Met Office

Land surface data assimilation at the Met Office and developments in snow depth analysis

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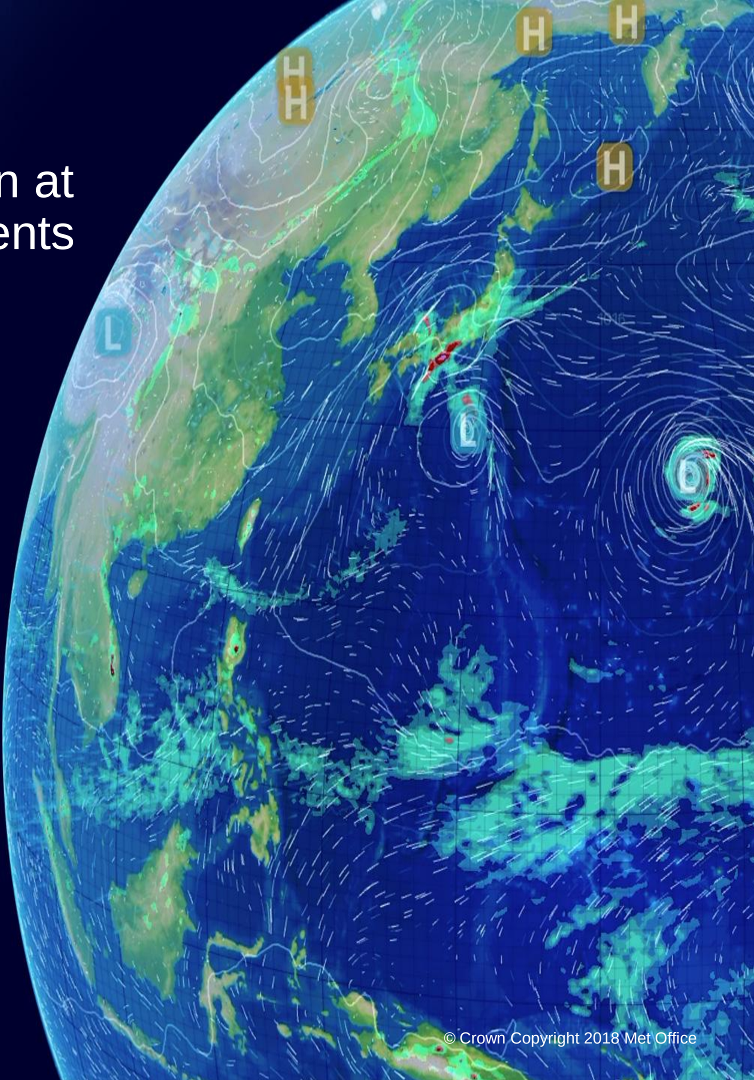
Thanks to Patricia de Rosnay (ECMWF)

ISWG/LSA SAF Workshop

Lisbon, 26-28th June 2018

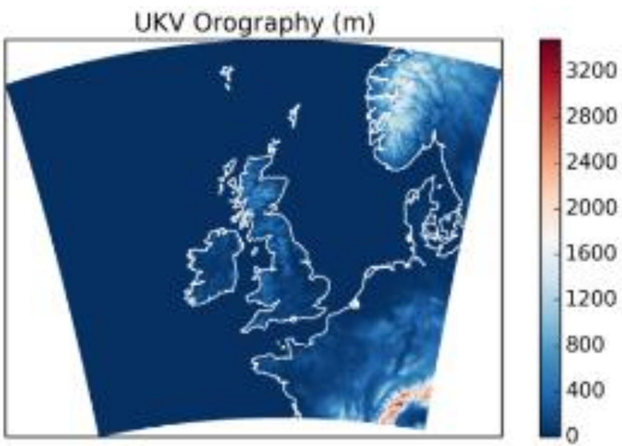


Outline

- Met Office NWP systems
- Current Land Surface DA
- Developments for the regional model
  - Soil moisture
  - Snow depth (main focus)
- Snow observations
  - Some of the issues
  - Improving in situ reporting practice and exchange of data

