Land Surface Data Assimilation: Moving towards coupled DA

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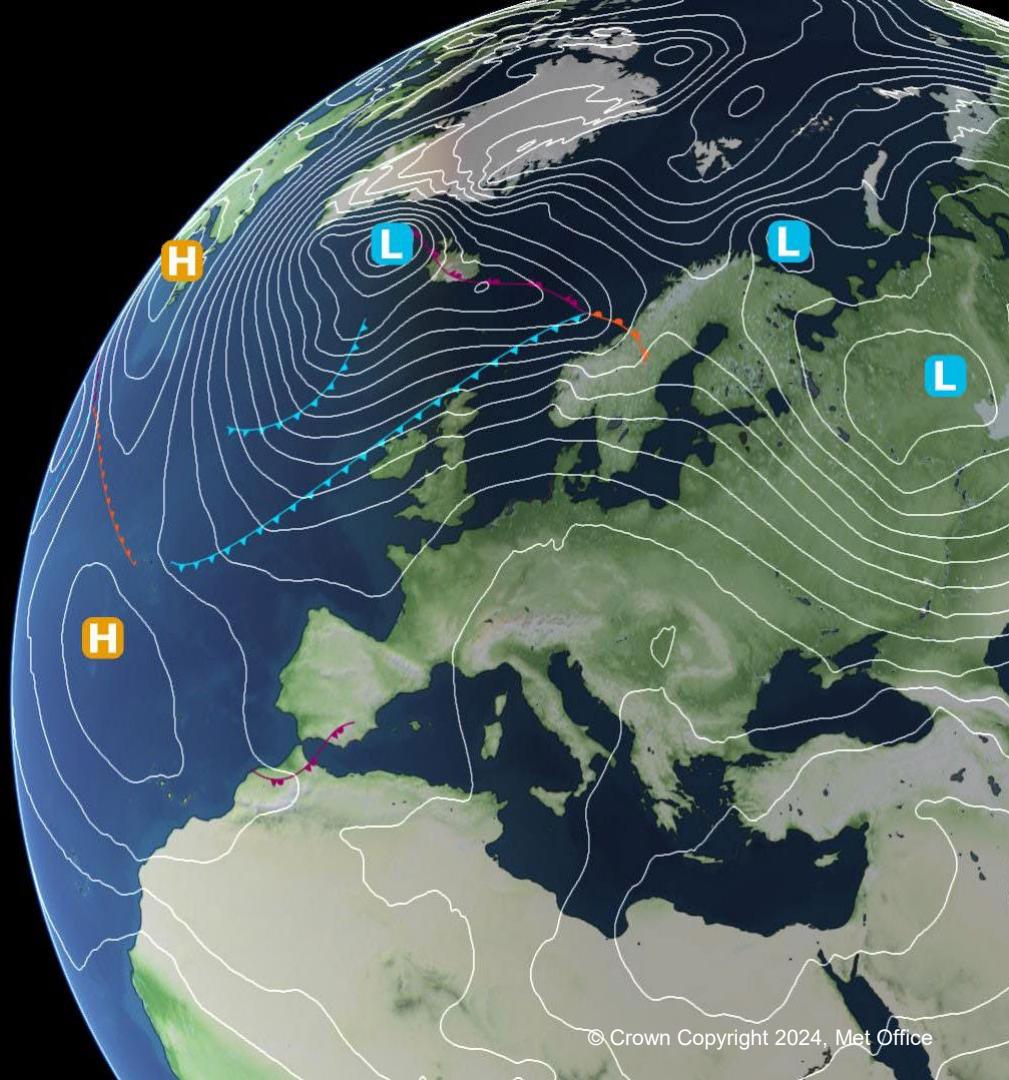
NWP-SAF Workshop on Satellite Observations of the Earth System Interfaces

ECMWF

21 November 2024



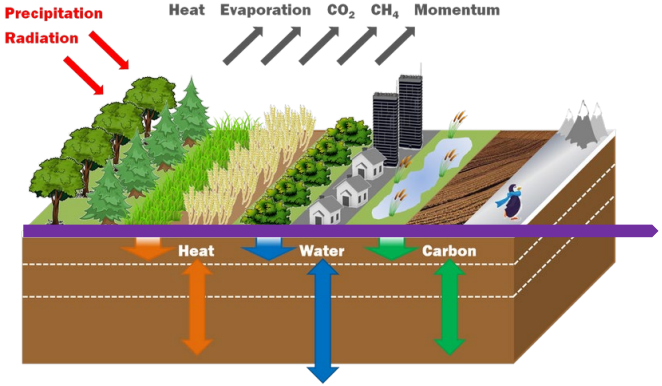
Outline

- Motivation for **L**and **S**urface **D**ata **A**ssimilation (LSDA)
- Current LSDA in Operations
- Next Generation LSDA
- Timeline
- Summary

We are currently building a unifying DA software system that will become the infrastructure to enable stronger coupling between the Earth system components in the Met Office system.

