Reliability of Extreme Significant Wave Height Estimation from Satellite Altimetry and In Situ Measurements in the Coastal Zone

Ben Timmermans[1], Andrew Shaw[2] and Christine Gommenginger[1]

[1]National Oceanography Centre, Southampton UK

[2]Skymat Ltd, Southampton UK

Contacts: Ben Timmermans (ben.timmermans@gmail.com), Andrew Shaw (agps@skymat.co.uk) and Christine Gommenginger (cg1@noc.ac.uk)

1 – Introduction

Measurements of significant wave height from satellite altimeter missions are finding increasing application in investigations of wave climate, sea state variability and trends, in particular as the means to mitigate the general sparsity of in situ measurements. However, many questions remain over the suitability of altimeter data for the representation of extreme sea states and applications in the coastal zone. Here, the limitations of altimeter data to estimate coastal Hs extremes (<10 km from shore) are investigated using the European Space Agency Sea State Climate Change Initiative L2P altimeter data v1.1 product. This product provides near complete global coverage and a continuous record of 28 years. It is used here together with in situ data from moored wave buoys at six sites around the coast of the U.S. The limitations of estimating extreme values based on satellite data are quantified and linked to several factors including the impact of data corruption nearshore, the influence of coastline morphology and local wave climate dynamics, and the spatio-temporal sampling achieved by altimeters. The factors combine to lead to considerable underestimation of estimated Hs 10-yr return levels. Sensitivity to these factors is evaluated at specific sites, leading to recommendations about the use of satellite data to estimate coastal extremes and their temporal evolution. Full results are at **https://doi.org/10.3390/jmse8121039** [1].

2 – Coastal regions examined

Sampling characteristics and hourly measurements provided in the Sea State CCI L2P v1.1 product were compared with in-situ observations from moored buoys both nearshore and offshore. The six regions around the U.S. are shown in **Figure 2.1**, together with the temporal duration of coverage and distance to coast of the each buoy.

