Met Office

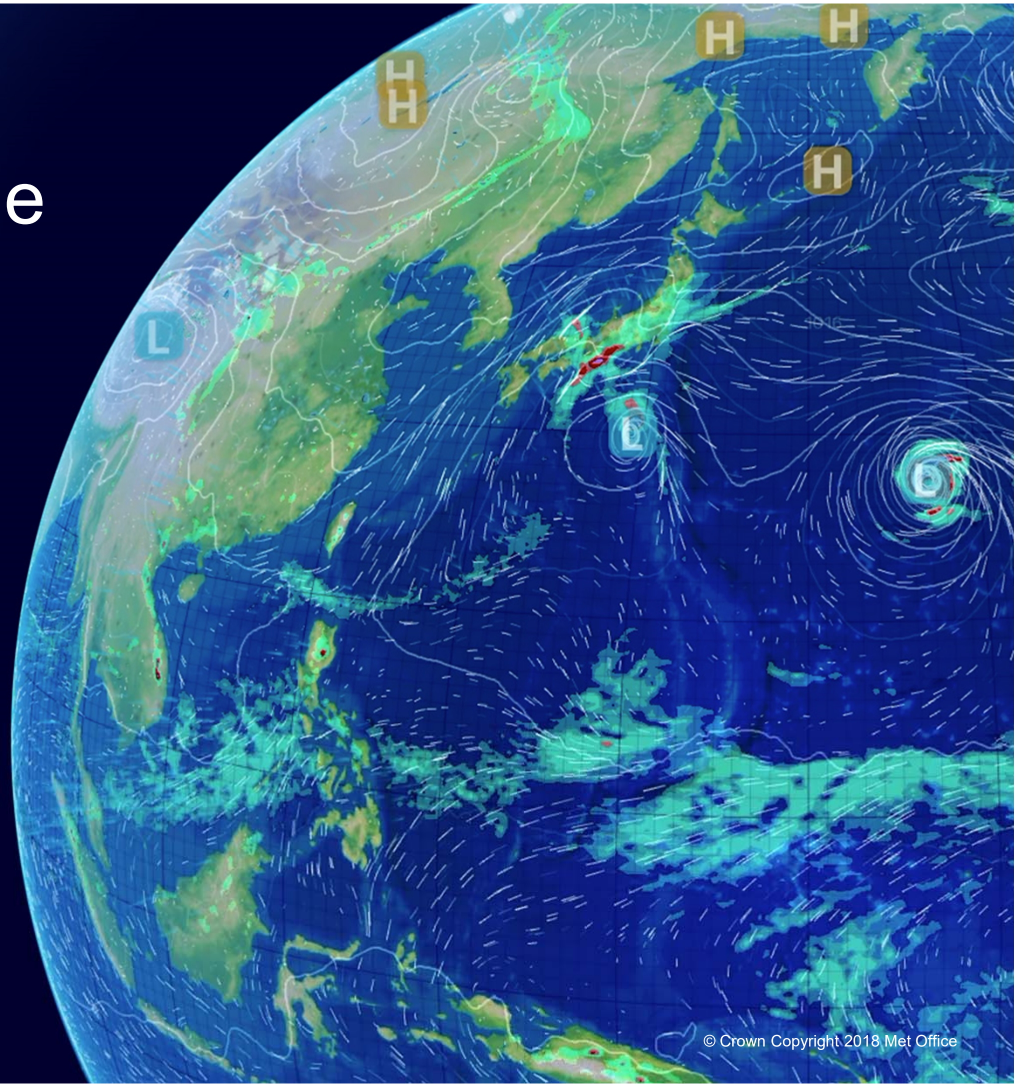
Land surface status at the UK Met Office

Samantha Pullen

Breo Gomez, Cristina Charlton-Perez, Chris Harris, John Edwards, Martin Best, Ed Pavelin, Stuart Newman

ISWG-3 July 2019

Montreal, Canada



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Outline

- Brief overview of current system
- Recent and near-future developments:
  - Land surface physics developments
  - Soil moisture assimilation in the UK NWP system
  - Land temperature analysis
  - Snow depth assimilation for the UK NWP system
  - Assimilation of sounding data over land
- Future challenges and opportunities

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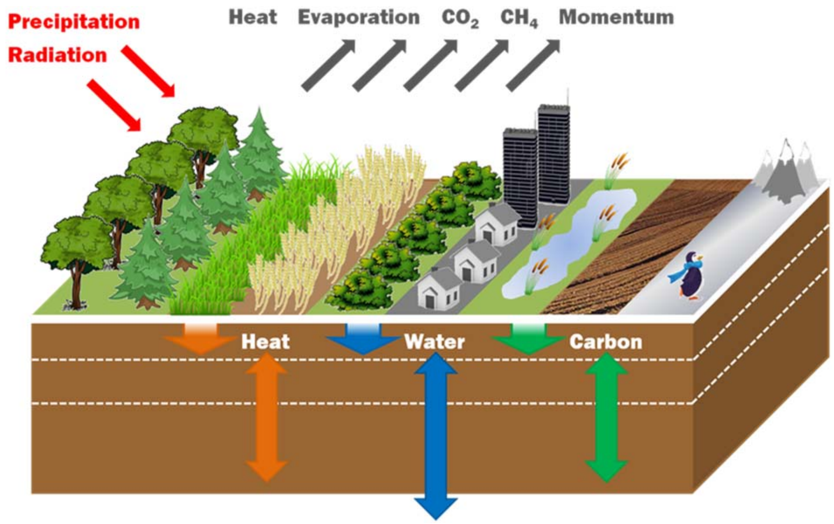
Land Surface Model: JULES



Input:

- Net radiation
- Precipitation
- Wind speed
- Temperature
- Humidity
- Surface pressure
- Surface properties (canopy, soil, snow)

Output:

Surface fluxes:

- •Heat
- •Moisture
- •Momentum
- •(Carbon)

Sub-grid heterogeneity of surface type:

5 Plant functional types:

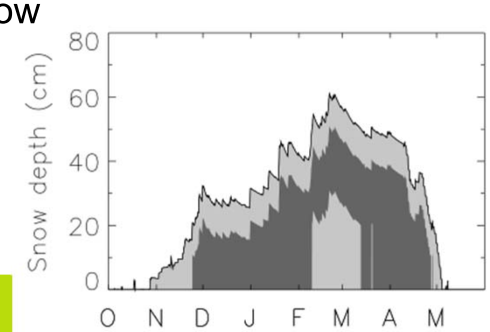
- •Broadleaf trees
- •Needleleaf trees
- •C3 grass
- •C4 grass
- •Shrubs

Plus:

- •Urban(2 types)
- •Inland water
- •Bare soil
- •Land ice

Processes:

- Radiation/surface energy balance
- Hydrology/soil thermodynamics
- Snow



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Land Surface Data Assimilation system

