TECHNICAL MEMORANDUM

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Accuracy of the ERS 1 altimeter derived Fast Delivery Products for wave data assimilation

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1. INTRODUCTION

After many years of active work by the Wave Modelling Group (WAM, *Komen et al*, 1994), operational wave forecasts over the globe and in the Mediterranean Sea started at ECMWF in July 1992, based on the WAM third generation model (*WAMDI*, 1989). On 16 August 1993, the assimilation of the ERS-1 altimeter-derived significant wave height (swh) was introduced into the operational global wave model (*Guillaume and Hansen*, 1993). In a comparison study over the period 14-31 July 1993, a noticeable impact is found: with assimilation the wave analyses and short-range forecasts compare better, on average, with buoy measurements (*Guillaume and Hansen*, 1993). With assimilation, waves are on average higher in the Atlantic and South-East Pacific, and lower in the Gulf of Alaska, the Southern Oceans and the Arabian Sea (Fig 1). The largest decrease is obtained in the areas of highest waves (Fig 2). Fig 3 shows that, after assimilation, the statistical distribution of the model swh under the satellite track is modified, with a sharper and more narrow peak. This new shape indicates that waves lower than 2 metre have been increased while waves higher than 2 metre have been decreased. Mean statistical results are not sufficient to analyse this behaviour and answer the following questions: is there an overestimation of the high waves (wind) by the models, or is there an underestimation by the altimeter; does the model underestimate the low waves (wind), or is there an overestimation by the altimeter? An underestimation of high waves by the altimeter has been explained theoretically (*Hayne and Hancock*, 1990; *Branger et al*, 1991) and has been found in other comparison experiments (*Guillaume and Mognard*, 1992; *Carter et al*, 1992). An overestimation of low waves by the altimeter was first reported by *Mastenbroek and Makin* (1992) in a comparison with buoy data in the North Sea but, to our knowledge, has not been further investigated. For the assimilation of altimeter data in the Mediterranean Sea, where low sea-states are often encountered, this issue needs to be clarified. In our comparison study, as well as in any study based on altimeter-derived data, some processing is performed on the Fast Delivery Products (FDP) in addition to the onboard and ground station processing performed by ESA. This paper reviews the various processing steps made at ECMWF on the ERS-1 Fast Delivery Products before comparing them with the model results and before assimilating them into the wave model. Some of these quality control tests have been designed to overcome certain deficiencies in the ERS-1 on-board treatment. This paper highlights how these affect the use of the data for assimilation in the wave models and for comparison studies.

2. QUALITY CONTROL OF THE ERS-1 FAST DELIVERY PRODUCTS

The ERS-1 altimeter data used for assimilation in the wave model and for real-time comparison studies are obtained from the ESA Fast Delivery Products (FDP). Some quality controls are first performed. These quality control tests were introduced by *Bauer et al* (1992) and updated for the present operational environment by *Hansen and Günther* (1992). All these quality control tests are based on the use of the significant wave height. When the swh is quality controlled/averaged or rejected, the same procedure of averaging or rejecting is applied to the accompanying wind. Based on the data set gathered for the period 14-31 July, 1993, the various processing steps involved in the quality control are reviewed. The impact of each quality control test on the original data set is shown.

2.1 In-coming data set

From each FDP record, the significant wave height (swh), 10 metre wind speed (u10), location and time are gathered. Fig 4.1 shows the statistical distribution of all the significant wave heights received during the period July 14-31, 1993. Fig 5.1 gives the distribution of all the 10 metre wind speeds received during the same period. The swh distribution (Fig 4.1) has a peak at 2.2 m and exhibits some erratic features, for the first bin (0 m) and for high waves. There is a cut-off at 0.5 metre which is due to a lack of measurement capability of the ERS-1 altimeter at low amplitude. However the count in the bin at 0.5 metre is 5 times higher the count in the bin for 0.6 m waves. This suggests there is a cut-off effect, which aliases the contribution of the 0.1, 0.2, 0.3, 0.4 and 0.5 metre waves. For the wind speed (Fig 5.1), the peak of the distribution is at 8 m/s, and there are just two erratic bins, at 0 and 34 m/s.

2.2 Elimination of the duplicate records

Some records are found several times in the FDP. After elimination of the additional duplicated records (3.5% of the total number of records), the swh and wind speed statistical distributions are essentially unchanged (Figs 4.2 and 5.2).

2.3 Land/Sea mask

The records reported outside the wave model grid are eliminated. One third (34.2%) of the total number of records are eliminated with this test. Fig 4.3 gives the new swh distribution. The erratic features highlighted in 4.1 are less important and there is a nearly complete disappearance of waves higher than 8 metres. The number of records in the 0.5 m band is now in accordance with the cut-off effect. For the wind speed (Fig 5.3) the two erratic bins, at 0 and 34 m/s are reduced, and the tail of the distribution no longer includes wind speed higher than 23 m/s. This suggests that in the FDP, many records of significant wave heights and wind speed are contaminated by land. However the present test does not seem to eliminate satisfactorily all these contaminated data.

2.4 Significant wave height out of range

The records corresponding to out of range swh are discarded. After an empirical investigation of the decoded FDP, an upper limit of 17.479 m and a lower limit of 0.441 m were chosen (*Günther and Hansen*, 1992). This test eliminates 6% of the total number of records. Fig 4.4 shows that in the swh distribution, the three suspicious bins have disappeared. Fig 5.4 gives the wind speed distribution for these selected records: the 34 m/s bin has disappeared and the 0 m/s bin is smaller.

2.5 Along track variability

The records are then organized into sequences of at most 30 consecutive observations, with a gap between observations less than 3 seconds. Each sequence is analysed. The next test is to verify that the sequence starts and ends smoothly, again to avoid any land contaminated data. Records showing a swh jump of more than 2 metres at the beginning or at the end of a sequence are rejected. Less than 0.4% of the records are rejected on this test. The swh distribution is not affected much (Fig 4.5) but, as before, the rejected records are for low and high waves (Fig 4.5a). This also applies for the wind speed distribution (Figs 5.5 and 5.5a).

2.6 Short sequences

Records corresponding to sequences shorter than 20 observations are rejected. Only 1.8% of the total number of records are rejected on this test, but again mainly corresponding to low and high wave (Figs 4.6 and 4.6a) and to low and high wind speed (Figs 5.6 and 5.6a).

2.7 Elimination of spikes

In each sequence, the records corresponding to spikes are eliminated. A spike is identified as soon as the swh value is more than a threshold, dh, apart from the mean swh of the sequence. dh is computed from the swh standard deviation of the whole sequence (std) according to dh = Min [1., 3 std], with S.I units for all quantities. Only 0.7% of the total number of records are eliminated with this test, corresponding again mainly to high and low values. (Figs 4.7 and 4.7a, Figs 5.7 and 5.7a).

