ICCE 2018

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

The State of the Art and Science of Coastal Engineering

SIMULATION OF SEA STORMS INCLUDING MULTIVARIATE STORM EVOLUTION

UNIVERSIDAD DE LA REPÚBLICA URUGUAY

Sebastián Solari

Universidad de la República, Uruguay

UNIVERSIDAD DE GRANADA

Miguel A. Losada

Universidad de Granada, Spain



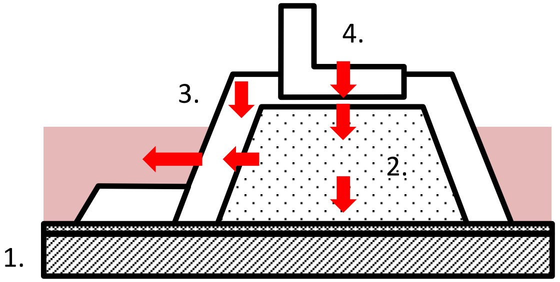

❑Content

- Introduction (Motivation / Objectives)
- Methodology
- Application (Results / Discussion)
- Conclusions

❑ Motivation

- The simulation of storms of met-ocean variables useful for probabilistic design and probabilistic coastal risk assessments (see e.g. Davies et al. 2017), and is required in case Damage Evolution is taken into account (ROM 1.1-18).

Slide Borrowed from 1468-"Accumulated Damage Evolution And Investment Costs Of Breakwaters"
Folgueras et al. ; Friday, August 3 ; 8:30 AM - 8:50 AM ; Grand Ballroom IX & X



