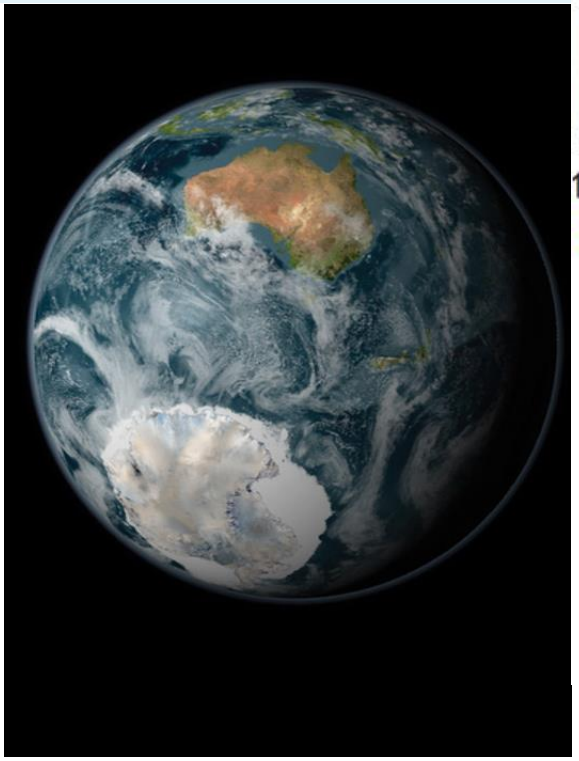
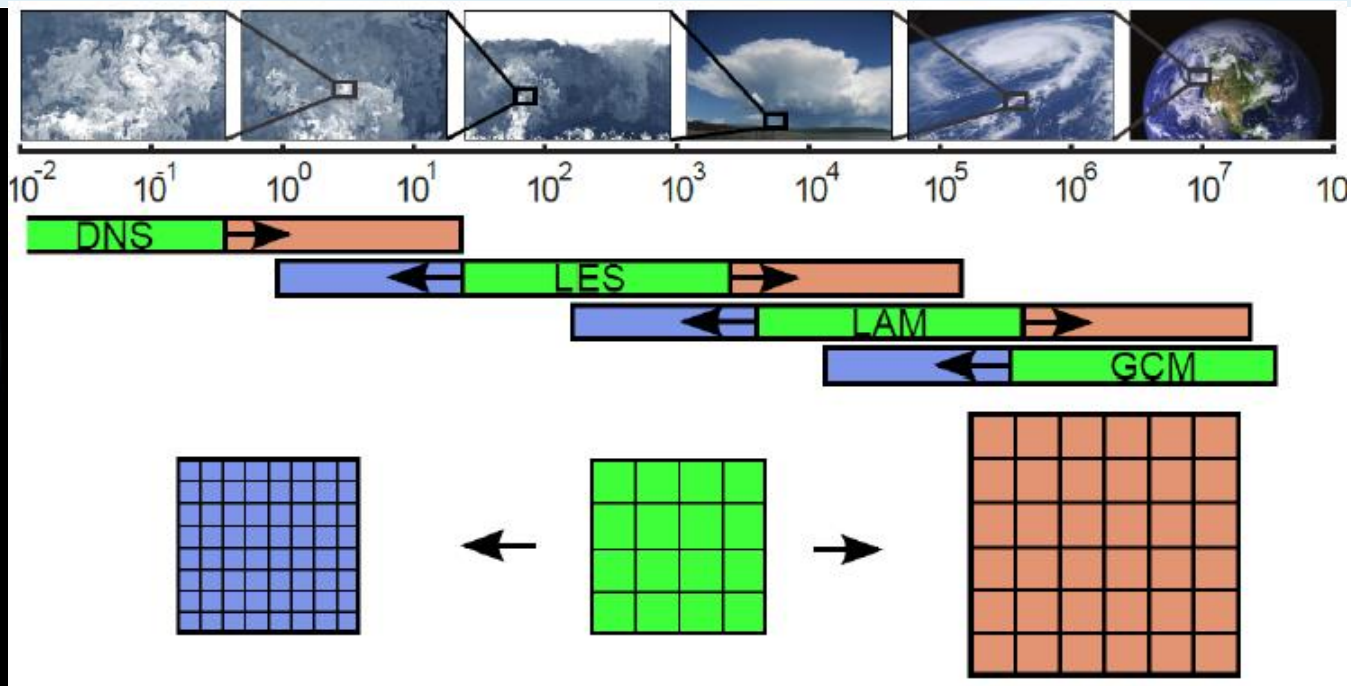
Australian Government
Bureau of Meteorology

Modelling across scales: towards seamless prediction and projection

Kamal Puri



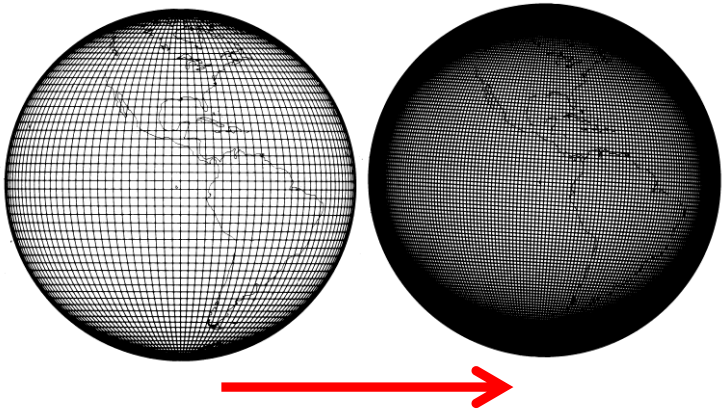


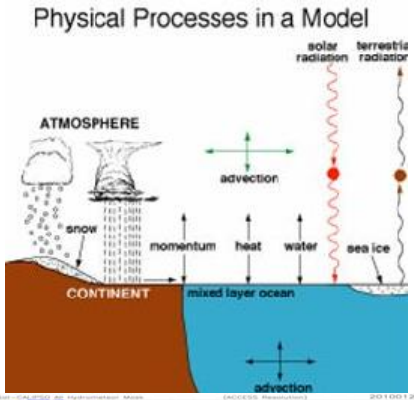
Progress since the 1990s

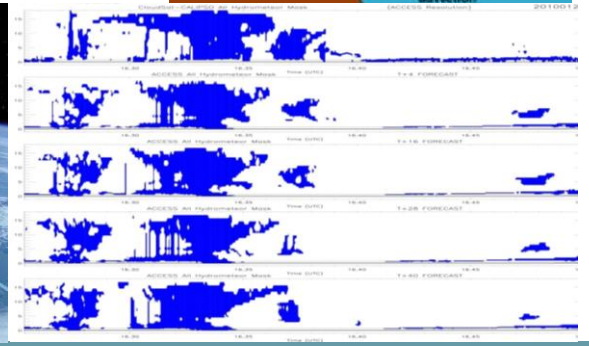
Past 2 decades has seen major improvement in ability to predict and project weather and climate

So what has changed?

- Model improvements
  - Increased resolutions
    - Global: ~200 km > ~15km
    - Regional: ~50km > ~ 2km
    - ~30 levels > 100+ levels
  - Improved understanding of processes
  - Improved verification