Met Office NWP Systems

Unified model (UM) coupled with JULES land surface model



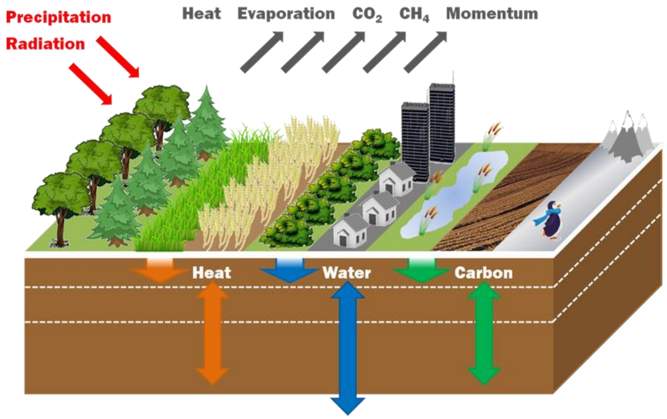
Global

- ~10 km, 70 levels, forecast range to 7 days
- Main and update runs 4x per day
- Main DA hybrid incremental 4D VAR
- Variational bias correction of satellite radiance observations
- Land surface DA – NH snow analysis, SEKF soil moisture, from screen errors in RH and T and ASCAT soil wetness.
- Ancillary daily update of aerosols, ozone, LAI

UK

- Variable resolution 4 km down to 1.5 km, 70 levels, forecast range to 5 days
- Lateral boundary conditions from global model
- Hourly cycles
- Main DA incremental 4D VAR
- VarBC radiance obs
- No land surface DA as yet – soil moisture interpolated from global model
- Ancillary daily update SST, Seaice, LAI/canopy ht, murk sources, ozone

Met Office Land Surface Model: JULES

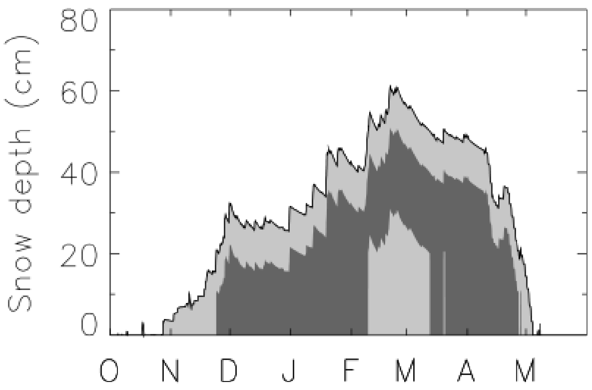


Tiled – sub-grid heterogeneity – fluxes for each surface type:

5 Plant functional types:
- Broadleaf trees
- Needleleaf trees
- C3 grass
- C4 grass
- Shrubs

Plus:
- Urban (2 types)
- Inland water
- Bare soil
- Land ice

Multi-layer snow module (Essery)



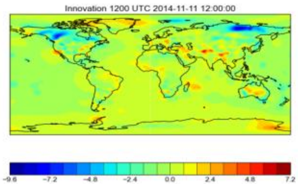
Prognostic snow variables:
- Snow depth
- Snowpack bulk density
- Number snow layers

Within layers:
- Thickness
- Ice mass
- Liquid mass
- Temperature
- Density
- Grain size

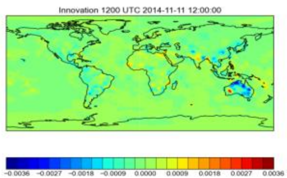
Current Land Surface DA

Soil Moisture Data Assimilation

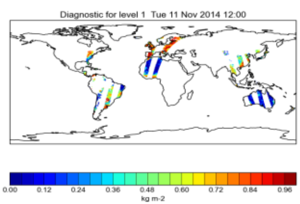
1.5m Temp (gridded)



1.5m Hum (gridded)



