Assimilation of ERS-1 and ERS-2 scatterometer wind data in ERA-40

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Abstract

ERS scatterometer wind data was not used in ERA-15 but is assimilated in ERA-40. The preliminary results show that ERA-40 benefits from the use of ERS scatterometer data. Longer period statistics prove that the data is of high consistent quality. Comparison of observation statistics for a range of observing systems measuring winds over the oceans also highlights the quality of ERS. The main drawback for ERS is the narrow swath with a smaller area covered than for TOVS data, resulting in a smaller general impact.

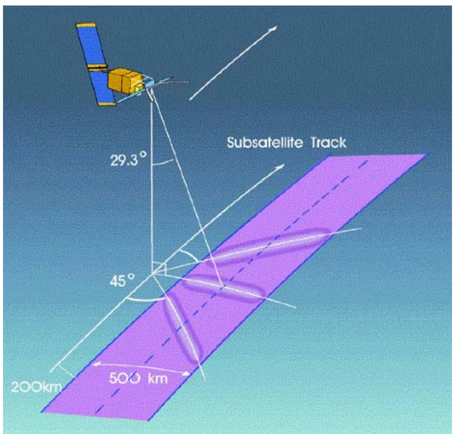
1. Introduction

This layout of this paper is as follows. First a description of ERS scatterometer instrument and derived wind data is presented. Next the quality of ERS scatterometer wind data is discussed. Then it is described how ERA-40 benefits from ERS data. Finally, before the conclusion some average wind statistics for ERA-15 and ERA-40 are presented.

2. A description of the ERS-1/ERS-2 satellites, the scatterometer instrument and the derived wind data

ERS-1 and ERS-2 are polar-orbiting satellites launched by ESA in respectively July 1991 and April 1995. They are large multi-instrumental platforms. This paper will describe the use 10 metre ocean winds derived from ERS backscatter microwave measurements. The winds are called scatterometer winds. Figure 1a shows the radar geometry for the wind scatterometer instrument. Three antennae cover a 500 km ocean surface. A geophysical model function CMOD4 (see Stoffelen and Anderson, 1997) derives winds at 10 metre height over the oceans representing a 50 km x 50 km footprint. The measurements are over-sampled, so measurements are available every 25 km across and along the swath. Figure 1b shows the typical coverage for a 6-hour period. It is clear from this figure that the coverage is rather limited compared to TOVS and SSM/I.

Fig 1a



Radar geometry for the Wind Scatterometer.

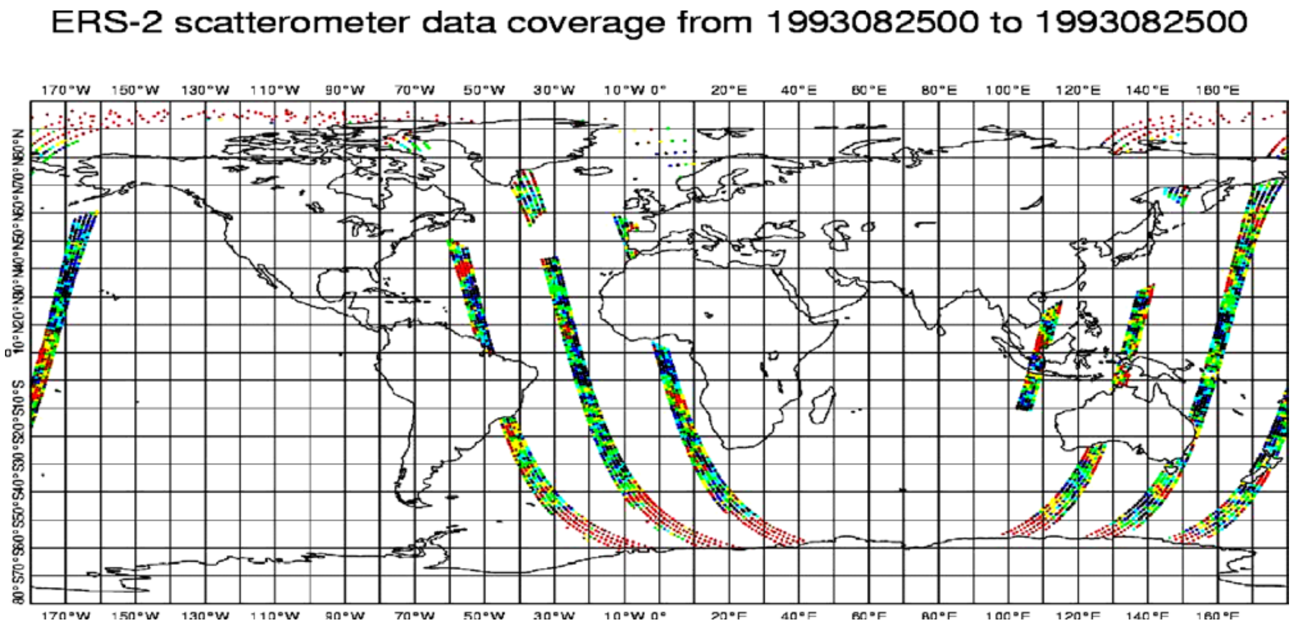


Fig 1b

Because the instrument use C-band (5.3 GHz (5.7 cm) wavelength) rain and clouds do not contaminate the observations. Therefore ERS is able to deliver wind measurements even near tropical cyclones and extra-tropical lows. An example of TC Bonnie is shown in fig. 2a. Due to the antennae geometry and measurement principle (see Stoffelen and Anderson, 1997) there will be two ambiguous wind solutions at each observation location. They have almost similar wind speed and are opposed by approximately 180 degrees. Figure 2b left panel shows the correct wind ambiguity near the centre of typhoon Keoni. Figure 2b right panel shows both ambiguities near typhoon Keoni's centre. The ERA-40 3D-Var assimilation system gets both ambiguous winds and selects one of the two during the assimilation process based on a dynamical selection criteria (see Isaksen and Stoffelen, 2000 for further details).

