Validating TOPEX's Rain Measurements

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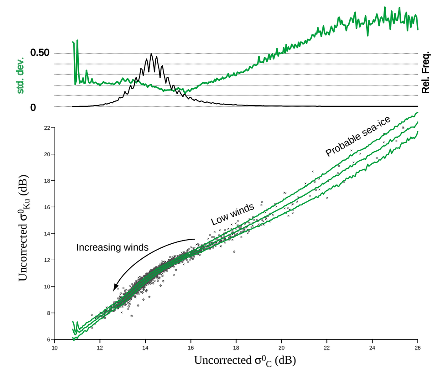
INTRODUCTION

For many years people have attempted to derive rain information from the σ^0 values at TOPEX's two frequencies. The section on TOPEX RAIN DETECTION details the assumptions and processing used, and gives some clear examples of rain cells traversed. The panel further to the right shows that on average the TOPEX-derived values are significantly less than in the GPCP CLIMATOLOGY.

To understand this we have undertaken a number of comparisons with simultaneous ground-based measurements. The questions we hope to address are:-

i) Does TOPEX detect all significant rain events?
ii) Is the TOPEX algorithm biased low at all rain rates, or is it that it just underestimates heavy rains?
iii) Is enhanced surface backscatter an important cause of the underestimation?
iv) Can TOPEX recover the typical length scales of rain events?
v) Does TOPEX often detect rain in error?

TOPEX RAIN DETECTION



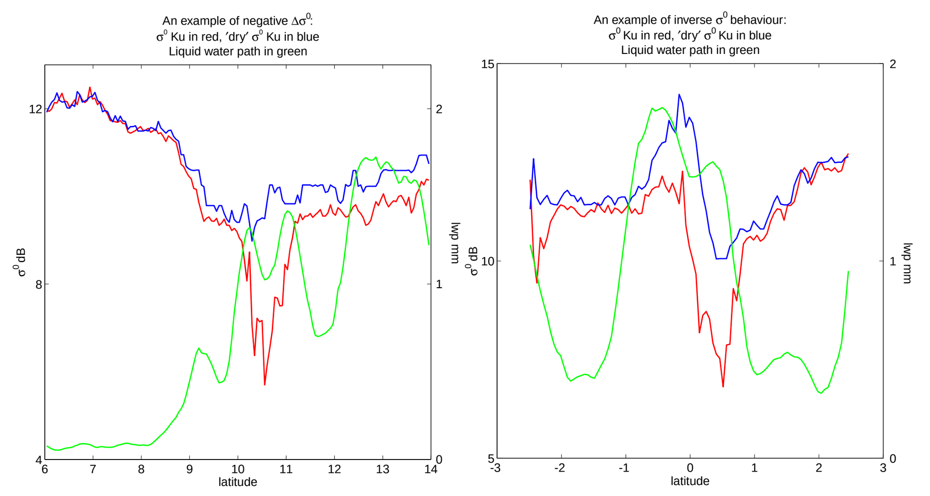
There is generally a very close agreement between the surface backscatter values at TOPEX's two frequencies (K_u-band and C-band) since they both respond to small-scale roughness induced by the wind.

Liquid water in the atmospheric column, however only really affects the K_u-band pulses. The observed attenuation, $\Delta\sigma^0$ (i.e. how far a point lies below the mean curve) is related to rain rate, R (in mm/hr) by

$$\Delta\sigma^0 = 2\,H\,a\,R^b$$

where H is the height of the rain column (assumed bounded by the melting layer), and the coefficients a, b are from Goldhirsh & Walsh (1982).

Distinct events with attenuation exceeding 2dB are common (see examples below). Here we convert the σ^0_C values to their K_u-band equivalent (according to the diagram to the left). This gives the value of σ^0_{Ku} expected from such wind values in dry conditions.



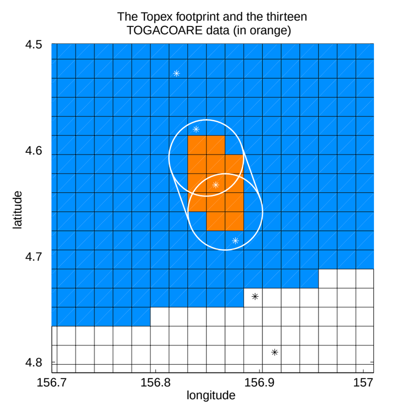
The values for σ^0_{Ku} show sharp drops, whilst the dry σ^0_{Ku} (rescaled σ^0_C) only changes gradually (mainly in response to winds). The existence of rain in these cases is confirmed by the Liquid Water Path (LWP) obtained from the broad footprint of the passive TMR.

