TECHNICAL MEMORANDUM

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ERS-scatterometer wind data impact on ECMWF's tropical cyclone forecasts

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Abstract

This paper describes the positive impact of ERS scatterometer data on tropical cyclone analyses and forecasts at European Centre for Medium-range Weather Forecasts (ECMWF). ERS-scatterometer data is especially valuable because they are available in the data sparse genesis regions of tropical cyclones, and because they are available in cloudy and rainy conditions. In November 1997, ECMWF introduced a four-dimensional variational assimilation system (4D-Var) in operational use. This system benefits from a better utilization of ERS-scatterometer wind data. ECMWF is using ERS-2 scatterometer wind data in the daily operational assimilation system. In order to understand and investigate the impact of ERS-scatterometer wind data, assimilations with and without use of scatterometer data has been performed for the most intense part of the 1995 Atlantic hurricane season. A comparison with the 1995 operational ECMWF optimum interpolation (OI) assimilation system's performance has also been done. Both intensity and positional errors of tropical cyclones are investigated for analyses and forecasts. The 4D-Var assimilation system shows great improvements compared to the previous OI assimilation system, the best results are obtained when ERS-scatterometer data are used in 4D-Var.

1 Introduction

ECMWF has since January 1996 used scatterometer winds from the European Space Agency's ERS satellites in the operational assimilation system. ERS microwave backscatter measurements are not affected by clouds and precipitation, allowing availability of near surface winds in the vicinity of tropical cyclones (TCs). Tomassini *et al.* (1998) describe scatterometer impact experiments with a three-dimensional variational data assimilation system, 3D-Var, at ECMWF, showing beneficial impact. The currently operational four-dimensional variational data assimilation system, 4D-Var (Rabier *et al.* 2000), is able to better interpolate the scatterometer data in space and time. This paper describes an impact study of ERS scatterometer winds on the analyses and forecasts of TCs in August and September 1995, using the ECMWF Optimum Interpolation (OI) and the 4D-Var data assimilation systems. OI was operational at ECMWF during the 1995 hurricane season investigated here. Improvements are seen for the whole range of 4D-Var experiments investigated: analyses and up to five-day forecasts. Unprecedented realistic five-day forecasts of tropical cyclones, and very favourable intercomparisons with other tropical cyclone forecasting centers' predictions were obtained.

In section 2, the data assimilation methodology used in Numerical Weather Prediction (NWP) is outlined, with special emphasis on the use of scatterometer data. Section 3 describes the experiments on the assimilation of scatterometer winds, and in section 4 their results are presented. After discussion in section 5 of some remaining problems, the main conclusions of the paper are presented.

2 Data Assimilation

All data assimilation system used at at ECMWF have been and are based on the physical laws that relate e.g. the balance between mass and wind to distribute the information from observations. In the assimilation system, these relations are described by statistically determined so-called structure functions that represent the typical spatial error structure of the background model field (see (Daley 1991) and (Hollingsworth and Lönnberg 1986). There are extreme events where this method is not optimal. The dynamics of TCs, as an example, is generally very different from the normal circulation in the tropics, so in a statistical method like this TCs are not represented properly because they occur seldom and have a limited geographical extent. In an assimilation system the background field is used to represent all prior information on the state of the atmosphere. This is typically represented by a short-range (six-hour) forecast which is updated by adding information from observational data.

Optimum Interpolation assimilation

Some of the pioneering assimilations of ERS scatterometer winds were performed by Bell (1994) at United Kingdom's Meteorological Office and by Hoffman (1993) in ECMWF's OI system. ECMWF used the OI assimilation system until January 1996 when the 3D-Var became operational. The OI system was designed in the early 1980'ies at ECMWF (Lorenc (1986). It can be described briefly as a six hour intermittent assimilation method where up to approximately 500 observational datum within a geographical region are used in a static multivariate statistical way (e.g. wind increments can modify pressure gradients) to calculate analysis increments. The statistically determined correlation structures between different observations result in barotropic increments.

In (Stoffelen and Anderson 1997a) it is described how ERS scatterometer data is used in the OI system. In a preprocessing step two ambiguous winds are retrieved at each node. An ambiguity removal filter subsequently selects a unique wind vector, partly based on background model wind information. This selected wind is then used in the assimilation. It is very important that only accurate and representative data enter the data assimilation procedure. To this end, the scatterometer data are quality controlled (QC) by checking for inconsistencies in the messages, checking the distance to the functional surface that represents wind observations, eliminating any possible land or ice contamination, rejecting wind speeds above 25 m/s, and by performing a tight monitoring of all scatterometer data in batches of 6 hours (Stoffelen and Anderson 1997c) and (Le Meur *et al.* 1997). Winds calculated using the CMOD4 transfer function (Stoffelen and Anderson 1997b) are usually too low compared to ECMWF model winds in high wind cases. A sufficient number of collocations between CMOD4 winds and ECMWF model winds are available to generate a reliable speed bias correction of CMOD4 winds up to 25 m/s (Le Meur *et al.* 1997), where the limit previously was 20 m/s. This increases the use of ERS data near TCs, even though 25 m/s is still far below maximum winds near TCs.

