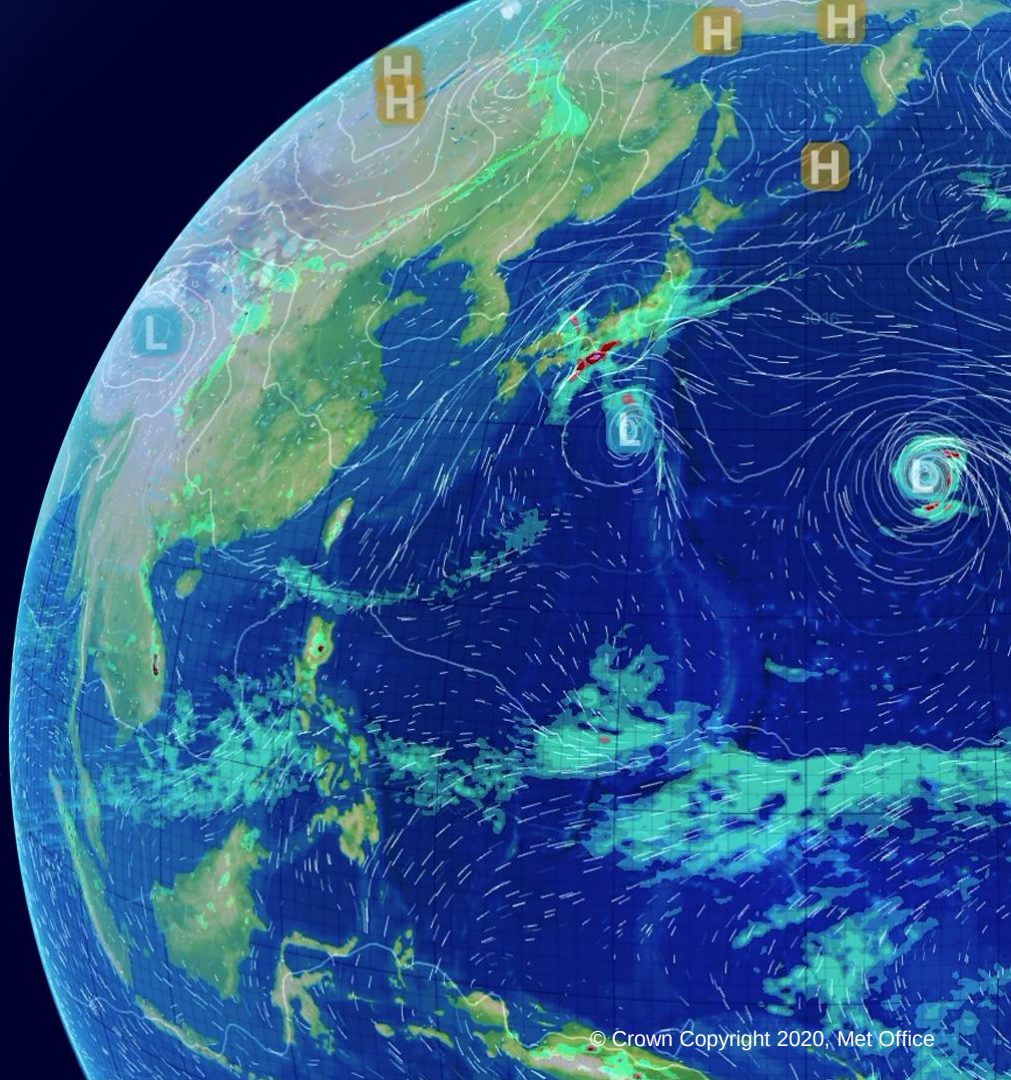
Land Surface Data Assimilation Overview Met Office

Cristina Charlton-Pérez,
Breogán Gómez, Samantha Pullen,
Chris Harris and Huw Lewis

