Using satellite-derived snow cover data to implement a snow analysis in the Met Office global NWP model

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1. Introduction

Snow cover and amount are important components in the interaction between the land surface and atmosphere, with considerable impacts on the radiative and hydrological properties of the land surface. Accurate representation of snow cover in NWP models is essential for calculations of surface exchange fluxes, and subsequent forecasts of atmospheric variables. An accurate knowledge of surface emissivities, which are affected by snow cover, is also important to enable the assimilation of satellite sounding data from surface-affected channels. Increases in the number of usable sounding channels could potentially yield considerable improvements to forecast accuracy, so efforts to improve the surface representation are also important from the satellite data assimilation point of view. Until 2008 no observational snow information was used in the Met Office's global NWP model. A northern hemisphere (NH) snow analysis, based on satellite-derived observations of snow cover, has recently been implemented in the Met Office's operational global NWP model. The primary aim is to improve the global model snow analysis, with no significant impacts on forecast skill anticipated.

2. Satellite data

Observations of snow cover are provided by the Interactive Multisensor Snow and Ice Mapping System (IMS) from the National Oceanic and Atmospheric Administration's National Environmental Satellite Data and Information Service (NOAA/NESDIS) (Ramsay, 1998). The IMS data consist of a daily map of NH snow cover and sea ice extent, which is drawn up by analysts on workstations that display data products and satellite imagery from a variety of sources, using the map from the previous day as the initial state. The primary data sources are visible imagery from polar orbiting and geostationary satellites, with satellite microwave products and ground weather observations also incorporated, to allow detection in cloudy or low solar illumination conditions. The analyst also has access to a range of other snow and ice analyses and products. The IMS data are produced daily at approximately 4 km resolution, consisting of snow cover (0 or 100%) and sea-ice fraction (0 or 1) records. Figure 1 shows the IMS snow and ice map for 20th February 2008.

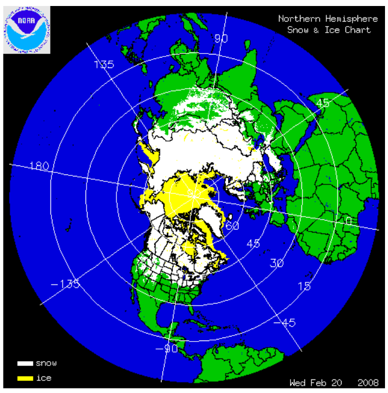

Figure 1. IMS NH Snow and Ice Chart for 20-02-08 where snow cover is shown in white and sea ice in yellow (National Ice Center)

3. Analysis method

While the IMS data provides a simple binary diagnosis of snow cover (fully covered or no snow), the Unified Model (UM) snow variable is snow amount, in kgm^{-2}, or areal density. The presence of snow cover indicates that some snow amount exists but gives no information about how much, and so there is no continuous relationship between the model states and the observations. Romanov *et al.* (2003) has shown that there is a close correlation between snow fraction and snow depth in non-forested areas, and this relationship presents a way of extracting information about snow amounts from snow cover data, if they can be converted to fractional cover data. Several NWP models derive fractional snow cover from a gridbox value of snow-water equivalent (e.g. Drusch *et al*., 2004), and a relationship such as this is already used in the UM for specifying albedo as an interpolation between the snow-free and snowy albedos (Essery *et al.*, 1999):

$$a = a_0 + \left(a_s - a_0\right)\left(1 - e^{-DS}\right) \quad (1)$$

Where a = actual albedo, a_0 = snow-free albedo, a_s = snowy albedo, S = snow-water equivalent, D = masking depth of vegetation.

This relation can be used to relate fractional cover to SWE in the following way:

$$S = \frac{\left(-\ln\left(1 - f_c\right)\right)}{D} \quad (2)$$

Where $f_c = 1 - e^{-DS}$ is the fractional snow cover and D is set to 0.2 m in the UM.

Figure 2 illustrates the relationship in (2) between SWE and fractional cover, for a masking depth of 0.2 m.

