2453-2

School on Modelling Tools and Capacity Building in Climate and Public Health

15 - 26 April 2012

Introduction to Climate observations and models

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ITALY

Introduction to climate observations and models

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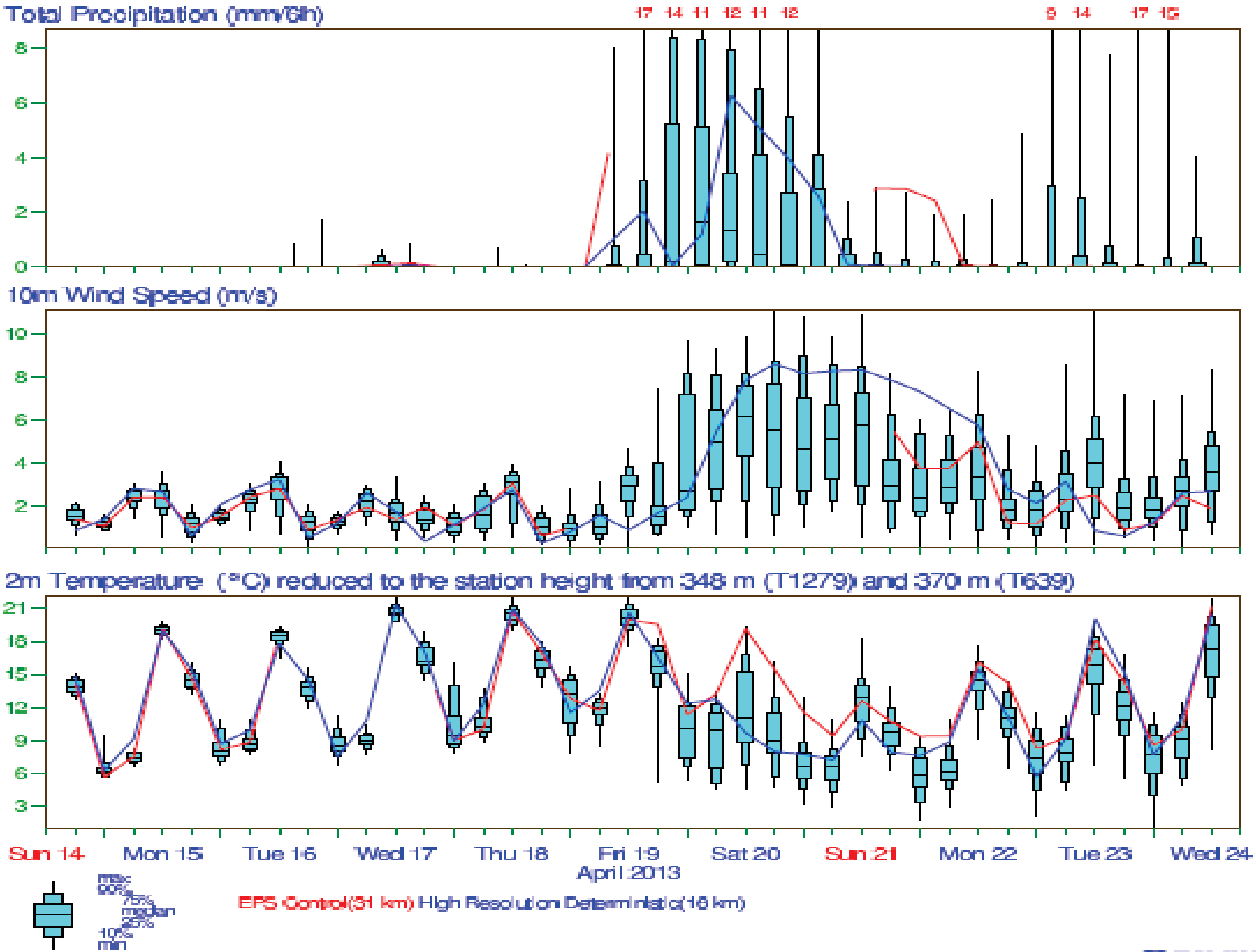
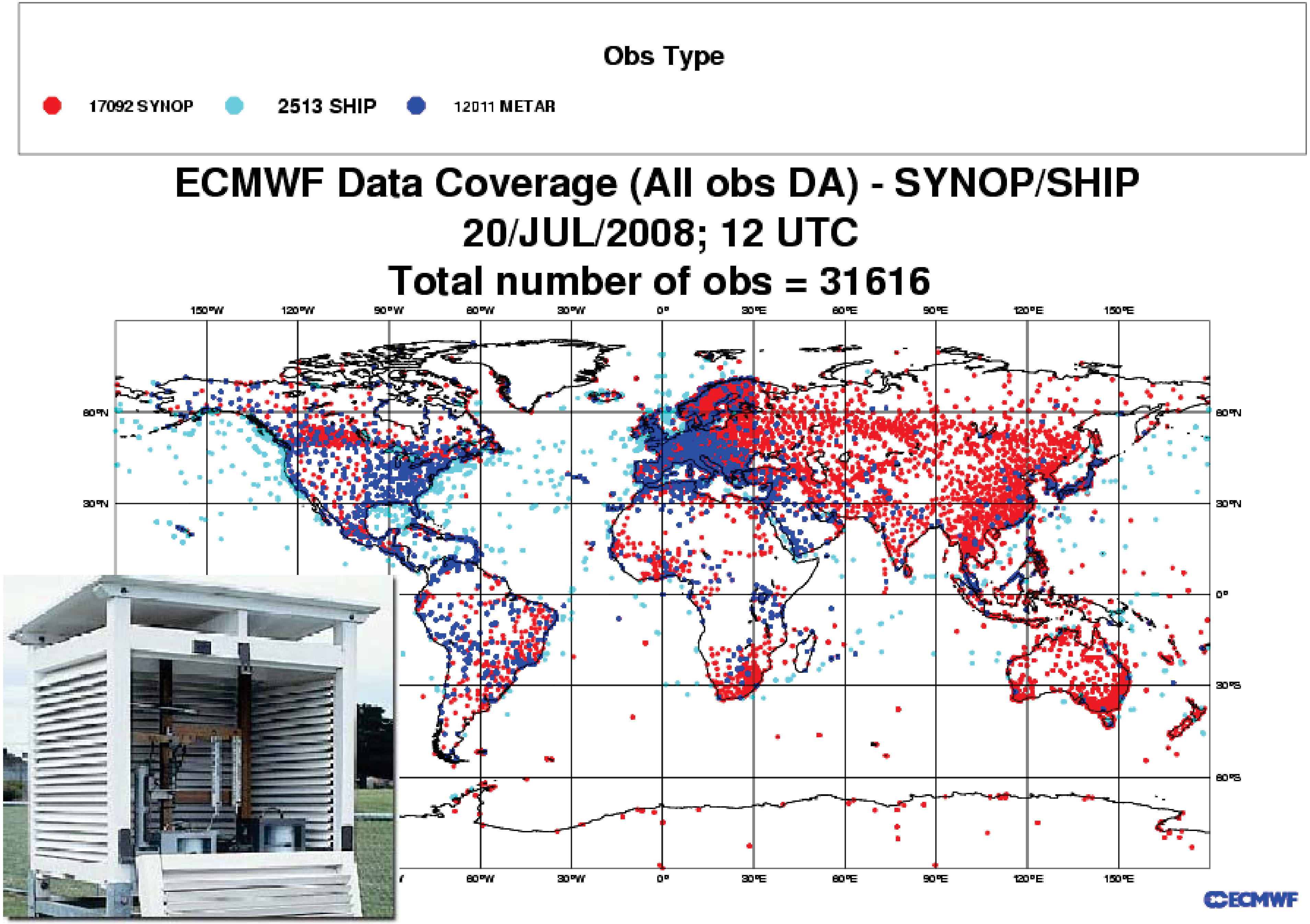

Total Precipitation (mm/6h)
10m Wind Speed (m/s)
2m Temperature (°C) reduced to the station height from 348 m (T1279) and 370 m (T639)
Sun 14
Mon 15
Tue 16
Wed 17
Thu 18
Fri 19
April 2013
Sat 20
Sun 21
Mon 22
Tue 23
Wed 24
max
90%
75%
median
25%
10%
min
EPS Control(31 km)
High Resolution Deterministic(16 km)

Climate and Health interactions

- Many hazards to health have climate drivers
- Key variables are
  - Precipitation
    - Water borne diseases – e.g. Cholera
    - Vector borne diseases – e.g. Schisto, malaria, dengue
  - Temperature
    - Heatstress related deaths
    - Vector borne diseases
    - Bacterial diseases – water borne diseases
  - Humidity
    - Virus transmission – e.g. Flu, SARS
    - Vector borne disease – impact on vector activity
  - Wind
    - Dust storms – Meningitus
    - Malaria vector tracking
    - Transport of pathogens,

STATION DATA – T, precip, winds and humidity



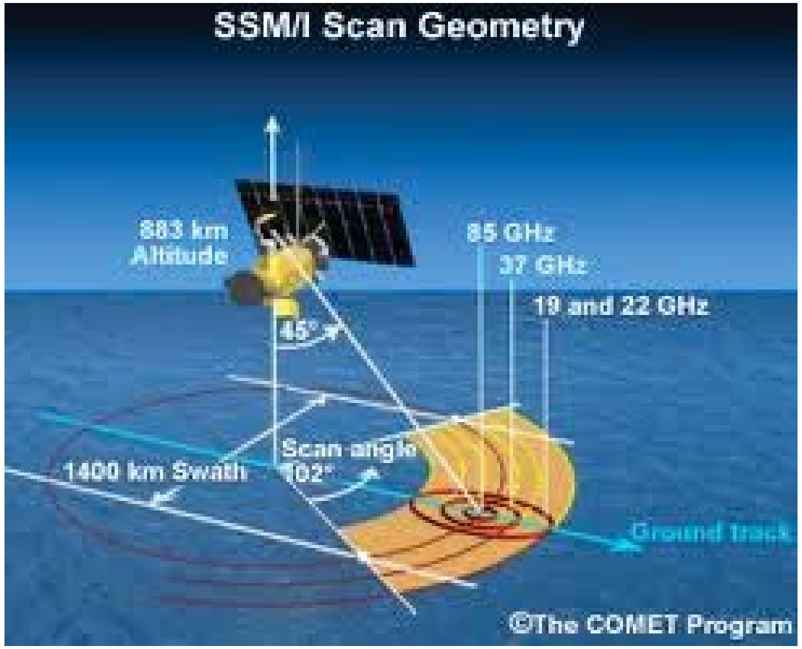
Station Data: Advantages and Disadvantages

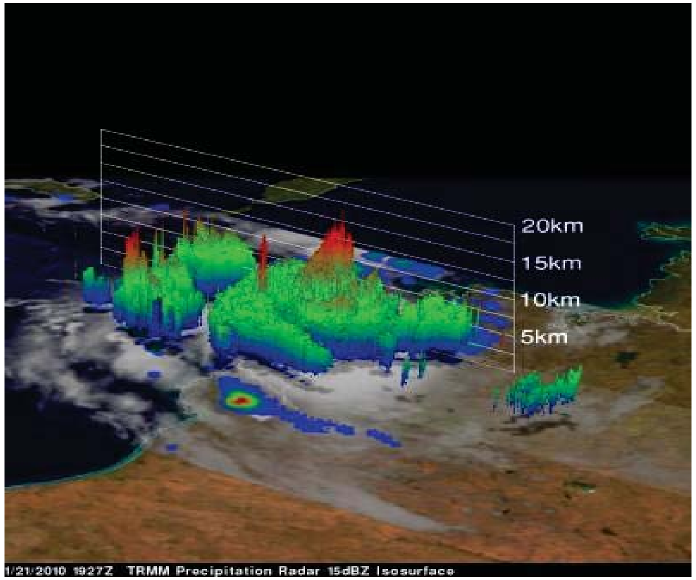
- Full array of variables
- Locally representative

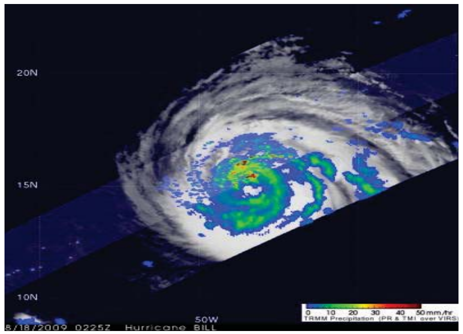
- Not often available locally
- Potentially data gaps, handling of bad data
- Representativeness over complex terrain

Satellite Data

- Surface Temperature
- Precipitation
- Humidity
- Winds







Satellite – Advantages and Disadvantages

(see Riccardo's lecture in week 2)

- Good spatial and/or temporal coverage (depending on swathe, scan, orbit...)
- Only way to get regional information in conventional data-sparse regions

- Large uncertainties
- Temperature is skin temperature
- Problems for clouds, aerosols, insects etc
- Vertical resolution of atmospheric variables poor
- Problems in many retrievals mechanisms over land

Tompkins, A. M. and A. A. Adebiyi, 2012: Using CloudSat Cloud Retrievals to Differentiate Satellite-Derived Rainfall Products over West Africa. J. Hydrometeor, 13, 1810–1816.

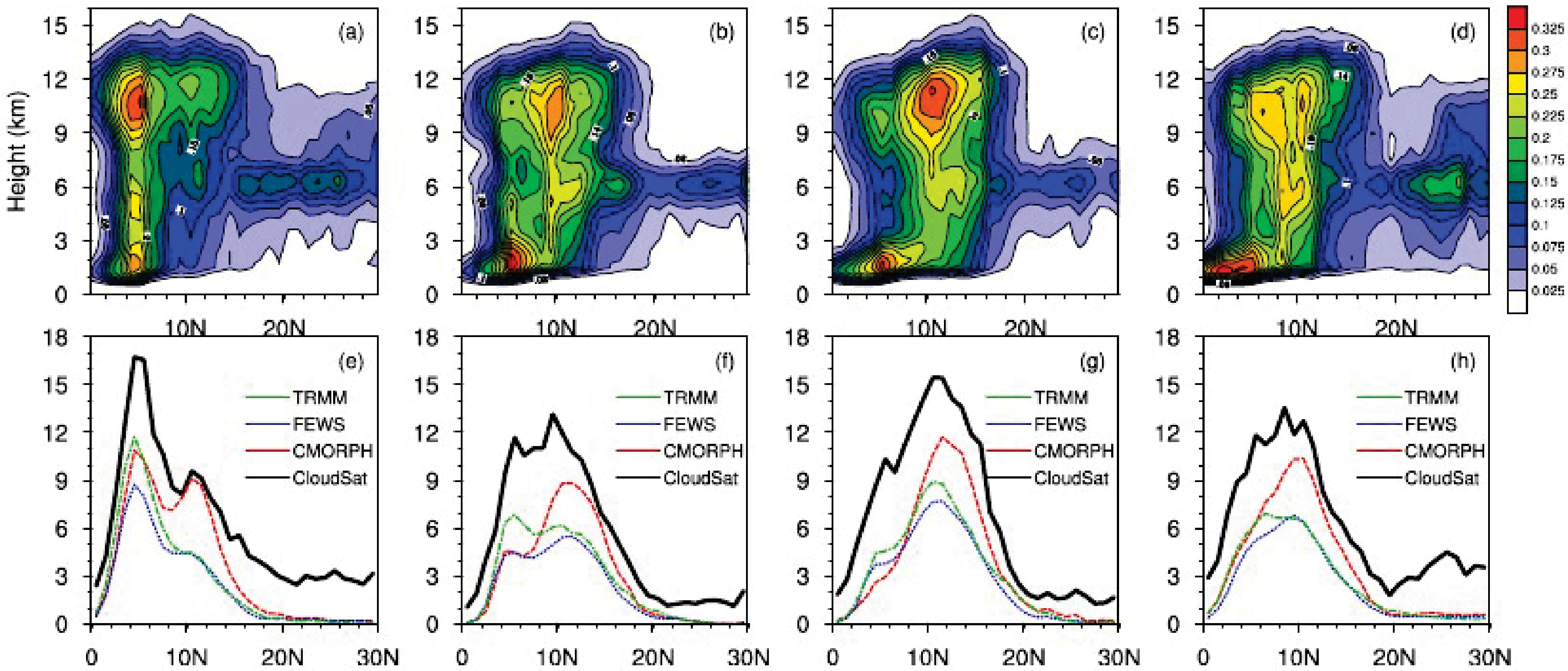


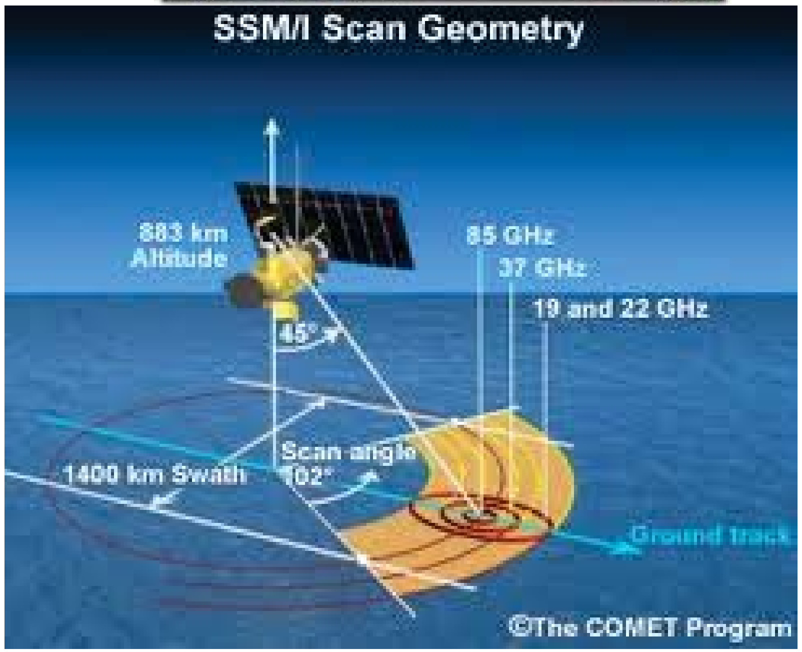
FIG. 2. Zonal averages (10 °W – 10 °E) of Cloud cover and precipitation for period 2006-2010, with each column giving a separate month during the monsoon (June to September). Panels a-d show CloudSat derived cloud fraction (%) while panels e-f compares height integrated mean cloud fraction from CloudSat (i.e. the vertical integral of panels i-l, units %) to the zonal mean of the three precipitation products of TRMM, CMORPH and FEWS, all with units of mm day^{-1}

Wide Choice of retrievals: e.g. Precipitation

- GPCP – 1995 daily (1 deg), 1979 monthly (2.5 deg) – not real-time. Mix of IR and raingauge
- CMAP – Similar to GPCP – monthly only at 2.5deg
- CMORPH – 2003-present, realtime. 30 mins. based on microwave channels, using IR to provide temporal resolution. 25/8km.
- FEWS – daily, only over Africa, using gauge if nearby, otherwise combination of IR/microwave channels, 11km resolution. Realtime, 2000-present.
- TRMM – 25km resolution, 1998-present, 3 hourly.
  - 2A25 – precip radar product – not gridded
  - 3B42 – merged, radar, IR and microwave using gauge calibration – realtime
  - 3B43 – ingests gauges on top of 3B42

Take home messages

- Station data are good where they exist, but they require careful treatment
- Satellite data useful for a regional view, but uncertainties are large, not all parameters are available, and the retrieval techniques are often obscure.