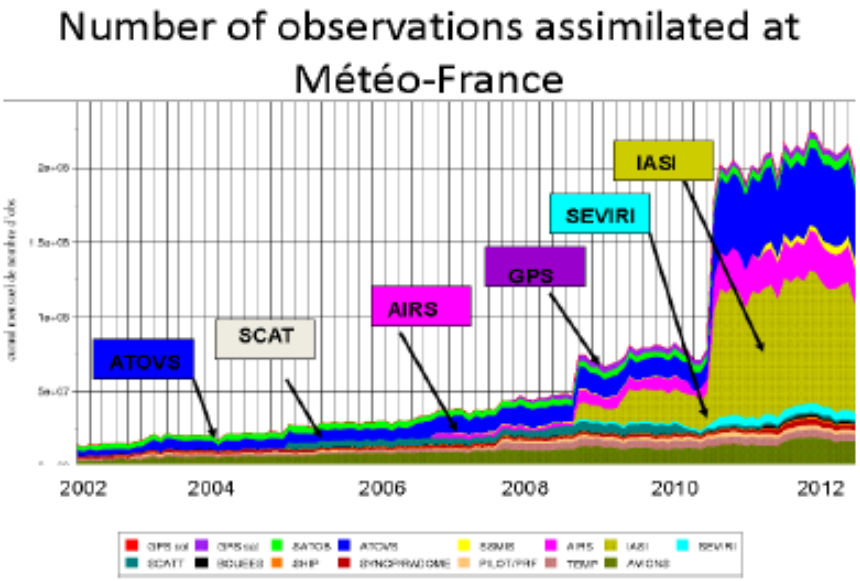


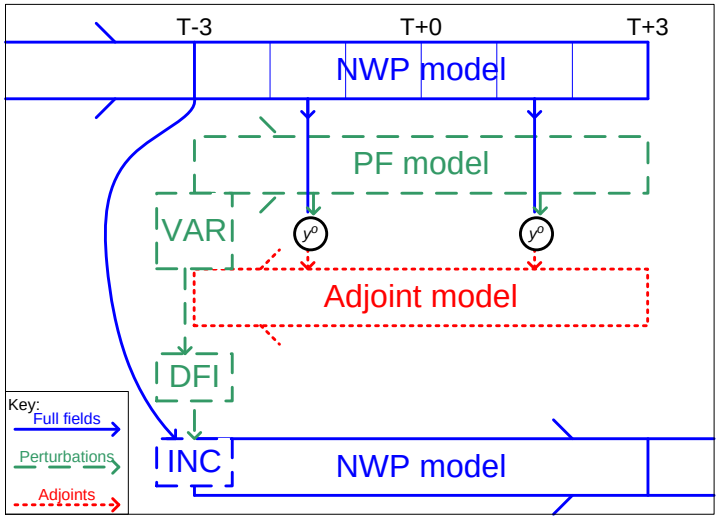


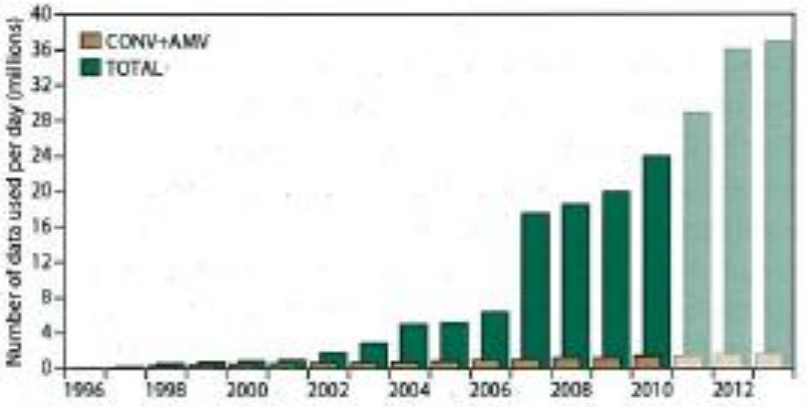
Progress since the 1990s

What has changed?

- Major increases in observation network particularly satellites
- Significantly improved ability to use observations consistently
  - ➢ Data assimilation formulation
  - ➢ 4DVAR
  - ➢ Direct assimilation of satellite radiances







Future directions

Current research issues: a challenge for WWRP and WGNE

- Improve the accuracy of short-range forecasts for security of people and properties, health, transport, defence and the energy market
- Develop climate services, i.e. improve seasonal prediction and assess decadal prediction

Gilbert Brunet
WGNE29, 2014

Future directions

- Additionally, as noted in the "The World Climate Research Programme Strategic Framework 2005-2015" (WCRP-123 WMO.TD-No.1291)1:

Developments in atmospheric science and technology provide the opportunity to address the predictability of the total climate system for the benefit of society and to address the seamless prediction of the climate system from weekly weather to seasonal, decadal and centennial climate variations and anthropogenic climate change

Future directions
Trends for NWP systems

- Integrated NWP systems (for efficiency)
- Seamless prediction
- Continued trend in increased resolution
- Generalisation of ensembles to impact models
  - ➢ Towards the end of deterministic forecasts?
- More scalable dynamical cores
- Towards coupled NWP with ocean, sea-ice, waves, chemistry and hydrology – environmental prediction

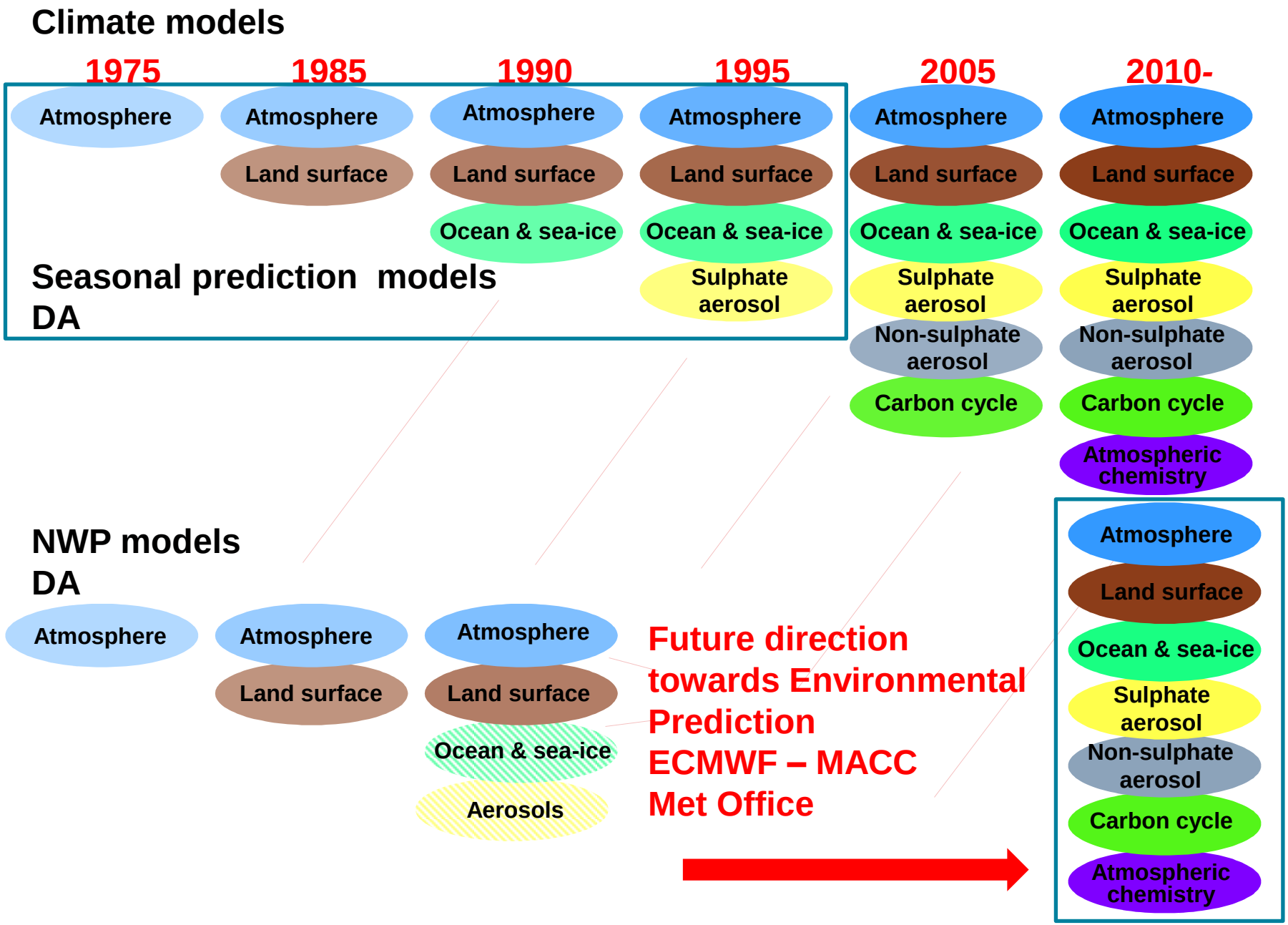
Future directions
Model physics

- More advanced microphysics
- Accounting for horizontal exchanges by turbulence and radiation for grid cells < 1km (e.g. urban NWP)
- Towards more conservatives variables (e.g. chemistry)
- Parametrisation of convection remains a difficult problem for grid cells > 5km
- More 'grey zone' problems as the integrated forecast systems will be used at various resolutions
- Inclusion of stochasticity in physical parametrisations

