USE OF SEAWINDS FOR WEATHER FORECASTING

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ABSTRACT

Scatterometers provide accurate and spatially consistent near-surface wind information. Hardware permitting, there is a continuous series of scatterometers with at times ideal coverage of the ocean surface wind in the coming two decades. ERS scatterometer observations have proven important for the forecasting of dynamical weather, such as tropical cyclones. In recent years, SeaWinds scatterometer measurements from QuikScat have become available. SeaWinds on QuikScat provides great coverage over the oceans. Quality monitoring, rain contamination, wind direction noise characteristics, and wind direction ambiguity selection are being investigated, now permitting routine and successful use in weather forecasting. The methodology developed for the successful application and assimilation of ERS winds is being generalised to include the newer scatterometer concepts, such as SeaWinds, as described in this paper. Moreover, some issues related to the use of the scatterometer winds in nowcasting, short range forecasting, and other applications are mentioned. The EUMETSAT Satellite Application Facilities (SAF) facilitates much of the development described in this paper.

1. Introduction

ERS scatterometer winds have proven to be very useful for the forecasting of dynamic weather (*Isaksen and Stoffelen*, 2000). Increased coverage, such as from tandem ERS-1 and ERS-2 measurements, clearly improve the forecasts of extreme events (e.g., *Stoffelen and Beukering*, 1998; *Le Meur et al*, 1997). Improved coverage from the Ku-band SeaWinds scatterometers has thus great potential (*Atlas and Hoffman*, 2000). After the development of improved data characterisation and assimilation procedures, operational assimilation of SeaWinds at KNMI, ECMWF, and NCEP is a fact. Moreover, shift meteorologists for nowcasting are using the data.

Severe storms that hit Europe often originate over the North Atlantic Ocean, where sparse meteorological observations are available. Consequently, the initial stage of severe storms is often poorly analysed and their development poorly predicted (*ESA*, 1999, *WMO*, 2000) as illustrated in figure 1. As a result, occasional devastating ocean or coastal wind and wave conditions remain a main challenge for NWP. The SeaWinds data coverage is such that developing storms are likely hit, thus depicting their position and amplitude. Moreover, the near-surface wind conditions drive the ocean circulation that in turn plays a major role in the climate system and in ocean life (e.g., fishery).

Figure 2 presents an example, showing the high spatial resolution in the QuikScat scatterometer winds, and the additional information content as compared to a NWP first guess. In this paper we discuss the pros and cons in the use of scatterometer data in weather applications.

