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Consistent Design Criteria for South China Sea with a Large-Scale Extreme Value Model

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Why Model Environmental Extremes

Hurricane Katrina effect in the Gulf of Mexico (2005)

Goal: Rational design and assessment of marine structures to withstand environmental **extremes**

Summary of Talk

- Motivation and Challenges:
  - Consistent estimation of design criteria for offshore structures
  - First of its kind application to the South China Sea

- Proposed approach with a large-scale extreme model
  - **SCEVA** or **S**patial **C**ovariate **E**xtreme **V**alue **A**nalysis
  - Address technical and computational challenges
  - Validation through robust diagnostics

→ Design criteria for large spatial domains estimated **efficiently**, **consistently** and with quantified **uncertainty**

Technical Challenges

- Motivated by asymptotic arguments:
    - Tail of distribution (above a **large threshold**) drives extremes
    - Hard to model behaviour with small sample size

- **Site-specific** analysis is current practice:
    - Analyse large-scale historical data with complex dependencies
    - **Time-consuming** and requires specialist expertise

Computationally challenging for **100-1000s of locations** with **multidimensional** covariates

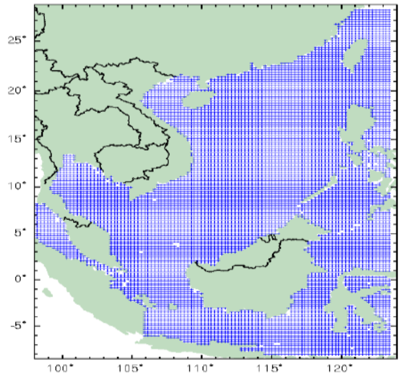
South China Sea Challenges

- **Inconsistent** previous estimates using different data and procedures
- Validation of **hindcast** (historical database)
- Robust identification of spatially-consistent **storm peak** events
- Addressing **seasonal** and bathymetric variations

Proposed Workflow

Proposed Workflow

SEAMOS Vs SEAFINE (2014)



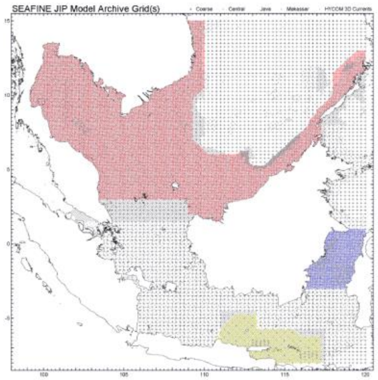


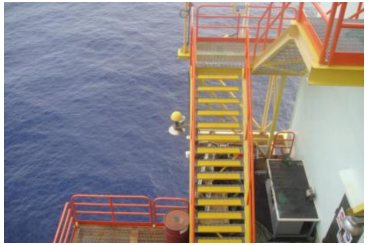
Image courtesy: Oceanweather Inc.

SEAFINE at **5x higher resolution** than earlier
SEAFINE has **5x extended period** of data than earlier

