Analysis of wave and sea level conditions causing extreme beach erosion along the Uruguayan coast

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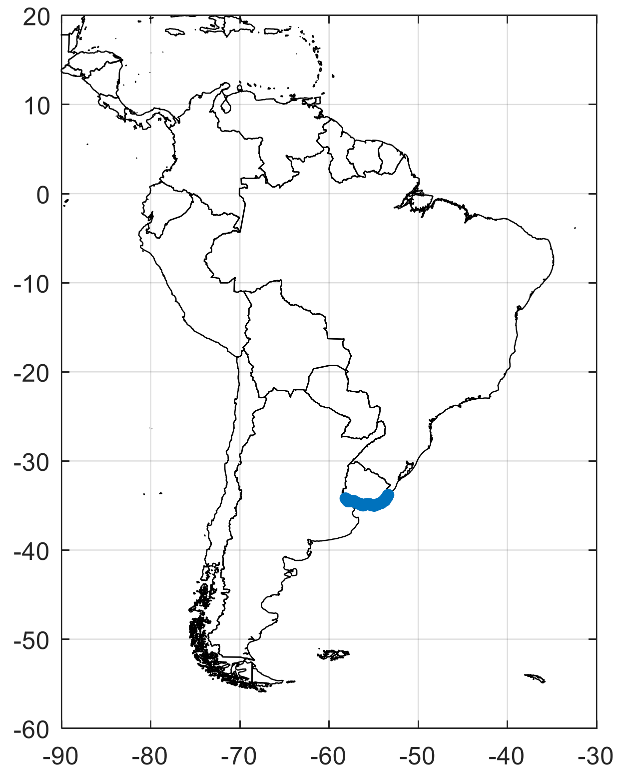
MOTIVATION and OBJECTIVES:

How extreme erosion events are produced? Are they associated with extreme waves and/or extreme storm surges?, or with groups of storms with short interarrival times?

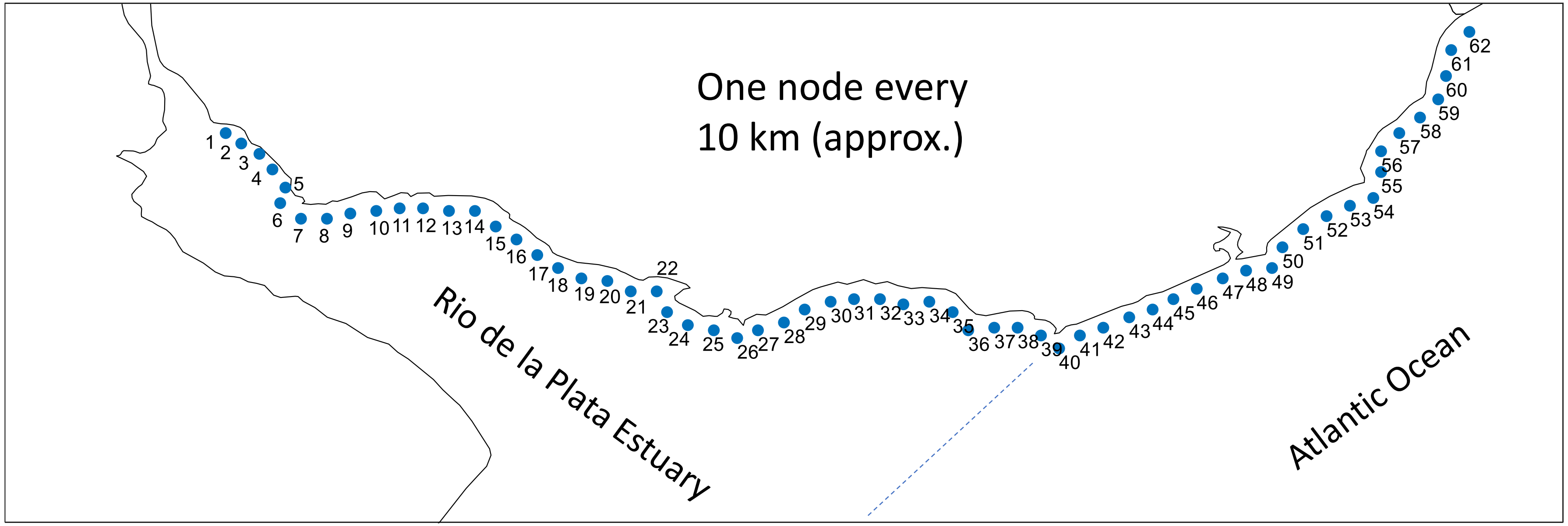
What is the footprint that is to be expected for a extreme erosion event? Could it be different storms types different characteristic footprints?

To gain insight of the spatial extent of extreme erosion events and on the expected value of the drives (Hs, SS, …) causing these extreme events.



DATA:

- In-house developed 32 years of high-resolution sea level and waves hindcast (1985-2016) → We use 62 nearshore points along the coast



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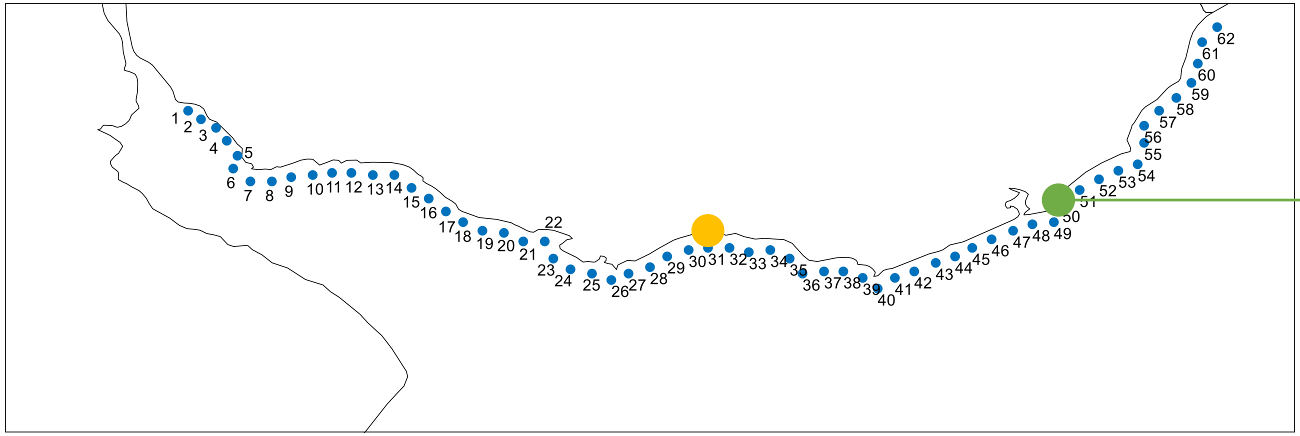

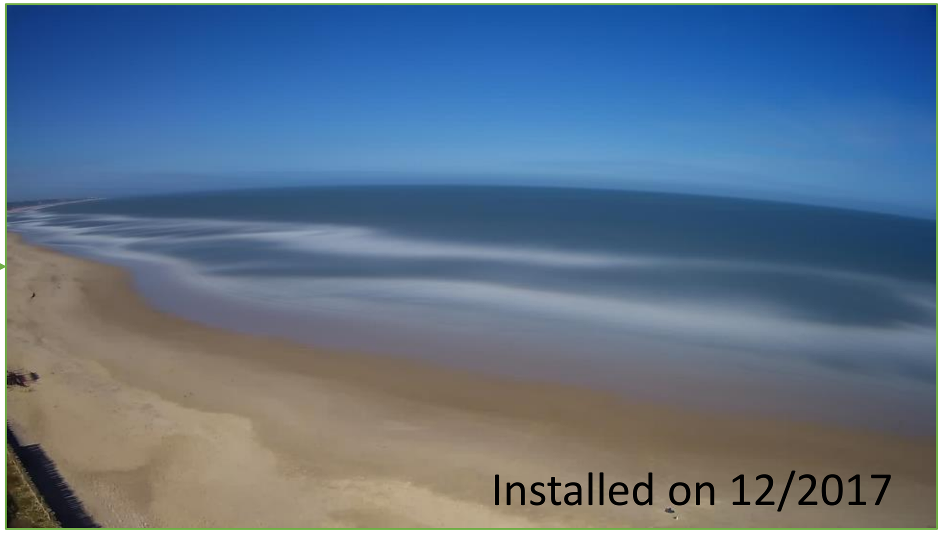

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METHODS:

1. Estimate a shoreline evolution (erosion/accretion) proxy based on Miller and Dean (2004) and Toimil et al. (2017).
2. Identify regions with homogeneous behavior and analyze the spatial footprint of the erosion events → Define a subset of representative points.
3. Analyze how extreme erosion is reached at these subset of points through a Monte Carlo simulation method.

