Meteorology Research and Development

The Impact of MetOp-A ASCAT ocean surface wind vectors on Met Office Global Model Forecasts

Technical Report No. 511

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Revision History.

Date of this revision: 27th March 2008
Date of next revision:

Revision Date	Previous Revision Date	Summary of Changes	Changes Marked
9th Oct 2007	N/A	First draft	No
24th Oct 2007	9th Oct 2007	Suggestions from D.O.	No
27th Nov 2007	24th Oct 2007	Minor amendments	No
9th Jan 2008	27th Nov 2007	Include new trials results	No
12th Feb 2008	9th Jan 2008	Minor changes	No
17th Mar 2008	12th Feb 2008	R.S. comments	No
27th Mar 2008	17th Mar 2008	R.S. comments, new title page	No

Approvals.

This document requires the following approval.

Name	Signature	Title	Date of Issue	Version
Roger Saunders		Hd. Satellite Applications		1.0

Circulation.

This document should be circulated to the following.

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Simon J. Keogh	Research Scientist		1.0
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Contents.

Abstract.

Surface wind observations from the MetOp-A advanced scatterometer (ASCAT) OSI-SAF wind product have been assimilated at the Met Office and demonstrated to show a positive impact in the global forecast model. This is a good result given the large volume of scatterometer data already assimilated from QuikSCAT and ERS-2. The forecast trial period contained a tropical cyclone (TC Gonu), which showed up well in the ASCAT data though there were gaps in the ASCAT wind data, apparently corresponding to the thick cloud, which indicates precipitation contamination. A conservative quality control scheme was initially designed to ingest the new ASCAT data and further work will be to fine tune this quality control to allow the assimilation of more observations.

Further assimilation trials presented in the discussion section demonstrate ASCAT delivers approximately the same benefit to Met Office global forecasts as QuikSCAT despite the conservative implementation. Further, these trials demonstrate beyond doubt that two global coverage scatterometer missions provide significantly greater benefit to the numerical weather prediction community than a single mission can deliver alone.

1. Introduction.

1.1 MetOp

The MetOp series of satellites are Europe's first polar-orbiting satellites dedicated to operational meteorology. MetOp-A was launched on 16th October 2006 carrying a variety of earth observation instruments. Amongst these instruments was the advanced scatterometer (ASCAT). ASCAT is an active C-band (5.3GHz) radar scatterometer that has VV polarisation.

1.2 ASCAT data products

The primary use of ASCAT is in determining the surface wind speed and direction over the ocean. In addition, ASCAT can also be used for determining sea-ice properties [1] as well as soil moisture conditions [2].

ASCAT wind vectors over the ocean are produced on the principle that radar energy will be backscattered from the sea surface differently according to its roughness. If we assume that the roughness of the sea surface is governed primarily by the surface wind field then it is reasonable to expect that there is a strong relationship between the wind and the radar backscatter signal [3]. This relationship is exploited by KNMI who produce a level 2 wind vector product from the radar backscatter signals (so called "sigma nought" or σ^0) for the ocean and sea ice satellite application facility (OSI-SAF).

The Met Office has strategically chosen to utilise the OSI-SAF level 2 50km wind product (at 25km spacing) produced by KNMI rather than develop its own level 2 processing scheme. This has the following advantages:

- Very good technical support from KNMI scatterometer team
- There is no need to upgrade/retune coefficients and algorithms when EUMETSAT issue new backscatter calibration data because the KNMI scatterometer team will do this leaving the change transparent to end users
- Less in-house code to maintain and support
- Users can spend more time exploiting the data rather than having to build up a detailed knowledge of wind retrieval and backscatter theory first

The delay in receiving level 2 ASCAT winds from KNMI, as opposed to processing level 1 data ourselves, is negligible thanks to the EUMETCAST data dissemination system.

ASCAT is currently in the calibration/validation phase and a stable calibration for the sigma nought values is awaited from EUMETSAT. Once this stable calibration is completed, it is expected that the OSI SAF level 2 product evaluated in this report will become operational with improved accuracy.

1.3 The Met Office global forecast model

The Met Office global forecast model used for these experiments has the following main characteristics:

- Resolution of ~40km in mid-latitudes
- 640 x 481 grid size
- 50 vertical levels
- Lid at ~63km
- Forecast out to 120 hours.

Both QuikSCAT and ERS-2 scatterometers are already assimilated into the model. The reader is referred to [4], [5] and [6] for further details of the assimilation methodology.

2. ASCAT surface wind product description.

The Met Office is working with the 50km level 2 OSI SAF ASCAT BUFR product produced by KNMI. A description of this product can be found in the ASCAT wind product user manual (ref. [1]). The product consists of ocean surface wind vectors with typically two directional ambiguities. This means that each observation is reported with two possible wind directions approximately 180 degrees apart. This is similar for ERS-2 wind vectors, which are also derived from C-band measurements. A flag is set in the BUFR to tell the user which of the two wind directions is most probable. However, this flag is not reliable because it relies on comparing the two wind directions with an old forecast. It is therefore replaced in the observations processing system by a new flag that corresponds to the wind vector closest to a more up to date Met Office forecast wind value.

2.1 ASCAT data coverage

The ASCAT instrument has left and right hand 500km swaths separated by a gap of 670km. This is illustrated in figure 1. The ASCAT swath has 42 measurement cells or "nodes". The backscatter measurement for each node is an average of many radar shots (~1111 shots for 50km x 50km product). These shots are weighted to produce 50km averages at 25km spacing, with shots closest to the centre of the node having greater weight than those near the edge.

During the assimilation time window ASCAT will trace out a typical pattern over the sea surface as illustrated in figure 2.

2.2 Quality of wind speeds

ASCAT has an improved accuracy in the wind speed compared to previous scatterometers. Figure 3 shows that the RMS O-B (observed – background[1]) wind speed is typically ~1.15m/s, which is better than ERS2 and QuikSCAT scatterometers. Although SEAWINDS and ERS-2 were assimilated into the previous forecast there is no evidence that there is any memory effect in the forecast, not least because the measurements in the previous forecast will have been in different locations due to the satellites orbital precessions. Figure 4 also shows that the ASCAT wind speeds appear to be almost bias free in the range 2-20m/s. Figure 5 shows that the wind speed quality is generally good across the swath and is best in the centre.

2.3 Quality of wind directions

It is evident from figure 6 below that there is very little directional bias across the ASCAT swath. However, the quality of the reported wind directions varies considerably. Standard deviations of 14.5-21.5 degrees are observed across the swath with the largest standard deviation in the O-B wind directions being observed in node 22, which is the innermost node on the right hand swath. The innermost node of the left hand swath (node 21) is also worse than the other nodes at reporting wind direction but not quite as obviously as node 22.

2.4 Distance to cone as a quality indicator

Distance to cone [3] provides a measure of how far away the backscatter measurements are away from 'ideal' measurements. A (dimensionless) distance to cone value is provided in the ASCAT BUFR for each wind ambiguity. It is a quantity. A limit of 1.8 has been set as an optimal cutoff threshold as this allows a large volume of data through (>90%) without allowing the lower quality wind measurements to contaminate the data set. Node 22 though presents a point of further work. It can be seen in figure 7 that more than 10% of the data reported on this node has been flagged by MetO quality control as failing the distance to cone threshold check during the period. This is nearly double the failure rate of the other ASCAT nodes. KNMI are aware of the

[1] Background values are those taken from a recent six hour forecast collocated at the observation location.

problems with node 22 and have updated the ASCAT product from 10th October 2007 (Marcos Portabella, personal communication) which has remedied this problem.

