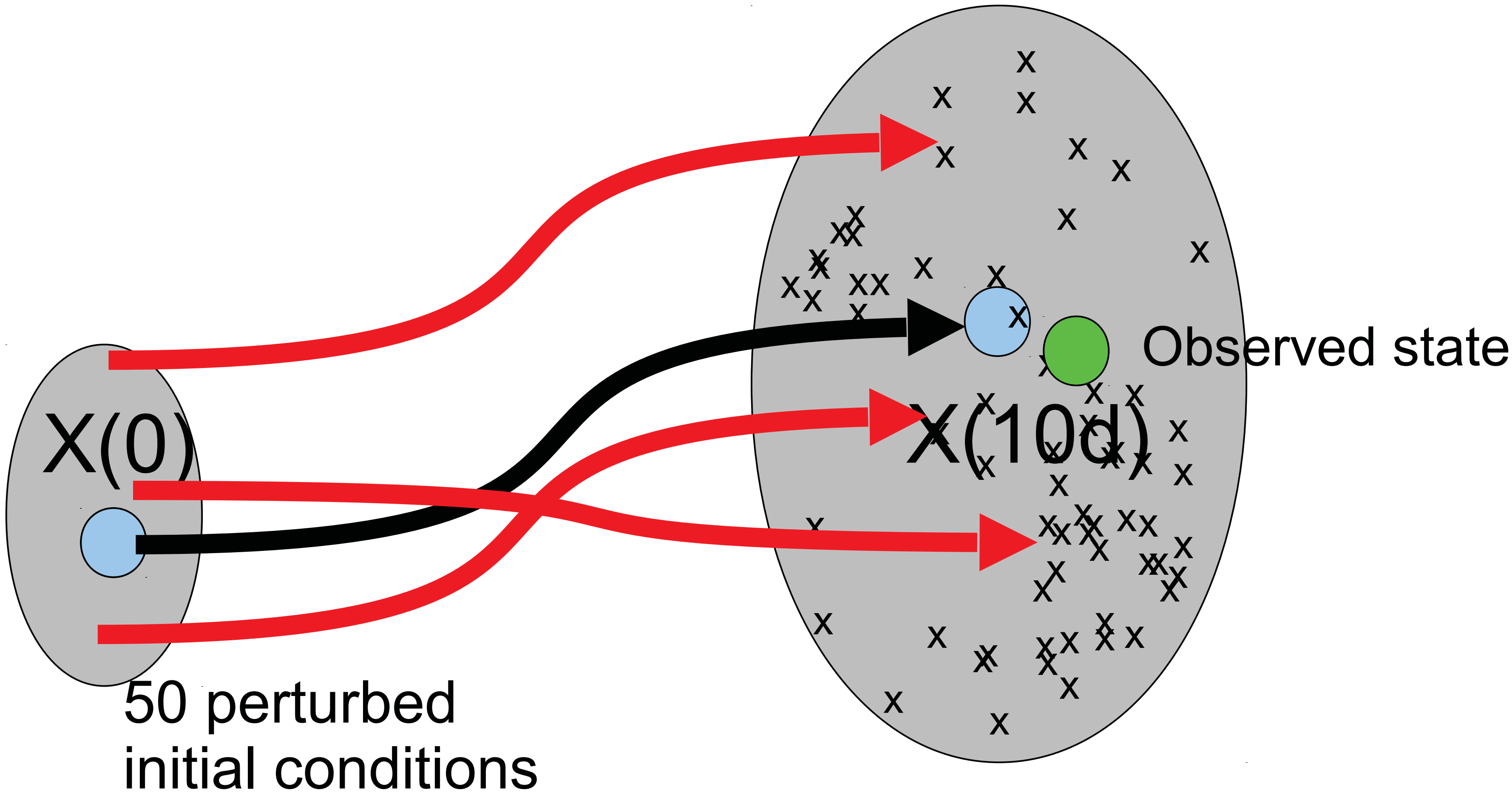
In general, for any given forecast lead time, we want the spread to be comparable to the RMS forecast error

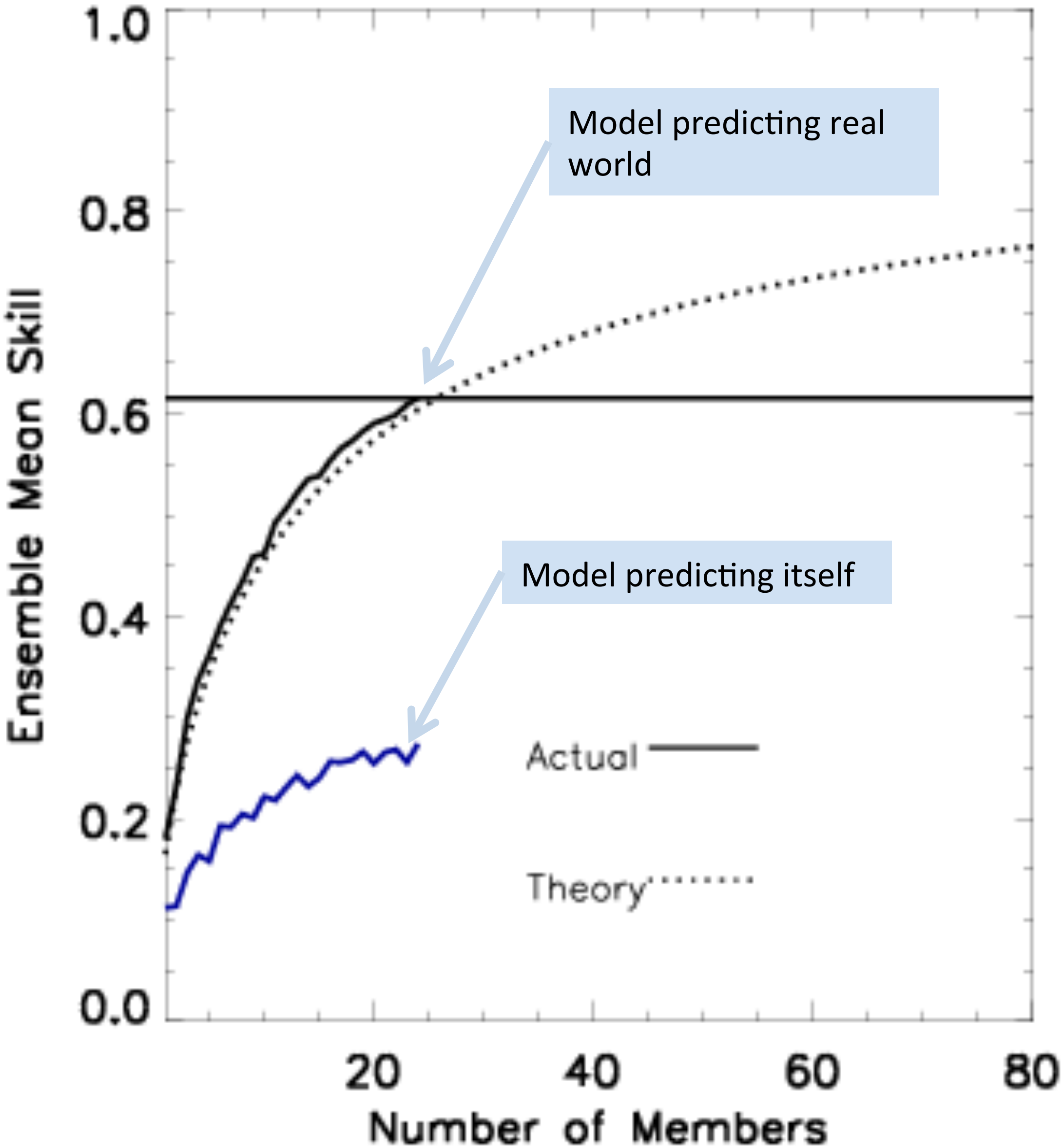


“Over-confident” forecasting system – observations often lie outside the ensemble



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

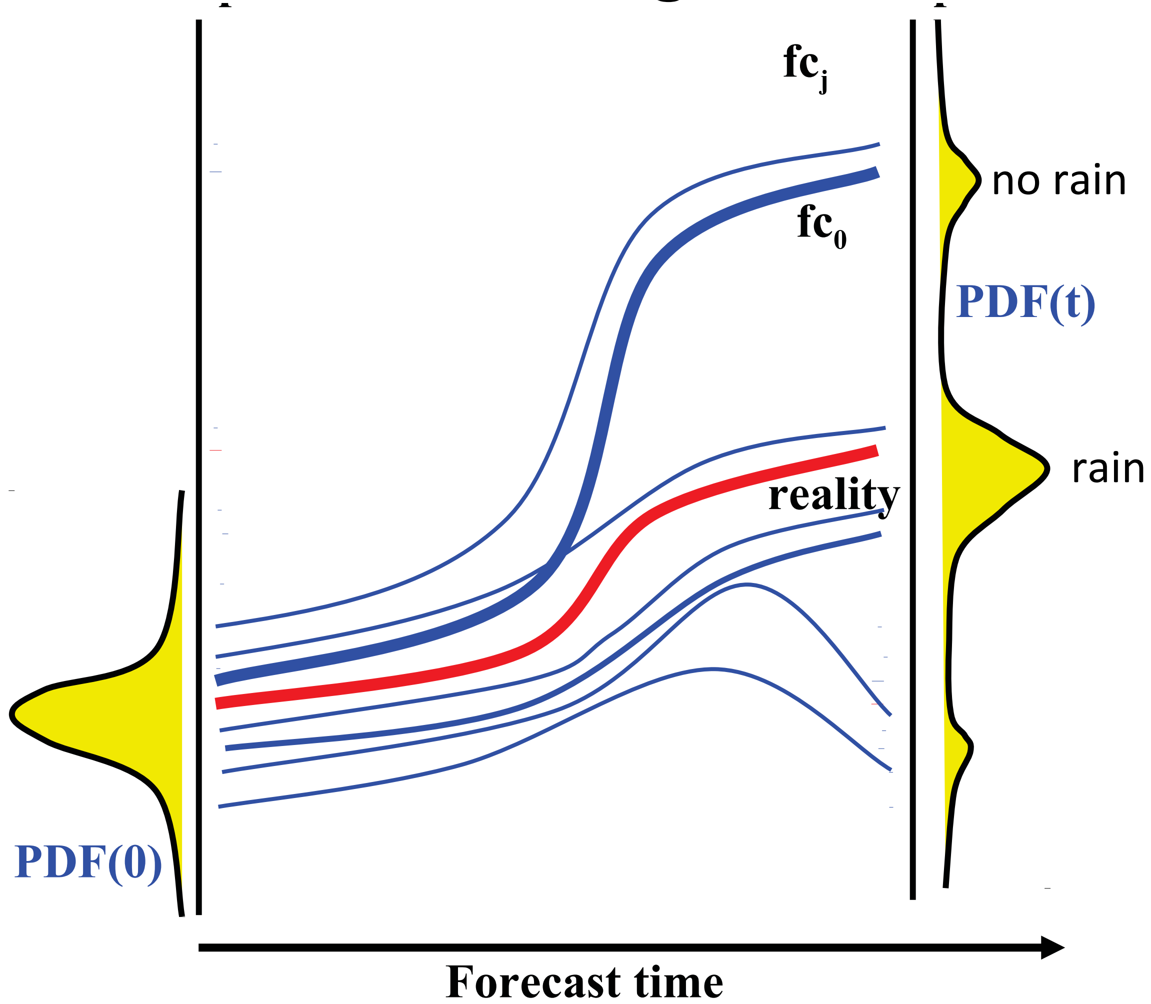




- Correlation skill score of ensemble mean forecasts of the NAO
- Model predicting itself is worse than model predicting observations of NAO.
- Interpretation is that model ensemble is under confident
- Larger ensemble sizes are beneficial

Figure courtesy of Doug Smith Met Office – see Scaife et al 2014, Eade et al 2014 for details

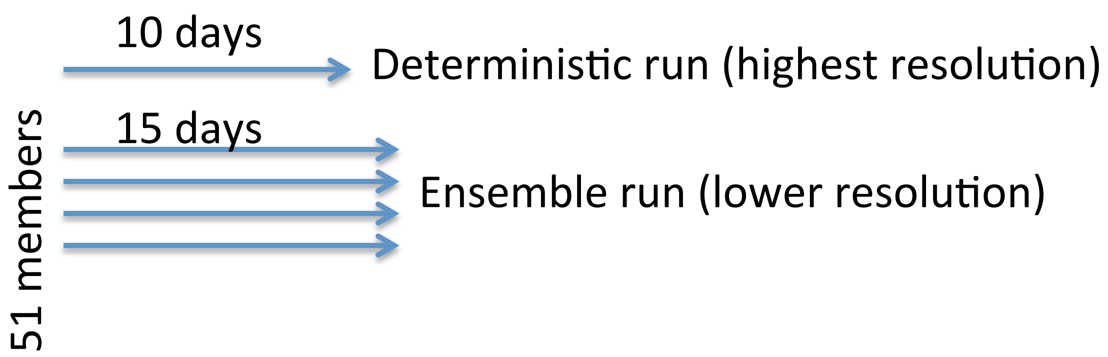
QUESTION: forecast states 70% chance of rain – and it rains – is this a good forecast?



An introduction to S2S timescales: The ECMWF framework

10 days → Deterministic run

An introduction to S2S timescales: The ECMWF framework



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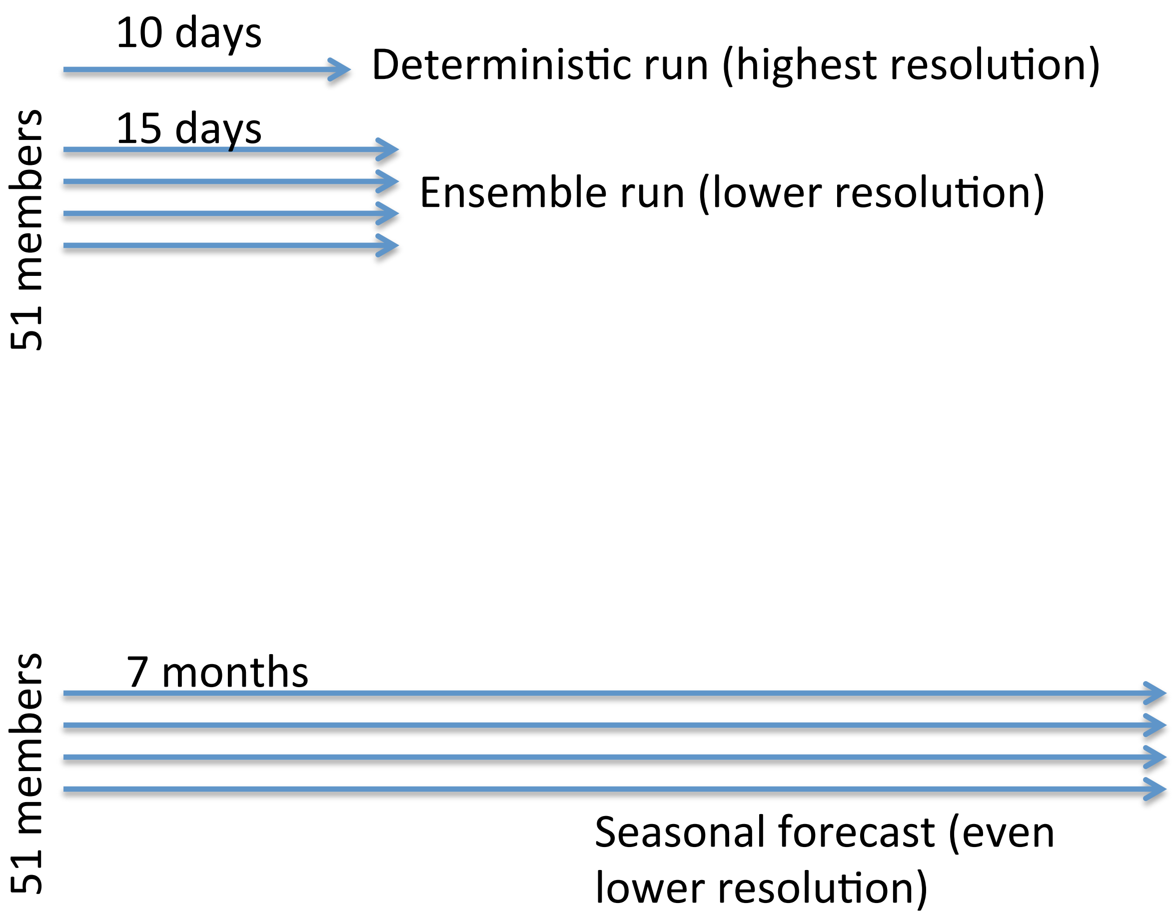