Step #1: Estimate a shoreline evolution (erosion/accretion) proxy based on Miller and Dean (2004) and Toimil et al. (2017).

Taken from references

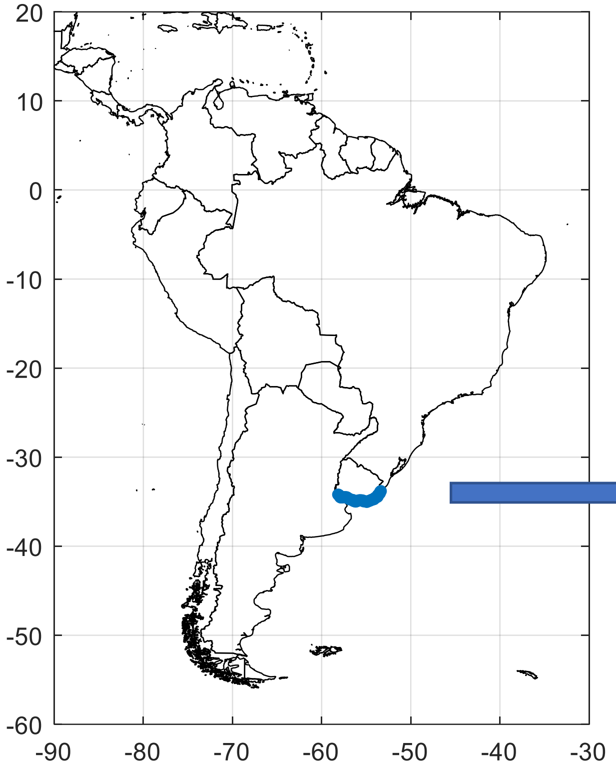
$$\frac{dy(t)}{dt} = k\left(y_{eq}(t) - y(t)\right)$$

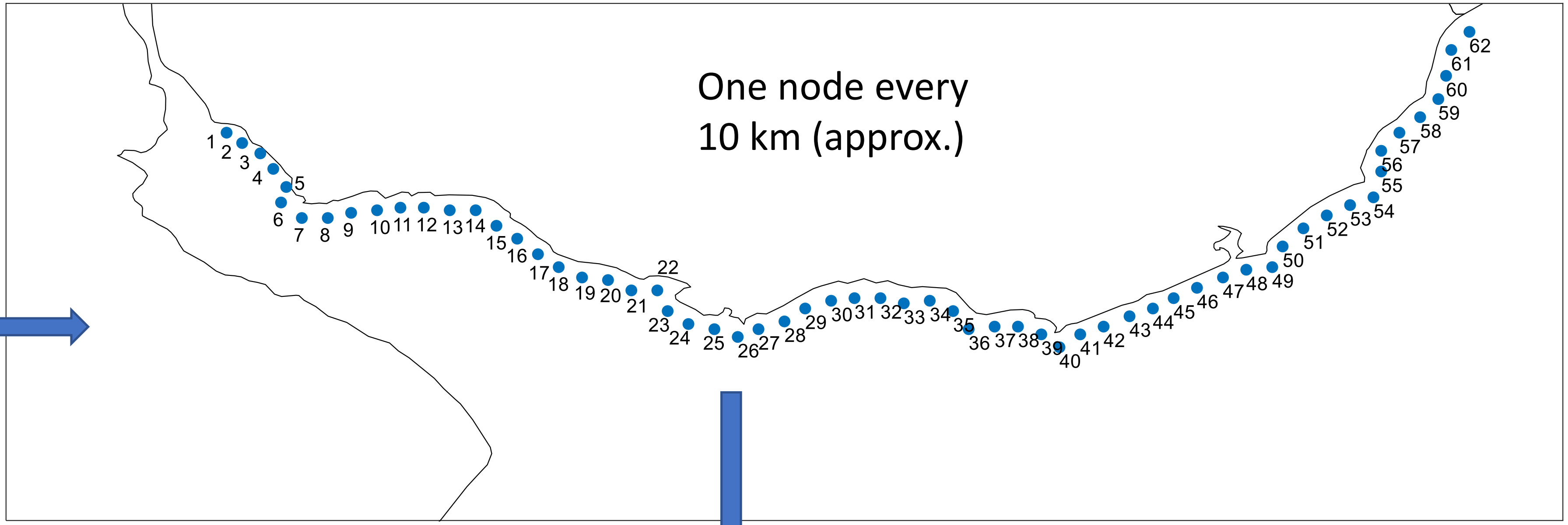
$$y^{n+1} = \frac{y^n + Q\left[\left(y_{eq}^{n+1} + y_{eq}^{n}\right) - y^n\right]}{1+Q}, \quad Q = \frac{k\Delta t}{2}$$

$$y_{eq}(t) = \Delta y_0 + \Delta y_{eq}(t)$$

$$\Delta y_{eq}(t) = -W^*(t)\left(\frac{0.106H_b(t) + SS(t) + AT(t)}{B + 2H_b(t)}\right)$$

Calibrated to obtain zero mean value of y(t)





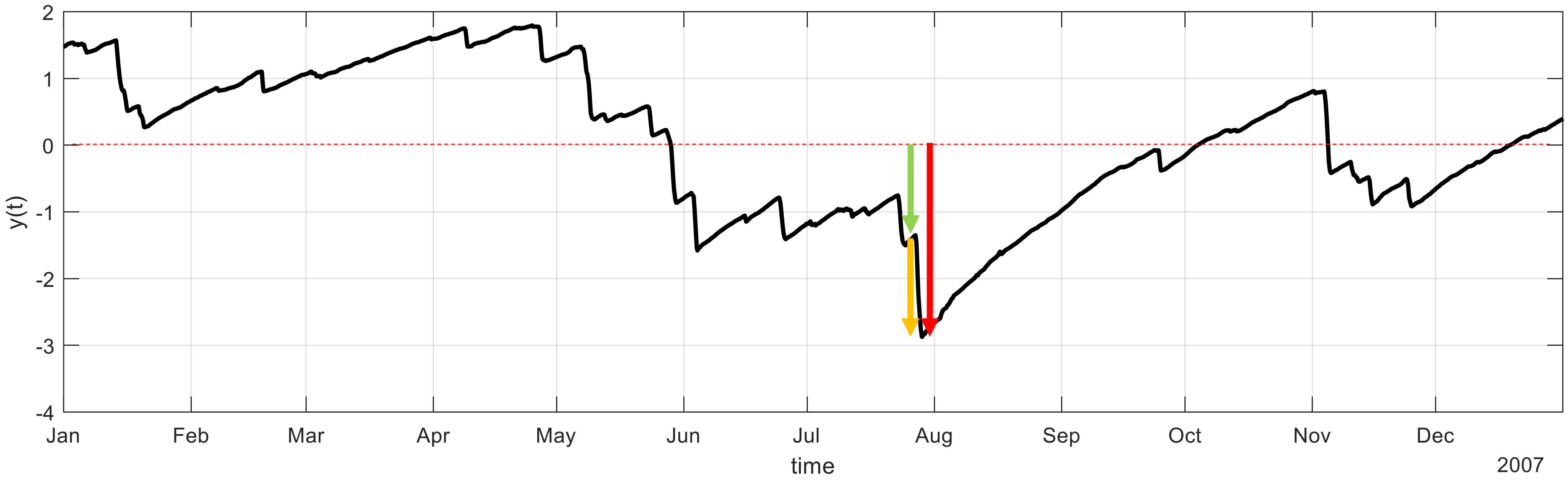
$$y(t) \Rightarrow \boldsymbol{y}^{*}(\boldsymbol{t}) = y(t)/\sigma_y$$

