Using satellite-derived snow information in NWP: assessing products for assimilation into the Met Office UK forecasting model

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3rd H-SAF Workshop, Reading, 3-6th November 2014

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- Use of satellite-derived snow information in NWP
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  - Products in use – now and future
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  - UK snow assimilation plans
  - Assessment of H-SAF snow cover over UK
  - SAR wet snow mapping
  - SYNOP reporting issues

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Remote sensing of snow

Snow extent – binary or fractional cover from optical sensors. Using spectral difference techniques, based on differing reflective properties of snow in visible and near-infrared relative to snow-free surface.
Pros - lots of imagers, global coverage, high resolution
Cons - can't see through cloud, no info on amount of snow, limited in low light levels of high lats
E.g.s - NOAA IMS, MODIS/VIIRS, H-SAF, GlobSnow, CRYOLAND, upcoming Sentinel-3 under Copernicus framework?

Snow Water Equivalent – from passive microwave radiometer, using BT differences between low and high frequency channels, based on different microwave scattering properties of snowpack. Emission model inversion, dependent on physical properties of snowpack (grainsize, density)
Pros - global coverage, no cloud effects, snow amount info
Cons - can't detect wet snow, thin layers, low resolution, uncertainties high – improved by dynamic grain size/denisty parameterisation
E.g.s - GlobSnow, H-SAF, AMSR-2 (JAXA)

Wet snow extent/melting area – from synthetic aperture radar (SAR). Using reduced backscatter from wet snow relative to dry snow or snow-free surface.
Pros - very high resolution, not cloud-affected
Cons - low temporal resolution, no dry snow detection
E.g.s - no wide-coverage operational products – NORUT runs Scandinavian service, upcoming Sentinel-1 over Europe?

Requirements for NWP

Continuity - operational robustness, long-term security to justify development work, succession of satellite sources...

Temporal resolution - daily sufficient for snow change timescales. Complementary data sources can have lower frequency

Level of derivation – preferably not assimilation products themselves, e.g. contain some model information (not consistent), contain ground-based obs (not suitable if model already assimilates)

Coverage - depends on model domain, global/NH common

Cloud cover - how extensively does it affect product? High temporal sampling can mitigate to some extent. Multi-sensor approach can allow gap-filling. Is it the only data source?

Errors - well-defined and documented, quality flags disseminated with product. SC 15-20%, SWE 10mm. Has to improve forecast/analysis to be used.

Availability in near-real-time - daily product within half a day, 6-hourly within 3 hours

Spatial resolution - guided by model resolution, doesn't have to match. Higher resolution allows fractional cover calculation on model grid. Too low, representativity issues.

Snow products used in operational NWP

Satellite-derived snow products are not widely used in operational NWP systems.

- Currently only snow cover
- More commonly, snow depth from ground-station obs

ECMWF – NOAA NESDIS IMS snow cover used to update model first guess before assimilation of SYNOP snow depths and IMS snow-free (as zero depth) points.

Met Office – IMS snow cover used in simple update scheme to adjust global model snow amount in daily analysis

JMA – Uses SSM/I snow detection to determine points on which to carry out SYNOP snow depth assimilation

Although snow cover can be valuable for helping constrain model snow extent, it is hard to retain assimilated information based on snow cover observations alone – no information on amount of snow

Research and development

Met Office

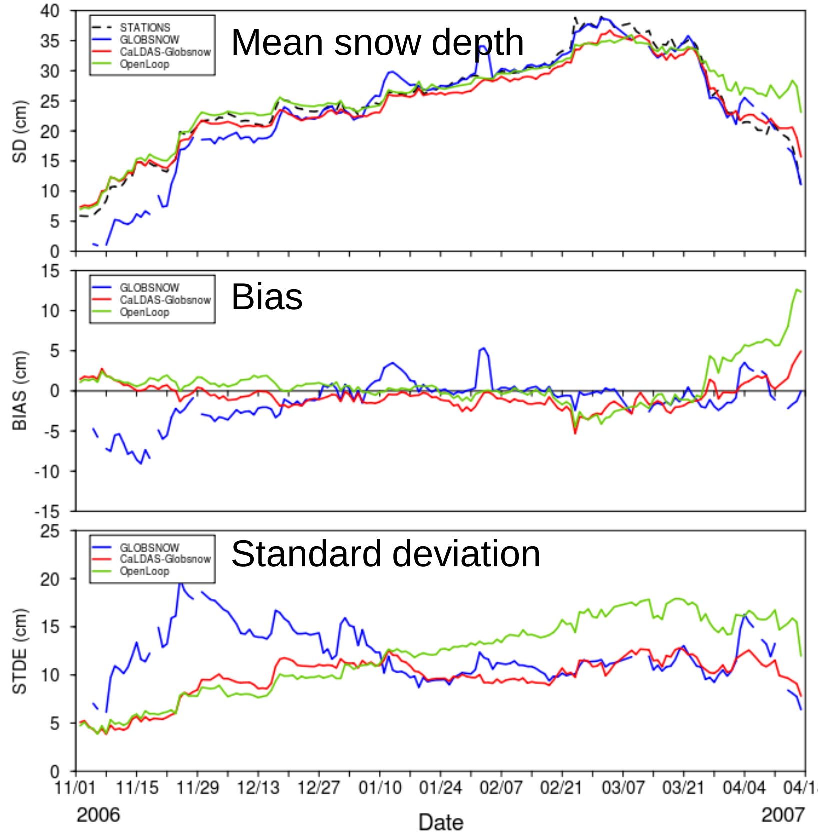
<u>Snow Water Equivalent is what we really want</u>
•Development of SWE retrieval products watched with interest by NWP community – uncertainty large.