➔ Higher quality results expected from higher quality input data

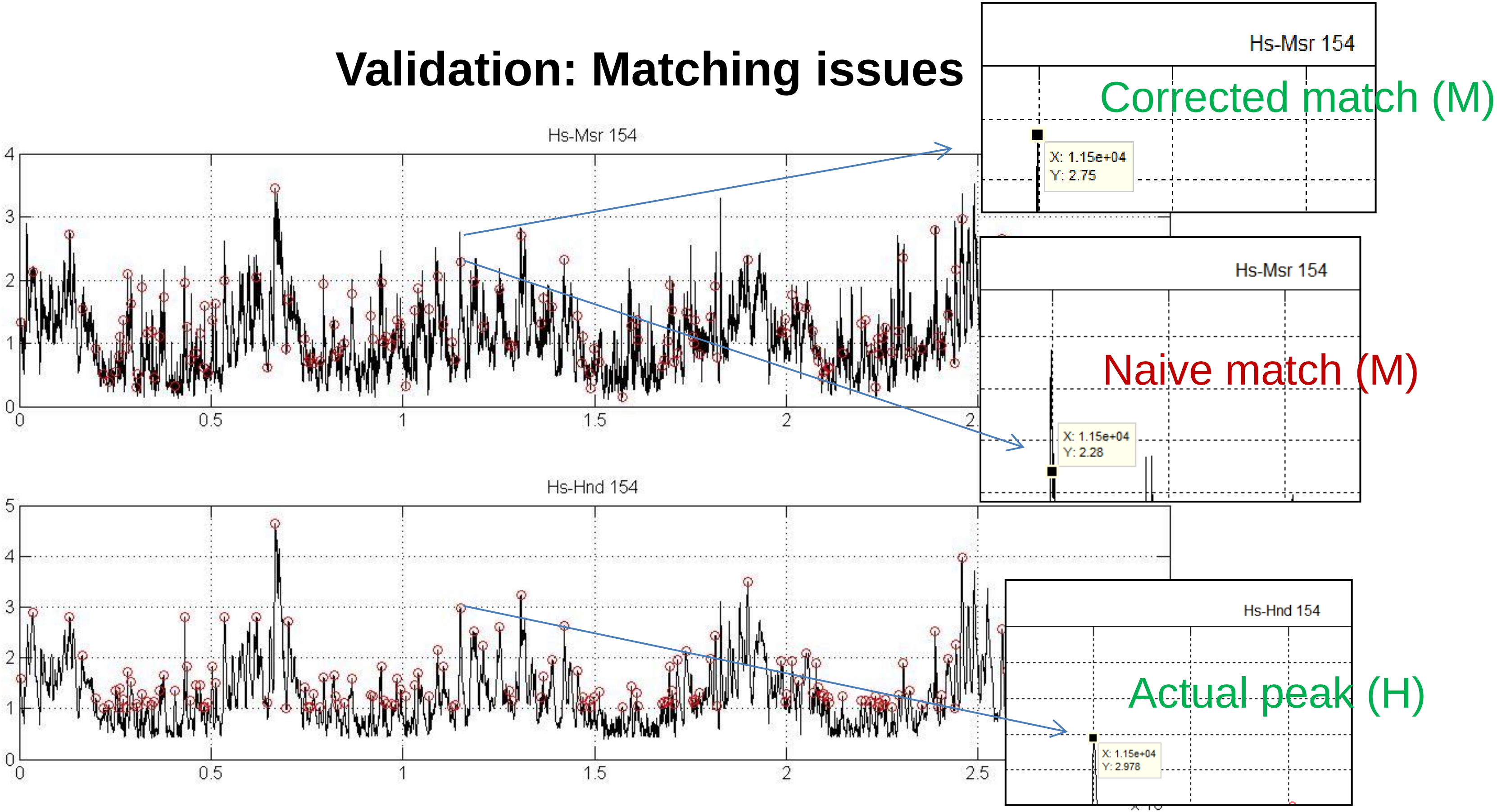
Proposed Workflow

Validation: Source of measured data

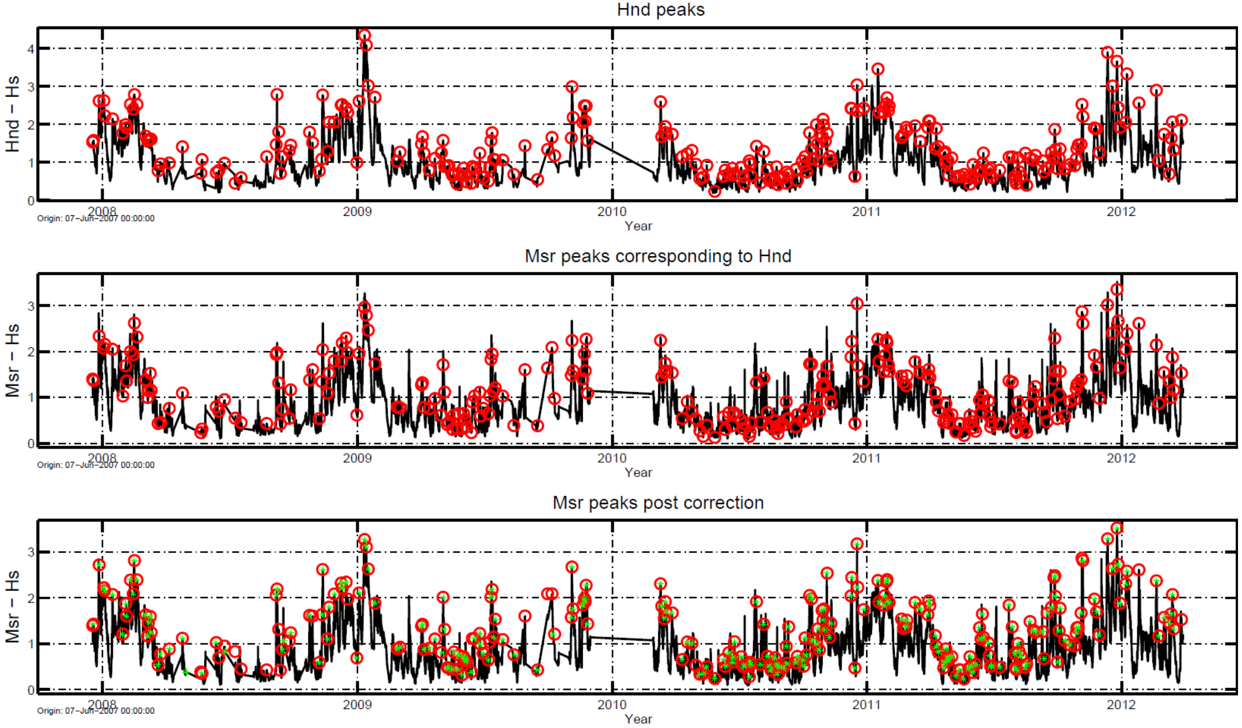


Platform measured data from 2008-2012 (Sarawak Shell Bhd.)