Dimensionless *y(t)*: used as a proxy of erosion/accretion conditions and as a mean to estimate erosion potential of the storms

Erosion events are identified from the dimensionless series and three variables are estimated for each one:

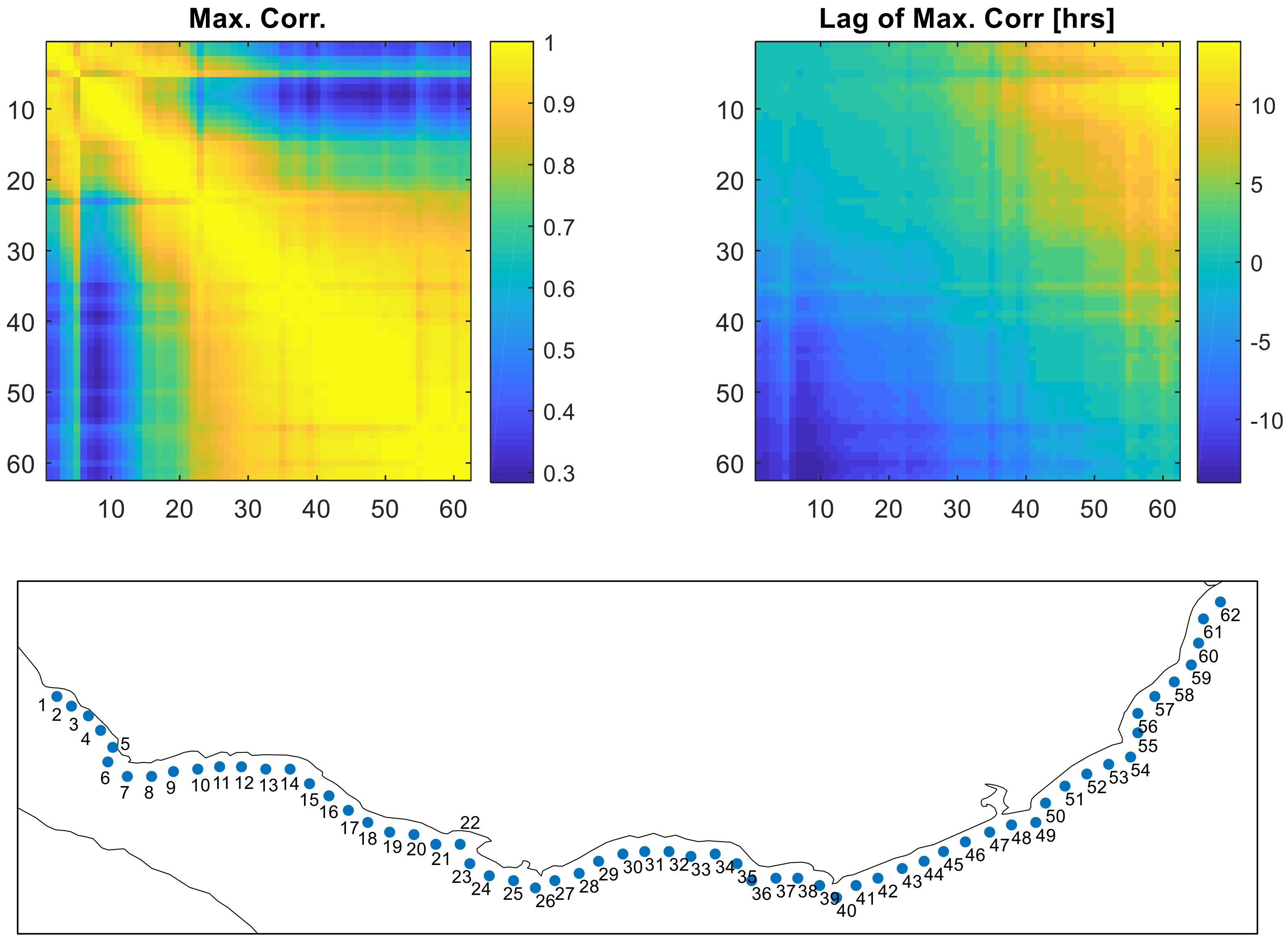
- Total erosion: y_{tot} (peak value of y(t)).
- Initial position: y_0 (value of y(t) when erosion starts).
- Event intensity: y_{event} (difference between initial and peak value of y(t)).

$$y_{tot} = y_0 + y_{event}$$



Step #2: Spatial analysis and regionalization:

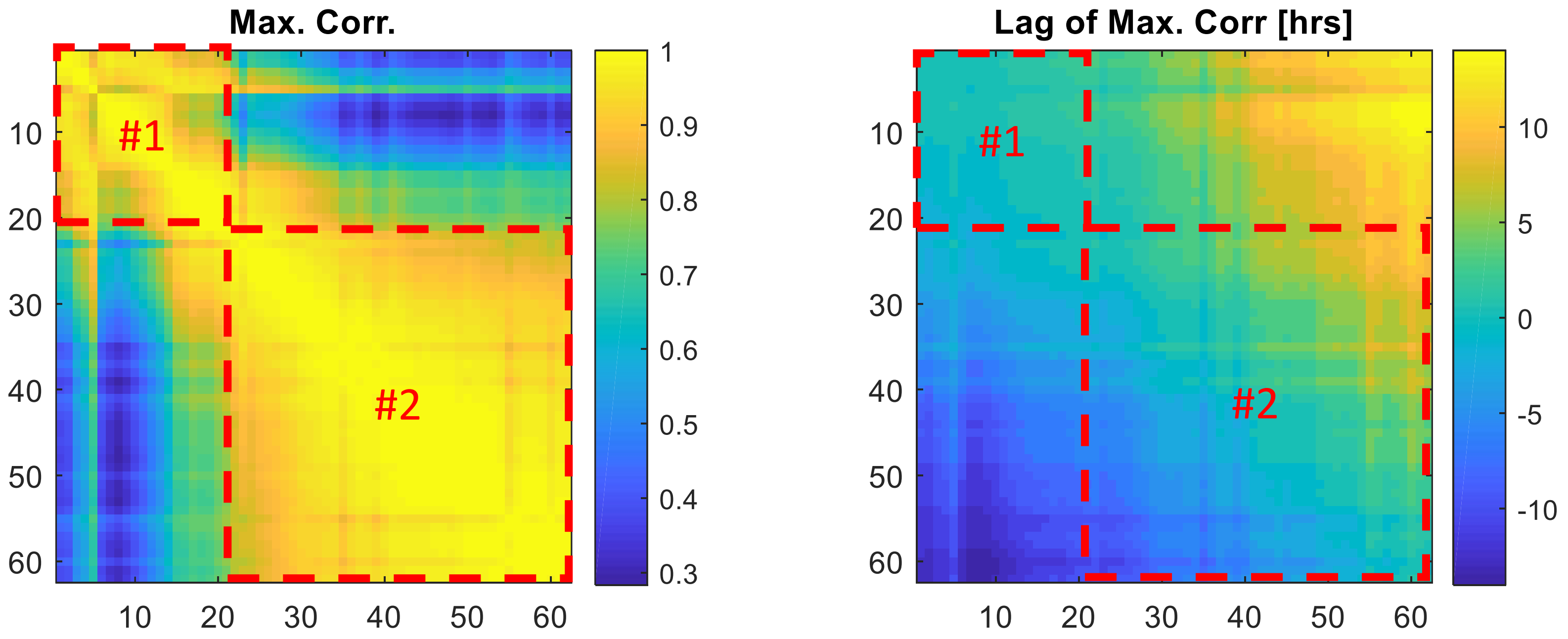
1. Correlation of shoreline position proxy time series for different time lags