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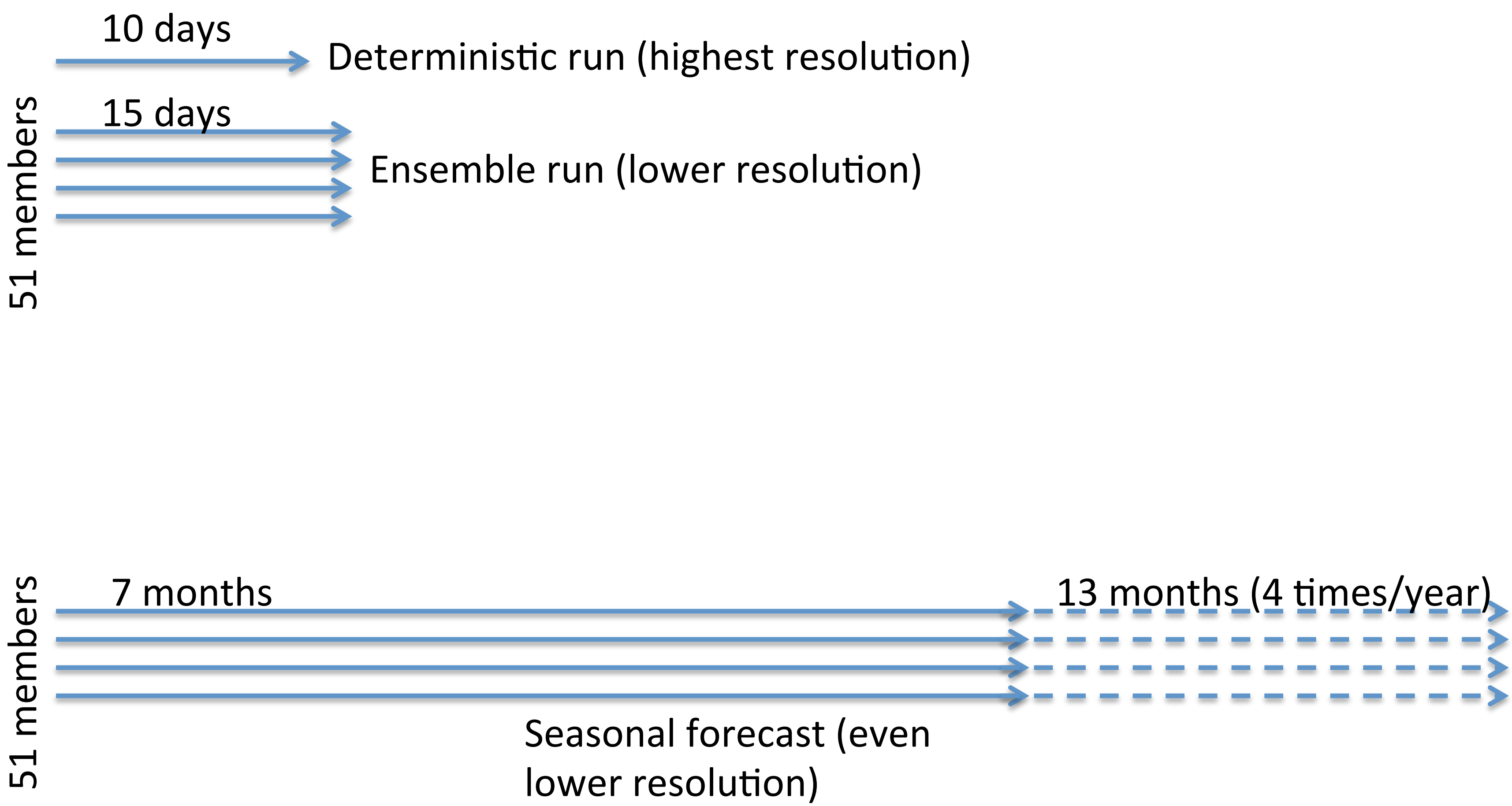

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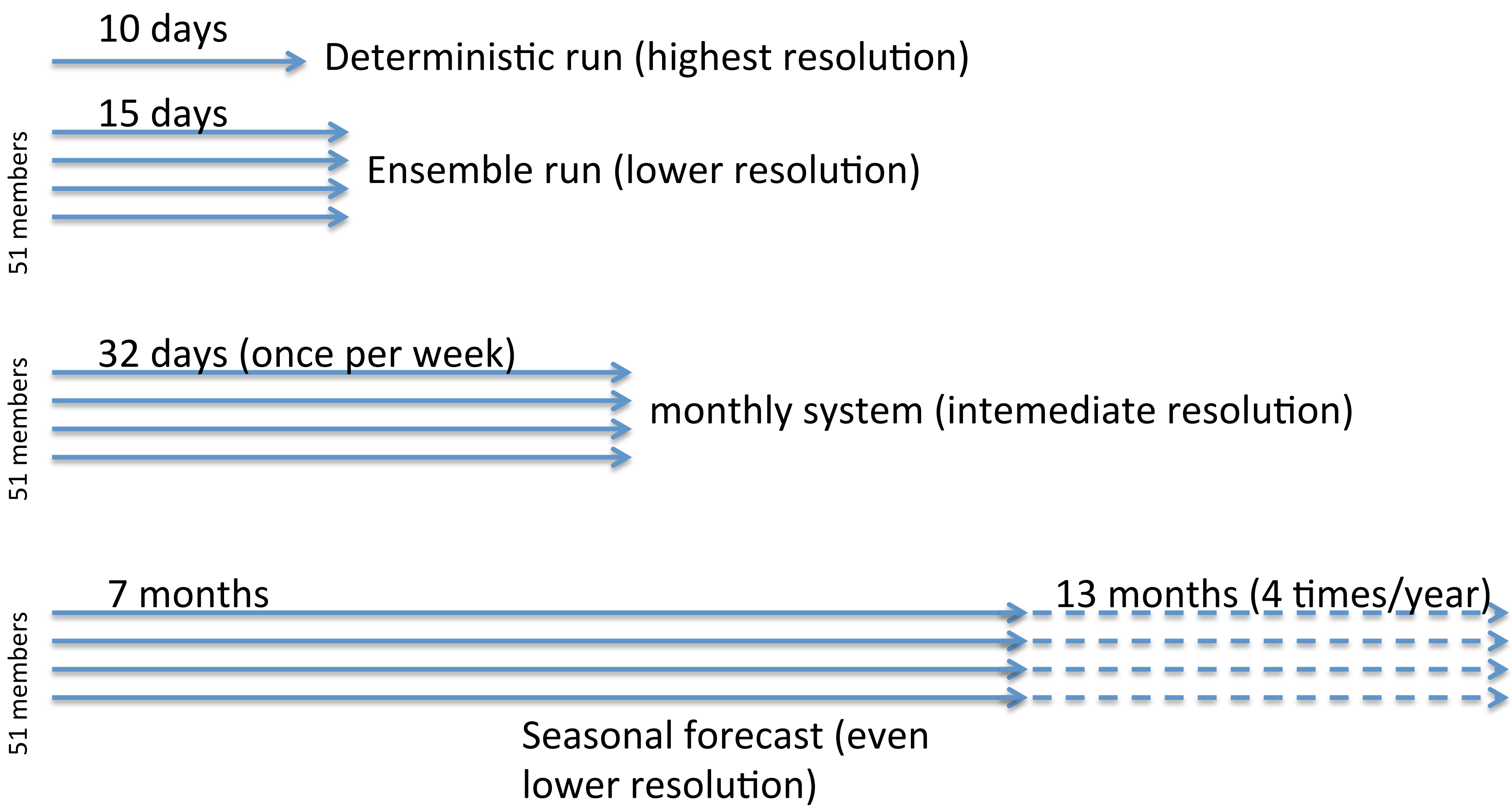

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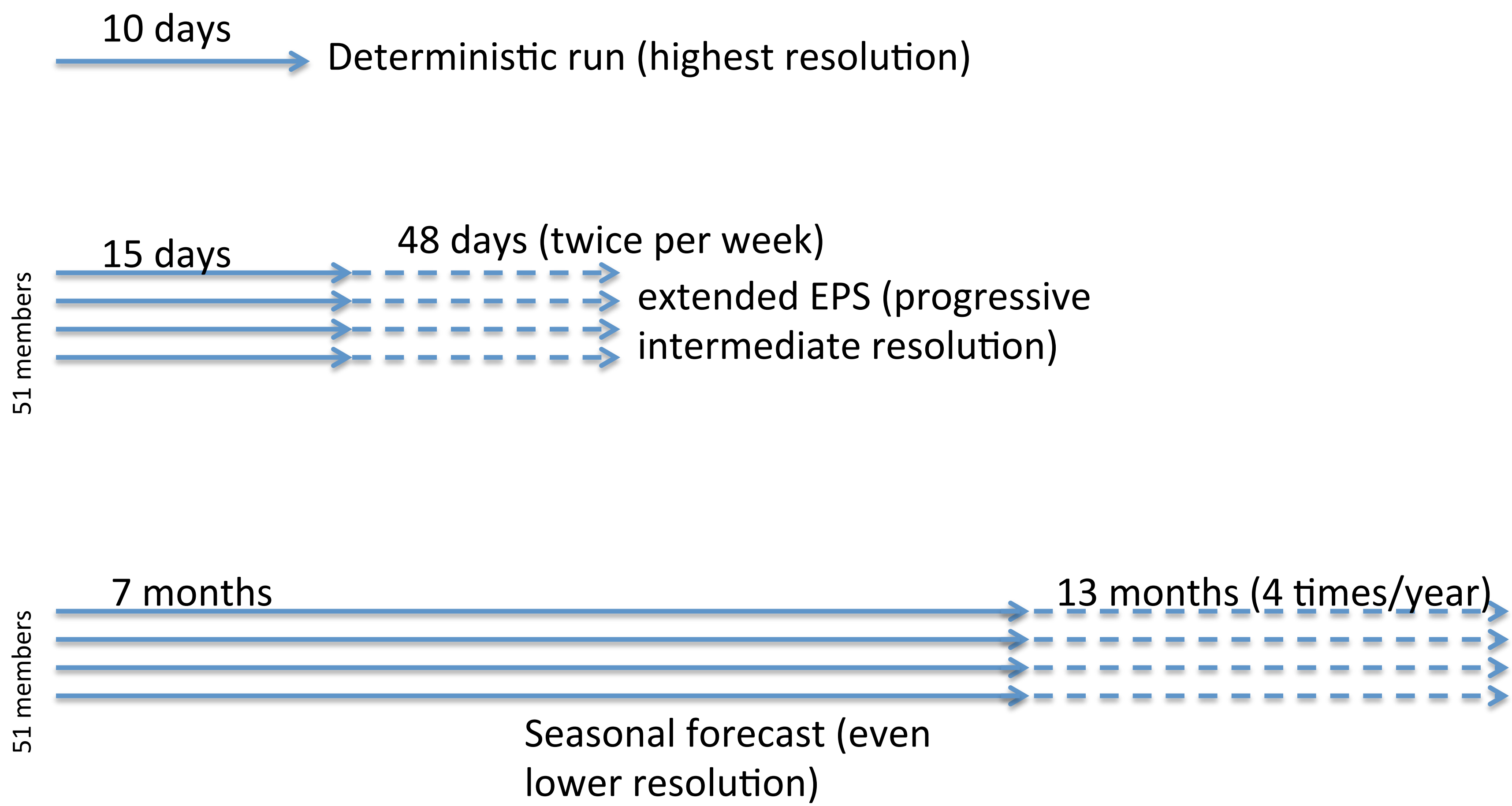

