Regional Reanalysis and Global Data Assimilation Activities at the Met Office

Richard Renshaw, Dale Barker, Peter Jermey, and many others

Outline

Global DAE Operational Upgrades

Coupled (Ocean-Atmosphere DA) Status and Plans

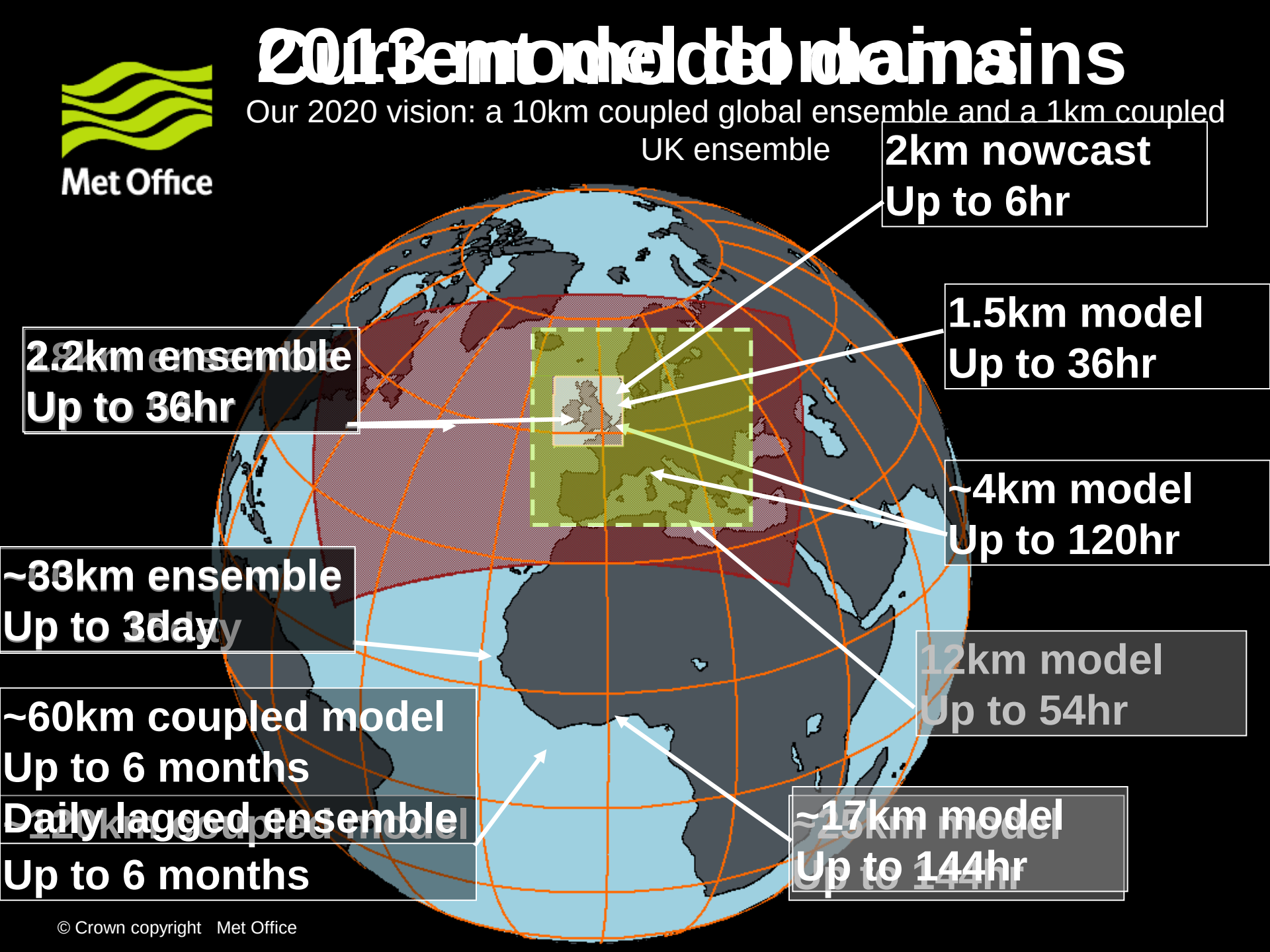
Progress with global 4DEnVar.

Forecast Sensitivity to Observations (FSO).

Regional Reanalysis

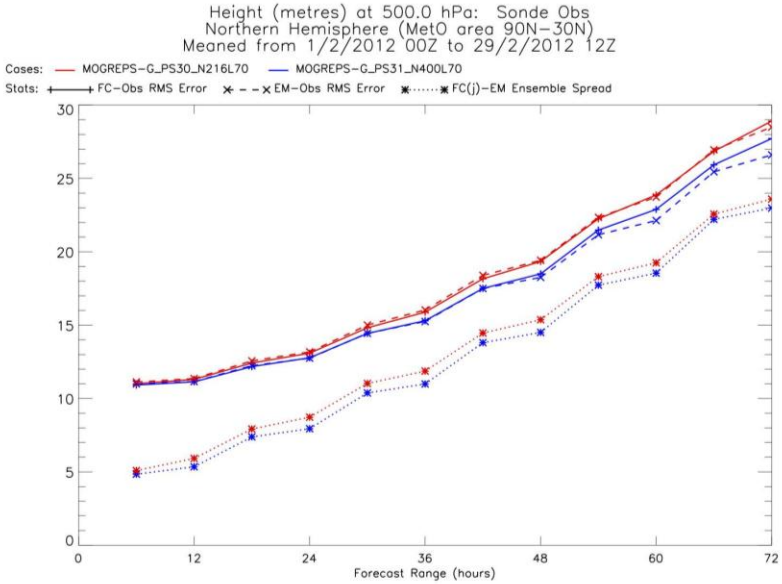
2013 model domains

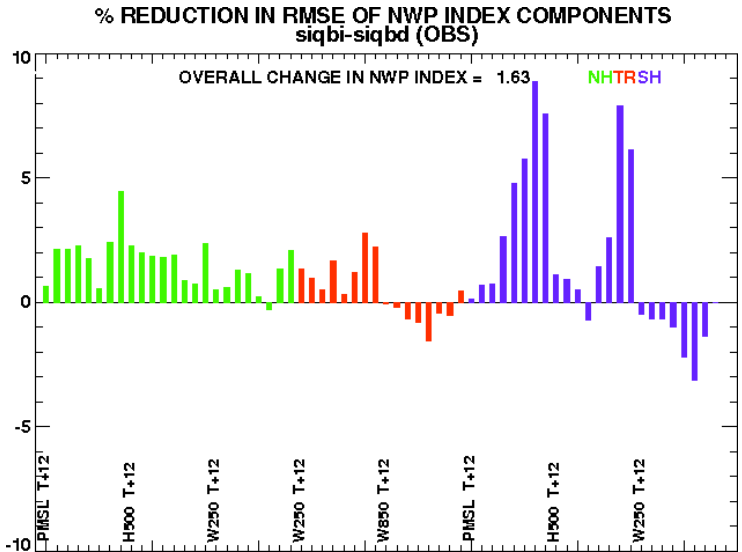
Our 2020 vision: a 10km coupled global ensemble and a 1km coupled UK ensemble



DAE Contributions to PS31 Global Operational Upgrade (16 Jan 2013):

- Short-range global ensemble (MOGREPS-G) resolution increased from N216 (~60km) to N400 (~33km).
- MOGREPS-G ensemble size for hybrid 4D-Var/ETKF data assimilation increased from 22 to 44 members.
- Mix of climatological/ensemble covariances in hybrid tuned.
- Large impact of DAE and SA upgrades in PS31 from trials: **~1-3pts** on the global (deterministic) NWP index.

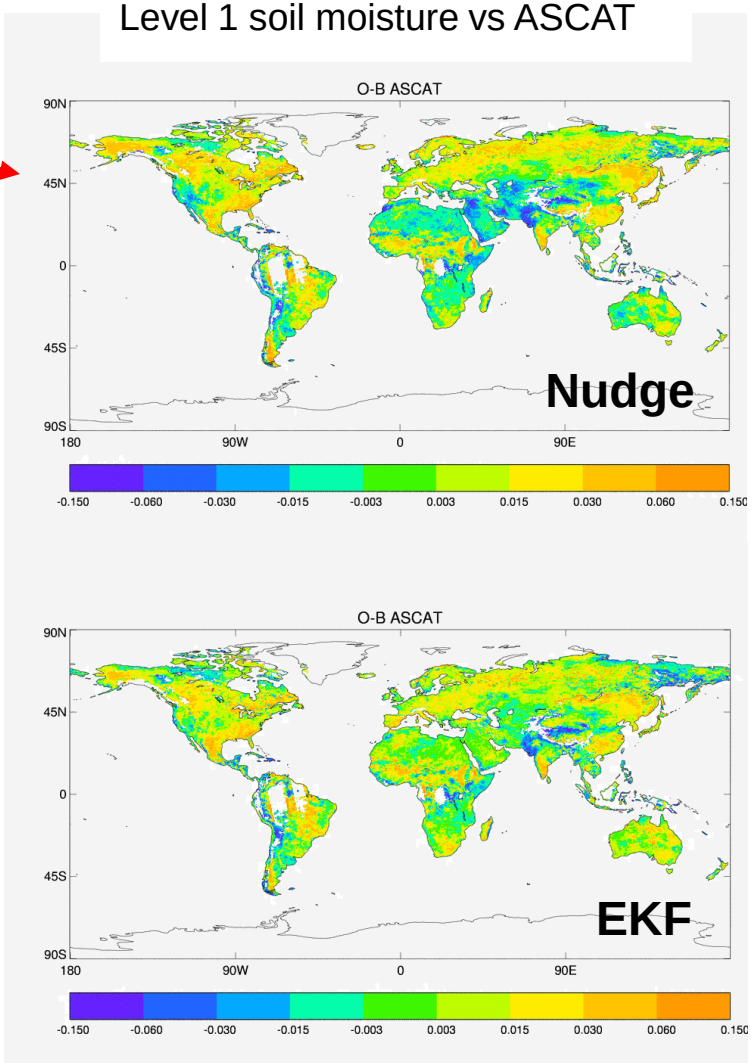




DAE Contributions to PS32 Global Operational Upgrade (30 Apr 2013):

- Extended Kalman Filter (EKF) land DA scheme.
- Assimilation of SEVERI/MODIS aerosol optical depth (AOD).
- ODB for observation monitoring
- Aircraft temperature bias correction.
- Small impact of DAE and SA upgrades in PS32: **~0.3pts** on the global (deterministic) NWP index.

Level 1 soil moisture vs ASCAT



Land DA plans: LST analysis, tuning, EnKF

PS33 Global Operational Upgrade (Feb 2014): Rose

Technical change only:

