HIRLAM coupled to a Wave Ocean Model.

Morten Køltzow and Øyvind Sætra
Norwegian Meteorological Institute.

1 Introduction

The main purpose of this work is to investigate the impact of sea-state dependent surface fluxes on HIRLAM forecasts and in particular on the development of polar lows. It is easy to imagine that a young wind sea with steep waves extracts momentum more efficiently from the atmosphere than swell does. Our hypothesis is that polar lows are particularly sensitive to variations in the fluxes of momentum and sensible and latent heat. Hence, we believe that the impact of such sea-state dependent fluxes may be stronger on polar lows than on synoptic low-pressure systems.

Several definitions of polar lows can be found in the literature: “A polar low is a small, but fairly intense maritime cyclone that forms poleward of the main baroclinic zone. The horizontal scale of the polar low is approximately between 200 and 1000 kilometres and surface winds near or above gale force” is given by Turner et al (2003). In addition many definitions put emphasis on a convective nature of the low (e.g. Rasmussen et al, 1989). Furthermore, polar lows appear in many forms, and the main forcing mechanism may vary from pure baroclinic to systems governed by deep convection and the release of latent heat. They are often characterized by strong winds, large surface fluxes and heavy precipitation. In some cases, mature polar lows show some striking similarities with tropical hurricanes, such as spirals of cloud bands caused by deep convection around a clear central eye. For this latter class of polar lows the main forcing is the supply of latent and sensible heat of the relatively warm ocean, and we expect that sea-state dependent surface fluxes may improve simulations of these systems.

For the purpose of this work, the atmospheric model HIRLAM has been coupled to the ocean wave prediction model WAM (Komen et al, 1994). First a description of the coupling between the models and the experimental set up are described. Then results on the general model performance are given before an evaluation of polar low forecasts is given. Finally we try to draw some conclusions on this work.

2 The coupling of HIRLAM and WAM

In HIRLAM the surface roughness over the ocean is given by the Charnock relation (Undén et al, 2002). This surface roughness is then applied to calculate surface fluxes of momentum, sensible and latent heat. This gives the same surface stress for a given wind speed and accordingly no sea-state dependent surface fluxes. In WAM, the Charnock relation is modified according to Janssen (1991) to take the sea state dependency into account. In this study, WAM is implemented as a subroutine in the HIRLAM code. So far all communication between WAM and HIRLAM is done on one processor, while the calculations in WAM are done on the same amount of processors as the rest of the HIRLAM code. The wave model is called at the start of every time step of HIRLAM with 10m winds from the previous time step as input and a sea state dependent surface roughness as output.

3 The experimental set up

This study consists of 3 months of forecasts from 1 January to 31 March 2007. A reference
experiment (REF) with no coupling between HIRLAM and the WAM model and one experiment (EXP) with HIRLAM coupled to WAM are performed. In the simulations HIRLAM version 7.1.3 is used with 40 vertical levels with 0.072° horizontal resolution. The version of the WAM model is used in daily forecasts at met.no and employs the exact same projection and horizontal resolution as HIRLAM to avoid any interpolation problems. The model domain is given in Figure 1.

Except for the coupling/no-coupling the experiments are similar with 4 forecasts, including 3D-var data assimilation and surface analysis every day. At 00UTC the forecasts are +60h, while at 06, 12 and 18UTC the forecasts are only +9hr. The latter to keep the assimilation process going through the experiment period. All analysis below is done on the +60hr forecasts starting from 00UTC.

4 Results - The general performance of the system

In Figure 2, the MSLP forecasts are compared with observations from 37 Norwegian synop stations as a function of lead time. The general impression is that the MSLP forecasts of the coupled and un-coupled system are of similar quality. For the systematic error very small differences are found (~0.05hPa). However, for the more random error as standard deviation (SDE) a decrease in quality of the coupled forecasts is found after ~48hours forecast. This is also seen in the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). Late in the forecasts the coupled MAE is approximately 5% higher than the uncoupled MAE. A similar comparison with observations was also done for variables like 2m air temperature, 10m wind speed and precipitation, but only negligible differences were found. A verification of the forecasts against observations over the ocean is difficult because of the relatively few available stations. However, compared with observations from Jan Mayen and Bjørnøya (isolated islands) and 6 oil-installations in the Norwegian Sea, the coupled forecasts has slightly higher skill in the first half of the forecast, while the opposite is true in the last part (not shown). However, the differences are small and probably not significant.