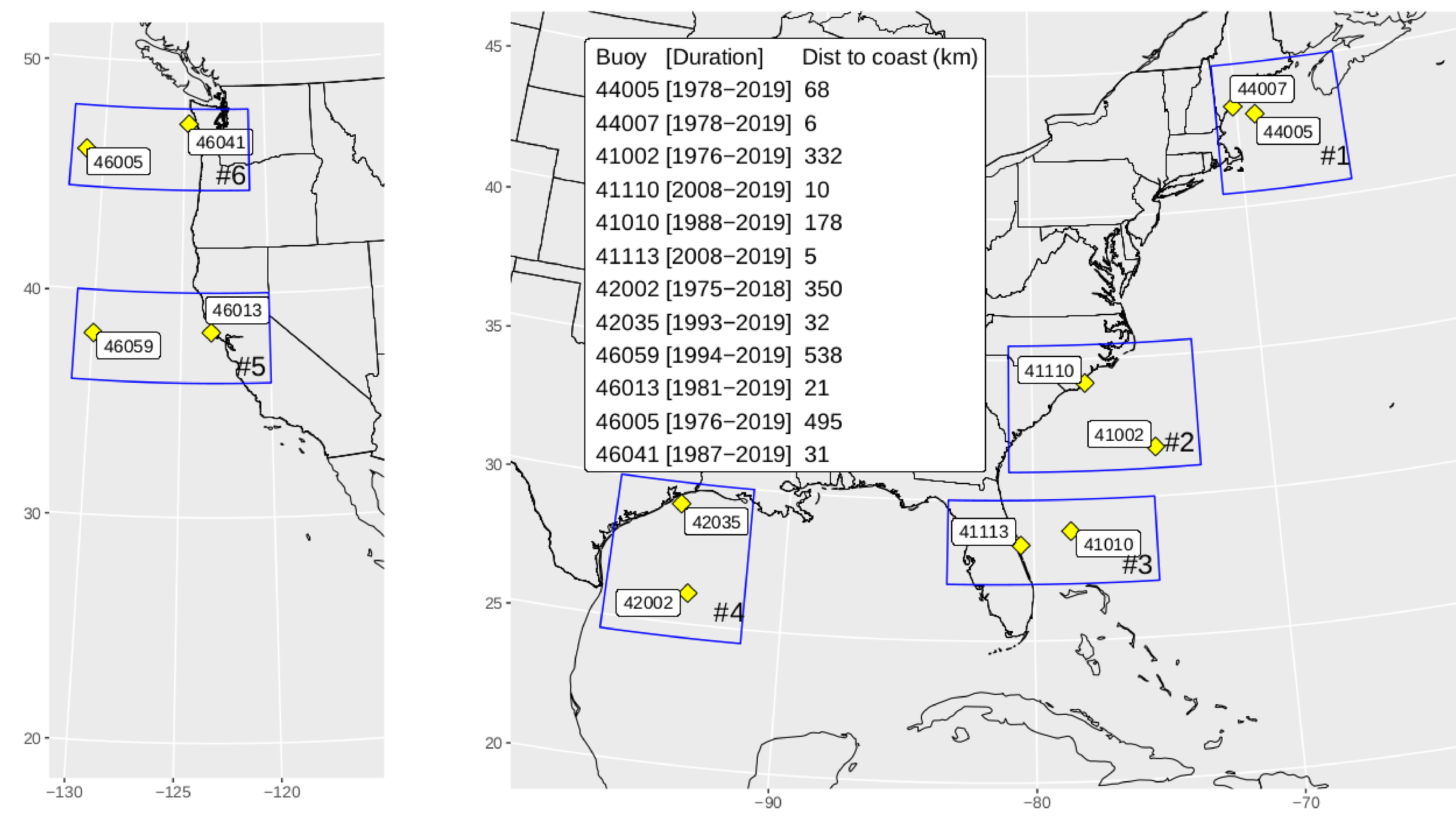


Figure 2.1: Map of the 6 regions where pairs of NDBC data buoys are located.

3 – Regional sampling variation

At coastal scales (5 – 50 km), considerable heterogeneity in spatio-temporal sampling occurs as a strong function of geographic location. This is affected by a range of factors including; historical period and active missions, satellite trajectory and orbital repeat cycle, altimeter operating mode, distance to coast, sampling area, coastal morphology and local wave dynamics. **Figure 3.1** shows how different missions contributed data between 2008 and 2018 at buoy 41113 (region #3).

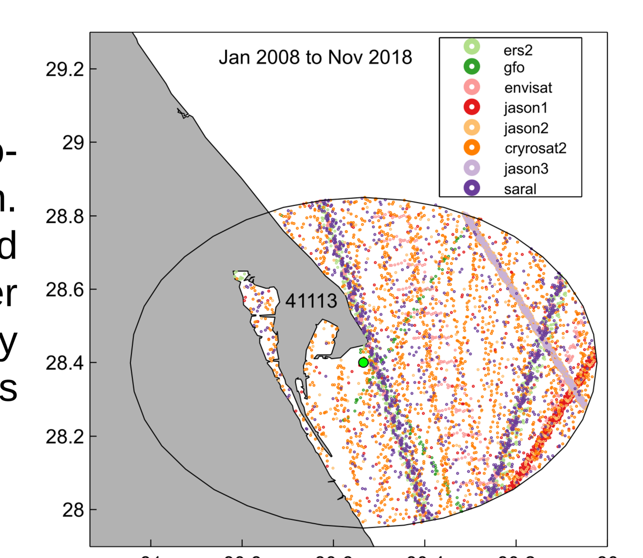


Figure 3.1: Tracks contributing to 50 km sampling radius between 2008 and 2018 by mission, at buoy 41113.

