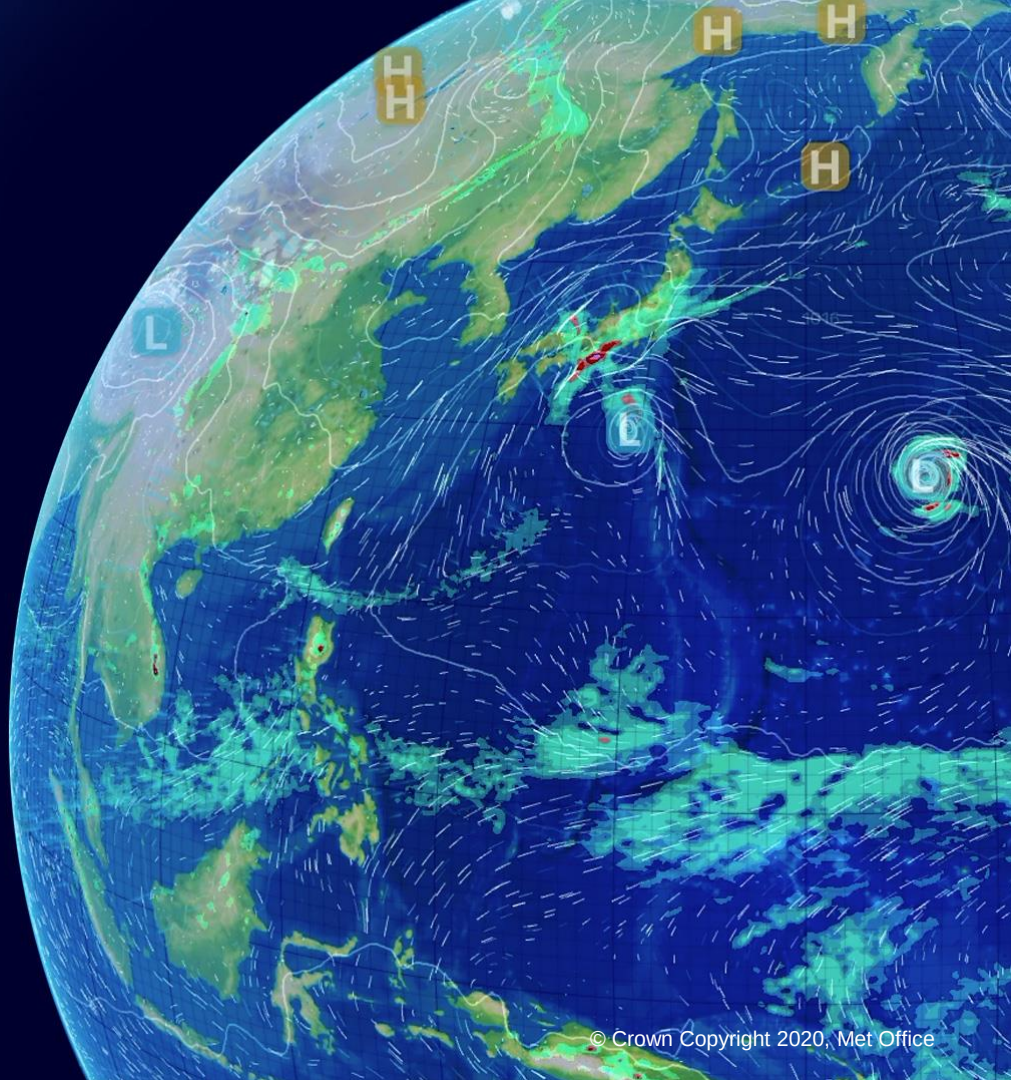
Land Surface Data Assimilation Overview Met Office

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

BoM-ECMWF-MO-UoR Workshop
16 December 2020



LSDA Overview

- Land Surface Data Assimilation (LSDA) in Met Office NWP
  - OS43: operational December 2019-2020
  - OS44: operational since December 2020
- Regional (UKV) soil DA now as in global system
- Snow DA now in UKV, but different from global scheme
- Future directions

Operational LSDA
(excluding snow amount)

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**

**OS44*

Frequency

- Global every 6h
- Regional UKV hourly

Simplified Extended Kalman Filter

- Horizontal error correlations are ignored.
- B and R are the same on all gridpoints. We use realistic observation and background errors
  - Comparisons with in situ soil moisture networks & other sources of soil moisture.
  - Desroziers diagnostics
- B is diagonal and R has error covariance term between screen temperature and screen humidity
- $H_i(x_i^b)$ is taken from the UM at previous cycle
- $\mathrm{H_i}$ is computed via finite differences using the JULES land model and represents instantaneous conditions

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

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

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

$$\mathrm{R} = \begin{pmatrix} \mathrm{EV_{scrT}} & \mathit{EC}_{\mathit{scrTvsQ}} & 0 \\ \mathit{EC}_{\mathit{scrTvsQ}} & \mathrm{EV_{scrQ}} & 0 \\ 0 & 0 & \mathrm{EV_{ASCAT}} \end{pmatrix}$$

Regional UKV LSDA changes (OS43)

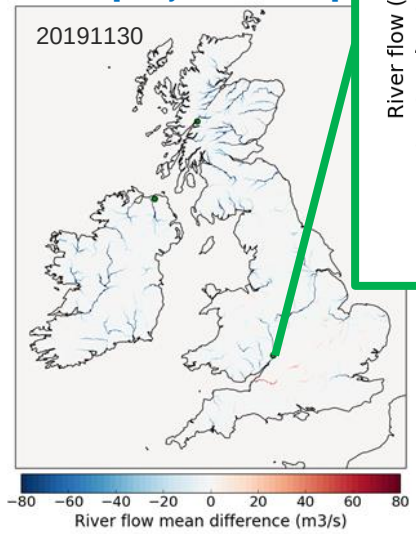
Old system OS42: Daily (09Z) UKV would receive an interpolated version of the global land analysis to use in forecasts. No active or direct DA of soil or snow.