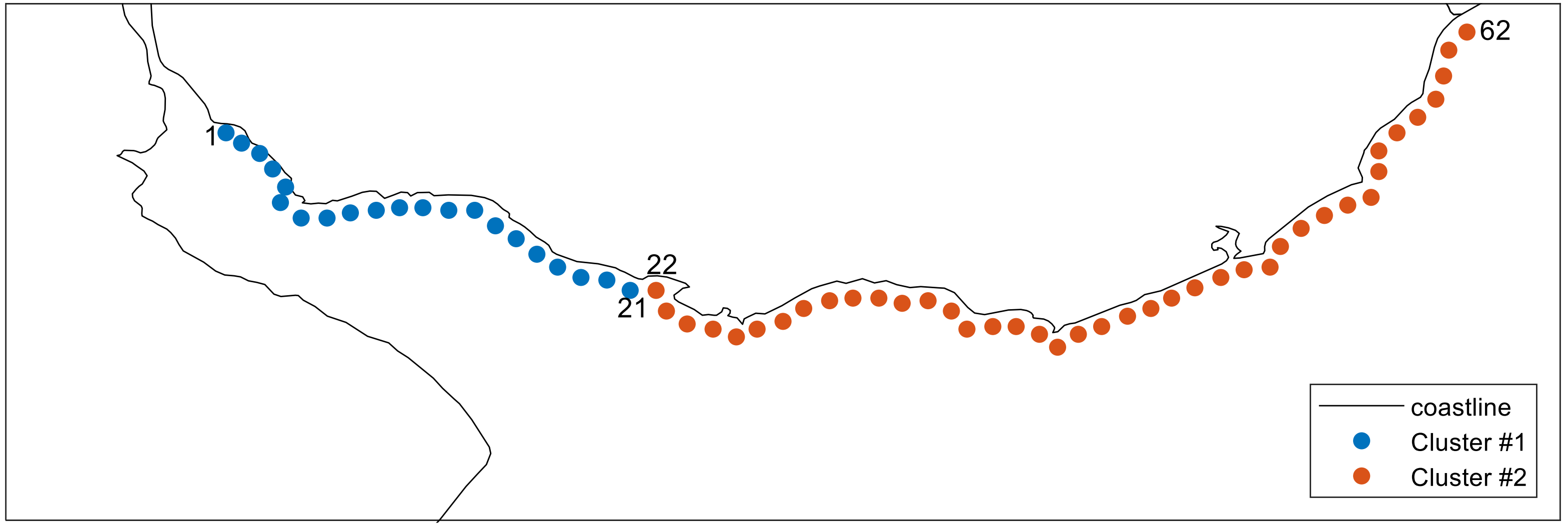


Step #2: Spatial analysis and regionalization:

1. Correlation of shoreline position proxy time series for different time lags

2. Clusters classification (k-means) of time series of shoreline positions





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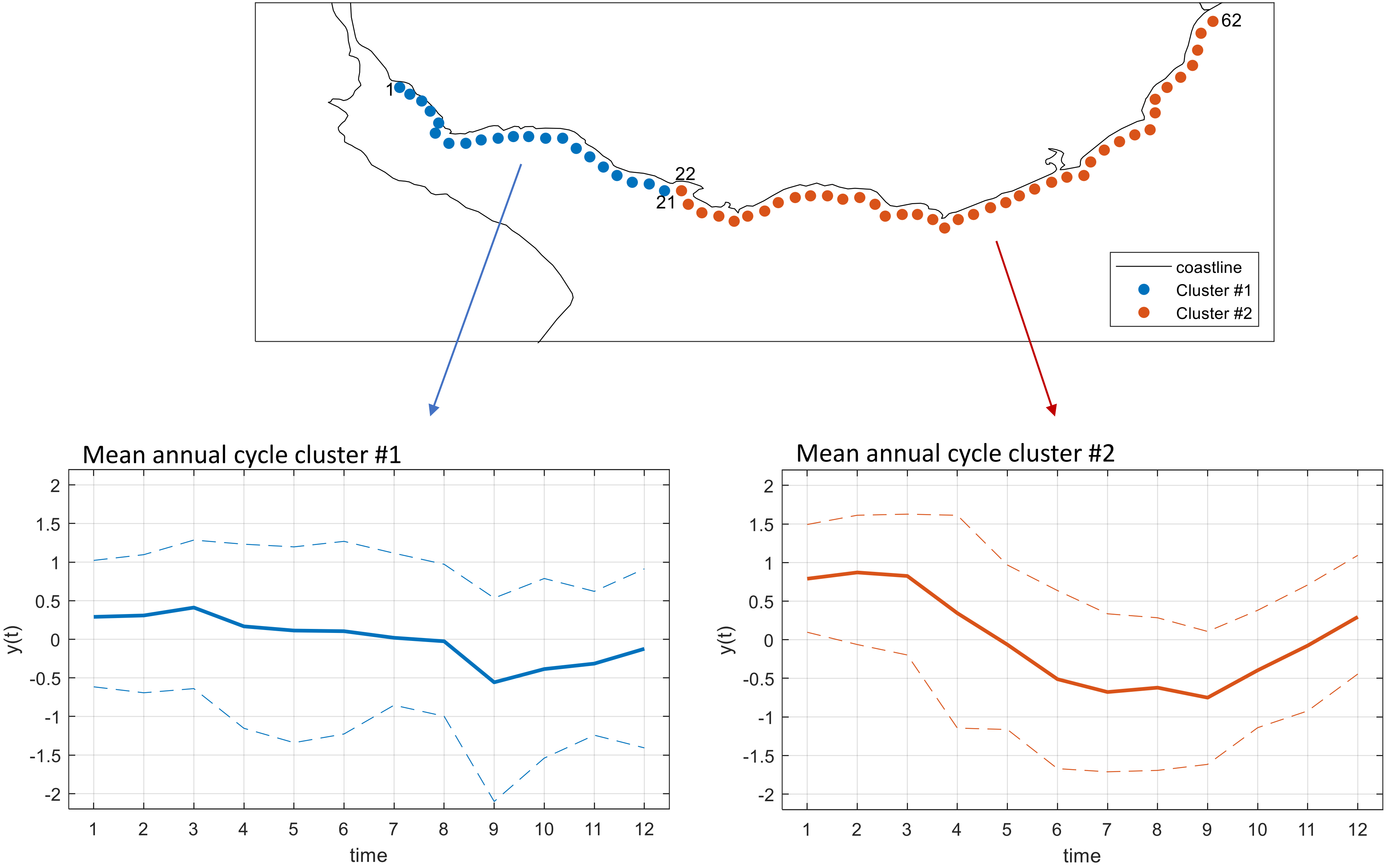

Step #2: Spatial analysis and regionalization:

1. Correlation of shoreline position proxy time series for different time lags
2. Clusters classification (k-means) of time series of shoreline positions
3. Cluster classification of the spatial footprint of the erosion events

Storms

Nodes

0	0	1	0	1	1	0	0	0	0	…
0	0	1	0	1	1	0	0	0	0	
0	0	0	0	1	1	0	0	0	0	
0	0	0	0	1	0	0	0	0	0	
0	0	0	0	0	0	0	0	1	0	
1	0	0	0	1	0	0	0	1	0	
1	1	0	0	0	0	0	0	1	1	
1	1	0	0	0	0	0	0	1	1	
⋮										

