Extreme wave predictions around the southern African coastline

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2nd INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES AND COASTAL HAZARDS
Melbourne, Australia

Motivation

The shipwreck of HMS Birkenhead, near Cape Town, South Africa, 1852.

By Charles Dixon - http://www.ancestryimages.com/proddetail.php?prod=f3117, Public Domain, https://commons.wikimedia.org/w/index.php?curid=14529460

Motivation

Modern shipwrecks due to the Cape of Storms.

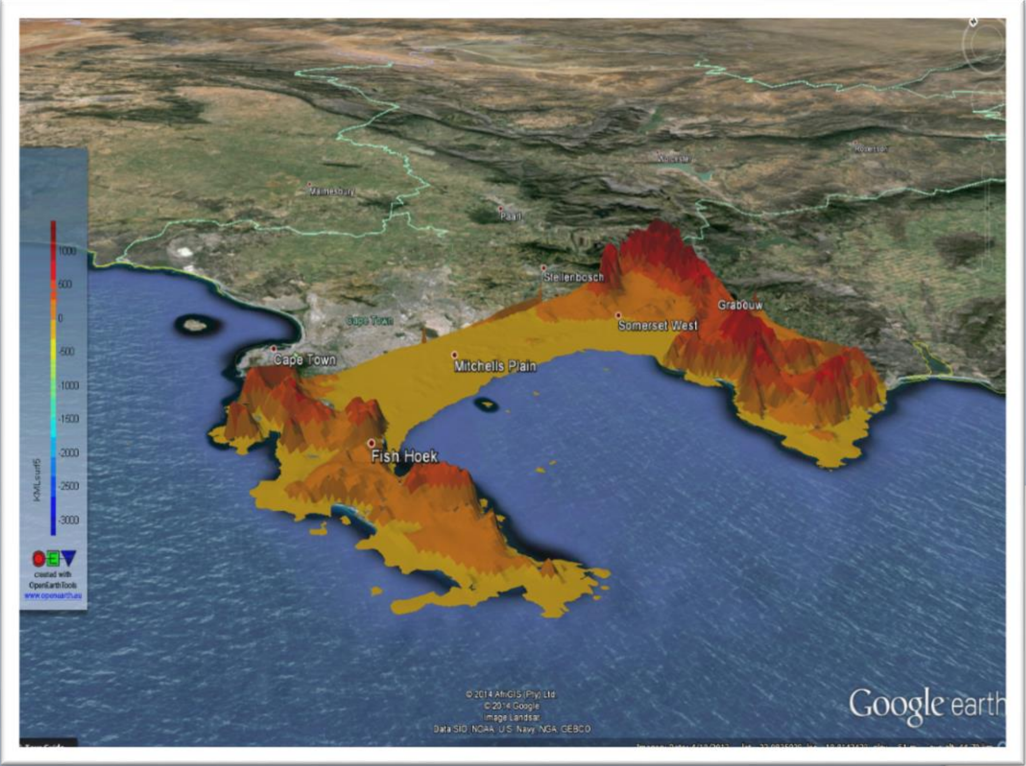
This cargo ship ran aground at Lüderitz, Namibia.

Shipwreck outside of Milnerton, close to Cape Town

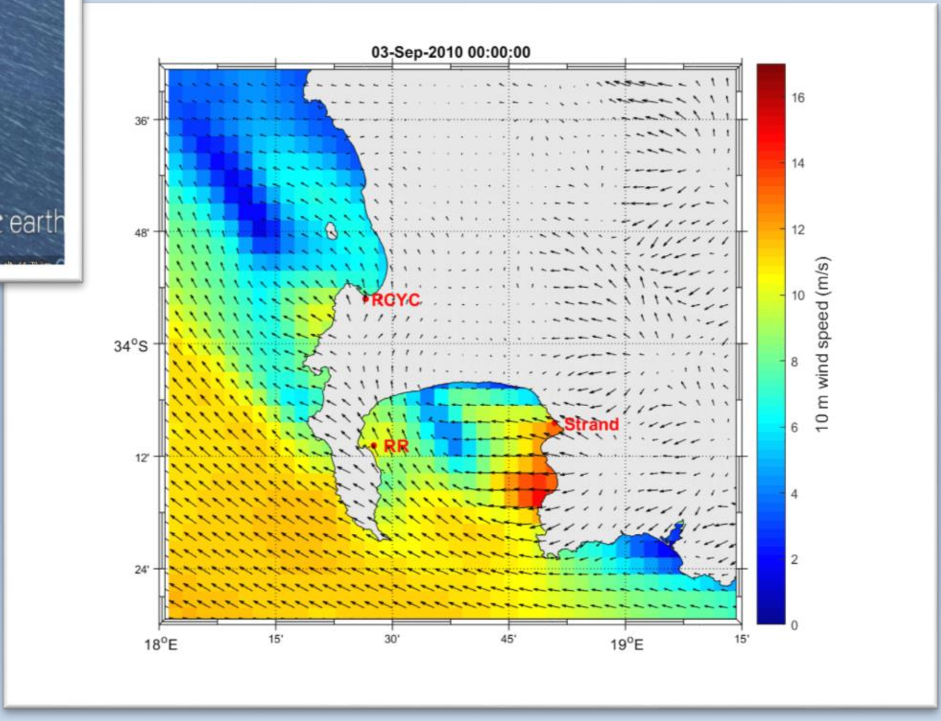
Containership dragging anchor in Table Bay due to sudden change in wind direction.

Motivation

Complex orography causes strong temporal and spatial gradients in local wind forcings.



High resolution nest



Complex flow and wave patterns emerge in False Bay and Table Bay. Thus lower resolution atmospheric forcings are not an option for accurate flow and wave modelling.