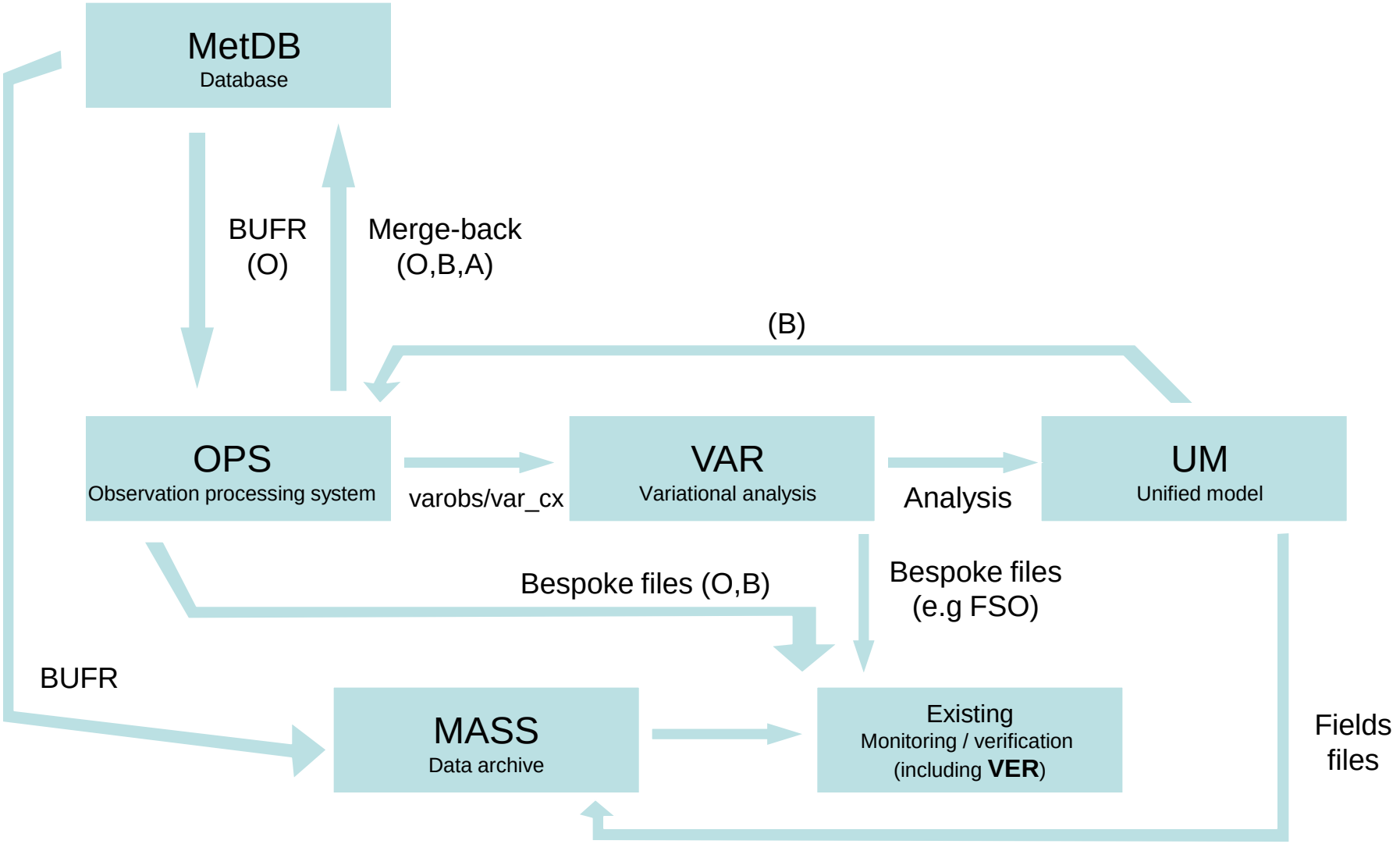
Rose suite scheduling system
based on Cylc (Hillary Oliver, NIWA)

Configured by text files
More flexible and adaptable

Observation Ingest: ODB, MetDB/MOODS

Previous scenario

Adam Maycock

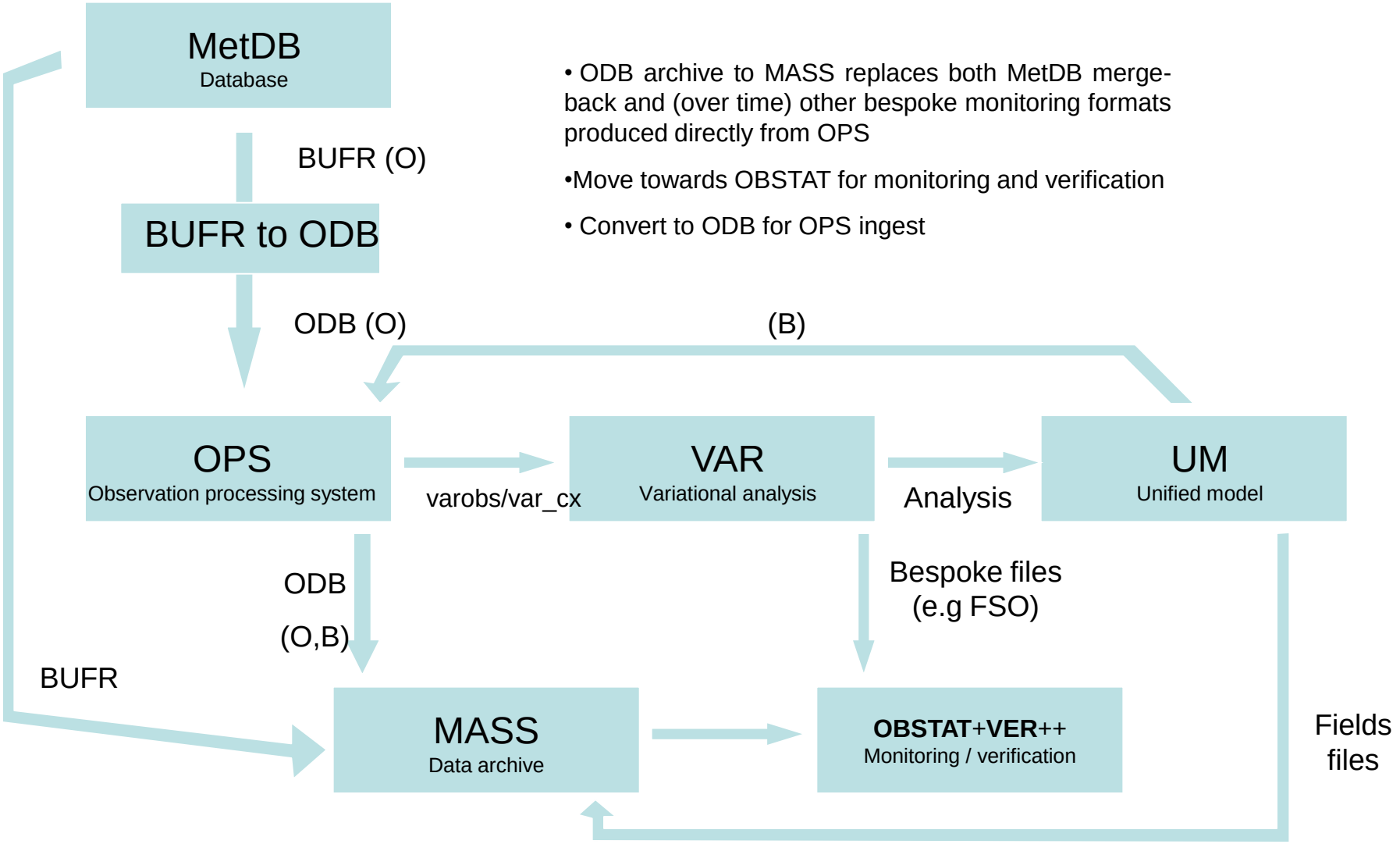


Observation Ingest: ODB, MetDB/MOODS

Since 2013

Adam Maycock

- ODB archive to MASS replaces both MetDB merge-back and (over time) other bespoke monitoring formats produced directly from OPS
- Move towards OBSTAT for monitoring and verification
- Convert to ODB for OPS ingest

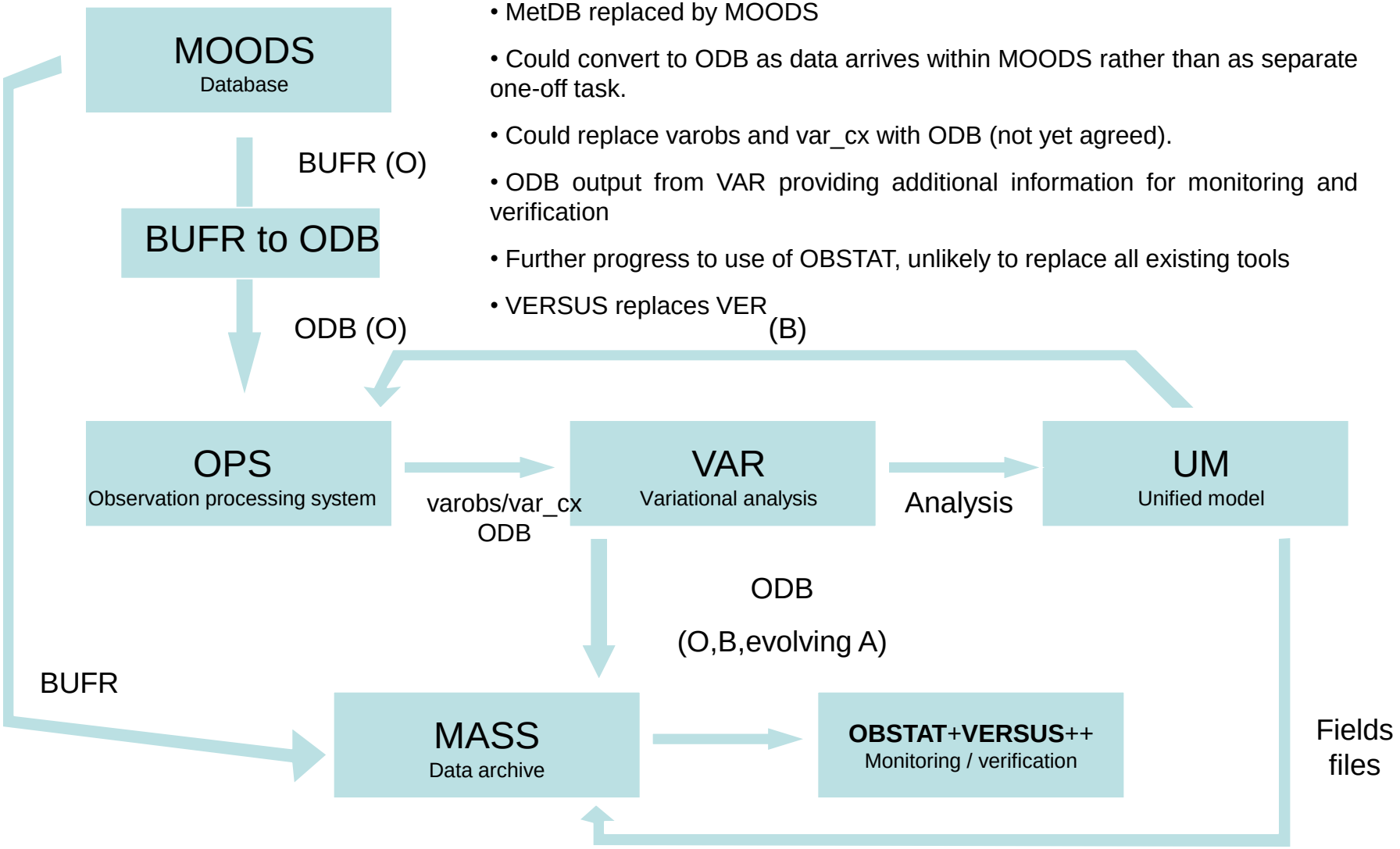


Observation Ingest: ODB, MetDB/MOODS

Adam Maycock

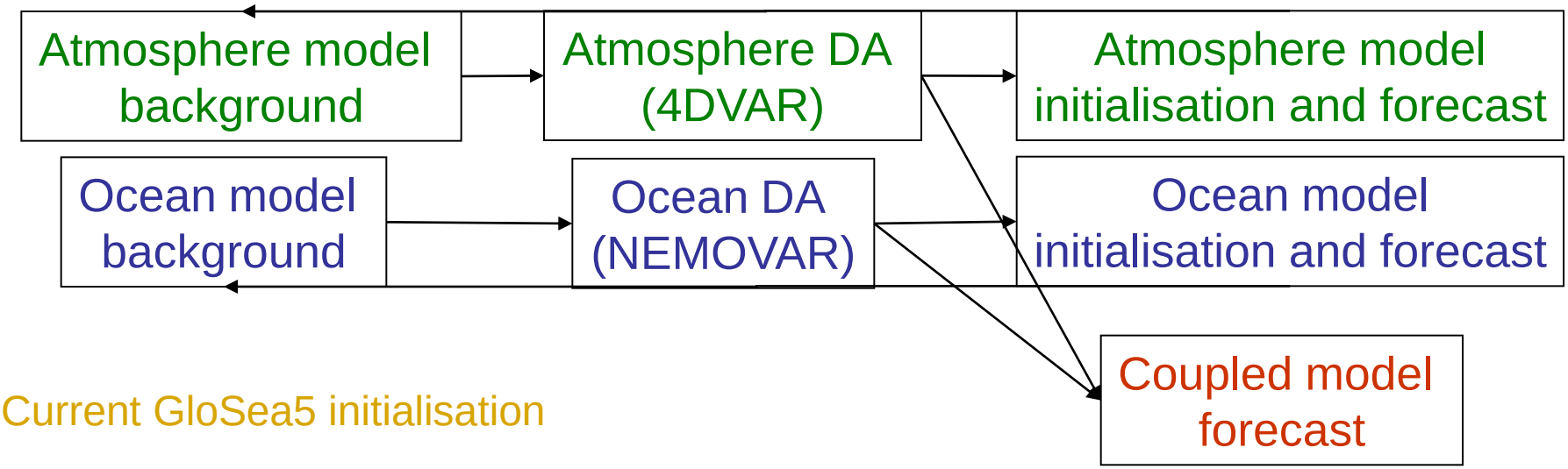
Future Scenario

- MetDB replaced by MOODS
- Could convert to ODB as data arrives within MOODS rather than as separate one-off task.
- Could replace varobs and var_cx with ODB (not yet agreed).
- ODB output from VAR providing additional information for monitoring and verification
- Further progress to use of OBSTAT, unlikely to replace all existing tools
- VERSUS replaces VER