An Alternative: (re)Analysis

To make accurate forecasts it is important to know the current weather

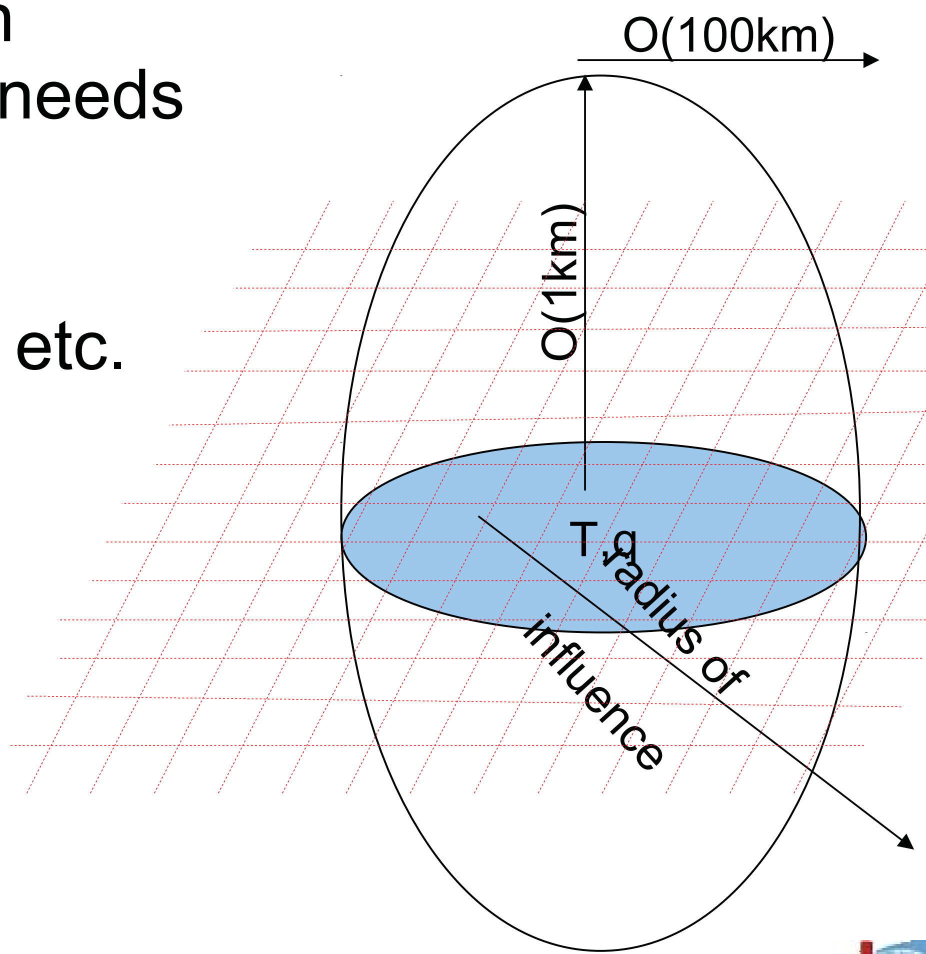
Thus analysis systems have developed over time to try and combine all available data into a picture of the atmospheric state.

Aim of "Data Assimilation" System

- To take a wide variety of variables (not necessarily model variables)...
- ...from a wide variety of instruments...
- ...with vastly different measurement densities...
- ...taking care to reject bad measurements...
- ...and combine them into an assessment of the atmospheric state, that is near balance with the forecast model "climate"
- Sounds Easy?

Data assimilation

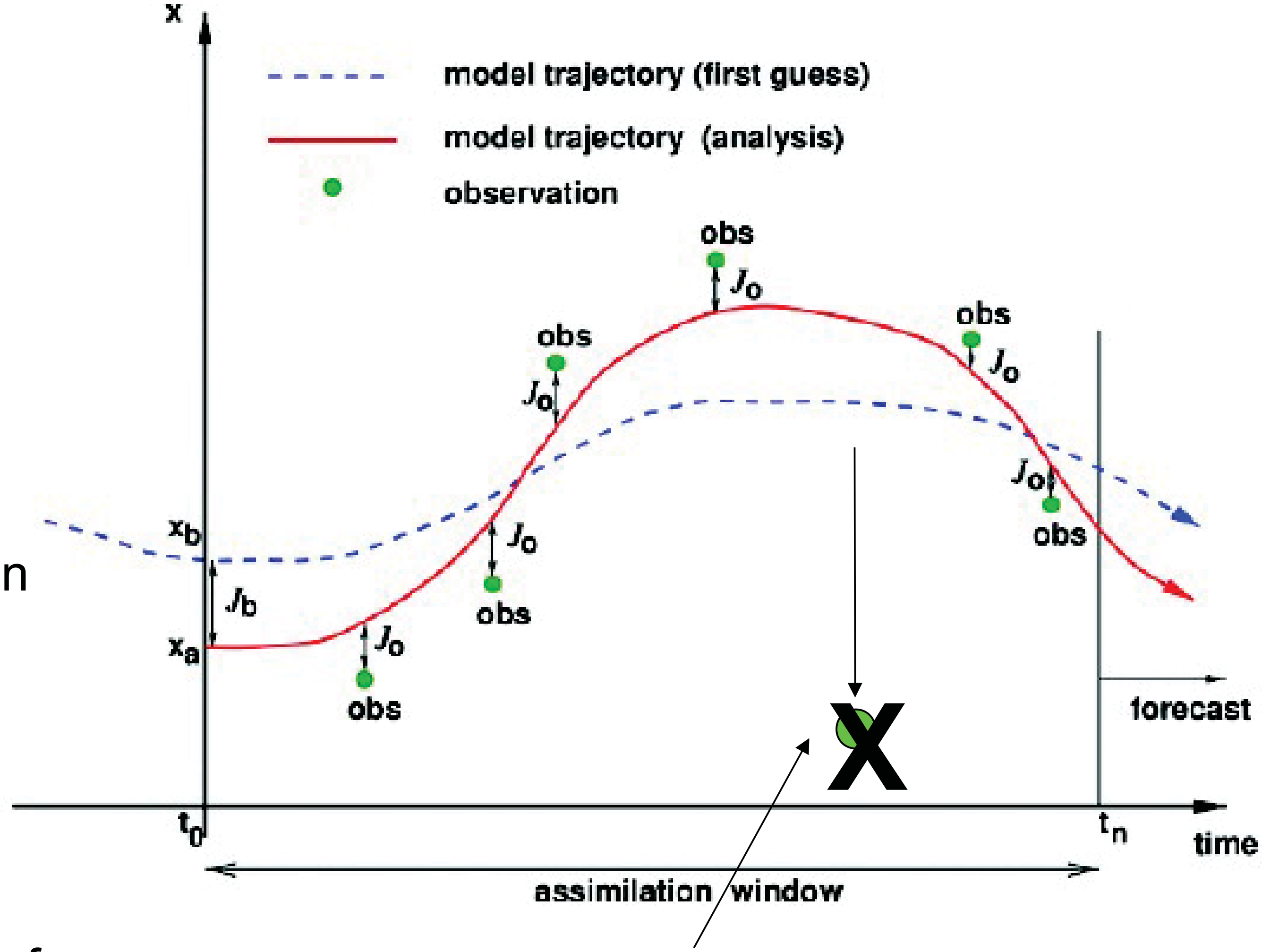
- Radius/distance of influence for each observation type needs to be defined
- Not obvious: e.g. Inversions, fronts etc.



from Marta Janiskova

4DVAR assimilation

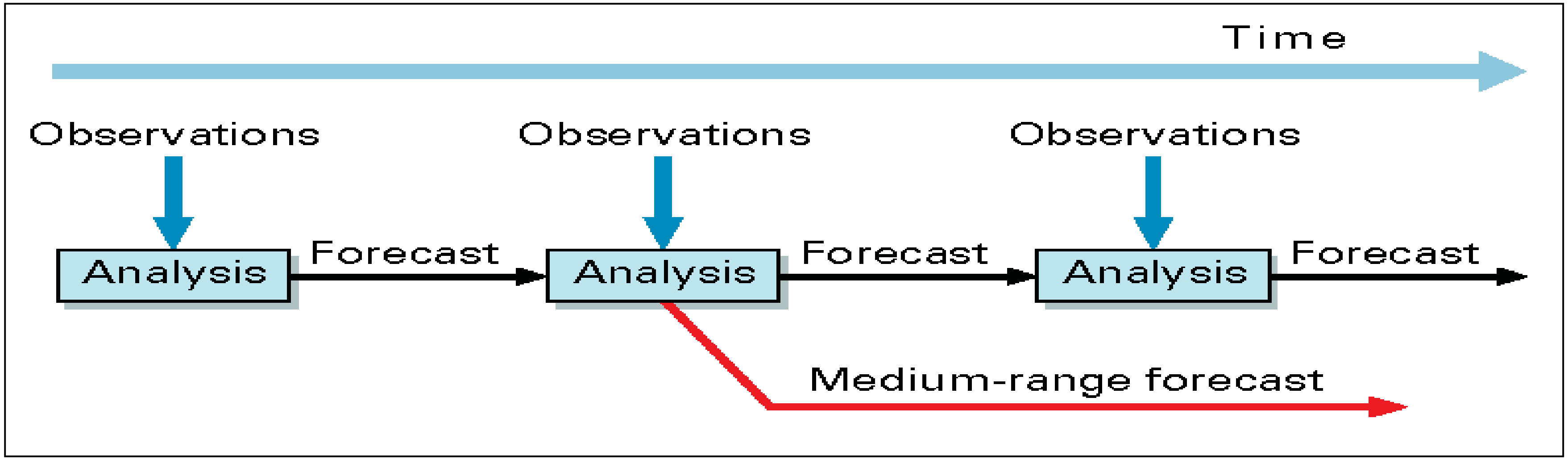
Goal: define atmospheric state x(t0) such that the “distance” between the model trajectory and observations is minimum over a given time period



Note that the quality of the forecast model is important for a good analysis!

Observations “too far” from the background forecast
are rejected as unreliable!!!

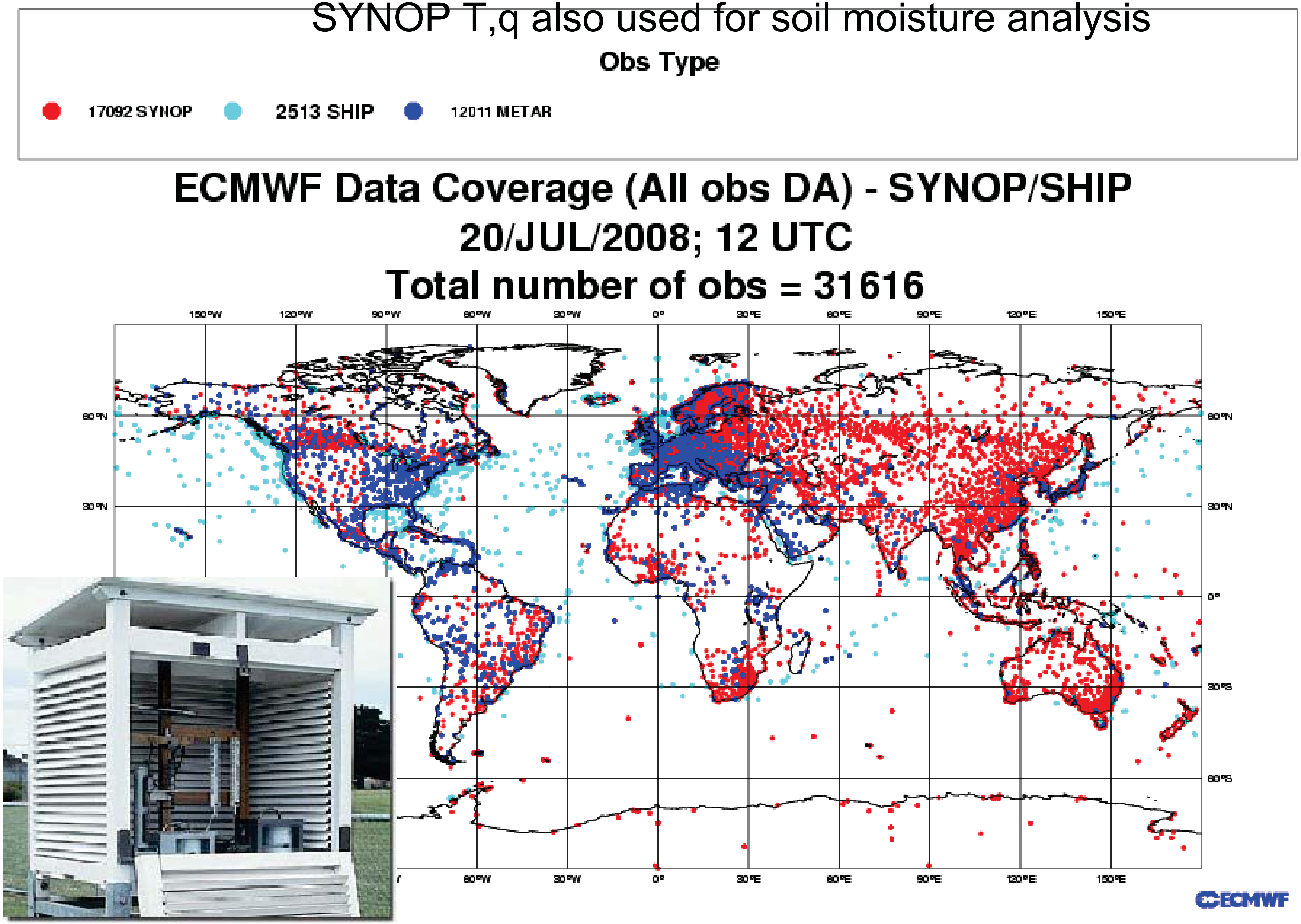
Obs are assimilated to estimate the state of the atm



- Observations are used to “correct” errors in the short forecast from the previous analysis time.
- At ECMWF, every 12 hours 4 – 8,000,000 observations are assimilated

DATA USED: Pressure, humidity during day
SYNOP T,q also used for soil moisture analysis

ECMWF Data Coverage (All obs DA) - SYNOP/SHIP
20/JUL/2008; 12 UTC
Total number of obs = 31616

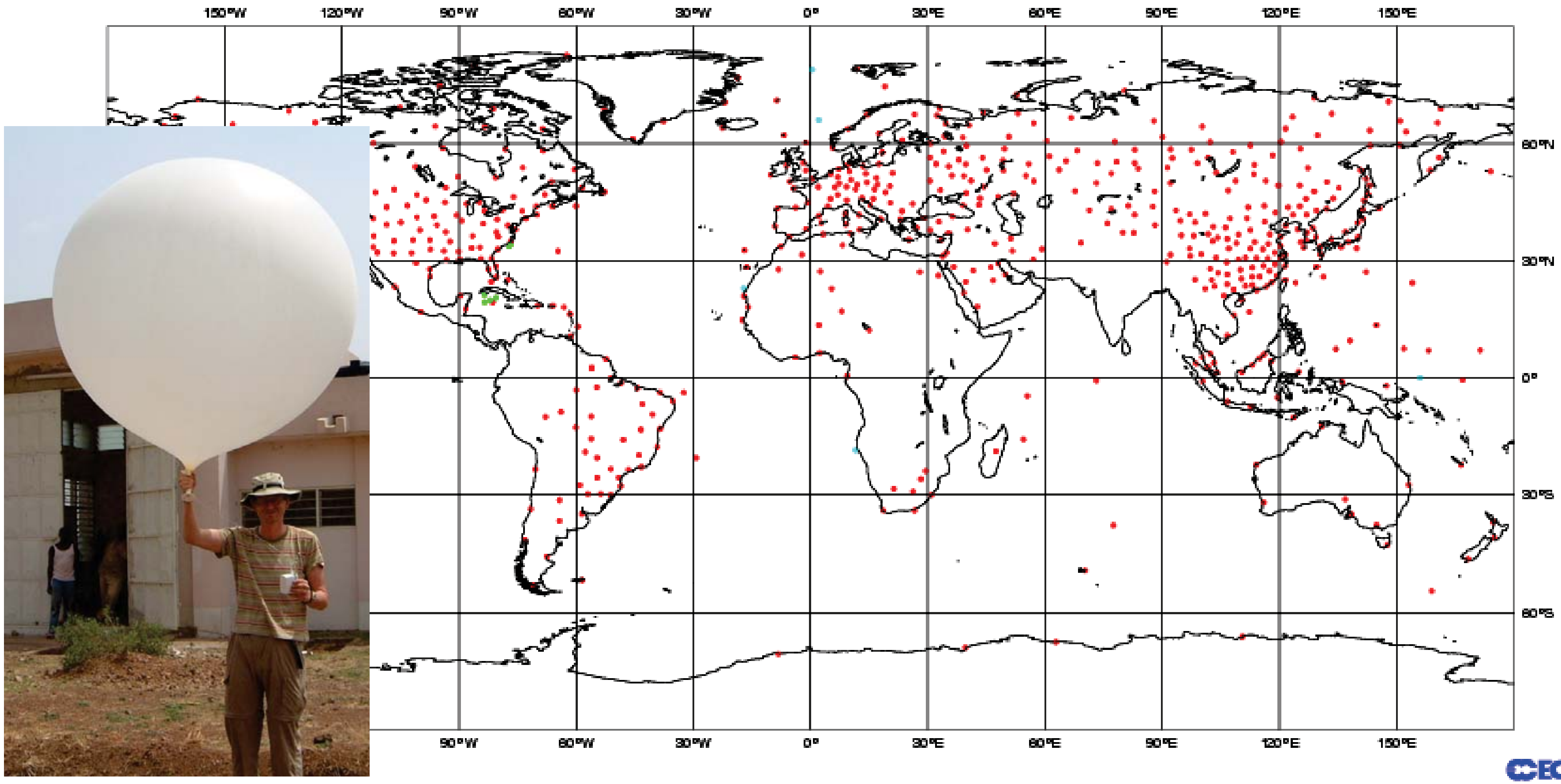


DATA USED: T,q,u,v – humidity to 300 or 100hPa

Obs Type

- 573 LAND
- 5 SHIP
- 7 DROPSONDE
- 0 MOBILE

ECMWF Data Coverage (All obs DA) - TEMP
20/JUL/2008; 12 UTC
Total number of obs = 585



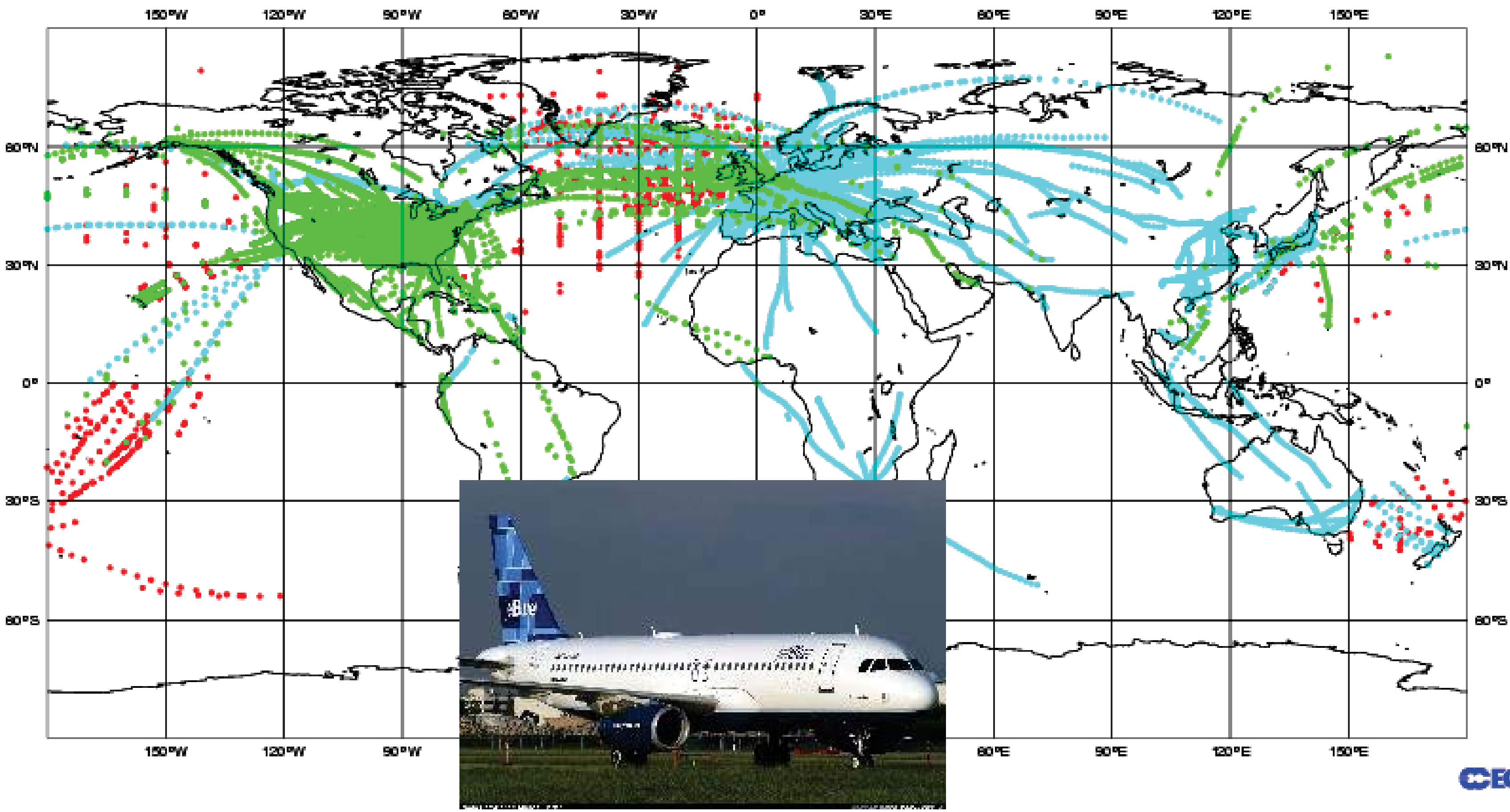
ECMWF

DATA USED: Temperature, winds
(mozaic humidity research product)

