Quantifying Wave Error on SWOT Sea Surface Height in the Southern Ocean

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Background

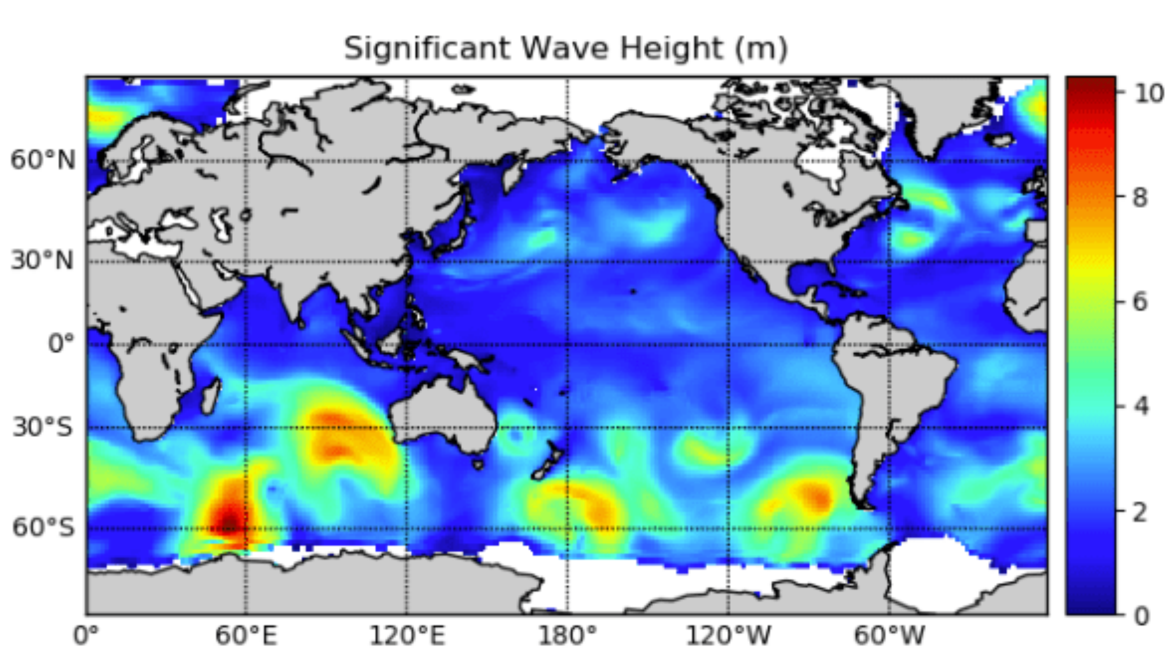

Figure 1. Global significant wave height from one day of Wavewatch III simulations. The global mean significant wave height (2.5m) is surpassed in the majority of the Southern Ocean, with some areas experiencing wave heights of 10m.

The Surface Water Ocean Topography (SWOT) satellite mission aims to measure mesoscale and submesoscale ocean processes at unprecedented resolution. The expected accuracy of the measured sea surface heights is less than two centimeters over an averaging area of 25 km^2 when surface waves are approximately three meters. This increased resolution would greatly increase our understanding of how eddy kinetic energy is changing in the Southern Ocean. Accurate measurements of SWOT sea surface height requires a complete understanding of errors that could inhibit observations. Significant wave height in the Southern Ocean can vary between ~6-7 meters and sometimes can be greater than 10 meters (**figure 1**). These wave heights lie outside the scope of the proposed error budget, which assumes waves will produce random error within the swath. Here we look at the effect of high significant wave heights on retrieved eddy kinetic energy from SWOT-like data.

