GLOBAL MODELLING

NUMERICAL MODELLING PROCESSES

ADAPTED FROM DAVIES, 2012

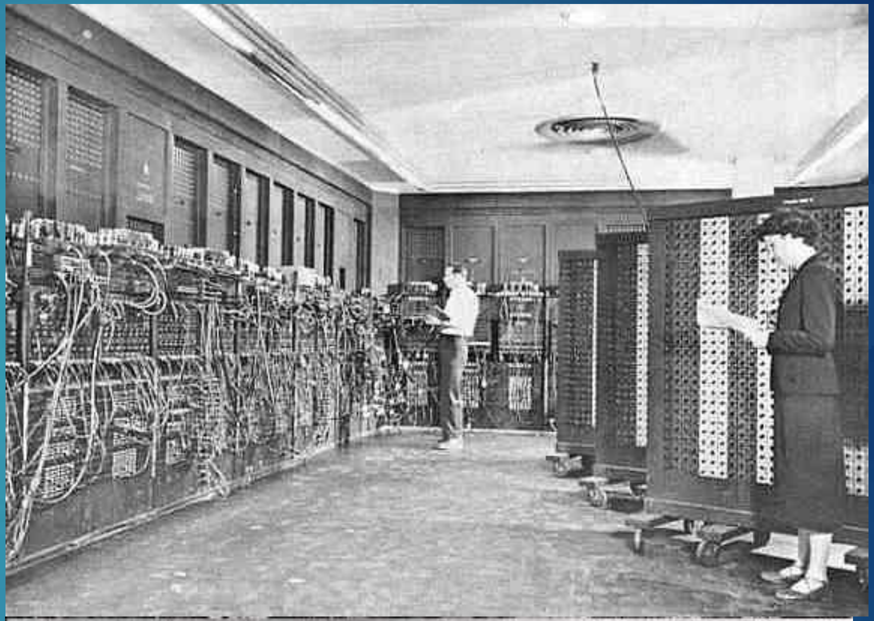
South African Weather Service
ISO 9001 Certified Organisation

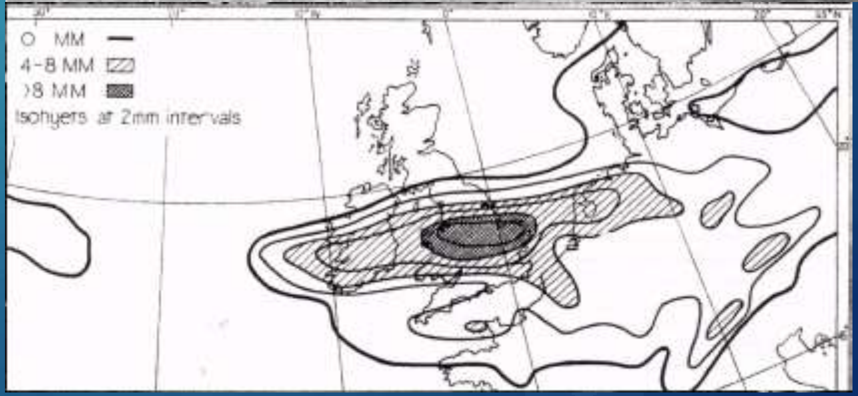
Changing Requirements

- Urban
- Climate Change
- Renewable Energy
- Computing
- Communication
- Sustainability
- Mobility
- Focus on Impacts

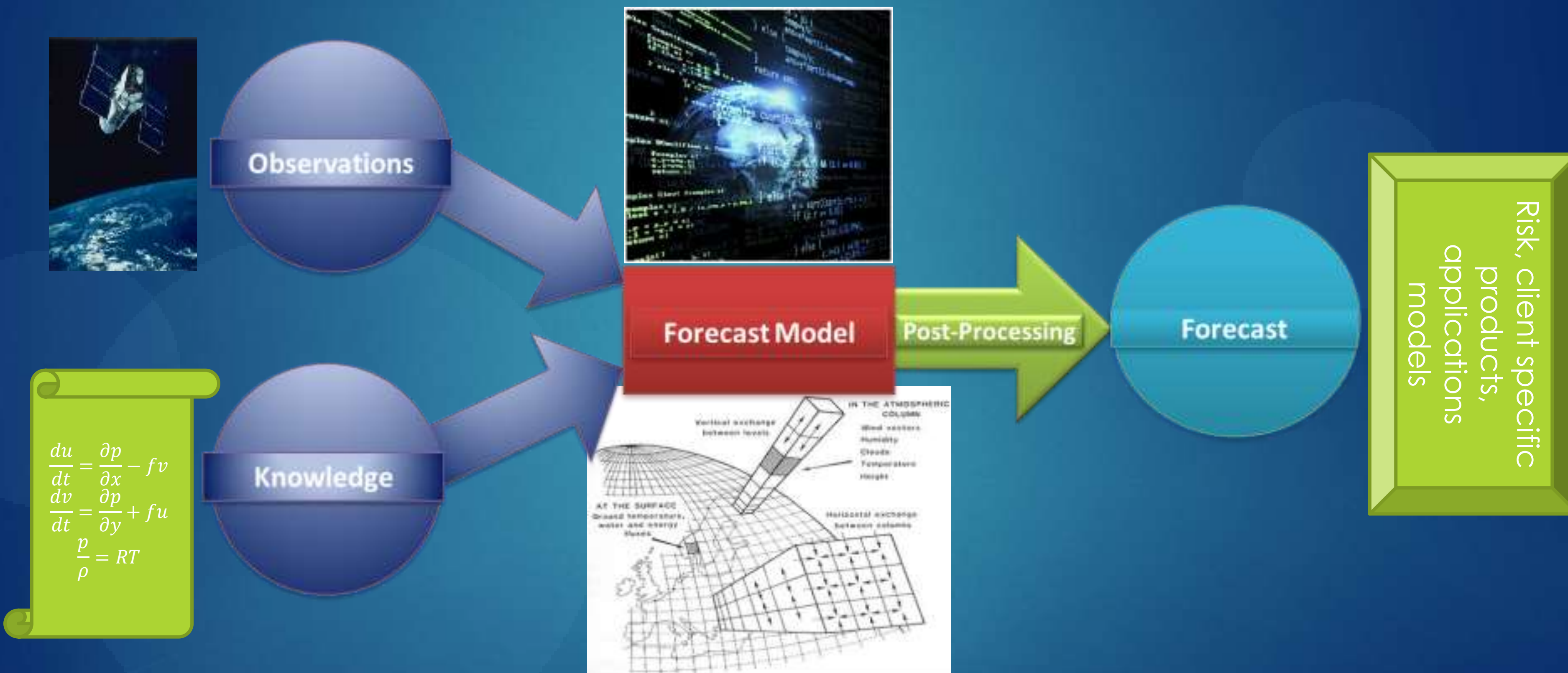
A Short History of NWP

- 1904: Weather prediction approached from the standpoint of mechanics & physics
- 1922: Weather Prediction by Numerical Process (Richardson & Bjerknes)
- 1950: The ENIAC experiment (**Electronic Numerical Integrator And Computer**) was the first electronic general-purpose computer.)
- 1967: Predicting frontal precipitation with a 10 level model