Obs Type

18035 ACARS

ECMWF Data Coverage (All obs DA) - AIRCRAFT
20/JUL/2008; 12 UTC
Total number of obs = 50089



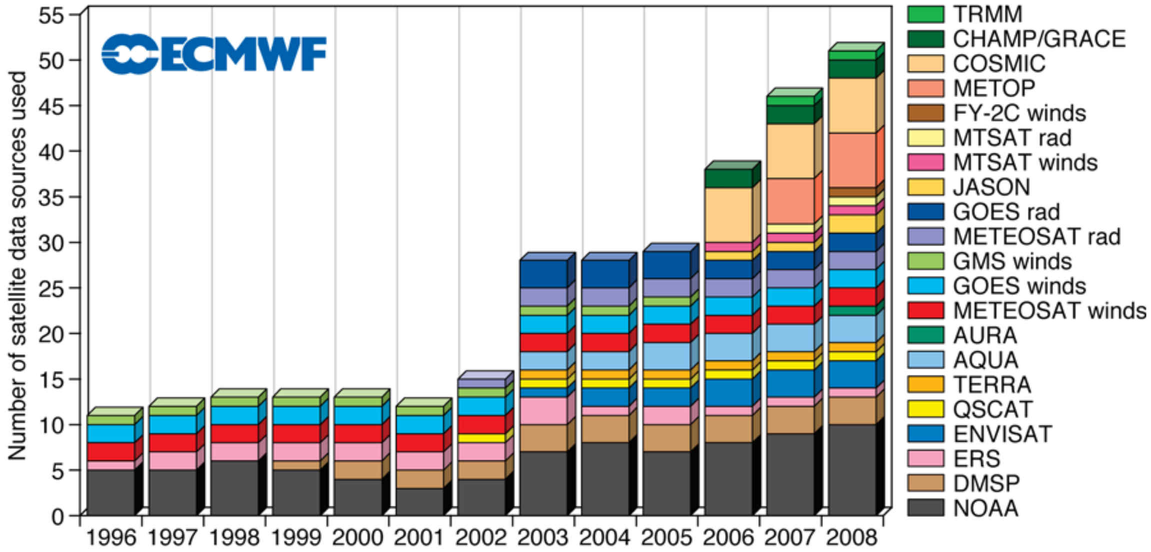
ECMWF

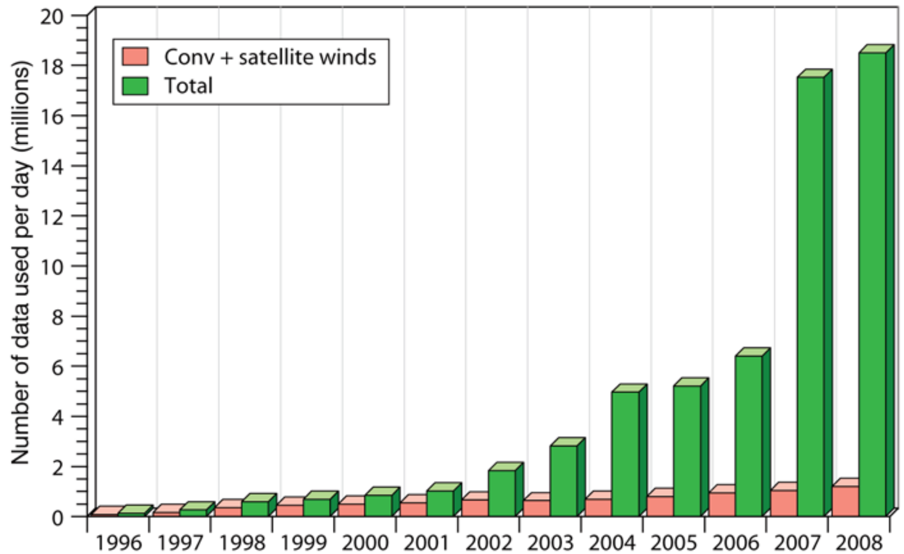
Satellite data used at ECMWF

A key factor for the advance in NWP is increase availability of satellite data.

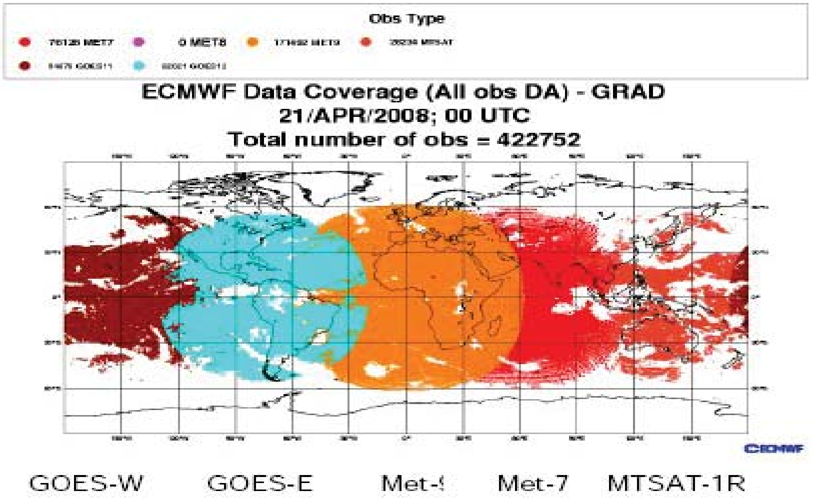
In 2008, ~ 300 million satellite observations from ~ 50 instruments have been received daily (top).

At ECMWF, ~ 6% of the available observations (~18 of the ~300 million) have been used daily (bottom).

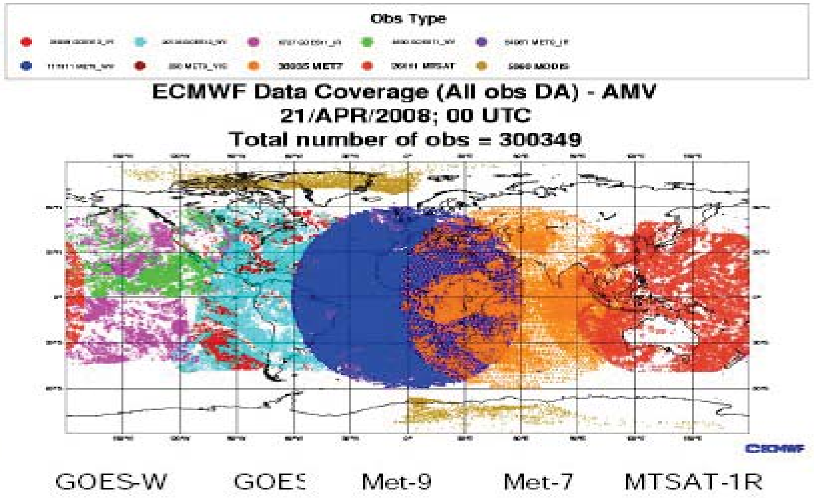




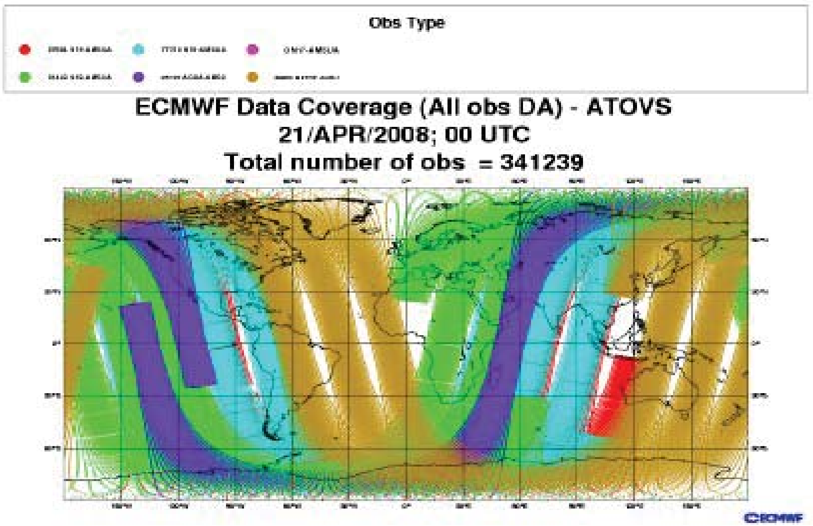
Clear-sky radiances



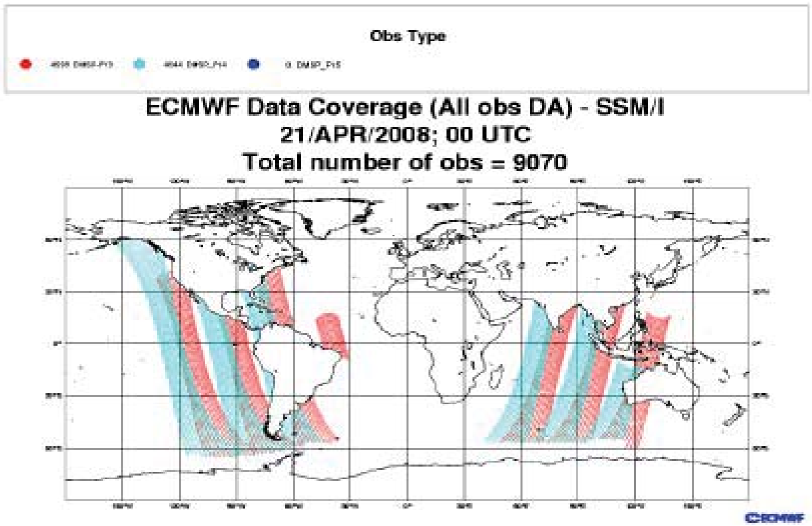
Atmospheric Motion Vectors



AMSU-A

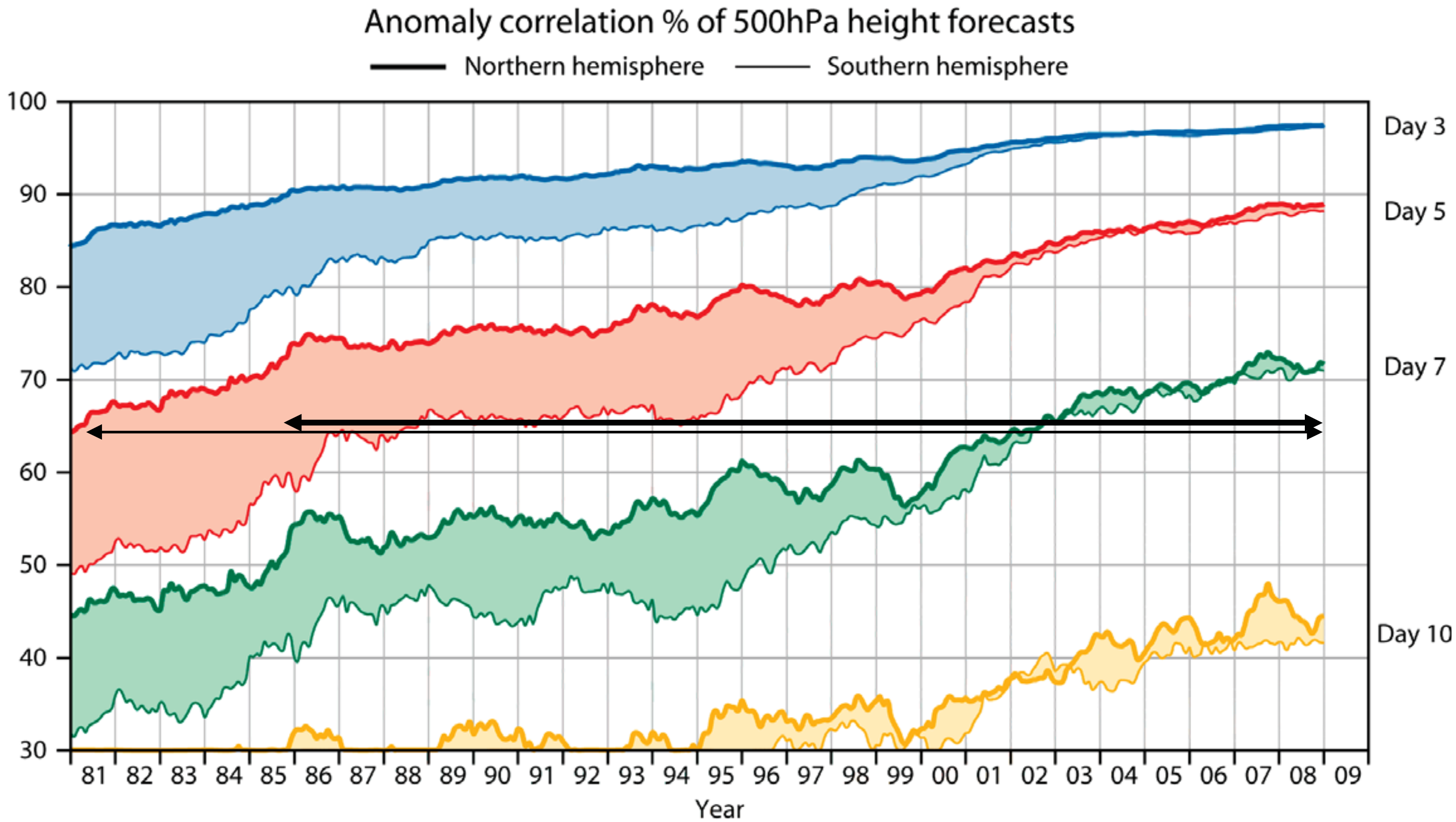


SSM/I



Evolution of ECMWF scores over NH and SH for Z500

- Over NH (SH) a day-7 single forecast of the upper-air atmospheric flow has the same accuracy as a day-5 in 1985 (day-3 in 1981).
- Note that Satellite data now implies equally good FC in NH and SH



Some common misconceptions

- Very little information concerning clouds or precipitation is directly assimilated into the model
- Clouds in the analysis are a model product from the model physics, their location/properties determined by temperature, humidity and dynamics.
- Thus the parameters most important for impacts modelling (e.g. esp. temperature and precipitation) are all influenced by the model physics even in the analysis

To analysis or reanalysis – that is the question?

Analysis

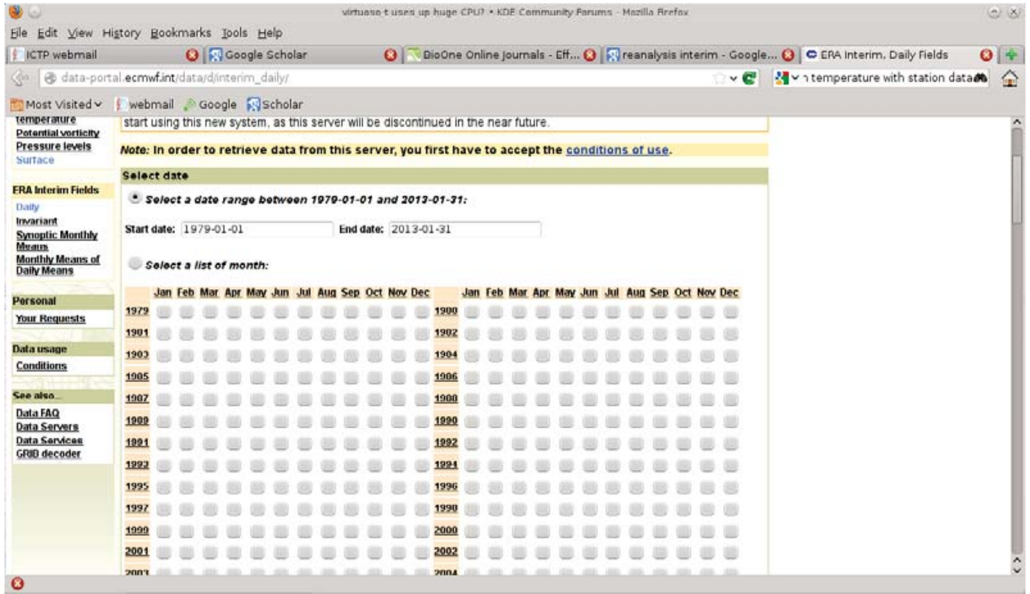
- Latest operational system
- High resolution
- Latest observation suite
- Model and observations change over time
- Not easily available
- Ideal for recent case study

Reanalysis (e.g. ERAI)

- Using same model system, rerun for long period
- More continuity, although observations change over time
- Low resolution
- Obsolete model (ERAI from 10 years ago)
- Ideal for long term study

Take home messages

- Analysis products are a useful supplement to observations
- Instantaneous fields are directly from the model analysis. Fluxes are from a short-range forecast.
- For recent case studies much better to use the analysis than reanalysis (higher resolution and better system)



Predicting the Future

- Days – Medium range weather forecasts

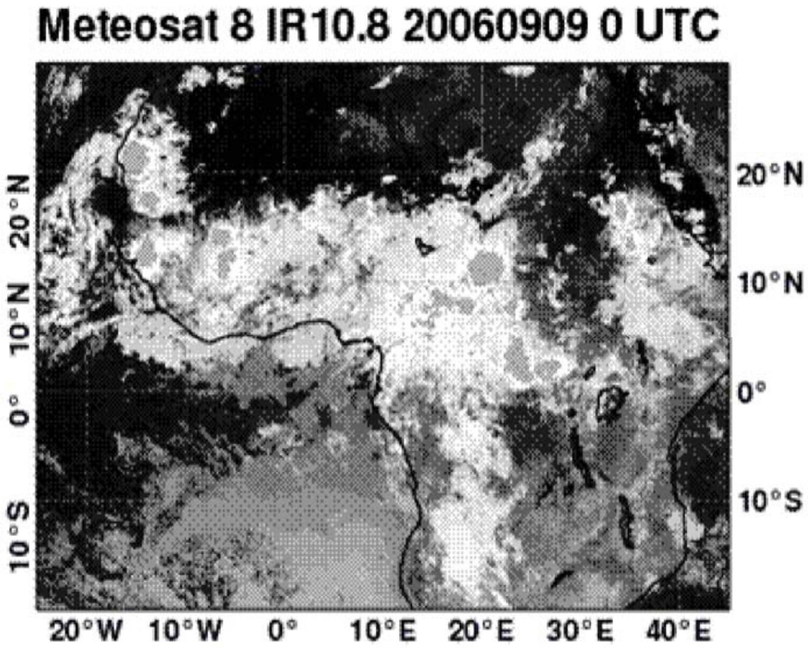
  Sensitivity to model error and atmospheric initial conditions

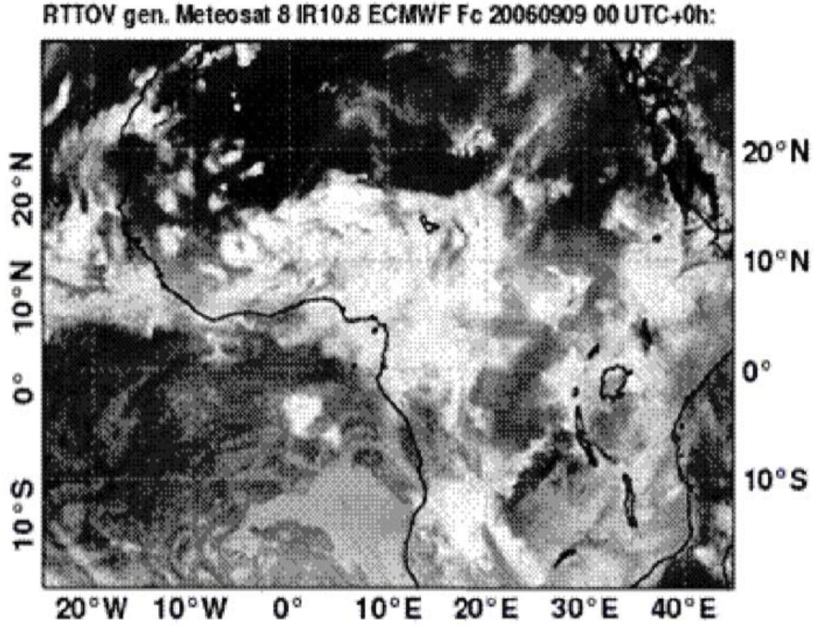
- Weeks – months – Ensemble seasonal forecasting