UM & LFRic both internally coupled to JULES:

Joint **U**K **L**and **E**nvironment **S**imulator



Heterogeneity of land modelled through tiled surface types.

- Broadleaf trees
- Needleleaf trees
- C3 (temperate) grass
- C4 (tropical) grass
- Shrubs
- Urban (roof/canyon)
- Inland water
- Bare soil
- Land ice (not sea ice)

JULES is the model used by the UM and LFRic to simulate land-atmosphere exchanges of heat, moisture, momentum and carbon.

In current operations our LSDA system uses JULES consistently to compute sensitivities for DA.

LSDA improves model surface initial conditions → Near surface fluxes → Atmospheric boundary layer

[JULES code]

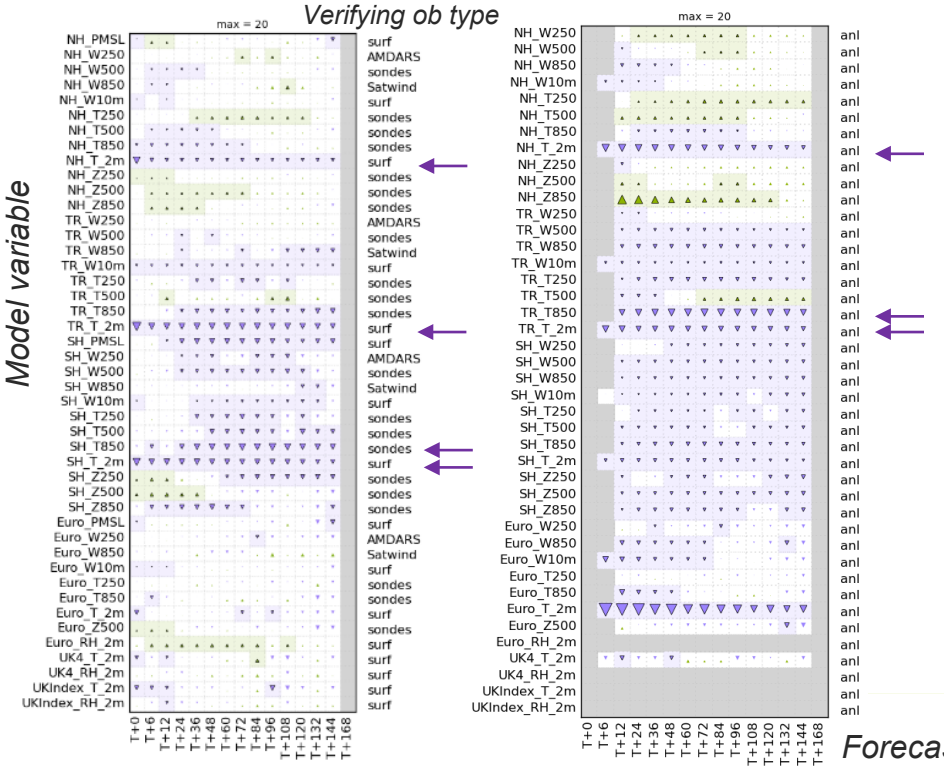
[JULES documentation on github]

No LSDA: Impact on global NWP from denial of all land observations in low resolution global trials

