High-resolution Wind Field Retrievals off the Norwegian Coast: Comparing ASAR Observations and MM5 Simulations

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ABSTRACT

An automatic system has been set up to routinely convert Envisat ASAR Wide Swath images to wind speed maps along the Norwegian coast and in the Barents Sea. The wind speed is calculated with the CMOD4-algorithm, taking wind direction input from the 0.5 degree resolution model of the Global Forecasting System (GFS) of the National Centers for Environmental Prediction (NCEP). The system has been running stably for several months, provinding wind fields at 500 m resolution as quickly as 3-9 hours after satellite aquisition. A wide range of atmospheric boundary layer wind features have been observed. An offshore wind front observed with ASAR is nicely reproduced by the mesoscale model MM5 with 9 km horizontal resolution. By reducing the horisontal resolution to 1 km, MM5 is also able to reproduce the SAR-observed wind jets coming out the fjords in Northern Norway.

1 INTRODUCTION

Global weather forecasts have today a resolution of about 25 kilometres, and variations at smaller scales are thus not precisely described. More detailed forecasts are, however, possible on regional to local scales at a shorter time scale by using non-hydrostatic mesoscale numerical models. Such detailed forecasts, of wind in particular, are of large interest to the general public, and also to commercial users. A major challenge of these forecasts is to initialise the model with a reliable description of the initial state of wind and other meteorological parameters.

Synthetic Aperture Radars (SARs), such as the ASAR sensor onboard Envisat, are able to derive the wind field with a resolution of about 1 km. However, unlike scatterometers, in many cases the SAR cannot retrieve both the wind speed and direction. Either the wind direction must be known a priori before the wind speed can be estimated (which is most common), or vice verca. Thus we see a large potential for exploiting the synergy of SAR and mesoscale atmospheric models. The models may provide the SAR with an initial value for the wind direction, and the high resolution SAR retrieved wind speed may serve the purposes of both validation and initialising of the numerical models.

We have set up a system to retrieve wind speed from Envisat ASAR Wide Swath images, taking wind directional input from the numerical model of the Global Forecasting System (GFS) of the National Centers for Environmental Prediction (NCEP). This system is described in the next section. Section 3 shows a comparison of the output with output from simulations with MM5 [1]. Conclusions and prospects for future work are given in section 4.

2 AUTOMATED WIND SPEED RETRIEVAL FROM ENVISAT ASAR

ESA are now archiving data from Envisat in near real time on http-servers. There are two web-servers, corresponding to receiving stations in Esrin, Italy and Kiruna, Sweden. ASAR imagery are available as quickly as three hours after aquisition, and are removed from the server after about one week (thus a «rolling archive»). At the Nansen Center in Bergen (NERSC), computer programs have been made to download scenes for specific regions for further processing. From the Rolling Archive web servers, a list of available filenames can be downloaded with the free command-line software cURL. The filenames contains, among other things, the start and end time of aquisition, as well as the absolute orbit number. From this information, as well as some parameteres related to the Envisat-orbit, the position of Envisat as well as the boundaries of the acquired image product at time of aquisition can be calculated. Imagery within a certain predefined area of interest is then fully downloaded, again using the cURL software. For this project, only Wide Swath imagery is used, due to its wide geographical coverage. Moreover, the scenes are calibrated, using auxiliary calibration data also disseminated by ESA via internet. Finally, the data is reduced into pixels sizes of about 500 metres to remove speckle and to make further processing significantly faster.

Since the wind speed algorithm to be used (CMOD4 [2]) takes vertically polarized data as input, horizontally polarized data is converted into vertical polarized data using a semi-empirical formula from [3].

Before retrieval of wind speed, land is masked from the ASAR scene by using external data from the GTOPO30-dataset. Sea ice is then masked away using ice concentration data available from the University of Bremen [4]. This data is based on AMSR-E passive microwaves, and is available via internet at 12.5 km resolution on daily basis with a delay of one day.

