Implementation and Development of Optimised Spectral Wave Hindcasting Techniques

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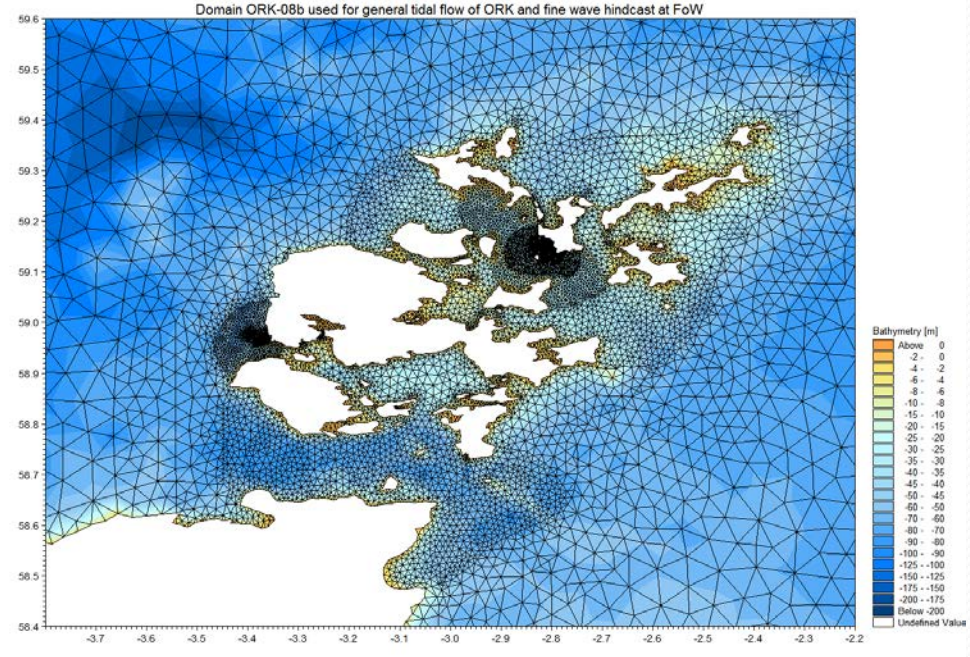
Motivation

- CPU time in downscaling simulations (deep water to shallow water) can be very high.
- Would like to develop a tool to provide quick long term statistics (in days rather than months) for people in a hurry.



Conclusions

- Hybrid downscaling can provide large reductions in simulation time in coastal downscaling applications.
- A useful option when fast results are required i.e. to assist operations or to provide preliminary design numbers.
- Needs to be used with care – extensive validation required.
- Method can be applied in more complex cases – this study has hinted at some of the approaches to tackling this.

What options do we have?

1. Get some more CPUs
2. Develop some transfer functions so that we only need to simulate a few key sea-states.

- This is referred to in the literature as “hybrid downscaling”
- Follow the approach of Camus et al. (2010)
- So what is hybrid downscaling?

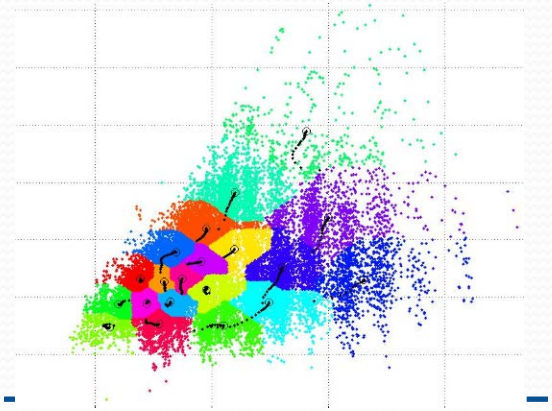
Hybrid Downscaling (following Camus et al. 2010)