1 = erosion event

0 = no erosion

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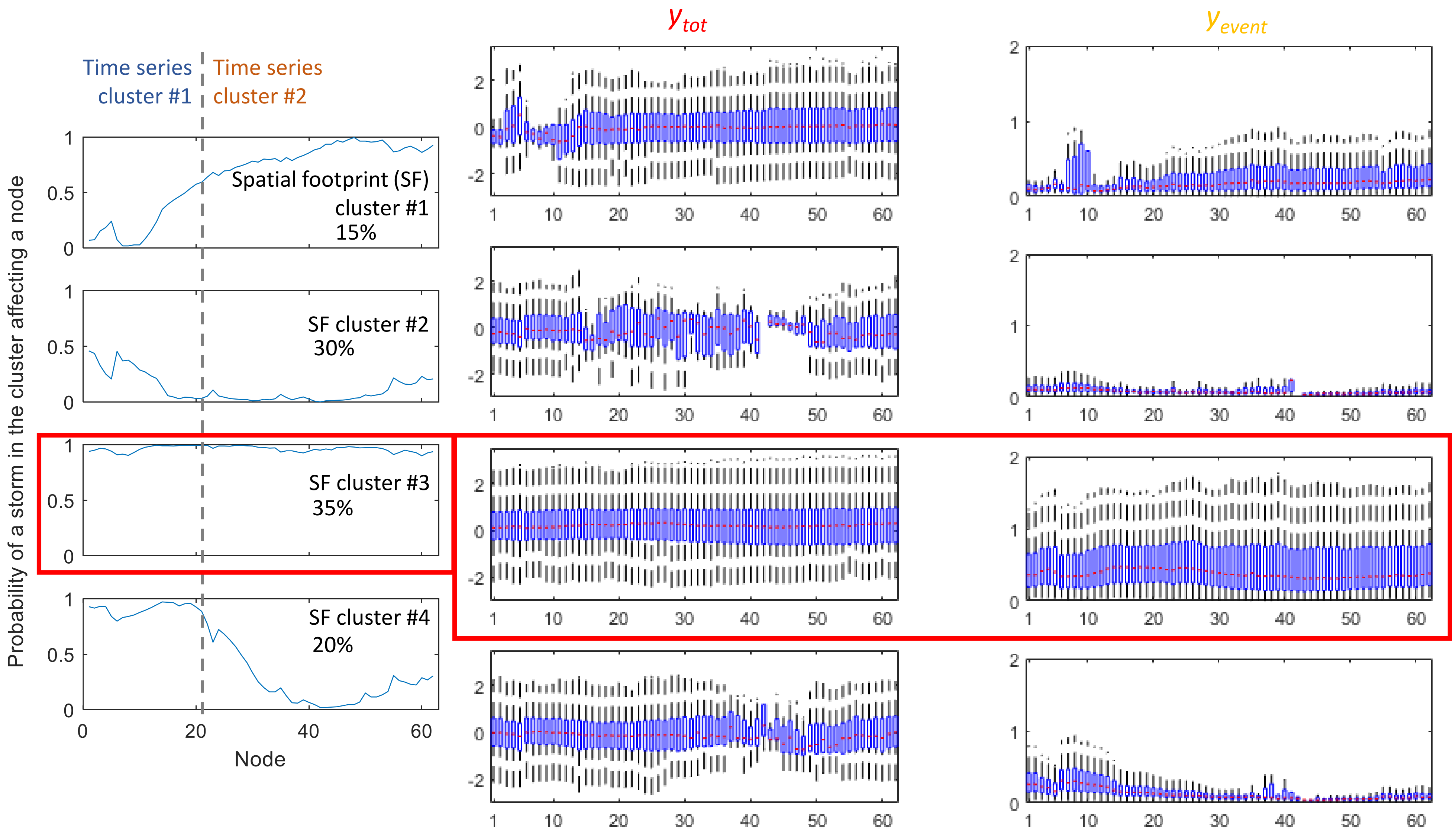

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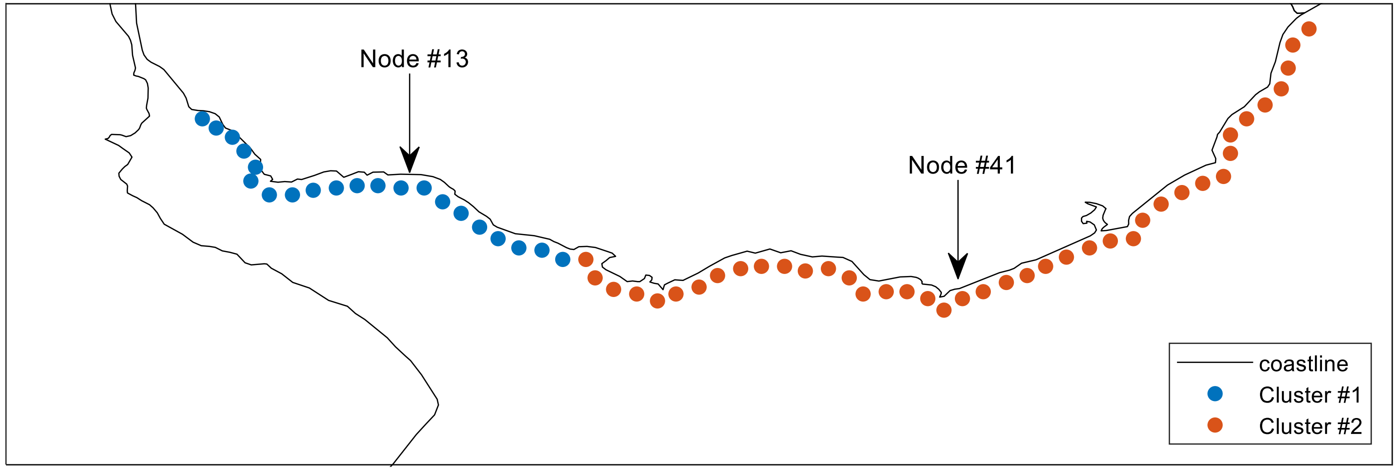
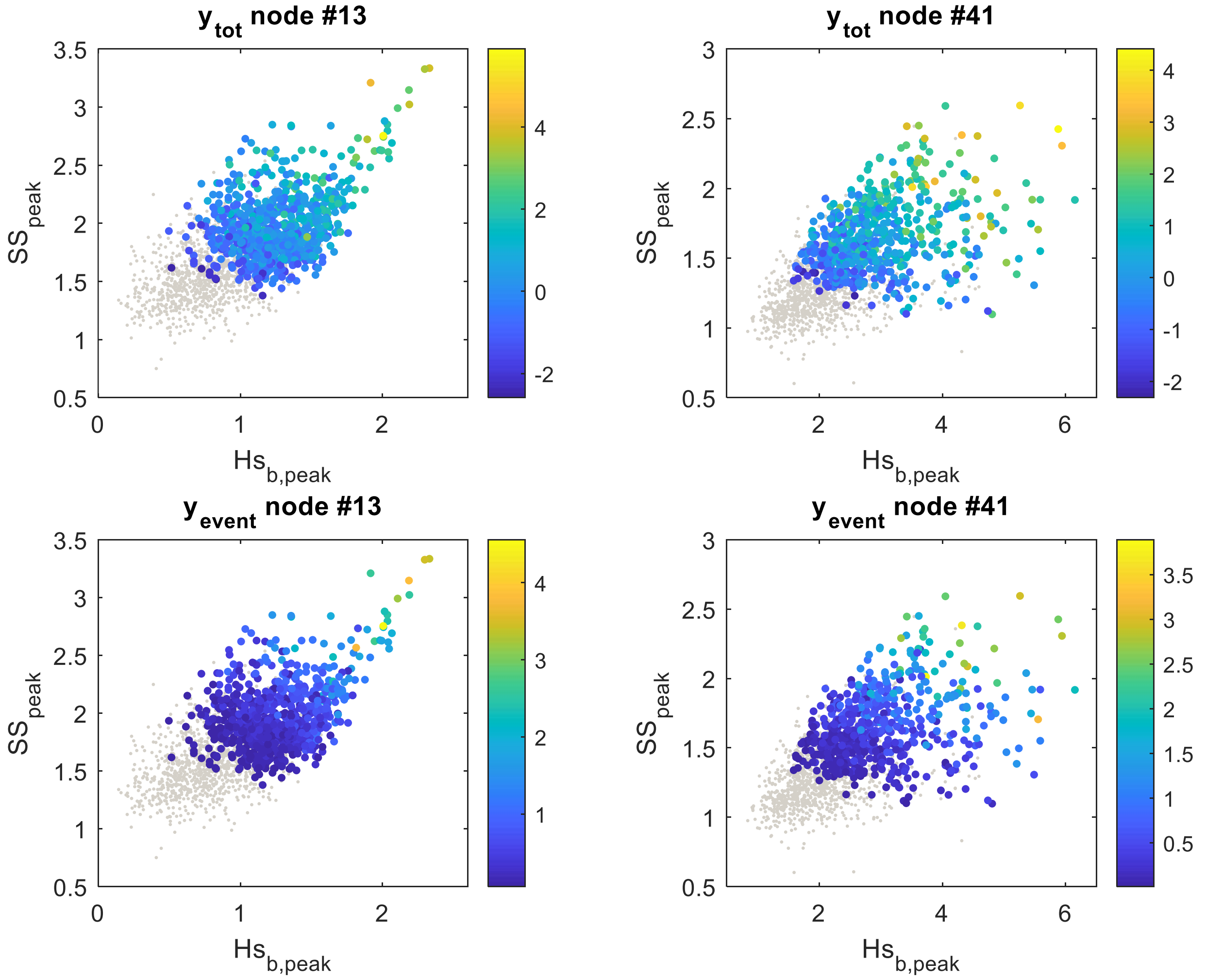
3. Cluster classification of the spatial footprint of the erosion events