3. Forecast trial evaluation of ASCAT.

3.1 The trial configuration

The forecast trial was configured as N216 (half the operational resolution) with 50 vertical levels and used 4D Var. The period of the trial was 24th May – 23rd June 2007. The control suite contained QuikSCAT and ERS-2 data as well as all the other observation data that would have been operationally assimilated during this period. The experiment was the same as the control suite except that ASCAT wind data was added in.

Table 1. Assimilation characteristics for each wind observation.

Scatterometer	U,V observation error (m/s)	Thinning priority	% of all scatterometer data assimilated
ASCAT	2.0	1	58
ERS-2	2.0	2	3
SEAWINDS	2.0	3	39

For details of the assimilation methodology for scatterometers at the Met Office see [4]. An observation error of 2m/s was assigned to the U and V components of the ASCAT winds, which is the same as that for other scatterometers as shown in table 1.This may well be conservative and will need revisiting in future. Figure 8 shows the observation fit against background U component winds for several observation types for a typical six hour forecast assimilation window. It is clear in the figure that ASCAT delivers the closest fit to forecast winds of any ocean surface wind vector measurement system. It should be noted that for data assimilation the observation error chosen (for example in table 1) will usually be larger than the fit against background as shown in figure 8. This is because the observation error often “mops up” other sources of error not easily dealt with in the data assimilation system e.g. representativity error. It is interesting to note that the assumed observation error for ship U/V wind components is also 2m/s (and only 1.7m/s for buoy winds), which is perhaps not large enough in the light of the results shown in figure 8.

ASCAT was added to the forecast experiment and had the following quality checks in addition to the quality control flagging in the BUFR product:

- Lower Sea Surface Temperature threshold set to 273.15K
- Nodes 21 and 22 were blacklisted due to lower directional quality
- Upper absolute distance to cone threshold set to 1.8
- Solution likelihoods used in the cost function [4] are replaced with 1.0/N, where N is the number of wind ambiguities (usually 2 ambiguities resulting in a 50% probability for each wind)

These extra checks are quite conservative, which is appropriate for a first implementation of the instrument in the forecast model. Scatterometer data are thinned to one observation per grid box (the chosen report is that closest to centre of grid box using 92km thinning distance). In the thinning process, which reduces the amount of observations to a manageable number for the assimilation system, ASCAT was given greater priority than the QuikSCAT and ERS-2 scatterometers due to the lower errors of the ASCAT wind measurements. The end result of thinning and quality control results in 58% of scatterometer observations being assimilated from ASCAT. It should be noted that ERS-2 now only contributes approximately 3% of the scatterometer data for assimilation due to reduced coverage resulting from an on-board tape recorder failure.

3.2 Results

The headline result is that the ASCAT experiment finished +0.35 up in terms of the NWP index (verified against observations) against the control suite. Given that ASCAT adds approximately another 50% in term of coverage (not counting overlaps) an improvement in the scatterometer related contribution to the NWP index of approximately 50% on the QuikSCAT only result is not unreasonable when ASCAT is added to the assimilation system. This result is therefore consistent with what was expected given that there was already a good deal of QuikSCAT and ERS-2 scatterometer data in the control suite. The variation in the NWP index over the trial period is shown in figure 9. It is demonstrated later in section 4 that QuikSCAT produced a benefit of +0.66 against a no-scatterometer control.

3.3 Tropical Cyclone Gonu

Forecast tracks for TC Gonu were improved by 30% at 3 days forecast range. This is not statistically significant in itself as tropical cyclone performance must be averaged over a large number of tropical cyclone cases but nevertheless it is an encouraging result. Though C band is less affected by rain than Ku band it can be seen in figure 10 that some ASCAT data were contaminated in and around tropical cyclone Gonu. However, far more data is available for assimilation than is the case for QuikSCAT (figure 11) where much more data is contaminated by rain.

4. Discussion and further work.

4.1 Implementation of ASCAT

The forecast experiment presented in section 3.2 demonstrated that the OSI SAF level 2 ASCAT wind BUFR product is suitable for assimilation even though the refined backscatter calibration has yet to be applied by EUMETSAT. Further, it has been shown that this product produces an expected, measurable benefit even though QuikSCAT and ERS-2 scatterometers are already routinely assimilated. It was therefore decided that this configuration should be used in parallel suite 17 (PS17) prior to going operational. PS17 was started on 16th October 2007 and ran successfully for 6 weeks. Operational implementation of ASCAT in the global model followed on 27th November 2007.

4.2 Comparison of forecast scores for all scatterometers

The following trials (table 2) were run based on a forecast experiment with the following specification: N216 horizontal resolution, 50 vertical levels, 4DVar assimilation with all current observations assimilated to mirror operations. QuikSCAT data was taken from the NESDIS level 2 Dirth BUFR product. The period of the 30 day forecast experiment was 24th May – 23rd June 2007. A “NOSCAT” control (secfb) was generated from this experiment by denying all scatterometer data (QuikSCAT and ERS-2) from the assimilation cycles.

Table 2. Description of forecast trials.

Trial	Description (experiment id)
ALLSCAT	QuikSCAT, ASCAT and ERS-2 scatterometers assimilated together (secfa)
NOSCAT	No scatterometers (secfb)
ASCAT only	ASCAT is the only scatterometer assimilated (secff)
QuikSCAT only	QuikSCAT is the only scatterometer assimilated (secfd)
QuikSCAT and ERS-2 only	QuikSCAT and ERS-2 only assimilated (sebua) which was the previous operational configuration

The following table summarises the index scores for four scatterometer trials. The performance of each of these four trials were compared against the NOSCAT control. The results can be seen in table 3. Scores are shown for verification against observations and analysis. As a guide, an uncertainty of about +/-0.05 should be assigned to observations and analyses scores.

Table 3. Skill scores against NOSCAT control for trials.

Trial compared with NOSCAT control	Score against observations (+/- 0.05)	Score against analysis (+/- 0.05)
ALLSCAT	+0.97	-0.07
ASCAT only	+0.61	+0.29
QuikSCAT only	+0.66	-0.08
QuikSCAT&ERS-2 only	+0.62	-0.06

There are three interesting results that can be drawn from the above table:

- The two trials that used ASCAT assimilation only and QuikSCAT assimilation only gave comparable forecast performance as verified against observations. This demonstrates clearly that ASCAT now provides data of as much benefit to the numerical weather prediction community as QuikSCAT has done for many years.

- It is clear in the scores against observations that the Met Office global forecasts benefit greatly from the addition of a second global coverage scatterometer (+0.97 for ASCAT&QuikSCAT versus approximately +0.6 for QuikSCAT or ASCAT only). This is a remarkable result and demonstrates that two global coverage scatterometer missions deliver significantly more benefit to forecasts than a single global coverage scatterometer mission operating alone.

- It is puzzling however to note that the scores against analyses are not consistent for all scatterometers. Only ASCAT shows a significant global benefit against analyses. On inspection of the output statistics (against analyses) is it was clear that the forecast performance of all scatterometers was generally acceptable except for tropical 850hpa winds. This also true for ASCAT but less apparent in the tropical wind skill scores. It should be stressed that these forecast degradations are not observable in the forecast performance statistics as verified against observations. Tropical wind validation against analyses is problematic and so this is not considered to be a problem with the scatterometer wind assimilation.

4.3 Further work

Some further work is required to better tune the quality control of ASCAT in the Met Office Observations Processing System with the expectation of a small improvement in forecast impact. A long time series of data collected after the implementation at KNMI of updated backscatter calibration following the EUMETSAT transponder calibration campaign will be useful for tuning the distance to cone threshold as well as investigating whether or not the blacklisting of the innermost node on the left and right hand swaths can be relaxed. Wind data retrieved from an updated sigma0 calibration are expected some time in early 2008.

