GLOBAL MODELLING

NUMERICAL MODELLING PROCESSES

ADAPTED FROM DAVIES, 2012

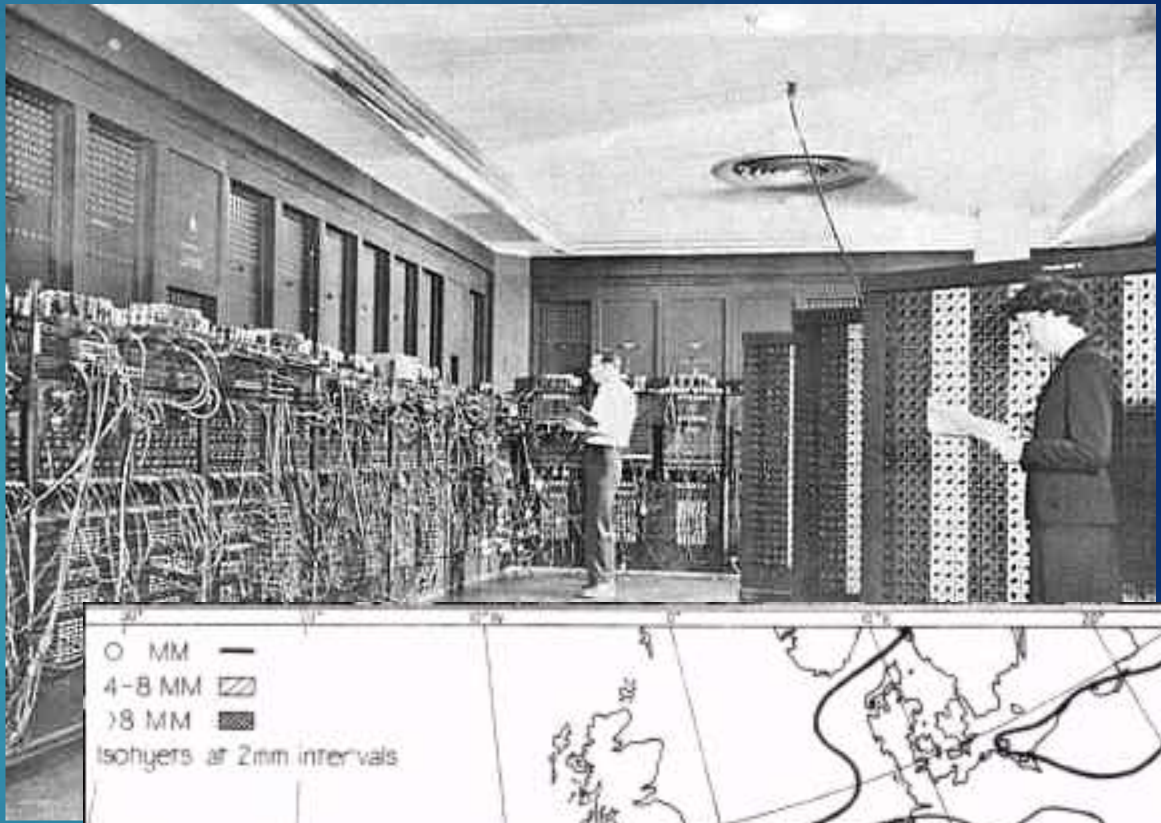
South African Weather Service
ISO 9001 Certified Organisation

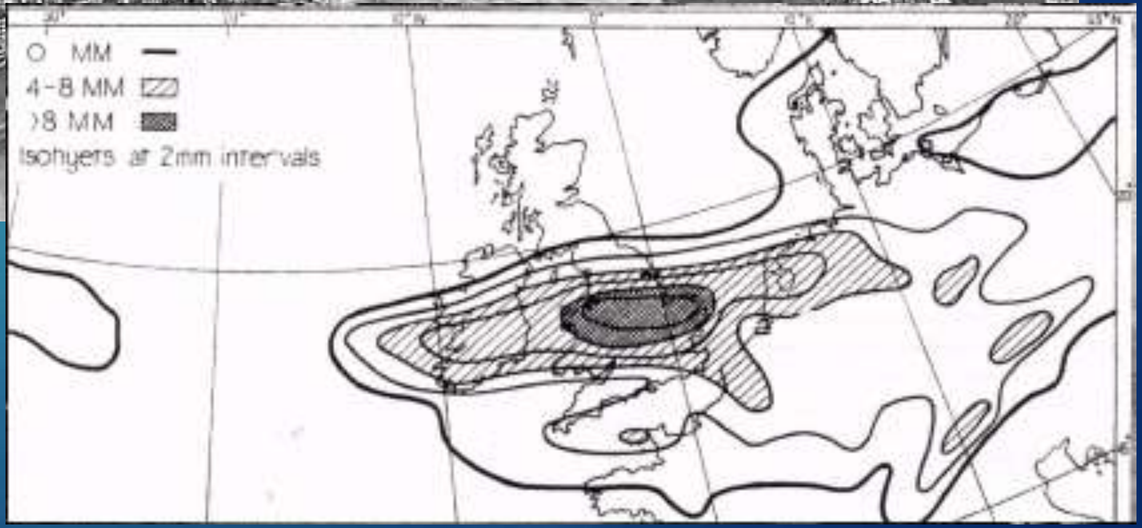
Changing Requirements

- 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
- 1950: The ENIAC experiment
- 1967: Predicting frontal precipitation with a 10 level model