2.8 Elimination of highly variable sequences

Finally all the records from a sequence with a too high swh standard deviation are eliminated. With the threshold chosen, higher than 0.5 m or more than half the mean swh, whichever is greater, no records have been eliminated in the period studied. The total number of ERS-1 altimeter measurements that are selected after these height tests for the period 14-31 July 1993 amounts to 469368.

3. FURTHER PRE-PROCESSING FOR COMPARISON AND ASSIMILATION

In order to match the spatial discretisation of the wave model, the altimeter significant wave height and 10 metre wind speed are averaged to produce "super-observations" that will be used later for the comparison with the model results or for assimilation. The averaging method is slightly different depending on the application. For the real-time comparison studies the records are averaged along track, over the sequences defined in section 2.5. For the assimilation the averaging is made over boxes centred at the wave model grid point and an additional quality control is added at this stage (*Janssen et al*, 1989).

3.1 Effect of along track averaging

Fig 6.1 shows the swh distribution after averaging over the along track sequences. The main effect is a nearly complete disappearance of the waves between 0.5 and 1 metre and a broadening of the peak (Fig 6.1a). Fig 7.1 shows the 10 metre wind speed distribution. There is a slight shift of the distribution towards lower wind speed (Fig 7.1a). After this averaging the number of super-observations produced is 15827.

3.2 Effect of box averaging

The data that have been selected after the quality control described in section 2, are averaged on a box whose size is the mesh size of the wave model grid. Figs 6.2, 6.2a, 7.2 and 7.2a show that for a 3 degree grid the box-averaging has similar effect on the swh and u10 distributions as the along-track averaging: a similar number of super-observations are produced (13171), there is a disappearance of the low waves, a broadening of the distribution peaks, and a shift of the wind distribution toward lower wind values. For a 1.5 degree grid, similar effects are found for a total number of 22951 super-observations. But for a mesh size of 0.5 degrees (Figs 6.3, 6.3a, 7.3 and 7.3a), the total number of super-observations is 74670, the peak of the distribution is broader and a greater percentage of high waves are found in the super-observations.

Before being assimilated these averaged data go through an additional quality control which assures that the average over a box is made over more than 4 points, and that the variability of data in the box is not too high. The effect of this quality control is shown in Figs 8 and 9 in the case of a 3 degree grid (Figs 8.1, 9.1) and 0.5 degree grid (Figs 8.2, and 9.2). With a 3 degree mesh, 10% of the data are discarded with this quality control, mainly high and low values (Figs 8.1a and 9.1a). For a 1.5 degree mesh, a similar effect is obtained. But for the 0.5 degree mesh size, up to 22% of the data are rejected (Figs 8.2a and 9.2a), mainly in the high and low wave range.

4. CONCLUSION

The quality control, which needs to be introduced to eliminate contaminated data (section 2), leads to an elimination of low and high sea-state data. Because the FDP products are already an average of 20 bin data

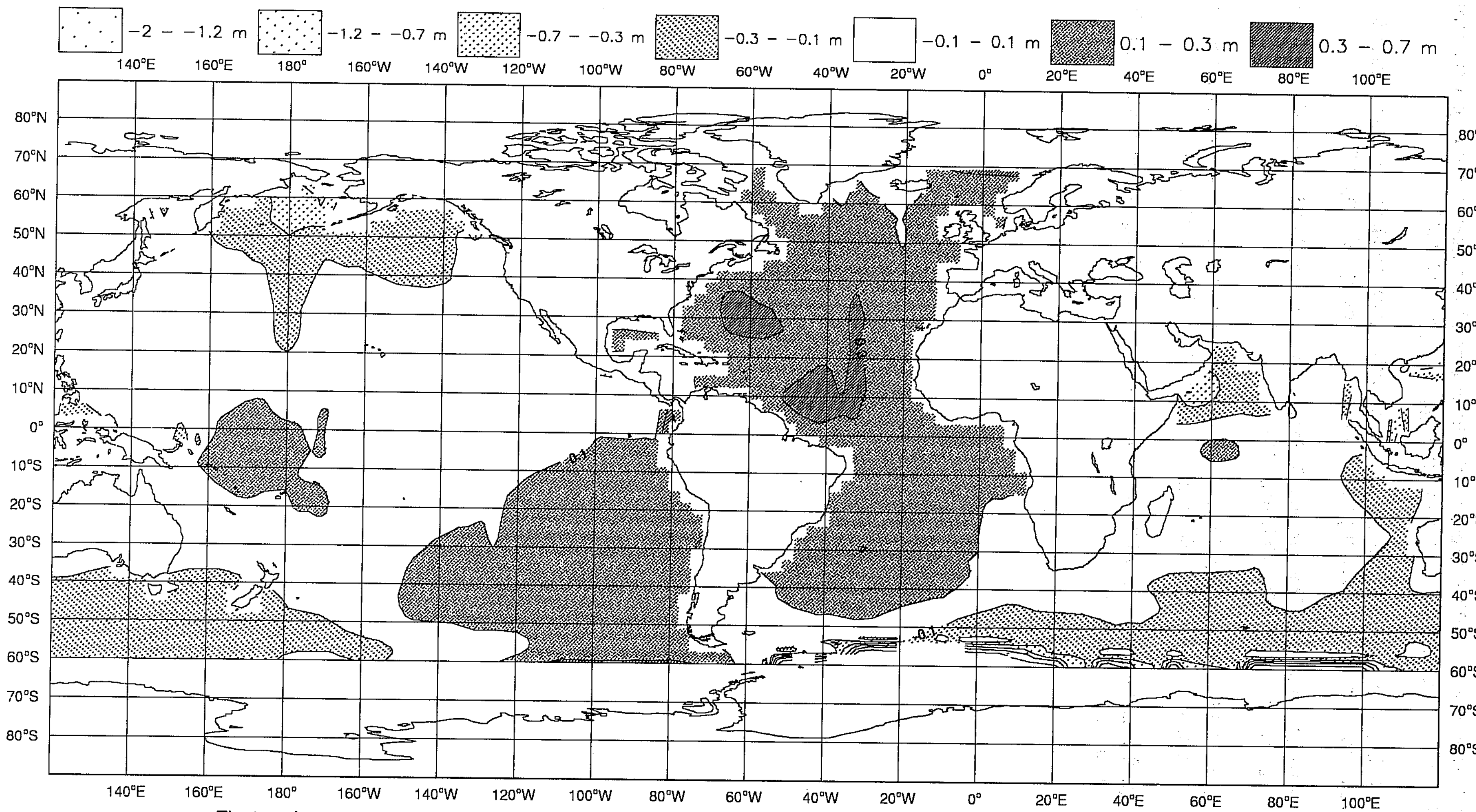


Fig 1 Impact of a continuous assimilation of altimeter significant wave height on the wave field analysis. Difference of the mean significant wave height for the period July 1993, 14-31 obtained with assimilation minus the one obtained without assimilation.

