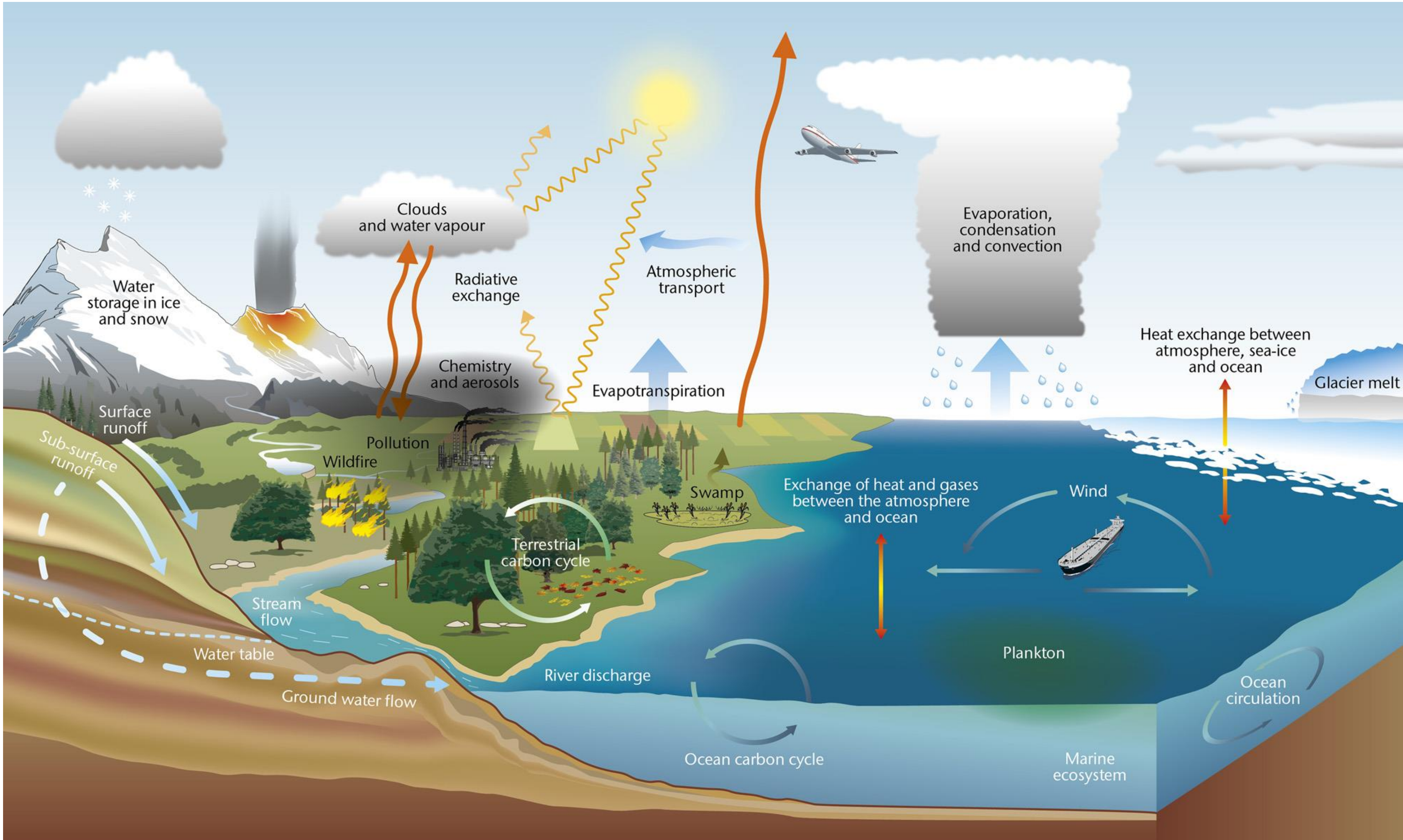
# Do we need an Earth-system model for 1-day to 1-year weather prediction?

Andy Brown

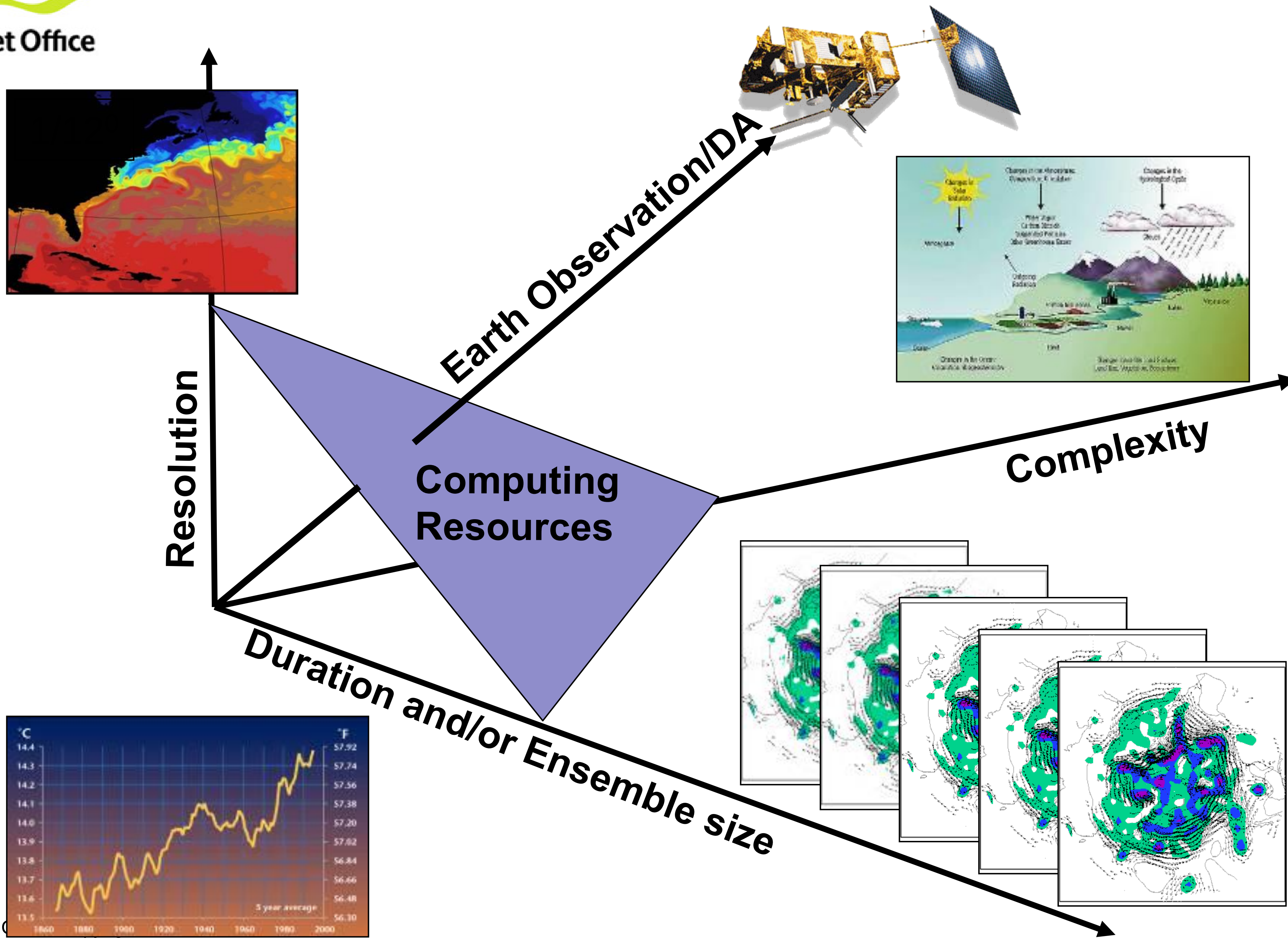
Director of Science, Met Office

Met Office

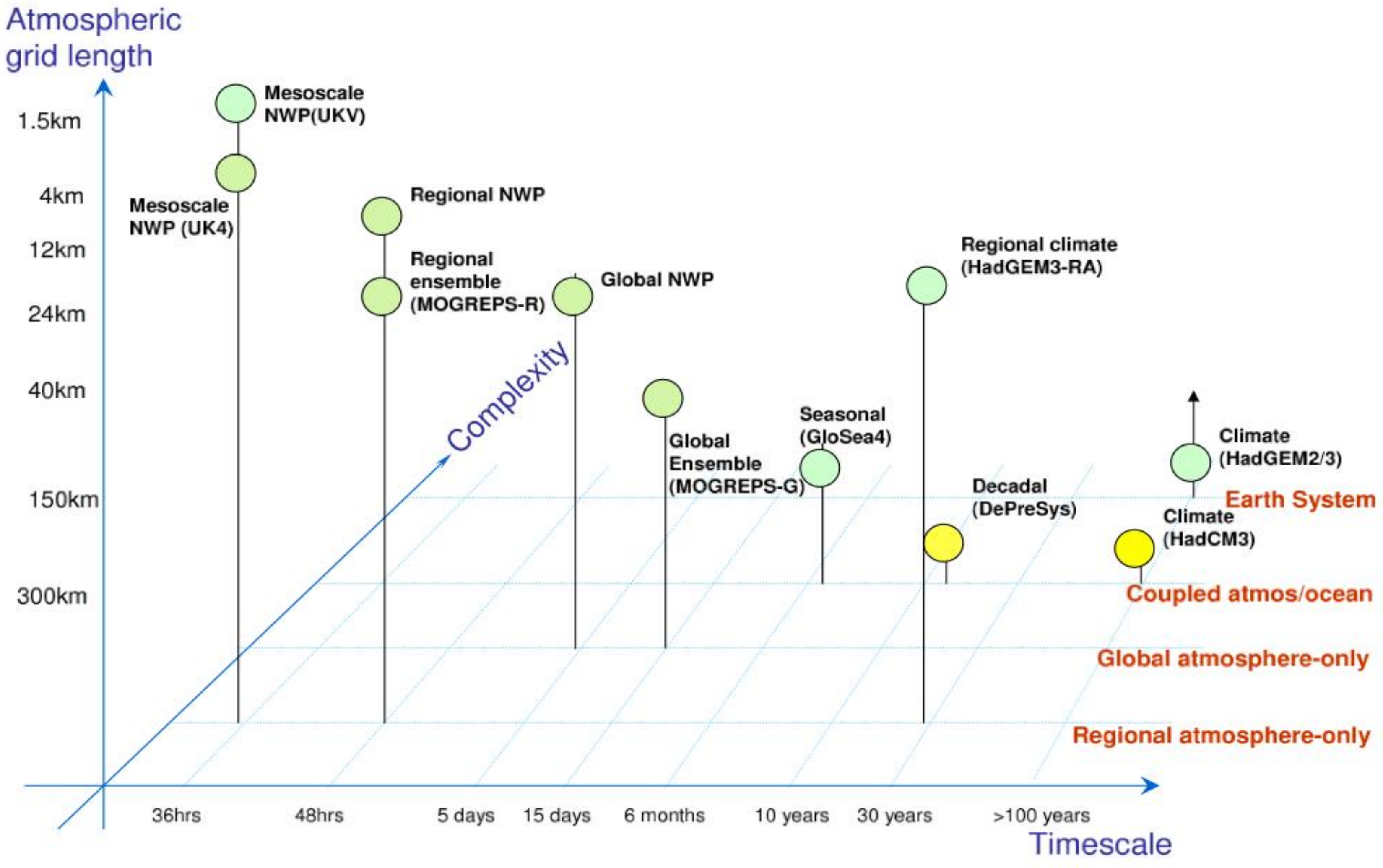


Clouds and water vapour
Radiative exchange
Atmospheric transport
Evaporation, condensation and convection
Water storage in ice and snow
Chemistry and aerosols
Evapotranspiration
Heat exchange between atmosphere, sea-ice and ocean
Glacier melt
Surface runoff
Sub-surface runoff
Pollution
Wildfire
Swamp
Exchange of heat and gases between the atmosphere and ocean
Wind
Terrestrial carbon cycle
Stream flow
Water table
Ground water flow
River discharge
Plankton
Ocean circulation
Ocean carbon cycle
Marine ecosystem

