Defining a Rain Flag for the Envisat Altimeter

Graham D. Quartly
Laboratory for Satellite Oceanography,
Southampton Oceanography Centre, Southampton, UK

Abstract

An altimetric rain flag has been very successfully applied to the TOPEX dual-frequency altimeter (K_u-band and C-band). This report details the extension of those ideas to the Envisat altimeter, RA-2, which operates at K_u-band and S-band. Care must be taken in the derivation of the mean relationship and scatter from wind-only conditions. The mean relationship between the backscatter at the two frequencies is found to have a dependency on wave height, and this may partially explain why the scatter about the mean relationship is not normally distributed at low wind speeds. Feedback from the RA-2/MWR CCVT meeting in March 2003 has led to the specification of an index of rain contamination rather than just a binary rain flag. The routine for rain flagging also allows for the detection of S-band anomalies (on account of their unusually high values for the normalized backscatter), and monitoring of the mean relationship between the backscatter values at the two frequencies provides an independent method of testing for instrumental drift.

1. Introduction

The basic premise of dual-frequency altimetric rain detection is that, for by far the majority of points, the observed σ^0 values at the two frequencies are dependent only upon wind. [This assumption will be addressed later on.] Consequently a scatter plot of the simultaneous σ^0 measurements at the two frequencies has a very tight relationship (see Fig. 1a). Such information can be condensed into a number density of points (Fig. 1b), a mean relationship (Fig. 1c), and the scatter about it (Fig. 1d). Observations that lie significantly below the mean relationship are assumed to be due to rain. This has been the basis for rain detection with the TOPEX altimeter (Quartly et al., 1996; Tournadre and Morland, 1997; Chen et al., 1997) and subsequent determination of rain rates (Quartly et al., 1999; McMillan et al., 2002). These papers may be consulted for more details of the technique.

2. Detailed definition of the mean and scatter

For the purposes of this report, we define σ^0 to be the <u>observed</u> backscatter strength, rather than the value adjusted for an assumed atmospheric effect. This means that we take the supplied σ^0 value and remove the atmospheric correction that has already been applied, but retain the instrument correction.

We wish to define a mean σ^0- σ^0 relationship, or better still characterise the difference *mean*(σ^0_{Ku} -σ^0_S) = F(σ^0_S), with a spread (standard deviation) given by S(σ^0_S). The key part in defining this 'wind only' relationship is to include as many data points as possible, encompassing a wide range of wind speeds and geographical regions, but not including any points likely to be affected by rain or sea-ice. In effect, this means that the selection of points is somewhat conservative.

We use data from cycles 10, 11 & 12 (4th Oct. 2002 to 6th Jan. 2003), but discarding periods known to suffer from the S-band anomaly. Normal editing criteria are applied:

Alt_land_flag = 0	Rad_land_flag = 0	Depth > 200m
Ocean_tkr_qual_Ku = 0	Ocean_tkr_qual_S = 0	Alt. Conf flags (MCD) = 0
No. of obs. for $\sigma^0_{Ku} \geq 17$	No. of obs. for $\sigma^0_S \geq 17$	

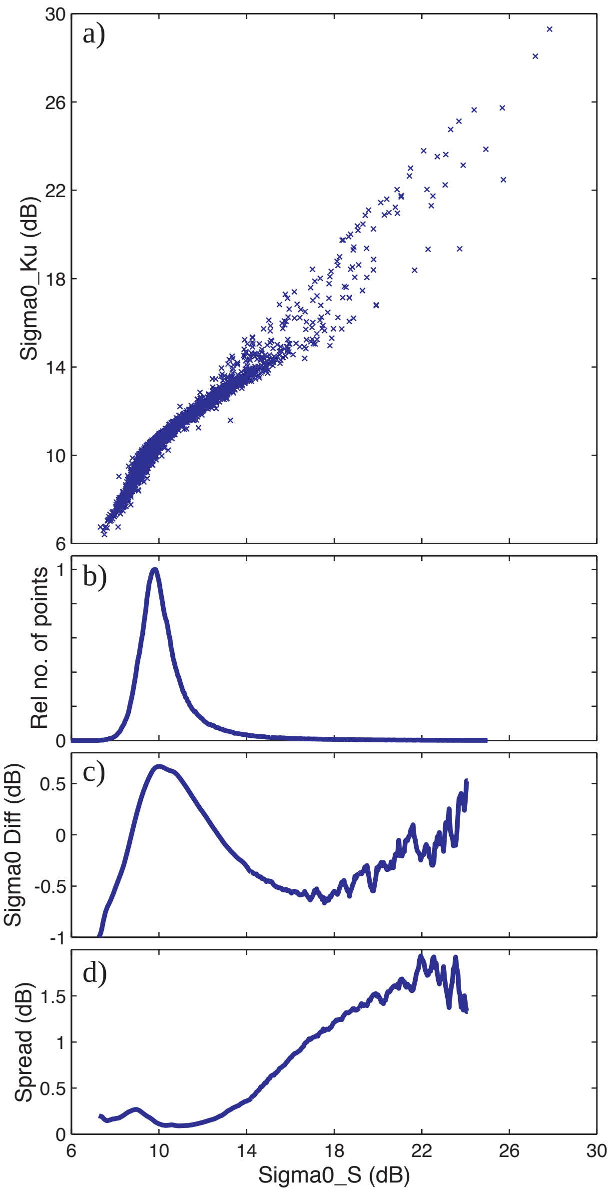

Figure 1 : Derivation of σ^0-σ^0 relationship. a) Scatter plot of σ^0_{Ku} against σ^0_S, b) Normalised histogram, c) Mean of σ^0_{Ku} -σ^0_S, d) Scatter (1 standard deviation) about mean curve.