The calibrated ASAR-data is converted into wind speed using the CMOD-4 algorithm. This algorithm takes as additional input information on the wind direction relative to the satellite look direction. While this information can often be retrieved directly from wind-streaks in the SAR-image by using FFT, this method is difficult to implement in an automated operational scheme since wind streaks are not always visible. Thus we use wind direction data from the numerical model of the NCEP Global Forecast System (GFS) in our operational scheme. These data are available on the internet in near real time at a 0.5 degree pixel size globally at a 3 hour time interval. Thus the maximum timing difference between the SAR-scene and the wind direction data is 1.5 hours. The wind direction data is interpolated to every pixel in the reduced resolution ASAR WSM images. Finally, the wind speed is calculated using the CMOD-4 algorithm. The total local processing from uncalibrated ASAR image format into wind speed takes about 10 minutes on a local Linux server. The final wind speed products are avaliable typically 3-9 hours after aquisition.

3 SOME EXAMPLES OF WIND FIELDS

Figure 1 shows an example of a calibrated Envisat ASAR WSM image at reduced resolution, together with a final wind speed product. The wind direction from GFS (white arrows) is very close to the direction of the wind streaks seen in the SAR image, in particular in the northwest region. Thus the wind direction input seems to be very precise in this case, and the accuracy of the estimated wind speed is expected to be about 1-2 m/s [5].