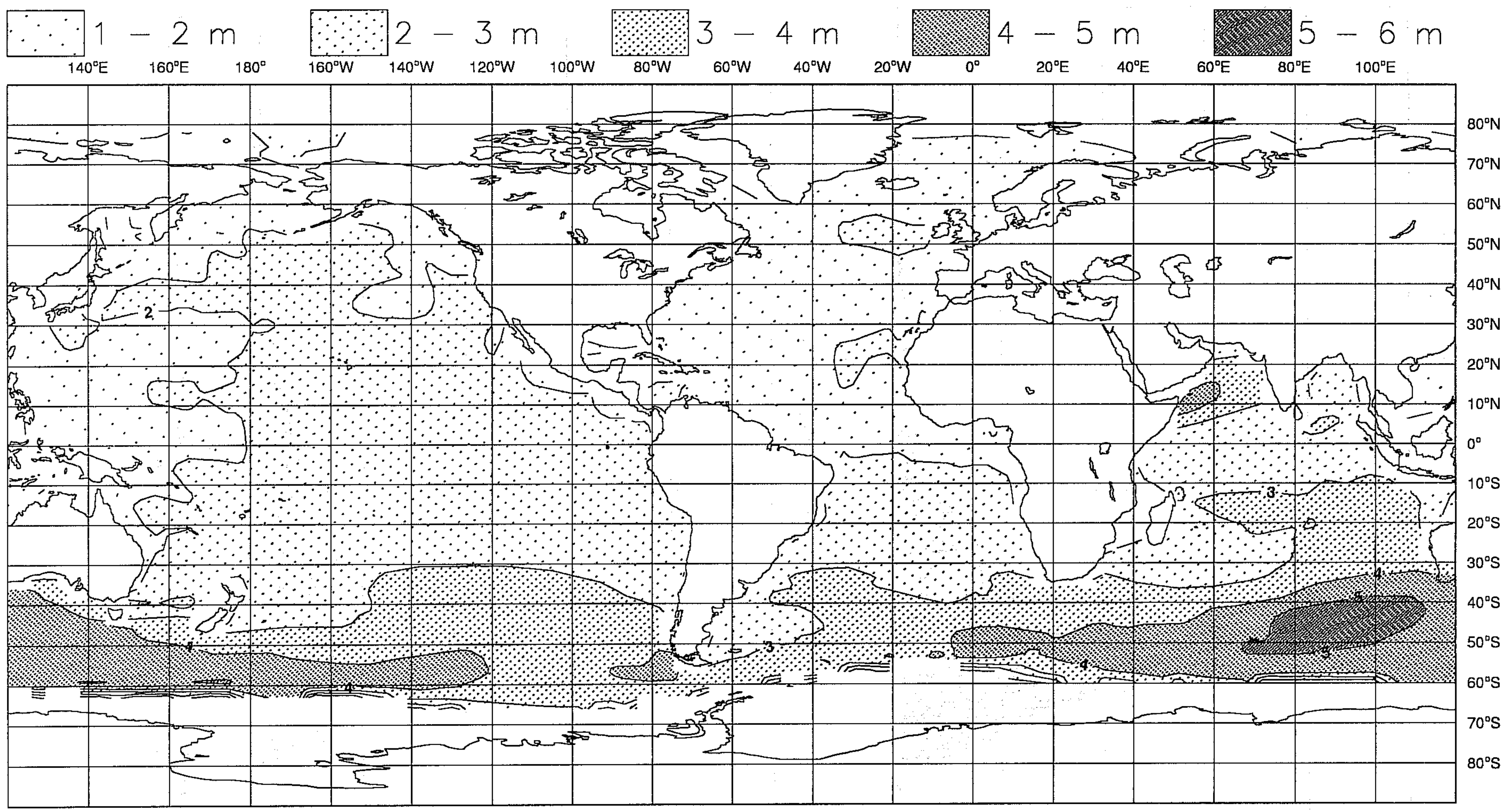


Fig 2 Mean significant wave height for the period July 1993, 14-31 obtained without assimilation.