NH Winter 2022-23

-0.46% against observations

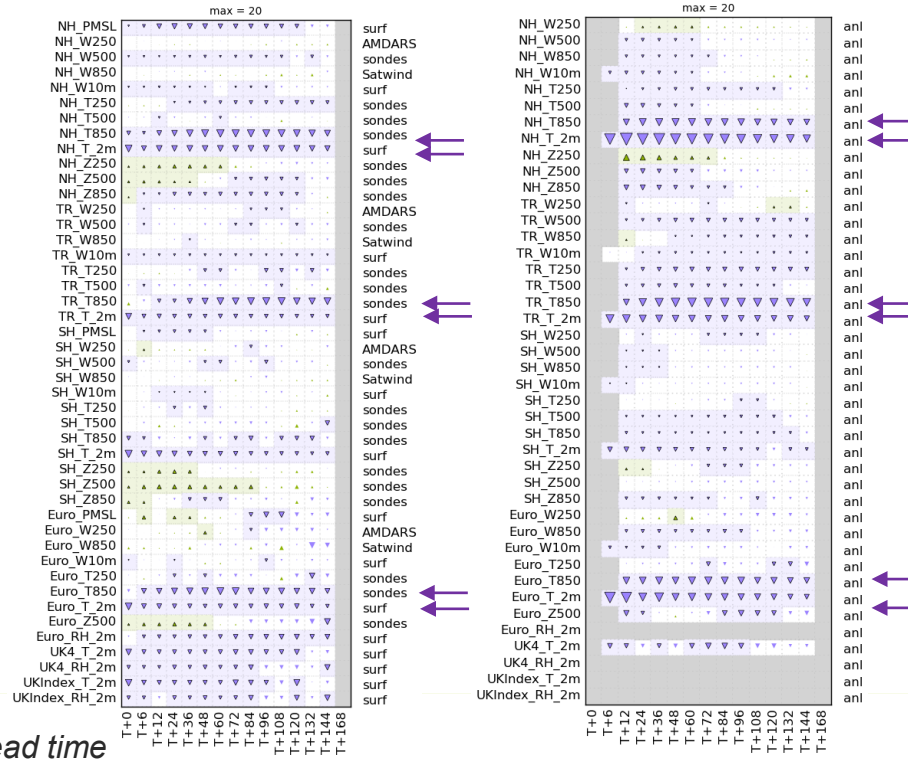
-0.62% against ECMWF analysis



NH Summer 2021

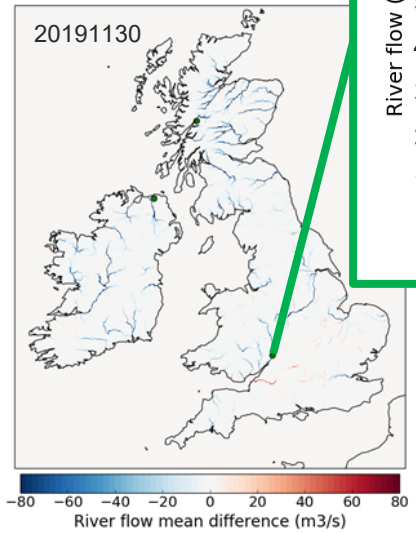
-0.75% against observations

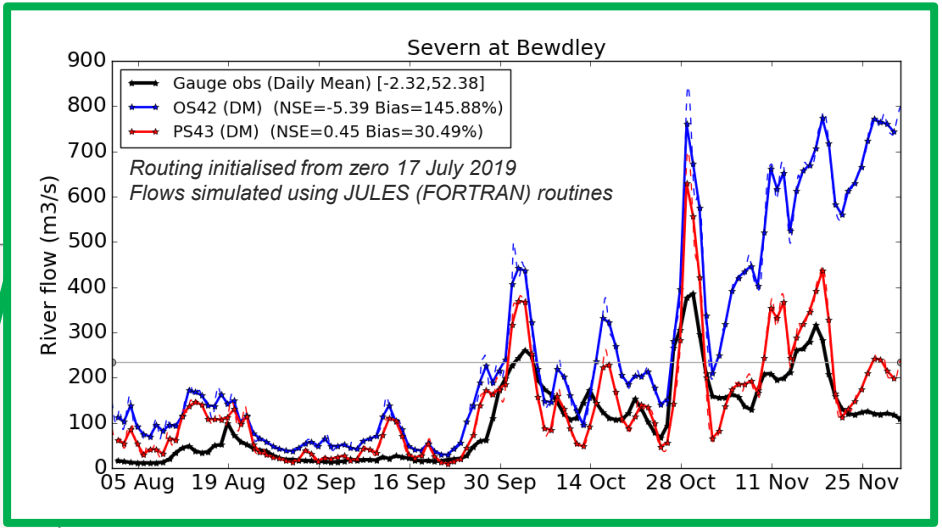
-1.08% against ECMWF analysis



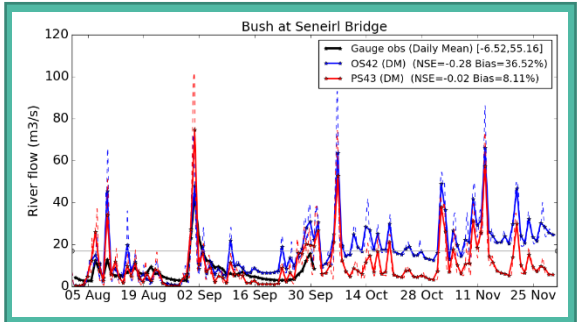
Impact of regional soil moisture DA on hydrological prediction

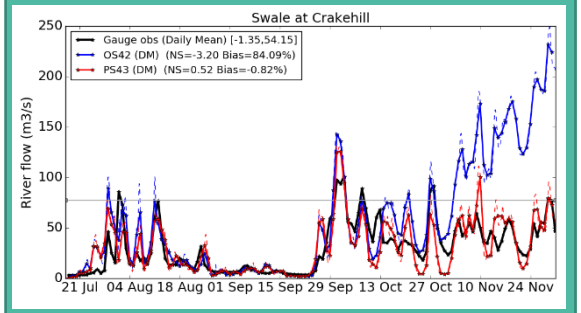
Output of offline routing of Control and Experimental runoff diagnostics using JULES RFM river routing code (default parameters) [Daily mean flows]

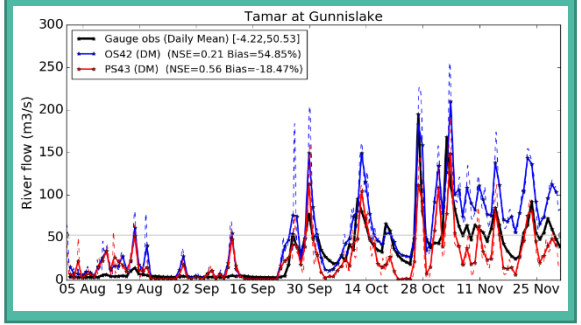




- Clear improvement to simulated river flows relative to observations using active LSDA surface and sub-surface runoff
- Substantial high bias when not using LSDA
- The basis of a hydrologically useful system?