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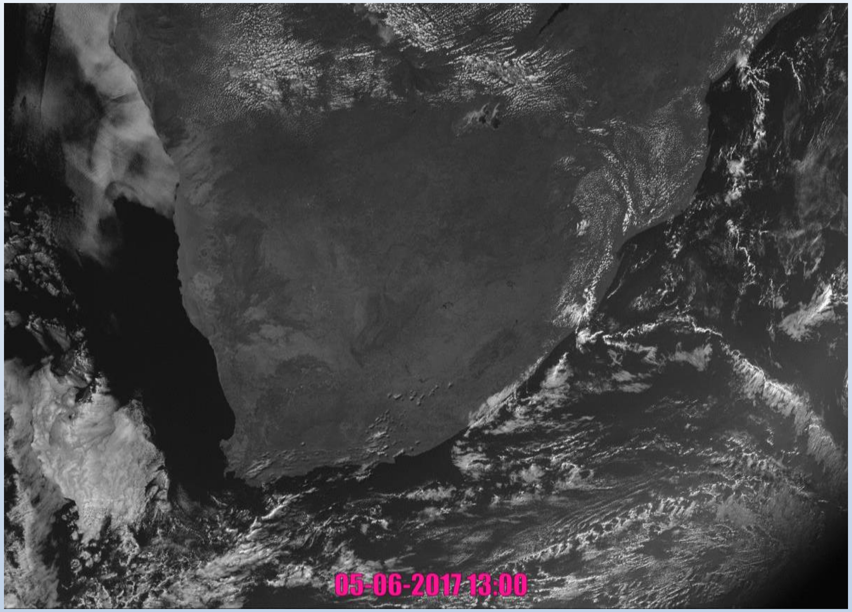
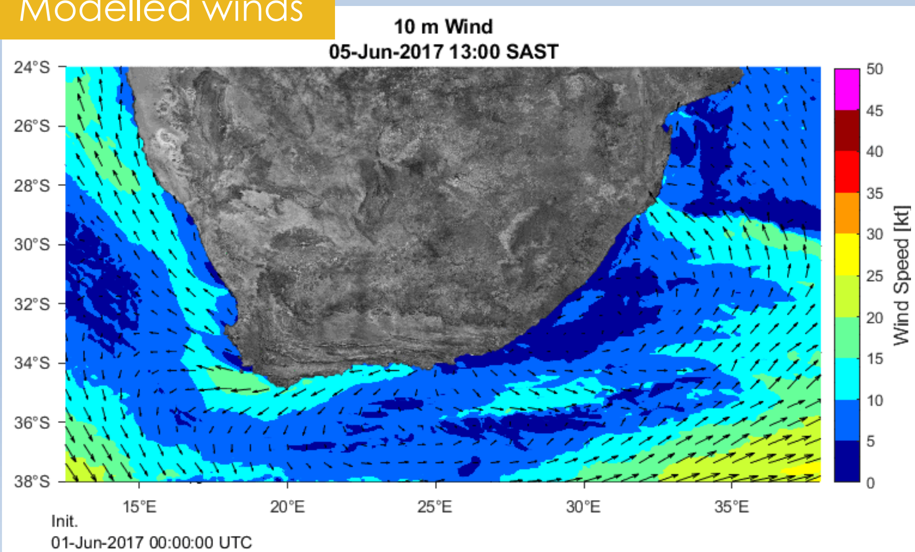
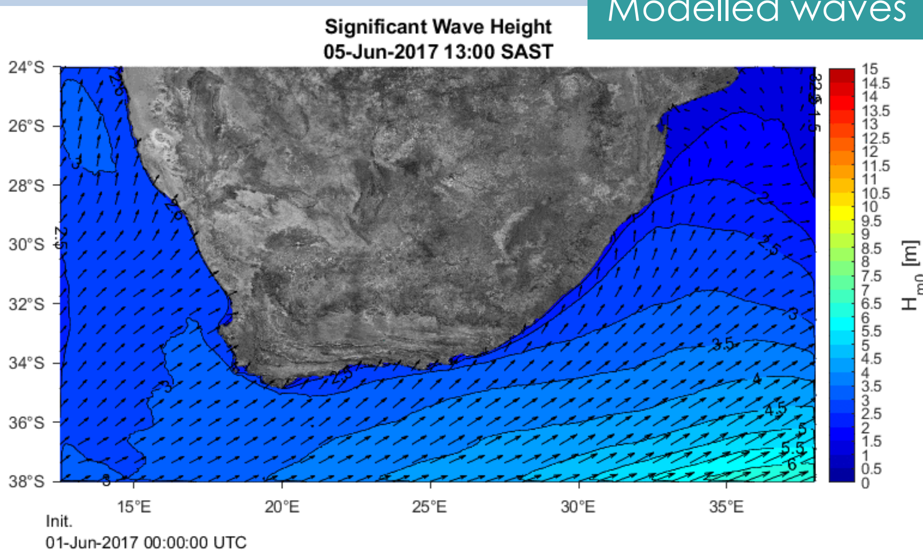
Motivation



Modelled winds



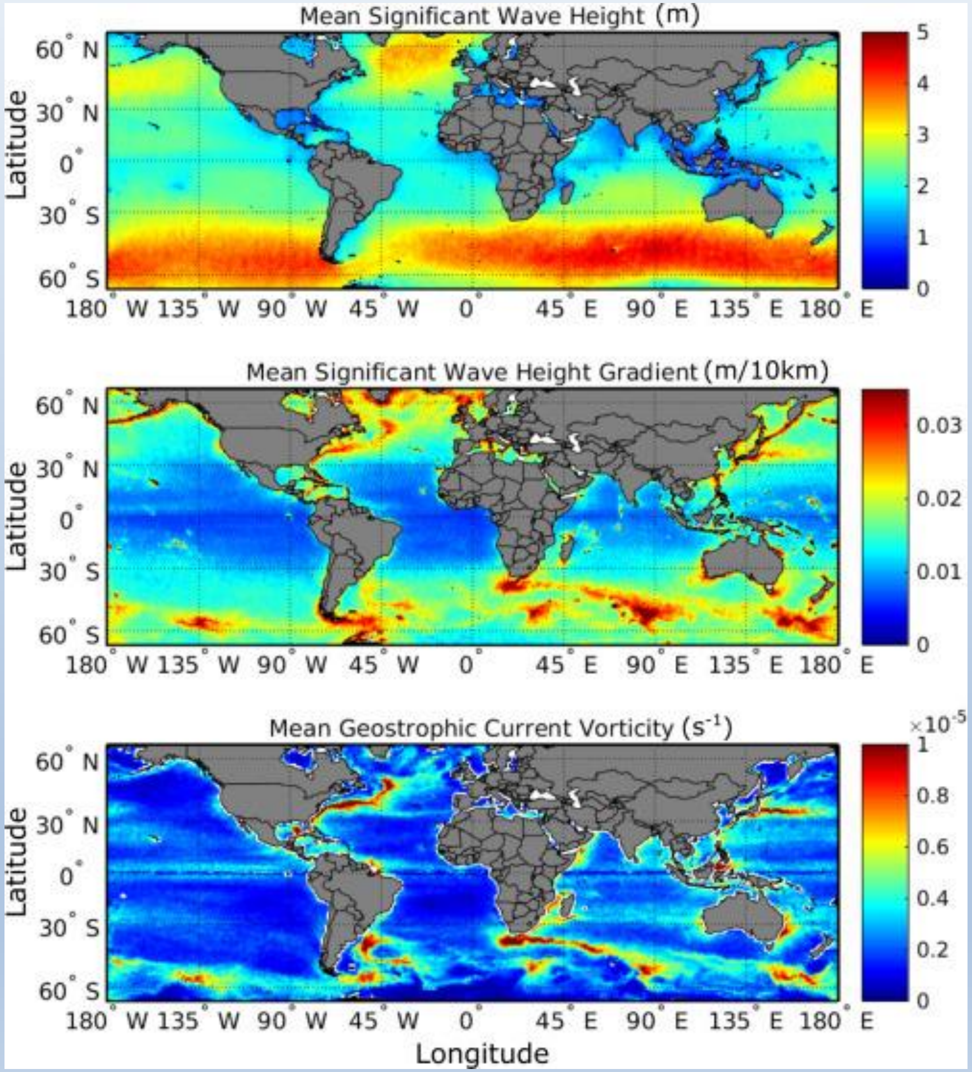
Modelled waves



Motivation

Fig. 13. 4-year mean (2013–2016) computed using the constellation of 4 satellite altimeters, onto a .5° × .5° grid, of top: significant wave height; middle: normalized gradient of significant wave height; bottom: absolute value of surface current vorticity.