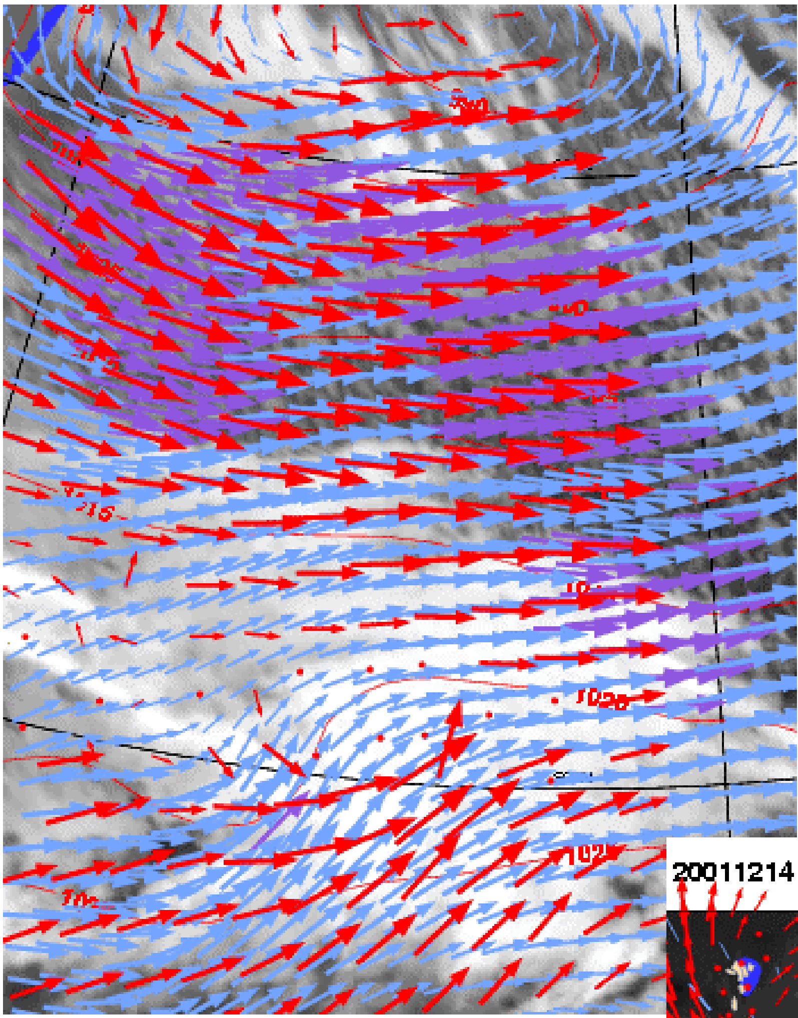

Figure 1: KNMI develops SeaWinds products and procedures for use in numerical and synoptic weather forecasting. Our emphasis lies on noise reduction, Quality Control, Quality Monitoring, and presentation. Link: www.knmi.nl/scatterometerThe plot shows a developing storm to the southwest of Ireland not captured in location and phase by the HIRLAM forecast model, but well depicted by QuikScat.
Legend:

SeaWinds KNMI HIRLAM model wind

METEOSAT IR cloud image

10 m/s

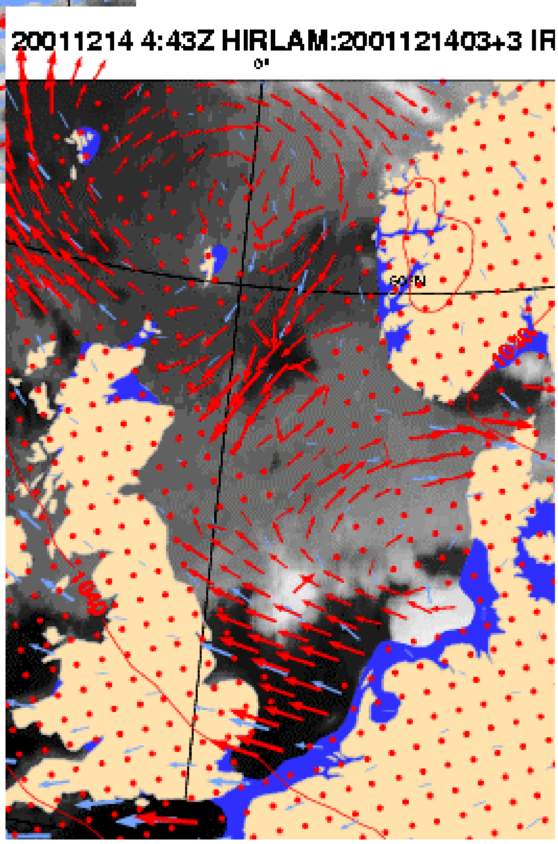

Figure 2: Legend as figure 1, but for a case with a small-scale development in the North Sea and at 25-km resolution. Numerical Weather Prediction models, such as HIRLAM, poorly forecast the jet pointing from the Norwegian coast towards Scotland. However, the jet resulted later in the day in a small-scale low in the middle of the North Sea causing unexpected rain and wind. Due to the generally cloudy conditions, the development was rather difficult to judge from geostationary satellite images. Oil platform and other conventional observations did also not provide much early evidence of the situation and development. SeaWinds provides a coverage that permits the routine and operational use by shift meteorologists.