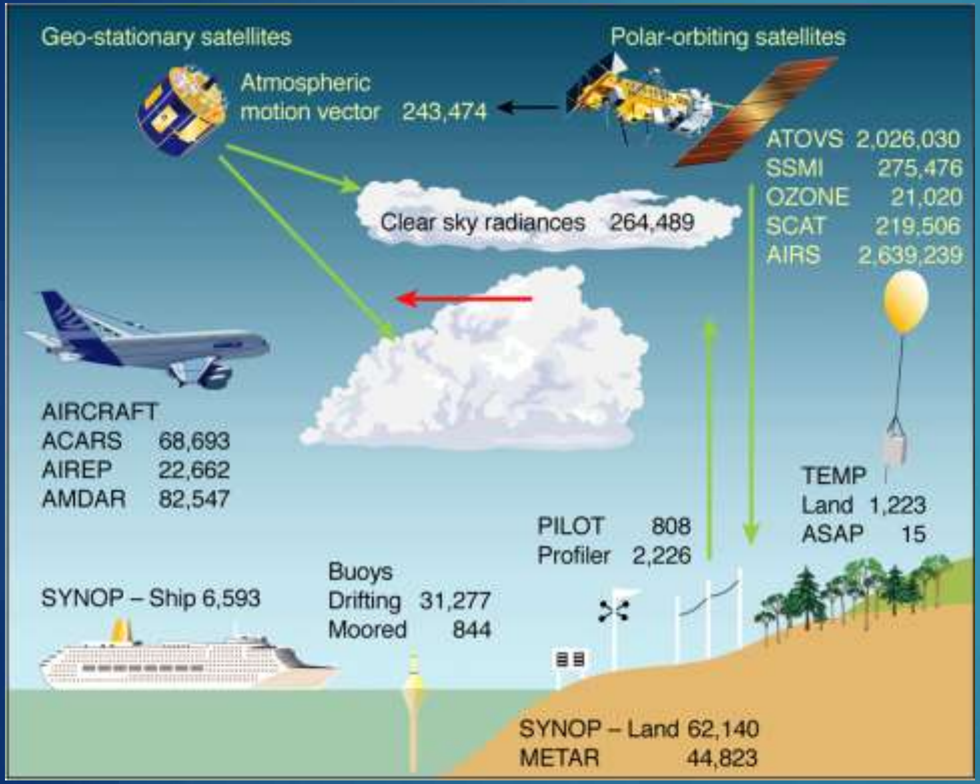


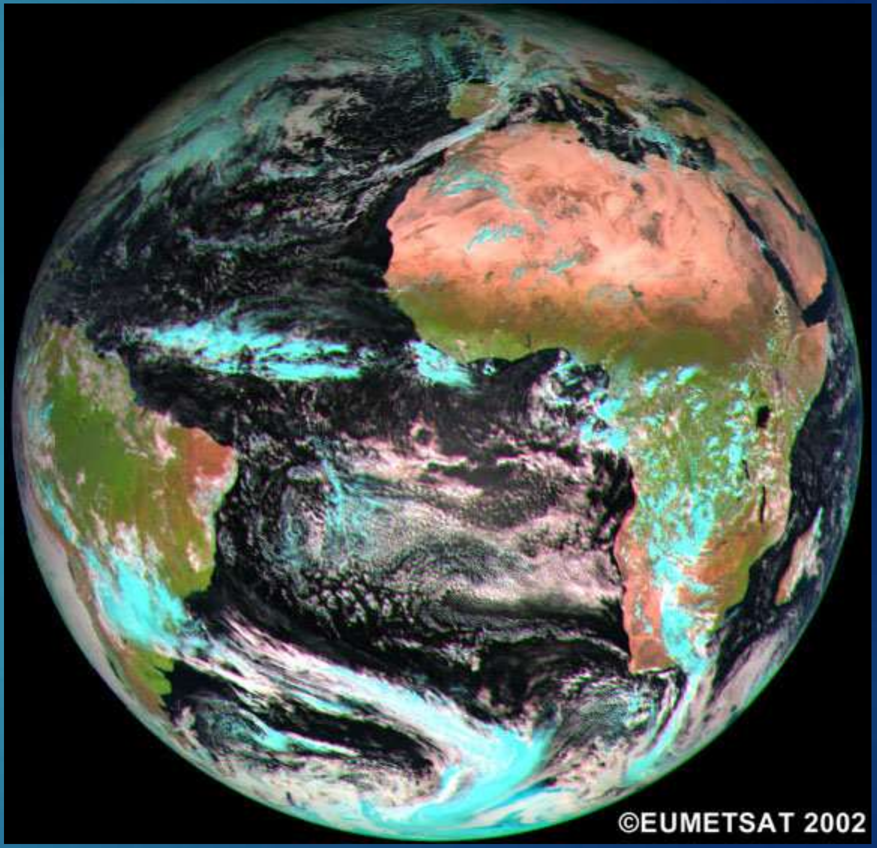


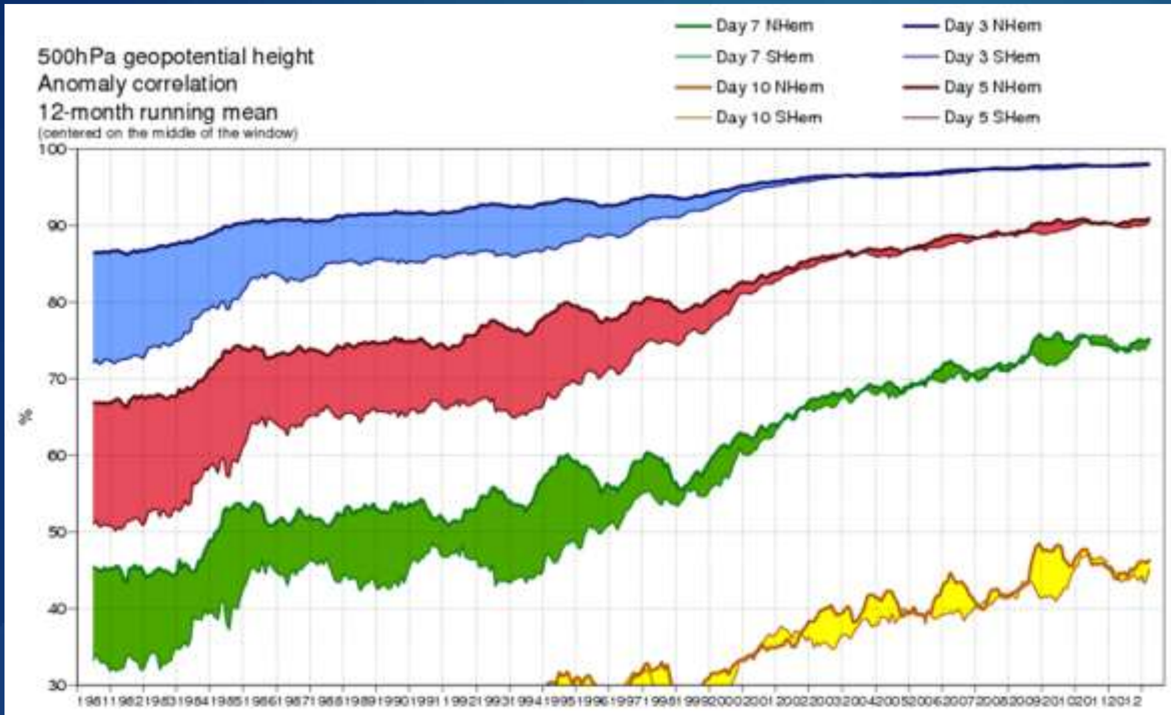
General Numerical Modelling System

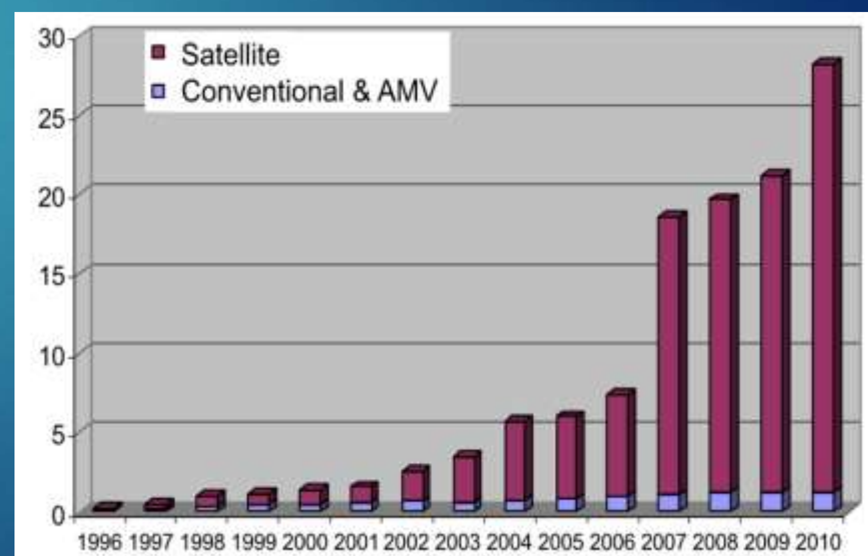


Observing the World

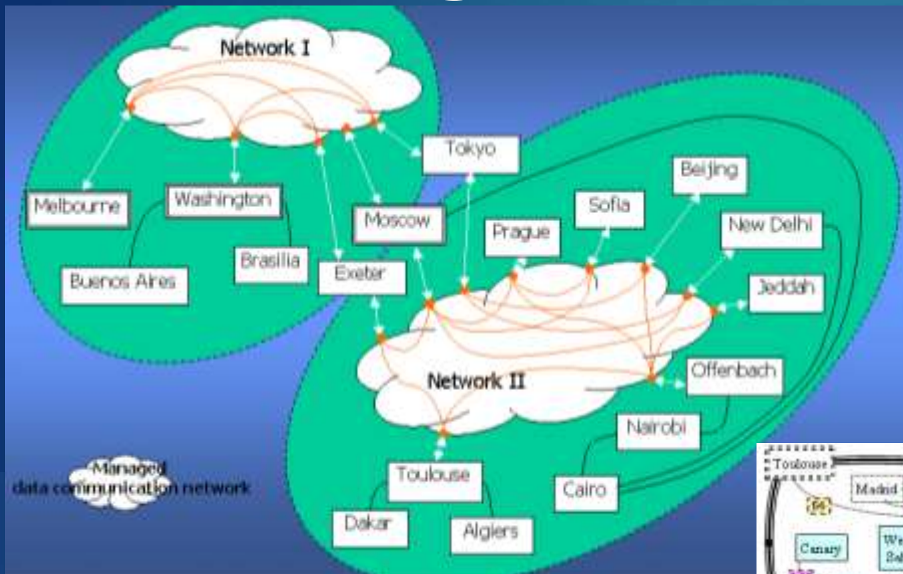


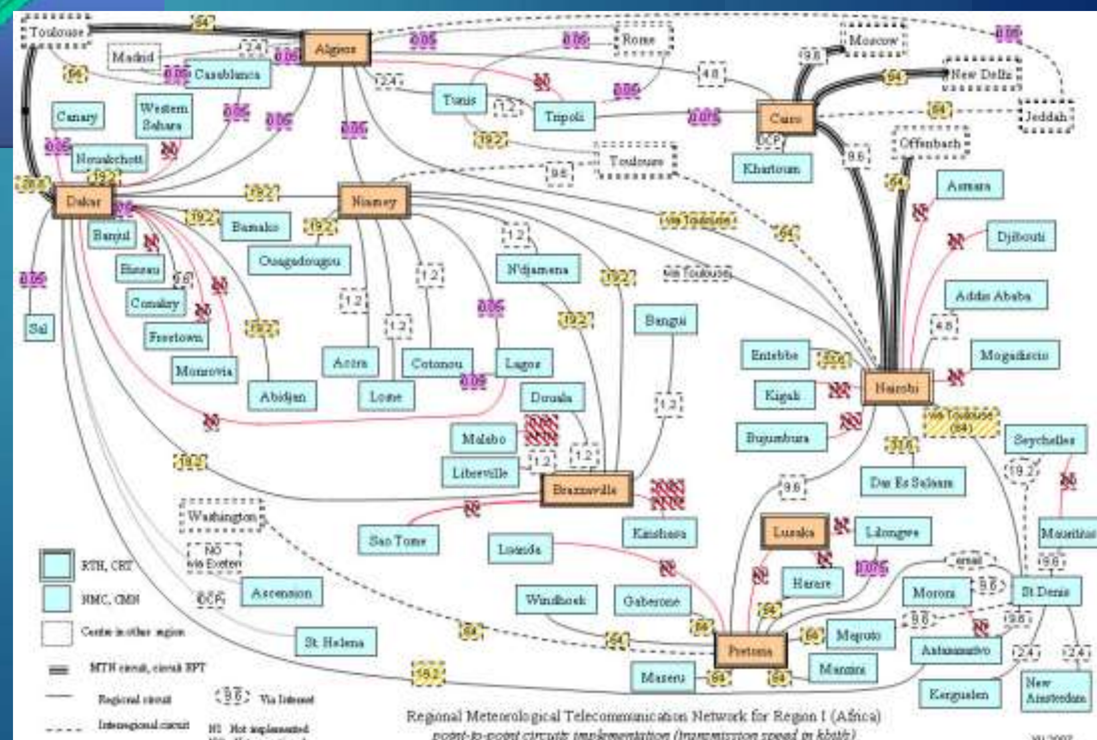



500hPa geopotential height
Anomaly correlation
12-month running mean
(centered on the middle of the window)
Day 7 NHem
Day 7 SHem
Day 10 NHem
Day 10 SHem
Day 3 NHem
Day 3 SHem
Day 5 NHem
Day 5 SHem
%
100
90
80
70
60
50
40
30


Satellite
Conventional & AMV
30
