Development of snow depth data assimilation for the Met Office UK forecasting system

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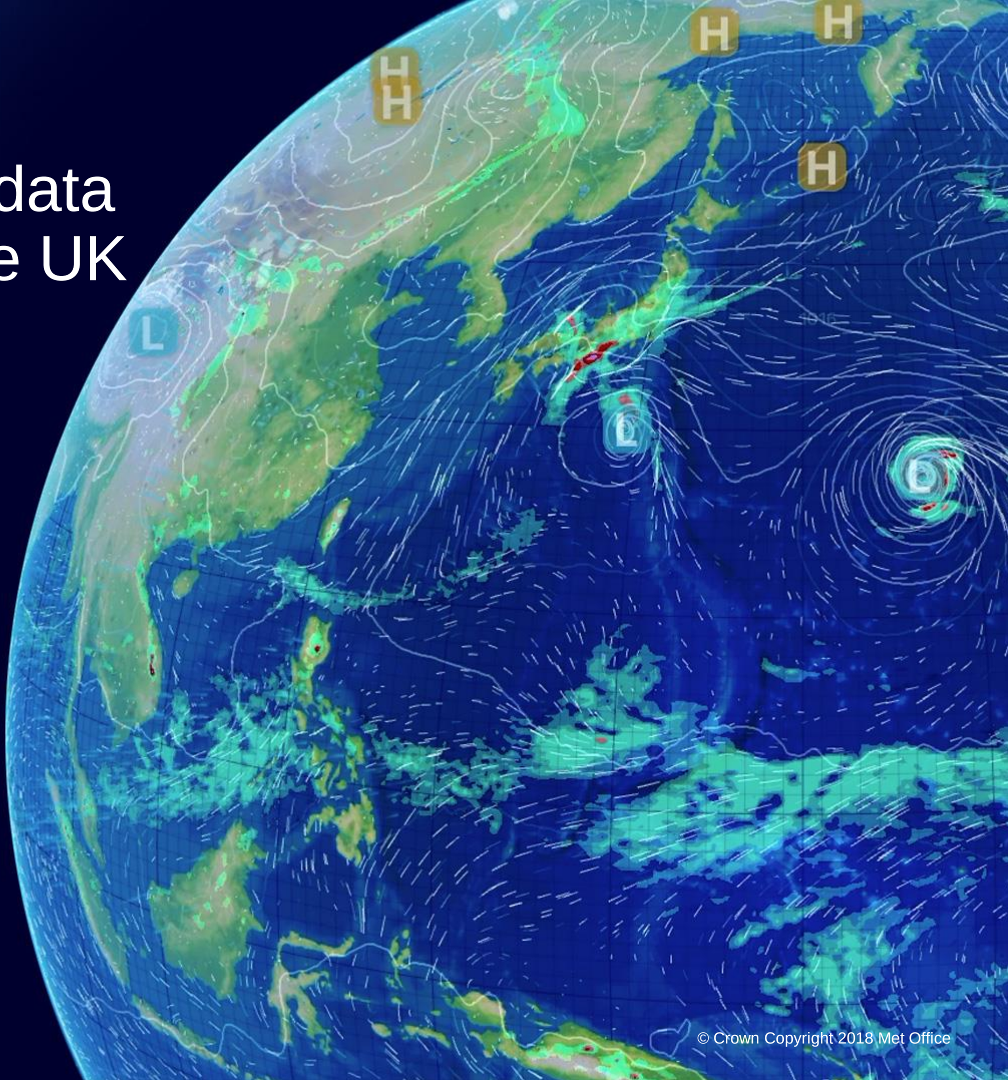
ECMWF, UK



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Outline

- Snow in the UK
- Land surface model and snow scheme
- Snow depth assimilation scheme
- Assimilation trials with the new snow DA scheme
  - Examples of observations and analysis
  - Experimenting with the horizontal length scale
  - NWP verification results
- Next steps