Future directions
Ensemble and data assimilation techniques

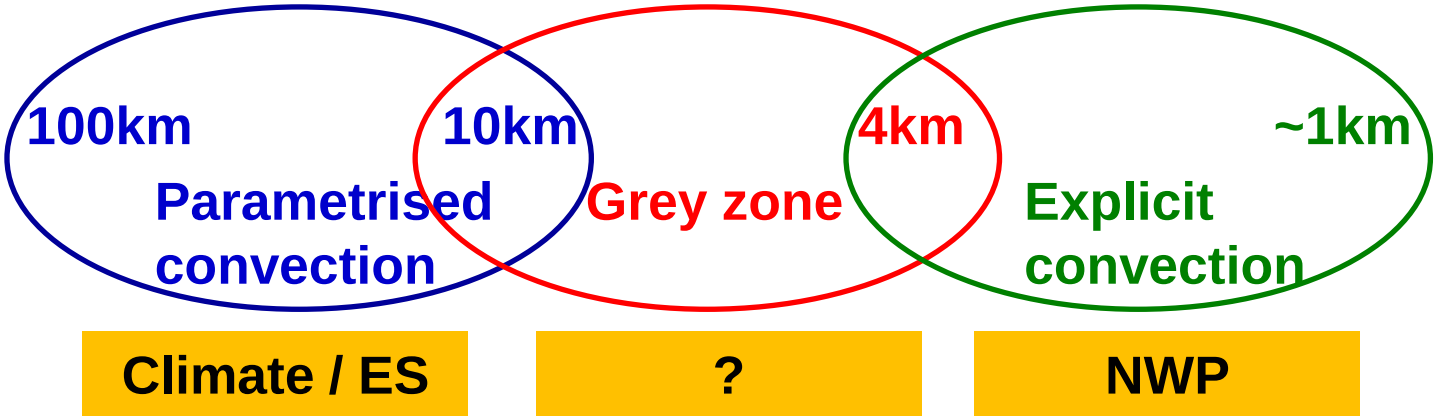
- Evolution driven by both progress in science and constraints from massively parallel machine architectures
- Increasingly hybrid methods (ensembles-variational)
- Work on improving description of model uncertainty
- Develop suitable verification techniques (deterministic, probabilistic, ensemble and high resolution)

Towards Seamless Prediction



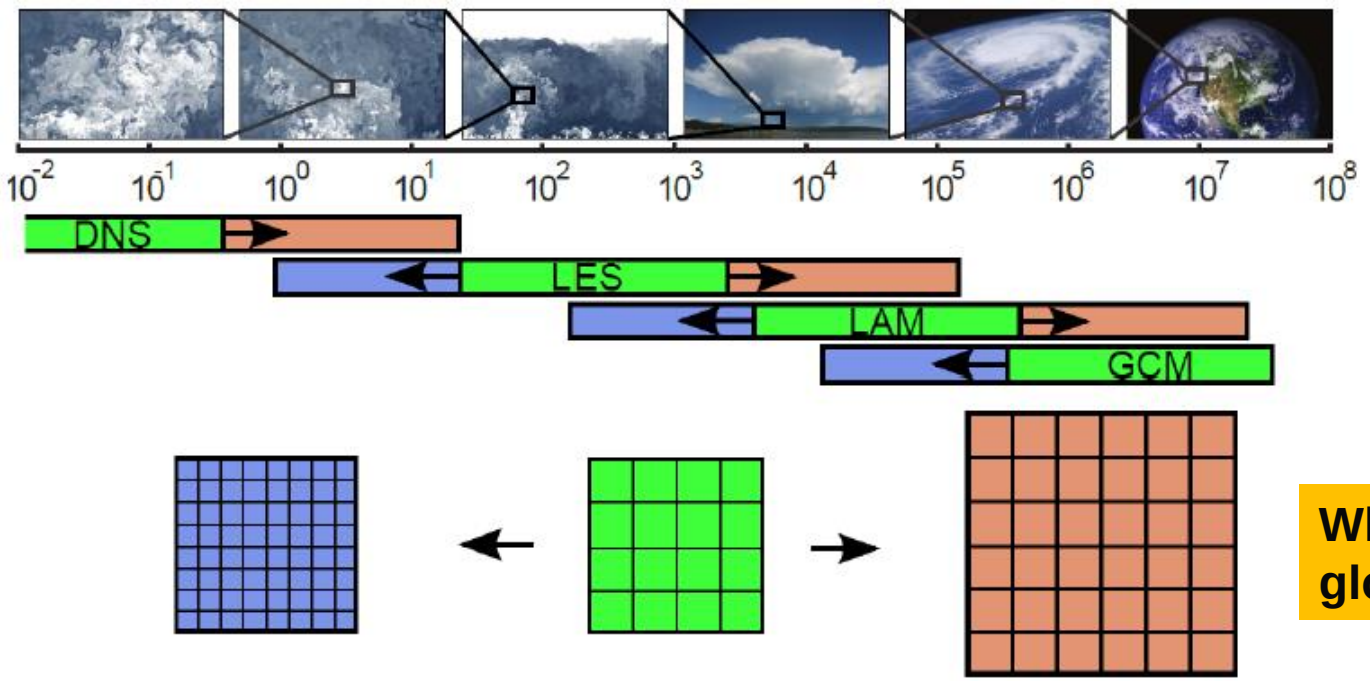
Towards seamless prediction

- With expected increase in computing power, the next 10 years will see global operational modelling systems for weather and climate using grid lengths from few km to ~100km



- For forseeable future weather and climate models will continue to use grid lengths where convection needs to be fully or partially parametrised

'The Grey Zone' (3km – 10km)



Where next for global models?

- Increasing model resolutions
- Operational models are in or approaching 'the Grey Zone'
- We do not know how to parametrise clouds, turbulence, convection processes in 'the Grey Zone'
- Yet it is these processes that are key for weather and climate

J. Petch: GEWEX Global Atmospheric System Studies

Towards Seamless Prediction

- Convection permitting models typically do not include deep convection
- However they often have similar physical parametrisations to global models for turbulence, shallow convection, micro-physics, radiation and surface processes
  - ➢ Physical processes operating at these scales are mostly the same
- This strongly supports the concept of seamless prediction of weather and climate which consist of developing models that can be used in a more or less continuous way over a wide range of spatial and temporal scales (Brown et al.)

Seamless prediction: definition
Jon Petch

- A consistent approach to tackle a range of problems using a modelling system with **traceable** differences
  - **Traceable** = deliberate and justifiable differences given the problem being addressed
- Seamless across **forecasting lead time** (days to centuries)
- Seamless across **spatial scales** – convective scale (regional/local) to coarser global scales

Seamless Prediction: Advantages

Efficient use of resources – need to support only one model
Enables identification and resolution (?) of systematic errors

