A 5-Year Global Precipitation Record from Ocean Altimetry

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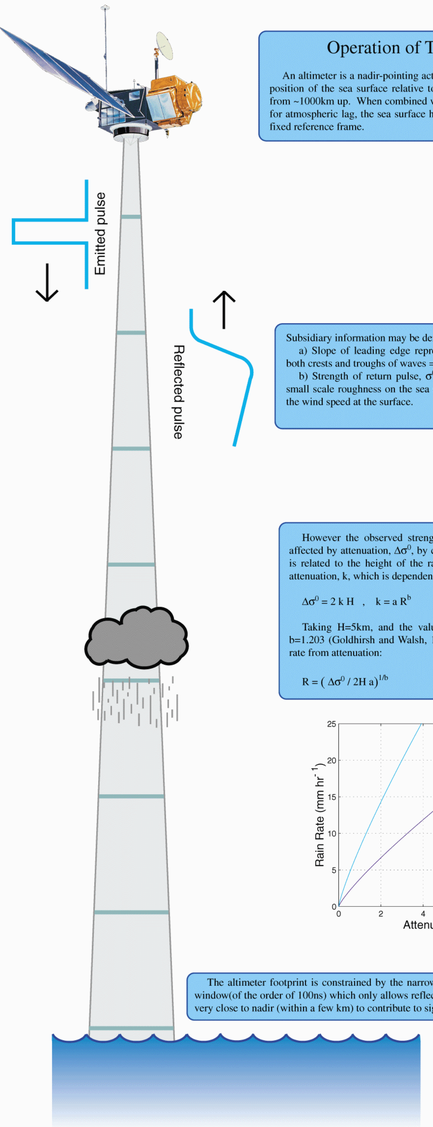


Operation of Topex Altimeter

An altimeter is a nadir-pointing active microwave device to measure the position of the sea surface relative to the satellite to within a centimetre from ~1000km up. When combined with an accurate orbit and corrections for atmospheric lag, the sea surface height may be calculated relative to a fixed reference frame.

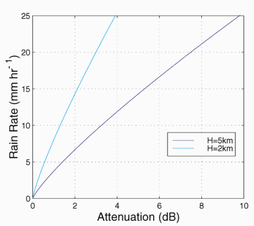
Subsidiary information may be derived from the return pulses:
a) Slope of leading edge represents smearing by reflection off both crests and troughs of waves ⇒ Significant wave height, H_s.
b) Strength of return pulse, σ^0; this *principally* represents the small scale roughness on the sea surface, which is dependent upon the wind speed at the surface.

However the observed strength of the return pulses may be affected by attenuation, $\Delta\sigma^0$, by cloud liquid water and rain. This is related to the height of the raining layer, H, and the specific attenuation, k, which is dependent upon rain rate, R, by:-

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

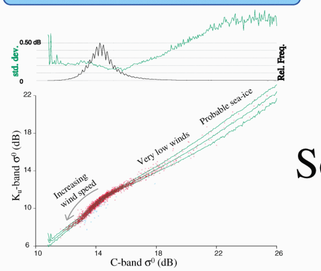
Taking H=5km, and the values for K_u-band of a=0.02 and b=1.203 (Goldhirsh and Walsh, 1982) we can invert to yield rain rate from attenuation:

$$R = (\Delta\sigma^0 / 2H\,a)^{1/b}$$



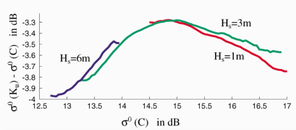
The altimeter footprint is constrained by the narrow "receive" window(of the order of 100ns) which only allows reflections from very close to nadir (within a few km) to contribute to signal.

To determine the amount of attenuation, it is necessary to know the σ^0 value in the absence of rain. This is possible with the Topex altimeter as it also operates at C-band, which can be used to infer the unattenuated value at K_u-band.

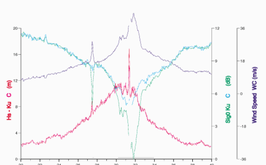


The above scatter plot shows the generally good agreement between the σ^0 values at K_u- and C-band; the scatter about the mean is typically less than 0.2dB. [In the plot, blue crosses are used to denote those points known to be affected by rain.] The mean relationship (shown by the central green line) can be used to convert the attenuated C-band σ^0 values into what would be observed at K_u-band in the absence of rain. Deviations from this represent the attenuation.

Because of the general scatter of points, a detection threshold of 0.5dB is used (corresponding to about 2.1 mm hr^{-1}), although recent improvements to the on-board software may reduce this by a factor of about 3. Attenuation up to about 10dB can be measured, implying rain rates of up to 25 mm hr^{-1}. At high rain rates, some allowance should be made for attenuation at C-band.



The σ^0-σ^0 dual frequency relationship is a complex one between the observed surface roughness on 2 different scales. For precise work, a single relationship cannot be used, but rather a series of curves which allow for the effect that sheltering by wave crests has on the roughness in the troughs.



The above figure illustrates a Topex pass across a typhoon in the NW Pacific. The sigma0 (σ^0) values decrease towards the centre, with good agreement initially between the K_u and rescaled C-band values; in these regions the inversion into wind speed is reliable. However at 30-32°N and also at 28°N there is marked discrepancy, corresponding to significant attenuation being present in the K_u-band signal. The derived wave height (SWH) information at both frequencies remains consistent throughout, revealing the high waves present in the centre of this storm.