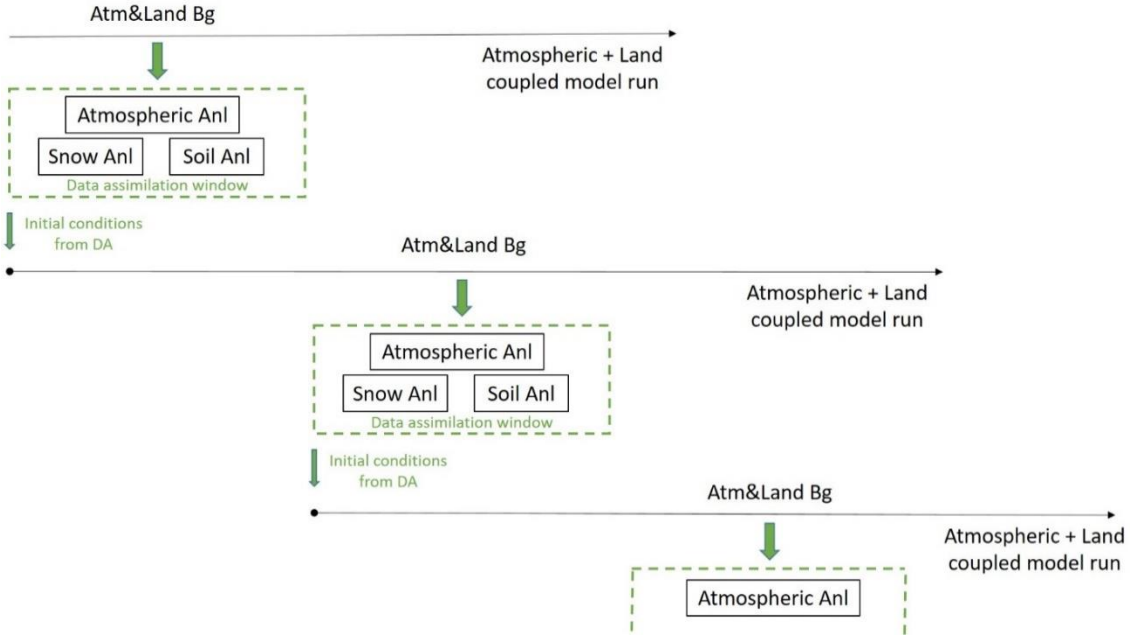
EWGLAM/SRNWP 29 September 2020



LSDA Overview

- Current status of Operational Land Surface Data Assimilation (LSDA) in Met Office NWP system since December 2019
- LSDA developments (PS44) intended for operations November 2020
- Global and Regional
- Met Office LSDA plans for next 1-2 years
- Future directions

Operational LSDA in Met Office NWP



- LSDA is *quasi-strongly* coupled with atmospheric DA
  - Interaction between the DA components happens at the model run initial time.
  - But DA systems are independent
  - Land uses obs from atmos
  - Background for next cycle result of coupled run: Atmosphere (UM) and Land (JULES) components are coupled

Operational LSDA

Observations

ASCAT soil wetness index
- MetOp-A, B
- MetOp-C from July 2019
- Bias corrected
- Converted to soil moisture
- QC'ed and interpolated

Simplified Extended Kalman Filter

Screen Temperature and Humidity
Produced by atmospheric variational assimilation step run only with surface observations to provide gridded fields
The atmospheric analysis is used as observation:

$x^a_{Atmos} \Rightarrow y_{Land}$

Because UM and JULES are coupled, the atmospheric background:

$x^b_{Atmos} \Rightarrow H(x^b)_{Land}$

Then atmospheric analysis increment is used as innovation:

$(x^a - x^b)_{Atmos} \Rightarrow (y - H(x^b))_{Land}$

Analysed fields

- **Soil moisture**
- *Soil temperature*
- *Skin Temperature*
- *Snow Temperature*

