Significant wave heights from Sentinel-1 SAR

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Frascati, Italy 12-December-2016

Outline

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    - **b) Validation – altimeters, buoys**
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3. **Conclusion and Outlook**

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Introduction

1. Introduction – Motivation
Current ESA L2 OCN Product

ESA L2 Product

- Quasi-linear SAR transformation ("swell" spectra) - wind-sea component is approximated using the SAR wind speed and the azimuth cutoff
- Loss of high frequency making an estimation of Hs impossible
- In high sea states (Hs>6 m) the azimuth cutoff is often large (>450 m) making most of the swell spectral components unreliable
- Current L2 OCN product is unreliable...

Motivation

- Hs is the most widely used sea-state variable! (and now considered an EOS – essential ocean variable)
- It is advantageous to compare SAR with other sources : models, altimeters, buoys - will aide in quality control of Sentinel-1

1. Introduction – History/Method

History

- ***CWAVE_ERS*** : Schulz-Stellenfeth, J., T. Knig, S. Lehner JGR 2007 – empirical method to estimate integral wave parameters using 20 orthogonal functions computed from the image spectrum and sigma0 and normalized variance (**22 input variables**) (Hs, Tm01, ECg)
- ***CWAVE_ENVISAT*** : Li, X.-M., S. Lehner, T. Bruns ITGRS 2011 – same approach as CWAVE_ERS but calibrated for ENIVSAT
- Romeiser et al., ITGRS 2015 – empirical functions for RADARSAT images in tropical cyclones (Hs, Tp, Dp)

Our approach

1) ***CWAVE_S1*** : use Schulz-Stellenfeth et al., (JGR 2007)

2) ***Fnn*** : Systematic approach by including variables (azimuth cutoff, sigma0, normalized variance, image skewness, peak wavelength, peak direction – **6 input variables**)
   - Train with WAVEWATCH3 spectra – large sample size!
   - Neural networks reduced number of coefficients and computationally fast