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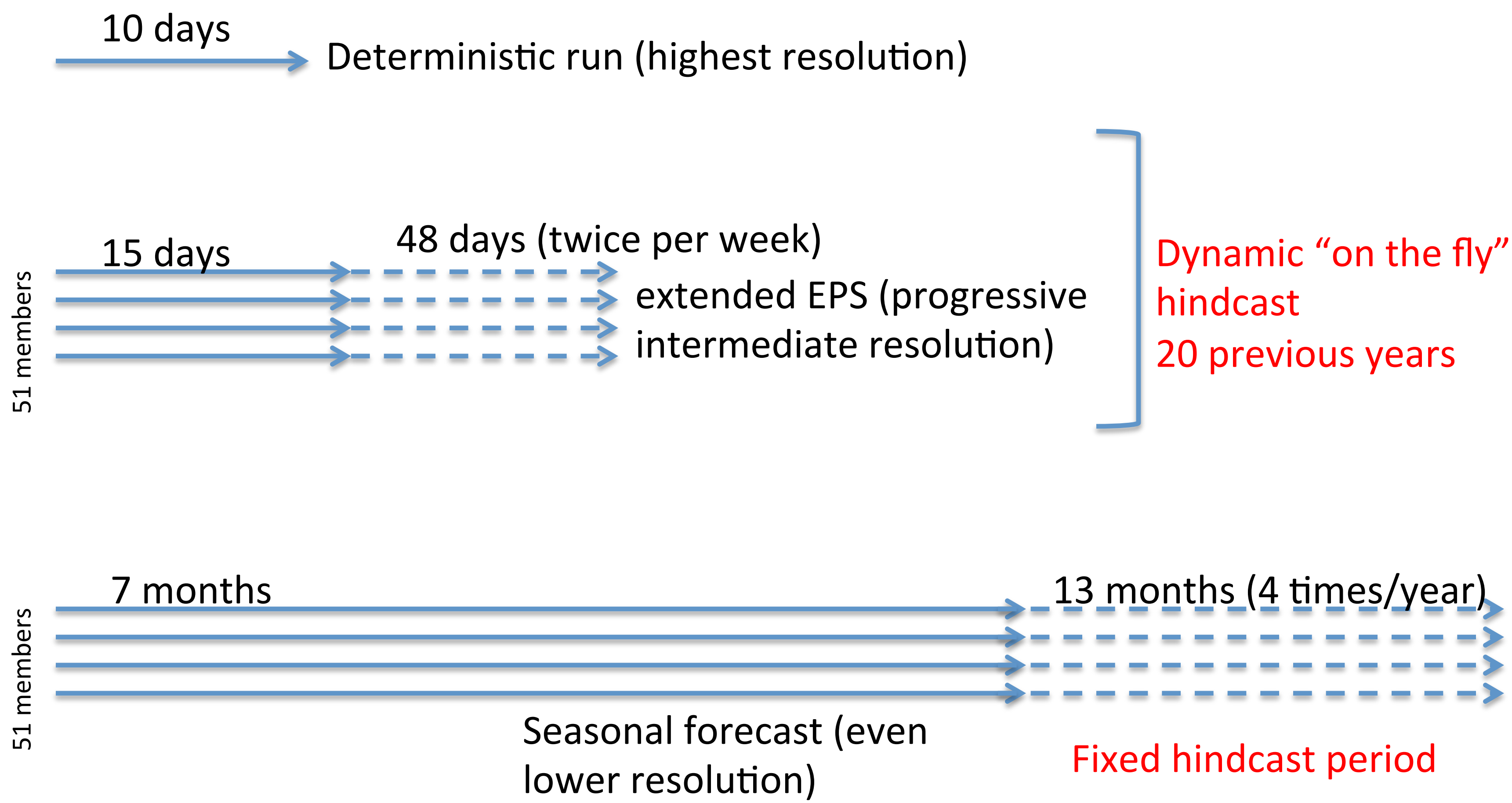
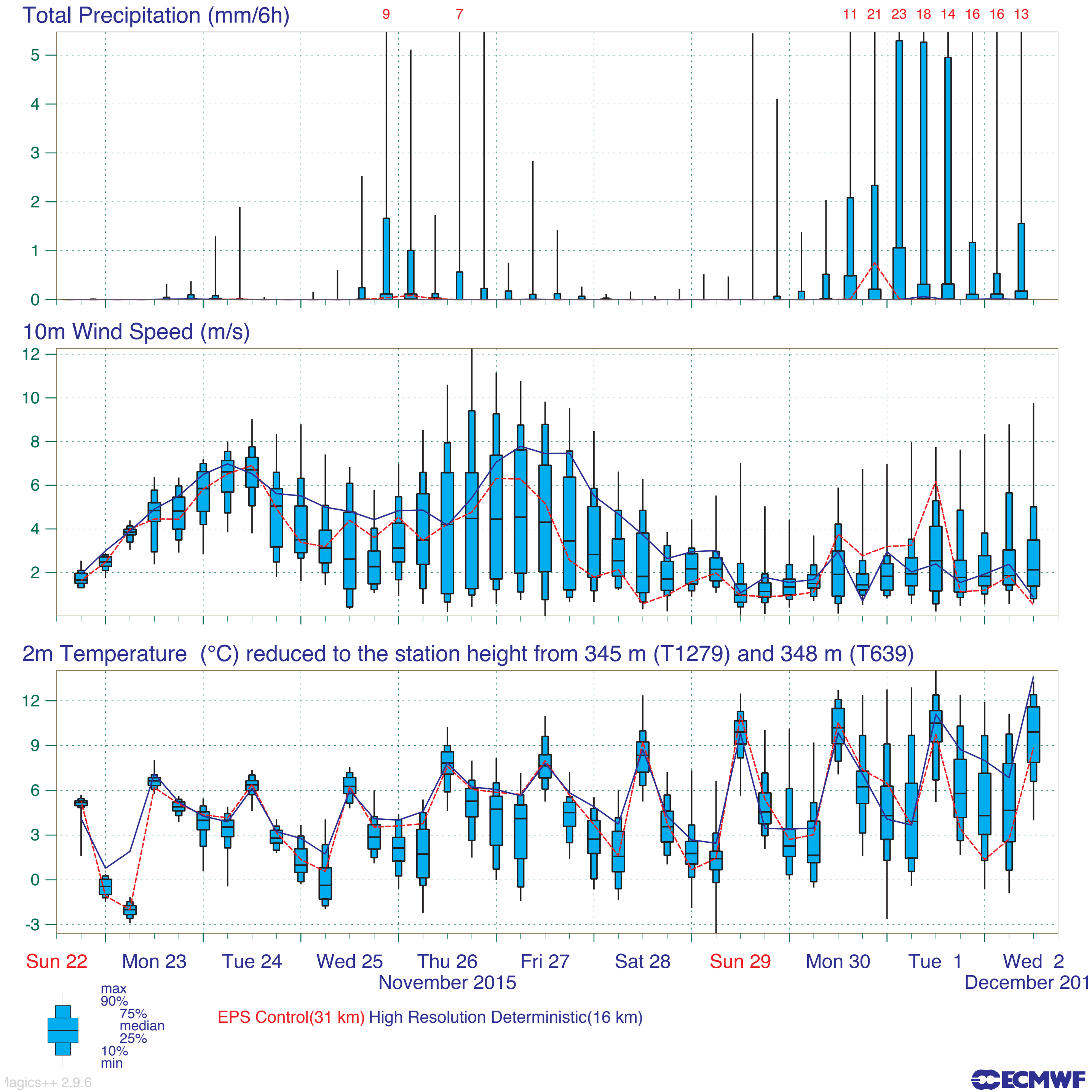
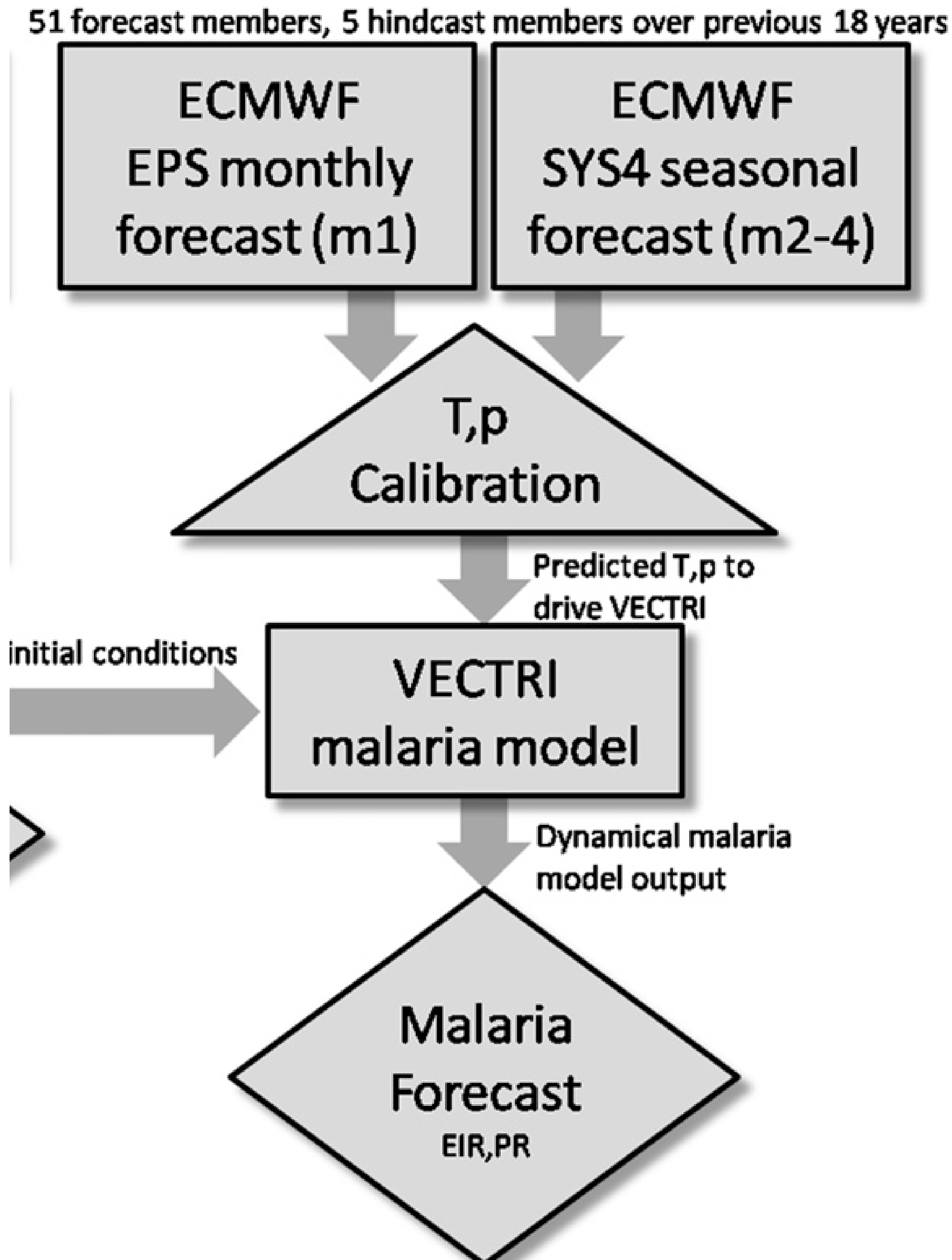


Forecast for Trieste



Overlap in week 1-6

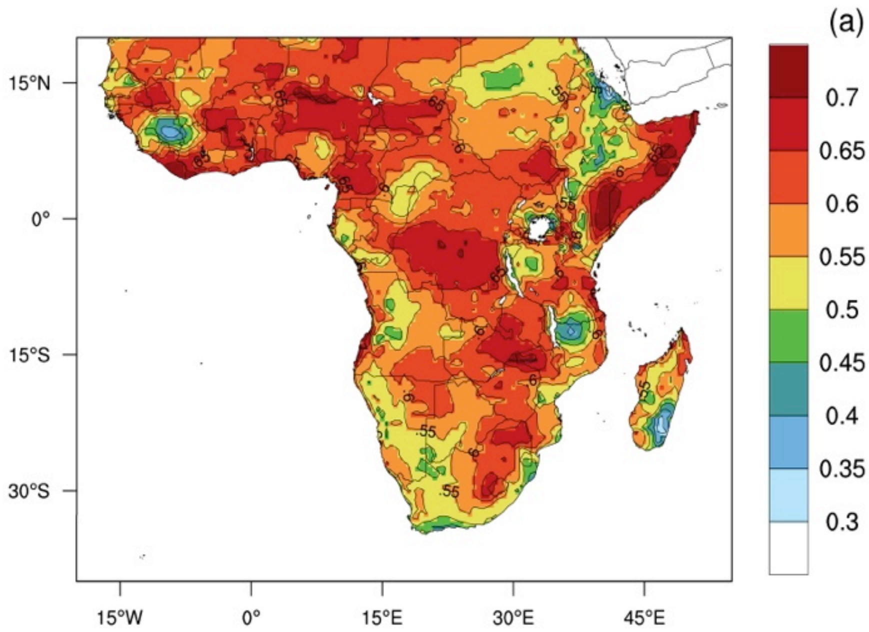
- possibility to use sub-seasonal products in the first 48 days
- why would one do this? is the monthly system better?



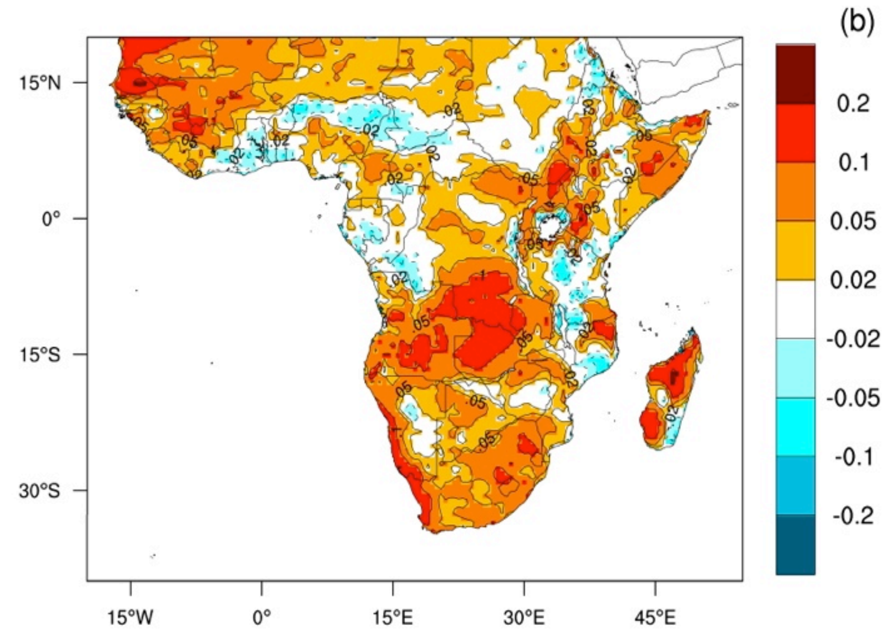
tompkins and Di Giuseppe, JAMC, 2015

Where do these gains in skill come from?

from Tompkins and Digiuseppe, JAMC, 2015



Correlation of day 1-32 T2m anomaly against ERA-Interim for 1994-2012 of Extended range EPS over Africa
12 start dates (First Thursday of each month)

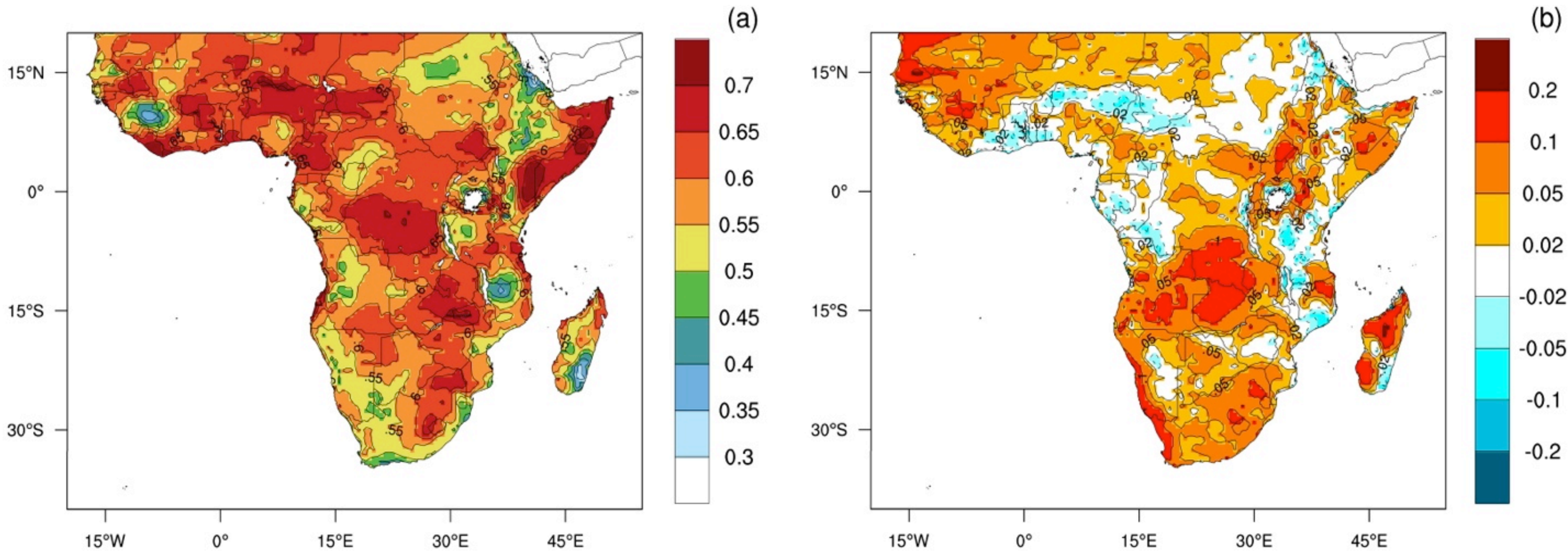


Increase in correlation relative to the exact same days predicted by the most recent seasonal forecast system

Where does this skill advantage come from?

Where do these gains in skill come from?

from Tompkins and Digiuseppe, JAMC, 2015

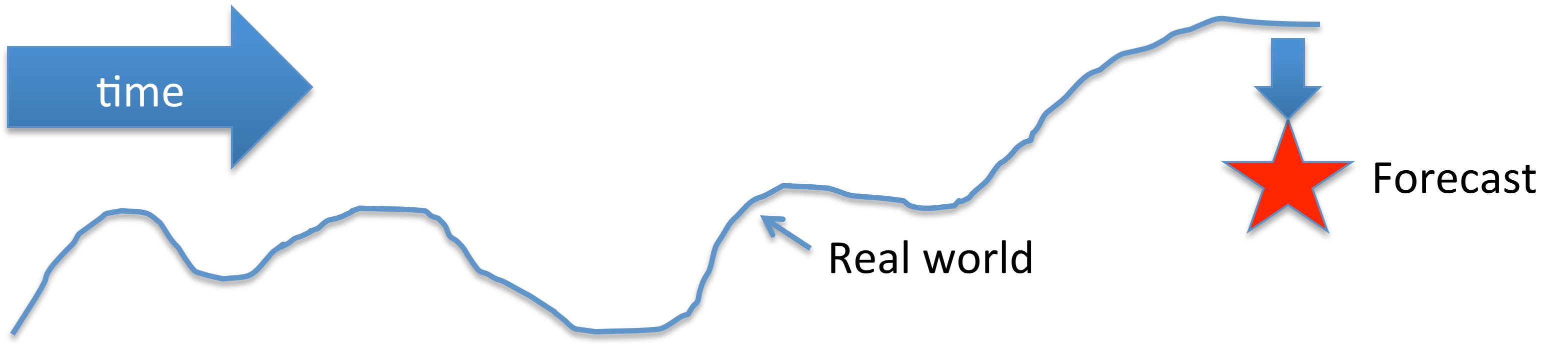


Correlation of day 1-32 T2m anomaly against ERA-Interim for 1994-2012 of Extended range EPS over Africa
12 start dates (First Thursday of each month)

Increase in correlation relative to the exact same days predicted by the most recent seasonal forecast system

1. Lead time advantage (more frequent updates)
2. Model physics (more frequent updates)
3. Framework (higher resolution, different ocean initialization...)