# Improving forecast skill and use

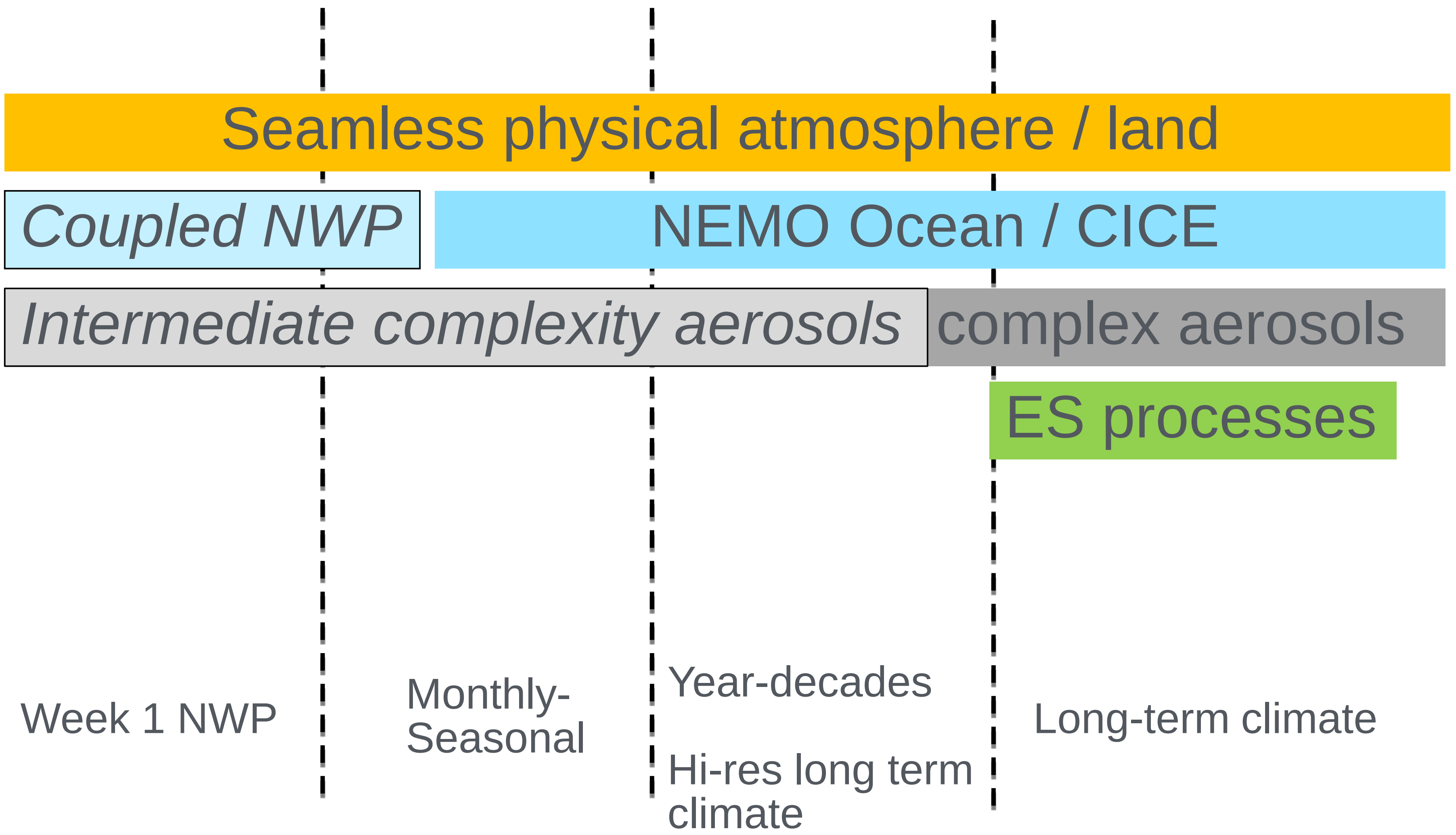


# Prediction Timescale vs. Resolution vs. Complexity




from Brown et al, BAMS, 2012

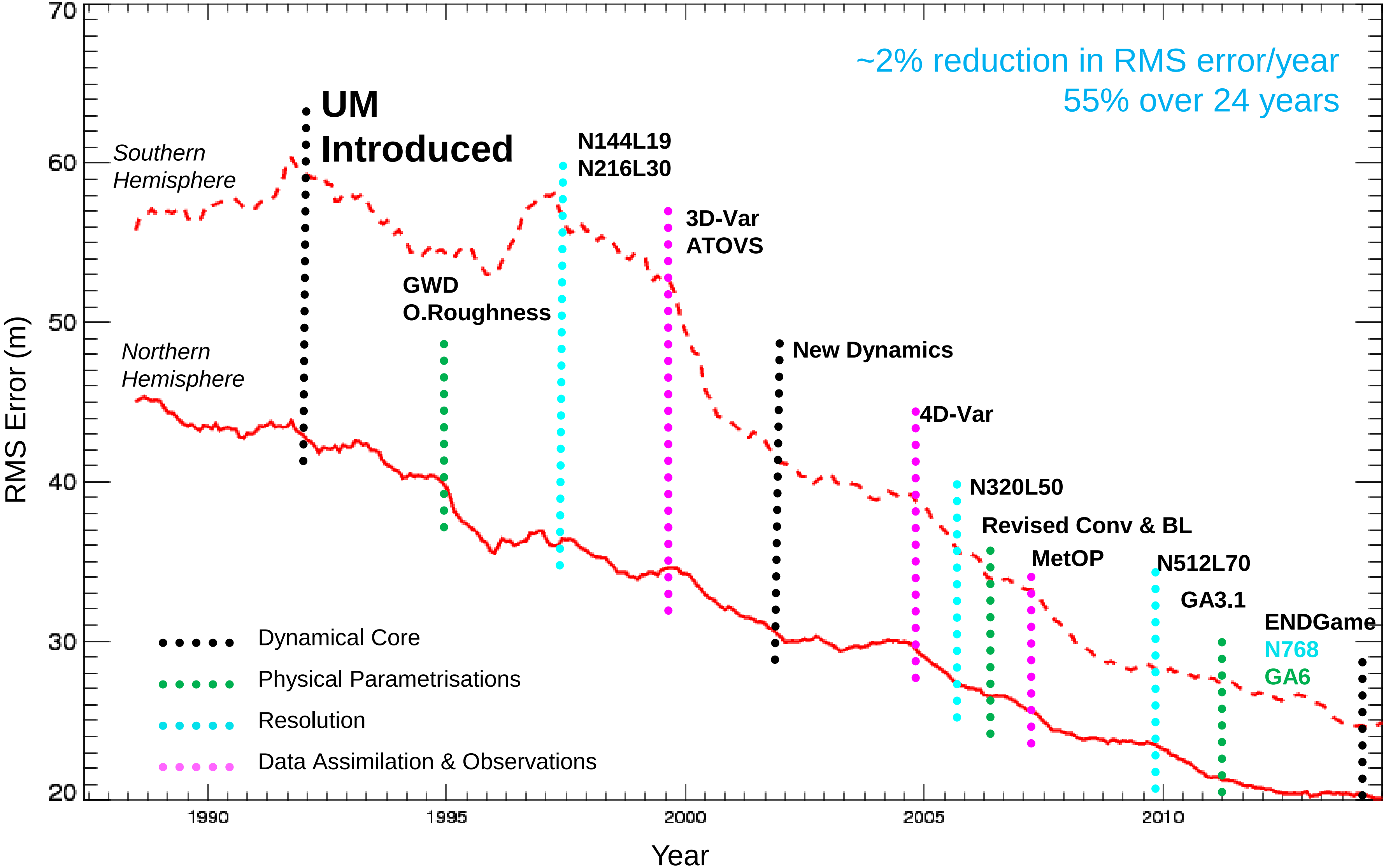
# Summary of Met Office global configurations



# Improving Global NWP Forecasts

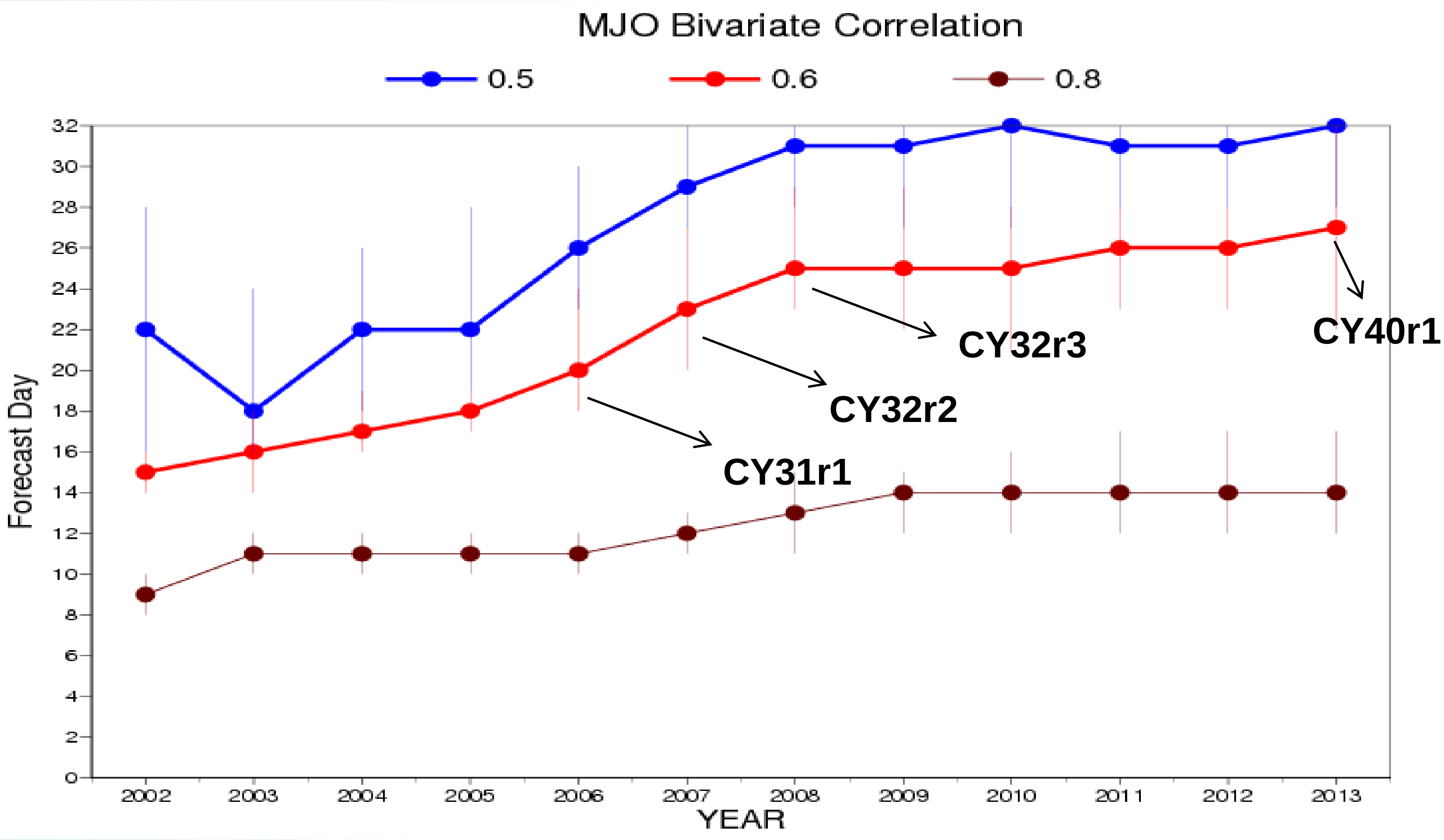
## 500hPa Height Day 3 RMS Error vs. Analyses

12 Month running Average



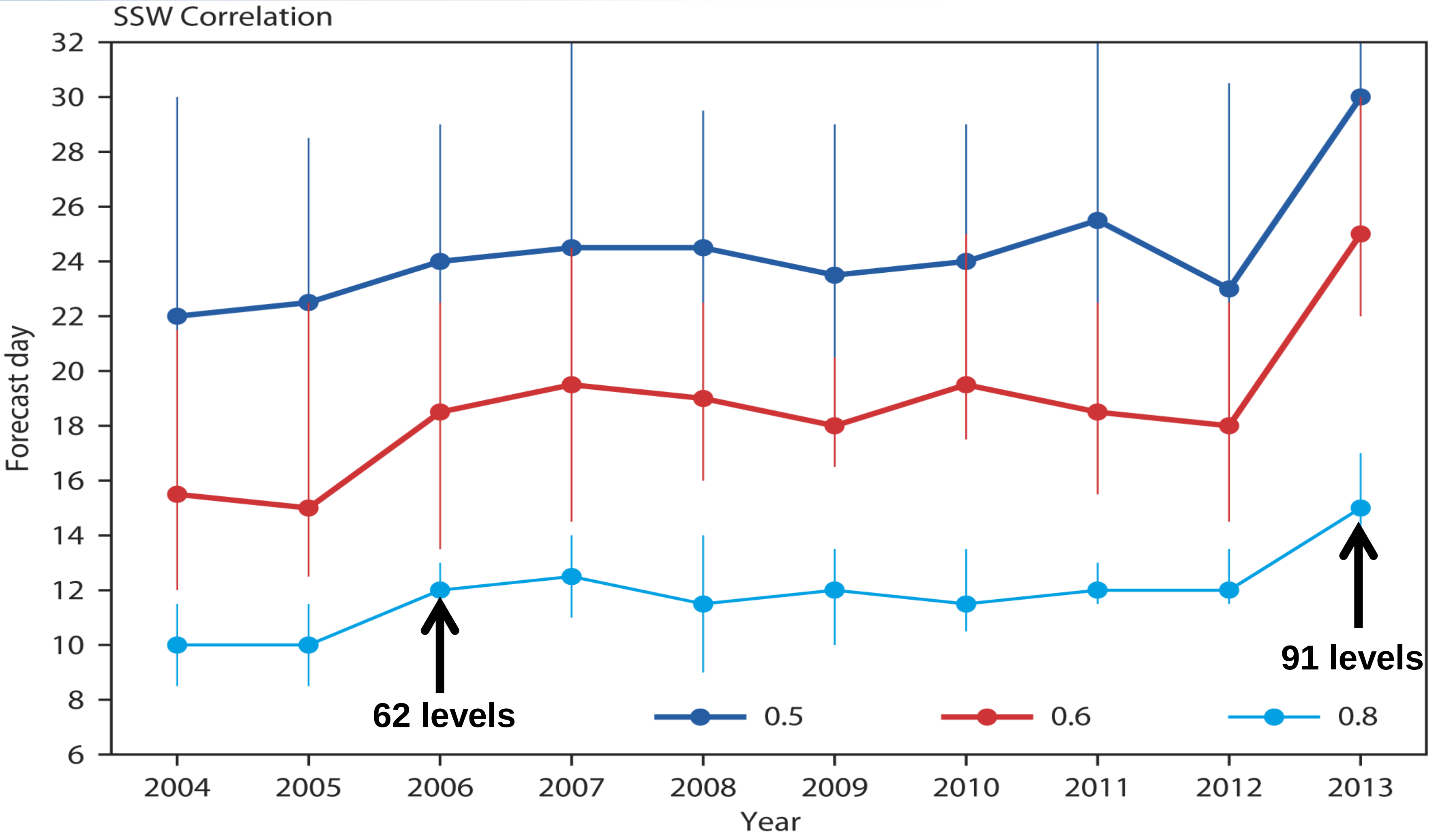
# Madden Julian Oscillation

Wheeler and Hendon (2003) Index




**CY31R1: Parameterisation of ice supersaturation**
**CY32R2: McRAD (radiation scheme)**
**CY32R3: Changes in convective scheme (Bechtold at al. 2008)**
**CY40R1: Improved diurnal cycle of precipitation …**

