A revisit of global ocean smooth surface conditions and temporal changes using the Topex-to-Jason altimeter time series data

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I. Background

An unanticipated complication for precision ocean altimetry has been the loss of valid ranging data under light wind or smooth water conditions that occur at length scales of 0.1-300 km over 4-6% of the global ocean, and to persist 20-30% of the time in certain tropical and sub-tropical oceans. Originally termed the AGC or sigma0 (σ_0) blooms, these quasi-specular conditions lead to greatly increased levels in the radar altimeter return and they also frequently lead to erratic estimates of range and platform pointing angle. Altimeter measurements under these conditions have been documented, using TOPEX, Jason and Envisat observations (Mitchum et al., 2004; Thibaut et al., 2007;Tournadre et al., 2006). In several respects, the ocean altimeter is better-suited to assess such surface conditions than other available ocean wind observing radar or radiometer systems.

This new investigation revisits the phenomena and its altimeter detection from several new aspects. First we seek to ascertain if long term ocean altimeter datasets can reveal additional information on spatial and temporal evolution of smooth water regions since 1992. σ_0 bloom data from the 10-day repeat altimeter missions, TOPEX to Jason-3, are harmonized to develop seasonal time series across ocean warm pools and then to evaluate interannual change. We are also exploring bloom data for other applications. New approaches to potentially delineate between calm wind and biogenic slick control of such smooth surface conditions, regional coincidence with marine debris and phytoplankton blooms, and the ability of the altimeter to detect predicted wind stress onset are all in the assessment phase.

II. Data and Methods

1 Hz data from altimeters TOPEX and Jasons 1,2,3 (1993–2017)

- Backscatter cross section in Ku and C bands, σ_{Ku} and σ_C
- Waveform (WF)-estimated altitude ζ_{wf}
- ECMWF model wind speed U_{10} (2000-2017)

Inter-mission calibration of

σ_{Ku} and ζ_{wf} for high σ_{Ku}>=14 db , with respect to TOPEX (**Fig.1**)

Two-step bloom identification/search per Mitchum et al. 2004

- In 1st step : search all points with σ_{Ku} >14dB with a coherence time (or length): termed "bloom duration"
- in 2nd step: search there is at least one point $\zeta_{wf} > \zeta_{max}$ where it is 0.3, 0.46, 0.44 and 0.44 for Tx, J1,J2 and J3 respectively.

Statistics of σ_0 blooms identified (Fig. 2)

- σ_0 bloom spatial extent (duration) ; always > 70 km (10 s)
- correlation between wind speed U_{10} and σ_{Ku} during events
- wind speed U_{10} distribution during a bloom
- spatial statistics within events (e.g. gradient, mean/max/min/variance of σ_{Ku} and ζ_{wf})

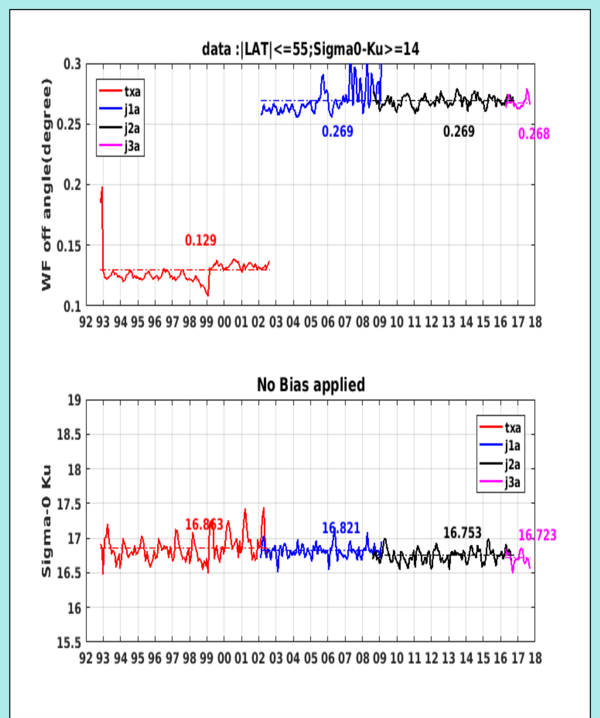


Fig. 1 (top) 1992-2018 monthly WF-estimated altitude ζ_{wf} , and (bottom) backscatter σ_{Ku} from TOPEX, Jason-1, -2, and -3.