A number of secondary editing criteria are considered to minimise rain/sea-ice effects:

MWR_liq_water_path $< 15\text{x}10^2$ kg m^{-2} — $55^\circ\text{S} \leq \text{lat} \leq 65^\circ\text{N}$

Peakiness_Ku ≤ 1.9 — Peakiness_S ≤ 1.9 — Mispointing_from_wform $< 1^\circ$

The MWR criterion should detect rain; the latitude criterion should minimise effects of sea-ice; and the peakiness and mispointing tests (all derived from waveform samples) should remove data contaminated by rain, sea-ice or glassy seas. The data passing these criteria were binned in intervals of 0.05 dB of σ^0_S, and the mean, $F(\sigma^0_S)$, and standard deviation, $S(\sigma^0_S)$, calculated within each bin. Then as a check, all data more than 3 std. dev. away from the mean are discarded and F and S recalculated. A number of combinations of the rain/ice flagging criteria (second set above) were tested. The lowest curve for the standard deviations is achieved by using all the extra criteria; this is the relationship given in the appendix for implementation in the automatic flagging, and is illustrated by the black solid line in Fig. 2. If none of the secondary tests are implemented, the results are significantly different (see the pink curve). Results very close to the black curve are achieved by applying only one or two of the above constraints. Thus, the F & S relationships are fairly robust to the choice of secondary editing criteria, as long as some are applied.

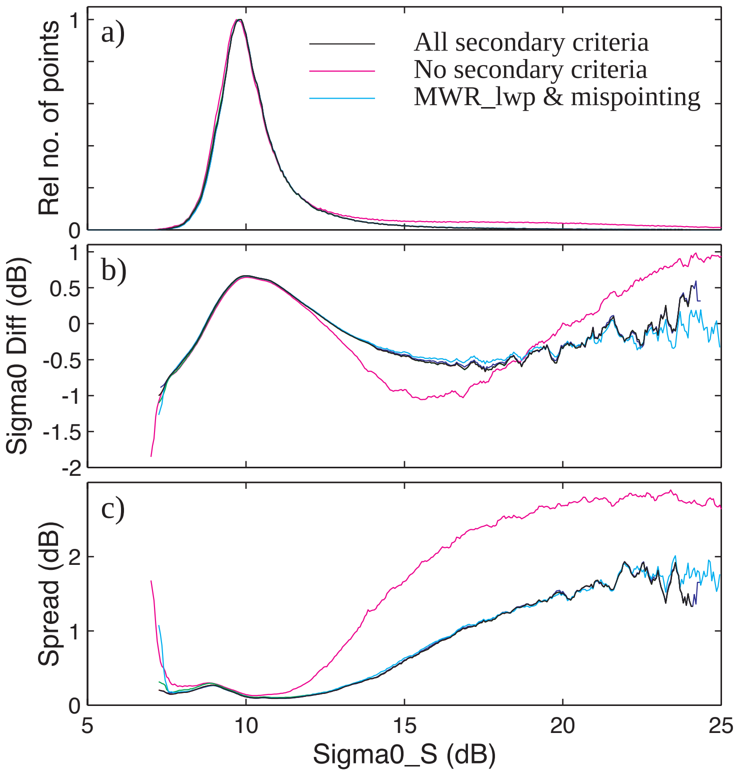

Figure 2 : Comparison of relationships obtained according to different editing criteria. The black curve shows the recommended relationship involving all the secondary criteria.

3. Wave height dependence

Interestingly, there is some variation in the relationship for wind-only conditions according to the wave height (see Fig. 3). The top plot shows the σ^0_S distributions associated with each wave height range. Apart from the lowest wave height range, these histograms are smooth and free of kinks. The mean relationships have similar shapes, with the higher wave heights being offset a little higher at the peak of the mean curve, and with a less steep slope for σ^0_S values above 12 dB. At these higher σ^0_S values, the standard deviation of the scatter increases with wave height. Note, such relationships cannot be defined much above 15 dB, because there are few points in that range for wave heights greater than 2m. This behaviour was noted for the TOPEX altimeter by Elfouhaily et al. (1998), and incorporated within the rain flagging of Quartly et al. (1999). A wave height dependence has not been incorporated within the σ^0- σ^0 relationship defined in the appendix for the operational rain flagging.

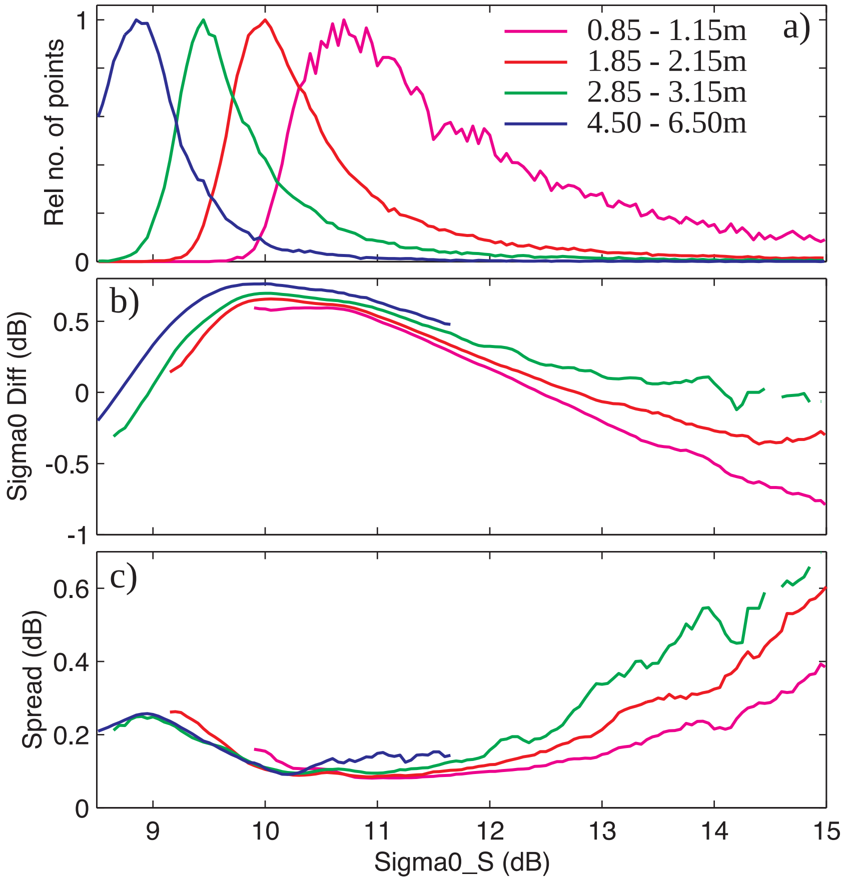

Figure 3 : Variation of σ^0-σ^0 relationship with wave height. a) Normalised histograms, b) Mean of σ^0_{Ku} -σ^0_S, c) Scatter (1 standard deviation) about mean curve.