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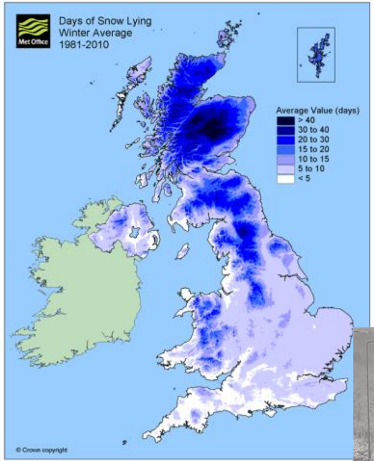
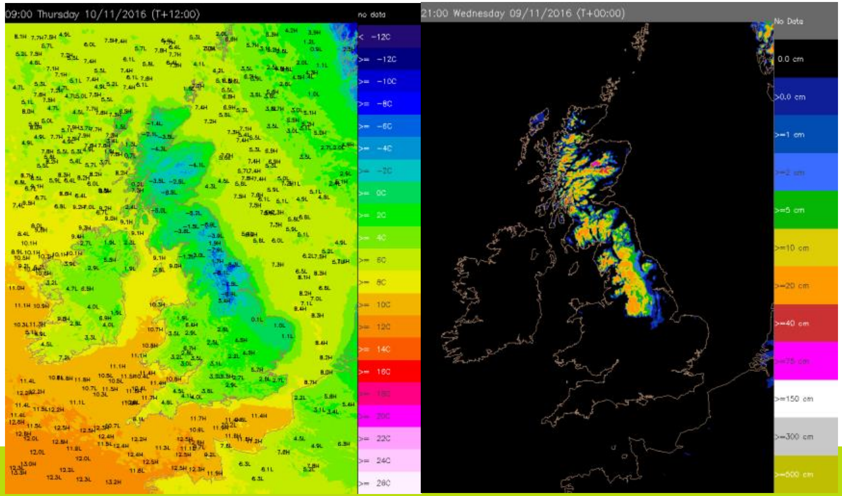
Why does snow matter in the UK?



- The UK does not experience regular widespread snowfall except in the Highlands of Scotland
- Tends to be transient, often wet, shallow, multiple snowfall/melt cycles in one season.
- Low frequency, but high impact event – accurate analyses and forecasts of snowfall and lying snow extremely important and affect calculations of surface exchange fluxes => forecasts of atmospheric variables
- Currently no snow observations assimilated in UK model (UKV)

Insulation effects – near surface T

Surface temperature biases



<u>Aim of performing snow analysis:</u>

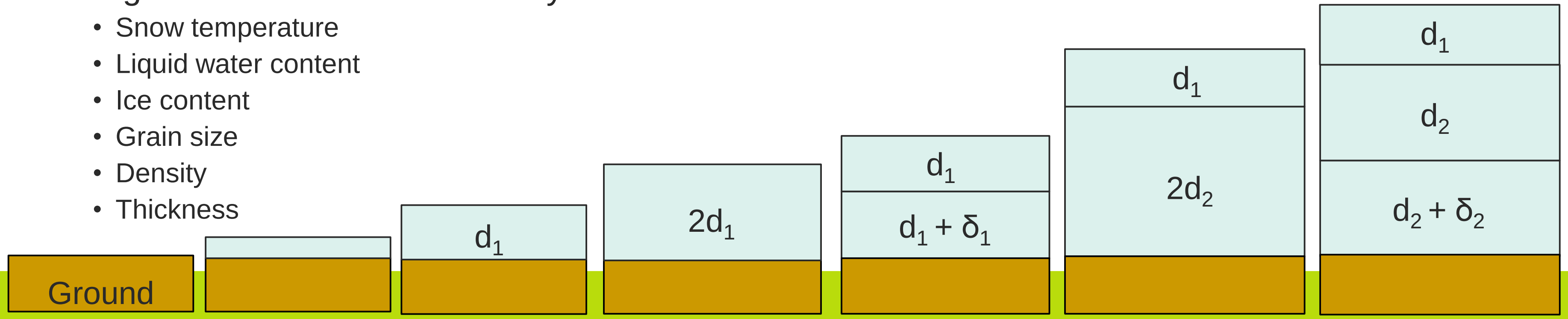
1. **Improve representation of snow in initial conditions**
2. Improve forecasts of screen level variables

Land surface model – snow physics

JULES Land Surface Model with multilayer snow scheme

Best *et al*: The Joint UK Land Environment Simulator (JULES), model description – Part 1: Energy and water fluxes, Geosci. Model Dev., 4, 677–699, https://doi.org/10.5194/gmd-4-677-2011, 2011

- Maximum 3 layers
- Snow accumulates to a max thickness, then splits into 2 layers. Continues to accumulate in lower layer, then splits again
- Compaction, canopy unloading, thermal conduction through air in snowpack, water infiltration
- Largest impact - insulation of the soil beneath the snowpack
- Prognostic variables for each layer:
  - Snow temperature
  - Liquid water content
  - Ice content
  - Grain size
  - Density
  - Thickness



