Satellite snow product assimilation in weather models

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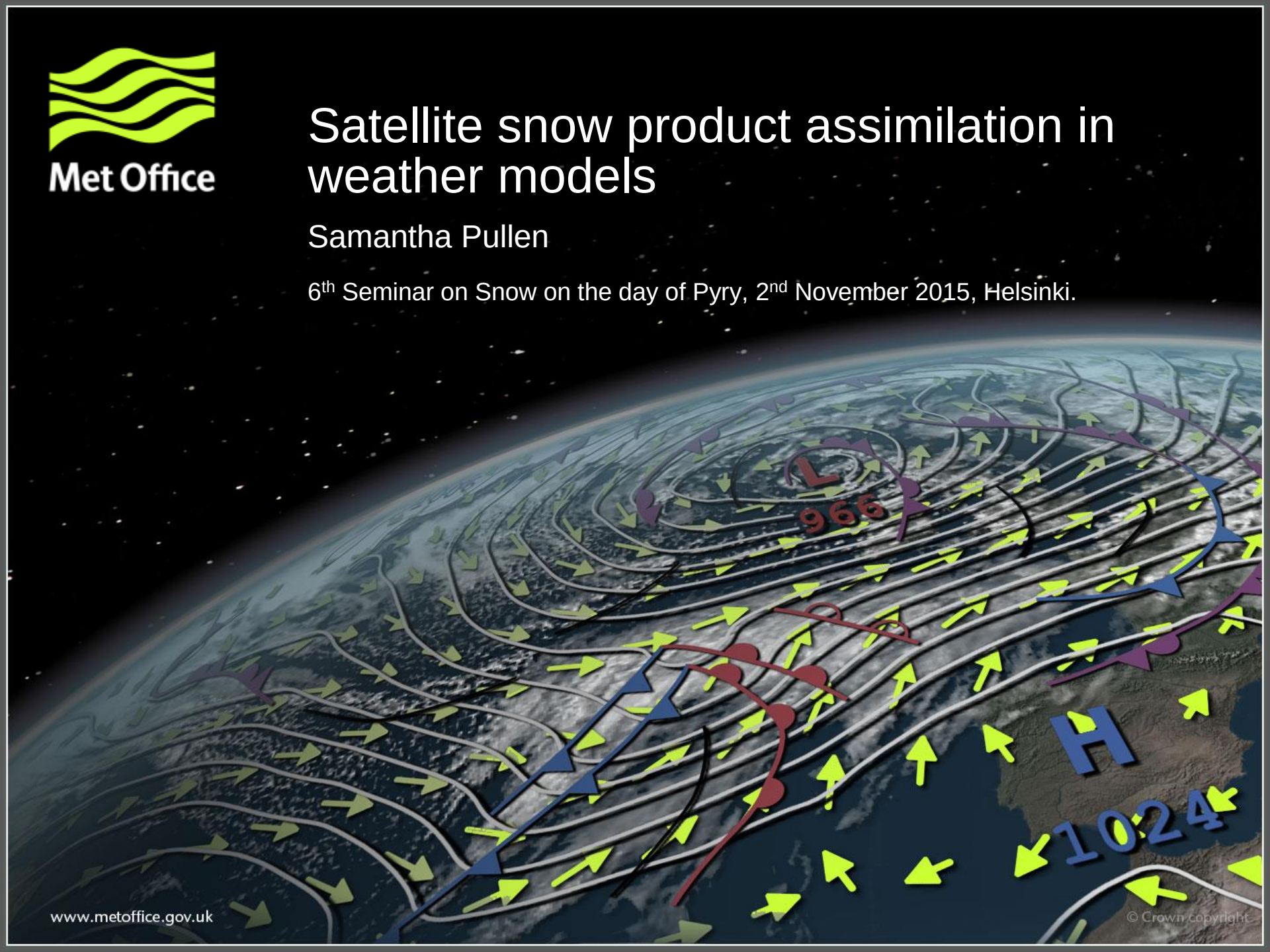
6th Seminar on Snow on the day of Pyry, 2nd November 2015, Helsinki.



Contents

- Remote sensing products for NWP
- Requirements for NWP
- What is used

- Development of UK snow DA system
- Method of H-SAF snow cover assessment
- Effect of cloud cover
- Assessment results
  - Overall results
  - Some specific cases
- Conclusions

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Remote sensing of snow for NWP

Snow extent

•Binary or fractional cover from optical sensors.
•Uses 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, forest

E.g.s - NOAA IMS, MODIS/VIIRS, H-SAF, GlobSnow, CRYOLAND, upcoming Sentinel-3 under Copernicus framework?

