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High Resolution Ocean Wave Characteristics from ICESat-2 following the CRYO2ICE Realignment

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Introduction

Laser altimetry has been shown to be able to provide high-resolution observations of ocean properties, which are crucial for global oceanographic monitoring. The Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) has demonstrated the ability to distinguish between individual ocean surface waves [1,5]. This provides physical observations far from coastal regions, where most in-situ gauges are located.

The CRYO2ICE campaign, which started in the summer of 2020, has provided periodic coincident orbits between ICESat-2 and CryoSat-2, allowing for the validation of ICESat-2 observations with radar altimetry. However, the data available was restricted to the northern hemisphere.

Since the summer of 2022, the CRYO2ICE campaign has performed a realignment, to get coincident orbits in the southern hemisphere, enabling ocean observations in a far larger area, as well as observing the overall higher significant wave height (SWH) in this region of the oceans. This is an opportunity to extend our dataset of observed sea states and get a better understanding of the performance from ICESat-2 at extreme wave heights.

Method

Determining the significant wave height (SWH) from the ocean surface, has two major approaches: surface variance or surface waves. Conventionally we would determine the surface roughness, and from this determine the SWH. However, with the LIDAR from ICESat-2 [2,3], we can observe the ocean surface in high enough resolution to be able to distinguish surface waves [1,5].

From the lidar observations, we can reconstruct the ocean surface, and collect the ocean waves. From this we can determine the SWH as the average of the highest one-third of the waves. The ocean surface waves are seen in segments at three locations in figure 1.

The comparison is divided into three kinds, the Surface Model, which utilizes the individual surface waves, the Conventional Model which determines the SWH by four times the standard deviation. And as a baseline, the ATL12 product is included in the analysis. This is all compared with the coincident Radar Altimetry measurements from CryoSat-2.