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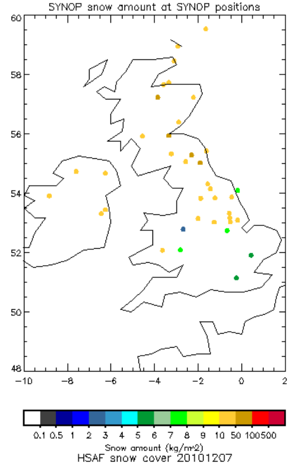
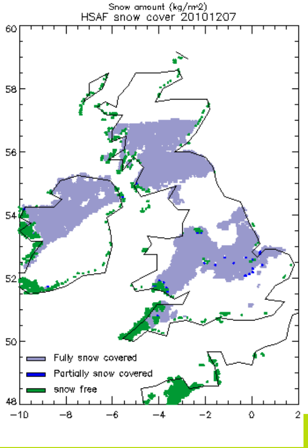
Snow DA for the UK NWP system





Observation source	Snow depth "observations"
Ground-based Synop network • snow depth	Reported snow depth
• state of ground (snow or no snow)	Zero snow depth from snow-free state of ground reports
Satellite data from MSG-SEVIRI • H SAF daily snow cover product (H31)	Zero snow depth from snow-free pixels
	0.05 m snow depth from snow-covered pixels where model snow-free

Model first-guess snow depth

Optimal Interpolation

Snow depth analysis

Initially once per day 0600 UTC

The EUMETSAT Network of Satellite Application Facilities

H SAF Support to Operational Hydrology and Water Management

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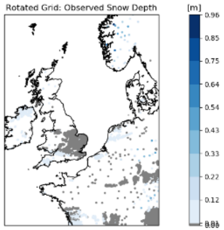
Quality control and tuning

QC on observations



In situ obs

- Reject observations with unrealistic snow depth for their reported screen temperature ($T_{1.5}$ > 278 K and SD > 1cm)
- Remove duplicate reports from same station (use the one closest to cycle time)

Satellite obs

- Reject snow-covered obs where model is also snow-covered
- Apply mountain mask (reject if >1500m)

QC on observation innovations (O – B)

Based on observation and background error variance

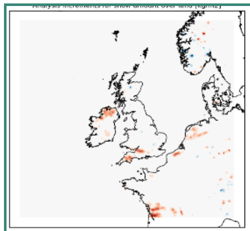
- Reject obs for which O – B > 0.25 m

(threshold set by: *tolerance* × $\sqrt{(\sigma_o^2 + \sigma_b^2)}$)

Observation and background errors

- Background error sdev (σ_b = 0.03 m)
- Synop observation error sdev (σ_o = 0.04 m)
- HSAF observation error sdev (σ_o = 0.08 m)

QC on analysis increments



- Max increment allowed = 37.5 kgm^{-2} (0.15 m)
- Positive increment allowed only if model $T_{1.5}$ < 281 K
- Check for negative snow amounts
- No increments on land ice, inland water, urban surface – increments scaled for remaining surface types for consistency with grid-box mean
- No increments where majority of gridbox is land ice + inland water + urban

Optimal Interpolation parameters

- Horizontal correlation length scale (L = 5.5 km)
- Vertical correlation length scale (h = 400 m)
- Search radius around gridbox within which obs can be used (R = 50 km)
- Max number of obs to consider for each gridbox (N = 50)