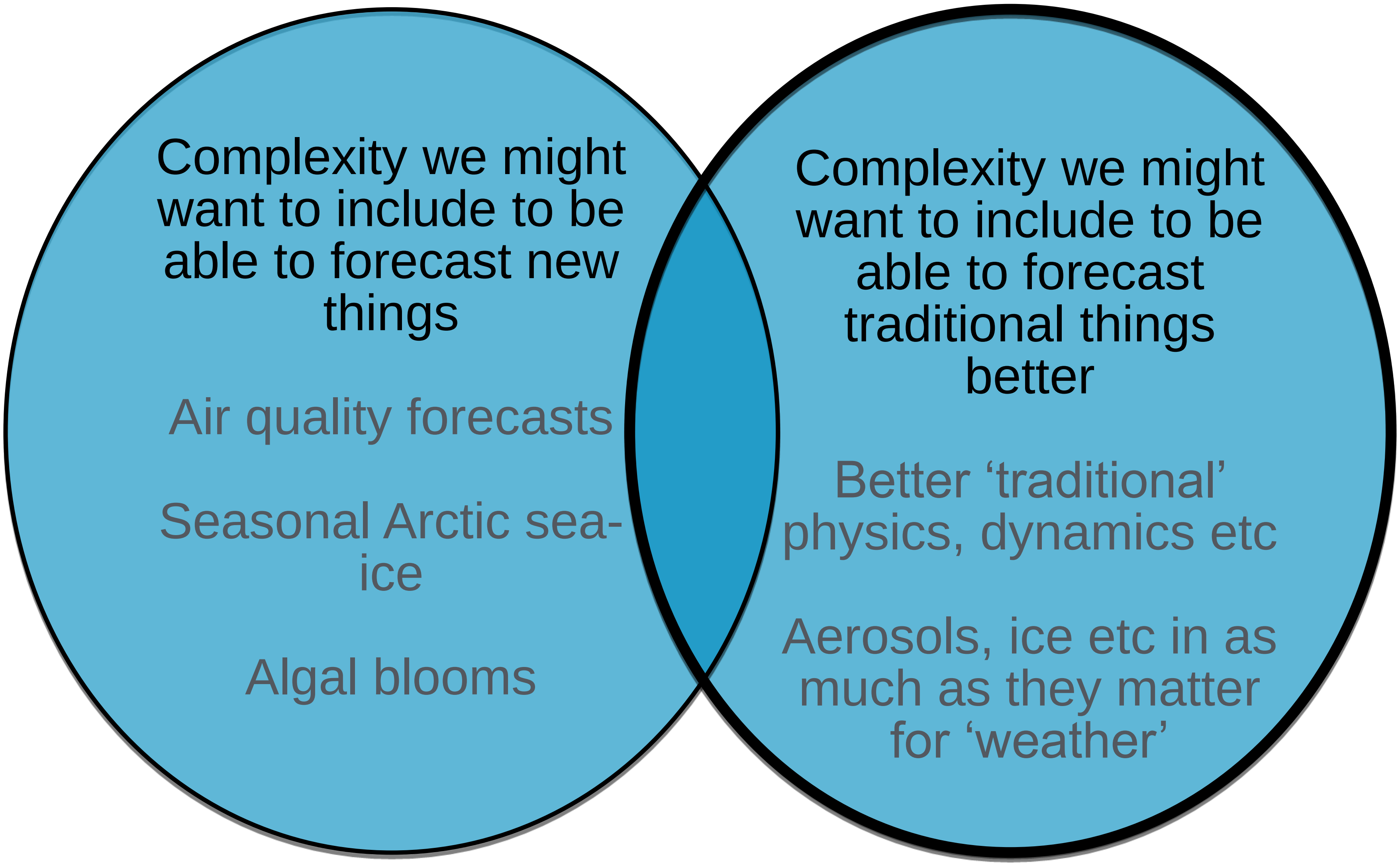
# Sudden Stratospheric Warming




*SSW index: Difference of temperature at 50hPa between 90N and 60N averaged over all the longitudes*

# How to move forwards?

# General considerations for inclusion of new processes or more complexity



# Considerations in implementing a new scheme

1. Does it give benefit?
   - Necessary (probably)
   - Not sufficient (definitely)

2. Do we really understand where benefit comes from? Is any additional complexity truly better representing reality (or are we misleading ourselves)?

# Understanding where benefit comes from

- Evaluation at detailed process level

- As implemented, is a scheme even doing what we think it is?
  - Numerical issues within scheme (limiters; vertical advection)
  - Are all aspects important or, even when we are using a full complex scheme, are simpler aspects actually dominant?
    - *Cloud fraction (Teixeira, MWR, 2000)*
    - *Strength of turbulent mixing (atmosphere and ocean)*

- Interactions with other parts of models and balancing of complexity
  - How much are we (consciously or subconsciously) compensating for / tuning against errors in other parts of the model (e.g. sea ice cf arctic cloud; detailed microphysics cf Semi-Lagrangian conservation issues)?
  - What does this mean for optimal choices of complexity of individual schemes?

# Considerations in implementing a new scheme

1. Does it give benefit?
   - Necessary (probably)
   - Not sufficient (definitely)

2. Do we really understand where benefit comes from? Is any additional complexity truly better representing reality (or are we misleading ourselves)?

3. What is incremental cost in widest sense - HPC, people, system maintenance overhead, DA issues, trialling or operational scheduling complications?
   - Note potential for negative effective cost if better leverages other timescale effort or wider community effort

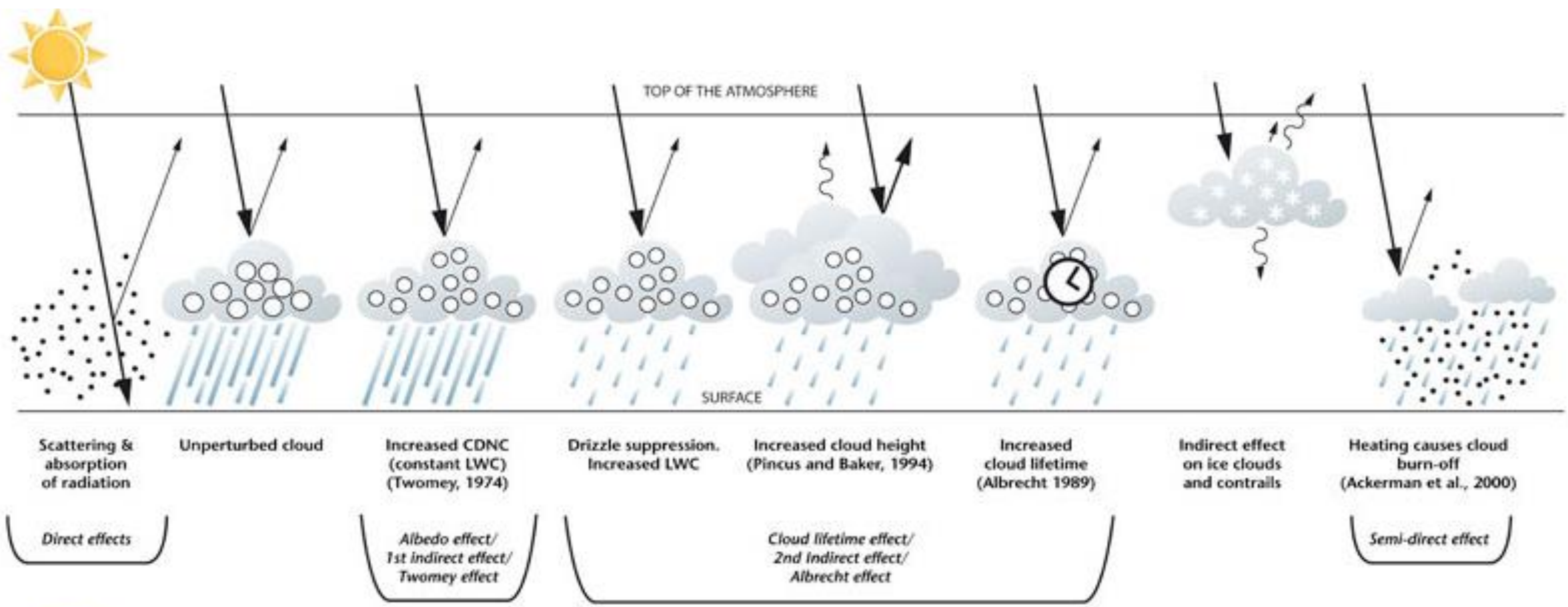
4. **How does overall cost-benefit look cf other options (opportunity cost)?**

# Example case study: aerosols

# Impact of aerosol complexity

*Jane Mulcahy*

- Direct & indirect aerosol effects:

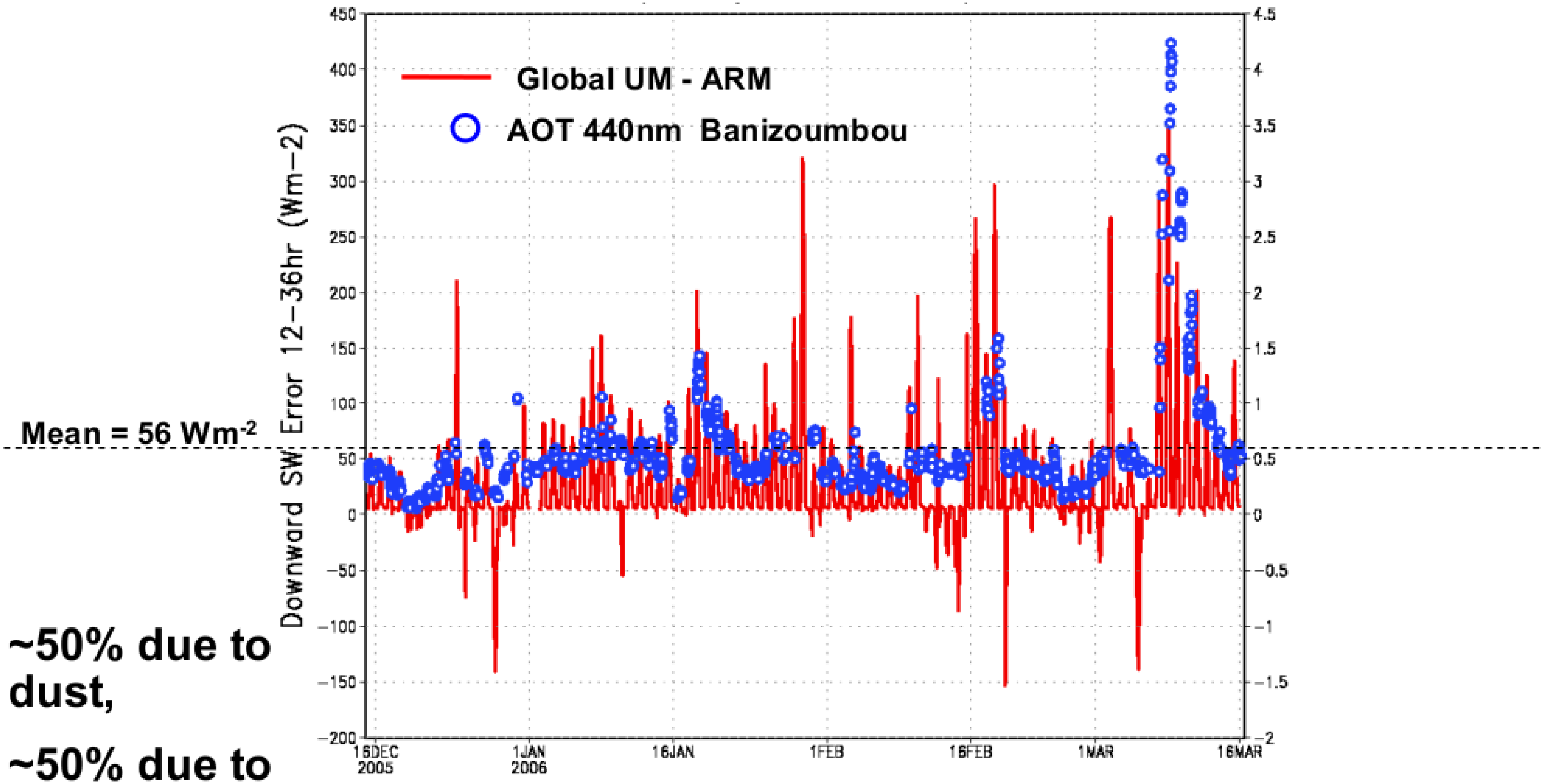



*Adapted from Haywood & Boucher (2000)*

Pre-2007: NWP models assume fixed values for land/sea
2007-2014: Direct effect only uses 3D climatologies

# Why go from monthly mean climatologies to prognostic aerosols?

The aerosol optical depth and global NWP model bias in surface SW radiation in W Africa




**~50% due to dust,**

**~50% due to smoke**

**Milton et al (2008)**

# Impact of aerosol complexity

## Experimental design

*Mulcahy et al, ACP, 2014*

Experiments run between 2009 and 2011:

- Test the impact of full prognostic (CLASSIC) aerosol scheme in operational-like NWP model
- N320 (~40km) forecasts using 4D-Var DA