•Environment Canada have experimented with assimilating GlobSnow SWE into CALDAS, with some success.

- •Now pursuing direct assimilation of microwave brightness temperatures, using the HUT snow microwave emission model (Pulliainen et al., 1999)

•GlobSnow SWE includes ground data, not suitable for UK snow retrieval

•AMSR-2 product – independent of ground data
V2 in development – Kelly et al (2003)
Dynamic estimation of grain size and density



Stephane Belair et al.

Hard for any single (remote-sensed) snow dataset to fulfil requirements for NWP assimilation – best approach may be to exploit the best features of a number of products to use in a complementary way.

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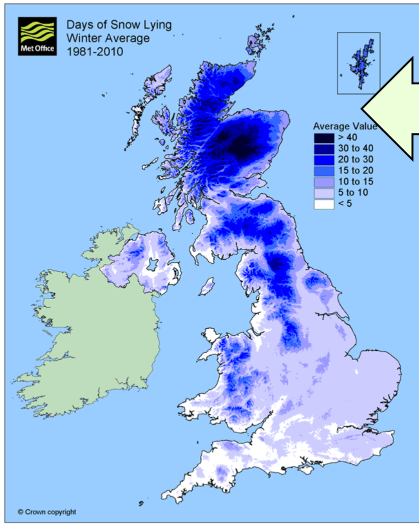
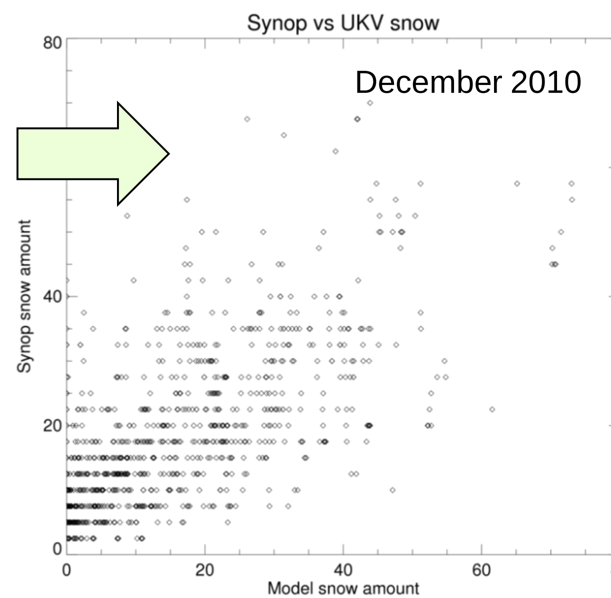
UK snow forecasting

- 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)



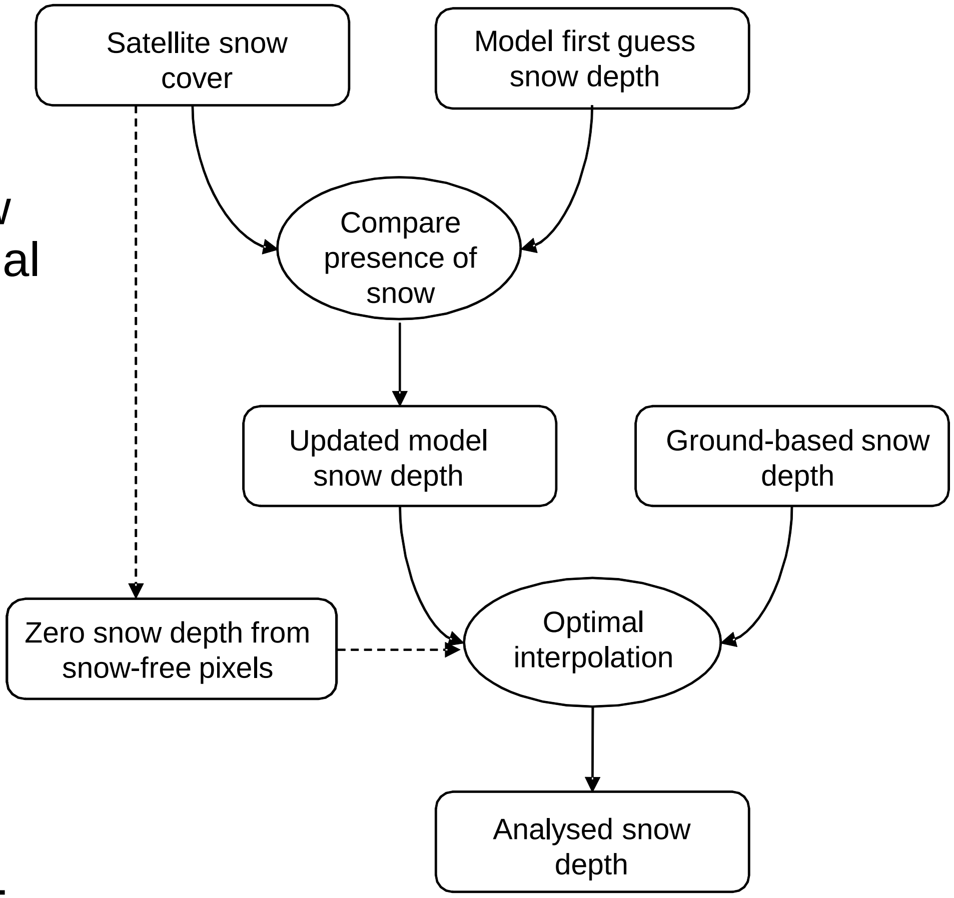
Comparison of model vs observed (SYNOP) snow depth shows considerable scatter - assimilating these snow depth obs could improve modelled snow amounts