Quilfen, Y., Yurovskaya, M., Chapron, B., & Ardhuin, F. (2018). Storm waves focusing and steepening in the Agulhas current: Satellite observations and modeling. Remote Sensing of Environment, 216, 561– 571. https://doi.org/10.1016/j.rse.2018.07.020



Motivation

- Strong wind and waves in the southern oceans
- Storm events are violent, sudden and unpredictable
- Significant orographic effects along the coast in multiple locations
- Enhanced waves due to strong surface currents i.e. Agulhas Current system
- Susceptible to storm surge and freak waves

Objectives

- Better characterize the environment in a modelling system, focusing on wave
- Improve boundary conditions
  - Accuracy
  - Logistics
- Quantify the effects of the boundary conditions on the extreme environment

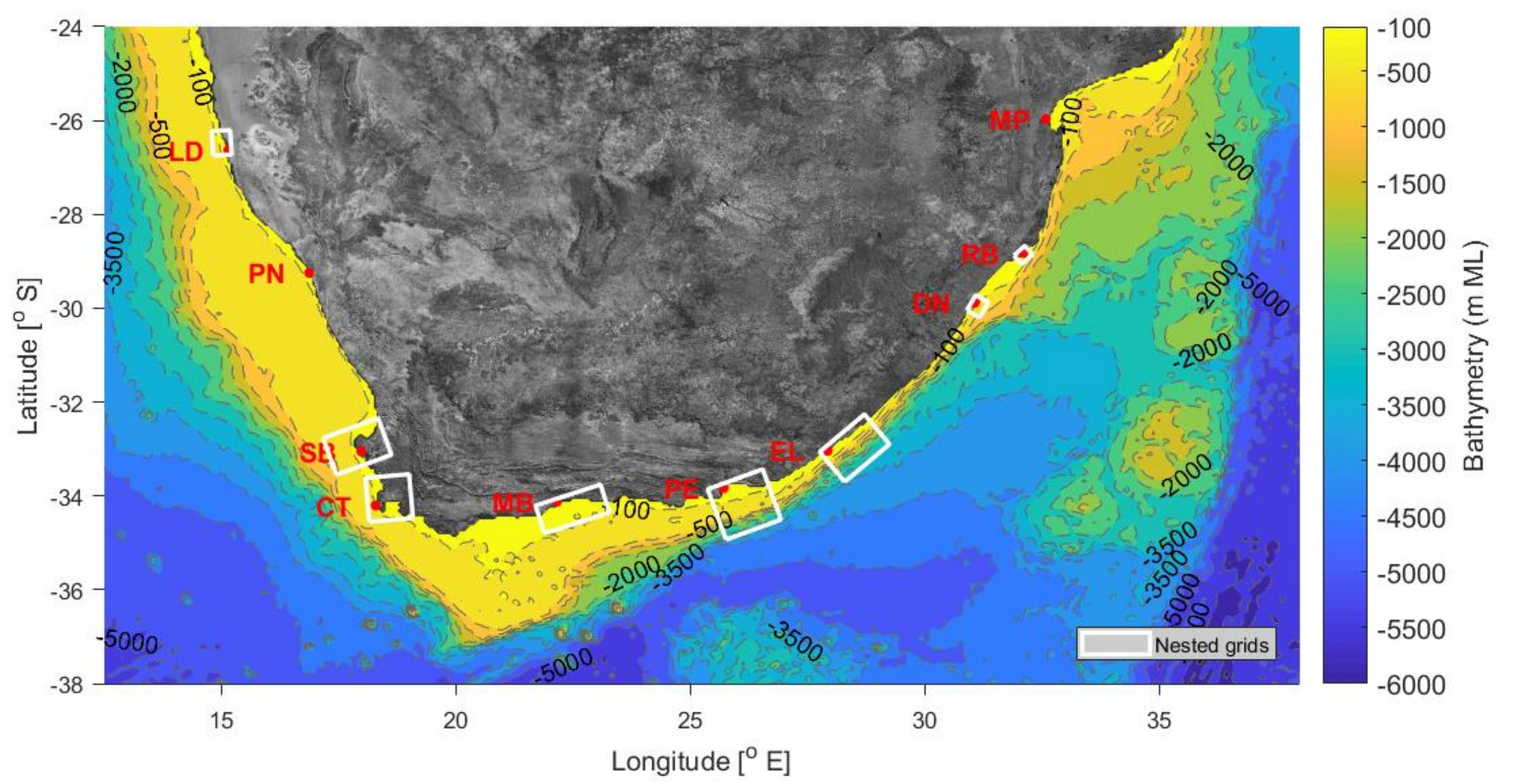
Background

- Wave modelling at SAWS
  - Delft3D, SWAN
  - Wave-current interaction (*Barnes and Rautenbach, under review*)
  - Research and operational development (*Rautenbach et al., under review*)
  - Boundary conditions
- Wave modelling at NRL
  - Global coverage COMPLETE
  - Boundary conditions are our business
  - Transitioning operational capability to FNMOC, the US Navy wave forecasting source

SWAN Wave Model

- Version 40.72
- 36 frequency and directional bins
- Whitecapping – Komen (numerics and physics, GSE, etc.)
- Curvilinear grid set up with Delft3D RFGRID, maintaining orthogonality
- Coupled hourly as Wave in Delft3D
- Host at 1/16th degree resolution, Nests at 1/48th.
- Winds from SAWS Unified Model 4.4 km resolution
- Non-stationary
- Bathymetry from GEBCO and SANHO
- BCs from global WAVEWATCH IIIs (operationally from NCEP)