Why do we need the hindcast suite?



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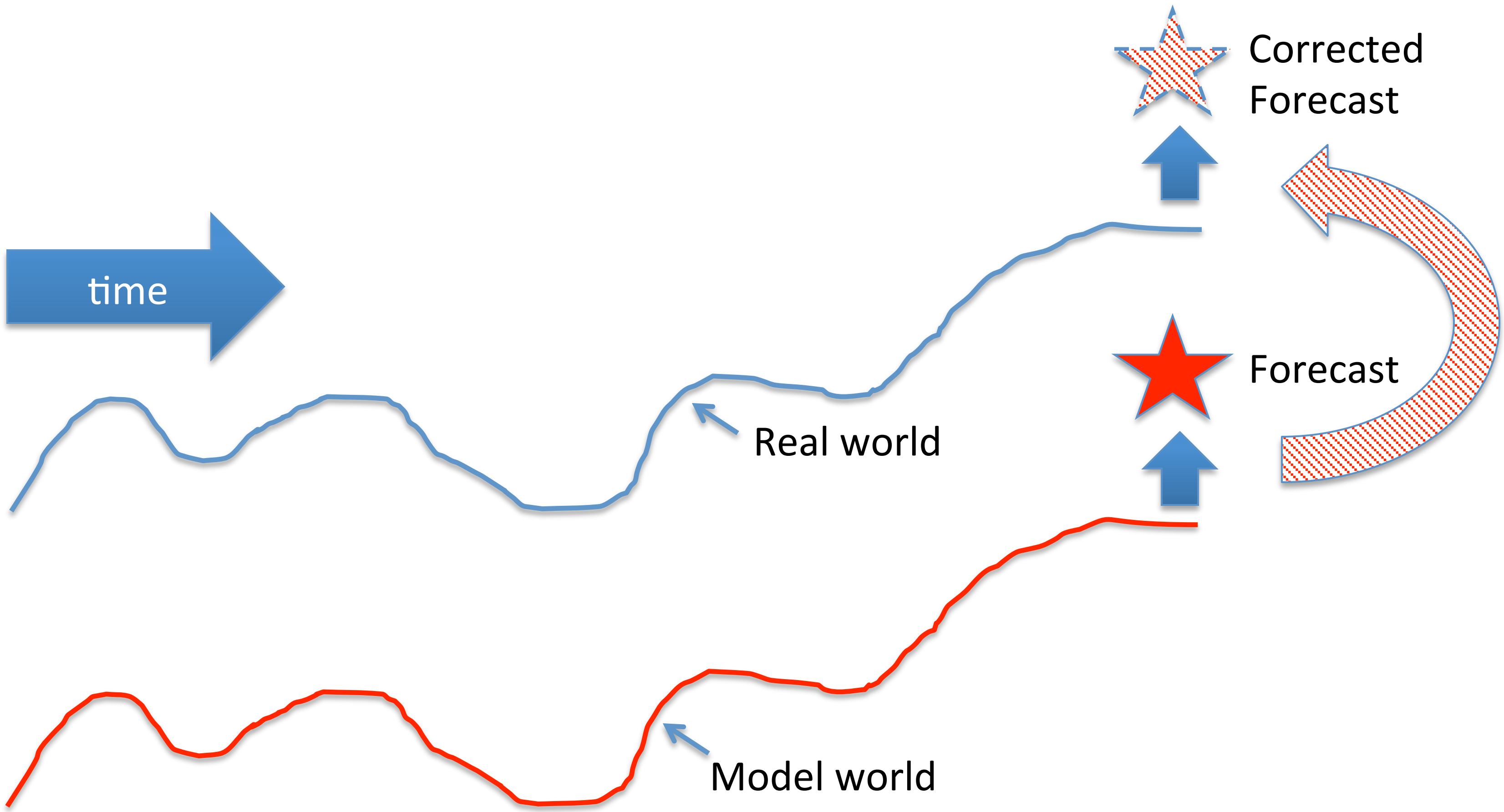

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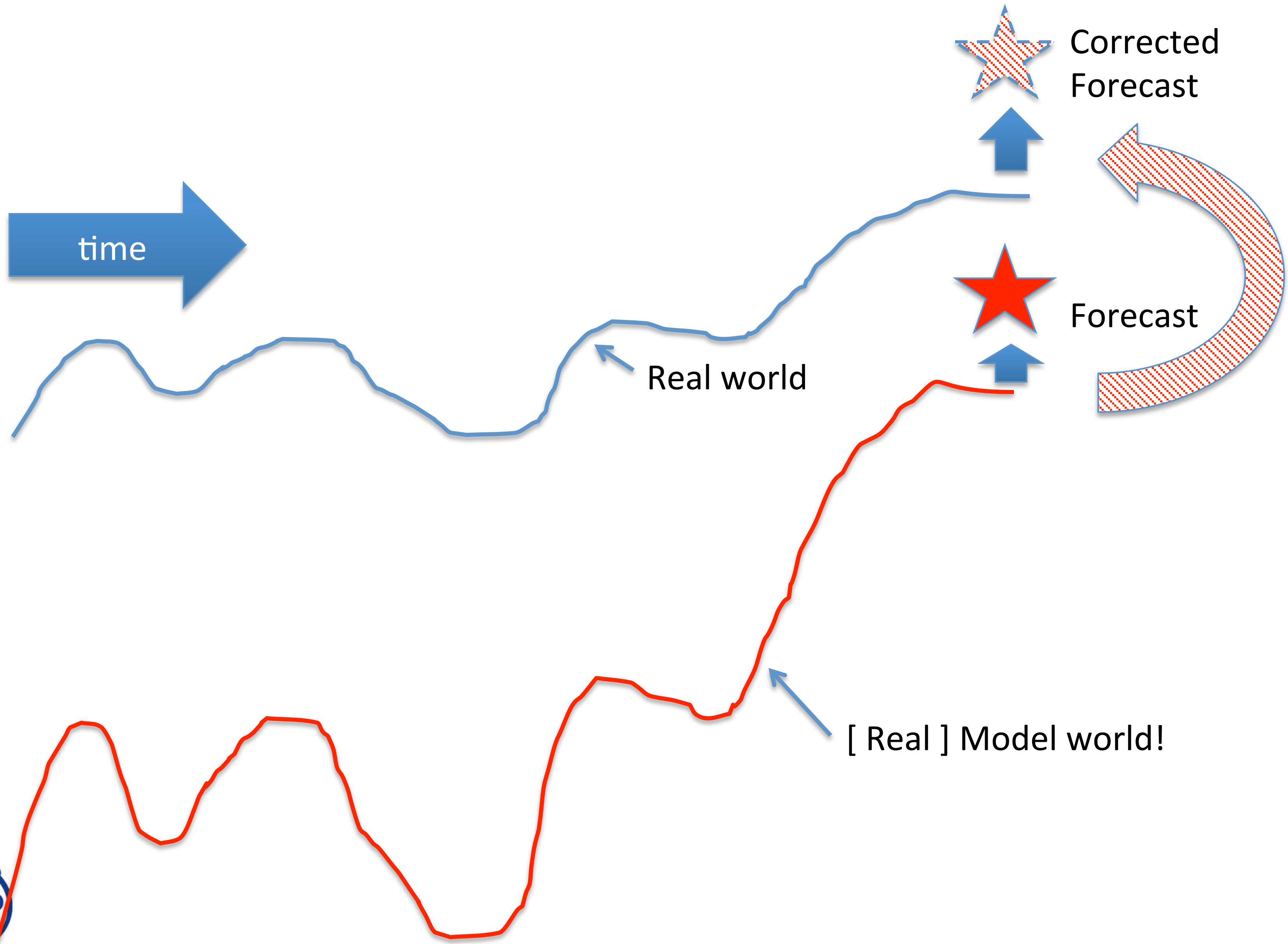
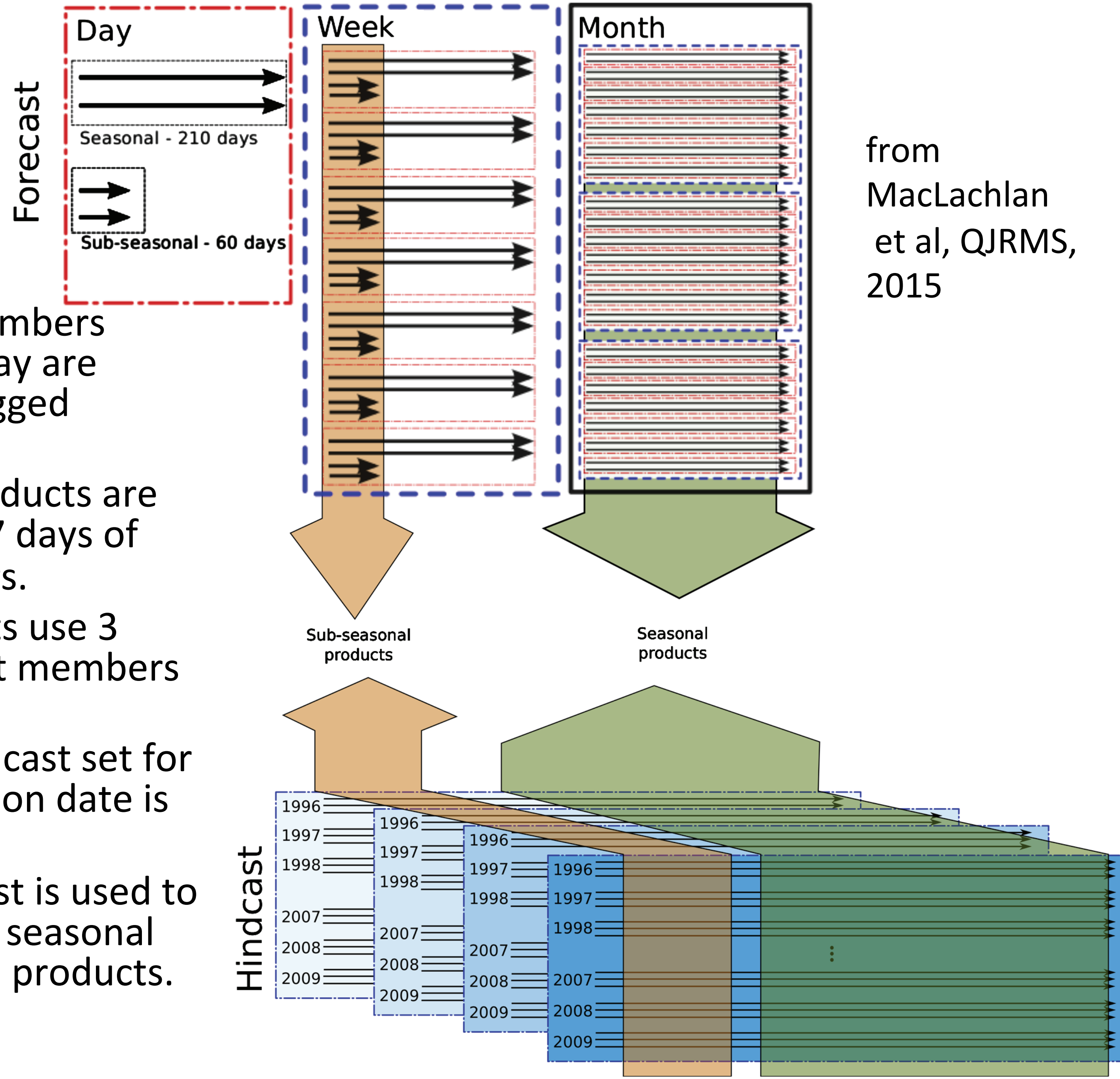


The Met Office system

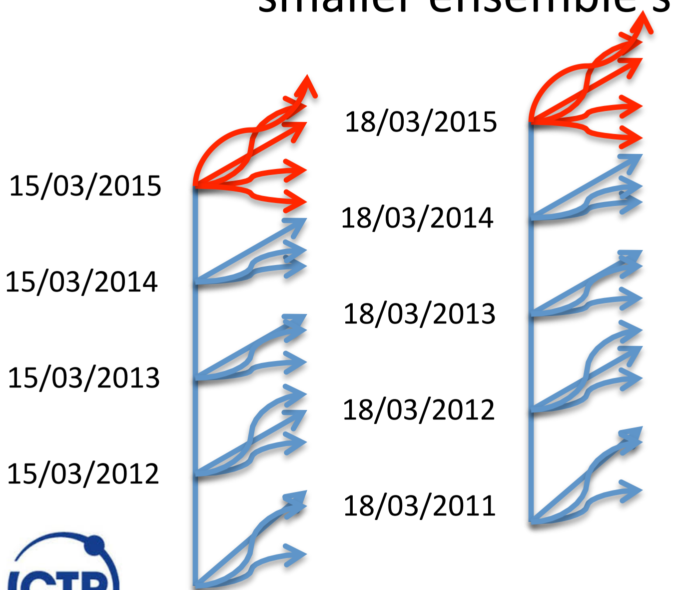


from MacLachlan et al, QJRMS, 2015

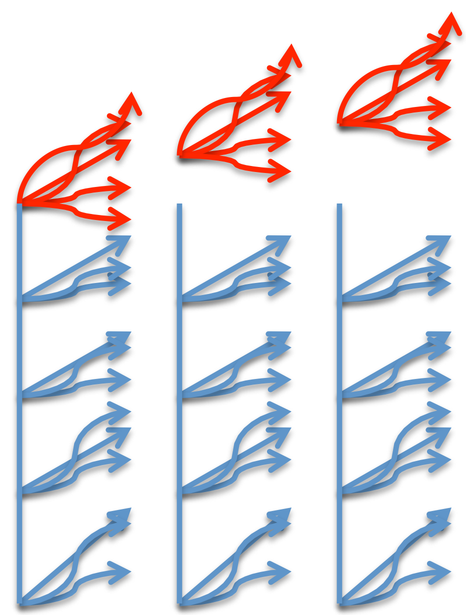
- Four forecast members initialized each day are combined in a lagged ensemble.
- Sub-seasonal products are generated from 7 days of forecast members.
- Seasonal products use 3 weeks of forecast members in the ensemble.
- Each week a hindcast set for a given initialization date is completed.
- The same hindcast is used to bias correct both seasonal and sub-seasonal products.