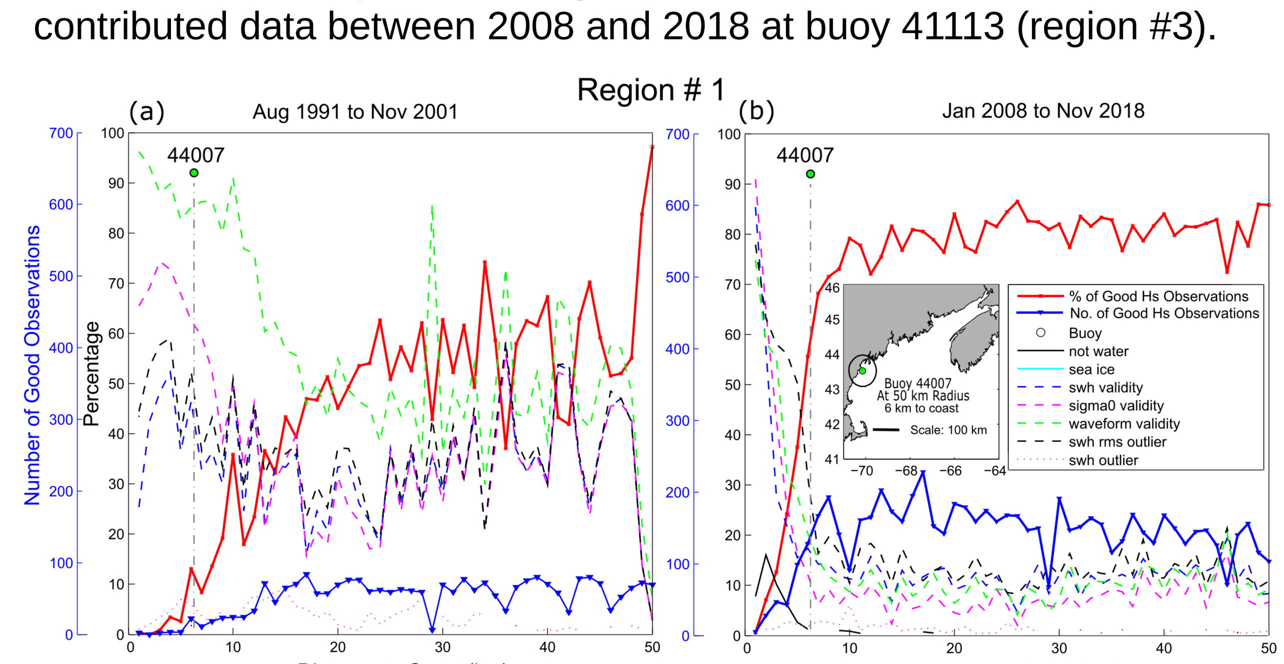


Figure 3.2: Altimeter sampling characteristics and data quality with distance to coast at the nearshore site, (a) 1991-2001; (b) 2008-2018