Whilst Met Office conservative quality control is responsible for flagging some of the data in the heart of TC Gonu, some of the data in the centre of the cyclone is unusable in the BUFR product. There are many reasons why this might be. It is well known for example that C band VV polarisation is less useful at wind speeds greater than 20m/s as the radar backscatter tends to saturate under these conditions. C band backscatter is affected in three ways from rain during a tropical cyclone:

- backscatter from rain in the atmosphere - though this a weaker effect than is the case for Ku band
- mechanical damping of surface waves by rain
- surface dielectric constant (and therefore reflectivity) changes due to surface salinity changes during strong rain events

The C band ENVISAT-ASAR imagery in figure 12 is shown below to demonstrate that surface wind is not the only factor affecting sea surface radar backscatter in C band. Further work is required to investigate optimal quality control methods in regions where there are tropical cyclones.

5. Acknowledgements.

The authors would like to acknowledge Mike Thurlow for suite support and Malcolm E. Brooks for support with post-processing of the forecast experiment using the new TRUI software.

6. References.

[1] ASCAT product user manual, KNMI, 2007.
http://www.knmi.nl/scatterometer/publications/pdf/ASCAT_Product_Manual.pdf

[2] Z. Bartalis; W. Wagner , V. Naeimi , S. Hasenauer , K. Scipal , H. Bonekamp , J. Figa , C. Anderson,; 2007: Initial soil moisture retrievals from the METOP-A Advanced Scatterometer (ASCAT), Geophysical Research Letters, in press.

[3] Kerkmann, J., 1998: Review on Scatterometer Winds, EUMETSAT technical Department Technical Memorandum No. 3.

[4] Candy, B., 2001: The Assimilation of Ambiguous Scatterometer Winds Using a Variational Technique: Method and Forecast Impact. Forecasting Research Tech. Rep. 349.

[5] Candy, B. and Keogh S.J. 2006: The Impact of Seawinds Scatterometer Data on Met Office Global Model Analyses and Forecasts, Forecasting Research Tech. Rep. 493.

[6] Keogh, S.J., Candy, B and Offiler D., 2006: ERS-2 scatterometer - reintroduction into Met Office global model. Forecasting Research Tech. Rep. 473.

Figures.

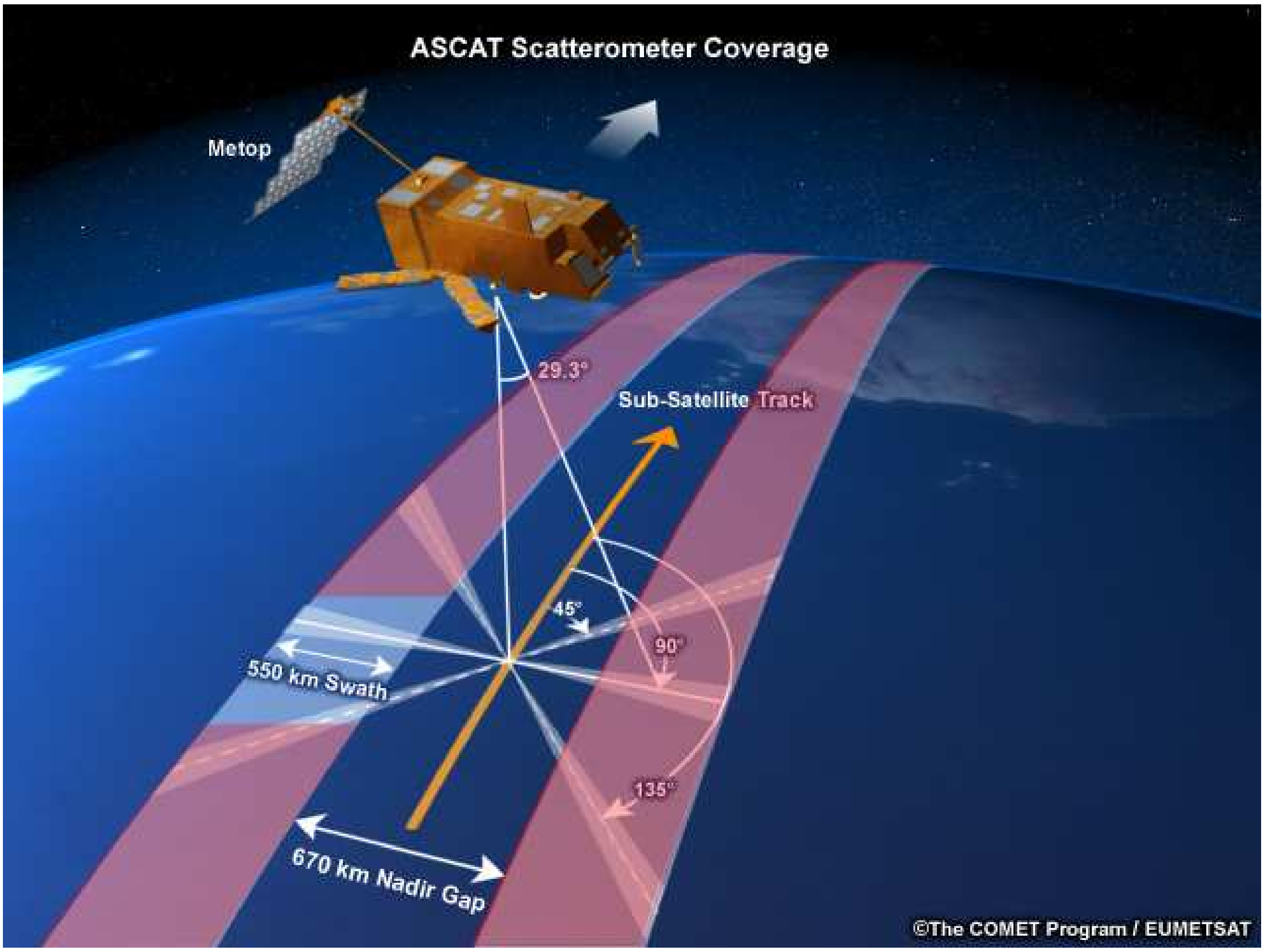

Figure 1. The ASCAT swath, from EUMETSAT web site.