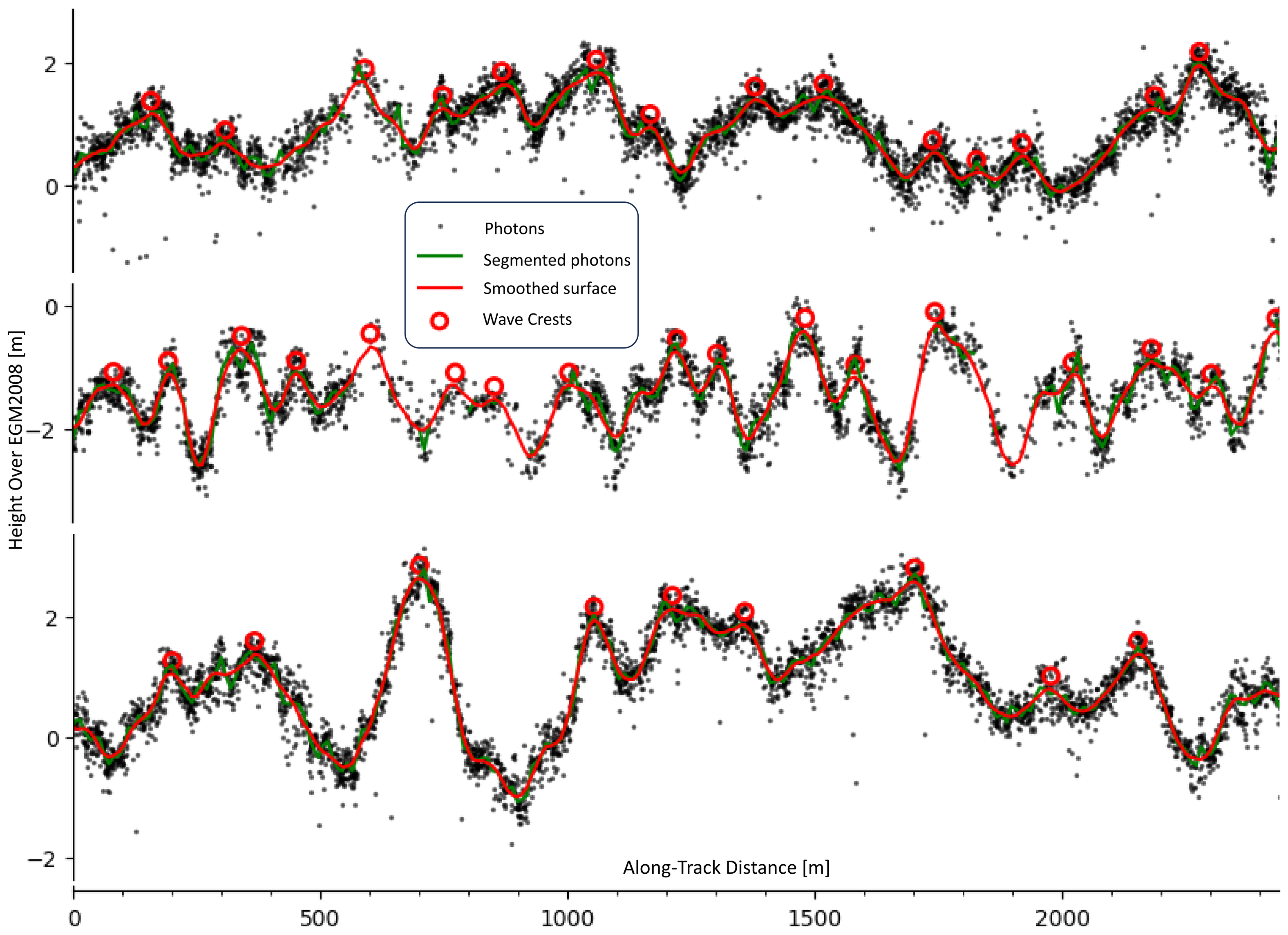


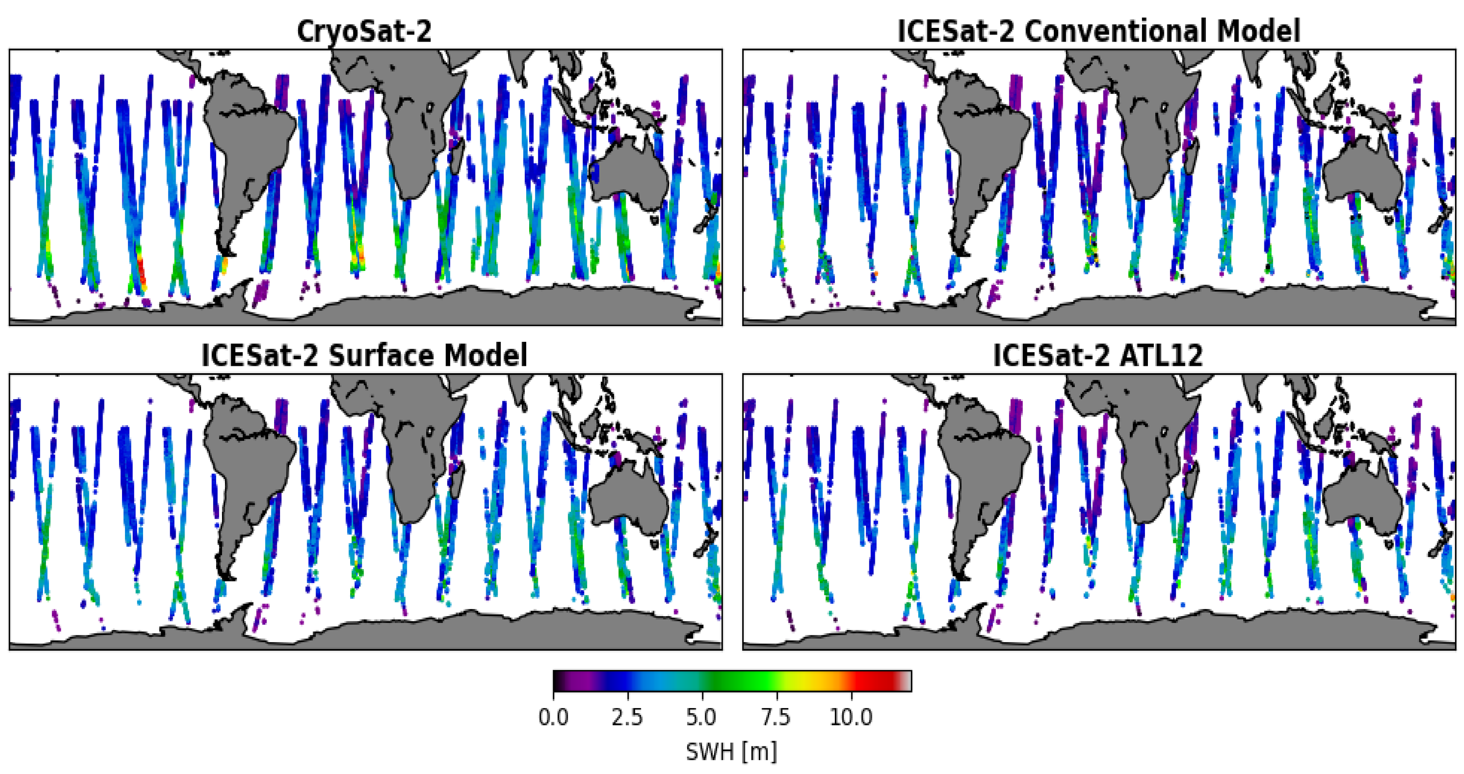
Figure 1:
Ocean surfaces as observed with ICESat-2. The individual photon returns (black) are shown as the cloud, with the noise-reduced (green) and smoothed (red) plotted over. The ocean wave crests are illustrated by red indicators.