In operations, ECMWF used OI during the 1995 hurricane season. The operational OI did not use ERS scatterometer data. In OI the difference between background and analysis is entirely determined by the structure functions. The vertical background error structures have a limited extent in the troposphere (Hollingsworth and Lönnberg 1986), so near-surface wind data will only affect the analysis in the lower troposphere. The forecast following the analysis may then treat this information as noise, if it is inconsistent with the upper troposphere flow, where often no observations are available in the tropics to support the surface observations.

Variational assimilation

In January 1996 a three-dimensional variational assimilation system (Courtier *et al.* 1998) was introduced operationally at ECMWF. The Variational systems minimize a cost function which has terms representing departures from observations, contraints that force meteorologically consistent increments and a term that penalizes unwanted gravity waves. The main advantage of 3D-Var system over OI is the ability to calculate observation departures in observation space, e.g. radiance space, instead of the OI requirement to convert observational quantities to model prognostic variables. Another advantage is the flexibility in the design of the cost function, where additional terms can be added as required.

A main advantage for ERS scatterometer winds in 3D-Var/4D-Var is the use of a cost function where both ambiguous winds are presented to the analysis (Stoffelen and Anderson 1997a). The analysis then implicitly performs the ambiguity removal in a dynamical way based on the model wind field, influenced by information from adjacent observations.

In ECMWF's 4D-Var assimilation system (Rabier *et al.* 2000), operational since November 1997, the best possible analysis is sought over a six-hour period, using the meteorological observations in this time window, the background field at the start of the time window, and a forecast model integration over the six-hour period. The iterative variational procedure of the analysis computations will gradually make the forecast fields in the six-hour period more and more consistent with the available observations, with the possibility to use some extreme but correct observations that would be rejected in a static system. The 4D-Var system is also able to propagate scatterometer wind information more properly in the vertical (possibility of baroclinic increments Thépaut *et al.* 1989) compared to the OI and 3D-Var assimilation systems. 4D-Var uses the observations at the proper time, which is very beneficial for scatterometer data. In OI and 3D-Var data is used at synoptic times, which can be off by up to three hours. The advantage of 4D-Var is most pronounced when meteorologically active dynamical systems are present. One example being tropical cyclones, where the use of the forecast model dynamics may result in more intense and correct background updates in the presence of spatially consistent data.

Technically the scatterometer data is used in 4D-Var similarly to the use in 3D-Var (Tomassini *et al.* 1998), i.e. the ambiguity removal is performed as part of the assimilation . The other QC elements are performed like in OI and 3D-Var, as described above.

In the incremental 4D-Var system at ECMWF (Courtier *et al.* 1994) the forecasts and comparisons of observed values with model background fields are performed at high resolution (approximately 100 km), whereas the resolution of the variational assimilation part is only around 250 km. Therefore, scatterometer winds are thinned to a resolution of 100 km before assimilation. It is shown later that the data, despite the thinning, are still valuable in the analyses of TCs. Stoffelen and van Beukering (1997) have shown that slight improvements of extra-tropical analyses can be obtained by averaging (instead of just thinning) the scatterometer winds at 100 km resolution, but similar studies of TCs have not yet been performed.

3 Experiments with 4D-Var

The aim of these experiments have been to investigate the treatment of TCs in ECMWF's 4D-Var assimilation system with and without ERS scatterometer data, and compare this with the performance of the 1995 operational OI system. The 15-day period in August/September 1995 used for this investigation had very intense TC activity. The synoptic description and the positions and intensities of the TCs are described in the reports (Avila 1995; Rappaport 1995; Lawrence 1996) from the National Hurricane Center at National Center for Environmental Prediction (NCEP). The positions and intensities are based on reconnaissance flight data, ship and synop observations, in addition to information from satellite images. Due to their proximity to the North American continent, the TCs discussed here were well monitored. During the period three hurricanes (Humberto, Iris, and Luis) and the tropical storm Karen were active in the Atlantic. TCs Humberto, Karen and Luis originated from the region near the Cape Verde Islands, which is most common for Atlantic hurricanes. These types of hurricanes can usually only be identified in their early life by ERS scatterometer observations, due to the very sparse coverage of conventional data in this region. Early identification is of vital importance for medium-range TC forecasting for the Caribbean and USA. Humberto and Iris were category 2 storms reaching 95 knots average maximum intensity. During 24th and 25th August 1995 Humberto and Iris interacted, causing Iris to move off its original westward track. Humberto was intensified, whereas Iris weakened during the 22-26 August 1999 due to the interaction. Karen only reached tropical storm strength, but it had important influence on TC Iris; it was 'swallowed' by Iris on 3 September 1995. This gave Iris new energy and helped it to develop into an intense extra-tropical cyclone causing trouble in Europe. Luis was a large category 4 hurricane (maximum average winds of 120 knots) that caused large human and economical damage in the Caribbean. In its extra-tropical life, it caused problems on Newfoundland and Greenland. The 24-72 hour track forecasts for Humberto (Avila 1995), Iris (Rappaport 1995) and Karen (Mayfield 1995)) from the range of operational hurricane forecasting models were similar to the 10 year average. The track forecasts of Luis (Lawrence 1996) were better than the 10 year average. Most models had problems handling the events where the TCs interacted.