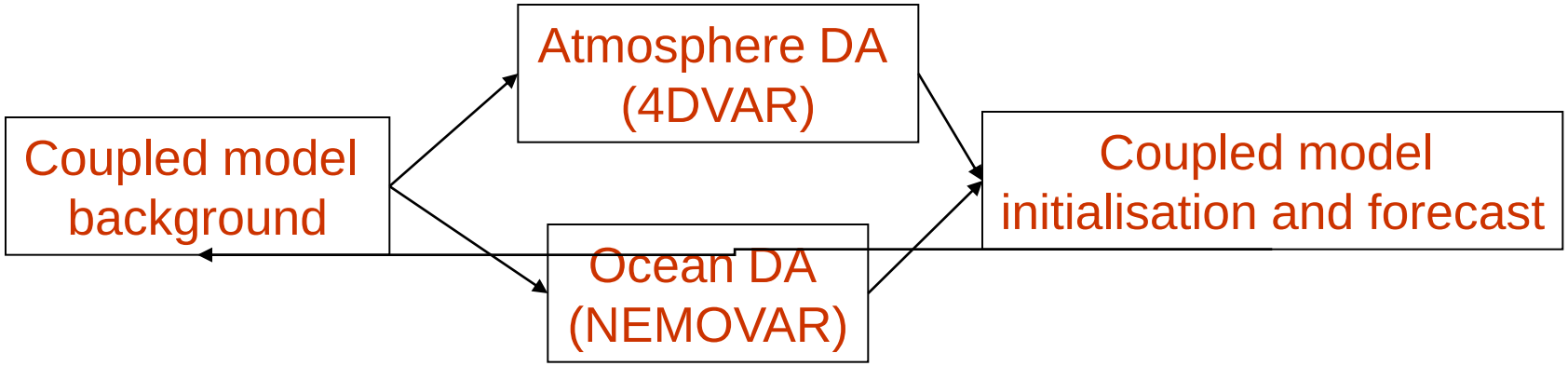
Coupled data assimilation: Current And Planned System

Matt Martin



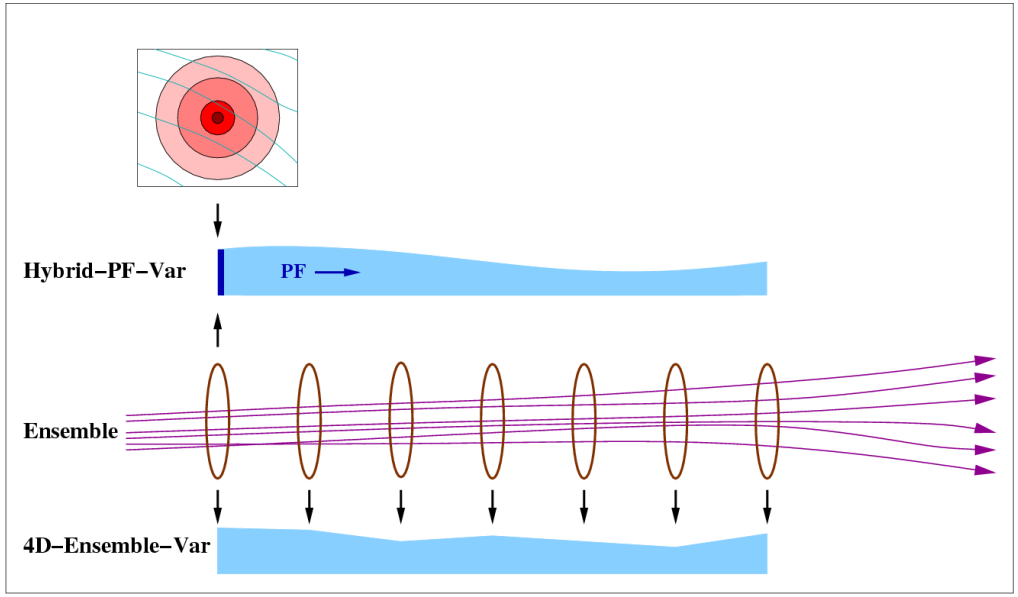
Current GloSea5 initialisation

Planned GloSea5 initialisation



Global Atmospheric DA Strategy: Ensemble-Variational Methods

- In short-term, perform refactoring/optimizing current VAR code.
- Also continue to develop hybrid in short/medium-term.
- Develop En4DEnVar (further integration of DA/MOGREPS) as a potential alternative to 4D-Var/ETKF



Comparison of 4DEnVar to 4DVar

Neill Bowler

4DEnVar Advantages:

- Cheap
  - Allows cost to be recycled into larger ensemble or outer loop
  - Can do DA at high-res
- No linear model
  - No maintenance
  - No concerns over neglected physics schemes

4DEnVar Disadvantages:

- Large memory and I/O requirement
- No propagation of static covariances
- Localisation may need to follow the flow
- No Jc term

4DEnVar Initial Trial Results

Neill Bowler

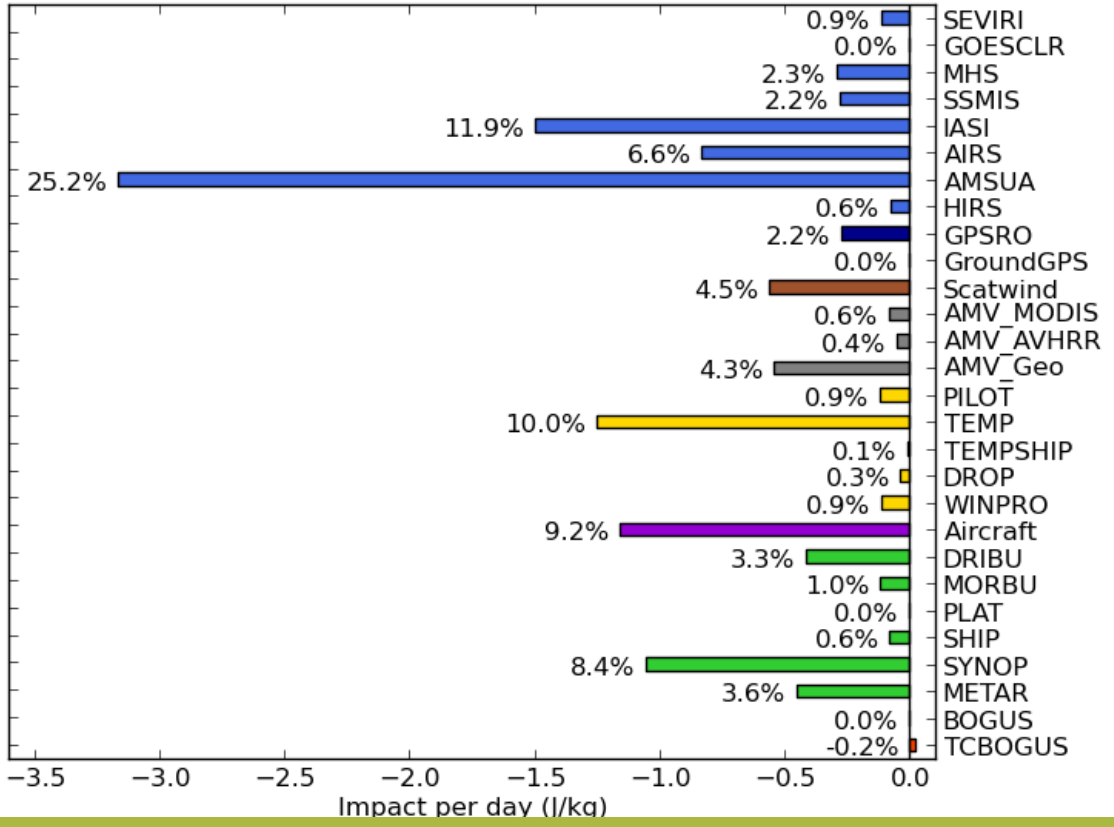
Control	Experiment	RMSE	NH	Tropics	SH
hybrid-3DVar^{44}	4DEnVar^{44}	-0.9%	10/113/0	0/123/0	7/112/4
4DVar(N108)	4DEnVar^{44}	+0.47%	10/111/2	1/106/16	6/90/27
hybrid-4DVar^{22}	4DEnVar^{44}	+2.4%	1/118/4	0/103/20	0/52/71
hybrid-4DVar^{44}	4DEnVar^{44}	+2.7%	0/100/23	0/102/21	0/44/79

Better/neutral/worse results ±2% RMSE thresholds)

- Preliminary results: very little tuning, low-resolution.
- 4DEnVar beating hybrid-3DVar.
- Comparable with 2011 MetO system (4DVar), but way off 2012 system (22 member hybrid-4D-Var)

Forecast Sensitivity to Observations (FSO): Impact Of Obs in Global NWP

Richard Marriott



- Impact of on T+24 forecast (global moist energy norm) (30 Jan–18 Mar 2012).
- Leading order: 1) AMSUA, 2) IASI, 3) TEMP, 4) Aircraft, 5) Surface, etc.
- Total impact shown, could also show impact/observation.
- **Major collaboration between MetO and KMA (Sang-Won Joo)**

The Statistical Nature of Observation Impact

Richard Marriott

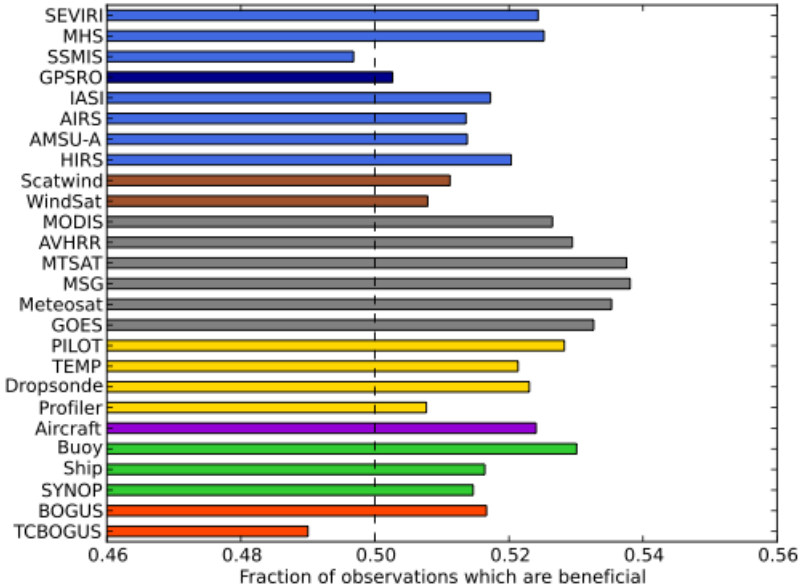
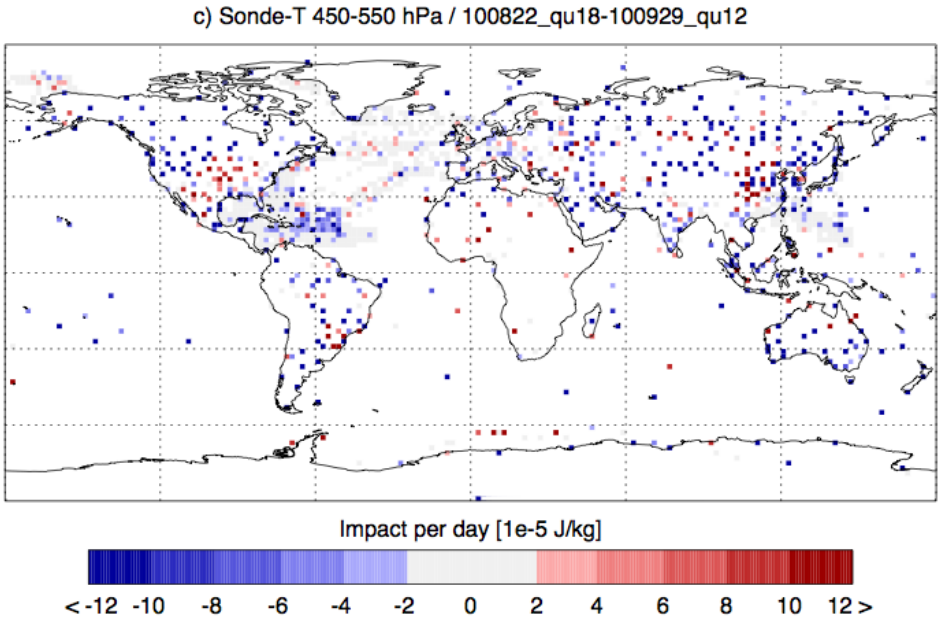


Figure 13. Fraction of beneficial 24-hour observation impact by observation-type for the full trial period.



