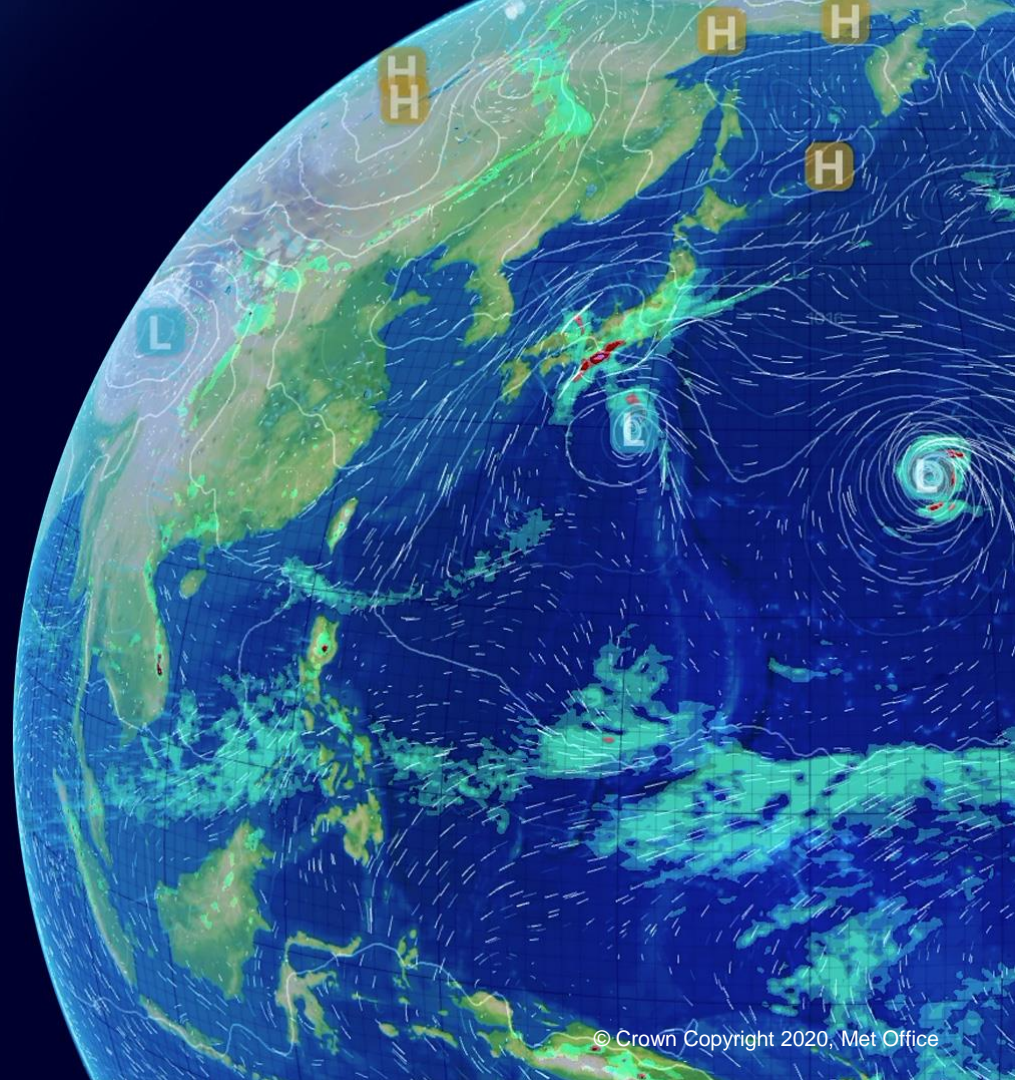


Land Surface Data Assimilation Overview Met Office

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ECMWF-MO-UoR Workshop
14 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

Observations**ASCAT soil wetness index**

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

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:

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

Operational LSDA

(excluding snow amount)

Simplified Extended Kalman Filter

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
- H_i is computed via finite differences using the JULES land model and represents instantaneous conditions

$$x_i^a = x_i^b + K_i [y_i^o - H_i(x_i^b)]$$

$$K_i = B H_i^T [H_i B H_i^T + R]^{-1}$$

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

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

Regional UKV LSDA changes (OS43)