Snow Water Equivalent

•From passive microwave radiometer
•Uses 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, thick layers, low resolution, uncertainties high – improved by dynamic grain size/density parameterisation

E.g.s - GlobSnow, H-SAF, AMSR-2 (JAXA, NOAA, NASA)

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.

What is used? What is planned?

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

- Currently only snow cover (ECMWF, Met Office, JMA, NOAA-NWS)
- More commonly, snow depth from ground-station obs

<u>Snow Water Equivalent is what we really want to use</u>

- 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) (using dynamic estimation of grain size and density)

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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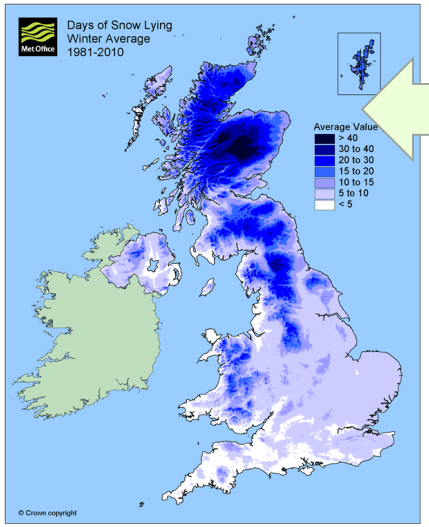
UK snow forecasting



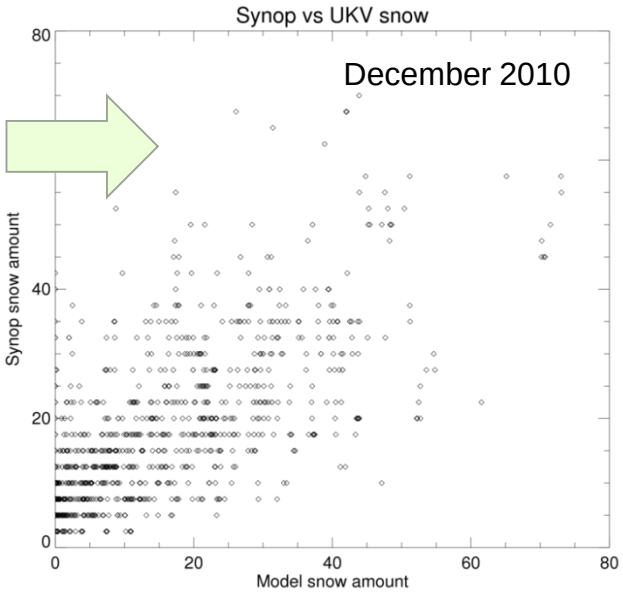
The UK does not experience regular widespread snowfall except in the Highlands of Scotland

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)

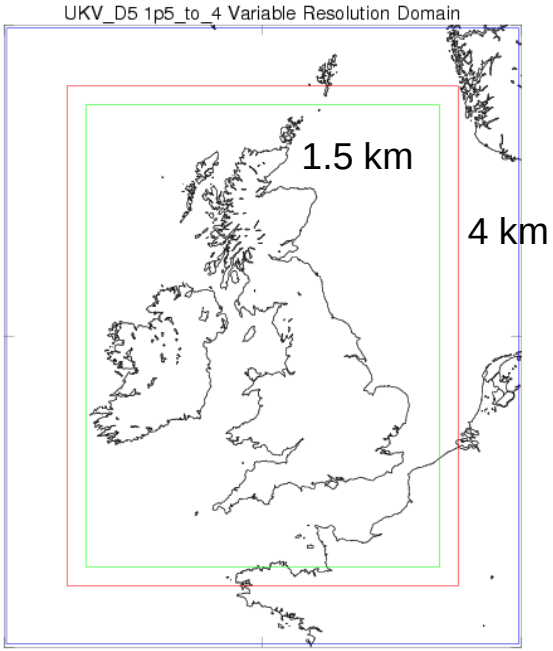
Comparison of model vs observed (SYNOP) snow depth shows considerable scatter – potential for improvement to freely-evolving snow amount



Snow DA for the UK NWP system

Met Office

UKV
Unified model (UM) coupled with JULES land surface model



No assimilation of land surface observations yet

In development….