ASCAT soil wetness index

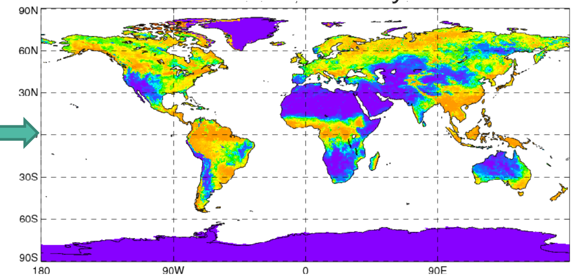


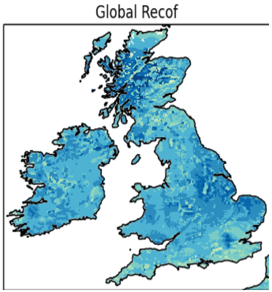
Simplified Extended Kalman Filter

$$x_i^b = x_i^b + K_i\left(y_i^o - H_i(x^b)\right)$$

$$\mathrm{K}_i = \mathrm{BH}^T\left(\mathrm{H}^T\mathrm{BH} + \mathrm{R}\right)^{-1}$$

Soil Moisture Analysis





Reconfiguration into UKV domain

- Global analysis every 6h
  - Jacobians (H) estimated from JULES model runs via finite differences
  - B and R matrices are diagonal and homogeneous
  - JULES climatology used to fit SWI to model soil moisture
- Implemented 2013
- UKV reconfiguration once a day

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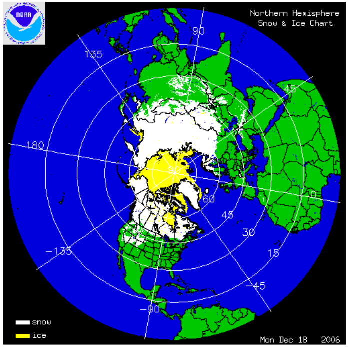
NH Snow analysis

A simple update scheme

- NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS)
  - 4 km, daily, vis/NIR/µwave/analyst, NH, operational, binary snow cover
- Model snow amount (kgm^{-2}) from 6 hour forecast (0Z T+6)



Operational 2008

Daily at 6UTC

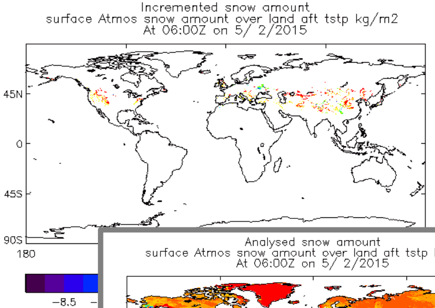
- Calculate fractional cover per gridbox from IMS snow cover
- Compare presence of snow in obs and model
  - Remove snow where obs snow-free and model snow-covered
  - Add snow where obs snow-covered and model snow-free – use empirical relationship to relate fractional cover to snow amount

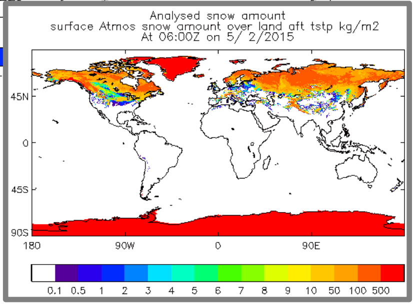
$$S = \frac{\left(-\log_e\left(1 - f_c\right)\right)}{D}$$

D=masking depth of vegetation (0.2 m^{2}kg^{-1})

Max. 10 kgm^{-2}

- Reconfigure into model to give 6Z T+0 snow amount (analysis)

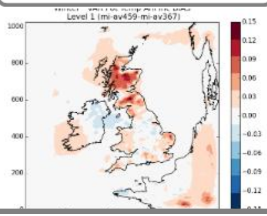




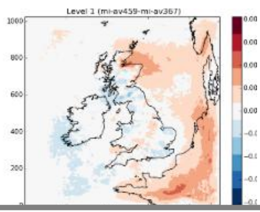
Developments for regional model

Met Office Soil moisture DA for the UK NWP system

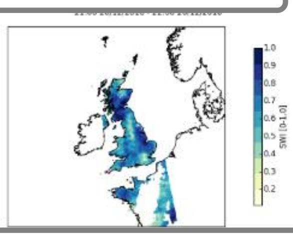
Observations



1.5 m Temp (from 4DVAR)



1.5 m Hum (from 4DVAR)