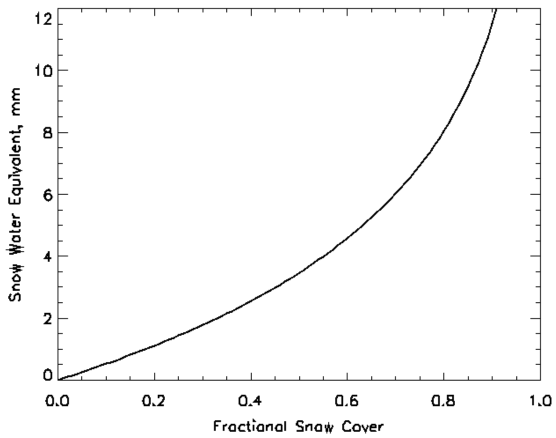

Figure 2. Relationship between snow water equivalent and fractional cover for a masking depth of 0.2 m

Fractional snow cover is derived from IMS snow cover by resampling onto the NWP model grid. The presence of snow can then be compared directly between the derived fractional cover and the model background snow amount field. Analysed snow is calculated following the following rules and illustrated schematically in figure 3:

1. Where fractional cover is zero, analysed snow amount is set to zero.
2. Where fractional cover is non-zero but UM background snow amount is zero, analysed snow amount is calculated according to the relation in (2), up to a maximum value of 10.0 kgm^{-2}.

3. Where both fractional cover and UM background snow amounts are non-zero no change is made.
4. Where UM background land ice is non-zero no change is made.

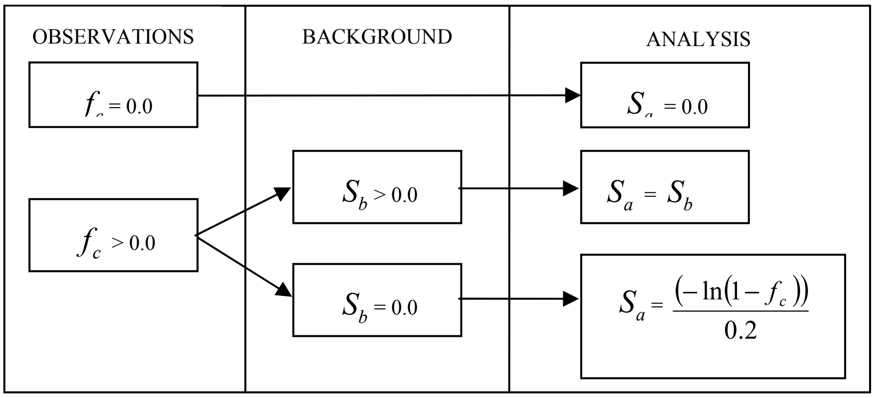

Figure 3. Schematic diagram showing how the snow analysis works, where f_c = fractional cover, S_b = background snow amount and S_a = analysed snow amount.

A demonstration of the scheme is illustrated in figure 4 where a snow analysis has been performed over Europe. Additions of snow over the Alps, northern Spain, and southern Sweden are clearly shown in (c) and (d) where none was present in the background snow field, but was present in the observations.