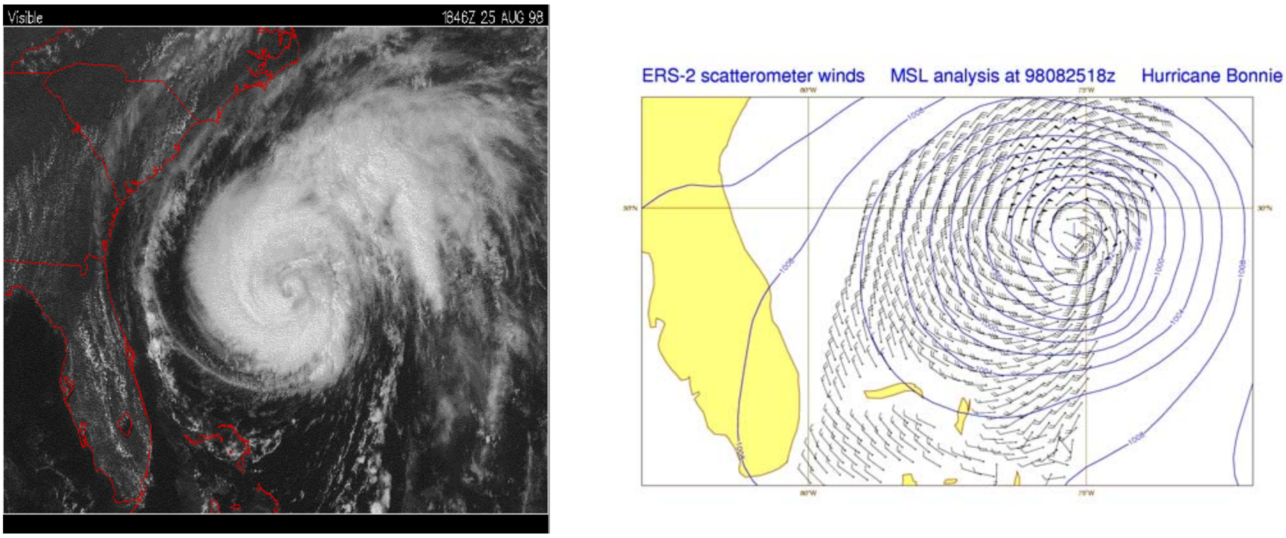


Fig 2a

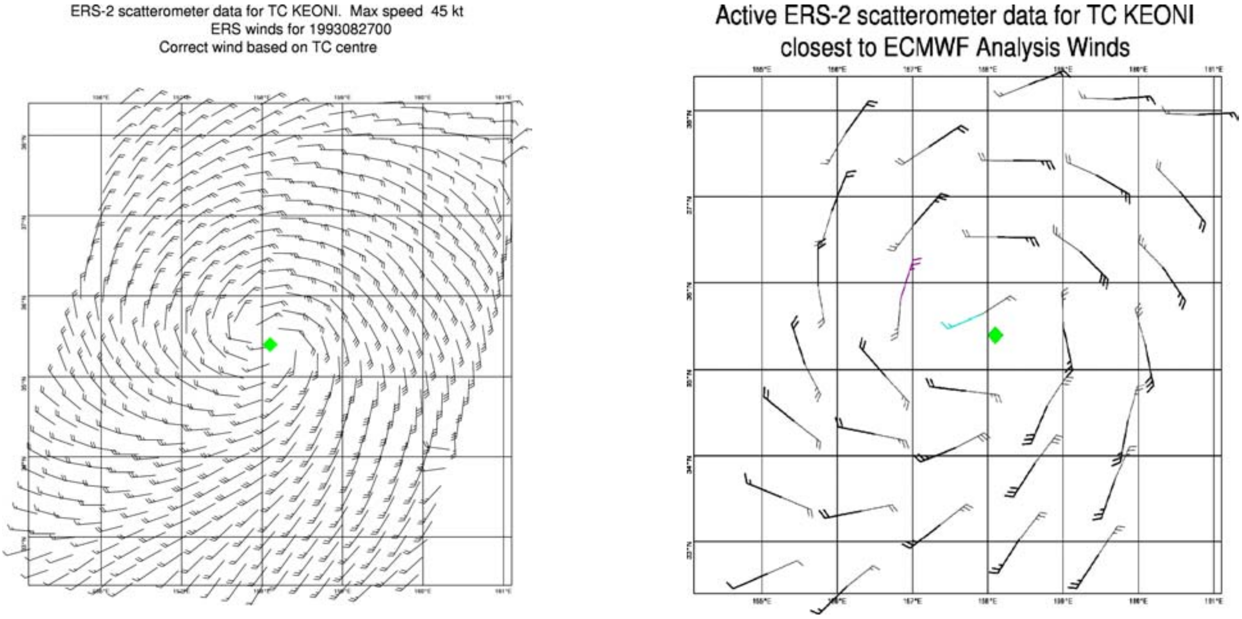


Fig 2b

3. The quality of ERS scatterometer wind data

ERS scatterometer winds are generally of uniformly high quality because ESA has carefully monitored the backscatter signal and assured constant performance. The quality of the winds is better than for SHIP and BUOY wind measurements. The backscatter signal almost saturates at 25 m/s and few first-guess winds or conventional wind observations above 25 m/ are available for the collocation necessary to determine the geophysical model function. Therefore only ERS winds below 25 m/s are used in the assimilation.