OFFSHORE HINDCAST

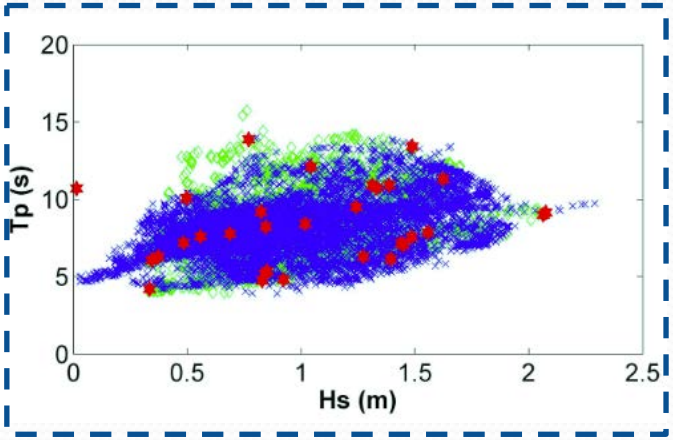
SELECTION OF "M" SEA-STATES

TRANSFORMATION OF "M" TO THE NEAR SHORE

RECONSTRUCTION OF THE COMPLETE DATASET NEARSHORE

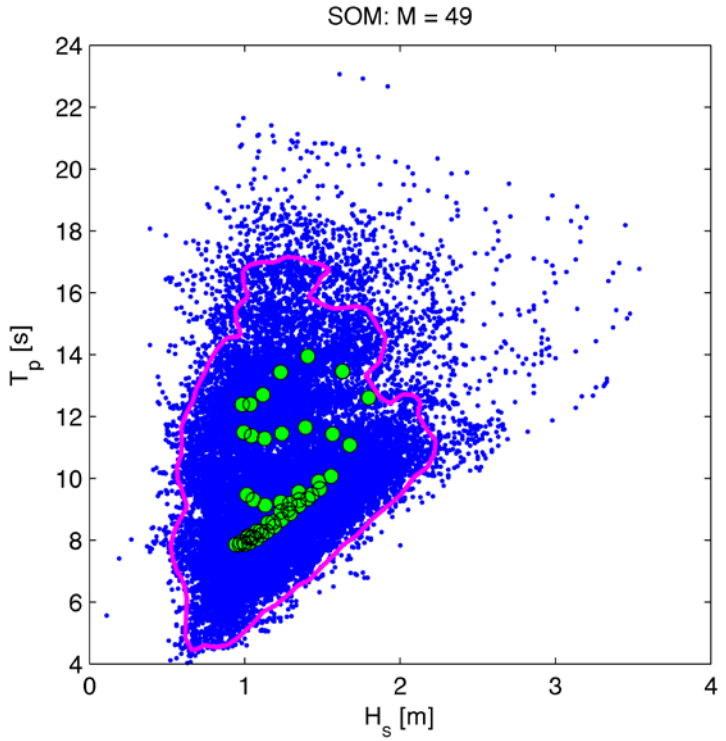


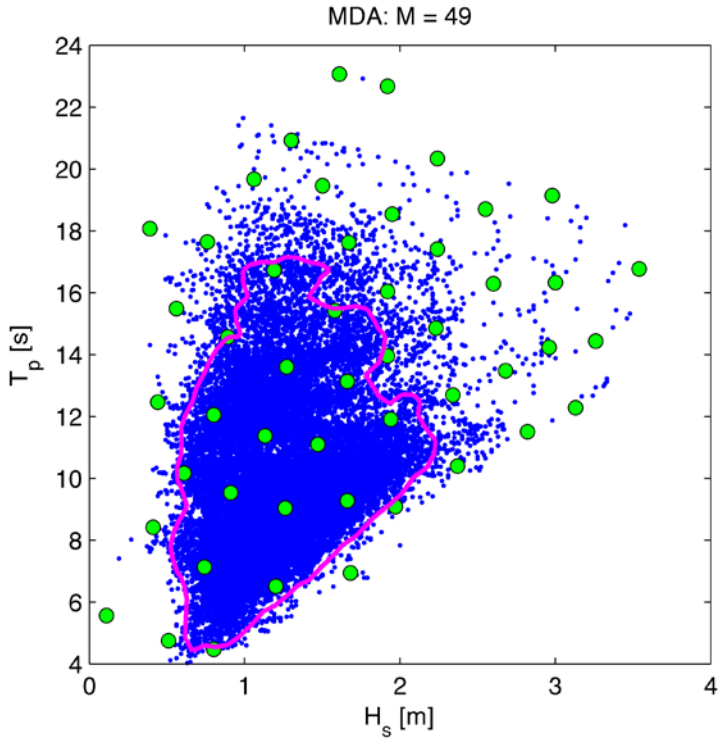
SPECTRAL WAVE MODEL



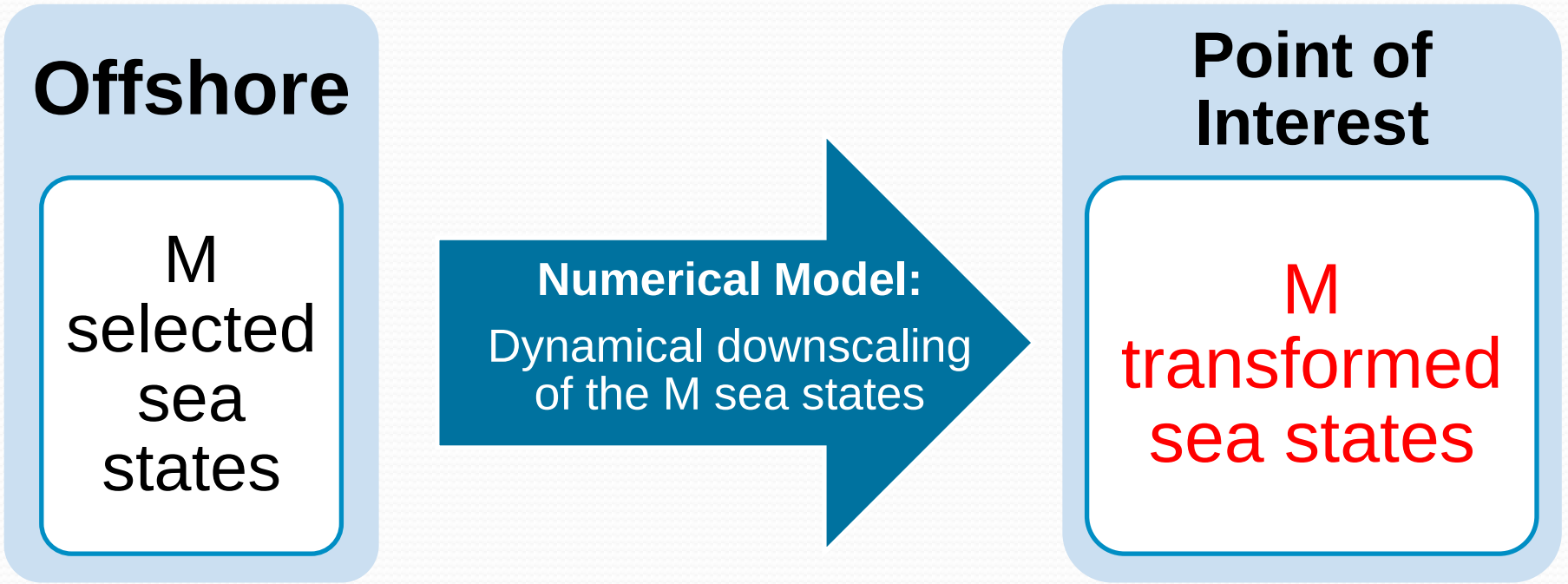
Sea-State Selection

- Camus et al. (2010) suggest MDA is best for hybrid downscaling.





Dynamical Downscaling



Reconstructing the Data Nearshore

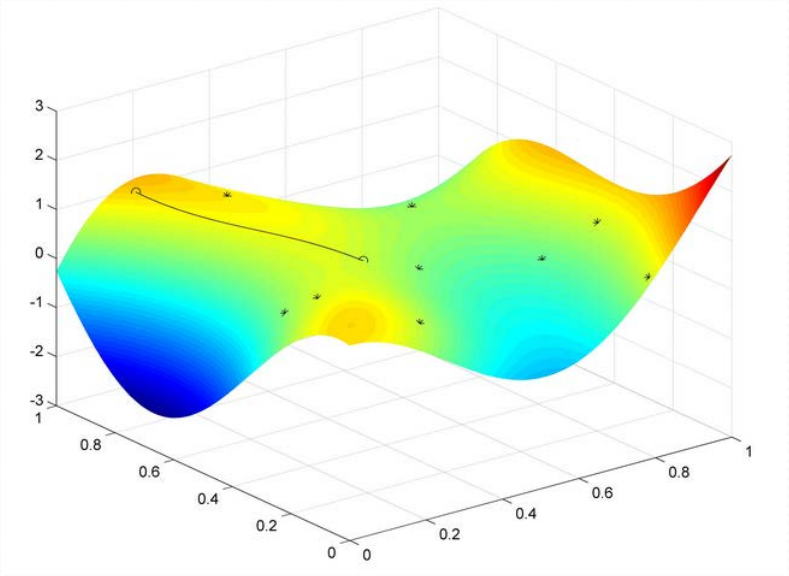
- We are looking for an interpolation routine that will:
  - Accommodate multivariate data and is;
  - Relatively fast
- Choice: **RBF (Radial Basis Functions).**
- Why?: Proven to be very effective at reconstructing scattered and multivariate datasets – see: Hardy (1990) and Franke (1982).
- Do how does it work?