In the second example, enhanced σ^0_C backscatter occurs on the edge of the rain cell, possibly due to the effect of raindrops damping the small-scale roughness (Tsimplis & Thorpe, 1989).

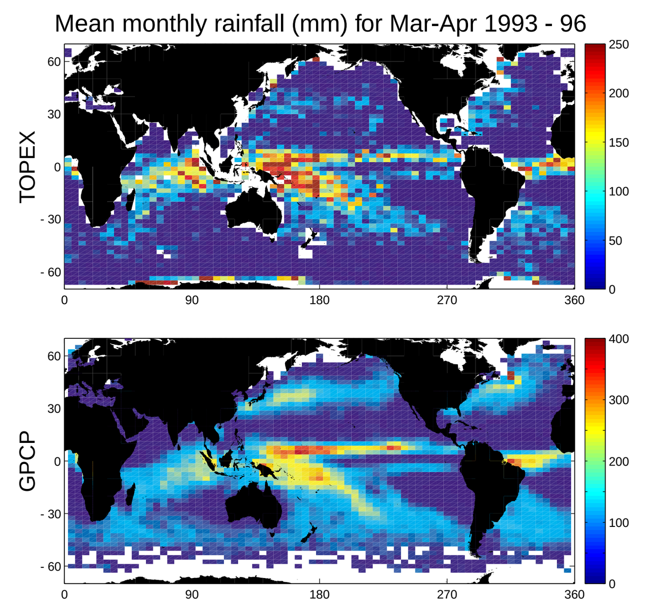
METHODOLOGY

For all these various comparison datasets, we are taking the scan nearest in time (usually within 5 minutes of the TOPEX overpass), and examining all the ground radar pixels that lie within TOPEX's 1-second footprint. (The latter corresponds to an 8km diameter disc, moving 6km along track in a second.) This is approximated by a grid of pixels as shown to the right.

To assess the TOPEX rain algorithms, we have taken the ground-based values as "truth", and calculated the attenuation that TOPEX would be expected to measure in that case. This can be expressed as an equivalent rain rate as deduced from TOPEX.

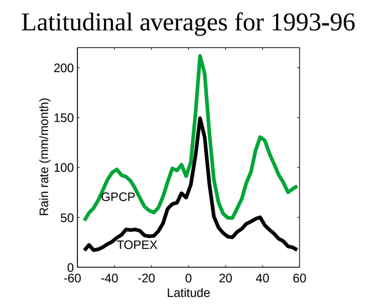


GPCP CLIMATOLOGY



The geographical patterns of precipitation found by TOPEX are similar to those of the Global Precipitation Climatology Project, whose data are from infra-red and passive microwave sensors.

However the magnitudes are very different, as is emphasised by the plot below, showing mean rainfall in each latitude band.



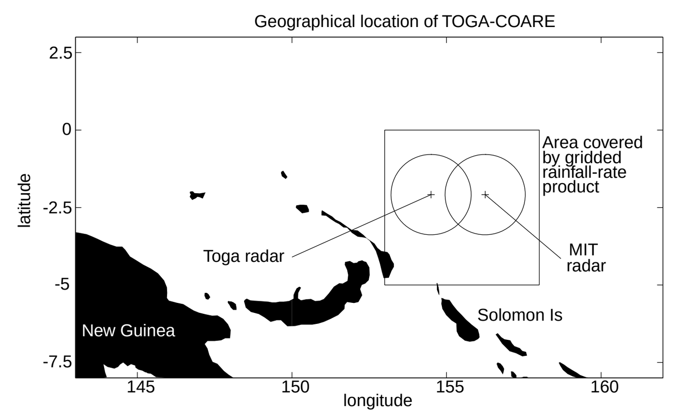
TOPEX mean values are 70% of GPCP at the equator, and a much smaller fraction towards the poles. Some of the causes of this disagreement are:-