1. Foundation and Terrain (FT)
2. Core (CO)
3. Armor Layer (AL)
4. Superstructure (SE)

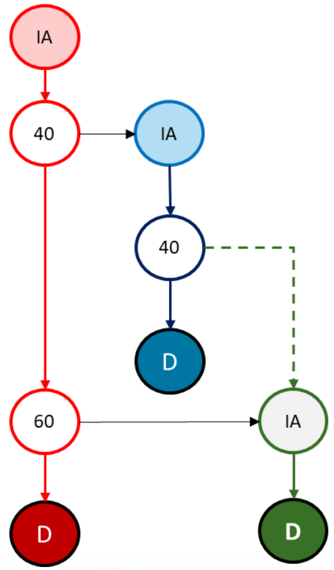
AL Failure Mode 1

SE Failure Mode 2

CO Failure Mode 3

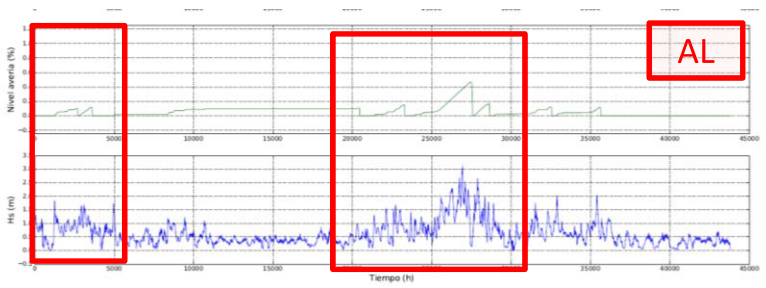
Damage Propagation Tree

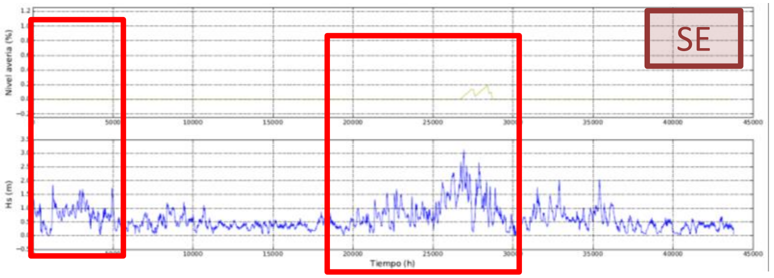
MF1 MF2 MF3

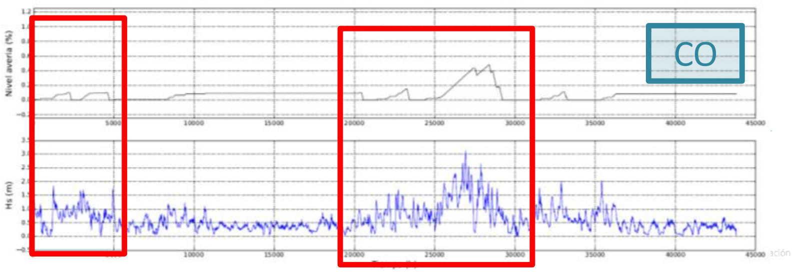


Damage Accumulation

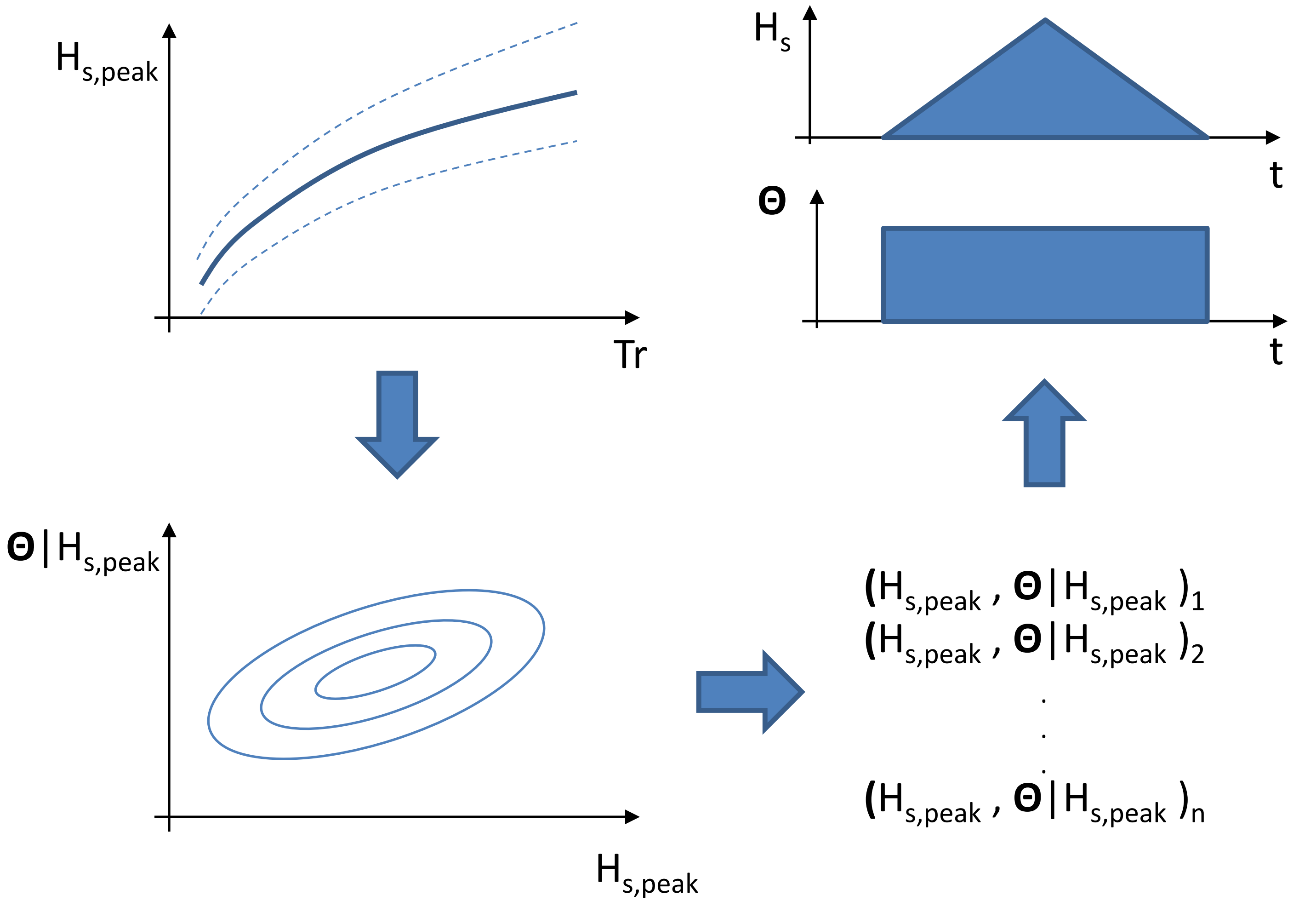
Same time series of sea conditions







❑ Motivation (traditional approach; Borgman 70's , Boccotti 90's)



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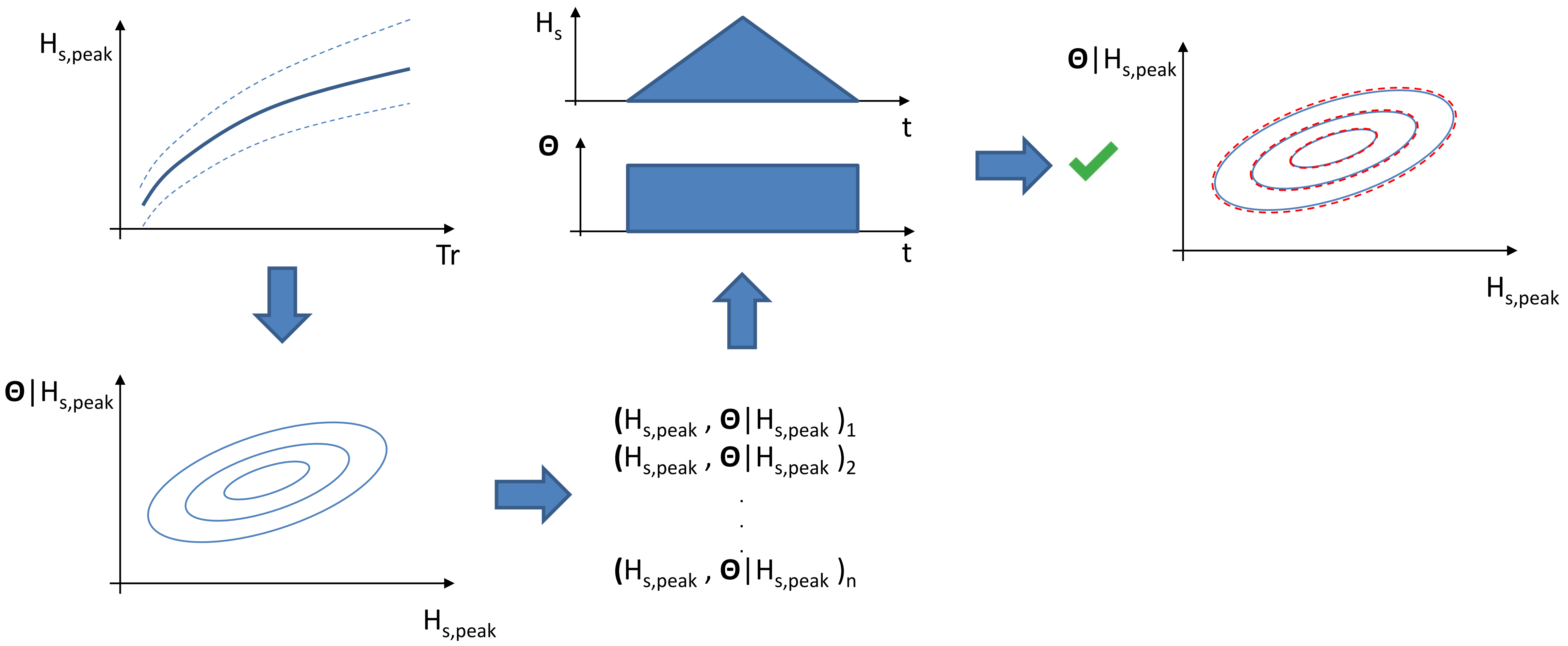
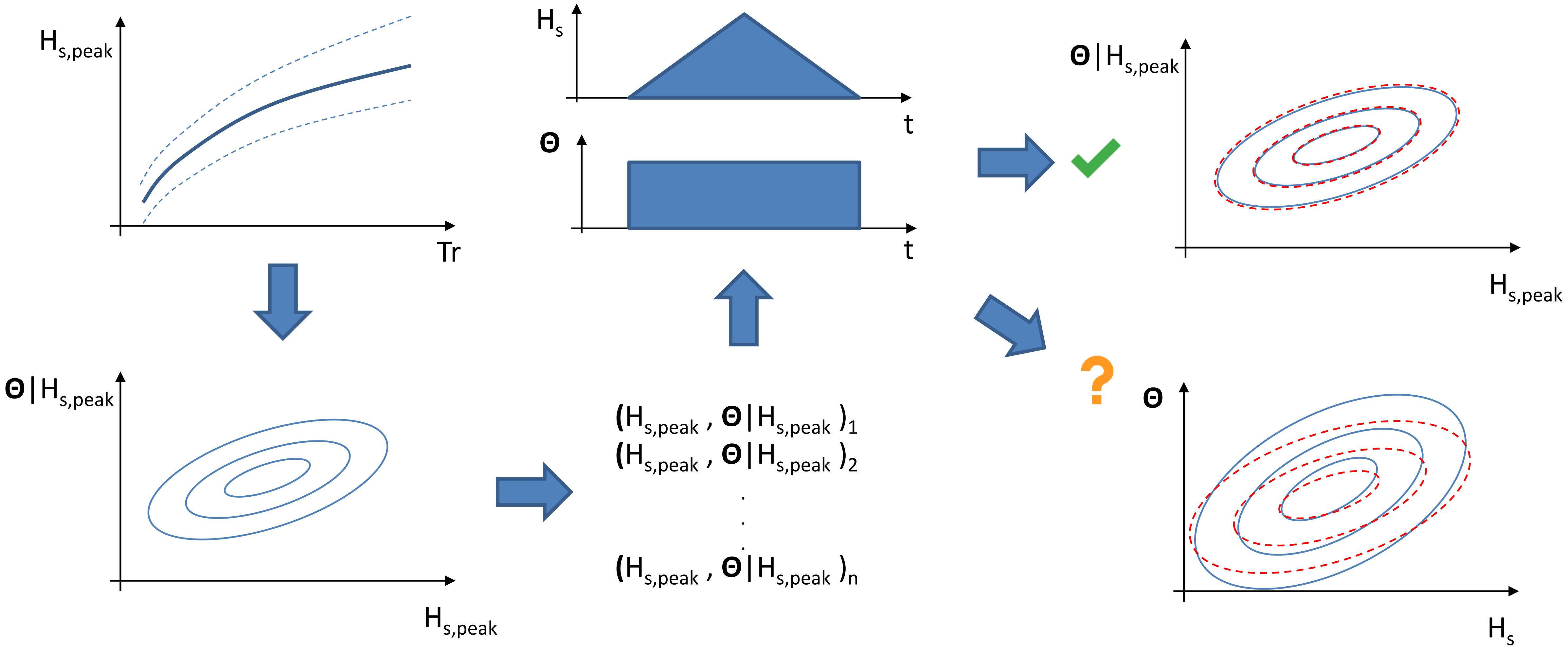