Figure 3a shows a comparison between ERA-15 10 metre winds and the standard CMOD4 geophysical model function (Stoffelen and Anderson, 1997) generated winds. Except for two adjustments by ESA of the backscatter level (on 14 September 1991 and 1 March 1992) the performance of ERS-1 is seen to be very

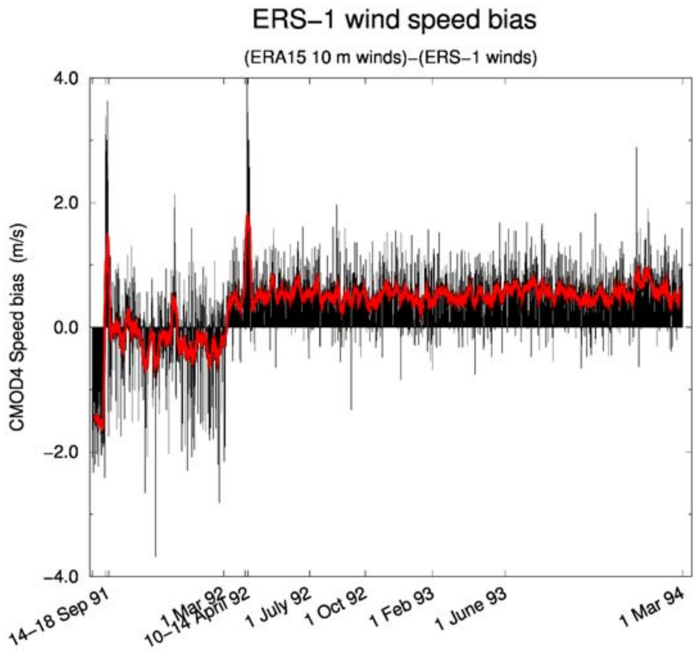


Fig 3a

consistent without trends or large variability from a constant bias level. Figure 3b, left panel shows the comparison of ERA-15 with CMOD4 winds for six months in 1992. There is a bias of -0.16 m/s and standard deviation of 1.76 m/s. Figure 3b, right panels shows the bias corrected winds, as they potentially would have been used in ERA-15. A simple constant speed bias correction has been applied based on ERA-15 winds during the first months of 1993. Verified for the independent data set the bias is reduced to -0.02 m/s and standard deviations are reduced a lot to 1.62 m/s. A similar method has been used in ERA-40. Here the ERS-1 data has been bias corrected based on a period in 1992 where ERS was monitored passively in ERA-40. The ERS-1 data has been used actively in ERA-40 from 1 January 1993. During the whole lifetime of ERS-1 a constant bias correction has been used with success.

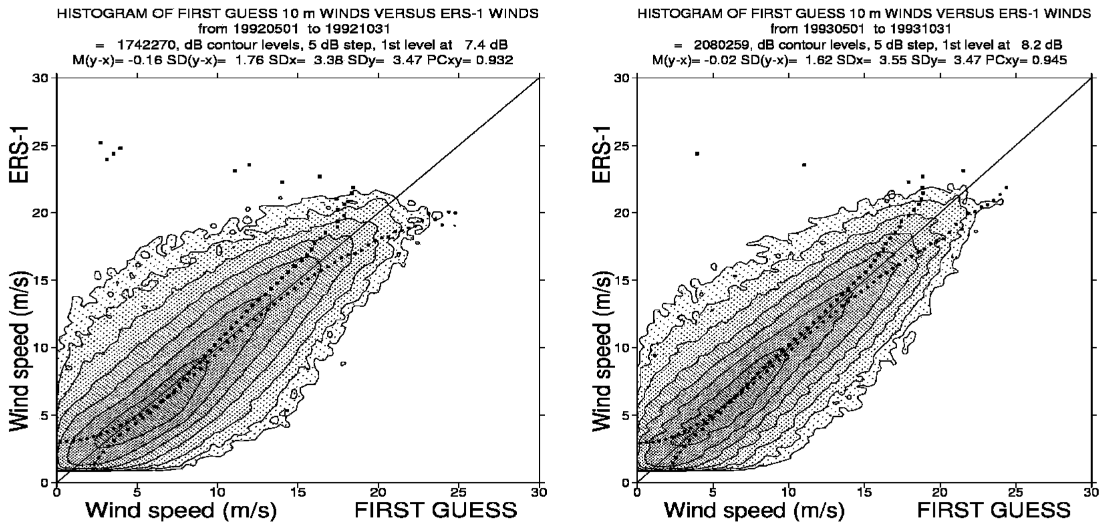


Fig 3b

4. How will ERS scatterometer data benefit ERA40

It is expected that ERS wind data will give a small but consistent positive contribution to ERA 40. The main benefits will be improved analyses and forecasts of severe weather systems, improved ocean surface wave forecasts, improved surface wind stress fields and improved surface fluxes over the oceans compared to ERA-15.

Figure 4a and 4b show the May 1993 *obs-firstguess* and *obs-analysis* statistics for for ERA40 during May 1993 for a number of observing systems measuring wind over the oceans. ERA40 is using data from ERS-1 scatterometer, SSM/I, DRIBU and SHIP. Figure 4a, left panel shows that ERS winds are very well assimilated in ERA-40. The standard deviation compared to analysis versus compared to first-guess fields show a very large reduction (i.e. for Southern Hemisphere a reduction from 1.78 m/s to 1.02 m/s). The SSM/I wind data does not seem to benefit ERA-40 very much because of the high first guess dependence of this data. Figure 4b shows the statistics for DRIBU and SHIP. It is seen that the quality is generally worse than for ERS-1 with larger biases and standard deviations compared against first guess fields. The *obs-analysis* statistics make it clear that DRIBU and SHIP data is not assimilated as well as ERS data.