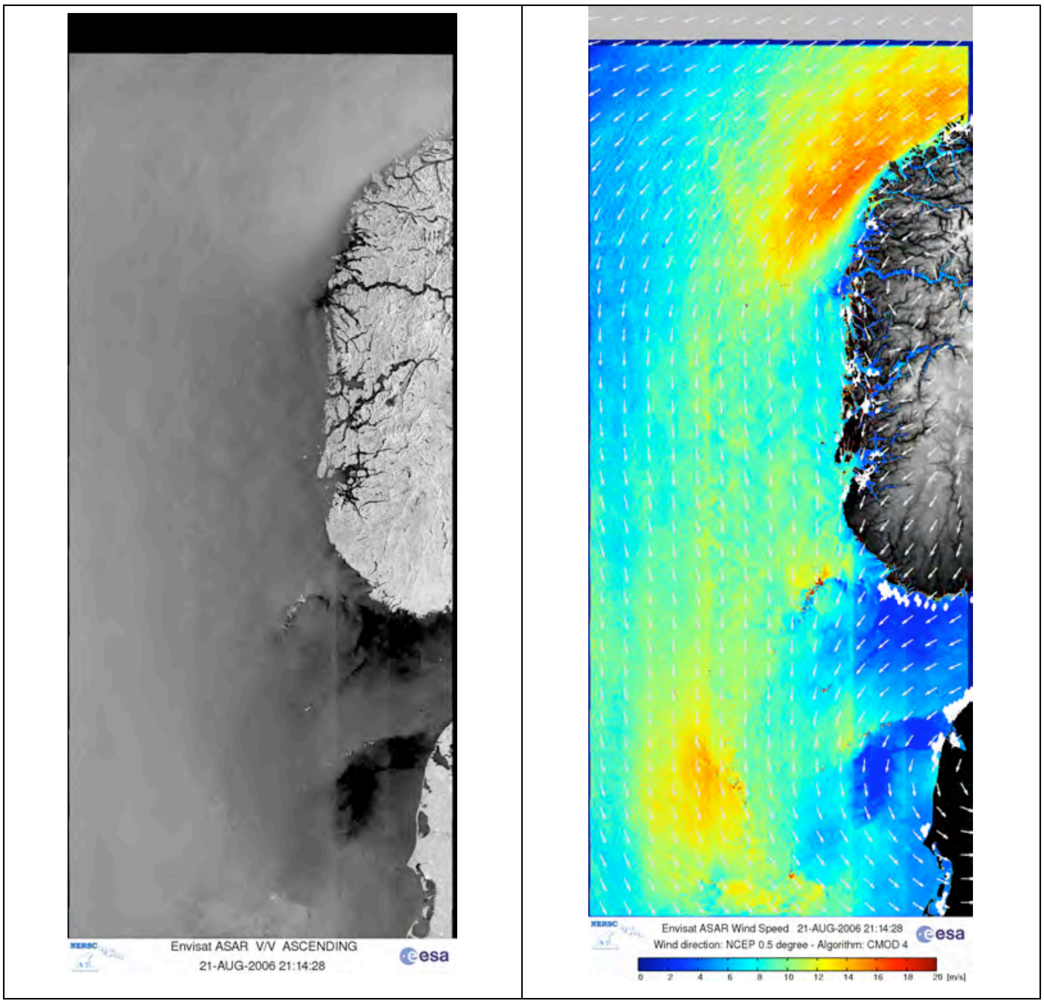

Figure 1: ASAR Wide Swath image of South-western Norway and the North Sea (left) aquired 14:28 UTC on 21 August 2006. Right image is wind speed derived from the ASAR image and wind direction input from NCEP GFS model (white arrows) using the CMOD4-algorithm.

Figure 2 shows another case where sharp variations in wind directions are seen in the SAR-image whereas the model wind direction is changing more smoothly. Given the obviously wrong wind direction input, the output wind speed will also have large errors.