Wave Generation

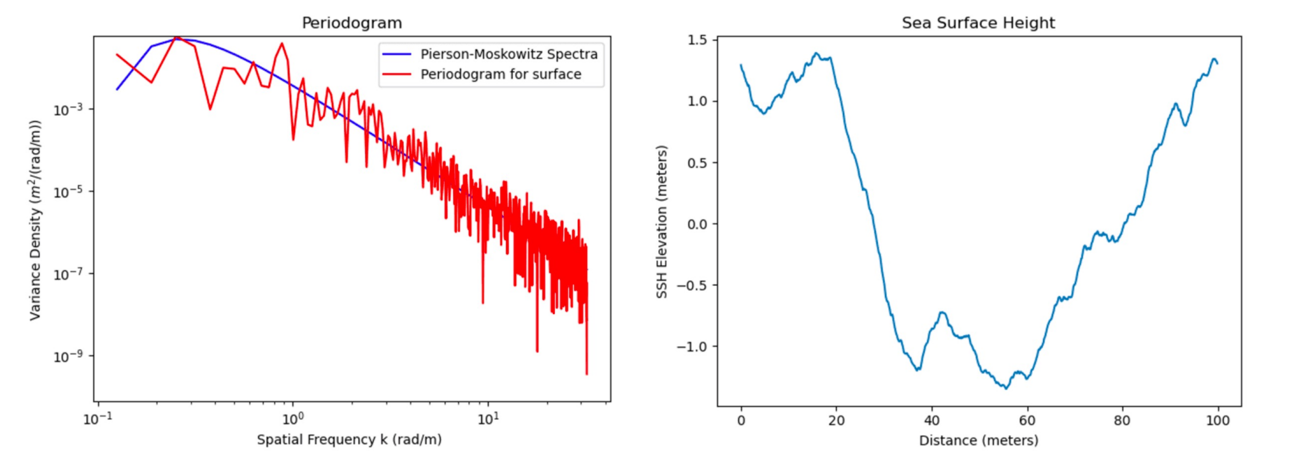

Figure 2. A random one-dimensional sea surface height realization generated from the Pierson-Moskowitz variability spectrum over a domain of 100 meters and 1024 samples. The periodogram for this surface is in good agreement with the original variability spectrum, and contains the random noise used to create the SSH.

For this project, we generated 100 wave surfaces for various significant wave heights. This was done using a Fourier Transform method to retain wave spectra variance while introducing random phase. The wave spectra used were Pierson- Moskowitz (1964) for one dimension **(figure 2)**, and Elfouhailey et. al (1997), and JONSWAP (Isherwood, 1987) for two dimensions. These surfaces were then observed with the SWOT point target response and then smoothed with the SWOT on board processing procedure.

SWOT onboard processing

Once surfaces were generated (as in figure 2) they were observed by SWOT. First they were fed to the point target response function, and then the surfaces were smoothed by the onboard processor. The point target response (PTR) function used was taken from the equation in Peral et. al (2015). The PTR function, when acting on waves, creates higher wave peaks and lower wave troughs (**figure 3**).