Improve forecast Degrade forecast

- Only just over 50% of observations reduce forecast error.
- Toy model results in Lorenc and Marriott (2012) show this is due to random observation Error, imperfect verifying analysis, imperfect DA (e.g. covariances), nalysis projecting onto growing and decay modes in forecast.
- Estimate: need 6 months time series to assess impact for single observing site.

Regional Reanalysis

EURO4M

EUROPEAN REANALYSIS AND OBSERVATIONS FOR MONITORING

Tracking changes in European climate

- EU-project, April 2010 – March 2014, 9 partners

- Goal: LONG-TERM CLIMATE DATASETS + ASSESSMENTS OF CHANGE
  …describing climate variability and change at the European scale
  …placing high-impact extreme events in a historical context

SEVENTH FRAMEWORK PROGRAMME

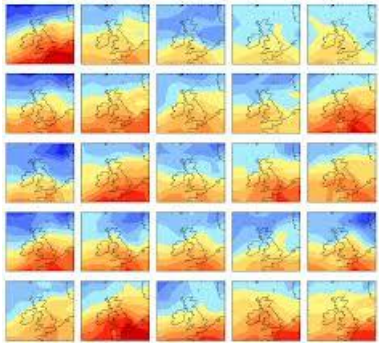
UERRA

Uncertainties in Ensembles of Regional Re-Analyses

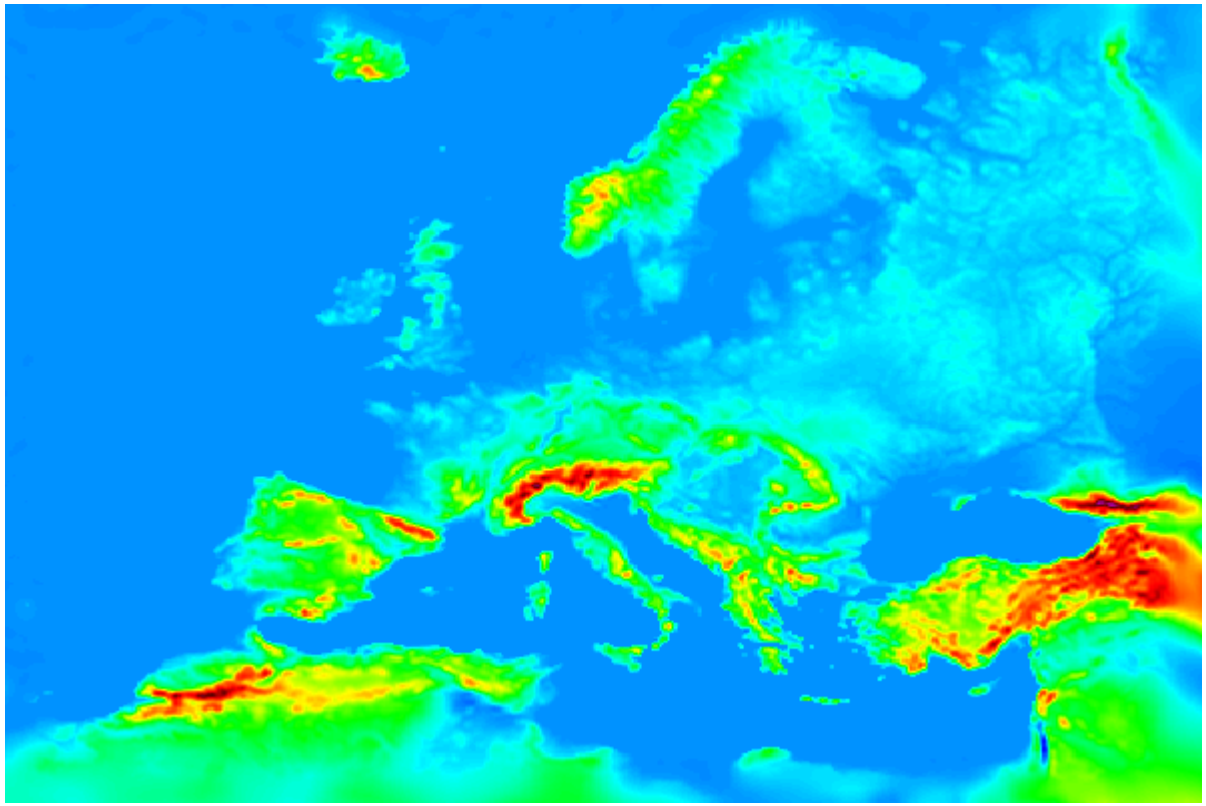
2014-2017

Met Office reanalysis:

- Satellite era 1978 - present
- Ensemble variational reanalysis



WP2.1 “Building capacity for advanced regional data assimilation”



reanalysis period 2008 - 2009

Model forcing

Surface fields

- SST and sea-ice from OSTIA
- Soil moisture and snow from Met Office operational Global

Initial and lateral boundary conditions

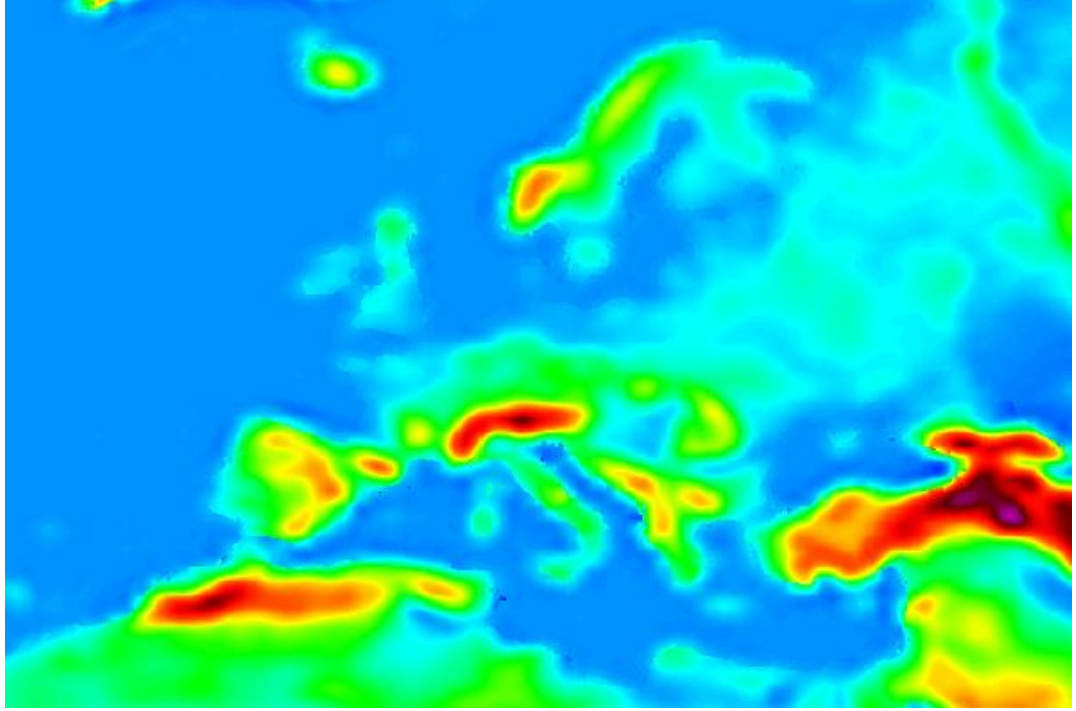
- 6-hourly **ERA-Interim** global analyses

model orography

ERA-Interim

Model T255 (**80km**)

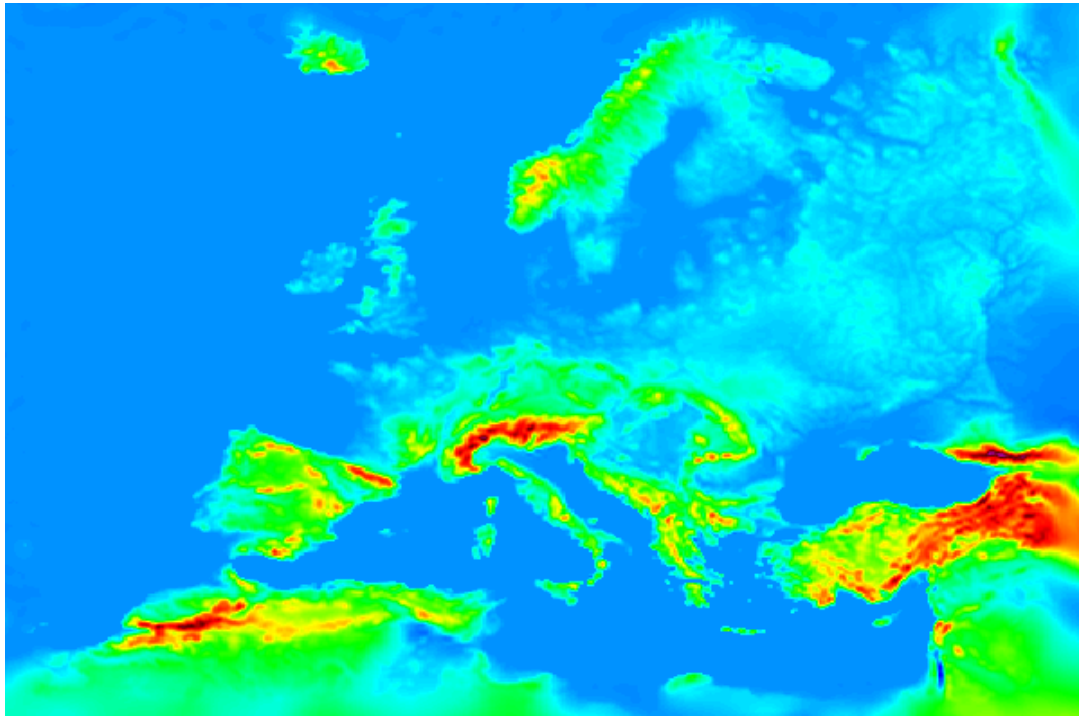
Var T159 (125km)



Met Office

Model **12km**

Var 24km



ERA-Interim vs EURO4M

Met Office

- T255 (80km), 60 levels
- T159 (125km) 4D-Var
- 12-hour analysis window
  - using:
    - conventional obs
    - satellite radiances

- 12km, 70 levels
- 24km 4D-Var
- 6-hour analysis window
  - using:
    - conventional obs
    - satellite radiances
    - GPS (ground-based & RO)
    - visibility
    - cloud
    - precipitation

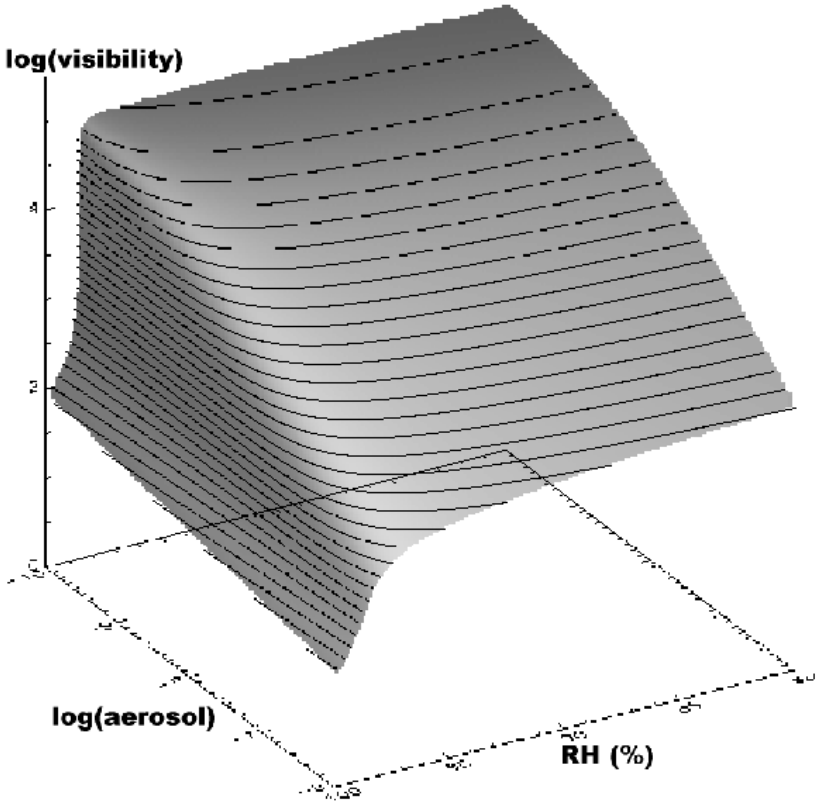
Observations

- Surface (SYNOP, buoy, etc)
- Upper air (sonde, pilot, wind profiler)
- Aircraft
- AMV (‘satwinds’)
- GPS-RO and ground-based GPS
- Scatterometer winds
- ATOVS
- AIRS
- IASI
- MSG clear sky radiances

Getting more from surface obs...