Radial Basis Function

$$RBF\,(x_j) = x_j^*$$

$$RBF\,(x) = \sum_{j=1}^{M} (\boldsymbol{a_j} * \Phi(\,\|x - x_j\|))$$

$$\Phi(\,\|x - x_j\|) = \exp\left(-(\|x - x_j\| * \boldsymbol{c})^2\right)$$



x_j* are the post-modelled sea-states
Φ is radial based function (shown in the figure above)
$\|x - x_j\|$ is the Euclidean normal distance between each M selected sea state all other data points within the cluster of data that it represents
$\boldsymbol{a_j}$ is a vector of coefficients relating the offshore points to the nearshore points
c is the shape parameter

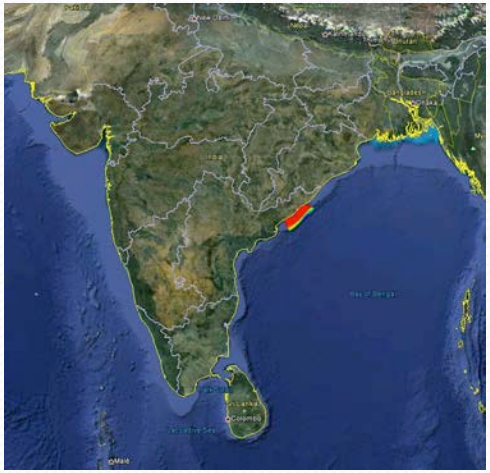
(image from Camus et al. (2010)

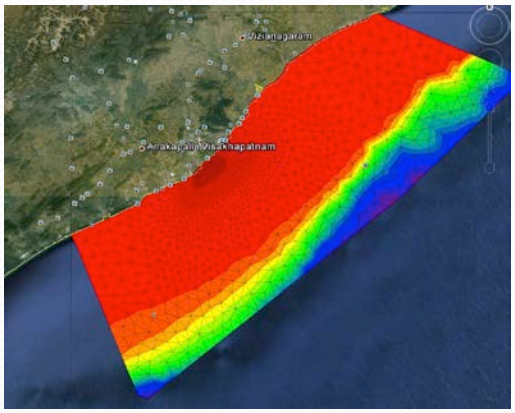
Reconstructing the Data Nearshore

- RBF provides a combined response surface.
- All offshore data points can now be easily transformed to the nearshore.
- Just multiply the complete offshore hindcast by the RBF.

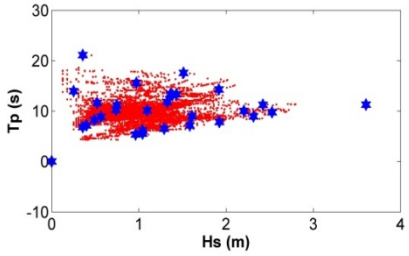
- Simple Example: Offshore India

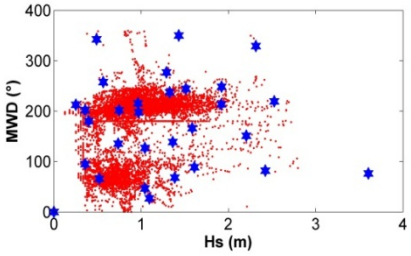
Example: Eastern India

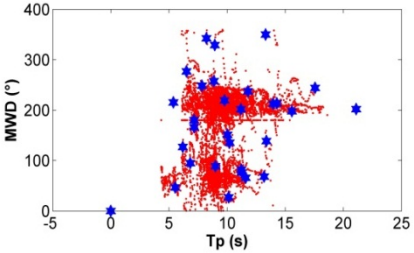




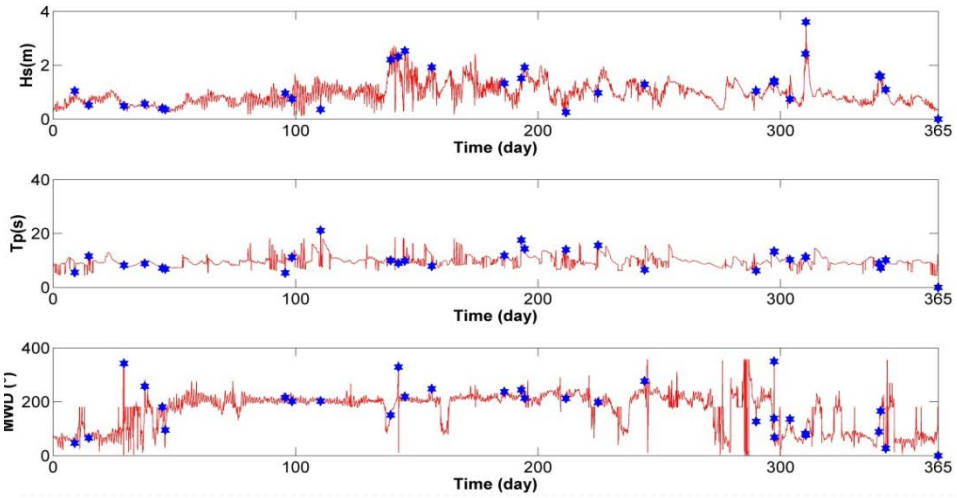
- Wave transformation for a new port – complete hind-cast data already available to benchmark method
- 30 sea-states selected (M=30)