  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


Meteosat 8 IR10.8 20060909 0 UTC
20°N
10°N
0°
10°S
20°W 10°W 0° 10°E 20°E 30°E 40°E


RTTOV gen. Meteosat 8 IR10.8 ECMWF Fc 20060909 00 UTC+0h:
20°N
10°N
0°
10°S
20°W 10°W 0° 10°E 20°E 30°E 40°E

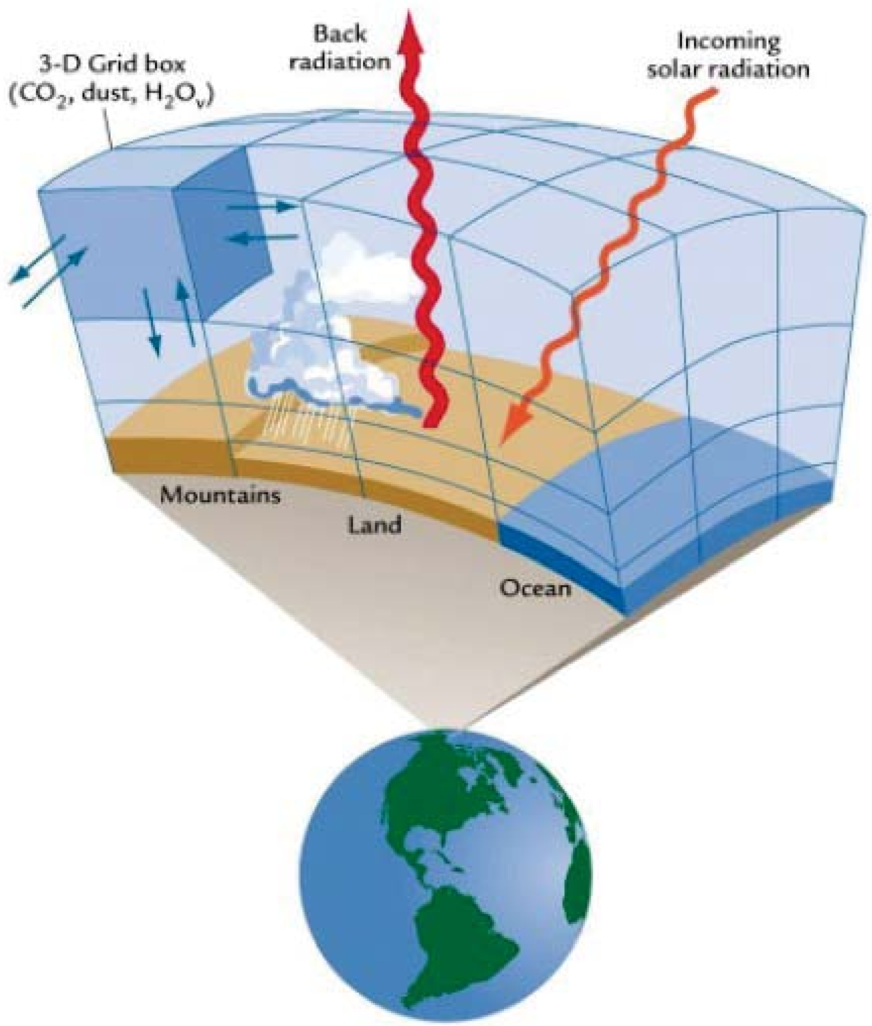
Climate and numerical weather prediction models are constructed using 5 fundamental set of equations

climate model equation set

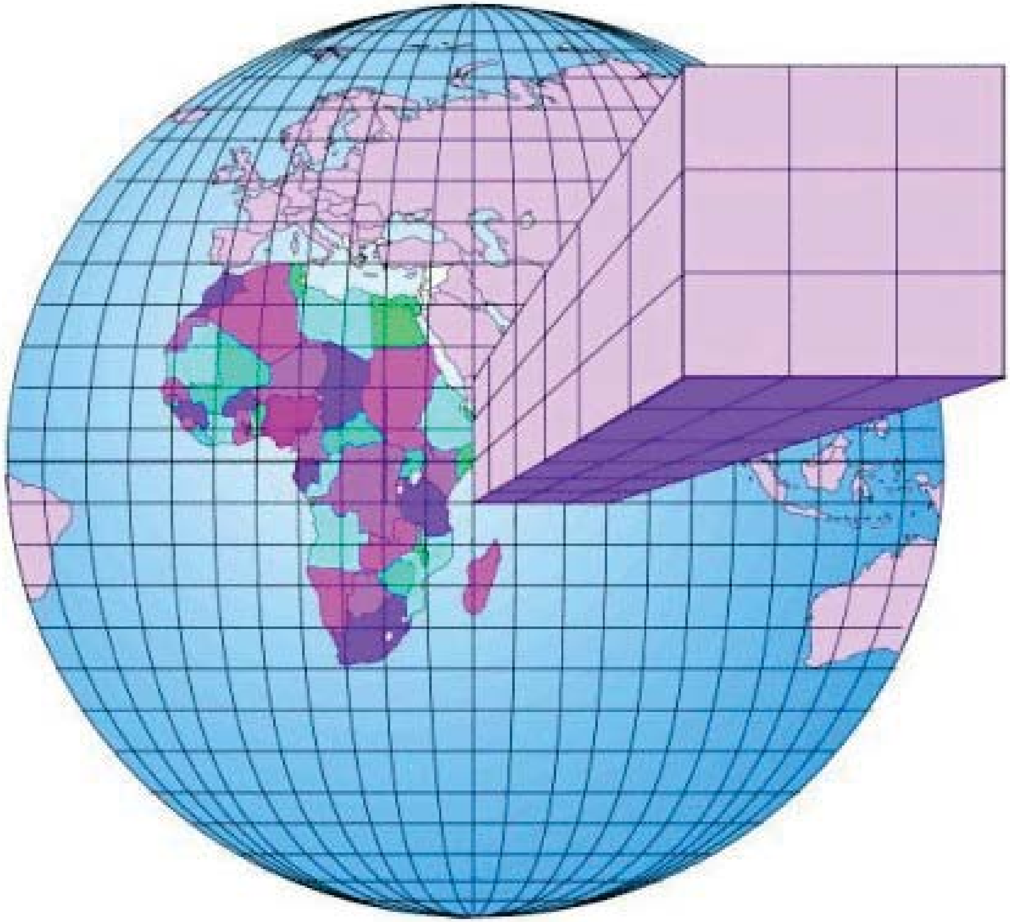
- equations of motion
- equations of state
- thermodynamic equation
- mass balance equation
- water balance equation

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.

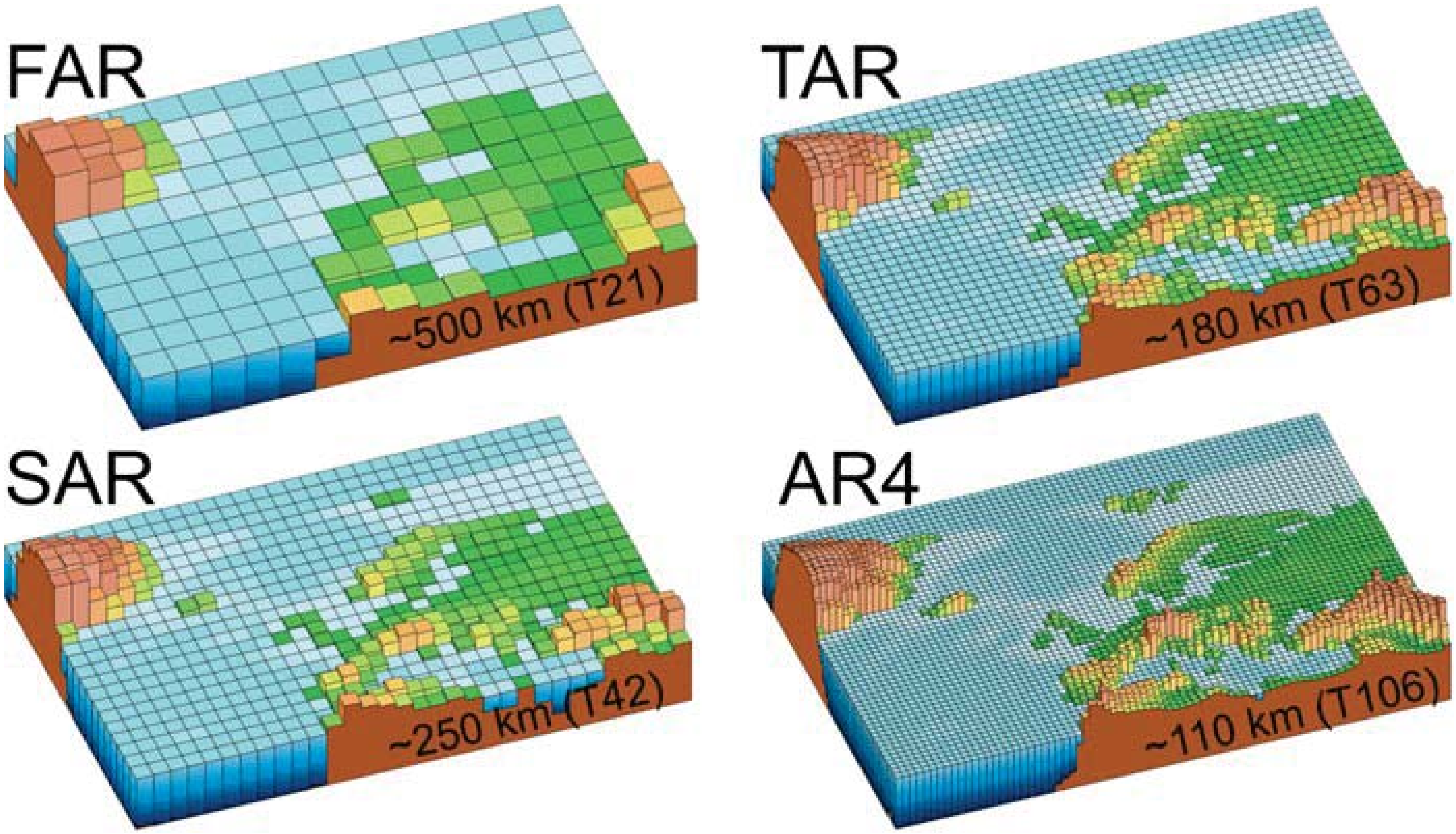
- Dividing the atmosphere into grid boxes
- Properties are considered uniform in each box
- Equations are integrated numerically forward in time



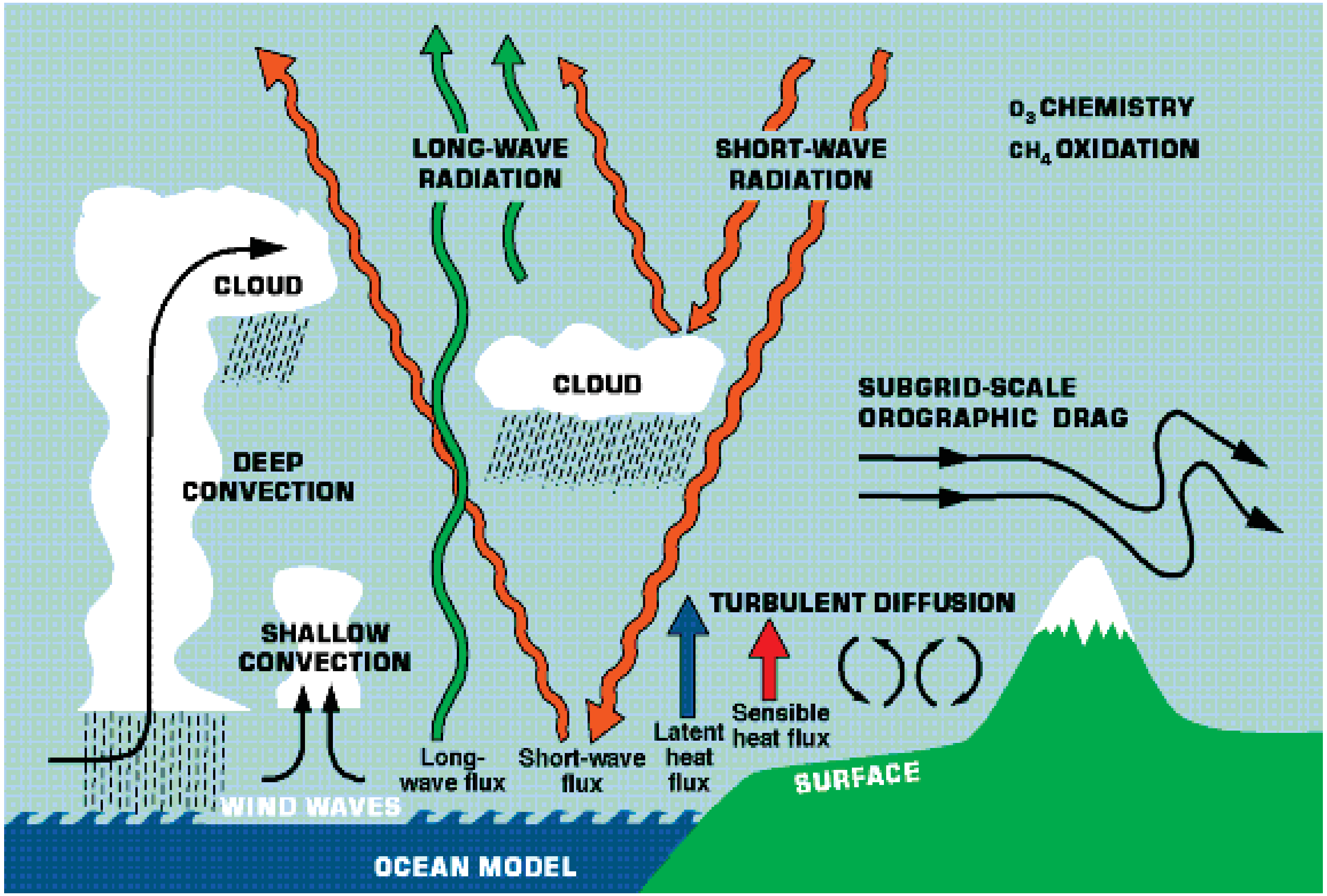
Computing power determines box size



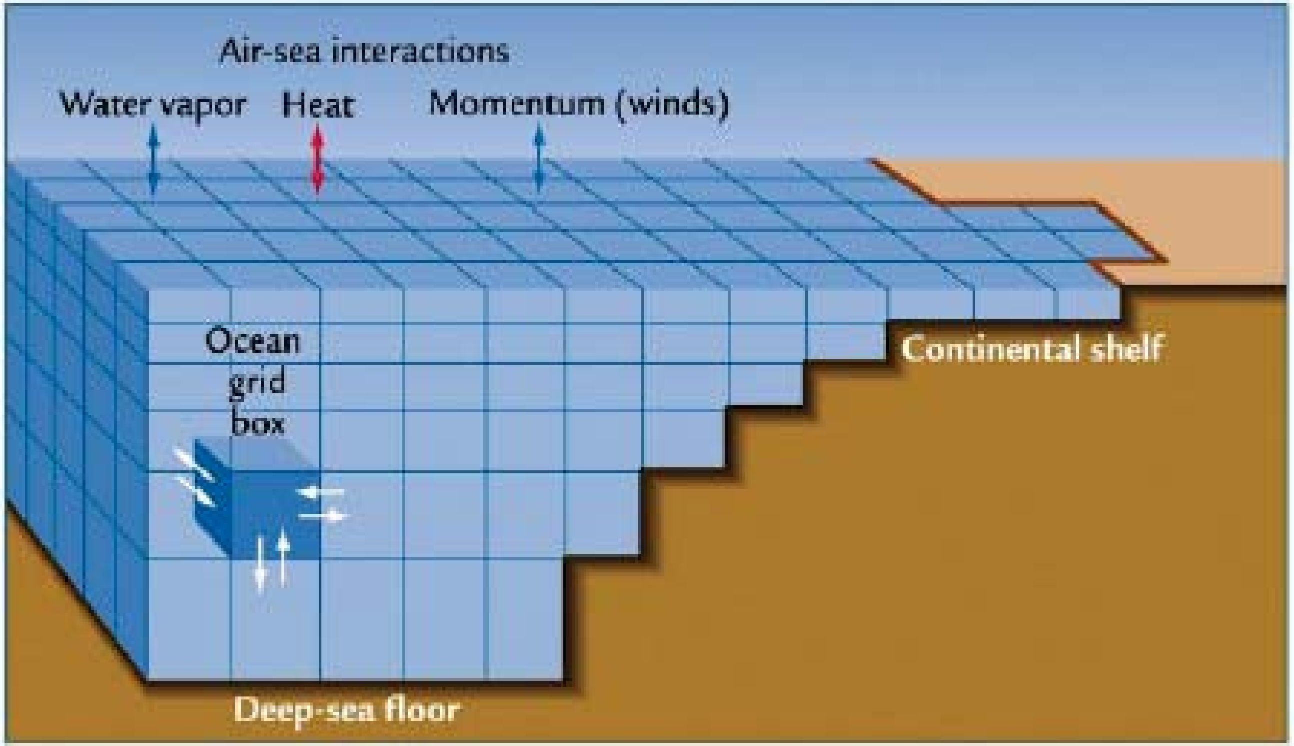
As seen by progression in IPCC models



But there are still many processes that can not be resolved and must be represented by parametrization schemes