Frequency

- Global every 6h
- Regional UKV hourly

Simplified Extended Kalman Filter

- Horizontal error correlations are ignored.
- Background **B** and observation error covariance **R** are the same for all model gridpoints.
- Realistic **B** and **R** determined by
  - Comparisons with in situ soil moisture networks & other sources of observed soil moisture (SMOS).
  - Desroziers diagnostics
- **B** is diagonal and **R** has error covariance terms between screen temperature and screen humidity
- $H_i\left(x_i^b\right)$ is taken from the UM at previous cycle
- $\mathrm{H_i}$ is computed via finite differences using the JULES land model. Represent instantaneous conditions

$$x_i^a = x_i^b + \mathrm{K_i}\left[y_i^o - H_i\left(x_i^b\right)\right]$$

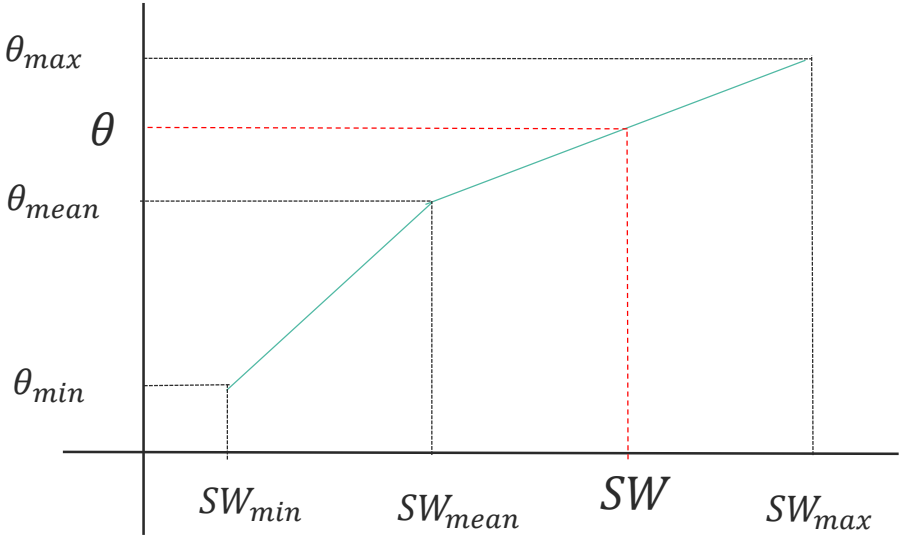
$$\mathrm{K_i} = \mathrm{BH_i^T}\left[\mathrm{H_i BH_i^T} + \mathrm{R}\right]^{-1}$$

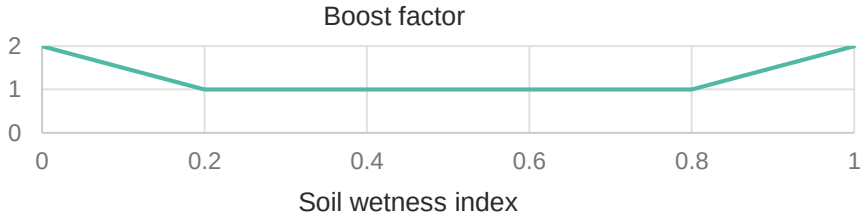
$$\mathbf{B}=\begin{pmatrix} EV_{sml1\text{-}4} & 0 & 0 & 0 \\ 0 & EV_{stl1\text{-}4} & 0 & 0 \\ 0 & 0 & EV_{skt} & 0 \\ 0 & 0 & 0 & EV_{swT1\text{-}3} \end{pmatrix}$$

$$\mathbf{R}=\begin{pmatrix} EV_{scrT} & EC_{scrTvsQ} & 0 \\ EC_{scrTvsQ} & EV_{scrQ} & 0 \\ 0 & 0 & EV_{ASCAT} \end{pmatrix}$$

ASCAT conversion and bias correction

- Soil wetness (SW) index must be converted to model soil moisture θ and bias corrected
- **New method at PS44**
- Use a piecewise linear function, loosely based on CDF matching (i.e. Quantile Regression)
- Climate model parameters $\theta_{\text{mean}}, \theta_{\text{max}}, \theta_{\text{min}}$ are estimated by statistics from a 40-year standalone JULES run at 0.5 deg forced by WFDEI dataset and CRU precipitation
- SW_{mean} provided with product.
- $SW_{min} = 0$ and $SW_{max} = 1$ by construction
- To account for higher errors in SW at extremes, compute an error boost factor before bias correction using a piecewise linear function.