ASCAT: Soil Wetness Index

Simplified Extended Kalman Filter

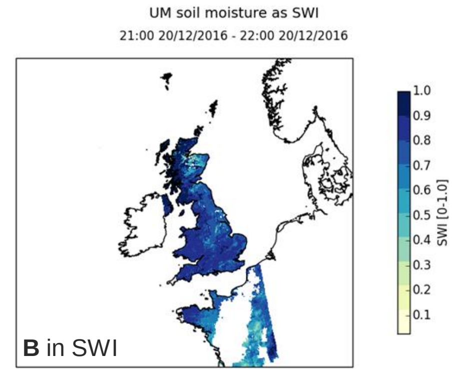
❖ BUT Native UKV soil climatology not yet available

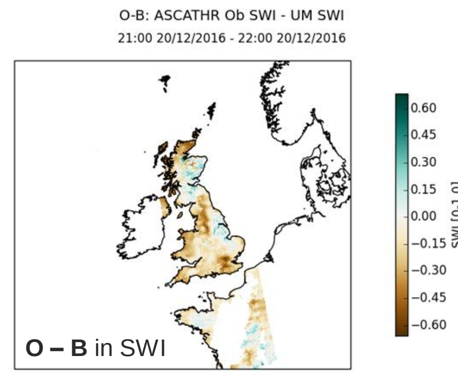
Instead of converting ASCAT SWI to a soil moisture content [kg/m2]…

❖ **Convert model soil moisture θ [m^3 m^{-3}] to SWI**

- Linear re-scaling based on known model soil parameters: wilting and saturation points on UKV grid
- θ_{min} = 10% of Wilting point
- θ_{max} = Saturation point
- Constrain UKV SWI to range [θ_{min} ,1.0]

$$SWI = \frac{\theta - \theta_{min}}{\theta_{max} - \theta_{min}}$$





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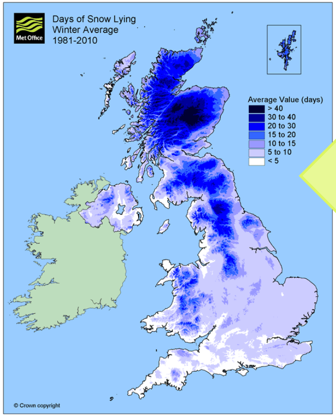
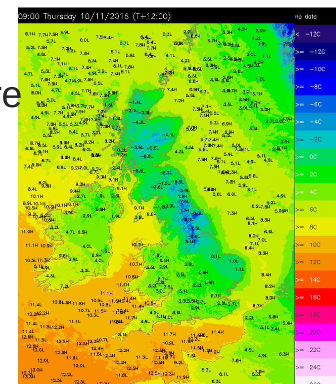
Met Office UK snow forecasting

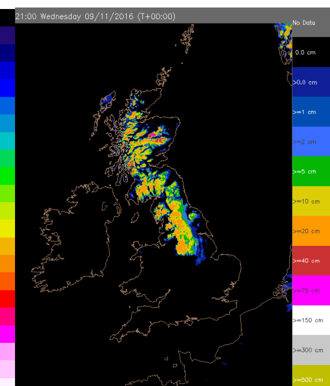


- The UK does not experience regular widespread snowfall except in the Highlands of Scotland
- Tends to be transient, often wet, shallow, multiple snowfall/melt cycles in one season.
- Low frequency, but high impact event – accurate analyses and forecasts of snowfall and lying snow extremely important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

Chaos and disruption

Surface temperature biases





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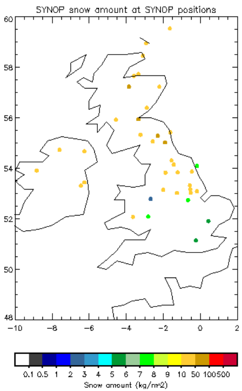
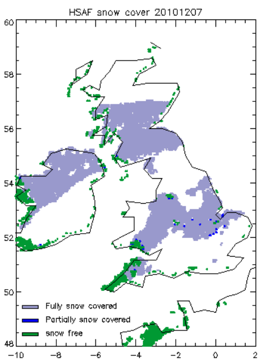
Snow DA for the UK NWP system





Data source

Snow depth values

Ground-based Synop network

- snow depth → SD where reported
- state of ground (snow or no snow) → 0 m SD from snow-free state of ground reports