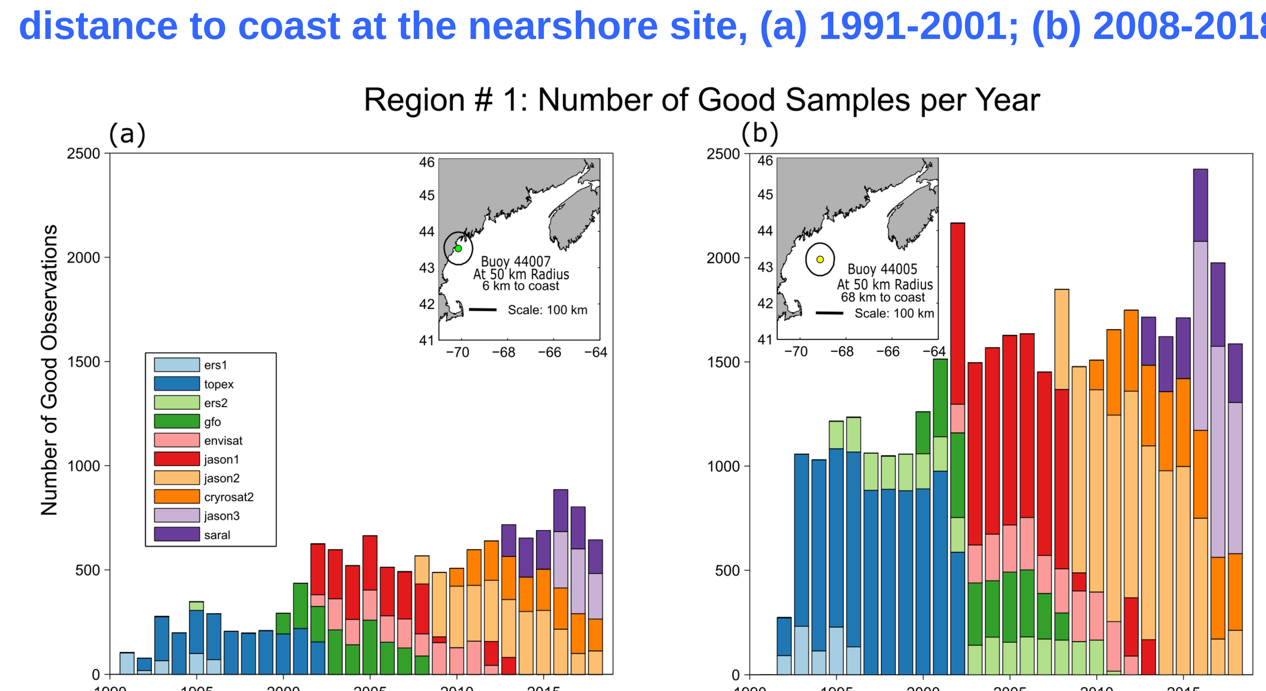


Figure 3.3: Total number of "Good" (qual_flag = 3) observations

The Sea State CCI L2P product provides a considerable amount of data quality information. In particular each 1 Hz observation is flagged for quality (*qual_flag* = 0,1,2,3), where 3 = "Good" data. Where data is judged to be spurious (*qual_flag* = 0,1,2), a *rejection flag*, that indicates the cause of the problem, is also provided. **Figure 3.2** shows these properties as a function of distance to coast (region #1), and compares them between the first decade and last decade of the dataset. **Figure 3.3** shows the temporal variation of "good" data (*qual_flag* = 3) by year, both nearshore and offshore. The striking temporal and spatial heterogeneity in the sampling is clear, in particular the improvement in recent years with increasing distance to coast. Similar analyses for all regions is provided in [1].

4 – Long term comparison with in-situ data and representation of extremes

Analysis of Hs hourly time series revealed very good agreement between L2P and buoys at both nearshore and offshore locations, in all regions. Nearshore observations just a few km's from the coast, flagged as "Good", were generally accurate. The apparent exception is on the east coast where positive bias was introduced due to the 50 km sampling radius (see **Figs 4.2 & 4.3**).