Operational Northern Hemisphere snow analysis

Observations

Snow cover

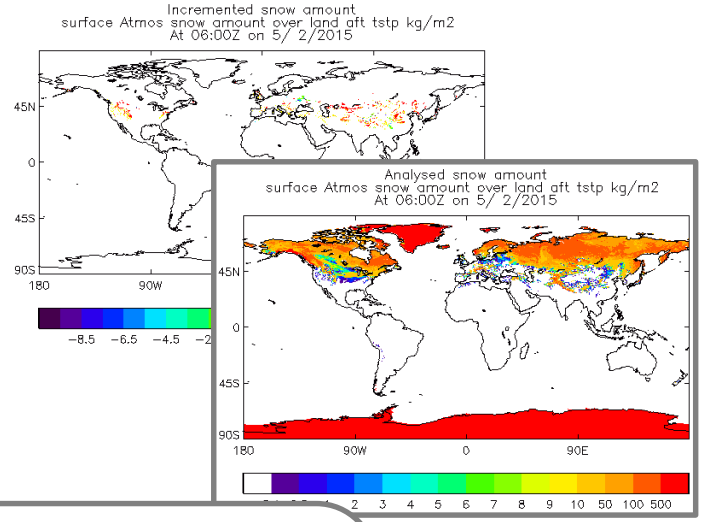
- NESDIS Interactive multisensor Snow and Ice Mapping System (IMS)
- 4 km resolution multi-sensor constructed product vis/NIR/μwave/analyst
- Binary snow cover over NH converted to fractional cover
- Use empirical relationship to relate fractional cover to snow amount $S = \frac{(-log_e(1 - f_c))}{D}$

Background

- Model Snow amount
- T+6 forecast from 00Z cycle
- Previous day's T+6

Daily (06Z) Update Scheme

- Where Obs and Background match, do nothing. Keep background as analysis
- Obs have snow, add snow to background
- Obs don't have snow, compare to previous day's background before removing snow



Results

Improved snow extent at analysis time Verification against in situ (SYNOP) stations 'state of ground' and snow depth

Forecast impacts largely neutral - some improvements in surface/low level T and RH, especially where snow is predominantly removed by the analysis.

Regional UKV LSDA changes (PS43)

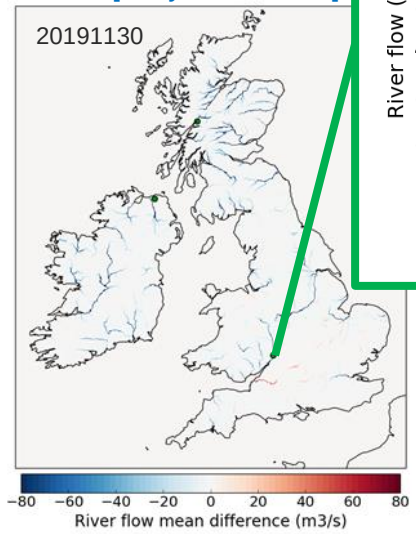
Old system: Daily (09Z) UKV would receive an interpolated version of the global land analysis to use in forecasts. No active or direct DA of soil or snow.