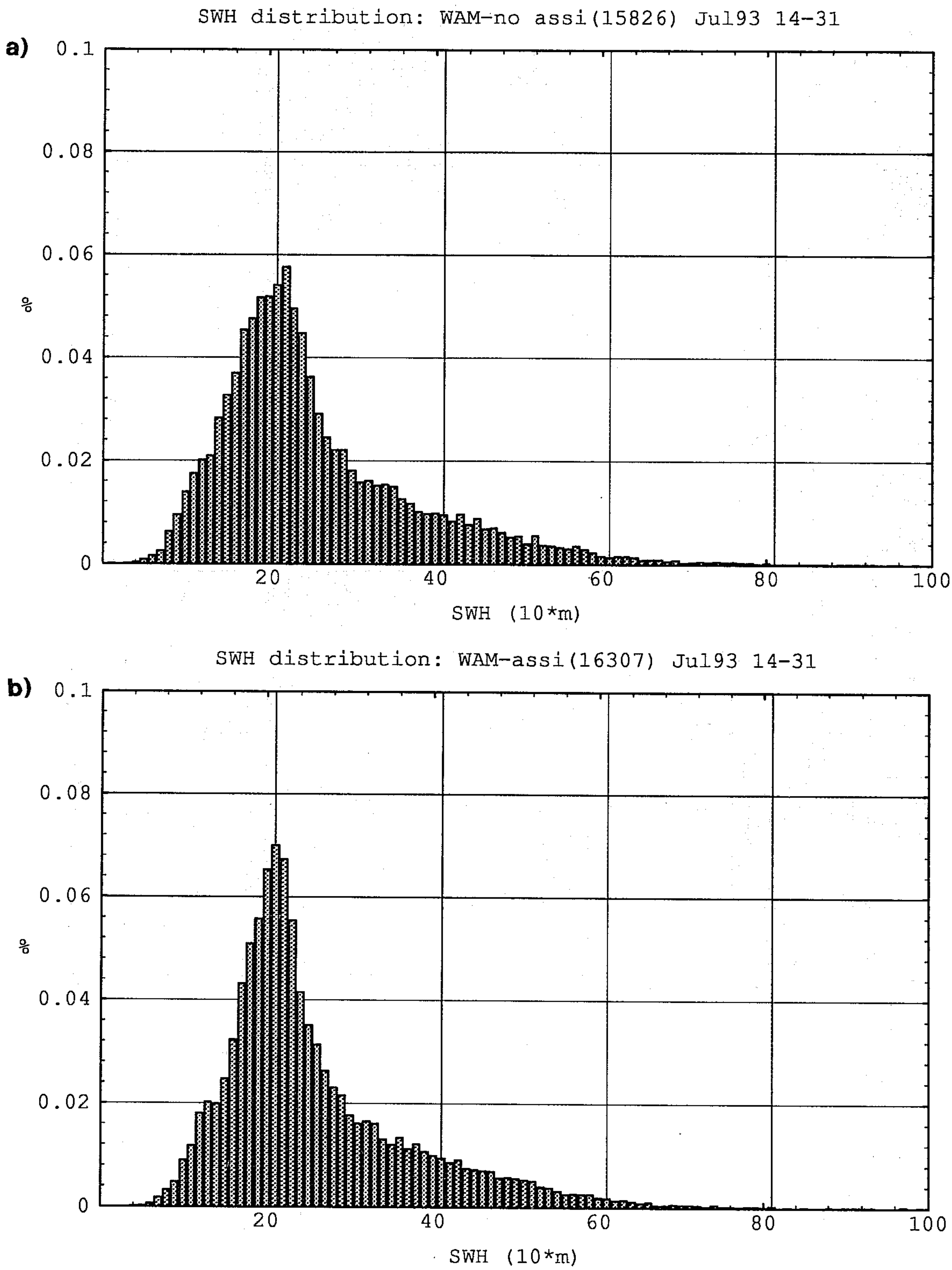


Fig 3 Statistical distribution of the model significant wave heights under the track of the satellite for the period 14-31 July 1993: (a) run without assimilation, (b) run with assimilation.

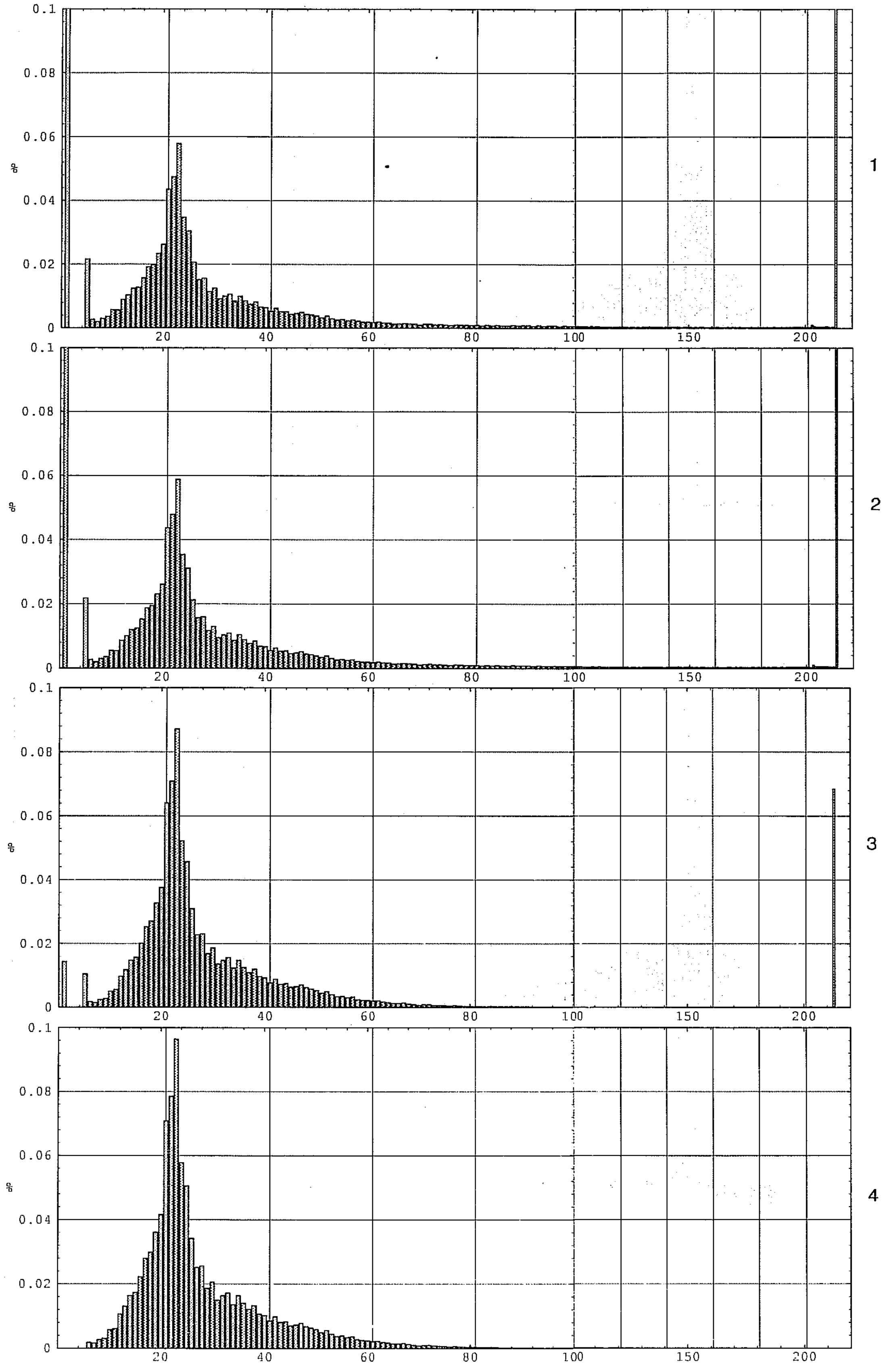
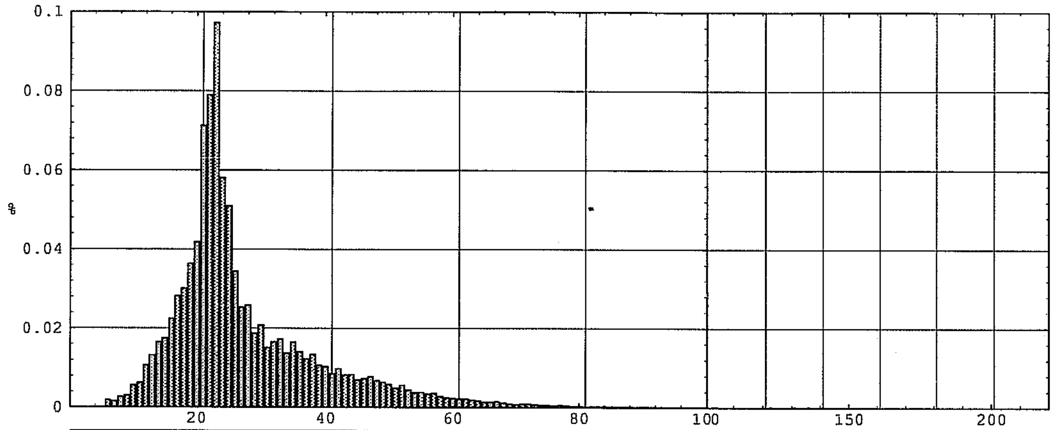


Fig 4 Impact of the ECMWF quality control on the statistical distribution of the significant wave height: (1) swh statistical distribution of all the in-coming Fast Delivery Products for the period July 1993, 14-31, (2) after elimination of the duplicate records, (3) after applying the wave model land/sea mask, (4) after elimination of the records with swh out of range. Thereafter, the data are organised into sequences, and the quality control discard records depending on the along track variability over the sequence: (5) after elimination of the records near to land, (5a) distribution difference to (4), (6) after elimination of short sequence, (6a) distribution difference to (5), (7) after elimination of spikes, (7a) distribution difference to (6), (8) after elimination of highly variable sequences, which is in this case identical to (7).