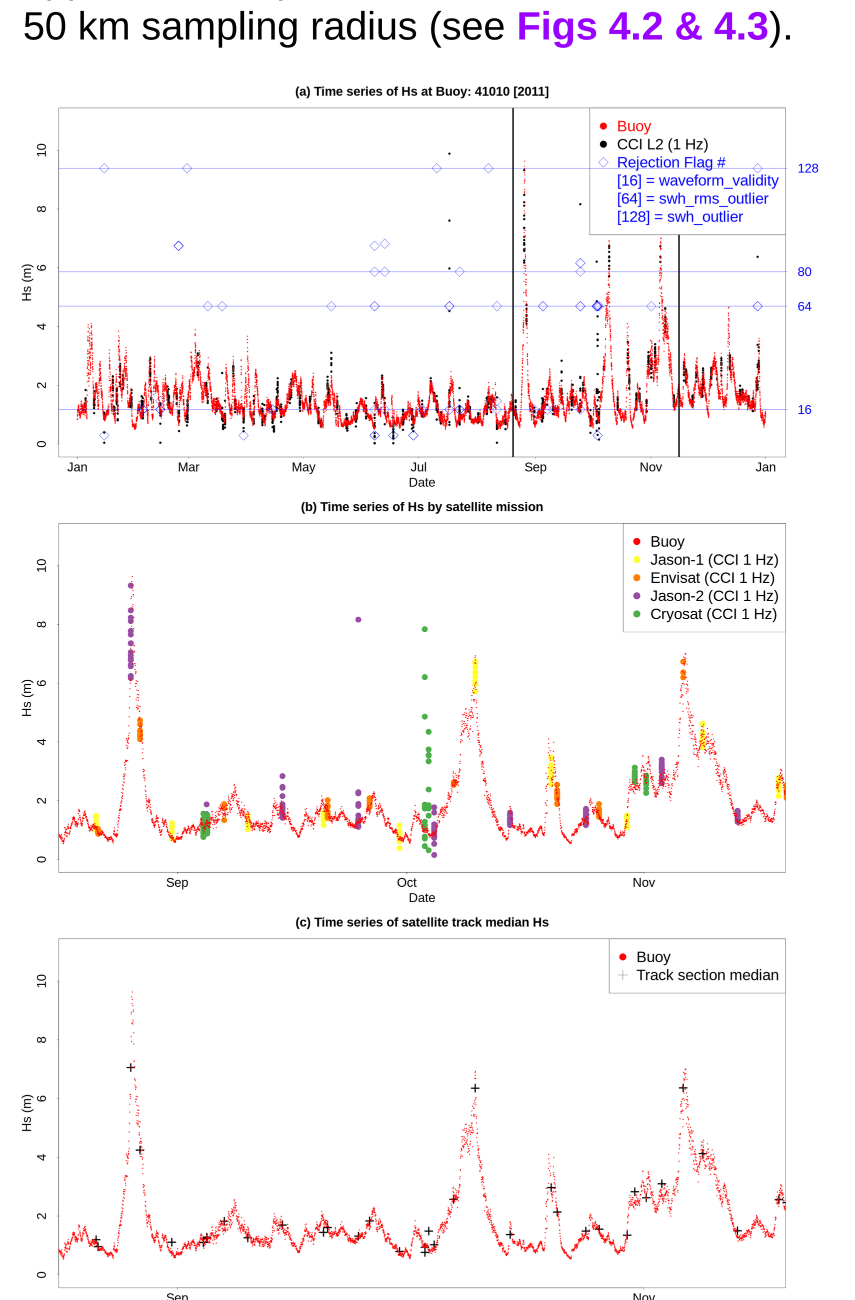
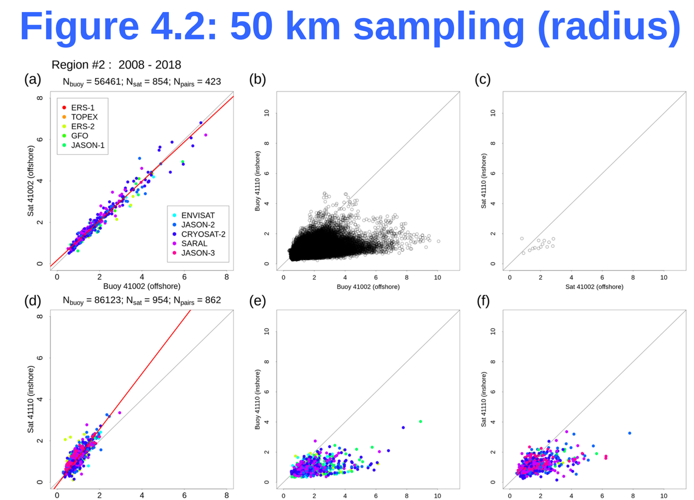
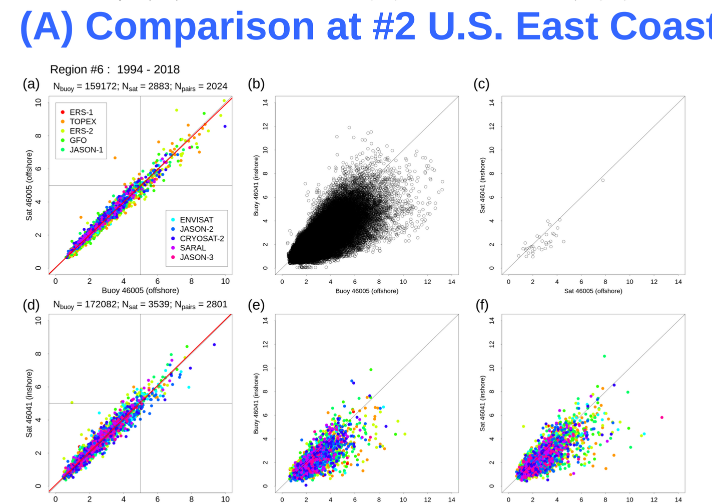


Figure 4.1 (Above): A comparison of measurements of Hs from buoy 41010 and satellite, based upon a 50 km sampling radius. Data with all quality flags (qual_flag = [1,2,3]) is shown in (a,b). Blue horizontal lines correspond to the right-hand axis and denote the rejection values more clearly. (b) is an enlargement of a section of (a) indicated by vertical black lines, and shows the same data but coloured by mission. (c) is similar to (b) but shows the median value (black crosses) of each track segment for 1 Hz measurements where qual_flag = 3 applied.