Today’s Numerical Modelling System

Observations

Forecast Model

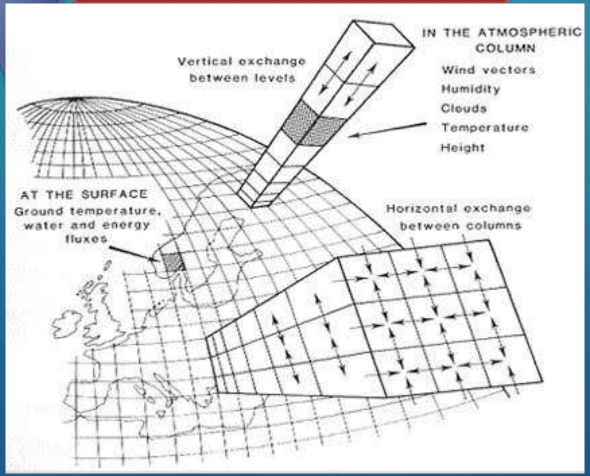
Post-Processing

Forecast

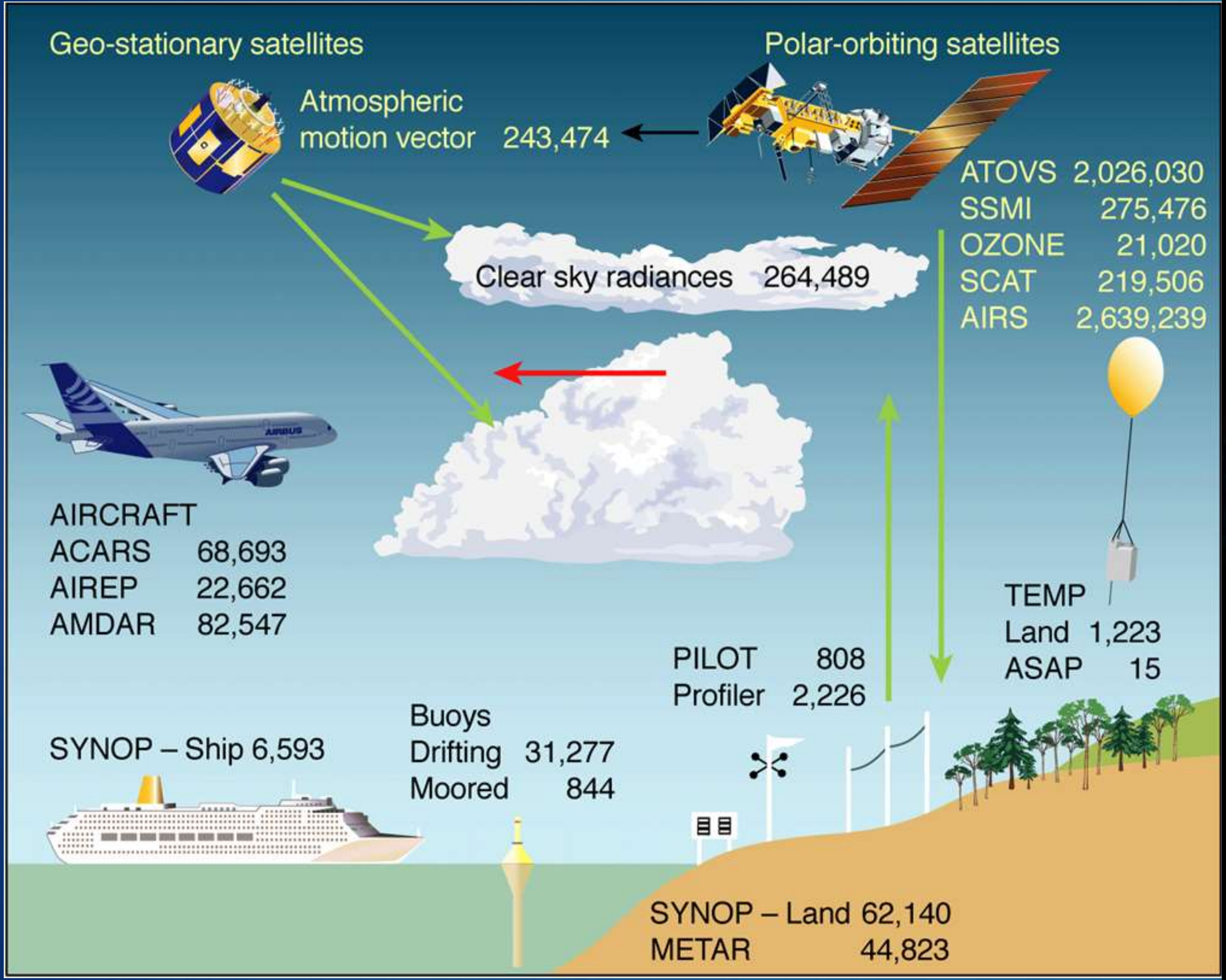
Risk Analysis & Communication

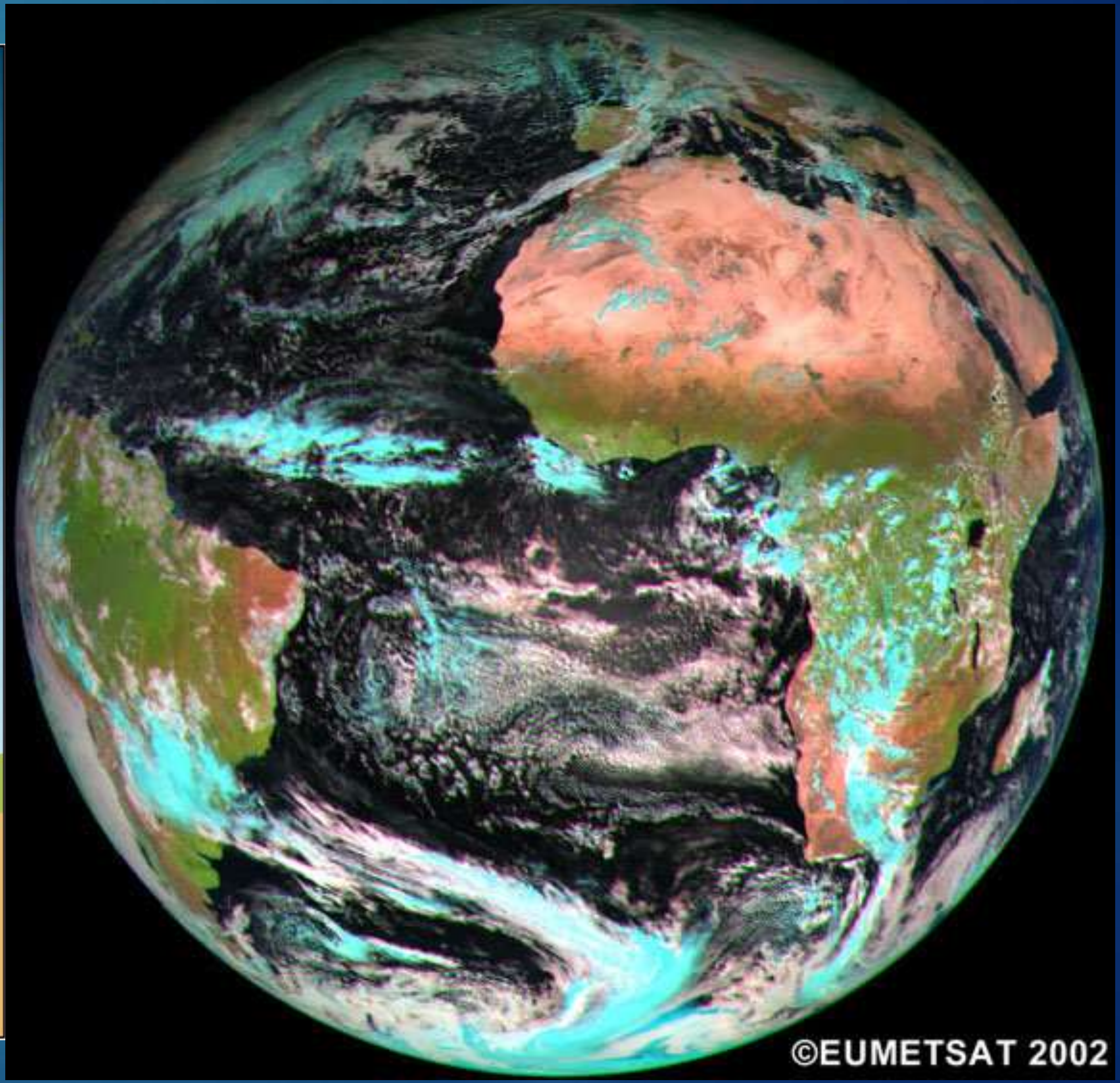
$$\frac{du}{dt} = \frac{\partial p}{\partial x} - fv$$
$$\frac{dv}{dt} = \frac{\partial p}{\partial y} + fu$$
$$\frac{p}{\rho} = RT$$