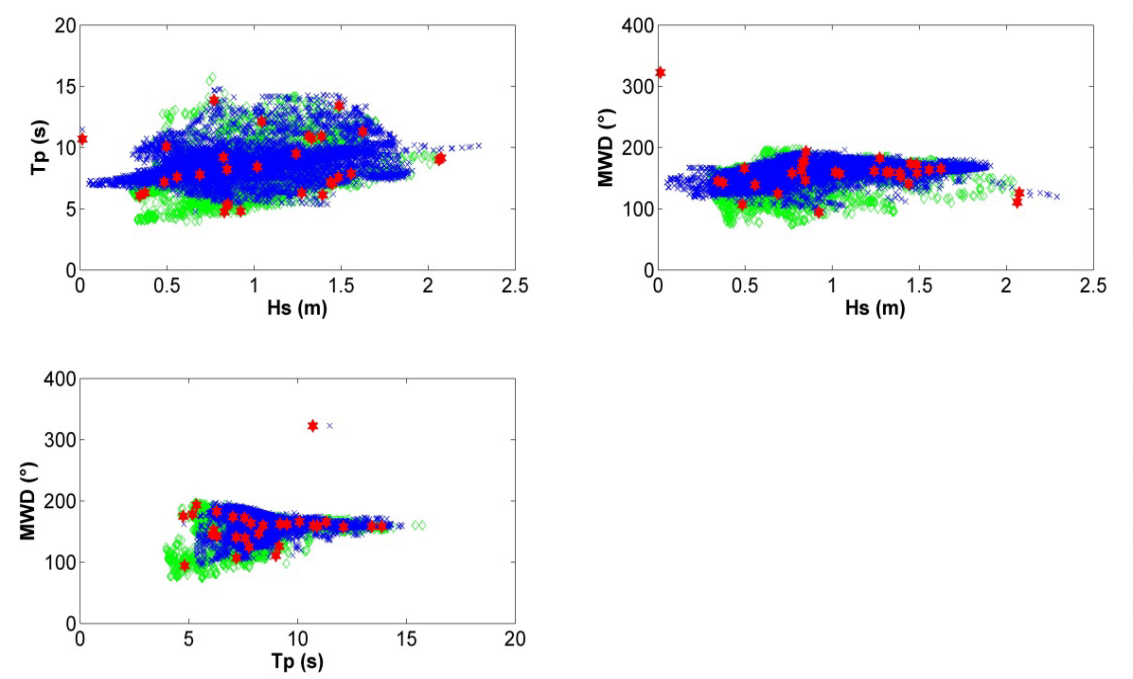


Blue stars: M selected sea-states from MDA



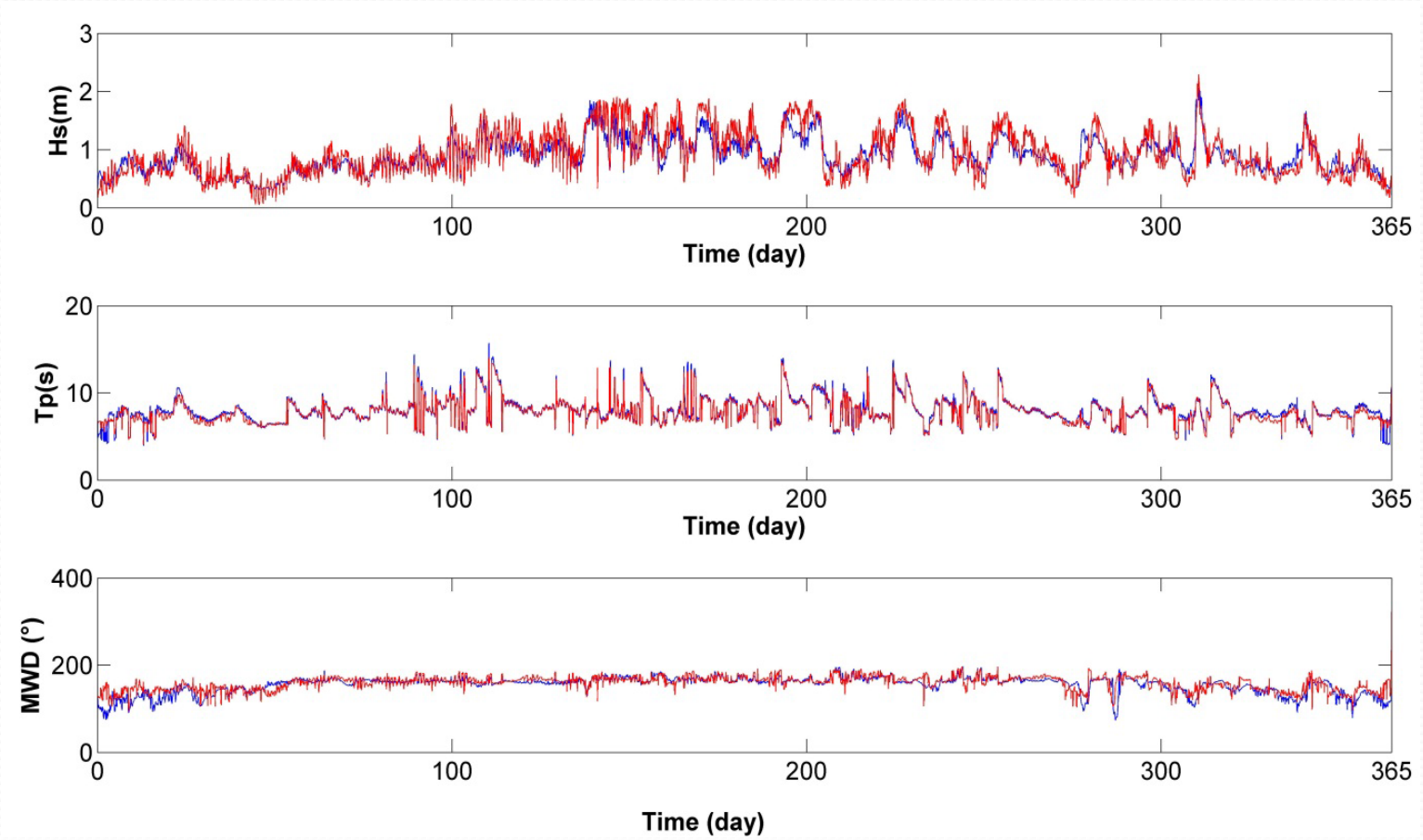
Reconstructed Data

- Transform the M sea-states to the near-shore using a spectral wave model and then reconstruct the complete dataset in the near-shore using the RBF.



Red stars: transformed 30 selected sea states (M)
Green circles: 8000 sea-states transformed by direct spectral simulation
Blue crosses: 8000 sea-states reconstructed by RBF applied to M

Reconstructed Data: Time series



Corr. Coeff.