25
20
15
10
5
0
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

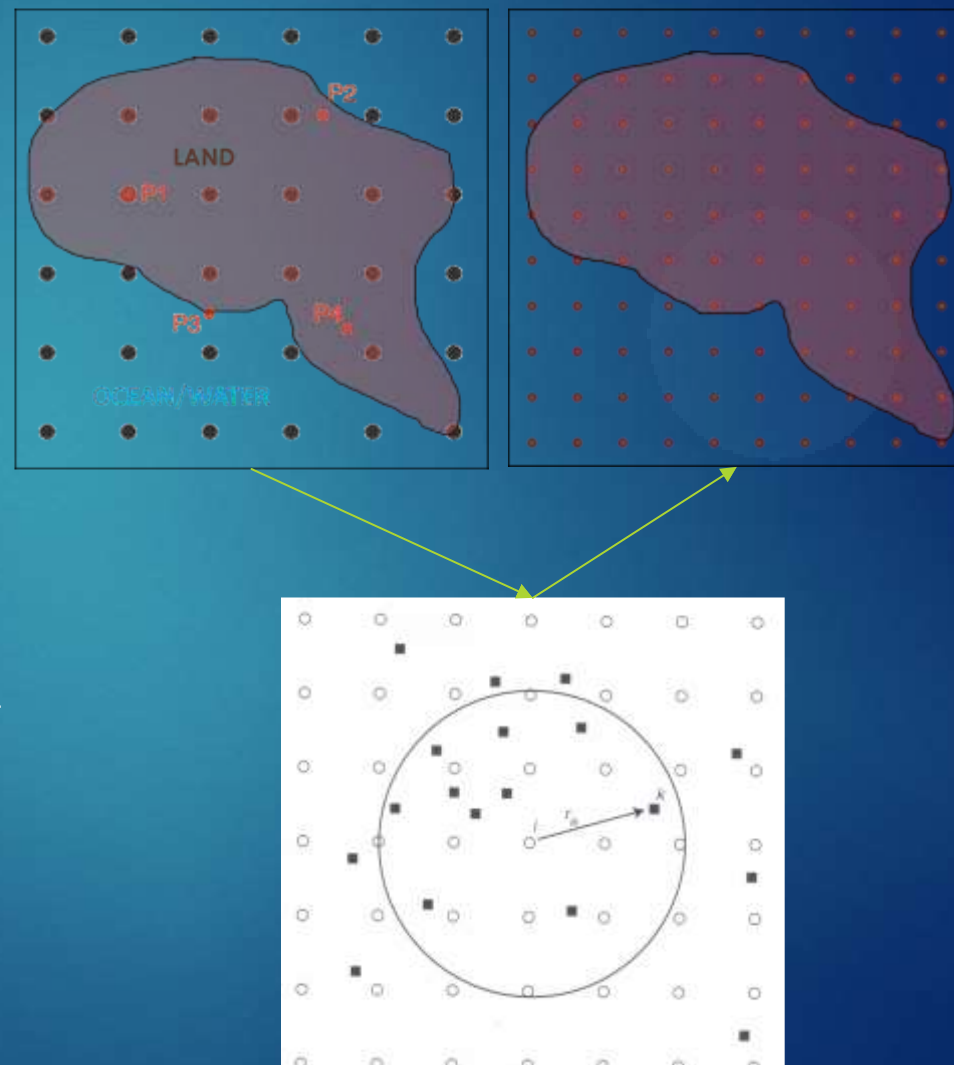
Sharing Data





Using Observations

- Quality Control
  - Buddy checks
  - Climatology
  - Temporal consistency
  - Background field
- Interpolated onto the model grid points
- Different types of data have different areas of influence



Using Observations

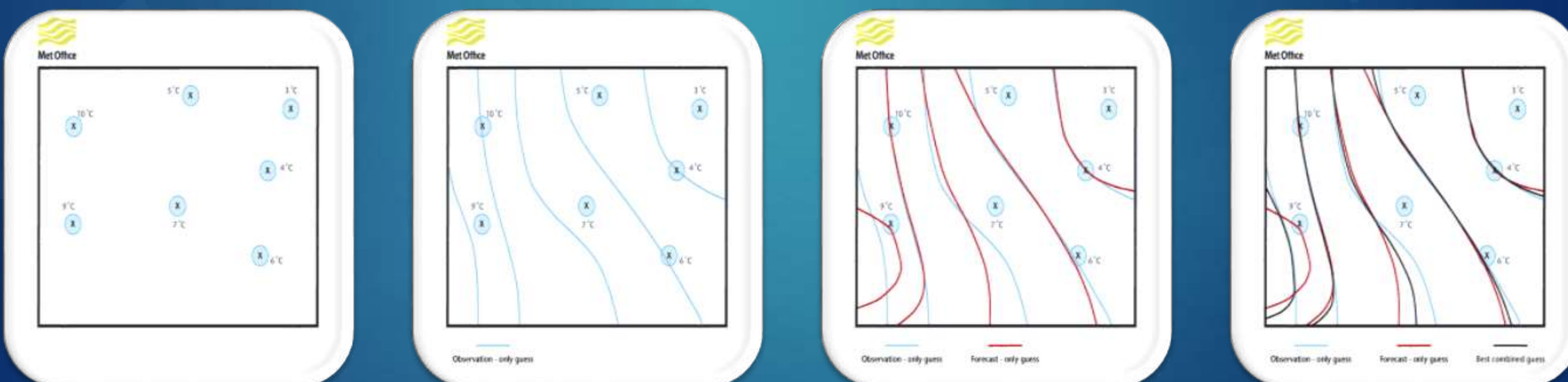
- NWP cannot rely solely on observations to produce its initial conditions
  - There are too few
  - Point observations may not be representative of a grid box