Hindcast Strategies

- "On the fly" – Each forecast is accompanied by a set of hindcasts starting on the same date for the previous N years
  - GOOD: same model version and set up
  - GOOD: Always same start date
  - BAD: Expensive to run, smaller ensemble sizes



- "Fixed" – Hindcast data set run once for a particular model cycle
  - GOOD: Cheaper (if system not updated too frequently), larger ensemble sizes possible
  - BAD: Not always matching dates



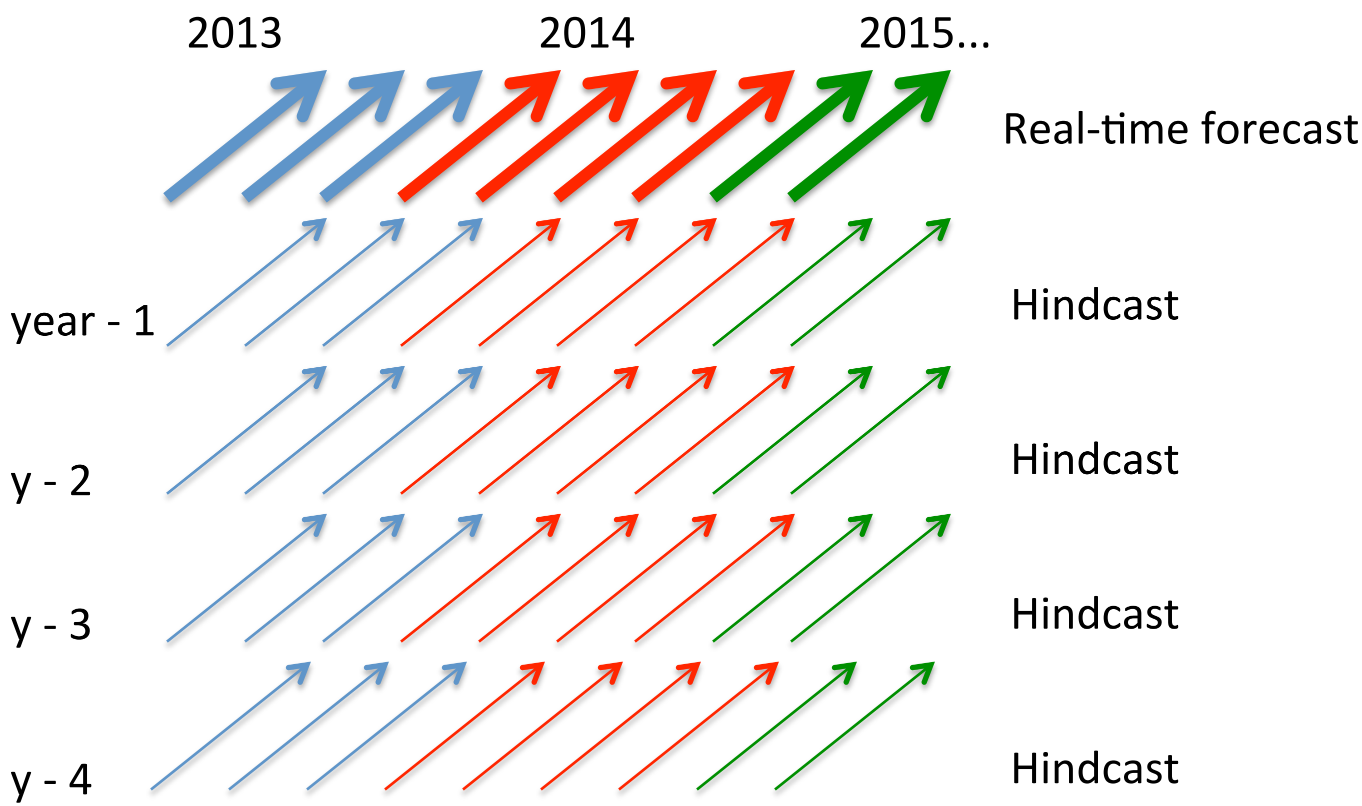
Assessing S2S model skill – the hindcast

- Hindcast primary function is to perform bias correction and output calibration.
- However also useful to assess model skill over interannual timescales since model system is identical
- Disadvantage is that ensemble size is smaller

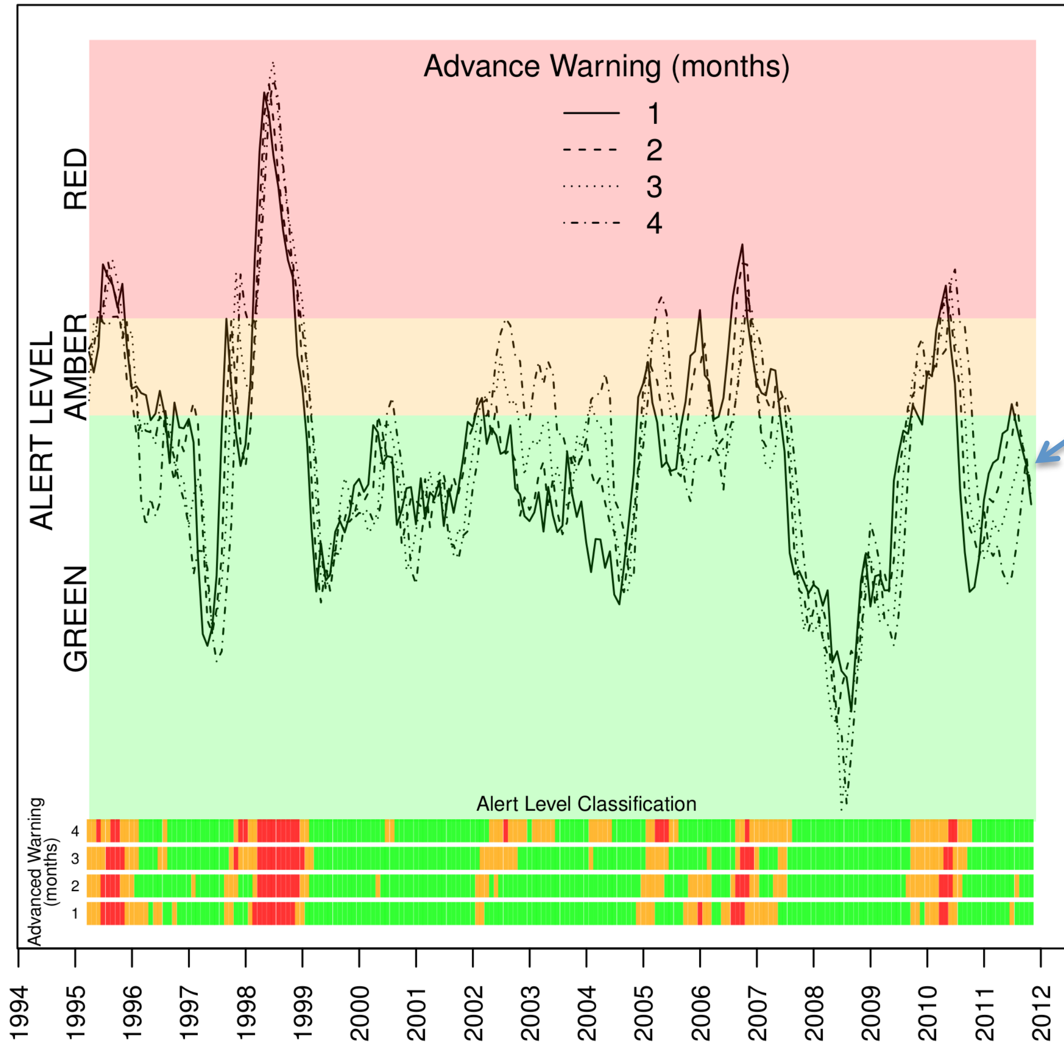
Colour represents model version

Arrow thickness indicates the ensemble size

(51 versus 5-15)



Example: malaria forecasts using extended ensemble and seasonal forecasts, limitations of dynamic hindcast suite



Mean of only 5 ensemble members

operational system changes

Maximum Hindcast date range

Tompkins and Di Giuseppe, JAMC, 2015

Intercomparisons

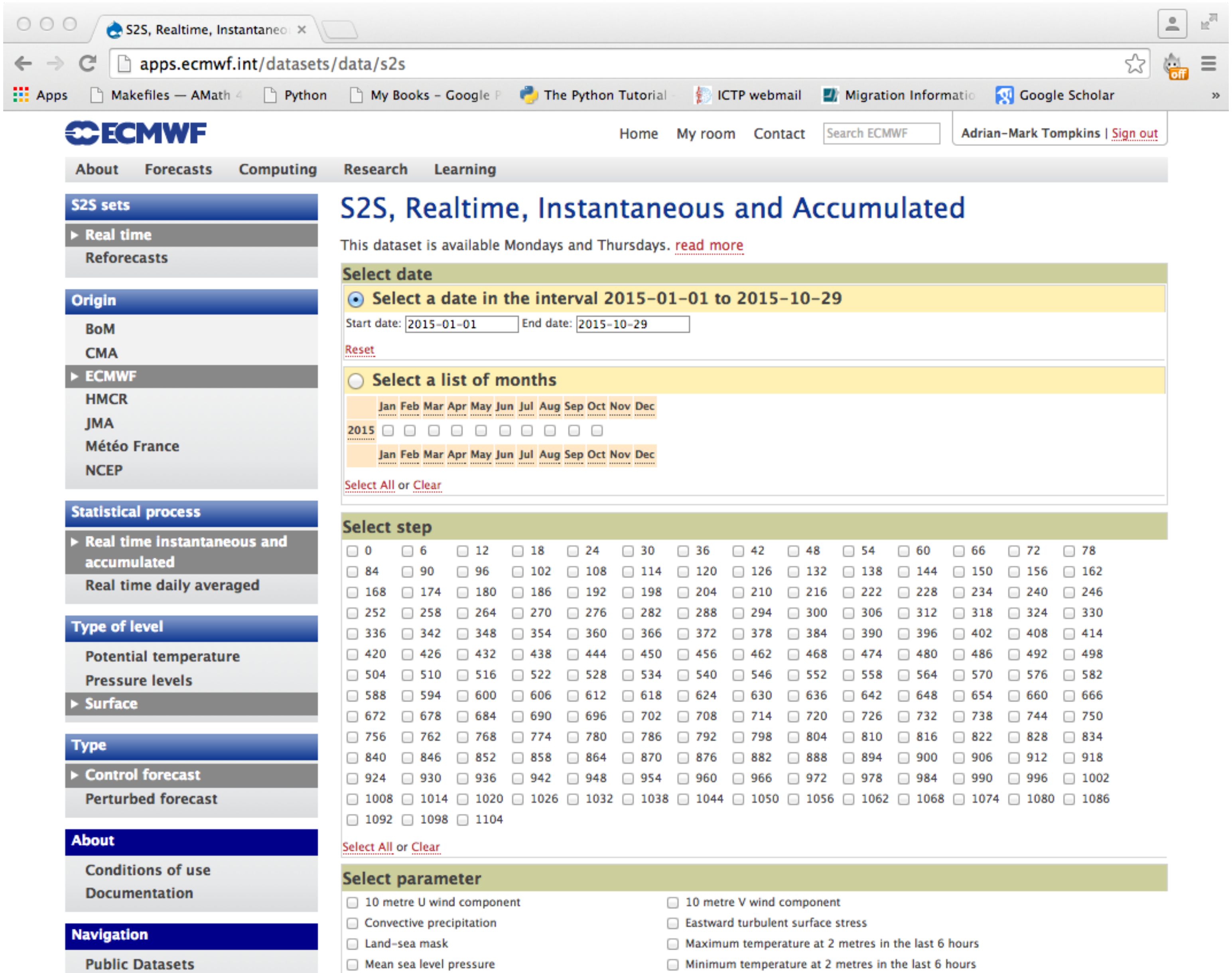
- No standard way of setting up the hindcast framework between centre.
  - Makes intercomparison of models challenging
  - and organising S2S and other similar databases (e.g. CHFP)
  - (although NMME is fairly standardized, see right)
- Aim of this week is to show how to retrieve S2S forecast and hindcast suites

TABLE 1. NMME partner models an

Model	Hindcast period
CFSv1	1981–2009
CFSv2	1982–2010
GFDL Climate Model, version 2.2 (GFDL CM2.2)	1982–2010
IRI-ECHAM4f*	1982–2010
IRI-ECHAM4a*	1982–2010
CCSM3	1982–2010
Goddard Earth Observing System, version 5 (GEOS5)	1981–2010
Third Generation Canadian Coupled Global Climate Model (CMC1-CanCM3)	1981–2010
Fourth Generation Canadian Coupled Global Climate Model (CMC2-CanCM4)	1981–2010

Kirtmann et al. BAMS 2014

Today and tomorrow's session:
http://apps.ecmwf.int/datasets/data/s2s



Additional Slides on climate modelling

Uncertainty in climate modelling

multiple forcing scenarios

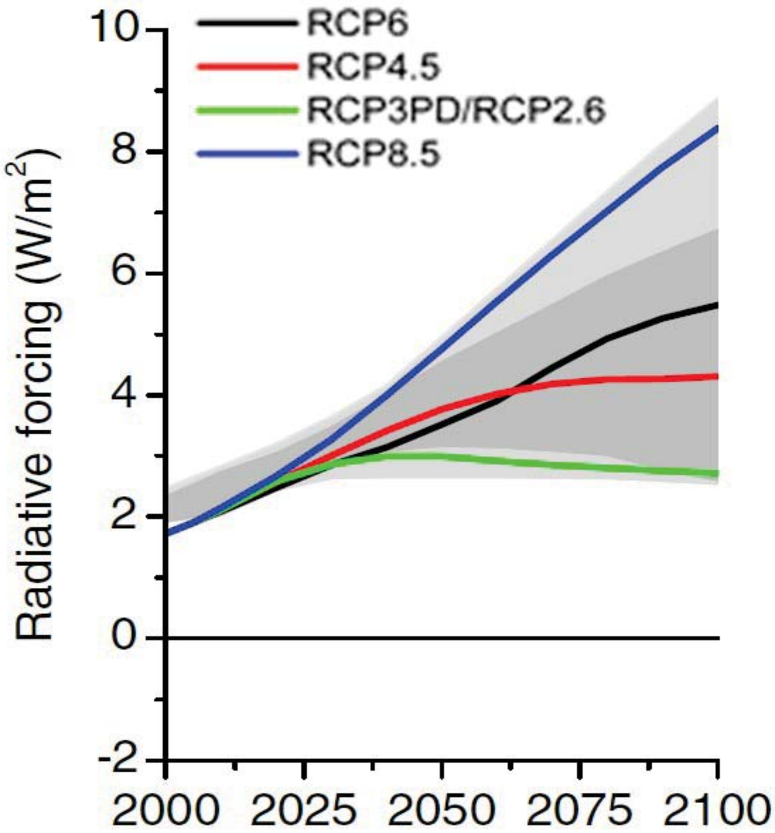
↓

multiple climate models

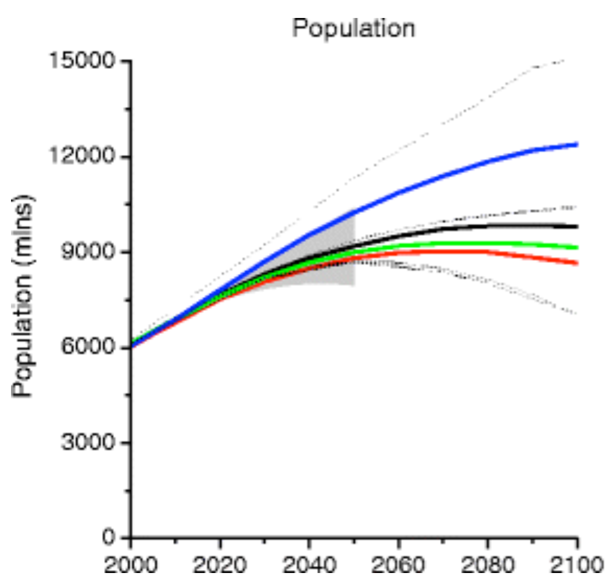
↓

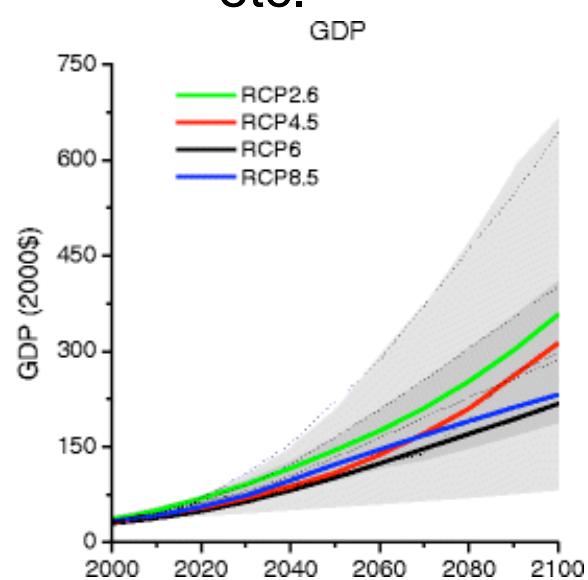
multiple integrations from different initial conditions