Data source	Snow depth values
Ground-based obs of snow depth, and state of ground (snow or no snow) from synoptic network	SD where reported 0 m SD from snow-free state of ground reports
Satellite-derived 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

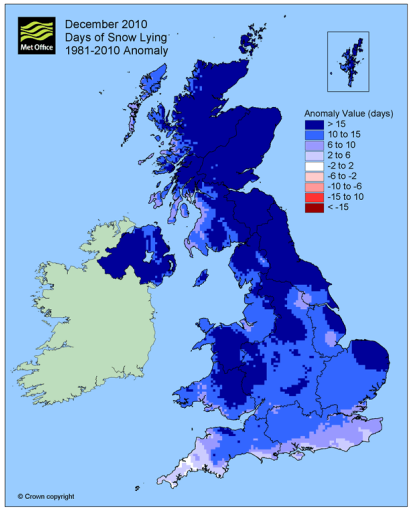
Model first-guess SD

Optimal Interpolation

Snow depth analysis

Assessment of H-SAF snow cover for potential assimilation

December 2010



- ❑Widespread snow across most UK, most of month
- ❑Multiple snowfall/melt cycles
- ❑Good test period for snow datasets
- ❑UK particularly valuable validation site for snow data products

Data sources

1. H-SAF daily snow cover (H31) – composite from temporal integration of scene classifications at 15 minute intervals, over previous 24 hours.
2. Ground-based snow depth reports from UK SYNOP network 06UTC. Positive snow depth measurements plus snow-free (zero depth) diagnosed from state of ground
3. UKV T+1 forecast fields from 06UTC. Snow amount (kgm^{-2})

Experiments

1. H-SAF (test) vs UKV (reference)
   closest grid box to each pixel
2. H-SAF (test) vs SYNOP (reference)
   closest pixel to each SYNOP, if classified
3. UKV (test) vs SYNOP (reference)
   grid box that SYNOP within

Compare diagnosed snow cover using model threshold:
Snow covered if snow amount > 0.1 kgm^{-2}

	Test snow-covered	Test snow-free
Reference snow-covered	a	b
Reference snow-free	c	d

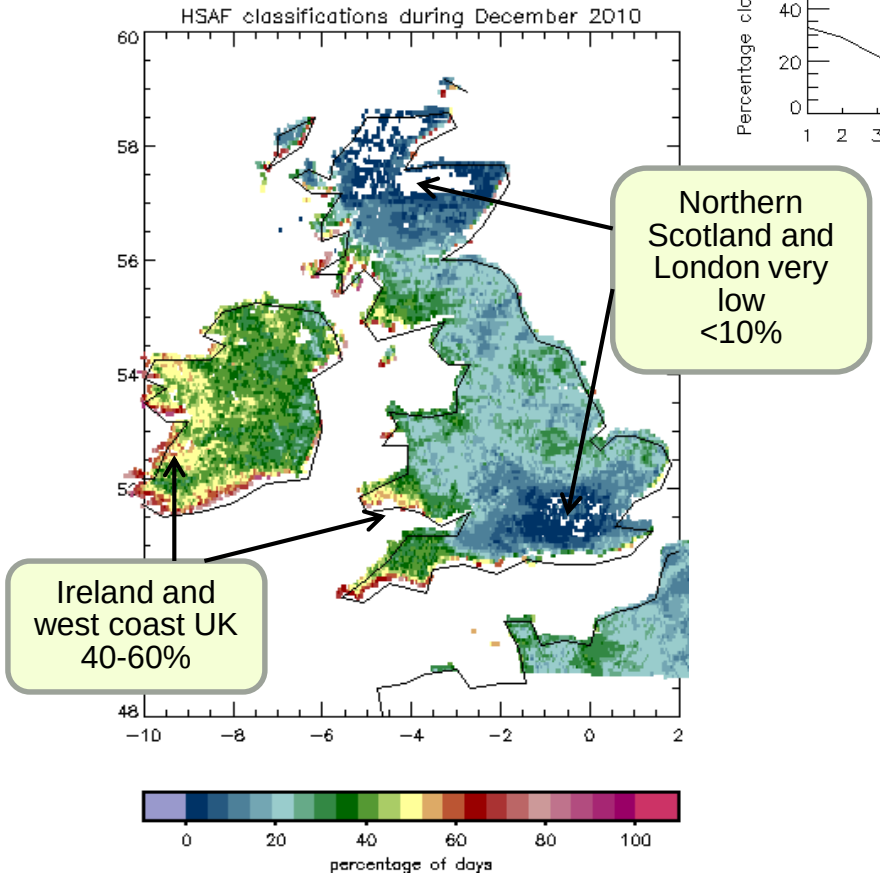
Rate of agreement $R_a = \frac{\sum^n(a) + \sum^n(d)}{n} \times 100\,\%$