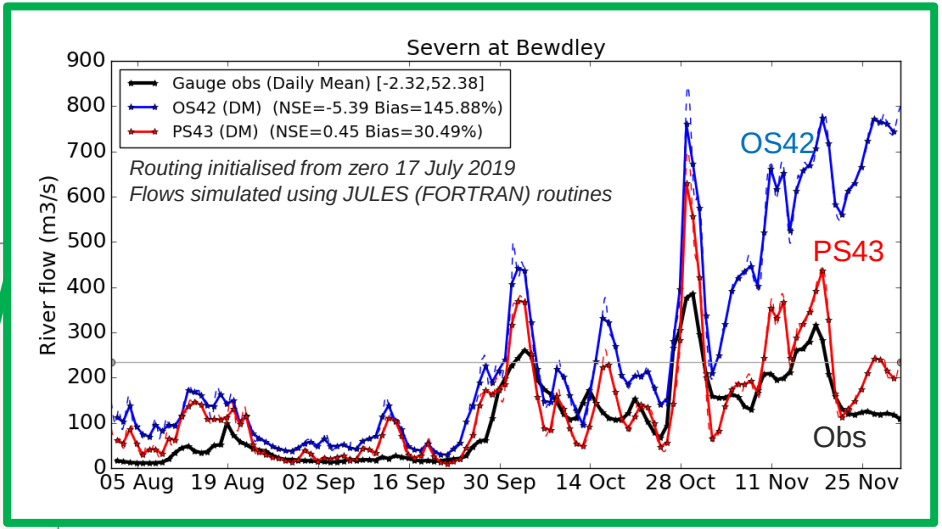
Since December 2019, UKV has active hourly cycling LSDA system same approach as the global model for soil moisture.

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

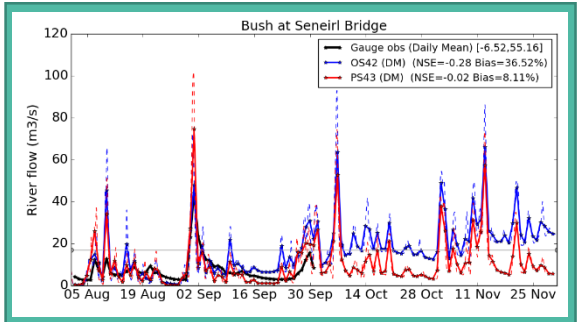
Impact of regional soil moisture DA on hydrological prediction

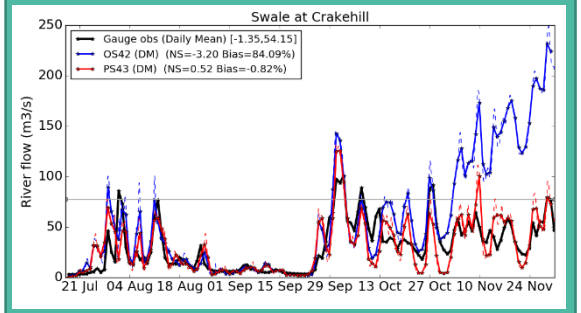
Output of offline routing of OS42 and PS43 runoff diagnostics using JULES RFM river routing code (default parameters) [Daily mean flows]

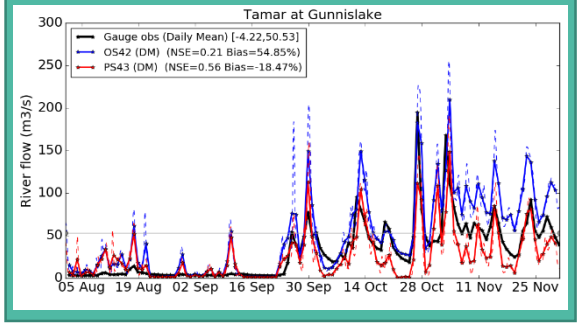




- Clear improvement to simulated river flows relative to observations using PS43 runoffs
- Substantial high bias when using OS42
- The basis of a hydrologically useful system?







Latest Operational LSDA (OS44)

- LSDA now includes Soil-, Skin- and Snow- Temperature analysis and is no longer restricted to gridpoints without snow or unfrozen soil.
- Screen observation errors have been tuned and an error covariance term between temperature and humidity has been added
- SURF analyses are provided as analysis increments instead of analysis fields and are ingested like the atmospheric DA increments via “IAU” code.
- New ASCAT bias correction scheme significantly improves conversion from soil wetness to soil moisture when the observation is far from its climate mean
- ASCAT error is boosted when soil wetness approaches extreme wet and dry state to represent observation processing error from radiances to soil wetness
- New (regional only) snow DA via Optimal Interpolation

Land temperature analysis

Soil, snow and skin temperature

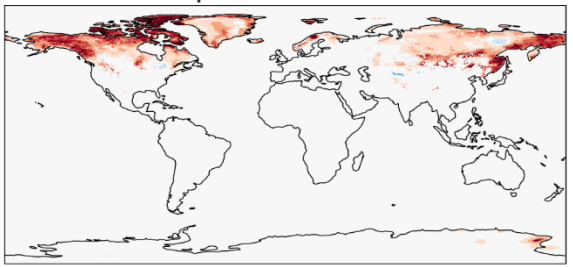
Land temperature Analysis

- At OS44 SURF provides:
  - Snow temperature analysis by expanding the analysis vector. Skin T & Soil T were already available.
  - SURF still uses the same observation types
  - Analysis moved to T-3 hr and ingested through the IAU as analysis increments
- This implies
  - Analysis variables increase 4 to 12; all are ingested
    - 4 Soil moisture levels
    - 4 Soil temperature levels
    - Skin Temperature
    - 3 Snow Temperature levels
  - Expanded B matrix
  - Additional JULES runs are required to estimate Jacobian