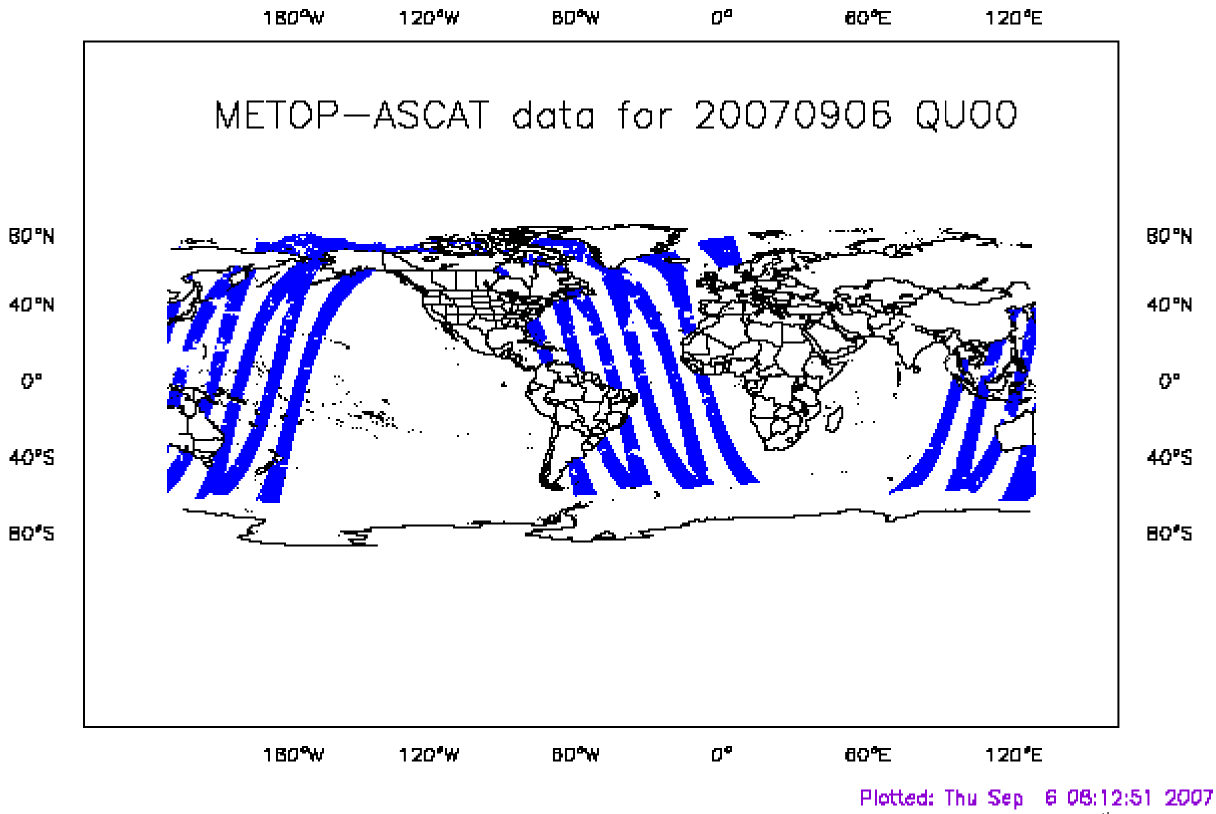

Figure 2. ASCAT coverage during the 0Z assimilation window for the Met Office global model on 6th September 2007.

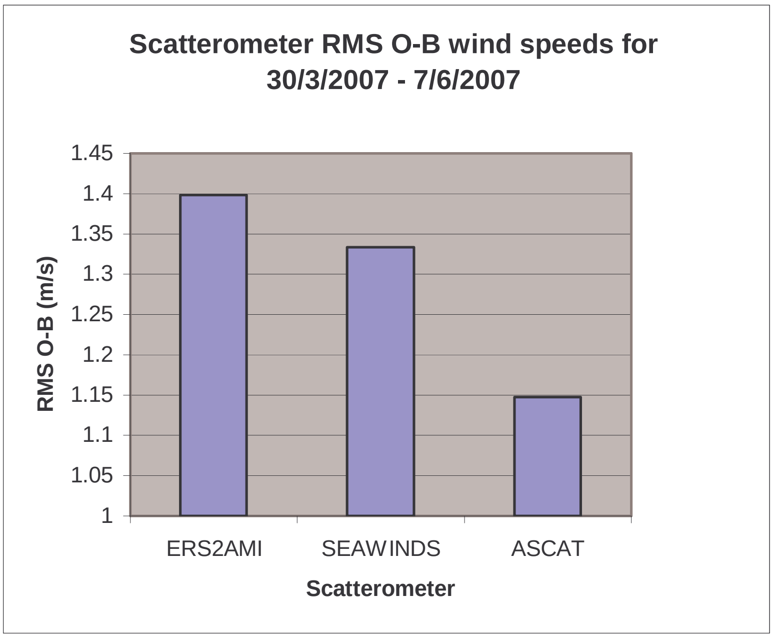

Figure 3. RMS O-B wind speed is lower for ASCAT than for other currently assimilated scatterometers, where O is the observed wind speed and B is the background model wind speed from the most recent Met Office 6 hour forecast. The values are calculated using quality controlled data from 30th March – 7th June 2007.

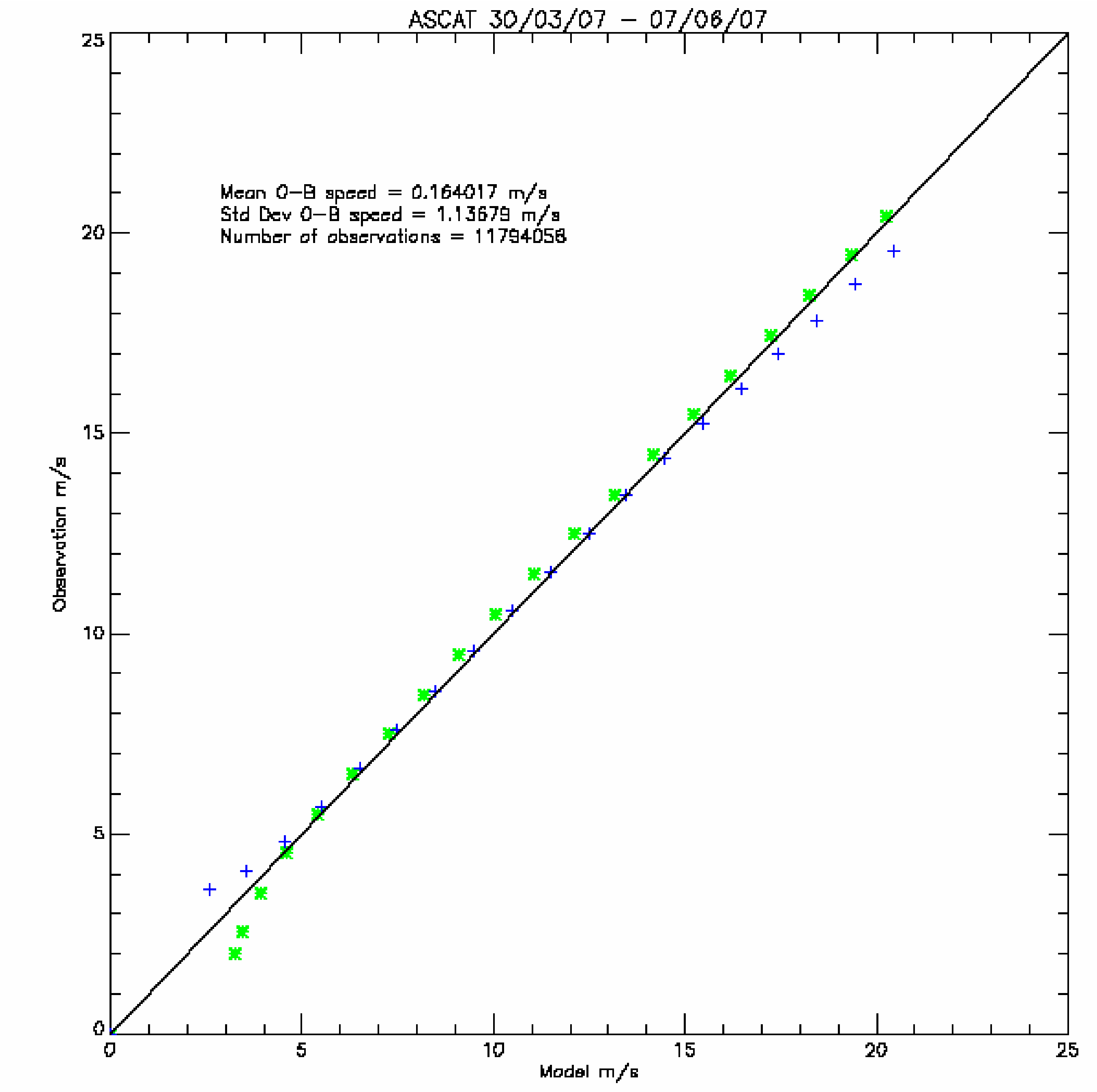

Figure 4. ASCAT is almost bias free compared to Met Office forecast model wind speeds between 2-20m/s. Green = data binned by observed values in 1m/s bins, Blue = data binned by model value in 1m/s bins. A small deviation can be seen at wind speeds less than 5m/s, though the symmetry of the blue and green symbols about the line y=x suggests this is largely due to representativity error rather than systematic bias.