Hs (0.92)

Tp (0.96)

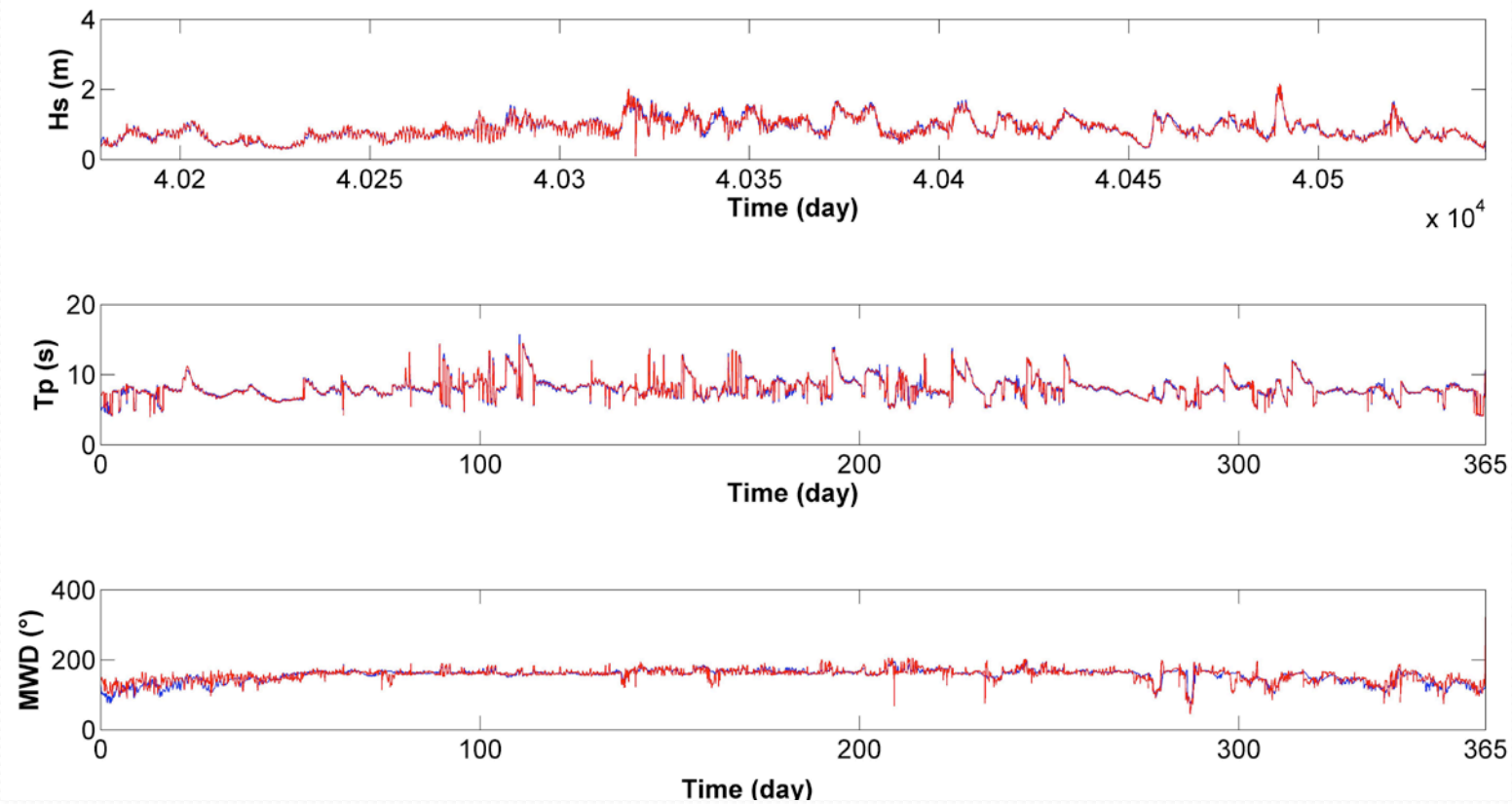
MWD (0.81)

Hindcast from simulation of **all 8000 sea states**

Hindcast from simulation of **only 30 sea-states**

~300 times speed-up

Increasing M to 200:



Corr. Coeff.

Hs (0.98)

Tp (0.98)

MWD (0.86)

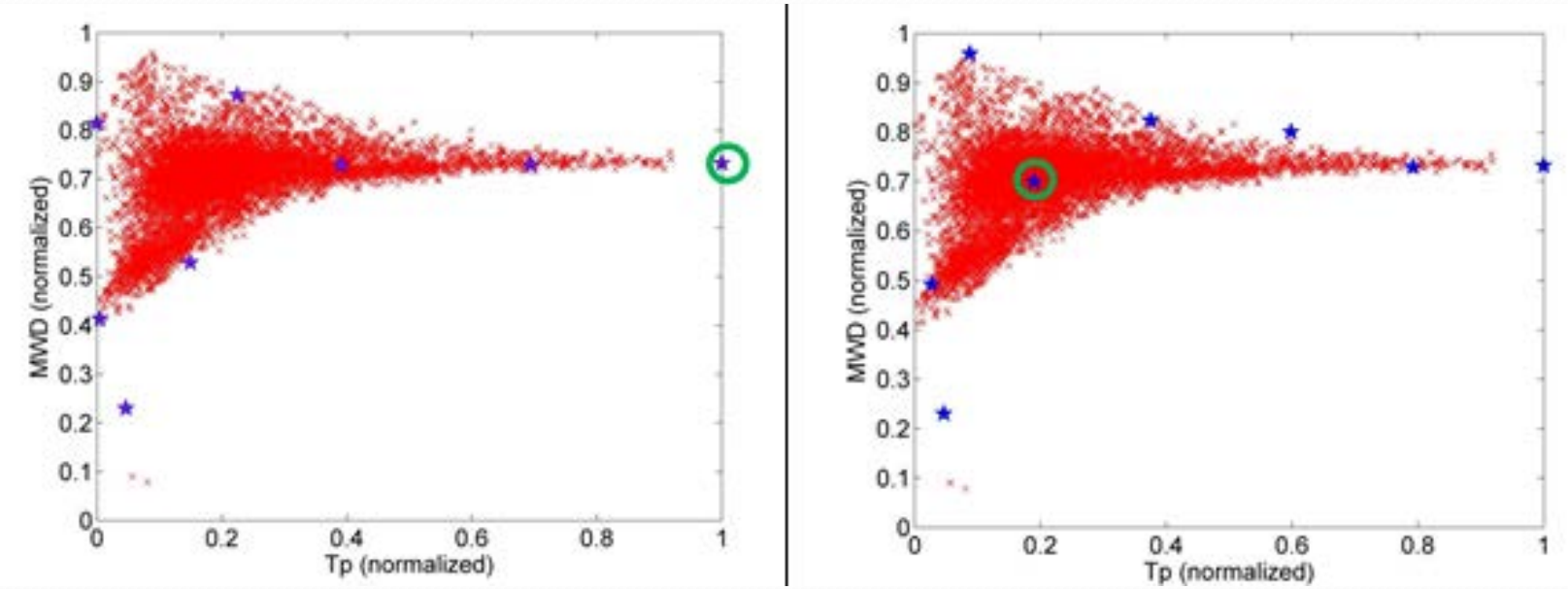
Hindcast from simulation of **all 8000 sea states**