Global model

- Soil moisture assimilation using Simplified Extended Kalman Filter (SEKF)
  - Screen analysis of 1.5m T and RH, ASCAT soil wetness

- Northern Hemisphere snow analysis using simple update scheme
  - Daily IMS NH snow cover product

- Land temperature analysis

UK model

- Daily reconfiguration of global SMC analysis

- Soil moisture assimilation using SEKF

- Snow depth assimilation using Optimal Interpolation

- Land temperature analysis

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Land surface physics developments
(and some sea-ice and ocean surface changes)

- Recently implemented:
  - Multi-layer snow scheme
  - Improved snow grain growth rate
  - Sea-ice drag parameterisation for marginal ice zones
- Coming soon:
  - Surface exchange over ocean for improved marine winds
  - Improved vegetative drag
  - Bare soil evaporation and representation of semi-arid soils

John Edwards, Martin Best, David Walters, Malcolm Brooks, Paul Earnshaw, Gabriel Rooney,
plus Richard Essery, Andrew Elvidge, Ian Renfrew

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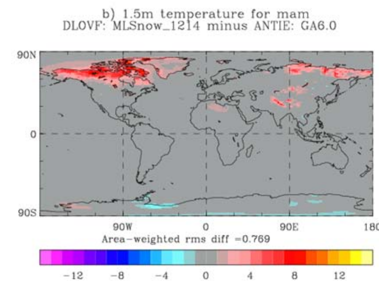
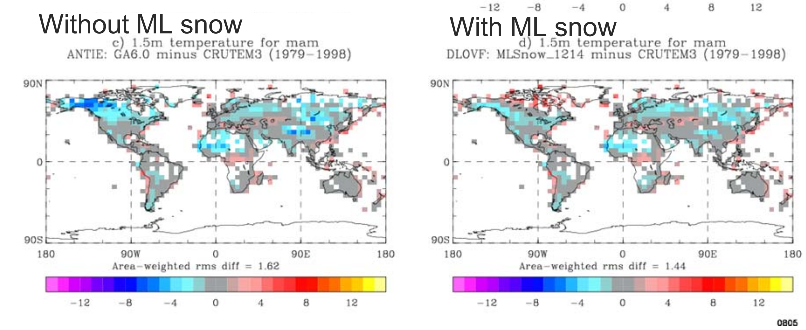
Multi layer snow scheme

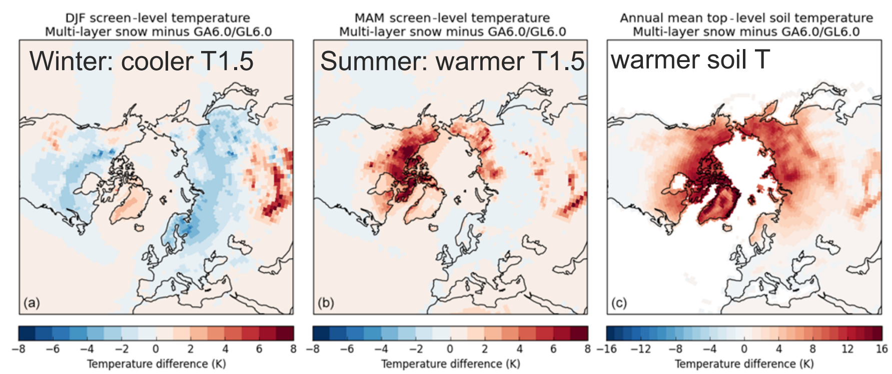
- Maximum 3 layers
- Prognostic variables for each layer – temp, liquid and ice content, grain size, density, thickness
- Snow accumulates to a max thickness, then splits into 2 layers. Continues to accumulate in lower layer, then splits again
- Compaction, canopy unloading, thermal conduction through air in snowpack, water infiltration

1.5m T bias and RMSE reduced





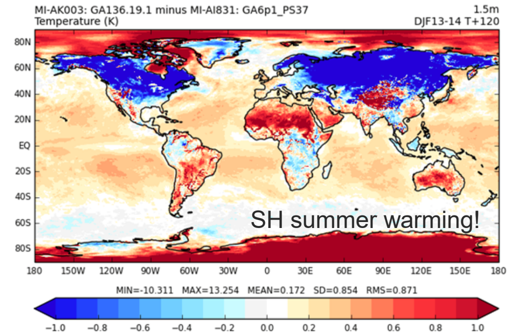
- Largest impact - insulation of the soil beneath the snowpack.
- DJF - near-surface air over the NH snowpack generally colder (reduced heat flux from soil to atmosphere)
- MAM - air warmer (snow-melt over warmer soils leads to less cooling from below)
- Annual mean - significantly warmer soil layer, from additional insulation. Improves a long-standing model bias, expect to improve simulation of permafrost.

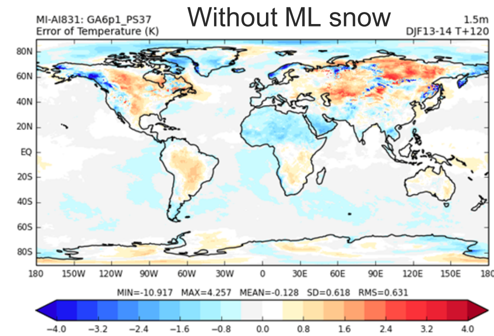


Best *et al*: The Joint UK Land Environment Simulator (JULES), model description – Part 1: Energy and water fluxes, Geosci. Model Dev., 4, 677–699, https://doi.org/10.5194/gmd-4-677-2011, 2011
Walters *et al*: The Met Office Unified Model Global Atmosphere 7.0/7.1 and JULES Global Land 7.0 configurations, Geosci. Model Dev., 12, 1909-1963, 2019 https://doi.org/10.5194/gmd-12-1909-2019

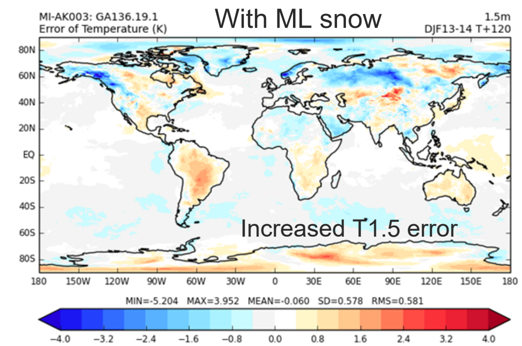
Met Office Implementing in operations

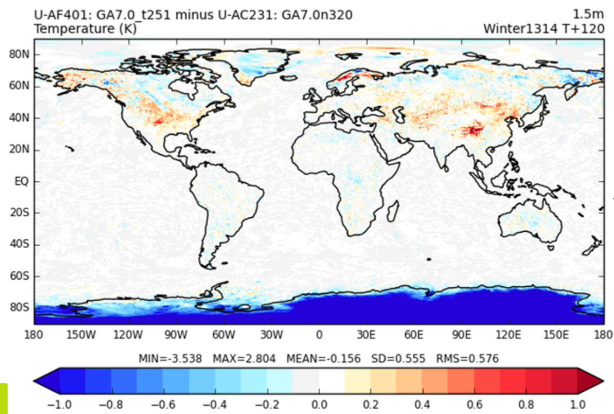
- Tests in full NWP system – skill score reduced, T1.5 warm bias over Antarctica
- Darkening of Antarctica in summer – thought to be good (improved outgoing SW vs climatology)
- But comparisons with in situ obs albedo and grain size → model too dark, grains too large