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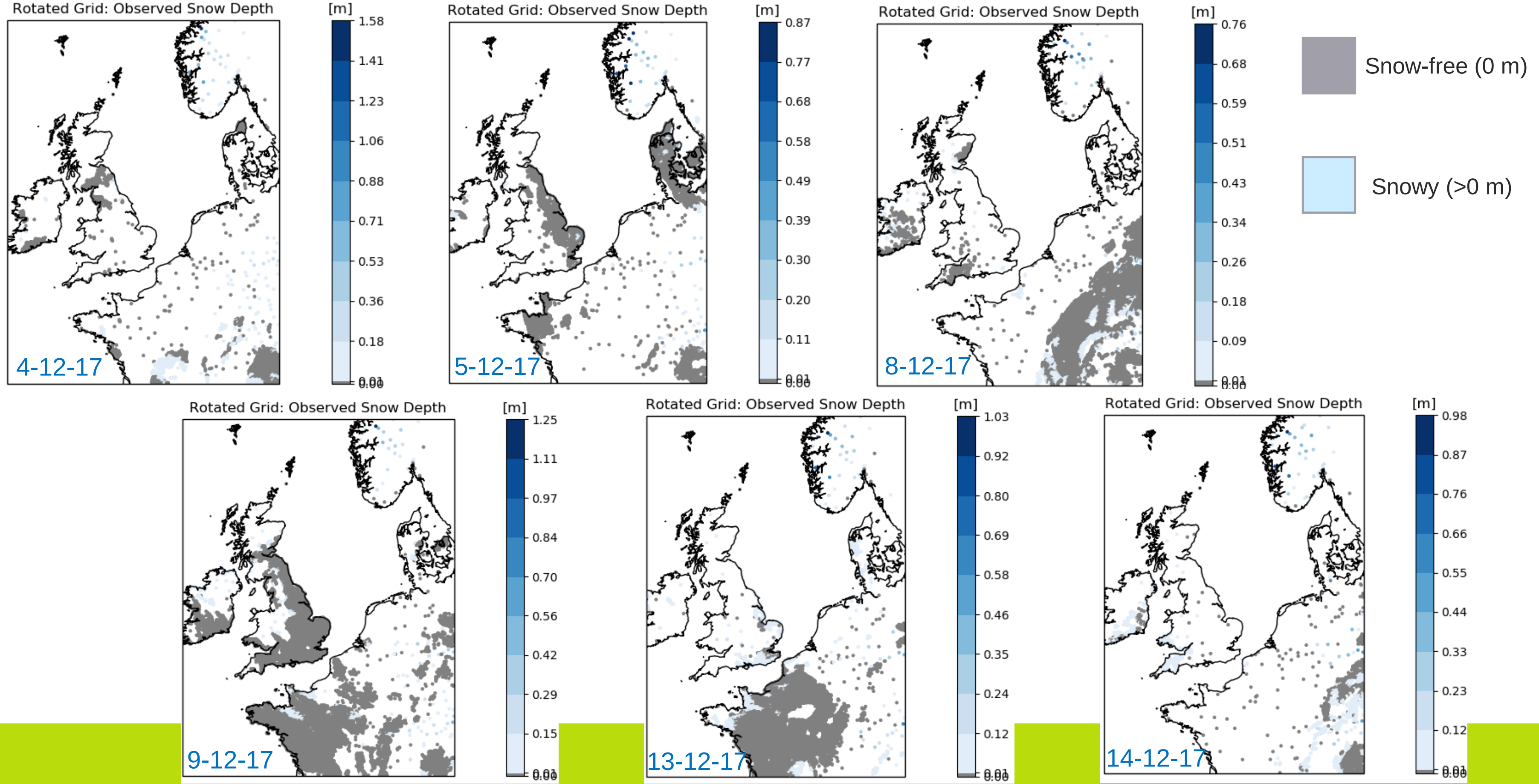
Assimilation trials

- Winter period: December 2017-February 2018
- Experimenting with horizontal length scale
- Verification of atmospheric forecast variables