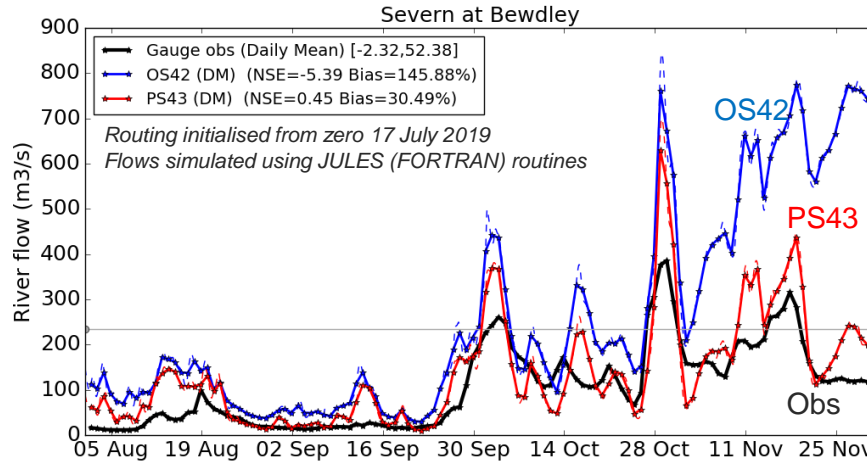
Old system OS42: Daily (09Z) UKV would receive an interpolated version of the global land analysis to use in forecasts. No active or direct DA of soil or snow.

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

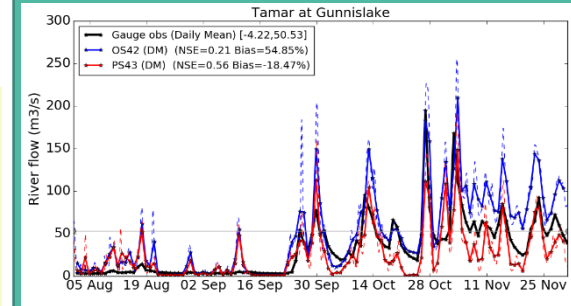
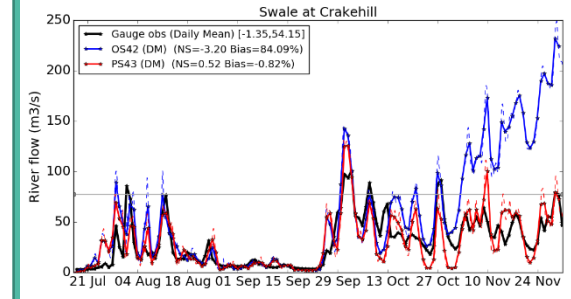
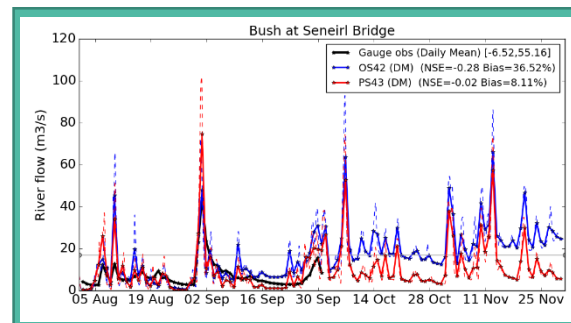
More consistent sub-surface runoff, illustrating both the benefit of consistent use of JULES and impact of screen level and ASCAT soil moisture assimilation to constrain soil moisture

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 (regional only) snow DA via Optimal Interpolation
- 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