- Parameterisation of growth of snow grains replaced by equitemperature metamorphism scheme by Taillandier et al., 2007
- Growth of grains reduced by factor of 7 < 30°C





Slower grain growth at cold temperatures

↓

Reduced warming over Antarctica

↓

Improved NWP skill score

Met Office NWP improvements – surface?

Multi-layer snow scheme, with updates to snow grain growth rate

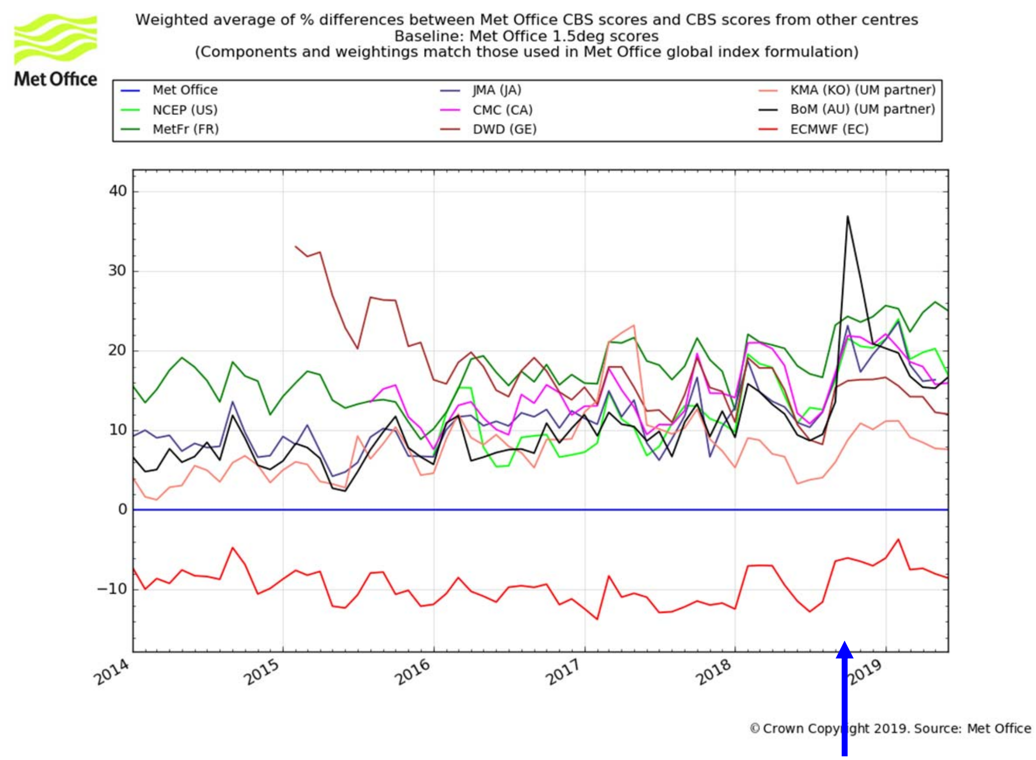
+

Sea-ice drag – parameterisation over marginal ice zones

- Aircraft obs used to tune drag coefficients
- Reduced drag coeff → reduced bias in momentum flux, wind spd., T

↓

Model upgrade (GL8.0) went operational September 2018

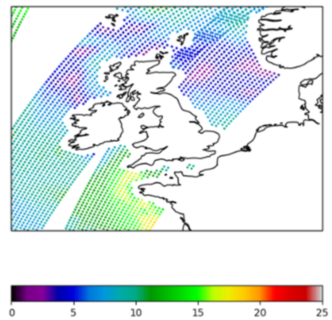


Upgrade Sep18

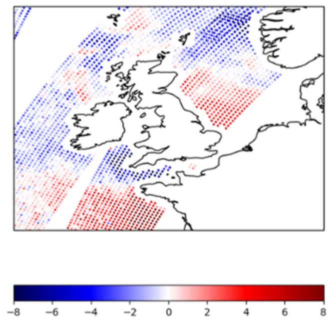
Met Office Upcoming developments

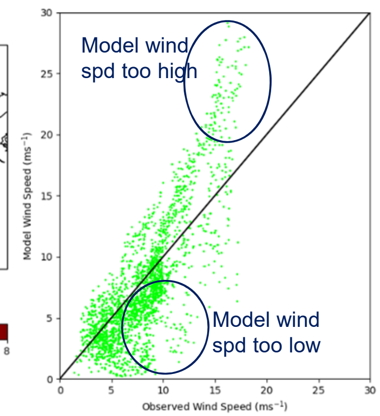
- Marine winds – improving ocean surface drag
  - Too much surface drag for low wind speeds, not enough for moderate wind speeds, need to cap or reduce drag at high wind speeds (observational evidence).
  - Drag coefficient at high wind speeds important for global model now resolution starting to be high enough to capture TC intensity

model

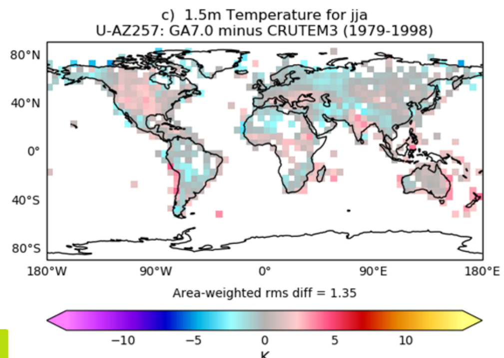


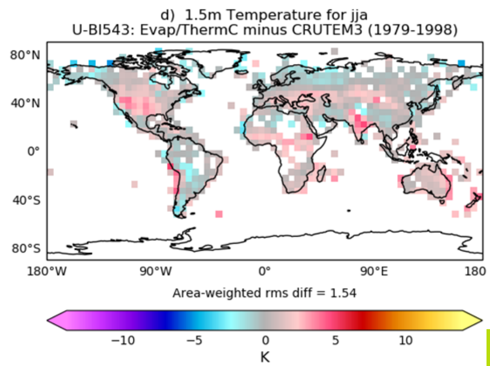
Model -ASCAT obs





- Improvements to vegetative drag
  - Momentum roughness lengths tuned using FLUXNET data and specified for each PFT – increased roughness for vegetated surface, improvement to high pressure bias over pole