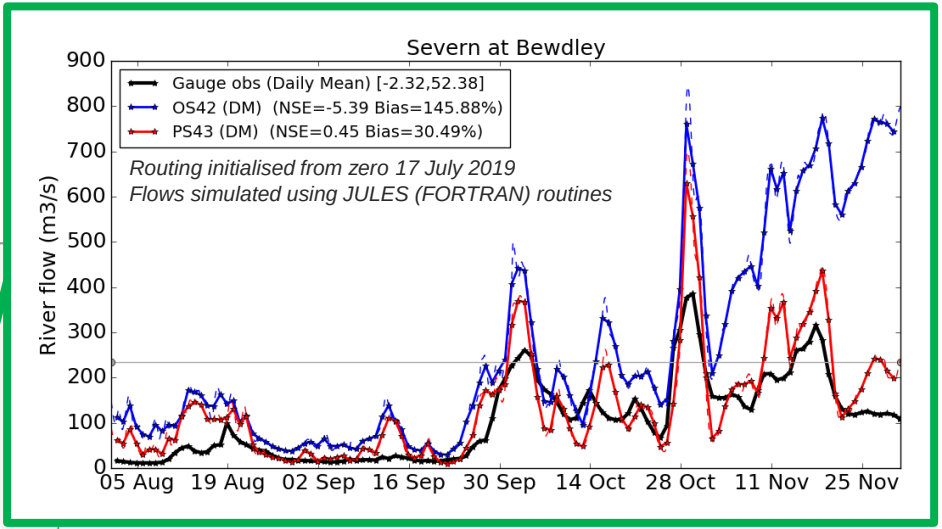
New since December 2019, UKV has active hourly cycling LSDA system same approach as the global model for soil moisture.

More consistent sub-surface runoff, illustrating both the benefit of consistent use of JULES and impact of screen level and ASCAT soil moisture assimilation to constrain soil moisture

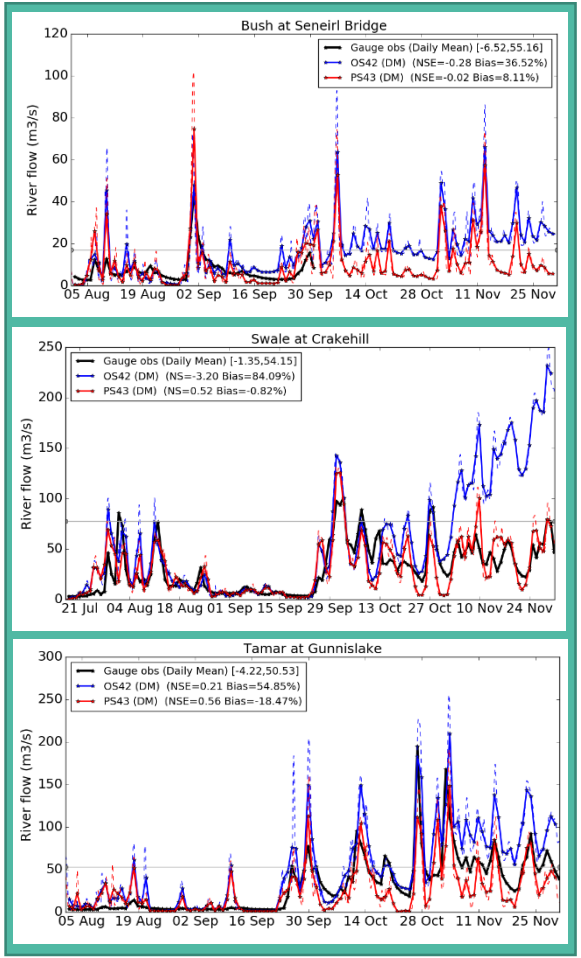
Impact of regional soil moisture DA on hydrological prediction

Output of offline routing of OS42 and PS43 runoff diagnostics using JULES RFM river routing code (default parameters) [Daily mean flows]





- Clear improvement to simulated river flows relative to observations using PS43 runoffs
- Substantial high bias when using OS42
- The basis of a hydrologically useful system?