Assimilation experiments over the 15-day period in August/September 1995 were performed with the 4D-Var system. Independent assimilation experiments using (SCAT) and not using (NoSCAT) ERS-1 scatterometer winds were performed. The only difference between SCAT and NoSCAT assimilation suites were the use of ERS-1 scatterometer data. This allowed a genuine investigation of the impact of scatterometer data in 4D-Var. For each of the 15 days a 12 UTC forecast was run from respectively the NoSCAT and SCAT analyses. A comparison was done with the original operational OI assimilation analyses and forecasts. As mentioned above, this system did not use ERS scatterometer data.

4 Results

Figure 1 features TC Iris at 0 UTC on 24 August 1995 (observed position from NHC is marked by a filled circle). Panel a) shows the background model Mean Sea Level (MSL) pressure field, panel b) the MSL analysis and winds at the ERS nodes used, and panel c) the analysis increments (analysis - background model), i.e. the impact of the scatterometer data on the analysis. For clarity, only unambiguous winds closest to the background field are shown in panel b). The analysis is, as explained in section 3, supplied with both ambiguities. This is a good example of how 4D-Var improves the analyzed position and intensity of the TC. The ERS scatterometer data has clearly been used properly to intensify Iris. A few cloud motion satellite winds and some measurements from one aircraft, all above 200 hPa, were the only additional conventional observations in the figure 1 area, so the excellent analysis of Iris is clearly due to ERS scatterometer data. Track and intensity of Iris in the forecast based on this analysis is also improved (not shown).

Although ERS winds in general clearly impact the data assimilation cycle, it is usually more difficult to demonstrate medium-range forecast impact. Generally it has been seen that 4D-Var analysis increments from ERS survive and help to improve forecasts to a larger extent than OI and 3D-Var (Isaksen 1997). Figure 2 shows an example of that from 12 UTC 26 Aug 1995. In panel c) the 5-day 4D-Var SCAT forecast is shown. It is based on an analysis (not shown) where the hurricane Iris is intensified and the structure of the TC has been better identified due to the ERS scatterometer data. Hurricanes Iris and Luis are easy to identify close to their observed position (marked with a filled circle and initial letter). Karen is also visible in the correct position, correctly, much weaker than the other two TCs. Comparing panel b) NoSCAT with panel c) SCAT, it is evident that the intensity increase and smaller positional error of hurricane Iris in the forecast is triggered by the scatterometer winds. Panel a) shows the inability of the OI system to capture the TCs properly. The verifying analysis of the TCs are shown in figure 3. The predicted 5-day SCAT-forecast positions of both Luis and Iris are very good. The intensity of Iris is too weak, but it is clearly identifiable, whereas Luis is intensified correctly.

Improvements in the forecasts are generally found even in cases where ERS-scatterometer data only is available on the fringe of the hurricane, i.e. several hundred kilometers away from the center. It supports the general view that the development and track of a hurricane is to a large extent determined by a proper description of the convergent inflow from the surroundings (Gray 1998).

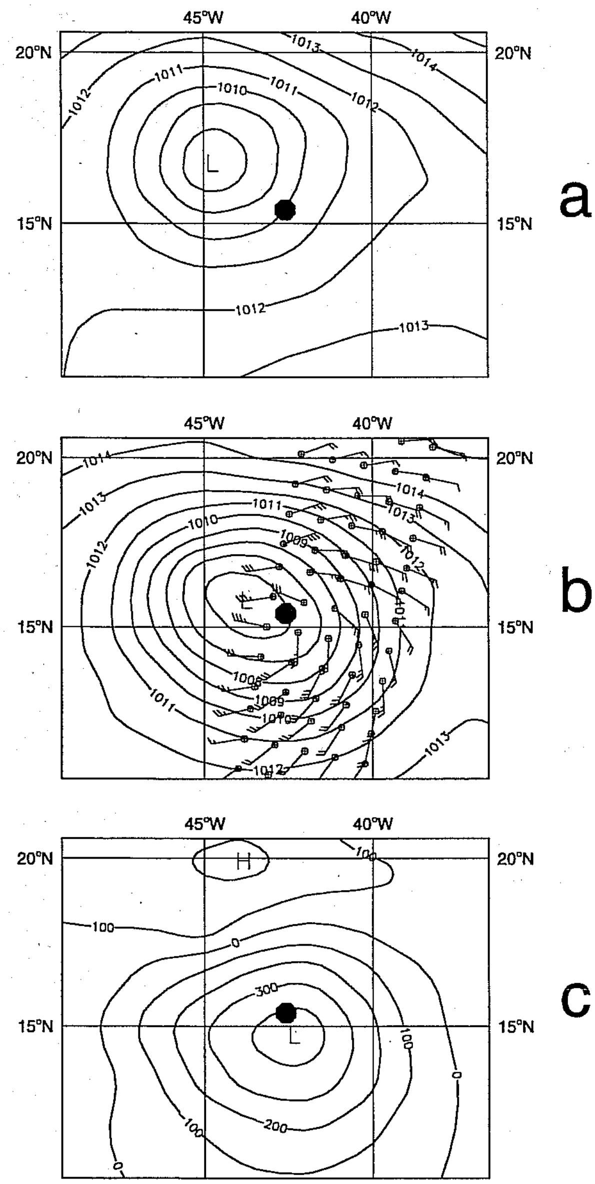

Figure 1: *Assimilation of ERS scatterometer data in 4D-Var for hurricane Iris on 0 UTC 24 Aug 1995. The observed hurricane position is marked with a filled circle. Panel a): Background model MSL pressure. Panel b): Analysis MSL pressure and ERS winds used (only one of the two ambiguous winds is shown). Panel c): Analysis MSL pressure increments (analysis-background model). Winds are shown as flags, where a full barb is 5 m/s. Isobars are shown at 1 hPa intervals.*