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Results

- Training
- Validation
- Verification

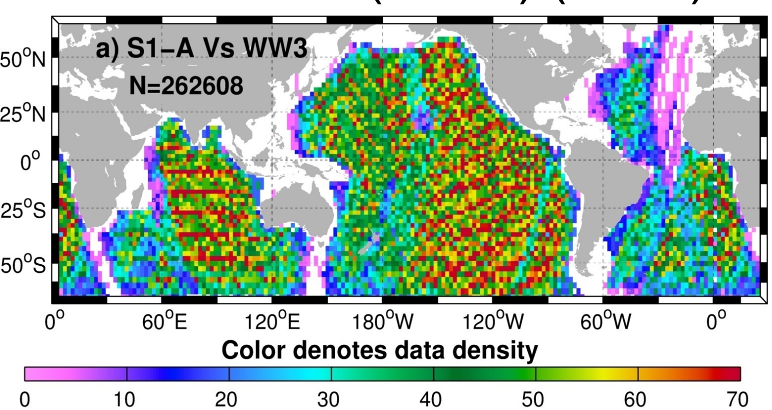
2. Results - Training

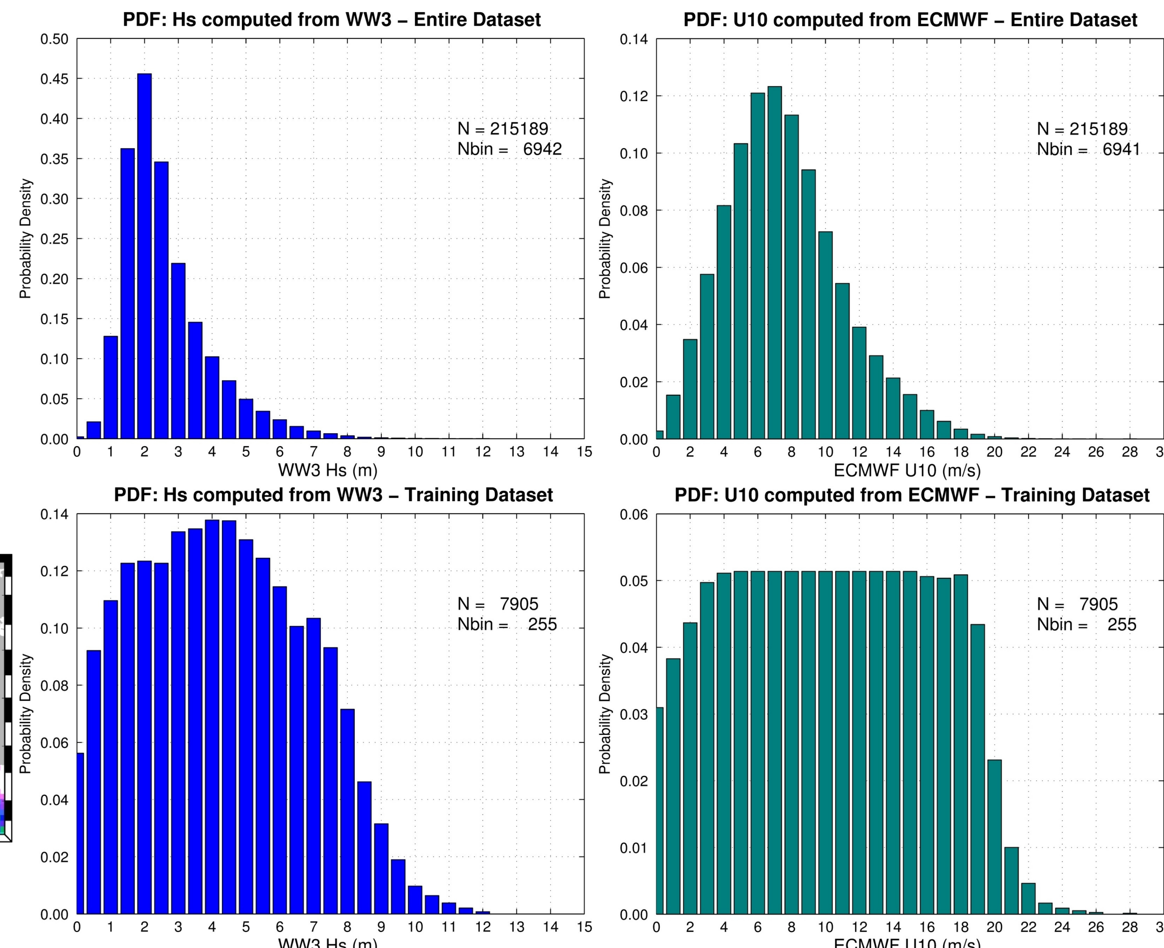
Dataset

- WAVEWATCH3I 2D wave spectra (bias ± 25 cm)
- 250,000 colocations July 2015 - July 2016 (Sep for independent validation)
- Sampling – full global coverage, common sea state Hs~2 m U10~7 m/s

Training

- Neural network - 3-layer multi-layer perceptron with back propagation using Levenberg-Marquardt method
- Equal sample size (N=100) for each U10 (0.25 m/s) and Hs bin (0.5 m) (3.5%)