Model Coverage and Bathymetry



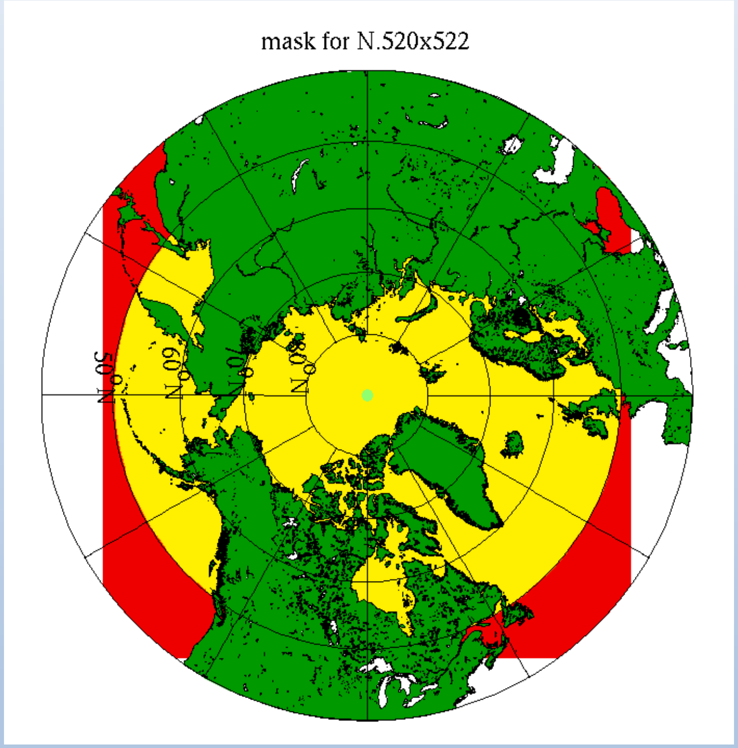
PN: Port Nolloth
SB: Saldanha Bay
CT: Cape Town
MB: Mossel Bay

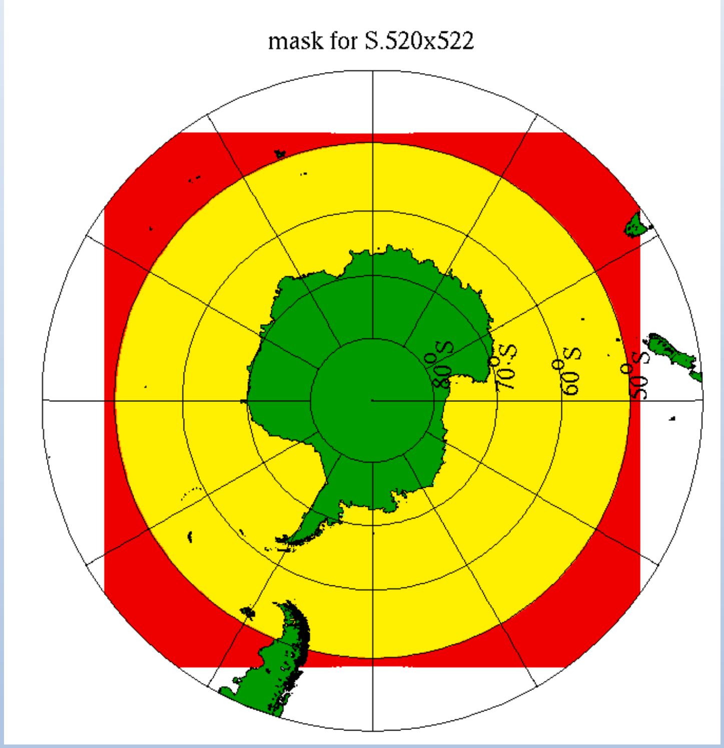
PE: Port Elizabeth
EL: East London
DN: Durban
RB: Rochard's Bay

WAVEWATCH III

- Dubbed Irregular-regular-irregular (IRI) system
- Global latitude-longitude grid - Spherical
  - 55^{o}S to 55^{o}N
  - ¼-degree resolution
- Polar Stereographic grids North (South) - Curvilinear
  - Starting 50^{o}N(S) (overlaps global grid) to nearly the poles
  - 18-km resolution at 70^{o}N(S)
- Spectral bins
  - 36 directional bins (10^{o} resolution), [5, 15, 25, …]
  - 25 frequency bins, with logarithmic spacing from 0.0418 to 0.7294 Hz (increment factor = 1.1)
- Bathymetry from ETOPO1, but deepest is 999 metres
- Obstruction grids identify sub-resolution features (Arun Chawla)
- Time steps: 3600 s maximum global, 720 s maximum CFL time step for x-y
- Assimilation altimeter observed significant wave heights every 6 hours
- Input ice fields from HYCOM-CICE and implementing IC4

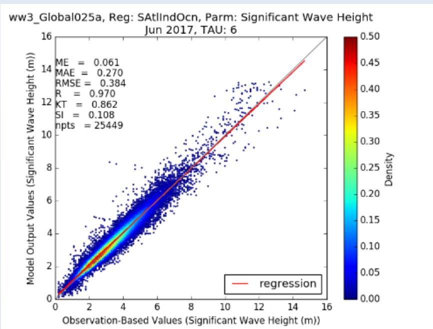
Curvilinear Grids at Poles

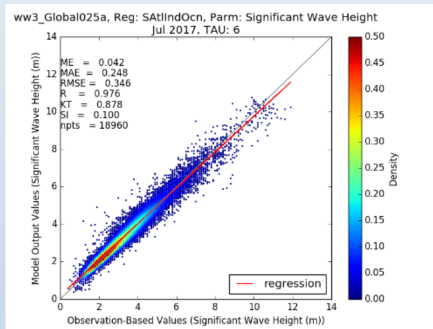


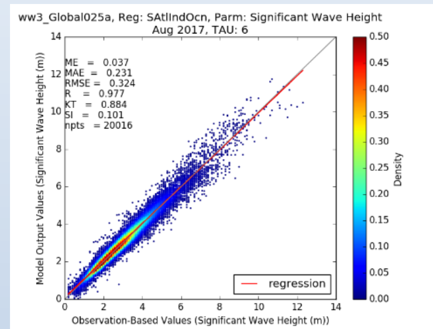


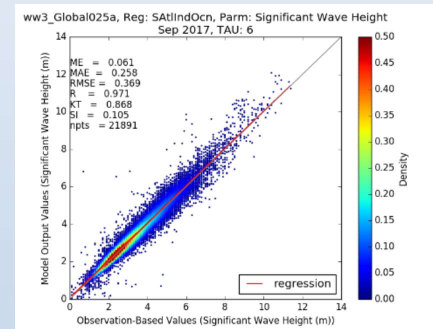
Computational points in the model region are depicted in yellow. Although a square grid is "draped" over the poles, the corners are "trimmed" off by using a mask depicted in red. Land is depicted in green.