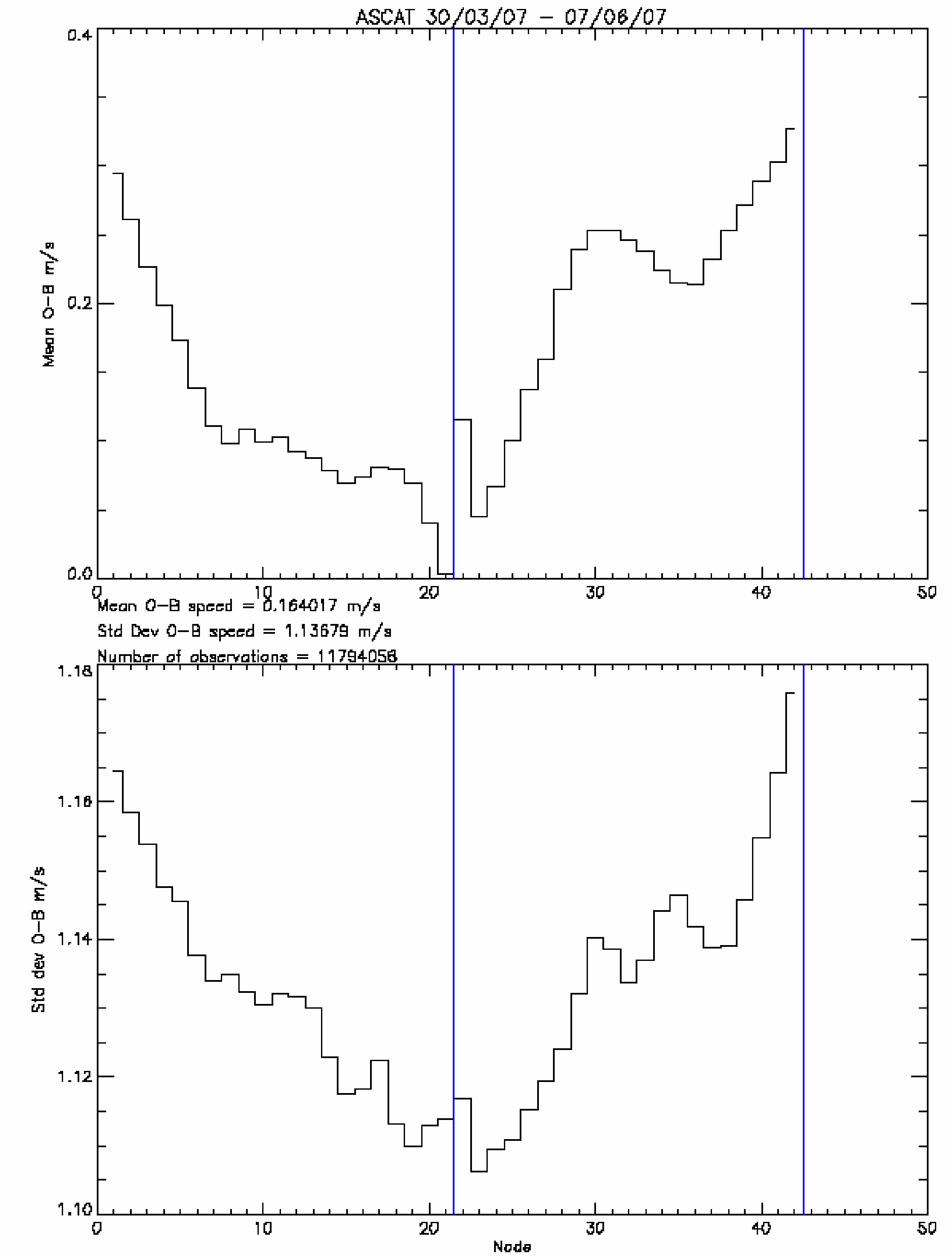

Figure 5. Wind speed data quality increases toward the centre of the swath where backscatter is greatest. Blue lines indicate the left and right hand swath boundaries. Upper= mean difference between observed and model values. Lower plot = standard deviation of difference between observed and model values. In the right hand swath it can be seen that there is increased noise in the wind speed measurements compared to what would be expected if the right hand swath were a symmetrical reflection of the left hand swath. This is could be a calibration or noise issue that may be addressed following the completion of the EUMETSAT transponder calibration campaign in early 2008.

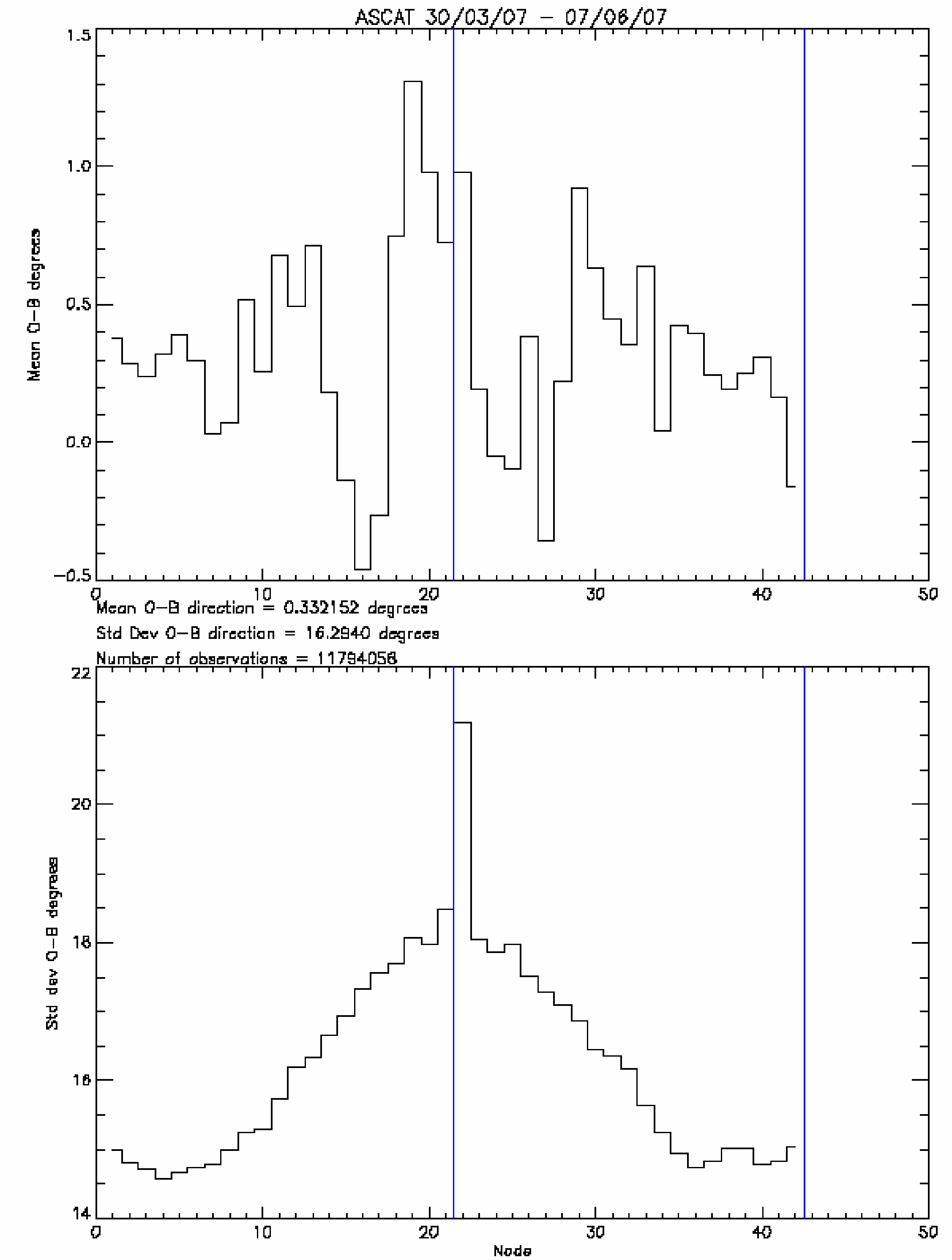

Figure 6. Wind direction quality is poorest in the centre of the swath where beam incidence angle is highest. The change in sigma0 with wind direction at these high incidence angles is smaller than for the outer nodes. Blue lines indicate the left and right hand swath boundaries. These plots were for wind speeds in the range 2-25m/s.