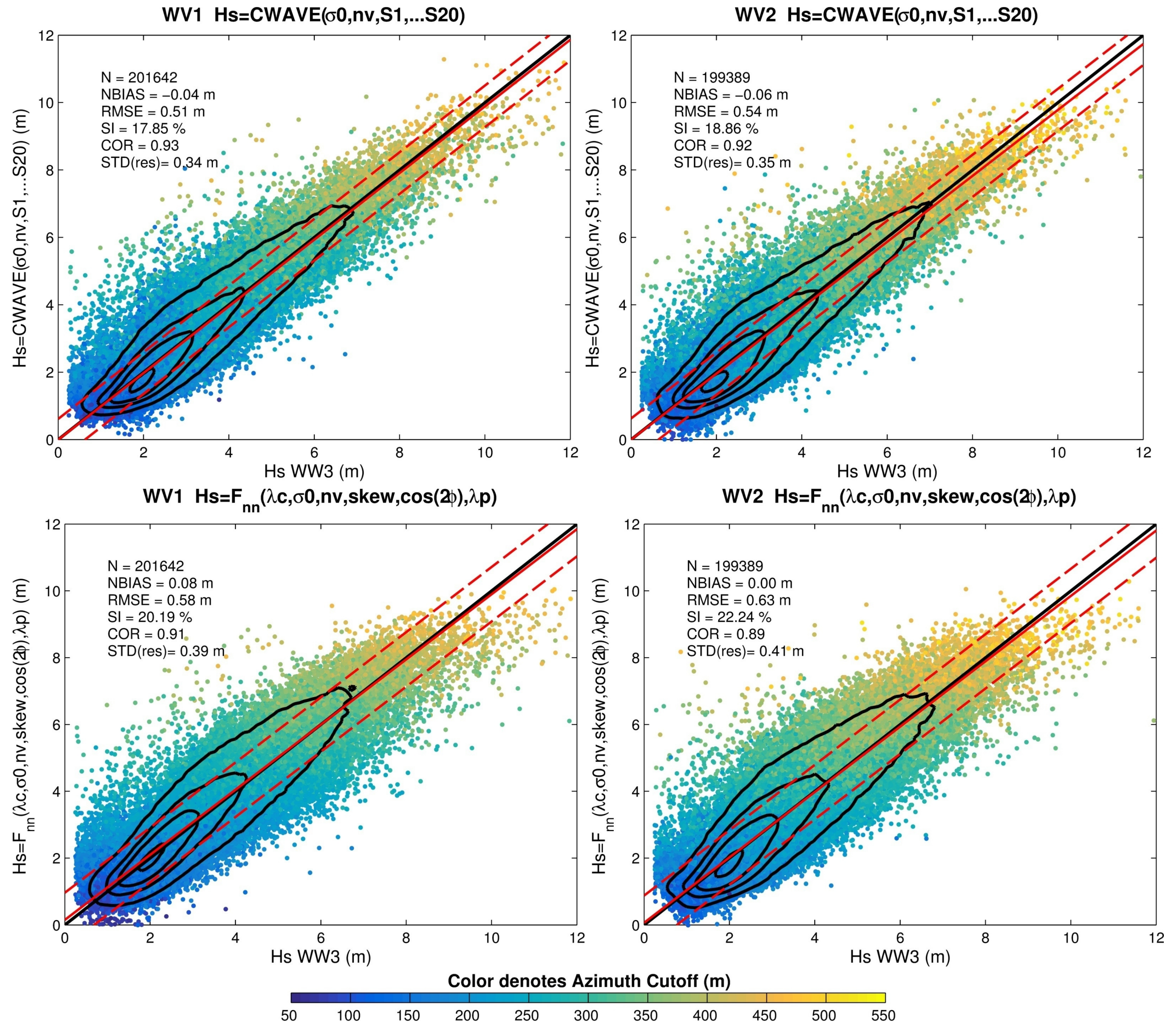


2. Results - Training

4 GMFs
- WV1 : *CWAVE*, *Fnn*
- WV2 : *CWAVE*, *Fnn*

All data
- Including training & testing
- Excluding Sep 2015, and altimeter and buoy colocations

Peformance
- CWAVE better
- WV1 less variablity better error metrics than WV2



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2. Results – Validation Comparison with Altimeters