To rigorously investigate the skill of OI versus 4D-Var NoSCAT, and 4D-Var NoSCAT versus 4D-Var SCAT the TC intensities and positions have been classified. For all 15 days, the analysis and forecast positions for the TCs were found by calculating relative vorticity maxima (RVM) at 850 hPa. Only RVM values above $5 * 10^{-5}s^{-1}$ were classified as potential TCs. The RVM disturbances were linked, if possible, to the four TCs in the Atlantic tropical region. Only RVM

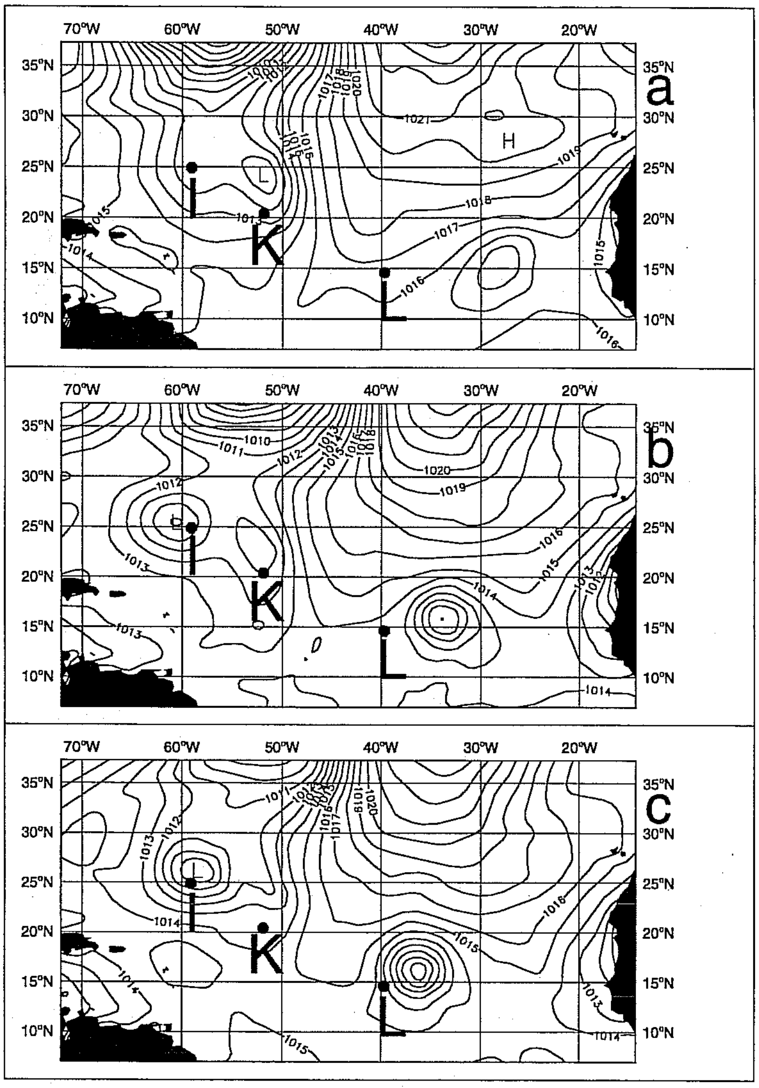

Figure 2: *5 day forecasts of hurricane Iris valid at 12 UTC 31 Aug 1995. Assimilation system used: panel a): OI, panel b): 4D-Var NoSCAT, and panel c): 4D-Var SCAT. The observed hurricane positions are marked with a circle.*

disturbances within 1200 km from the observed positions (as reported by NHC) were taken into account. In each forecast the tracks of the TCs were followed carefully to identify if a RVM could consistently be associated with any of the four TCs. For each forecast during the period of investigation, 4D-Var developed spurious TCs only in very few cases. In some other cases, the TCs dissolves in the 4-5 day forecasts, this happens most often in OI.