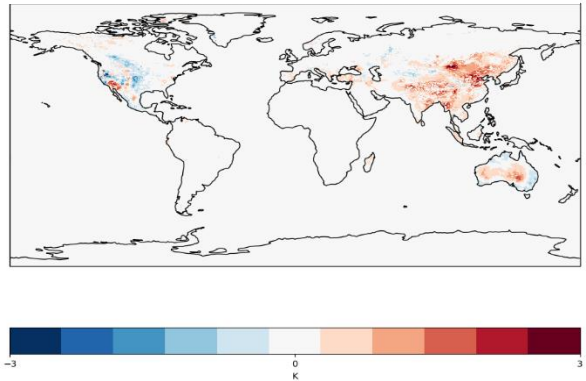
$$B=\begin{pmatrix} EV_{sml1\text{-}4} & 0 & 0 & 0 \\ 0 & EV_{stl1\text{-}4} & 0 & 0 \\ 0 & 0 & EV_{skt} & 0 \\ 0 & 0 & 0 & EV_{swT1\text{-}3} \end{pmatrix}$$

New terms

Snow temperature increments



Level 1 Soil temperature increments



Land temperature Analysis: Review R observation errors

- Operational (OS43) R matrix errors:
  - Screen Temperature = 1.5K
  - Screen Humidity = 8%
  - ASCAT Soil Moisture = 0.035 m^3 m^{-3}
- First tested different Screen T and Screen Humidity observation errors.
- Desroziers diagnostics used to evaluate the R matrix values
- R-matrix
  - Screen Temperature ~ 0.75K
  - Screen Humidity ~ 4%
  - ASCAT Soil Moisture ~ 0.035 m^3 m^{-3} (no change)
- Diagnostics also suggest a non-zero error covariance.
  - Screen Temperature vs. Screen Humidity ~ 1K%

ASCAT Bias Correction

Operational assimilation of ASCAT surface soil wetness at the Met Office.

by I. Dharssi, K. J. Bovis, B. Macpherson and C. P. Jones

Hydrol. Earth Syst. Sci., 2011

ASCAT to Model: Variable

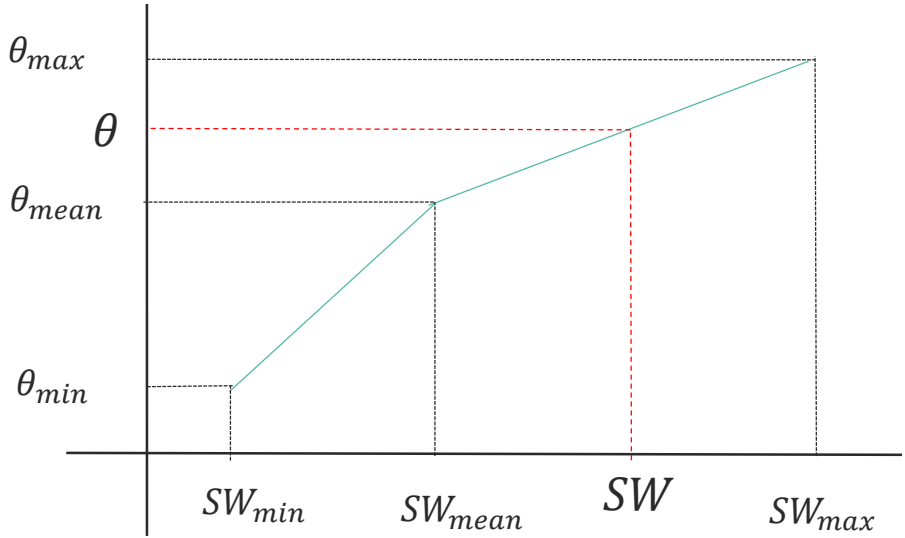
- ASCAT soil wetness converted to UM units: Soil Moisture Content [kg/m^2]
- Bias correction applied using soil moisture climatology.

$$\theta_{L1} = \overline{\theta_{L1}} + \frac{\theta_{DR}}{SW_{DR}}(SW - \overline{SW})$$

- $\overline{\theta_{L1}}$ estimated by running standalone JULES at 0.5deg with WFDEI forcing
- SW ASCAT Soil Wetness Index measurement
- $\overline{SW}$ ASCAT Soil Wetness Index climatology
- θ_{DR} Soil moisture dynamic range per grid point can be determined by
  - OS43: Soil and land surface properties: Saturation - (1.0-BareSoil)*Wilting
  - JULES soil moisture climatology: Maximum – Minimum
- SW_{DR} Soil wetness index dynamic range (1.0)

ASCAT conversion and bias correction

- Soil wetness (SW) index must be converted to model soil moisture θ and bias corrected
- **New method at OS44**
- Use a piecewise linear function, loosely based on CDF matching (i.e. Pseudo-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