Plans for UK snow assimilation

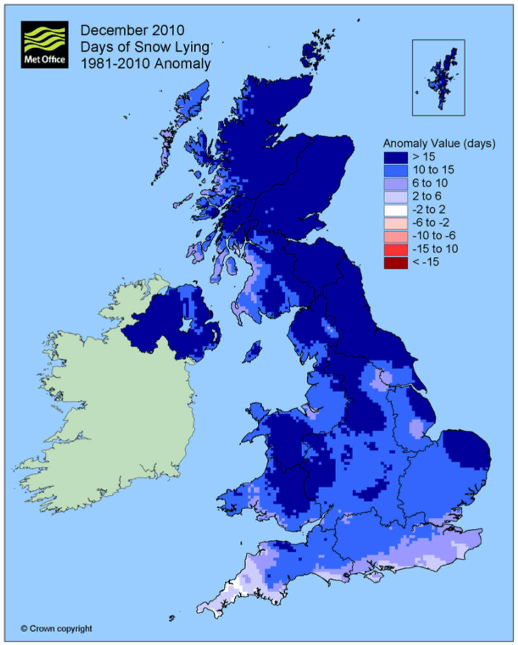
Met Office

- **Satellite snow cover** - initial analysis step to adjust model background snow extent – comparison of presence of snow in satellite product and model with nominal snow addition where mismatch (as in global snow analysis)
- **SYNOP snow depth** – Optimal interpolation, with updated model snow field providing first guess, to produce analysed snow depth field.
- Snow-free pixels of satellite snow cover can also be used in the OI as proxy for observations of zero snow depth
- Plan to use **H-SAF snow cover product**



Based on method employed at ECMWF:
de Rosnay, P., G. Balsamo, C. Albergel, J. Munoz-Sabater, and L. Isaksen, 2012: Initialisation of Land Surface Variables for Numerical Weather Prediction, *Surv. Geophys.*, DOI:10.1007/s10712-012-9207-x

Assessment of H-SAF snow cover over UK

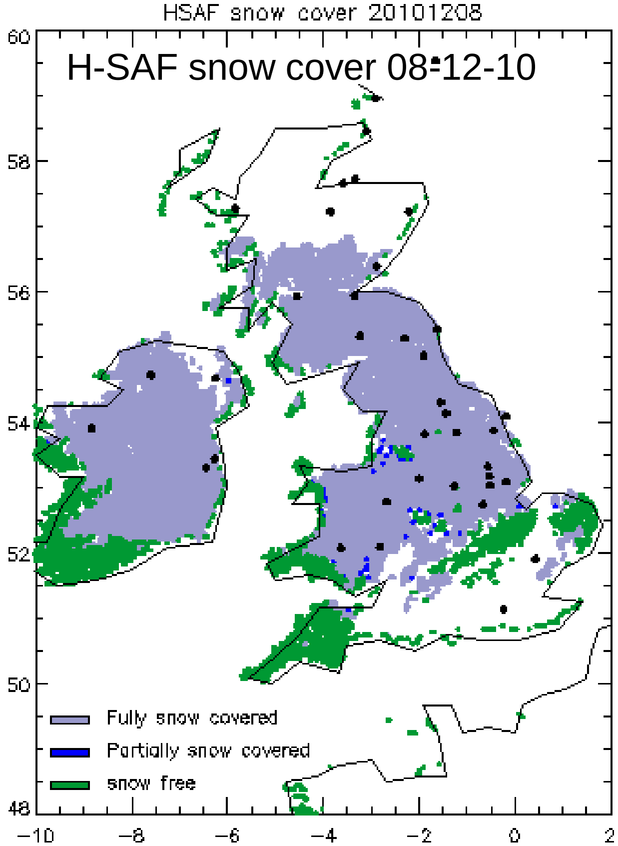


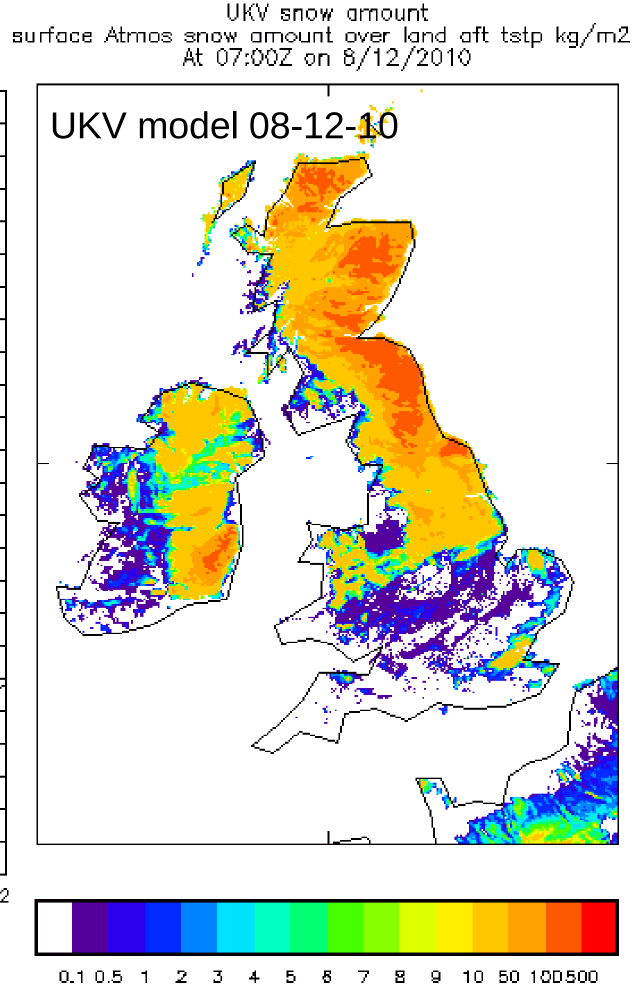
- Comparison with UKV snow fields and SYNOP observations of snow during prolonged snowy conditions of December 2010.
- Widespread snow across most of UK for much of the month, multiple snowfall/snow melt cycles in some areas, good test of observational and modelled snow datasets.