4. Monitoring of σ^0 performance

With the TOPEX altimeter, there was found to be slight changes in the mean σ^0-σ^0 relationships, due to variations in calibration (drift in σ^0), and also degradation of the altimeter (change in point target response) so it was recommended that rain flagging was performed using a relationship derived for each cycle (10 days) of data. The data passing all the editing criteria listed in section 2 above, were divided into 4 consecutive blocks representing different periods of time. Points were then further filtered to keep only those with a wave height between 2.5m and 2.7m (to avoid a change in mean wave height between the individual quarters affecting the result). Analysis to produce F & S were applied to each separately, and the results are shown in Figure 4. There is some change in the histograms, presumably representing a change in the mean winds over the ocean. Although the other curves are very similar to one another, a slight difference can be discerned. A better co-alignment of the mean curves (Fig. 4b) can be obtained by shifting each successive curve left by 0.013 dB and up by 0.013 dB. These observations are consistent with a slight drift in the σ^0_S values during these 3 months, increasing by about 0.0006 dB day^{-1}, but with no discernible drift in σ^0_{Ku}. Similar analysis was automated for the TOPEX altimeter to check for step changes between individual cycles, and drift over the duration of the mission (Quartly, 2000).

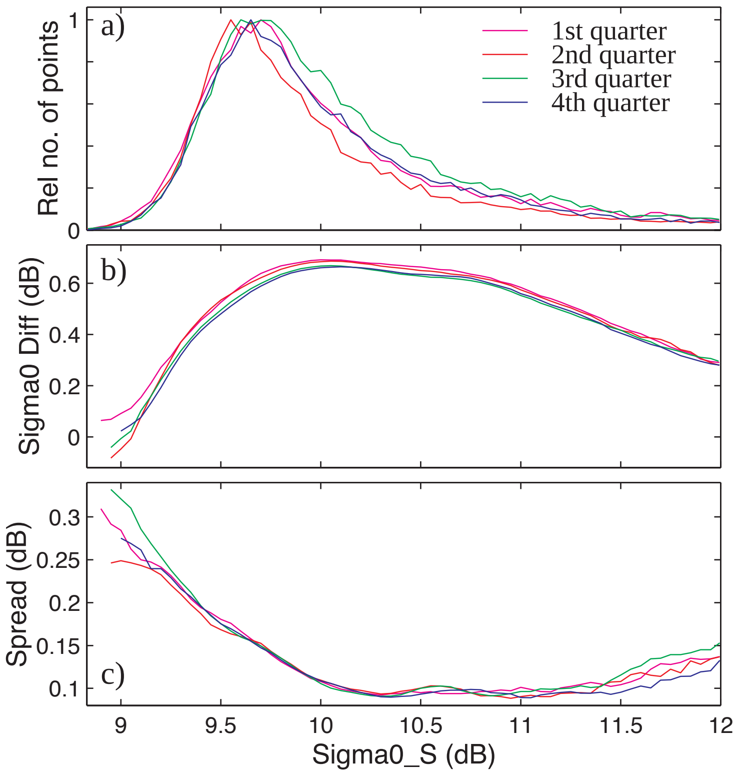

Figure 4 : Assessment of differences in σ^0-σ^0 relationship between 4 periods of the dataset. a) Normalised histograms, b) Mean, c) Scatter.

5. Comparison to TOPEX

It is useful to compare the Envisat RA-2's dual-frequency σ^0- σ^0 relationship with that observed for TOPEX. For this comparison, I have used data from cycles 239-242, which are early in the use of the B-side of the TOPEX altimeter. The mean σ^0-σ^0 relationships of the Envisat and TOPEX-B altimeters have been co-aligned by shifting the TOPEX one left ('reference sigma0' = σ^0_C-4.6 dB), and also adjusting the mean relationship upward by adding 3.92 dB. These adjustments are purely for ease of comparison, and are not based on any calibration data.

Clearly after adjustment, then peaks of the two mean relationships coincide (Fig. 5b). However, the Envisat one has the sharper peak, which is to be expected as its two radar wavelengths have a greater separation than those for TOPEX, leading to a greater difference in the roughness at the two scale lengths. The TOPEX relationship is fairly flat for 'reference sigma0' > 13 dB, whereas Envisat's curve increases again. The histograms of the two altimeters are similar (Fig. 5a), with the TOPEX one being 0.17 dB to the left of Envisat; this demonstrates that the peak in Envisat's mean σ^0-σ^0 relationship occurs at a slightly higher wind speed to that for K_u- and C-band. The scatter about the mean (Fig. 5c) is similar for Envisat and TOPEX, except for at high values of σ^0_S when the spread of values for Envisat is much greater. This corresponds to the very low wind speed regime, when there is a poor relationship between backscatter and wind speed, and rain detection using the TOPEX altimeter alone has been shown to be unreliable (McMillan et al., 2002).