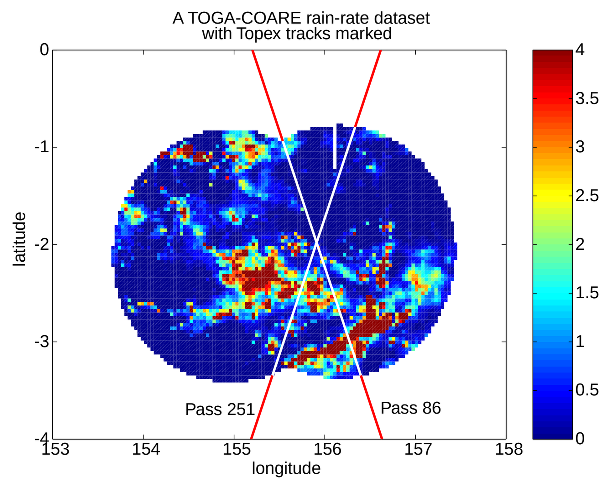
- Inappropriateness of using melting layer height, H, = 5km everywhere
- TOPEX's inability to detect light rain (because we impose a 0.5dB detection threshold).

However it must be borne in mind that the GPCP values could be overestimates in regions. Consequently we choose to compare the TOPEX data with various ground-based observations on a point-by-point basis, so as to better understand the errors.

Ground-based comparisons

TOGA-COARE

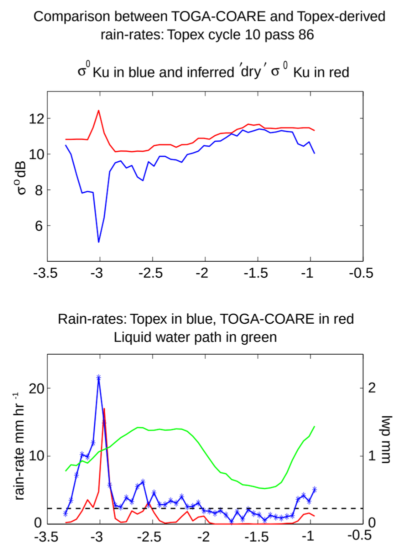




The TOGA-COARE comparison

From November 1992 to February 1993 there was a dedicated campaign to record the rain rate in a region of the western equatorial Pacific. As well as a series of island rain gauges, two rain radars were sited on ships occupying the same locations during that time. The radars had a range of about 150km, and scans were made every 10 minutes.

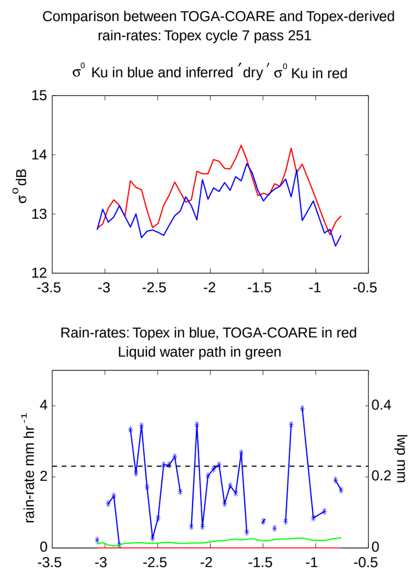
The data were converted to rain rates on a 2km x 2km grid by Short and Kucera.



Discussion of results

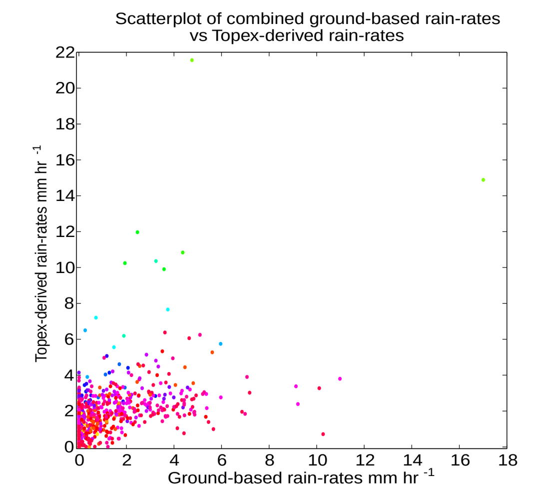
The comparison on the left shows a good agreement between the rain-rates, with TOPEX apparaently picking up small rain-cell features. However, the TOPEX data seem to be shifted by about 6km along track relative to the TOGA-COARE data, a discrepancy that we have yet to explain. Note also the enhanced backscatter observed in the σ^0_C backscatter as TOPEX passes over the main rain cell.