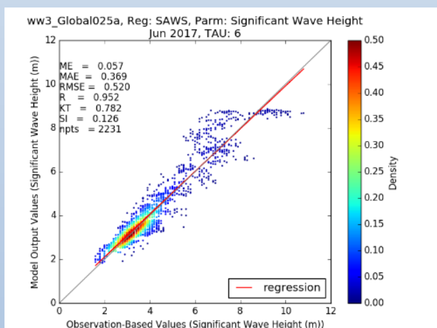
Model Performance of Significant Wave Height

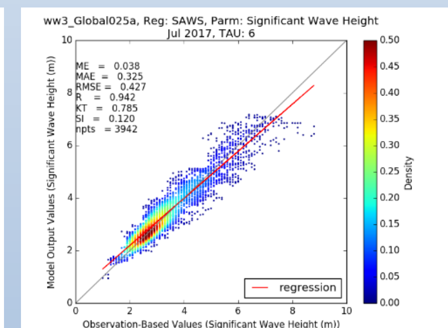


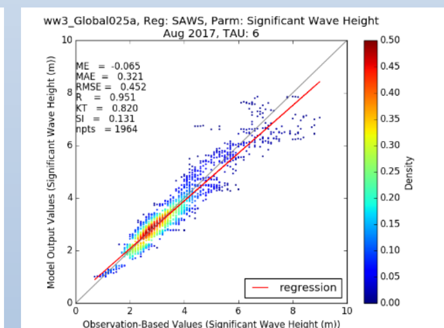


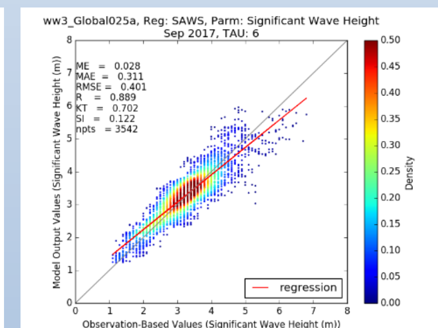










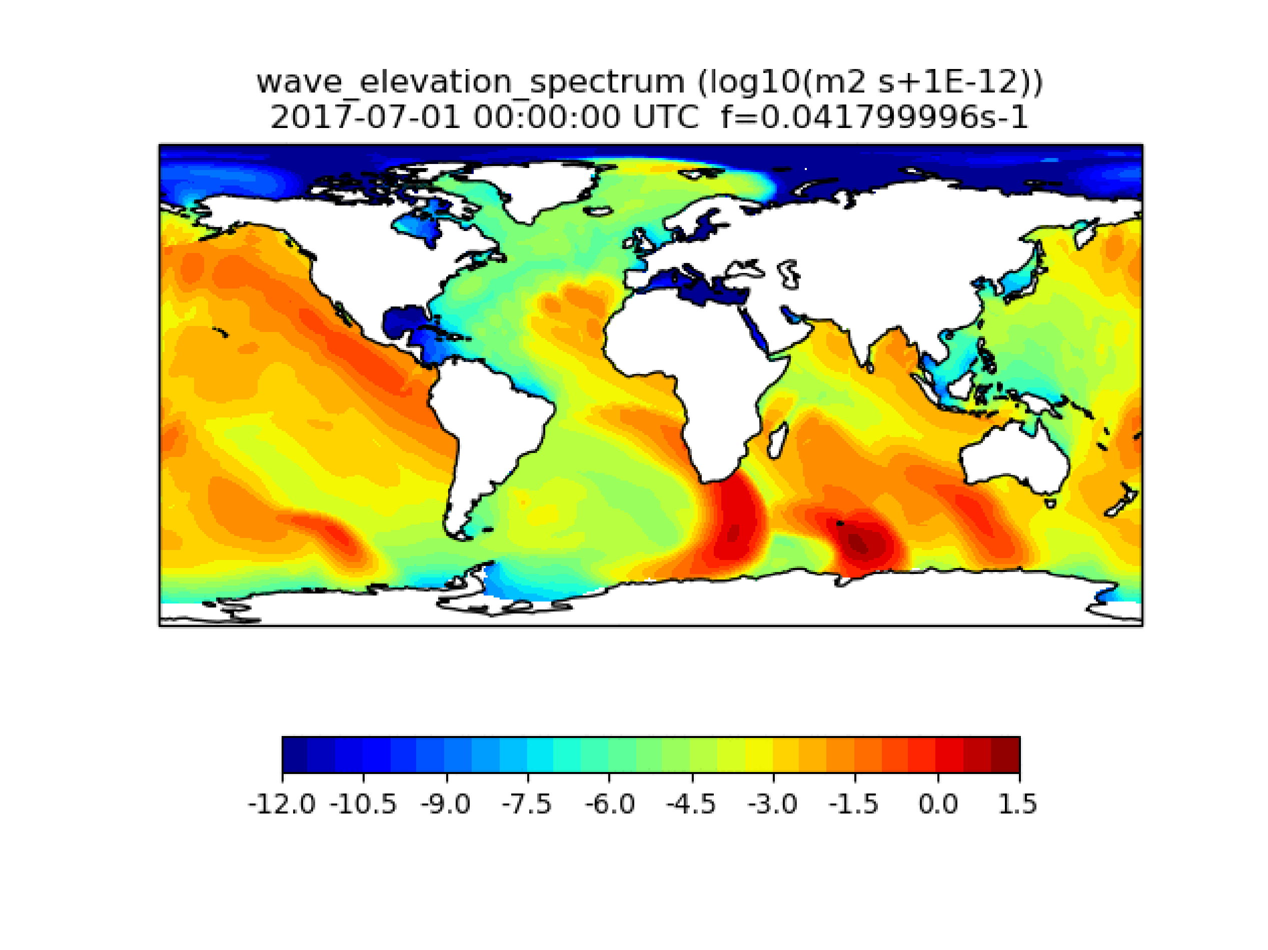


Statistics of model performance against altimeter measurement for each of four months in 2017. For the top row plots altimeter points were subsampled for every 30 km in a region bounded by the equator and the South Pole and by the 65 W and 150 E. The bottom row covers the model domain used by SAWS. Matchups were made with observations timed within 1.5 hours either side of TAU 06.