**Operational aerosols (used from 2007-2014):**

- Direct effect used 3D speciated time-varying climatologies
- Indirect effects used simple land/sea split:
  - Potential CDNC (land) = 300cm$^{-3}$
  - Potential CDNC (sea)  = 100cm$^{-3}$

# Impact of aerosol complexity

## Experimental design

*Mulcahy et al (2014)*

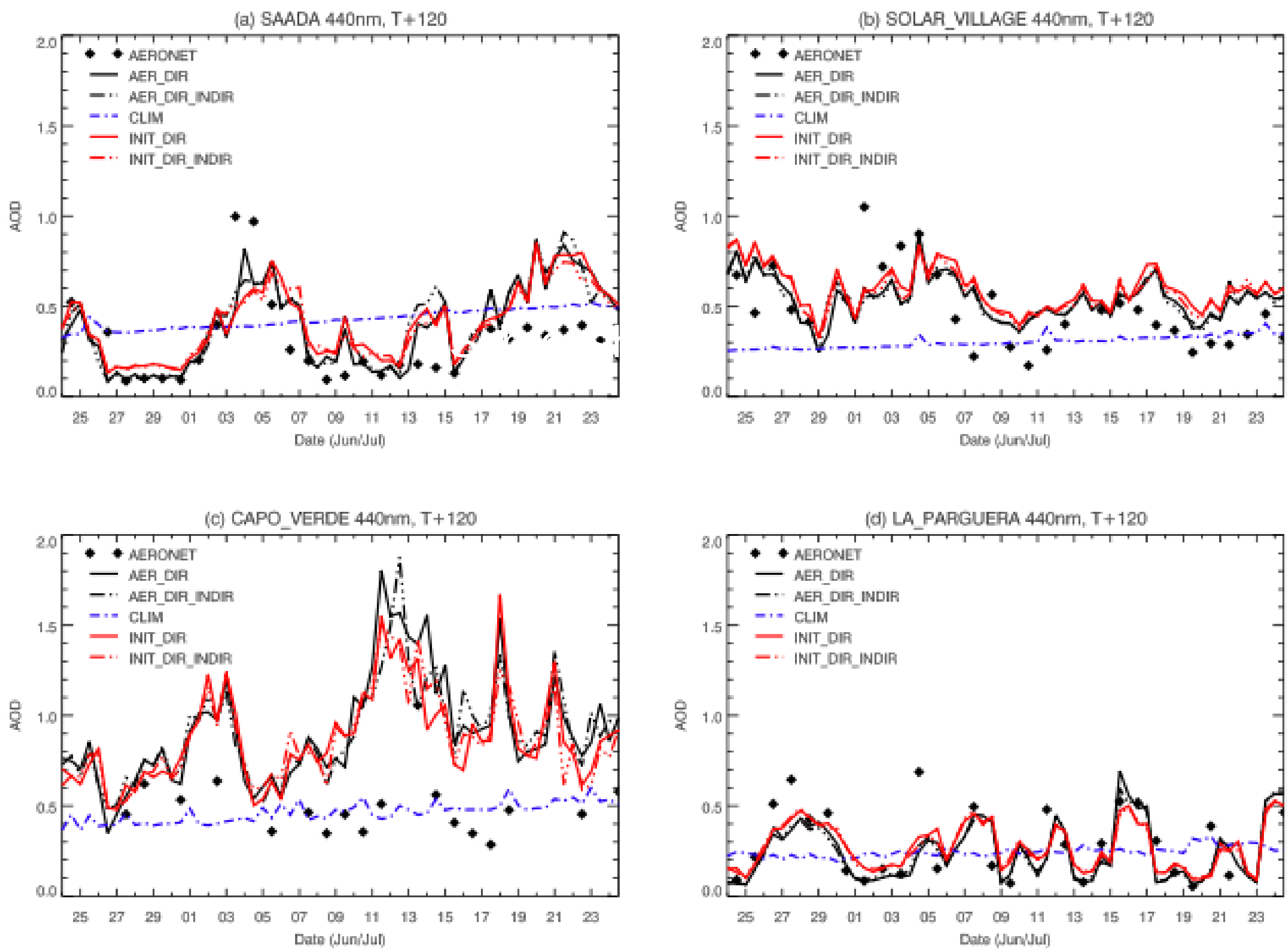
**Tests (heirachy approach):**

| Direct Effect | Indirect effects | Aerosol init. |
|---|---|---|
| Cusack (1998) | Land/sea split (*as op)* | N/A |
| CLASSIC clims (*op*) | Land/sea split (*op*) | N/A |
| Prognostic CLASSIC | Land/sea split (*as op)* | Spun up/run free |
| Prognostic CLASSIC | Prognostic CLASSIC | Spun up/run free |
| Prognostic CLASSIC | Prognostic CLASSIC | Initialised from MACC |

# Impact of aerosol complexity

## Shows good aerosol simulations (dusty AOD)

*Mulcahy et al (2014)*

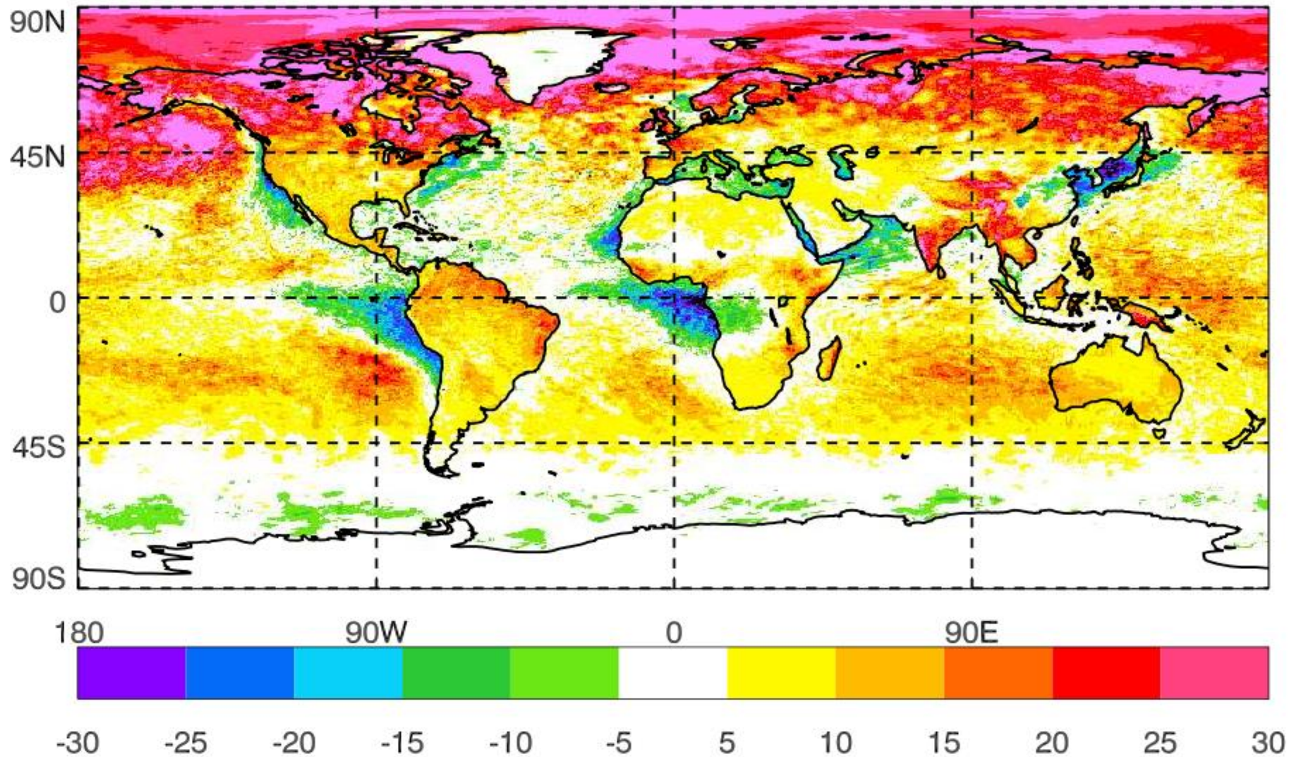


# Impact of aerosol complexity

## Surface SW: Prognostic CLASSIC - Cusack

*Mulcahy et al (2014)*

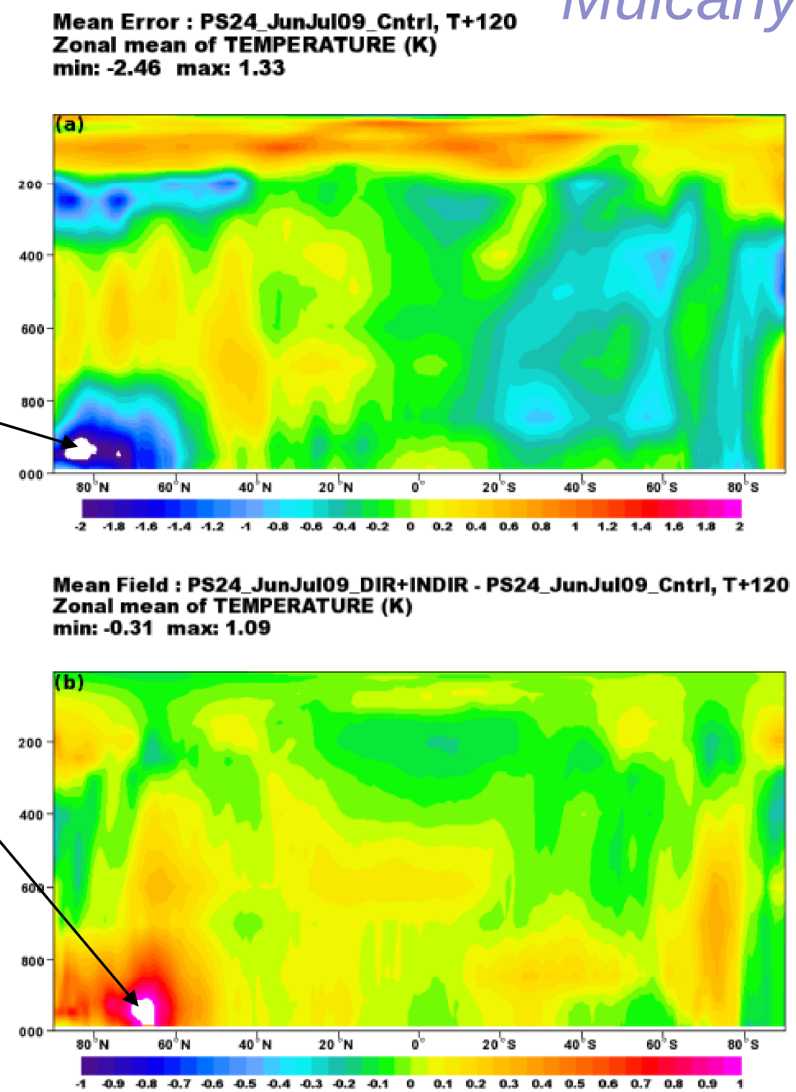
Impact of full CLASSIC aerosol scheme on surface SW ($W/m^2$) at day 5 in 1 month of rerun global NWP forecasts (June 2012):



# Impact of aerosol complexity

## Zonal mean T+120 T errors

*Mulcahy et al (2014)*




- Control has largest errors near surface at high latitude
- Much warmer in test with prognstic aerosol as fewer CCN means less bright cloud

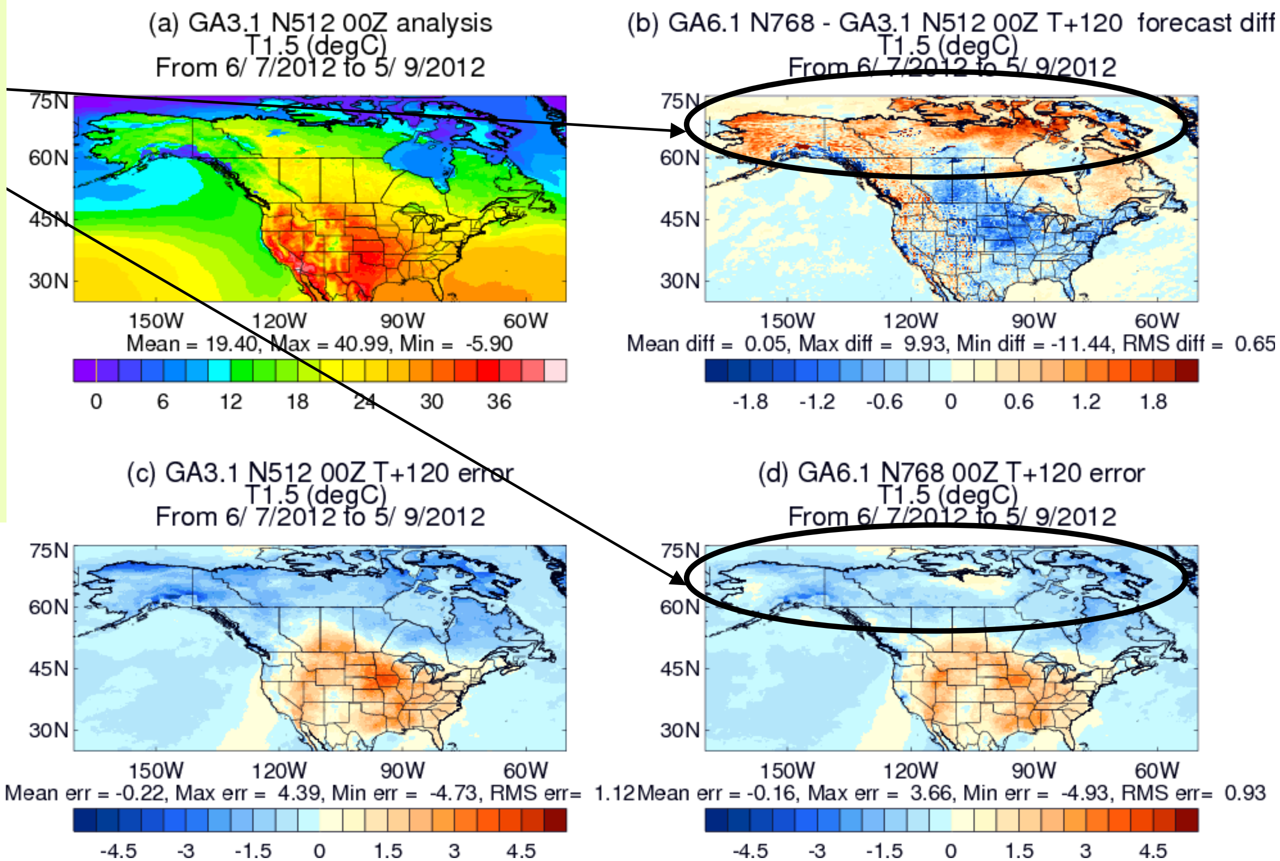
# Impact of aerosol complexity

## An example of seamless model development

*Tom Riddick*

- Impact on operational implementation (alongside other model changes)