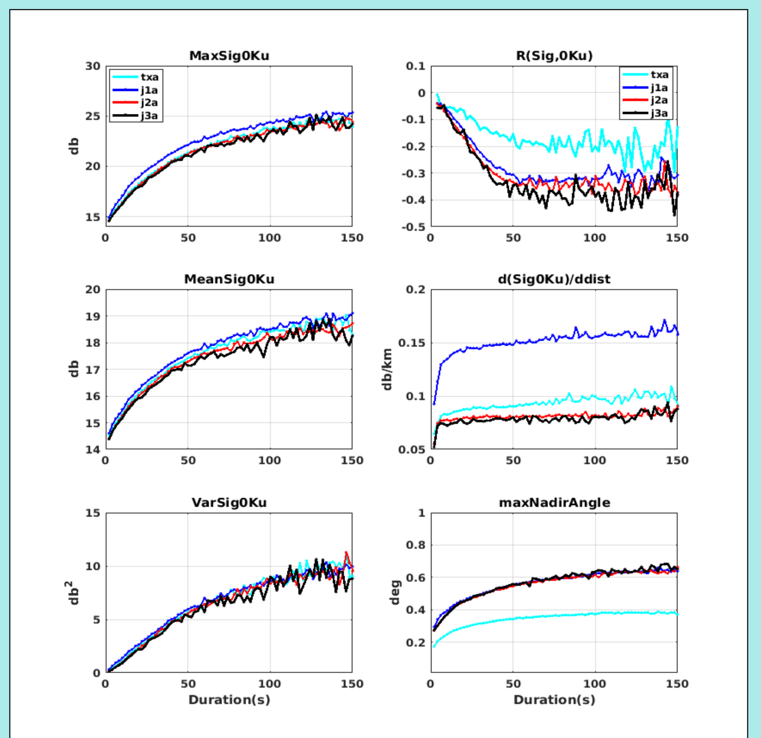


Fig. 2 Sigma0 bloom duration (secs) vs. (a) max Sigma0_{Ku}(b) meanSigma0_{Ku} (c) variance of Sigma0_{Ku}(d) correlation between Sigma0_{Ku} and model wind speed, e) mean σ_{Ku} gradient and f) max altitude ζ_{wf}

III. Space/time sigma bloom variations using T/P, J-1,-2,-3 data

1993-2018 averaged data showing spatial variation in bloom event duration, wind, and within event NRCS variability