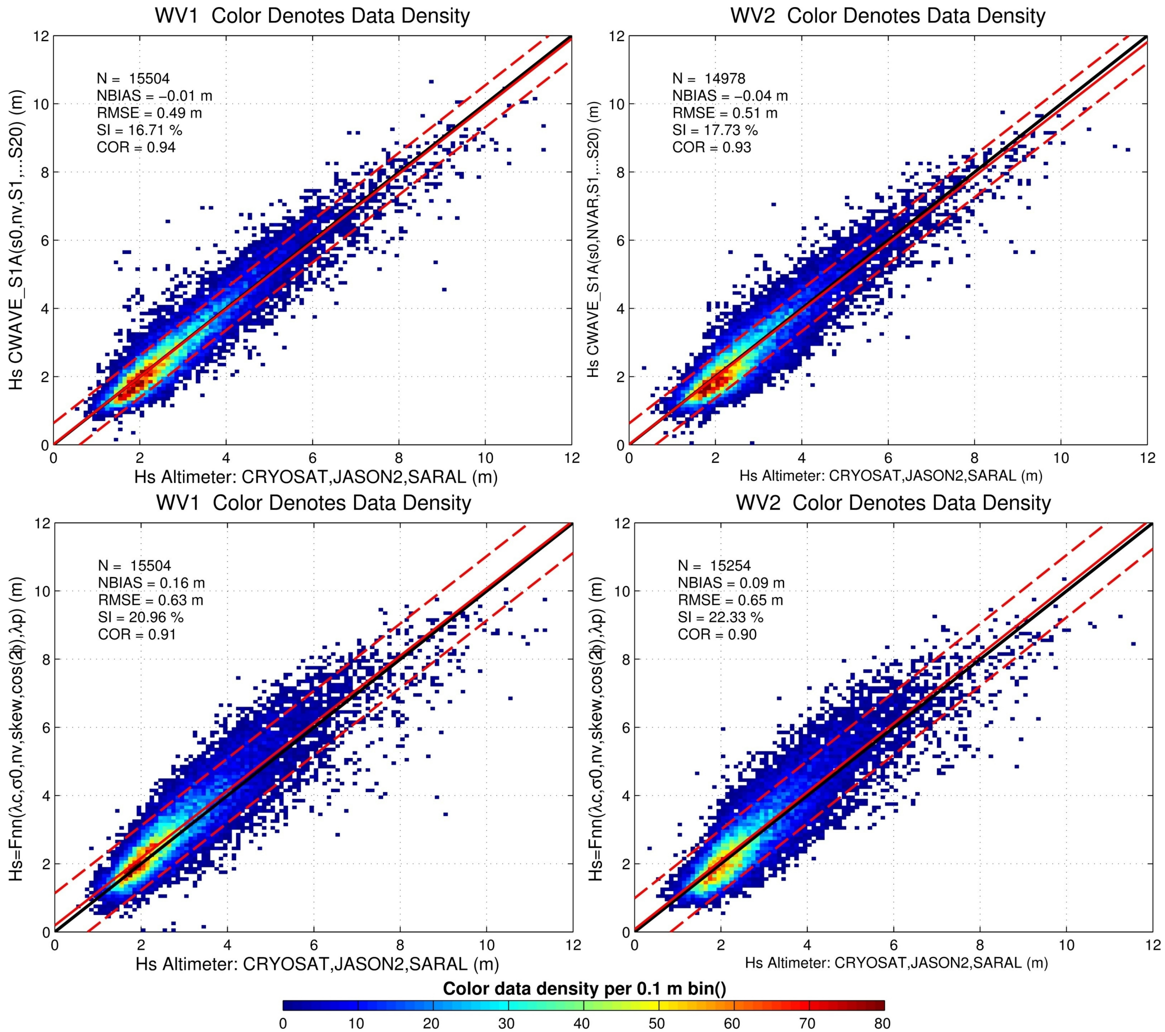
July-December 2015

- 15000 altimeter colocations
- CRYOSAT, J2, SARAL

Peformance

- Same as before
- CWAVE
  - ➔ RMSE~0.5 m, SI~17%
- Fnn
  - ➔ RMSE~0.6 m, SI~ 22%

- Hs~2m Bias=0.0 m RMSE~0.25 m, SI~15%
- Reasonable up to 10 m!
- Hs>12 m hard to say...