Hindcast from simulation of **only 200 sea-states**

~40 times speed-up

Improvements 1.

- For low M we often don't have an point in the core of the data cluster:
- Solution: Change the MDA so we do and target the high density part of the data cluster:



MDA of Camus et al. (2010, a)
Correlation coefficient: 0.97

Improved MDA
Correlation coefficient: 0.99

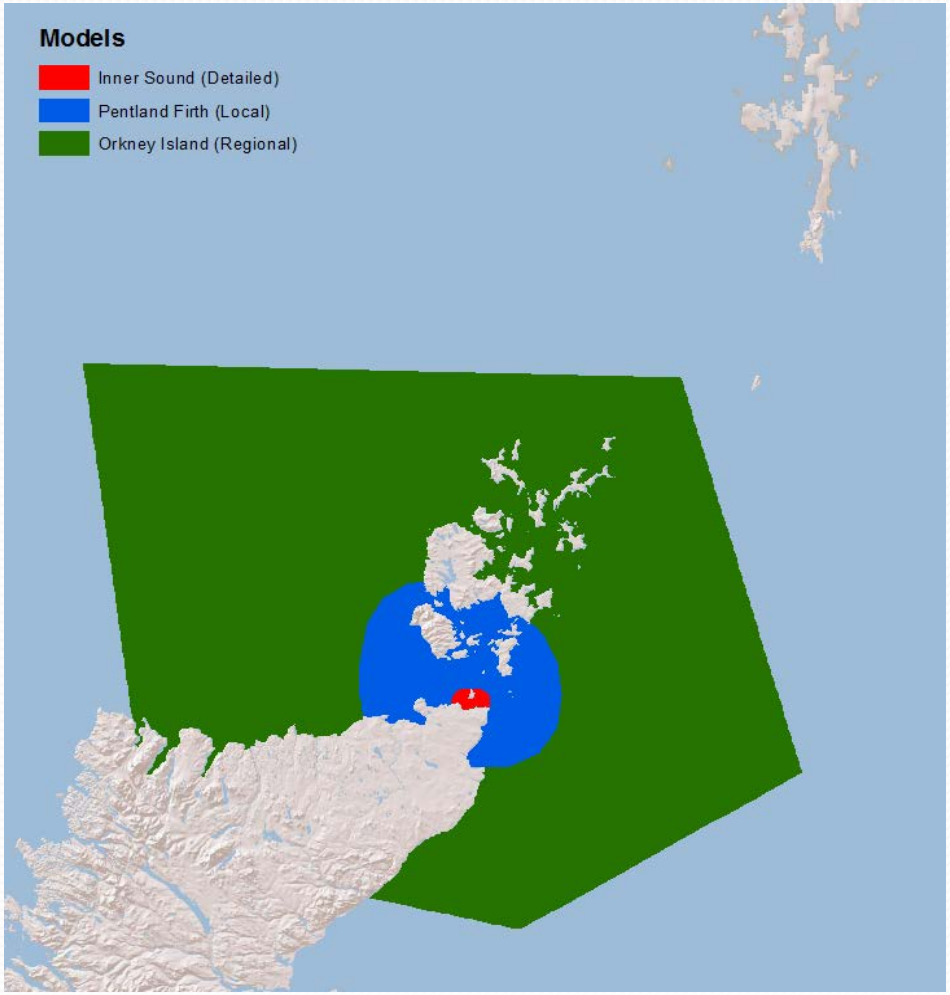
Improvements 2.

Speed-up the RBF routine:

- Previous approach used the Matlab function "*fminbnd*" to compute the error term required for the RBF shape function of each M.
- Re-wrote *fminbnd* to give a more accurate reconstruction of the response surface for each M.
- Importantly, faster reconstruction (6 times faster than *fminbnd*).
- Details in the paper.