- Visibility
- Cloud
- Rainfall

Visibility assimilation



Visibility = f(aerosol concentration, humidity)

Cloud assimilation

Operational NAE assimilates 3D cloud fields

from nowcasting system

(combines satellite imagery + surface reports)

EURO4M reanalysis uses surface reports directly

Cloud from SYNOP report

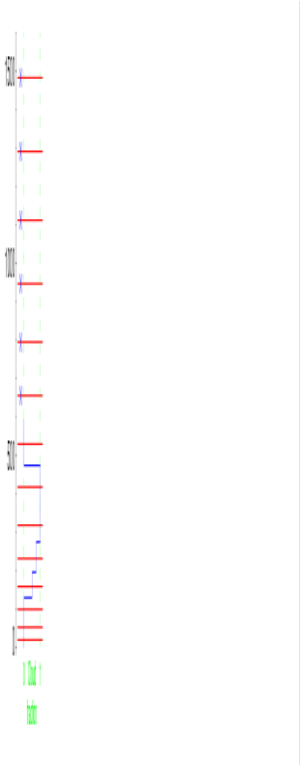
Wattisham, 00Z 2012/03/13

AAXX 13004 03590 11238 83504 10064 20060 30240 40352 53002 60001 71022
886// 92350 333 55/// 20411 84703 86706 88708

84703 4 oktas Stratus from 90m

86706 6 oktas Stratus from 180m

88708 8 oktas Stratus from 240m



Pete Francis

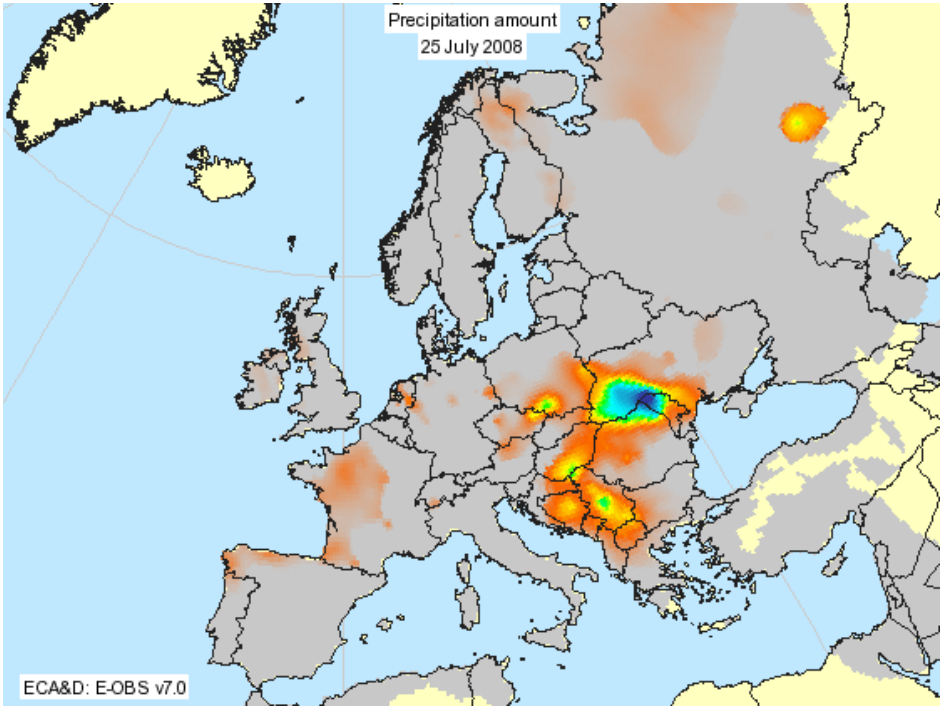
Precipitation assimilation

- Operational UK models assimilate radar rainrate (latent heat nudging)

- For IMDAA, aim to assimilate raingauge accumulations

Precipitation assimilation

E-Obs gridded daily precipitations



Precipitation assimilation

Target

Use E-Obs gridded daily precipitations

System to disaggregate 24hr accumulations to 6hrs

Use Var outer loop

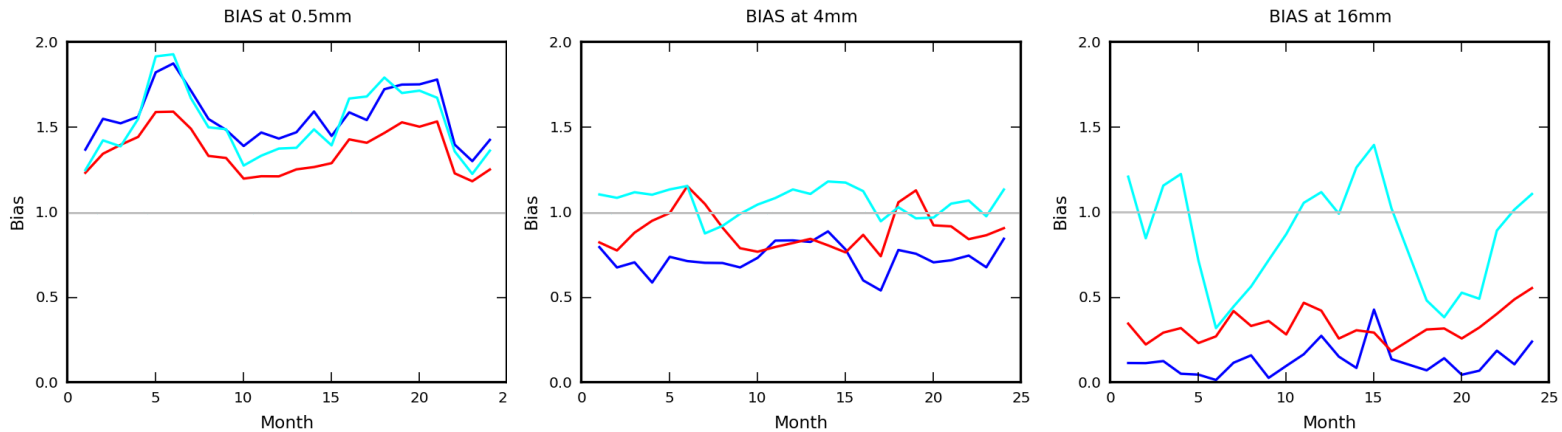
Collaboration – Cross-Validation

Compare our reanalysis against:

- SMHI/HIRLAM 22km 3D-Var
- ERA-Interim
- Obs climatologies

Peter Jermey

Frequency bias



6hr

At low thresholds models over-represent

At high thresholds models under-represent, but …

… bias is reduced by increased resolution & 4DVAR assimilation

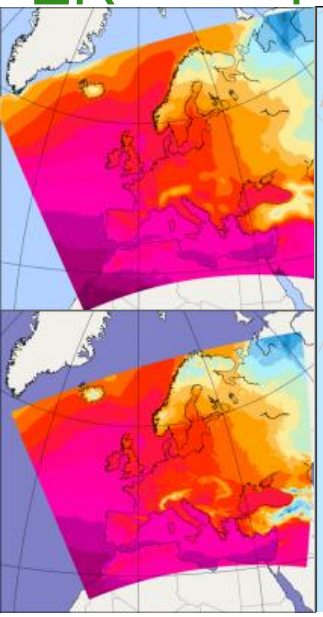
HIRLAM ERA Interim UKMO

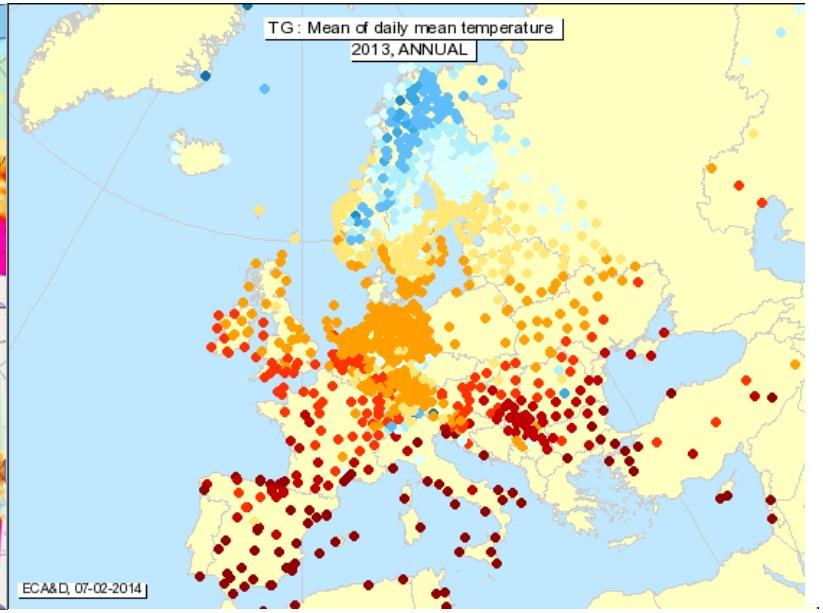
Climate Statistics

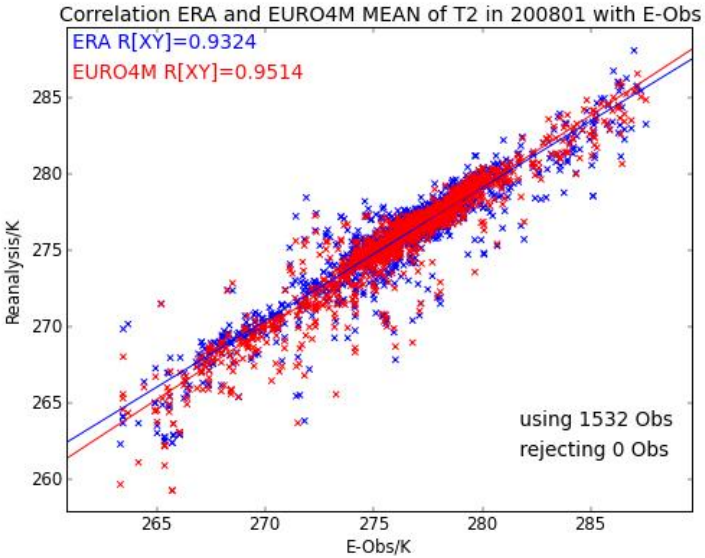
Monthly Means

Compare with ECA&D statistics from obs stations

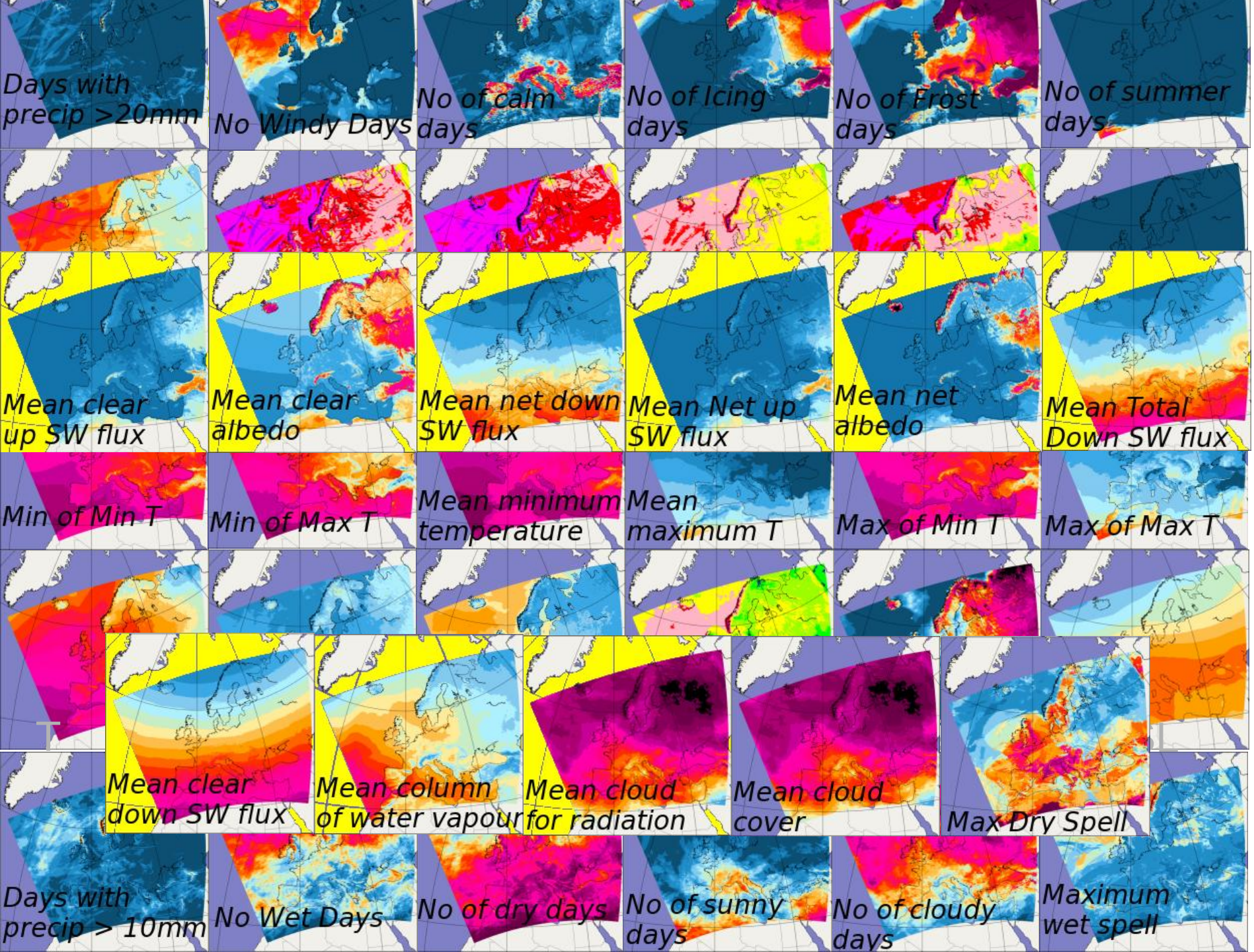
ER







MO


Days with precip >20mm
No Windy Days
No of calm days
No of Icing days
No of Frost days
No of summer days
Mean clear up SW flux
Mean clear albedo
Mean net down SW flux
Mean Net up SW flux
Mean net albedo
Mean Total Down SW flux
Min of Min T
Min of Max T
Mean minimum temperature
Mean maximum T
Max of Min T
Max of Max T
Mean clear down SW flux
Mean column of water vapour
Mean cloud for radiation
Mean cloud cover
Max Dry Spell
Days with precip > 10mm
No Wet Days
No of dry days
No of sunny days
No of cloudy days
Maximum wet spell

Indian Monsoon Data Assimilation and Analysis (IMDAA)

A collaboration between NCMRWF, IMD and the Met Office, 2014-2017

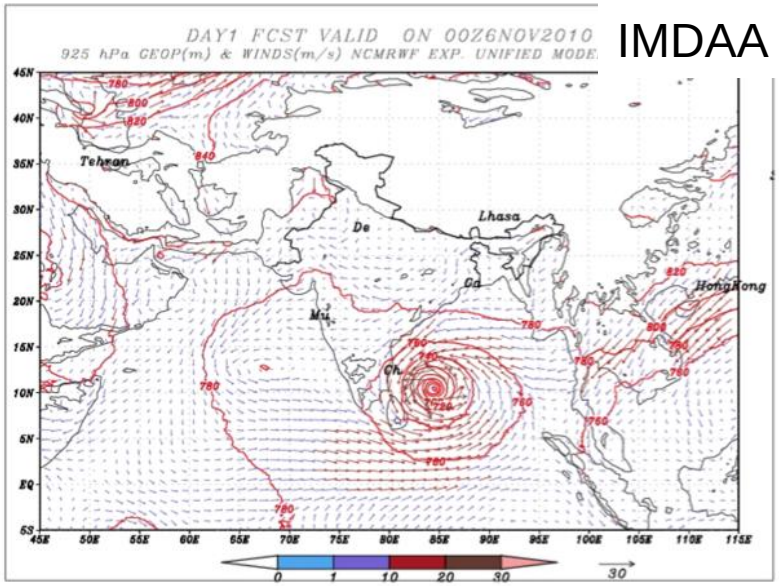
Funded under the MoES National Monsoon Mission

E. Rajagopal, D. Barker

Indian Monsoon Data Assimilation and Analysis (IMDAA)

The IMARR project will:

- *leverage the massive effort undertaken to develop UM internationally.*
- *leverage UM regional reanalyses efforts performed in the EURO4M European regional reanalysis.*
- *be developed in parallel with, and contribute to, NCMRWF's regional UM NWP application.*
- *Perform a 35yr deterministic reanalysis, and a shorter ensemble reanalysis (IMARR-E) to demonstrate reanalysis uncertainty.*



Met Office

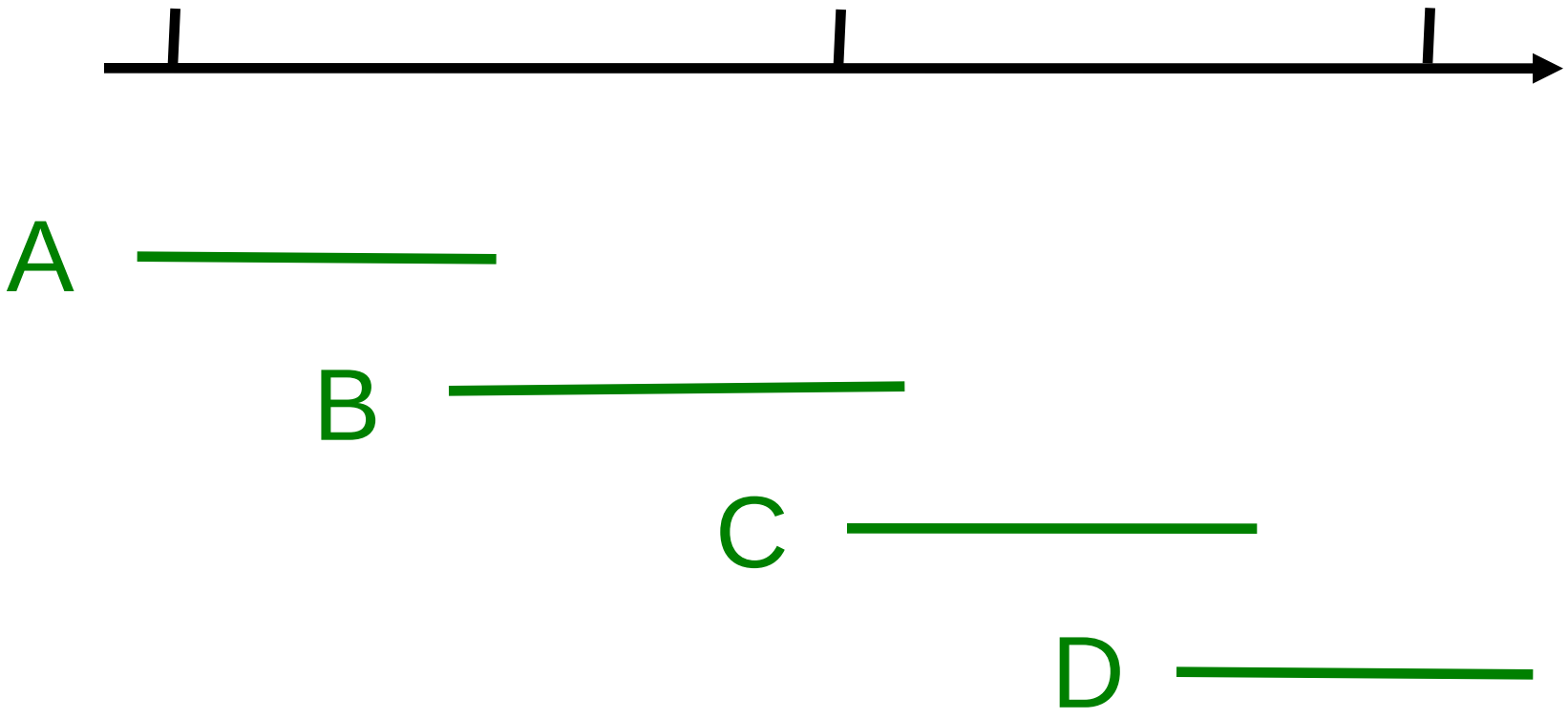
Thank you

http://www.euro4m.eu/Deliverables.html

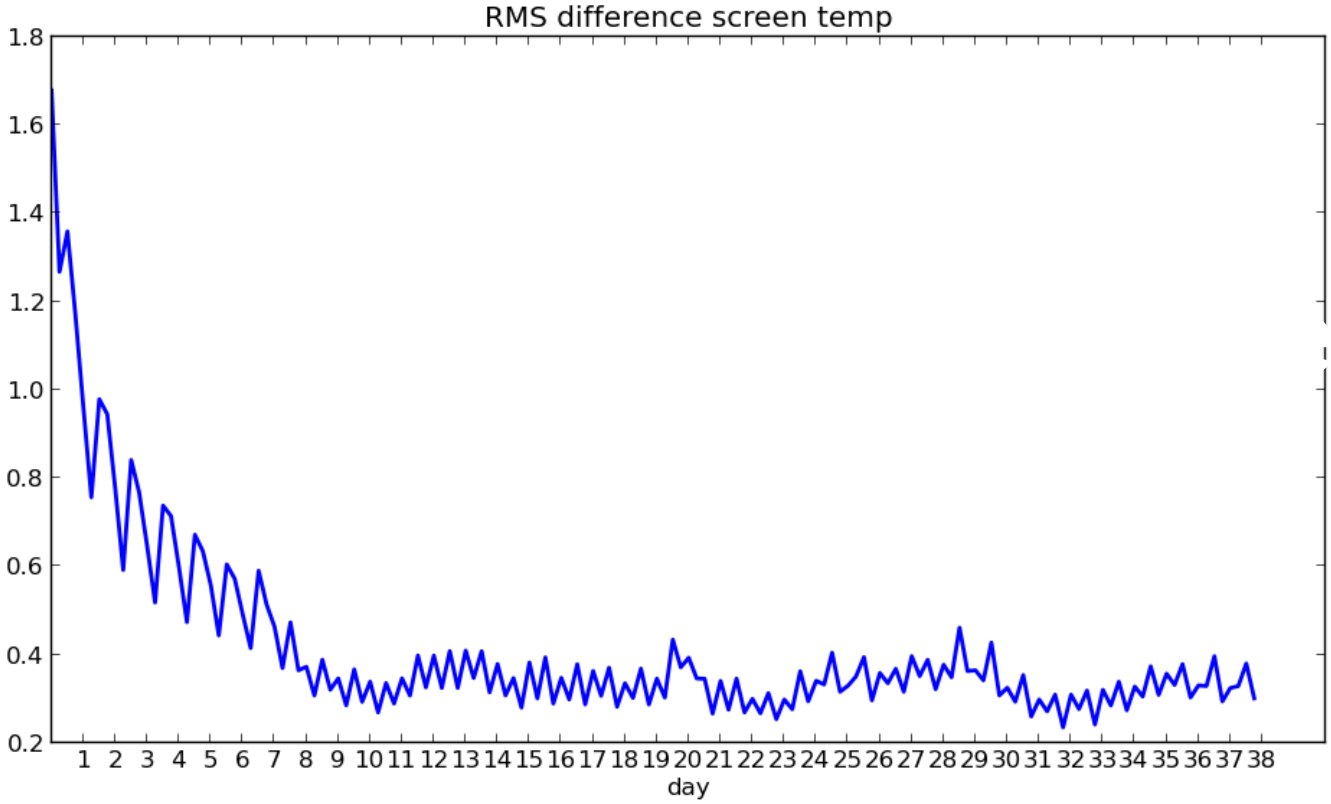
Met Office

Extra slides...

4 Parallel Streams



How long to spin up ?