- A short period forecast from a previous run of the model fills the gaps
  - Model background field

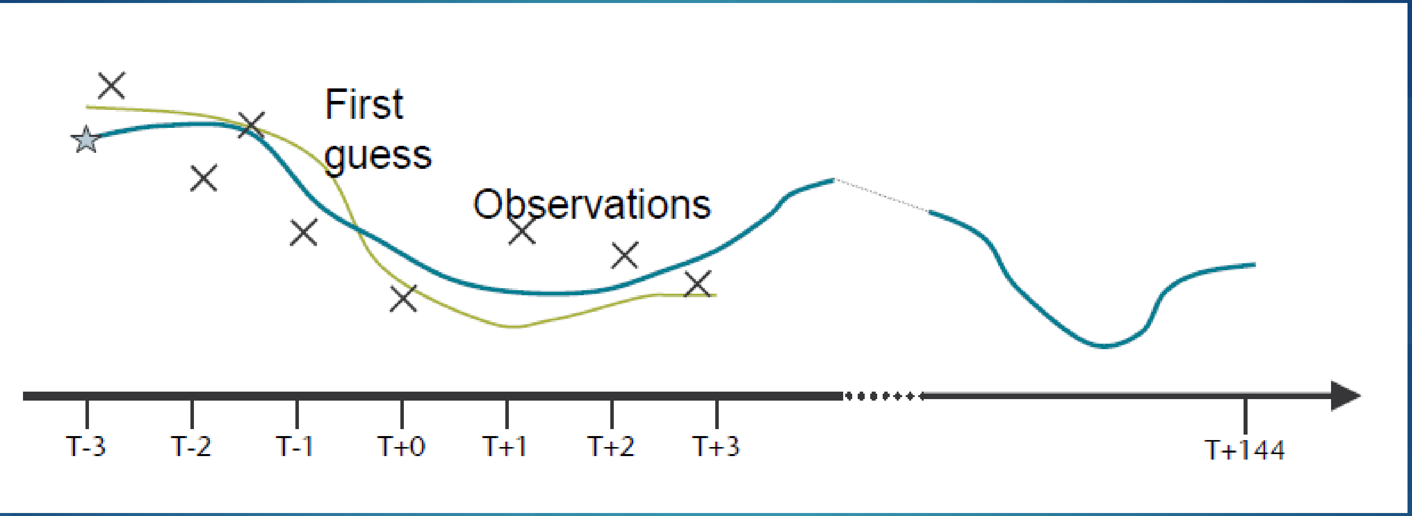
Assimilation is the process of finding the model representation which is most consistent with the observations

Data Assimilation

- Method used to blend real and model data
- Model is run for an assimilation period prior to the forecast
- Data is inserted into the run at or near their validity time to nudge the model towards reality