Observations going into OI



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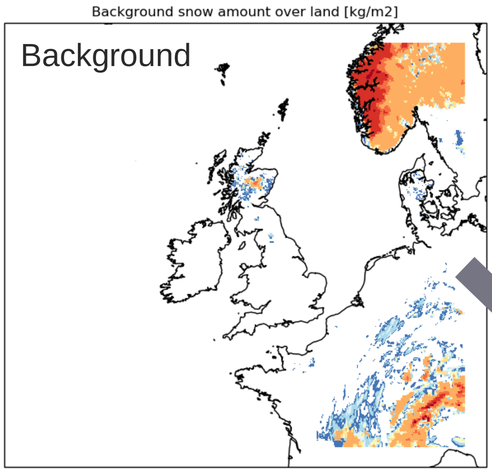
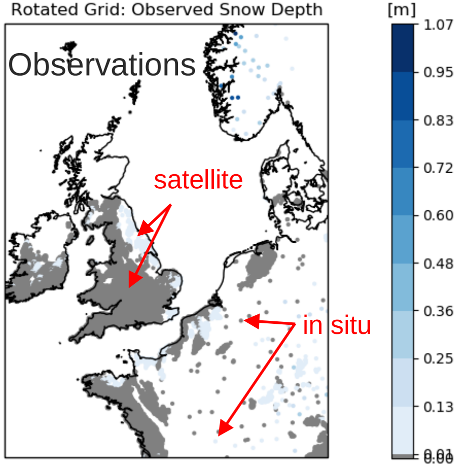
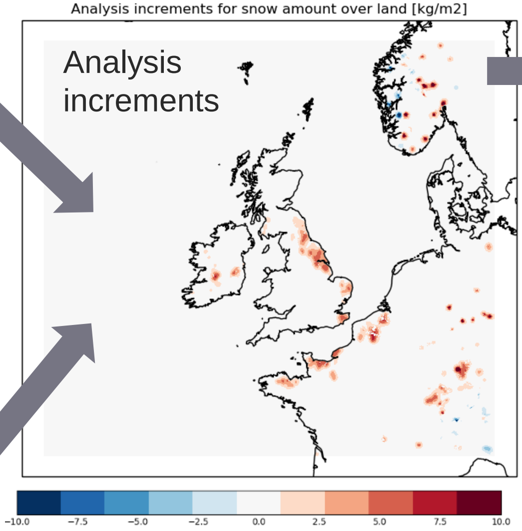
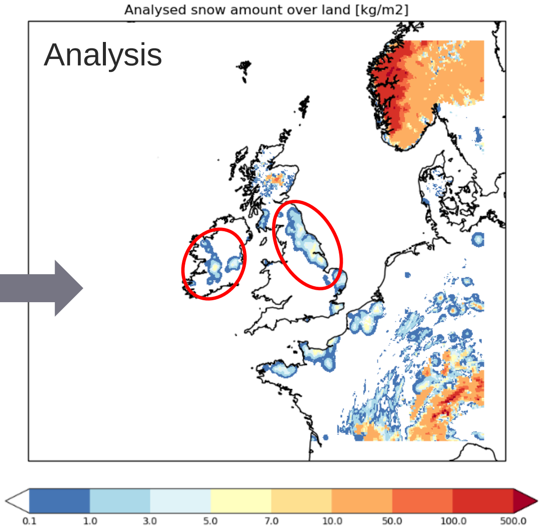
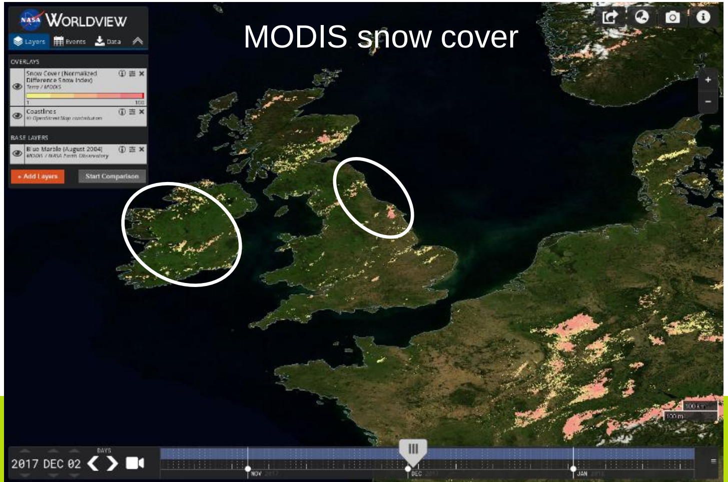
2^{nd} December 2017