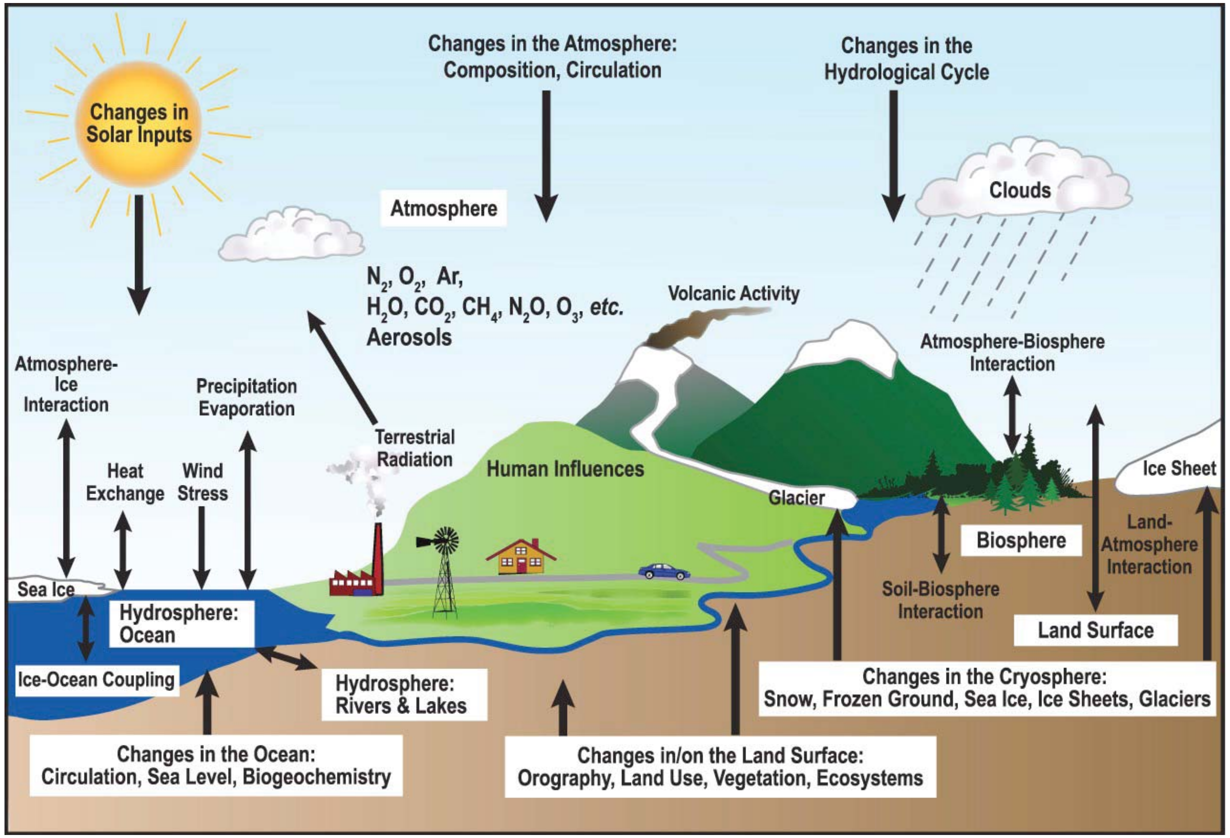


Seasonal forecast and climate models also require representation of the ocean

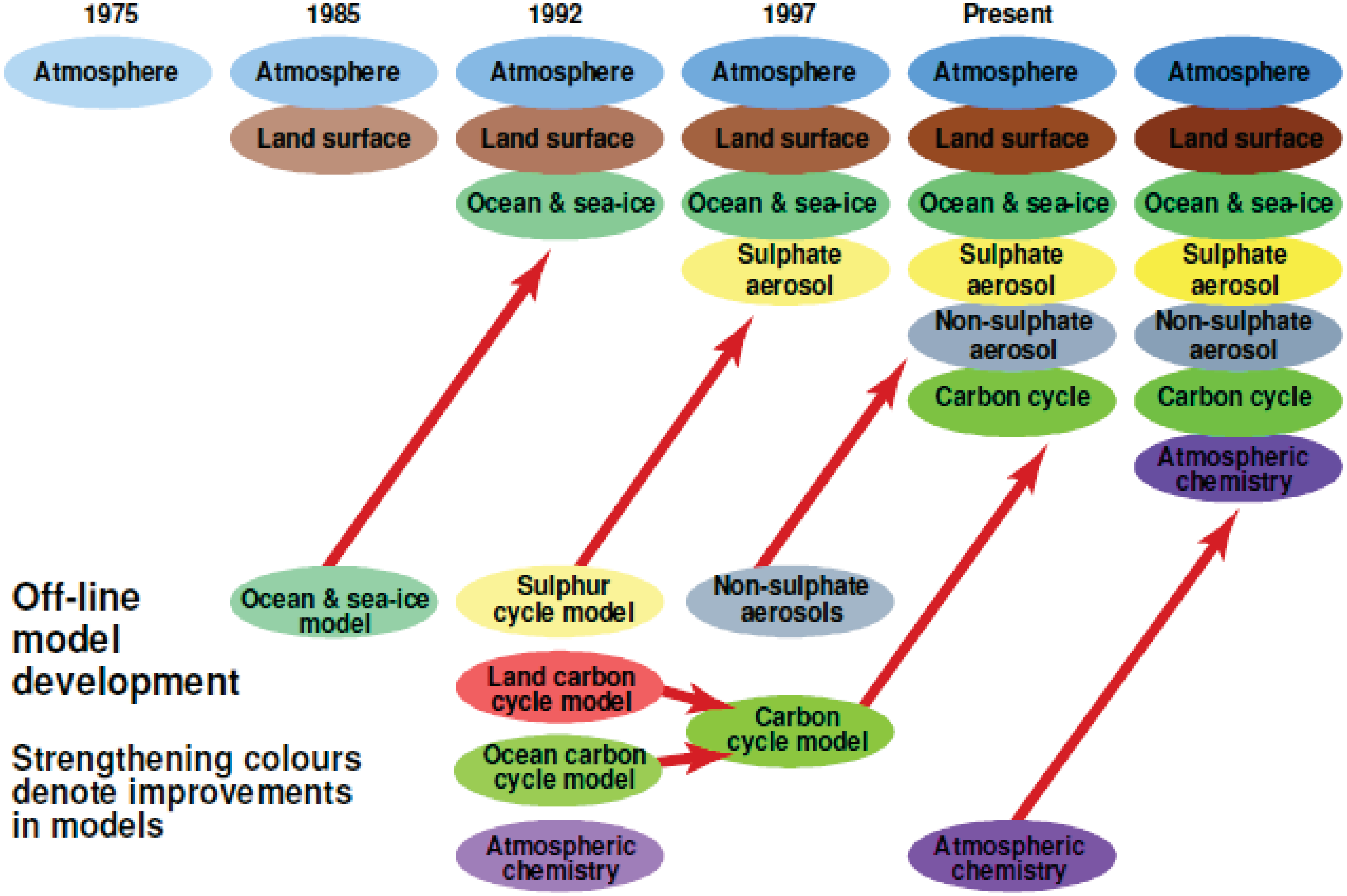


Climate models also must describe slower components of the climate system

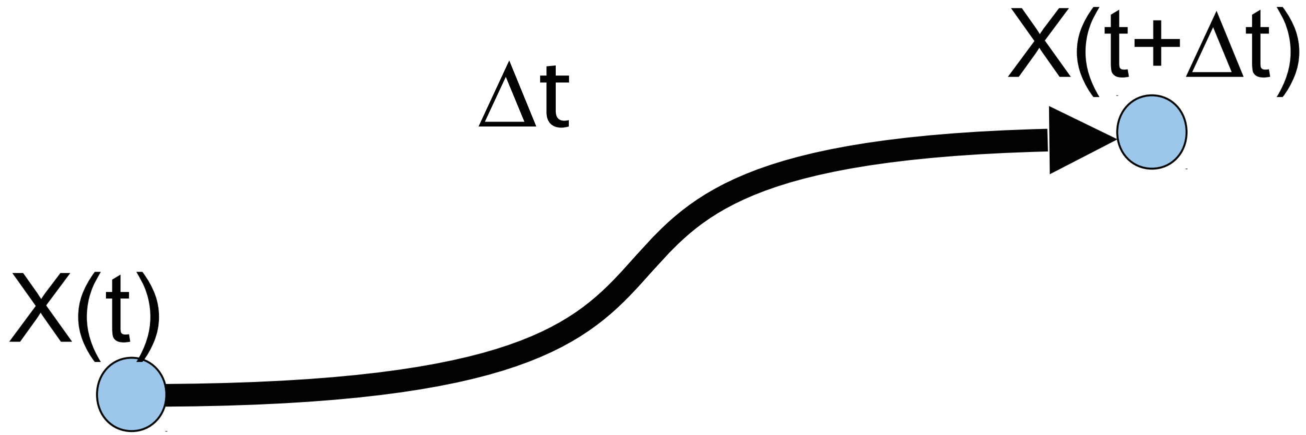
- Sea ice
- Land cover and vegetation
- Land hydrological cycle
- Carbon cycles
- Biogeochemistry cycles



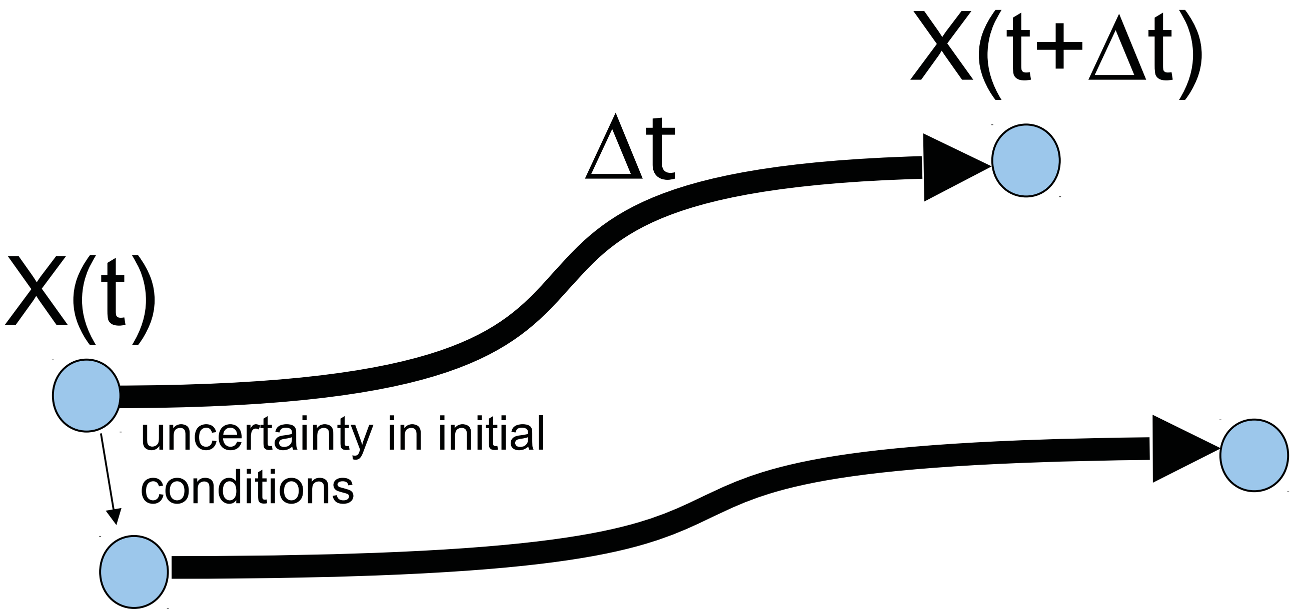
Towards Comprehensive Earth System Models
Past present and future



Accounting for Uncertainty
In numerical weather prediction the two main causes are...?

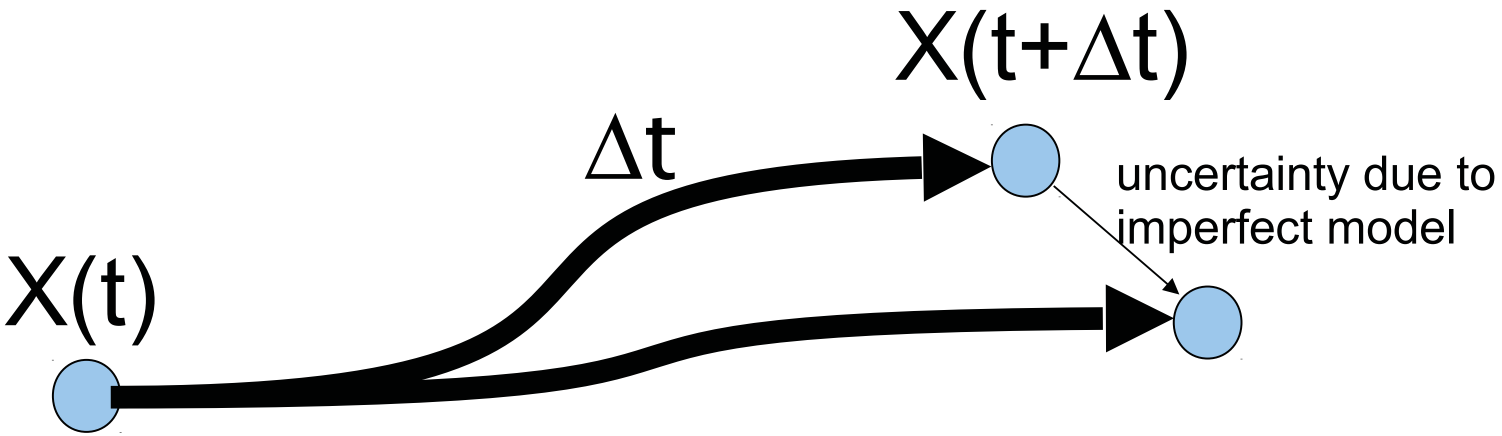


i. Uncertainty in initial conditions



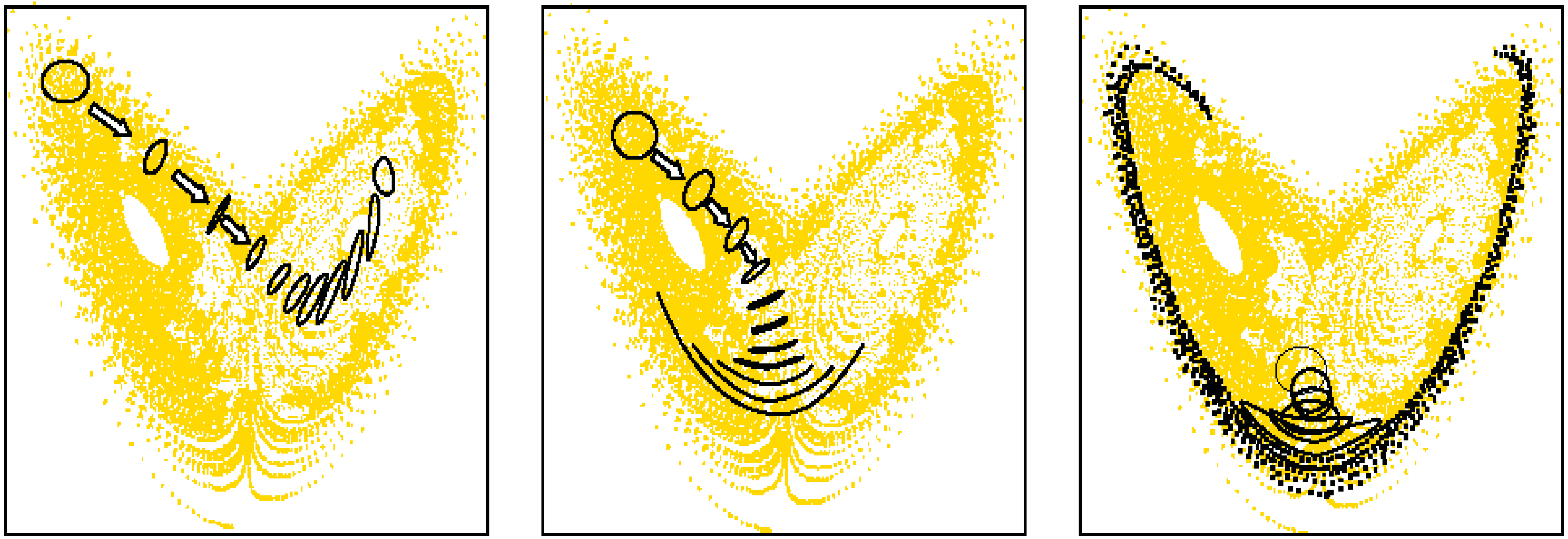
"Butterfly Effect"

ii. Imperfect model



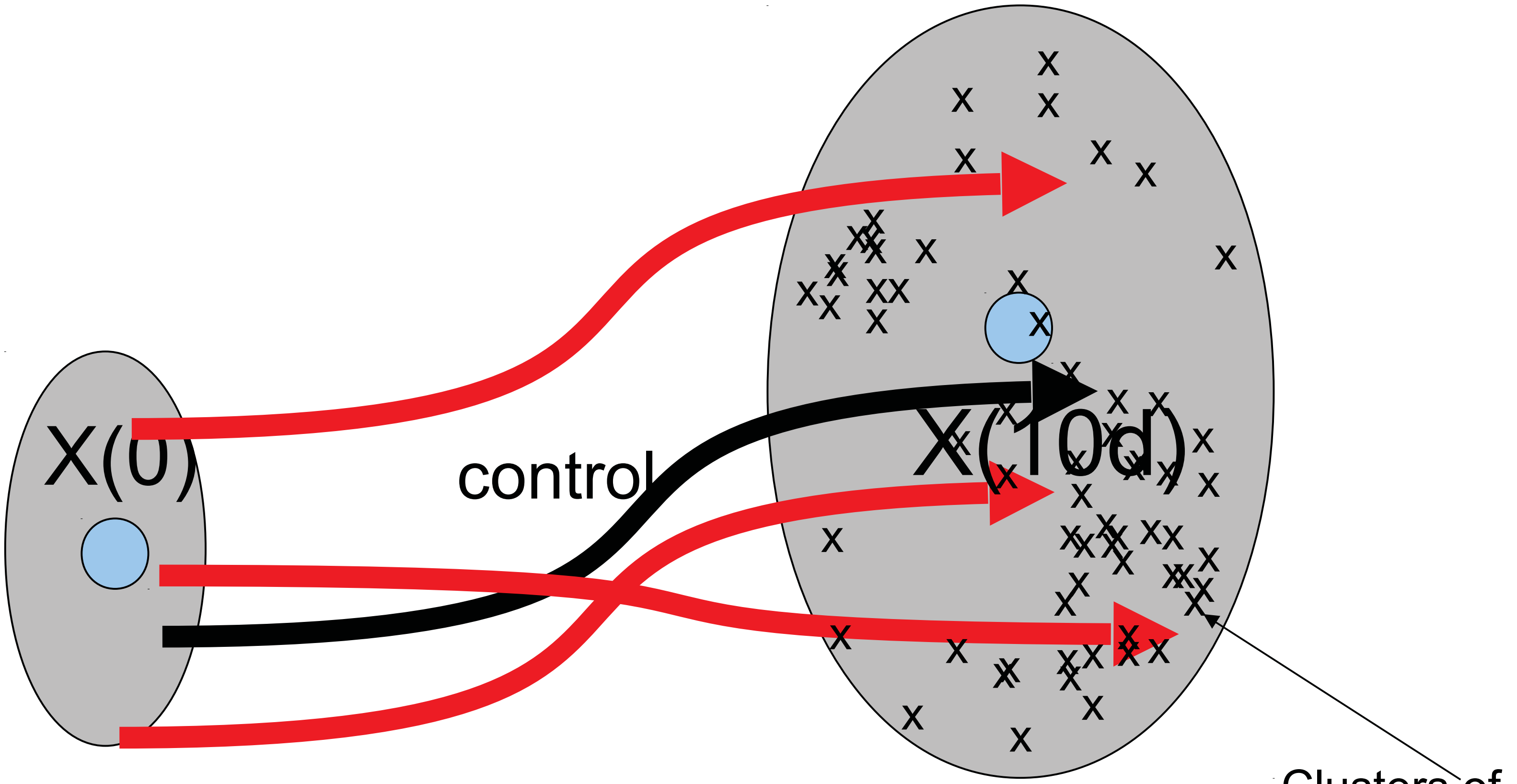
Initial and model uncertainties, and chaotic behavior

As a further complication, the atmosphere is a chaotic system! Error growth due to initial and model uncertainty is flow dependent.