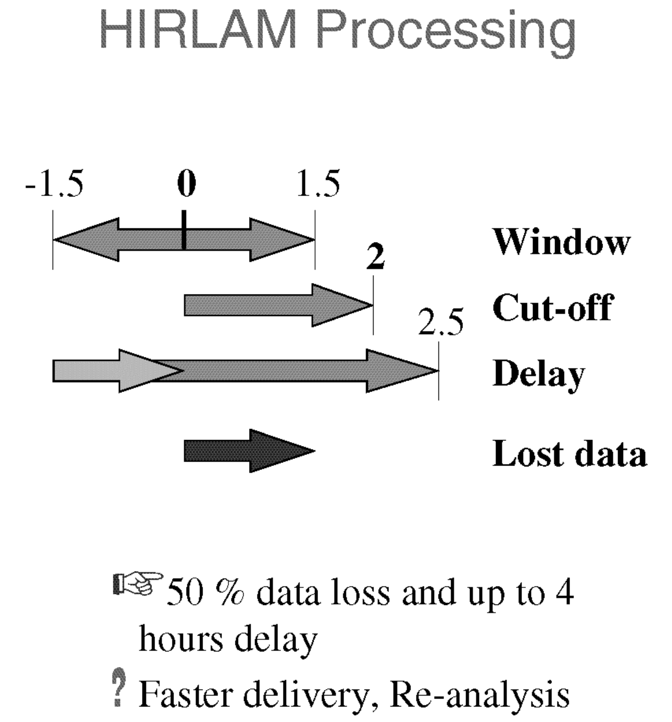

Figure 3: Timeliness of polar satellite observations. In the operational HIRLAM processing at KNMI a 3-hour assimilation window is used (top). The analysis is run after 30 minutes implying a 2-hour cut-off with respect to the processing window center time (second row). For a delay of 2.5 hours of the orbit satellite data, HIRLAM would generally use 50% of the data (as for SeaWinds). Only in case of a large beneficial impact of the data, data assimilation centers would consider a new-analysis in order to provide a better background for the next analysis cycle. Direct read-out facilities at satellite level would be most useful to facilitate the effective use of the high-resolution scatterometer information.

2. Timeliness

Scatterometers are flown in polar orbits with ground link once per orbit or about 100 minutes. As such, scatterometer winds are delivered orbit-by-orbit within 3 hours.

However, for weather forecasting high spatial resolution observations are particularly relevant on the short time scales. Be it rapid cyclogenesis (see figure 1) or sub-synoptic scale developments (figure 2), observations need to be timely. Figure 3 presents an example from the HIRLAM data assimilation scheme at KNMI, where scatterometer data are available on average after 2.5 hours. The cut-off time is a trade-off between quality and timeliness. The longer the cut-off, the more observations are available, but the later the meteorologists can use the output NWP analyses and forecasts. Scatterometer observations are only one of the many data types available. The combination of cut-off time and scatterometer data availability for HIRLAM causes 50% of the data to be lost, which is a great pity since HIRLAM output is used for short range forecasting.

Ground link capability over the full 100-minute orbit is a costly affair. On the other hand, as explained above, most of the benefit of the high spatial resolution scatterometer winds is lost for weather forecasting, if this capability does not exist. Direct broadcast capability for scatterometer data should be developed for nowcasting applications.

To overcome the problem depicted in figure 3, one could consider re-analysis. A reanalysis with a long cut-off time would incorporate more observations, 50% more in the case presented here, and thus provide a better analysis and background field for the next analysis. As such, the quality of the next analysis may be somewhat improved. The procedure would mean that all analyses are performed twice. The analysis is the most expensive part of the NWP forecast suite, so re-analyses are not desirable.