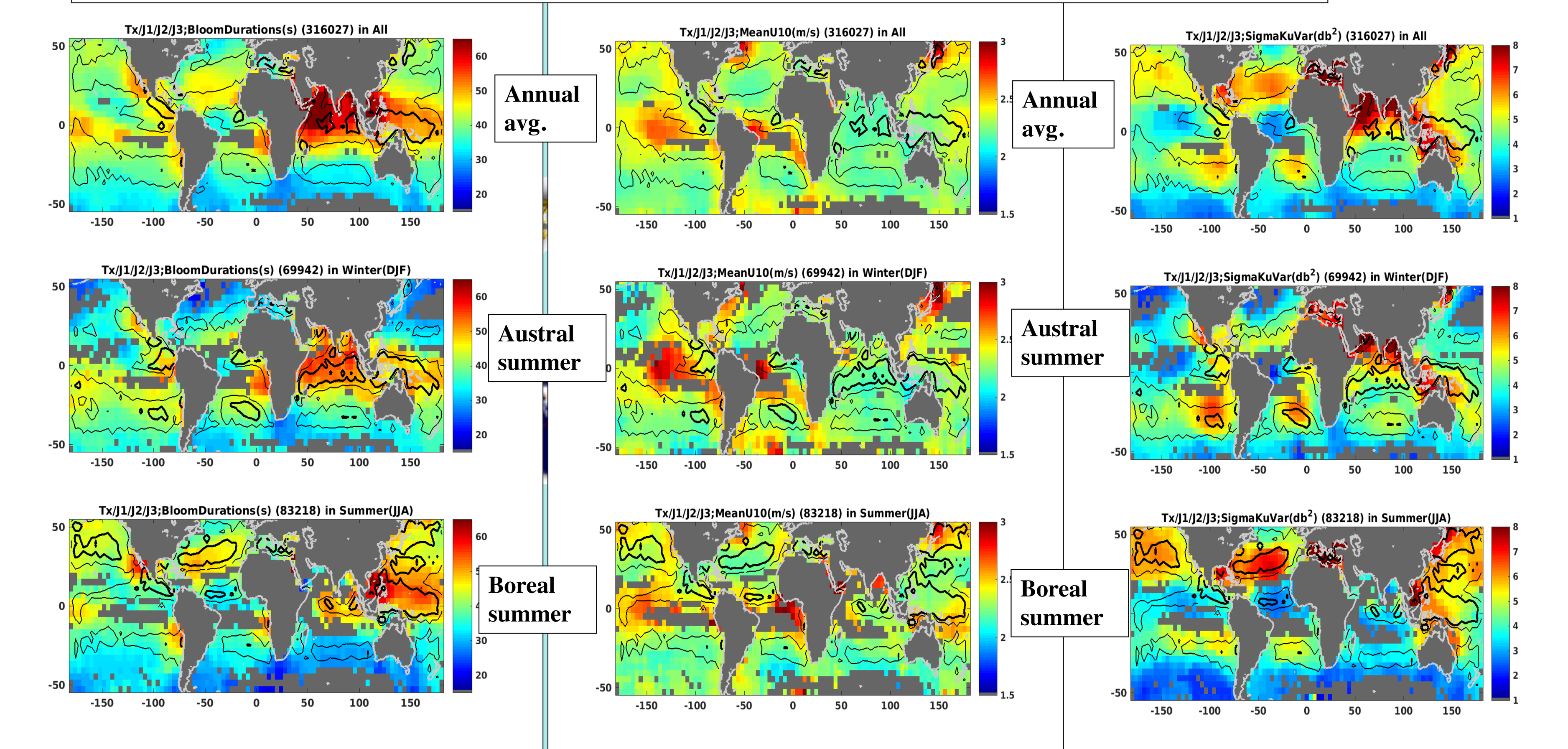


Fig. 3 Spatial distributions of **3a) bloom duration** (second), **4b) mean wind speed U10** (m/s) during blooms, and **3c)** Variance of sigma0Ku (db^2). Note that blooms observed with the duration>10s are included in this analysis, and are averaged in 2°lat-2°lon bins. In each of figures 3a/3b/3c, three vertical panels represent (**top**) all seasons, (**middle**) austral and (b**ottom**) boreal summer averages, respectively. In each panel, the two contours in thick & thin black lines represent high and moderate **bloom occurrences** respectively. Also note that the grayed areas indicate low bloom occurrence regions with < 20 (all year round) and <5 (NH winter and summer) bloom events.