- Bare soil: reduced evaporation and improved representation of semi-arid soils
  - Improvements to RMSE soil moisture, but increased warm 1.5m T bias
  - More work needed – longer term goal

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Soil moisture assimilation in the UK NWP system

- Replaces the daily reconfiguration of the Global SMC analysis
- Operational implementation November 2019
- More details in Cristina Charlton-Perez’s talk (Tues 09:50: Overview of the Met Office land surface data assimilation system)

Breo Gomez, Cristina Charlton-Perez,
Huw Lewis

Soil moisture analysis for the UK NWP system

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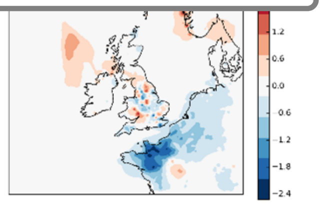
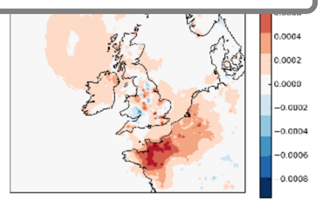
Observations

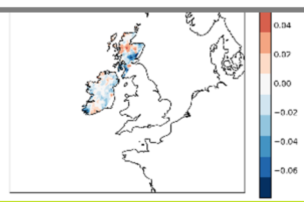
1.5m Temp (Gridded)



1.5m Spec Hum (Gridded)



ASCAT Soil Moisture



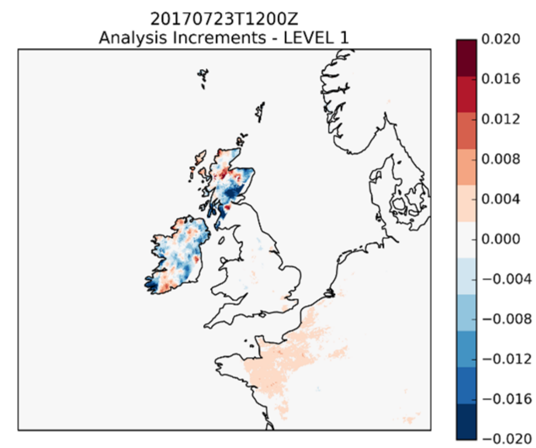
Simplified Extended Kalman Filter

$$x^a = x^b + K\left(y - \mathcal{H}(x^b)\right)$$

$$K = \mathrm{BH}^T(\mathrm{HBH}^T + \mathrm{R})^{-1}$$

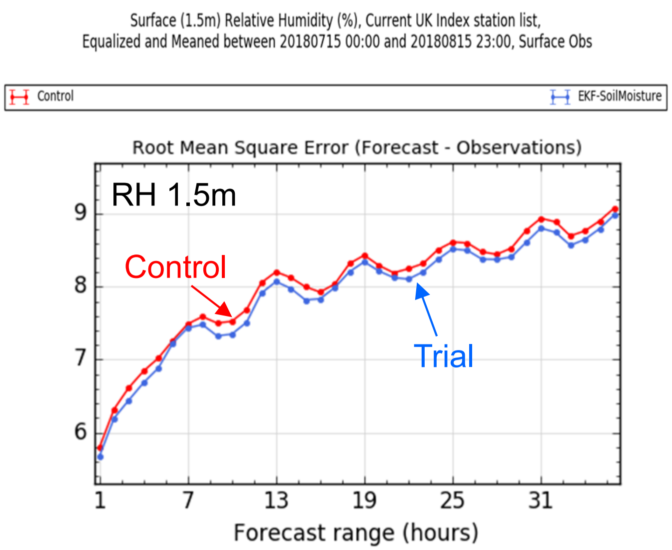
- Adapts the methodology used for the global model
- Regional analysis every 1h
- Obs interpolated to model grid
- B and R diagonal and isotropic, using realistic values of model and obs errors
- *H(x)* taken from model background
- Kalman Gain K estimated by finite differences, running offline Jules model with perturbed IC.

Soil moisture analysis increments



Met Office UK soil moisture analysis - forecast impacts

Summer and winter assimilation trials:
- Neutral impact on atmospheric variables
- Small improvement RMSE summer screen humidity

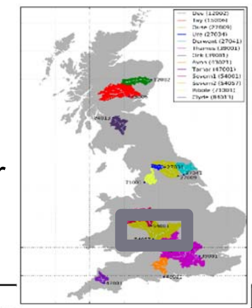


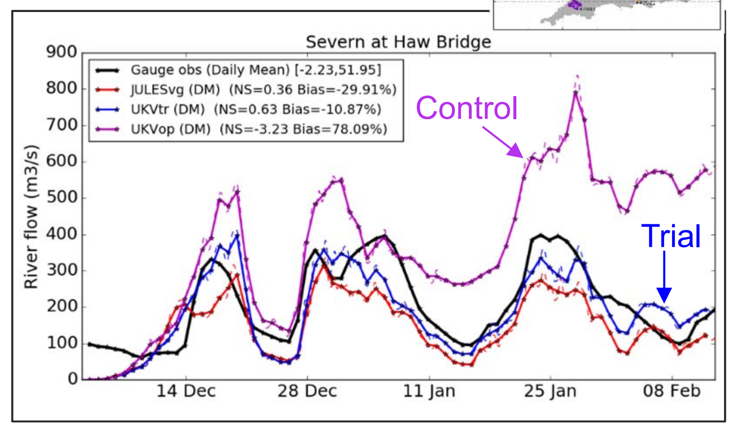
Much larger impact on hydrology:
- Biggest contribution is to the surface and sub-surface runoffs.

Surface and sub-surface runoff routed with JULES river model

Simulated river flows are much more realistic for the trial with EKF

Severn river basin





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Land temperature analysis

- Using land temperature increments from the EKF
- Undergoing trialling for global and UK model implementation

Breo Gomez

Land temperature Analysis

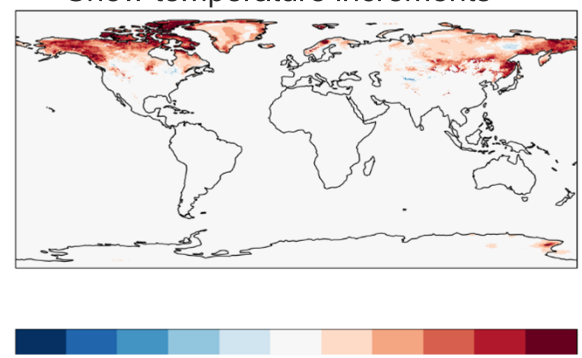
Operations: land temperature increments are provided by the atmospheric increments at the lowest level