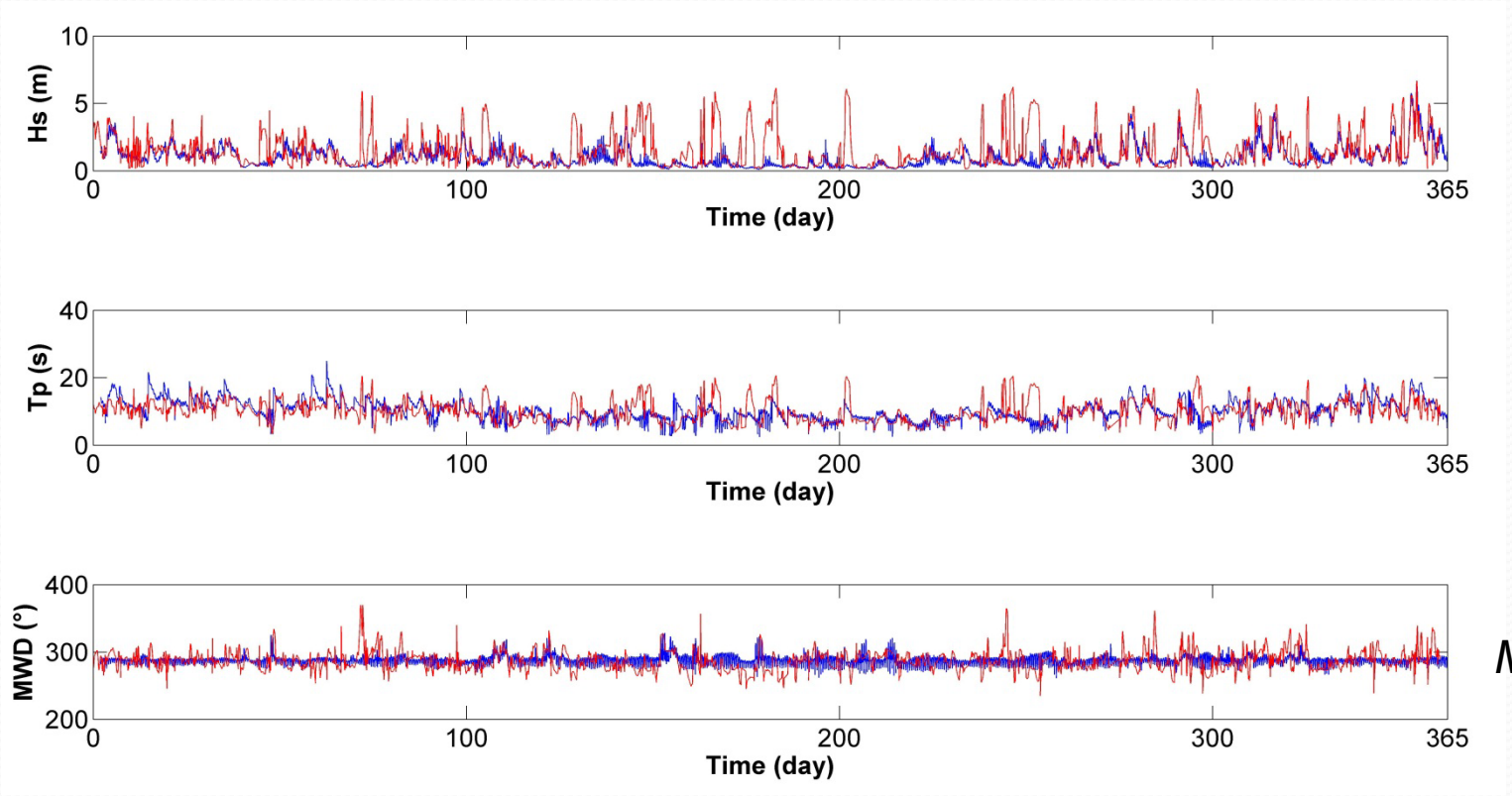
A more complicated case

- Orkney Islands, UK.
- Planned tidal turbine field.
- Severe wave-current interaction.
- Combined wave and current spectral wave model with resolution <25m in turbine field.
- Long run times on high-end PC (24 core HP) – order of months.



1st attempt using hybrid downscaling:

Corr. Coeff.



Hs (0.39)

Tp (0.24)

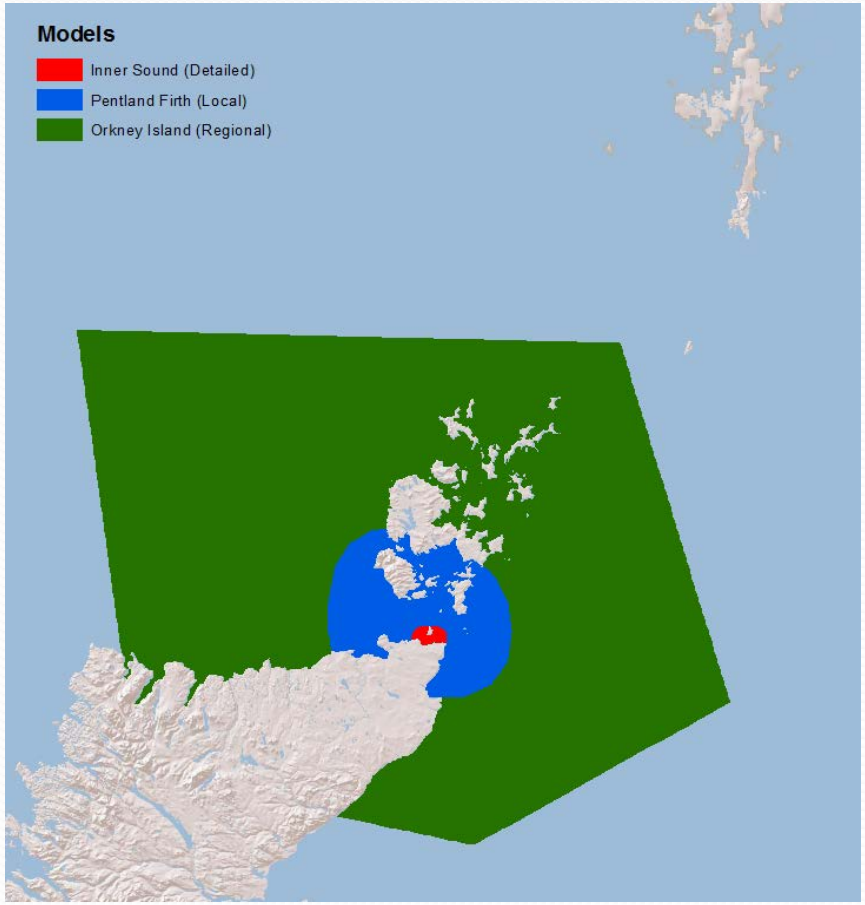
MWD (0.06)