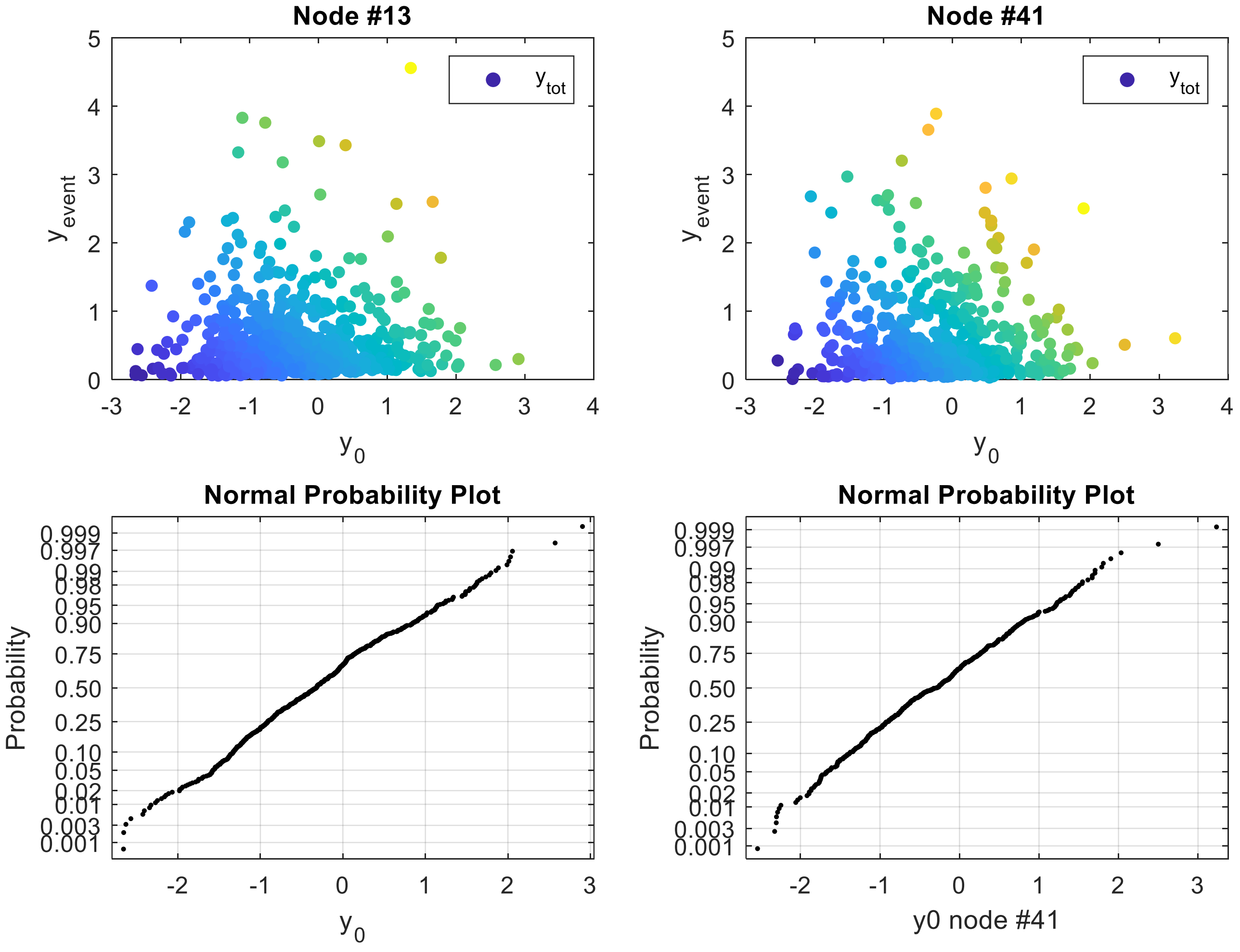
- There are at least two areas with differentiated behavior in terms of shoreline evolution
- These two areas are distinguished also when looking at the footprint of erosion events, but most extreme erosion events tends to affect the whole coast.

One representative node per cluster is chosen for the analysis of the condition causing extreme erosion



Step #3: Analyze how extreme erosion is reached at these subset of points through a Monte Carlo simulation method.