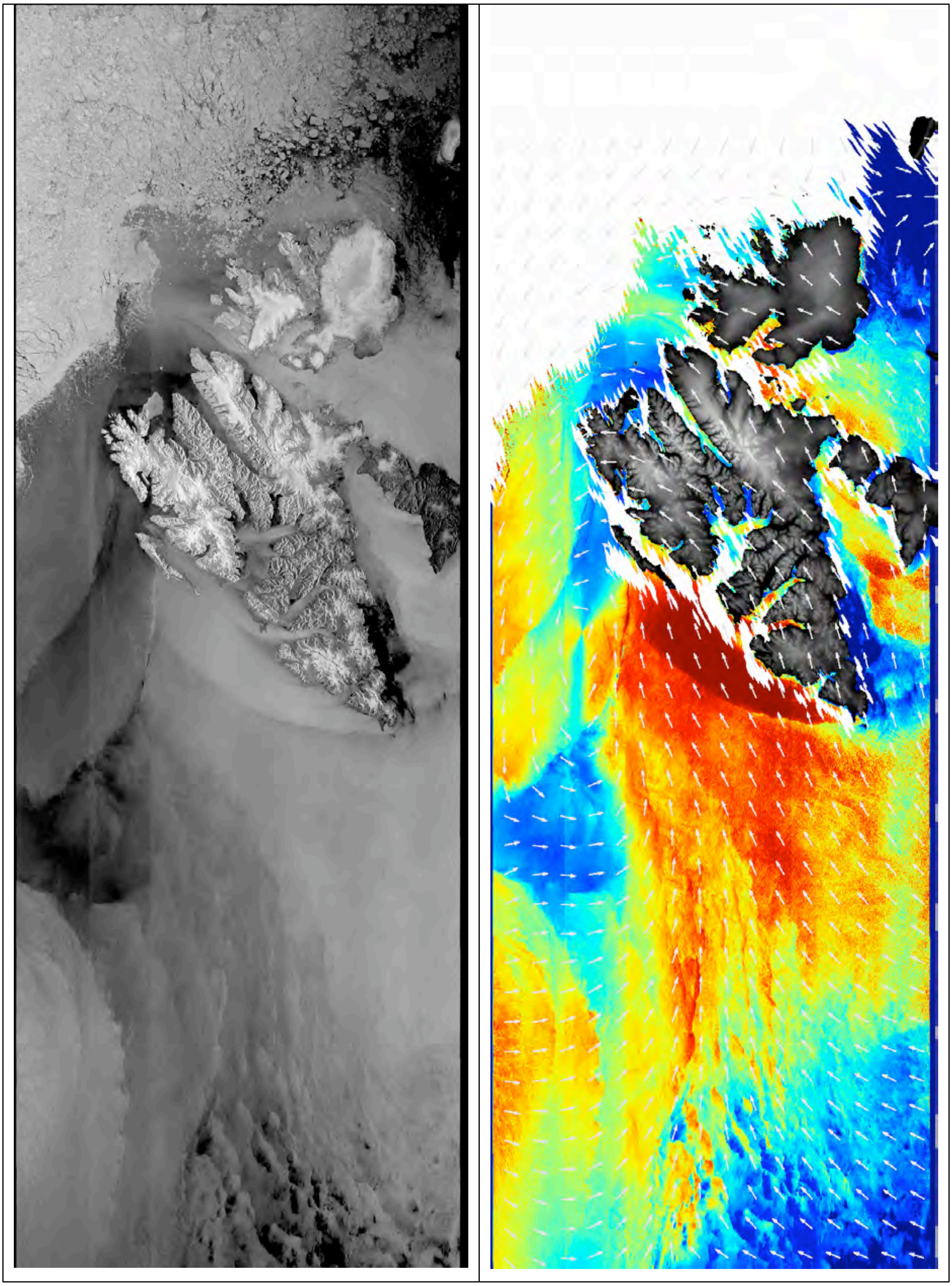

Figure 2: Same as for Figure 1, but the image is from an area around Spitzbergen at 10:36 UTC 6 October 2006. Ice is masked with white, using AMSR-E ice concentration data available from the University of Bermen.

One of the advantages of an automated near-real-time processing algorithm as described above is that the wind speed products are available very quickly, thus making them of practical interest for both forecast and monitoring operations. A second advantage is that generation of a large set of high resolution wind fields makes it easier to identify both rare and interesting situations, as well as phenomena that seem to reoccur frequently. As an example of the latter, it is observed by studying almost 100 images around Svalbard, that lee waves are frequent east of Spitzbergen when the wind is from the west, whereas for easterly winds, fjord jets instead of lee waves are seen to the west of Spitzbergen. Other observed persistent phenomena are small regions with frequent high winds (jets) on the north-west coasts of both Spitzbergen and Finnmark (northern part of Norway).