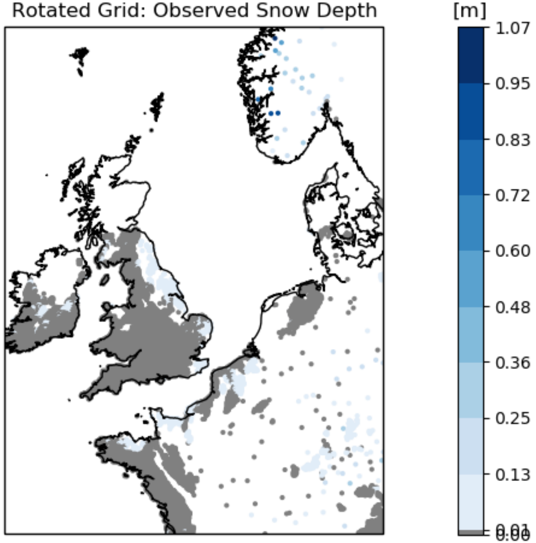


MODIS snow cover only available in cloud-free areas

Horizontal length scale

2[nd] December 2017

Observations

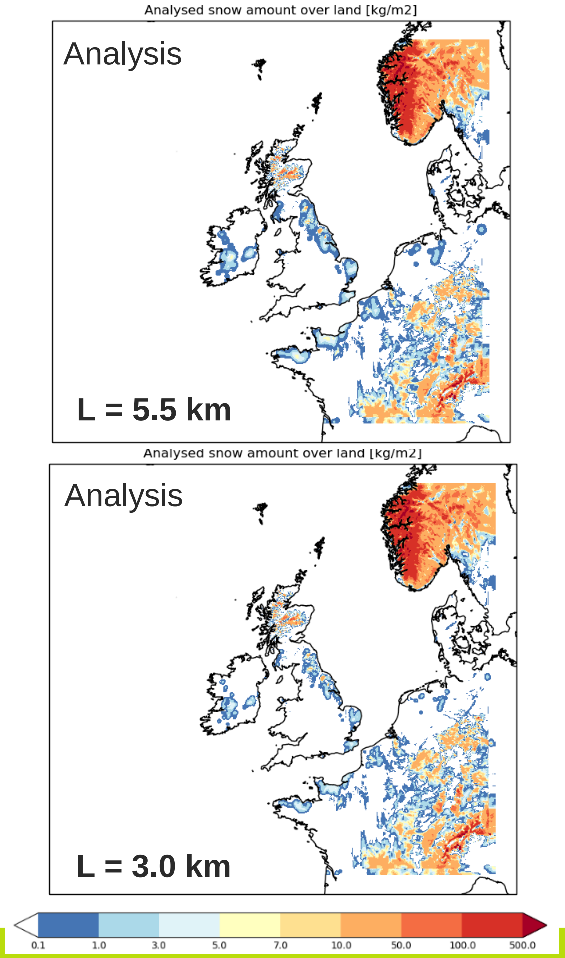


$$\mathbf{W} = (\mathbf{B} + \mathbf{O})^{-1}\,\mathbf{b}$$

$$\sigma_b^2 \times \alpha(r_{ij}) \times \beta(\Delta z_{ij})$$

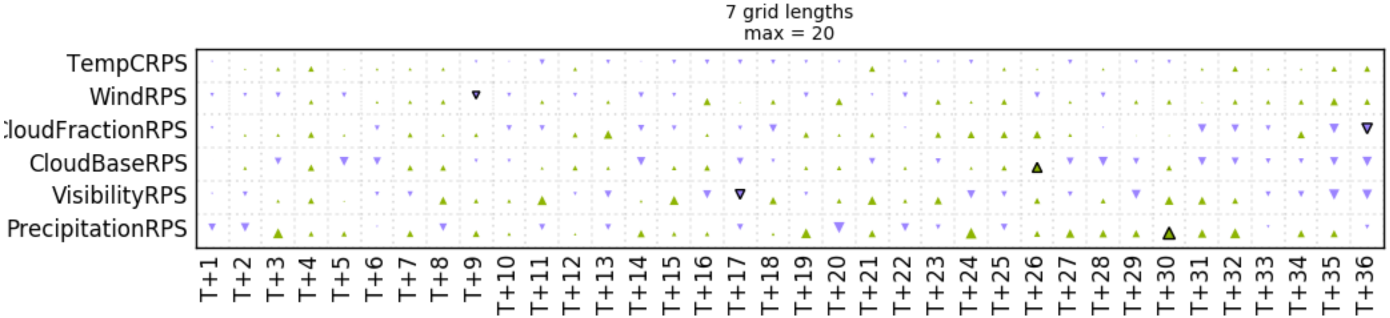
$$\alpha(r_{ij}) = \left(1 + \frac{r_{ij}}{L}\right) exp\left(-\frac{r_{ij}}{L}\right)$$

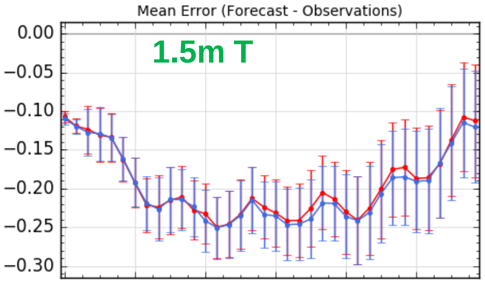
L = horizontal length scale



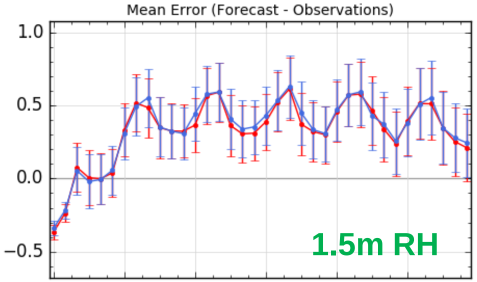
NWP forecast verification

Continuous Ranked Probability Score: % Difference (trial – control)