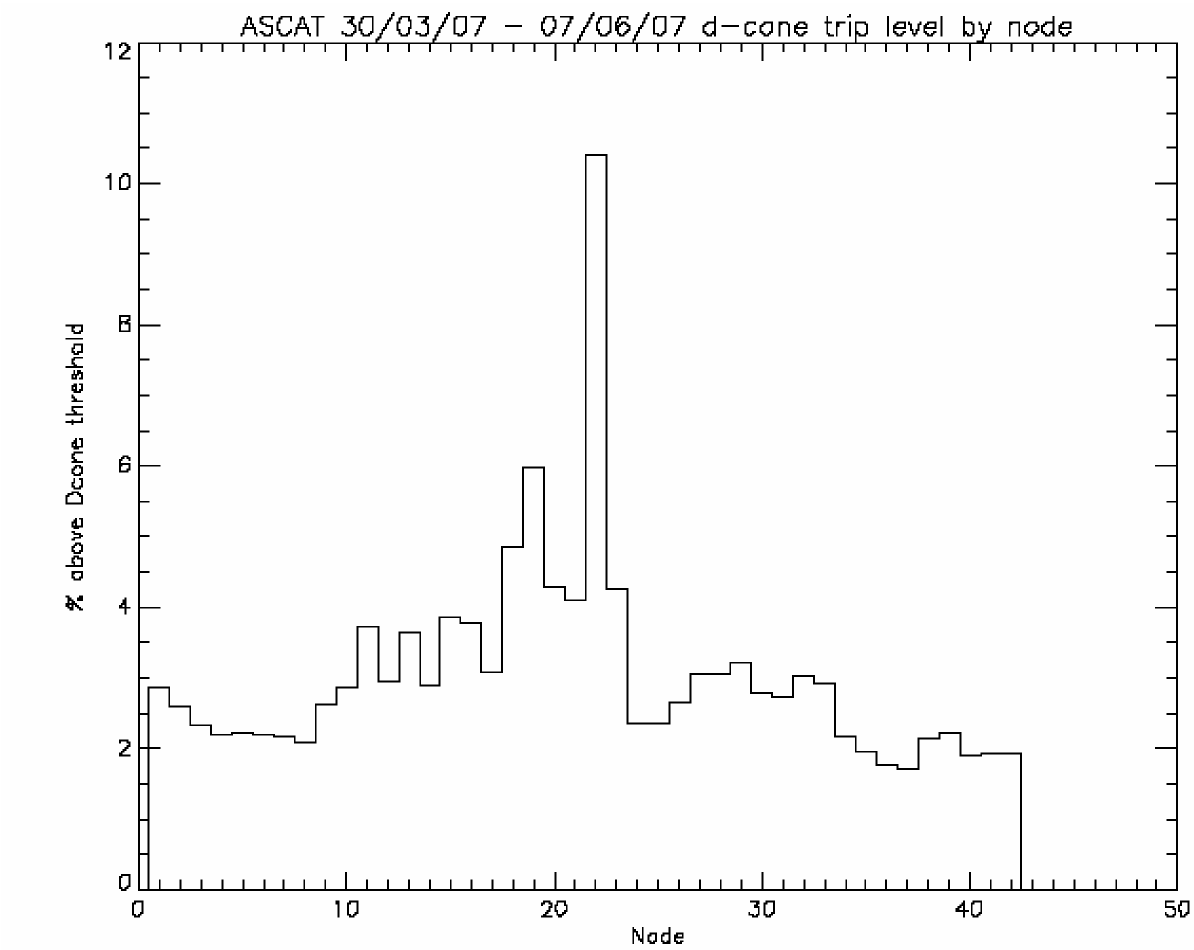

Figure 7. Percentage of reports with |distance to cone| > 1.8 for each of the 42 ASCAT nodes. Node 22 has almost double the failure rate of other nodes. This has now been reduced by KNMI's new processing since 10th October 2007, with the trip rate for node 22 being around 7.5% as opposed to 10.5%.

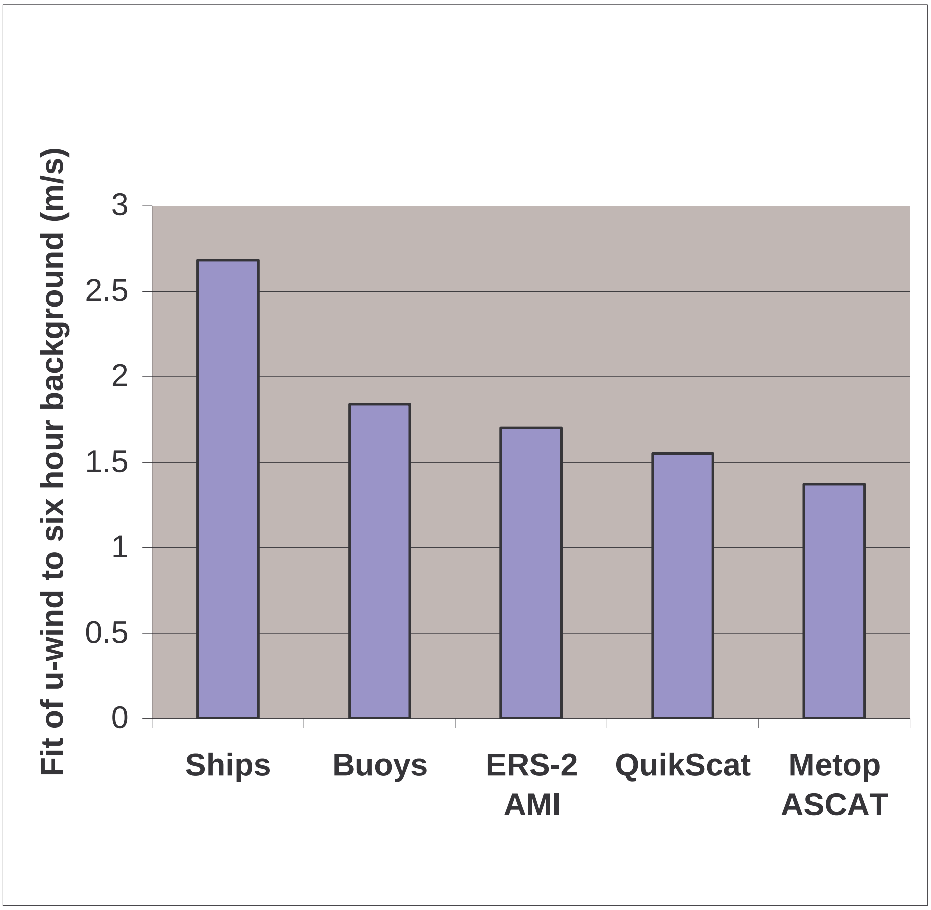

Figure 8. Fit of U wind components over the ocean against Met Office global background for various observation types. ASCAT displays the best fit to the background of any ocean surface wind vector observation type.