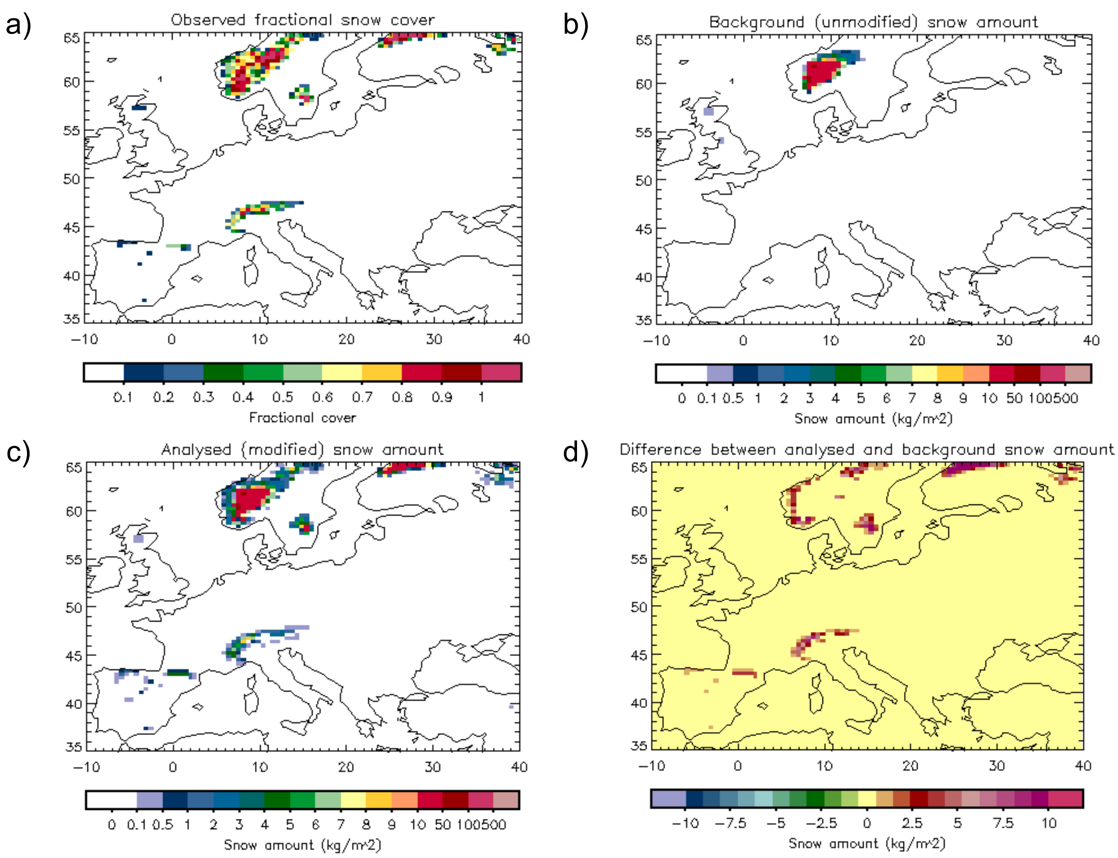

Figure 4. A snow analysis performed on 10th November 2008 over Europe, showing (a) the observed fractional cover, (b) the background snow amount field, (c) the analysed snow amount field, and (d) the snow amount increments.

4. Assimilation experiments

Global model assimilation experiments have been run during the two main seasons that are affected by snow in the NH. A 1-month experiment was run for December 2006, during snow accumulation, and a 3-month experiment was run from March-May 2007, encompassing the majority of the snowmelt season. Controls for the experiments consisted of equivalent model runs without execution of the snow analysis.

For the December experiment forecast skill impacts were small but slightly positive. There were small improvements in surface or low level temperature forecasts, and in relative humidity forecasts where snow was removed. Snow was consistently added in the Sierra Nevada and Rocky Mountain ranges of North America, and removed in the region of the Tibetan Plateau. Snow was initially added, then removed over large areas along the Eurasian snowfield edge. The net effect over the course of the experiment was snow removal. As an example, the snow increments for 14th December 2006 are shown in figure 5.

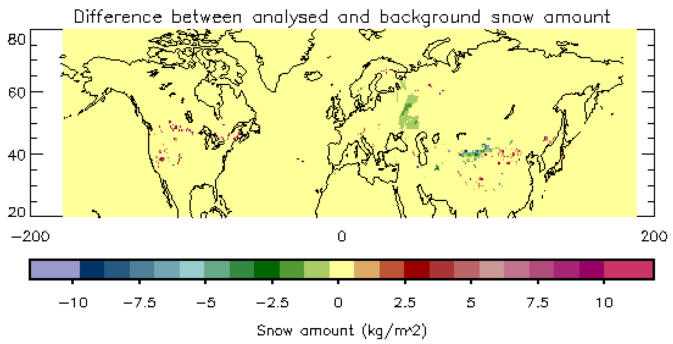

Figure 5. Analysis increments for 14th December 2006

For the longer NH springtime experiment forecast skill impacts were small and slightly negative. There were snow additions over progressively larger areas at the edges of the snow field in North America and Eurasia, as the analysis attempted to restore snow that had been prematurely melted by the model. However this added snow was not retained by the model and the slight reduction in forecast skill for NWP variables was probably due to the effects of the model repeatedly melting large areas of snow added by the analysis. Extensive snow additions are shown by the snow analysis increments for 15th April 2007, in figure 6.