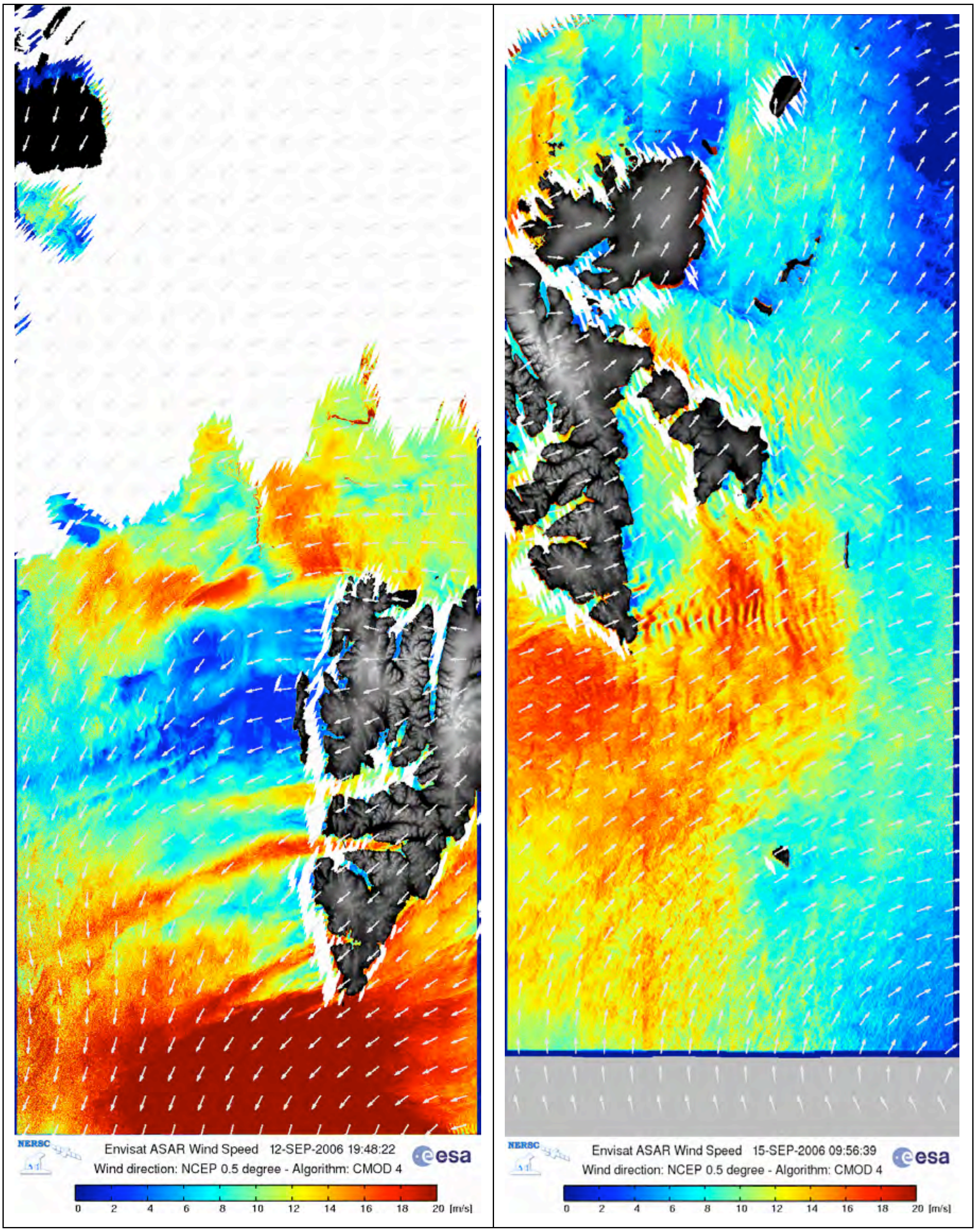

Figure 3: ASAR-derived wind speed for typical situations with easterly (left) and westerly (right) winds over Spitzbergen.

3.1 Comparison with MM5-Simulations

When comparing SAR-retrieved wind with a numerical model, the quantitative difference may be calculated by comparing the corresponding pixels closest in space. However, such a quantitative comparison has clear weaknesses; if, for example, a wind front is seen on both the SAR- and the model fields, but is shifted in space, the qualitative measure will give poor result even if the shape of the front and wind speeds and directions around the front are very much similar. Thus qualitative comparisons may be more valuable if one wish to understand either the shortcomings of the model setup or the physics of the observed wind pattern itself.