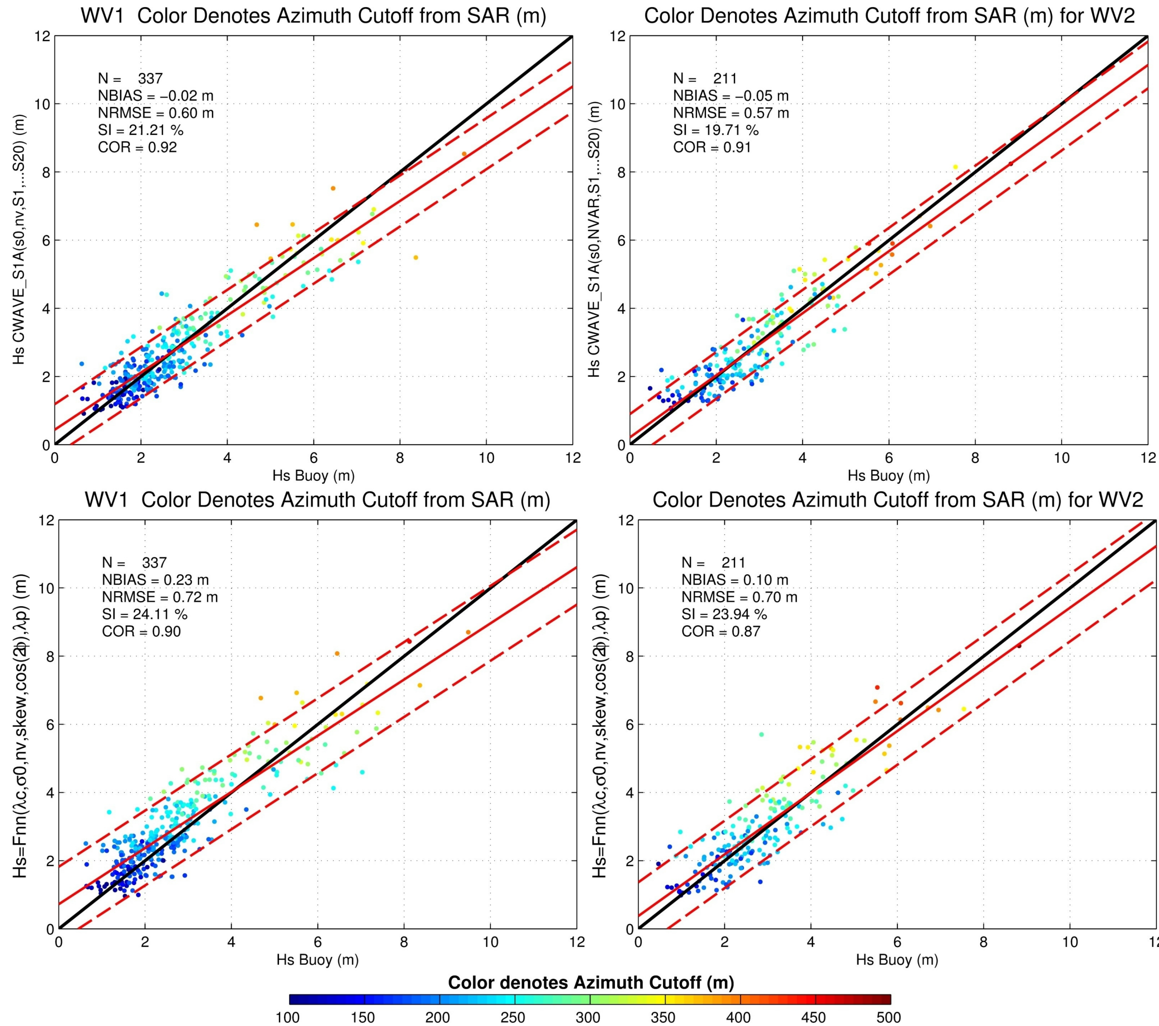
2. Results – Validation Comparison with Buoys

July 2015 -July 2016

- 200-330 buoy colocations
- NDBC, MEDS, CDIP

Peformance

- Same as before
- More scatter, but we have a small sample size
- Performance is the same in deep or shallow water