Based on this general verification the impact of coupling WAM and HIRLAM has a neutral or slightly negative impact (at the end of the forecasts). One explanation for this behaviour of the coupled system might bee that the uncoupled HIRLAM is “tuned” to the original applied surface roughness. This has however, not been investigated in detail in this study, but the new sea-state...
dependent surface roughness over ocean is on average 20% higher than in the original scheme. In accordance with this we find an increase in sensible heat flux from the ocean to the atmosphere of 4.4% in the coupled scheme. However, the latent heat flux has decreased with 1.4% so that in total it is only a 0.1% change in the total heat flux from the ocean to the atmosphere. The coupled model system therefore stays in a sort of equilibrium of heat exchange between the ocean and the atmosphere. The opposite sign of the changes in sensible and latent heat flux is non-trivial, but the interaction between the ocean and the atmosphere is highly non-linear. Even if the total amount of energy exchanged between the ocean and atmosphere is similar in the two experiments it is obvious from visual inspection that a re-distribution takes place in connection with different weather systems.

Comparing model results with a limited amount of observations is not a trivial task since the
geographical resolution of observations is sparse. Comparing model and observations is also a question of what they both represent. To take some of these considerations into account the model forecasts is also compared to the model analysis. In Figure 3, the MSLP forecasts are compared with analysis (the coupled forecasts are compared with the coupled analysis and the uncoupled forecasts are compared with the uncoupled analysis). Based on this Figure an average evaluation for the entire domain is found. The systematic surface pressure errors are small through the forecasts, and there are only negligible differences in quality between the control and experiment forecasts. The latter is also true when studying the RMSE, but the RMSE increases with forecast length. The same pattern is valid when looking for only ocean areas in the model, given in the same Figure.

5 Results – Polar lows

In the 3 months long experiment period, the duty forecasters for Northern Norway defined 5 polar lows inside the integration domain applied in this study. 4 out of 5 of these were well forecasted by both the coupled and uncoupled system. The quality of the forecasts varied somewhat from case to case, but the coupled and uncoupled forecasts show similar skill. So far no analysis of false alarm rate in the forecasts has been done, but this will be included in future analysis. An important feature of all polar lows in the period is that they are very weak or missing in the analysis. However, the large scale flows in the models trigger the development of the polar lows. A visual inspection of the forecasts indicates that the HIRLAM model is able to forecast polar lows that are not initially present in the analysis of the model.

For one of the polar lows a real difference in the forecast abilities between the coupled and uncoupled system appear. On the 21.January a polar low developed in the north-easterly flow in the Barents Sea. The polar low (seen as two closed isolines in the surface pressure) and the general synoptic situation in the coupled forecast are seen in Figure 1. The development of the disturbance is shown for the two forecasts (starting on 00UTC 20.January) in Figure 4. Corresponding satellite pictures are presented in Figure 5. The two forecasts show a different description of the polar

Figure 4. MSLP in uncoupled forecast (left) and in coupled forecast (right) starting from 00UTC 20.January. The forecasts are valid for +27h (upper left), +30h (upper right), +39h (lower left) and +48h (lower right) and they correspond to the satellite pictures given in Figure 5.
low in the Barents Sea. While there are several minor disturbances in the MSLP pattern initially in both forecasts, it is only the coupled forecast which has a development that corresponds to the satellite pictures (Figure 5). In the uncoupled simulation a clear polar low is first seen after +49h forecast. In the coupled simulation it is possible to follow the polar low from when it is initiated and then advected southwards, which is similar to what is seen in the satellite pictures. The strength of the polar low is difficult to determine from the observations since no ground observations or scatterometer measurements have been available to this investigation. However, the position in the forecast is good, only a small displacement put the polar low slightly too close to the coast.

The polar low described here is of the type “reversed-shear” with warmer air to the left of the flow and a pronounced low level velocity maximum. The disturbance is quite shallow and only minor signs of it are seen above 500hPa in the model. The maximum surface (10m) wind speed associated with the polar low in both forecasts are approximately 20m/s, but appears for a longer period and cover a larger area in the model version. The latent and sensible heat fluxes associated with the polar low is higher in the coupled forecast. Maximum 6hr averaged total heat flux is ~400W/m² and ~325W/m² in the coupled and uncoupled forecasts, respectively. Also for these variables, the maximum is present over a larger area and for a longer period in the coupled simulation.

6 Conclusions

HIRLAM (version 7.1.3) was coupled to the wave ocean model WAM and forecasts were done for a 3 month winter period. The main objective was to investigate if such a coupling increased the ability
of HIRLAM to forecast polar lows. In the experiment period, both the coupled and the uncoupled forecasts simulated 4 out of 5 polar lows. For the last polar low, there were huge differences between the forecast skills of the two systems with the coupled system as the better one. The general performances of the systems are equal in skill up to +48h forecasts, while for the last 12h of the forecasts, the uncoupled system is slightly better compared to observations. A conclusion so far is that a coupled system shows promising results regarding polar low forecasts, but there are still some issues on the general performance of such a system.

References.