For each day in the assimilation period the analysis and forecast TC positional error relative to the NHC observed position was calculated for the four TCs. The intensity of the TCs in analyses and forecasts were always lower than observed, even when the relatively low resolution of the assimilation system was taken into account. So increased intensity of TC analyses or forecasts were considered positive in the statistics presented in figs. 4 and 5. If the center position

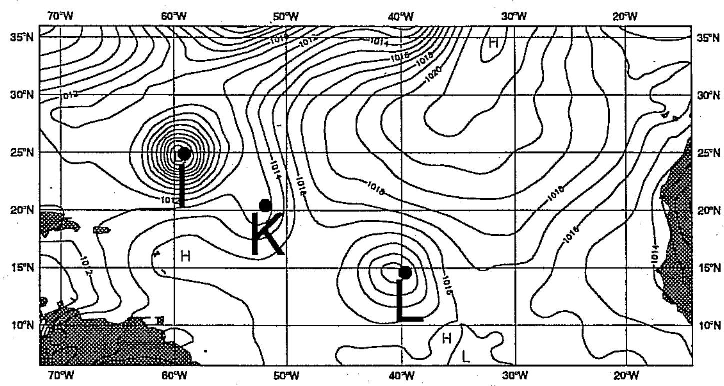

Figure 3: *Verifying analysis of TCs Iris, Karen and Luis valid at 12 UTC 31 Aug 1995*

(or intensity) in the two systems compared (NoSCAT versus OI and SCAT versus NoSCAT) differed by less than 10 %, the case was classified as neutral, otherwise it was classified as either positive (NoSCAT better than OI, or SCAT better than NoSCAT) or negative. If an acceptable TC could be found in one assimilation but not in the other, the case was classified as a positive for the first assimilation. If no acceptable TC was found in either of the two assimilations compared, the day was not included in the statistics.

From figure 4 it is evident that 4D-Var NoSCAT performs much better than OI. Both intensity and position statistics are positive on average in 66 % and negative on average in only 23 % of the cases for the analysis and the 1-, 2-, 3-, 4-, and 5-day forecasts. So the analyses and forecasts of TCs are greatly improved when the more dynamically based 4D-Var system is used. Some of the improvements may also be due to forecast model improvements since 1995. It was then investigated if ERS scatterometer winds could improve TC forecasts even more by including these observations in the 4D-Var assimilation. Figure 5 shows the difference in position and intensity forecast skill for the 4D-Var SCAT versus the 4D-Var NoSCAT. It is seen that scatterometer data generally improve the position and intensity forecast skill of tropical cyclones. It is clear that 4D-Var manages to assimilate and use ERS scatterometer winds well with the benefit of improved TC forecasts. Previous studies (Isaksen 1997) have shown that ERS-scatterometer data have a beneficial effect on extra-tropical forecasts in the 4D-Var system as well, especially in the more energetic and active winter hemisphere. The main improvement in the extra-tropics happens when cyclones are captured by ERS in the early or in the mature stage. In a way, this is very similar to how improvements are obtained in TC cases.

The case study was performed during an intense hurricane period, but the sample size is still fairly small (see table 1), so it was found useful to perform a statistical significance test of the hypothesis that OI and NoSCAT are of equal skill. The results are presented in table 1, where it is seen that the 4D-Var assimilation clearly is significantly better than the OI assimilation. This is especially true for the intensity comparison. A similar significance test was performed for SCAT versus NoSCAT. In table 1 it is seen that the SCAT is significantly better than the NoSCAT in 50 % (between 0.1-7 % significance level) of the analysis/forecast categories investigated. There are no incidences where NoSCAT is significantly better than SCAT.

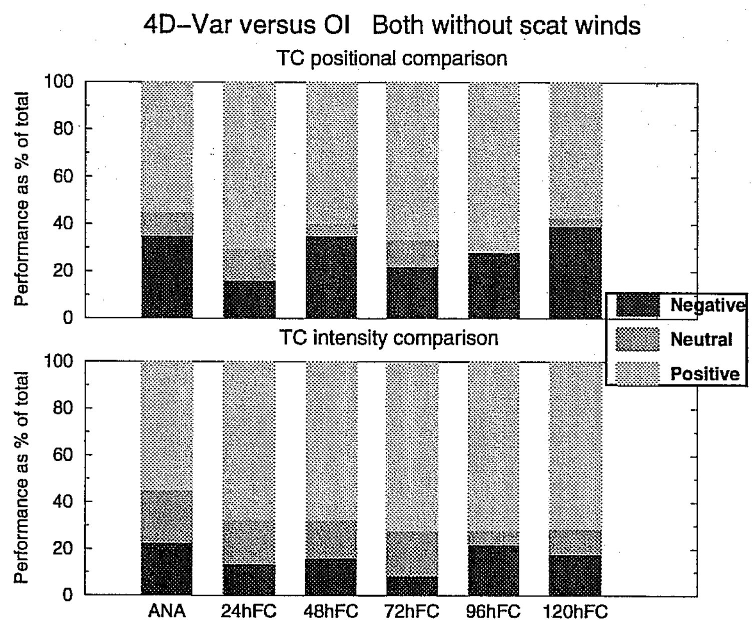

Figure 4: *Comparison of 4D-Var NoSCAT and OI analyses and forecasts of intensities and positions of four Atlantic tropical cyclones*