Overall comparisons between model and H-SAF snow cover are good, where cloud cover allows. Positions of SYNOP obs of snow coincide almost entirely with areas where H-SAF not classified explicitly as snow-free (i.e. Snow-covered or unclassified)

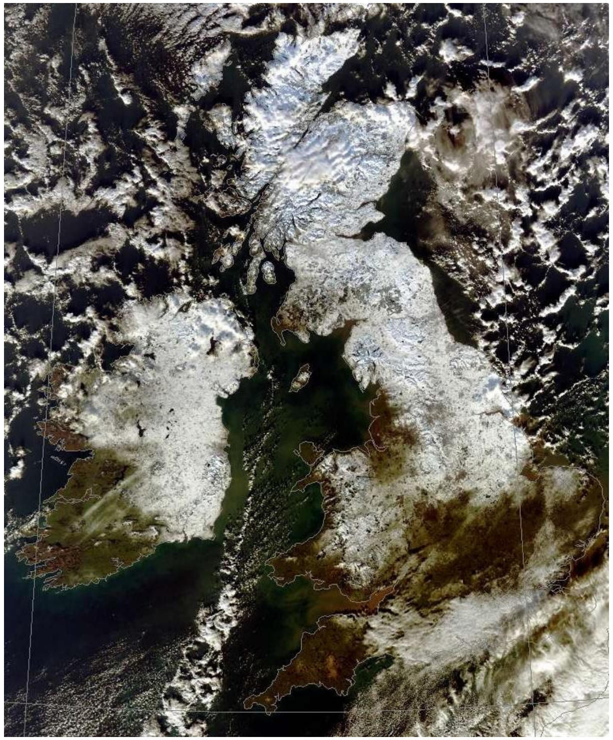
Qualitative assessment

- Large proportion of UK classified (cloud-free)
- Good comparison with model snow-covered area in general
- No SYNOP snow observed where H-SAF snow-free





MODIS visible image 08-12-10



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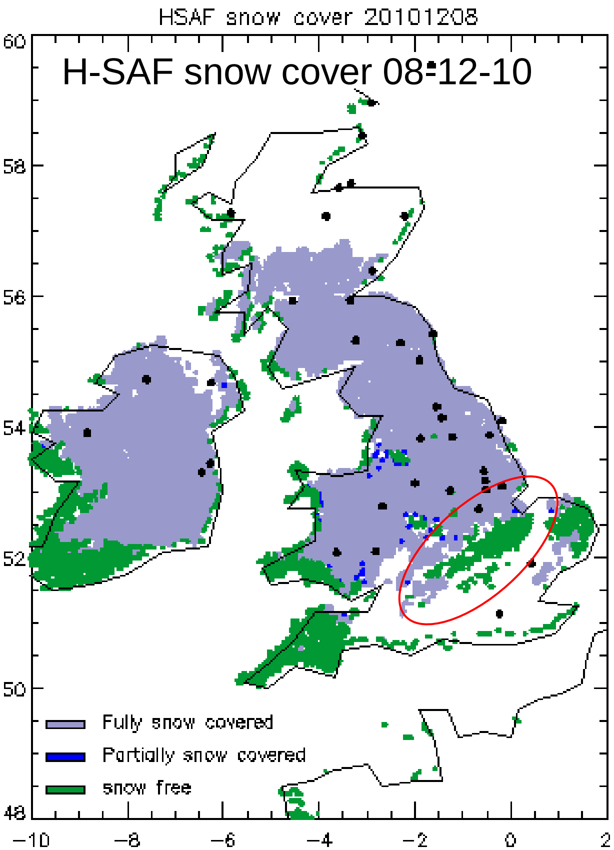