Emissions scenarios in CMIP5

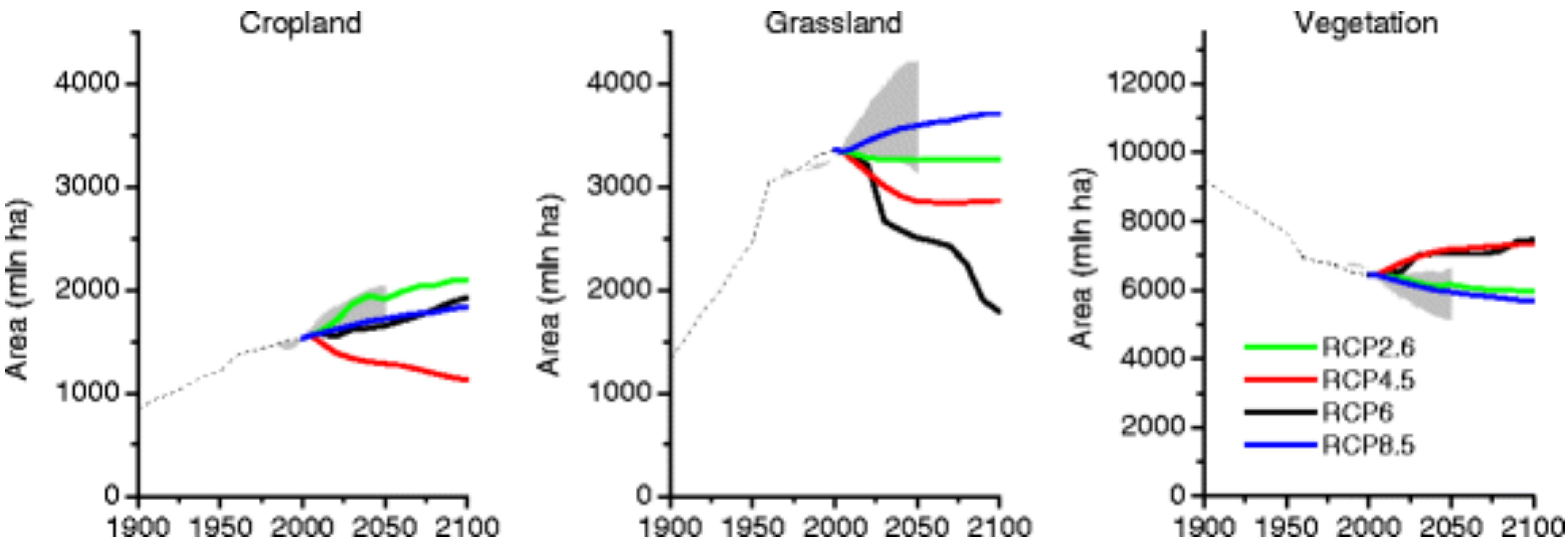


- Each scenario known as a representative concentration pathway (RCP)
- Provided by a different impacts assessment model (IAM)
- Accounting for GDP, population, energy etc.





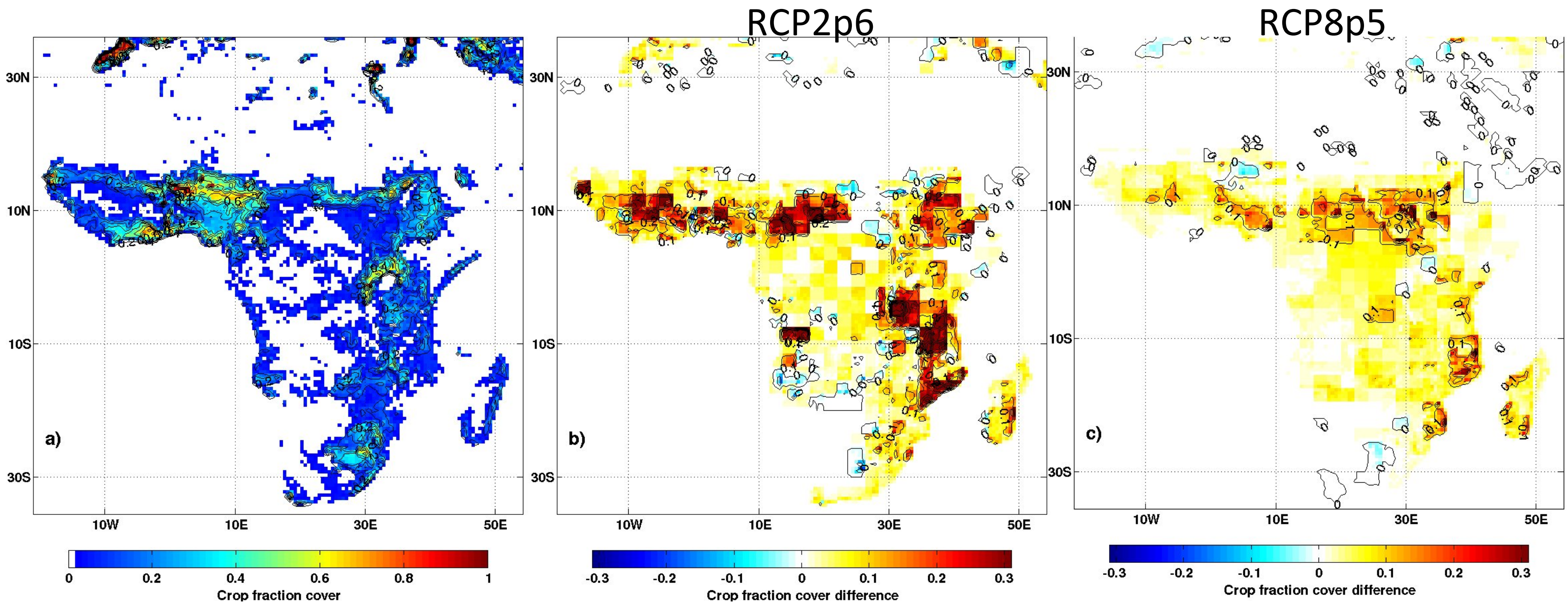
RCP2p6 is not all good news...



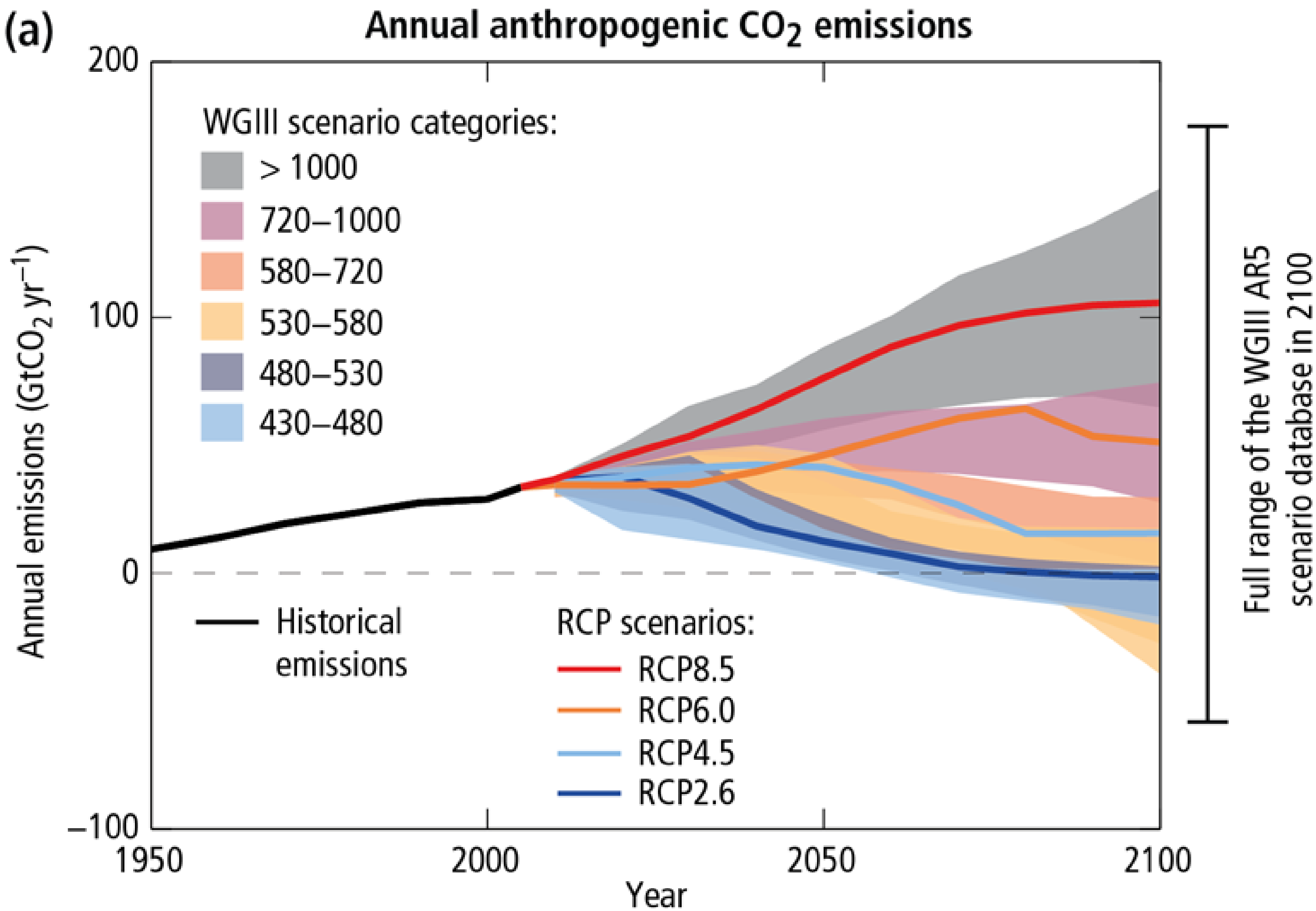
- RCP2p6 and 8p5 are surprisingly similar due to high use of biofuels needed to respect 2p6 Wm^{-2}

HYDE output example (using CLM)

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

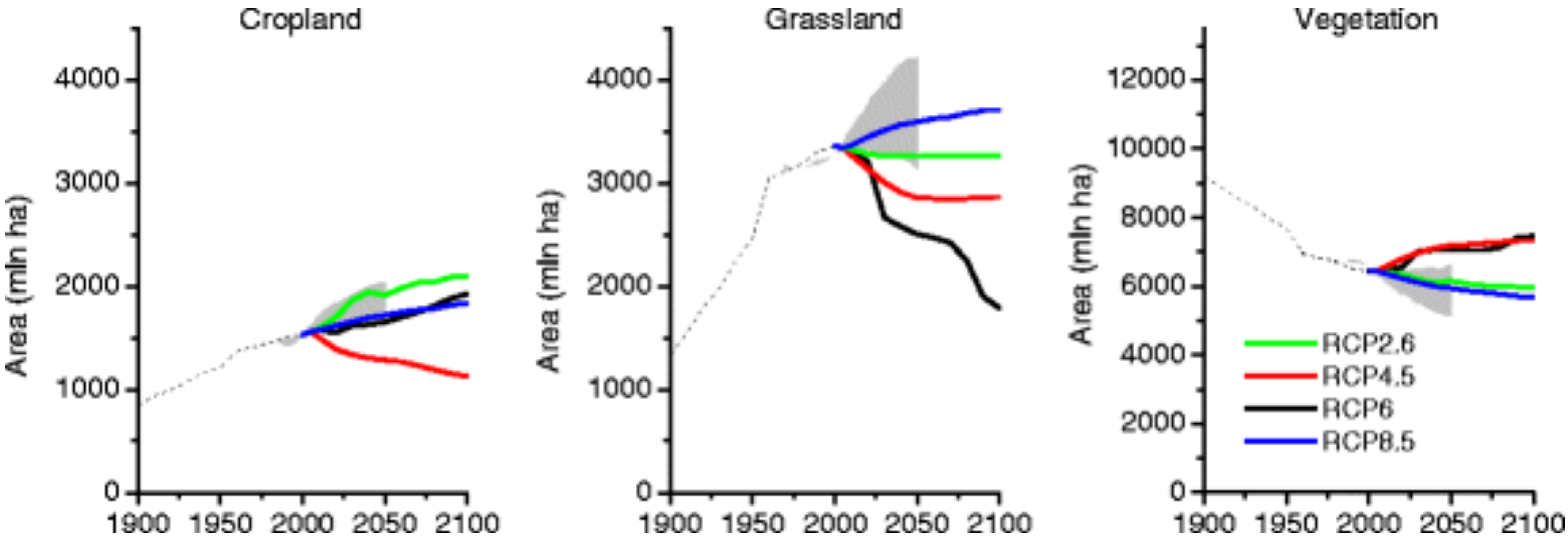


Leads to emissions scenarios for major greenhouse gases



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

RCP2p6 is not all good news...



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

Uncertainty in climate modelling

multiple forcing scenarios

↓

multiple climate models

↓

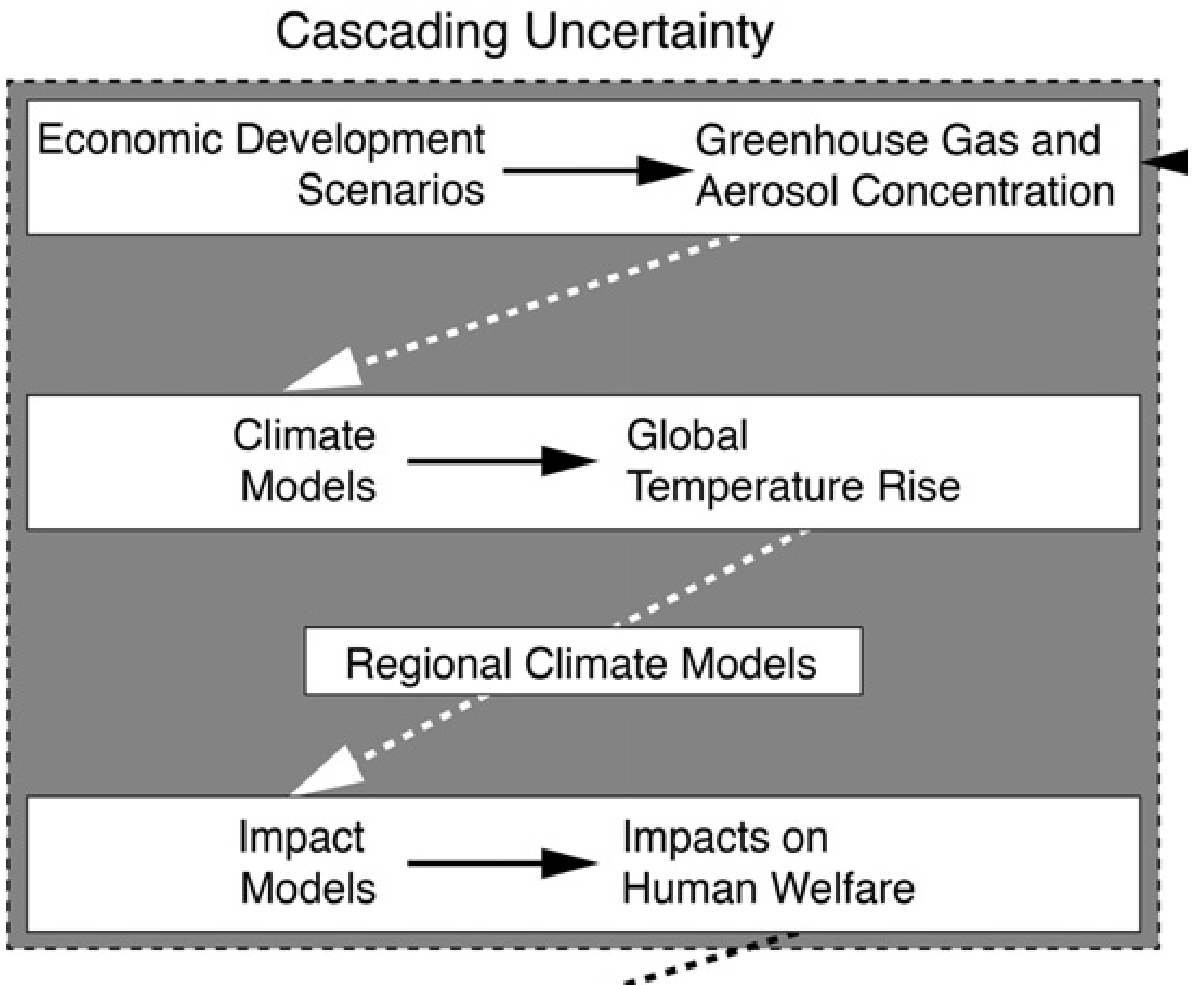
multiple integrations from different initial conditions