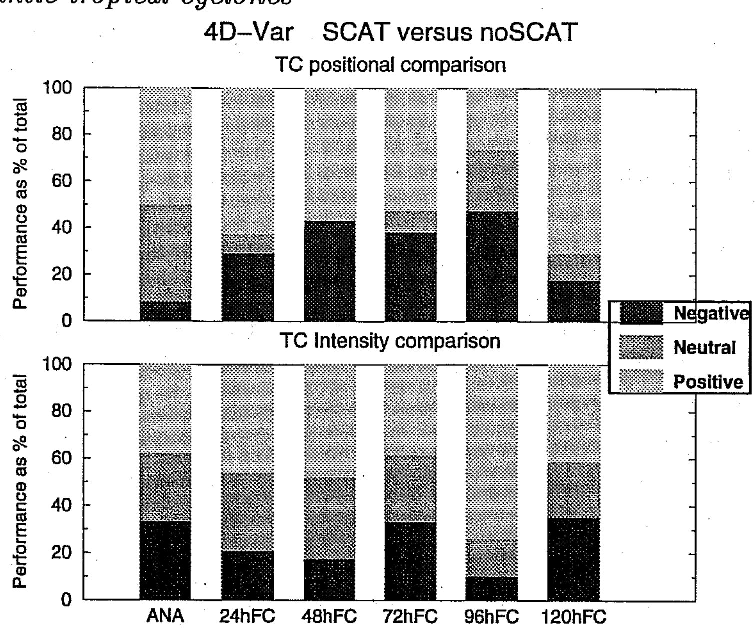

Figure 5: *Comparison of 4D-Var SCAT and 4D-Var NoSCAT analyses and forecasts of intensities and positions of four Atlantic tropical cyclones*

NoSCAT v. OI	Cases	Signif. (pos.)	Signif. (int.)
Analysis	40	9%	1%
24 hour forecast	37	0.1%	0.1%
48 hour forecast	37	7 %	0.1%
72 hour forecast	36	0.1%	0.1%
96 hour forecast	32	1 %	0.1%
120 hour forecast	28	Not	0.1%
SCAT v. NoSCAT	Cases	Signif. (pos.)	Signif. (int.)
Analysis	24	0.5%	Not
24 hour forecast	24	5 %	7 %
48 hour forecast	23	Not	4 %
72 hour forecast	23	Not	Not
96 hour forecast	19	Not	Not
120 hour forecast	17	1 %	0.1%

Table 1: Number of cases in each sample, and statistical significance of positive TC position and intensity for NoSCAT versus OI and SCAT versus NoSCAT, respectively. Non significant events are marked **Not**.

5 Remaining issues

Despite the overall beneficial impact of scatterometer winds in 4D-Var, some remaining issues of concern can be identified. In a way, it is surprising that a general purpose global assimilation system like ECMWF's can analyze and forecast TCs so well. The intensity will always be underestimated and the horizontal extent made broader than it is in reality, because the assimilation system does not represent the small scales of TCs properly. This is also affected by the structure functions (described in section 3) that in the present assimilation system do not represent scales below 200 km. In addition, the typical statistical correlation structures in the tropics cause the structure functions to be very broad and large scale. ERS scatterometer data is sampled over 50 km regions and can thus measure more intense TC features than the present assimilation system can represent. But even at the 50 km resolution ERS is not able to represent the extreme winds near TCs properly. Studies by Quilfen *et al.* (1998) shows that much more realistic TC winds can be obtained by using 25 km sampling of ERS signals. Another matter is deficiencies in the backscatter to wind transfer functions in these extreme events, resulting in too low ERS winds. Attempts to improve the transfer functions at high wind speed are ongoing (Donnelly 1999; Saavedra de Miguel 1998). Assimilation of higher winds will require increased resolution of the assimilation system, especially for the variational assimilation part, in order to be able to represent the smaller scales properly. Assimilation of ERS data is sometimes hampered by the insufficient coverage of TCs due to the relatively narrow swaths of ERS scatterometer winds, and also by occasional errors in the ambiguity removal. Here these two issues will be exemplified.

Problems related to narrow swaths.

If the TC is only partially captured by scatterometer data the structure functions are used by the assimilation system for extrapolation of scatterometer wind information outside the swath. This can result in a weakening of a TC present in the background field, because observed winds e.g. 500 km from the TC center are typically much weaker than near the center of the TC. This is not a scatterometer specific problem, conventional observations (e.g. ships) will have the same potentially damaging effect on the analysis.

Figure 6 shows a case where the scatterometer swath partially samples TC Humberto at 0 UTC on 26 August 1995. The background field TC position is approximately 200 km too easterly, but well identified and intense (as shown in panel a). An ERS scatterometer track passes on the eastern side of the observed Humberto center location but fairly close to the background field TC center location where high winds prevail in the background field. The ERS winds are correctly fairly weak due to the distance from Humberto's center. Some ERS winds are even affected by hurricane Luis (visible in the south-east corner of figure 6). The assimilation system has clearly got a very difficult task in this situation. The correct wind information from the ERS measurements are propagated by the assimilation system to surrounding areas, and Humberto background model winds are dampened substantially by the analysis. In a perfect system, the analysis should have shifted the hurricane center 200 km westerly, but has no observations west of Humberto to justify this. If no ERS observations had been available, the background estimate would have been left virtually unmodified, i.e. keeping a stronger TC.

In other cases (not shown) when say 50% of an intense TC is captured, the combined effect of the structure function impact and probable too low ERS wind speeds in extreme conditions can cause the TC to be weakened only on one side. This can cause asymmetries in the analyzed TC structure, which can result in a poor TC forecast.