1993-2018 variation in avg. sigma0 bloom alongtrack extent

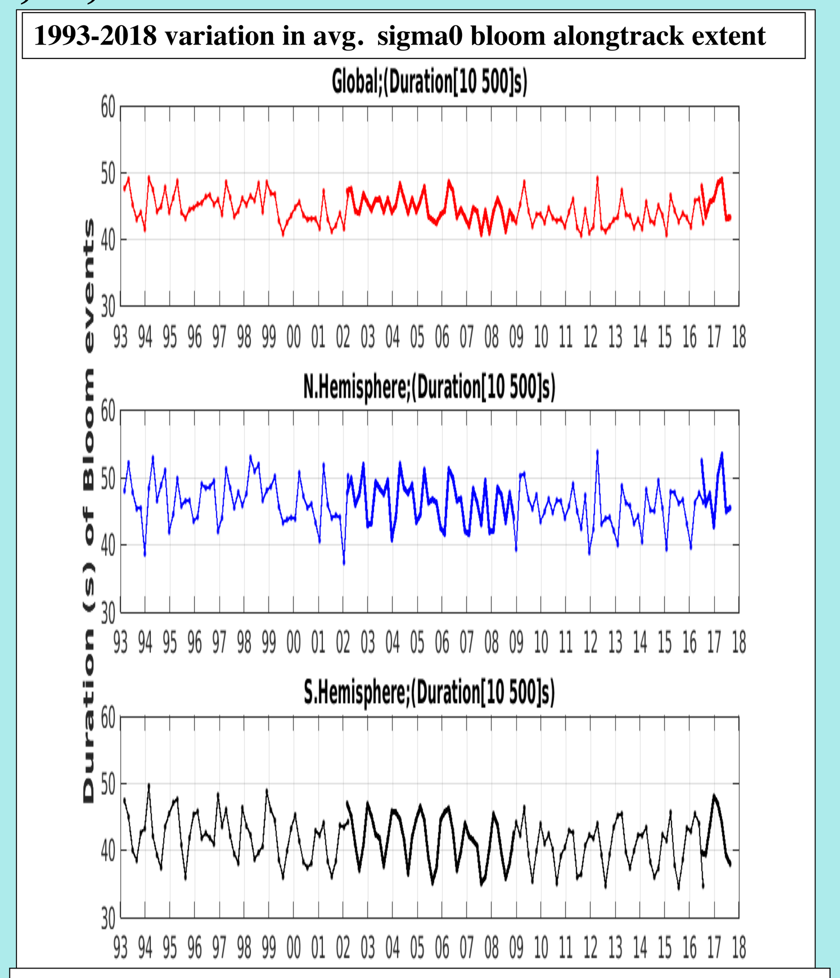


Fig. 4 (top/middle/bottom) Time series of avg. bloom duration (in s (40 s~=280 km)) globally (top), N. and S. Hemisphere, respectively.
- Note the consistent results across missions
- Note the clear seasonality, indicating longer duration in summer
- Note also the **relative stability** at interannual scales

IV. Comparison of blooms and marine debris

Global map of altimeter bloom event density in summer periods (contours also seen in Fig.3)

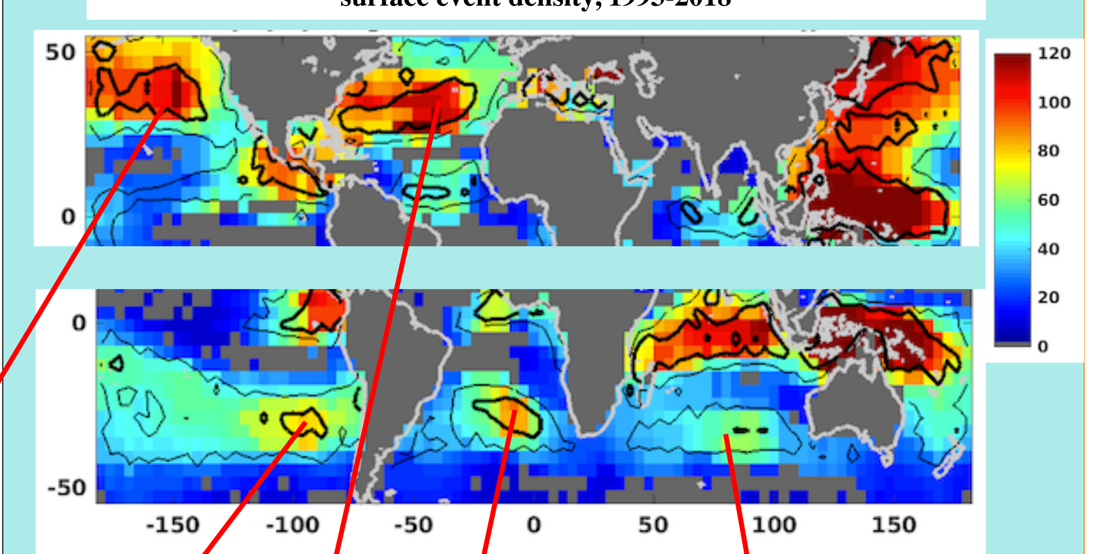
compared to

Global mapping of plastic debris measured in five key ocean gyres (per Beans, 2014). This based on nine-month, worldwide expedition in 2010.

1) Note similarity between the spatial distributions

2) Coincidence? - or can some characteristics of bloom events align with surface and wave properties impacted by debris?