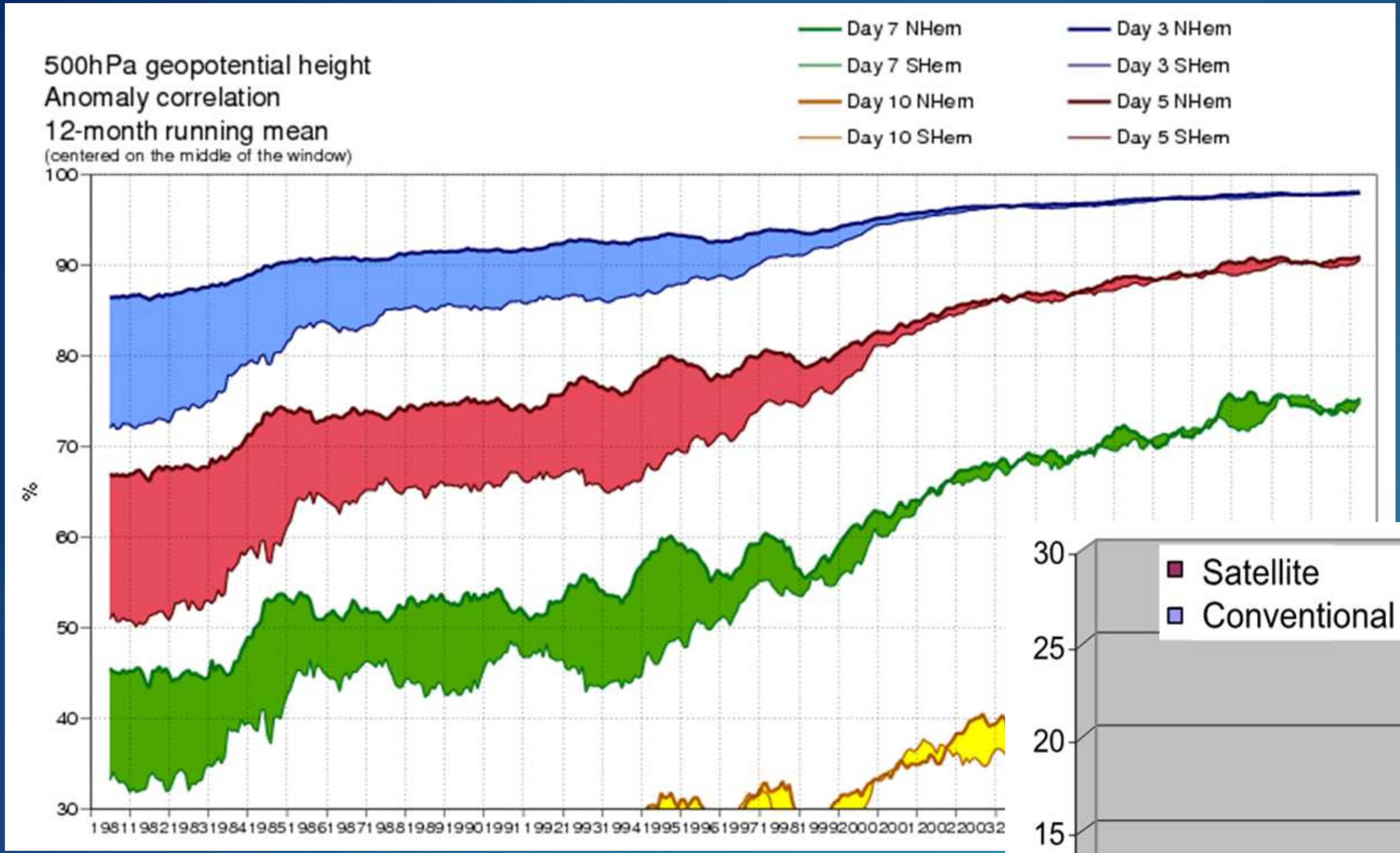
Knowledge

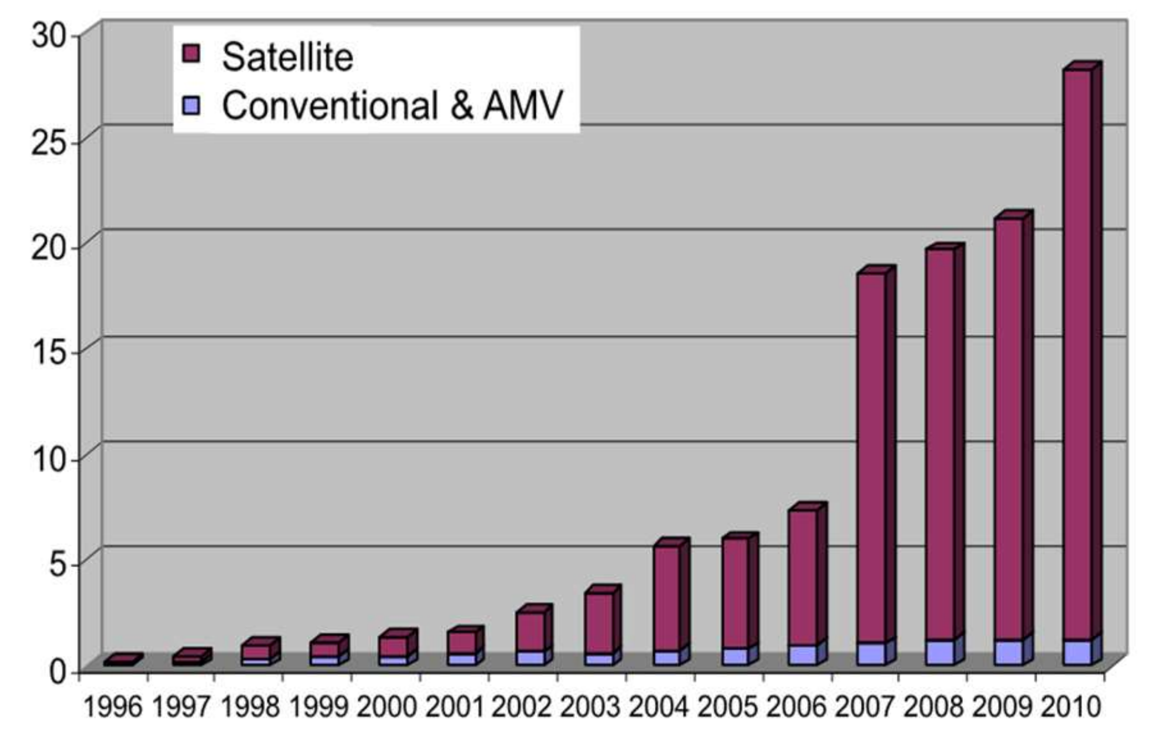


Observing the World

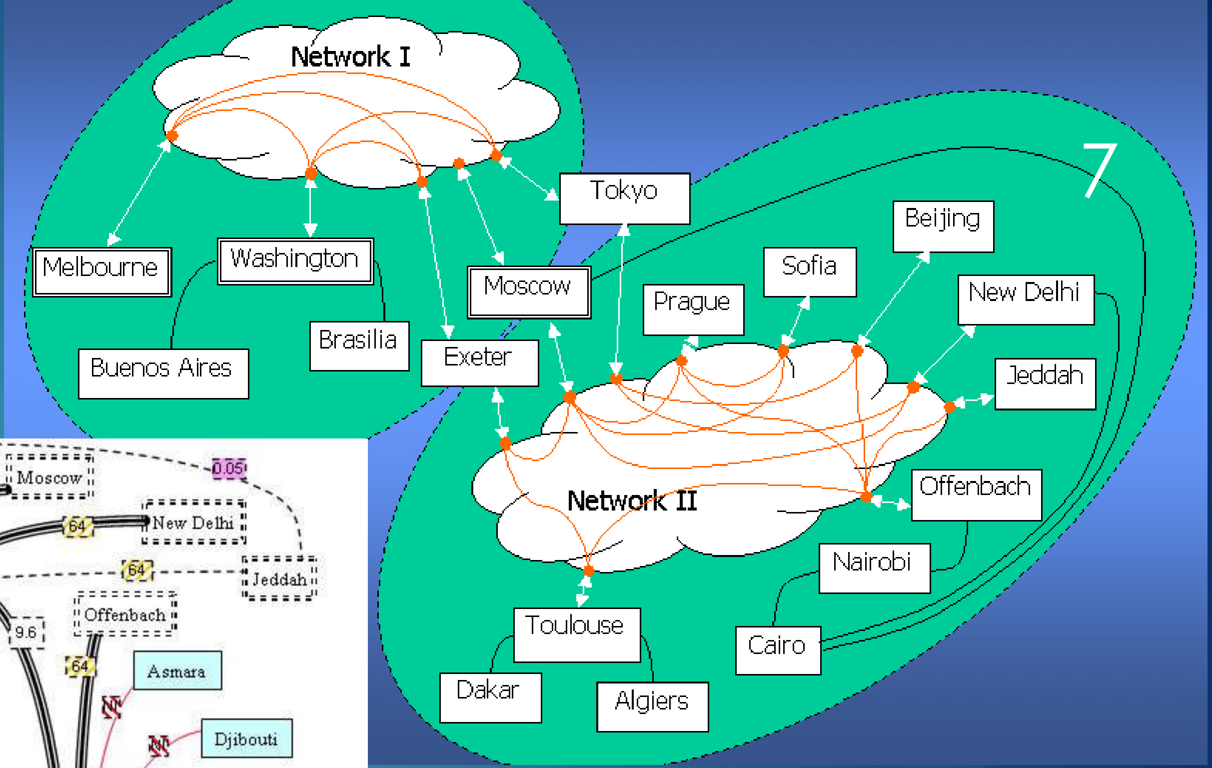


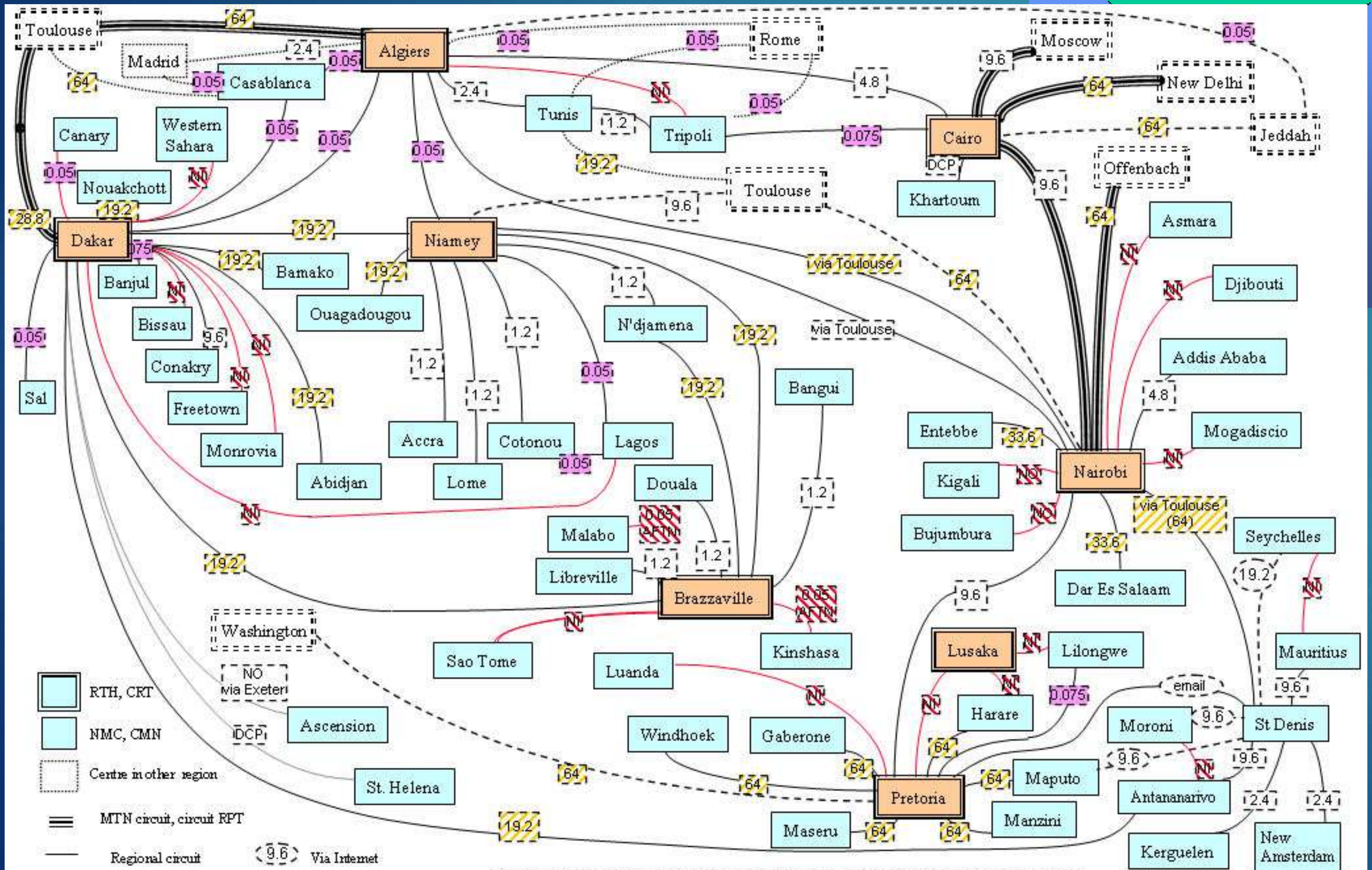



500hPa geopotential height
Anomaly correlation
12-month running mean
(centered on the middle of the window)
Day 7 NHem
Day 7 SHem
Day 10 NHem
Day 10 SHem
Day 3 NHem
Day 3 SHem
Day 5 NHem
Day 5 SHem
%


Satellite
Conventional & AMV

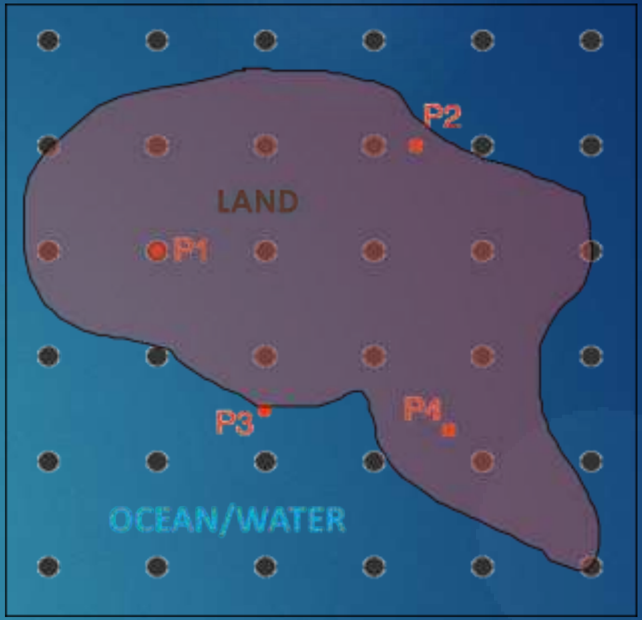
Sharing Data



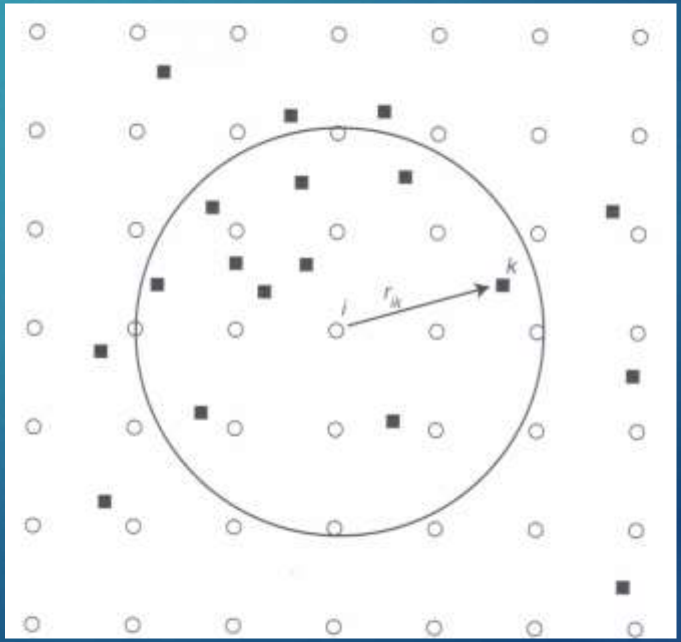


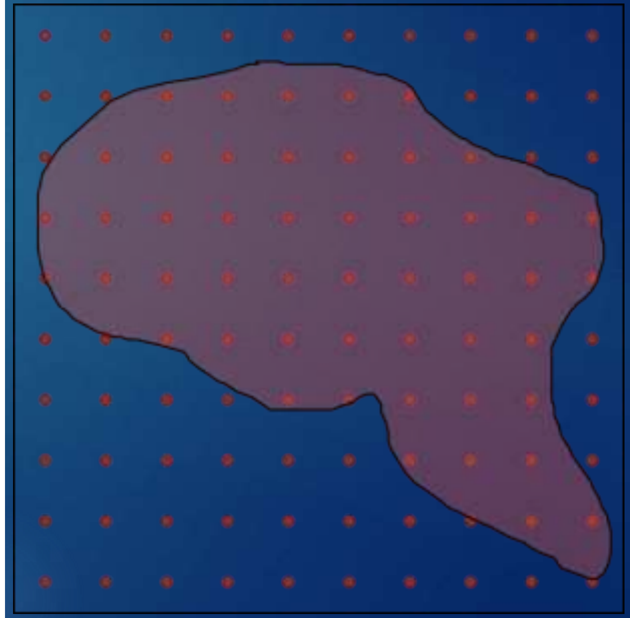
Regional Meteorological Telecommunication Network for Region I (Africa)
point-to-point circuits implementation (transmission speed in kbit/s)