Preserving Directional Spectra Using Fourier Series Coefficients

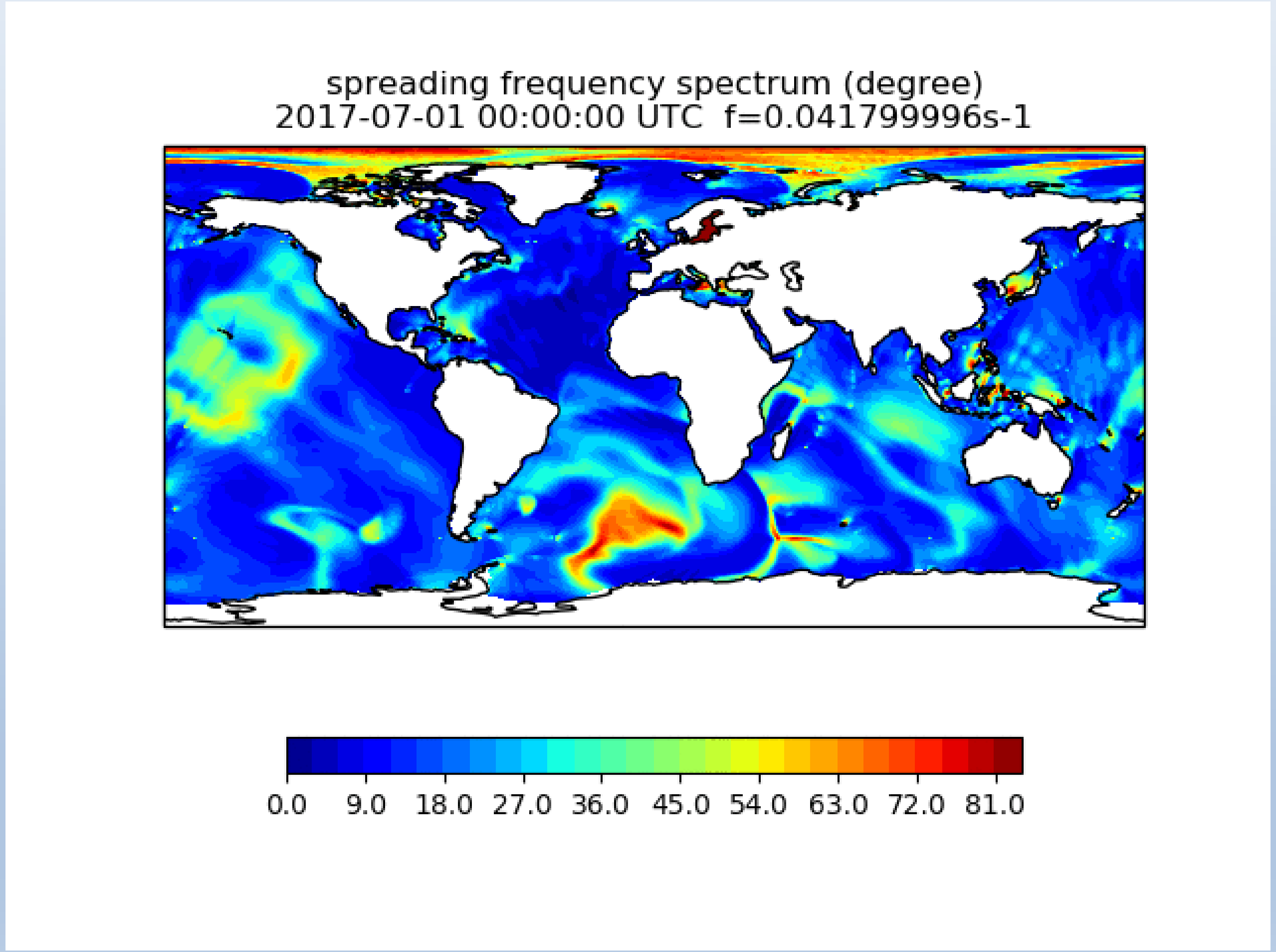
- $E(f)$, $\theta_1(f)$, $\sigma_1(f)$, $\theta_2(f)$, and $\sigma_2(f)$ based on $F(\sigma, \theta)$, $a_1(f)$, $b_1(f)$, $a_2(f)$, $b_2(f)$
- Fixed error in model code for $\theta_2(f)$ and $\sigma_2(f)$)
- For all computational points in domain
- Can be integrated easily into that one large global domain from pole to pole
- Easily processed into netCDF, conveniently readily available
- Occupies 1/10 the space of full spectra
  - 3029 Mbytes for one snapshot of restart files
  - 299 Mbytes for one snapshot of reduced spectra files
- Can be reconstructed to the approximated full spectrum using MLM and/or MEM
- Increases flexibility of spectral dimensions
- Preliminary tests demonstrate suitability as boundary conditions for SWAN
- Will be incorporated into the Spritzer, a newly developed WAVEWATCH III application

Frequency Spectra



Plotted from netCDF right out of the box, i.e. passing along metadata as-is.

Directional Spreading



Plotted from netCDF right out of the box, i.e. passing along metadata as-is.