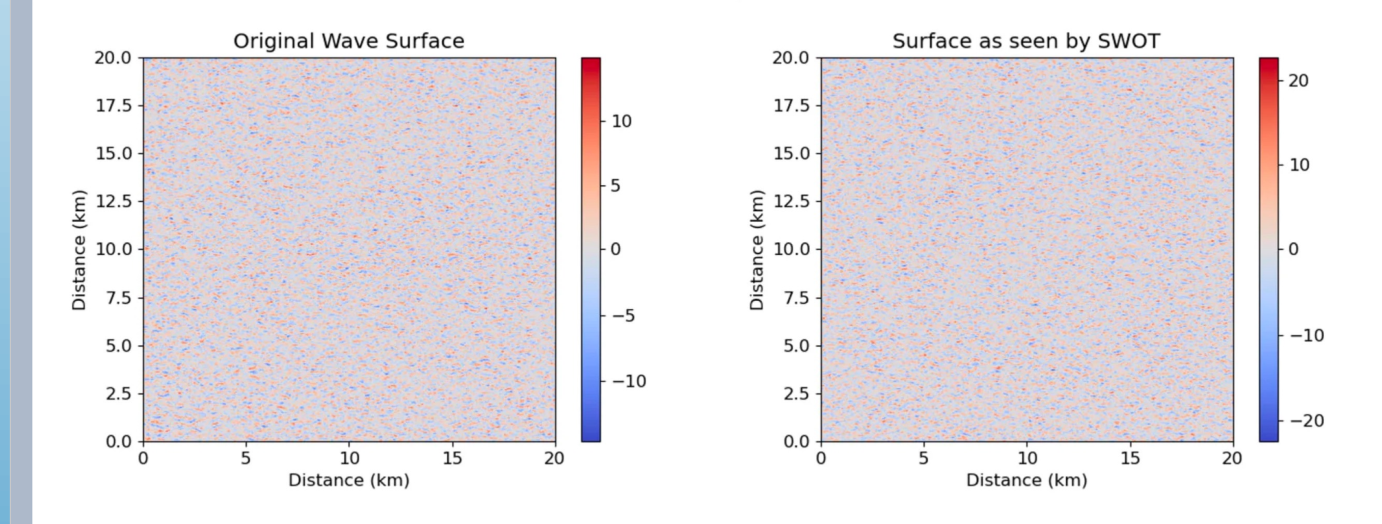

Figure 3. On the left, a randomly generated wave surface with a significant wave height of 12 meters. The surface spans 20 km x 20 km and has a resolution of 1 meter. On the right, the same surface as SWOT sees it because of the point target response. The result of the cumulative sum is higher wave peaks and lower wave troughs.

Noise is reduced on board the satellite by using a Gaussian average. This takes data observed and reduces the resolution down to 2 km (**figure 4**). For this project we used a Gaussian average with a 2 km standard deviation.

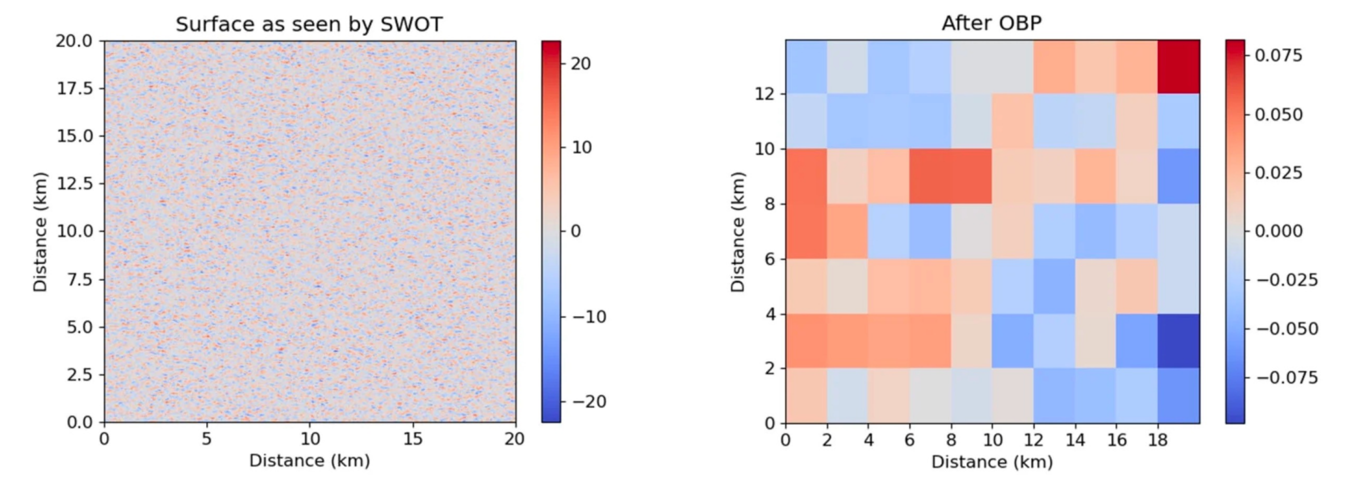

Figure 4. On the left, a randomly generated wave surface with a significant wave height of 12 meters. The surface spans 20 km x 20 km and has a resolution of 1 meter. On the right the same surface after smoothing due to the SWOT on board processing. This process reduces the resolution to 2 km.

