Waveform aliasing in satellite radar altimetry

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Waveform Aliasing

- From SeaSat through Jason-CS, all altimeters employ "full deramp" of a linear FM chirp
  - A discrete Fourier transform (DFT) of the digitized receiver output yields a time series of complex amplitude coefficients, z_t.
  - The sampling rate of z_t is correctly matched to the chirp bandwidth, B, according to Nyquist-Shannon sampling theorem.
  - The waveform is the average of the power, which is the squared magnitude of z_t: $p_t = |z_t|^2$.
  - Squaring doubles frequency, so z_t should be resampled before forming p_t [Jensen, IEEE, 1999].

Squaring doubles frequency

If $y(t) = \cos(2\pi f t)$ is sampled at the Nyquist rate

$y_t = \{1, -1, 1, -1, ...\}$ and then squared

$[y_t]^2 = \{1, 1, 1, 1, ...\}$ a wrong result is obtained.

Squaring doubles frequency

$$[y(t)]^2 = \frac{1}{2}[1 + \cos(4\pi f t)]$$

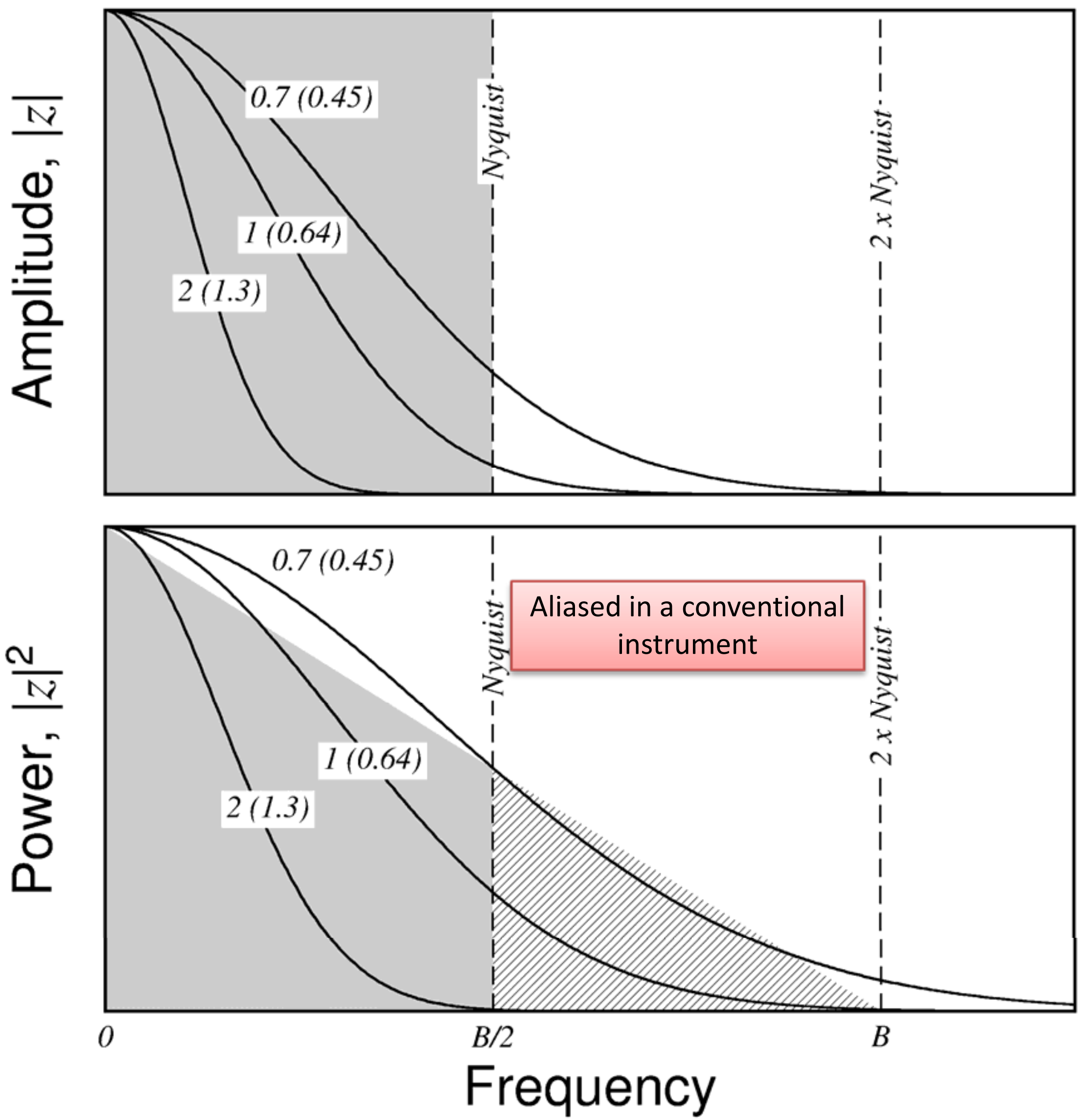
We must double the sampling rate

$$y_t = \{1, 0, -1, 0, 1, 0, -1, 0, ...\}$$

And then squaring gets correct result.

$$[y_t]^2 = \{1, 0, 1, 0, 1, 0, 1, 0, ...\}$$

Theory for bandwidth needed



Jensen [1999] supposed z_t is full-bandwidth (upper rectangle), so p_t fills the lower triangle. We derive the bandwidth expected from a Gaussian rough surface. A label such as 2 (1.3) means that curve is for 2 m SWH if B = 320 MHz (Ku band) or SWH = 1.3 m if B = 500 MHZ (Ka band). Aliasing should be most significant at lower values of SWH, and less of a problem for AltiKa.

CryoSat FBR provide a test

CryoSat's "FBR" data product provides $N = 128$ digitized receiver samples per echo, prior to the DFT.

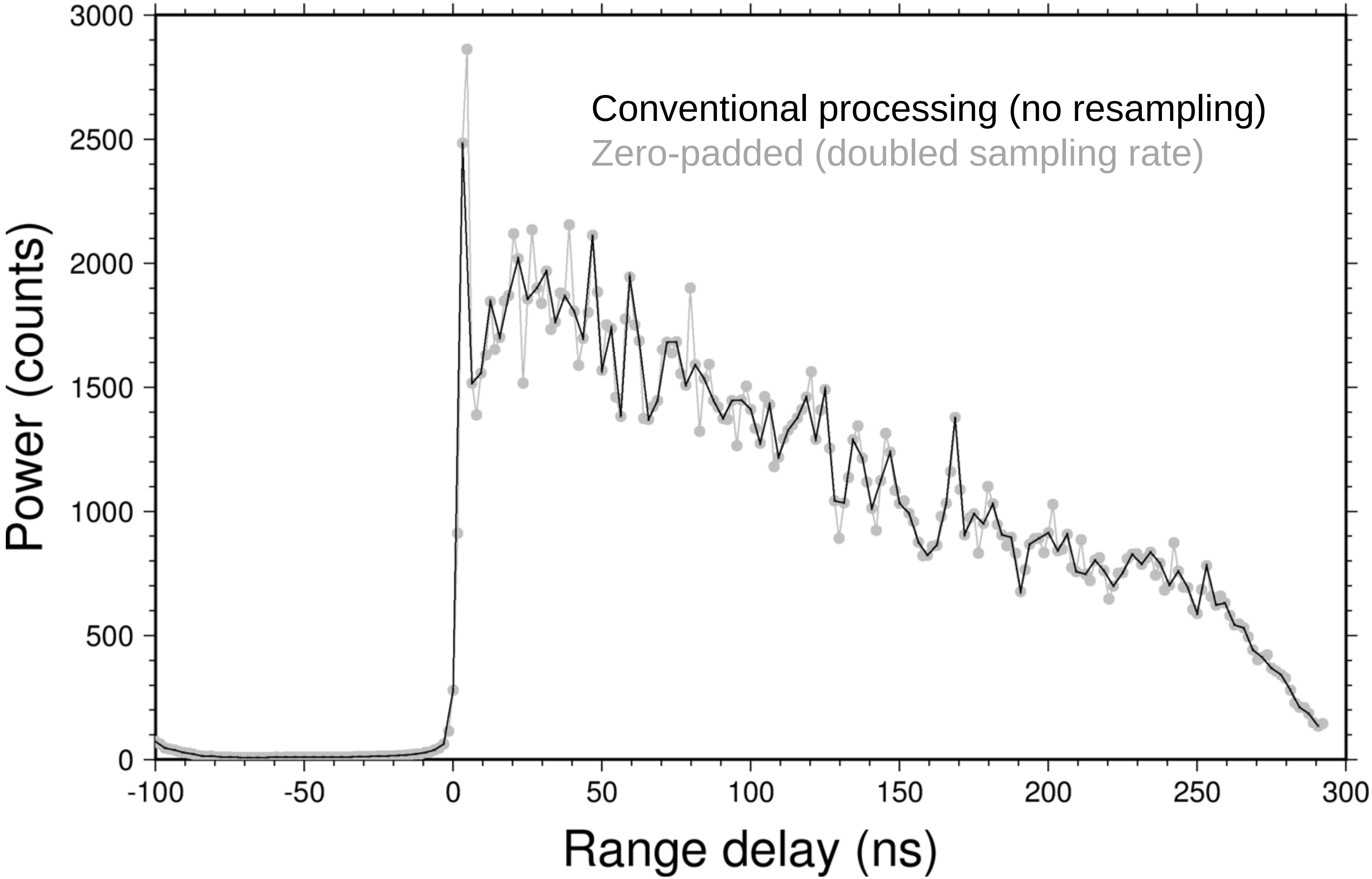
Conventional, 128-element waveform:

- We simply form z_t as a 128-element DFT of the FBR, and then $p_t = |z_t|^2$.

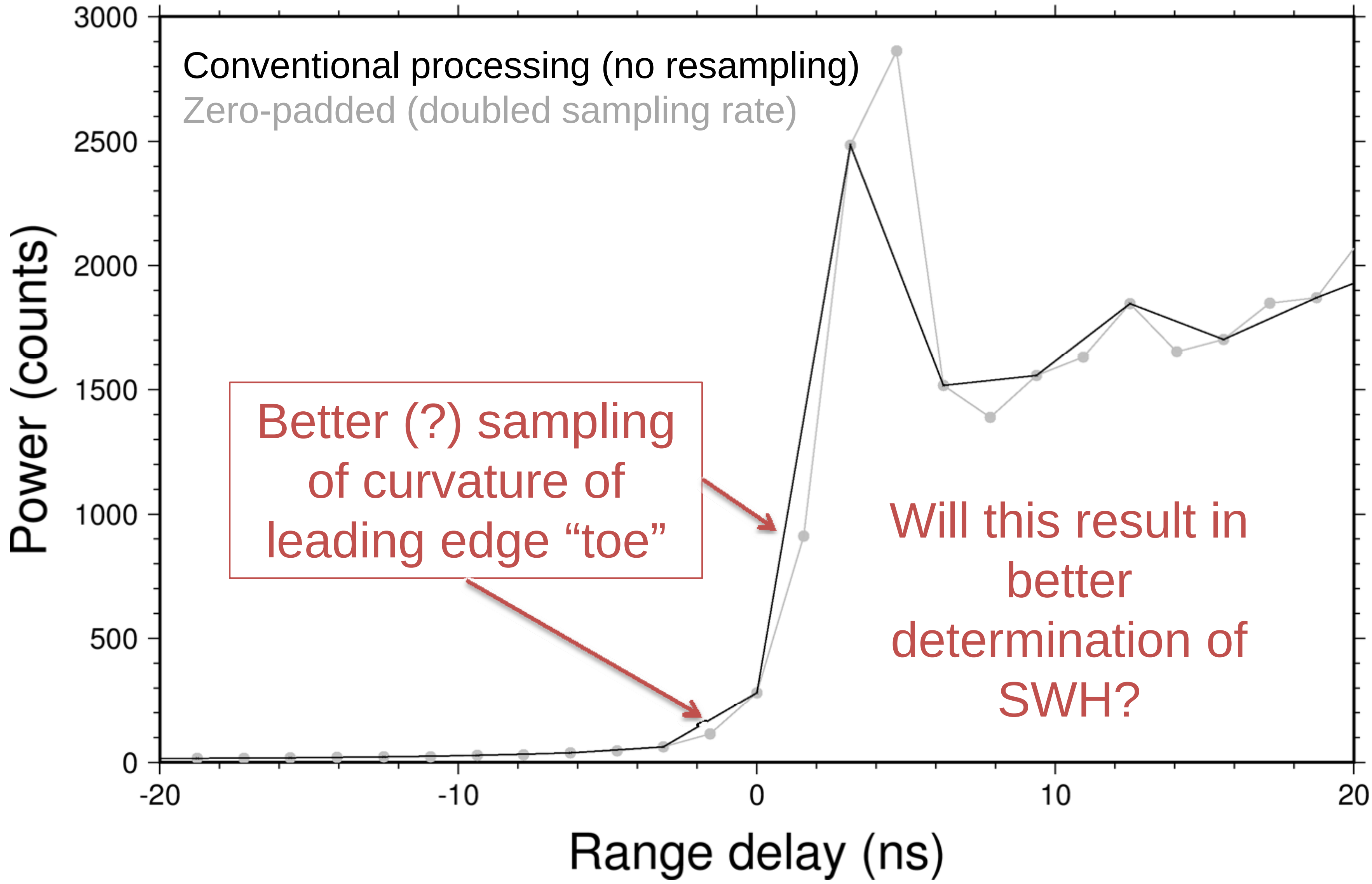
Double-sampled, 256-element waveform:

- We extend the 128-element FBR data by padding with 128 zeroes prior to doing a 256-element DFT. This yields a 256-element z_t and $p_t = |z_t|^2$.

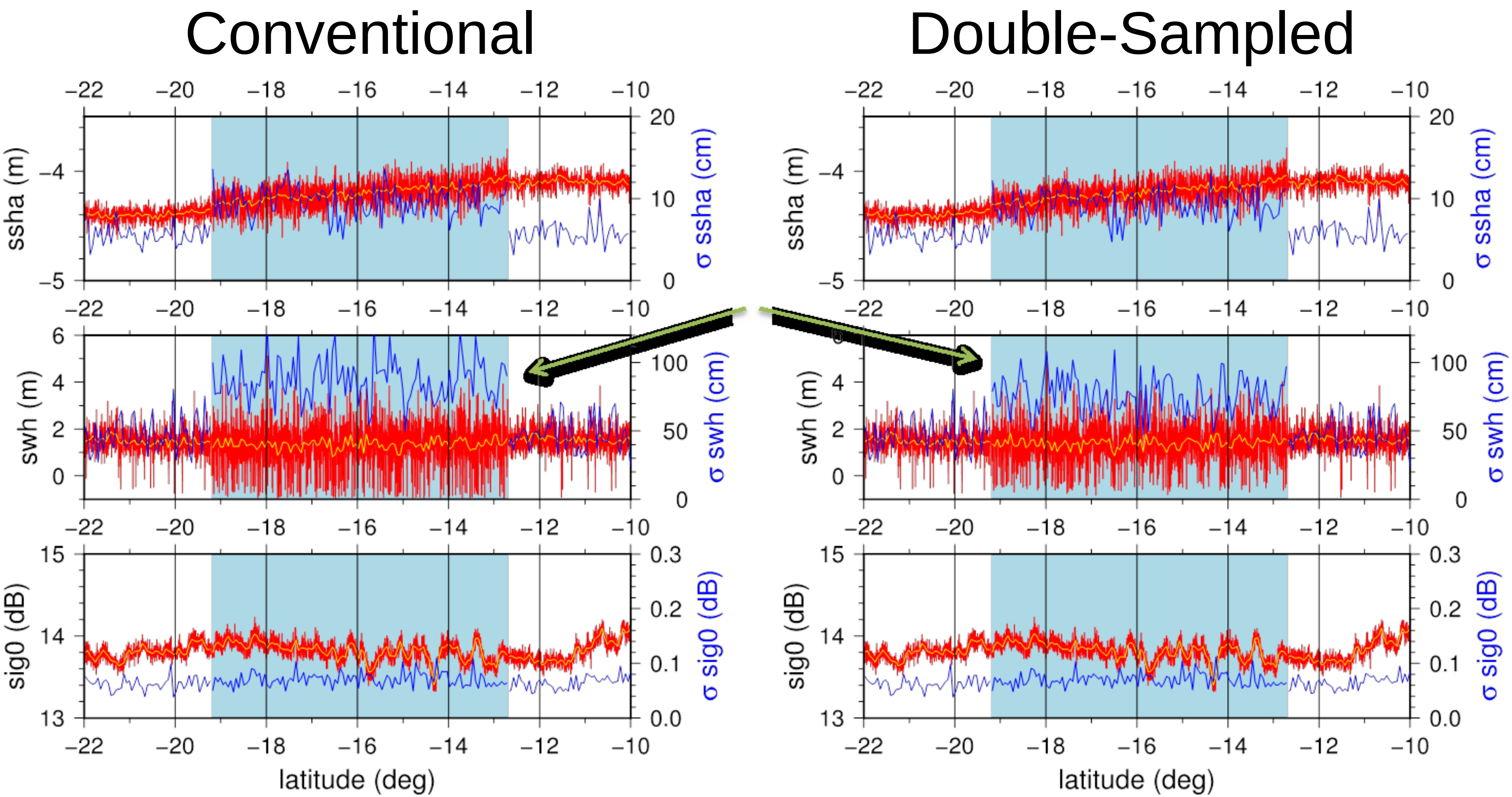
PLRM waveforms from FBR



PLRM from FBR (zoomed in)