ACCESS1.3 N96L38

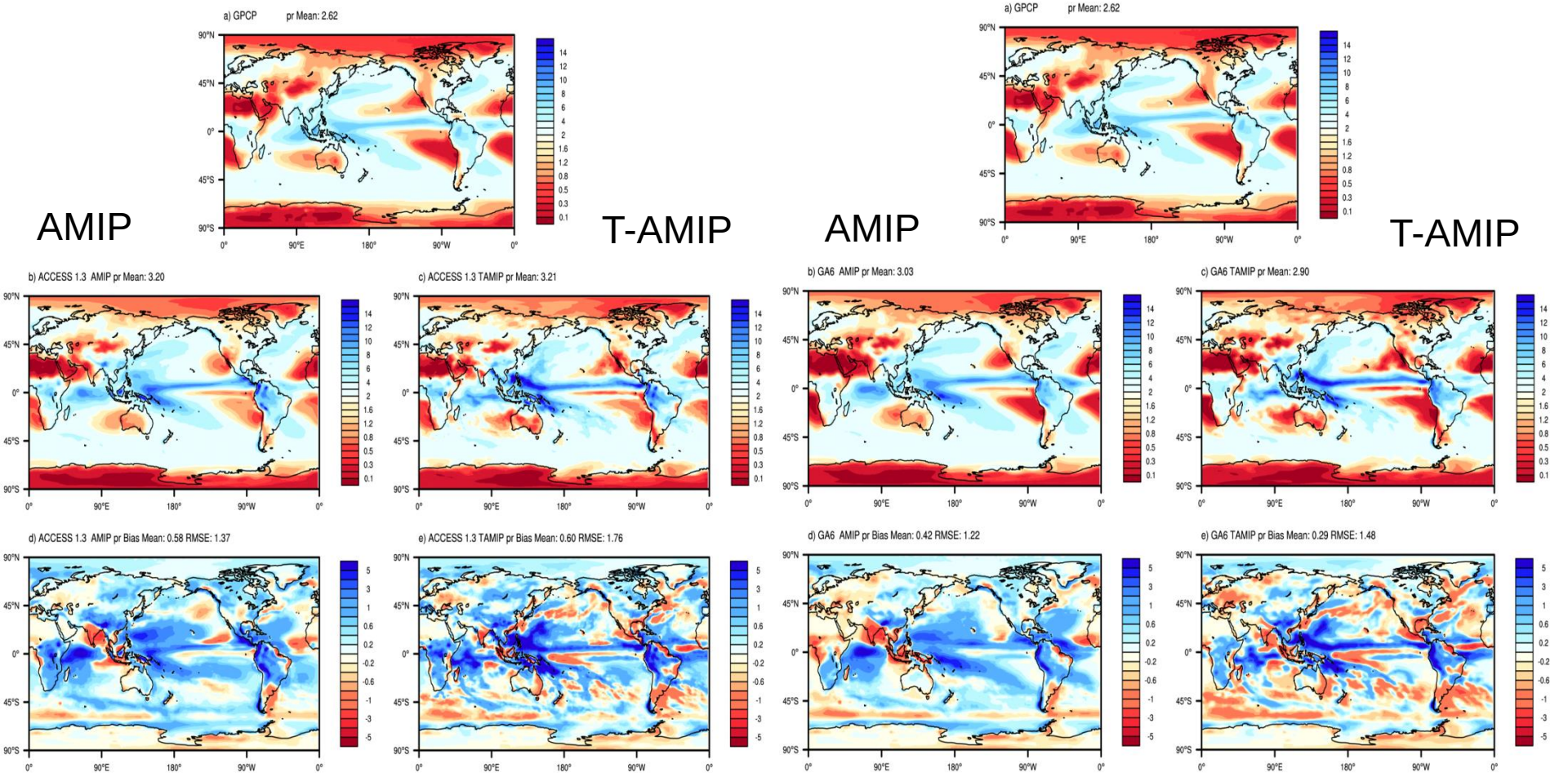
GA6N96L85

AMIP

T-AMIP

AMIP

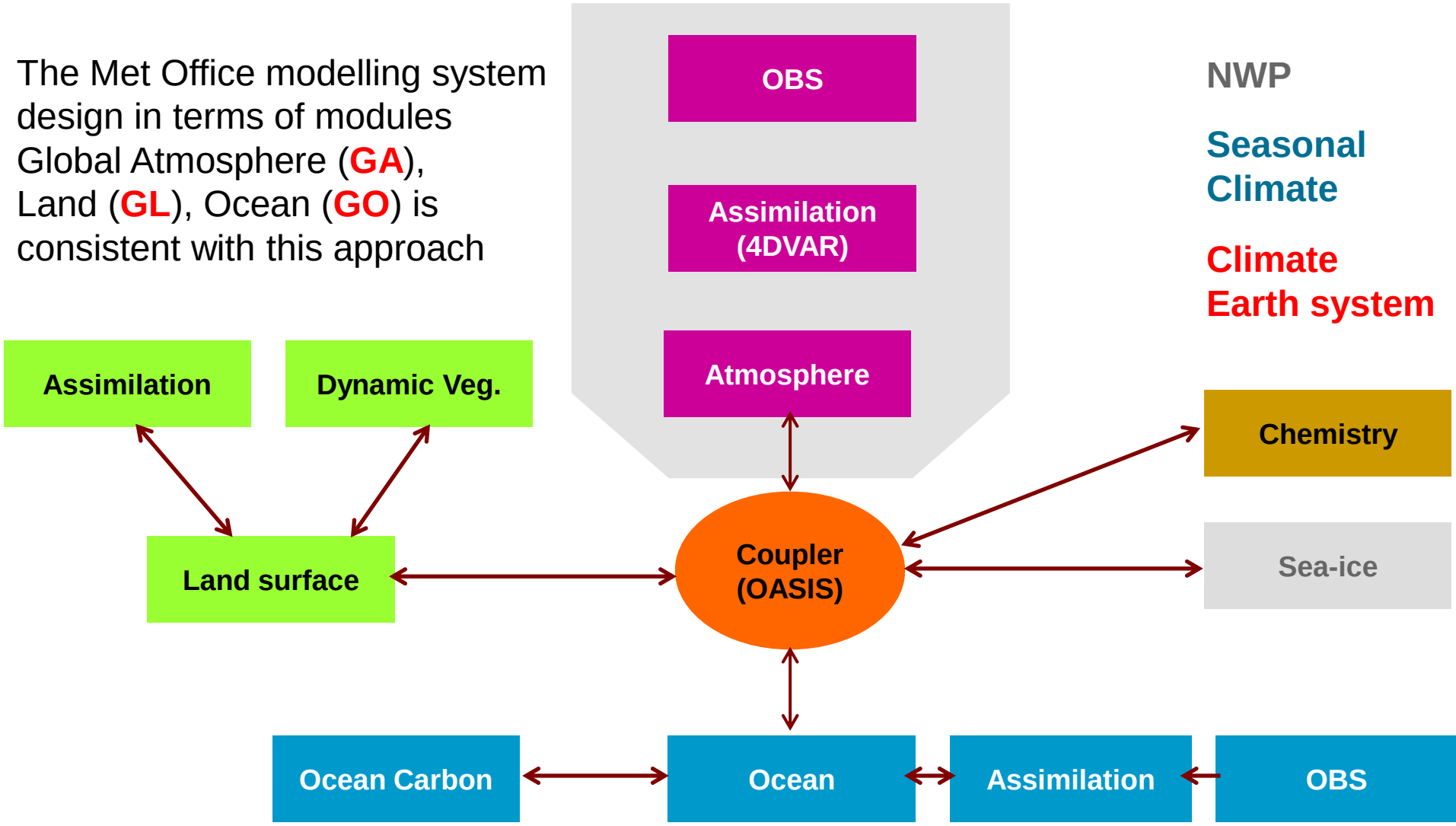
T-AMIP



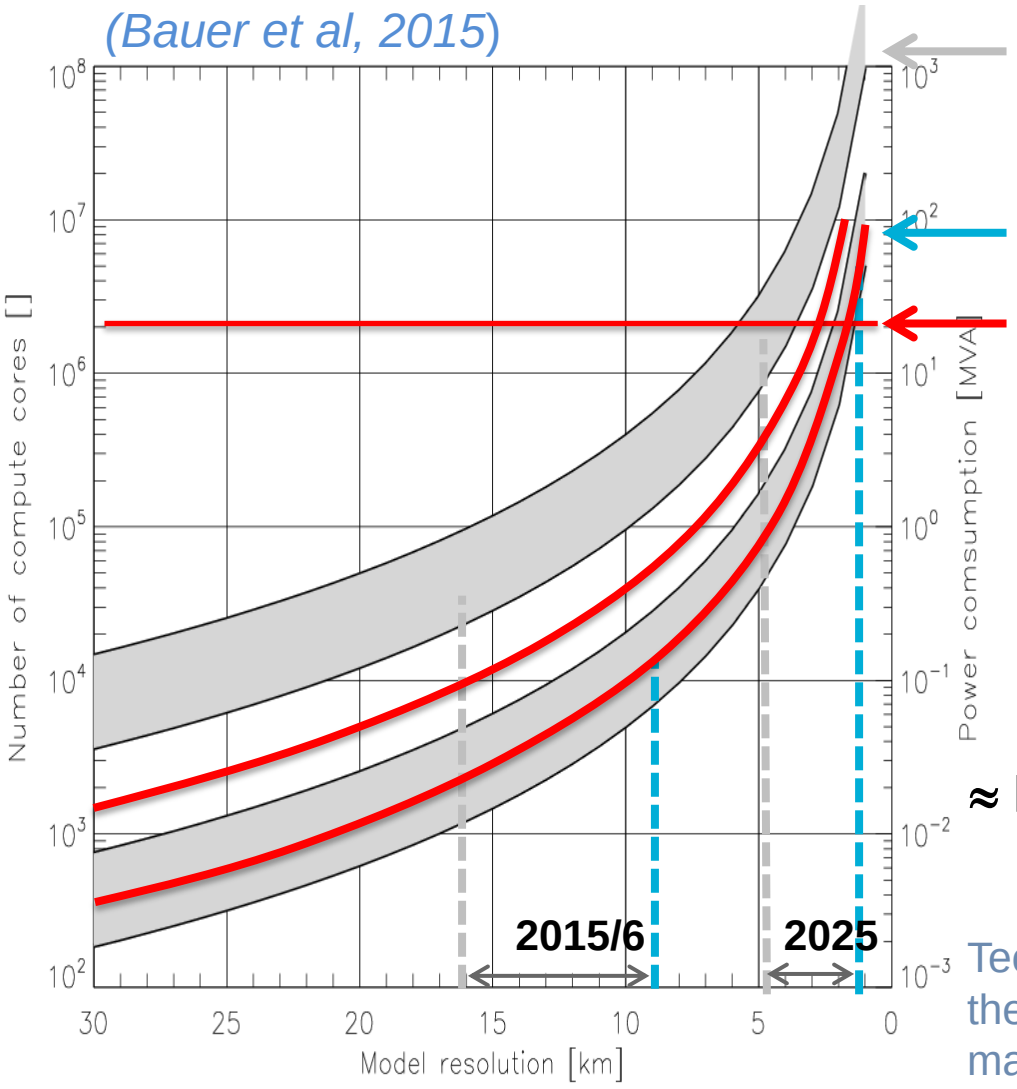
Greg Roff

Seamless Prediction: Possible design

The Met Office modelling system design in terms of modules Global Atmosphere (**GA**), Land (**GL**), Ocean (**GO**) is consistent with this approach



Affordability – the art and cost of computing



50 member ensemble

1 member

Hard limit for entire HPC ~20MW ?

