

Results of the SAT-MAP-CLIMATE project

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1. Introduction

The objective of SAT-MAP-CLIMATE is: satellite-based bio-geophysical parameter mapping and aggregation modeling for weather forecasting and climate modeling. For several reasons the focus is on Denmark and surrounding waters.

In numerical weather prediction (NWP) and climate modeling there has been a growing need for representing important properties of the highly heterogeneous Earth's surface in high spatial and temporal resolution. Representation of heterogeneity in NWP and climate modeling is usually limited by the horizontal model resolution by assuming horizontal homogeneity within a grid cell or within each fraction (e.g. land, sea and ice) of a grid cell. The temporal resolution of important surface properties, for example albedo, momentum roughness length (z_0) and leaf area index (LAI), is usually limited to seasonal or monthly time scales. Results of the present project indicate that benefit can be achieved by more extensive use of Earth observation (EO) satellite data. The benefit is obtained from their inherent information about surface inhomogeneity and temporal changes in surface properties on spatial scales down to the pixel scale of the EO data and on temporal scales down to about 5 days. The latter appears in practice to be a lower limit in Advanced Very High Resolution Radiometer (AVHRR) data provided by the National Oceanic and Atmospheric Administration (NOAA).

2. Experiments

A number of experiments has been performed with the DMI-HIRLAM forecasting system. In these experiments one or more surface parameters, provided by the operational climate file generation system (Sattler, 1999) or obtained by a kind of surface analysis, have been replaced by corresponding fields derived one way or another from EO satellite data for Denmark and nearby surroundings. The latter necessarily puts question marks on the more general validity of the results obtained in the project.

For a majority of the experiments the period from 15 April to 15 May 2000 was selected. This period was considered to be particularly interesting, because rapid (relatively speaking) changes occurred in key surface parameters such as albedo, sea surface temperature (SST) and z_0 . These changes were not resolved by the "frozen" monthly changes in albedo and z_0 in the operational system. Also the observed rapid increase of SST in the Danish coastal waters was poorly represented in the SST-field used operationally. The latter contained SST-analyses from the European Centre for Medium Range Weather Forecasts (ECMWF).

Three types of experiments are discussed here. The first concerns surface albedo, the second deals with SST and the third is about z_0 .

Albedo and SST for the Danish region was derived from AVHRR data with updated fields every fifth day in the period 15 April to 15 May 2000. Two z_0 fields (for summer and winter, respectively) were generated by aggregation (see section 5).

3. Albedo

The experiments showed that frequent (every fifth day) updates of surface albedo based on AVHRR data only had a marginal impact on the predicted temperature at 2 m height (T2m). The absolute value of the difference in T2m between the operational and experimental forecasts was less than 0.5 K in the performed experiments. It is likely that a somewhat larger impact would be seen if the surface albedo was correspondingly modified on a much larger scale (for example the European), and in particular if applied in regional scale climate modeling.

4. SST

Much larger impact on a day to day basis is seen by applying "fresh" SST's in the Danish coastal waters. An example of the impact on T2m is shown in Figure 1. The SST's (in °C) applied in the experimental forecasts were derived from calibrated and geometrically rectified NOAA AVHRR images using

$$SST = a_1 \cdot c_4 + a_2 \cdot (c_4 - c_5) + a_3 \cdot ((c_4 - c_5)(\cos(\pi \cdot \alpha))^{-1}) - 278.43, \quad (1)$$

where a_1 , a_2 and a_3 are constants ($a_1 = 1.017342$, $a_2 = 2.139588$, $a_3 = 0.779706$), c_4 and c_5 is the black body radiation temperature (in K) in channel 4 and 5, respectively, and α is the satellite view zenith angle.

The relative large impact on T2m is considered to be the result of an increase of SST in the Danish coastal waters of about 10 K in the considered period. The rapid increase of SST, shown by in situ SST measurements (Figure 2), is better captured by the experimental forecasts using "fresh" satellite derived SST's than by the operational system applying analyzed SST's from ECMWF (Figure 1). The experiments clearly indicate that there is a potential for improved prediction of T2m by applying "fresh" EO-based SST's, particularly in coastal regions. A hint in that direction is also given by the substantial negative T2m bias at Danish coastal stations seen in routine verification for the second quarter (figure not shown).

5. Momentum roughness length

Two z_0 -fields, one for summer and one for winter, have been calculated by aggregation (up-scaling). The aggregation involves a 2 dimensional hydrodynamic model (Hasager and Jensen, 1999). This model takes as input local z_0 values on satellite pixel scale, and the output of the model is grid-cell average (here approximately 15 km · 15 km) friction velocity $\langle u_* \rangle$ and the corresponding effective momentum roughness length $\langle z_0 \rangle$. It is assumed that $\langle u_* \rangle$ and $\langle z_0 \rangle$ are related by the logarithmic wind law. The EO satellite data is used in a land cover type classification of each pixel.