Reconstructed Spectra

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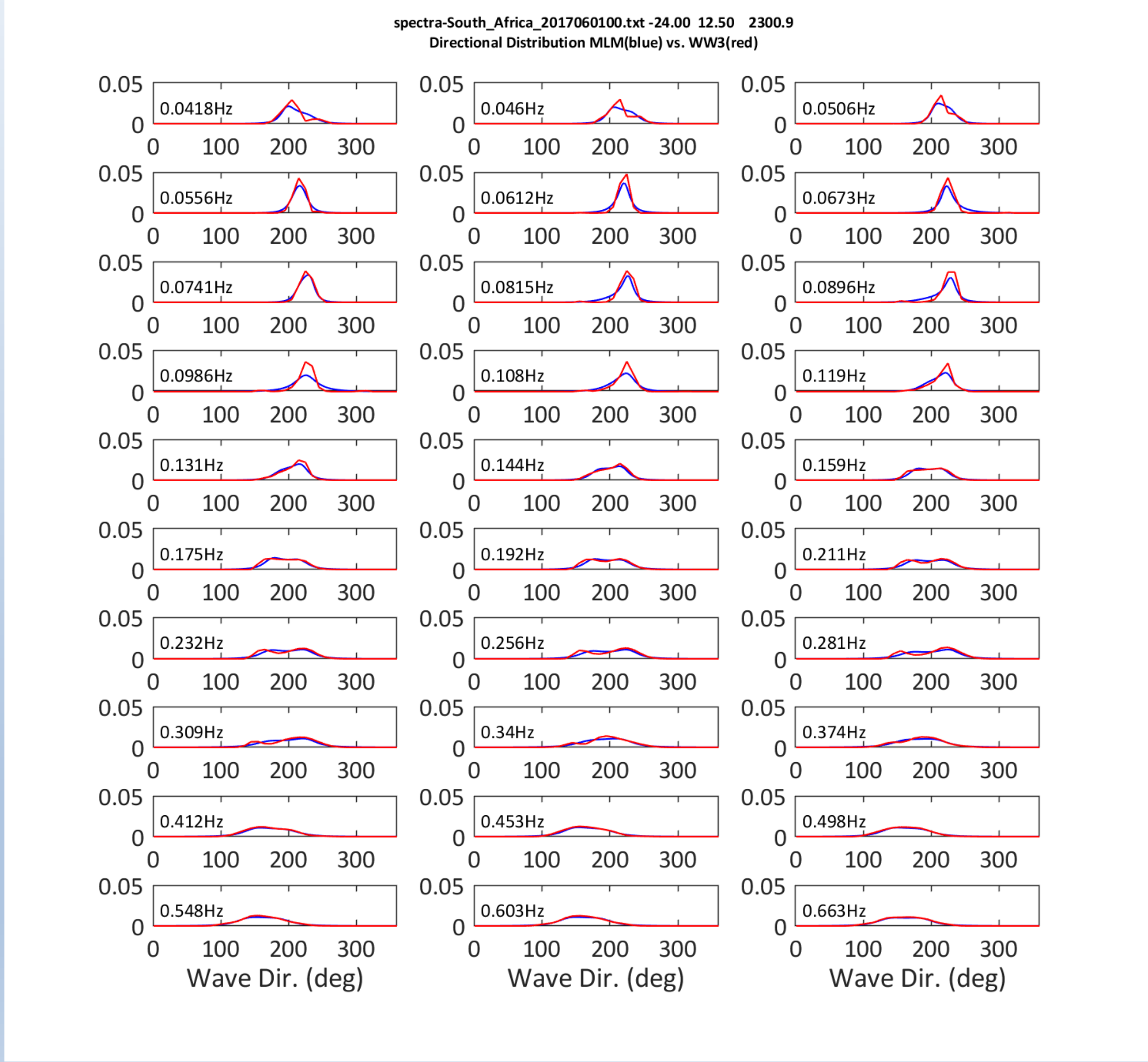
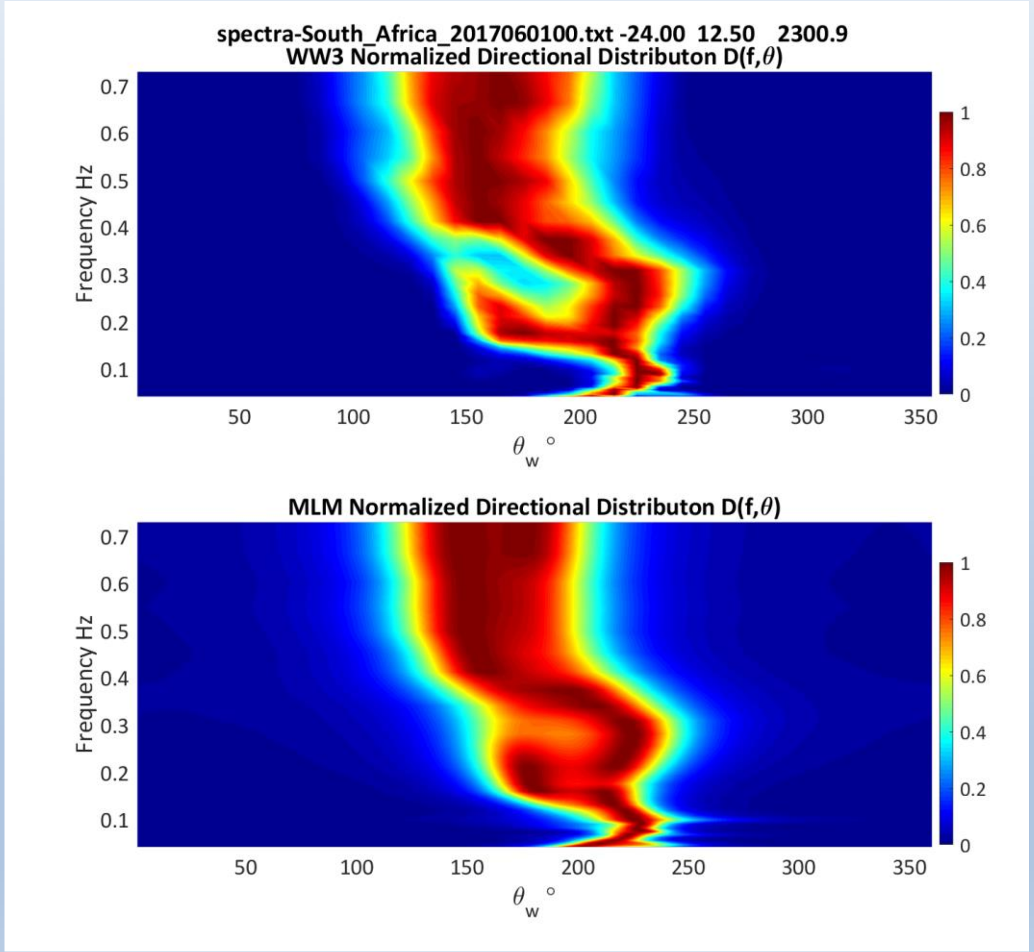
Directional distribution of energy from the original WAVEWATCH III model output for 01 June 2017 is compared to MLM reconstruction of the first five moments output from the same model. This point is sampled from a location at the boundary of the SAWS domain.