ECMWF have run their global spectral model at **T_L7999 > ~2.5km!**

≈ M€ electricity/year

Technology advances may move the energy scale by one order of magnitude, so we need to be ready! *(Aurora 180PF, HPCwire April 2015)*

Seamless Prediction
Some requirements

- Future seamless modelling systems will place severe constraints on dynamics and physics

Dynamics

- Must operate over scales ranging from 100s of kilometres to 100s of metres

Staniforth & Thuburn (2012) identified ten "*Essential and desirable properties of a dynamical core*":

1. Mass conservation
2. Accurate representation of balanced flow and adjustment
3. Computational modes should be absent or well controlled
4. Geopotential gradient and pressure gradient should produce no unphysical source of vorticity

$$\nabla\times(\nabla p) = 0$$

Nigel Wood

Seamless Prediction
Some requirements: Dynamics

5. Terms involving the pressure should be energy conserving

$$\mathbf{u}\cdot\nabla p + p\nabla\cdot\mathbf{u} = \nabla\cdot(\mathbf{u}p)$$

6. Coriolis terms should be energy conserving

$$\mathbf{u}\cdot(\boldsymbol{\Omega}\times\mathbf{u}) = 0$$

7. There should be no spurious fast propagation of Rossby modes; geostrophic balance should not spontaneously break down
8. Axial angular momentum should be conserved
9. Accuracy approaching second order
10. Minimal grid imprinting

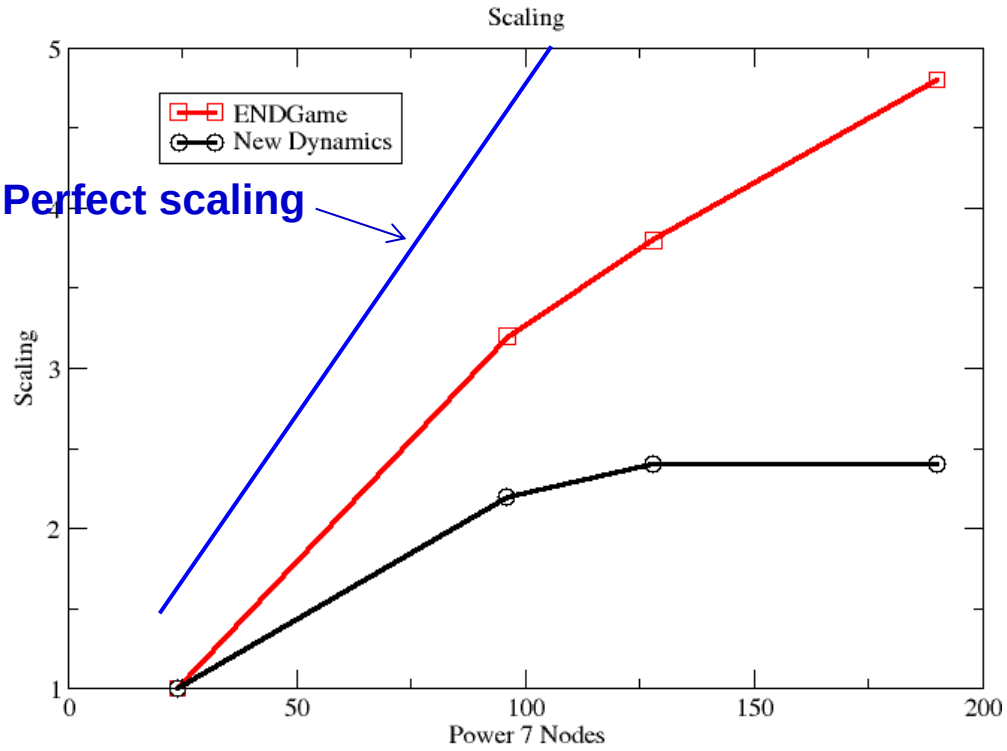
Nigel Wood

Seamless Prediction
Some requirements: Dynamics

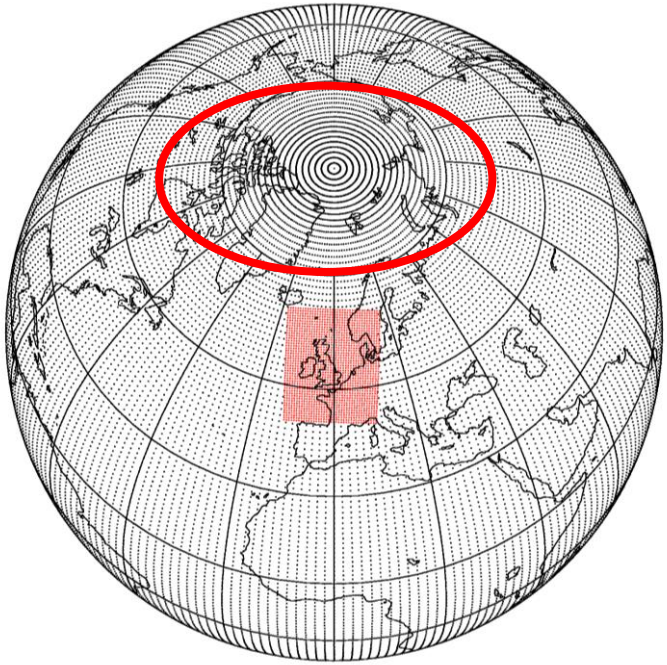
- Additionally
  - Exact conservation of moisture and tracers
  - Accurate transport of moisture and tracers
  - Temporal discretisation
  - The vertical coordinate and discretisation
  - Physics-dynamics coupling (more below)

Scalibility

(17km) N768 - New Dynamics vs ENDGame



The finger of blame…

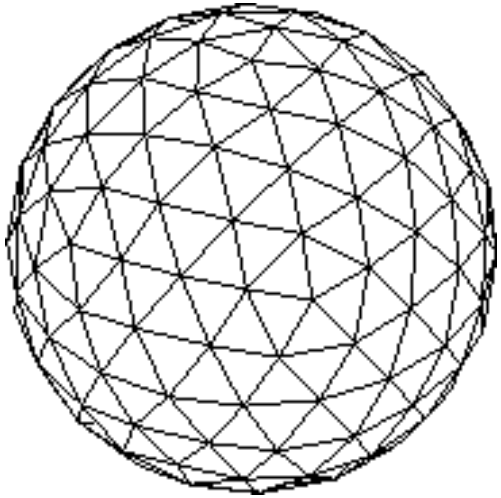


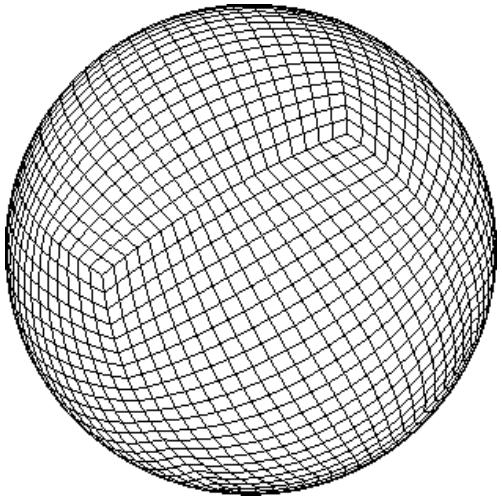
- At 25km resolution, grid spacing near poles = 75m
- At 10km reduces to 12m!

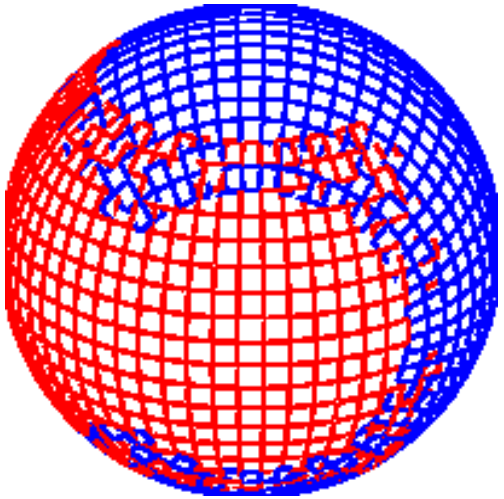
Nigel Wood, Met Office

A new grid?

- Scalability – remove the poles!