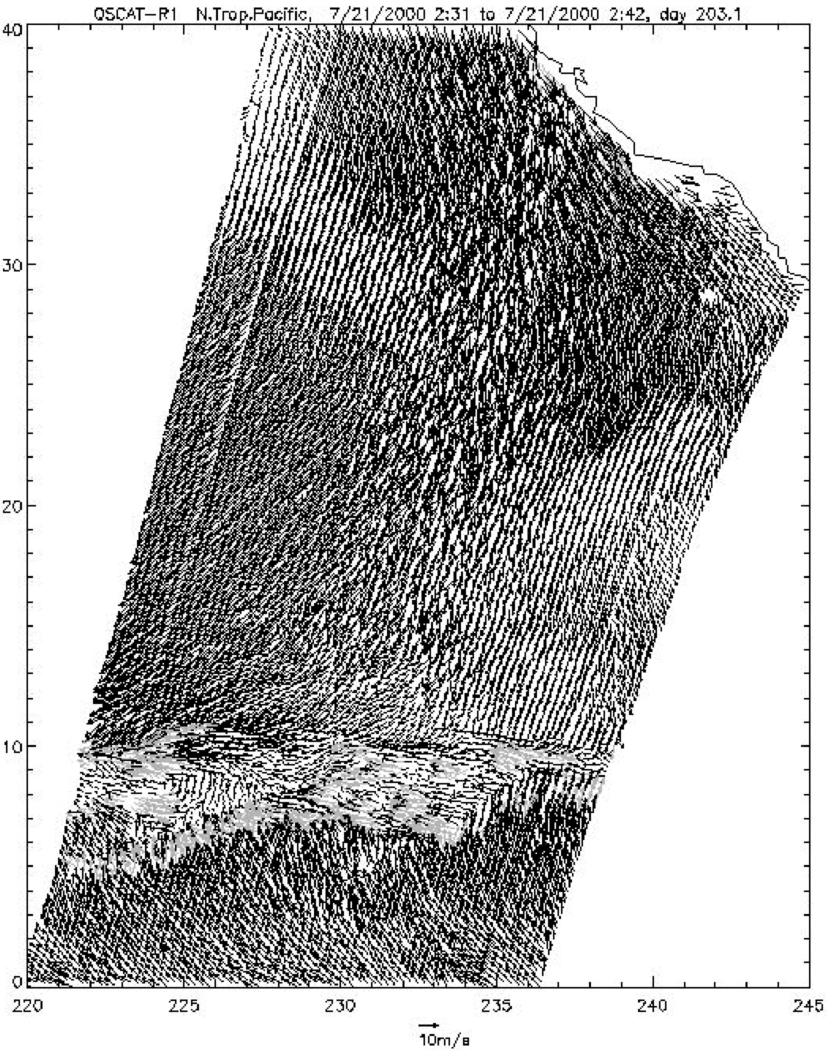

Figure 4: Sample archive SeaWinds product of JPL at 25-km resolution. A 1400-km wide central swath can be seen that is viewed by the inner and the outer beam of SeaWinds. Two outer swath strips of 200 km are visible that are viewed only by the outer beam. In the middle (nadir) region excessive noise is visible, which is due to the poorer azimuth sampling in this area. In a horizontal area at around 10N gray areas denote rain contamination as flagged by JPL (SeaWinds, 2002).

3. Satellite Application Facilities (SAF)

Both scatterometer research and development, and routine processing and monitoring are funded by EUMETSAT through the SAFs (EUMETSAT, 2002). More specifically, KNMI participates in the NWP SAF, the Ocean and Sea Ice (OSI) SAF, and the Climate (CM) SAF for these purposes.

In the context of these SAFs KNMI provides

- Tailor-made SeaWinds QC in order to avoid unrepresentative wind data (e.g. rain contaminated);
- Generic scatterometer backscatter data inversion;
- Procedure to average backscatter measurements in a resolution cell of varying size, in order to provide spatially representative and accurate winds to NWP models;
- Generic scatterometer cost function to cope with all kinds of scatterometer data;
- Routine processing and monitoring of wind and in the future surface stress;
- Web-based product presentation, and distribution by FTP; and
- Web-based monitoring reports.SAF activity is currently mainly focused on SeaWinds, although much of the algorithms and software are generically applicable for ERS scatterometer and ASCAT on METOP.

4. Use of SeaWinds

Figure 4 displays part of the SeaWinds swath as processed by JPL at 25 km. The figure clearly denotes different parts of the swath, and developments are ongoing to apply all these parts of the swath. The so-called sweet swath excludes the outer swath and the nadir region, and is the most uniquely determined and accurate part of the swath. The nadir (middle) region has the same amount of nadir views, but the views are closer together and as such provide less independent information on wind direction, leading to less unique and accurate winds, as may be noted from the figure. In the outer swath region only two azimuth views are available in a single radar polarization, which means that no residual information is available for the quality control (QC) of the resulting winds. This is problematic, since the measurements are affected seriously by rain.

Following similar methods in use for the QC of ERS scatterometer winds, KNMI developed a QC method for SeaWinds that rejects rain cases and cases with other geophysical interpretation problems. Differences with the JPL rain flag were investigated and a QC procedure for SeaWinds derived (Portabella and Stoffelen, 2002). We apply this procedure on the 25-km SeaWinds data prior to the wind inversion.