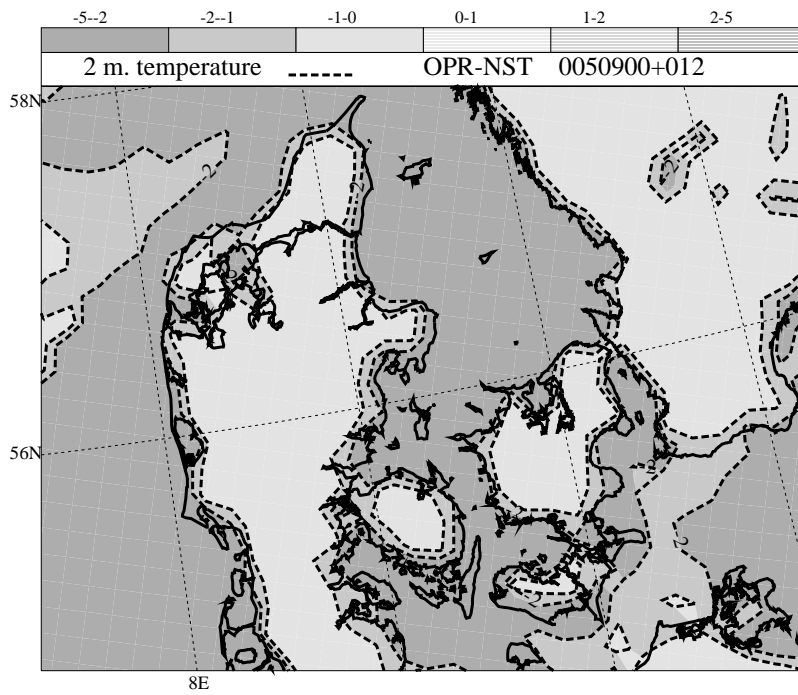


Figure 1: Difference in T2m between operational (OPR) and experimental (NST) 12 h forecasts valid 12 UTC 9 May 2000. Contour intervals $[-5, -2[$, $[-2, -1[$, $[-1, 0[$ are shaded and intervals $[0, 1[$, $[1, 2[$ and $[2, 5[$ are hatched. Shown contours (dashed lines) are -2, -1 and 0 K.

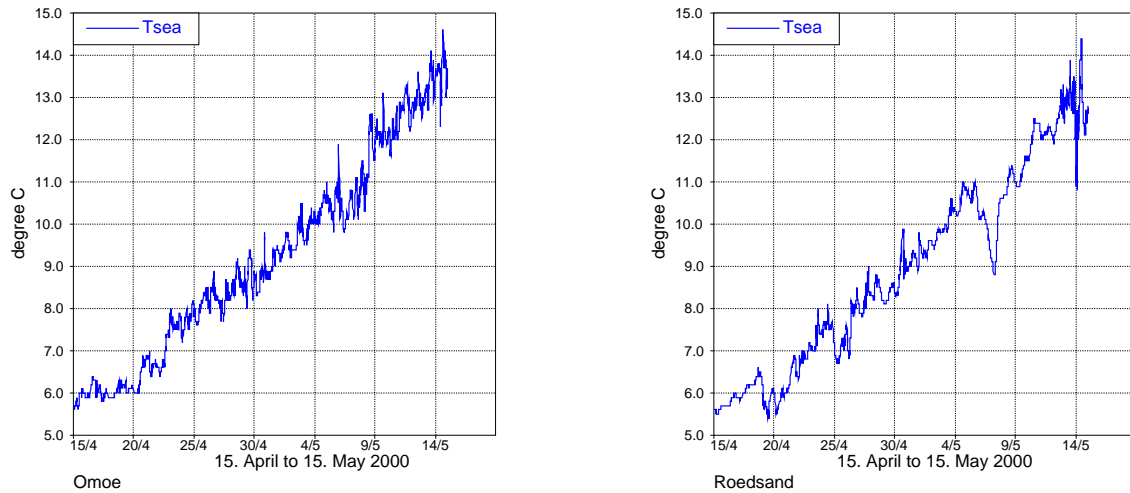


Figure 2: In situ SST measurements in Danish coastal waters at Omoe (left) and Roedsand (right). (Observations from SEAS). Period: 00 UTC 15 April to 00 UTC 15 May 2000.