Satellite data

- snow cover from H SAF (MSG-SEVIRI) daily product → 0 m SD from snow-free pixels; 0.05 m SD from snow-covered pixels where model snow-free

Model first-guess SD

→ Optimal Interpolation → **Snow depth analysis**

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

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

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

$$\beta(\Delta z_{ij}) = exp\left(-\left[\frac{\Delta z_{ij}}{h}\right]^2\right)$$

Horizontal correlation length scale (L = 5.5 km)

Vertical correlation length scale (h = 400 m)

Background error sdev (σ_b = 0.03 m)

Synop observation error sdev (σ_o = 0.04 m)

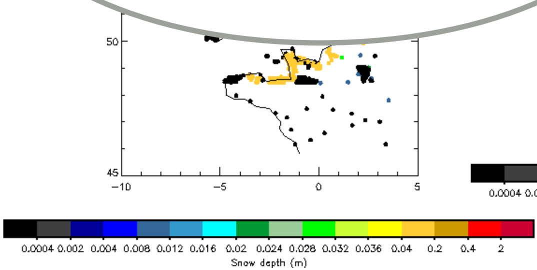
HSAF observation error sdev (σ_o = 0.08 m)

Test case – observation innovations

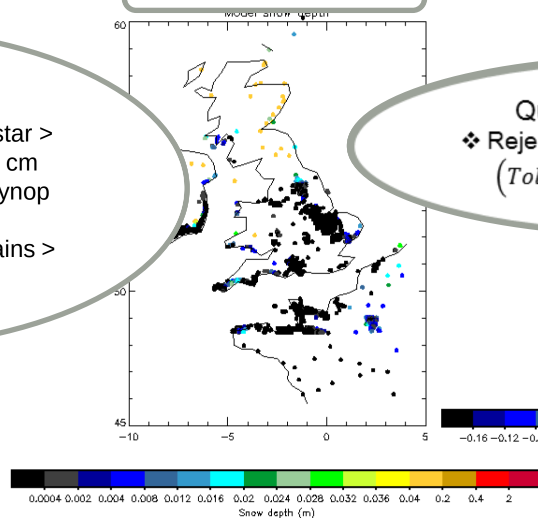
17th December 2010

Black = snow-free

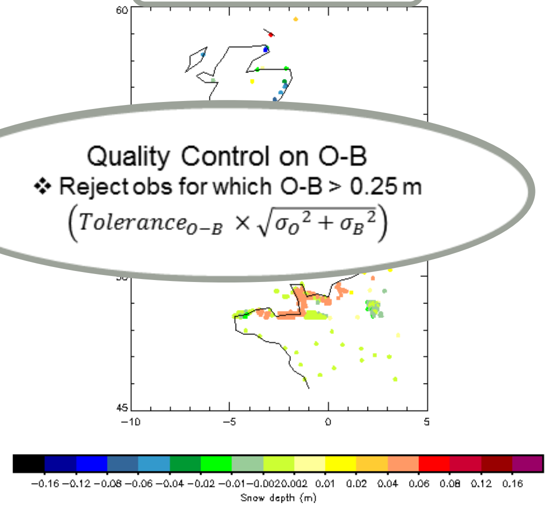
Observations entering OI



Model SD at ob locations
(B)



Observation innovations
(O – B)



Quality Control on O

- Reject synop ob if observed Tstar > 278 K and obs snow depth > 1 cm
- If multiple reports from same synop station, use closest to 06Z
- Reject satellite ob over mountains > 1500 m