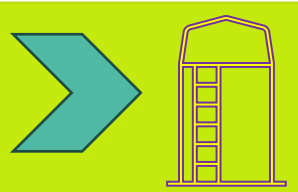


Slide courtesy Huw Lewis

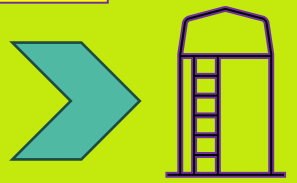
Met Office

Current operational **L**and **S**urface **D**ata **A**ssimilation (LSDA) system

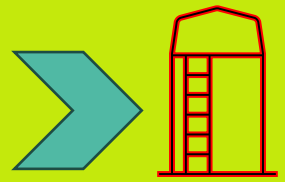
- Northern Hemisphere NESDIS IMS snow cover



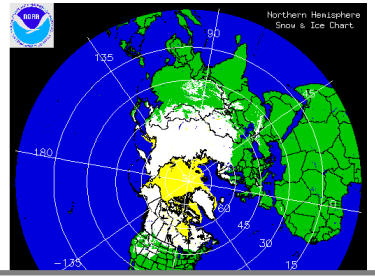
- Regional SYNOP Station snow depth
- Regional EUMETSAT H-SAF snow cover product H31



- ASCAT soil wetness product
- Pseudo-observations of near surface temperature and humidity

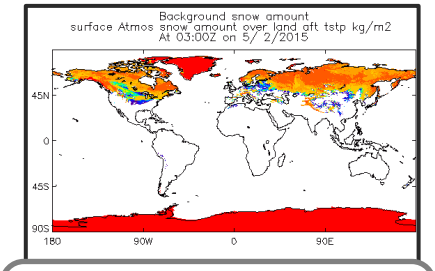


Operational Global Snow DA



NOAA-NESDIS IMS 4km

Observation
Snow cover converted into gridbox Fractional Cover



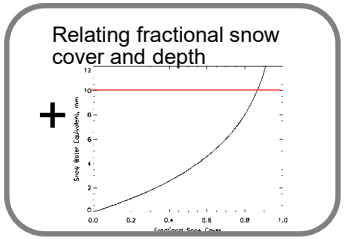
UM N1280 ~10km

Background
Snow amount (kg m^{-2})
T+6 from previous cycle

Observation/Background

no snow/no snow or snow/snow
⇨ do nothing

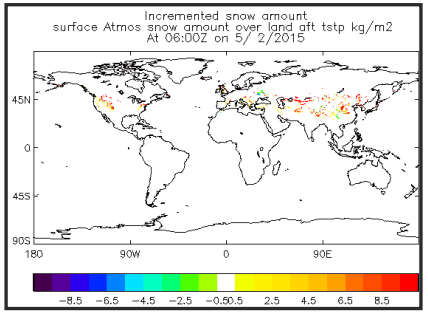
snow/no snow ⇨



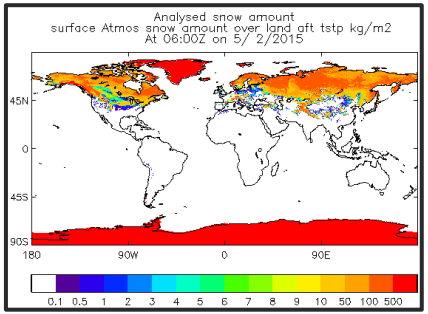
no snow/snow ⇨ Remove snow

Time delay check
Using T+6 from previous day

06 UTC Increments



06 UTC Analysis

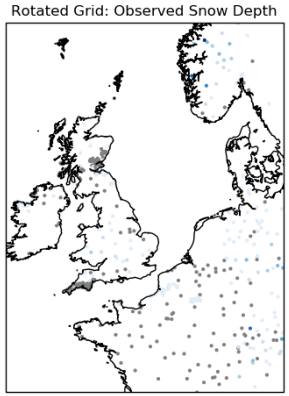


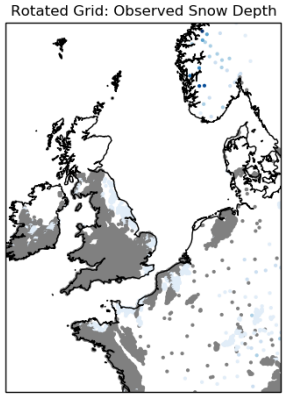
Analysed snow amount

[Using Satellite-Derived Snow Cover Data to Implement a Snow Analysis in the Met Office Global NWP Model (Pullen et. al., 2011)]