Rate of overestimation $R_o = \frac{\sum^n(c)}{n} \times 100\,\%$

Rate of underestimation $R_u = \frac{\sum^n(b)}{n} \times 100\,\%$

Cloud-free classification rates

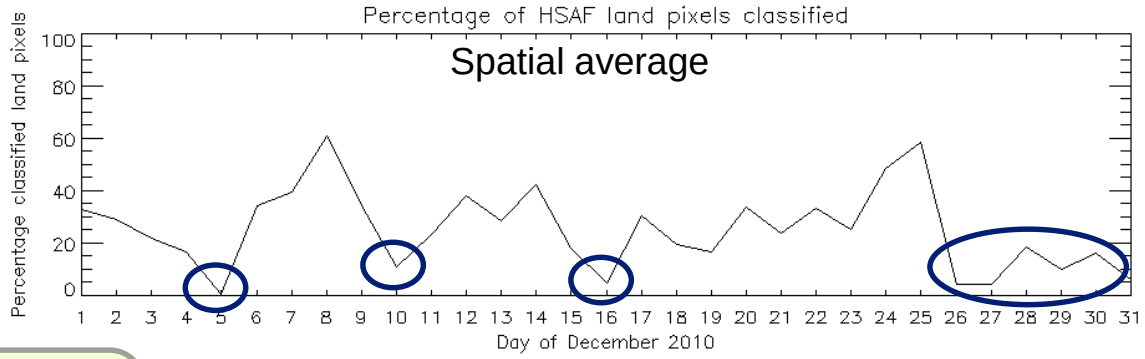
Temporal average



Northern Scotland and London very low <10%

Ireland and west coast UK 40-60%

Spatial average



Most of UK, only 20-40% cloud-free classifications With very high temporal variability.

Some days allow very few scene classifications

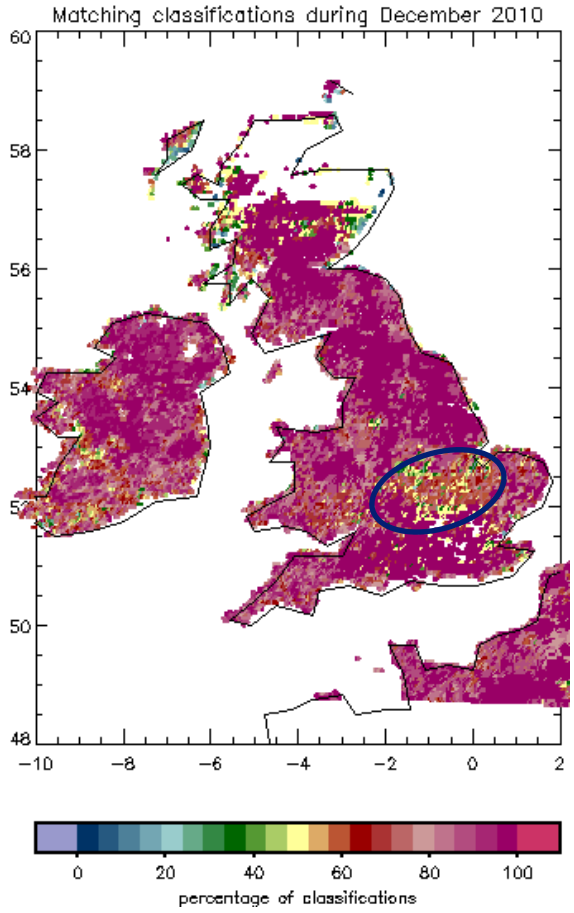
However…..
High temporal sampling of H-SAF product results in large reductions of cloud-affected pixels in composite product relative to products from sun-synchronous sensors