- Assumes a synchronization between atmosphere and land evolution
- Independent from Soil moisture analysis, increments are inconsistent

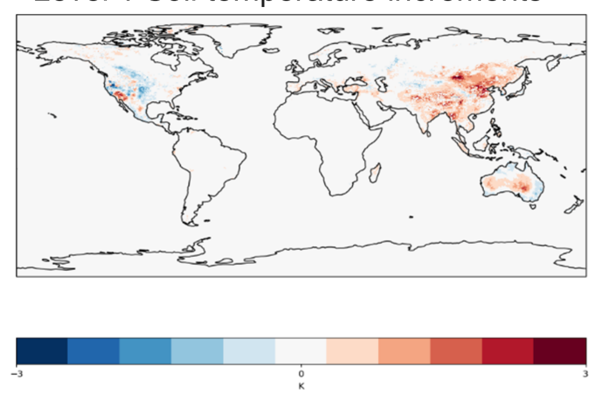
EKF for soil moisture analysis is able to provide Skin, Soil and Snow temperature analysis

- Better consistency between land and atmosphere
- Increased coupling

Snow temperature increments



Level 1 Soil temperature increments



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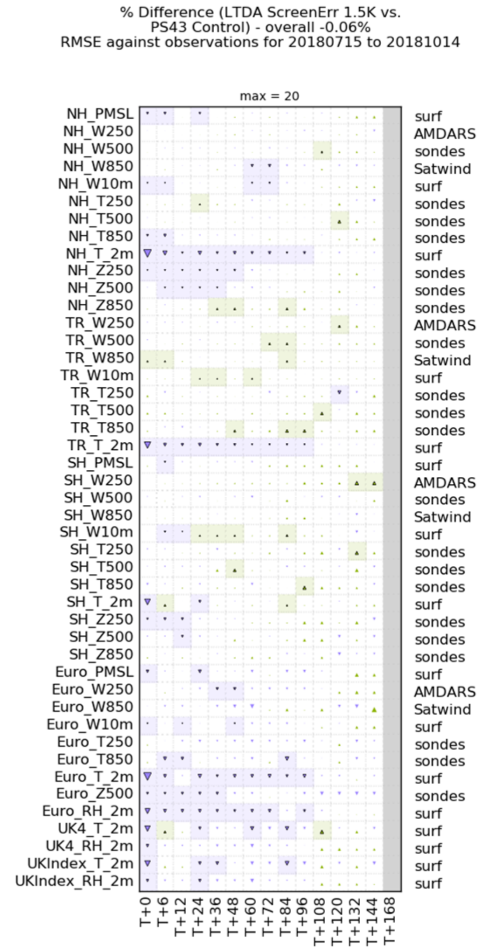
Land temperature Analysis

Initial tests applying these land temperature increments with the same error covariance parameter showed poor results

R-matrix

- Screen Temperature = 1.5K
- Screen Humidity = 8%
- ASCAT SM = 0.035 m3/m3

We use Desroziers diagnostics to evaluate the R matrix values.

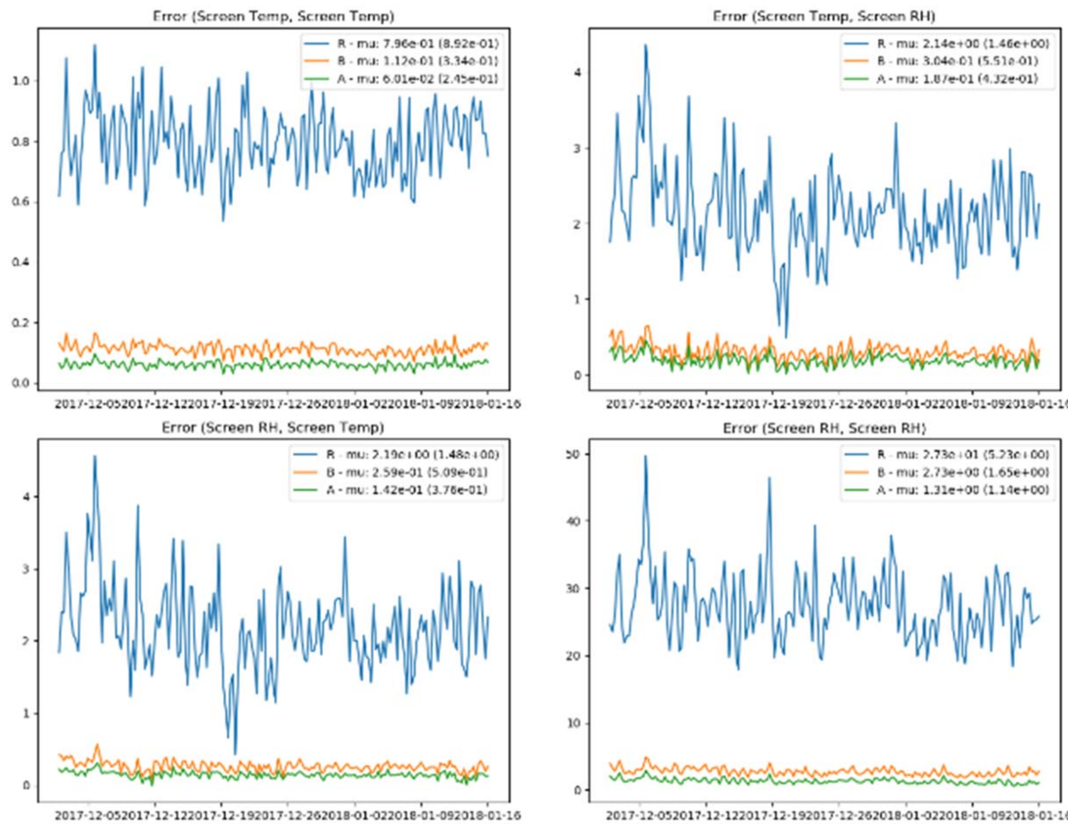


Land temperature Analysis

Deroziers stats suggests

- R-matrix
  - Screen Temperature ~ 0.75K
  - Screen Humidity ~ 4%
  - Ascat SM ~ 0.035 m3/m3 (no change)
- It also suggests a non-zero error covariance.
  - ScreenTvsScreenRH ~ 1K%

Tested on a N320 suite, 3 months, Summer and Winter.