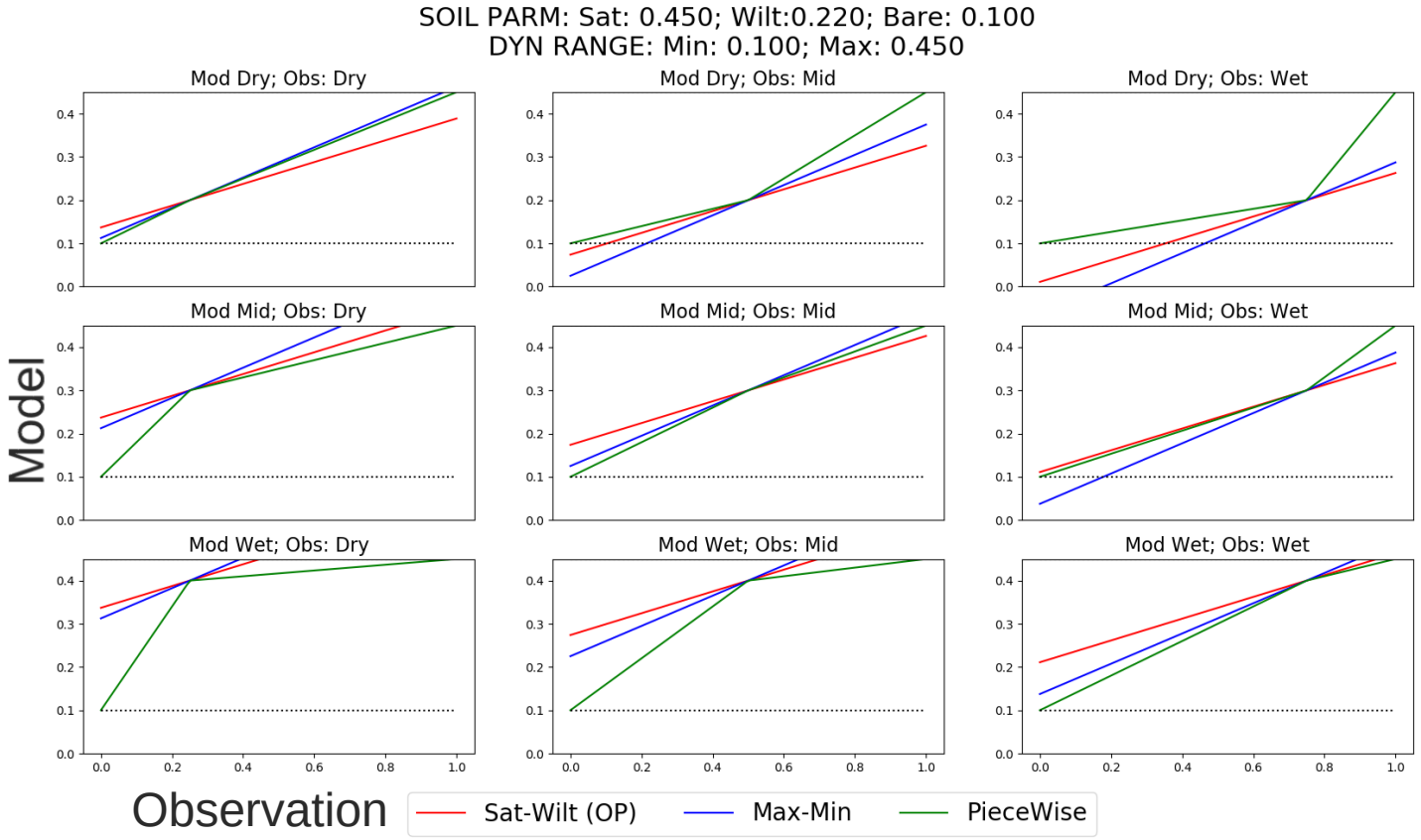


How do the linear BC methods work?

All methods work well near the SM mean but old method fails at the extremes

Dynamic range = Max - Min

Piecewise interpolation matches the mean and respects the entire model range of SM values



Observation Climate Mean = 0.25, 0.5, 0.75 [swi u.]
Model Climate Mean = 0.2, 0.3, 0.4 [$m^3\ m^{-3}$]

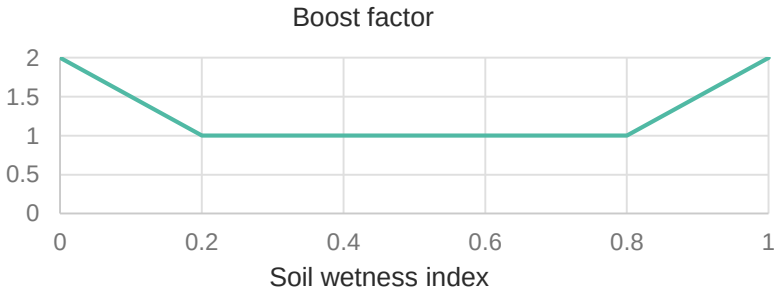
ASCAT Error boost

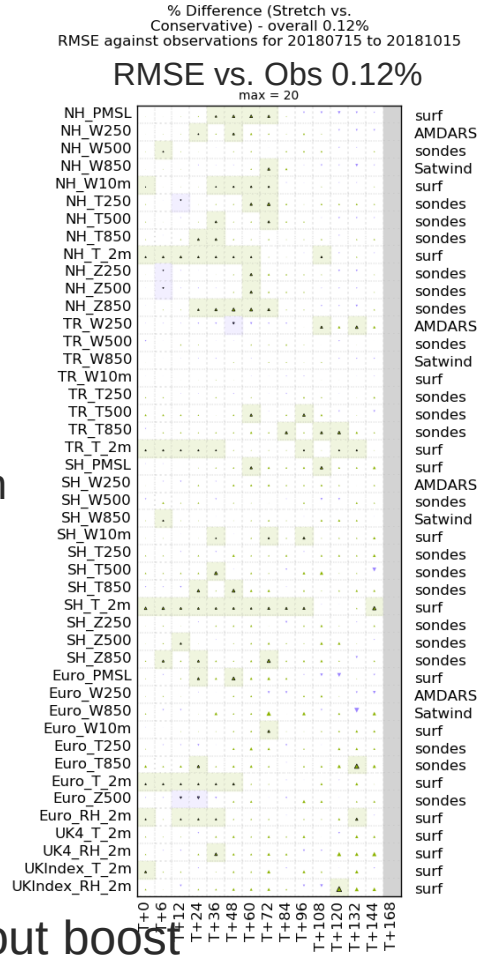
ASCAT Observation Error is “boosted”

