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Beginning with Seasat and continuing through the design for Jason-CS, all satellite radar altimeters have employed a pulse compression scheme known as full-deramp of a linear FM chirp. The process by which all conventional altimeters create a waveform from digitized radar echoes can lead to aliasing of the waveform. This was first noted by Bob Jensen in a 1999 paper (IEEE TGRS 37(2):651-658, doi:10.1109/36.752182). We have examined the problem both theoretically and experimentally, using raw digitized echo samples from CryoSat's SAR mode.

We derive theoretically the chirp bandwidth necessary to resolve sea surface height (SSH) and significant wave height (SWH) in waveforms of echoes scattered by a Gaussian rough surface approximating the ocean. A chirp bandwidth of 320 MHz, as used in Ku-band altimeters, is not wide enough to fully record the echo when SWH is less than about 1 meter, and aliasing should occur. AltiKa's wider bandwidth, 500 MHz, should be prone to aliasing when SWH is less than about 64 cm.

This theoretical aliasing through a bandwidth limitation applies to the raw digitized receiver output of an altimeter. This output is then converted to a time series of complex echo amplitudes by a discrete Fourier transform (DFT). After the DFT, a conventional altimeter obtains the power by simply squaring the magnitude of the discrete sequence, without resampling. Since squaring a signal doubles its frequency, the sampling rate for power may under-sample the sequence, and it is this under-sampling of a squared sequence that is the potential source of aliasing that Jensen's 1999 paper notes. This problem can be fixed by zero-padding the digital receiver output prior to the DFT, which effectively doubles the sampling rate of the waveform gate samples. This resampling must be done prior to forming the power in individual echoes, and thus prior to forming the mean power echogram averaged over a radar cycle (nominally 1/20 of one second) known as the waveform.

We processed 29 days of CryoSat SAR mode data over oceans, forming simple pulse-limited (pseudo-LRM) waveforms at a 20-Hz rhythm by the conventional method and by the zero-padded and resampled method. Geophysical retrievals were then made by MLE3 retracking of both the conventional and resampled waveforms.

SSH variance is reduced by about 10% and SWH variance is reduced by up to 22% when zero-padding is employed. The significance of the variance reduction is shown by the statistical F-test. The error reduction and its significance are functions of SWH, and show that zero padding is most useful for SSH estimation when SWH is less than 2 m, and for SWH estimation when SWH is less than 4 m. Zero-padding makes a very small but statistically significant change in backscatter estimates as well. The 20-Hz range uncertainty decreases by 5 mm and the 20-Hz SWH uncertainty decreases by 9 cm when zero-padding is employed. The bias in SSH is unchanged, SWH changes by up to 5 cm, and backscatter changes by 0.051 dB when zero-padding is employed.

When CryoSat is in SAR or SARIN mode it still employs the conventional (no zero padding) processing scheme to obtain a waveform known as the tracking echo, which drives the automatic gain control and range tracking feedback loops. These ultimately govern the digital echo samples that it can make available. We suggest that future altimeters should be designed to include zero-padding in the chirp deramp DFT so that the echo power sampling process does not introduce any aliasing.

However, for very low values of SWH, even zero-padding cannot overcome a fundamental limitation: the roughness of the surface can be too small for the bandwidth available to the altimeter. We conjecture that this aliasing may contribute to the phenomenon known as sigma-naught blooms, in which a very specular echo drives the altimeter loops to yield poor results.

OSTS session

Instrument Processing