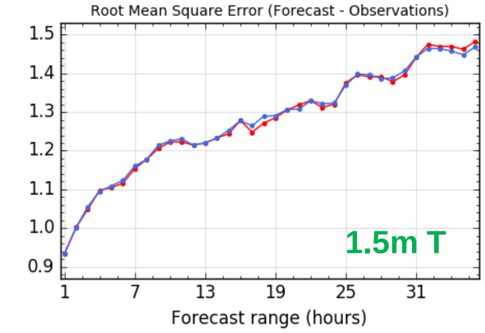




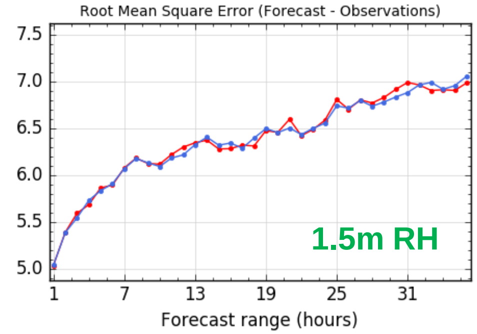
Mean Error



Fc – obs over UK station obs
2-12-17 to 4-1-18



RMS Error



Trial - with snow OI

Control – no snow assimilation

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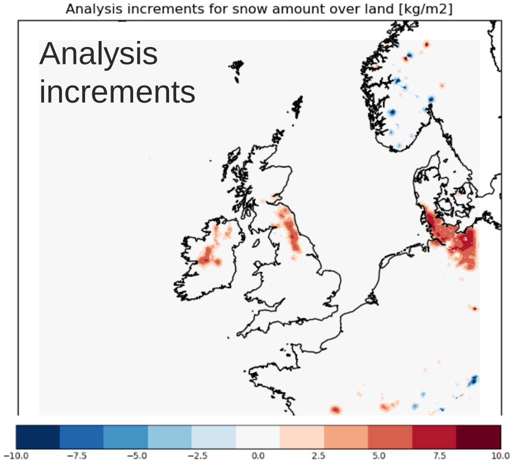
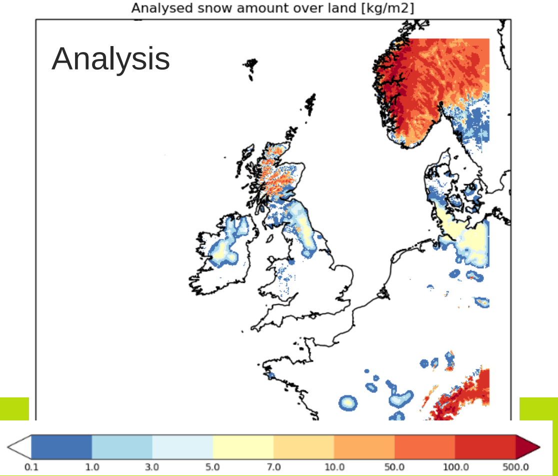
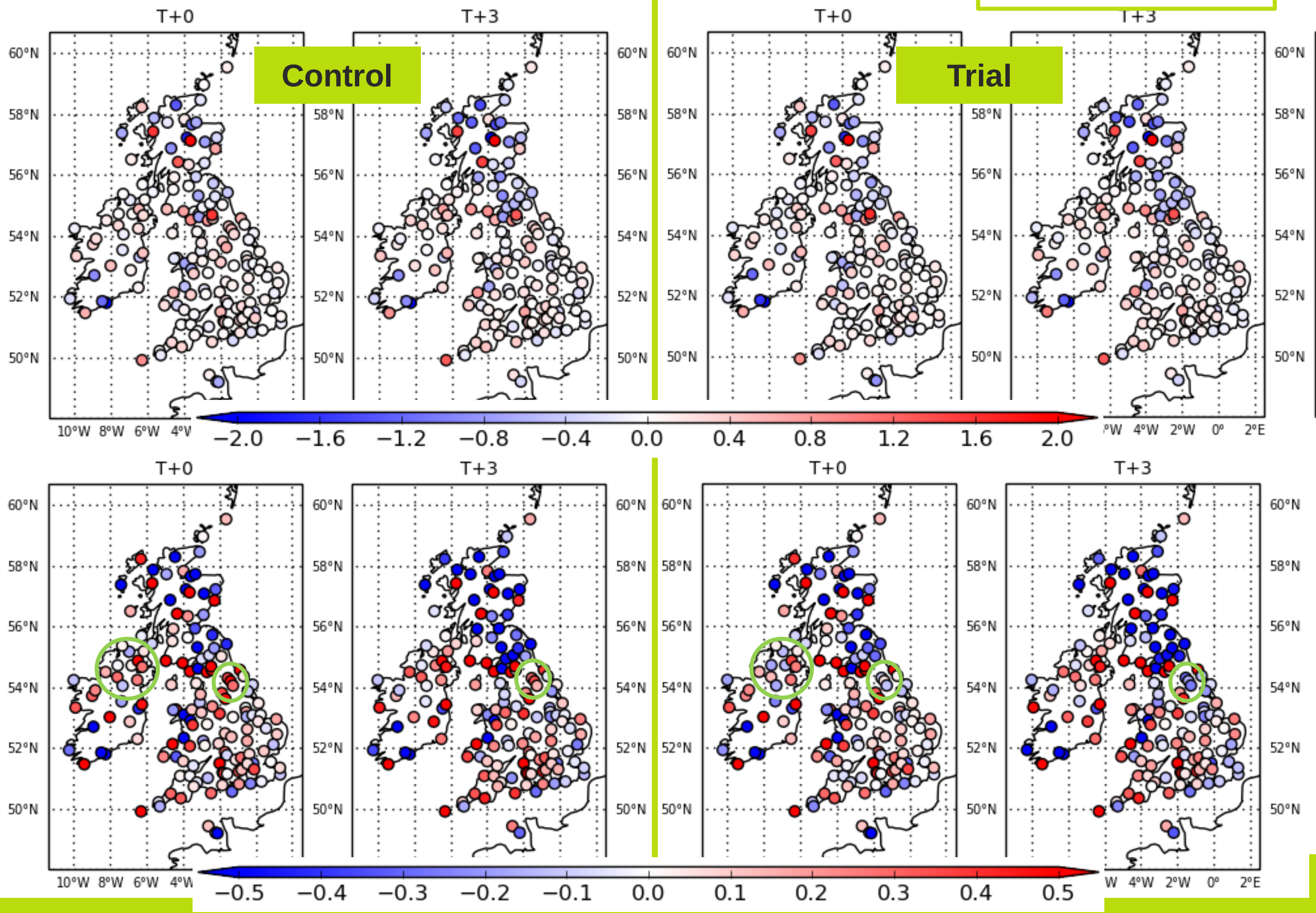
Station based error maps