We utilized eddy kinetic energy calculations of the smoothed surfaces to ascertain if the energy from waves is thoroughly removed even when significant wave heights exceed 2 meters. (**figure 6**)

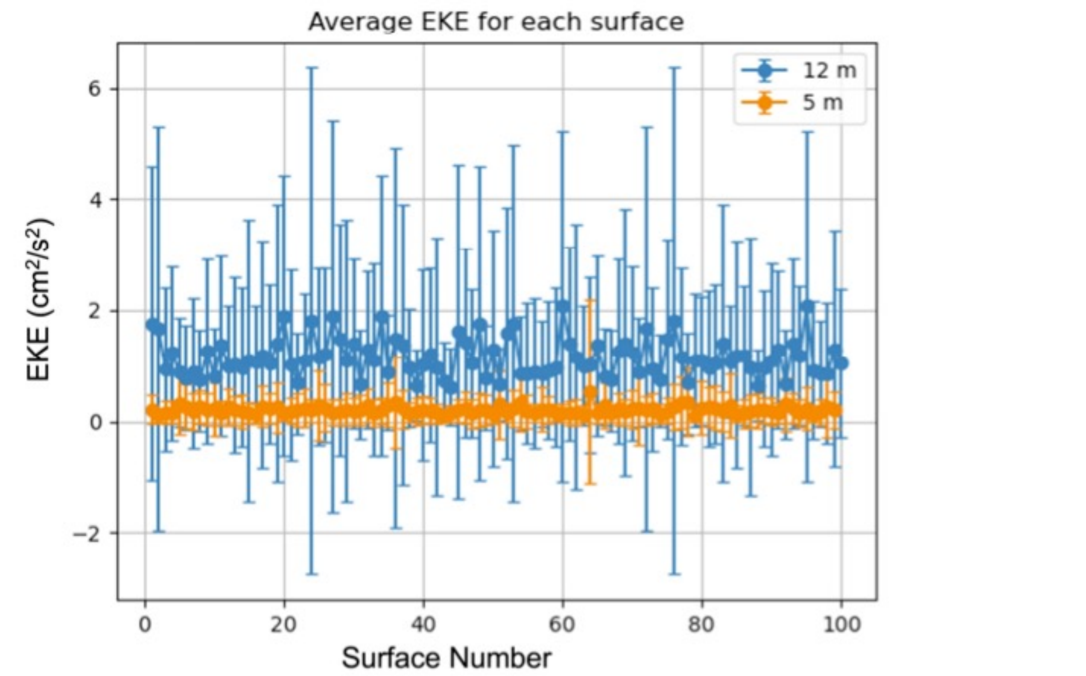

Figure 6. The average eddy kinetic energy from 100 generated surfaces at a significant wave height (swh) of 5 meters and 12 meters. The error bars denote one standard deviation. From these surfaces it was found that the average eddy kinetic energy was 0.21 cm^2/s^2 for 5 m swh, and 1.15 cm^2/s^2 for a 12 m swh.

Eddy kinetic energy

Sea surface heights were used to produce eddy kinetic energy (EKE) calculations via central difference method. EKE was calculated for both HYCOM model sea surface heights in addition to smoothed wave surfaces.
From HYCOM we generated annual means of EKE in three regions associated with high, medium, and low EKE (**figure 5**). These means are then compared to the EKE of the smoothed surfaces.