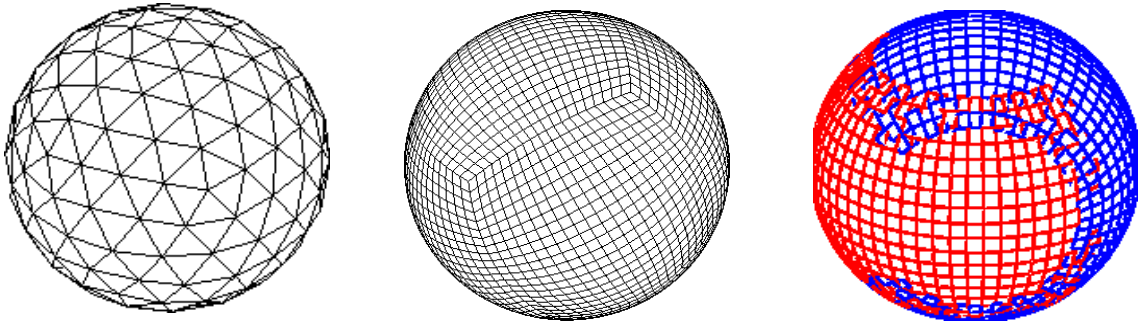




GungHo!

Globally
Uniform
Next
Generation
Highly
Optimized

工合



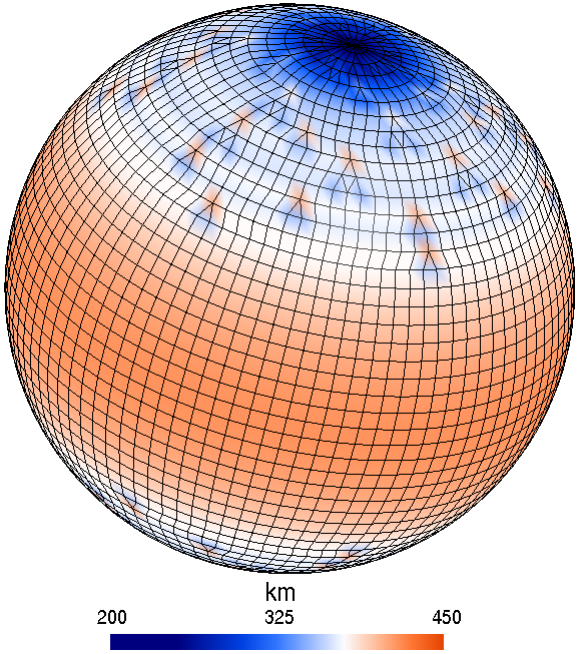
NATURAL ENVIRONMENT RESEARCH COUNCIL

Science & Technology Facilities Council

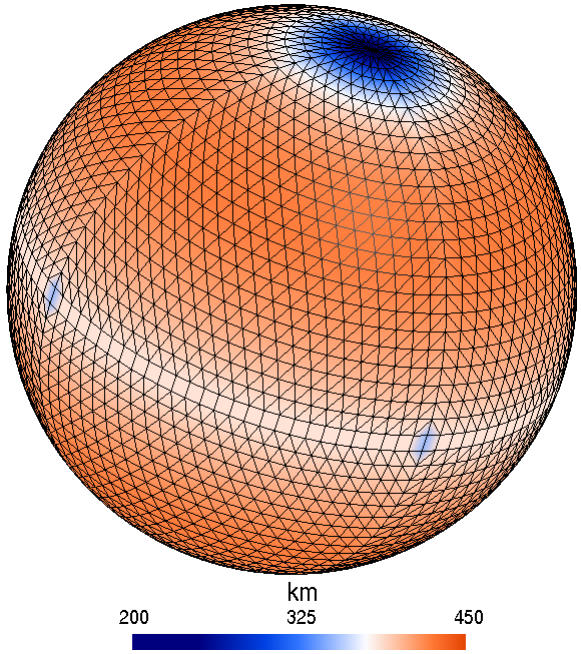
"Working together harmoniously"

Nigel Wood, Met Office

Dual mesh resolution



Reduced Gaussian grid



Octahedral Gaussian grid

Equal area parallel decomposition at TCo1279

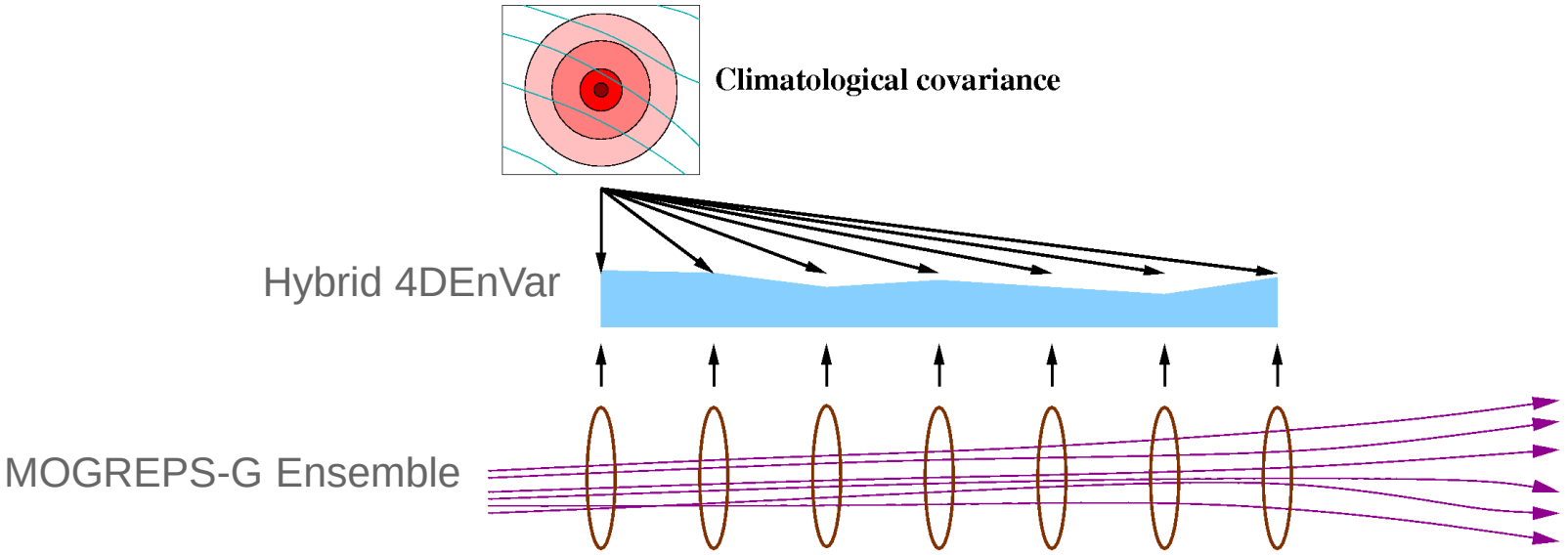
Next ECMWF model upgrade to 9km (imminent)

Seamless Prediction
Some requirements

Physics

1. Independent of horizontal resolution
2. Semi-independent of ES components
3. Treatment in the 'Grey zone'
4. Introducing stochasticity in physics parametrisations
5. Adequate treatment of physics/dynamics coupling in convection-permitting models
   - Explicit convection results from complex feedback between buoyancy (dynamics) and condensation/evaporation (physics) (Brown et al.)

4DVar > Hybrid 4DVar > 4DEnVar
Met Office plans



No PF model – more appropriate DA for coupled ESM and LFRic?

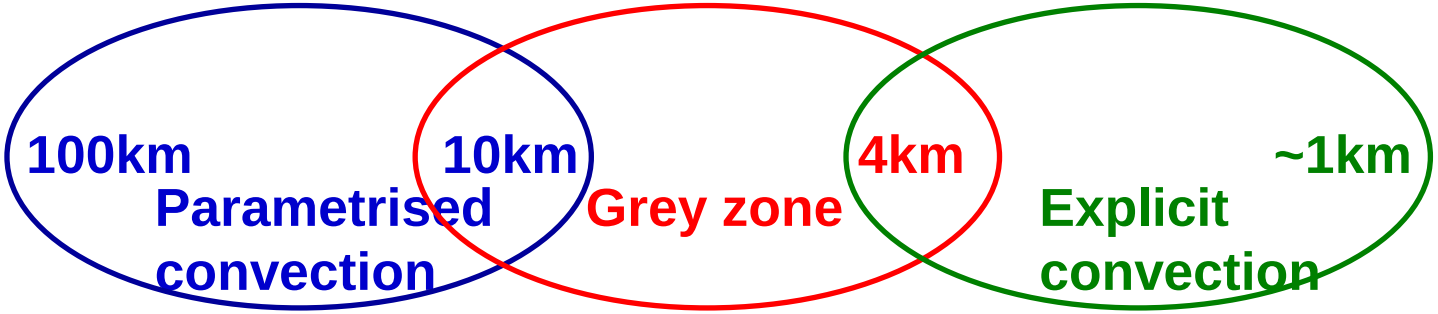
4DEnVar ~1/11 cost of 4DVar for fixed M – afford higher res/more members.

I/O and memory challenges.

DA for convection-permitting models?
DA for coupled models?
Data for convection-permitting models?