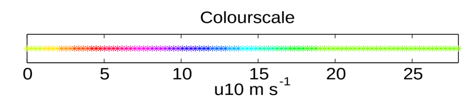
The comparison on the right shows a typical poor comparison, in which the TOPEX algorithm indicates rain when the TOGA-COARE data show none. These false positives can be attributed to the skittish nature of the σ^0 backscatter at low surface windspeeds, i.e. less than about 3 m/s.



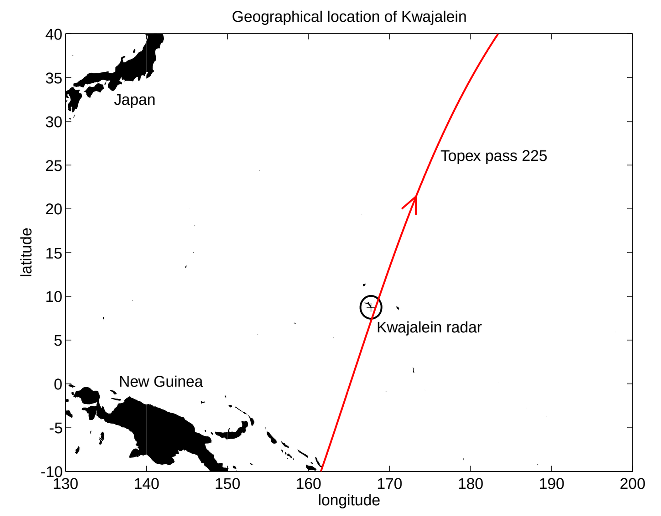
Scatterplot

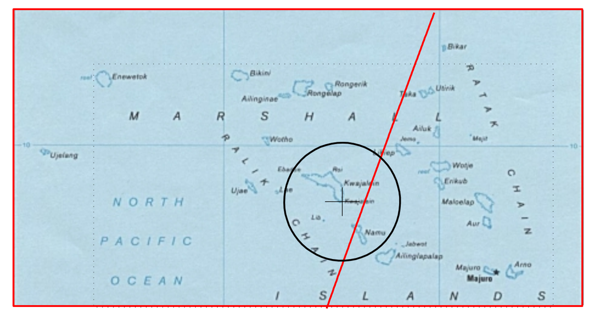
The data from the TOGA-COARE and Met Office comparisons were edited for windspeed. For the TOGA-COARE comparison, those data corresponding to windspeed less than 2.8 m/s were rejected. For the Met Office comparison, those data corresponding to wind speed less than 1.5 m/s and greater than 20 m/s were removed. These editing criteria were chosen purely empirically, and removed almost all of TOPEX's 'false' cases of significant rain, with the loss of less than 3% of the 'true' rain. The combined results are plotted on the right, with the data colour coded for wind speed.