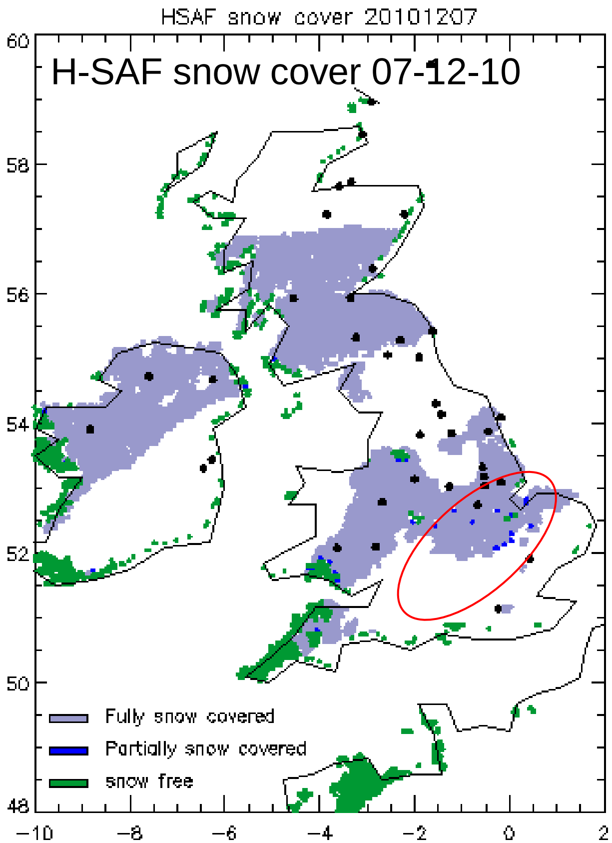

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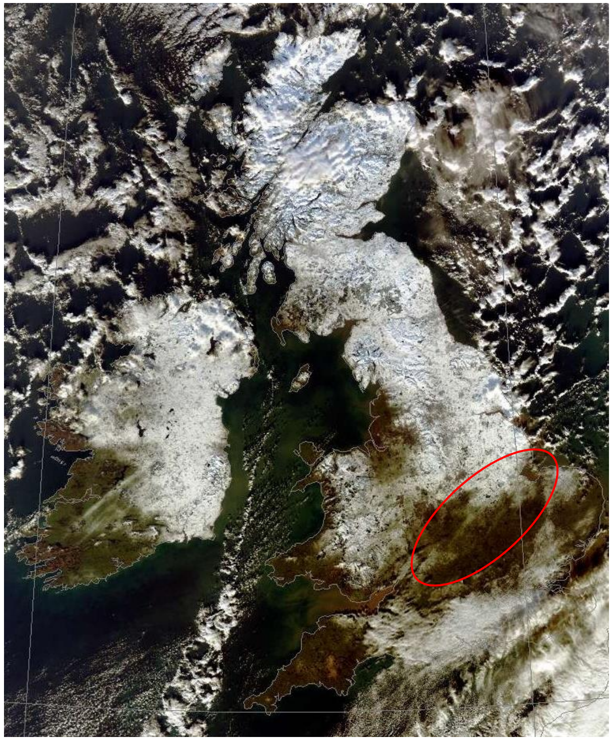
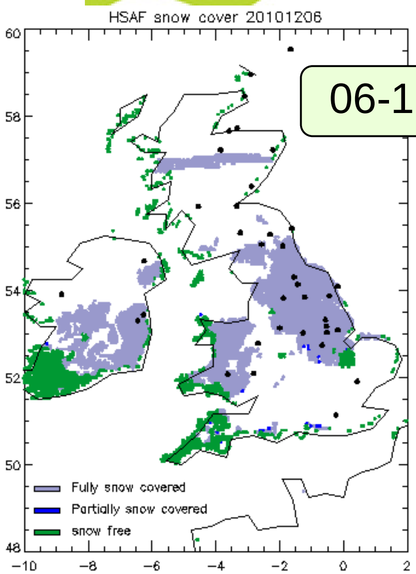
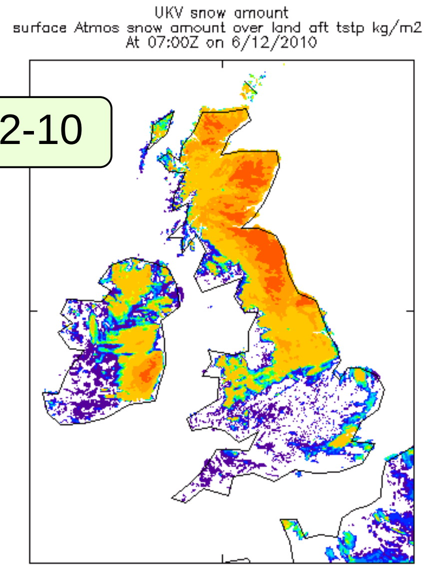
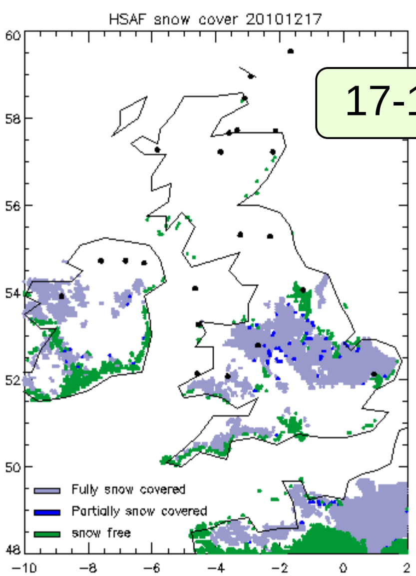


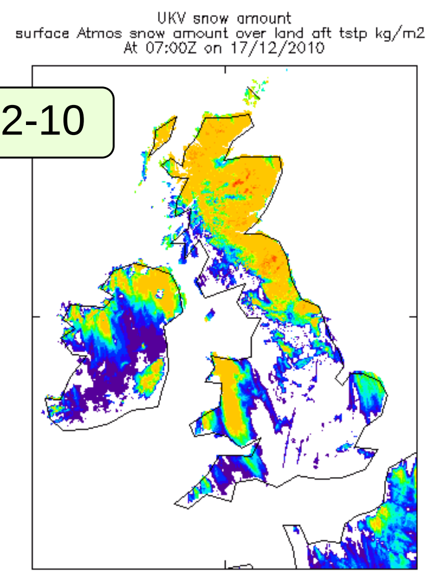
Qualitative assessment

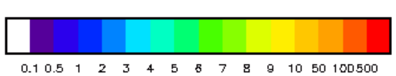




- Good match between H-SAF snow-covered areas and SYNOP snow obs
- More snow-free area in H-SAF than UKV in western coastal areas, especially southern Ireland