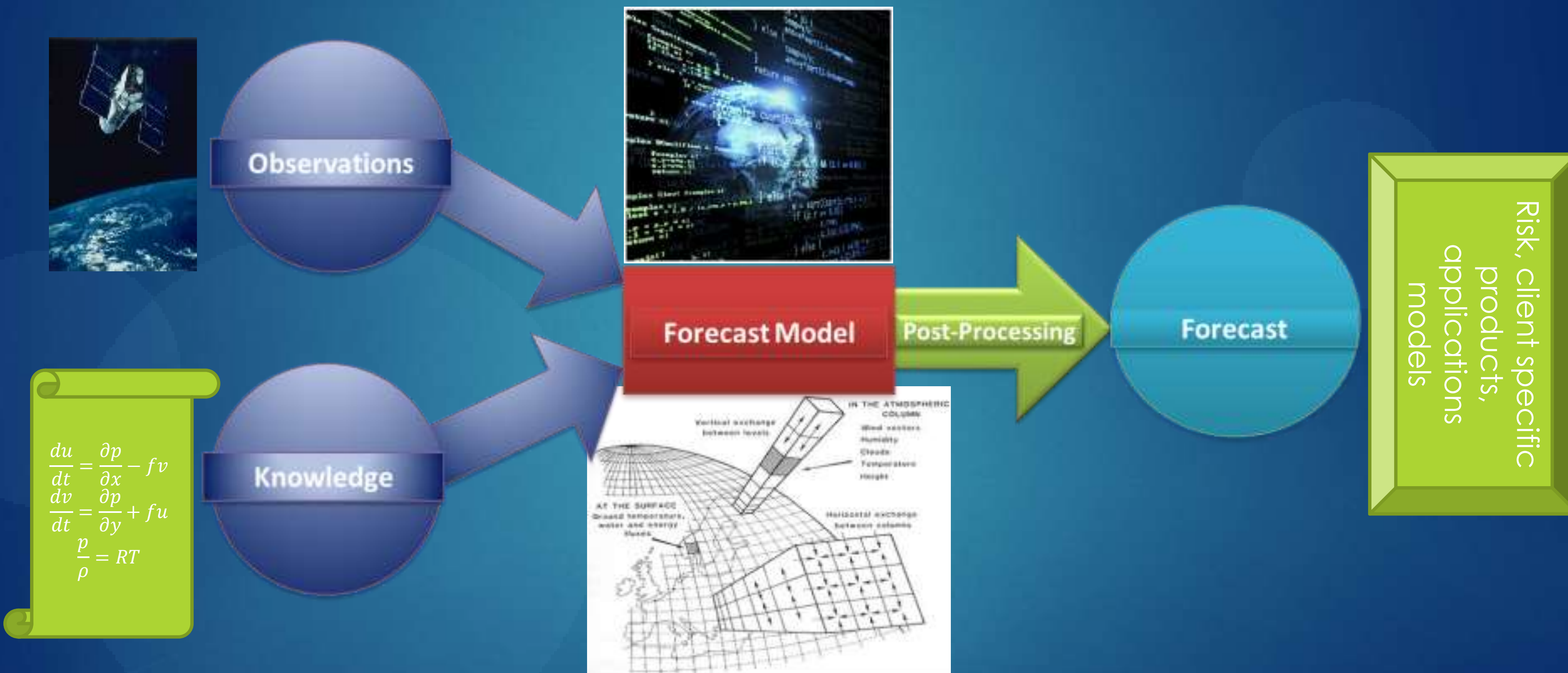
Data Assimilation



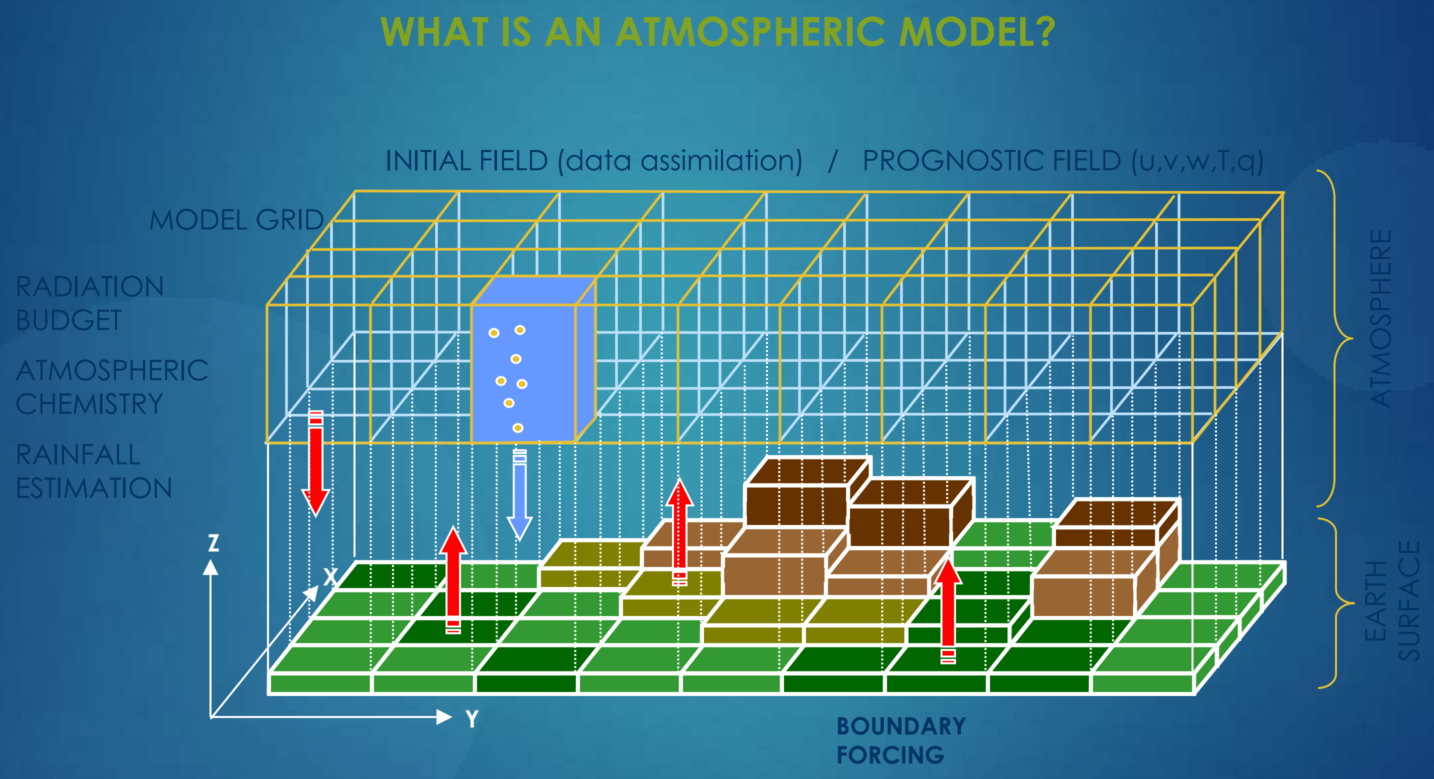
The Challenge

- To compute the model state from which the resulting forecast best matches the available observations

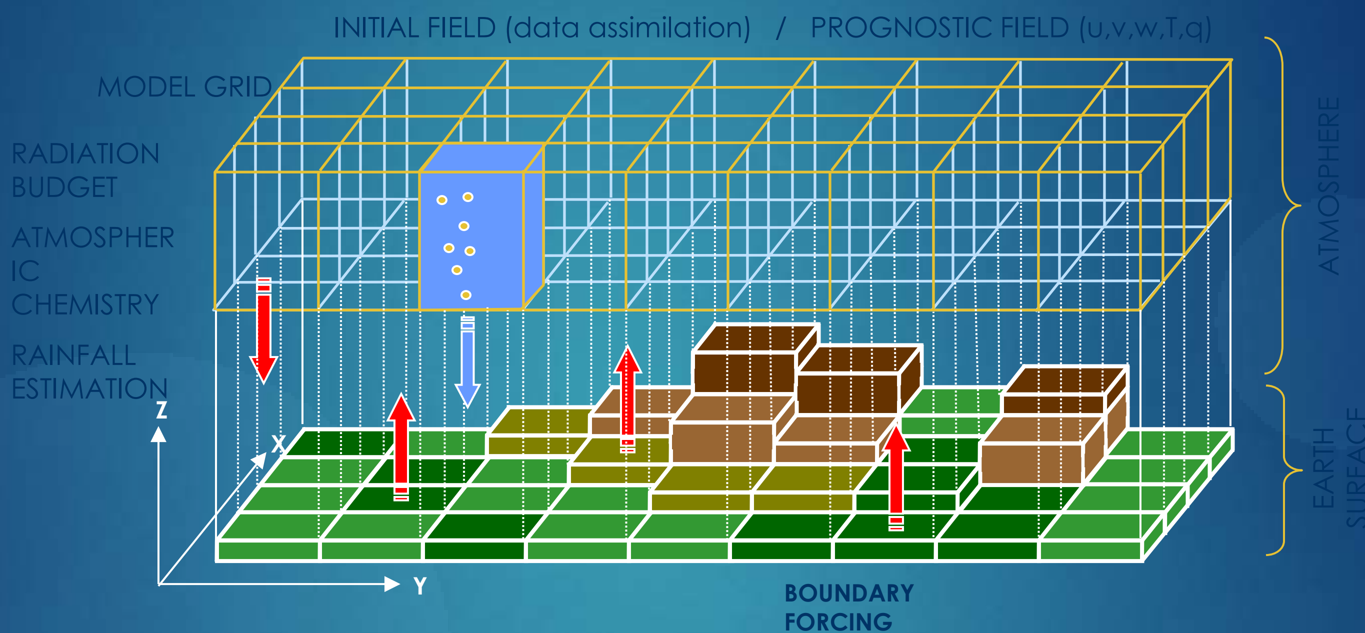
General Numerical Modelling System

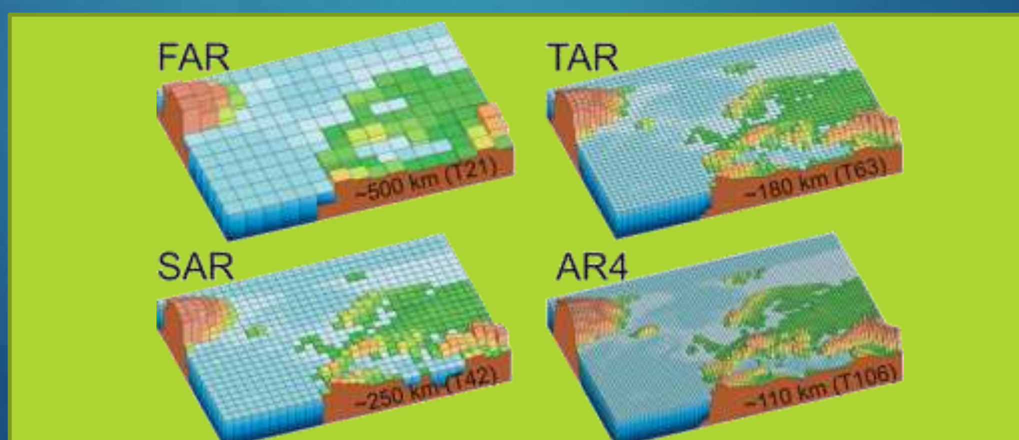


Horizontal & Vertical Resolution



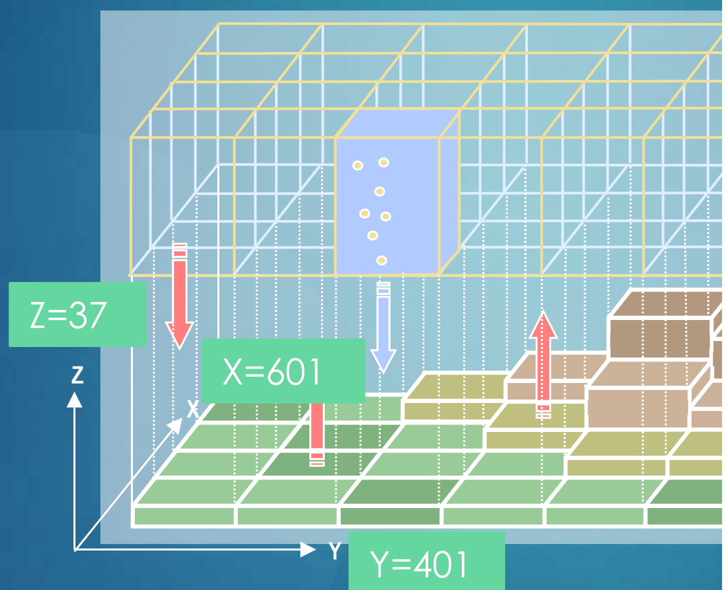
Horizontal Resolution

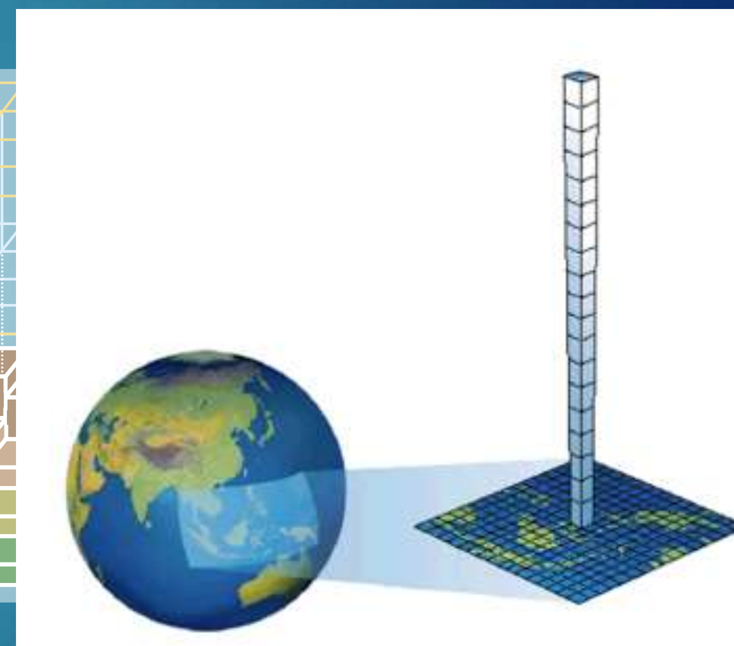




Vertical Resolution

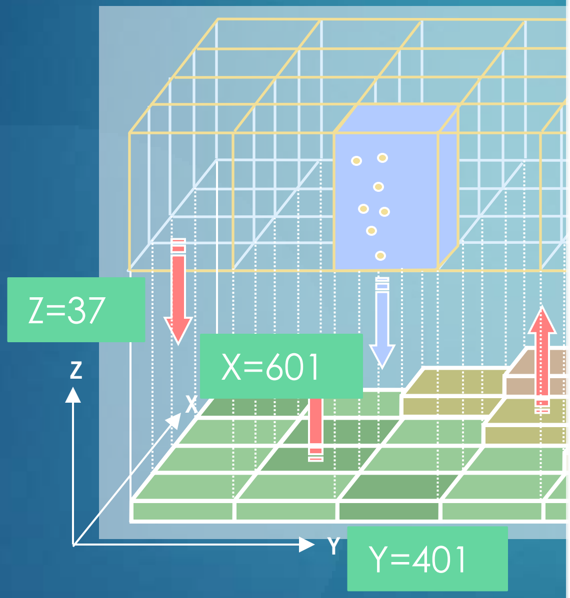
WHAT IS AN ATMOSPHERIC MODEL?