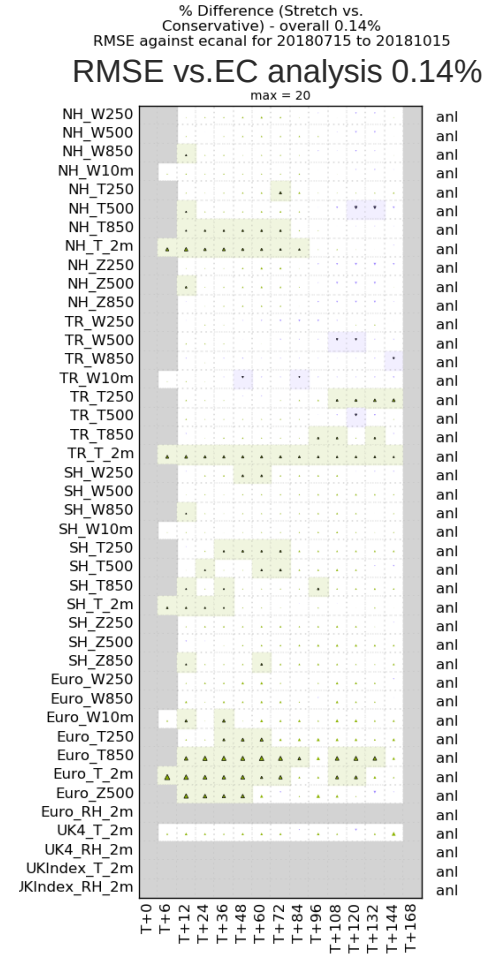
Accounts for higher errors in SW at extremes

Calculated using SW before bias correction

Factor is modelled as a piece wise linear function and is user-configurable







3 month global, low res trials with and without boost

Summary

- New ASCAT BC with piecewise linear matching to mean and max/min values improvement over old scheme
- Model climatologies used in BC are consistent with latest science configuration in the UM-JULES land component.
- Error Boost when observations approach extremes has shown some benefit
- Evaluation of global (low resolution) trial Winter/Summer and over the UK (Summer 2018) show improvement of temperature diurnal bias and RMSE
- Similar results in other parts of the globe

Benefits of new LSDA Package (PS44)

Global Trials:

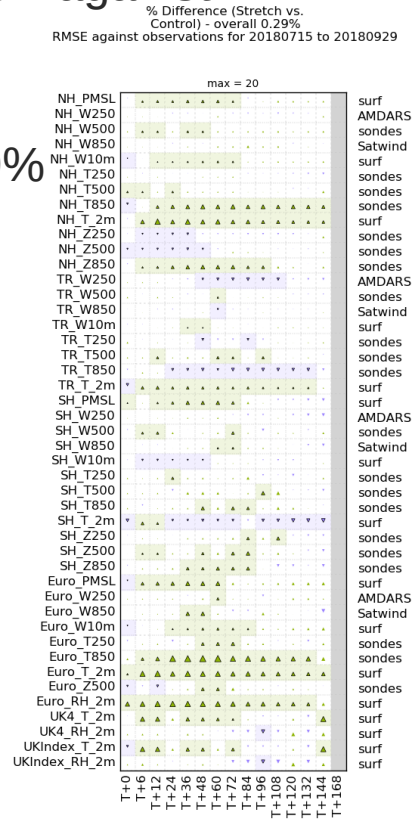
- Three month trials both Winter and Summer
- Low resolution (n320)
- Control is OS43