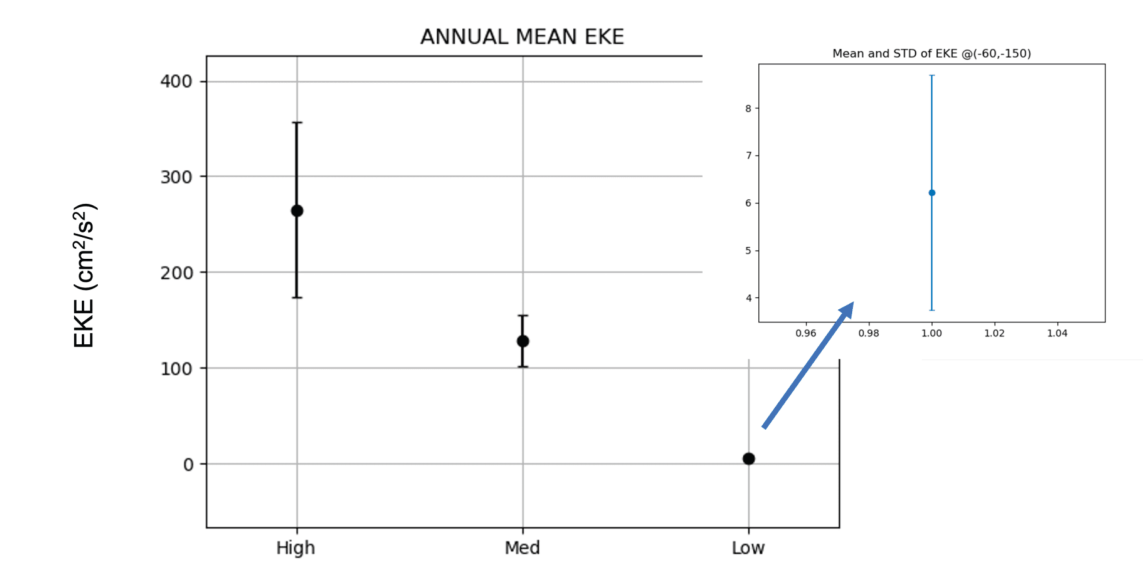

Figure 5. Annual mean eddy kinetic energy for selected regions in the Southern Ocean from HYCOM. EKE was calculated from sea surface heights. The error bars represent the standard deviation from the mean. Each region encompasses a 2° x 2° box with center points selected from maps generated by Zhang et al (2021).

The EKE from the smooth surfaces is seen in **figure 6**. At a significant wave height of 5 meters, the average of 100 surfaces was found to be 0.21 cm^2/s^2. At a signficant wave height of 12 meters the average of 100 surfaces was found to be 1.15 cm^2/s^2.

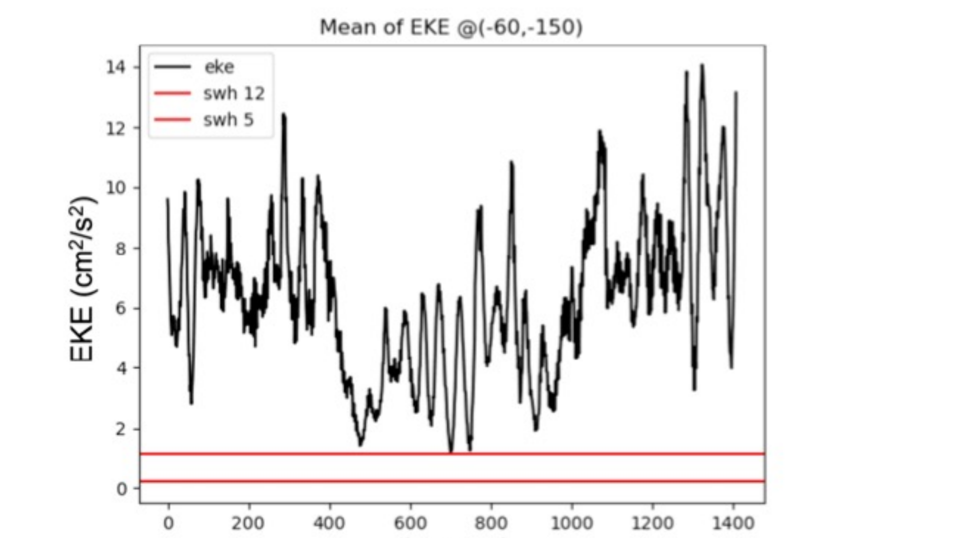

Figure 7. Annual time series of eddy kinetic energy from HYCOM in a low EKE area. The red lines denote the average EKE from surfaces with a significant wave height of 5 and 12 meters. Even at 12 meters SWH, the energy from the waves does not overpower the energy occurring in HYCOM.

Future Work

As seen in **figure 7**, a high significant wave height does not appear to produce more EKE than sea surface heights from HYCOM. However, there are points where, within the low eddy kinetic energy area, the EKE of the smooth wave surface and the EKE of the sea surface heights are equal. This will cause difficulties with SWOT observations when attempting to observe the submesoscale dynamics of an area. Because of this, it is important to study the seasonality of EKE in low eddy kinetic energy areas.

Further work needs to be done to know if energy from waves can be disentangled from SWOT observations in low EKE areas. It is highly possible that seasonality will play an important role in the dynamics able to be recovered.

References

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