- High lat improvements obtained from aerosol climatologies
- Lower lat improvements from other changes



# Impact of aerosol complexity

## Lessons for the reader

- Running experiments with additional complexity teach you *both* about the potential benefits of complexity *and* the short-comings of your less complex approach

- Adopting a *traceable* approach (e.g. to reproduce the mean behaviour of the fully complex scheme) may go a long way to achieving the benefits of the full scheme

- Once this approach is adopted, one can ask again what the benefits are of the full complexity and implement key parts

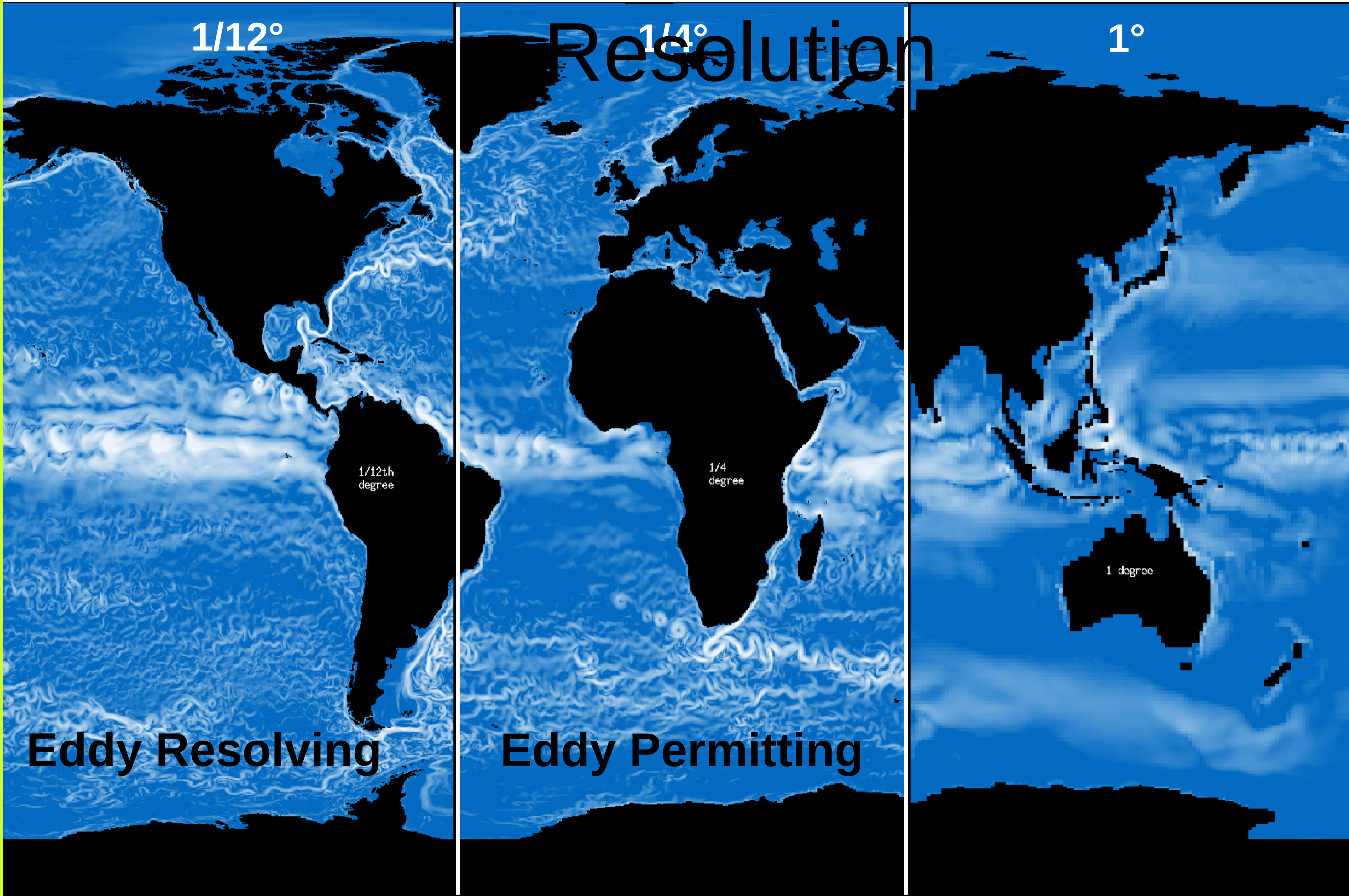
    - E.g. Prognostic dust operational and improves T_surf

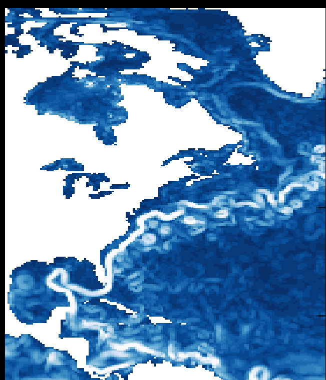
# Example case study: coupled ocean

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

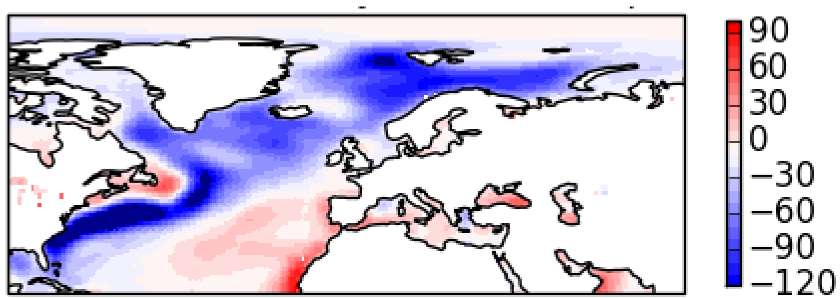
NEMO Global Ocean

# Ocean Model Resolution

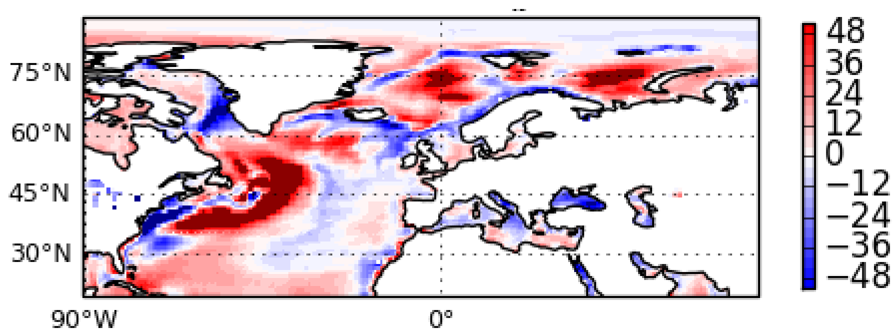




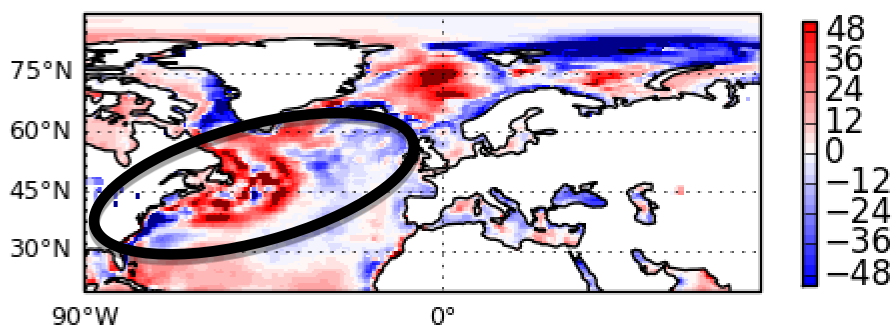
# N Atlantic surface heat fluxes




**DEEP-C dataset**



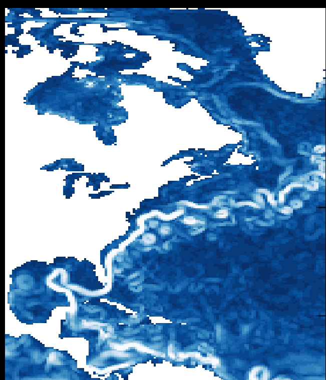

**Model error in eddy-permitting**

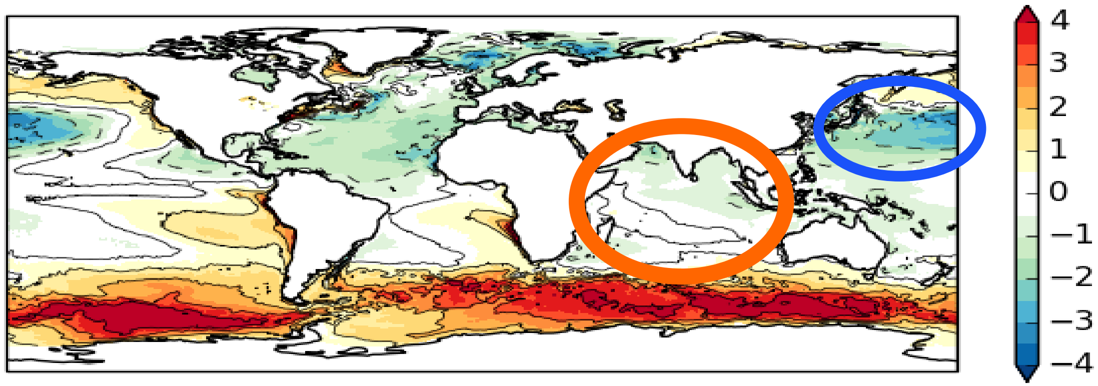



**Model error in eddy-resolving**

# Model Resolution-Reduced SST Biases and Overturning

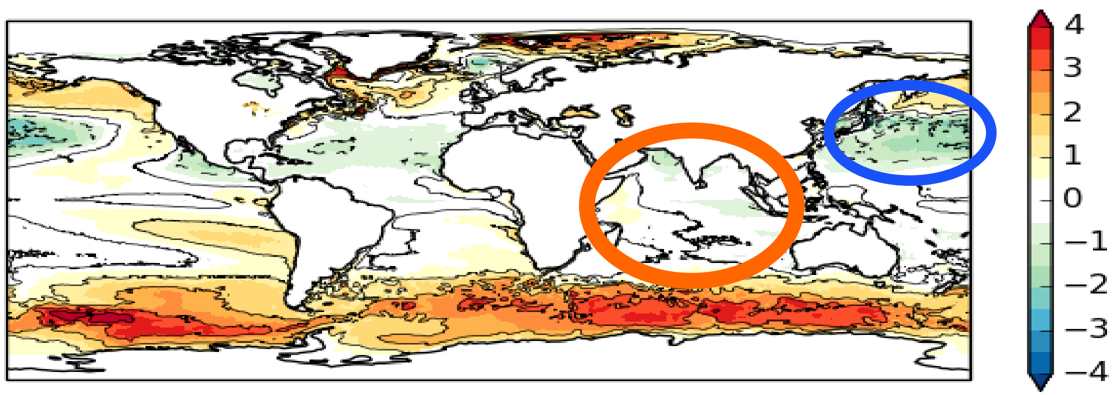







**N216 ORCA025**

**60km atmosphere ¼ degree ocean**




**N512 ORCA12**

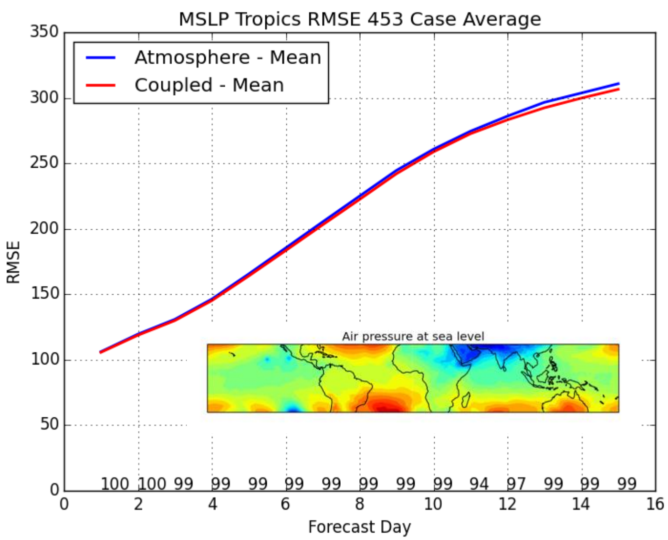
**25km atmosphere 1/12 degree ocean**

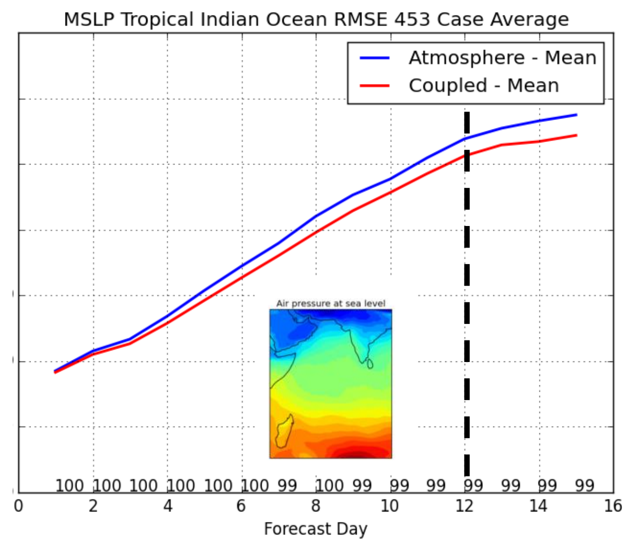
Benefits of high resolution ocean appear substantial and robust