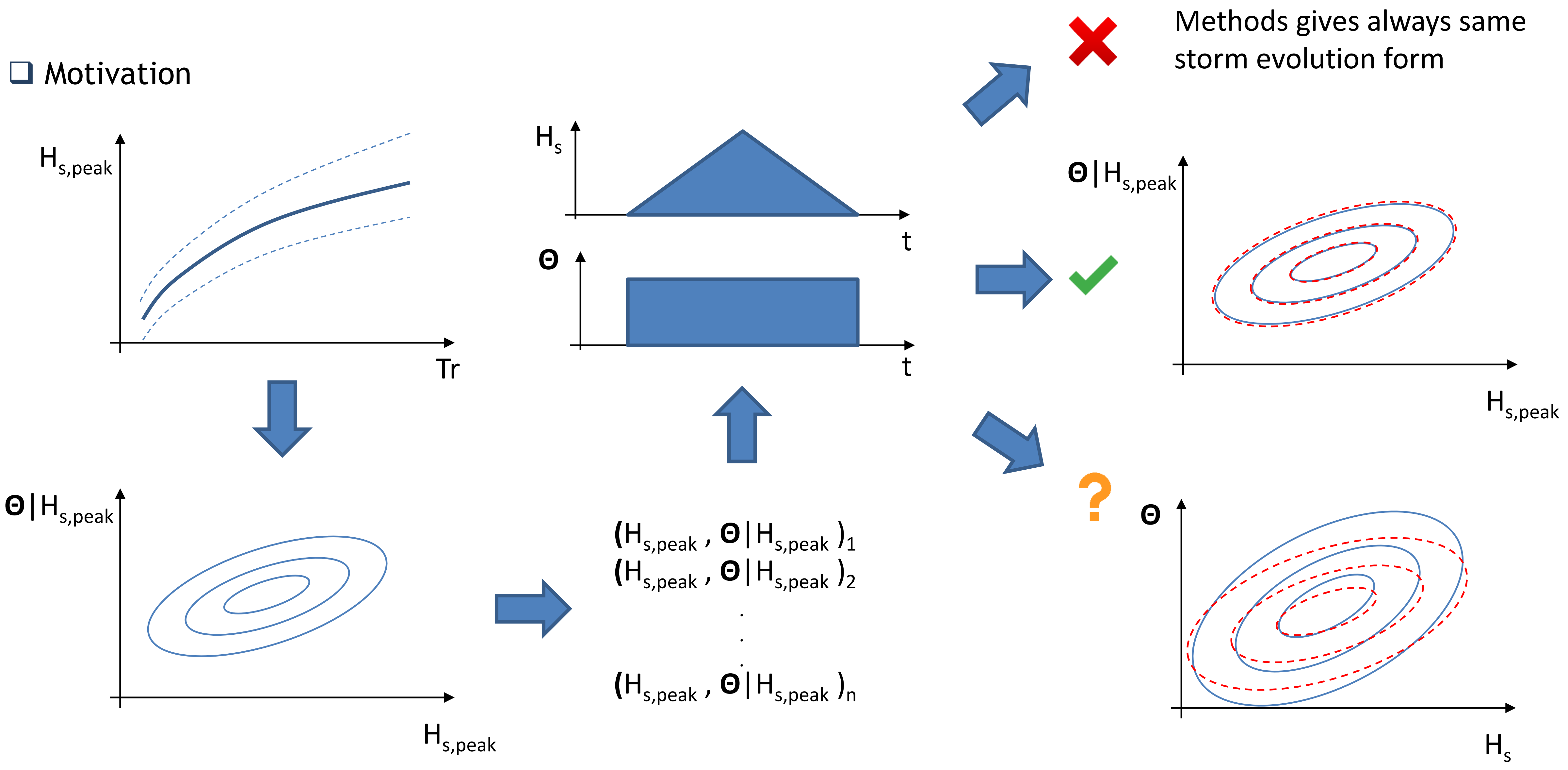
H s,peak
Tr
H s
t
Θ
t
Θ|H s,peak
H s,peak
Θ|H s,peak
H s,peak
(H s,peak , Θ|H s,peak)1
(H s,peak , Θ|H s,peak)2
(H s,peak , Θ|H s,peak)n

❑ Motivation



H s,peak
Tr
Θ|H s,peak
H s,peak
H s
t
Θ
t
(H s,peak , Θ|H s,peak)1
(H s,peak , Θ|H s,peak)2
(H s,peak , Θ|H s,peak)n
Θ|H s,peak
H s,peak
?
Θ
H s

❑ Motivation



Methods gives always same storm evolution form
$H_{s,peak}$
Tr
$\Theta|H_{s,peak}$
$H_{s,peak}$
H_s
t
Θ
t
$(H_{s,peak}, \Theta|H_{s,peak})_1$
$(H_{s,peak}, \Theta|H_{s,peak})_2$
$(H_{s,peak}, \Theta|H_{s,peak})_n$
$\Theta|H_{s,peak}$
$H_{s,peak}$
?
Θ
H_s

❑ Objectives

- To devise a methodology for multivariate sea storm simulations that:
    - Properly reproduces the multivariate distribution of the variables at storm peak, but…
    - also reproduces the multivariate distribution of all sea states included in the storm, and…
    - is capable of innovation in the storm evolution (for all variables involved).

- To test this methodology in a case study.

❑ Methodology

- Multivariate storm evolution given by an **expected multivariate evolution plus multivariate noise**
- Noise modeled using a Vector Autoregressive model
- Expected multivariate evolutions given by few form that cluster in the ($H_{s,peak}$-Duration) space