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

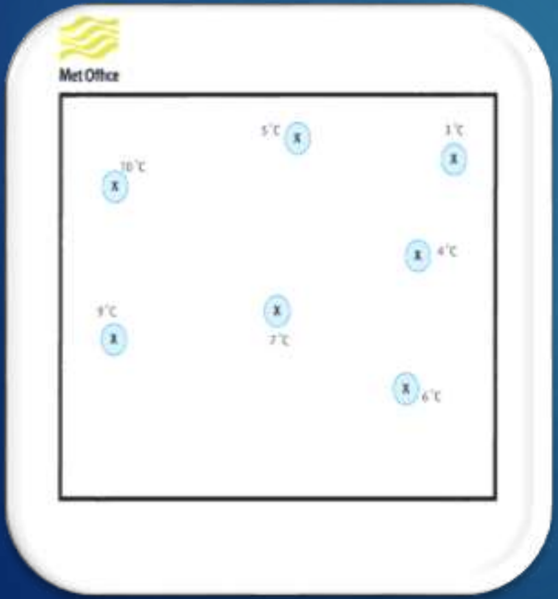
- NWP cannot rely solely on observations to produce its initial conditions
  - Why not?
  - There are too few
  - Point observations may not be representative of a grid box

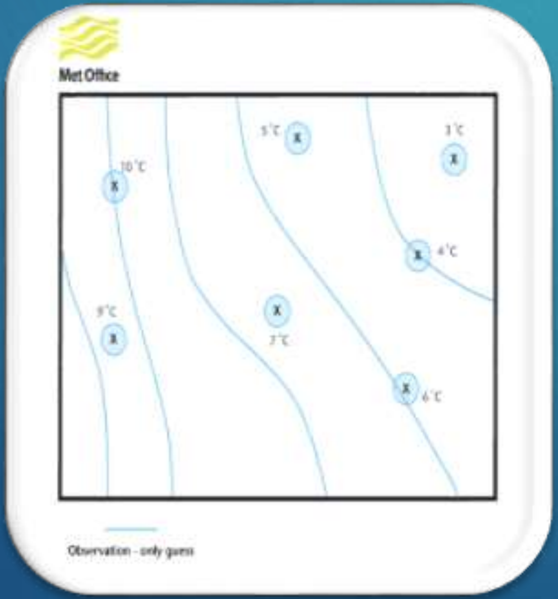
- A short period forecast from a previous run of the model fills the gaps
  - Model background field

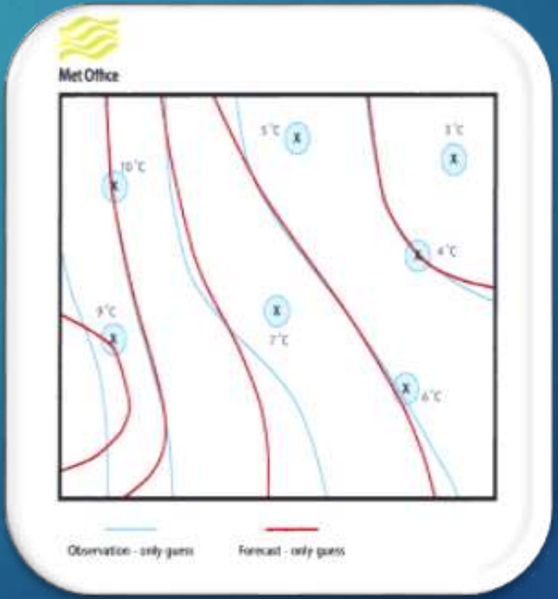
Assimilation is the process of finding the model representation which is most consistent with the observations