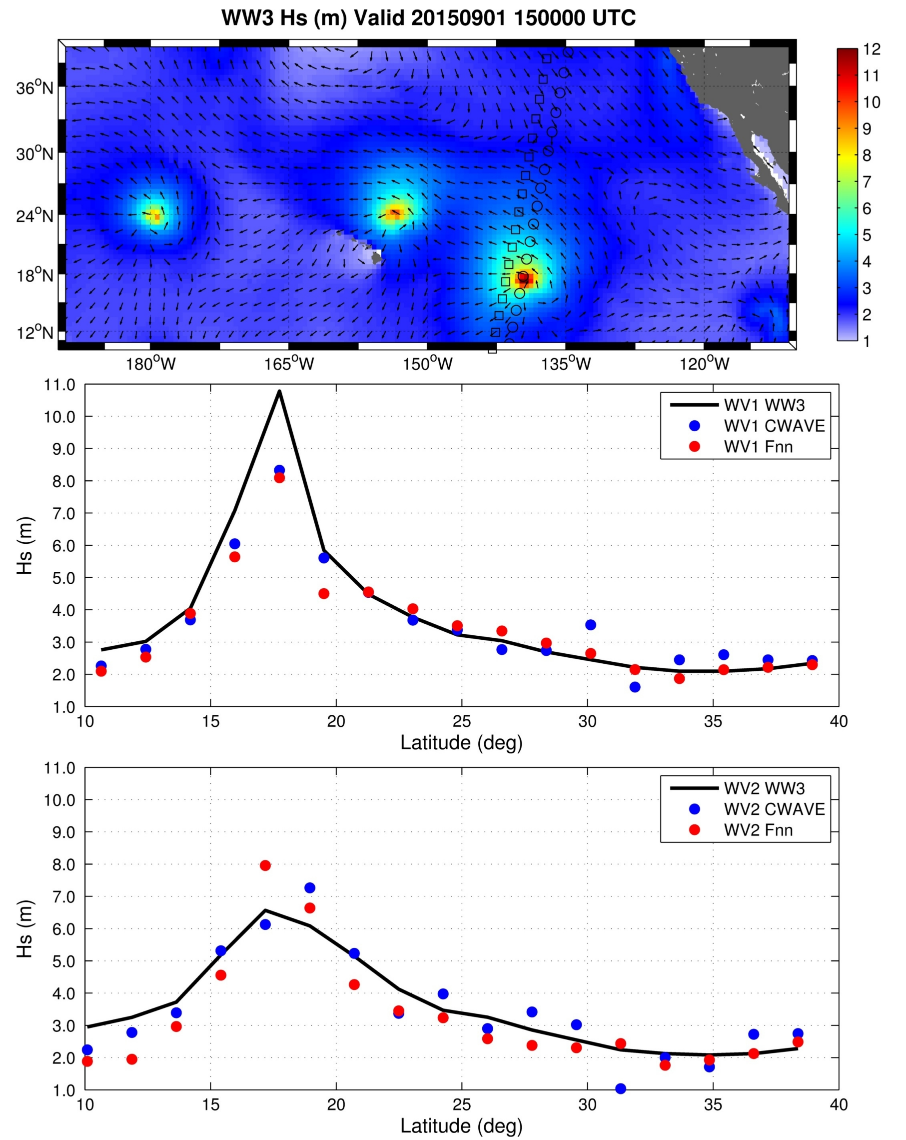


2. Results – Verification Tropical Cyclone

Hurricane Jimena 1-Sep-2015

- Very active tropical season!
- Relatively small storm (Rmw~35 km)
- CAT4
- Sentinel-1A crossed close the eye

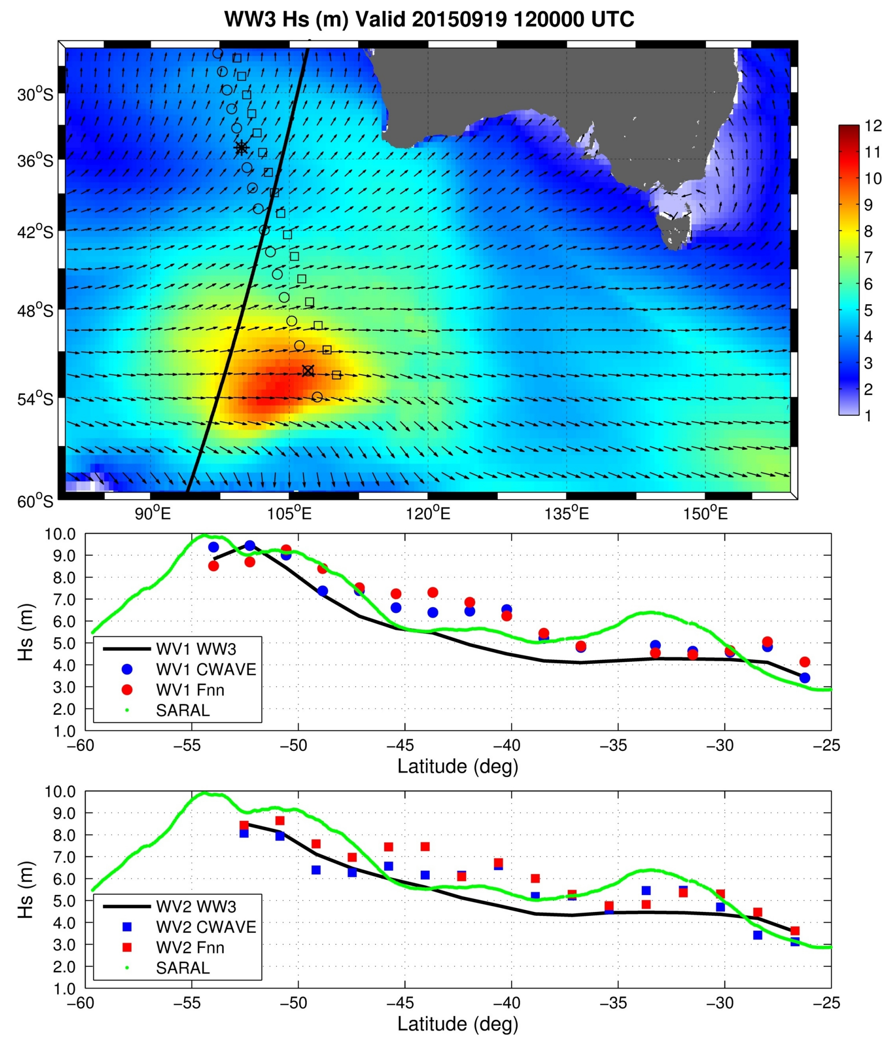
- WV1 under-estimated
- WV2 over-estimated
  - ➔ Suggests the location of the storm in the ECMWF winds might be incorrect
- In the far-field both functions well match WAVEWATCH3 (±0.5 m)
- No altimeter passes