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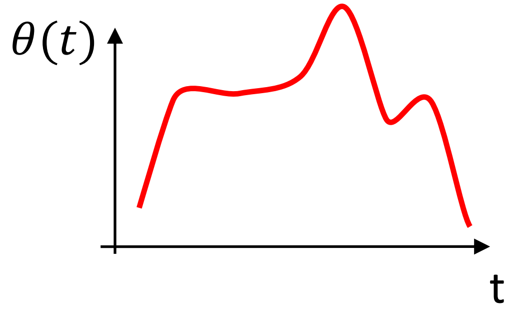
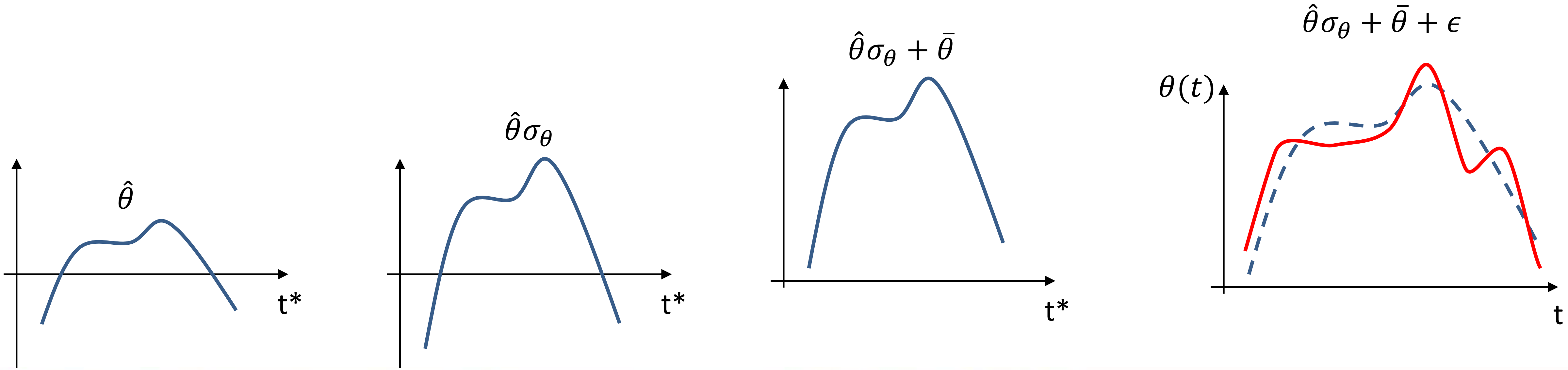


$$\theta(t) = \hat{\theta}(t)\sigma_\theta + \bar{\theta} + \epsilon(t)$$



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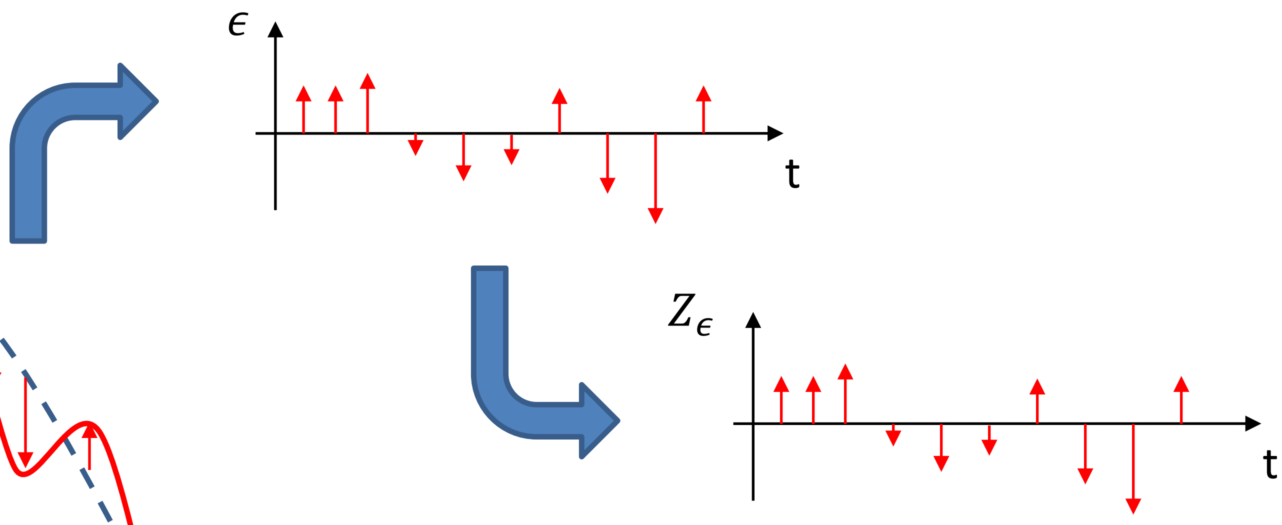

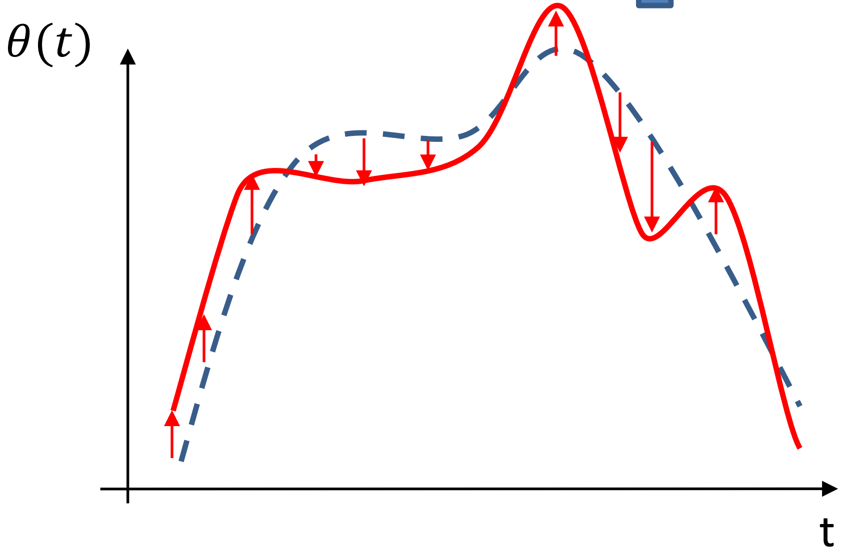

$$Y_t = V + \sum_{i=1}^{p} A_i Y_{t-i} + U_t$$

$Y_t =$ vector of Z_ϵ for all variables at time t

$V, A_i =$ parameters of the VAR model

$U_t =$ multivariate normal noise

Methodology

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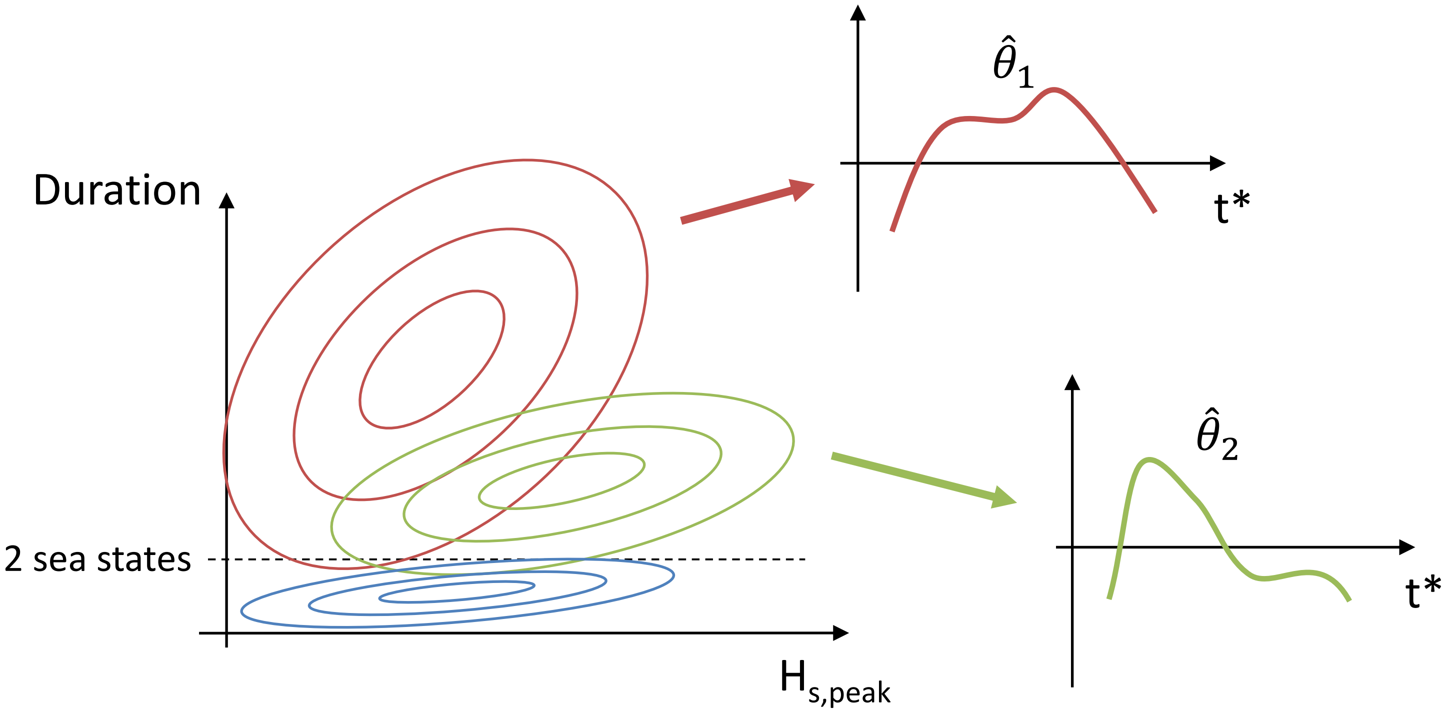