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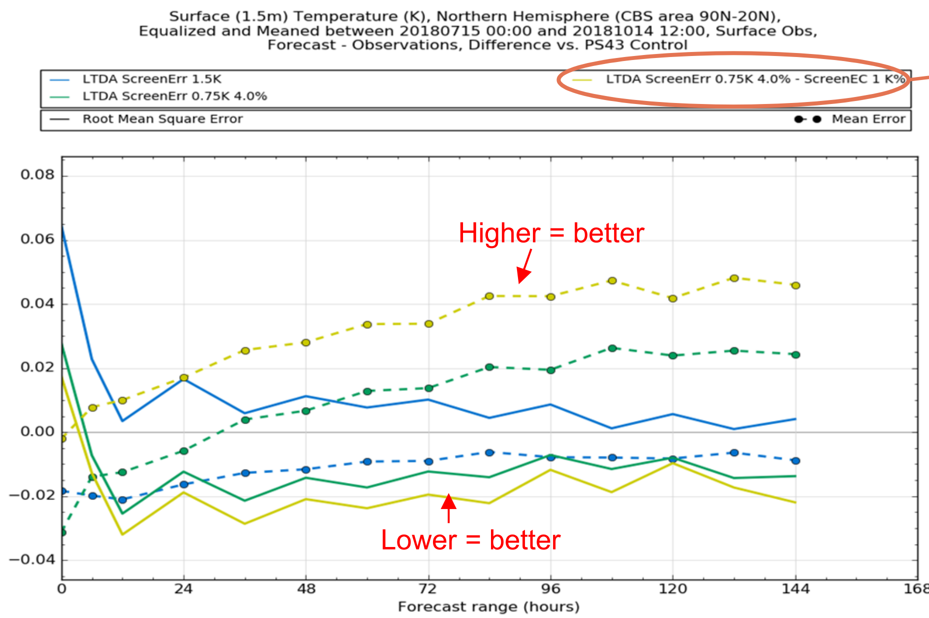
Land temperature Analysis

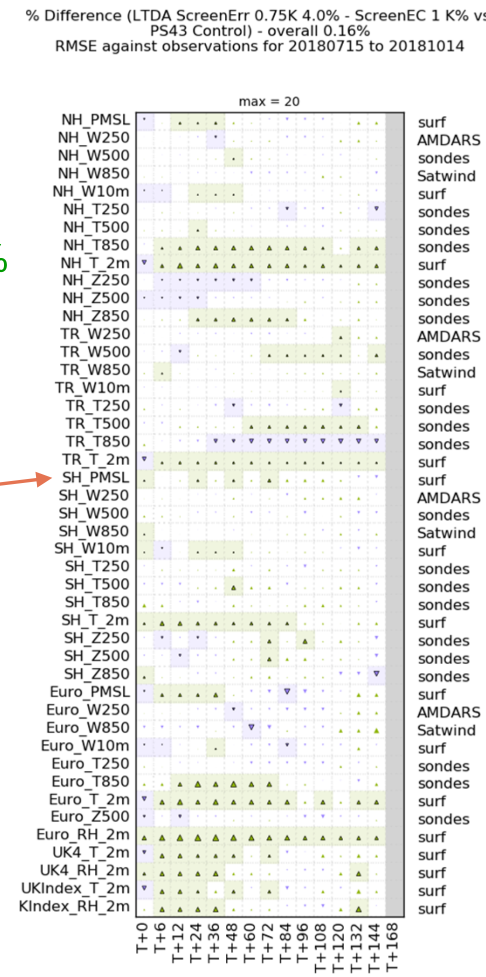
Control: Surf SM analysis, Land temperature inc from Atmospheric analysis

Experiments with SMC and temperature analysis from SURF:

1. Error: ScreenT 1.5K / ScreenRH 8%
2. Error: ScreenT 0.75K / ScreenRH 4%
3. Error: ScreenT 0.75K / ScreenRH 4%, Errorcovariance: ScreenT vs ScreenRH: 1K%

NH / 1.5m Temperature RMSE and BIAS Experiment – Control / N320 Summer





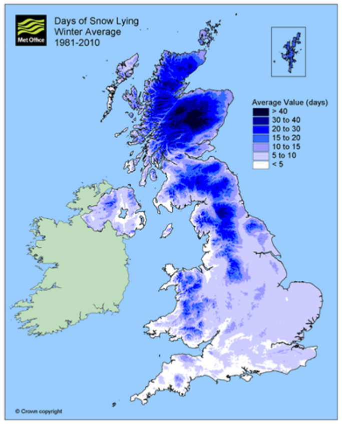
Snow depth assimilation for the UK NWP system

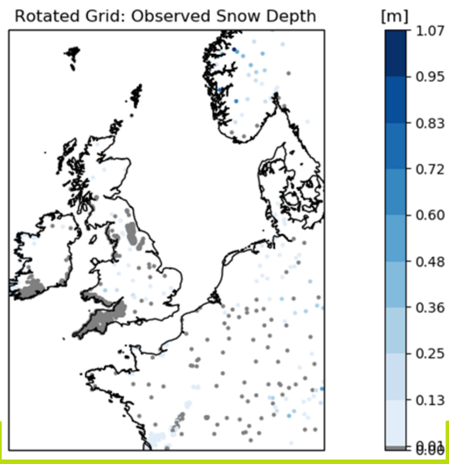
- New assimilation scheme using OI
- Undergoing assimilation trialling
- More details in Samantha Pullen's talk (Wed 09:50: Snow data assimilation developments at the Met Office)

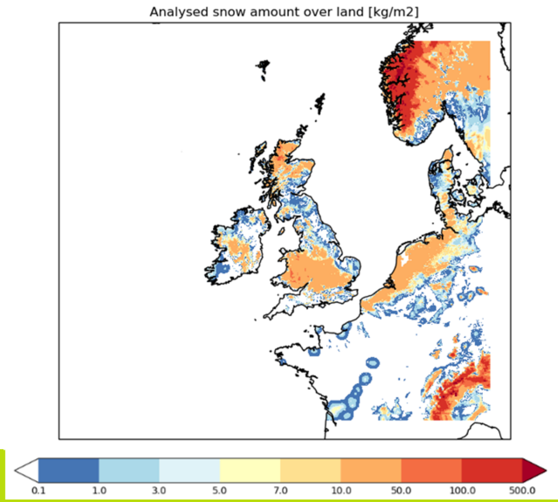
Samantha Pullen, Cristina Charlton-Perez

Snow assimilation for the UK NWP system

- Currently no assimilation of observations of snow properties into UK NWP model
  - Snowpack properties evolve freely
- Optimal interpolation snow depth analysis developed
  - *In situ* reports of snow depth and state of ground from SYNOP network
  - Satellite observations of snow cover from H SAF (MSG-SEVIRI)
- Initial assimilation trials run, further trials underway
- Full details on Wednesday!