- Large proportion of UK un-classified (cloud-covered)
- H-SAF has more snow cover than model in South/Central UK, but this is supported by SYNOP snow obs

Assimilation of H-SAF snow cover could improve model snow extent in these cases

Quantitative assessment

A correct snow-free classification is as important as a correct snow-affected classification for snow cover assimilation, so the rates calculated are:

	H-SAF: snow	H-SAF: snow-free
model: snow	TRUE POSITIVE (TP)	FALSE NEGATIVE (FN)
model: snow-free	FALSE POSITIVE (FP)	TRUE NEGATIVE (TP)

Correct classification rate

100 × (TP + TN) / Number classified obs

Overestimation rate

100 × FP / Number classified obs

Underestimation rate

100 × FN / Number classified obs

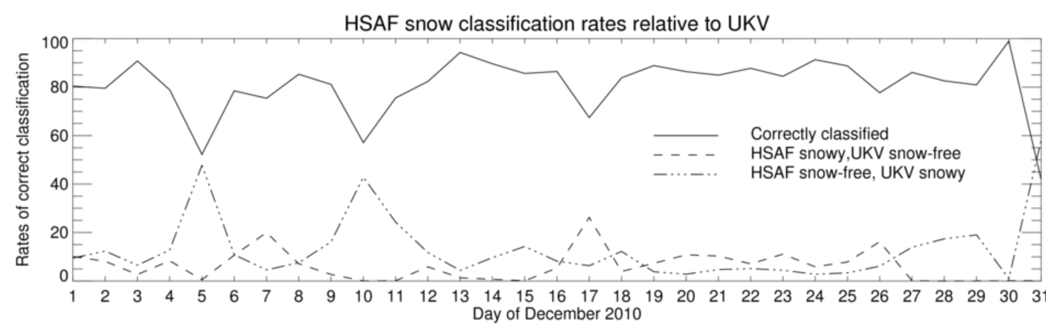
Mean rates for December 2010

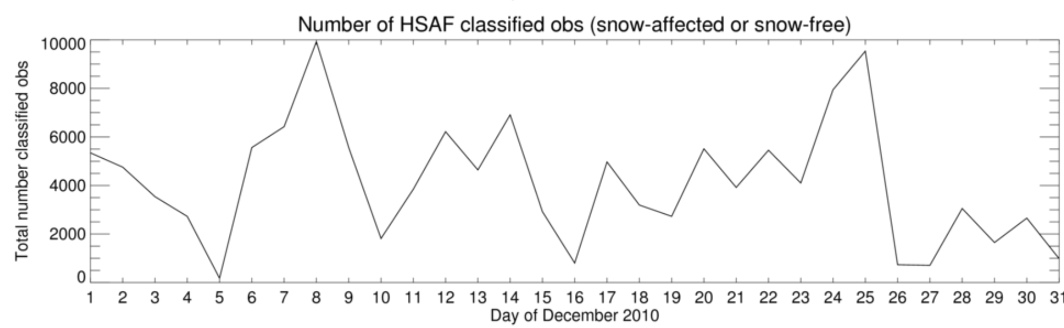
Correctly classified: 80.8%

Overestimated: 6.2%

Underestimated: 13.1%

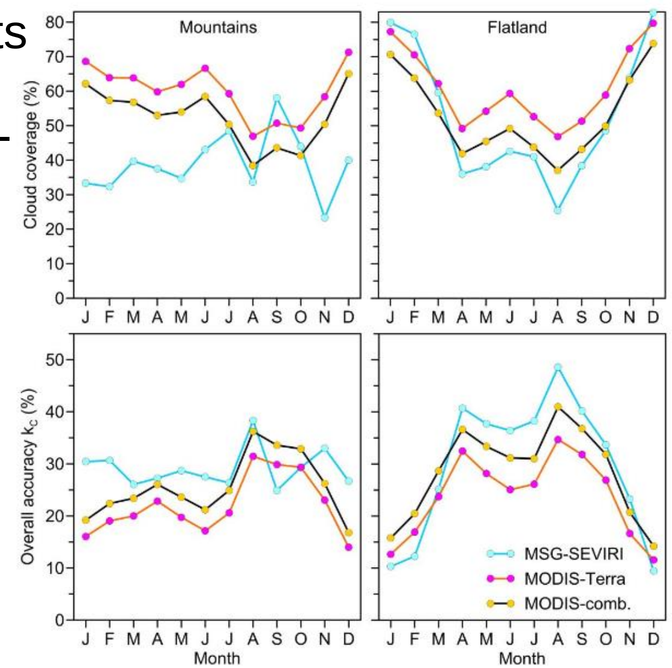
Rates strongly affected by instances of low numbers of classified pixel – QC to be explored to make optimal use of data



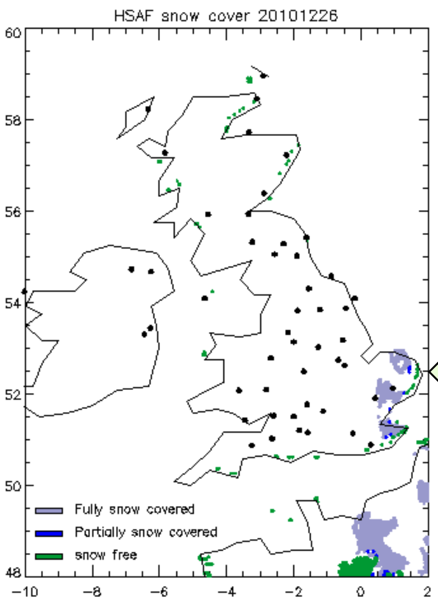


Cloud cover issues

- UK - high instance of cloud cover associated with snowy conditions. Limited value from optical sensors, transient snow may never be seen.
- High temporal sampling of H-SAF product results in large reductions of cloud-affected pixels in composite product relative to products from sun-synchronous sensors.