Kwajalein

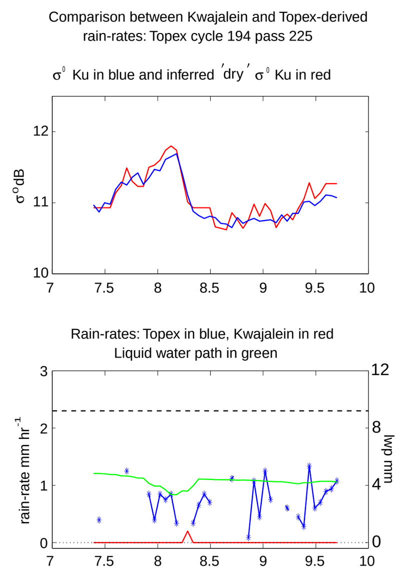




The Kwajalein comparison

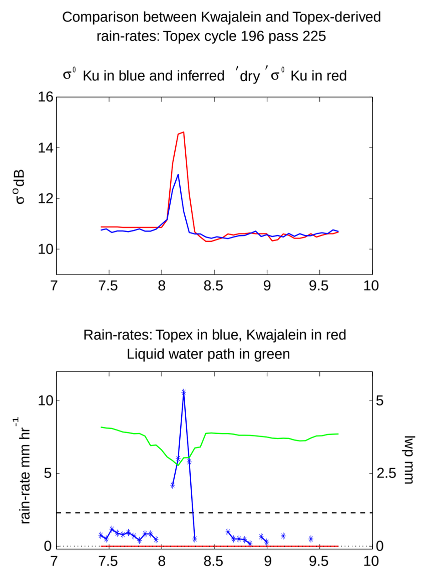
Kwajalein is a large atoll, part of the Marshall Islands, a United Staes Trust Territory of the western Pacific. The Kwajalein rain radar is being used as part of the TRMM validation process, and has been in operation since December 1997. Unfortunately, only a few months of data are available to-date, and at none of these times did TOPEX pass over any active rain cells. All of the instances when the TOPEX algorithm indicated significant rain rates coincided with it passing over a small atoll called Namu, south-east of Kwajalein. Only about half the passes generated these anomalous rain rates, due perhaps to Namu being completely submerged at high tide.

These data were collected by NASA and provided by David Marks.

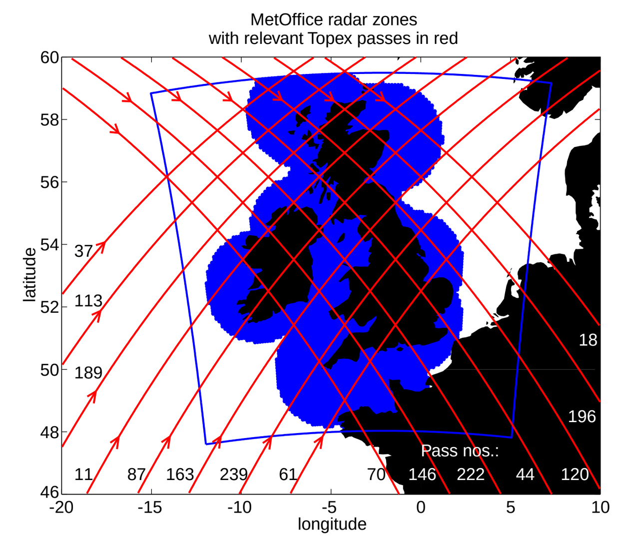


Discussion of results

In the instance on the right, TOPEX shows an anomalous enhanced backscatter as it passes over a small atoll, generating a bogus rain-rate. In the instance on the left, no such effect is observed, possibly due to the atoll being submerged by the tide.