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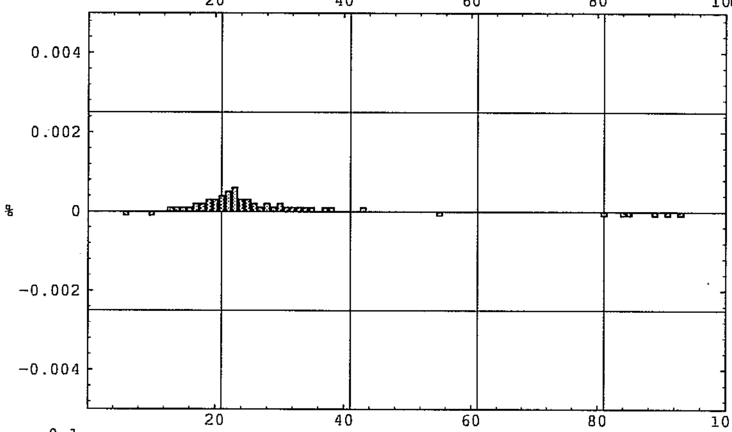

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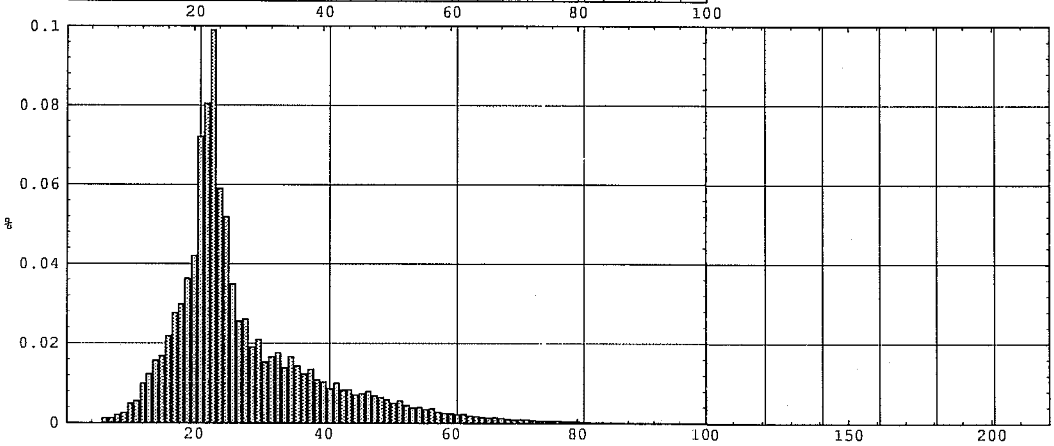

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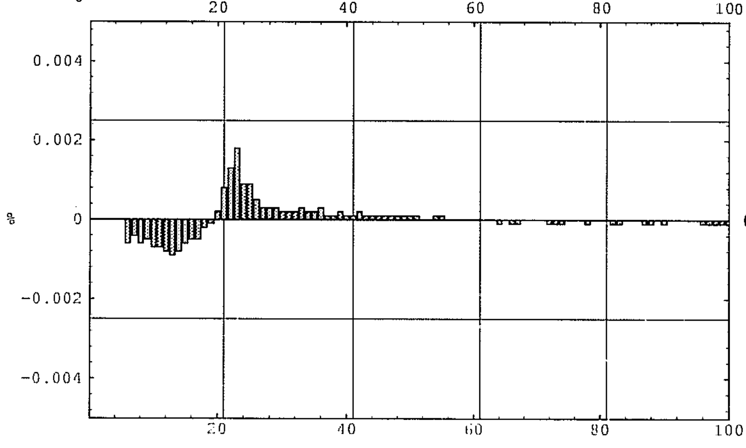