1.5m T fc – obs
9-1-2018







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Next steps…

- Further assimilation trials
  - Reduced horizontal length scale
  - New season (winter 2018)
  - Interaction with land temperature analysis
- Snow cover validation with other satellite products and guidance from forecasters
- Aim to implement in next operational upgrade (May 2020)
- Increase frequency of snow analysis to 4 times daily, or even hourly
  - Could H SAF snow cover be provided hourly or 4-hourly?

- Adapt for use in global model
  - Alternative satellite snow cover data
  - Use additional national network snow depth and snow water equivalent (SWE) obs

Thank you for your attention!

Any questions?

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Extra slides…

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Optimal interpolation method

Following Brasnett et al, 1999, and ECMWF operational snow DA

The analysis is represented by a weighted combination of the background and observations, where optimum weights are found in order to give the minimum variance of analysis error.

$$x^a = x^b + W[y - Hx^b]$$

$$\Delta S_g^a = \sum_{i-1}^{N} W_i \, \Delta S_i$$

Analysis increments are calculated as the sum of weighted observation innovations for each gridbox

$$\mathbf{W} = (\mathbf{B} + \mathbf{O})^{-1} \mathbf{b}$$

Weights are calculated from ob and bg error covariances, which depend on relative horizontal and vertical separations between obs and gridbox, and their error variances

$\mathbf{b}$: $\sigma_b^2 \times \alpha(r_i) \times \beta(\Delta z_i)$

$\mathbf{B}$: $\sigma_b^2 \times \alpha(r_{ij}) \times \beta(\Delta z_{ij})$

$\mathbf{O}$: $\sigma_o^2 \times \mathbf{I}$

Bg error variance

Horizontal separation

Vertical separation

Ob error variance

$$\alpha(r_{ij}) = \left(1 + \frac{r_{ij}}{L}\right) exp\left(-\frac{r_{ij}}{L}\right) \qquad \beta(\Delta z_{ij}) = exp\left(-\left[\frac{\Delta z_{ij}}{h}\right]^2\right)$$