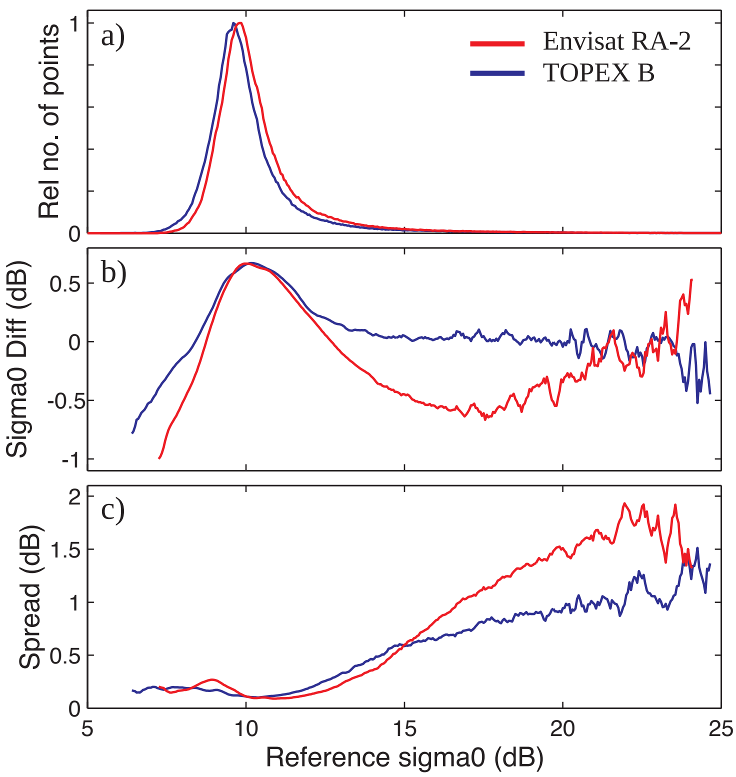

Figure 5 : Comparison of σ^0-σ^0 relationships for Envisat RA-2 and TOPEX-B.
a) Normalised histograms, b) Mean, c) Scatter.

6. Distribution of scatter

So far we have considered the distribution of σ^0-σ^0 pairs to be adequately represented by a series of Gaussian distributions, described by a mean and a standard deviation as a function of σ^0_S. However, this is not exactly the case. We define the departure of a point from the mean relationship, $\Delta\sigma^0$, by:

$$\Delta\sigma^0 = (\sigma^0_{Ku} - \sigma^0_S) - F(\sigma^0_S)$$

and plot the relative distribution of $\Delta\sigma^0$ values for particular values of σ^0_S. By using a logarithmic y-axis, a Gaussian distribution will be represented by a parabola, and an exponential distribution by a straight line.

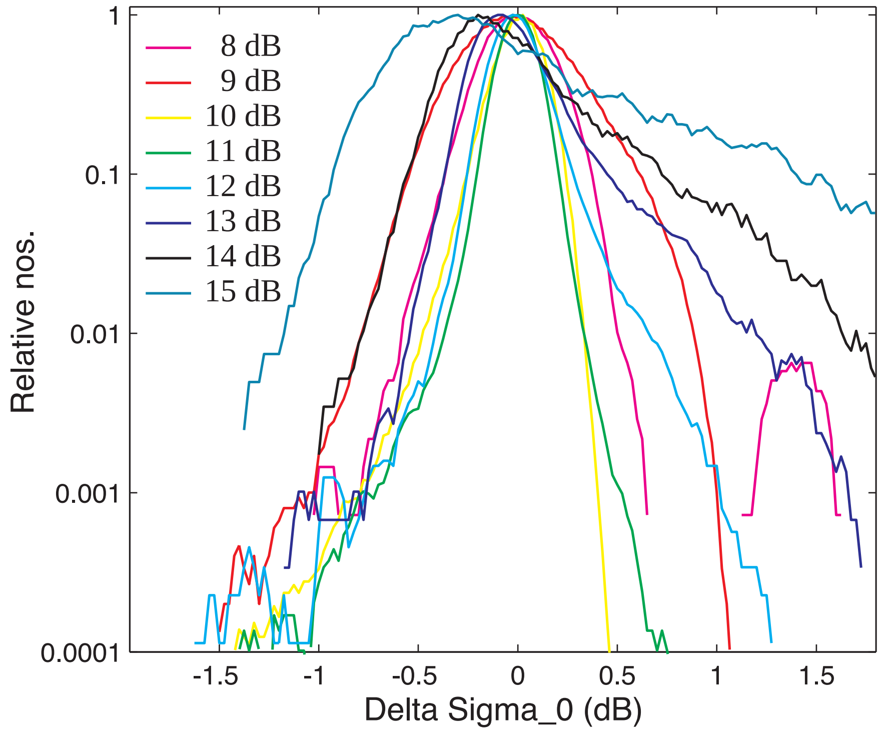

Figure 6 : Histograms of derived attenuation, $\Delta\sigma^0$ as a function of σ^0_S.

All the data portrayed in Fig. 6 have been screened for rain, sea-ice and glassy seas using the full set of criteria listed in section 2. For σ^0_S values of 8, 9, 10 & 11 dB, the distributions are symmetric above a relative frequency of 0.001, apart from the existence of an unexplained secondary peak for σ^0_S=8 dB at $\Delta\sigma^0$=1.5 dB. However, for σ^0_S=12, 13 and 14 dB, the distribution is no longer symmetric, with a much more gradual slope for positive $\Delta\sigma^0$ than for negative values. This skewness is readily seen in Fig. 1a, and is likely to be at least partially due to occasional high wave heights (2-3m swell) for which the mean of σ^0_{Ku} -σ^0_S is higher than for the normal low wave heights associated with these winds (see Fig. 3b). For σ^0_S=15 dB the distribution is very asymmetric, with the mode no longer near zero (the mean), and for σ^0_S=16, 17, 18, 19 & 20 dB (not shown) the distribution is very broad, with the mode further to the left of the mean. Clearly Gaussian statistics are not adequate for describing these situations.