Operational Regional Snow DA

Observations





Ground-based Synop network

- snow depth
- state of ground (snow or no snow)
- 4 times per day

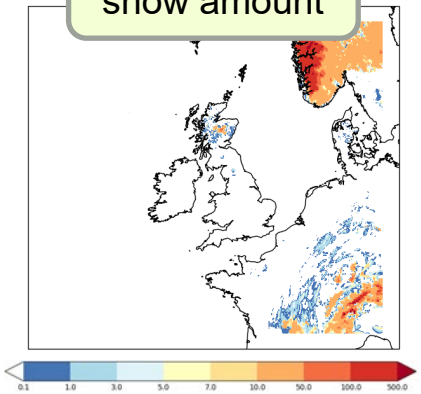
Satellite data from MSG-SEVIRI

- H SAF daily snow cover product H31
- Once per day

"Observed" snow depth

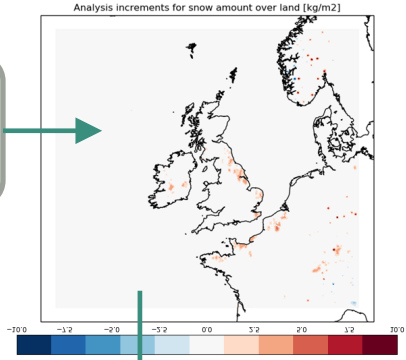
(0.05 m snow depth from snow-cover product where model snow-free)

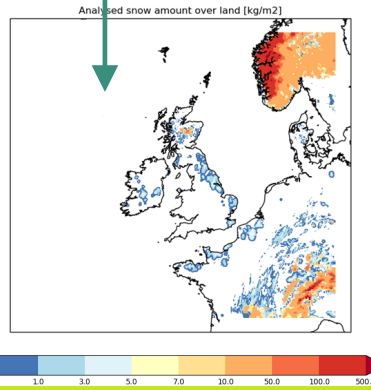
Background snow amount



2D Optimal Interpolation

Analysed snow amount

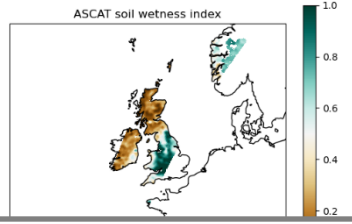




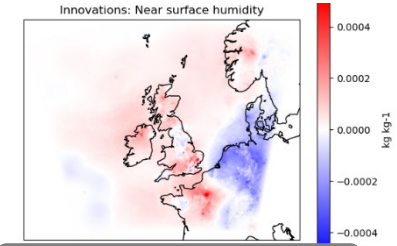
A Global Analysis of Snow Depth for NWP (Brasnett, 1999)

Operational Global & Regional Soil DA

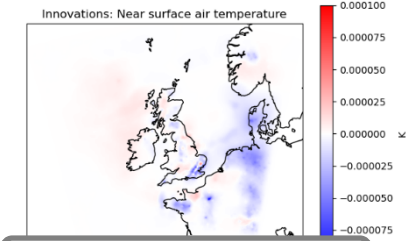
Observations



ASCAT soil wetness index



1.5 m Hum (Gridded)



1.5 m Temp (Gridded)

1. ASCAT Bias Correction
2. Simplified Extended Kalman Filter

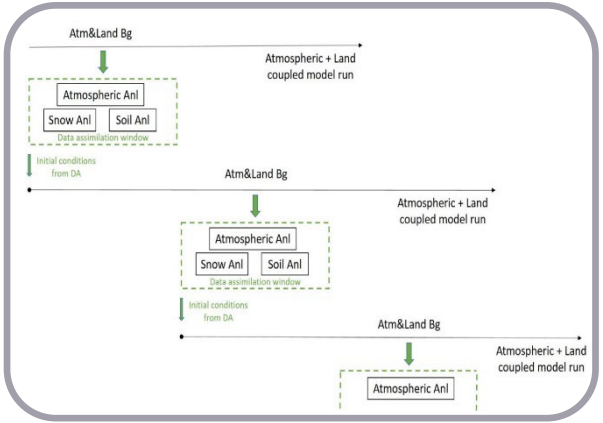
$$x_i^a = x_i^b + \mathrm{K_i}\left[y_i^o - H_i\left(x_i^b\right)\right]$$

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

- Column-based system (1D)
- JULES land surface model used to estimate Jacobian
- UKV regional analysis every hour
- Global analysis every 6 hours

Analysed variables

- Soil T and moisture on 4 layers
- Snow T up to 3 layers and tiles
- Skin T on tiles
- Global: 9 tiles (1 urban)
- UKV: 10 tiles (2 urban)



The Met Office Operational Soil Moisture Analysis System (Gomez, Charlton-Perez, Lewis, Candy, 2020)