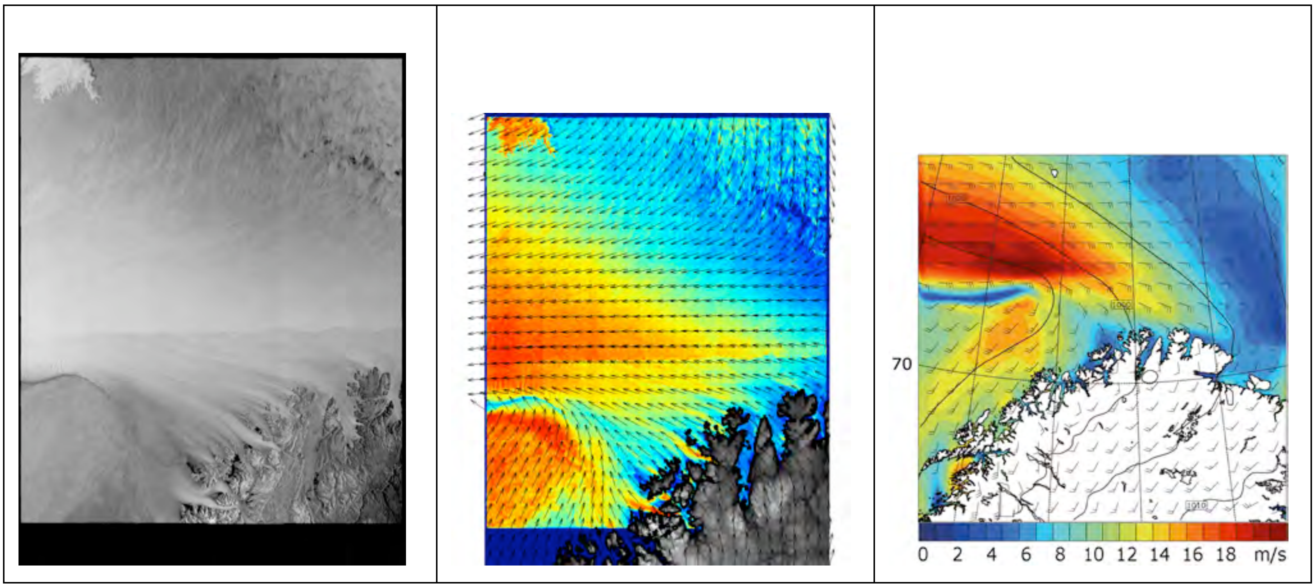

Figure 4: ASAR Wide Swath image off the coast of Northern Norway at 09:21 UTC on 15 February 2006 (left). Middle image shows wind speed estimated from the SAR image with CMOD-4, taking wind directions from the global forecast model of the European Centre for Medium-Range Weather Forecasts (black arrows). Right image shows wind field at 9 UTC the same day modelled with MM5 at a 9 km resolution.

Figure 4 shows an example of a sharp front off the coast of Northern Norway, both observed with ASAR and modelled with MM5. For the SAR-retrieved wind field (middle figure), the wind directions are in this case taken from the 0.25 degree resolution model of the European Centre for Medium-Range Weather Forecasts (ECMWF). When compared with the raw ASAR backscatter image (left) the turning of the wind seems to be very well modelled, however the front seems to be shifted slightly southwards. The estimated wind speed is is only about 5 m/s in the narrow region where the wind is turning, but is about 13-18 m/s only a few kilometres to the sides. The MM5-simulated wind field (right part of the figure) is seen to match the SAR-observations quite well. Both the location and the shape of the front is very much similar, except that the region of low wind speed seems more narrow on the SAR-image. Also quantitatively the wind fields are in close correspondence, giving credit to both the SAR wind speed retrieval algorithm and the MM5-model setup. On the SAR-retrieved wind field one can see narrow jets of high wind speed out the fjords in the lower, middle part of the image. These jets are visible 200 km out from the coast, and give changes in wind speed from 5 to 18 m/s over only a few kilometers when travelling in the cross-jet direction. These jets are not clearly visible at the shown MM5-output. However, when increasing the MM5 resolution from 9 to 1 km, fjord jets which are at least qualitatively similar to the SAR-jets become visible (figure not shown here; see [6] for a discussion of this same case from a modelling point of view). Thus the SAR-retrieved wind gives aid to determining which model resolution is needed to resolve various meso- or local scale wind phenomena.

4 CONCLUSIONS AND FURTHER WORK

An automated system to download and process Envisat ASAR Wide Swath imagery into wind speed has been set up at the Nansen Center in Bergen, Norway. The system has for several months provided a good coverage in both space and time of high resolution (~500 metres) wind fields. The finished SAR-derived wind products are available typically only 3-9 hours after satellite aquisition, thus sufficiently fast for many forecasting and monitoring operations. All in all it has been demonstrated that SAR data is today well suited for operational services such as offshore monitoring and forecasting. Mass production of SAR-derived wind fields are also of great value for scientific investigations. An example for the case of the Norwegian coast is the influence of fjord jets on the variation of the meandering Norwegian Coastal Current, a topic to be further investigated in the near future.

The SAR derived wind fields compare well both qualitatively and quantitatively with wind output from the high resolution (1-9 km) model MM5. A sharp wind front offshore is nicely reproduced by MM5 with a resolution of 9 km. To reproduce the SAR-observed wind jets in the fjords of Northern Norway, a resolution of 1 km for the MM5-simulations is seen to be necessary. Thus the SAR derived wind fields are highly variable for validation of such high resolution wind modelling.

By studying several hundred SAR-derived wind fields, some frequently reoccuring wind patterns are observed at specific locations related to near shore topography in Northern Norway and in Spitzbergen. Future work will include making a climatology of the SAR-derived wind speeds to formalise such findings.

Future work will also be conducted to validate both the SAR-derived and the MM5-modelled wind fields against in situ measurements. Both synoptic stations along the coast and on weather ships will be used, as well as available measurements from near future in situ campaigns.

ACKNOWLEDGMENTS

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