"Butterfly Effect"

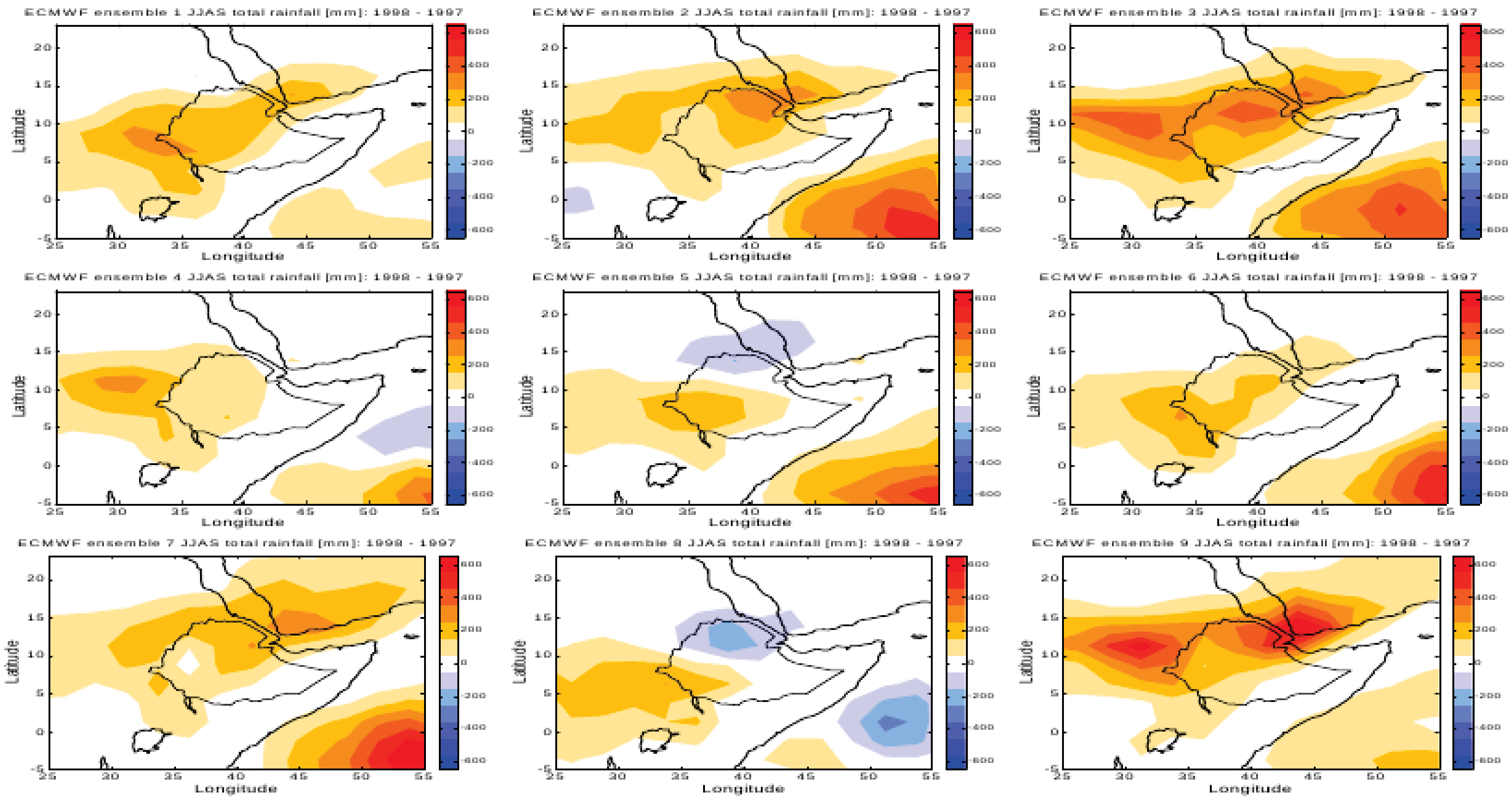
Account for this
1. perturbing initial conditions
2. perturbing the forecast model physics



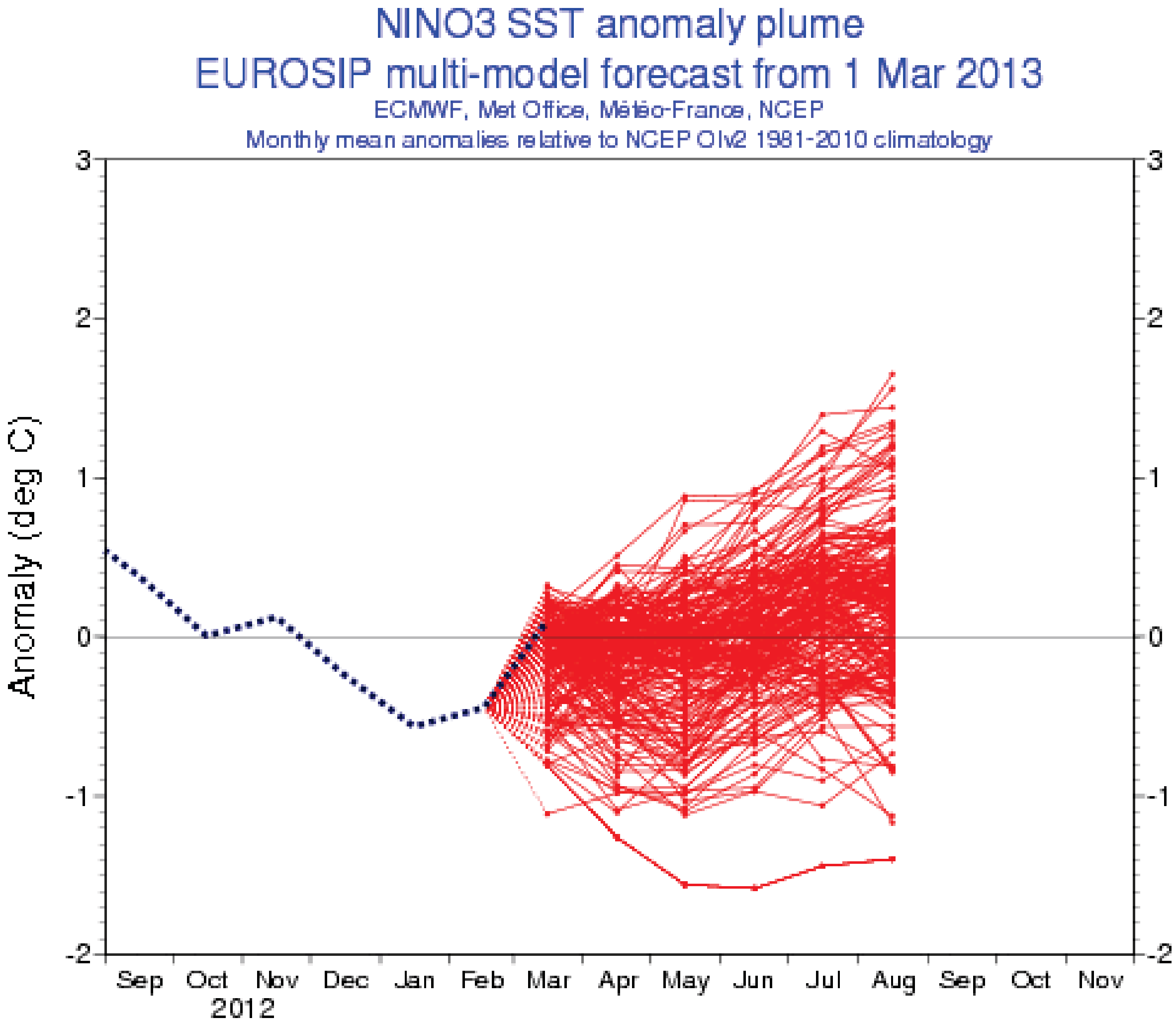
Many (~50) perturbed initial conditions

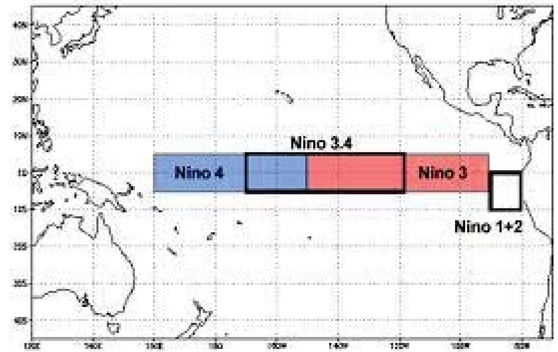
How?

- 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



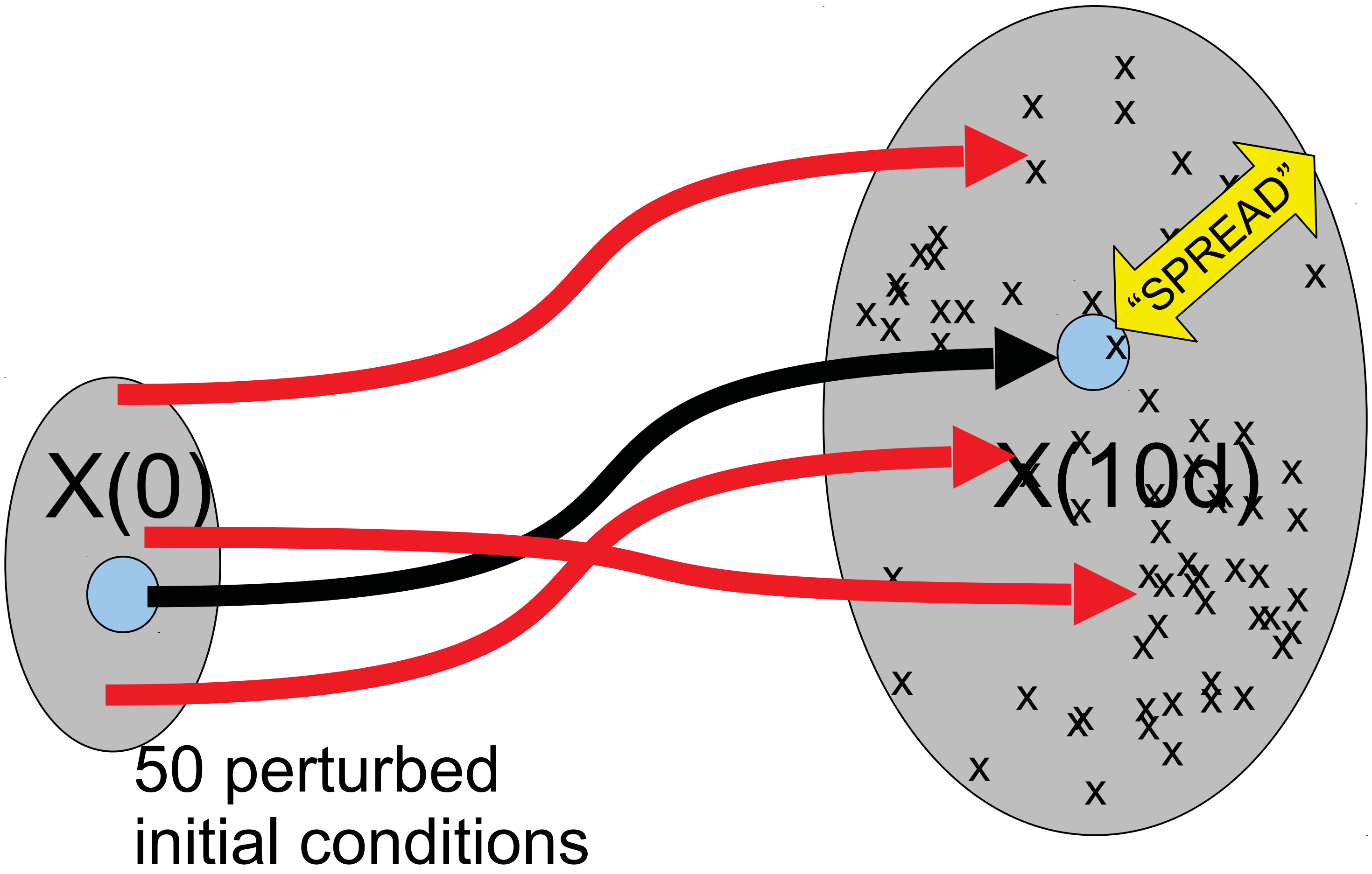
Latest El-Nino forecast plume – 3 models



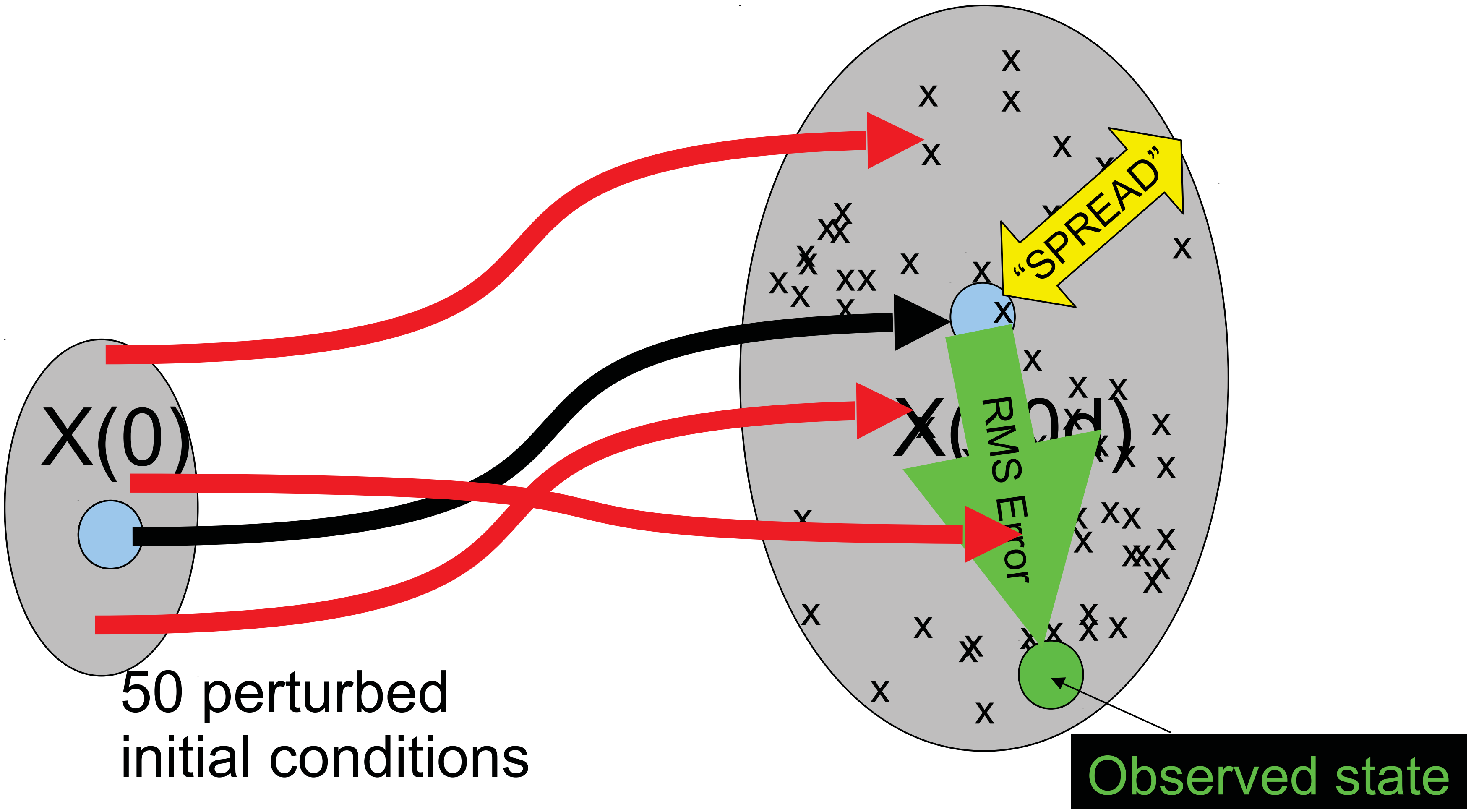


ECMWF

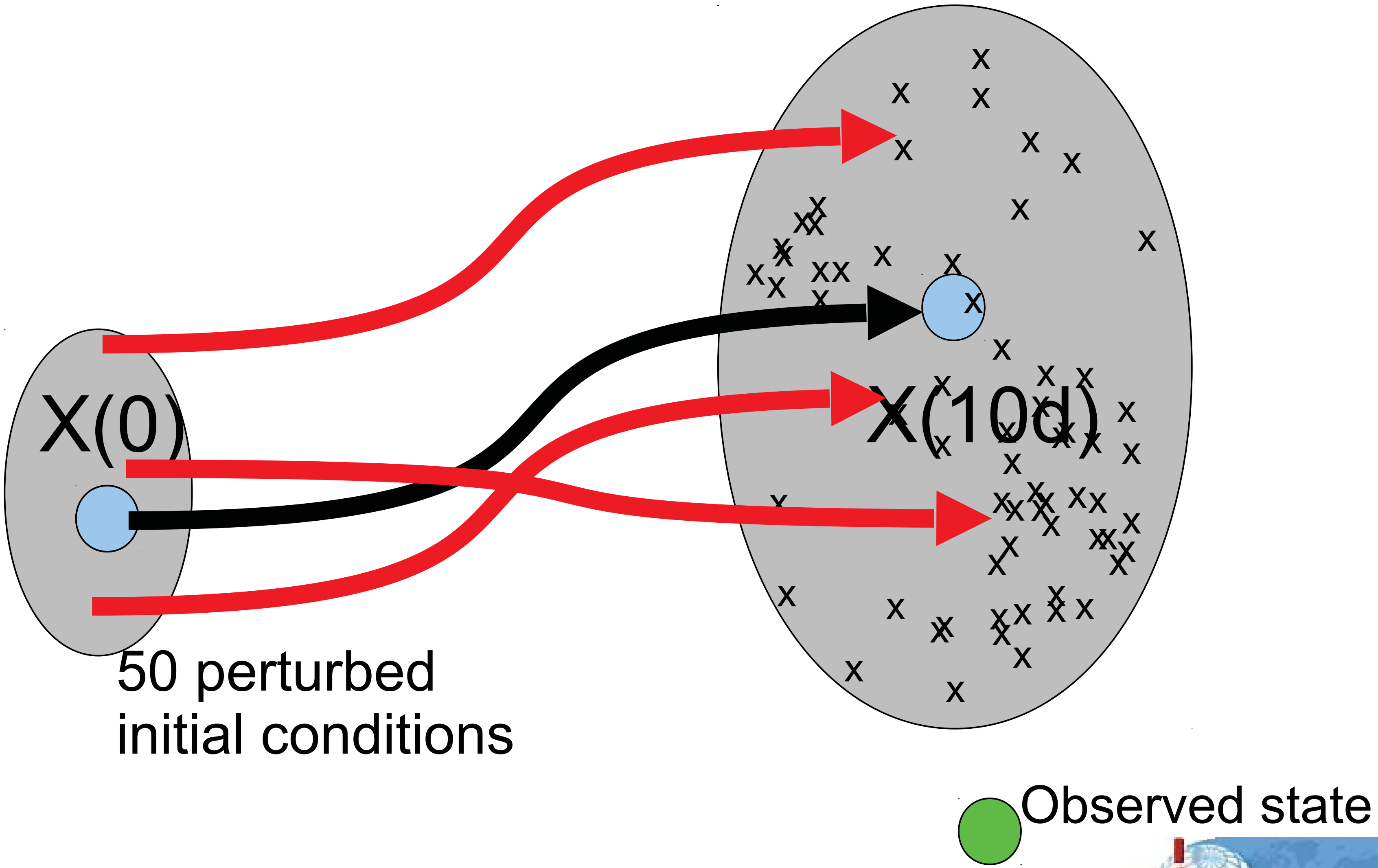
Result: clusters of possible outcomes



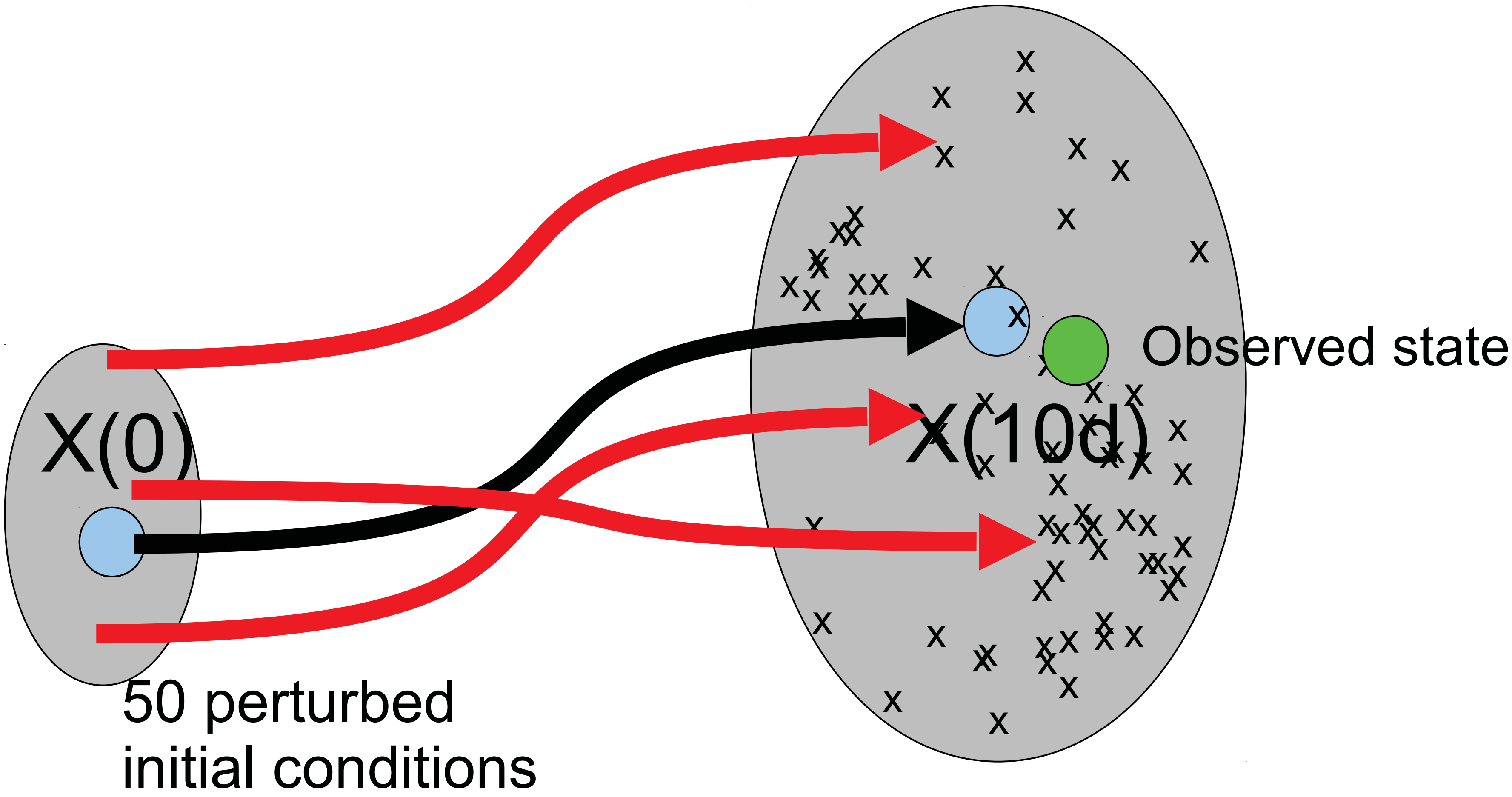
Desire:
RMS forecast error to be = ensemble "spread"