To study the general impact of ERS scatterometer data in ECMWF's assimilation system a one month assimilation study with and without use of ERS scatterometer data was performed. Figure 5a shows the scores for this experiment for the Southern Hemisphere. A small but significant positive impact is found for this region. For the Northern Hemisphere the impact in the experiment is neutral (not shown). Figure 5b shows the impact on the 10 metre windspeed analysis increments when ERS was made active in ERA-40 on

1 January 1993. The standard deviation plot shows a jump, showing that ERA-40 is influenced by the addition of ERS data. The bias level stays at a constant near zero level. Both these signals are positive, but do not say anything about the benefit of ERS data.

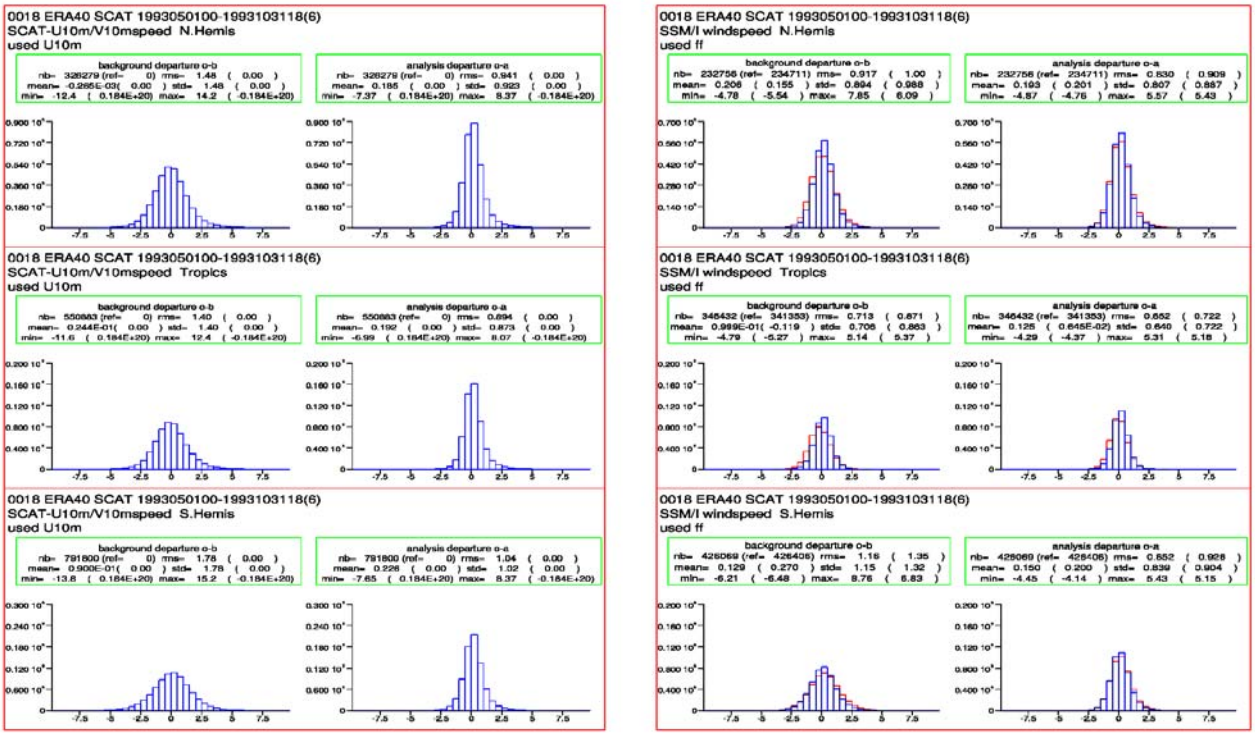


Fig 4a

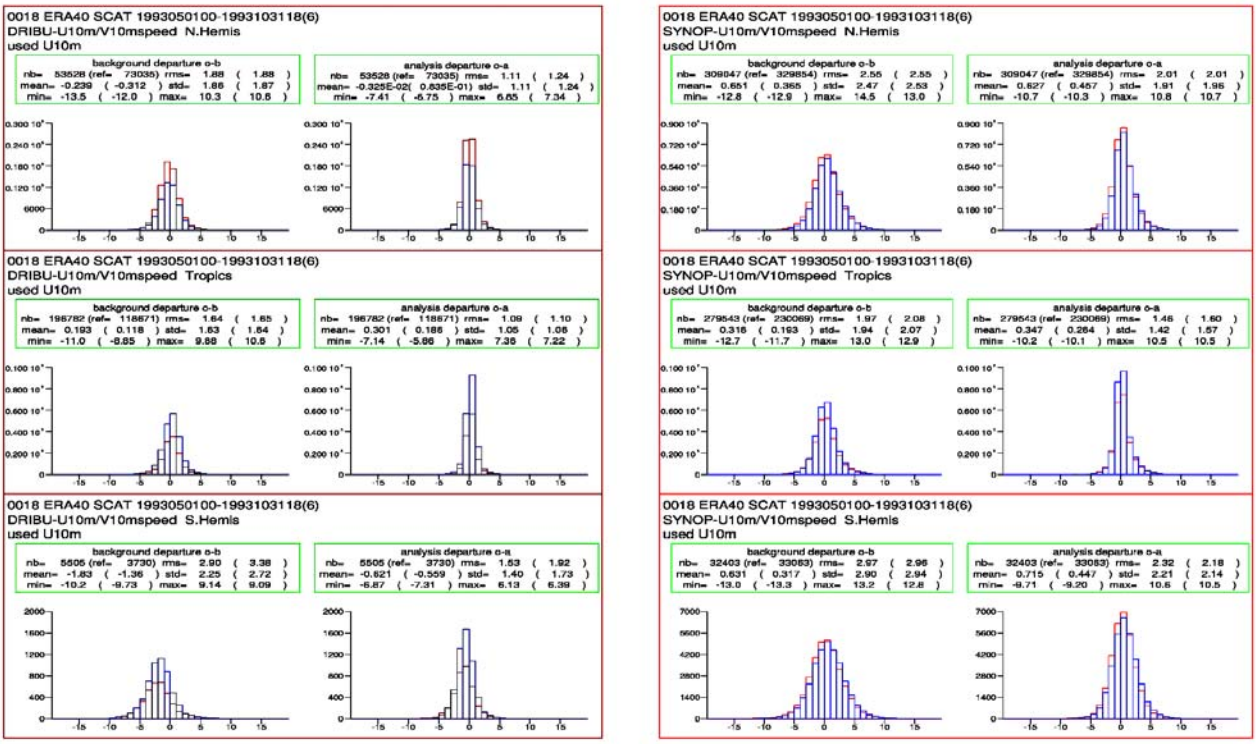


Fig 4b