Quality Control on O-B

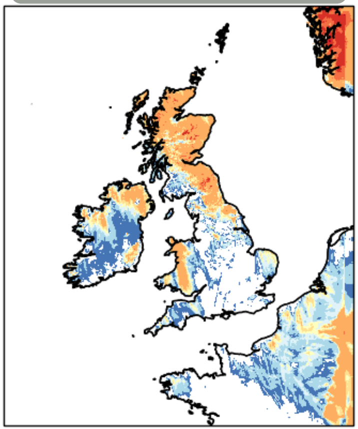
- Reject obs for which O-B > 0.25 m

$$\left(Tolerance_{O-B} \times \sqrt{\sigma_O^2 + \sigma_B^2}\right)$$

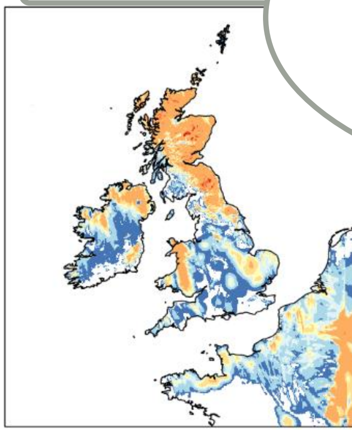
Test case – analysis increments

17th December 2010

Background snow amount

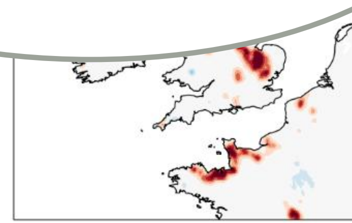


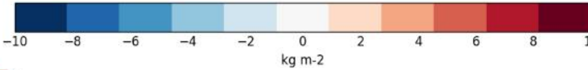
Analysed snow amo

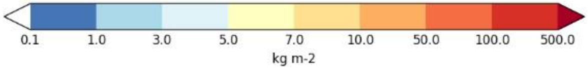


Quality Control on Increments

- ❖ Max increment allowed = 37.5 kgm-2 (0.15 m)
- ❖ Positive increment allowed only if model T* < 281 K
- ❖ Check for negative snow amounts
- ❖ No increments on land ice, urban, inland water tiles



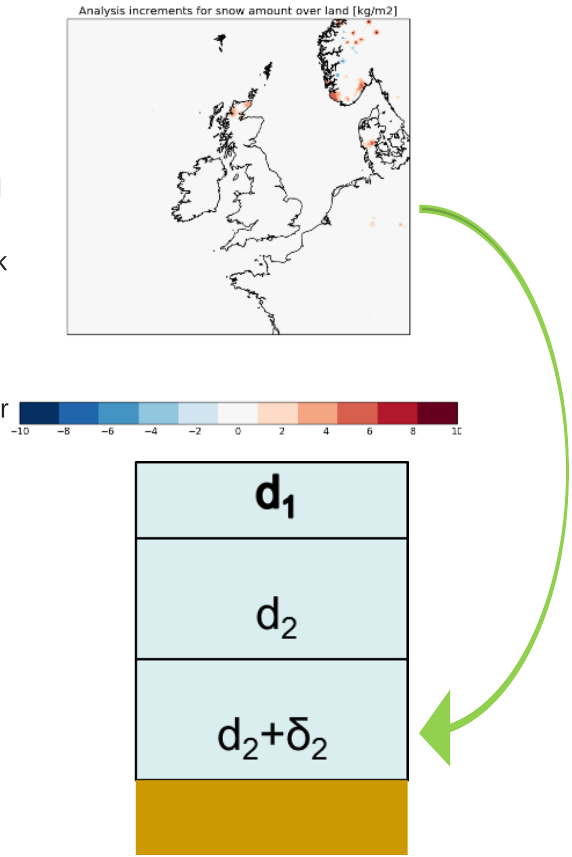




Met Office Assimilation experiments

Case study snow event – snow poorly forecast by UKV

- November 2016 – 9-10th, excess snow depth and extent in UKV led to strong cold biases in overnight surface temperature minima.
- Add increments to lowest snow layer to preserve evolved snowpack characteristics as far as possible.
- Allow JULES to repartition the layers as a result of changes to the total snow amount
- Examine model output for first few timesteps of forecast run in order to examine model response to incremented snow amounts throughout the snowpack (multi-layer snow prognostic variables)



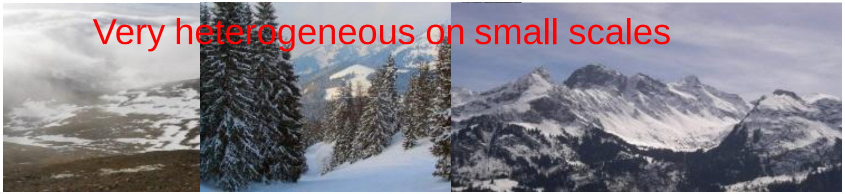
Whole winter season assimilation trial

- Examine impact on atmospheric forecast variables – forecast RMSE, bias
- Particular focus on surface and near surface temperatures
- Validation against independent snow obs where possible
- Implement Winter 2018/19 (?) or 2019/20

Snow observations

Met Office

Snow is hard to observe!