7. Choosing a threshold

For TOPEX rain flagging, the Southampton Oceanography Centre group used a threshold 0.5 dB below the mean (for a 4.5 km high melting layer height, this corresponds to a minimum detection equivalent to 2.3 mm/h, whatever the wind speed); whereas the IFREMER group used a threshold of 1.8 or 2 std. dev. below the mean. [The IFREMER group also incorporated information from the radiometer (Tournadre and Morland, 1997) which was shown to reduce the number of false detections (McMillan et al., 2002).] In order to cope with the high σ^0 (low wind) observations, we recommend that for Envisat a multiple of the standard deviation is used rather than some uniform value below the mean. This may need to be revised if instrumental drift becomes a problem, as clearly a shift in the distribution of 0.1 dB will dramatically affect rain flagging at low σ^0_S where the standard deviation, S, is low.

Discussion at the 6th RA2/MWR CCVT highlighted the different needs of different users. Those involved in climate studies may wish to discard any data possibly affected by rain, as they can use temporal or spatial averages to overcome missing data. On the other hand, those providing a service of near real-time sea surface height would only discard data probably contaminated by rain, as they cannot utilise data from previous or subsequent passes. Those involved in studies of rainfall at sea would be even more cautious, as not all contaminated data are necessarily due to rain.

Thus rather than set a simple rain flag for all users, we provide a definition for an altimeter-only flag, a radiometer-only flag, and a rain index, enabling the more discerning user to choose their own threshold. The recommended flagging algorithm is:

```
LWP_thresh = 50x10^2 Kg m^-2    % This threshold discards ~3 % of data.
S-band_anom_flag  = 1           % Default = 'anomaly present or unknown'
MWR_rain_flag = 2               % Default MWR flag unavailable (delay in getting
                                   data, MWR anomaly, or land contamination)
ALT_rain_flag = 2               % Default ALT flag unavailable (lack of S- or Ku-
                                   band data)

if (MWR available and MWR_LWP ≥ LWP_thresh)
     MWR_rain_flag = 1          % Rain present according to MWR
else if (MWR available and MWR_LWP < LWP_thresh)
     MWR_rain_flag = 0          % No rain present according to MWR
end

if (sigma0_Ku and sigma0_S available)
     ibin = 1 + round (sigma0_S / 0.05 )   % round to nearest integer up/down.
     delta_sigma0 = sigma0_Ku - sigma0_S - F (ibin)    % F from lookup table
     rain_index = delta_sigma0 / S (ibin)  % S from lookup table
     if (delta_sigma0 > -15)
          S-band_anom_flag  = 0
          ALT_rain_flag = 0     % No rain present according to altimeter
          if (abs(rain_index)≥2)    % ALT test for rain
              ALT_rain_flag = 1     % Rain present according to altimeter
          end
     end
end

Values to be returned:
     S-band_anom_flag (0/1)
     MWR_rain_flag (0/1/2)
     ALT_rain_flag (0/1/2)
     delta_sigma0 (real number in range -15 to +15, with a precision of 0.01)
     rain_index (real number in range -10 to +10, with a precision of 0.01)
                                   Note, at a later stage 'rain_index' may be
                                   replaced by a 'probability of rain'.
```

For the general user, it is recommended that they use data if either MWR_rain_flag or ALT_rain_flag is set to 0, i.e. not to discard data if only one test indicates rain, unless other test is unavailable. More advanced users can tune their editing criteria based on the rain_index. Note, this is not a 'probability of rain', as that would require further work on the distributions of rain-affected and rain-free points as a function of σ^0_S. The recommended rain flag clearly corresponds to abs(rain_index)≥2; discard rates for other choices are given in Table 1. A further editing criterion, namely on σ^0_S is also included, as there have been recommendations on discarding TOPEX data at high σ^0, and it is clear that the Gaussian assumption of the rain flag algorithm is not valid for σ^0_S greater than about 14 dB (Fig. 6).

	abs(rain_index) ≥ 1.8	abs(rain_index) ≥ 2.0	abs(rain_index) ≥ 2.2	abs(rain_index) ≥ 2.4	No test on rain_index
$\sigma^0_S > 14$ dB	28.5	26.0	24.1	22.8	15.9
$\sigma^0_S > 16$ dB	26.2	23.6	21.7	20.3	12.2
$\sigma^0_S > 18$ dB	24.2	21.4	19.4	17.8	9.0
$\sigma^0_S > 20$ dB	22.1	19.3	17.1	15.5	5.9
No σ^0_S threshold	17.5	14.4	12.1	10.3	0.0

Table 1 : Percentages of data discarded according to various criteria
(Values given correspond to data being flagged by either or both of the tests. Global average over cycles 10-12 for data passing the first set of editing criteria).

The discard rates listed in Table 1 seem high, given that a 2 std. dev. test on a Gaussian distribution would discard ~5% of data. The value in the table for a 2 std. dev. test alone (no σ^0_S threshold) is 14.4%, which reflects the fact that the underlying distributions are not truly Gaussian, and also that the test is developed on rain-free data, and genuine rain events will lie outside the ±2 std. dev. acceptability bounds, with the global occurrence of rain being of the order of 5-10%, according to the minimum rain rate detectable. The addition of a test to discard if σ^0_S >14 dB leads to more than a quarter of the data being filtered out, which is probably only acceptable for long-term climate studies. Global precipitation studies will need more stringent tests for definitive rain detection.

In the most populous region (σ^0_S between 8 and 12 dB), the spread of points, described by S is very small. It is quite possible that the rain flag is successfully detecting low rain rates (with an attenuation of just 0.2 to 0.3 dB) but for which the altimeter data are otherwise unaffected. Thus, even though these may be rain events, such data need not be discarded by the general user. Possibly a more relevant test is to ensure that the derived attenuation ($\Delta\sigma^0$) is at least 0.5 dB and at least twice the observed scatter, S. Further evaluation will be needed to clarify this, but such an amendment to the routine is easily incorporated by changing 'ALT test for rain' line to

```
if (rain_index≤-2 AND delta_sigma0≤-0.5)    % ALT test for rain
```

8. Demonstration of usefulness of altimetric rain flag

To complete this report, I include a brief demonstration that an altimetric rain flag is efficacious at removing untrustworthy data. Individual case studies for TOPEX (Quartly et al., 1996; Tournadre and Morland, 1997) and Envisat (Quartly and Srokosz, 2003) have shown how sea surface height, wave height, and their uncertainties (σ_h and σ_{Hs}) may be affected by rain (typically ssh has a sharp decrease; the others a sharp increase). Figure 7 shows the distributions of σ_h and σ_{Hs} as functions of wave height. [As rain will affect individual wave height values, a 7-point running median is used to provide a representative local value.]