Important open questions re mixing parametrizations

# Tropical Performance – Coupled NWP vs Control

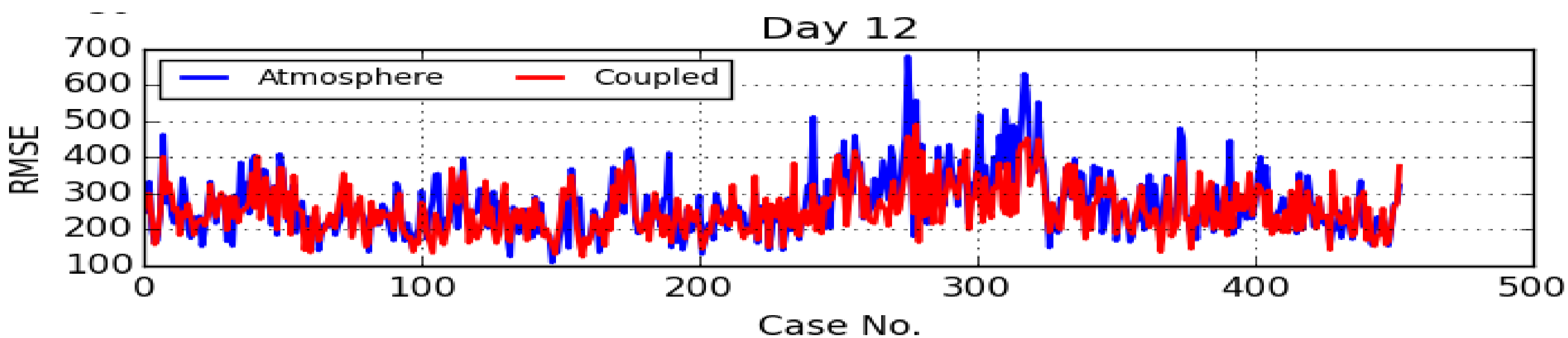
## 453 NWP Cases 2008-2012 MSLP Verification vs. ERA-I




N216 (60km)
UM Atmosphere

¼ degree
NEMO ocean

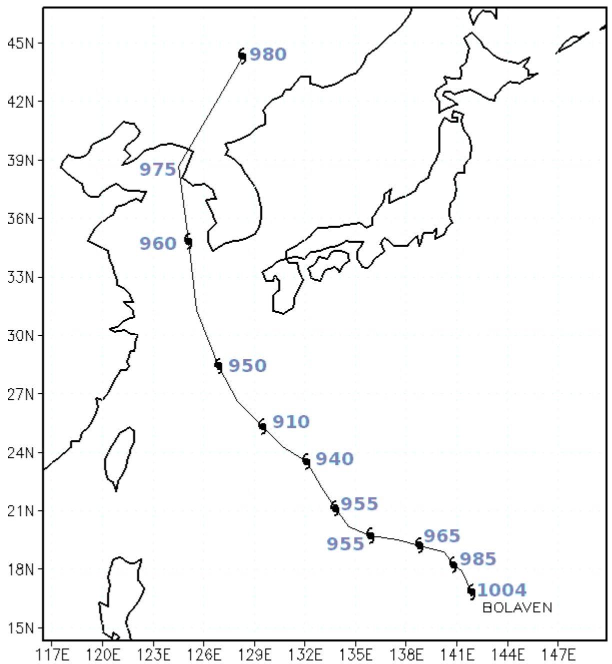


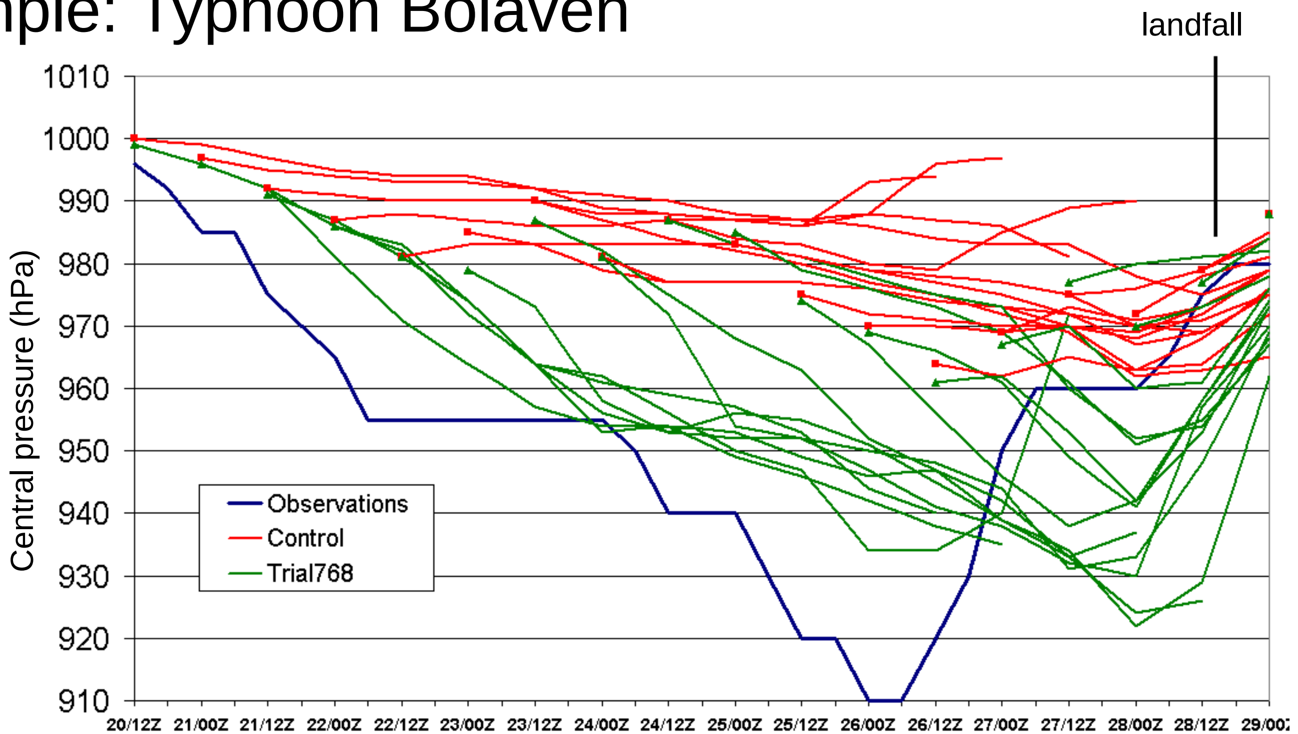
*Julian Heming*

Met Office

# Tropical cyclones

## TC example: Typhoon Bolaven




- Recent upgrade to atmosphere only NWP (dynamical core/resolution/physics) dramatically improved TC intensities and tracks
- Now for first-time beginning to see evidence of over-deepening as move into sub-tropics
- Experimental coupled results looking promising – example of real physical process that it is only appropriate to include when overall performace reaches a certain level of maturity

# Example case study: multi-layer snow

# GL7.0 Global Land developments

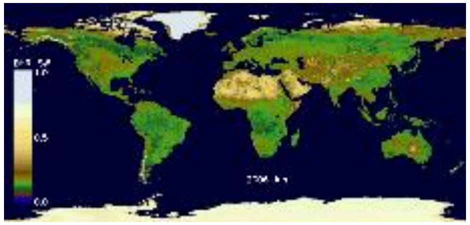
Changes from GL6.0

Multilayer snow scheme

Global Land 7.0/7.1

JULES Joint UK Land Environment Simulator

Further albedo improvements



http://www.globalbedo.org

Surface exchange improvements

- **Current operational scheme 0-layer**
  - Snow and first soil treated together
  - Implicated in warm biases in NWP and poor simulation of permafrost in climate work
- **Multilayer scheme**
  - Explicit representation of the snow pack
  - Mechanical compaction & thermal metamorphism
  - Dependence of thermal conductivity on density included
  - Liquid and ice stores

*R.Essery*
*J.Edwards*
*M.Brooks*

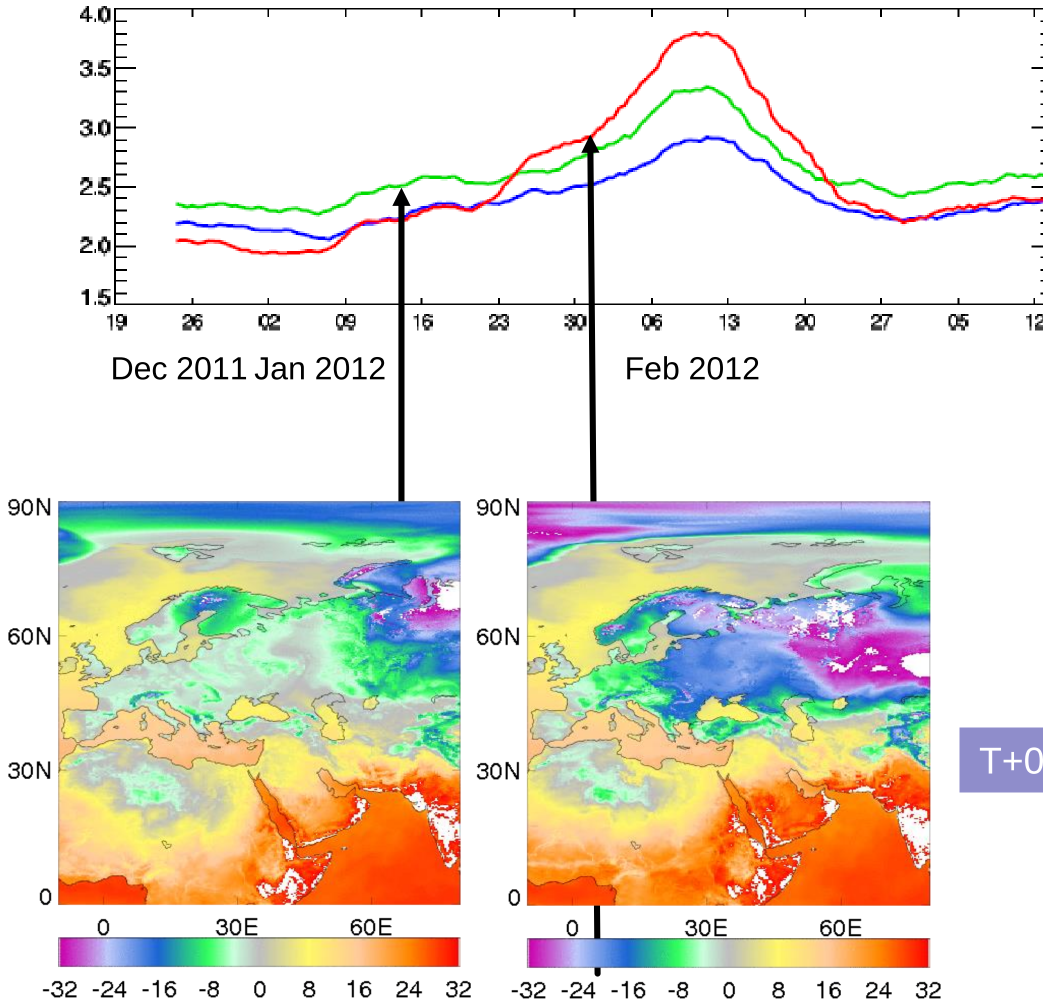
# Global Land

## Multilayer snow scheme

*R Essery, J Edwards*

- Current scheme treats snow and first soil layer together
  - Underestimates insulation of ground
  - NWP warm biases when temperature falls rapidly
  - Example from 2011/12
  - Poor simulation of permafrost and cold spring temperatures in the climate model