Inverted scatterometer winds are ambiguous. Ambiguity removal presents an intricate problem when NWP model background information of inferior quality is used. This is, if the background information consists of a 6-hour forecast, ambiguity removal appears usually not problematic, while, if it consists of a 24-hour forecast, serious ambiguity removal errors are discernible. In a data assimilation system that can accept ambiguous winds, the background wind will be fresh, and ambiguity removal errors can be minimized. Stoffelen (2000) presents a generic method for assimilating ambiguous scatterometer winds.

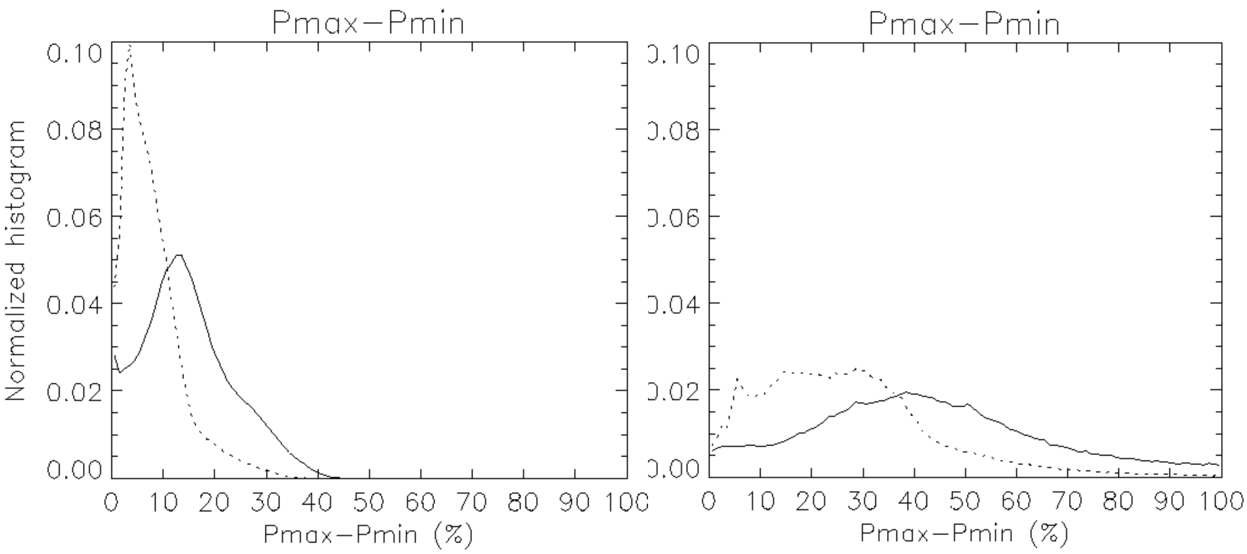

Figure 5: Probability density function of differences in probability of the highest and lowest probability SeaWinds solution for a 25-km wind-vector cell (WVC) (left) and a 100-km WVC (right). The solid line denotes sweet swath and the dotted line the nadir swath. The probability discrimination or uniqueness of the 100-km winds is much better than that of the 25-km winds; also, sweet swath is more unique than the nadir region (Portabella and Stoffelen, 2002).

It proves very difficult to assimilate sub-synoptic scale scatterometer wind information into NWP models. In fact, data thinning procedures are often employed leading to more beneficial impact of many observation data types. In line with this and in order to increase accuracy and uniqueness of the SeaWinds data we developed a method whereby SeaWinds backscatter information is averaged prior to its inversion. Figure 5 presents results of our work and demonstrates that the probability discrimination between the different ambiguous wind solutions of the 100-km winds is much better than that of the 25-km winds, where all 2-4 solutions tend to be of similar probability. Also, the sweet swath is more unique than the nadir region (see also Portabella and Stoffelen, 2002). The better uniqueness and quality of the 100-km winds provide a clear motivation to assimilate these winds.

For use in nowcasting, 100-km winds are less optimal. Often small-scale wind information in the coastal area is important for the local weather (as in figure 2). However, also in this case it is important that systematic effects as seen both in figures 2 and 4 are removed. Now that the 100-km processing and monitoring algorithms have been developed, KNMI starts to investigate processing at 50-km resolution, in particular to serve nowcasting and short-range weather forecasting purposes.