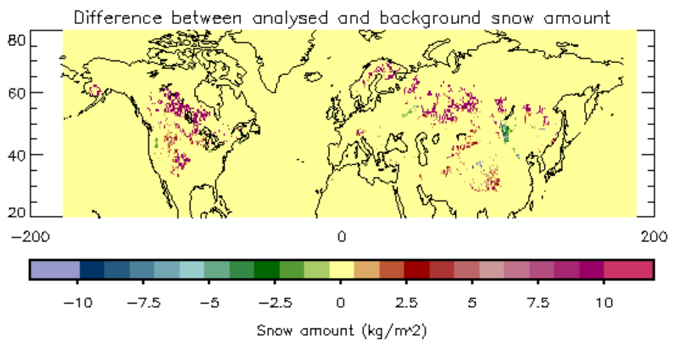

Figure 6. Analysis increments for 15th April 2007

Snow depth analyses from the National Operational Hydrologic Remote Sensing Center (NOHRSC) were used as semi-independent qualitative verification over the United States (US). Comparison of NOHRSC daily analyses with UM background (before modification) and analysed (after modification) snow amounts, in terms of presence or absence of snow, shows generally improved snow cover representation in the UM analyses compared to the UM background. Figure 7 shows comparisons for a case from each of the experiment periods. On 13th December 2006 the analysis has added snow in the Sierra Nevada mountain range and around the Great Lakes, leading to improved snow cover representation. Addition of snow in mountain ranges, such as the Sierra Nevadas, occurred frequently in both experiment seasons. The comparison for 14th April 2007 shows the huge improvements made by the snow analysis during the springtime snow melt. The background snow field has been almost completed depleted over the northern US but the analysis has reintroduced snow to give a much better comparison with the NOHRSC product.