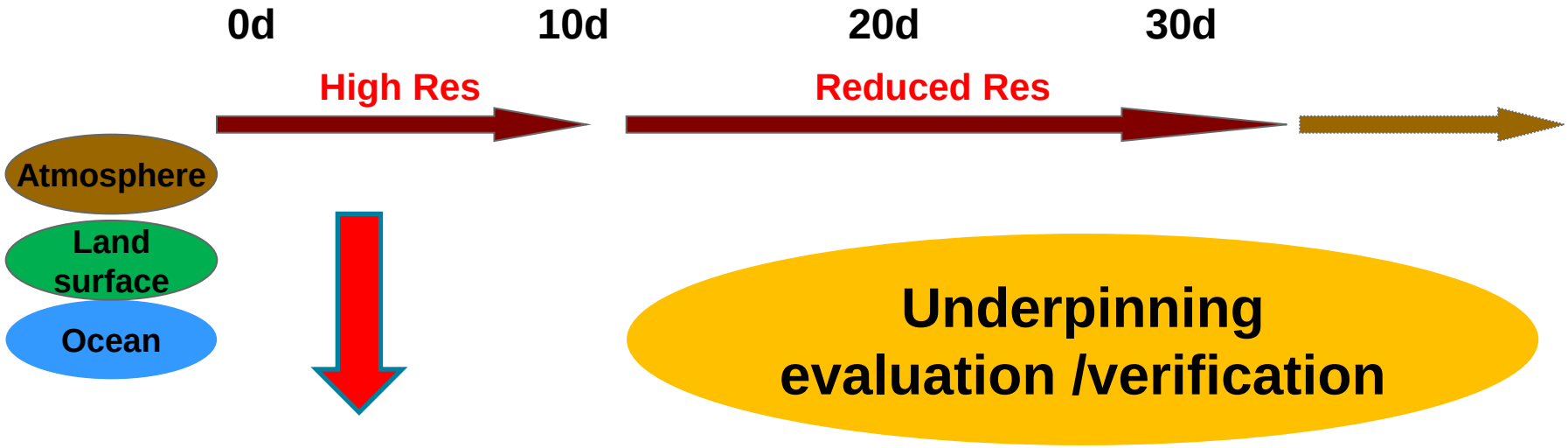
Dale Barker, Met Office

Towards seamless prediction
Additional considerations

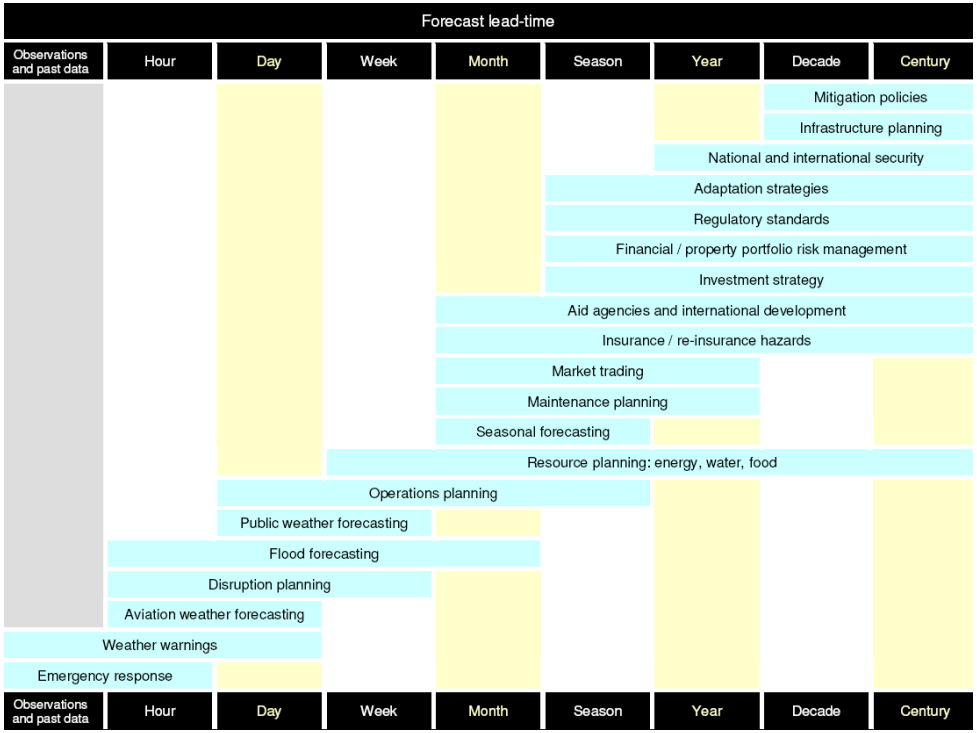


- We do not know how to parametrise clouds, turbulence, convection processes in 'the Grey Zone'
- So where next for global beyond horizontal resolutions of ~10km
  - Greater emphasis on ensemble prediction?
  - End of distinction between deterministic and ensemble prediction?