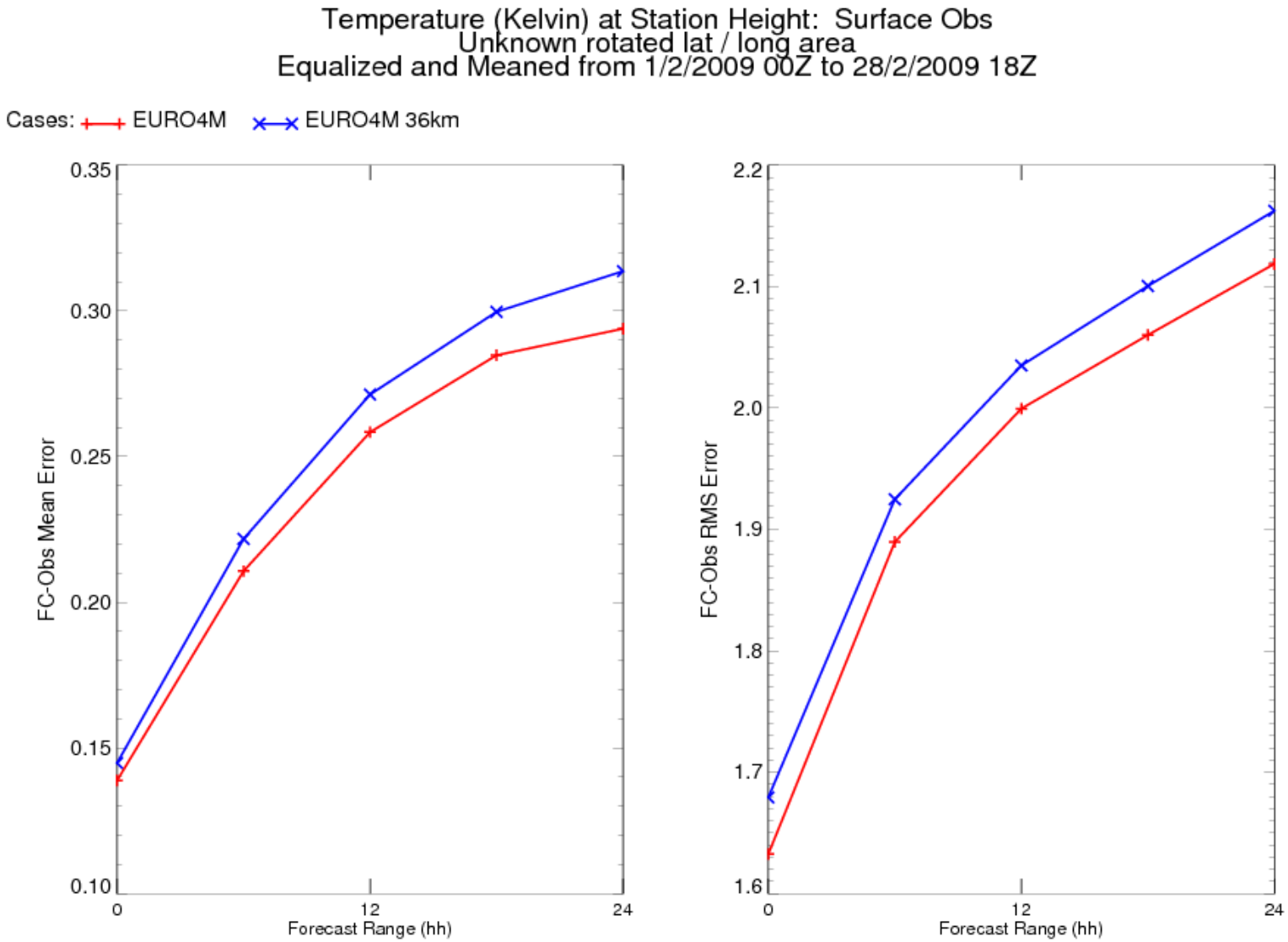
Var Resolution

4DVar run time:

- 36km 1 node hour
- 24km 3 node hours
- 12km 20 node hours

UM T+24 1.5 node hours

Var Resolution: 24 vs 36 km



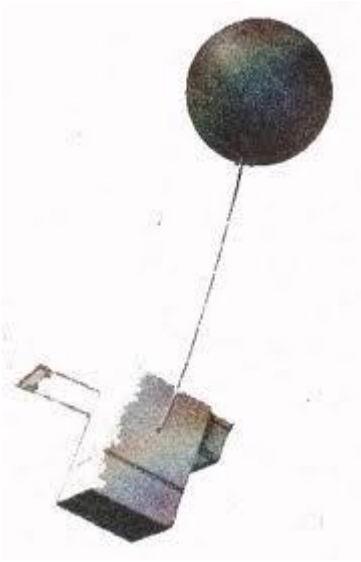
Observations from ECMWF

- Surface (SYNOP, buoy, etc) incl visibility
- Upper air (sonde, pilot, wind profiler)
- Aircraft
- AMV (‘satwinds’)
- ATOVS
- AIRS
- IASI
- GPSRO
- MSG clear sky radiances

Observations from MetDB

- Ground-based GPS
- Scatterometer winds

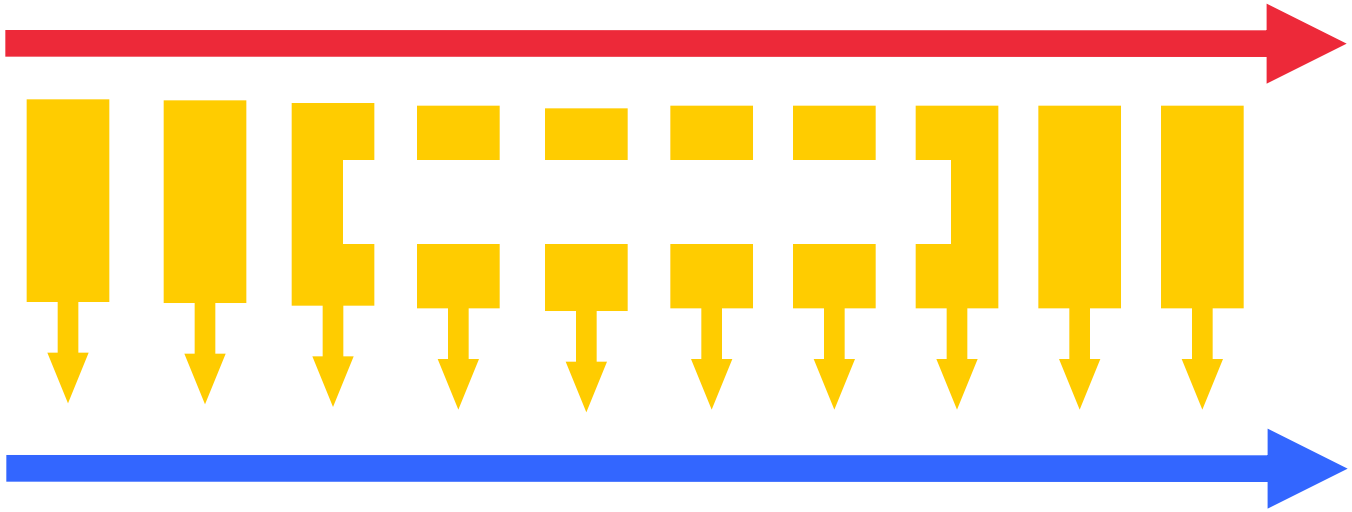
Observation processing



ODB – obs monitoring database

- ODB stores observations + qc + O-B + O-A + ...
  - Established ECMWF database + utilities
    - Array of tools available “for free”
  - Metview macros (quick look)
  - Obstat (detailed stats / graphics)

Met Office



Any Questions?

PS31: estimated impacts

Component	Key items	NWP index	Costs in global
Hybrid	MOGREPS size (44)	+0.6	Reduction in VAR costs (optimisation). [Costs significant in MOGREPS]
	MOGREPS N400	+0.2	
	Modes weights	+0.1	
Satellite	Satwind thinning	+0.6	Minor extra OPS
	Rest of package	+0.4	
Other	OSTIA	+0.5	Nil

Coupled data assimilation: Overview

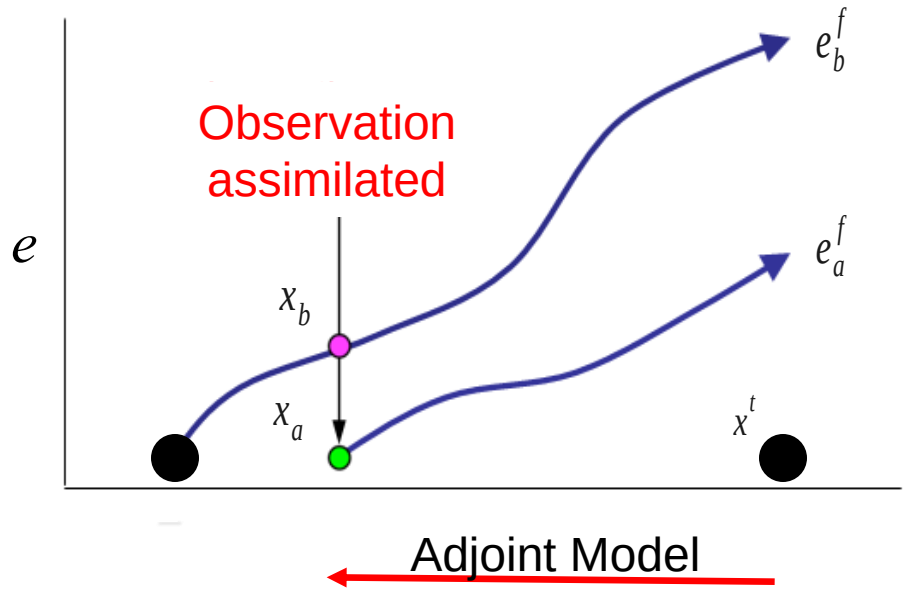
Matt Martin

- Currently the GloSea system uses initial conditions generated separately from ocean-only (FOAM), and atmosphere-only (NWP) model/assimilation systems.
- We plan to develop coupled data assimilation, to begin with using a “weakly” coupled data assimilation approach (see next slide).
- This development is being done using the GloSea5 model components with their associated DA schemes:

Model components	**Resolution**	**DA scheme**
UM atmosphere	N216L85 (~60km)	4DVar
UM land	N216 (~60km)	Soil moisture nudging + ASCAT
NEMO ocean	ORCA025L75 (~25km)	3DVar-FGAT
CICE sea-ice	ORC025 (~25km)	3DVar-FGAT

Forecast Sensitivity to Observations (FSO)

Energy-weighted forecast error norms



background analysis

Observation impact is quantified as the difference in forecast error norm

$$\delta e = e_a^f - e_b^f$$

Adjoint of NWP model/DA system used to derive analysis/observation sensitivity.

- FSO technique can estimate individual contribution of **every** observation.
- Reduces need for expensive data denial experiments.
- Assists optimal design of observation networks.

Comparison of En-4DEnVar with En-4DVar and EnKF

En-4DVar (ECMWF)

- Ensembles of 4D-Var (EDA)
- Ideal, update mimics data assimilation
- Very expensive
- Uses static covariances in ensemble update?