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Fig. 4 Continued

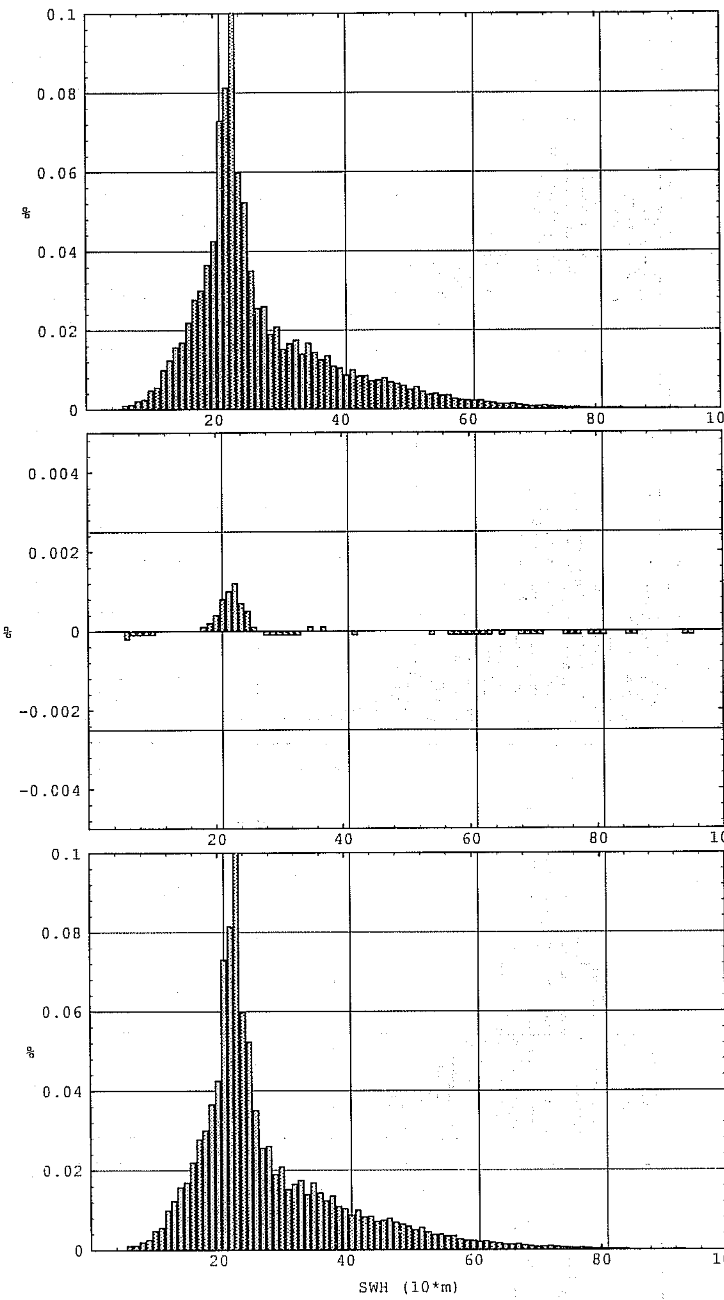

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Fig. 4 Continued

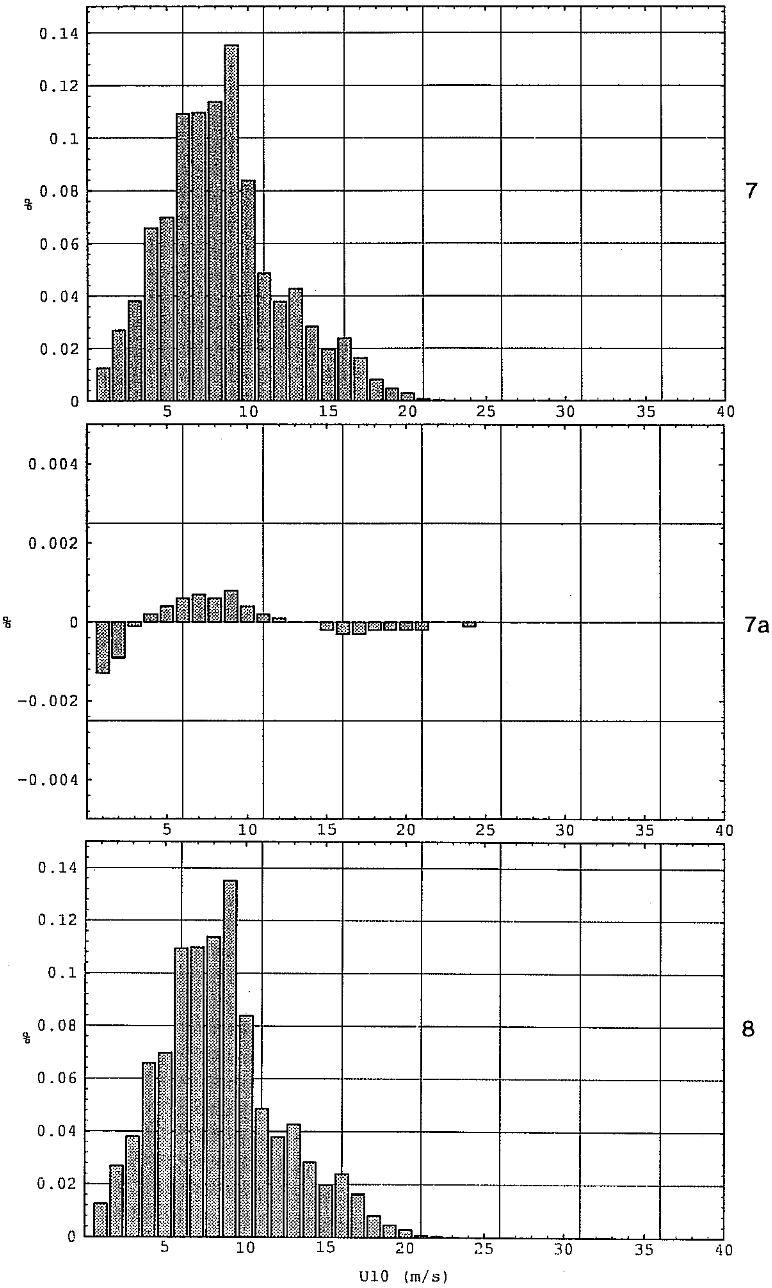

Fig. 5 Continued

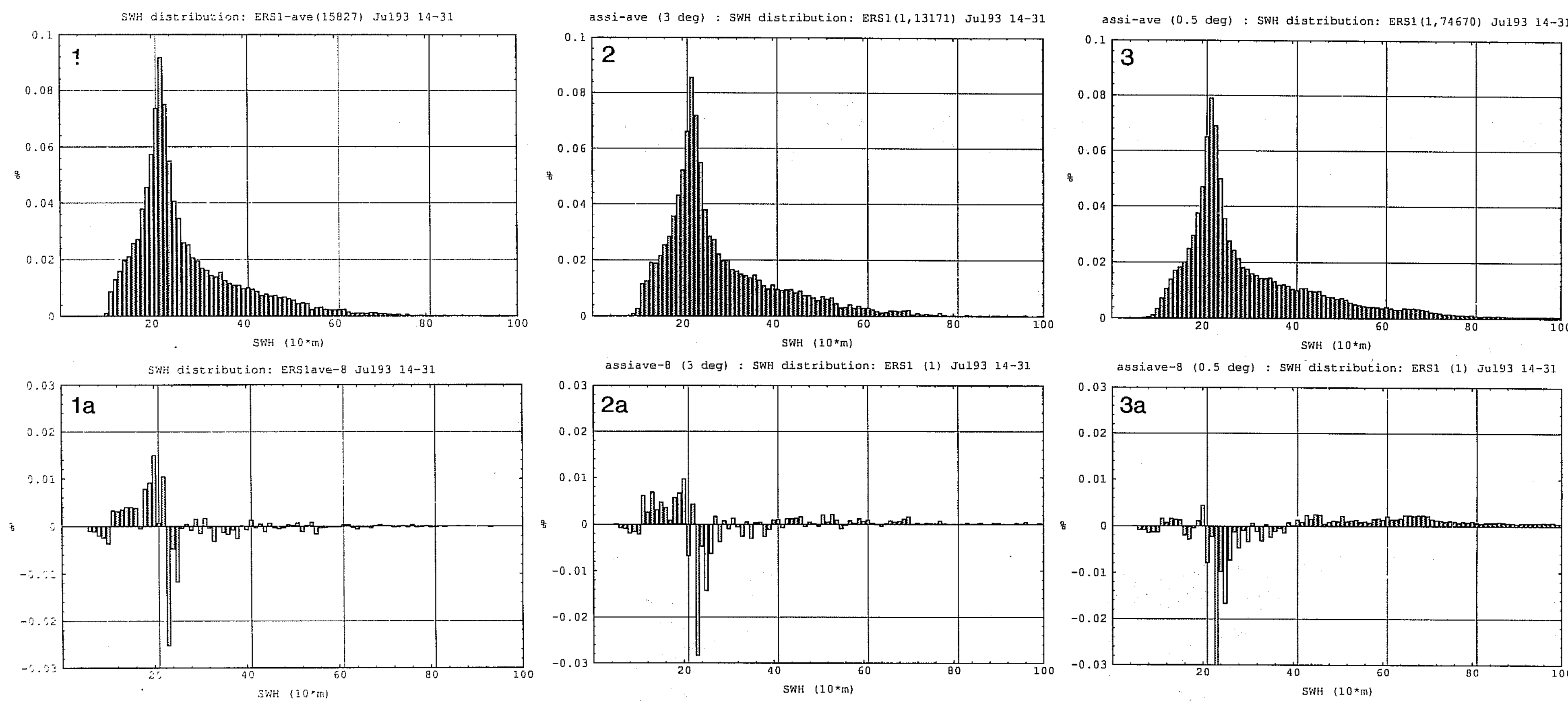

Fig 6 Impact of the averaging applied to derive swh super-observations from the FDP: (1) statistical distribution of the swh super-observation obtained by along track averaging over 20 to 30 observations, (1a) difference to the distribution of Fig 4.8, (2) obtained by box averaging over 3 by 3 degree boxes, (2a) difference to the distribution of Fig 4.8, (3) obtained by box averaging over 0.5 by 