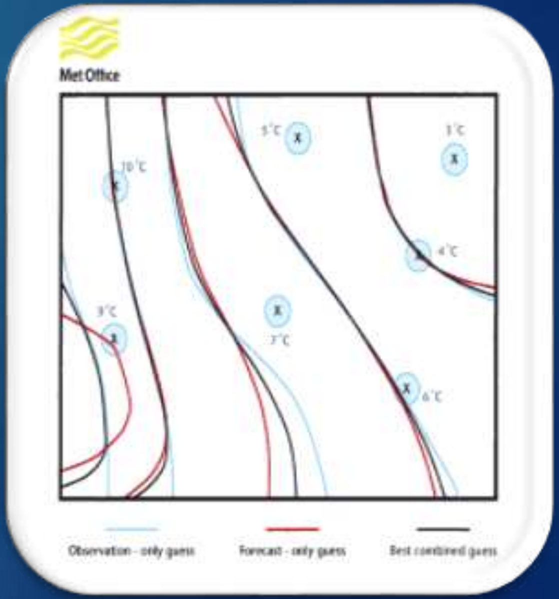
Data Assimilation

- 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

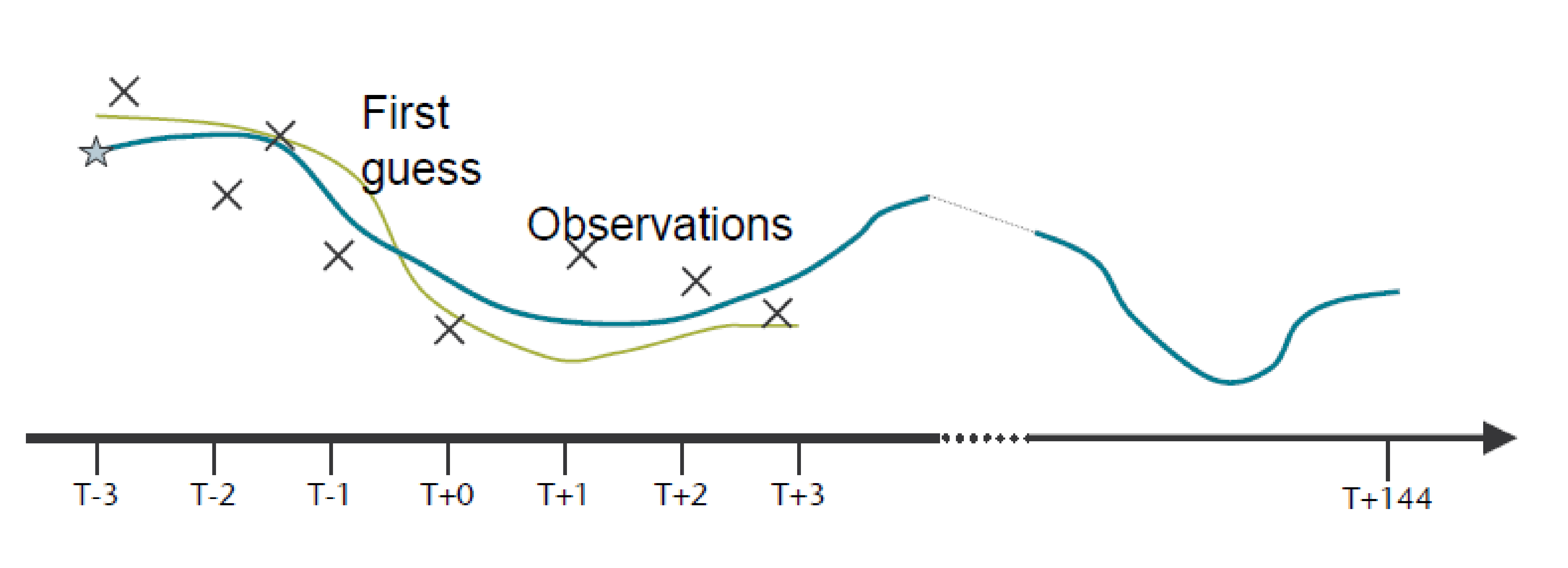








Data Assimilation

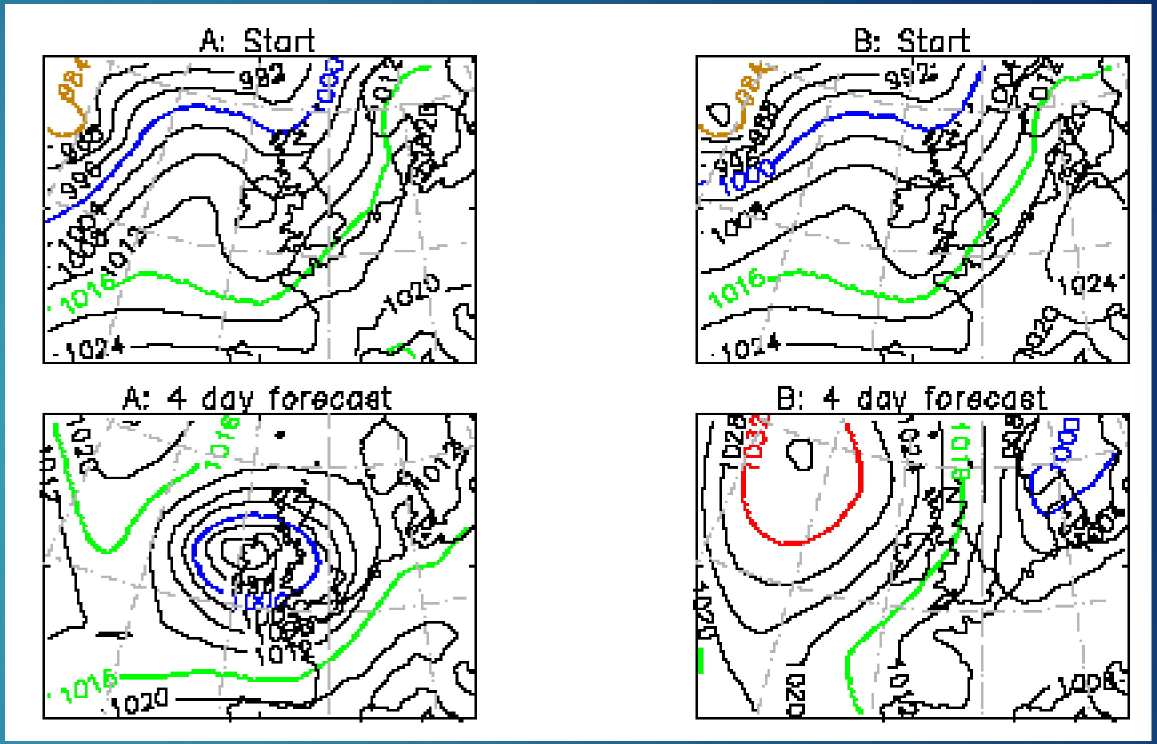


The Challenge

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

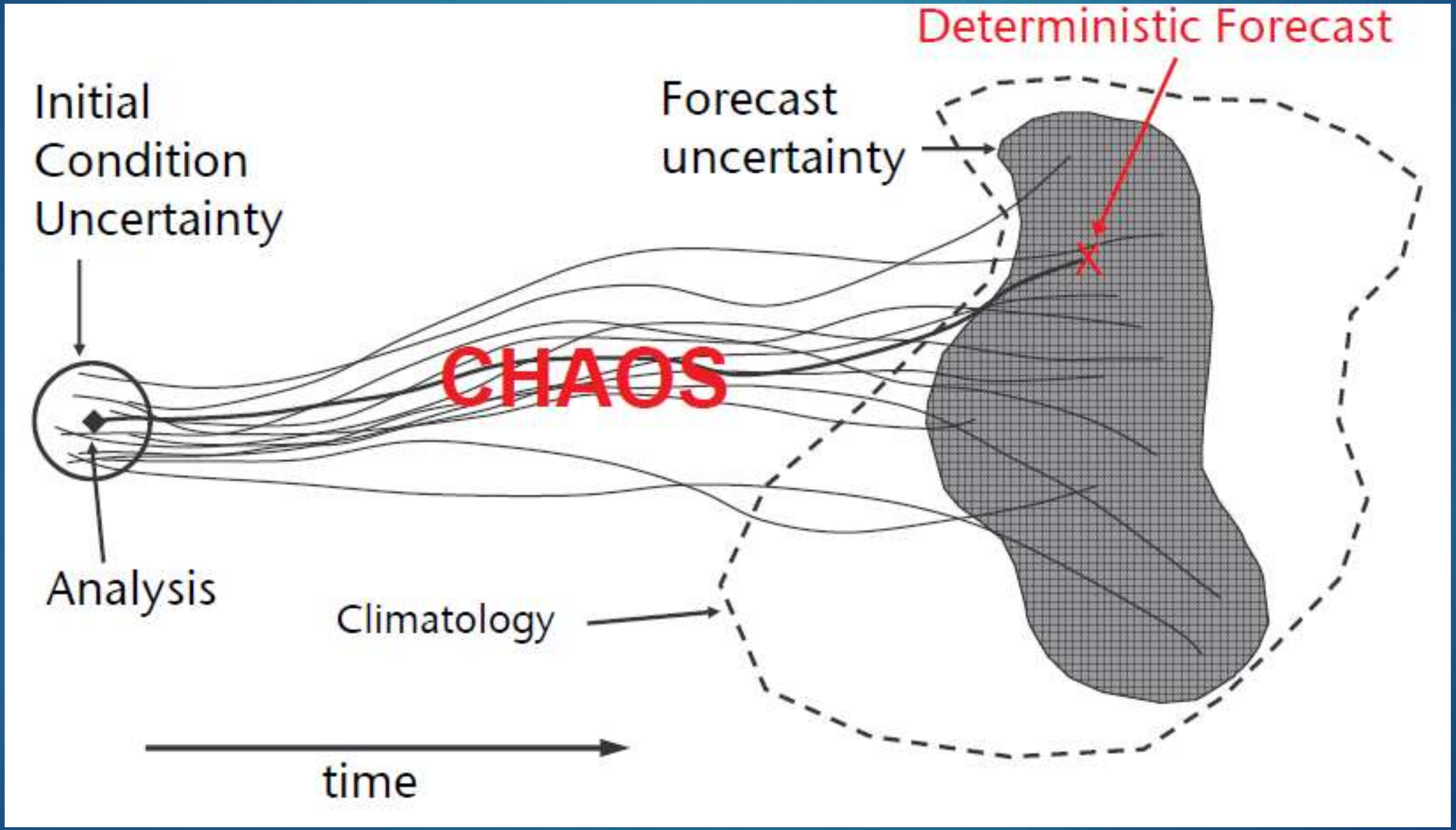
Chaos in the Atmosphere

- 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.

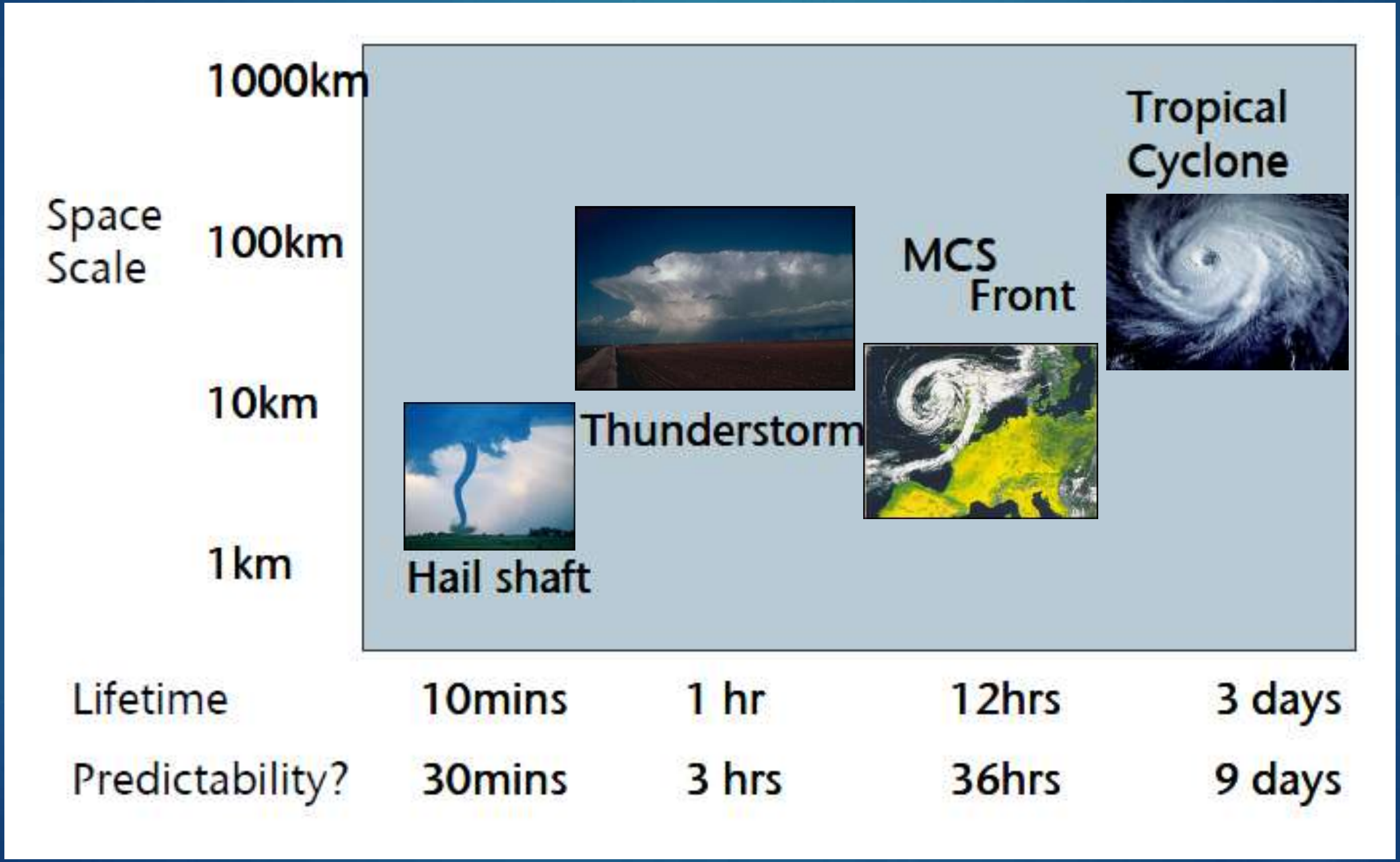


The atmosphere is a chaotic system:
"…one flap of the seagull's wing may forever change the future course of the weather."
(Lorenz, 1963)

Quantifying Uncertainty with Ensembles



Temporal and Spatial Resolution



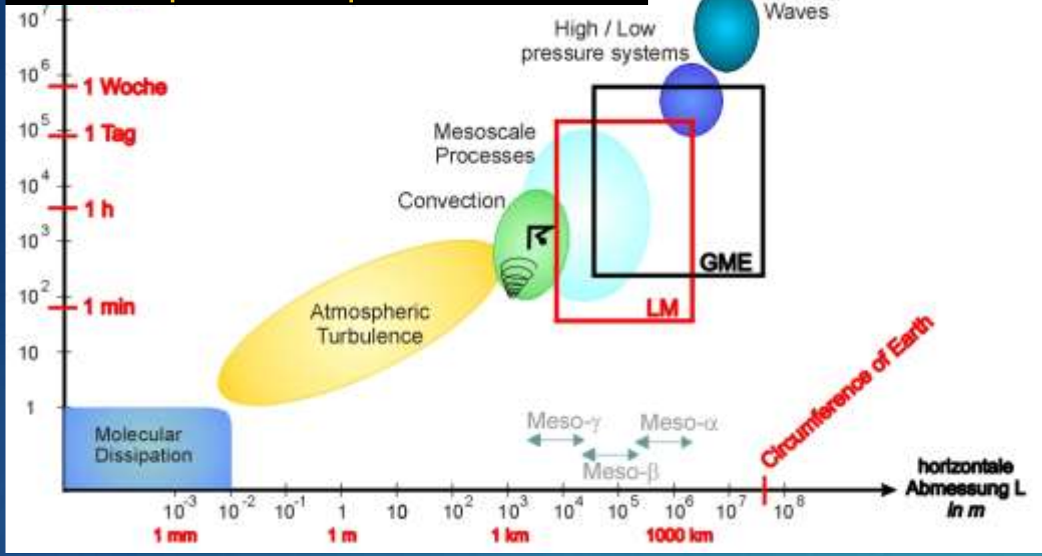
Parameterization

- 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: 50 km
  Global: 100~200 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.