Given
($H_{s,peak}$-Duration)

(π_1, π_2, π_3)

where π_i is the probability of the storm having mean time evolution $\hat{\theta}_i$

❑ Methodology

- In summary we need…

$$\theta(t) = \hat{\theta}(t)\sigma_\theta + \bar{\theta} + \epsilon(t)$$

$\hat{\theta}(t)$:

Multivariate mean (normalized) evolution forms $\hat{\theta}$, as obtained by cluster analysis of the data.

Probability of the mean forms conditional to H_{s_peak} and *Duration.*

Marginals and joint distribution of H_{s_peak} and *Duration.*

$\sigma_\theta + \bar{\theta}$:

A model for the mean $\bar{\theta}$ and the standard deviation σ_θ of the storm evolution, for every variable involved (e.g. wave period, storm surge, etc.), conditional to H_{s_peak} and/or *Duration*.

Could be one multivariate model or several bivariate models (by means of e.g. regression, copulas, etc.).

$\epsilon(t)$:

A VAR model for the noise of the storm evolution.

❑ Application

- Case study: Wave and total sea level hindcasts off Montevideo coast, in Rio de la Plata estuary

22 years hindcast data

Variables: (Hs,Tm,Dm,SL)

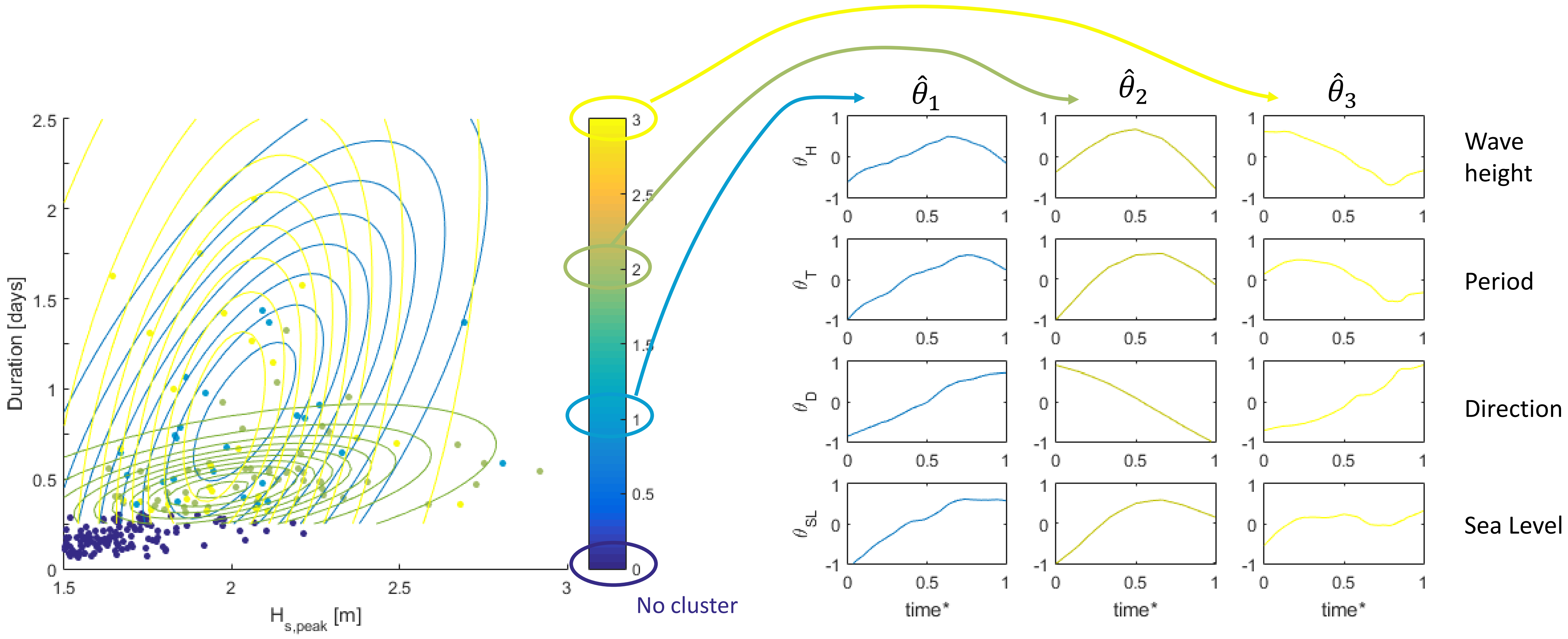
Water depth approx. 7m; mostly sea and no swell

Astronomical tides amp. O(10 cm)