Seamless Prediction



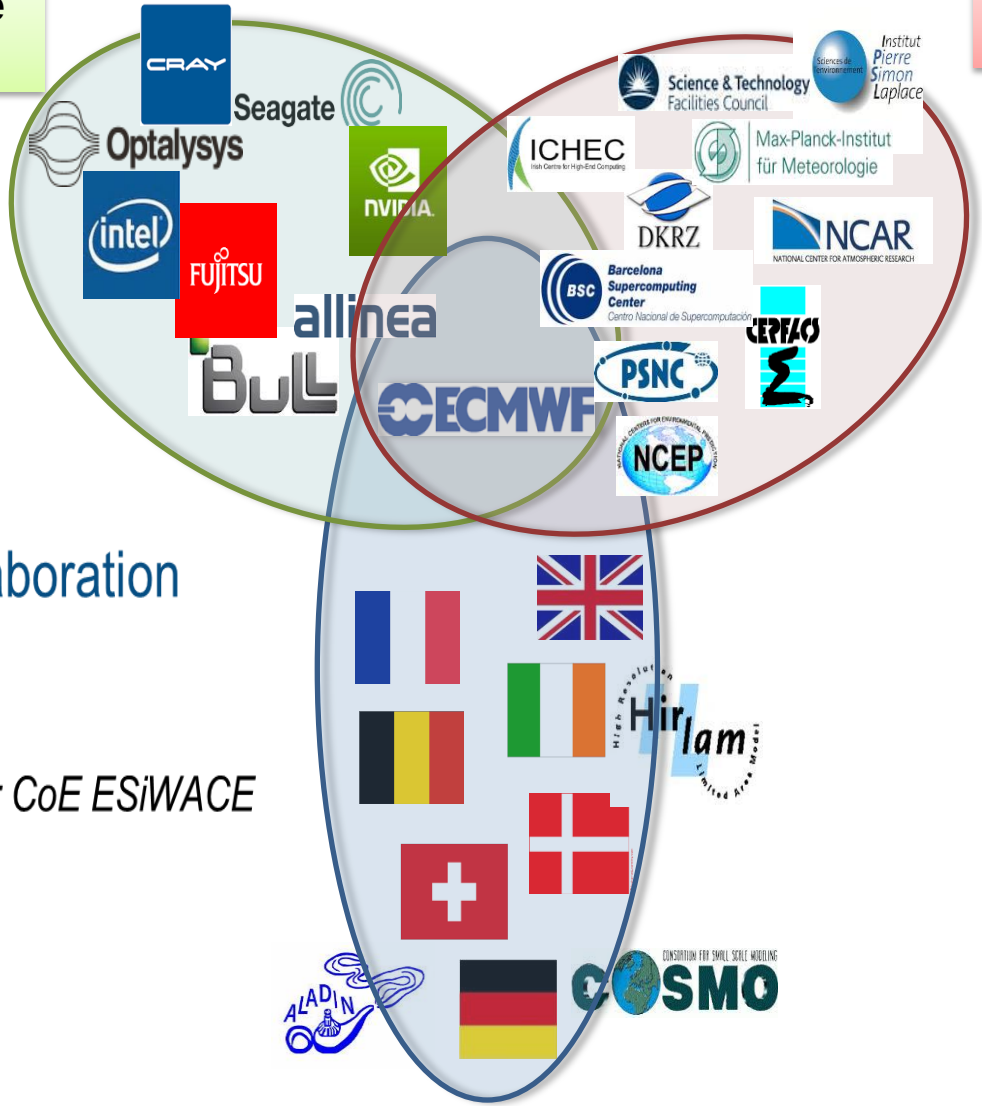
Seamless Services



Scalability Programme needs Partnership

Hardware vendors

International Community



International collaboration

Horizon 2020

ESCAPE; NextGen-IO; CoE ESiWACE

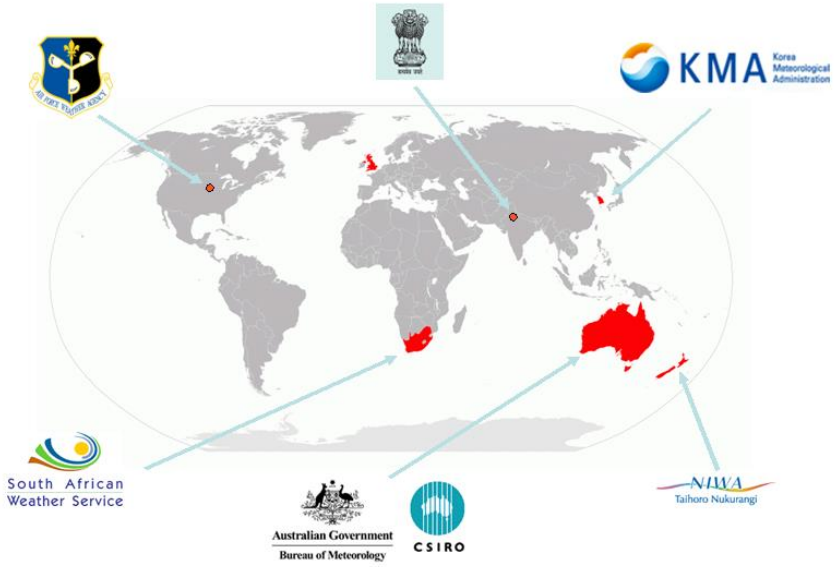
European Commission

ECMWF Member States

Nils Wedi

UM partnerships form the foundation of our relationships with other institutions enabling joint work across all areas of our met services

- forecasting
- science and model development
- jointly growing our businesses



Share science, model evaluation and technical developments:

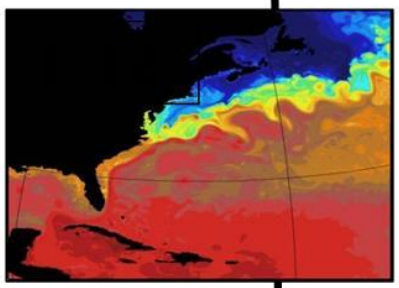
- Joint process evaluation groups
- User workshops
- User tutorials
- Technical infrastructure teams

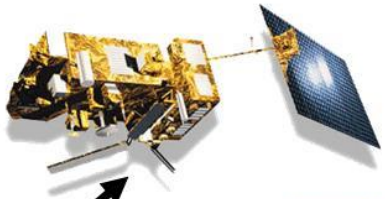
Operational users are complimented by:

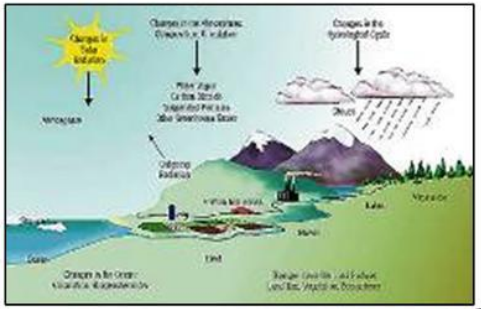
- various research partners in national and international universities and institutions.
- various capacity development and consultancy projects with other partners

Improving forecast skill and use

Met Office







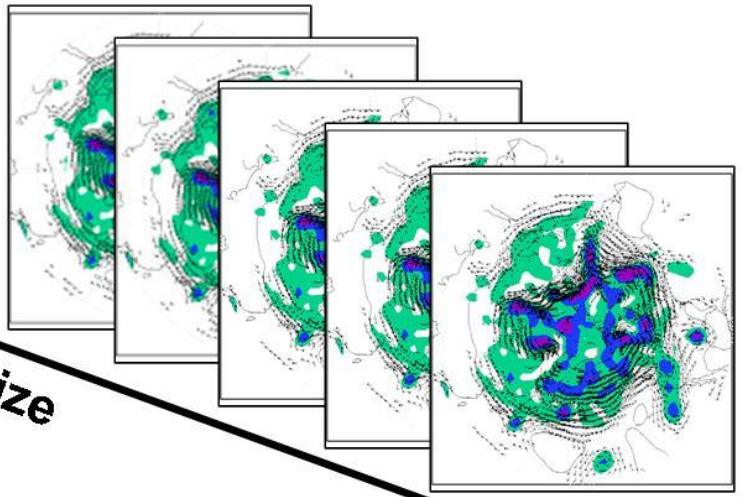
Earth Observation

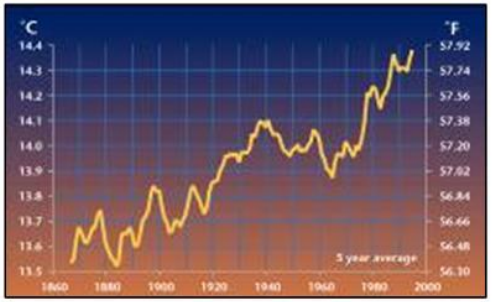
Resolution

Computing Resources

Complexity

Duration and/or Ensemble size

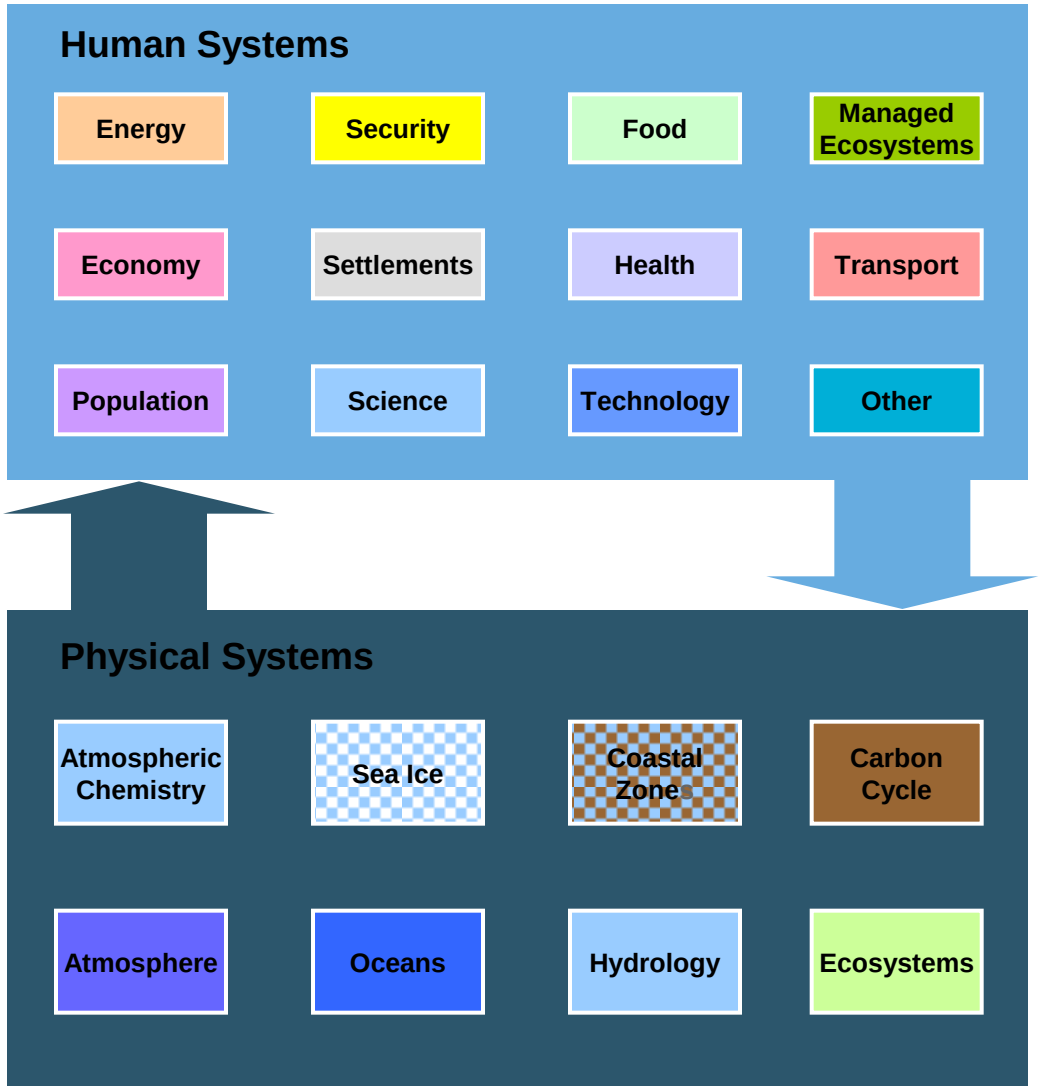




Dale Barker, Met Office

Beyond physical models

Integrated Assessment Model



Exciting times lie ahead!

Australian Government
Bureau of Meteorology

Thank you…

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