Regional UKV LSDA changes (PS44)

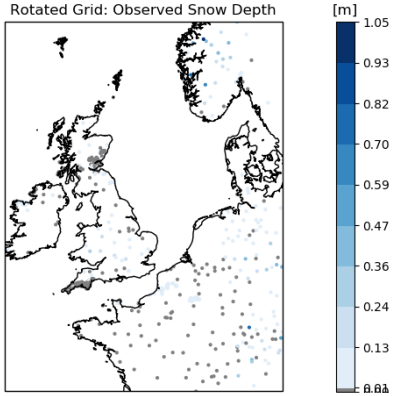
Latest improvements on the active hourly cycling LSDA system:

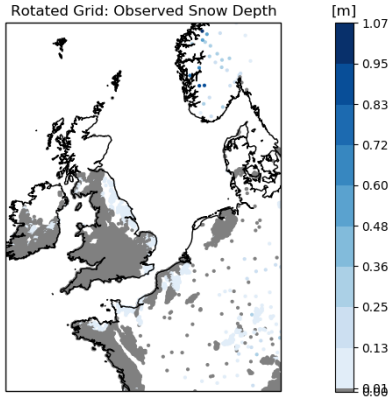
- Skin-, soil- and snow temperature increments provided via LSDA system
- Improved ASCAT soil moisture bias correction
- Snow OI
- Results include improving near surface temperature forecasts (eg. during drier periods)

Daily Regional (UKV) Snow assimilation

PS44 operational in November 2020

Observations





Ground-based Synop network

- snow depth
- state of ground (snow or no snow)