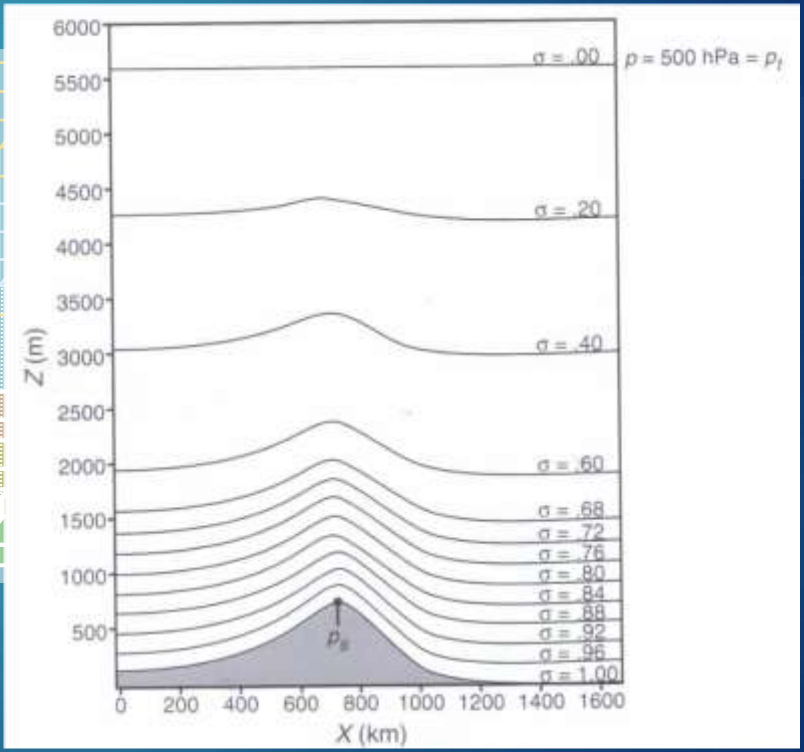




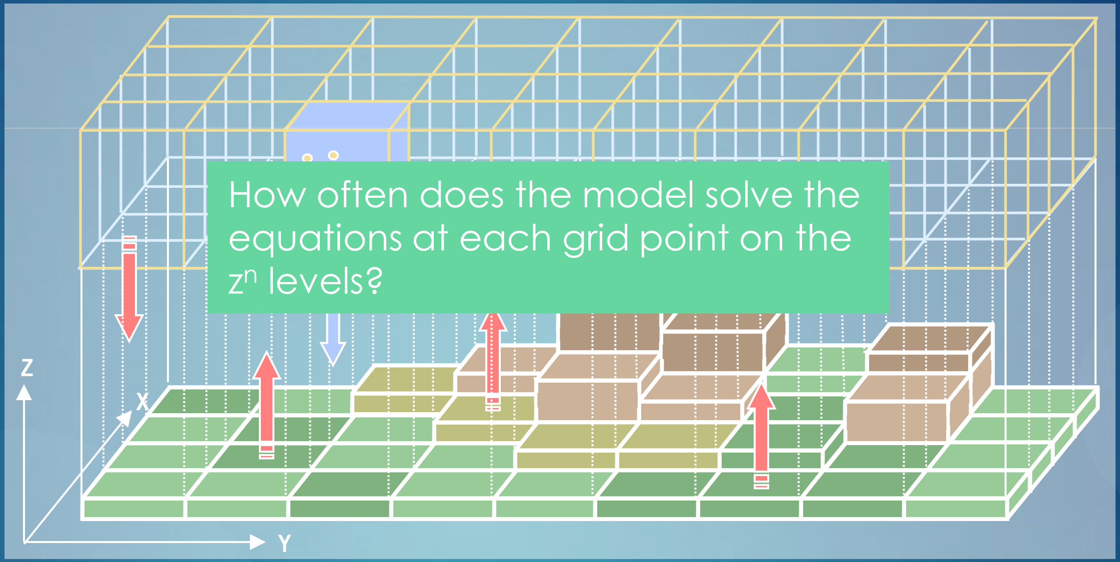
Vertical Resolution

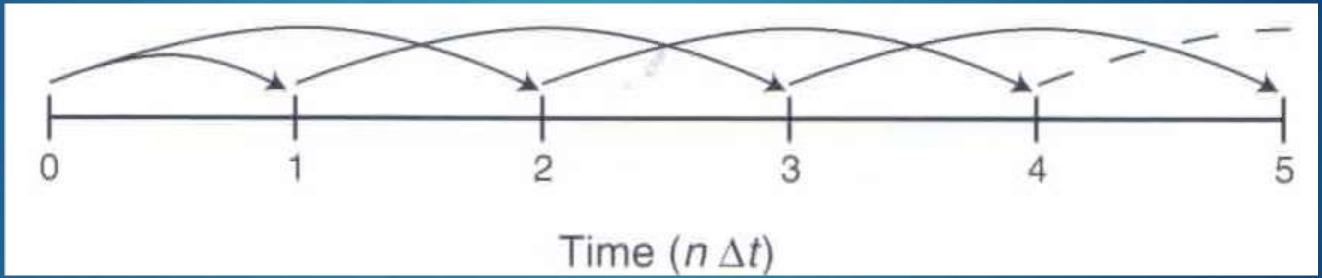
WHAT IS AN ATMOSPHERIC MODEL?