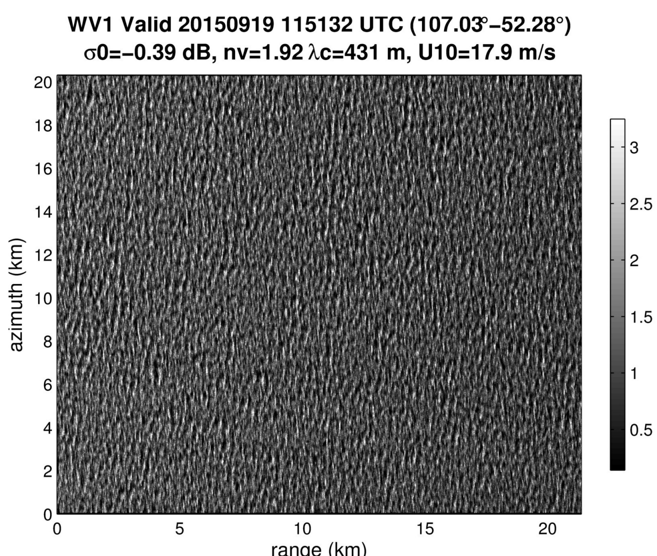


2. Results – Verification
Extra-tropical Cyclone

Extra-tropical storm 19-Sep-2015

- Typical event (Hs>10 m)
- Reduced spatial gradients
- Sentinel-1A crossed the maximum Hs
- Both functions match Hs=10 m
- In the far-field S1A larger than WW3
- SARAL 1 hr earlier confirms results
- Image spectra near storm center is strongly affected by the azimuth cutoff – making L2 spectra not usable





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Conclusion and Outlook

3. Conclusion

- Developed neural networks are trained with WW3 data and validated versus altimeters and buoys
- Both CWAVE and Fnn perform well RMSE ~0.5-0.6 m
- CWAVE performs better than Fnn
- Fnn has 6 input variables compared to 22 for CWAVE!
- Verification events not used in the training show the GMFs can retrieve wave heights in large sea states where observations are sparse and most of the quasi-linear spectra is unreliable