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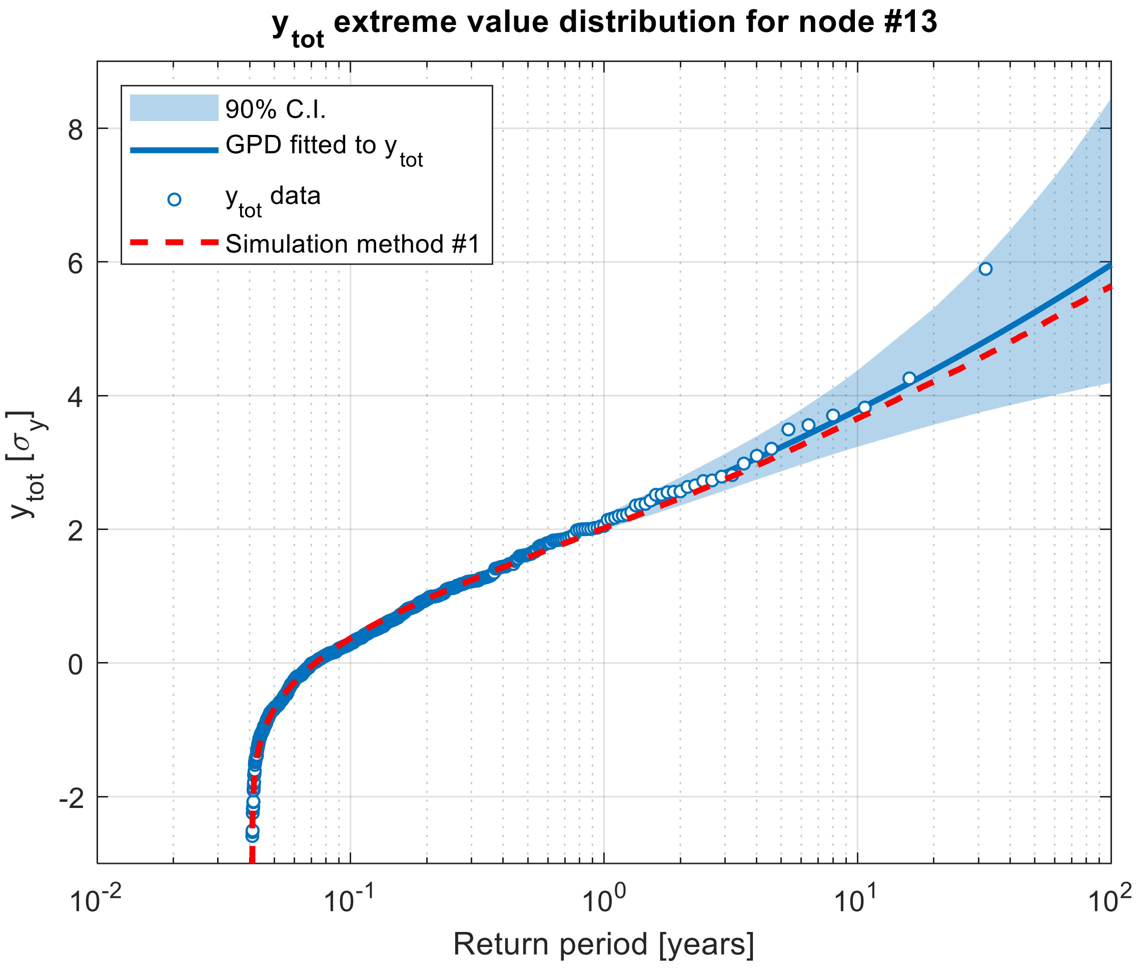
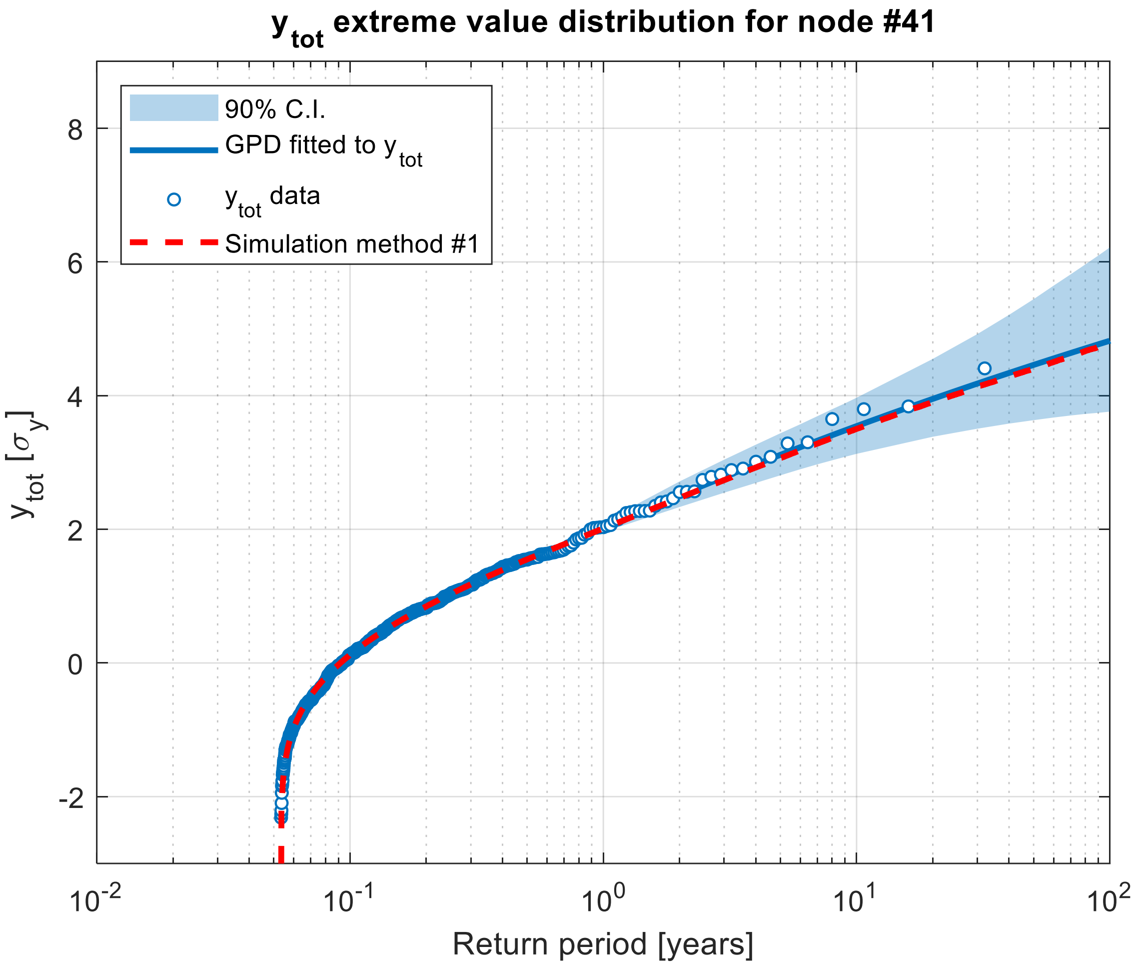
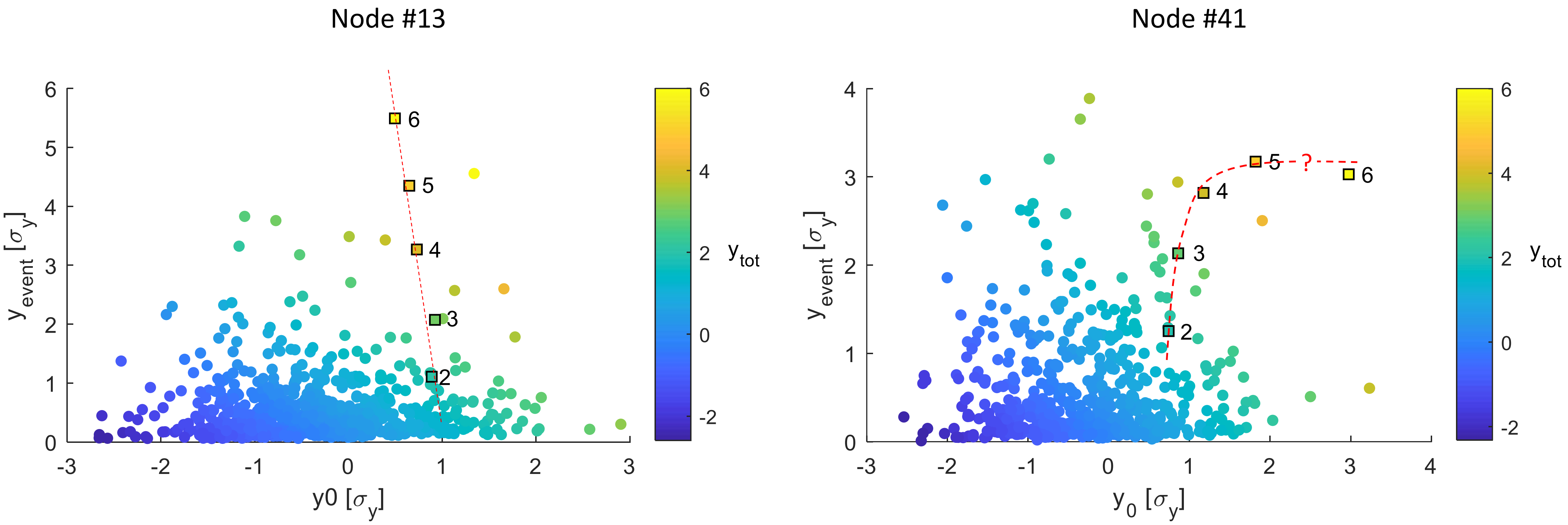
Response approach:	Extreme Value Analysis (EVA) of y_{tot}				→ No information on how extreme erosion is reached is obtained
Simulation method #1: (*quasi* response approach)	EVA of y_{event}	→ Simulate y_{evet} Simulate y_0	→ Reconstruct y_{tot}		→ Some information on how extreme erosion is reached is obtained
Simulation method #2: (event approach)	EVA of *Hs*, *SS*, …	→ Simulate *Hs*, *SS*, …	→Estimate $y_{event}(Hs,SS,\ldots)$ Simulate y_0	→ Reconstruct y_{tot}	→ Some information on how and what conditions cause extreme erosion is obtained


y_{tot} extreme value distribution for node #13
90% C.I.
GPD fitted to y_{tot}
y_{tot} data
Simulation method #1
y_{tot} [σ_y]
Return period [years]
8
6
4
2
0
-2
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