A more dense data coverage (like available from QuikSCAT) would mean that TC's typically would be captured completely once or twice daily, with a greater chance to analyze the TC properly. This again will improve the background field forecast which will reduce the number of difficult cases (like the one shown in figure 6) for the assimilation system to handle.

Ambiguity removal problems.

Figure 7 shows the analysis of TC Humberto at 12 UTC on 29 August 1995. The background field shows a TC approximately 200 km too far south-west of the observed position (marked with a filled circle). The analysis correctly deepens the TC, but not nearly enough considering the high wind speeds measured by ERS. For this case the maximum speed provided by CMOD4 (Stoffelen and Anderson 1997b) amounts to 40 knots, whereas the ECMWF-bias corrected ERS winds (Le Meur *et al.* 1997) are 50 knots. These winds look realistic when it is kept in mind that they represent a scatterometer footprint with a diameter of 50 km. In this case the assimilation system uses the wrong ambiguous winds on the western side of the observed hurricane eye position. The wrong ambiguities agree with the background field winds because the background

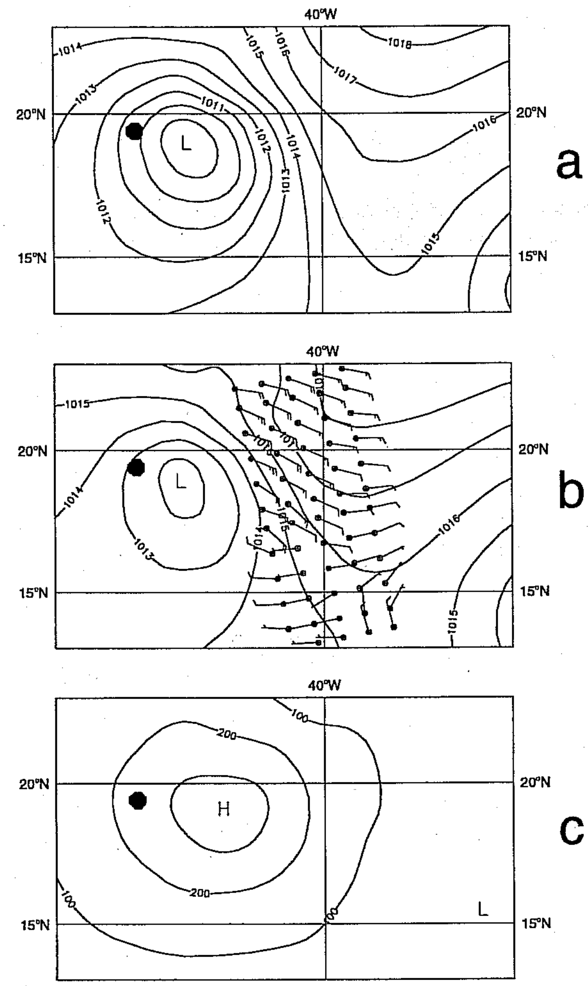

Figure 6: *Analysis of hurricane Humberto at 0 UTC on 26 August 1995. Luis is just visible in the south-eastern corner of a) and b). Layout like in figure 1.*

hurricane position is too far westerly. Based on this wrong directional assumption the wind gradients (and implied pressure gradients) are very much reduced compared to the true observed gradients, which explains why the hurricane is only intensified slightly.

Because of the spatial consistency of the scatterometer winds, the spatial extent of a TC can be visually well estimated, even when it is only partially captured. As such, during the assimilation process towards the end of the fitting process, one could apply a scheme where the spatial extent of the structure functions is reduced ('TC structure functions'), in order to achieve a more optimal fit in those locations where the nominal structure function does not provide a close fit of the analysis to the scatterometer observations. This could, potentially, also improve the analysis of fully captured tropical cyclones. On the other hand, there may be a risk of reducing the ambiguity removal skill somewhat. When a TC has been identified in this manner, the 'TC structure functions' should also be applied to other observations in the vicinity of the TC. A method like this should be further investigated. Another issue for further