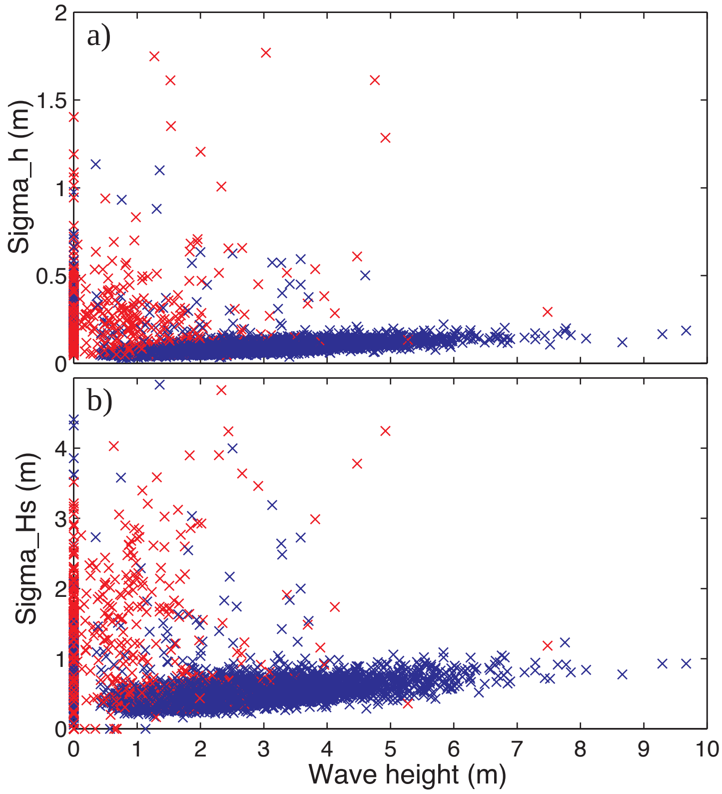

Figure 7 : Scatter plots of a) σ_h and b) σ_{Hs} as a function of wave height. Red crosses indicate points for which the altimetric rain flag would be set (using only abs(rain_index)≥2); blue crosses otherwise. (The value on the abscissa is the result of a 7-point along-track median smoother to avoid spurious high Hs values caused by rain contamination.)

Most points have a value of $\sigma_h < 0.2$m and have $\sigma_{Hs} < 1$m. Of those exceeding these values, the majority are detected by the proposed rain flag. Of the rain-free points (blue crosses) above these values, nearly all correspond to σ^0_S >14 dB, again highlighting the advantage of the user incorporating a σ^0_S (or σ^0_{Ku}) threshold in their editing criteria.

9. Summary

Analysis of 3 cycles of Envisat dual-frequency altimetric data has shown the relationship between σ^0_S and σ^0_{Ku} to be very similar to that between σ^0_C and σ^0_{Ku} for TOPEX. This enables an altimetric rain flag to be developed (section 7), which is efficacious at detecting untrustworthy data (section 8). The specified algorithm provides for independent MWR- and ALT-derived rain flags, along with a rain index. This conforms to the request of the 6th RA2/MWR CCVT to provide the users with options rather than only a single rain flag.

It is noted that at low winds (σ^0_S >14 dB), the scatter of the σ^0-σ^0 relationship about the mean line is far from Gaussian or even symmetric. Clearly a wave height dependence should be incorporated in a future algorithm, and further work done to determine the meaningfulness of a 2 std. dev. test on a non-Gaussian distribution. Many users may wish to also discard data if σ^0_S > 14 dB, although that significantly increases data loss, and may be a problem in low wind regions, like the tropics.

The specified algorithm also contains a test for the 'S-band anomaly', as this was felt important irrespective of rain studies. The constancy of the shape of the mean σ^0-σ^0 relationship (once sufficient editing criteria are used) enables us to monitor the σ^0 calibration of the altimeter. Initial results show the calibration of σ^0_S increasing during the 3 cycles at approximately 0.0006 dB day^{-1}, with no change detected for σ^0_{Ku}.

Appendix

The table below contains the values for F and S as a function of σ^0_S between 7 and 25 dB. There are very few marine observations outside this range. To extend the range to 0-40 dB, use the values at σ^0_S =7 dB for all values of σ^0_S < 7 dB, and the values at σ^0_S =25 dB for all values of σ^0_S > 25 dB.