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

Commentary

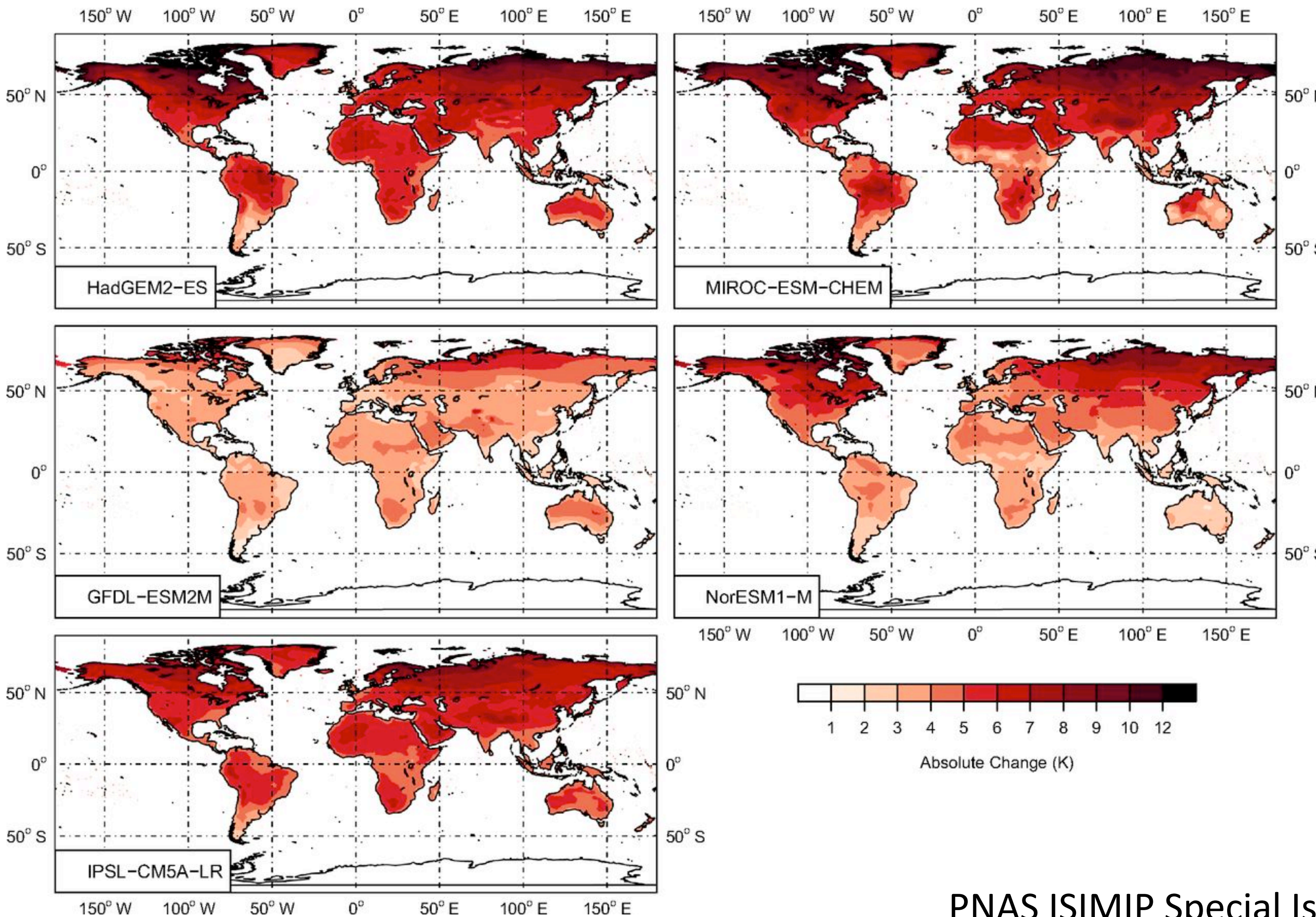
Cascading uncertainty in climate change models and its implications for policy

MARK MASLIN



Question: Where is the initial condition uncertainty?

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

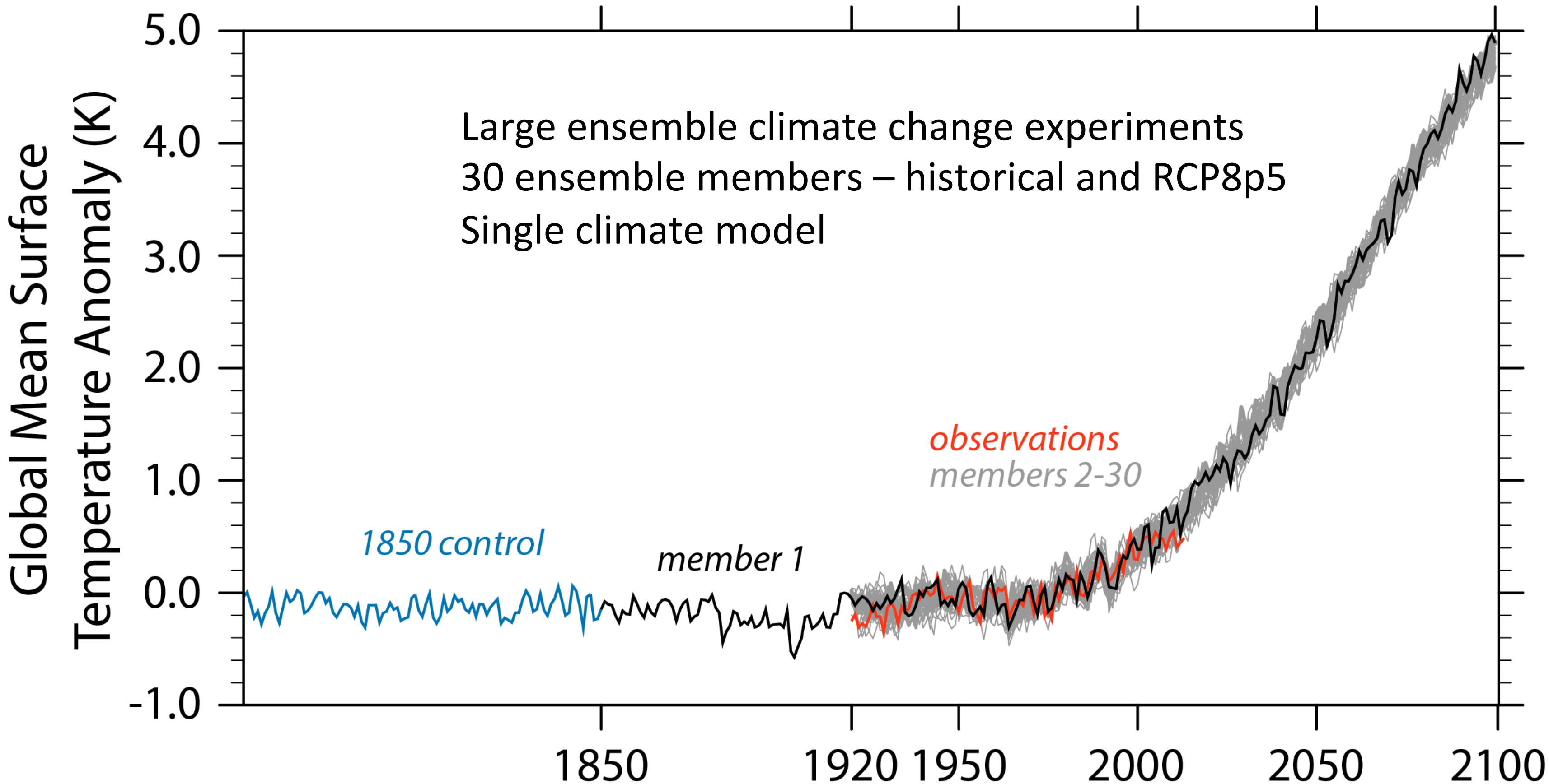


PNAS ISIMIP Special Issue 2014

Ensemble techniques in climate modelling

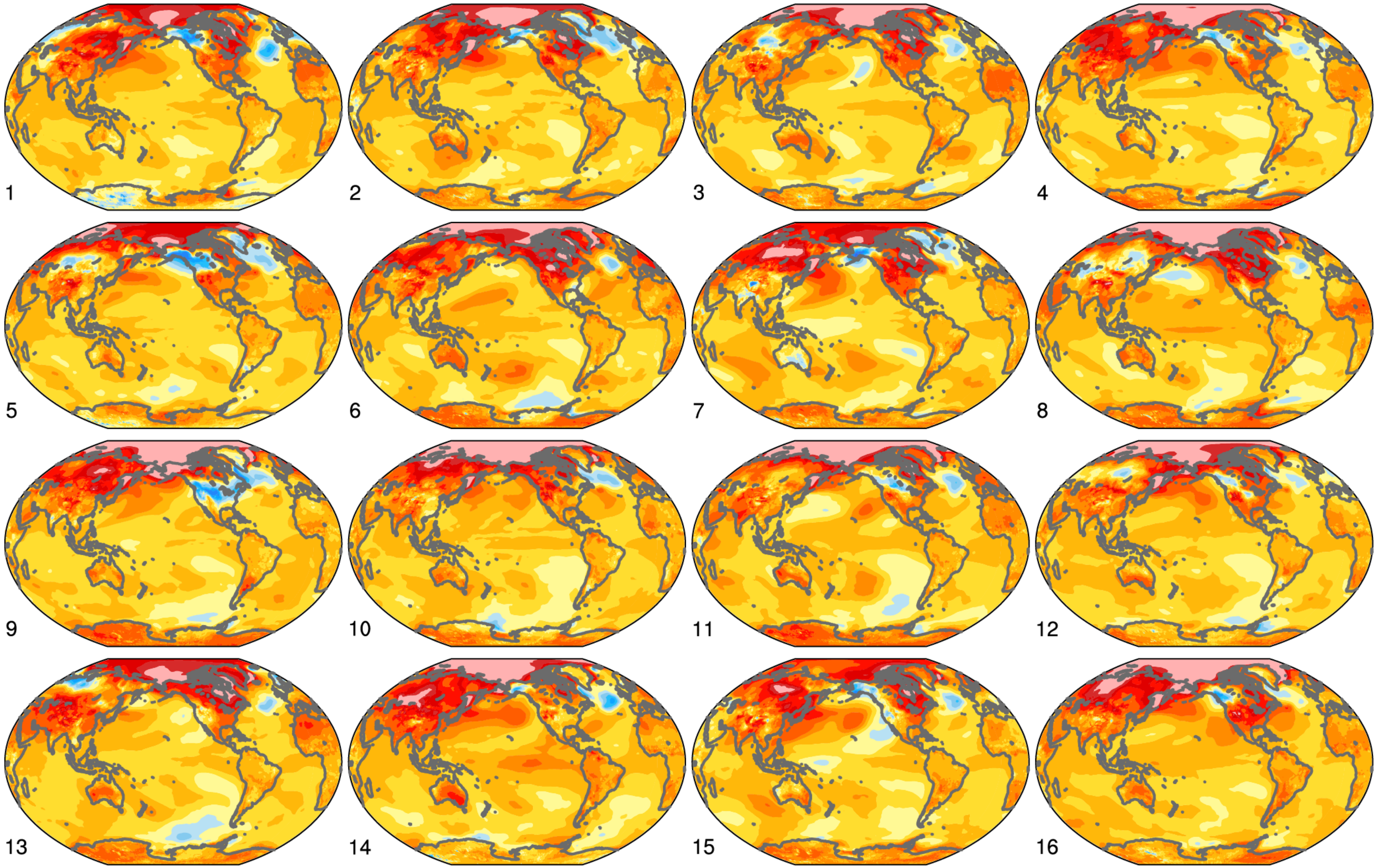
- Ensembles techniques less well developed
- Season/decadal - Initial condition error:
  - Atmosphere (relatively) unimportant > seasonal
  - Perturbations to Sea Surface Temperature are key
  - However, the way to do this effectively is unknown:
    - Surface wind perturbations in ocean analysis system
    - 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.



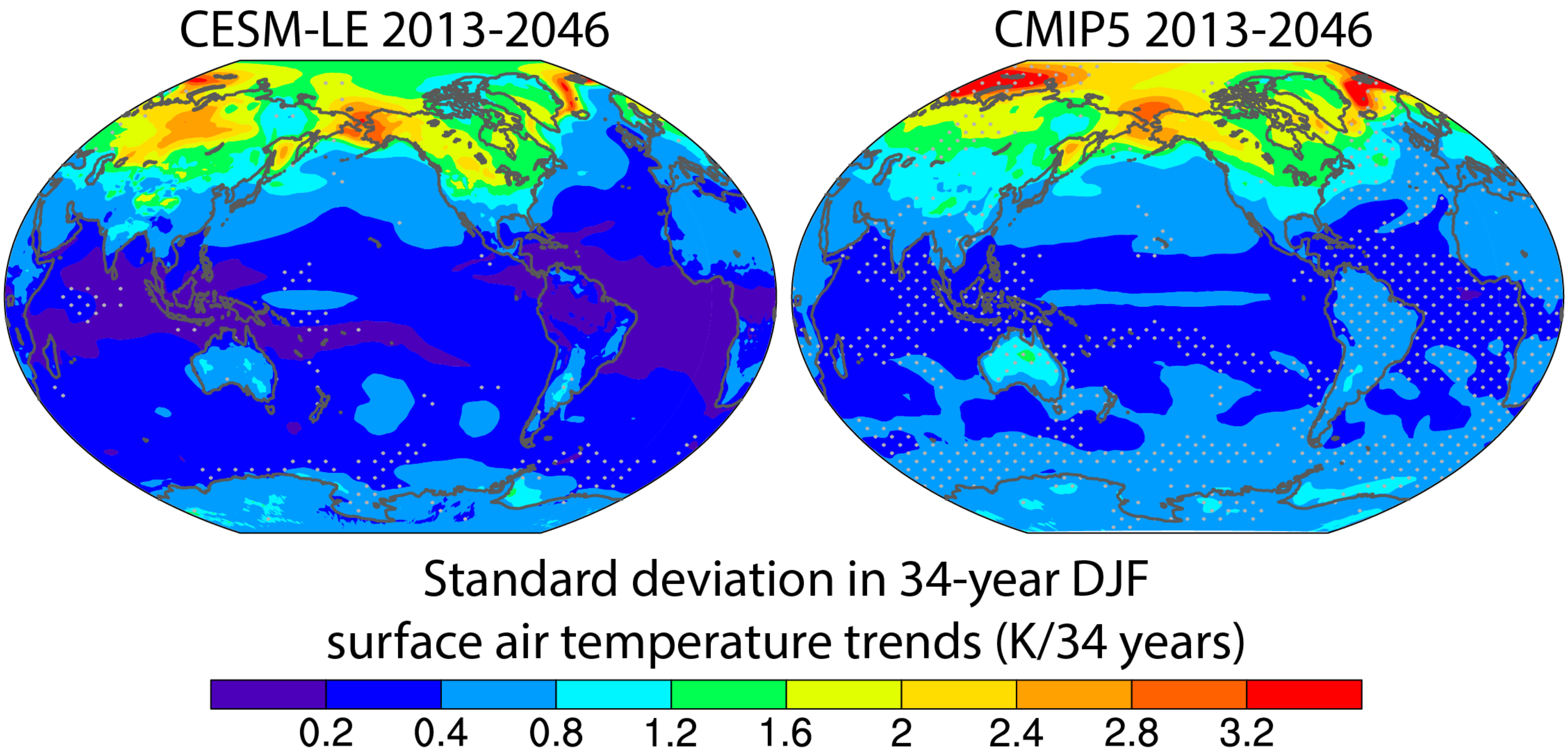
Key et al. BAMS to appear 2015: http://dx.doi.org/10.1175/BAMS-D-13-00255.1