Data

The analysis ranges from June 1st, 2022, to August 3th, 2022, after the realignment of the CRYO2ICE configuration enabling coincident data from the southern hemisphere. The maximum separation distance between CryoSat-2 and ICESat-2 is at 50 km, and the separation time between 1.6 and 1.8 hours. In this timeframe there has been 50 coincident tracks, which are plotted in figure 2.

Figure 2:

Ground-Track of CryoSat-2 with the SWH shown in color. Few gabs in each track is present.	The conventional method based on ICESat-2. Here showing gabs in the data resulting, assuming to be from cloud coverage.
The surface model from ICESat-2 surface observations, showing similar coverage to the conventional methods.	The ATL12 standard data output provided, using the same principle as the conventional method.



Conclusion & Outlook

In this analysis, we have determined the behavior of SWH observations from ICESat-2 compared with CryoSat-2. With the observations from the southern hemisphere, more observations from higher SWH is collected, even though the collection of observations at these SWH are still challenging. A summary table of statistics are seen in table 1.

With this comparison, we see that we can expand the global ocean surface observations offered by ICESat-2. This can be achieved through the utilization of higher resolution modes, enabling us to discern certain ocean features instead of solely depending on statistical ocean properties. However, more work on the ICESat-2 models are possible, to allow for more accurate SWH determination at certain sea states.

Table 1:
Summary statistics of the different models, using the coincident CryoSat-2 orbits as a baseline.

Method	Mean. Diff [cm]	RMSE [cm]	Corr.	N
Surface Model	-0.7	46.6	0.89	22632
Conventional	-31.3	50.8	0.93	24759
ATL12	-21.9	40.2	0.94	20369

References

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Results

Figure 3:
Segment from the East Pacific, showing the SWH determined with the four methods previously described. CryoSat-2 (black) seen as the backdrop, with a large SWH (~8 m) around 50 degrees south, and quite calm seas around the equator. What we then see from ICESat-2 is the challenge of obtaining observations at high SWH, probably due to cloud coverage.