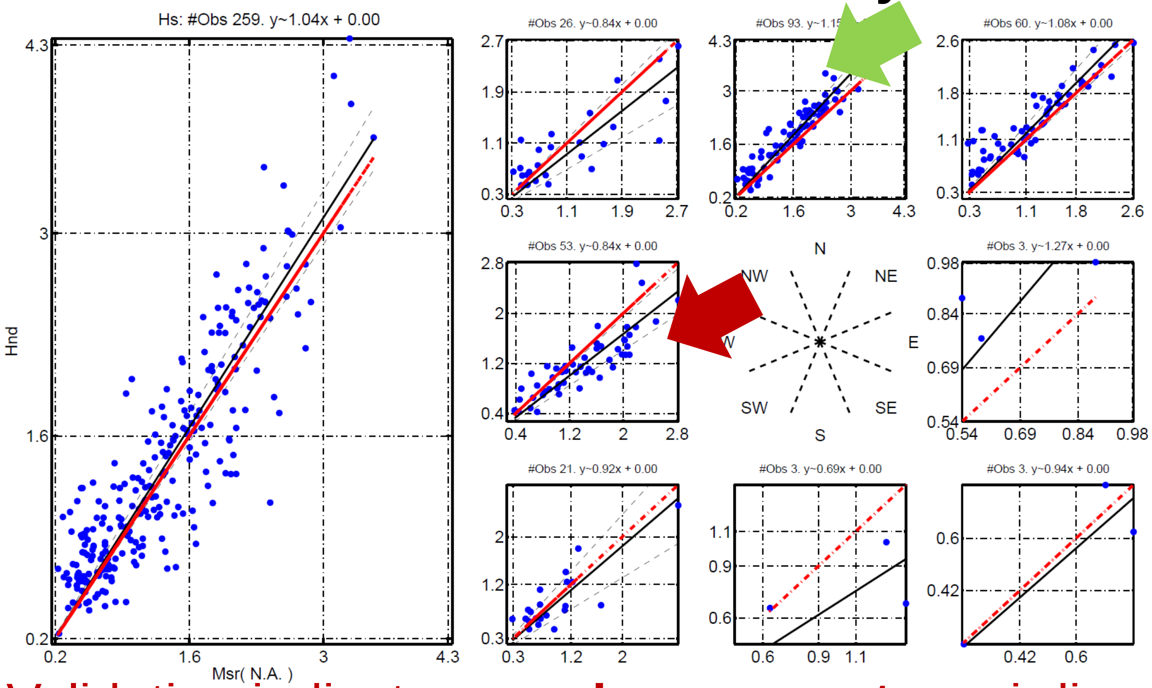
Validation: Matching issues



Validation: Addressing Peak Matching



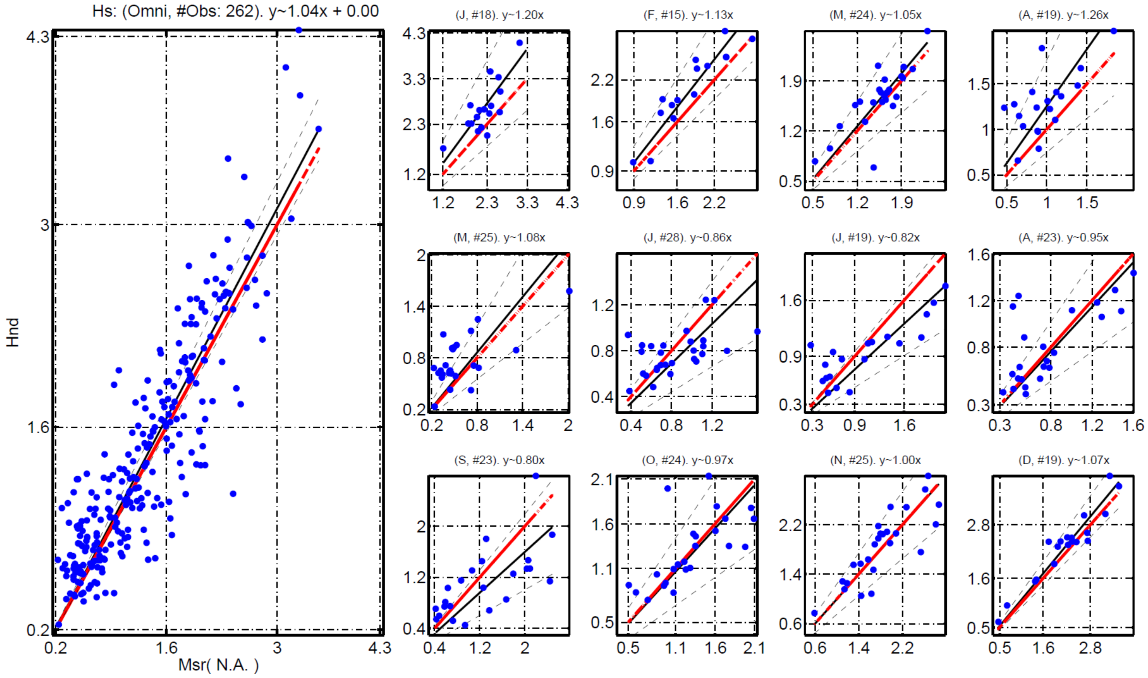
Validation: Directional Analysis



Validation indicates **good agreement** omni-directionally

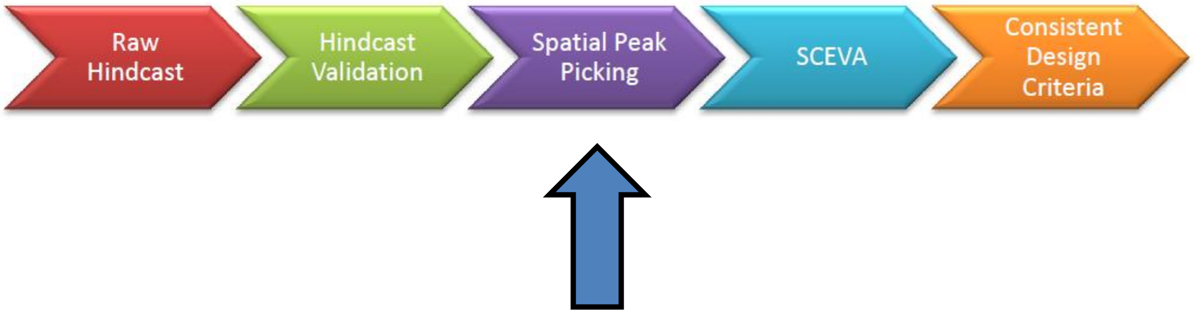
→ Some location-specific variations in certain sectors

Validation: Seasonal Analysis



Good **overall agreement**, different bias effects in winter and summer

Proposed Workflow



Spatial Peak Picking Challenges

- Previous hindcast with specific storm period information across locations (GOMOS, NAMOS, etc.)