ASCAT BC and error boost discussed in another talk later today

Land temperature analysis

Soil, snow and skin temperature

Met Office 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

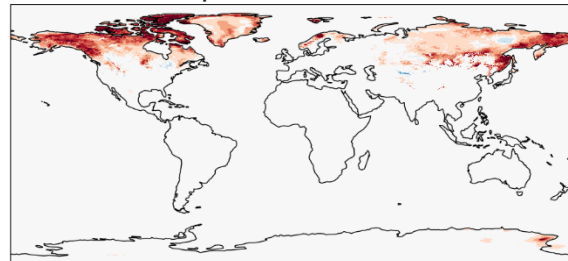
• This implies

- 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

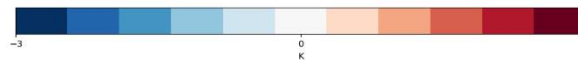
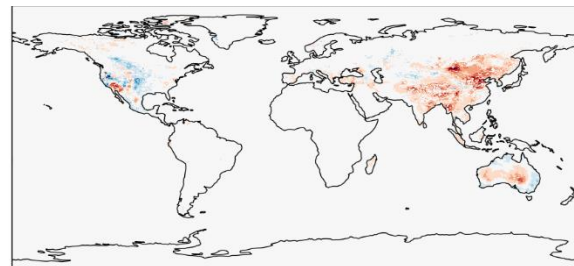
$$B = \begin{pmatrix} EV_{sml1-4} & 0 & 0 & 0 \\ 0 & EV_{st1-4} & 0 & 0 \\ 0 & 0 & EV_{skt} & 0 \\ 0 & 0 & 0 & EV_{swT1-3} \end{pmatrix}$$

New terms \nearrow

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 m³ 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 m³ m⁻³ (no change)
- Diagnostics also suggest a non-zero error covariance.
 - Screen Temperature vs. Screen Humidity ~ 1K%

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

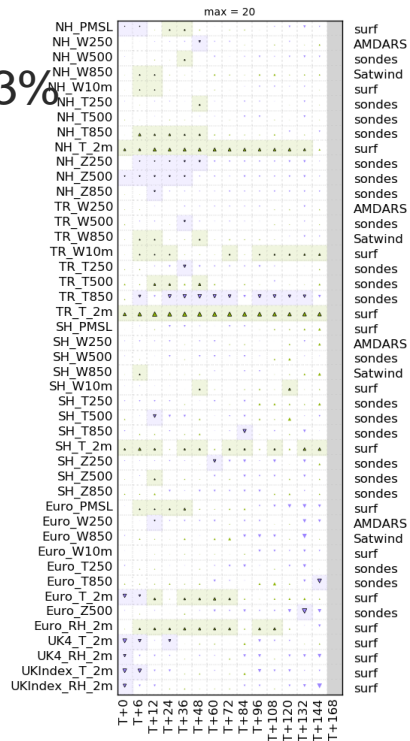
% Difference (Stretch vs. Control) - overall -0.03%
RMSE against observations for 20181201 to 20190216

% Difference (Stretch vs. Control) - overall -0.01%
RMSE against ownanal for 20181201 to 20190216

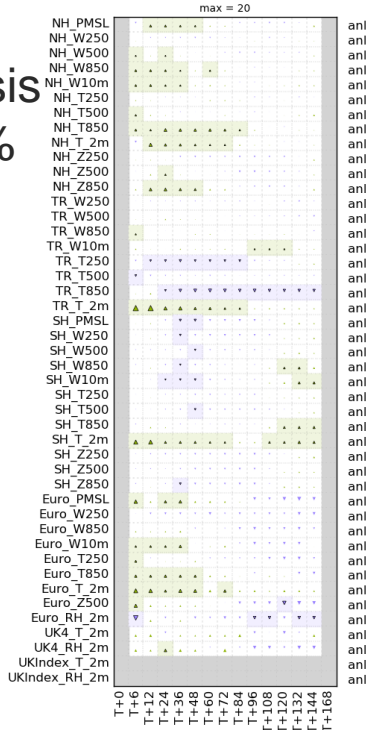
% Difference (Stretch vs. Control) - overall -0.0%
RMSE against ecanal for 20181201 to 20190216