Hindcast from simulation of **all 8760 sea states**

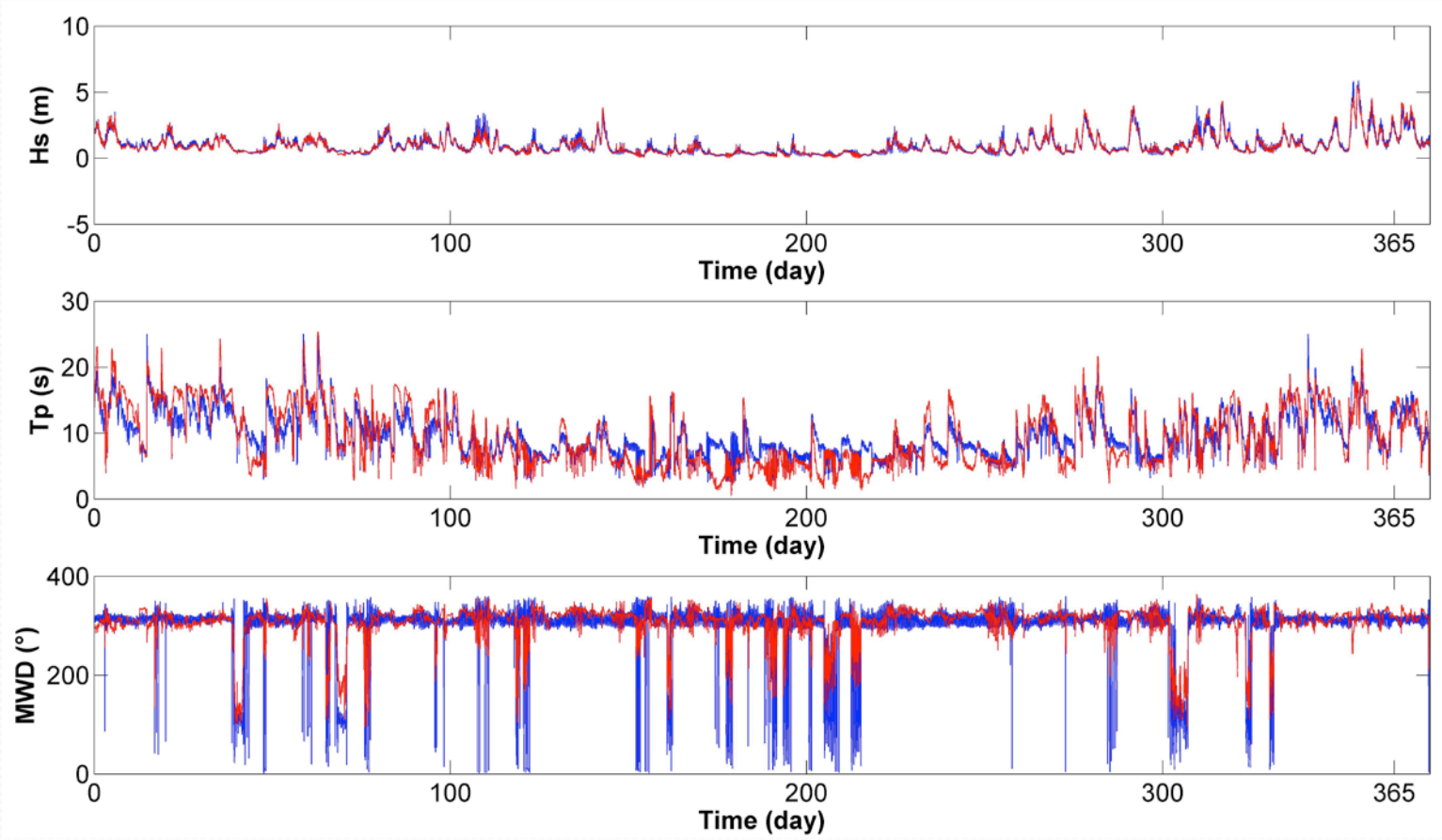
Hindcast from simulation of **only 100 sea-states**

Improving performance

- However, green and blue domains are cheap to run (order of hours).
- Possible solution: simulate all conditions up to red boundaries and then use statistical downscaling only in the red domain.



Improved result



Corr. Coeff.

Hs (0.97)

Tp (0.83)

MWD (0.66)

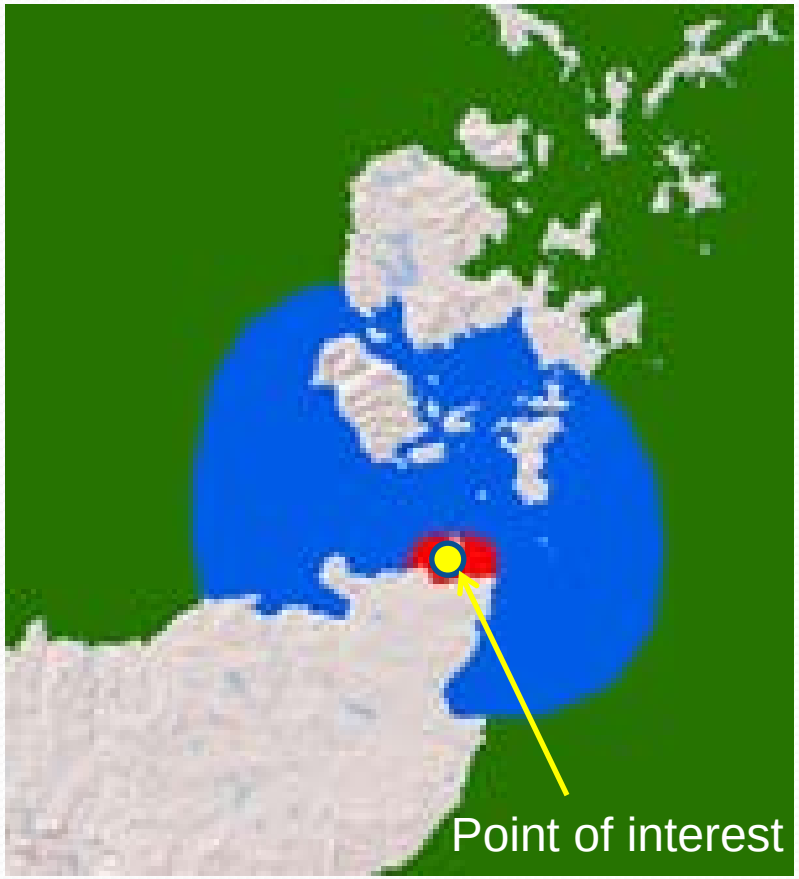
Hindcast from simulation of **all 8760 sea states**

Hindcast from simulation of **only <u>30</u> sea-states** 300 times faster

20

Possible 3rd approach

- Blue and Green models both provide solutions at the point of interest.
- Perform the MDA and RBF on the blue model solution at the point of interest
- This becomes an “offshore” boundary condition.
- Then only require small number of high resolution simulations on red domain – saves massive CPU time.
- No time to test unfortunately.



Conclusions

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- A useful option when fast results are required i.e. to assist operations or to provide preliminary design numbers.
- Needs to be used with care – extensive validation required.
- Method can be applied in more complex cases – this study has hinted at some of the approaches to tackling this.
- Possible Further Improvements:
  1. Development of spectral transfer functions (rather than using only bulk parameters).
  2. Further improvements to the RBF algorithm

St Jude storm - at Praia do Nort, Portugal, 28th Oct 2013