  → Peak identification straightforward [Raghupathi et al. (2016).]

- SEAFINE is **continuous hindcast** with **mixed** meteorology (primarily monsoon and typhoons)

- Techniques developed after careful study of storm peak propagation over time and space

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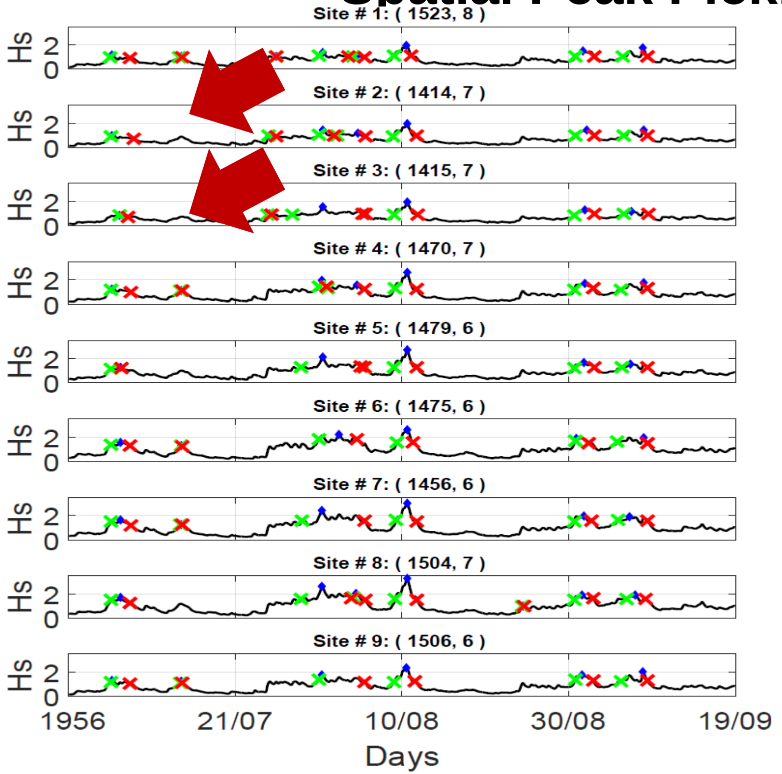
L. Raghupathi et al. Fast Computation of Large Scale Marginal Spatio-Directional Extremes. *Comp. Stat. Dat. Anal.*, 95C:243--258, 2016.

Spatial Peak Picking: Results



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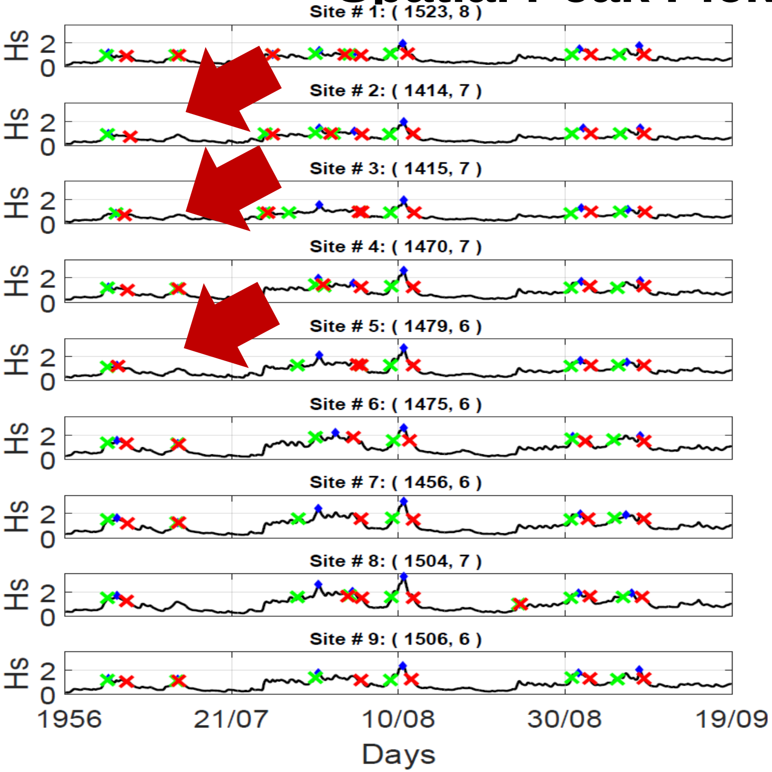