Obs

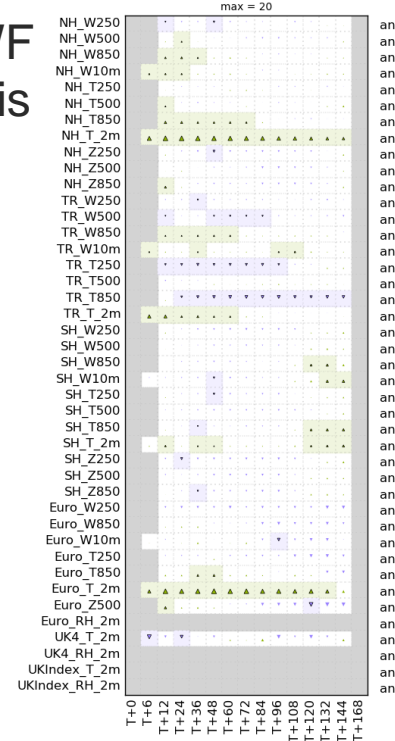
-0.03%



Own
Analysis
-0.01%



ECMWF
Analysis
0%



Snow DA

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

Observations

Snow cover

- NESDIS Interactive multisensor Snow and Ice Mapping System (IMS)
- 4 km resolution multi-sensor constructed product vis/NIR/ μ wave/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

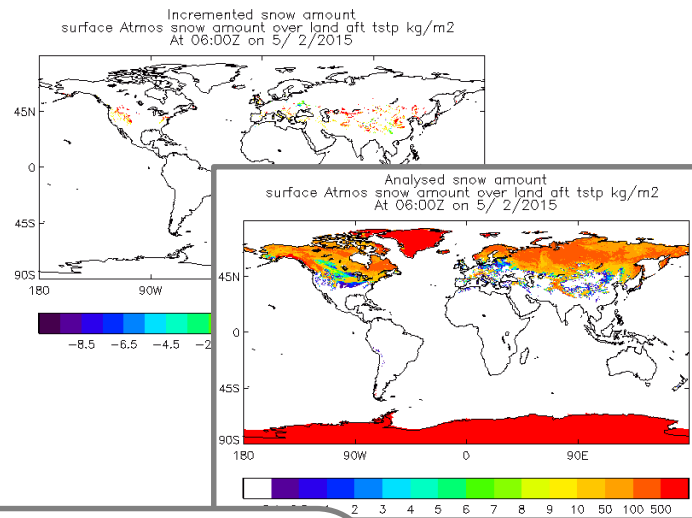
Daily (06Z) Update Scheme

- 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.

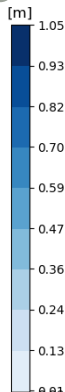
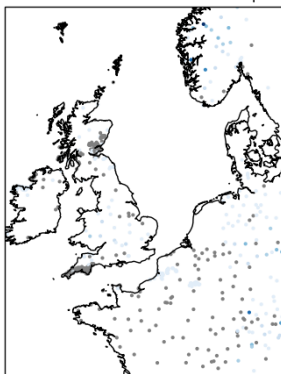


Daily Regional (UKV) Snow assimilation

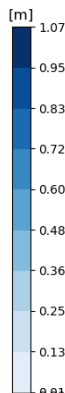
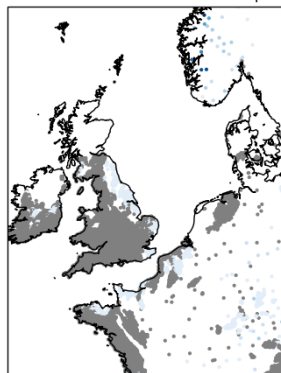
OS44 operational in December 2020