Surer et al., 2013. doi:10.5194/hessd-10-12153-2013



- Results in comparable or higher mapping accuracy, despite the coarser spatial resolution of SEVIRI product.

BUT this still happens

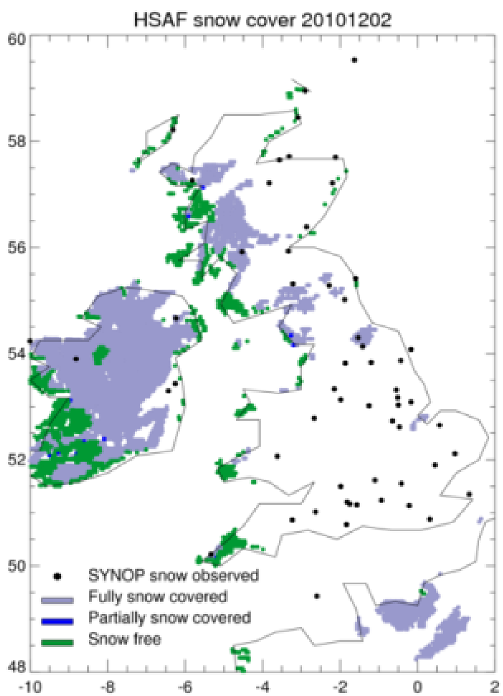
Combine optical snow cover with additional data sources that are not affected by cloud?

SAR wet snow mapping

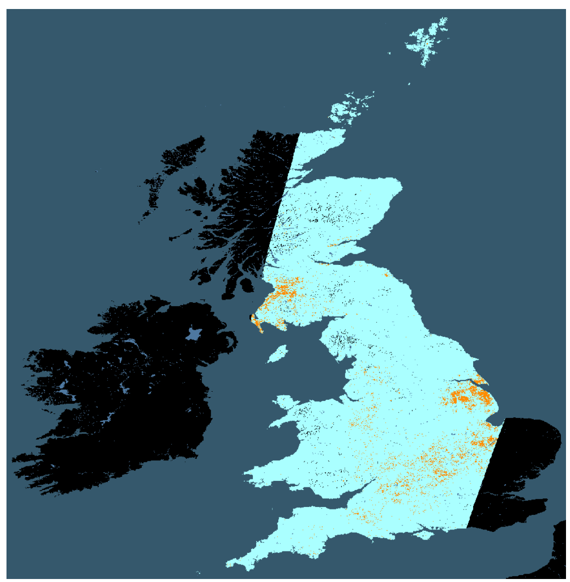
With thanks to Heidi Hindberg and Erik Malnes, NORUT

Met Office

- C-band SAR wet snow detection – ENVISAT ASAR, Radarsat, soon from Sentinel-1 (NORUT, Norway)
- High resolution, unaffected by cloud, BUT no distinction between dry snow and snow-free surface, temporal resolution 2-3 days at best.
- Developed for mapping snow melt in Scandinavia and areas with significant seasonal snow.
- Potential for use in UK - snow often wet, often affected by extensive cloud cover.



NORUT



H-SAF snow cover for 2-12-10 severely affected by cloud cover - use of the SAR wet snow map in addition to the optical snow cover could provide valuable additional snow cover data.

Potentially well-suited to UK snow detection – snowfall often wet, transient, conditions often cloudy

A valuable complementary snow extent product?

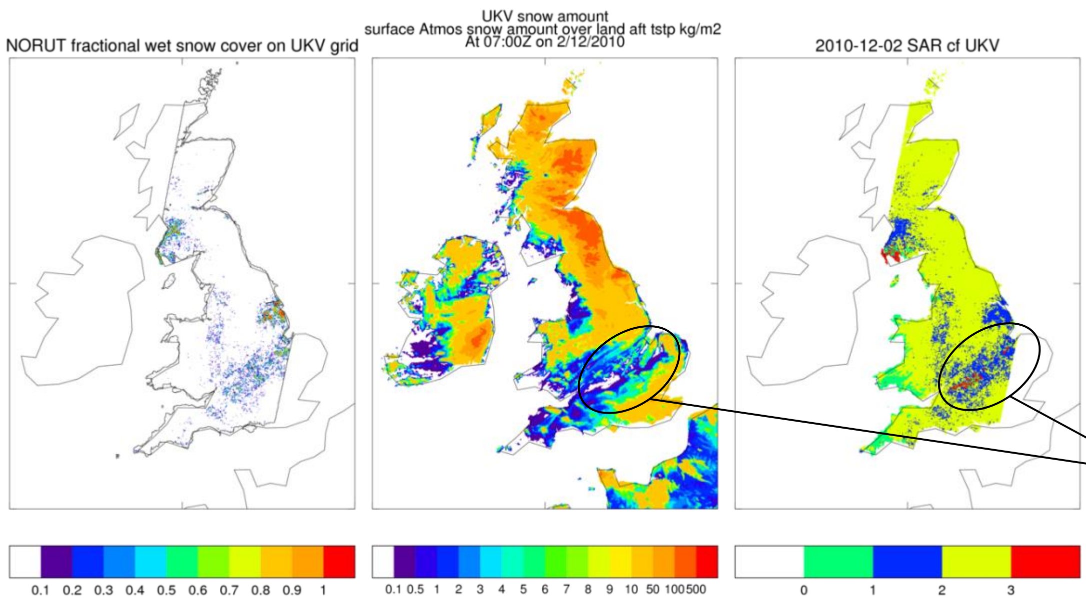
Assessment of wet snow maps

With thanks to Heidi Hindberg and Erik Malnes, NORUT

- All available wet snow binary data for December 2010 have been averaged onto UKV grid to give grid-box fractional wet snow cover, and compared with UKV snow amount using a range of thresholds to indicate presence of snow
- Unambiguous comparisons can only be made for grid-boxes with positive SAR wet snow classification