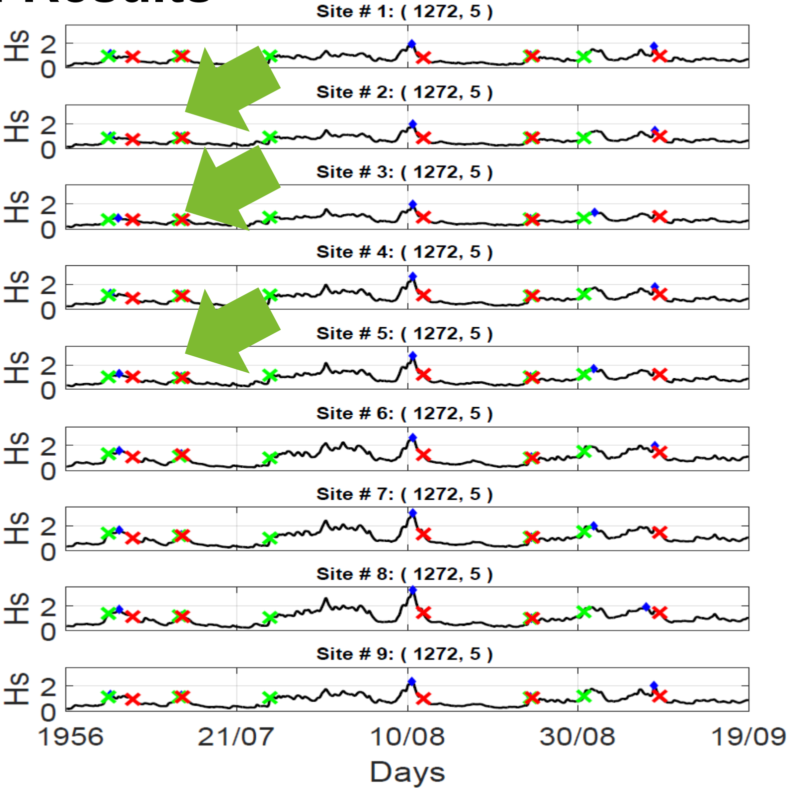

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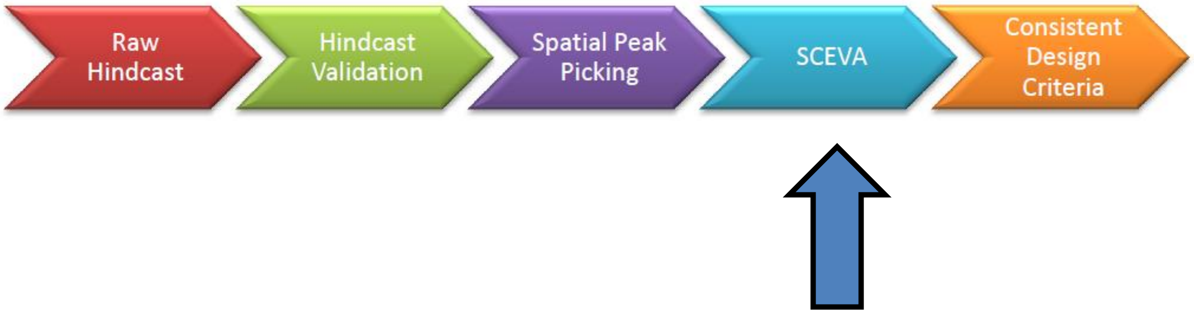
Proposed Workflow