5. NWP Assimilation of Ambiguous Winds

Generally data assimilation systems constrain to a background or first guess field and to observations (e.g., *Lorenc*, 1988; and *Courtier et al*, 1998) in a minimisation problem of the objective function

$$J = J_b + J_o \tag{1}$$

where J_o is the observation cost function and J_b the background field cost term.

The observation term consists of a contribution from each observation and is related to the probability of a meteorological state, given the measurements. For scatterometer data we write (Stoffelen, 2000)

$$J_o^{SCAT} = \left(\frac{\prod_{i=1}^{N} K_i}{\sum_{i=1}^{N} K_i} \right)^{1/P} \tag{2}$$

where he uses P = 4 and after *Stoffelen and Anderson* (1997c) he redefines

$$K_i = \left[\left(\frac{u - u_i}{\varepsilon_u} \right)^2 + \left(\frac{v - v_i}{\varepsilon_v} \right)^2 - 2 \ln P_i \right]^P \tag{3}$$

with (u, v) the wind components and ε_u and ε_v their respective error estimates. P_i represents the relative probability of each solution i. Referring to figure 5, one can note that the righthandside term of equation 3 acts to penalize low probability solutions, and as such the uniqueness of the wind product will have an impact to improve the analysis. The 100-km averaged product is thus preferred for avoiding spatially correlated ambiguity removal errors. Figure 6 illustrates the effect of the righthandside term of equation 3.

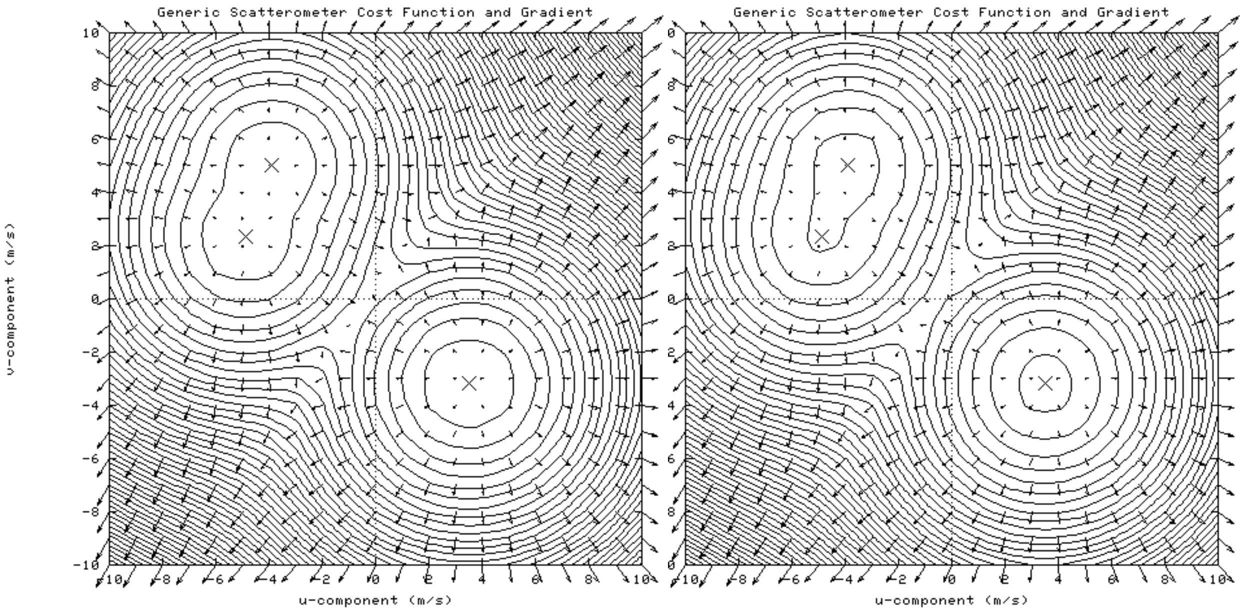

Figure 6 : Plot of the scatterometer cost function with solution probability not included (left) and appropriately included (right). The relative importance of a minimum is clearly affected by its probability.