SAR no wet snow, UKV no snow | SAR no wet snow, UKV snow
SAR wet snow, UKV snow ✓ | SAR wet snow, UKV no snow ✗

Mean rate of classification for December 2010 = 86.3%

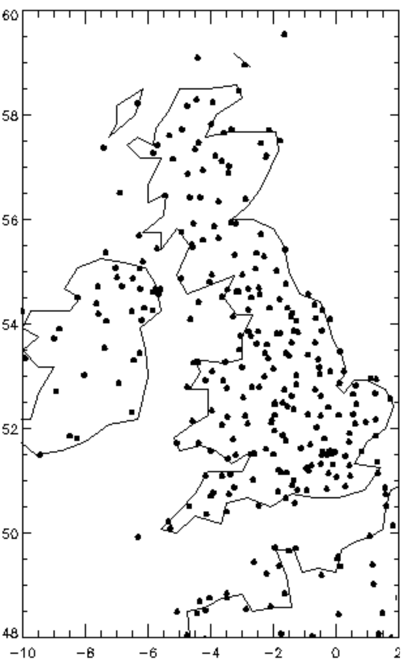


Product appears to work well for UK snow and offers a significant increase in classified snow points for potential assimilation over H-SAF product alone

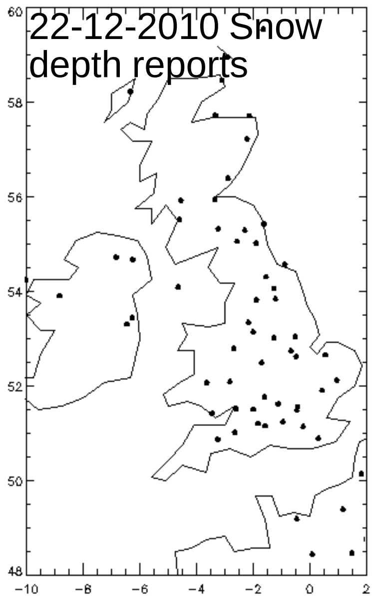
Good match in area in which fresh snow was falling, with subsequent melt over a period of a few days – transient, wet snow.

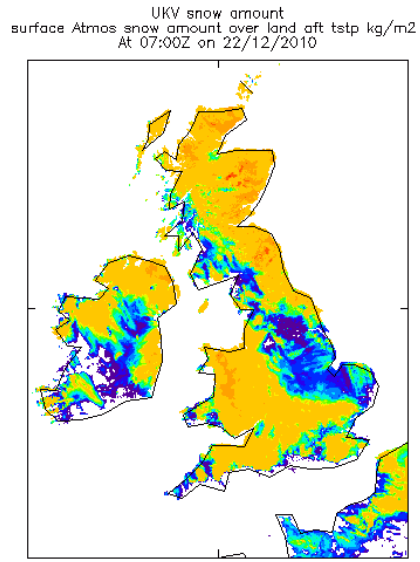
SYNOP reporting issues

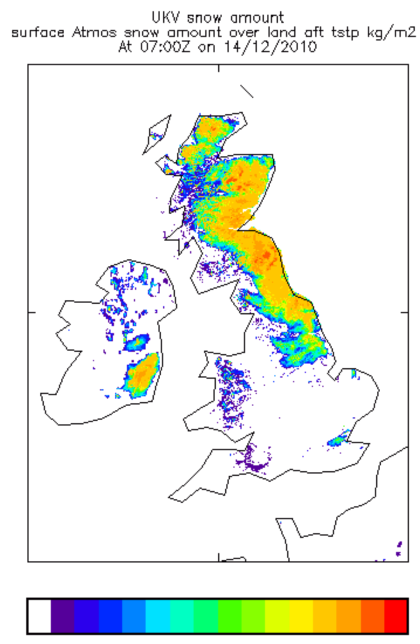
0600Z 22-12-2010



All SYNOP reports







- Sparse even when snow is extensive – representativity problems
- No snow reports in regions of highest topographical variation
- No zero snow depth reports – loss of valuable data on snow-free surface to inform model snow extent
- Need to encourage snow reporting at every station possible regardless of presence of snow
- Satellite-derived SWE to provide supplementary data? AMSR-2 product from JAXA to investigate

Concluding remarks

- Use of satellite-derived snow products by NWP requires sustainable, operational services.
  - Many good products developed, but few pulled through into operational capability.
  - Need long-term funding, continuity, ensure fulfil potential of Sentinel missions
- Not much satellite derived snow information used in NWP – currently only snow extent, yet snow depth information offers the most value.
  - New generation of SWE products with dynamic grain-size parameterisation? - to be watched with interest
- Many challenges delivering snow products that meet requirements for NWP. Best approach may be to use complementary data from different sources – exploit best features of each.
  - e.g. Optical snow cover + SAR wet snow, ground-based snow-depth + microwave SWE
- Ground station reporting – still the most important source of snow depth observations for NWP – need to take action on improving reporting practice.
  - Increased density of reporting stations
  - Reporting of zero snow depth

Thank you for your attention

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