The Merits of a TOPEX-derived Rain Climatology

The Topex altimeter was not designed with rain studies in mind, and there are certain difficulties in its use for such a purpose. However it can complement TRMM (Tropical Rainfall Measuring Mission, launched Nov. 1997) and SSM/I by providing subsidiary information.

1) There is a 5-year record from a single instrument; however, a given location is only revisited every 10 days, and care is required to allow for instrumental effects and drift.

2) It provides near-global coverage (66°S to 66°N), which is larger than that for TRMM.

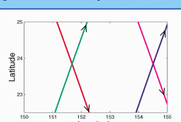
3) There is good along-track resolution (5.8km, or 2.3km for analysis of the high resolution waveform data), which is comparable to TRMM; however there is minimal swath width, as it is solely a nadir-viewing instrument.

4) The instrument provides a dynamic range of 1 to 25 mm hr^{-1}, with a theoretical accuracy of ~1 mm hr^{-1}; however in practice errors are higher due to uncertainty in the height of the melting layer, and the dependence of the attenuation coefficient, k, on the temperature and drop size distribution (DSD) of the rain.

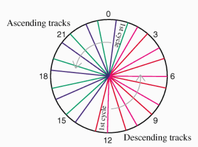
5) Concurrent wind speed and wave height measurements are available, allowing study of the wind-wave conditions associated with the rain.

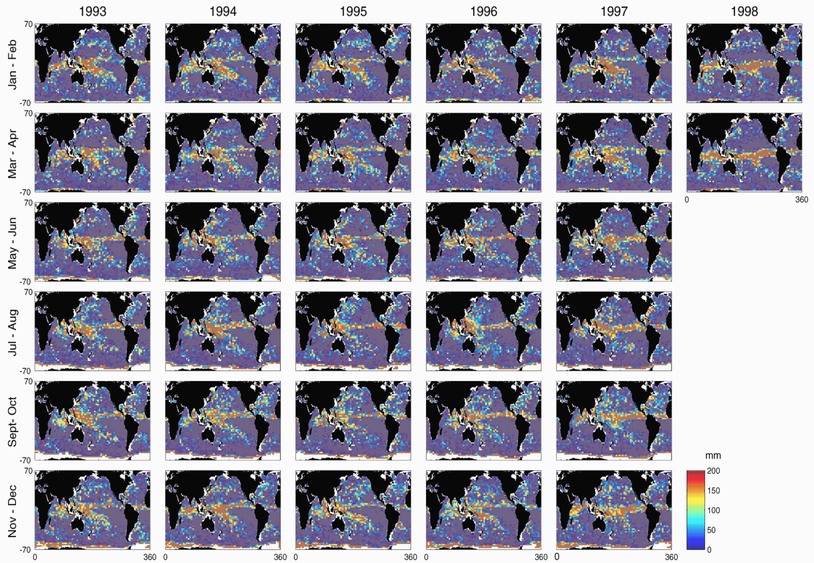
Forming a 5-year Climatology from Topex passes

The Topex satellite is in a precessing orbit that repeats itself every 9.92 days, with parallel tracks lying 2.7° apart. We have analysed the data in boxes 5° in longitude by 2.5° in latitude, grouping the data in 2-month periods.



Each region typically contains 4 satellite tracks, providing ~24 300-km sections in each period. Crucially, since the satellite repeat cycle is ~2 hours short of 10 days, six cycles allows the ascending and descending tracks to fully sample the diurnal cycle.





Global Topex Precipitation Product

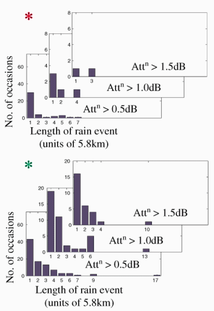
The above picture shows the monthly average rainfall for 2-month intervals spanning the Topex mission. The Inter Tropical Convergence Zone (ITCZ) crossing the Indian, Pacific and Atlantic Oceans is very prominent, as is the South Pacific Convergence Zone (SPCZ), running from Indonesia towards the Drake Passage. Points to note:

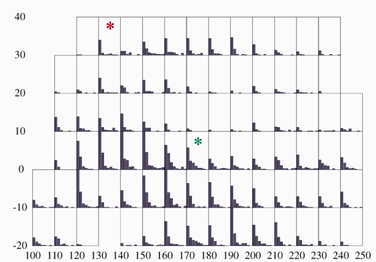
i) The "marine deserts", lying at the east of the ocean basins to both the north and south of the ITCZ, in which the monthly mean rainfall is less than 10mm.
ii) The second zonal precipitation band to the south of the ITCZ in March-April.
iii) The apparently high rain rates near the coast of Antarctica.
iv) The seasonal migration and broadening of the ITCZ, and of course, from mid 1997 onwards the increased precipitation levels associated with El Niño.

Examination of Length Scales

As an indicator of the size of rain events, we simply note the length of track for which attenuation is greater than the chosen threshold. Note sections askance from the centre of a feature will underestimate its size.

Results here are displayed in terms of units of 5.8km along track, as this is one of the basis sampling distances of the Topex altimeter.





The above diagram shows the histograms of length scales present in each 10° box in the North and Equatorial Pacific. The displays are for attenuation greater than 0.5dB, for lengths of 1 to 8 consecutive data points (where one point is every 5.8km). Full height on each histogram is 75 occurrences in the given 40-day period.

For this particular period, it appears that there is a wide span of length scales in the Equatorial region, whereas around 30° to 40°N, the rain seems to occur predominantly on scales of about 5km.

The collection of histograms shown above provides greater detail on the length scales in the 2 different 10° boxes highlighted, adding in the lengths of data passing higher thresholds.