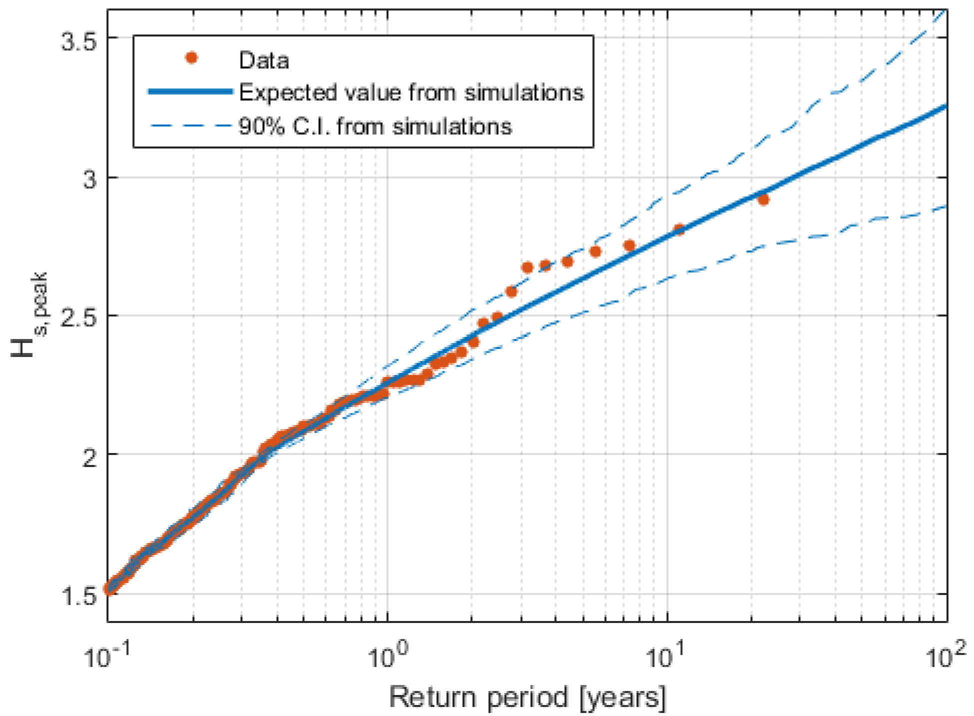
Storm surges O(1 m)

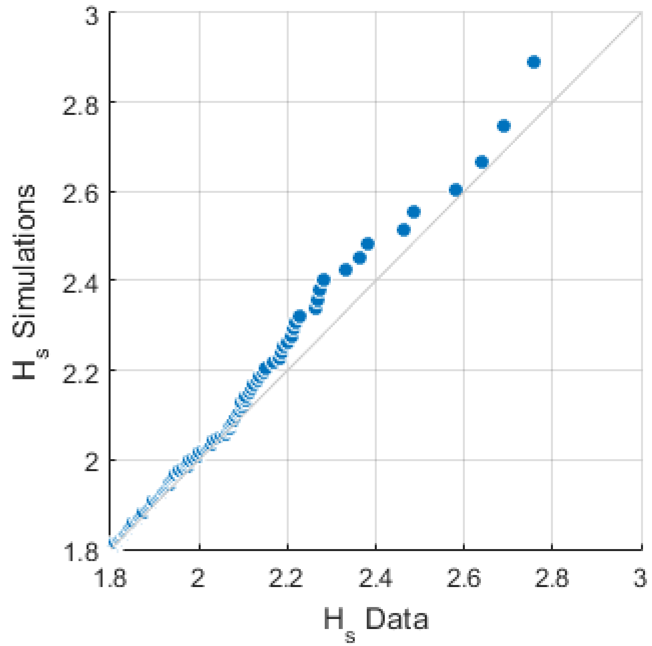
$$\theta(t) = \boxed{\hat{\theta}(t)}\sigma_\theta + \bar{\theta} + \epsilon(t)$$