σ^0_S	F	S	σ^0_S	F	S	σ^0_S	F	S	σ^0_S	F	S
7.00	-0.93	0.18	11.50	0.38	0.10	16.00	-0.57	0.83	20.50	-0.35	1.54
7.05	-0.93	0.18	11.55	0.37	0.10	16.05	-0.58	0.83	20.55	-0.34	1.55
7.10	-0.93	0.18	11.60	0.35	0.10	16.10	-0.57	0.85	20.60	-0.29	1.58
7.15	-0.93	0.18	11.65	0.33	0.10	16.15	-0.56	0.86	20.65	-0.32	1.59
7.20	-0.93	0.18	11.70	0.32	0.11	16.20	-0.56	0.88	20.70	-0.34	1.61
7.25	-0.93	0.18	11.75	0.30	0.11	16.25	-0.57	0.88	20.75	-0.26	1.61
7.30	-0.93	0.18	11.80	0.28	0.11	16.30	-0.56	0.89	20.80	-0.20	1.61
7.35	-0.90	0.18	11.85	0.27	0.12	16.35	-0.58	0.90	20.85	-0.22	1.60
7.40	-0.88	0.17	11.90	0.25	0.12	16.40	-0.60	0.90	20.90	-0.18	1.63
7.45	-0.84	0.17	11.95	0.24	0.12	16.45	-0.60	0.91	20.95	-0.07	1.58
7.50	-0.80	0.16	12.00	0.22	0.12	16.50	-0.60	0.93	21.00	-0.20	1.66
7.55	-0.75	0.16	12.05	0.21	0.13	16.55	-0.59	0.94	21.05	-0.20	1.68
7.60	-0.72	0.15	12.10	0.19	0.13	16.60	-0.60	0.95	21.10	-0.21	1.68
7.65	-0.68	0.15	12.15	0.18	0.13	16.65	-0.56	0.98	21.15	-0.15	1.65
7.70	-0.65	0.15	12.20	0.16	0.14	16.70	-0.59	0.99	21.20	-0.17	1.65
7.75	-0.63	0.15	12.25	0.14	0.14	16.75	-0.60	1.00	21.25	-0.07	1.62
7.80	-0.61	0.15	12.30	0.13	0.15	16.80	-0.62	1.01	21.30	-0.06	1.60
7.85	-0.58	0.16	12.35	0.11	0.15	16.85	-0.63	1.03	21.35	-0.06	1.64
7.90	-0.55	0.16	12.40	0.09	0.15	16.90	-0.65	1.02	21.40	-0.02	1.61
7.95	-0.52	0.16	12.45	0.08	0.16	16.95	-0.64	1.03	21.45	-0.01	1.61
8.00	-0.49	0.16	12.50	0.06	0.16	17.00	-0.63	1.04	21.50	0.05	1.57
8.05	-0.46	0.17	12.55	0.05	0.16	17.05	-0.61	1.05	21.55	0.06	1.56
8.10	-0.44	0.16	12.60	0.03	0.17	17.10	-0.57	1.05	21.60	0.08	1.57
8.15	-0.41	0.17	12.65	0.02	0.18	17.15	-0.56	1.05	21.65	-0.03	1.62
8.20	-0.38	0.17	12.70	-0.00	0.18	17.20	-0.54	1.06	21.70	-0.07	1.68
8.25	-0.35	0.18	12.75	-0.01	0.19	17.25	-0.58	1.05	21.75	-0.14	1.74
8.30	-0.32	0.19	12.80	-0.03	0.19	17.30	-0.58	1.08	21.80	-0.18	1.78
8.35	-0.29	0.19	12.85	-0.05	0.20	17.35	-0.62	1.10	21.85	-0.19	1.81
8.40	-0.26	0.20	12.90	-0.06	0.20	17.40	-0.62	1.11	21.90	-0.22	1.90
8.45	-0.22	0.21	12.95	-0.08	0.21	17.45	-0.66	1.11	21.95	-0.28	1.94
8.50	-0.18	0.22	13.00	-0.09	0.22	17.50	-0.64	1.14	22.00	-0.25	1.91
8.55	-0.14	0.22	13.05	-0.10	0.23	17.55	-0.69	1.12	22.05	-0.24	1.89
8.60	-0.10	0.23	13.10	-0.12	0.24	17.60	-0.64	1.12	22.10	-0.23	1.87
8.65	-0.05	0.23	13.15	-0.13	0.25	17.65	-0.66	1.14	22.15	-0.15	1.80
8.70	-0.01	0.24	13.20	-0.14	0.26	17.70	-0.65	1.14	22.20	-0.13	1.77
8.75	0.04	0.24	13.25	-0.15	0.26	17.75	-0.64	1.14	22.25	-0.16	1.74
8.80	0.08	0.25	13.30	-0.17	0.27	17.80	-0.61	1.16	22.30	-0.16	1.74
8.85	0.13	0.25	13.35	-0.18	0.27	17.85	-0.62	1.16	22.35	-0.27	1.79
8.90	0.17	0.26	13.40	-0.19	0.28	17.90	-0.60	1.18	22.40	-0.28	1.77
8.95	0.21	0.26	13.45	-0.20	0.28	17.95	-0.59	1.20	22.45	-0.34	1.83
9.00	0.25	0.26	13.50	-0.21	0.29	18.00	-0.58	1.21	22.50	-0.34	1.92
9.05	0.29	0.25	13.55	-0.22	0.29	18.05	-0.59	1.22	22.55	-0.31	1.93
9.10	0.32	0.25	13.60	-0.23	0.30	18.10	-0.59	1.24	22.60	-0.10	1.81
9.15	0.36	0.24	13.65	-0.24	0.30	18.15	-0.60	1.23	22.65	-0.13	1.86
9.20	0.39	0.23	13.70	-0.24	0.32	18.20	-0.59	1.24	22.70	-0.05	1.79
9.25	0.42	0.22	13.75	-0.25	0.33	18.25	-0.55	1.24	22.75	-0.03	1.71
9.30	0.45	0.21	13.80	-0.26	0.33	18.30	-0.52	1.24	22.80	0.00	1.66
9.35	0.48	0.20	13.85	-0.27	0.34	18.35	-0.49	1.24	22.85	-0.11	1.73
9.40	0.50	0.20	13.90	-0.28	0.35	18.40	-0.49	1.26	22.90	-0.09	1.71
9.45	0.53	0.19	13.95	-0.30	0.35	18.45	-0.47	1.28	22.95	-0.05	1.71
9.50	0.55	0.18	14.00	-0.31	0.35	18.50	-0.52	1.30	23.00	-0.16	1.82
9.55	0.57	0.18	14.05	-0.32	0.36	18.55	-0.54	1.32	23.05	-0.01	1.68
9.60	0.60	0.17	14.10	-0.35	0.36	18.60	-0.58	1.32	23.10	0.12	1.59
9.65	0.62	0.16	14.15	-0.36	0.37	18.65	-0.58	1.31	23.15	0.07	1.53