Very heterogeneous on small scales

Currently the only source of obs of snow amount suitable for use in NWP

In situ observations of snow depth

high accuracy, snow amount info, (frequent, timely)

sparse coverage, non-representative, inconsistent reporting practice and data exchange, often no zero snow

Satellite-derived snow extent – optical sensors

lots of imagers, global coverage, high resolution, snow-free ground

affected by cloud, no info on amount of snow, limited in low light levels of winter high latitudes, forest

Satellite-derived snow water equivalent – passive microwave

global coverage, unaffected by clouds, snow amount info

can’t detect wet snow, thin layers, thick layers, low resolution, uncertainties high – improved by dynamic grain size/density parameterisation

Global SWE from satellite identified as “key gap” in the observing system (http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html#SOG)

Hard for any single snow dataset to fulfil requirements for NWP assimilation – best approach may be to exploit the best features of a number of data sources to use in a complementary way.

Met Office

In situ snow depth observations – improving reporting practices and data exchange

A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction

ESSEM COST Action ES1404

cost

In situ measurements of snow depth are of vital importance for global Numerical Weather Prediction and are currently the only quantitative observation of snow depth of sufficient quality for assimilation into operational weather forecasting models.

There is ongoing activity by **GCW Snow Watch** and **COST HarmoSnow** to improve the reporting practices for in situ snow observations, to promote exchange of real-time observations between member states, and to improve availability of in situ snow depth reports on the GTS.

GCW
Global Cryosphere Watch

3 key issues:

1. Many countries <u>do not report snow routinely and consistently or make their observations available</u> in near-real-time.
2. Snow depth is often <u>reported only when snow is present</u>, with “missing data” used otherwise. Active reports of zero snow depth provide extremely valuable data for assimilation in weather forecasting models
3. Some countries have dense national (non-SYNOP) snow observing networks, which could provide valuable data for global forecasting centres, but <u>do not exchange</u> these data in near-real-time on the GTS

Following several years of activity, consultation with WMO Member States, and some iterations, a decision was **approved**, at WMO EC-69 (May 2017), bringing in important changes to the global observing guidelines:

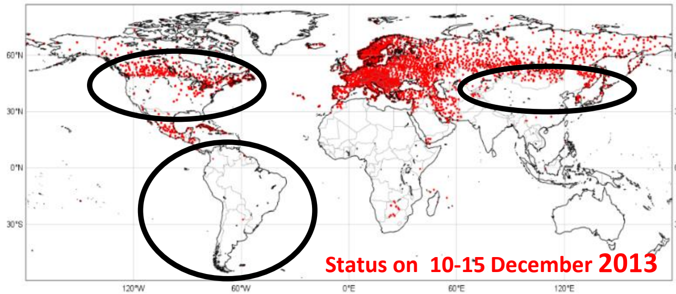
- ***<u>mandatory requirement</u>*** - daily (at least) reporting of snow depth, including **<u>values of zero</u>** where snow is not present, at all stations where snow is experienced, and the capabilities exist.
- ***<u>requested/encouraged</u>*** – reporting of snow depth 4 times a day, and exchange of in situ snow reports in real-time in BUFR on the GTS

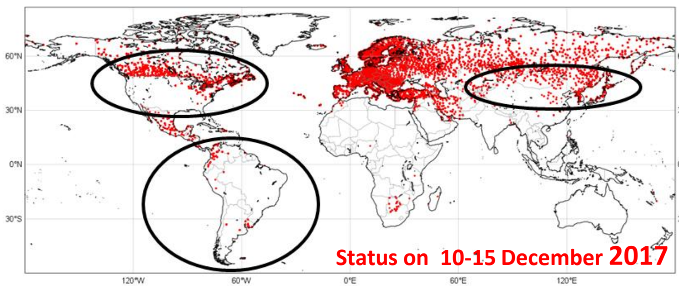
Courtesy of Patricia de Rosnay (ECMWF)