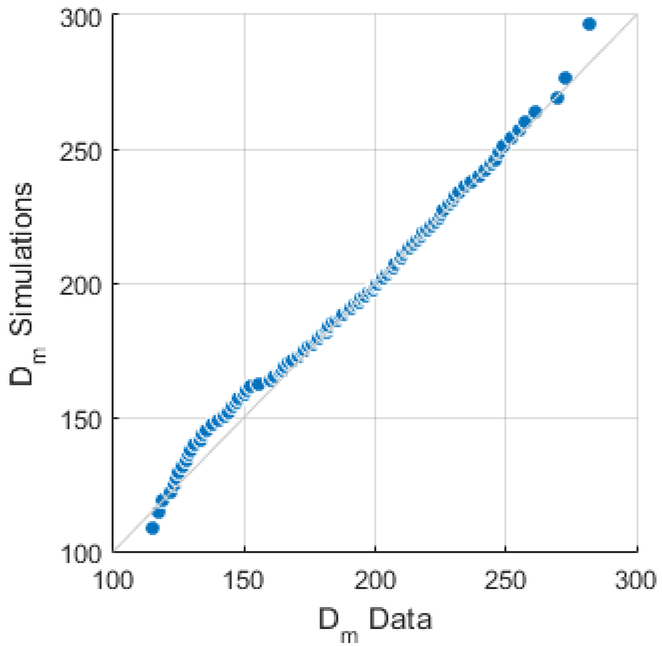
❑ Results and discussion



❑ Results and discussion

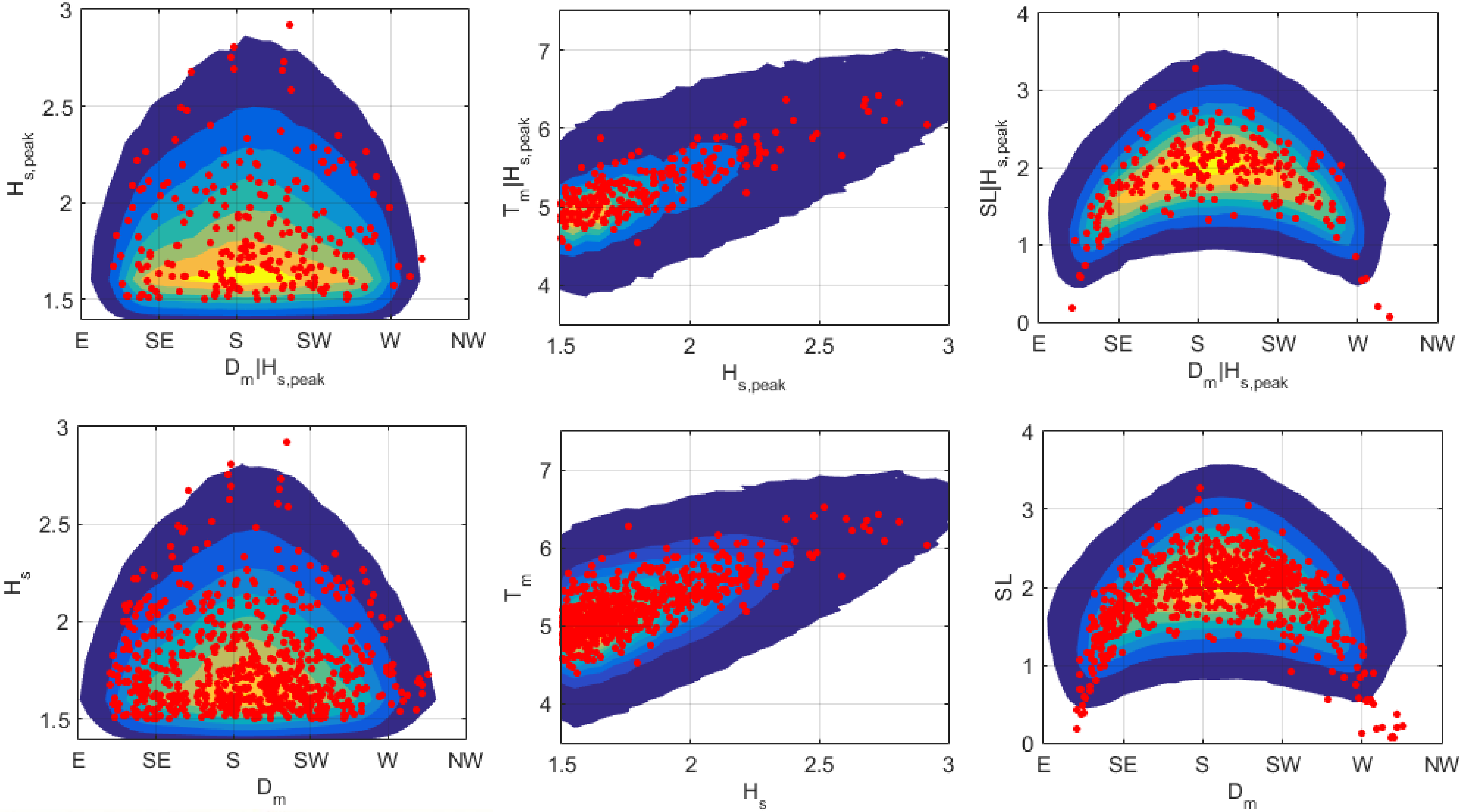






Red Dots: Data

Color Contours: Simulations



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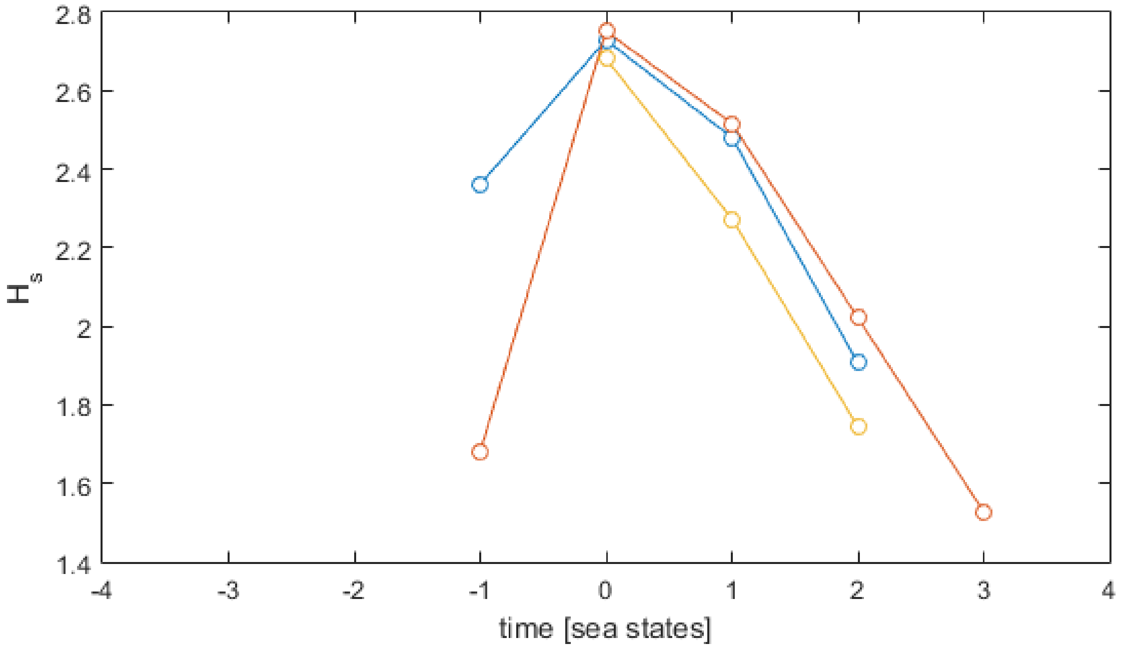
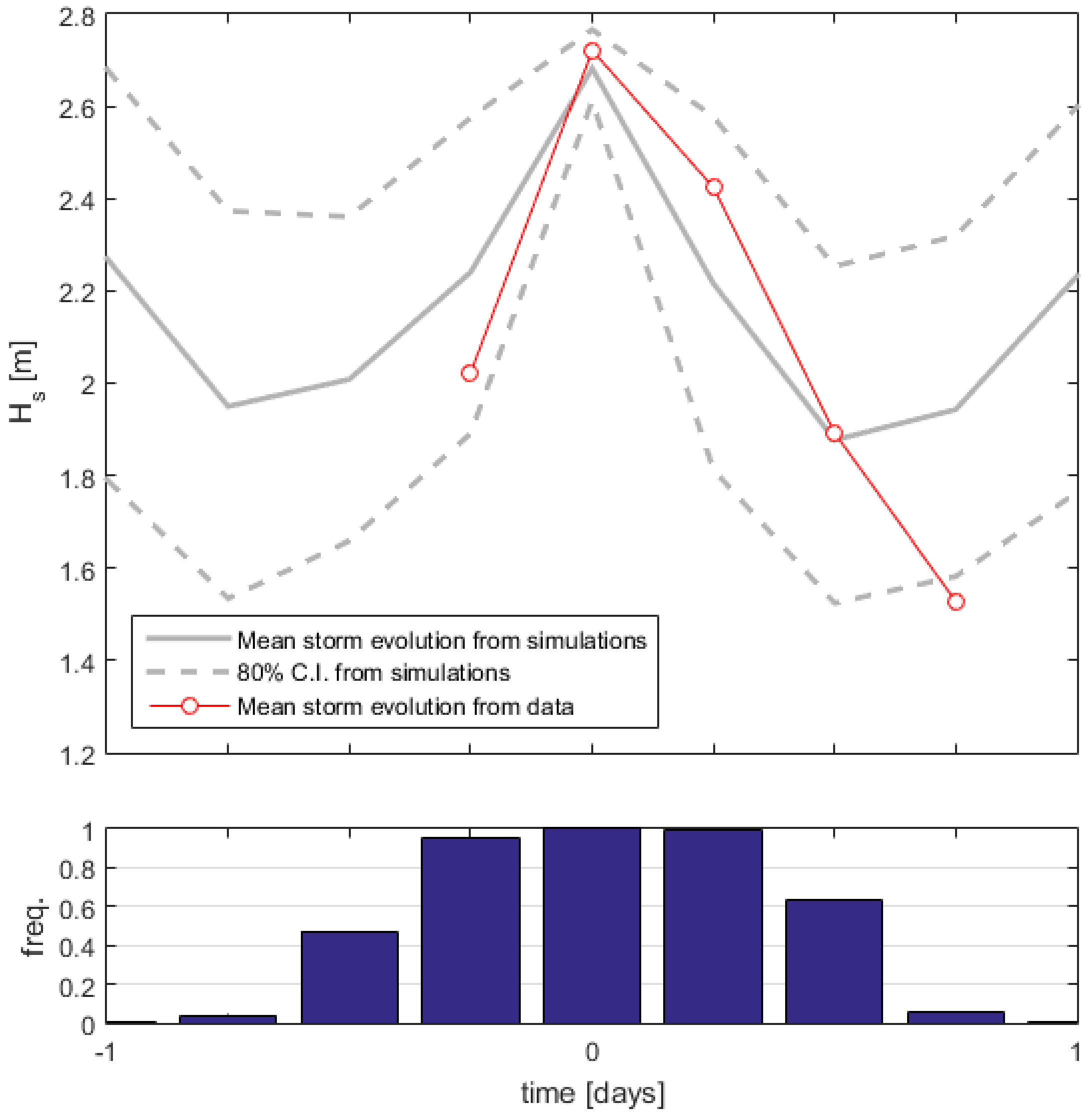
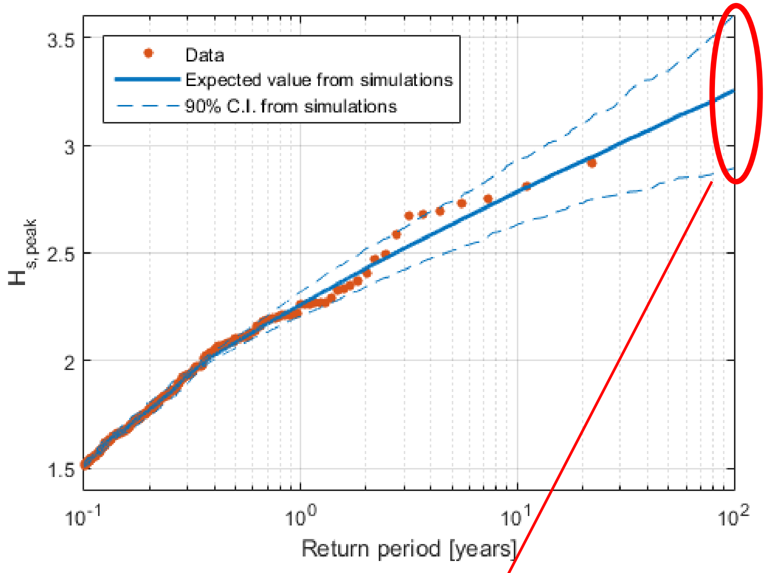
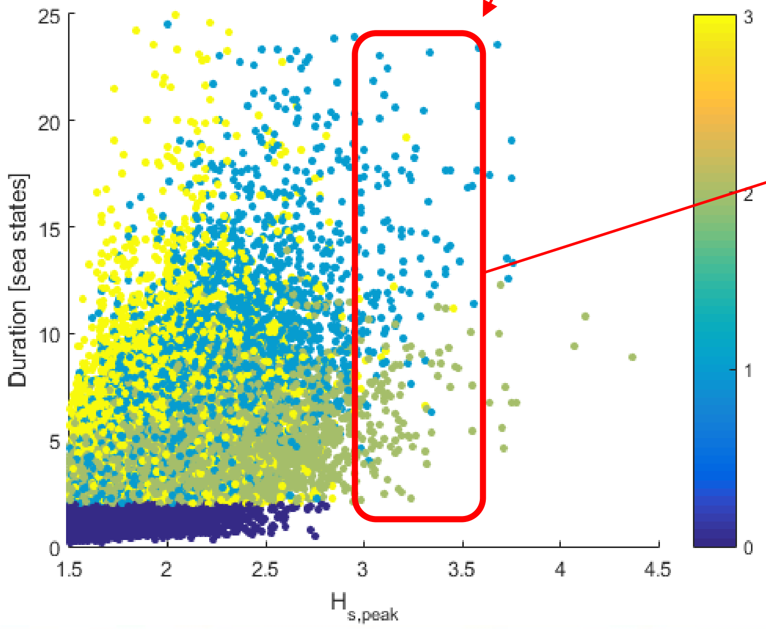
❑ Results and discussion