9.70	0.63	0.15	14.20	-0.37	0.38	18.70	-0.63	1.32	23.20	0.12	1.47
9.75	0.65	0.14	14.25	-0.37	0.39	18.75	-0.57	1.33	23.25	0.25	1.38
9.80	0.66	0.13	14.30	-0.38	0.40	18.80	-0.56	1.34	23.30	0.05	1.52
9.85	0.67	0.12	14.35	-0.39	0.41	18.85	-0.52	1.36	23.35	-0.01	1.60
9.90	0.67	0.12	14.40	-0.39	0.43	18.90	-0.50	1.36	23.40	-0.03	1.66
9.95	0.67	0.11	14.45	-0.39	0.45	18.95	-0.44	1.35	23.45	-0.11	1.80
10.00	0.67	0.11	14.50	-0.40	0.46	19.00	-0.46	1.34	23.50	-0.07	1.82
10.05	0.67	0.10	14.55	-0.41	0.47	19.05	-0.42	1.35	23.55	-0.10	1.92
10.10	0.67	0.10	14.60	-0.42	0.48	19.10	-0.42	1.36	23.60	0.00	1.80
10.15	0.67	0.10	14.65	-0.42	0.51	19.15	-0.41	1.37	23.65	0.18	1.75
10.20	0.66	0.09	14.70	-0.44	0.51	19.20	-0.40	1.39	23.70	0.35	1.56
10.25	0.66	0.09	14.75	-0.43	0.52	19.25	-0.41	1.42	23.75	0.37	1.51
10.30	0.65	0.09	14.80	-0.44	0.54	19.30	-0.38	1.40	23.80	0.40	1.38
10.35	0.64	0.09	14.85	-0.45	0.56	19.35	-0.38	1.40	23.85	0.31	1.46
10.40	0.64	0.09	14.90	-0.46	0.55	19.40	-0.33	1.41	23.90	0.32	1.35
10.45	0.63	0.09	14.95	-0.45	0.58	19.45	-0.37	1.41	23.95	0.24	1.50
10.50	0.63	0.10	15.00	-0.45	0.60	19.50	-0.32	1.40	24.00	0.36	1.40
10.55	0.63	0.10	15.05	-0.46	0.60	19.55	-0.38	1.44	24.05	0.53	1.33
10.60	0.63	0.10	15.10	-0.46	0.62	19.60	-0.45	1.46	24.10	0.53	1.33
10.65	0.62	0.09	15.15	-0.47	0.63	19.65	-0.51	1.45	24.15	0.53	1.33
10.70	0.62	0.09	15.20	-0.48	0.63	19.70	-0.54	1.49	24.20	0.53	1.33
10.75	0.61	0.09	15.25	-0.50	0.63	19.75	-0.57	1.50	24.25	0.53	1.33
10.80	0.60	0.09	15.30	-0.51	0.65	19.80	-0.57	1.52	24.30	0.53	1.33
10.85	0.58	0.09	15.35	-0.52	0.66	19.85	-0.50	1.53	24.35	0.53	1.33
10.90	0.57	0.09	15.40	-0.52	0.67	19.90	-0.46	1.54	24.40	0.53	1.33
10.95	0.56	0.09	15.45	-0.52	0.68	19.95	-0.36	1.51	24.45	0.53	1.33
11.00	0.54	0.09	15.50	-0.52	0.71	20.00	-0.38	1.53	24.50	0.53	1.33
11.05	0.53	0.09	15.55	-0.53	0.72	20.05	-0.34	1.50	24.55	0.53	1.33
11.10	0.51	0.09	15.60	-0.53	0.72	20.10	-0.33	1.48	24.60	0.53	1.33
11.15	0.50	0.09	15.65	-0.55	0.74	20.15	-0.29	1.44	24.65	0.53	1.33
11.20	0.48	0.09	15.70	-0.55	0.74	20.20	-0.32	1.43	24.70	0.53	1.33
11.25	0.47	0.09	15.75	-0.55	0.75	20.25	-0.29	1.42	24.75	0.53	1.33
11.30	0.45	0.09	15.80	-0.54	0.78	20.30	-0.32	1.46	24.80	0.53	1.33
11.35	0.43	0.09	15.85	-0.55	0.78	20.35	-0.32	1.46	24.85	0.53	1.33
11.40	0.42	0.09	15.90	-0.55	0.80	20.40	-0.36	1.52	24.90	0.53	1.33
11.45	0.40	0.10	15.95	-0.55	0.81	20.45	-0.35	1.55	24.95	0.53	1.33
									25.00	0.53	1.33

References

Chen G., B. Chapron, J. Tournadre, K. Katsaros and D. Vandemark, 1997, "Global oceanic precipitation: A joint view by TOPEX and the TOPEX microwave radiometer", J. Geophys. Res., 102, 10457-10471.

Elfouhaily, T., D. Vandemark. J. Gourrion and B. Chapron, 1998, "Estimation of wind stress using dual-frequency TOPEX data", J. Geophys. Res., 103, 25101-25108.

McMillan, A. C., G. D. Quartly, M. A. Srokosz and J. Tournadre, 2002, "Validation of the TOPEX rain algorithm: Comparison with ground-based radar" J. Geophys. Res., 107 (D4), pp. 3.1-3.10.

Quartly, G. D., 2000, "Monitoring and cross-calibration of altimeter σ^0 through dual-frequency backscatter measurements" J. Atmos. Oceanic. Technol., 17, 1252–1258.

Quartly, G. D. and M. A. Srokosz, 2003, "Rain-flagging of the Envisat altimeter" Proc. of IGARSS 2003, 21st-25th July 2003, Toulouse, France (3pp).

Quartly, G. D., T. H. Guymer and M. A. Srokosz, 1996, "The effects of rain on Topex radar altimeter data" J. Atmos. Oceanic. Technol., 13, 1209–1229.

Quartly G.D., M.A. Srokosz and T.H. Guymer 1999, "Global precipitation statistics from dual-frequency TOPEX altimetry", J. Geophys. Res., 104,31489-31516,.

Tournadre, J. and J. C. Morland, 1997, "The effects of rain on Topex/Poseidon altimeter data" IEEE Trans. Geosci. and Remote. Sens., 35, 1117-1135.