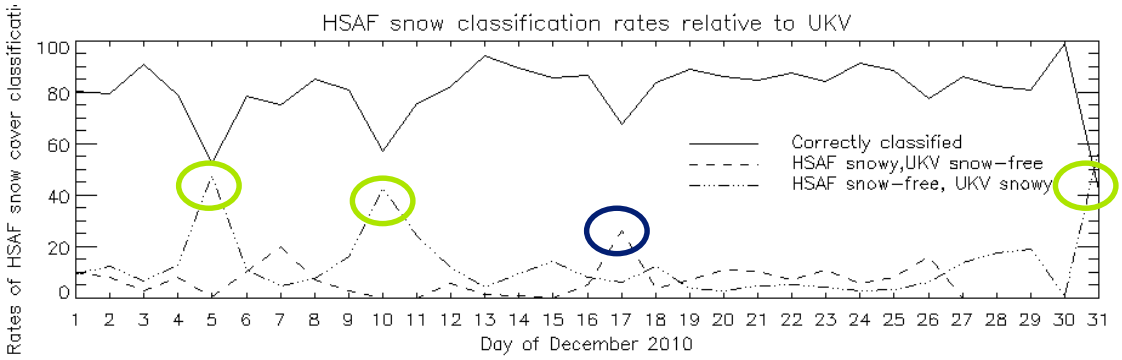
Results in comparable or higher mapping accuracy, despite coarser spatial resolution of SEVIRI product (Surer et al., 2013 doi:10.5194/hessd-10-12153-2013)

H-SAF comparison with UKV

Disagreements do not necessarily indicate errors in H-SAF product – most likely combination of H-SAF and model errors

Rate of agreement





Rate of agreement 80-90% over most of UK, most of time

High rates of underestimation seem to correspond to cases of particularly low classification rate (extensive cloud cover)

High rate of overestimation rate on 17th associated with new snowfall sweeping south.
Rapidly changing snow cover - representation likely to differ between datasets with different time windows.

H-SAF and UKV comparisons with SYNOP

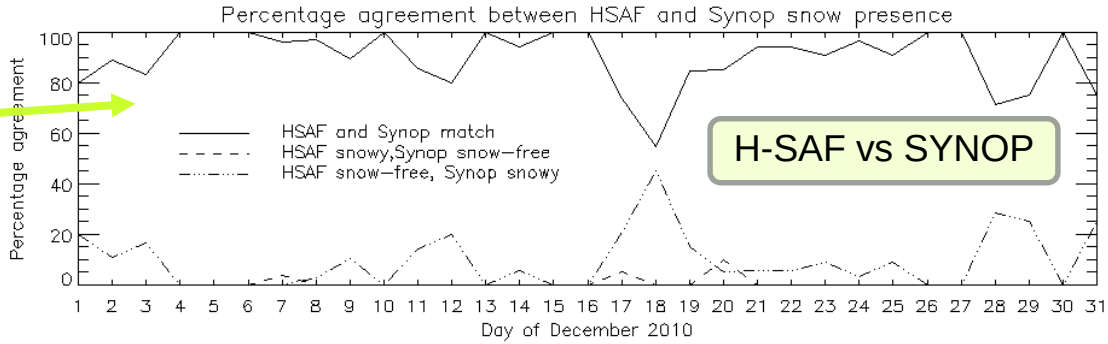
H-SAF vs SYNOP agreement well over 90% most of period

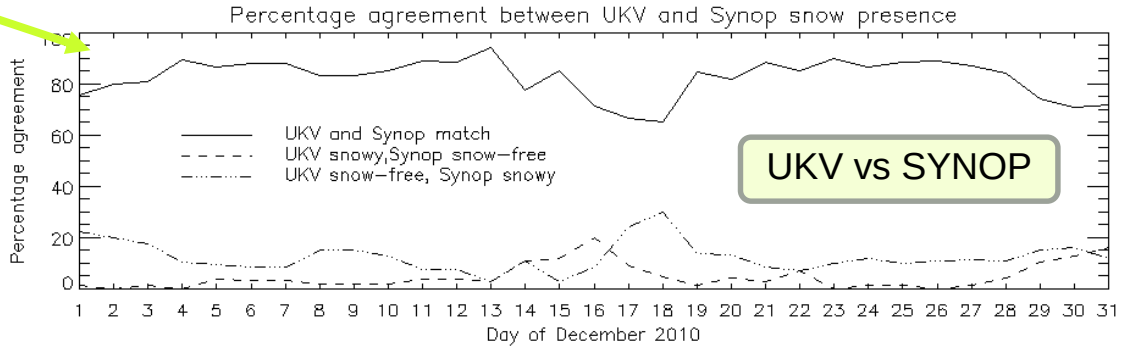
Often low coincidence of SYNOP with classified pixels - beware

UKV vs SYNOP agreement high but not as high as H-SAF

Large reduction in agreement rate 17-19th (both comparisons).