Recall: Snow DA has not changed for the global model

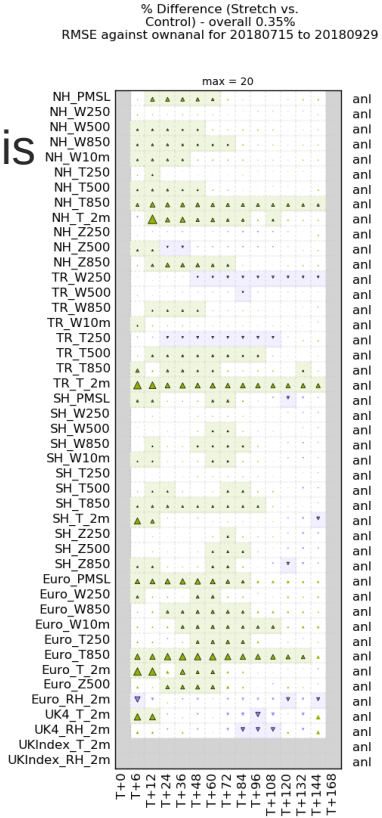
Global LSDA Package – JAS 2018

RMSE against

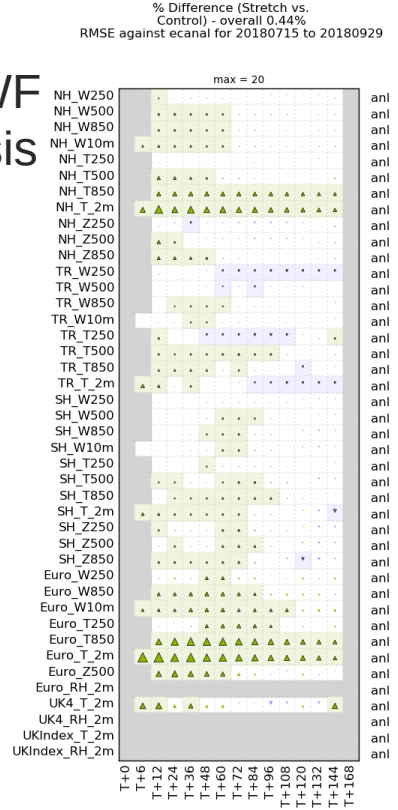
Obs
0.29%



Own
Analysis
0.35%

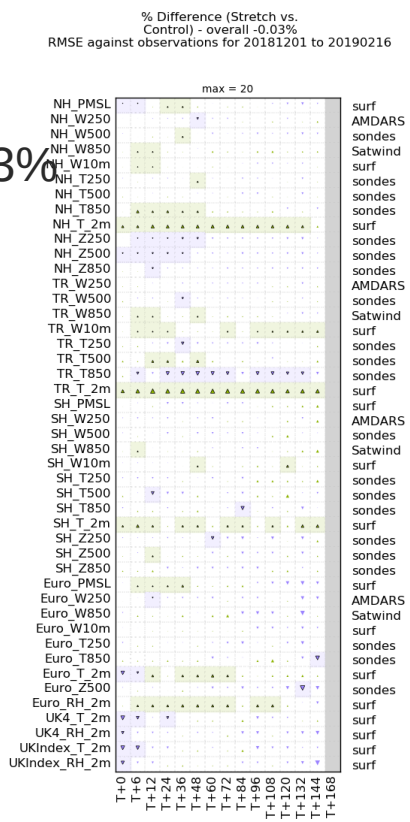


ECMWF
Analysis
0.44%

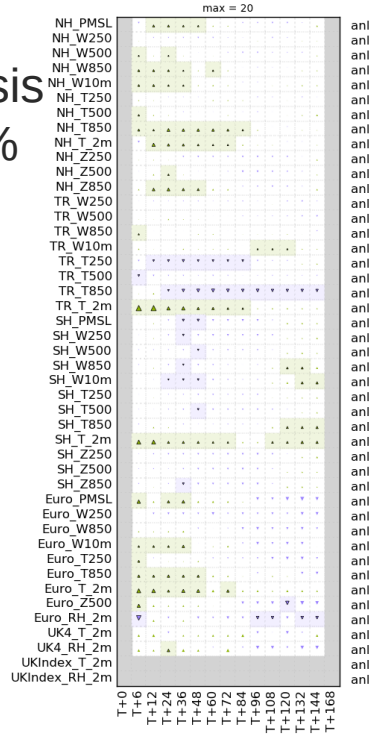


Global LSDA Package – DJF 2018/19

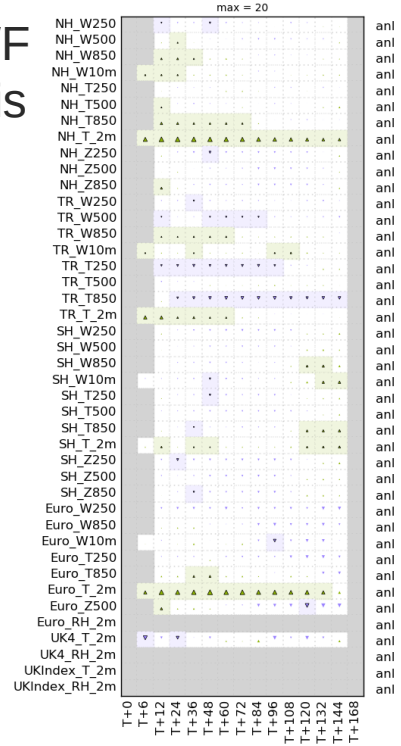
Obs -0.03%



Own Analysis -0.01%



ECMWF Analysis 0%



Snow DA

- Global NH: Update scheme
- Regional (UKV): Optimal Interpolation

Operational Northern Hemisphere snow analysis

Observations

Snow cover

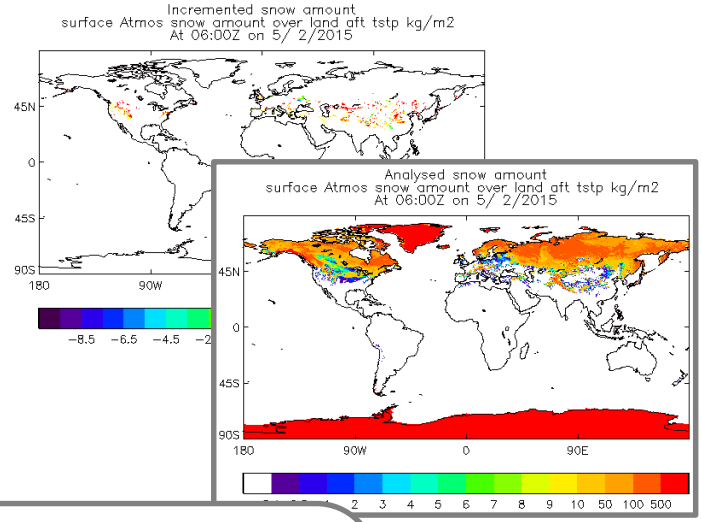
- NESDIS Interactive multisensor Snow and Ice Mapping System (IMS)
- 4 km resolution multi-sensor constructed product vis/NIR/μwave/analyst
- Binary snow cover over NH converted to fractional cover
- Use empirical relationship to relate fractional cover to snow amount $S = \frac{(-log_e(1 - f_c))}{D}$