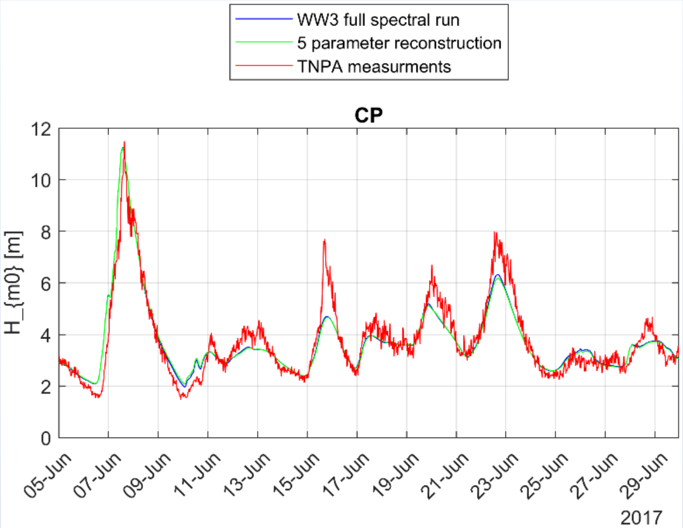
Reconstructed Spectra

- Original

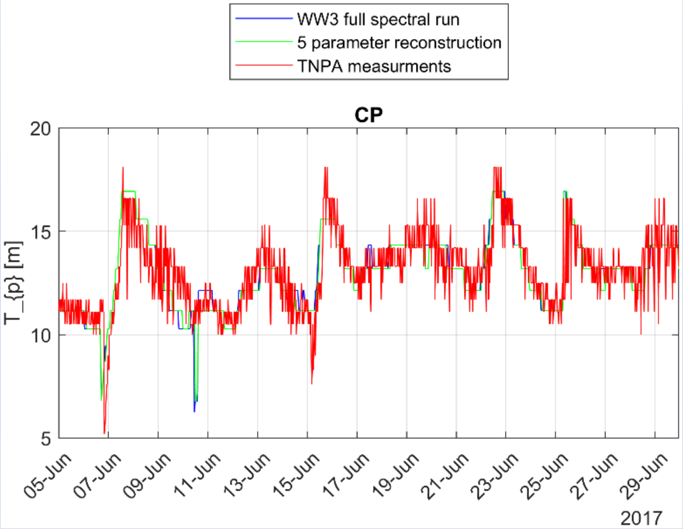
- Reconstructed

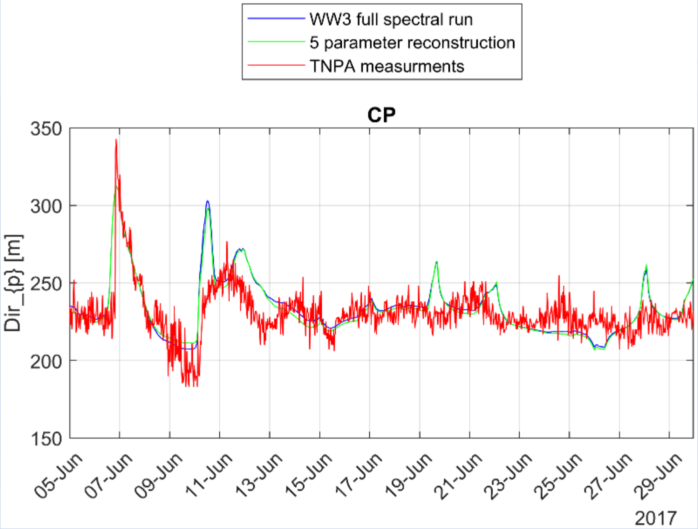


Results

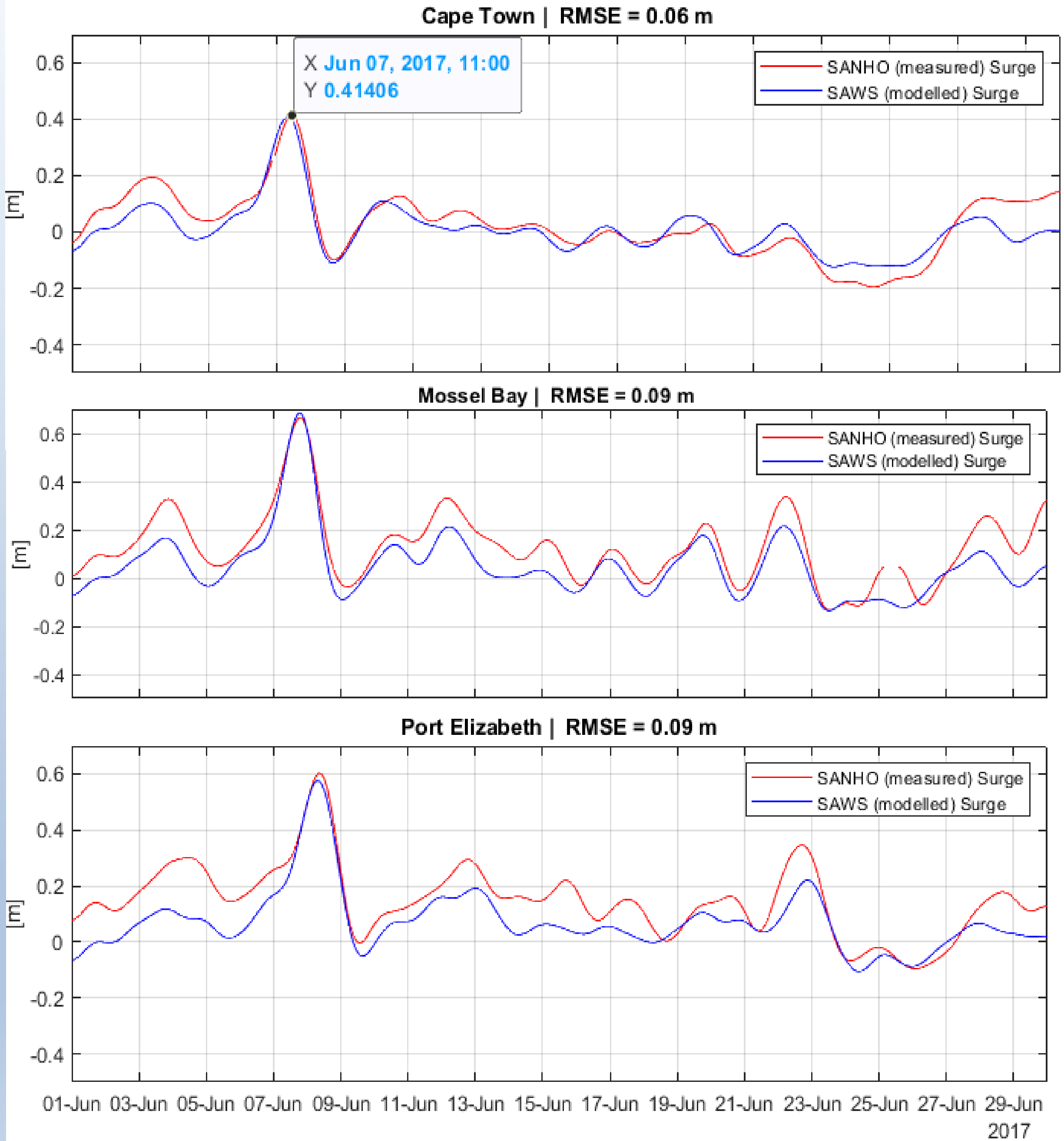


Model output using original and reconstructed spectra are virtually identical.





Also surge on that fateful day.



Conclusions

- Work to use described approach shows promise:
  - Improving operations particularly with WAVEWATCH III host providing BCs to SWAN nest
  - Further research in modelling interesting domain
- Results using Navy global and SAWS regional wave models in area with extreme wave conditions are successfully demonstrated
- Featured website: Marine forecasts from SAWS: http://marine.weathersa.co.za/Forecasts_Home.html

Further Work

- Work on sensitivities (to extreme wave conditions) due to boundary conditions
- Set up product exchange between centers operationally
- Try different whitecapping formulations
- Try different bottom friction formulations
- Implement rogue wave estimator (developed at NRL)

Acknowledgements

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Thanks to team NRL, SAWS and the memory of Paul Wittmann.