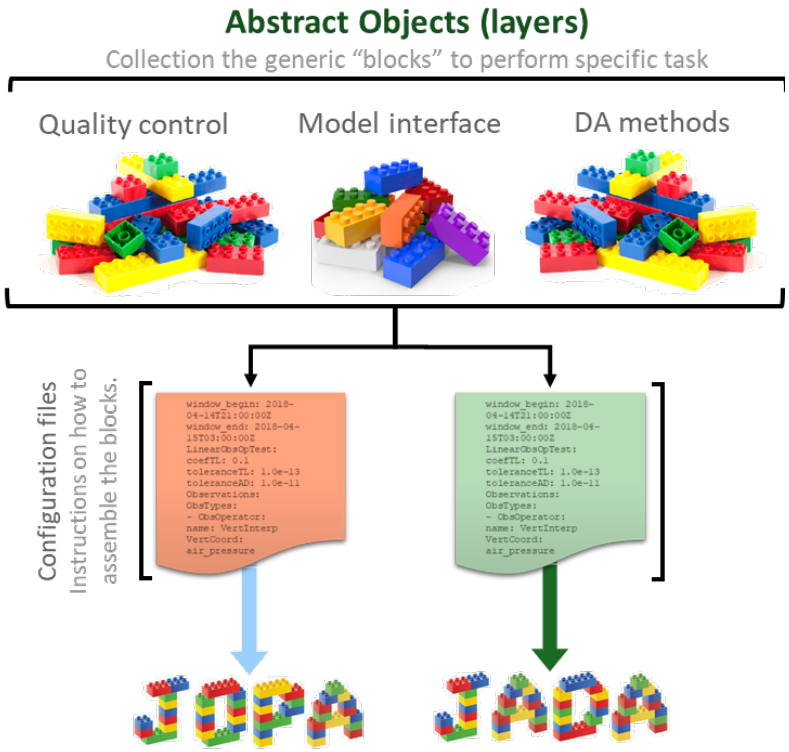
Plans: Next Generation DA

Adopting **JEDI: J**oint **E**ffort for **D**ata assimilation **I**ntegration code framework developed in collaboration with the Joint Centre for Satellite Data Assimilation (JCSDA), we will create global and regional data assimilation systems to replace current Met Office DA for the atmosphere and land surface.

JEDI

- offers modularity and flexibility using a generic object-oriented (C++) programming.
- is based on a standard interface between models, observation, and data assimilation algorithms.
- is agnostic to the model and method choices reducing need for customised code in operational systems.
- is collaborative and advances quickly (github).
- makes system development easier via use of configuration files (yaml) to experiment with new methods (separation of concerns).
- will work from research to operations “one size (system) fits all”.
- will speed-up the implementation of assimilation of new land-relevant observation types.

Plans: Next Generation DA



JOPA: **J**EDI-Based **O**bservation **P**rocessing **A**pplication

New observation processing system will select, quality control, bias correct and transform observations as required for assimilation.

JADA: **J**EDI **A**pplication for **D**ata **A**ssimilation

Brand-new DA system.

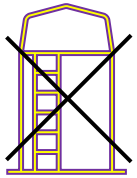
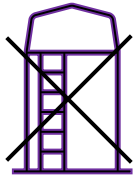
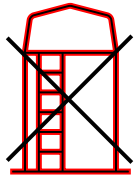
NEXT GENERATION JOPA-land PROCESSING AND ASSIMILATION OF OBSERVATIONS

Observation processing for all current land surface observations.

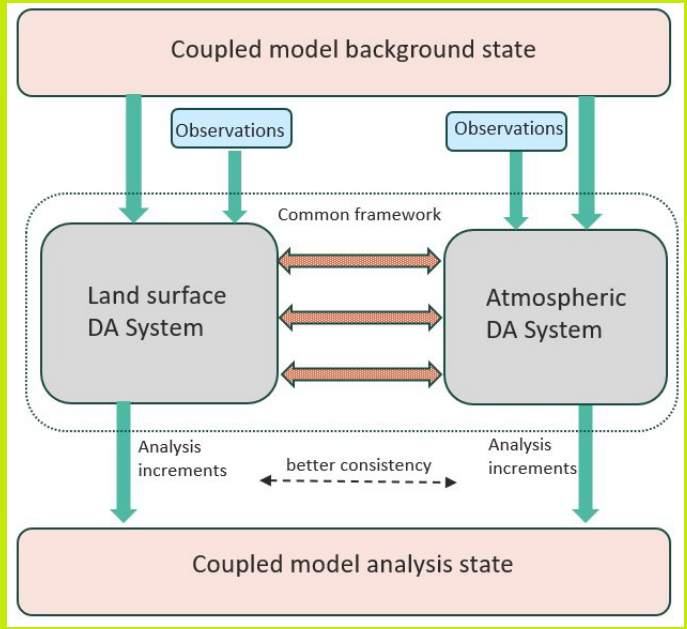
NEXT GENERATION JADA-land PROCESSING AND ASSIMILATION OF OBSERVATIONS

Ensemble DA methods will be used to create land surface analyses.