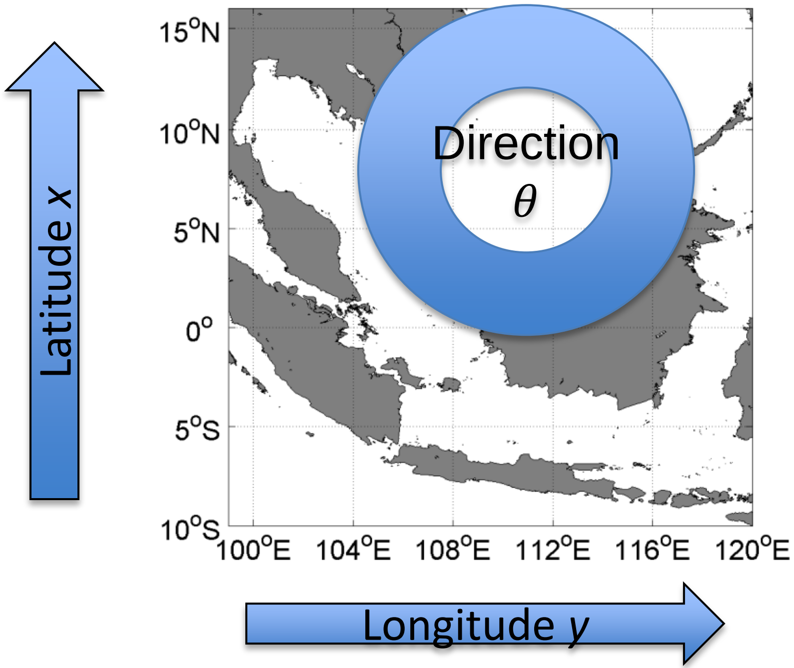
SCEVA Model

Sample $\{\dot{z}_i\}_{i=1}^{\dot{n}}$ **storm peak** significant wave heights *Hs* observed with storm peak directions $\{\dot{\theta}_i\}_{i=1}^{\dot{n}}$ and locations $\{\dot{x}_i, \dot{y}_i\}_{i=1}^{\dot{n}}$

Model components:

1. **Threshold** function φ above which observations $\dot{z}$ are assumed to be extreme estimated using quantile regression
2. **Rate of occurrence** of *n* threshold exceedances modelled using Poisson model with rate $\rho \triangleq \rho(\theta, x, y)$
3. **Size of occurrence** of threshold exceedance using GP model with shape and scale parameters ξ and σ

Region of interest



Parameterising Covariates

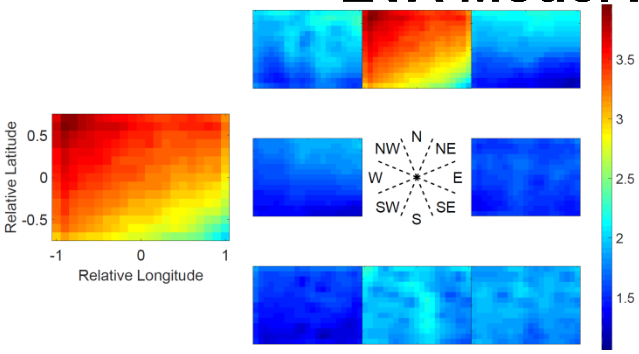
Define a basis matrix for the three-dimensional domain *B* using tensor products of marginal basis matrices.

$$B = B_y \times B_x \times B_\theta$$

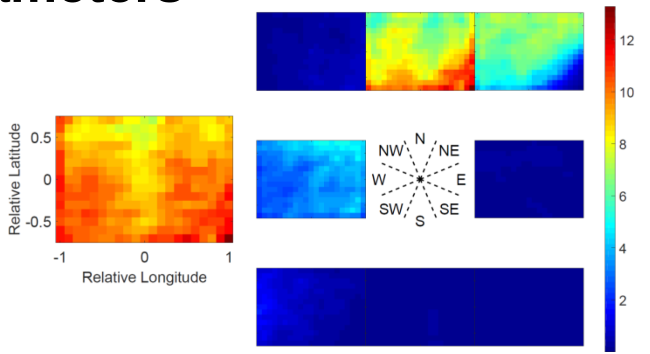
provides an $m \times p$ basis matrix (where $m = m_\theta m_x m_y$, and $p = p_\theta p_x p_y$) for modelling each of *φ, ρ*, ξ and σ on the corresponding "spatio-directional" index set of size *m*.

➔ **Faster computation** by avoiding explicit matrix storage and arithmetic and acceleration using **parallel computing**