In situ snow depth observations

GTS Snow depth availability

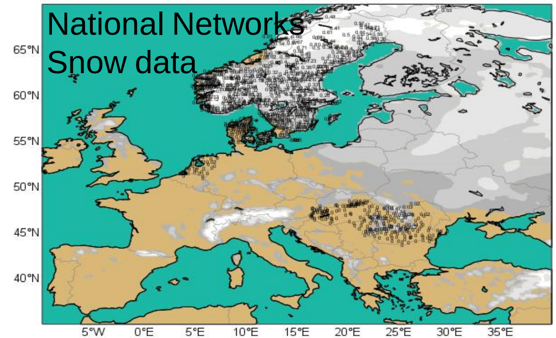
SYNOP TAC + SYNOP BUFR + national BUFR data





- Improvement in China (since status in de Rosnay et al, ECMWF NL article 143, 2015)
- Expected improvement over the US (SHEF to BUFR conversion needed)
- Slight improvement in South America(?)
- Overall upward trend since 2013

2016 01 15 at 06UTC



Additional data from national networks from up to 7 countries:
Sweden, Romania, The Netherlands, Denmark, Hungary, Norway, Switzerland.

→ **Dedicated BUFR for additional national data**

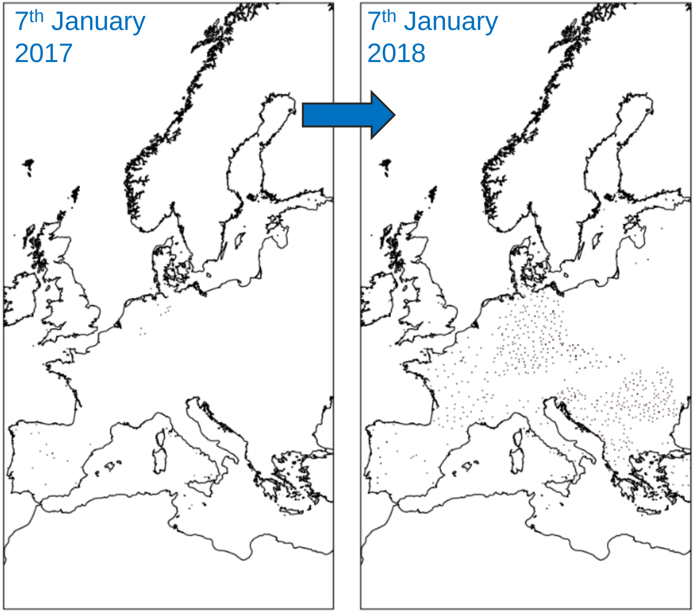
(de Rosnay et al. ECMWF Res. Memo, R48.3/PdR/1139, 2011)

More zero snow depth reports

Large increase in number of stations and countries reporting values of zero snow depth in the last year.

BUFR reports on GTS from synoptic network with
snow depth = 0 m

0600 UTC 7th January: 2017 vs 2018



<u>Promote changed guidance:</u>
Work with NMS observing sections to raise awareness of new guidelines, encourage adoption of recommended reporting practice – it's a cultural change (*ongoing – COST Action on snow: HarmoSnow very much aligned, provides an excellent platform for promoting awareness and encouraging action within Europe)*

<u>Provide evidence of value:</u>
Use new observations - Impact studies by NWP centres to show value of additional snow depth obs when they become available

Long term – considerable increase in valuable observations of snow depth for use in NWP and research applications

Met Office

Summary

- Met Office runs global and regional (UK) NWP systems
- Currently Land Surface DA in global model only
    - Soil moisture EKF
    - NH snow analysis
- LSDA for the UK model in development
    - Soil moisture EKF
    - Snow depth Optimal Interpolation
- Different sources of snow observations available – differing limitations
- In situ snow depth reports currently the only observations of snow depth/amount suitable for assimilation in NWP
- Efforts to improve in situ snow depth reporting practice and exchange of data
- Best approach for NWP may be to exploit the best features of a number of data sources to use in a complementary way