Next generation LSDA

- Harmonised multi-variate system for consistent analysis of all current variables. Easier to extend to new analysis variables and observation types
- Leverage existing code by extending atmospheric observation processing to land observations
- Generic for example able to work with UM structured or LFRic unstructured grids
- Align with atmospheric DA to facilitate future development of coupled DA

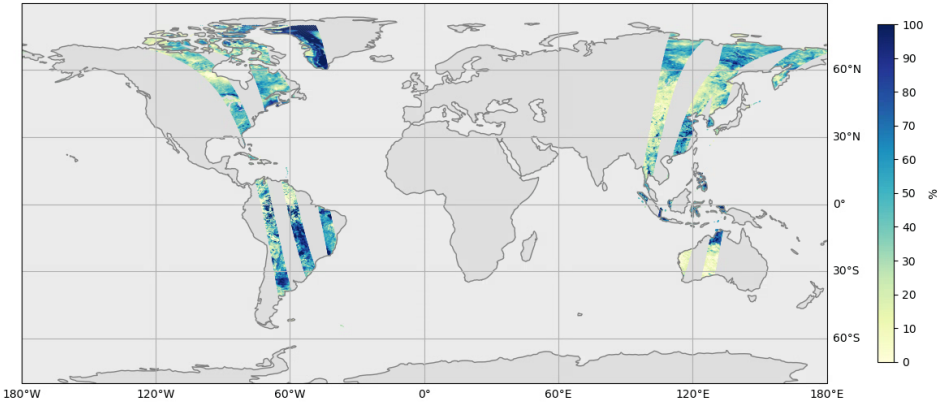


ASCAT
Soil Wetness Index

Met-Op B 14/01/2024 : 0000Z - 0259Z

Number of obs: 153282, Min: 0.0, Mean: 41.07379209561462, Max: 100.0

ASCAT SWI



Current Operations:

- ASCAT BUFR data extracted directly from MetDB – no ODB files
- QC using metadata distributed with the observation

Work in model space

- ASCAT Soil Wetness Index (SWI) data interpolated to model grid
- ASCAT SWI converted to soil layer 1 soil moisture content using JULES climatology data interpolated to model grid
- QC on model grid
- Processed observations input to DA (SEKF) on model grid

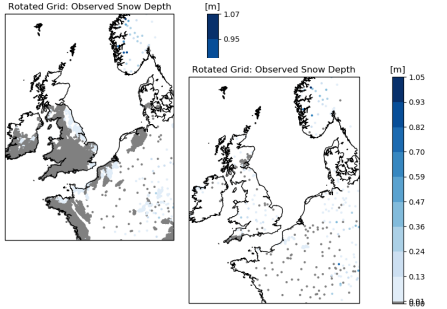
Future operations: ASCAT processing in JOPA

- New code to create ASCAT (SWI) ODB files
- QC using metadata distributed with the observation

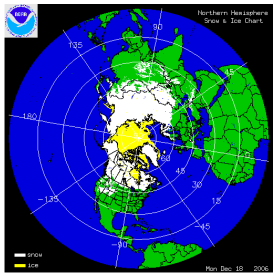
Work in observation space

- Convert ASCAT (SWI) to volumetric soil moisture using gridded JULES model climatology data interpolated to obs locations
- QC the observation using model values at obs location

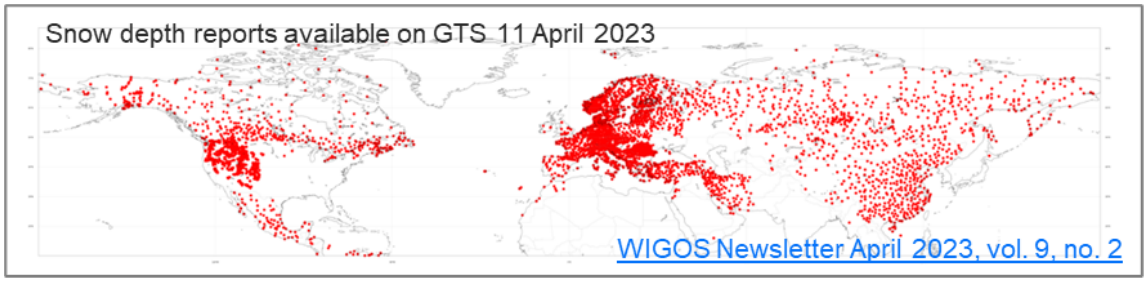
Snow depth and snow cover



SEVIRI (H31) and LNDSYN



IMS



Current operations:

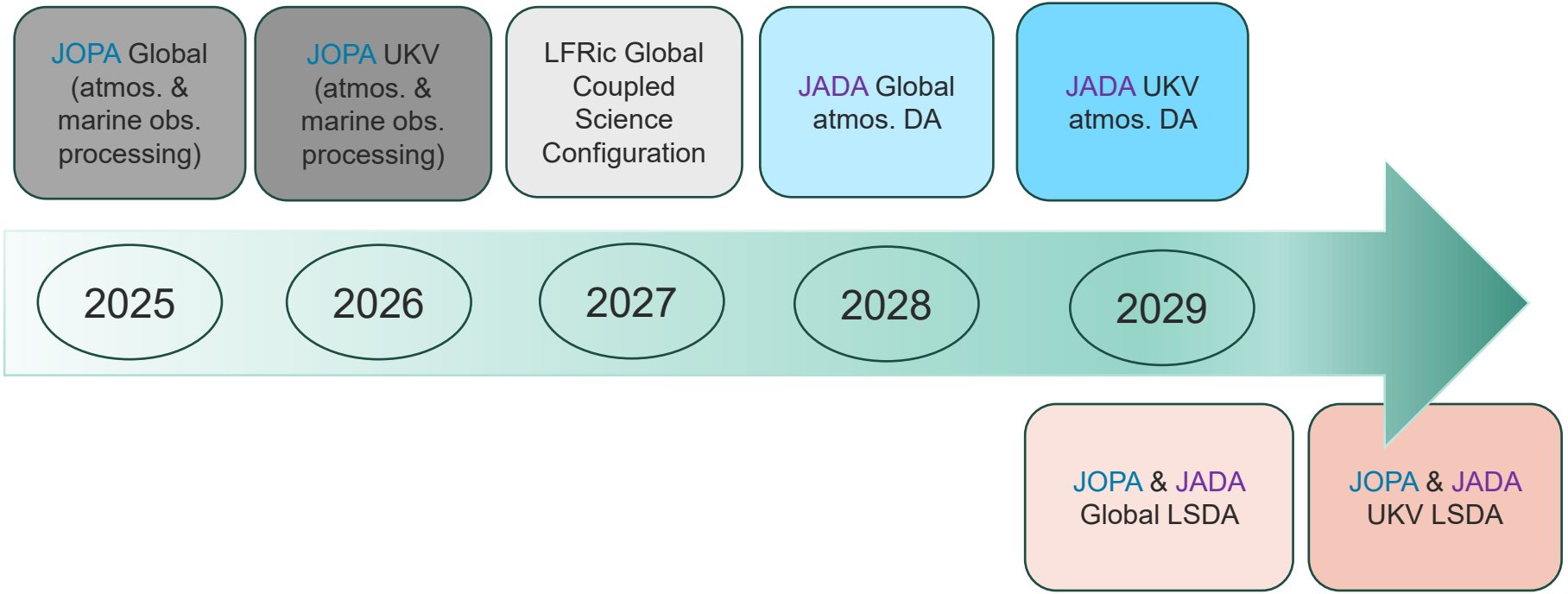
- Station snow depth and state-of-ground only from LNDSYN over UKV domain
- Satellite snow cover from SEVIRI (UKV) and IMS (global)
- Obs extracted directly from MetDB – no ODB files
- Snow depth assigned for snow cover and state-of-ground obs (UKV)
- Processed in observation space (UKV)
- Processed observations passed to DA (2D OI) at observation locations (UKV)

Future operations: Snow processing in JOPA

- Add new observations: LNDSYB and SNOWB station snow depth and state-of-ground
- Observation operator to simulate snow depth from snow amount
- Snow depth assigned for snow cover and state-of-ground obs
- Processed in observation space – use same QC approach as before
- Introduce use of stationlist for global snow station reports
- Thinning of IMS obs
- Height-dependent obs error assignment for station obs

Current Timeline

Current LSDA system remains operational with continued maintenance and support



Summary

- Current LSDA operational system is no longer under scientific development
- Met Office has adopted the JEDI framework for processing observations (JOPA) and performing DA (JADA)
- JEDI is a collaborative effort with JCSDA
- JEDI framework is flexible, modular, generic and model-agnostic
- Next Generation JEDI-based LSDA will start by assimilating the same observations that are in operations now
- Observation processing will build on JOPA capability introduced for our atmospheric DA.

Summary

- Next generation LSDA will be harmonised: producing a single multi-variate analysis (snow depth, soil moisture, skin-, soil-, snow temperatures)
- Next generation LSDA must use an ensemble DA method to provide land initial conditions for our ensemble NWP system.
- Aim is to align LSDA with atmospheric DA. **Choice of DA method should enable future enhanced coupling between atmosphere and land surface.**
  - For example, in global we will use an ensemble of 3D-Vars for LSDA because the atmospheric DA will be a variational system.
  - Current plan for regional atmospheric DA is to use an Ensemble Kalman Filter. Therefore, regional LSDA will follow a similar approach. The atmospheric regional DA development has not started yet.

Please get in touch with any questions

c.charlton-perez@metoffice.gov.uk

We are currently building a unifying DA software system that will become the infrastructure to enable stronger coupling between the Earth system components in the Met Office system.