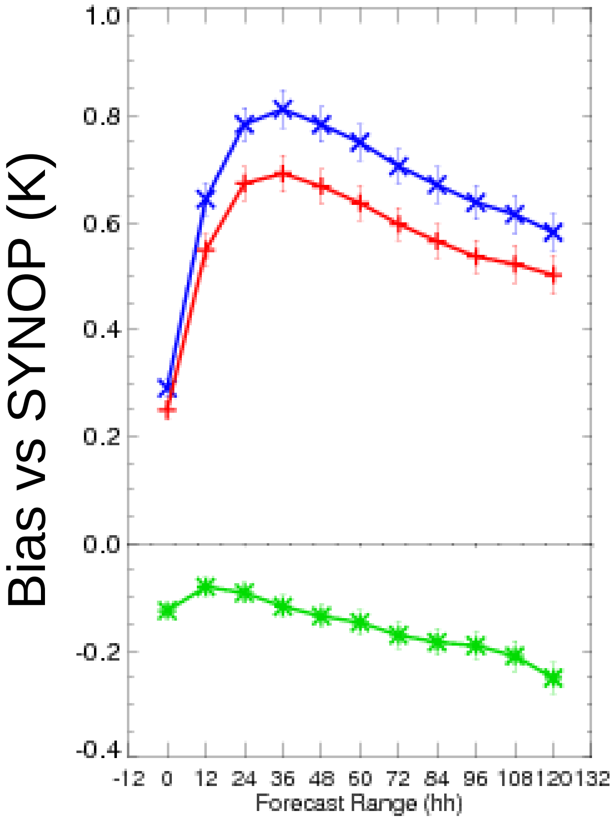
NAE area T+72 10 day rolling mean $T_{1.5m}$ bias (vs SYNOPS):
Met Office ECMWF NCEP

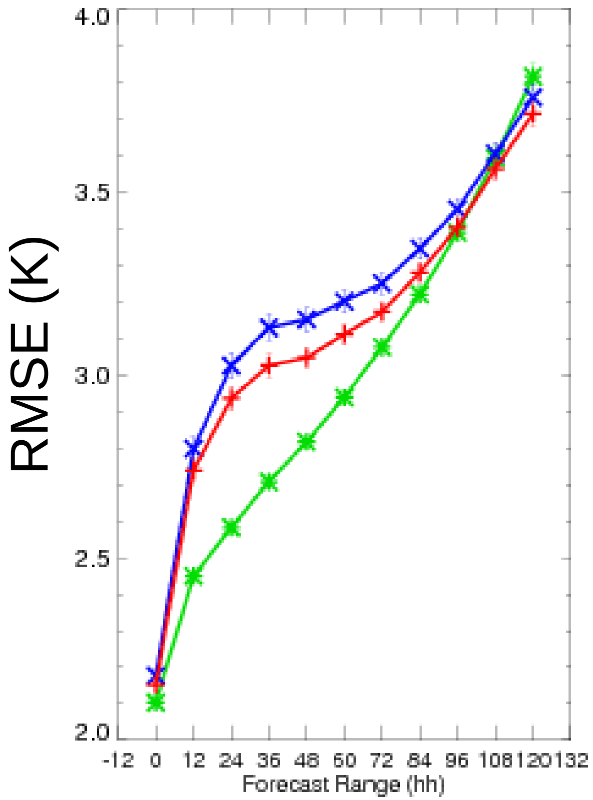



T+0 $T_{skin}$

# Weather performance

NH $T_{1.5m}$ from winter N320 coupled/hybrid VAR trial



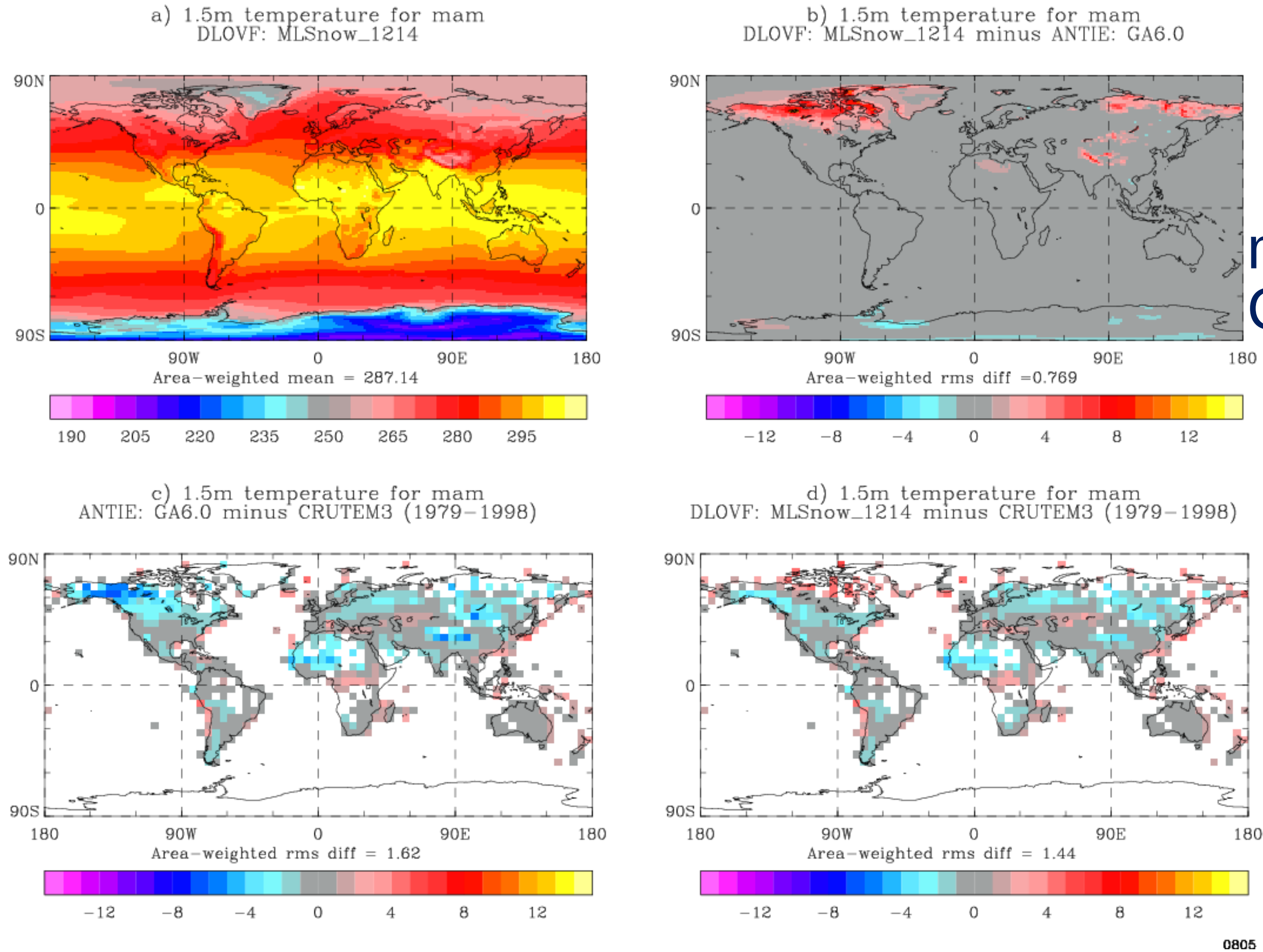

GA6.0

GA6#136.11 (zero layer snow scheme)

GA6#136.12 (three layer snow scheme)

*M Brooks*

# Impact on 1.5m temperature in March-April-May (climate run)




Test minus Control

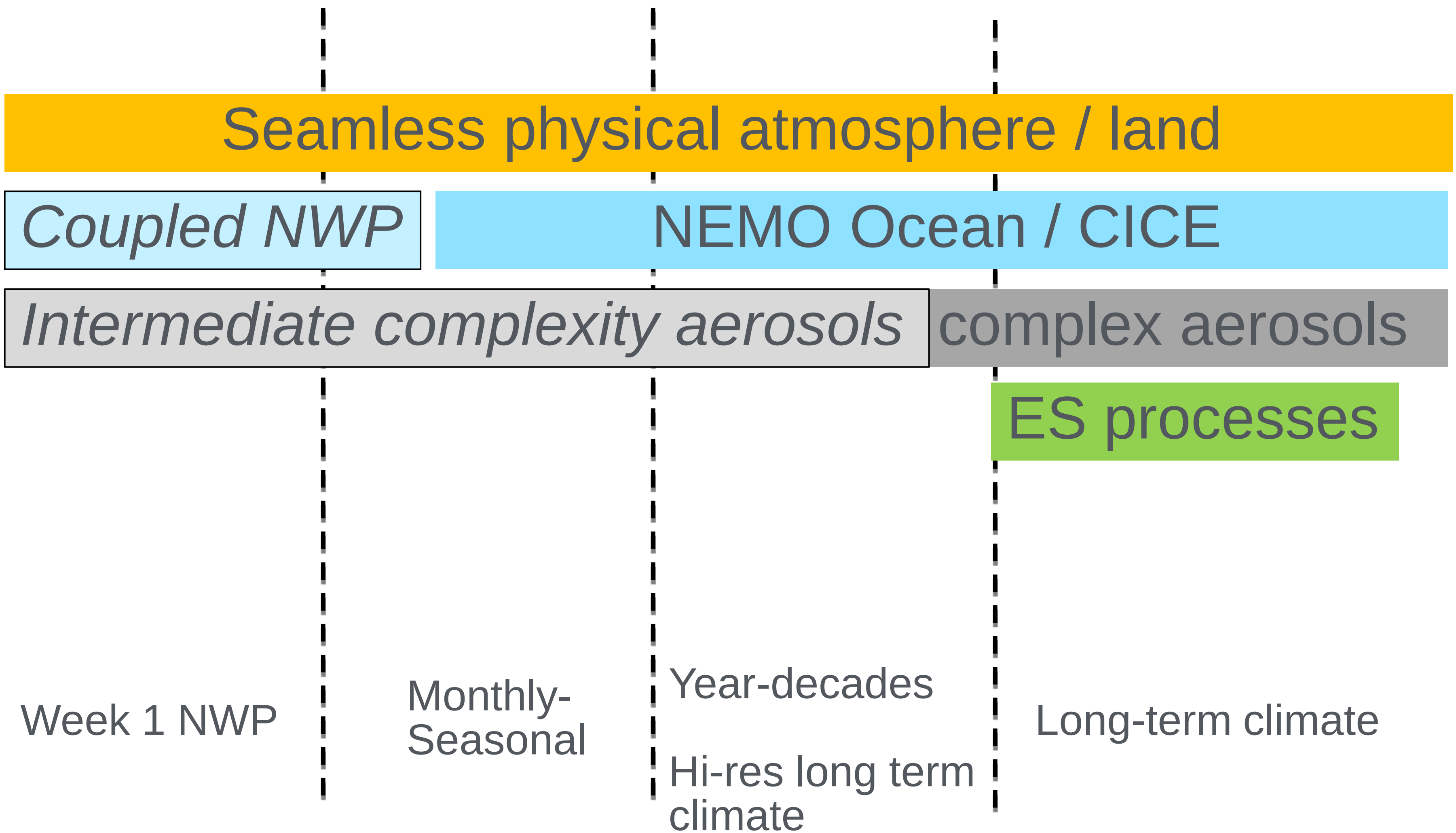
Control bias

Test bias

Simpler scheme believed to be fundamentally incapable of representing (important aspects of) reality; complexity justified

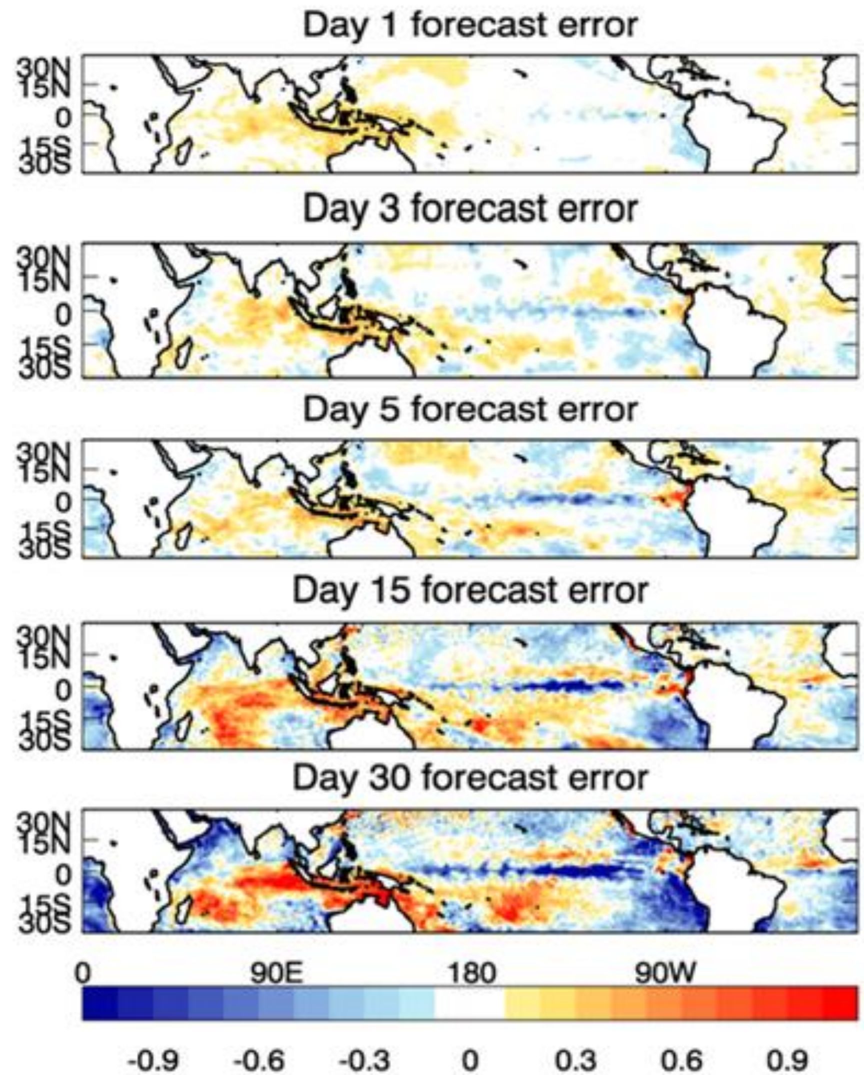
# Priorities

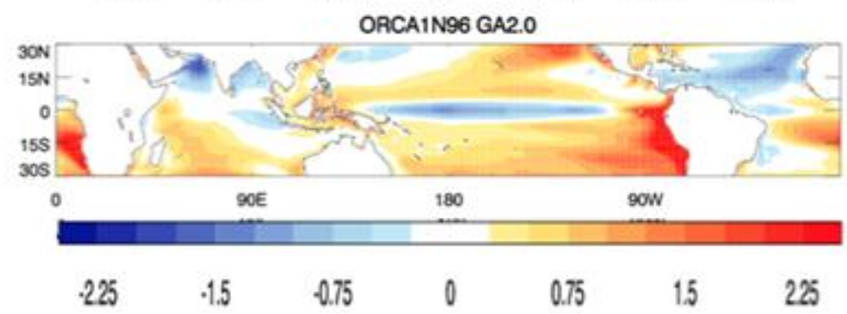
# Summary of Met Office global configurations