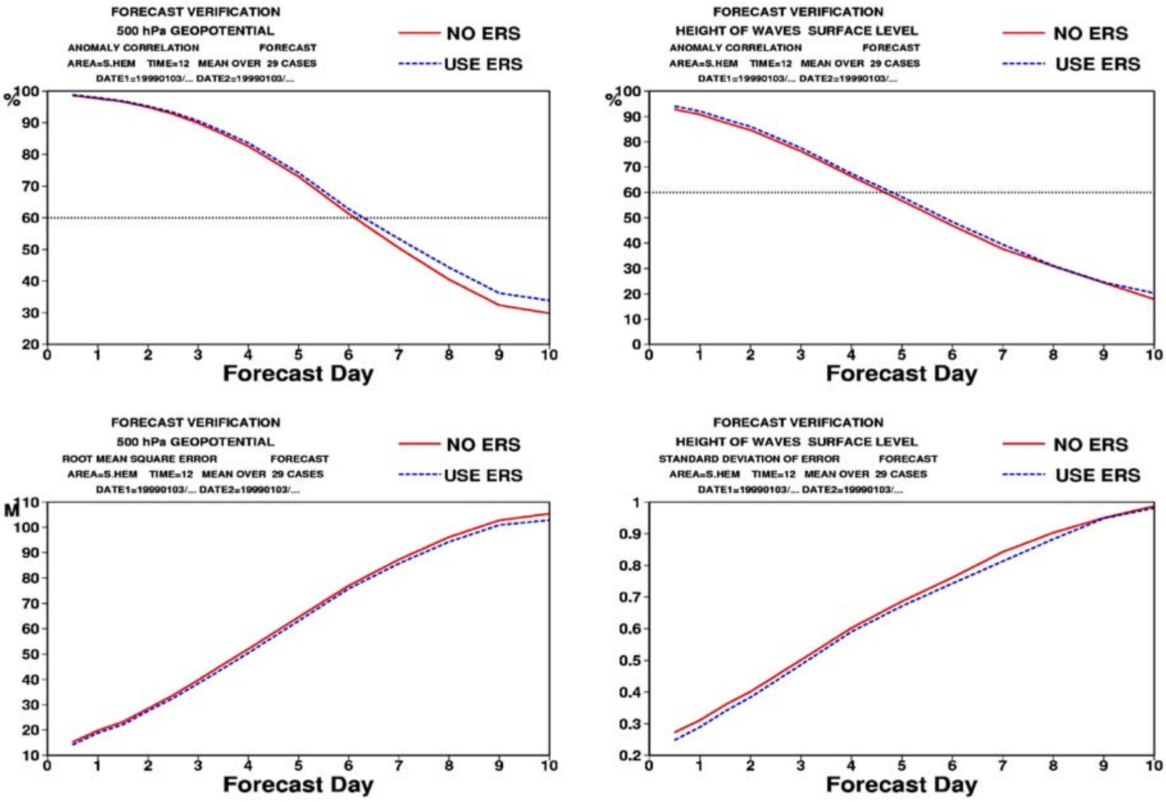


Fig 5a

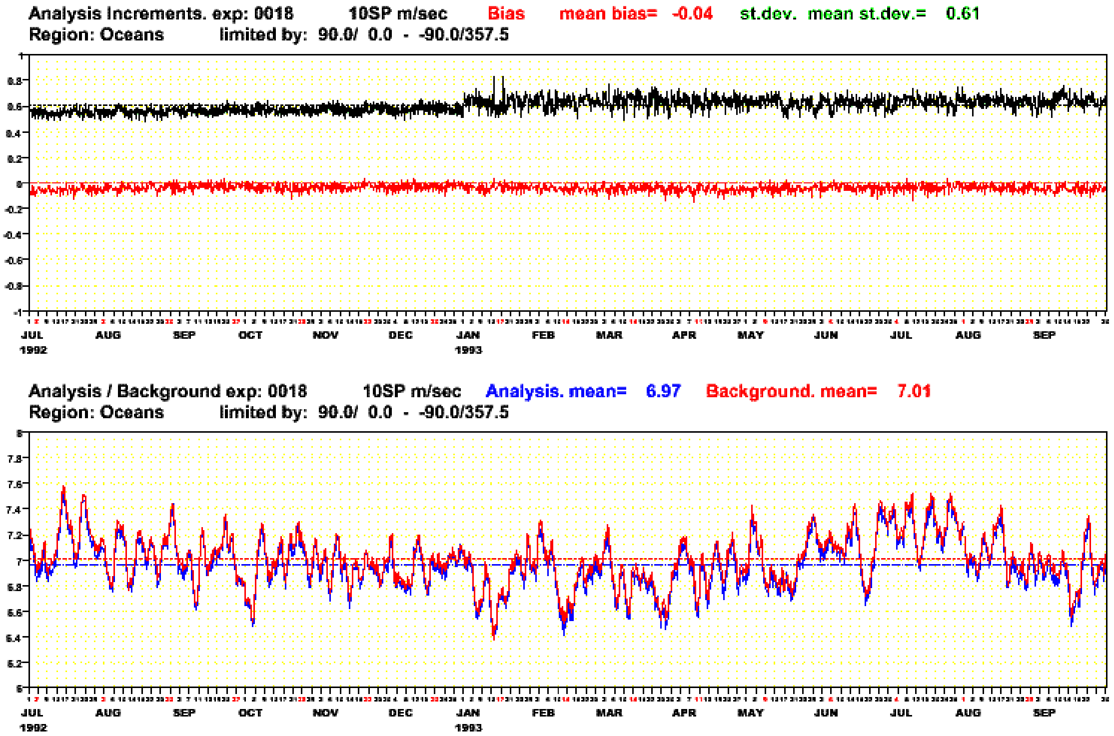


Fig 5b

Figure 6a and 6b are from previous ERS scatterometer tropical cyclone impact studies, where the assimilation system was run with and without ERS scatterometer data (see Isaksen and Stoffelen 2000 for further detail). Panels 6a shows that 4D-Var handles this tropical cyclone forecast much better than the previous OI assimilation system. The addition of ERS scatterometer data to the assimilation system further improves the forecast of the tropical cyclone. This is representative of the general result of a longer period of tropical cyclone related assimilation studies. Figure 6b show an example where ERS scatterometer data is responsible for a dramatic and correct movement of a tropical cyclone in the Indian Ocean. This tropical cyclone is also intensified and gets a more proper shape.