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

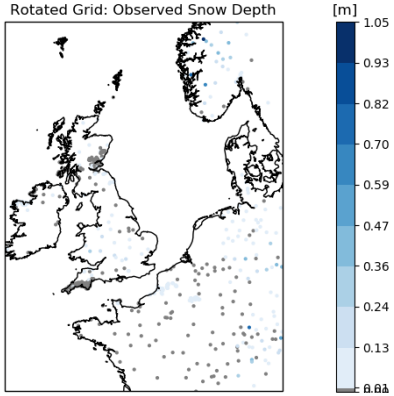
Improved snow extent at analysis time Verification against in situ (SYNOP) stations 'state of ground' and snow depth

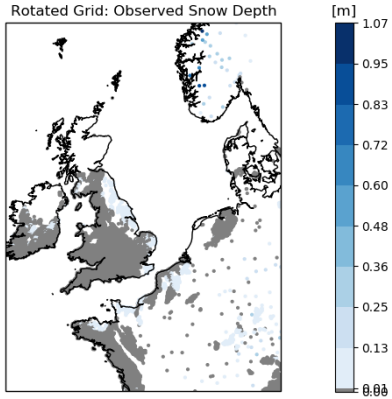
Forecast impacts largely neutral - some improvements in surface/low level T and RH, especially where snow is predominantly removed by the analysis.

Daily Regional (UKV) Snow assimilation

OS44 operational in December 2020

Observations





Ground-based Synop network

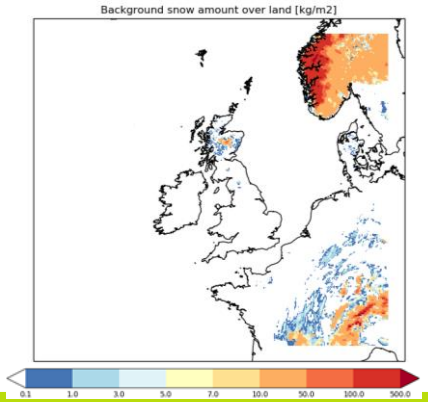
- snow depth
- state of ground (snow or no snow)

Satellite data from MSG-SEVIRI

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

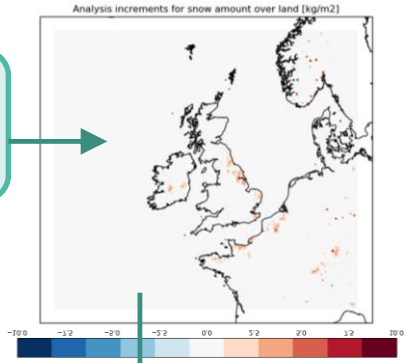
"Observed" snow depth

Background snow amount

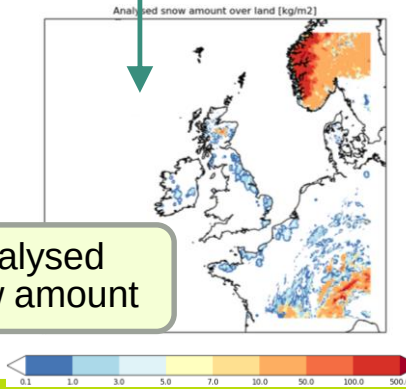


2D Optimal Interpolation

Snow amount increments



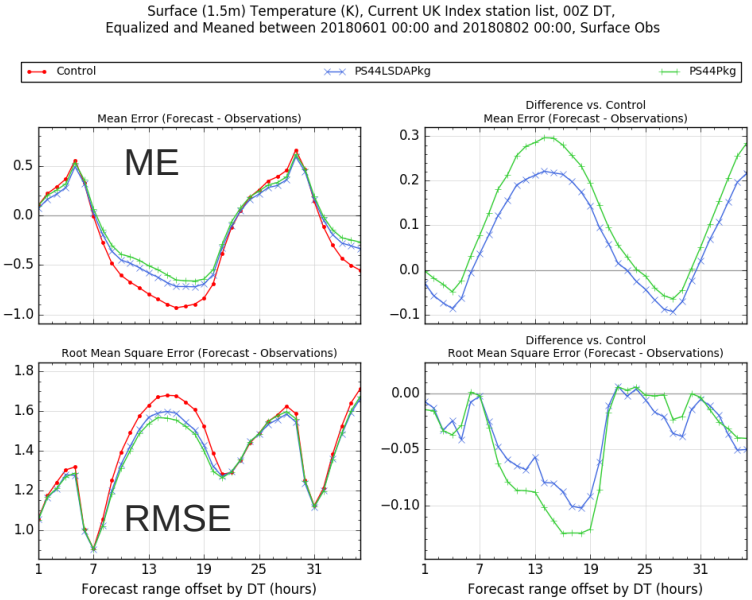
Analysed snow amount

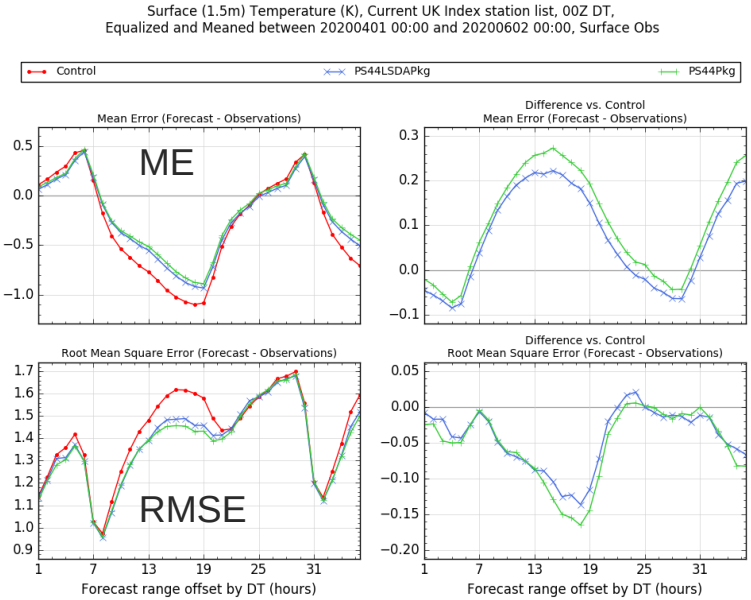


Regional Verification against Obs

Control, LSDA changes, all changes

Temperature [K]