- Rapidly changing snow cover, timing of obs relative to falling snow, model evolution.
- SYNOP too sparse for detailed validation of snow edge.





Overall results

(Repeated using common set of SYNOP for direct comparison)

	R_A	R_O	R_U
H-SAF vs UKV	**80.82**	**6.16**	**13.05**
H-SAF vs SYNOP	**89.38 (89.10)**	**0.64 (0.33)**	**9.98 (10.57)**
UKV vs SYNOP	**82.65 (85.64)**	**4.86 (3.83)**	**12.49 (10.53)**

H-SAF closer to ground truth than UKV

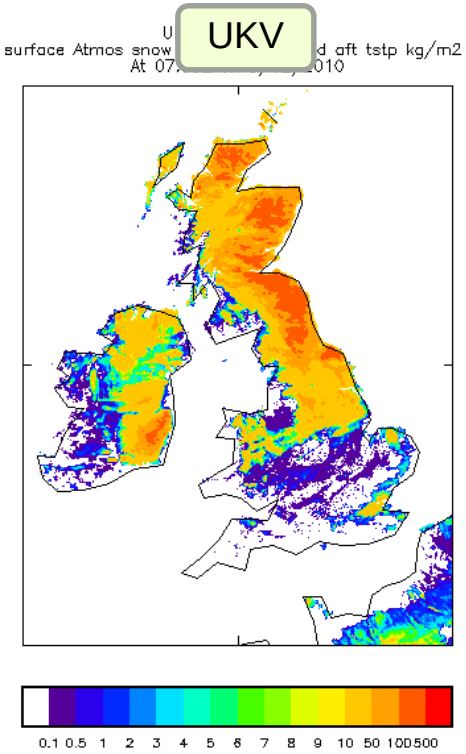
Where H-SAF and UKV differ, can infer that UKV errors proportionally greater than H-SAF errors on average