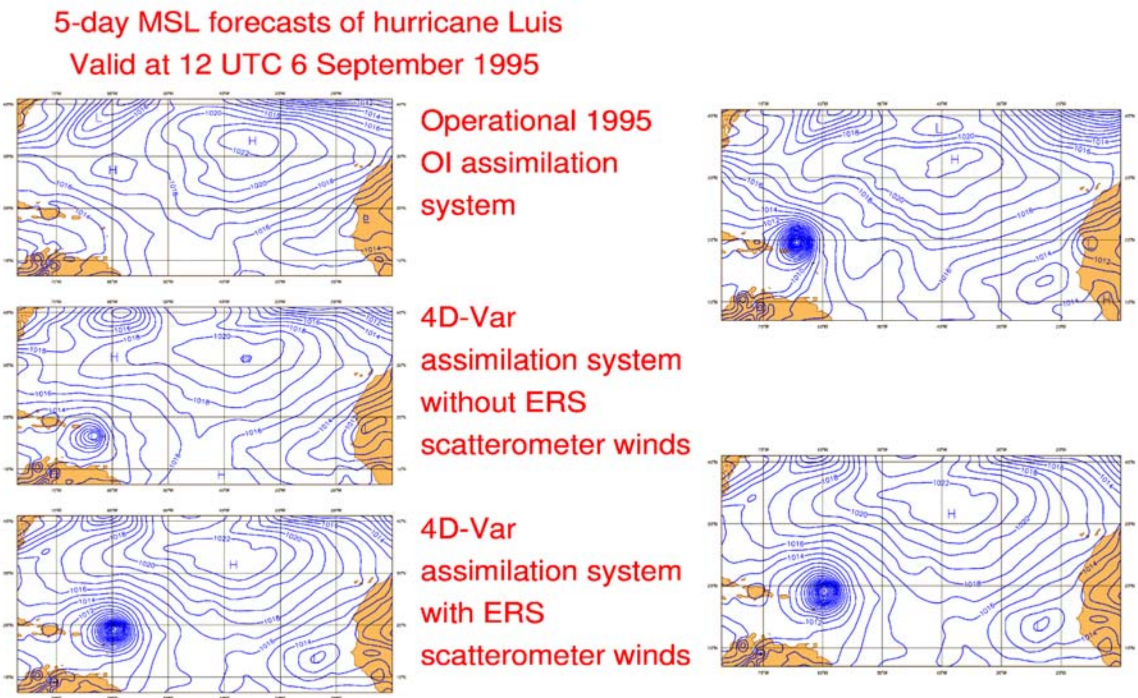


Fig 6a

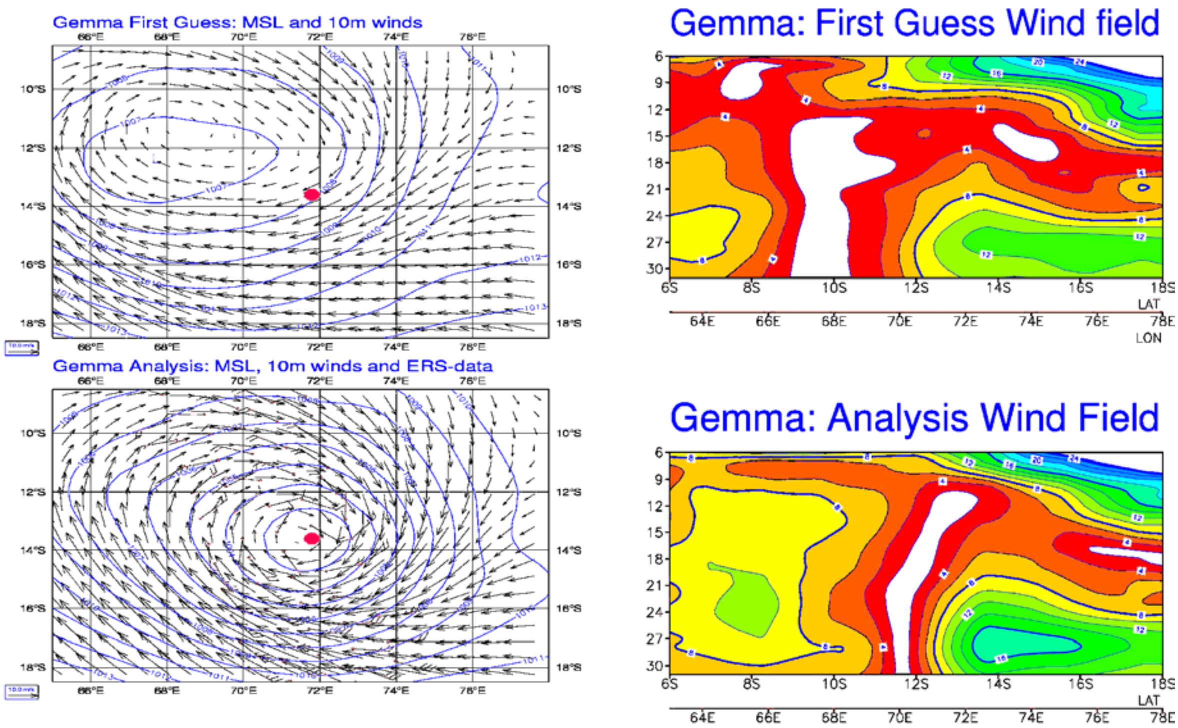


Fig 6b

5. Comparison of 10 metre wind climatologies in ERA-15 and ERA-40

To study further the general impact of ERS data in ERA-40 the average wind speed calculated from the ERA-15 and ERA-40 fields for the years 1991, 1992 and 1993 were compared. Figure 7a and 7b show the wind speed difference between ERA-40 and ERA-15 averaged over a whole year. The wind speed of ERA-

40 is generally slightly lower than in ERA-15, expect for the well-known problem with Pacific islands in ERA-15. In ERA-40 most wind measurements from ships are now used at their proper height, this is one reason for the lower winds in ERA-40, especially