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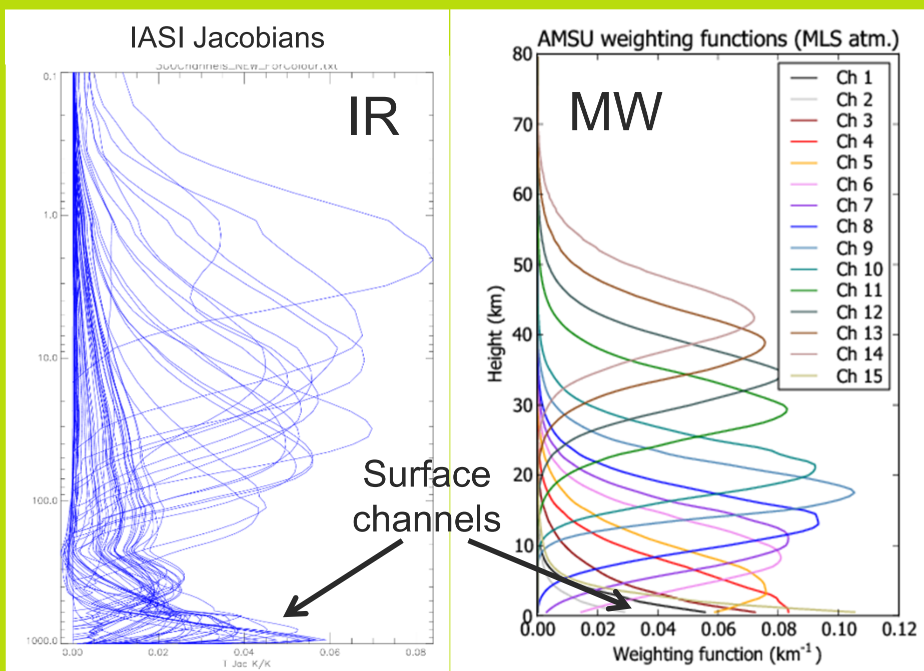
Assimilation of sounding data over land



- 1D-Var retrieval of surface state
- Assimilating microwave humidity information over land
- Improved infrared radiance assimilation over land

Ed Pavelin, Stuart Newman

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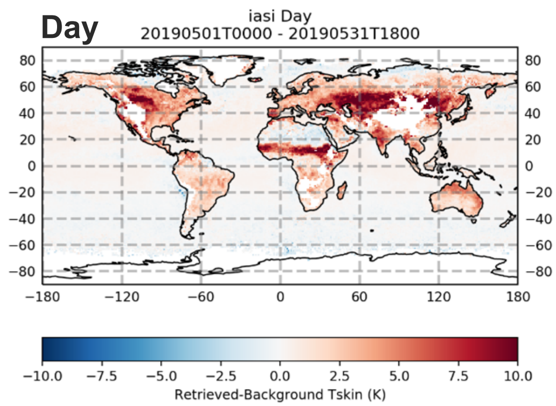
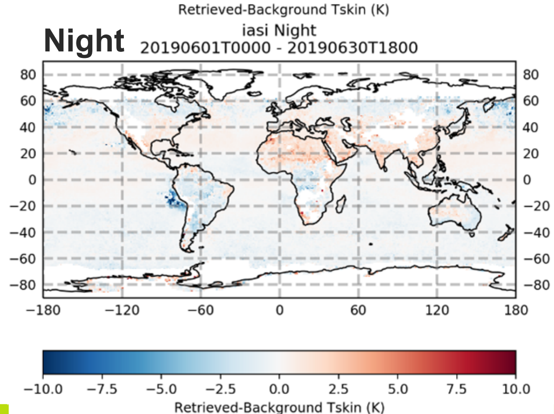
The challenge





Variability of land surface emissivity and skin temperature presents challenges to the use of surface-sensitive radiances over land

- Large daytime Tskin bias in model – hot/semi-arid surface
- Land surface emissivity not sufficiently well known

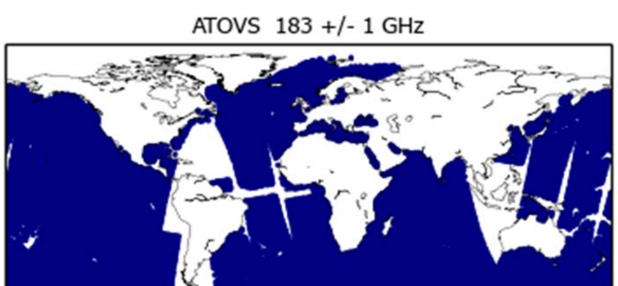
- 1D-Var used in pre-processing to retrieve surface variables:
    - Surface skin temperature
    - MW emissivity
    - IR spectral emissivity (in PC form)
    - Used in 4D-Var as fixed constraints in RT calculation
- IR surface-affected channels only used at night
- Use of new emissivity atlases as the first guess for the 1D-Var retrieval

Microwave humidity information over land

(Stuart Newman)

Motivation

- Current use of microwave humidity information over land is limited (only SAPHIR in the Tropics is assimilated in the Met Office global model)
- Quality control issues over land include surface sensitivity (Tskin and emissivity) and availability of cloud tests (scattering effects at higher frequencies)

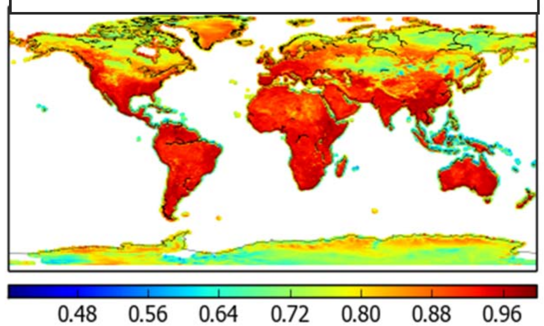


Usage of MHS channel 3 during 6-hour window

Surface retrievals

- Monthly gridded emissivity atlas (F. Karbou, CNRM) used as a first guess for 1D-Var retrieval
- Retrieved Tskin and emissivity passed to 4D-Var

Example emissivity atlas (150 GHz, Jan)



Into operations

(1) Extend QC: additional cloud test using scattering index over land

(2) Retrieved emissivity at 150 GHz is used for channels at 183 GHz

Assimilate MHS channels 3/4/5 over land (global model)

- Trials showed improved background fits to independent humidity-sensitive observations
- Upgrades undergoing parallel testing, due operational in Nov19

Improved IR radiance assimilation over land

(Ed Pavelin)

Use of CAMEL emissivity atlas in NWP

- For IR radiance assimilation: Met Office performs a 1D-Var land surface emissivity retrieval (AIRS, IASI and CrIS) (Pavelin *et al.* 2014)
- First guess for retrieval: Currently using a relatively crude emissivity atlas (annual mean, 1° resolution)
- Plan to use CAMEL climatology – combines UWisc UWIREMIS atlas with JPL ASTER database (Borbas *et al.* 2017)
  - Monthly climatology of spectral emissivity
  - 0.05° resolution
  - Integrated into RTTOV 12.3
- Currently being tested for future operational upgrade (2020)
  - Expect improved analysis of surface temperature and cloud variables
  - Expect modest NWP forecast improvements

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Future goals and challenges

- Near term
- Further ahead

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Challenges and opportunities