Fig. 5 – Boreal (upper) and austral (lower) summer altimeter smooth surface event density, 1993-2018



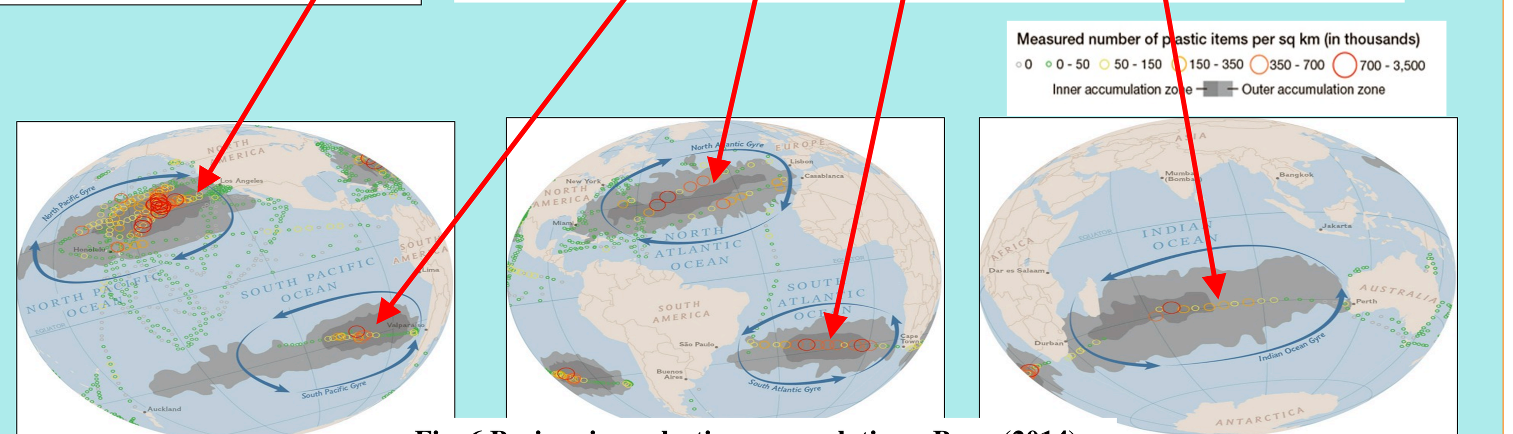
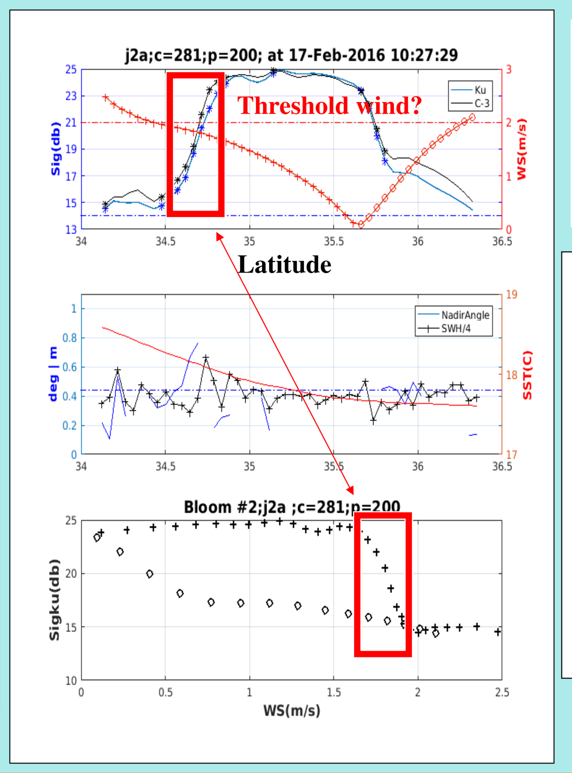


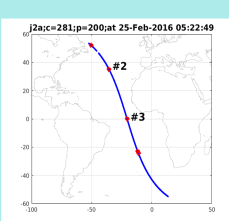
Fig. 6 Basin micro-plastics accumulations, Bean (2014)

V. Can altimeter detect critical wind speed/wind stress threshold for wind-wave generation near U=2.1 m/s? Does Ku-band show SST impact?