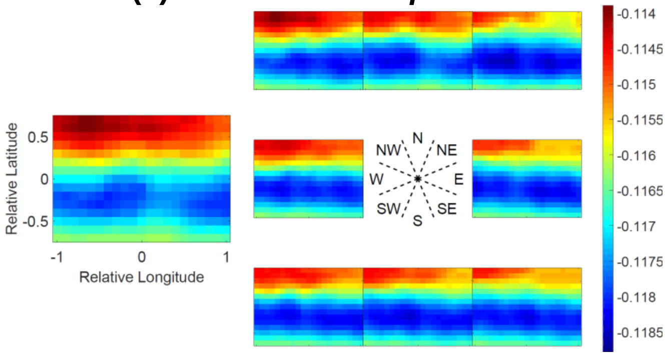
EVA Model Parameters



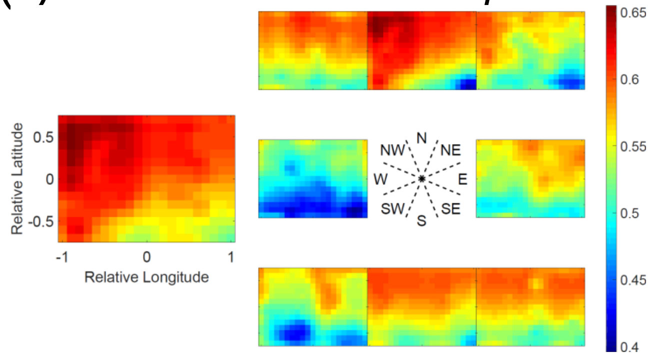
(i)Threshold φ



(ii) Rate of occurrence ρ

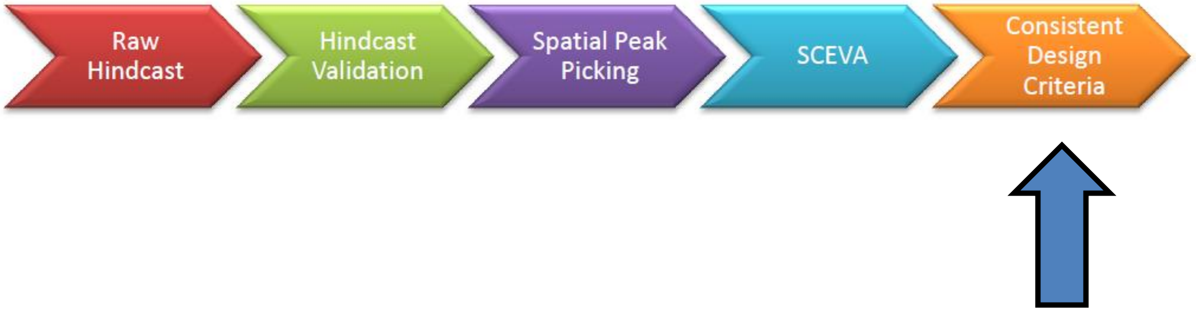


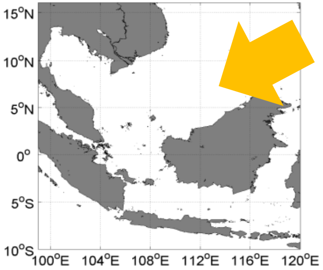
(iii) GP Shape ξ



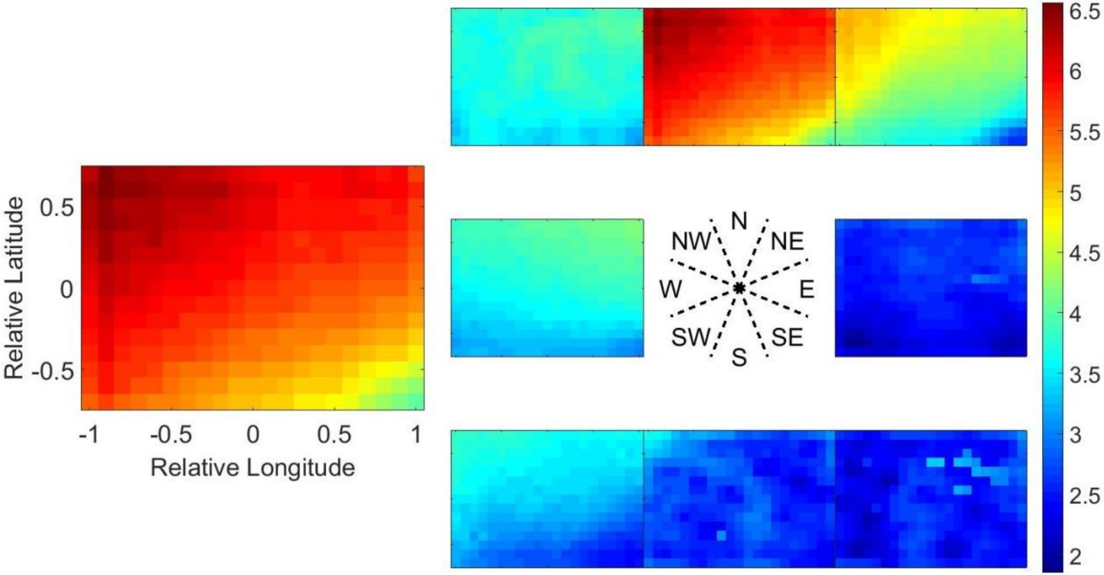
(iv) GP Scale σ

Proposed Workflow





100-Yr Hs Estimates (in meters)



→ Single model for design estimates of any spatial location and direction, generated by a thorough consistent approach

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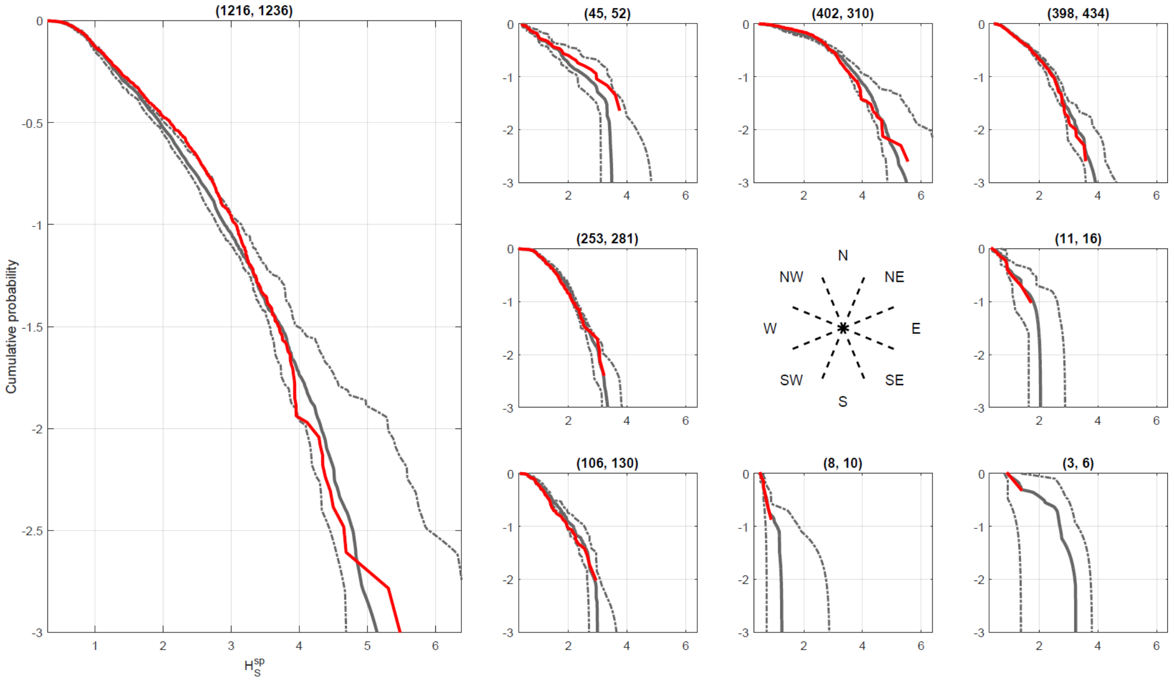
Method Validation