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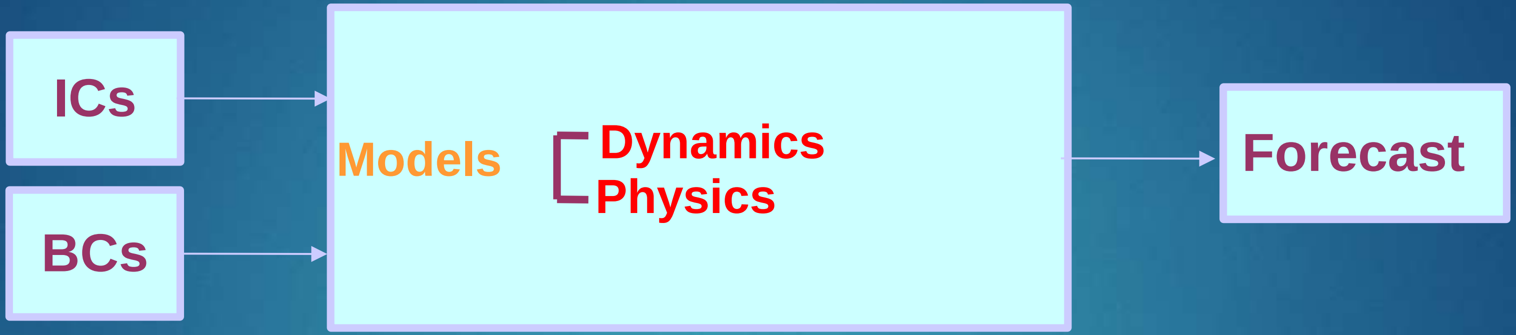
Why do we need parameterization?



- **Dynamic core of models**

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

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

$$p\alpha = RT$$

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

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

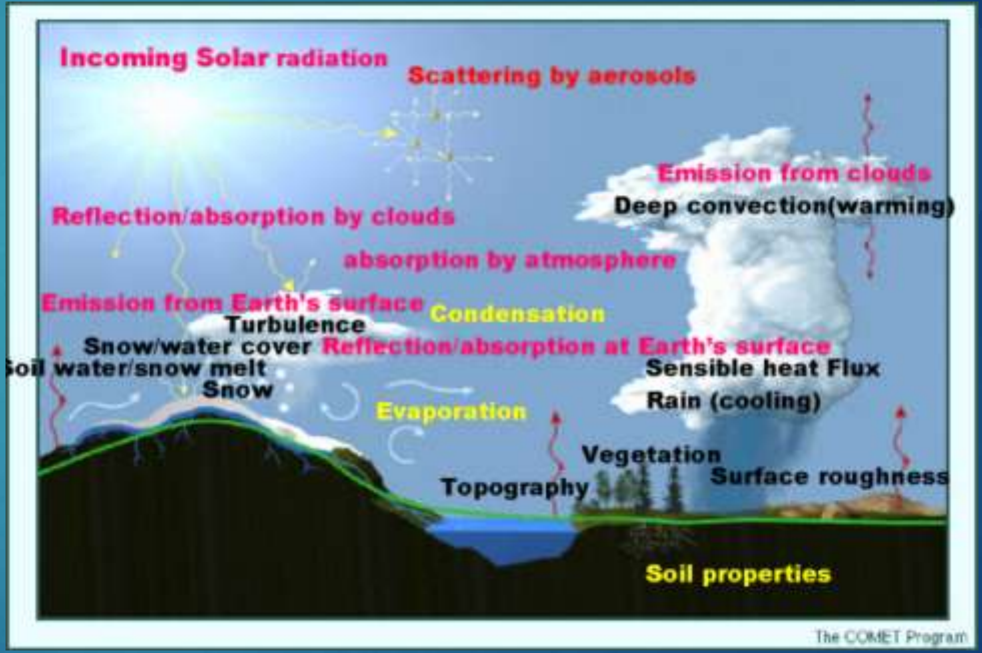
- **Model physics:**
  - Processes such as phase change of the water are in too small scale and too complex.
  - Processes such as cloud microphysics are poorly understood.

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)

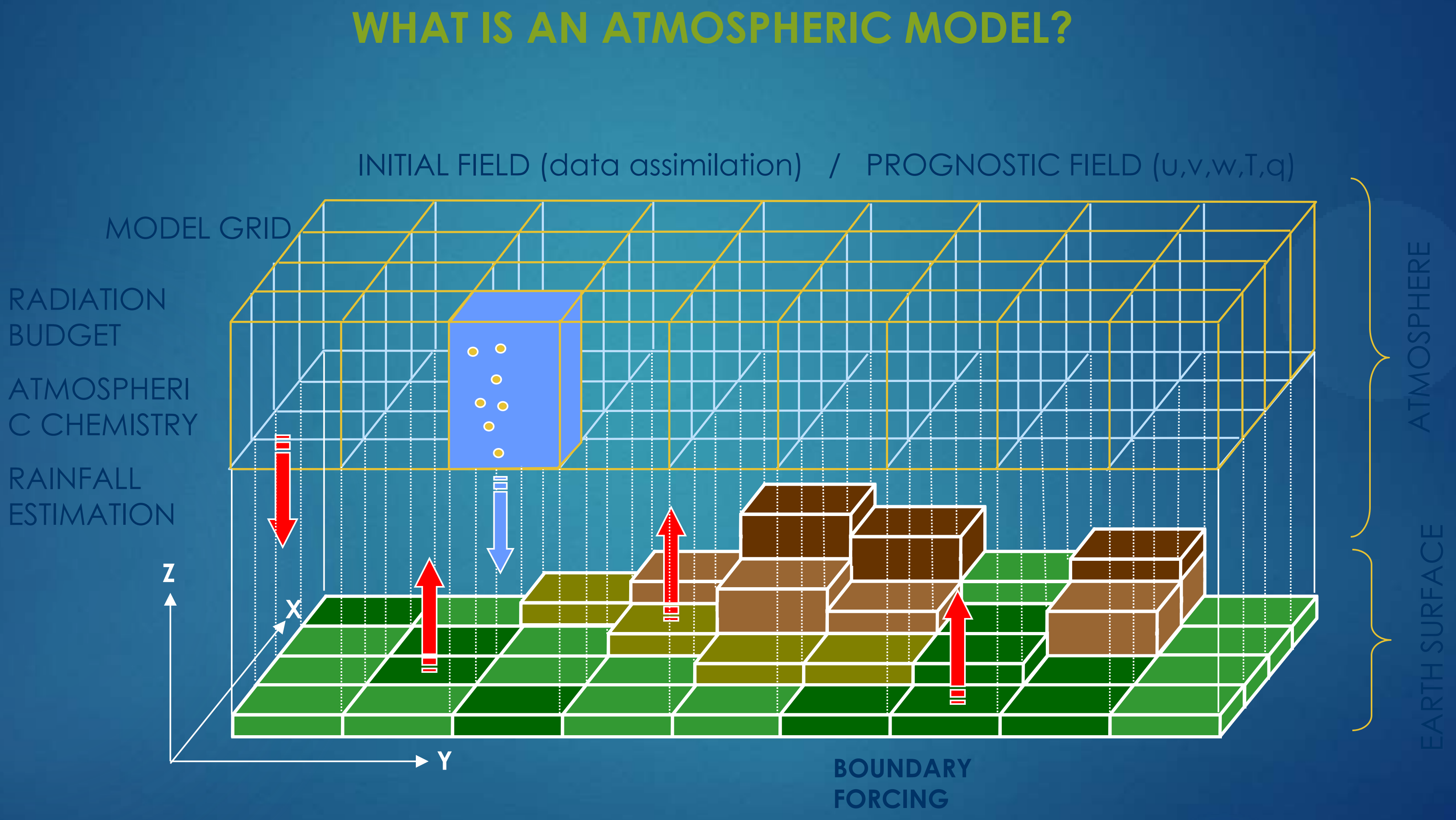
Adapted from:
www.inscc.utah.edu/~reichler/6030/Sample_talk.ppt

How do we do Parameterization in models?