Model over-confident: Spread too small and does not reflect error

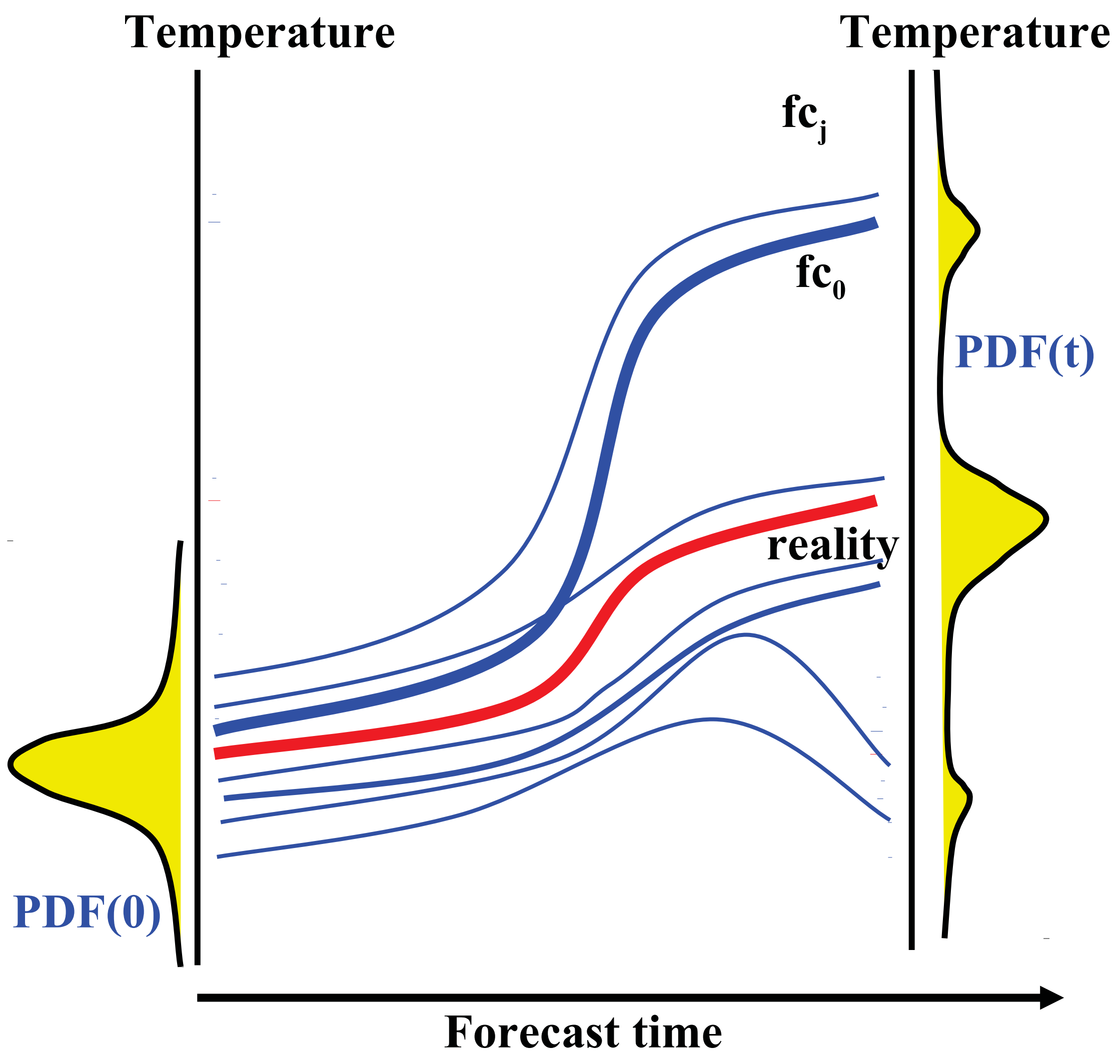


Model under-confident: Spread too large and ensemble forecast has low skill



Ensemble prediction systems

Ensemble prediction based on a finite number of deterministic integration appears to be the only feasible method to predict the PDF beyond the range of linear growth.



Accounting for uncertainties in climate models

multiple forcing scenarios

↓

multiple climate models

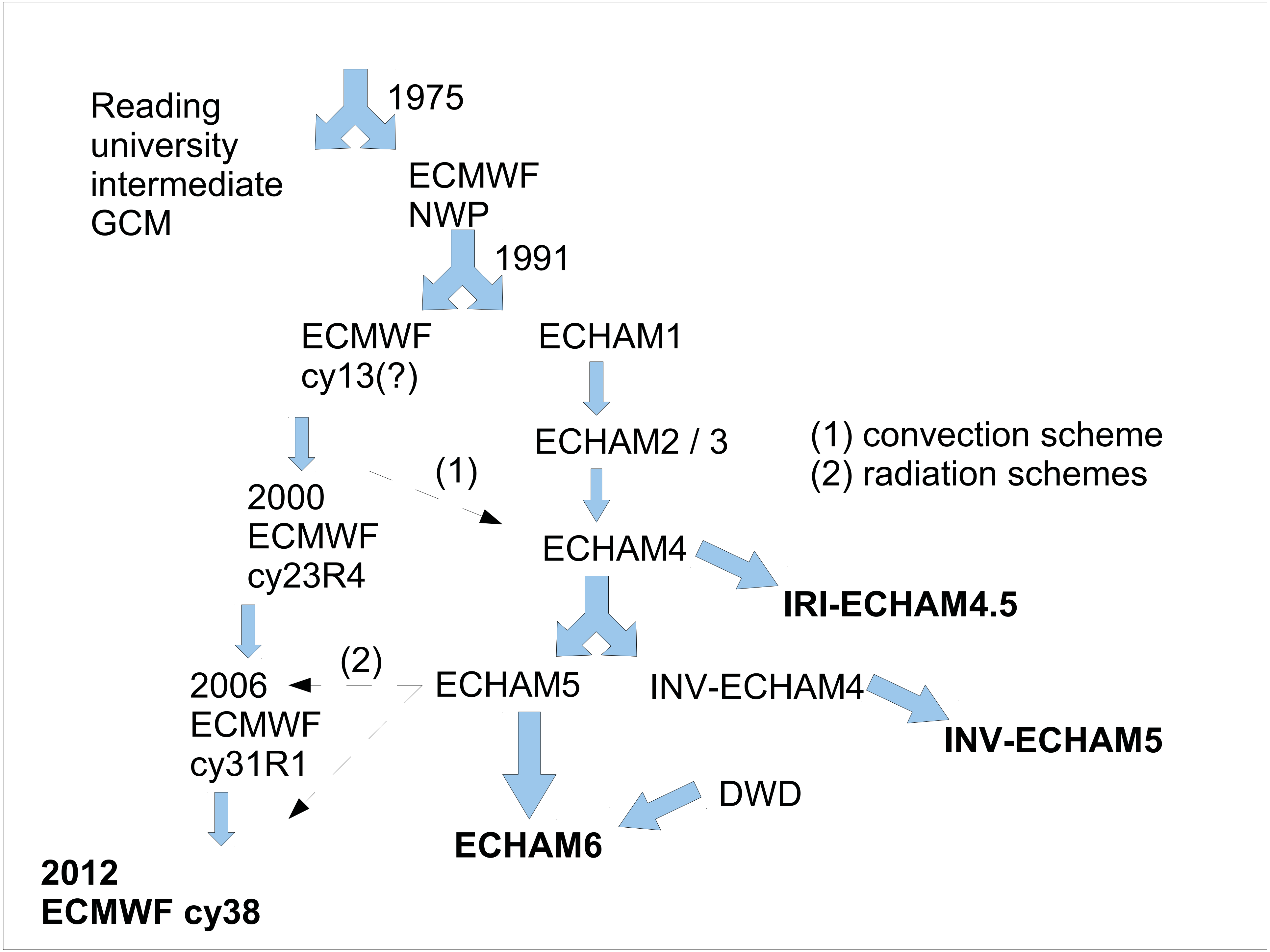
↓

multiple integrations from different initial conditions

- Note – there is no accepted method for determining acceptable "spread" in climate integrations!

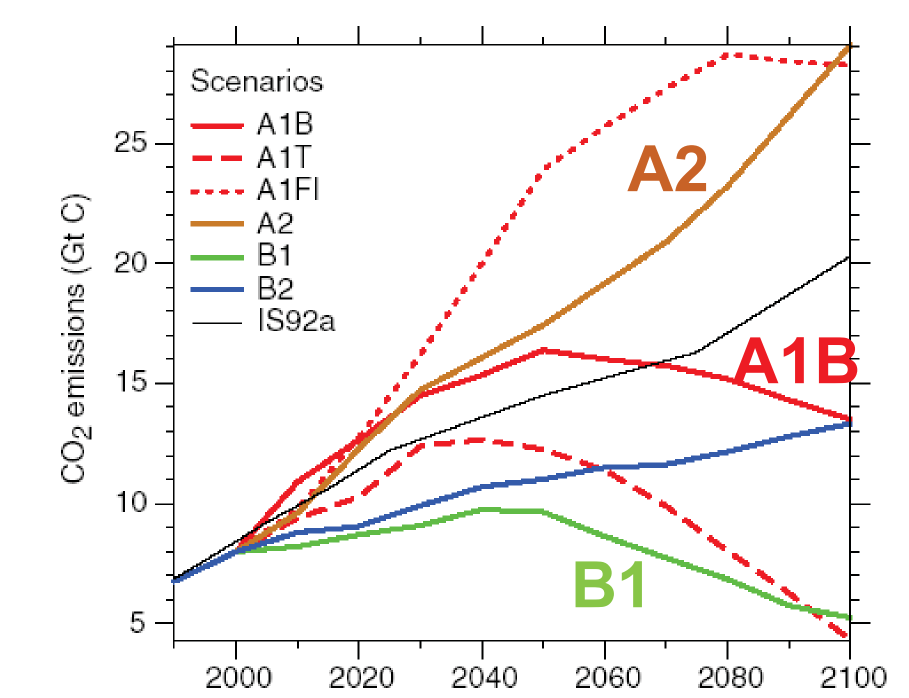
Problem: Seasonal and Climate Ensembles

- 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)

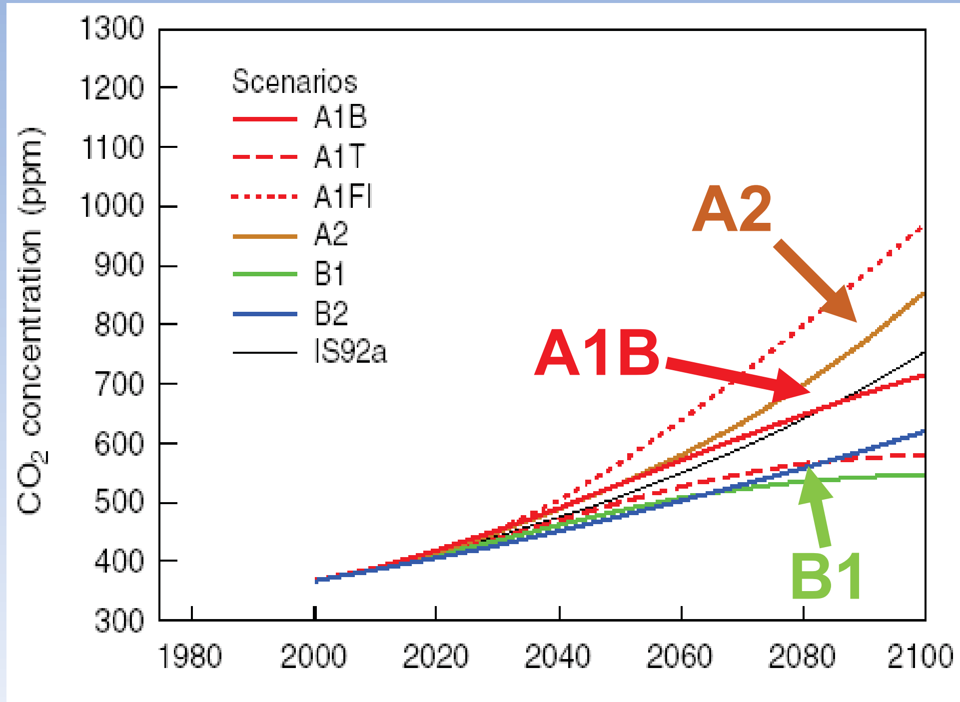

Reading university intermediate GCM
1975
ECMWF NWP
1991
ECMWF cy13(?)
ECHAM1
ECHAM2 / 3
(1) convection scheme
(2) radiation schemes
(1)
2000 ECMWF cy23R4
ECHAM4
IRI-ECHAM4.5
(2)
2006 ECMWF cy31R1
ECHAM5
INV-ECHAM4
INV-ECHAM5
DWD
ECHAM6
2012 ECMWF cy38

Greenhouse gas emission and concentration scenarios (IPCC-2000)