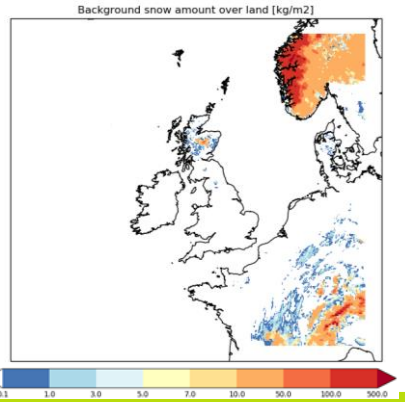
Satellite data from MSG-SEVIRI

- EUMETSAT H-SAF (H31) daily snow cover product

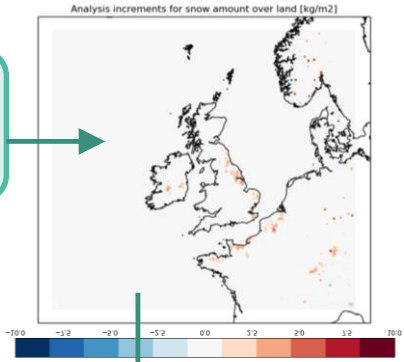
"Observed" snow depth

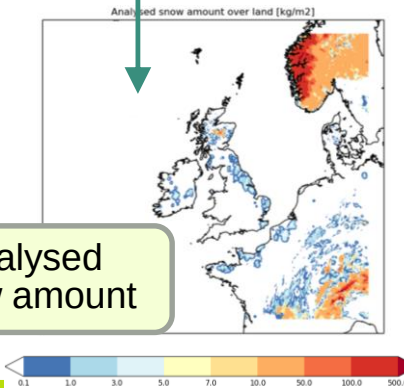
Background snow amount

2D Optimal Interpolation



Snow amount increments

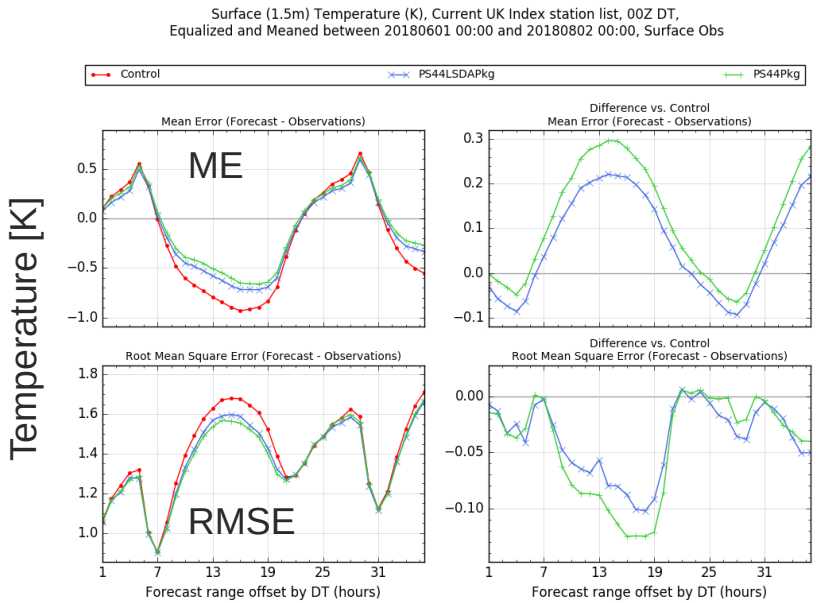




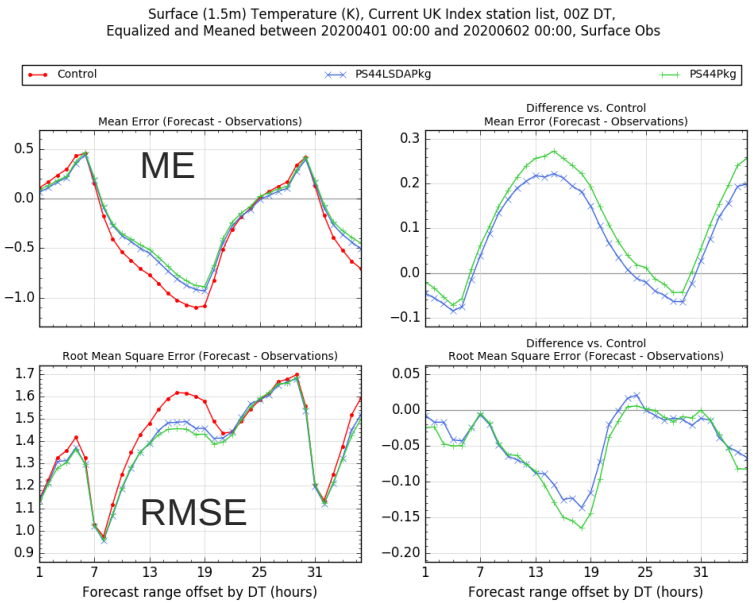
Analysed snow amount

Regional Verification against Obs

Control, LSDA changes, all changes



June-July 2018



April-May 2020

Summary

- Land DA is quasi-strongly coupled with atmosphere (including Snow DA)
- Soil DA uses same approach Global and Regional
  - Simplified Extended Kalman Filter with estimated H operator (Sensitivity matrix between analysis and observation quantities estimated by running multiple standalone JULES)
  - Assimilate screen data (temp. & humidity) and ASCAT soil wetness product
  - Improved bias correction of ASCAT and error boosting at extremes.
  - Land analysis now includes skin temperature, soil temperature, snow temperature.
- Snow DA
  - Global: Daily update scheme uses NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS) 4 km vis/NIR/μwave/analyst, NH, operational, binary snow cover
  - Regional: Daily OI run assimilates ground station snow depth and state of ground reports, and a SEVIRI snow cover product from the EUMETSAT H SAF (H31).

Development plans

- Global implementation of OI for snow assimilation
  - Alternative satellite snow cover data
  - Use additional national networks snow depth and snow water equivalent observations
- Increase frequency of regional snow analysis to 4 times daily
- Assimilation of other soil moisture products (eg. SMOS NRT NN)
- Porting to new HPC (PS47 2022)

Future

- SEKF Method is currently affordable but becomes expensive if analysis variables increase. May drive future developments at MO.
- Land surface temperature (LST) DA to improve skin temperature.
  - Is there interest in LST?
  - Which products are being used in the community for LSDA?
- Stronger coupling between atmosphere and land DA
- Move towards a more integrated DA system sharing components between atmosphere and land

Questions?

Email:

c.charlton-perez@metoffice.gov.uk

Paper submitted to special issue

Remote Sensing of Land Surface and Earth System Modelling

The Met Office Land Surface Data Assimilation System

Gómez, Charlton-Pérez, Lewis and Candy