### Land Surface Data Assimilation Overview Met Office

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### 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



## 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<sub>i</sub> is computed via finite differences using the JULES land model and represents instantaneous conditions

$$x_i^a = x_i^b + K_i [y_i^o - H_i (x_i^b)]$$
  
$$K_i = BH_i^T [H_i BH_i^T + R]^{-1}$$





## 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

# Met Office Impact of regional soil moisture DA on hydrological prediction





#### Slide courtesy Huw Lewis LSDA Overview at the Met Office

# 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

**Met Office** 



### Land temperature analysis

Soil, snow and skin temperature

### Set 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

B=

- 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

Snow temperature increments









EV<sub>stl1-4</sub> 0

New terms /

EV<sub>skt</sub>

0

EV<sub>swT1-3</sub>

EV<sub>sml1-4</sub>0

0

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### Met Office 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<sup>3</sup> m<sup>-3</sup>
- 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<sup>3</sup> m<sup>-3</sup> (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 <u>Hydrol. Earth Syst. Sci., 2011</u>

# ASCAT to Model: Variable

- ASCAT soil wetness converted to UM units: Soil Moisture Content [kg/m<sup>2</sup>]
- 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
- *SW* ASCAT Soil Wetness Index climatology

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- $\theta_{DR}$ 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<sub>DR</sub>* Soil wetness index dynamic range (1.0)

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LSDA Overview at the Met Office © Crown

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#### Met Office ASCAT conversion and bias correction

- Soil wetness (SW) index must be converted to model soil moisture  $\theta$  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<sub>mean</sub>* 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<sup>3</sup> m<sup>-3</sup>] <sup>LSDA Overview at the Met Office</sup>

December 2020

## **Met Office** ASCAT Error boost



% Difference (Stretch vs. Conservative) - overall 0.12% RMSE against observations for 20180715 to 20181015

	RMSE vs. Obs 0.12%	b l
ASCAT Error boost	NH_PMSL	surf NH AMDARS NH sondes NH Satwind NH surf N sondes N sondes N
ASCAT Observation Error is "boosted"	NH_1220 NH_2250 NH_2250 NH_2250	sondes Ni surf N sondes N sondes N sondes N
Accounts for higher errors in SW at extremes	TR_W250 TR_W500 TR_W850 TR_W10m	AMDARS TF sondes TF Satwind TF surf TR
Calculated using SW before bias correction	TR_1250 TR_T500 TR_T850 TR_T850 TR_T_2m	sondes T sondes T sondes T surf T
Factor is modelled as a piece wise linear function and is user-configurable	SH_PMSL SH_VU250 SH_VU250 SH_VU500 SH_W850 SH_W10m SH_T250 SH_T250 SH_T250 SH_T250 SH_T250	surf SH AMDARS SH sondes SH Satwind SH surf SH sondes S sondes S
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# 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

**Met Office** 

% Difference (Stretch vs. Control) - overall 0.29% RMSE against observations for 20180715 to 20180929

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RMSE against ownanal for 20180715 to 20180929

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#### Global LSDA Package – DJF 2018/19 **Met Office**

% Difference (Stretch vs. Control) - overall -0.01%

RMSE against ownanal for 20181201 to 20190216

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

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% Difference (Stretch vs.

Control) - overall -0.0%

RMSE against ecanal for 20181201 to 20190216

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### Snow DA

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

### Met Office Operational Northern Hemisphere snow analysis





LSDA Overview at the Met Office

December 2020



# 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

LSDA Overview at the Met Office

December 2020

### Summary Summary Sector

- 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?**

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Paper published in special issue

Remote Sensing of Land Surface and Earth System Modelling

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#### The Met Office Land Surface Data Assimilation System

Gómez, Charlton-Pérez, Lewis and Candy

### Set Office 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%



### Set Office Land temperature Analysis

### Deroziers stats suggests

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