0.5 degree boxes, (3a) difference to the distribution of Fig 4.8. The along track averaging is used for model comparison studies and the box averaging for data assimilation.

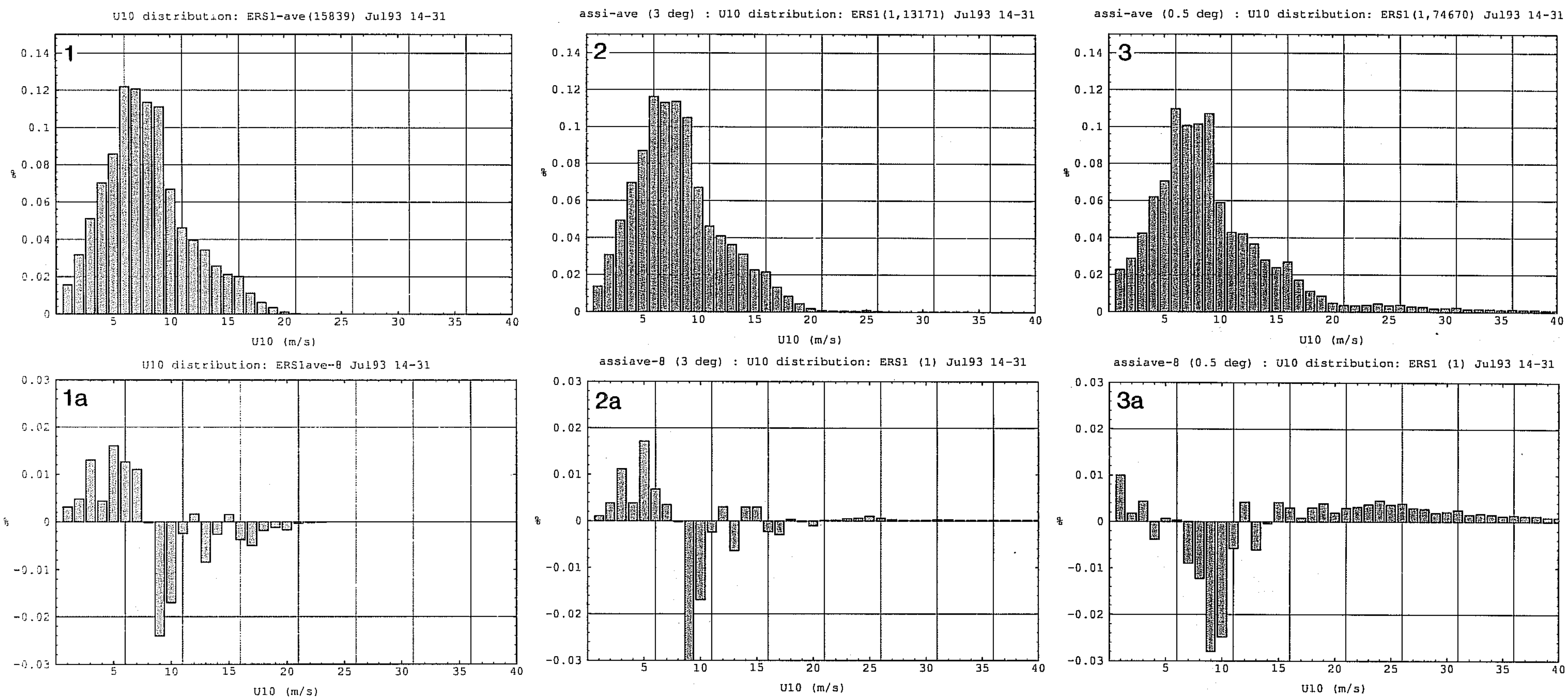

Fig 7 Impact of the averaging applied to derive the u10 super-observations from the FDP: (1) statistical distribution of the u10 super-observation obtained by along track averaging over 20 to 30 observations, (1a) difference to the distribution of Fig 5.8, (2) obtained by box averaging over 3 by 3 degree boxes, (2a) difference to the distribution of Fig 5.8, (3) obtained by box averaging over 0.5 by 0.5 degree boxes, (3a) difference to the distribution of Fig 5.8.