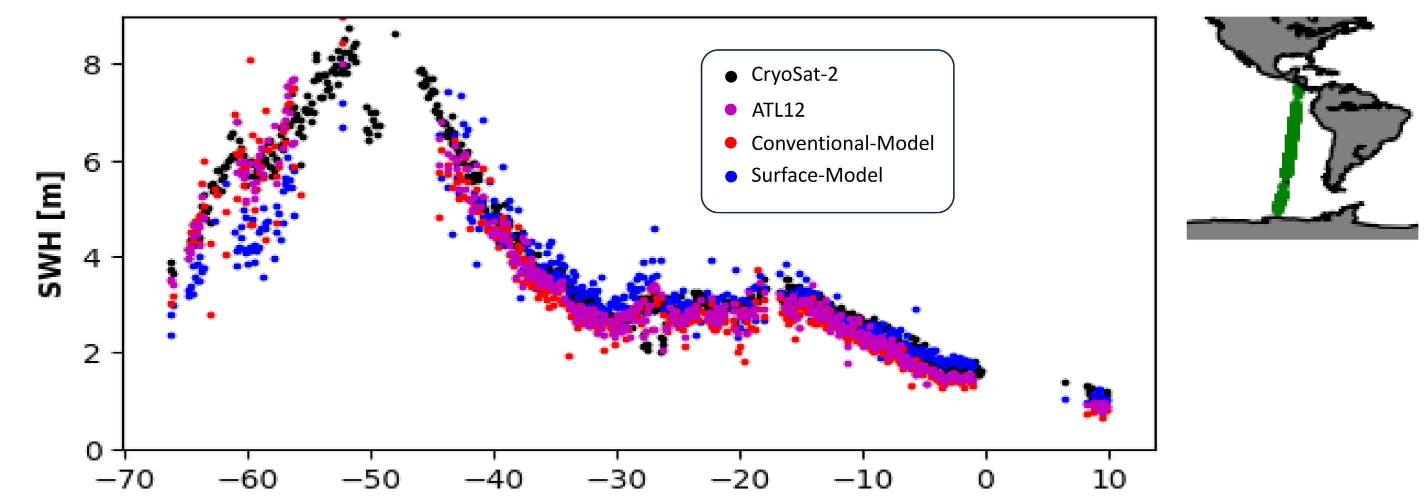

Figure 4:
As in figure 3, we have a segment from the Indian Ocean, where se have problems obtaining data from high SWH conditions.

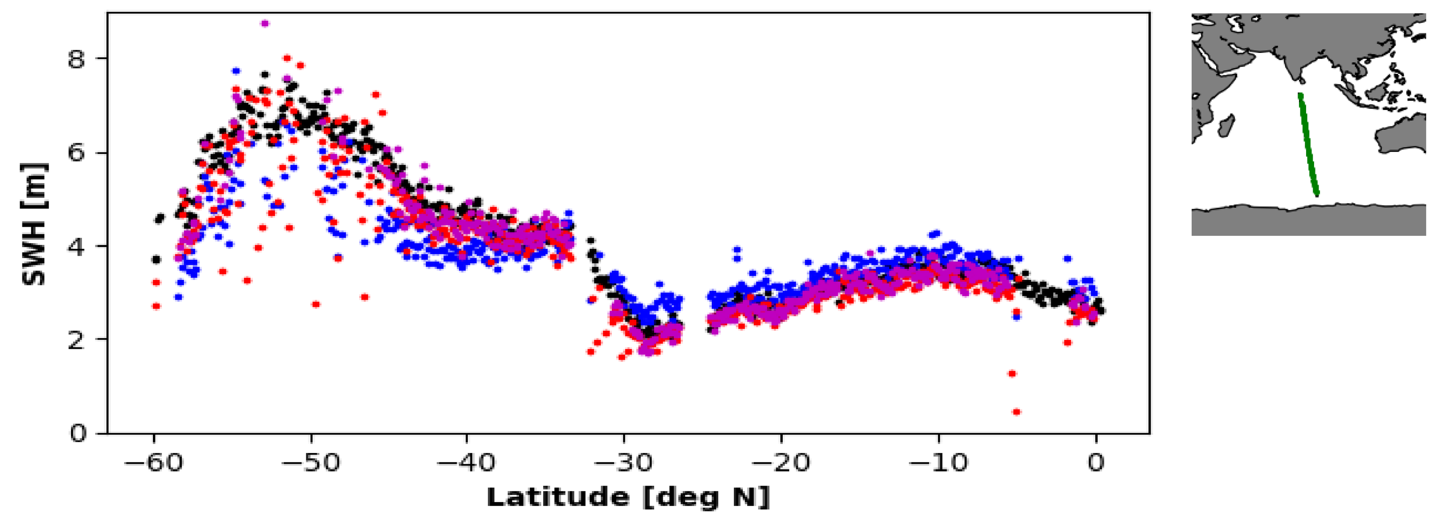

Figure 5:
We see ICESat-2 models as a function of CryoSat-2 SWH as a baseline. Dividing the observations into equal size segments (as determined from ATL12, see last plot), we see how the performance changes depending on sea state.

In the first plot, we see how the percentage error for each model is almost constant, with only a slight increase at higher SWH. Here with ATL12 having the lowest error.