Assimilation of H-SAF into UKV will add value

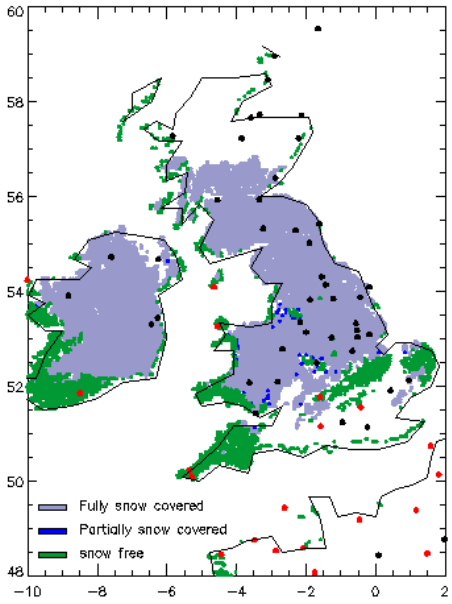
8th December 2010

Fresh snow, little cloud, good agreement overall…

UKV

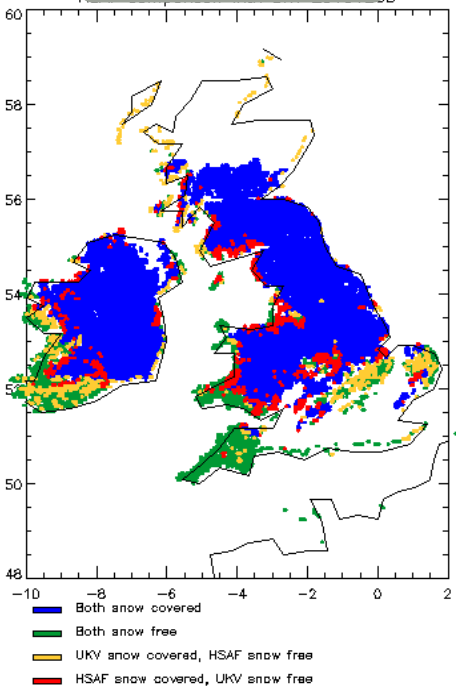


H-SAF + SYNOP



Black dots = snow-covered SYNOP
Red dots = snow-free SYNOP

H-SAF vs UKV

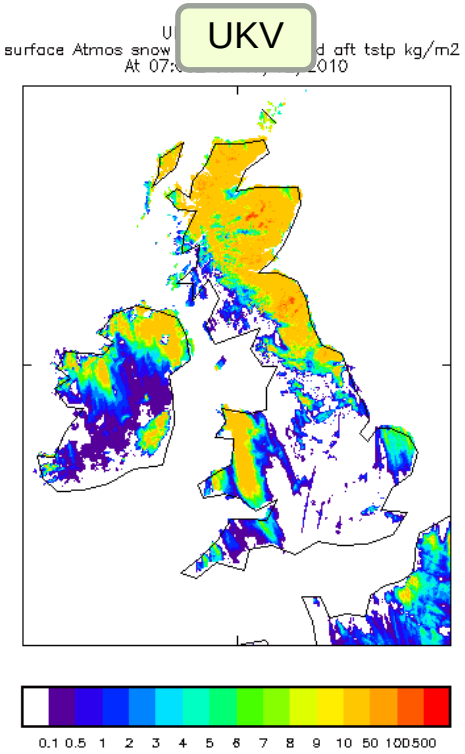


- Valuable case for intercomparison – snow cover extensive, very little cloud cover, lot of available data
- Disagreements mainly on western and southern edge of snow field, but ground station coverage not dense enough to verify which is closer to reality
- Good coincidence of SYNOP and H-SAF pixels ⇨ 97% agreement (UKV vs SYNOP 89%)

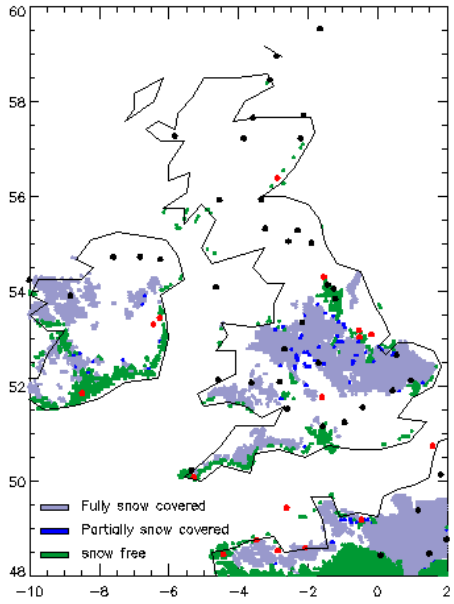
17th December 2010

Fresh snow fall sweeping south, extensive cloud cover

UKV



H-SAF + SYNOP



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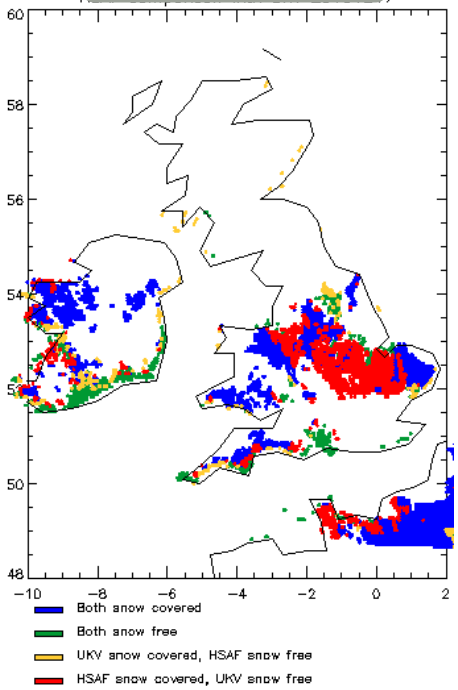
H-SAF vs UKV