Example along-track bloom events where wind is growing/dying U=0-2 ms; Donelan and Plant (2009)

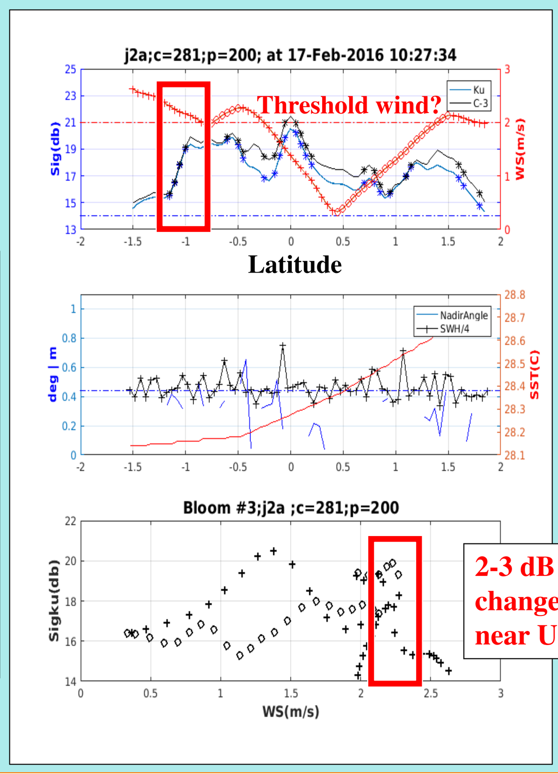
Fig. 3 Two bloom events identified on a Jason-2 track (cycle 281, Pass 200) labeled #2(left) and #3(right) (see also inset map). Left and right panels each with **Top:** σ_{Ku} and $\sigma_{C\text{-}3db}$ (left axis) and ECMWF wind U10 (right axis); **Middle:** off nadir angle ζ_{wf} , SWH/4 (left axis) and SST (right axis). **Bottom:** Scatter plot of σ_{Ku} against model wind speed U10 .





Left – mid latitude event with strong/sharp sigma0 change near U=2

Right – tropics, more confused wind-sigma0 characteristics, but steps also evident



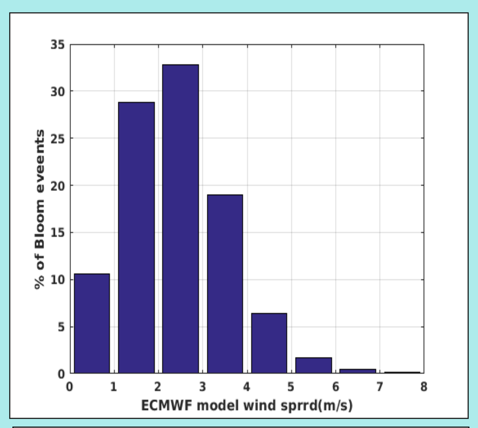


Fig. 4 The normalized distribution of ECMWF wind speeds during Sigma0 blooms. Note >~90% blooms corresponds to <4m/s .

Note: NWP model winds a non-ideal proxy, especially in tropics.

Jason-2 roughness increase with increasing wind - Global avg. over all bloom events

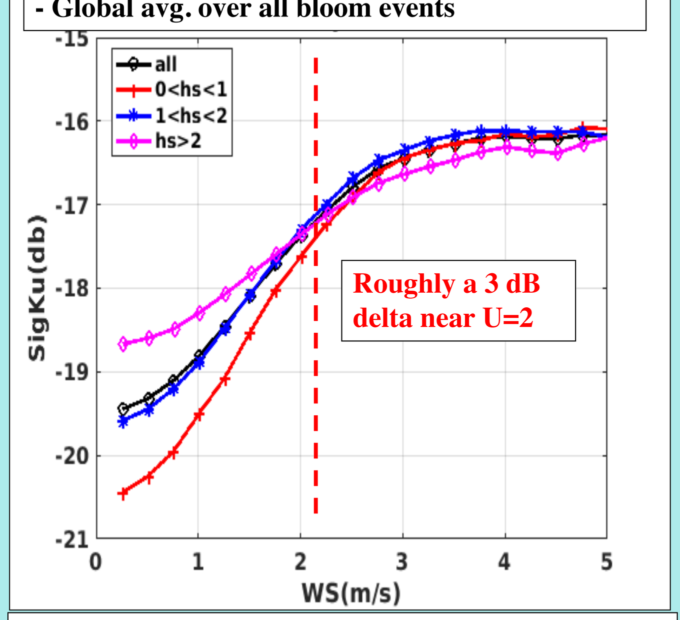


Fig7. All bloom event sigm0 σ_{Ku} (inverted to negative #s) is binned on ECMWF wind speed at different significant wave height bins based on Jason 2 bloom data. Note there is a threshold at ~2.1-2/.5m/s.