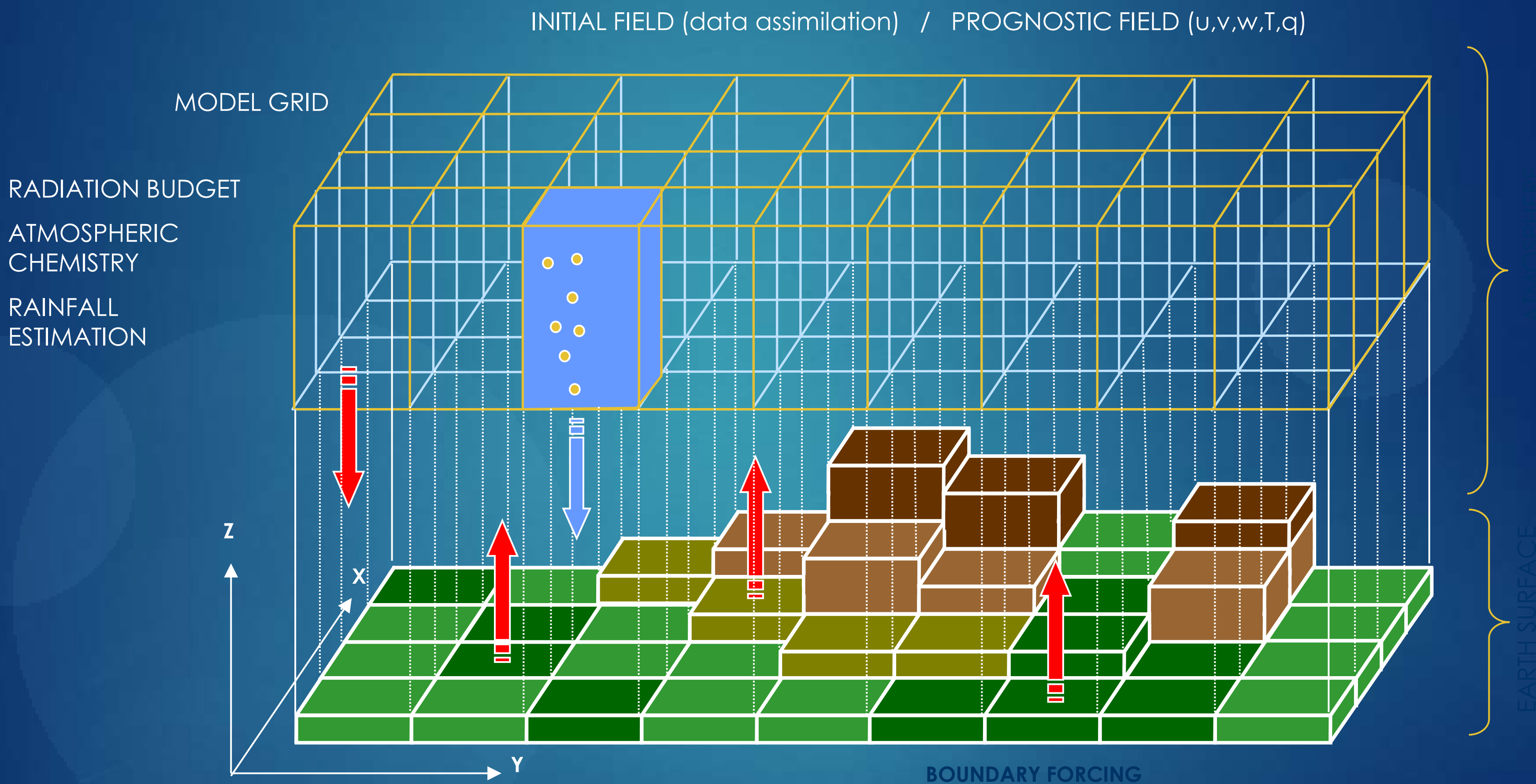


Temporal Resolution





- Relationship between horizontal resolution and time step for calculations
- Ratio of 1:6
- Time-step=DX*6 (i.e. 10 km = time-step of 60s)


INITIAL FIELD (data assimilation) / PROGNOSTIC FIELD (u,v,w,T,q)
MODEL GRID
RADIATION BUDGET
ATMOSPHERIC CHEMISTRY
RAINFALL ESTIMATION
ATMOSPHERE
EARTH SURFACE
Z
X
Y
BOUNDARY FORCING

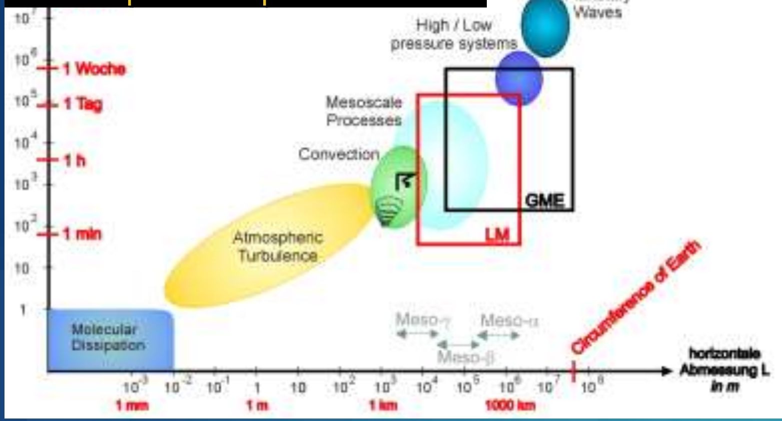
Parameterization

- What is physical parameterization and why we need physical parameterization?
- What processes should be parameterized?
- The problems in parameterization
- How do we do parameterization in models?

Adapted from:
www.inscc.utah.edu/~reichler/6030/Sample_talk.ppt

What is Parameterization?

Characteristic scales of atmospheric processes

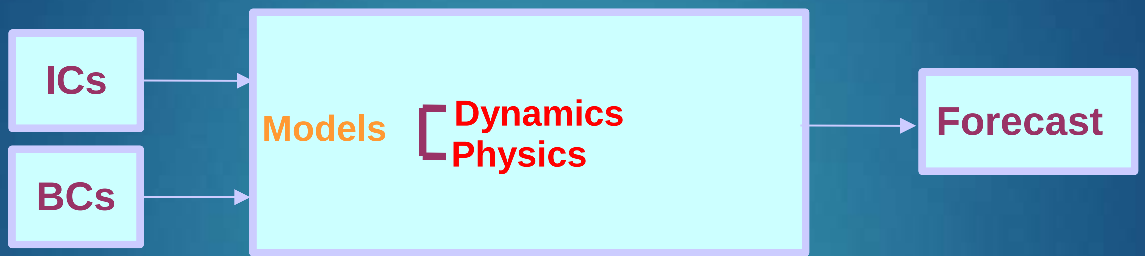


- Processes too small for model resolution
- Radiation, convection and boundary layer exchanges
- To represent these changes is called parameterization
- Constrained by:
  - Computational power
  - Understanding of the processes

- Atmospheric motions have different scales.
- Climate model resolutions:
  - Regional: ~4 km
  - Global: ~20 km
- Sub-grid scale processes: Atmospheric processes with scales can not be explicitly resolved by models.
- Physical parameterization: To represent the effect of sub-grid processes by using resolvable scale fields.

Adapted from: *www.inscc.utah.edu/~reichler/6030/Sample_talk.ppt*

Why do we need parameterization?



- **Dynamic core of models**

$$\frac{d\vec{V}}{dt} = -\alpha \nabla p - \nabla \Phi + \vec{F} - 2\Omega \times \vec{V}$$

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \vec{V})$$

$$p\alpha = RT$$

$$Q = C_p \frac{dT}{dt} - \alpha \frac{dp}{dt}$$

$$\frac{\partial \rho q}{\partial t} = -\nabla \cdot (\rho \vec{V} q) + \rho (E - C)$$

- **Model physics:**
  - Processes such as phase change of the water are in too small scale and too complex.
  - Processes such as cloud microphysics are poorly understood.

Adapted from:
www.inscc.utah.edu/~reichler/6030/Sample_talk.ppt

What should be Parameterized?

Model Physics include:

- Radiation transfer.
- Surface processes.
- Vertical turbulent processes.
- Clouds and large-scale condensation.
- Cumulus convection.
- Gravity wave drag.

16 major physical processes in climate system. (from http://www.meted.ucar.edu/nwp/pcu1/ic4/frameset.htm)

Adapted from:
www.inscc.utah.edu/~reichler/6030/Sample_talk.ppt

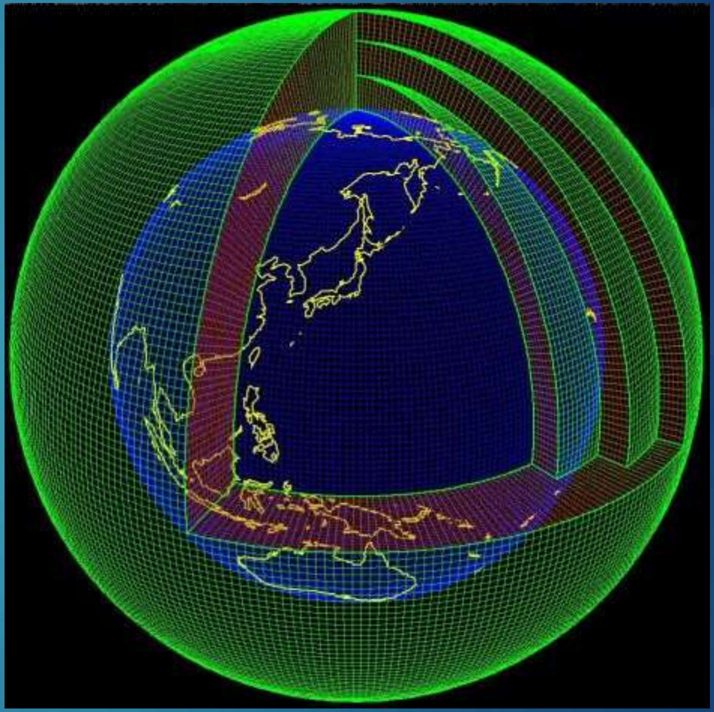
How do we do Parameterization in models?

- Ignore some processes (in simple models).
- Simplifications of complex processes based on some assumptions.
- Statistical/empirical relationships and approximations based on observations.
- Nested models and super-parameterization: Embed a cloud model as a parameterization into climate models.