Observations

Rotated Grid: Observed Snow Depth



Rotated Grid: Observed Snow Depth



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

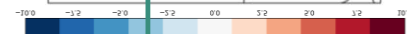
“Observed” snow depth

Background snow amount

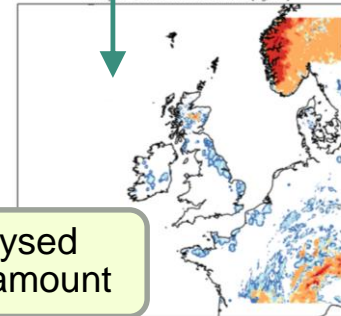
2D Optimal Interpolation

Snow amount increments

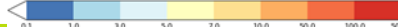
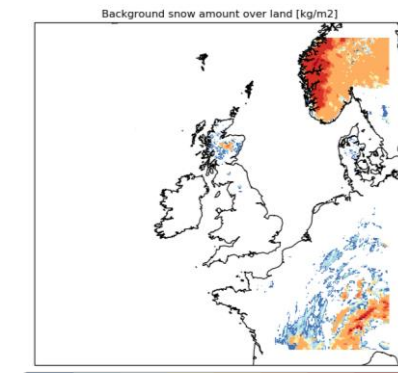
Analysis increments for snow amount over land [kg/m²]



Analysed snow amount over land [kg/m²]



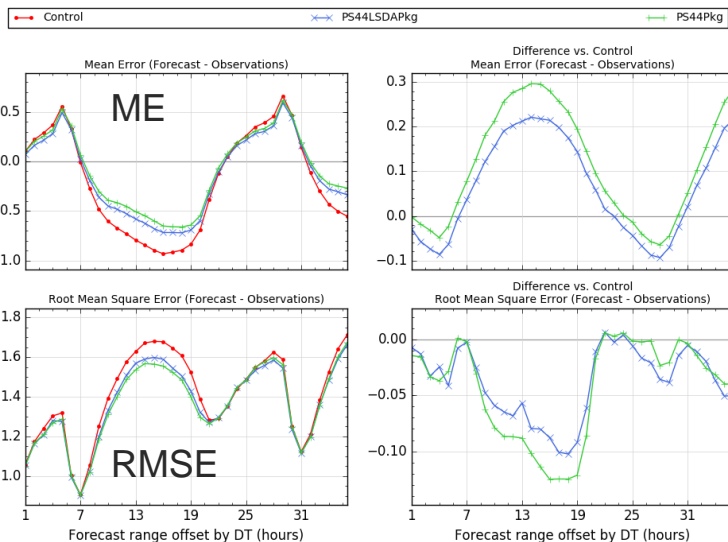
Analysed snow amount



Regional Verification against Obs

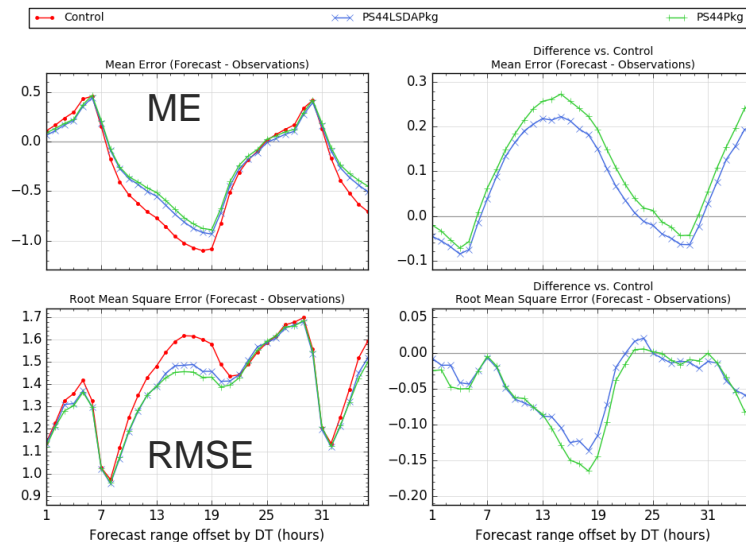
Control, LSDA changes, all changes

Surface (1.5m) Temperature (K), Current UK Index station list, 00Z DT, Equalized and Meaned between 20180601 00:00 and 20180802 00:00, Surface Obs



June-July 2018

Surface (1.5m) Temperature (K), Current UK Index station list, 00Z DT, Equalized and Meaned between 20200401 00:00 and 20200602 00:00, Surface Obs



April-May 2020

- 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/ μ wave/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 (trailing 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?

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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