Figure 4.2: 50 km sampling (radius)

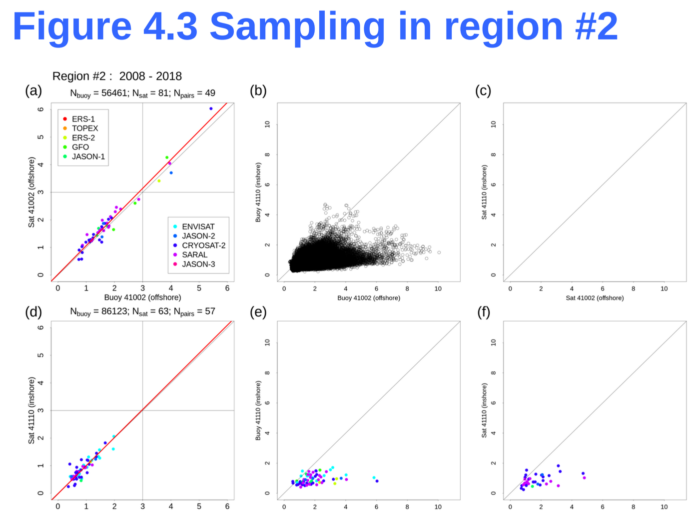


(A) Comparison at #2 U.S. East Coast

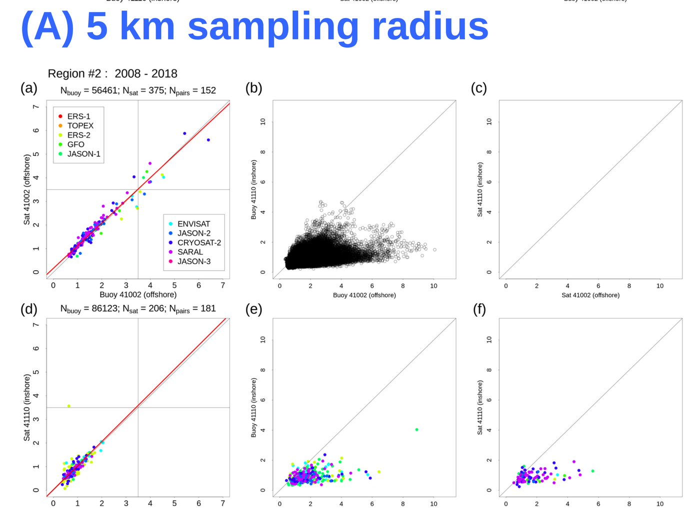


(B) Comparison at #6 U.S. West Coast

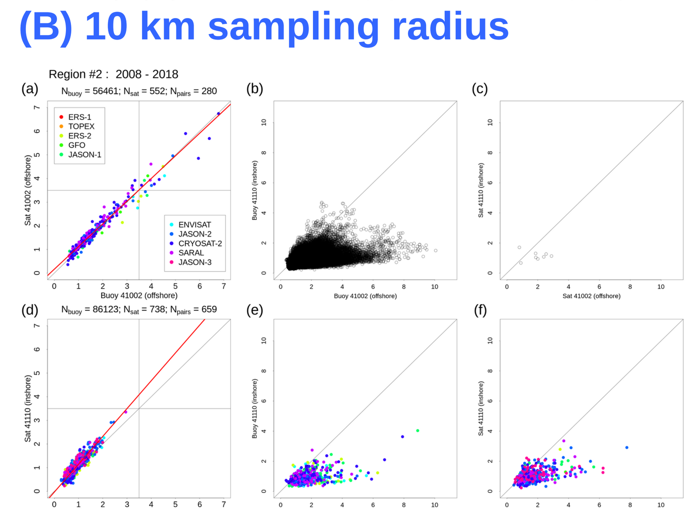
Figure 4.3 Sampling in region #2



(A) 5 km sampling radius



(B) 10 km sampling radius



(C) 30 km sampling radius

Figures 4.2 A,B: (Top right)