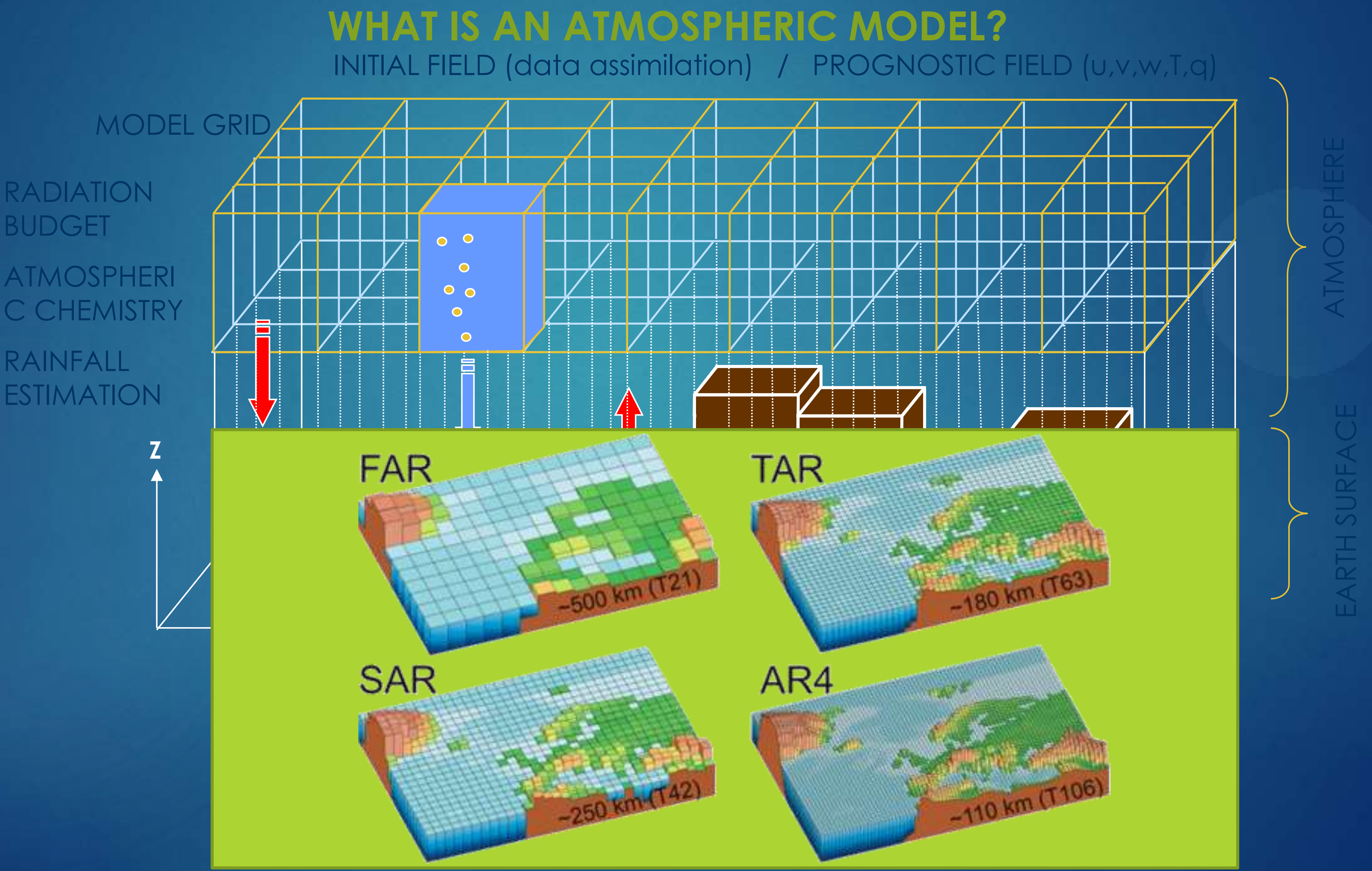
- Ignore some processes (in simple models).
- Simplifications of complex processes based on some assumptions.
- Statistical/empirical relationships and approximations based on observations.
- Nested models and super-parameterization: Embed a cloud model as a parameterization into climate models.

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

Horizontal & Vertical Resolution

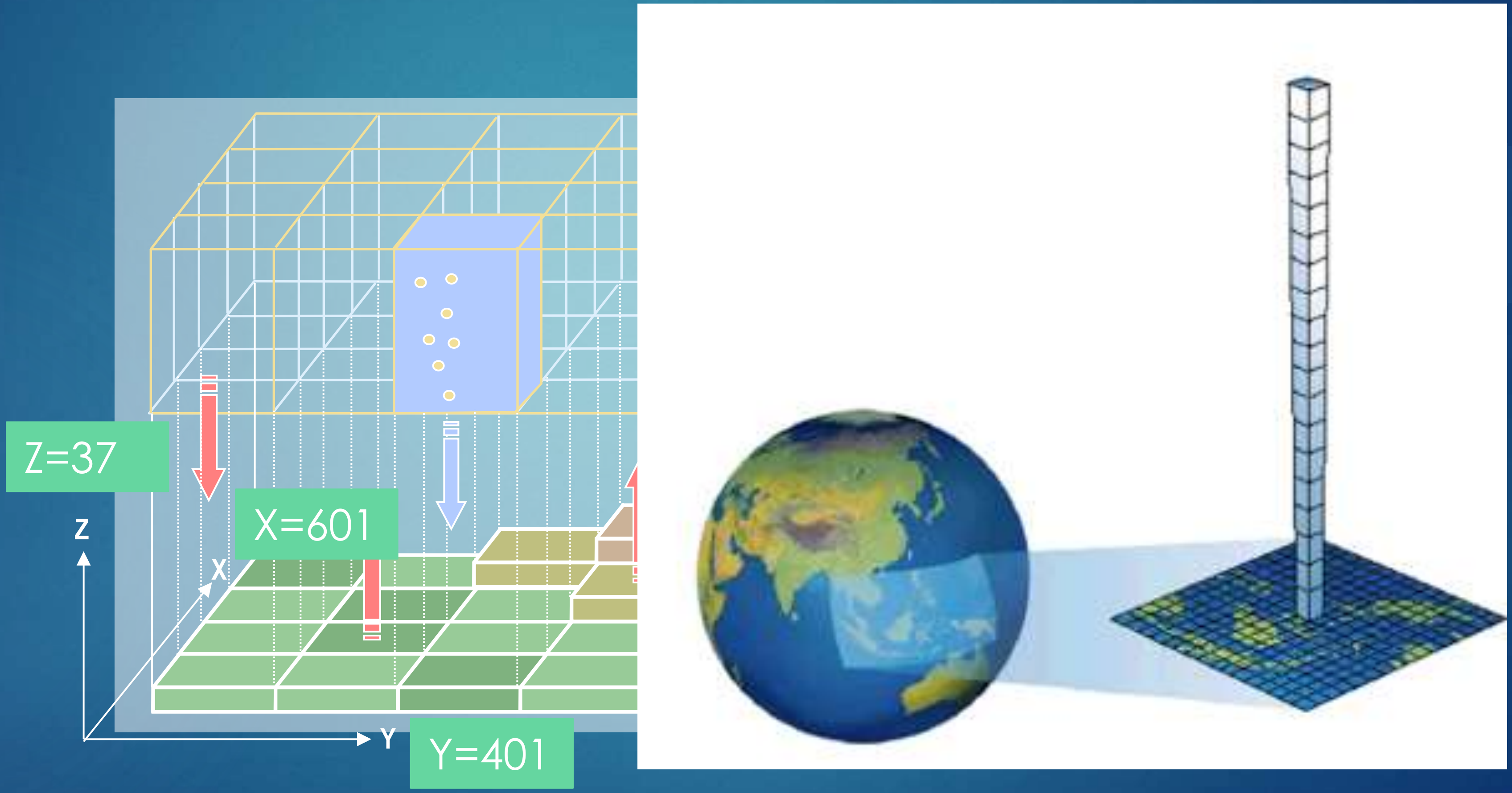


Horizontal Resolution



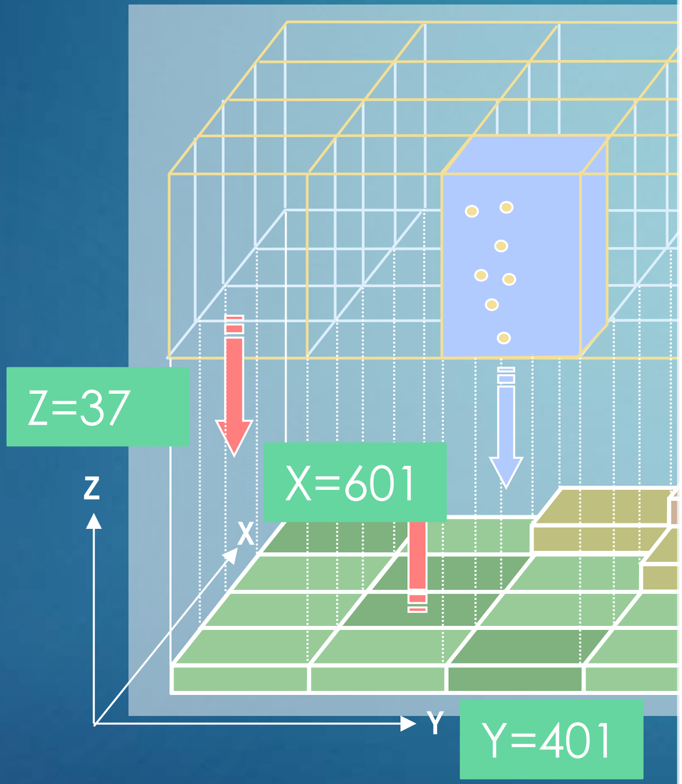
Vertical Resolution

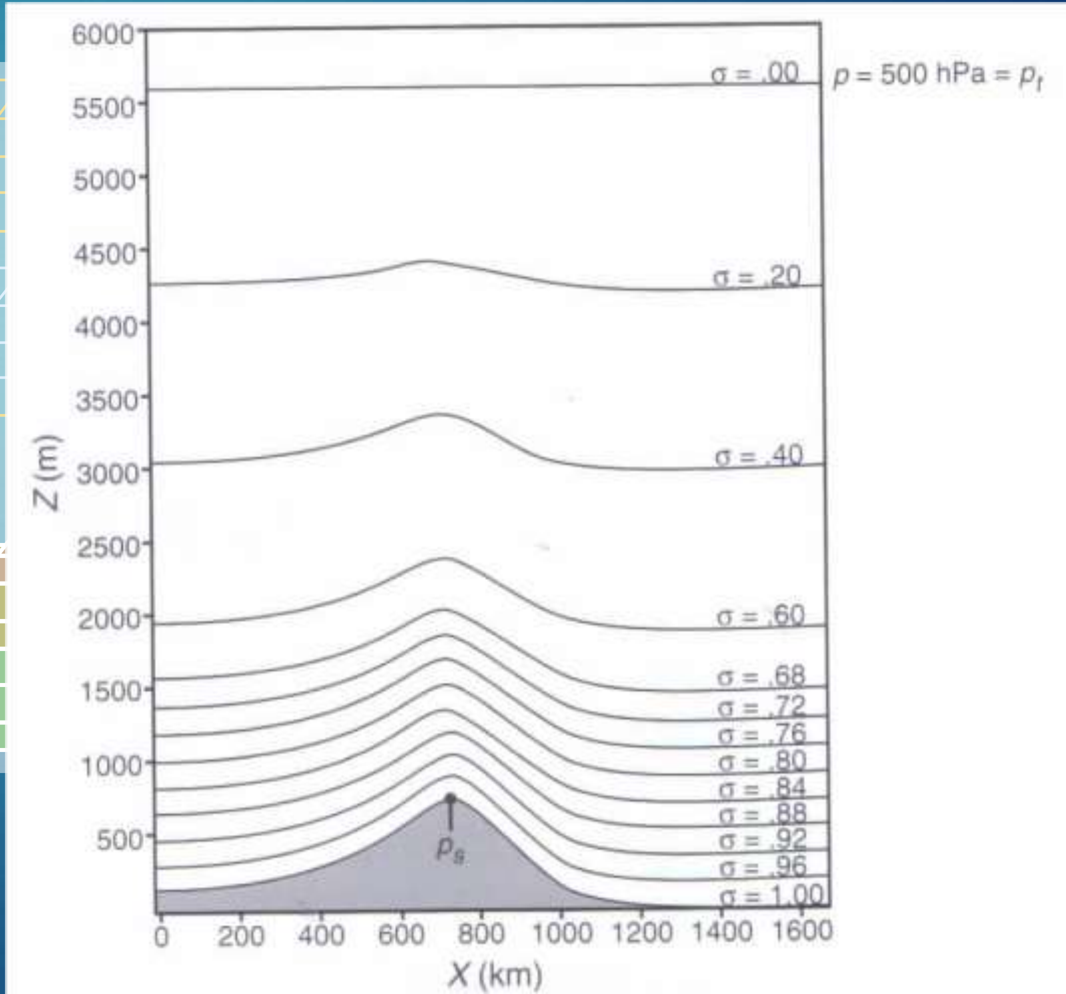
WHAT IS AN ATMOSPHERIC MODEL?