3. Outlook

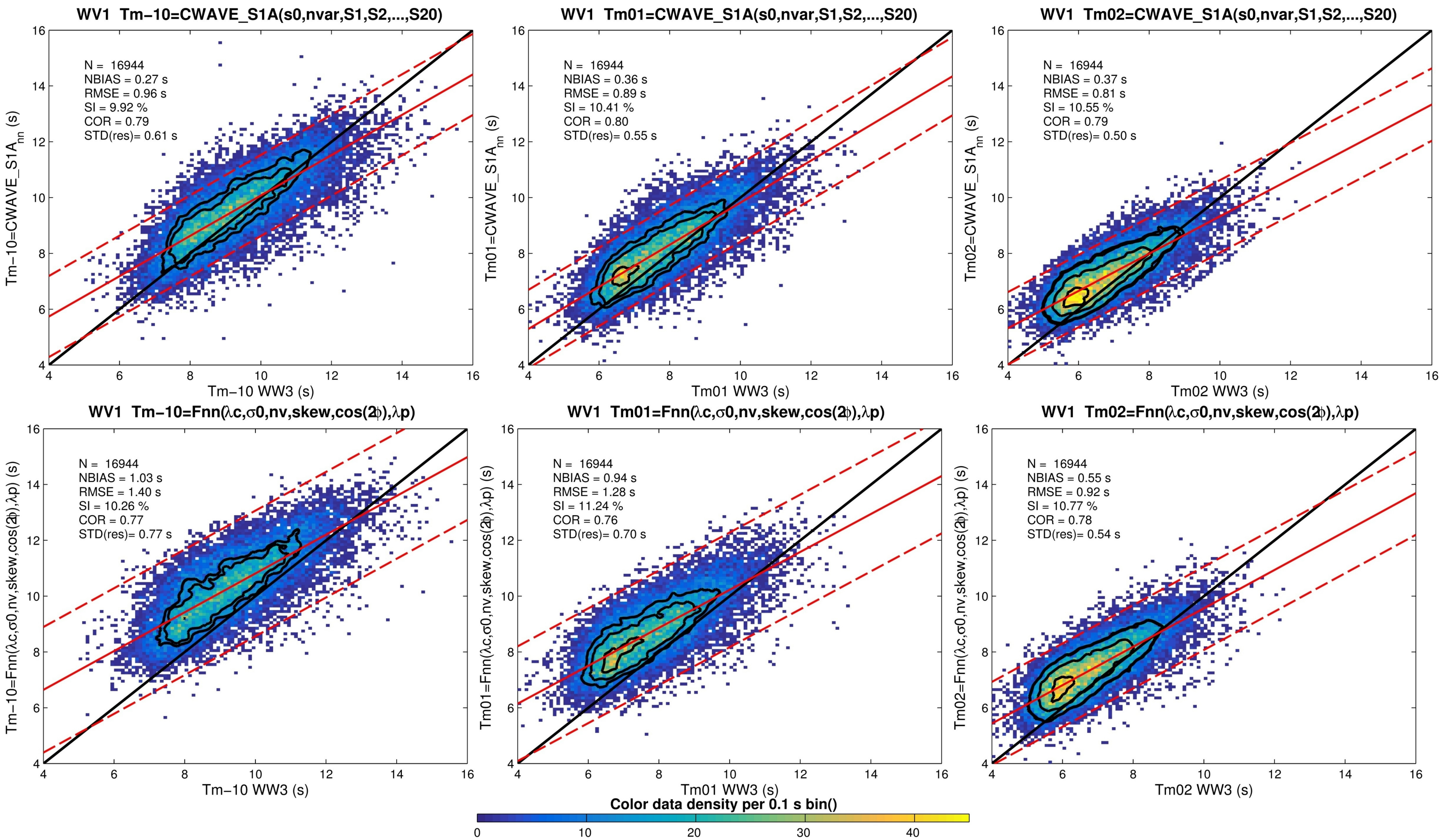
- Further validation and verifcation with more data! (train with altimeters?)
- Incorporate into ESA L2 OCN product
- Develop an automated routine to compare Hs with models to assess the data quality of S1A/S1B

- Estimate a wind-sea wave height
- Other parameters: Tm01, Tm02 (done), wave energy, Stokes drift,...
- Further assess the Schulz-Stellenfeth et al., (2007) input variables and try to better optimize by reducing the number of input parameters (motivated reason for Fnn)

- Improve the estimation of the swell spectra in the quasi-linear transform by having a more accurate estimation of the wind-sea component: $H_D(\mathbf{k})$

$$S_I(k)=H_D(\mathbf{k})T(\mathbf{k})\Psi(\mathbf{k})+S_N(\mathbf{k})$$

2. Results – Average wave period



- Reduced precision compared to Hs
- Similiar to Schulz-Stellenfeth et al., 2007 worse than Li et al., 2011