Equation 3 can be used to allow variational quality control. In that case, one needs to add a solution with let us say $\varepsilon_s >> 100$ and P_i equal to the expected gross error rate. For the nadir and far swath parts this could be a way to use the winds, but with more stringent QC. Moreover, in the sweet swath a few remaining rain contaminated points may be rejected. This procedure is currently being investigated at KNMI.

Ambiguity removal (AR) selects the wind vector solution at each observation point in a way that results in a spatially and meteorologically consistent wind field. AR is required when the 1st rank skill is not 100%. For the 100-km SeaWinds product the rank 1 skill is about 90% facilitating the AR process. Thus, despite a substantial fraction of nodes with three or four solutions the AR does not seem complex, since the 2nd, 3rd, and 4th solutions are much less probable (see fig 5). With the cost function as specified above an implicit AR will be done in 3D-Var or 4D-Var. Moreover, KNMI developed a 2D-VAR for the real-time AR of ERS and SeaWinds scatterometer winds (*Stoffelen, Voorrips, and de Vries*, 2000).

6. Outlook

Scatterometers provide accurate and spatially consistent near-surface wind information. Hardware permitting, there is a continuous series of scatterometers with at times ideal coverage of the ocean surface wind in the coming two decades. In many data assimilation systems, ERS scatterometer observations have proven important for the forecasting of dynamical weather, such as tropical cyclones (*Isaksen and Stoffelen*, 2000). For example, figure 7 shows a case where 4D-Var improves on the forecast of a tropical cyclone, but where the addition of ERS data provides a much more accurate day-5 forecast of the system.

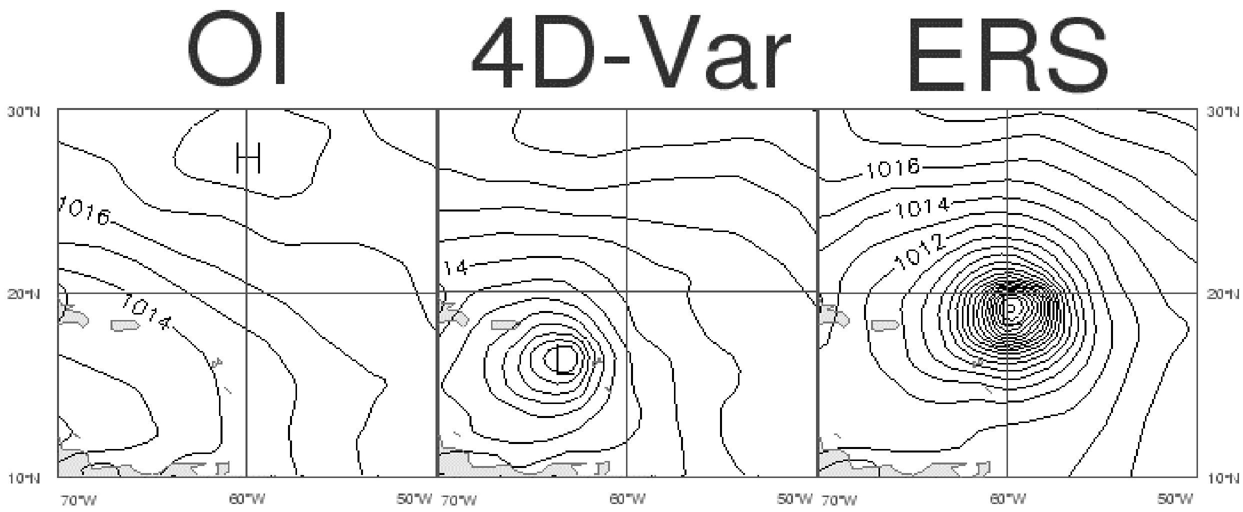

Figure 6 5-day forecasts of tropical cyclone Luis in the Atlantic for 6 September 1995 12 UTC after, respectively from left to right, OI assimilation (operations without ERS), 4D-Var without scatterometer winds, and 4D-Var with ERS scatterometer wind assimilation. The analysis showed the storm with the same vigour as the 5-day 4D-Var ERS forecast, but about 3 degrees to the West of the forecast position. In many cases medium-range forecast tropical cyclone conditions improve with scatterometer data (Isaksen and Stoffelen, 2000).

The SAFs provide support for the application of scatterometer data for weather forecasting and climate studies. Both scatterometer research and development, and routine processing and monitoring are pursued

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