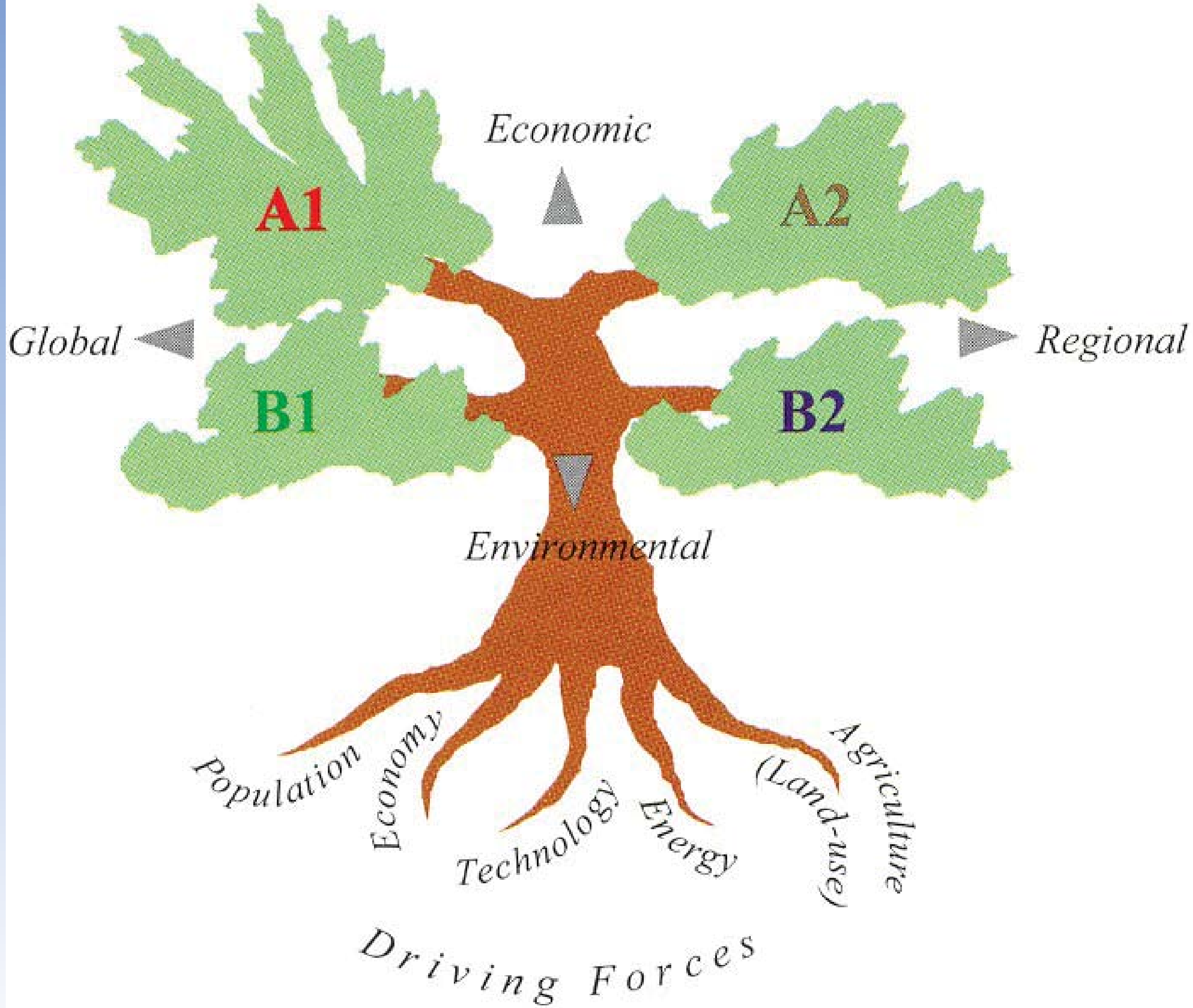
CO2 emissions



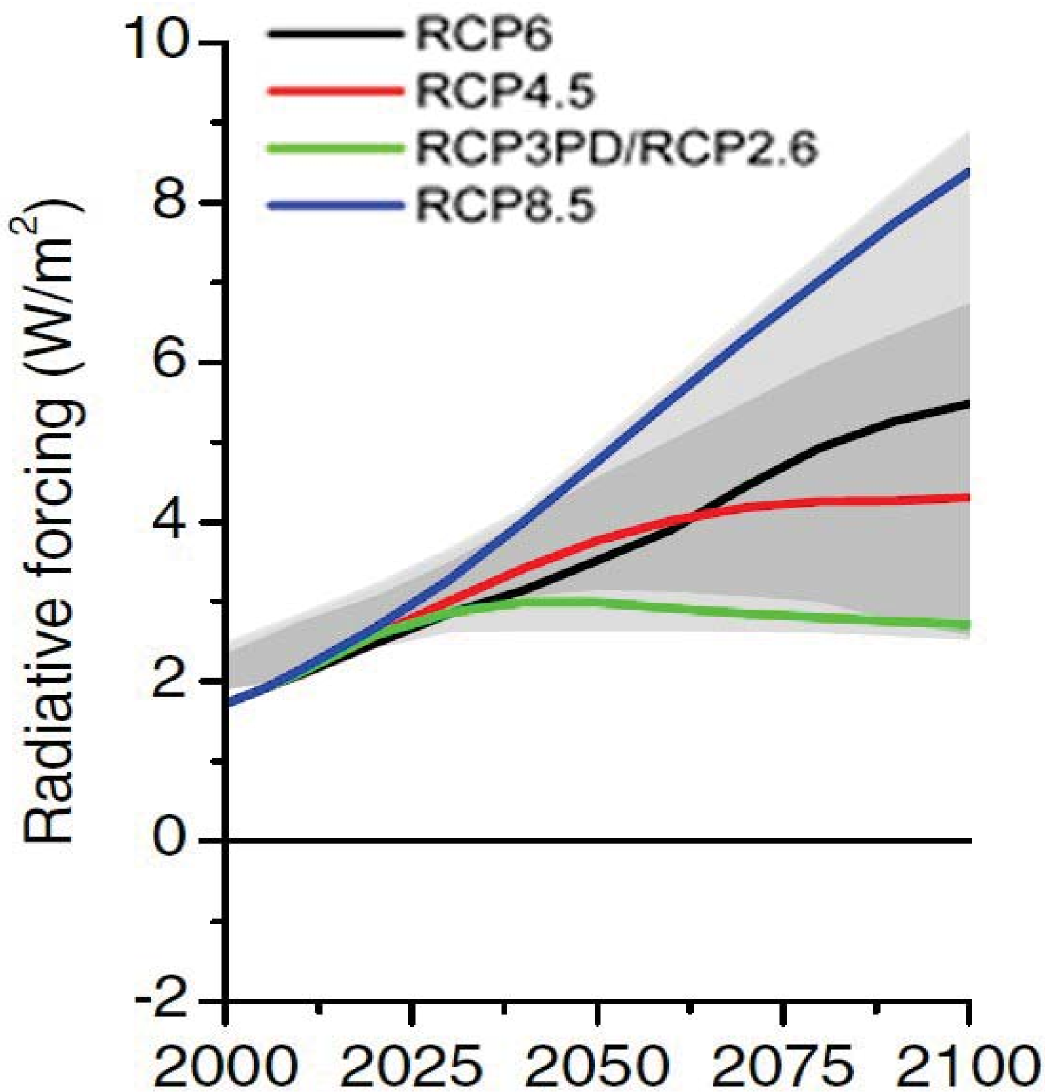
CO2 Concentrations



SRES Emission Scenarios

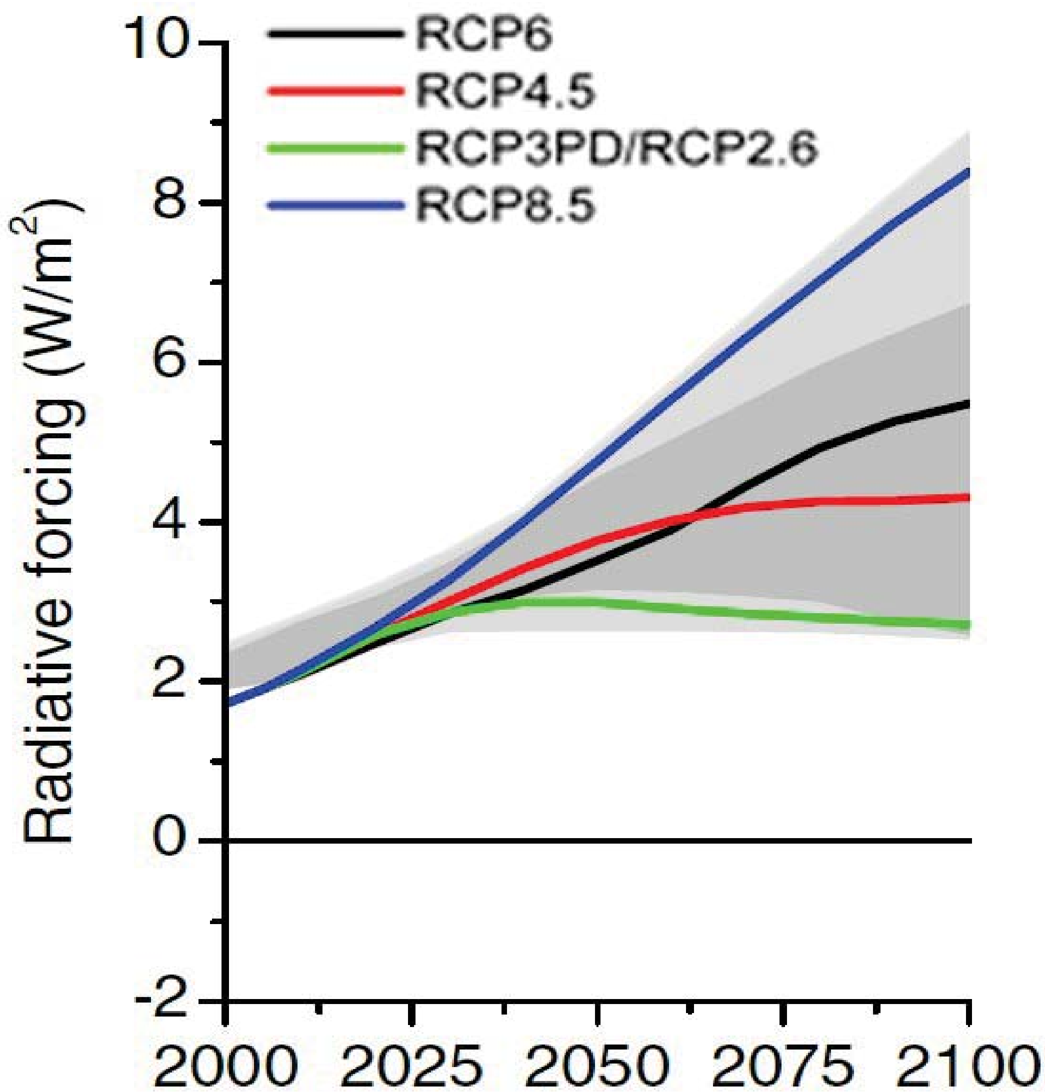


Scenarios in CMIP5



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

Scenarios in CMIP5



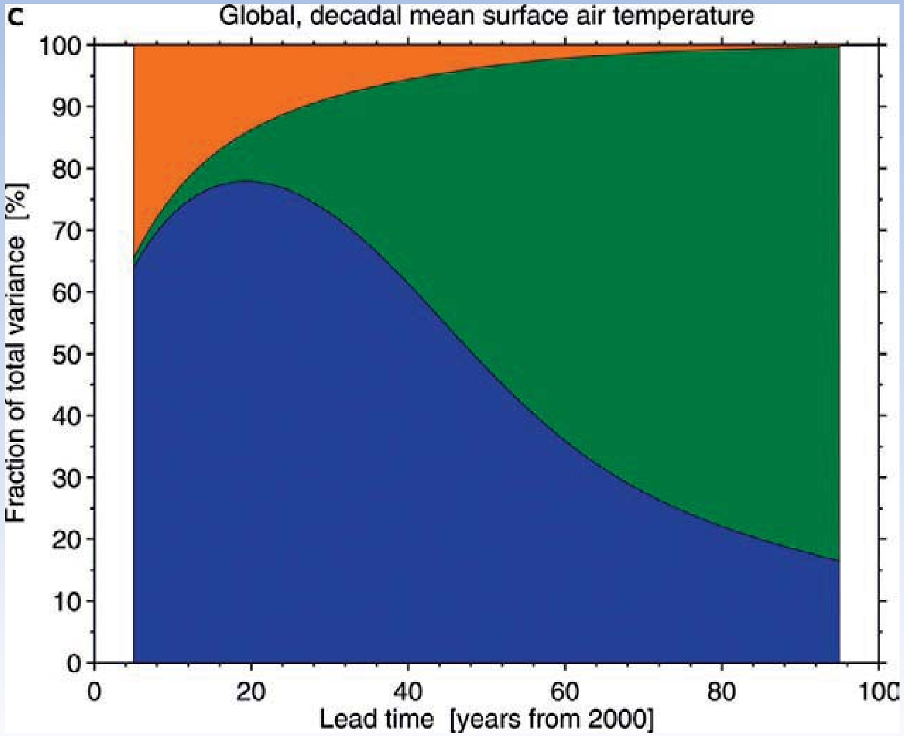
- Each scenario known as a representative concentration pathway (RCP)
- Provided by a different impacts assessment model (IAM)
- Accounting for GDP, population, energy, land-use, etc.

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

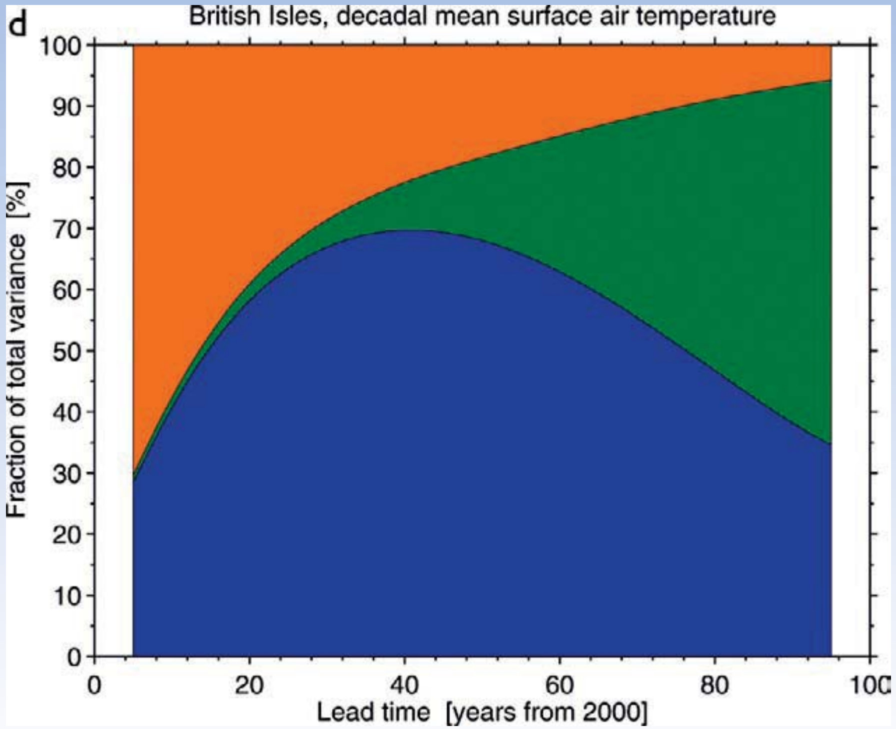
Internal variability
Scenario uncertainty
Model configuration uncertainty

Hawkins and Sutton 2009

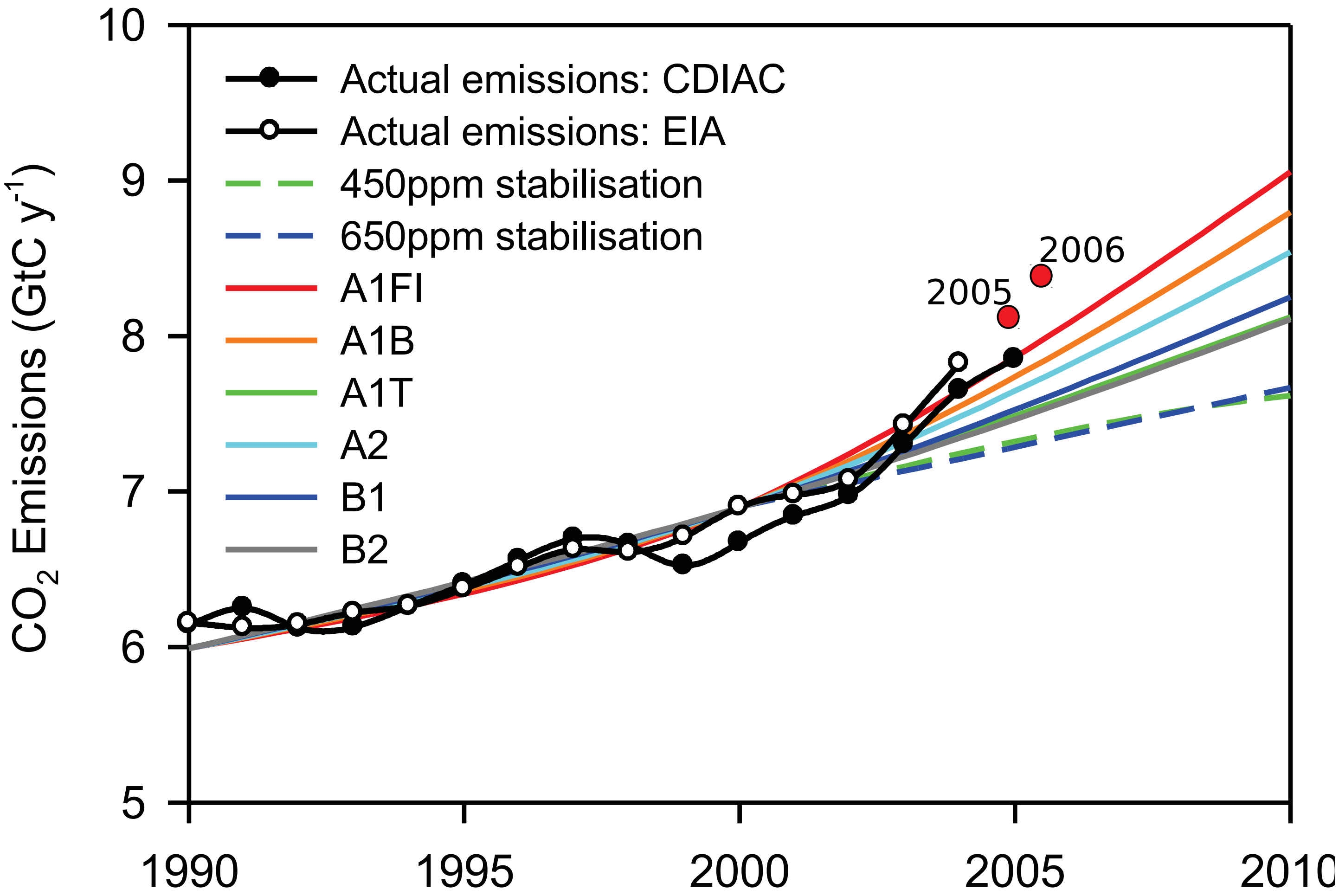
Decadal temperature - Global



Decadal temperature – British Isles



Trajectory of Global Fossil Fuel Emissions

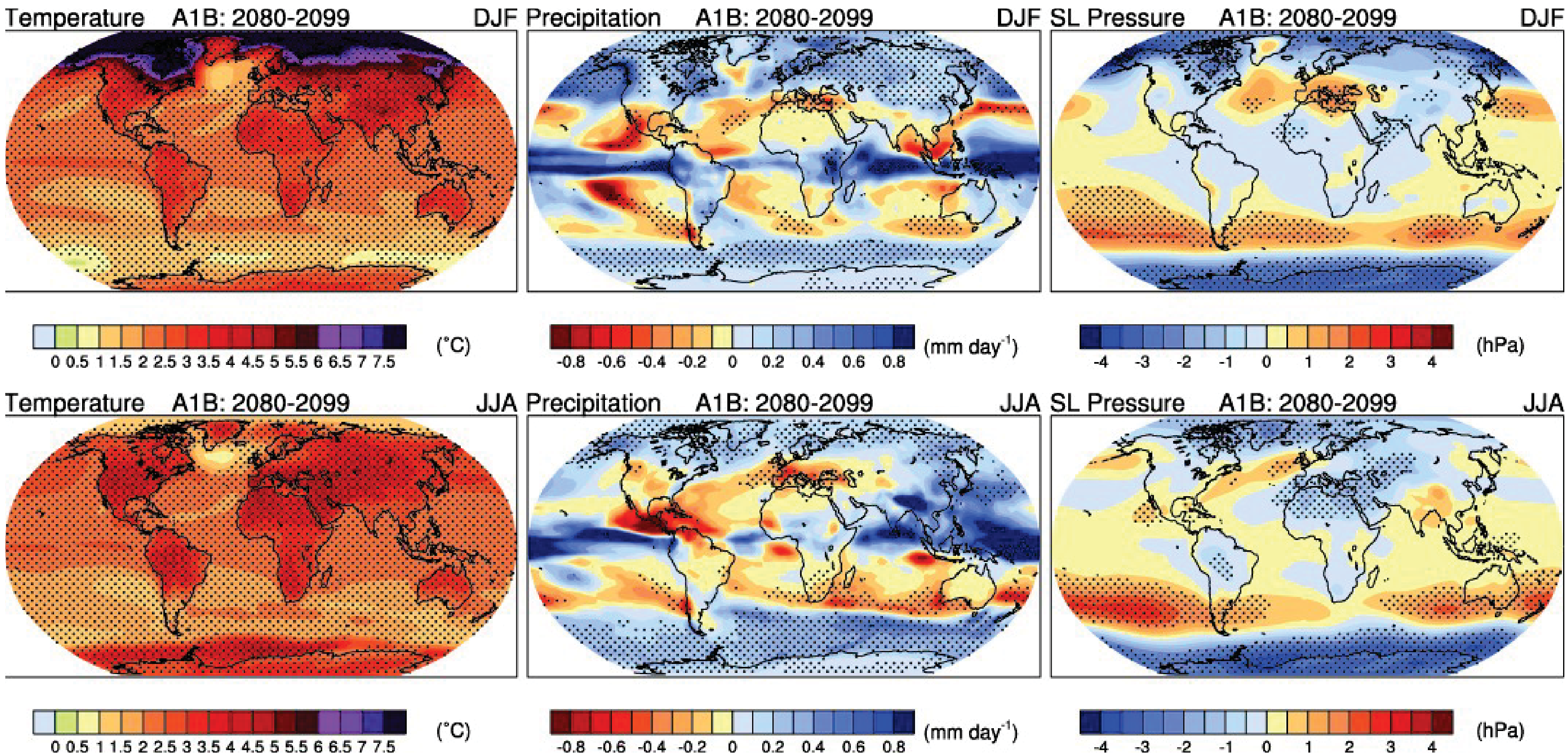


growth rates in % y^{-1} for 2000-2010:

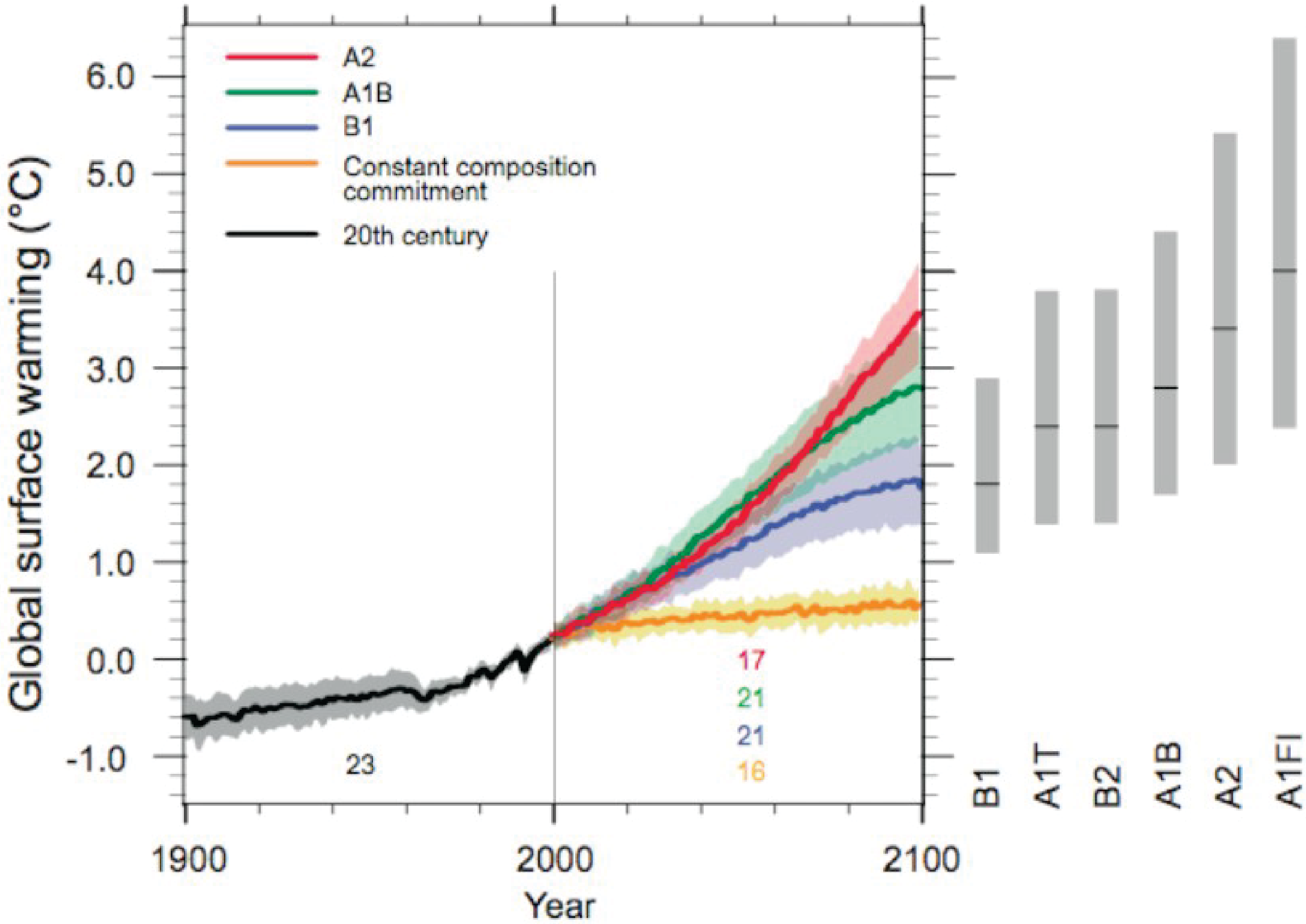
A1B: 2.42
A1FI: 2.71
A1T: 1.63
A2: 2.13
B1: 1.79
B2: 1.61

Observed 2000-2006 3.3%

Raupach et al. 2007, PNAS


Temperature A1B: 2080-2099 DJF
Precipitation A1B: 2080-2099 DJF
SL Pressure A1B: 2080-2099 DJF
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
(mm day-1)
-4 -3 -2 -1 0 1 2 3 4
(hPa)
Temperature A1B: 2080-2099 JJA
Precipitation A1B: 2080-2099 JJA
SL Pressure A1B: 2080-2099 JJA
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
(mm day-1)
-4 -3 -2 -1 0 1 2 3 4
(hPa)

IPCC – 2007: Global temperature change projections for the 21st century



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
- Uncertainty is accounted for by running ensembles of integrations to sample the possible space. However, unlike the weather forecasting problem, there is no presently accepted theory to design these ensembles for climate change.