The median error for each segment shows if the models are under- or over-estimating as specific sea-states. As expected, the conventional model and ATL12 perform almost identical, however the surface-model does experience a drift.

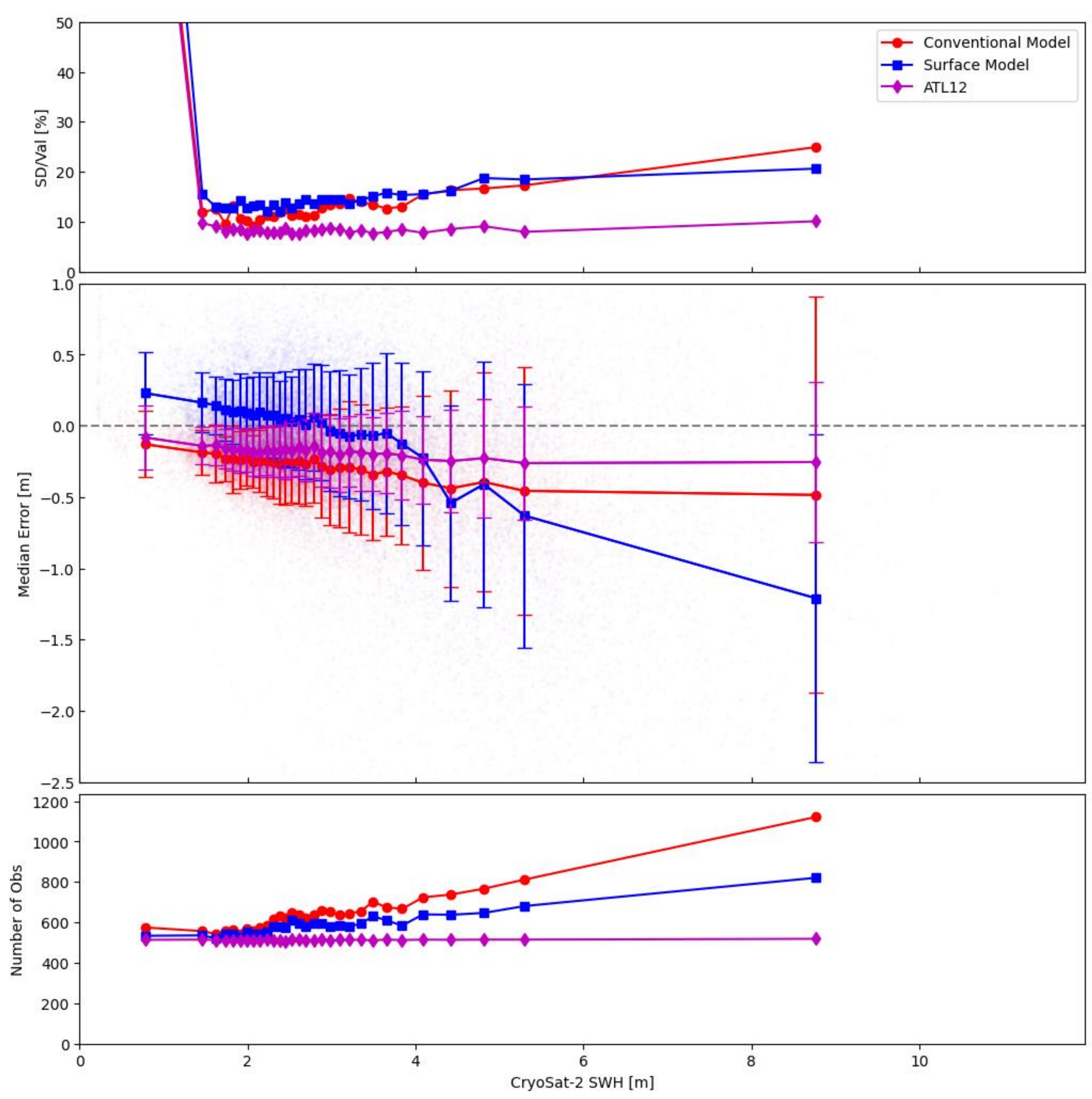

Figure 6:
Scatterplots showing the correlation between CryoSat-2 SWH and ICESat-2 SWH models. Showing an overall correlation, as opposed to figure 5.