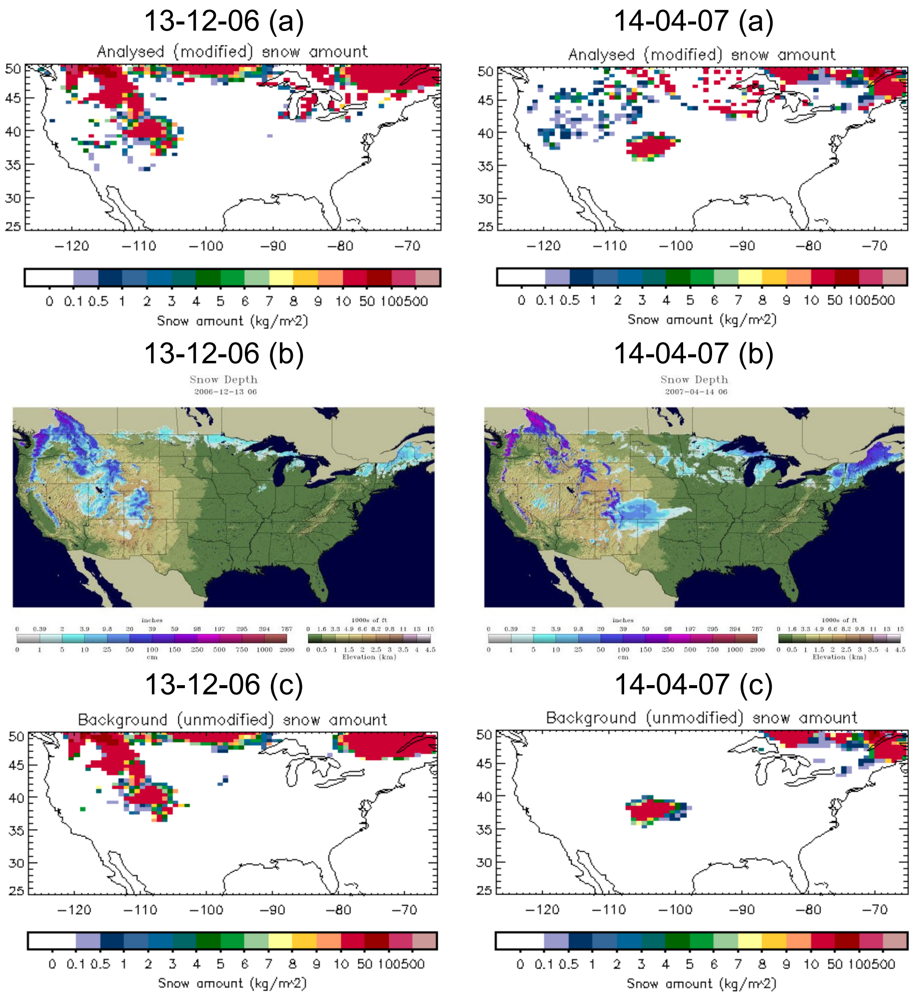

Figure 7. Analysed snow amounts (a), NOHRSC snow depth (b) and background snow amounts (c) for 13th December 2006, and 14th April 2007, over the US. (NOHRSC)

SYNOP "state of ground" reports were used to compare presence of snow between station and model data, over Europe, for a 2-week period within each experiment. The percentage of model grid points over Europe with snow presence in agreement with SYNOP snow reports was increased, compared with a control run without snow assimilation, for both seasons, but particularly during the snow melt season. Results for both are shown in figure 8 and can be taken as evidence that the snow analysis has improved the model snow cover representation at analysis time.

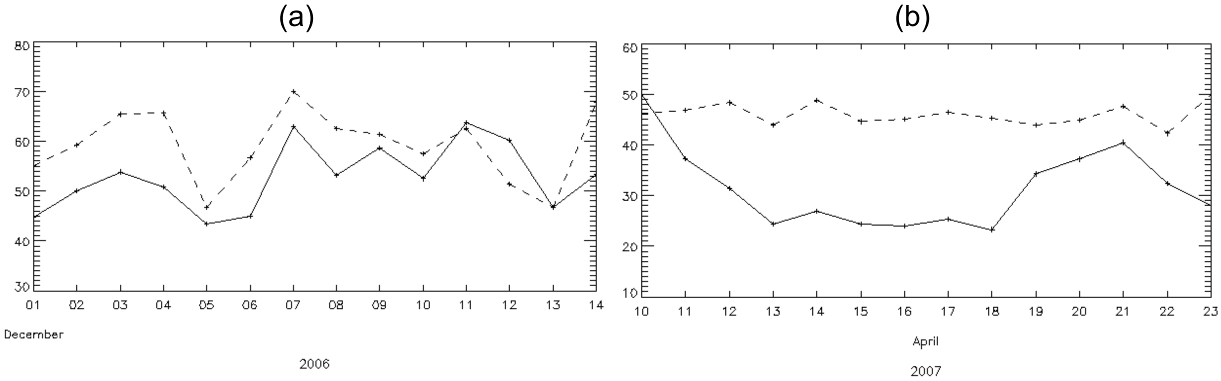

Figure 8. Percentage of model grid points, in Europe, with snow presence in agreement with SYNOPS snow reports within them for (a) 1-14th December 2006 and (b) 10-23rd April 2007. Control run, without snow analysis, is shown by the solid line and experiment run by the dashed line.

5. Summary

A daily NH snow analysis, using NESDIS IMS snow cover data, has been developed and implemented in the UK Met Office's operational global NWP model. Assimilation experiments have been run during the NH snow accumulation and snow melt periods (December 2006 and March-May 2007). There is clear evidence that the snow analysis improves the analysed snow field in terms of presence or absence of snow. There is also some evidence of small improvements to surface and low level temperature and humidity forecasts, especially where snow is predominantly removed by the analysis. Overall, the snow analysis yields a neutral impact on forecast accuracy. Unfortunately little of the information introduced by the snow analysis is retained in subsequent forecasts, especially where snow has been added. Future development of the model snow physics may help to address this problem. An upgrade to the analysis has recently been developed to mitigate the effects of time delays in the IMS data which can lead to exclusion of snowfall events from the analysis. This upgrade is planned for implementation in operations in 2010.

References

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