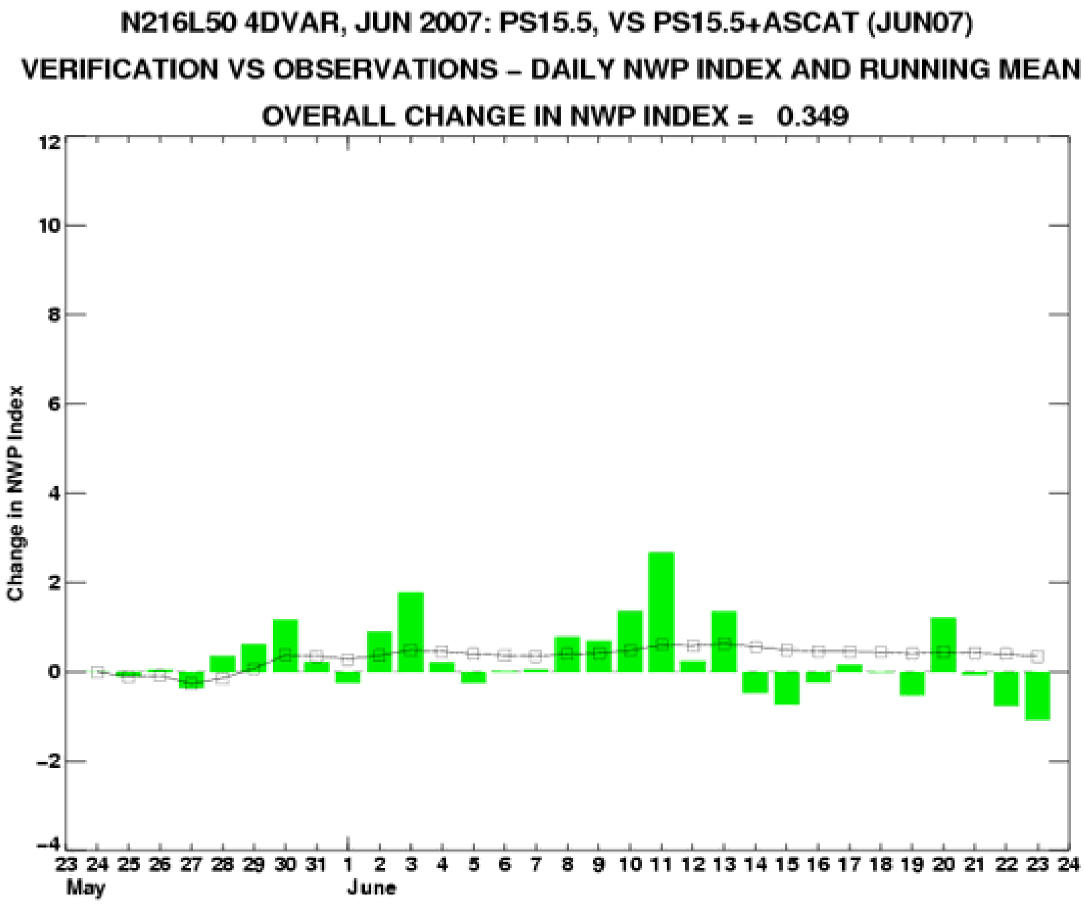

Figure 9. The NWP index varies over the trial but has some strong positive signals over the period.

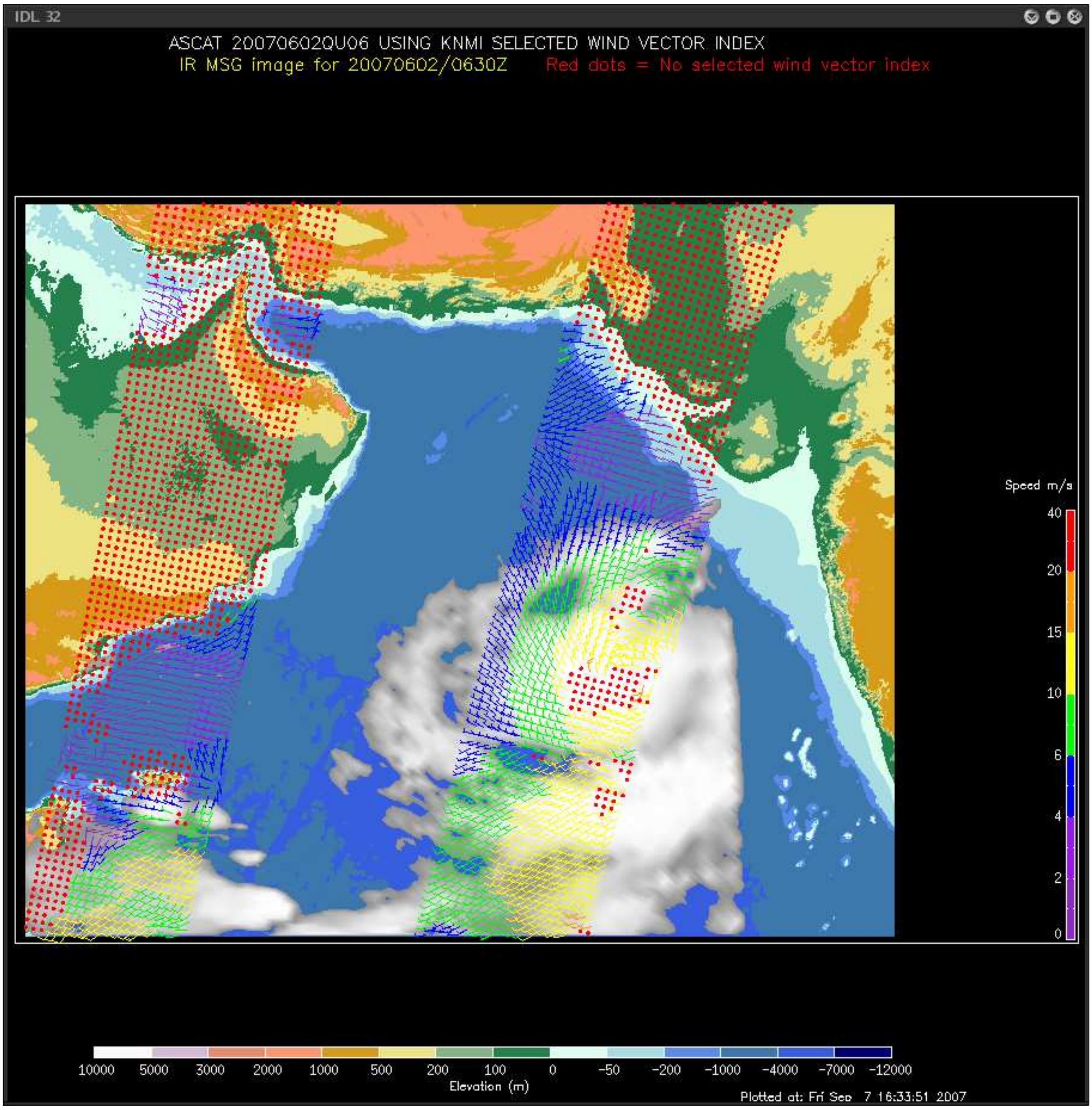

Figure 10. Red dots mark data where KNMI have not provided a chosen wind index in the BUFR. Cloud image is constructed from infra red data from Meteosat 2nd Generation. Note that thinning has not been applied to these data. Also note that KNMI wind alias is selected in this image rather than UK Met Office. In this case the centre of the tropical cyclone is clear in the ASCAT scatterometer data.