- Spatially-consistent design estimates available
- For period of data and a given spatial-location
  - Generate return value distribution from a **site-specific** model
  - Generate return value distribution from **large-scale spatial** model
  - Compare model diagnostics and establish equivalent **goodness of fit**

Model diagnostics: Comparison with site-specific model



Site-specific model diagnostics

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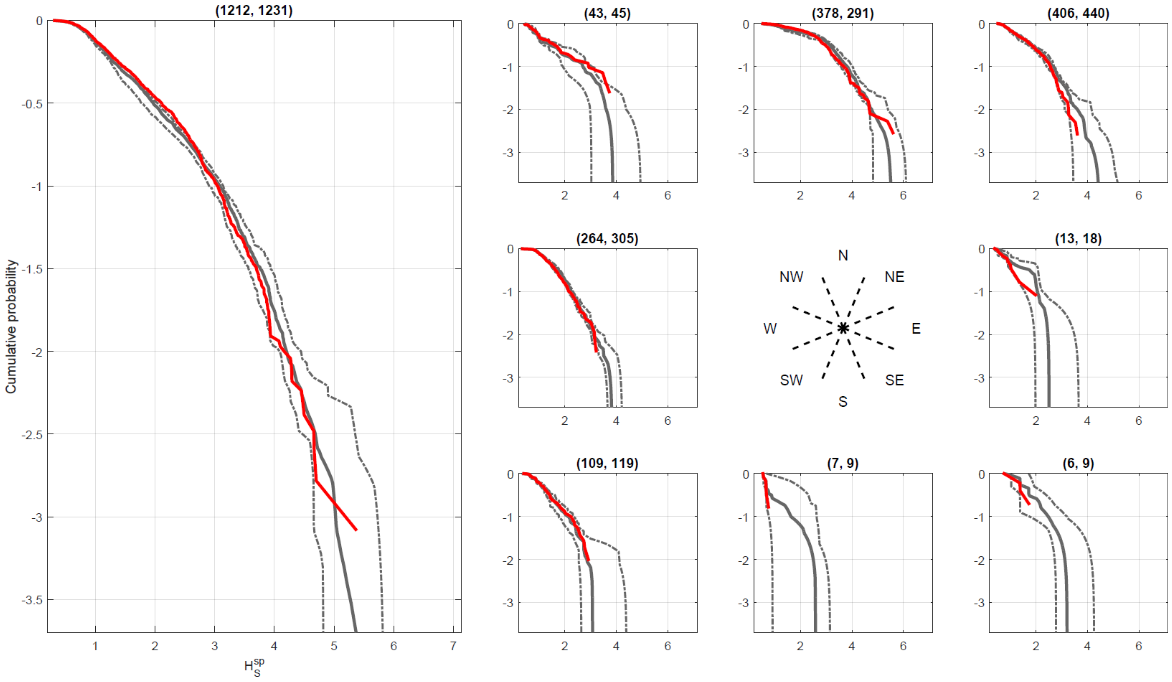
Model diagnostics: Comparison with site-specific model



Spatio-directional model → Equivalent goodness of fit

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Discussion

- Advantages of a single spatial model evident
  - Eliminates repeated site-specific analysis
  - Improved reliability of estimates due to efficient use of data

- Further improvements
  - Incorporate seasonal effects in the spatial context requiring improved parameterisation
  - Incorporating joint criteria with directional and seasonal effects
  - Improved hindcast by incorporating calibration with measurements

References

- I. D. Currie, M. Durban, and P. H. C. Eilers. Generalized linear array models with applications to multidimensional smoothing. *J. Roy. Statist. Soc. B*, 68:259--280, 2006.

- P. Jonathan and K. C. Ewans. Statistical Modelling of Extreme Ocean Environments with Implications for Marine Design : A Review. *Ocean Eng.*, 62:91--109, 2013.

- L. Raghupathi, D. Randell, P. Jonathan, and K. Ewans. Fast Computation of Large Scale Marginal Spatio-Directional Extremes. *Comp. Stat. Dat. Anal.*, 95C:243--258, 2016.

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