Land surface emissivity and skin temperature

- Improved modelling, especially semi-arid regions, bare soil properties
- Snowpack microphysical and RT modelling developments (evaluation of MACSSIMIZE campaign)
- Enable more/better use of sounding data over land and snow/ice
- Enable satellite LST assimilation, help snow assimilation

More use of observations in LSDA

- Global snow OI – take advantage of improved reporting and exchange of *in situ* snow obs (snow depth, SWE)
- Additional soil moisture obs (SMOS/SMAP)

Improve coupling between surface and atmosphere

- Boundary layer sensitivity to surface fluxes – get more impact from LSDA

Development of Next Generation NWP systems (*)

- Common framework for land and atmosphere?
- New ensemble methods, multivariate assimilation, direct radiance assimilation using forward models

Coupled Land/Atmosphere DA (*)

- Coupled Ocean/Atmosphere due 2021
- Explore possible SMRT coupling to RTTOV for snow/sea-ice TOA radiance simulations
- Surface and atmosphere increments from the same observations

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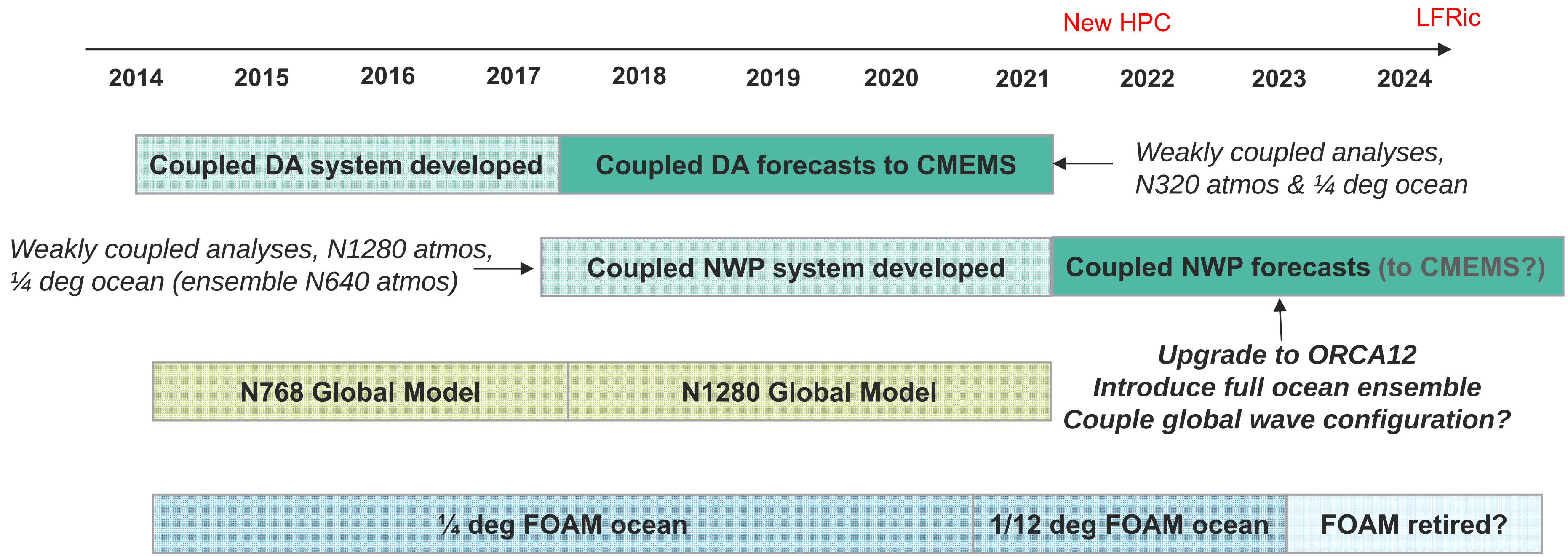
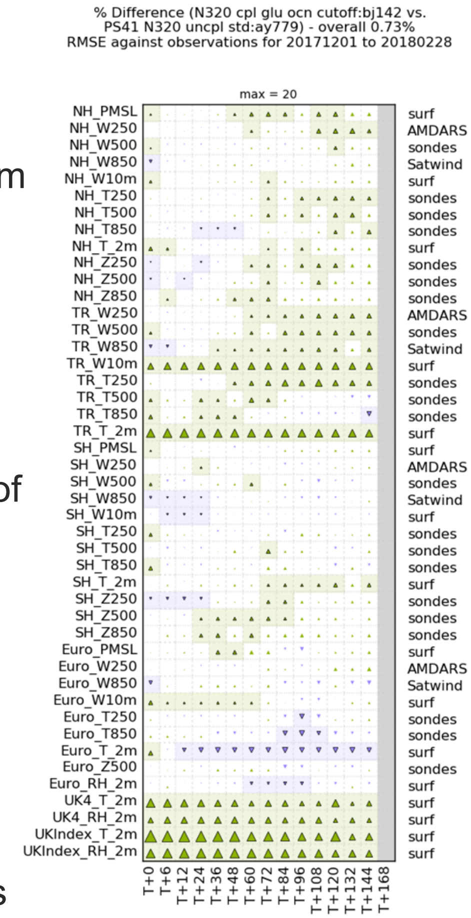
Questions?



- ‘Coupled DA’ system (with observational & other routine upgrades) will deliver to CMEMS until ocean products from ‘Coupled NWP’ system is able to replace it
- Ocean-only FOAM will remain at least until we have the resource (on the next HPC) to upgrade coupled ocean to ORCA12

Met Office — Coupled NWP Status and Plans

- Working towards transitioning operational global NWP to an atmosphere-ocean coupled system on the current HPC in 2021
  - Initial focus will be NWP but will expect to provide ocean forecasts from this system on the next HPC when the ocean model resolution has been upgraded from 1/4 to 1/12 deg
  - ‘Weakly coupled’ data assimilation using coupled model background fields but independent DA codes
- Building on previous work including the low resolution coupled DA system which provides ocean products to the Copernicus Marine Service
- Observation scorecard shown is for a 3-month winter 2017/18 trial period of an N320 atm-ocn coupled model (hybrid mode but with archived atm-only ensemble data) compared to a standard N320 atm-only PS41 set-up
- Shorter N640 trials (with N320 atm-ocn ensemble) show similar impact
- No trialling yet at operational (N1280) deterministic resolution but coupled forecasts (from un-coupled analyses) are being run routinely in near-real-time and have shown benefit for long lead time track prediction for strong tropical storms, and for Madden-Julian Oscillation forecasts
- Currently assessing best approach for ensuring late arriving ocean observations are not lost from system and how approaches to address this may interact with other proposed developments like multiple outer loops



JULES to UM - fluxes

UKV (runs with multiple tiles)

Global (runs with aggregate tile)