in the North Atlantic and North Pacific areas. It is not clear if ERS is responsible for the relatively lower wind speeds in 1993. It could also be due to more ship observations, because the signal is strongest near the ship route lines.

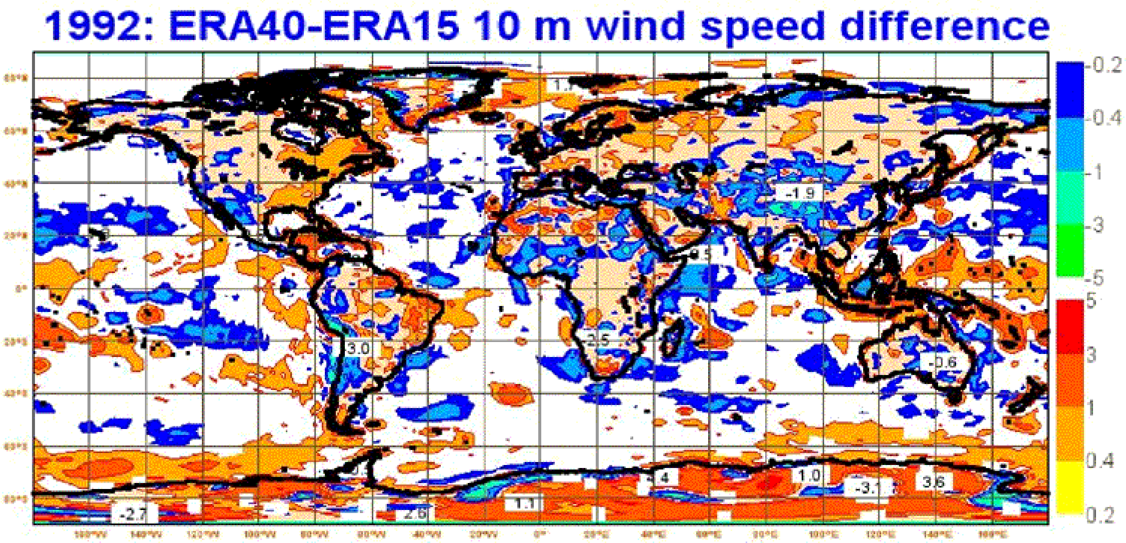


Fig 7a

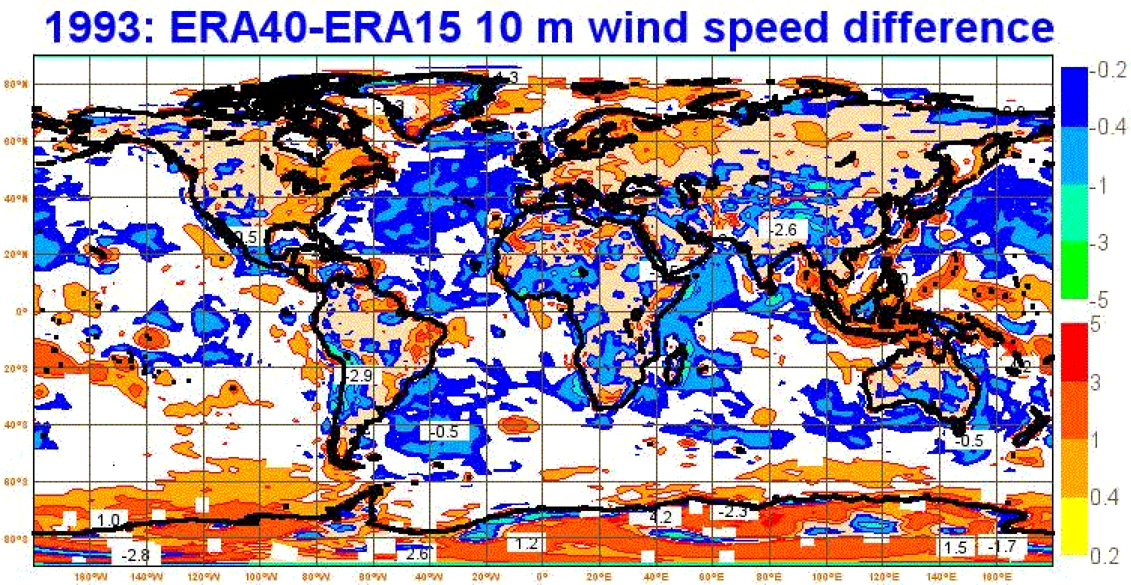


Fig 7b

Figure 8a and 8b show the difference in wind speed standard deviation for 1991 versus 1992 and 1992 versus 1993, respectively. It is seen that 1992 performs better than 1991 and 1993 performs better than 1992 because the values in the plots are mainly negative (blue). This is a very positive result, showing that ERA-40 performs better when more data is avail assimilated.