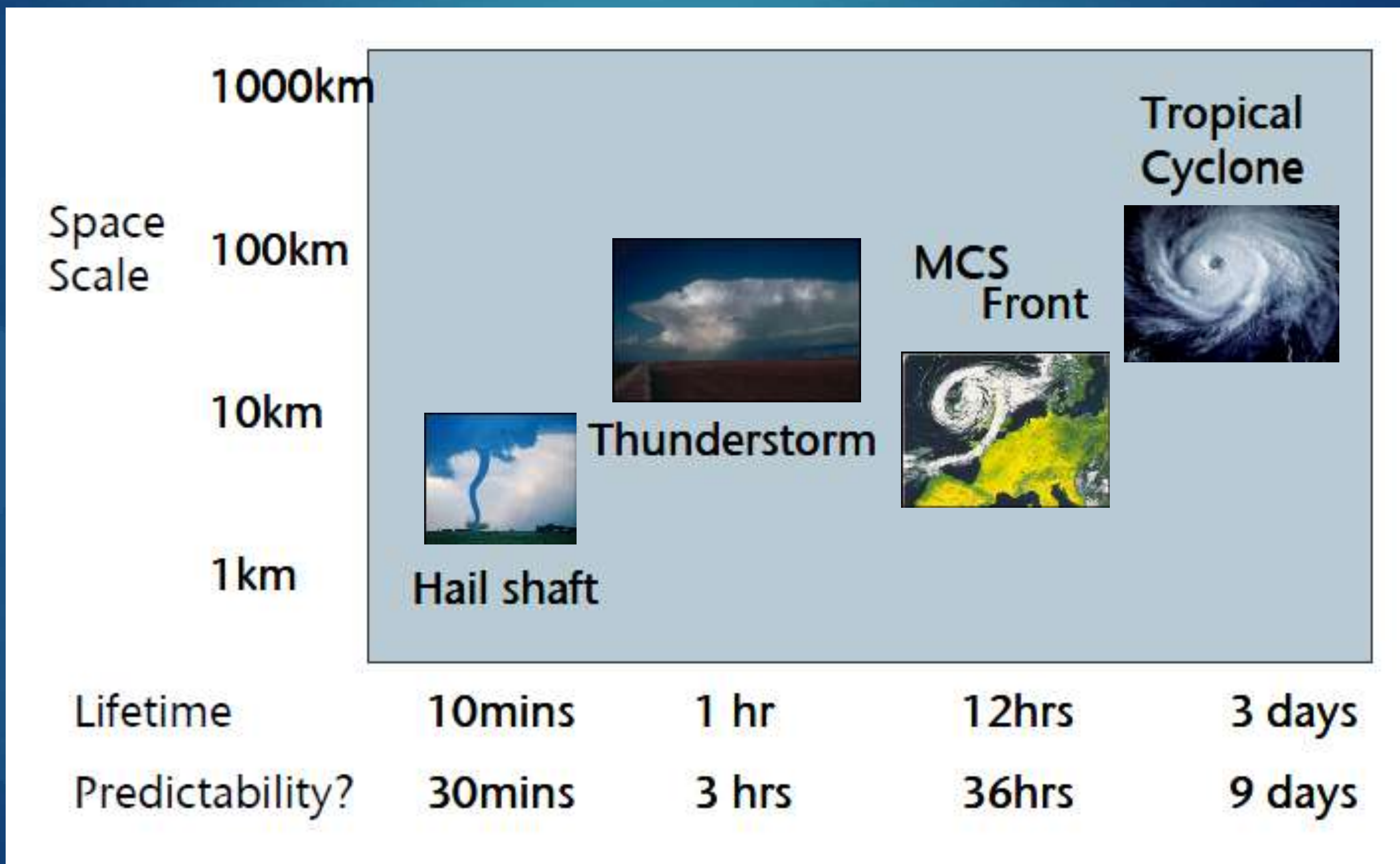
Adapted from:
www.inscc.utah.edu/~reichler/6030/Sample_talk.ppt

Atmospheric Modelling

1. Initial State
2. Primitive Equations
3. Resolution
4. Time Range

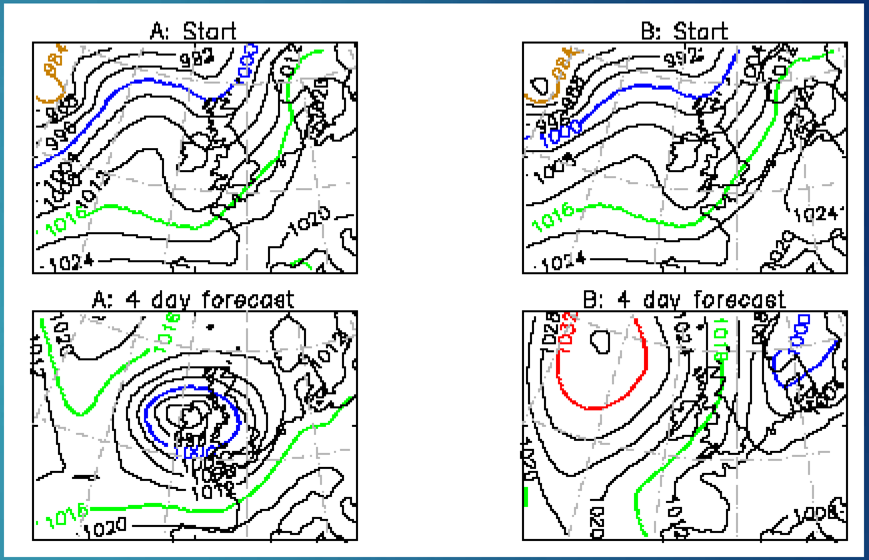


Temporal and Spatial Resolution



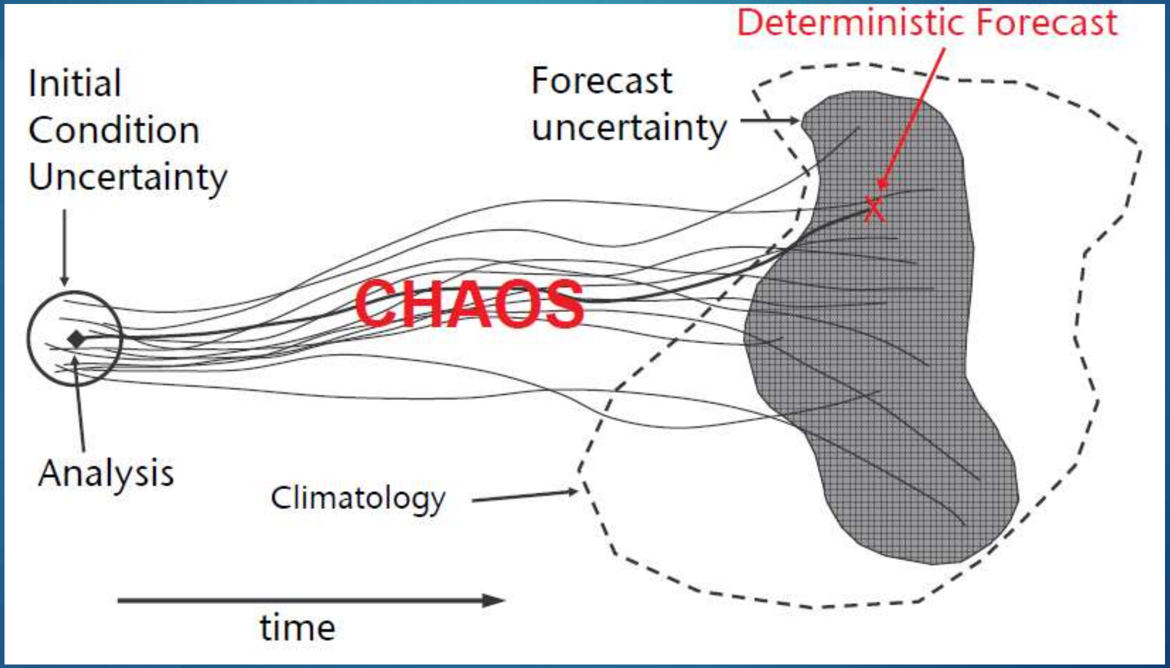
Chaos in the Atmosphere

- When potential energy is available for conversion to kinetic energy and a trigger is present, small disturbances may grow rapidly into weather systems.
- Small errors may rapidly lead to large forecast errors.



The atmosphere is a chaotic system: "…one flap of the seagull's wing may forever change the future course of the weather." (Lorenz, 1963)

Quantifying Uncertainty with Ensembles



Improving Accuracy of NWP

- finer resolution
- larger domains
- longer forecasts
- better use of observations
- better representation of atmospheric processes

Increasing computer speed and memory has enabled that research to be implemented.

Additional Information

Register on www.meted.ucar.edu

- Model Fundamentals: https://www.meted.ucar.edu/training_module.php?id=700#.UoCIbeI-u2A
- Optimizing the Use of Model Data Products: https://www.meted.ucar.edu/training_module.php?id=778#.UoCHpuI-u2A
- How NWP fits into the Forecast Process: https://www.meted.ucar.edu/training_module.php?id=755#.UoCH1uI-u2A
- Understanding Assimilation Systems: https://www.meted.ucar.edu/training_module.php?id=704#.UoCH_uI-u2A
- How Model Produce Precipitation and Clouds: https://www.meted.ucar.edu/training_module.php?id=701#.UoCIIeI-u2A