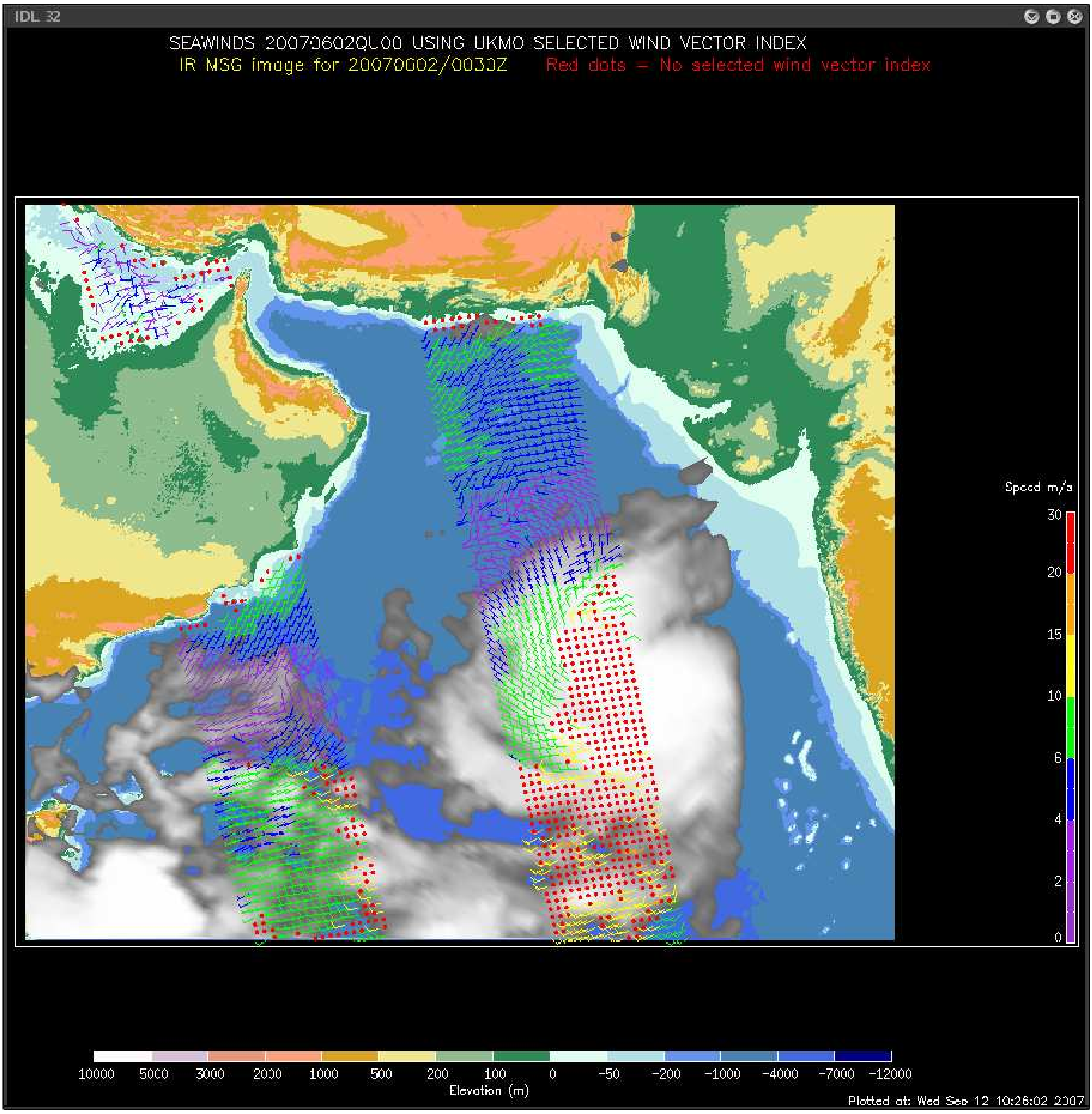

Figure 11. This figure demonstrates how much more data fails QC for QuikSCAT than for ASCAT for this TC Gonu case, thereby demonstrating the benefit of using C band rather than Ku band in rainy conditions. The centre of the tropical cyclone is not obvious from the above QuikSCAT data.

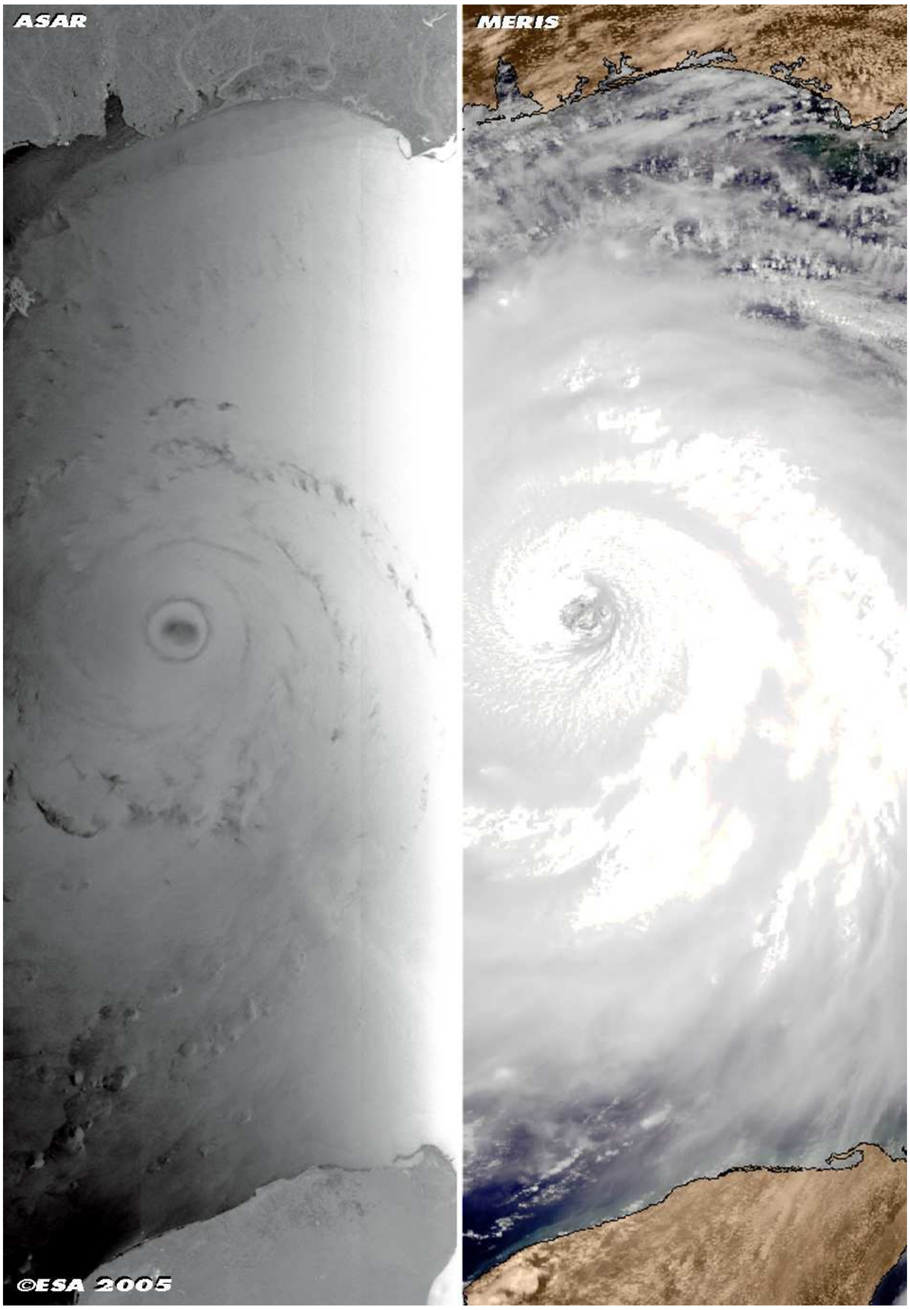

Figure 12. C band ENVISAR ASAR radar backscatter during Hurricane Katrina in Gulf of Mexico alongside MERIS cloud imagery. Imagery acquired on 28th August 2005.