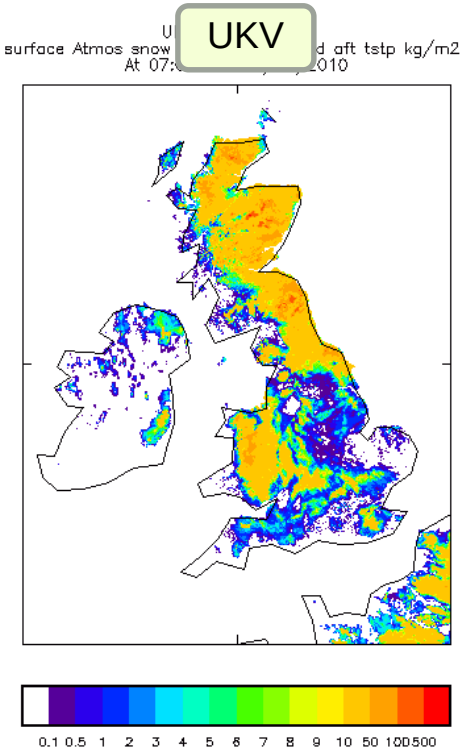


- Discrepancy between H-SAF and UKV and between UKV and SYNOP
- SYNOP mainly corroborated H-SAF in area of disagreement
- Model underestimation, or just validity time of datasets in rapidly evolving snow cover
- Model snow cover extended over next few days and its agreement with H-SAF and SYNOP improved

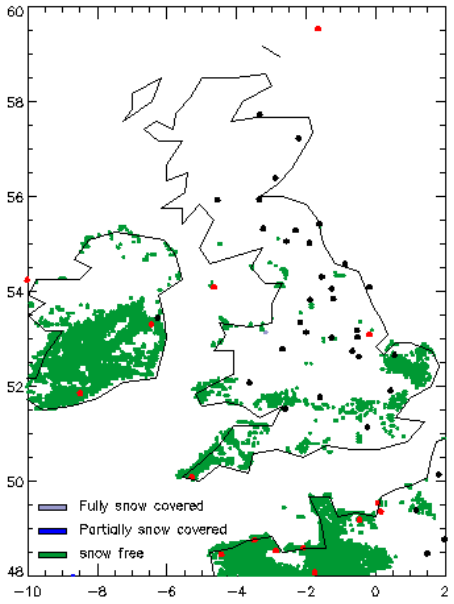
28th December 2010

Widespread snow melt, extensive cloud cover

UKV



H-SAF + SYNOP



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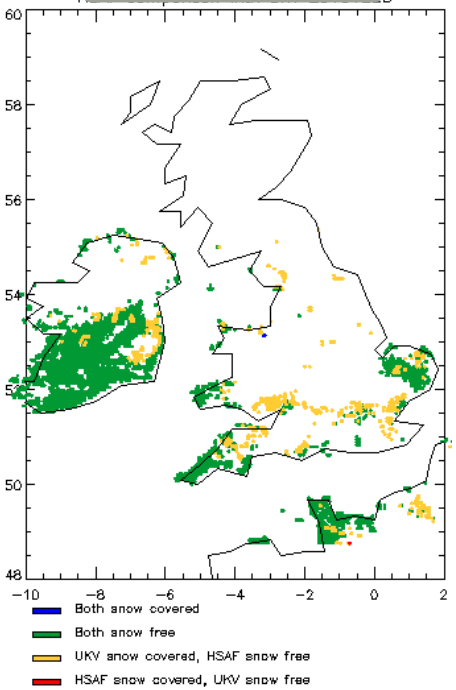
H-SAF vs UKV



- Snow-free agreement generally good
- Disagreements are all underestimations of H-SAF relative to UKV, common behaviour during the snow melt
- UKV agrees better than H-SAF with SYNOP
- Consistent with findings of increased rate of underestimation of H-SAF relative to UKV on severely cloud-affected days

Conclusions of H-SAF snow cover assessment

- Generally good agreement between H-SAF and UKV snow cover, with an overall rate of agreement of over 80%

- On particularly cloud-affected days there was a tendency for the H-SAF product to underestimate snow cover relative to UKV

- Agreement between H-SAF and in situ data was extremely high, > 89% overall. This was higher than the equivalent comparison between UKV and in situ data (85%).

- Proportionally more underestimations than overestimations in H-SAF-SYNOP comparisons than UKV-SYNOP comparisons, consistent with there being an overall bias in H-SAF product towards underestimation of snow cover.

- Overall H-SAF product is closer to ground truth than UKV. Using H-SAF product to constrain UKV should add value to the model snow cover representation.

- H-SAF snow cover will add valuable additional snow data to supplement the rather sparse and variable coverage by SYNOP observations, in particular contributing important observations of snow-free surface.

Met Office

Questions?

Thank you