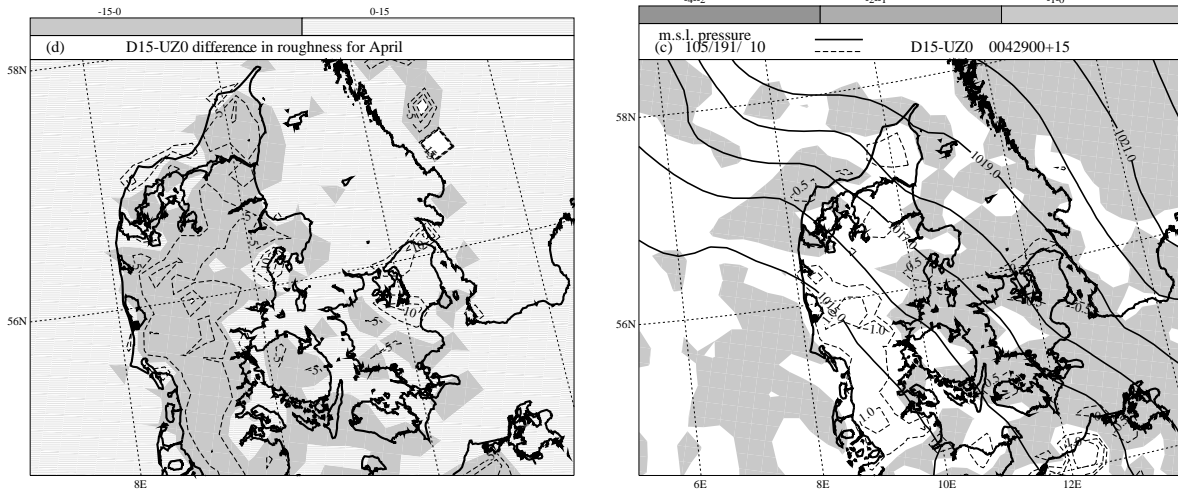


Figure 3: Left: Difference in roughness length (dashed lines, contour interval 5 cm and negative difference shaded) between D15 and UZ0 for April. Right: Sea level pressure for D15 (full lines, interval 1 hPa) and difference in W10m (dashed lines, contour interval -2, -1, -0.5, 0.5, 1, 2 ms^{-1} , and negative difference shaded) in 15h forecasts valid 15 UTC 29 April 2000.

Typical z_0 values for each land cover type are then used to create a map of local roughness on the pixel scale used as input to the aggregation model (for details see Hasager et al., 2002). Note that the aggregation technique handles only the roughness variation due to land cover types, not the orography roughness. However, in the flat terrain of Denmark this is not a serious limitation.

Land cover classifications based on Landsat TM and SPOT images (Bøgh et al., 2000), on the CORINE land use map, and on the Land Cover Map Plus Areal Information System (AIS) have been applied at selected sites in Denmark. For each of the classifications the output from the aggregation model (i.e. $\langle u_* \rangle$ and $\langle z_0 \rangle$) was compared with corresponding values derived from detailed field measurements at one or more of the selected sites in Denmark. It was found that the aggregated values generally were smaller than those derived from the measurements, particularly in summer. It was suspected that the discrepancy to some extent could be due to the effect of hedges. Roughness of hedges is not taken into account in the local z_0 -field based on the land cover types. Inclusion of the roughness effect of hedges resulted in a much better agreement between the aggregated and measured $\langle z_0 \rangle$ (Hasager et al., 2002).

Figure 3a shows the difference in roughness length between the field used operationally for April and the corresponding summer-field applied in the experimental forecast (UZ0). The latter field is calculated in two steps. In the first step a preliminary $\langle z_0 \rangle$ is calculated by aggregation with input of local z_0 values with a spatial resolution of 25 m obtained from the AIS land cover map for Denmark. In the second step the contribution z_0' from hedges is added to $\langle z_0 \rangle$. It is shown in Hasager et al., 2002 that z_0' can be approximately calculated from

$$\frac{z_0'}{\langle z_0 \rangle} = 0.5 \frac{h C_D}{D \kappa^2} \left(\ln \left(\frac{h}{\langle z_0 \rangle} \right) \right)^3, \quad (2)$$

where κ is the Von Karman constant, h is the height of the hedges, D is the distance between them, and C_D is their drag coefficient. According to Figure 3a the resulting effective roughness length is generally higher than in the field used operationally. This is in particular the case in Jutland, where the density of hedges tends to be higher than in the eastern part of the country. Figure 3b shows an example of the impact of the change in roughness on the wind speed at 10 m height (W10m). Note the clear negative correlation between the differences in roughness (Figure 3a) and wind speed (Figure 3b). Routine verification of the operational forecasts for the second quarter of 2000 shows a positive W10m bias of about 0.5 ms^{-1} for the Danish land stations (Nielsen and Amstrup, 2000). This indicates, but does not prove, that in summer a replacement of the operational roughness map with an effective roughness map, including the effect of hedges, will reduce the bias of W10m over Denmark. A proof of this hypothesis requires parallel runs over extended periods, which has been outside the scope of the present project.

6. Conclusions

The results obtained by the SAT-MAP-CLIMATE project indicate that benefit, for example in terms of improved verification scores for near-surface parameters such as T2m and W10m, can be obtained by more extensive use of EO satellite data in NWP and climate modeling. In the present project EO data has been applied on the local scale of Denmark. This scale is clearly too small to see any impact on the evolution of larger scale weather systems. The obtained results indicate that it may be worth while to extend the work to at least the European scale. This would require international collaboration similar to the ongoing research within the European Satellite Application Facility (SAF) projects.

References

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