June-July 2018

April-May 2020

Summary

- Global LSDA package trials (PS44): neutral in Winter (benefit seen in T2m) and overall positive in Summer
- Regional (UKV) PS44 trials over challenging dry periods show improvements in screen temperature RMSE and ME
- 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
  - Land analysis now includes skin temperature, soil temperature, snow temperature.
  - Improved bias correction of ASCAT and error boosting at extremes.
- 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 (trialling now in UKV)
- Assimilation of other soil moisture products (eg. SMOS NRT NN)

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.
- Stronger coupling between atmosphere and land DA
- Move towards a more integrated DA system sharing components between atmosphere and land

Questions?

Email:

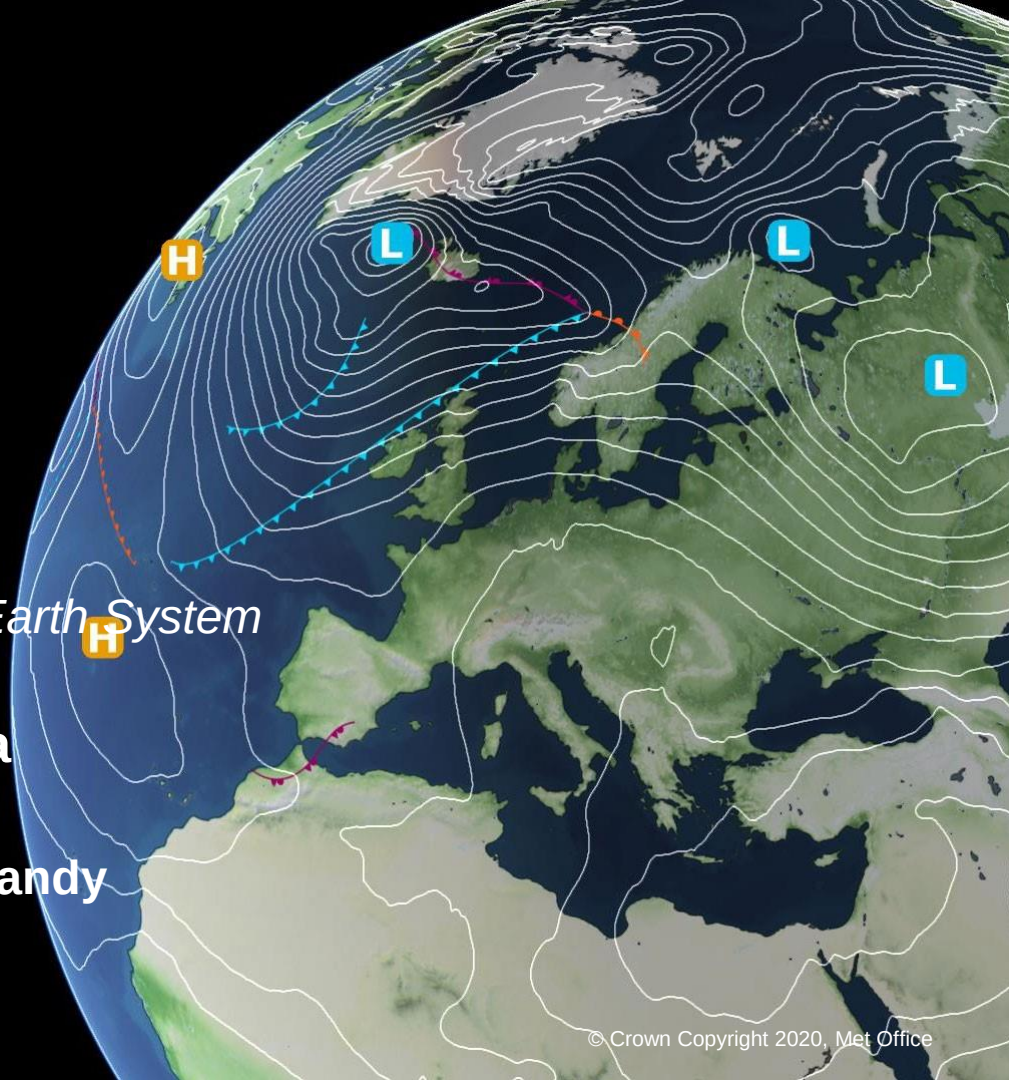
c.charlton-perez@metoffice.gov.uk

Paper published in 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



Land temperature Analysis

- We test this on a N320 suite, 3 months, Summer and Winter.
- 4 Experiments:
  - Control (OS43): SURF SM analysis, Land temperature increments from Atmospheric analysis
  - Soil moisture and temperature analysis from SURF:
    - Error: ScreenT 1.5K / ScreenRH 8%
  - SMC and temperature analysis from SURF:
    - Error: ScreenT 0.75K / ScreenRH 4%
  - SMC and temperature analysis from SURF:
    - Error: ScreenT 0.75K / ScreenRH 4%
    - Errorcovariance: ScreenT vs ScreenRH: 1K%

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

Land temperature Analysis

Deroziers stats suggests

- R-matrix
  - Screen Temperature ~ 0.75K
  - Screen Humidity ~ 4%
  - Ascat SM ~ 0.035 m^3 m^{-3} (no change)
- It also suggests a non-zero error covariance.
  - Screen T vs. Screen H ~ 1K%