En-4DEnVar (MetO)

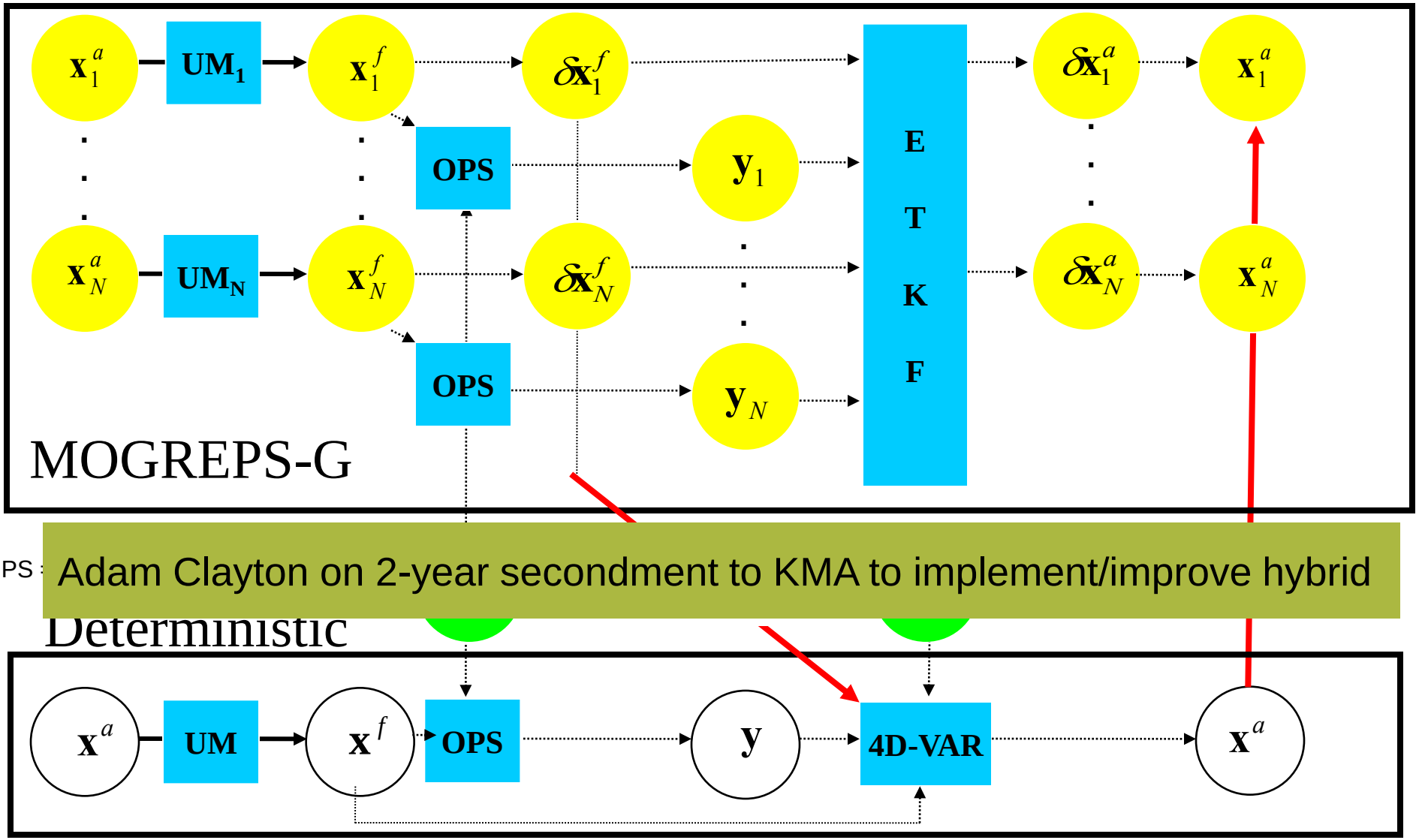
- Ensembles of 4DenVar
- Close to data assimilation
- Fairly expensive
- Some things come for free
  - Parameter transform
  - Localisation in model space

EnKF (Env. Canada)

- Highest maintenance cost
- Update algorithm relatively simple
- Quickest to run
- Possible (difficult) to do hybrid
- May need a linear observation operator

Hybrid 4D-Var/ETKF DA

$$\mathbf{y}_n = H(\mathbf{x}_n^f), \sigma_o, \ldots \qquad \mathbf{x}_n^a = \mathbf{x}^a + \delta\mathbf{x}_n^a$$



Adam Clayton on 2-year secondment to KMA to implement/improve hybrid

Coupled data assimilation: Status

Matt Martin

- A weakly coupled data assimilation (WCDA) system has been set up by combining HadGEM3, VAR, SURF, OPS, NEMOVAR into a single Rose suite.
- The system runs on a 6-hour cycle (the impact of using this time-window on the ocean has been investigated).
- Two one-month trial periods are now being run (Dec 2011 and June 2012) in order to assess the impact of the WCDA system on the short-range forecasts:

1. Weakly coupled DA → 5-day coupled forecasts set 1

2a. Atmosphere only DA (forced by OSTIA SSTs/sea-ice)

2b. Ocean only DA (forced by fluxes from 2a)

} 5-day coupled forecasts set 2

Medium-range Ensemble and ‘Seamless’ Forecasting

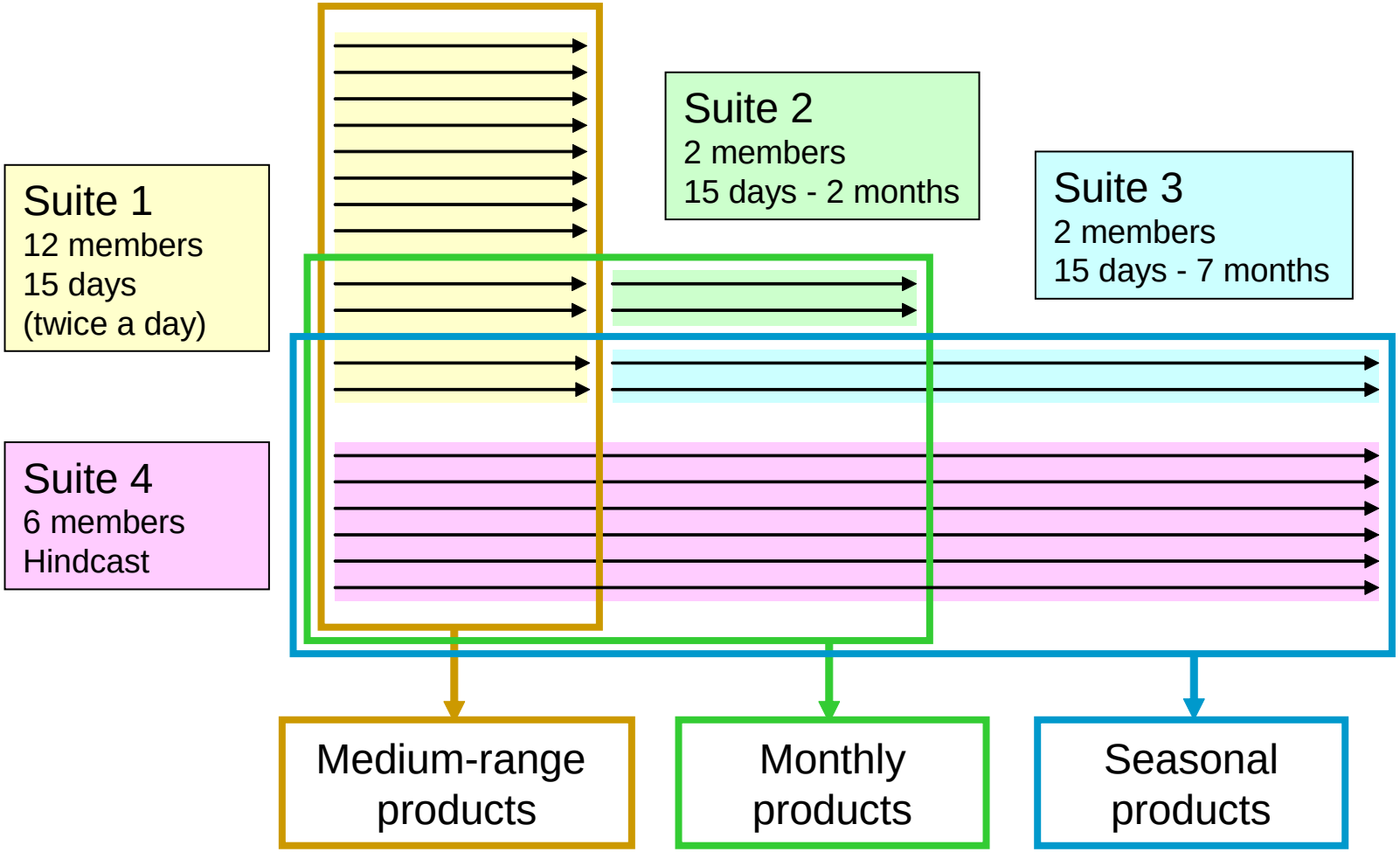
- Before PS31, medium-range ensemble (MOGREPS-15) based on short-range MOGREPS-G (N216/60km 70-level), but run to 15 days using UK member-state computer time at ECMWF.

- **Change in strategy**: Hold-off resolution upgrade (->33km) to uncoupled MOGREPS-15, and instead merge with monthly to seasonal (GloSea5) in a common N216 (60km) 85-level configuration:
  - Initial condition perturbations from ETKF and, in longer term, Ensemble Data Assimilation System;
  - Coupled model to better represent ocean-atmosphere interactions.

- A more comprehensive comparison of MOGREPS-15 and GloSea5 ensembles is currently underway, at N216L85 resolution.

Schematic of possible coupled medium-range/monthly/seasonal EPS

Richard Swinbank



Main changes in the use of satellite data in NWP: 2012-13

John Eyre

- Metop-B added – ATOVS, IASI, ASCAT, GRAS (Dec 12 – Apr 13)
- IASI - correlated obs errors introduced (Jan 13 – PS31)
- OSCAT winds added (scatterometer on India's Oceansat-2) (Jan 13)
- AMVs - revised thinning (6 hours → 2 hours) (Jan13)
- Suomi-NPP added – ATMS and CrIS (Apr 13 – PS32)

- **Overall, satellite data volume assimilated has increased by ~50%**

- Other changes:
  - Locally-received AIRS data (more timely regional data) (Jan 12)
  - Ground-based GPS - now in global (was in NAE and UKV) (Mar 12)
  - Updated radiative transfer model (RTTOV version 9) (Sep 12)
  - ATOVS - variable obs errors (with scan angle, surface type, …) (Jan 13)
  - GPS-RO - new satellite (CNOFS); revised obs errors (Jan 13)
  - Geo clear-sky radiances – GOES-13, GOES-15, MTSAT-2 added (Jan-Apr 13)
  - MODIS aerosol optical depth assimilated (Apr 13)

Satellite data: plans for 2013

John Eyre

- RTTOV-v11 released (Jun 13)
- ROPP-v7 released (Sep 13)

- Assimilation of near-surface MW sounder channels over land
- Improved treatment of obs errors for AMSU, ATMS, SSMIS
- System for processing FY-3 MW sounder data

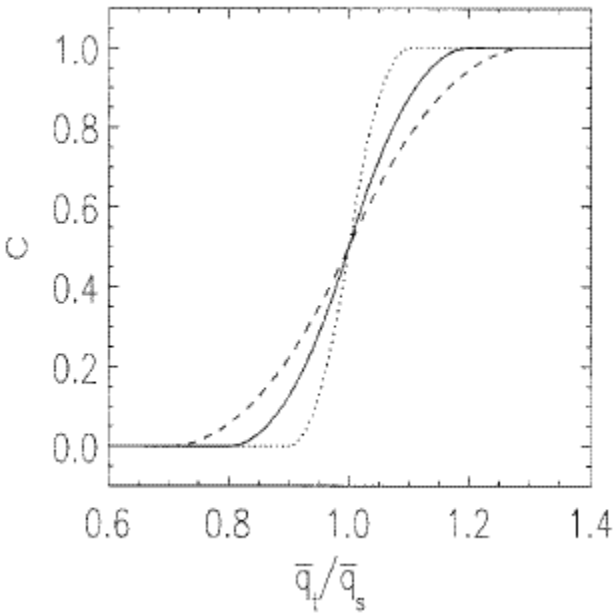
- Improved modelling of clouds in IR radiance assimilation
- IASI data in UKV

- Assessment of VarBC for key satellite data types

- High-resolution AMVs in UKV
- Enhanced aerosol optical depth assimilation
- System to verify UM forecasts using simulated imagery

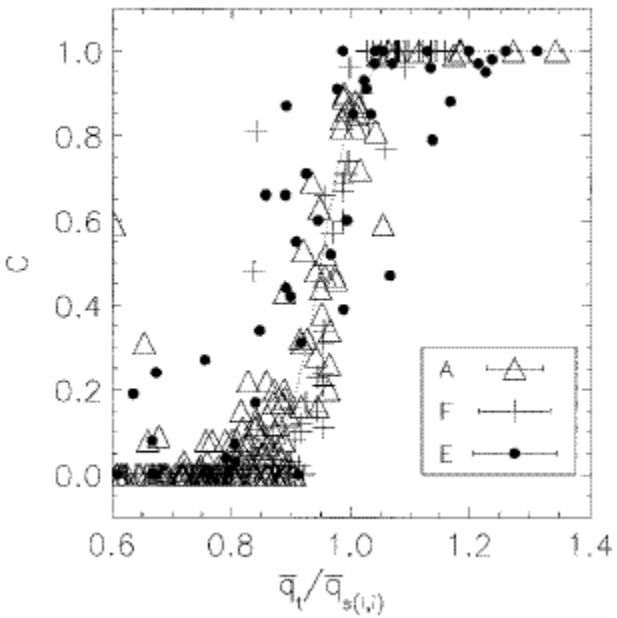
- Report on winds from MTG-IRS (EUMETSAT fellowship)

Cloud-RH diagnostic



Smith scheme

QJRMS 1990



aircraft data

Wood & Field, JAS 2000

Variational Bias Correction

Airmass-dependent bias correction of satellite radiances
(based on Harris and Kelly, 2001)

$$bias = c^{scan} + \sum_{i=1}^{n} ci^{air} \; f(x_b)$$

VarBC allows Var to analyse {*c*}