Met Office

## Time evolution of coupled model SST errors



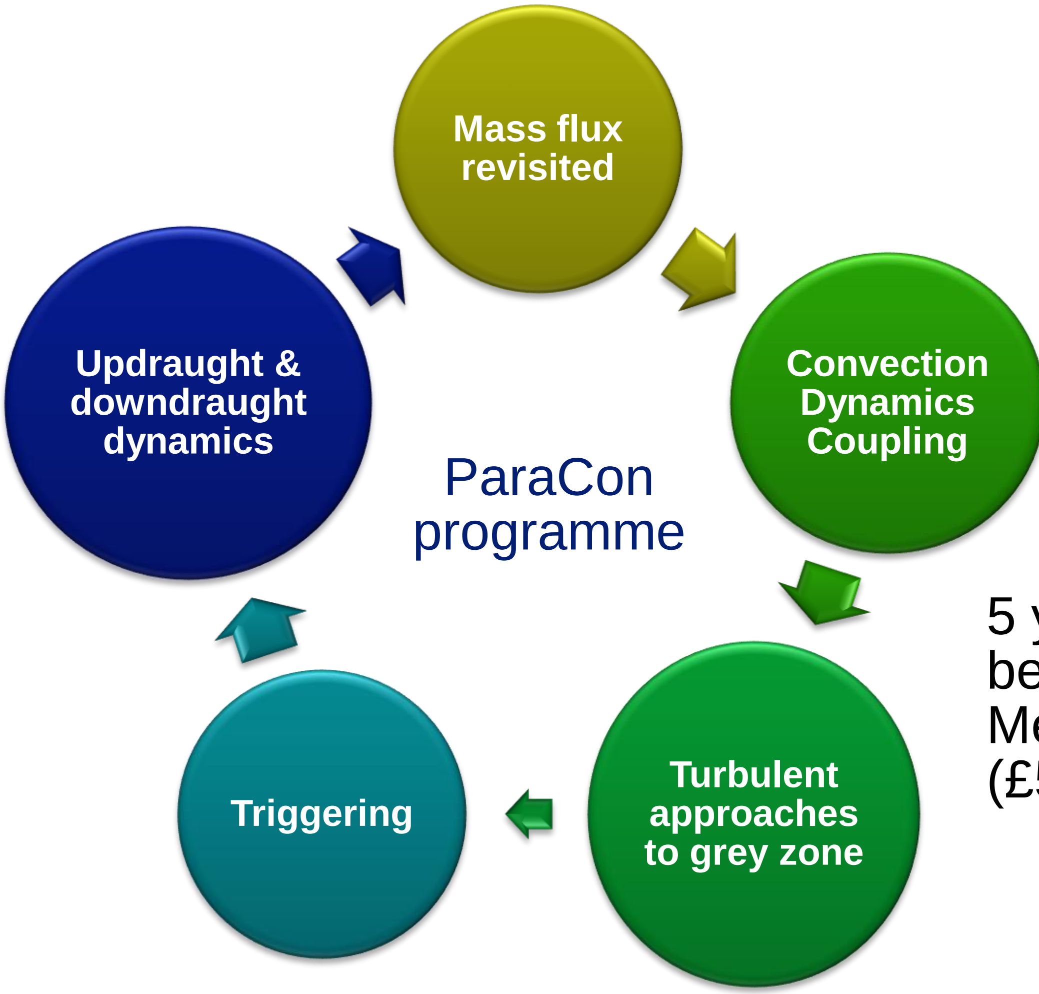

"Errors in the representation of fast physical processes remain a key limiting factor in the skill of our models across all timescales from short to sub-seasonal to seasonal timescales"

*Report from 2010 WMO subseasonal to seasonal prediction workshop (available from WMO S2S page at http://www.wmo.int/pages/prog/arep/wwrp/new/S2S_project_main_page.html)*

Met Office

# Convection Programme

NERC SCIENCE OF THE ENVIRONMENT



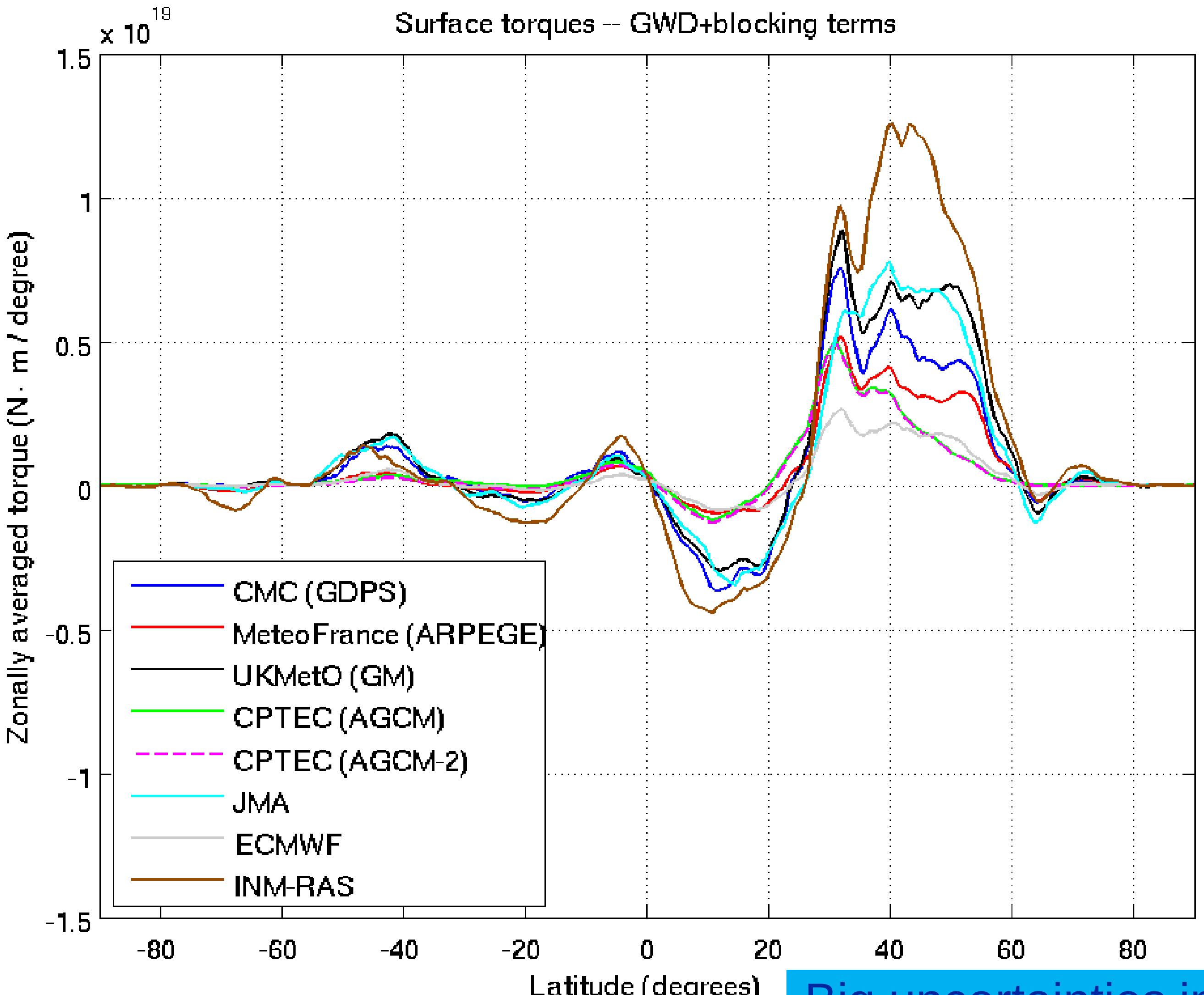

5 year joint programme between NERC and Met Office
(£5M investment each)

http://www.metoffice.gov.uk/research/collaboration/paracon

University of Cambridge | University of Exeter | University of Leeds | Met Office | National Centre for Atmospheric Science | NERC Science of the Environment | University of Reading

# WGNE DRAG-project, torque inter-comparison Step0-24 January 2012

subgrid orography



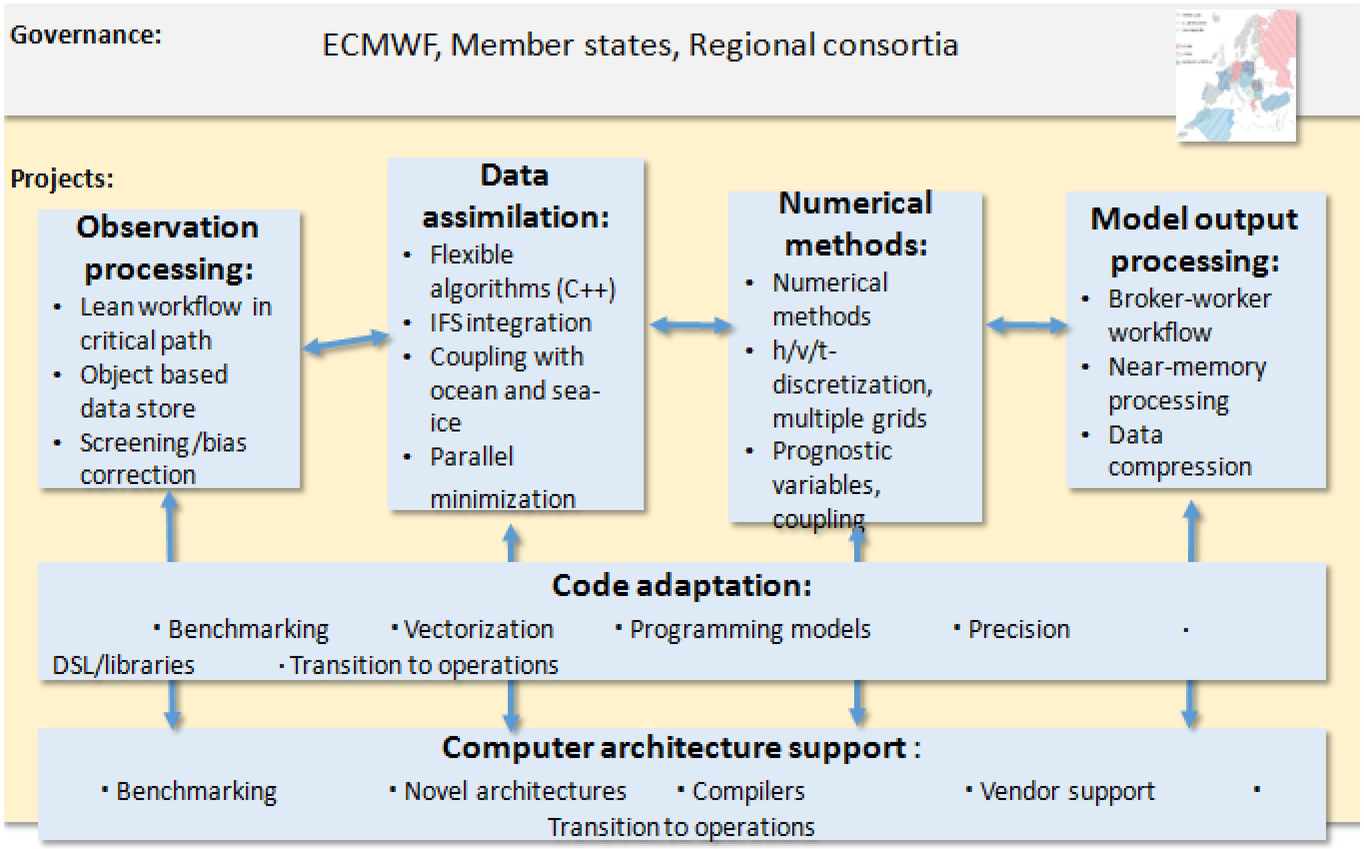

Thanks to:

Ayrton Zadra

Big uncertainties in many important aspects of model physics

Small community working on them

# Scalability Challenges




ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS PETER BAUER 2016

Scalability challenges big

Computational efficiency on future hardware driving science choices (numerical techniques, grids, DA...)

Issues needs to be front and central in thinking re extra complexity

Continue to invest (HPC, people) to do the ‘traditional’ things better (atmospheric and oceanic resolution, drag, convection, physics/dynamics coupling and stochastic physics, ensembles, DA.....)

Cross-timescale testing is hugely valuable, especially if fast physics common across systems, and strong focus on NWP ‘weather’ metrics as well as synoptic scores

Do invest in complexity, but selectively, taking (increased?) care to be sure to understand what the complexity is truly giving, and to consider overall cost-benefit compared to other investments

# Final thoughts......

- Model development an exciting and important science in its own right
    - Operational centres and academia together

- Needs both insight into detailed processes and broad understanding of how whole modelling systems work as one

- International collaboration key (knowledge sharing; co-ordinated work to learn generic lessons)

- New WCRP/WWRP prize for model development in recognition of its importance

- A good career choice!