Vertical Resolution

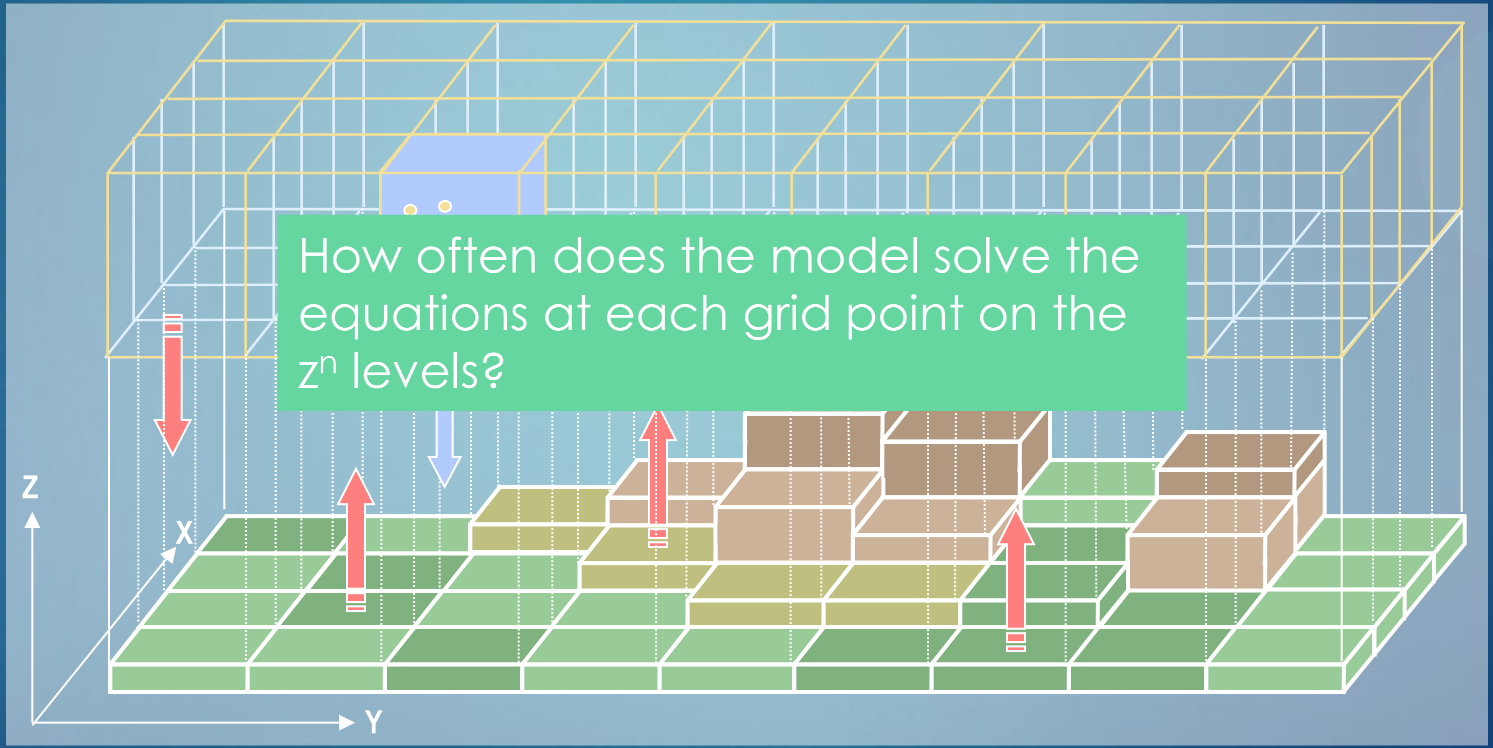
WHAT IS AN ATMOSPHERIC MODEL?





Temporal Resolution

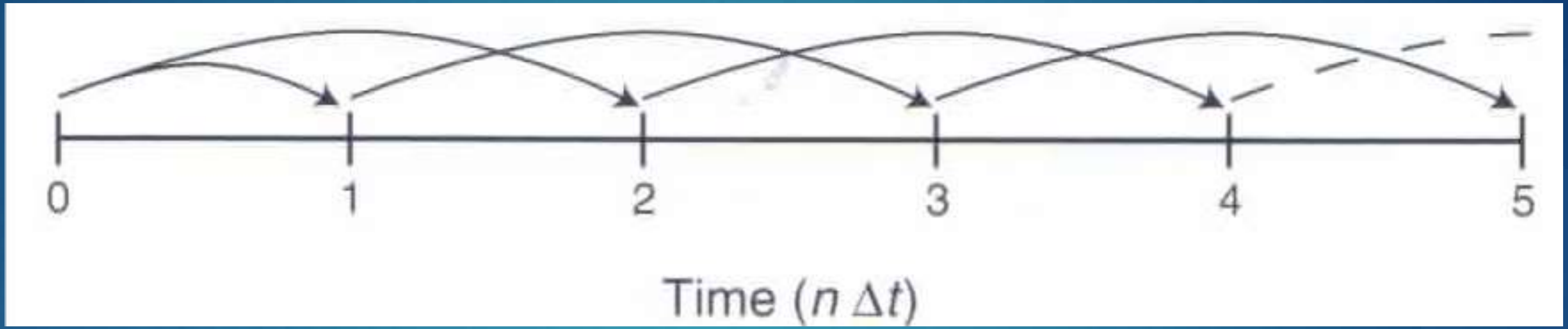
WHAT IS AN ATMOSPHERIC MODEL?



How often does the model solve the equations at each grid point on the z^n levels?

Temporal Resolution

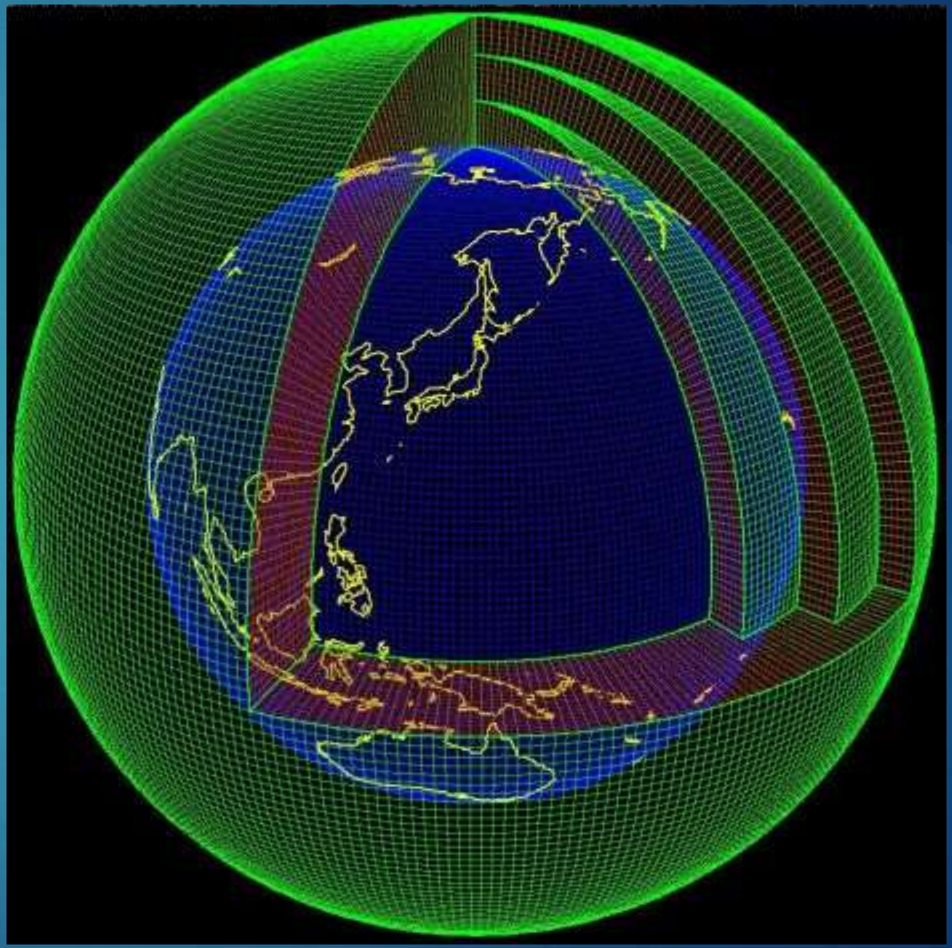
WHAT IS AN ATMOSPHERIC MODEL?



- 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)

Atmospheric Modelling

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



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#.UoClbel-u2A
- Optimizing the Use of Model Data Products: https://www.meted.ucar.edu/training_module.php?id=778#.UoCHpul-u2A
- How NWP fits into the Forecast Process: https://www.meted.ucar.edu/training_module.php?id=755#.UoCH1ul-u2A
- Understanding Assimilation Systems: https://www.meted.ucar.edu/training_module.php?id=704#.UoCH_ul-u2A
- How Model Produce Precipitation and Clouds: https://www.meted.ucar.edu/training_module.php?id=701#.UoCIlel-u2A