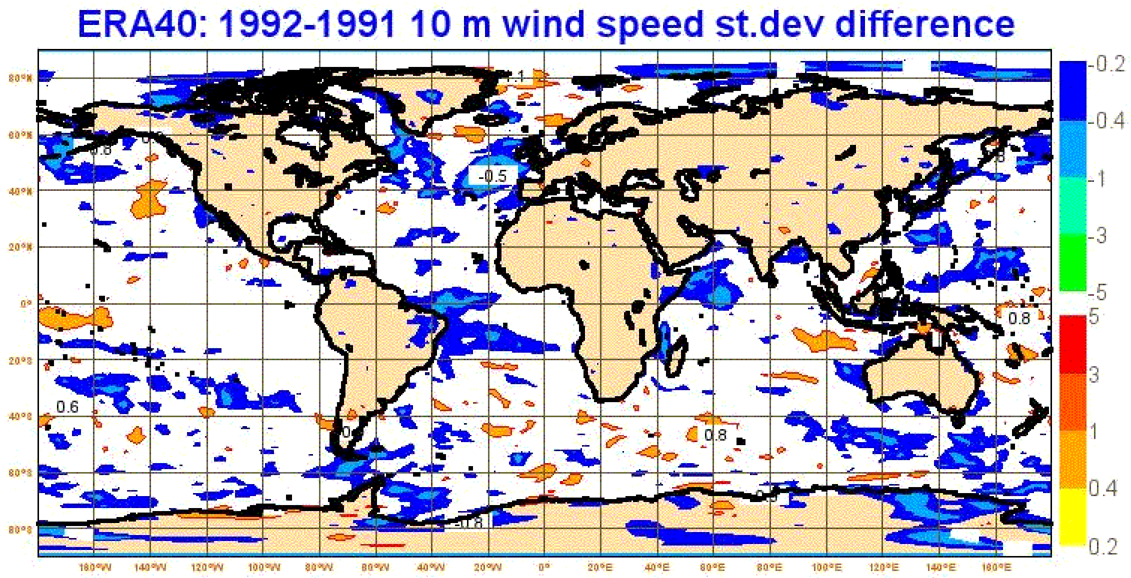


Fig 8a

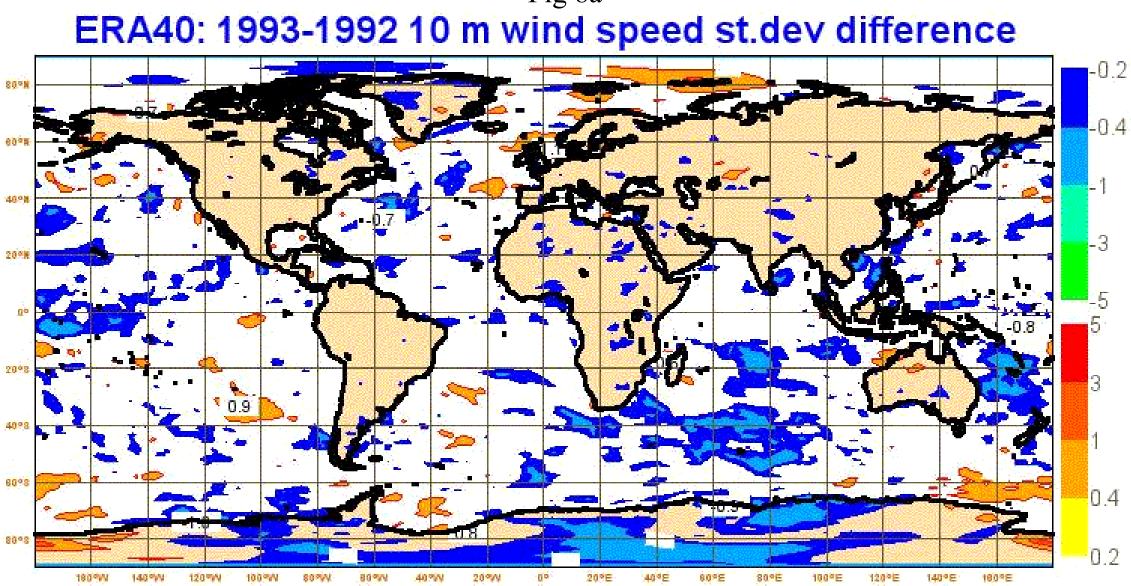


Fig 8b

6. Conclusions

This paper shows that ERA-40 benefits from the use of ERS scatterometer data. Due to the narrow swath, resulting is fairly low data coverage, the impact is in general only small. It has been shown that the ERS scatterometer data is of high consistent quality without cloud/rain contamination problems. It has been shown that ERA-40 assimilates the ERS scatterometer data well (better than SSM/I, DRIBU and SHIP data). It is expected that ERS will improve ERA-40's handling of tropical cyclones and intense extra-tropical cyclones, but this has not been investigated by this study

References

Isaksen and Stoffelen (2000). ERS-scatterometer wind data impact on ECMWF's tropical cyclone forecasts. *Trans.Geosc. and Remote Sensing,* 38, 885-1892.

Stoffelen and Anderson (1997). Ambiguity removal and assimilation of scatterometer data. *Q.J.R.Meterolog.Soc.,* 123, 491-518.