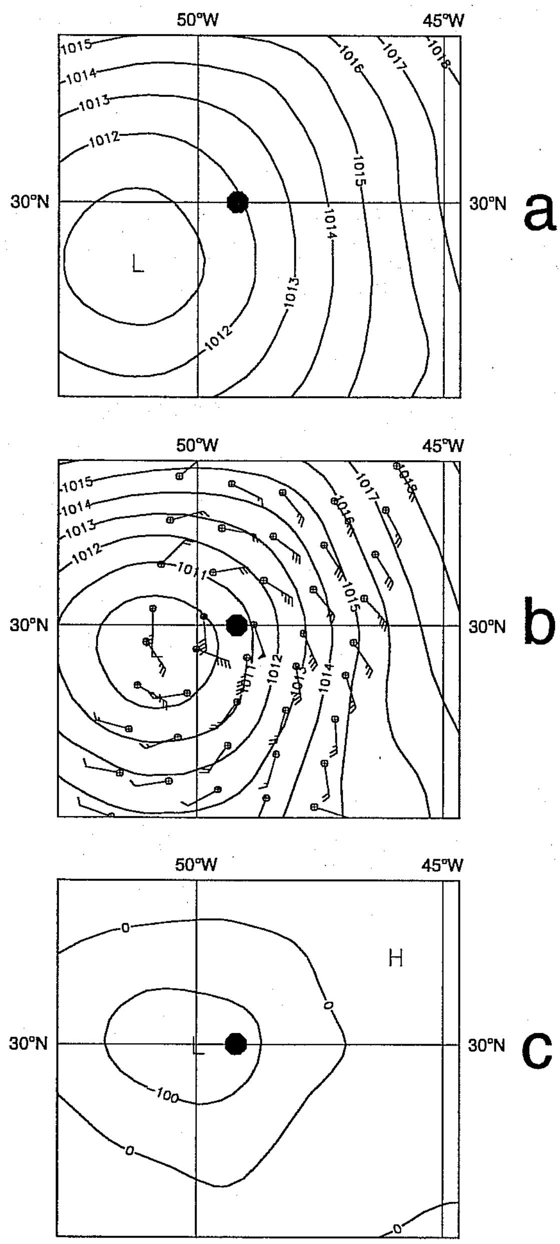

Figure 7: *Analysis of hurricane Humberto at 12 UTC on 29 August 1995. Layout like in figure 1.*

study is the analysis of the vertical structure of TCs in 4D-Var.

In this Humberto case, the scatterometer winds fully captured the hurricane as can be seen in figure 8. In this case, it would have been possible to perform a correct ambiguity removal selection based solely on a maximum vorticity (or minimum divergence) constraint on the observed data, perhaps combined with the use of the aft-fore beam pattern signal, as described in (Saavedra de Miguel 1998). The background field information does more harm to the ambiguity selection in this case. This is not true in general, but it happens occasionally when tropical cyclones, intense extra-tropical cyclones and frontal zones are misplaced in the background field.

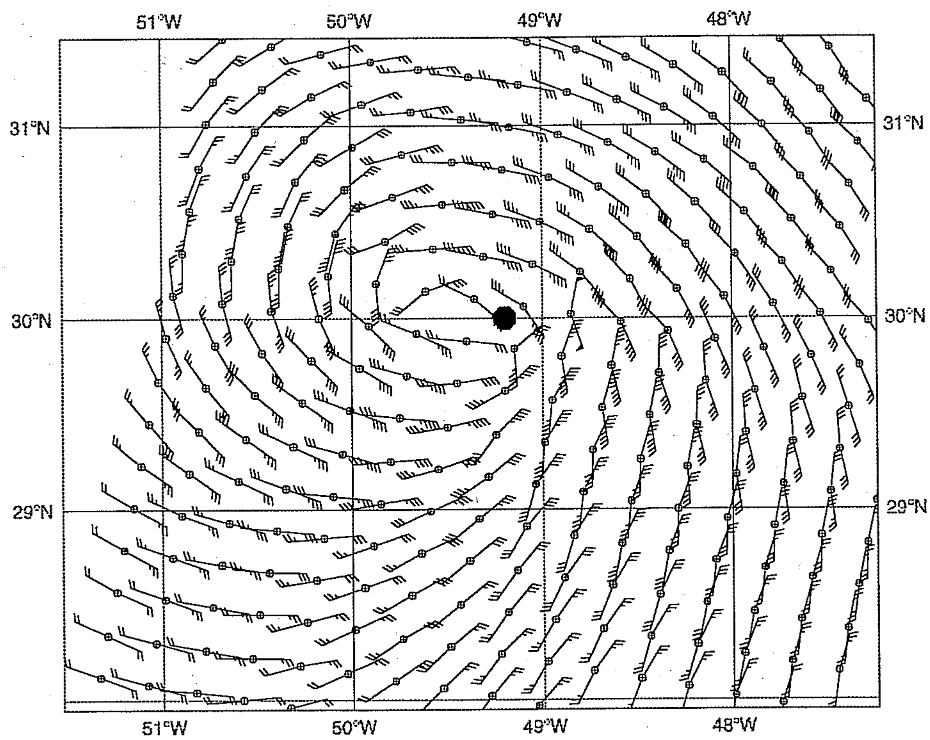

Figure 8: *All available ERS winds close to hurricane Humberto at 12 UTC on 29 August 1995. The observed hurricane position is marked with a filled circle*

6 Conclusions

This paper shows that the ECMWF 4D-Var data assimilation system performs better analyses of TCs compared to the OI assimilation system. The use of ERS scatterometer winds further enhances the impact. Unprecedented high-quality forecasts of TCs, up to day five, are shown in this paper. More recent experiments with 4D-Var confirm the beneficial effect of ERS scatterometer winds in 4D-Var. The spatial consistency of scatterometer winds may be used to further optimize the analyses and forecasts. In this respect, a larger coverage of winds, such as that from SeaWinds on QuikSCAT, launched in June 1999, is expected to be very useful for the further improvement of cyclone analyses and forecasts. This is confirmed by tandem ERS-1 and ERS-2 scatterometer experiments carried out at ECMWF (Le Meur *et al.* 1997) and at KNMI (Stoffelen and Beukering 1997).

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