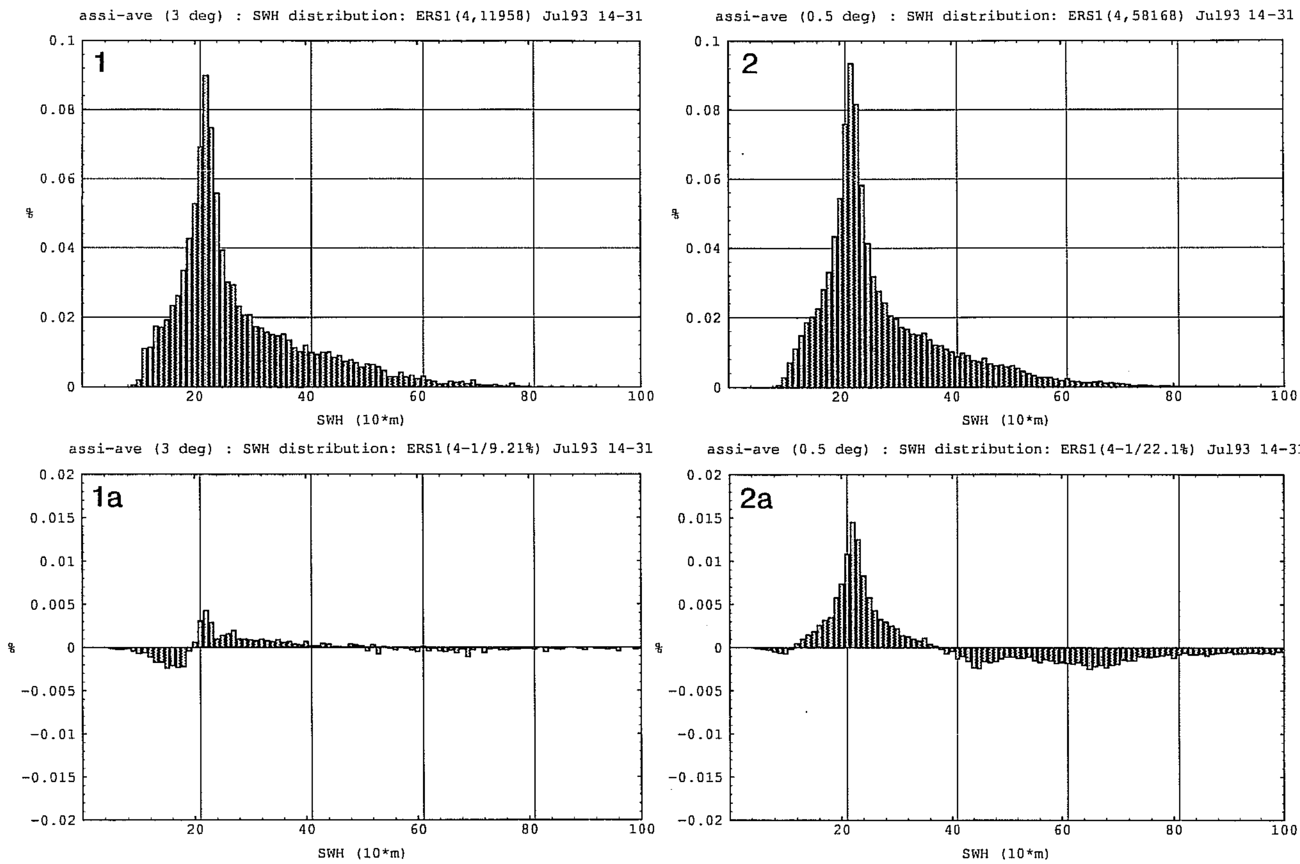

Fig 8 Impact of the second quality control that is applied during the box-averaging. Statistical distribution of the swh super-observation after this quality control: (1) for the 3 degree box size averaging, (1a) difference to the distribution of Fig 6.2, (2) for the 0.5 degree box size averaging, (2a) difference to the distribution of Fig 6.3.

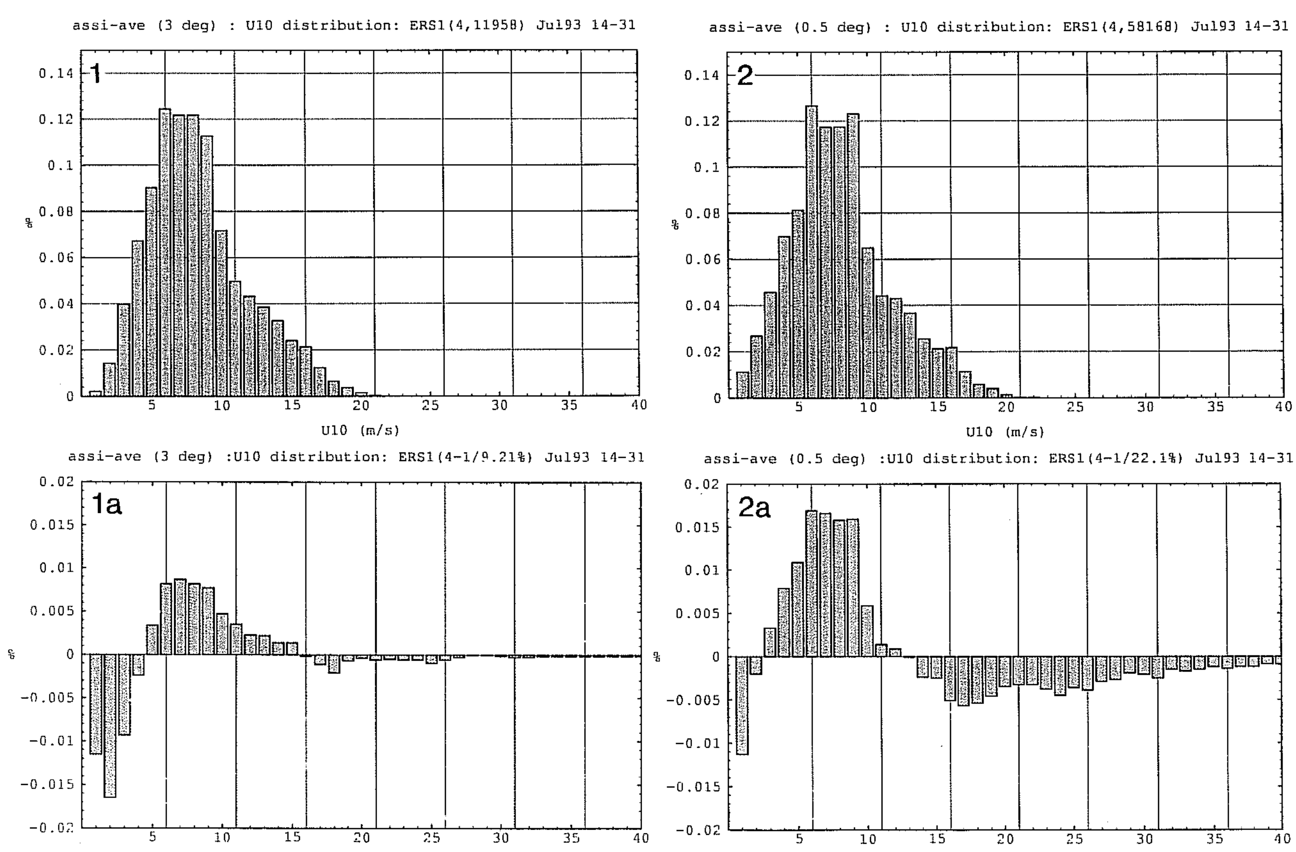

Fig 9 Impact of the second quality control that is applied during the box-averaging. Statistical distribution of the u10 super-observation after this quality control: (1) for the 3 degree box size averaging, (1a) difference to the distribution of Fig 7.2, (2) for the 0.5 degree box size averaging, (2a) difference to the distribution of Fig 7.3.