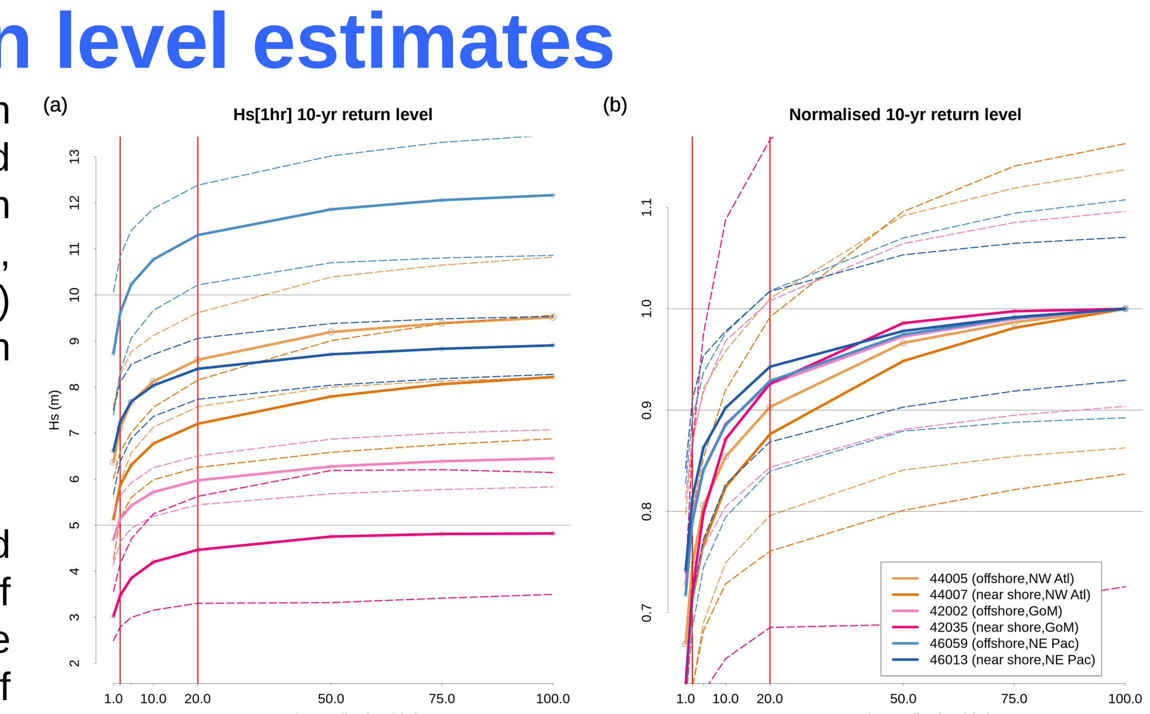
Scatter plots for combinations of Hs hourly time series data, both nearshore and offshore pairs, in regions #2 (U.S. east coast) and #6 (U.S. west coast). Points located in the upper right quadrants of Fig. 4.2 A(a,d) & B(a,d) reveal good agreement between the CCI L2P data and moored buoys in the extremes, both offshore and nearshore. High bias in the CCI L2P nearshore data is apparent in Fig. 4.2 A(d). However, the 50 km sampling radius at buoy 41110 spans an area of variable sea state, leading to a high bias.

Figures 4.3 A,B,C: (Bottom right)

Figs 4.3 A(d) - C(d) reveal that as the sampling radius around the buoy is decreased from 30 km to 5 km, the nearshore bias is systematically reduced. However, very few hourly data pairs remain at this spatial scale. Note, this effect is not observed on the U.S. west coast (region #6) where the wave climate is more homogeneous. See **Figure 4.2 A(a,d)**.

5 – Hs 10 year return level estimates

Through a resampling approach based on in situ data, we determined that estimated Hs 10 year return levels based on altimeter sampling are underestimated, typically by > 20%. The figure (right) shows how the estimate converges with increased sampling rate.



Future work:

In summary, we have conducted a detailed study of the sampling characteristics of satellite data provide in the ESA Sea State CCI L2P v1.1 product at a number of locations in a range of geographic regions around the U.S. coasts. Comparison with in situ data and found good agreement in the extremes, including close to the coast (up to 5 km). However, sampling deficiencies have been quantified.

The imminent release of Sea Stae CCI version 2 brings improved retracking close to the coast and is anticipated to improve data abundance and quality. In addition, in more recent years, further observations are also provided by imaging SAR which will also serve to increase observation sampling density.

National Oceanography Centre

References

B. Timmermans, A. G. P. Shaw and C. Gommenginger (2020), Reliability of Extreme Significant Wave Height Estimation from Satellite Altimetry and In Situ Measurements in the Coastal Zone, *J. Mar. Sys. Eng.* 8(12) https://doi.org/10.3390/jmse8121039.