Predictions/Observations:

- Expect (Donelan and Plant, 2009) short wind waves to disappear below an avg. wind speed of 2 m/s – a 'critical' wind speed
- Altimeter observes a crudely estimated change of 3 dB (nearly the same for C (not shown) and Ku-band
- Clearest for case of low SWH where background waves are minimal factor
- **At right** – a look at possible shift in critical wind stress with SST change due to water viscosity. We see similar result wave tank work - colder water has higher threshold wind.

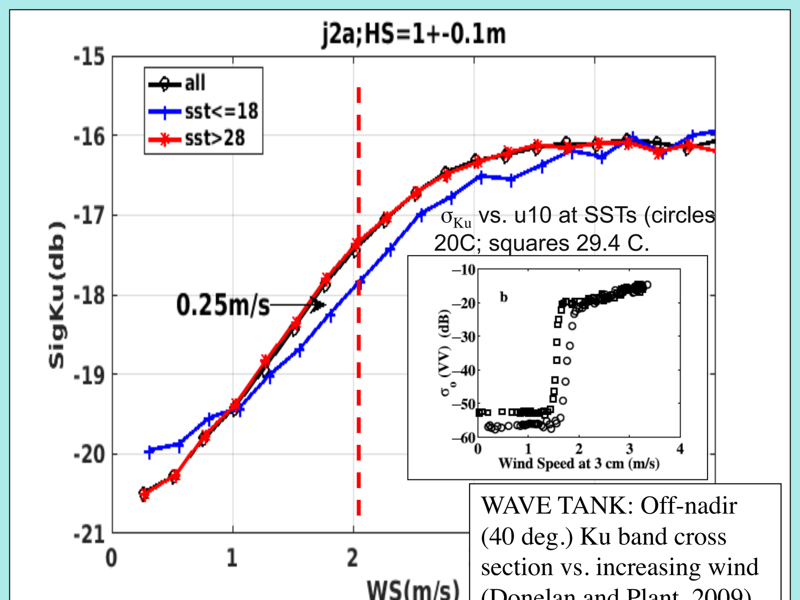


Fig8. σ_{Ku} is binned on U10 at sea surface temperature SSTs at Hs=1±0.1m. Note there is ~0.25 in U10 threshold increase at U10 [1.5-3.0m/s] from 18C to >28C, a wind sea growth mechanism proposed by Donelan and Plant (2009) (see inset figure).

V. Conclusions and next steps

First Conclusions

- Two decade plus long altimeter (Tx-J3; 1993-2007) data are being used to build up harmonized time series and spatial maps in smooth surface (bloom) conditions and to evaluate spatial-temporal characteristics; consistence amongst platforms is apparent
- Collocated ECMWF wind data shows >85% blooms corresponds to low winds<4m/s and longer/shorter bloom durations correspond to relatively higher/lower winds – as expected.
- Smooth surfaces (blooms) were identified with distinct statistics of σ_0 and U10 suggesting likely different controls of these smooth conditions => predominantly low-wind, but also other causes.
- Bloom condition data show some potential new applications, such as wind threshold change for wind sea growth (Figs 7-8) and bloom mapping to better identify convergence zone behaviors

Next steps: One goal is to design new approaches to potentially delineate between calm wind and other (biogenic slicks) control of these smooth surface conditions.

- Identify 2-4 event classes in terms of selected statistics of blooms, such as duration, correlation of U_{10} and σ_0, other statistics of σ_0,U10 and ζ_{wf} during a bloom, leading to low wind or biogenic slicks
- Assess identified bloom classes in space/time:
  - Collocation with ocean color in time (monthly and seasonal) and space (9km or longer) scales
  - 20Hz SGDR data retracking of C and Ku band data for these cases (e.g. Tournadre et al., 2006)
  - alongside RAMA, PIRATA and TAO mooring data

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- Tournadre, J., B. Chapron, N. Reul, and D. C. Vandemark (2006), A satellite altimeter model for ocean slick detection, J. Geophys. Res., 111 (C4), C04,004, doi: 10.1029/2005JC003109.

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NASA OSTST meeting , Miami, Florida, USA, 23-27 October 2017