First 16 members: 2013-2046 temperature trend

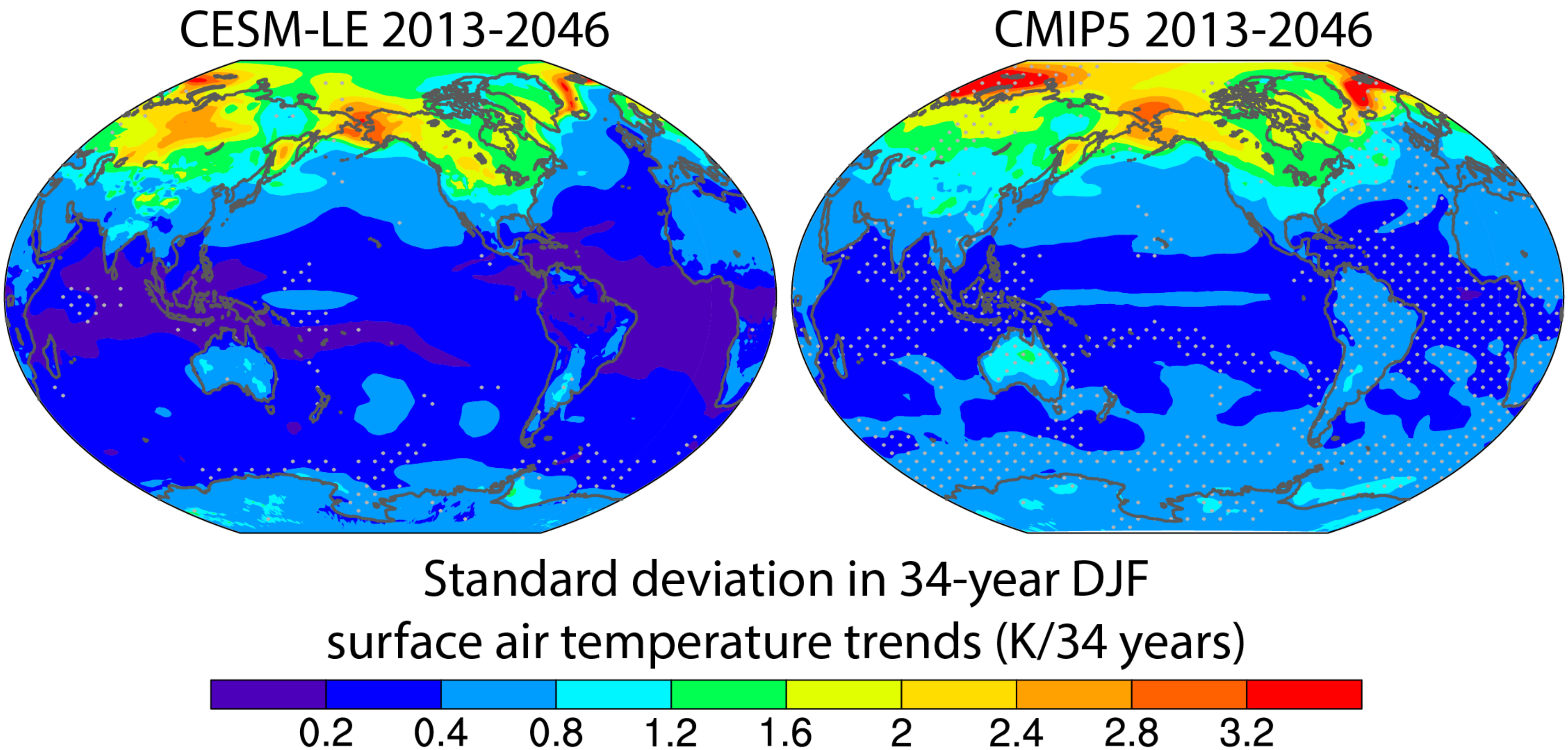


http://dx.doi.org/10.1175/BAMS-D-13-00255.1

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

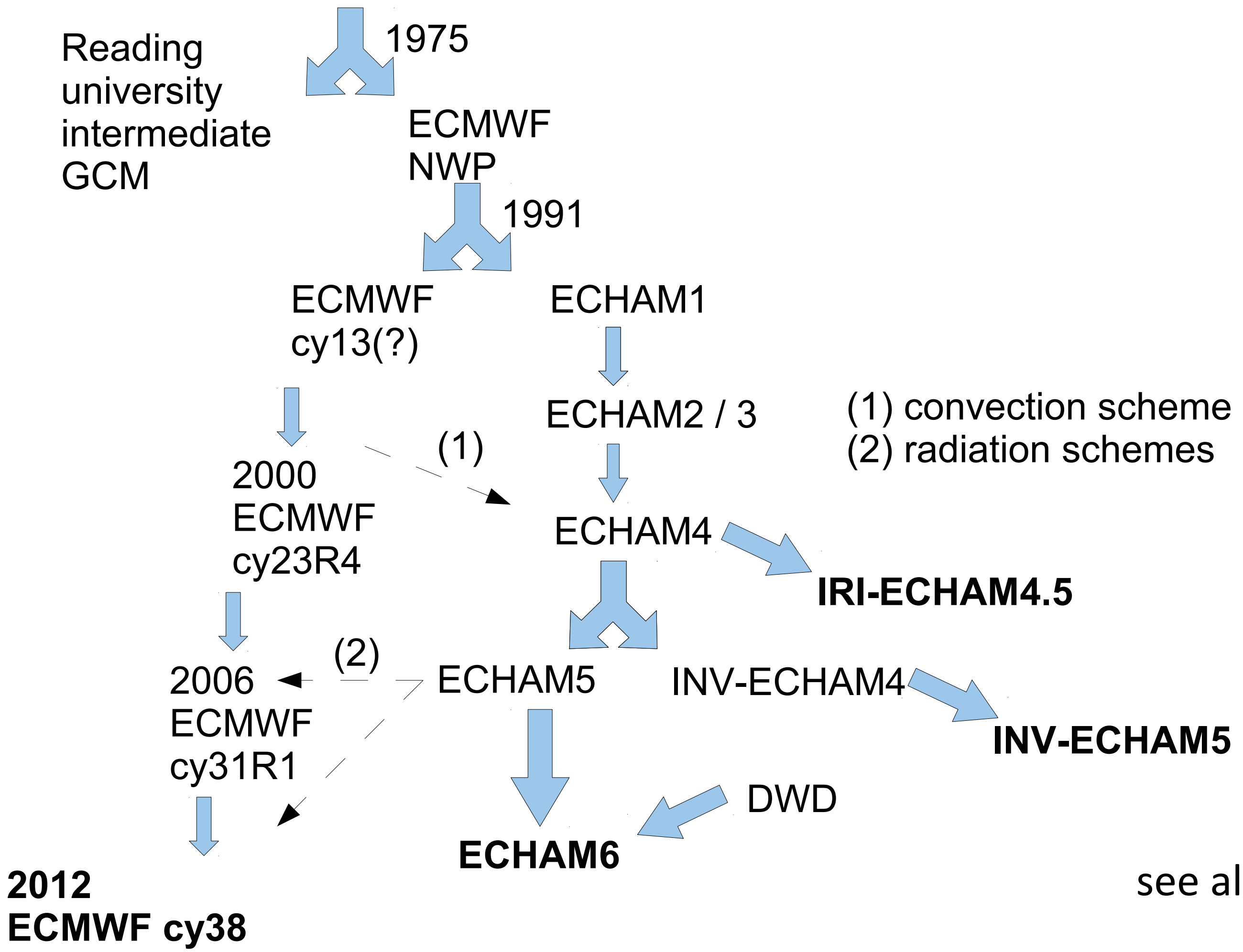


Left: 30 members single model = sampling uncertainty
Right: 38 CMIP5 models, one member per model



Question: 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?

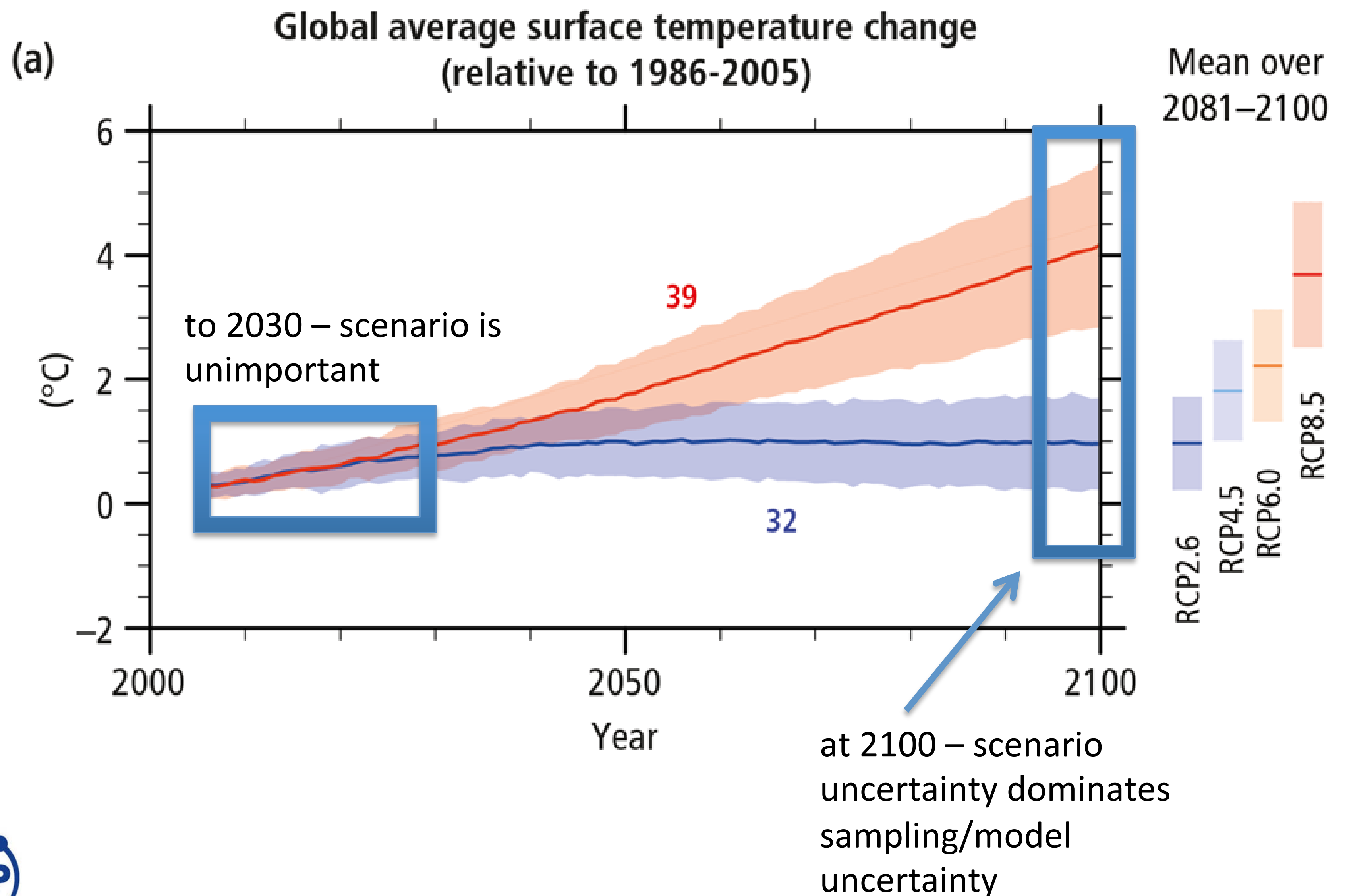


see also in GRL (2013):

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



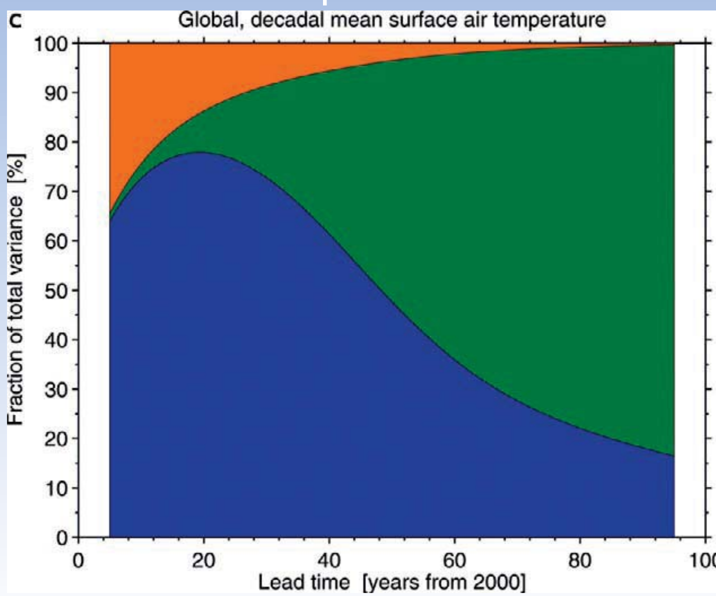
The source of uncertainty depends how far ahead you look...

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

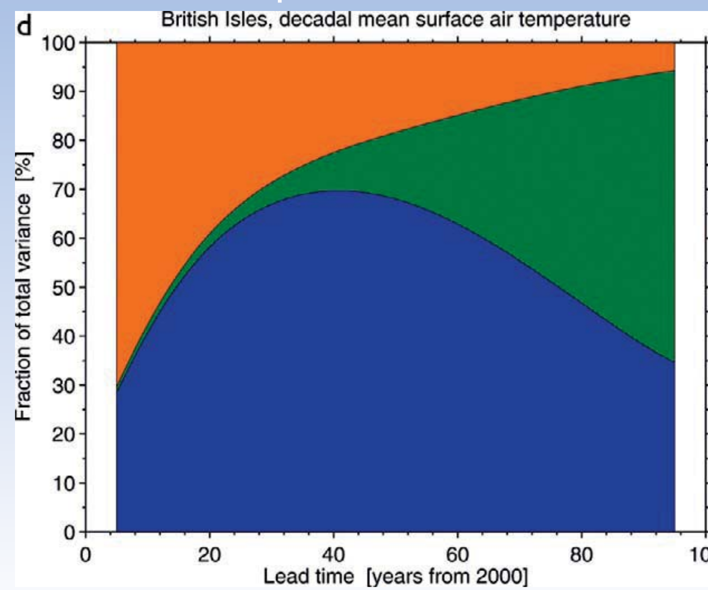
Internal variability
Scenario uncertainty
Model configuration uncertainty

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