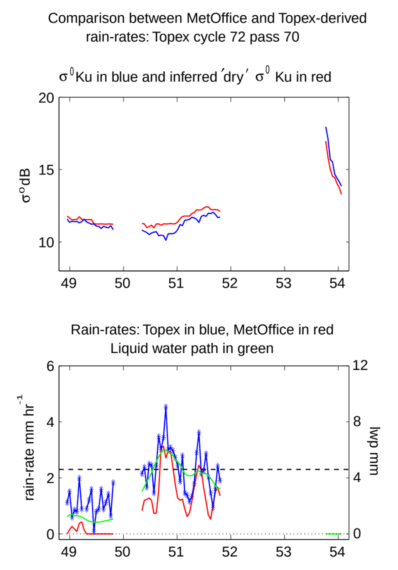
UK Met. Office



The Met Office Comparison

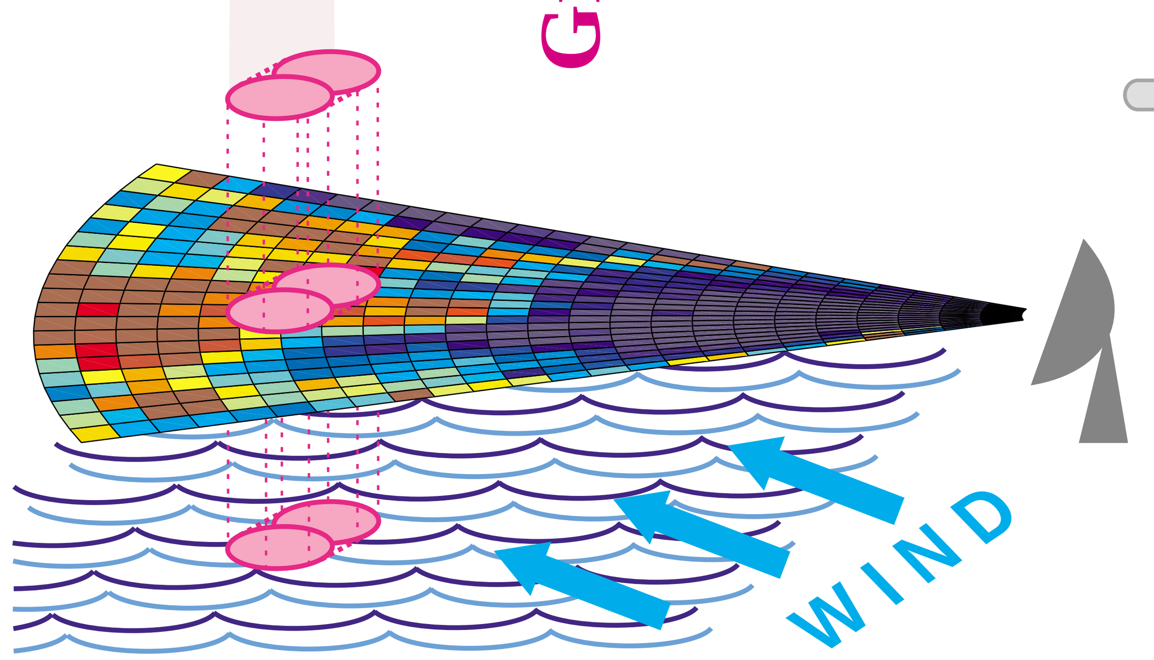
The UK FRONTIERS system is a Met Office run set of rain radars that provide half-hourly gridded rain rate data from January 1993 until the present. Given the volume of data, values were only requested for those times at which the TOPEX algorithm indicated significant rain events. Thus the dataset is not likely to contain many instances of rain where TOPEX found none.

These data were provided by Peter Panagi and Ed Dicks of the University of Reading.



Discussion of results

The comparison on the left shows some good agreement between the rain rates in the central region, as TOPEX passes from southern Ireland to Land's End. However, at the higher latitude, as TOPEX approaches Northern Ireland, a significant positive $\Delta\sigma^0$ is observed. The difference in behaviour can be explained by the fact that the surface windspeed is about 5m/s south of Ireland, and only about 1m/s north of Ireland. Low surface wind speeds almost always generate unreliable values of $\Delta\sigma^0$ due to the extreme sensitivity of the power of return to small disturbamces over a calm area of sea. However, the circumstances under which one wavelength is favoured over another are not fully understood.



Conclusions

EFFECT OF WIND SPEED

A point-by-point comparison between the TOPEX-derived rain-rates and those derived from ground-based rain radars shows a few cases of very good agreement. However, there are also a large number of cases in which the TOPEX algorithm indicates significant rain when the ground-based radars do not. Most of these cases are attributable to low wind speed, when the powers of return of the two frequencies are very sensitive to small changes in the sea surface state. This makes the values of σ^0 very skittish and so $\Delta\sigma^0$ becomes unreliable as an indicator of rain. Removing low wind cases removed almost all of the 'false' rain, with virtually no loss of 'true' rain.

ENHANCED BACKSCATTER

As far as false negatives are concerned, the Met Office data are of minimal use since only those times at which the TOPEX algorithm indicated rain were examined. Future work may remedy this deficiency. However, in the TOGA-COARE comparison, whenever the ground-based radars indicated rain, TOPEX showed some response, although sometimes this took the form of an enhanced backscatter rather than the expected reduction in backscatter.

In general, an examination of the separate responses of the two σ^0 backscatter coefficients revealed a complex pattern of behaviour, with instances of enhanced backscatter quite common. Whether this effect is due to rain-damping of the sea-surface, to convective down-draughts or some other cause is not yet clear. A further understanding of how these processes preferentially affect one frequency over another, thereby determining $\Delta\sigma^0$, is required to properly understand the information that this algorithm gives.

COMPARISONS TO TRMM

Comparisons with the TRMM satellite may yield more information about these effects. There are several hundred occasions when TRMM and TOPEX have passed over the same area of sea within 10 minutes of each other in the eighteen months from December 1997 to May 1999. The range of information derived by the various TRMM instruments about type of rain, the height of the melting layer etc., offer the possibility of a more insightful comparison then those so far conducted.

Ultimately a knowledge of the statistical behaviour of TOPEX's response to rain is sufficient since the poor sampling of TOPEX necessitates large-scale averaging in order to derive gridded rainfall rates. Since TOPEX has a greater latitudinal coverage than TRMM and predates TRMM by several years, it provides a unique radar view of rain that is complementary to other sources of rainfall data.