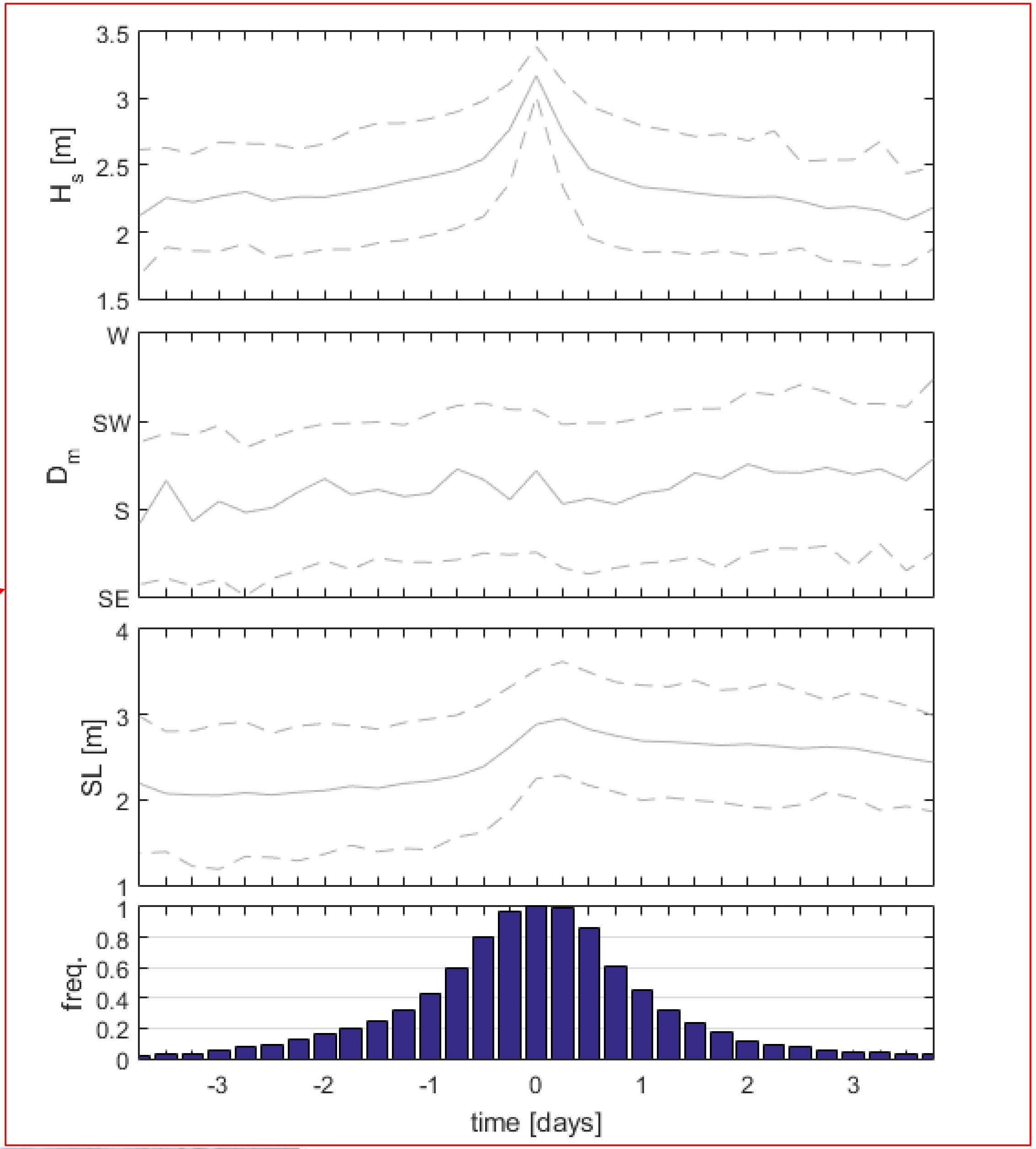
Data: 3 storms with duration approx. 1,5 days and $H_{s,peak}$ between 2.6 m and 2.8 m.











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❑ Conclusions

- The methodology is able to reproduce marginal and joint distribution of the values occurring simultaneously (all values simulated indirectly).
- Although some features of the bivariate distributions still missing
- Simulated storm evolutions mimics observed evolution, and the “innovation” in the storm evolution forms seems reasonable.

- The methodology allows for the simulation of multivariate sea storms that can be used for probabilistic verification and risk analysis including damage evolution of structures (or beaches).