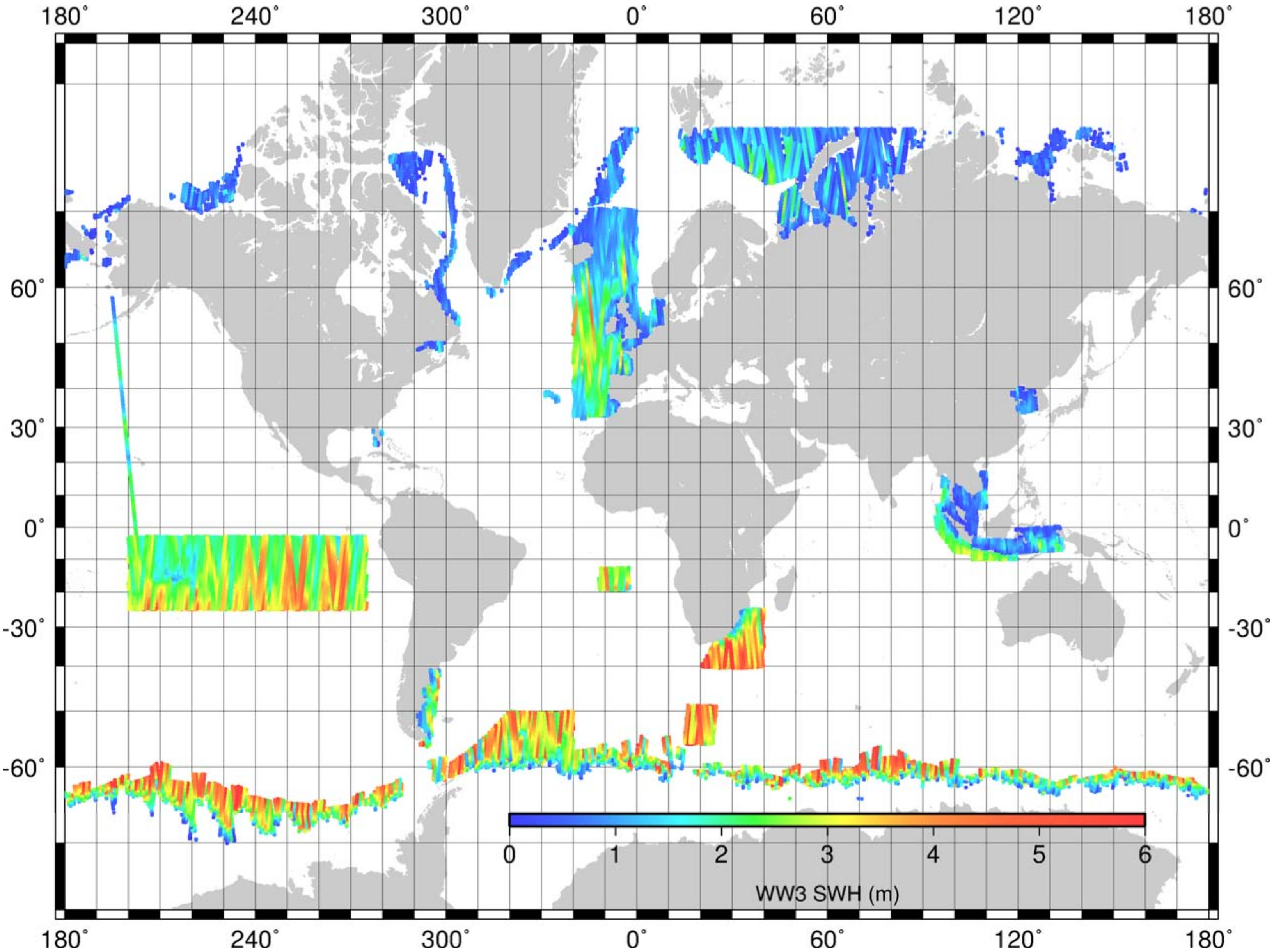


Result of MLE3 retracking along a pass

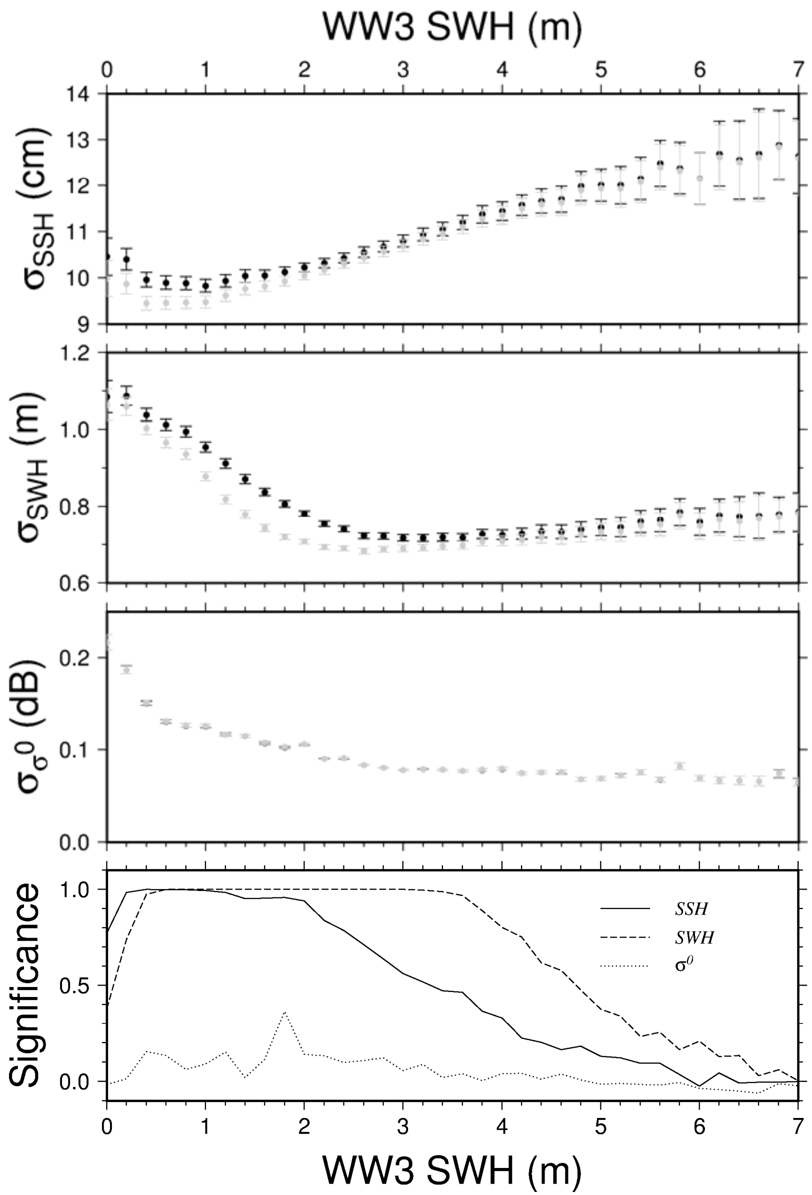


Resampling lowers noise in SWH estimate

We analyzed a 29-day cycle of ocean data

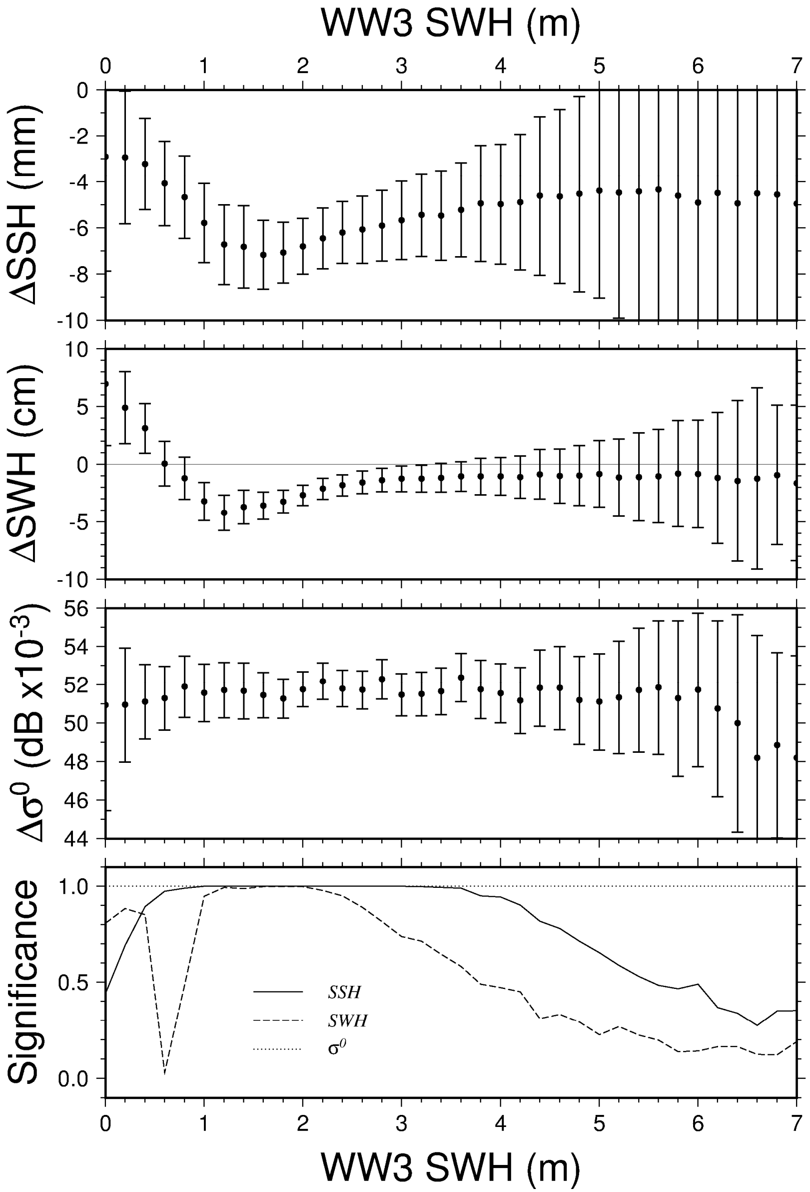


Cycle averages: 20-Hz std. dev.



Conventional (black) and double-sampled (gray) standard deviations in MLE3 retracker outputs at 20 Hz (top 3 panels), & significance of the variance reduction (bottom). Range s.d. reduced up to 5 mm; SWH s.d. up to 9 cm.

Cycle averages: 20-Hz change in mean (bias)



Double-sampling changes the mean SSH by a few mm, and the mean SWH by a few cm (sea state bias applied might cancel SSH effect), depending on wave height. Sigma0 changed uniformly by only 0.051 dB. Changes are significantly different from zero.

Conclusions

CS2 Baseline B for SAR was implemented because resampling proved better for sea ice (specular echoes).

We find that resampling is also good for conventional LRM altimeters when SWH is less than about 4 m. That is, ***conventional waveforms are, in fact, aliased.*** Jensen [IEEE, 1999] was correct.

Resampling prior to forming power yields variance reductions of order 10% in range and 20% in SWH estimates. Backscatter improvement is less dramatic.

Future altimeters should use resampling when computing waveforms. (Even SAR altimeters do this to compute the “tracking echo” used on-board for the AGC and target tracking loops.)

References & Acknowledgements

The problem of aliasing was brought to our attention by a 1999 paper by Bob Jensen. The paper was mainly about how on-board split-gate trackers could be modified to track delay-Doppler (SAR) waveforms. But he remarked that the conventional altimeter process was prone to aliasing.

Jensen, J. R. (1999) Radar altimeter gate tracking: theory and extension, *IEEE Trans. Geosci. Remote Sensing*, *37*(2):651–658, doi:10.1109/36.752182

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