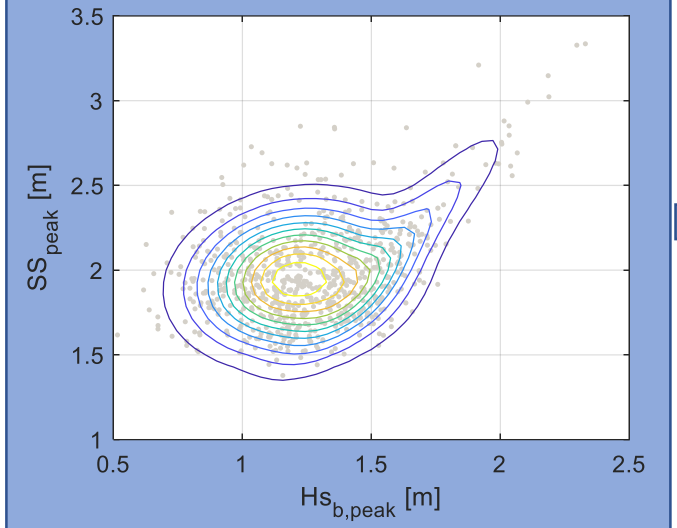

y_{tot} extreme value distribution for node #41
90% C.I.
GPD fitted to y_{tot}
y_{tot} data
Simulation method #1
y_{tot} [σ_y]
Return period [years]
8
6
4
2
0
-2
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}



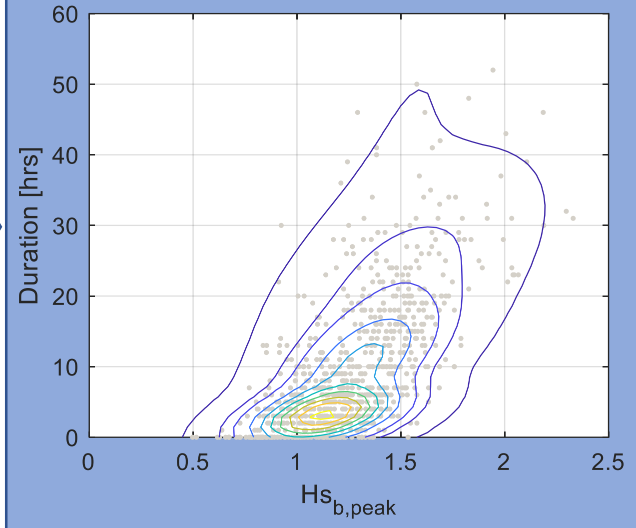
dots → original data

4 squares → expected (y_0,y_{event}) combination for a given value of y_{tot}, from simulated data

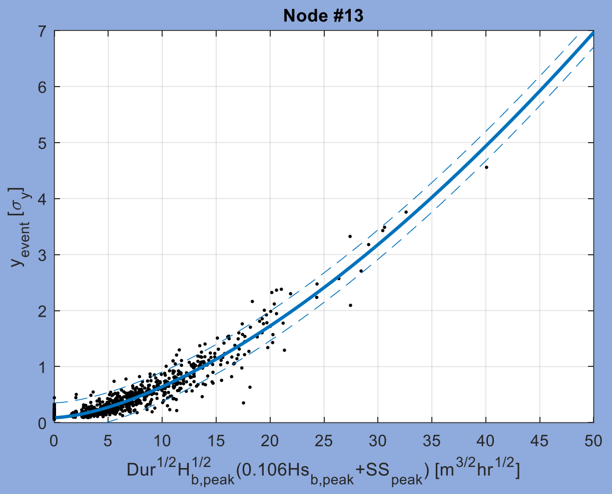
(1) Simulate $Hs_{b,peak}$ and SS_{peak} from their joint distribution

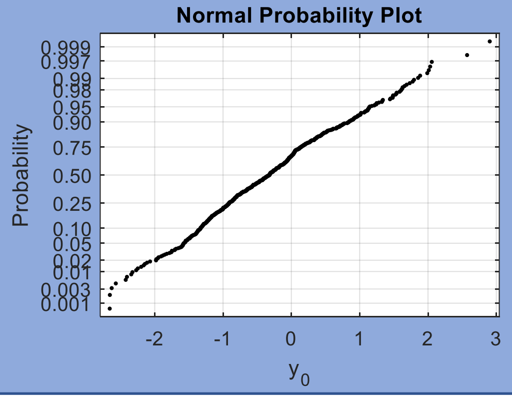


(2) Simulate Duration conditional to $Hs_{b,peak}$ from their joint distribution



(3) Estimate y_{event} from $Hs_{b,peak}$, SS_{peak} and Duration using a regression.

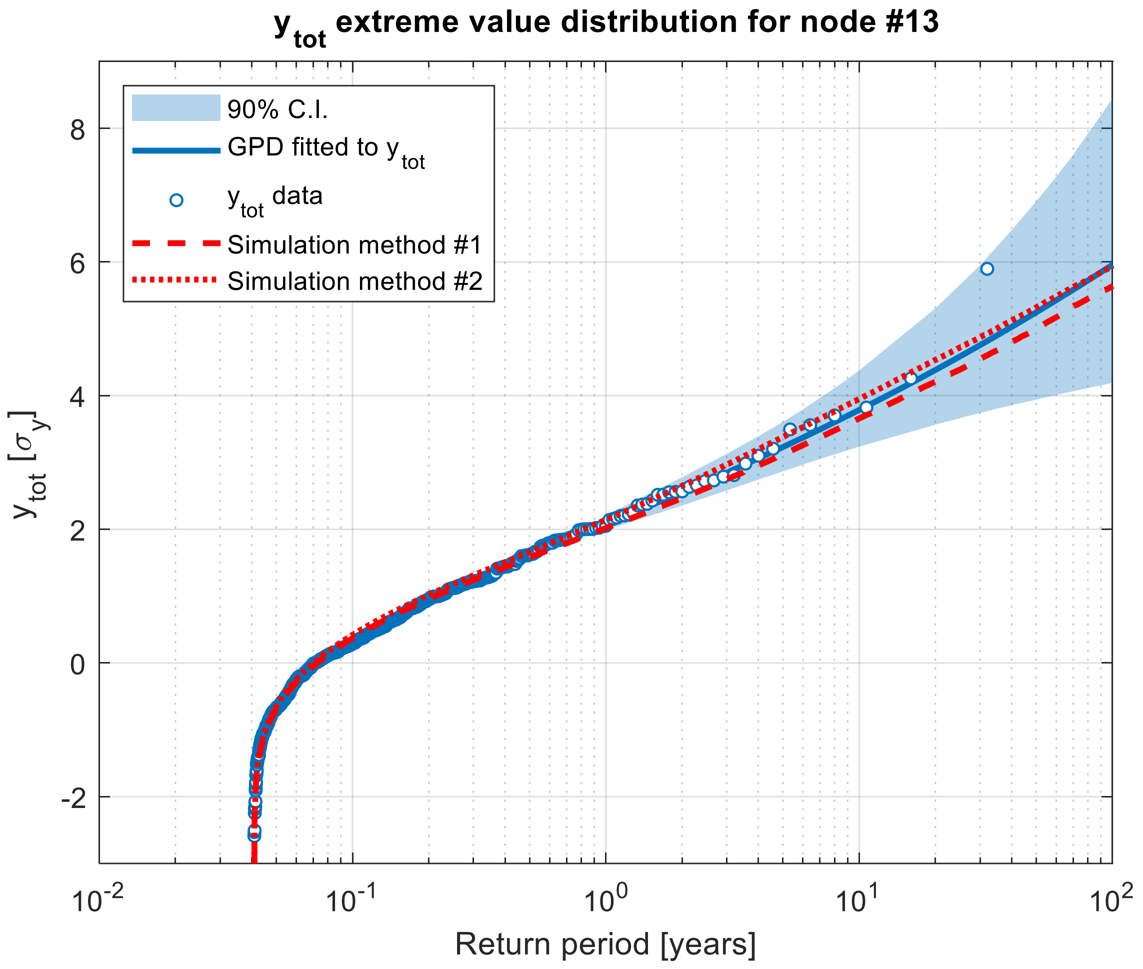


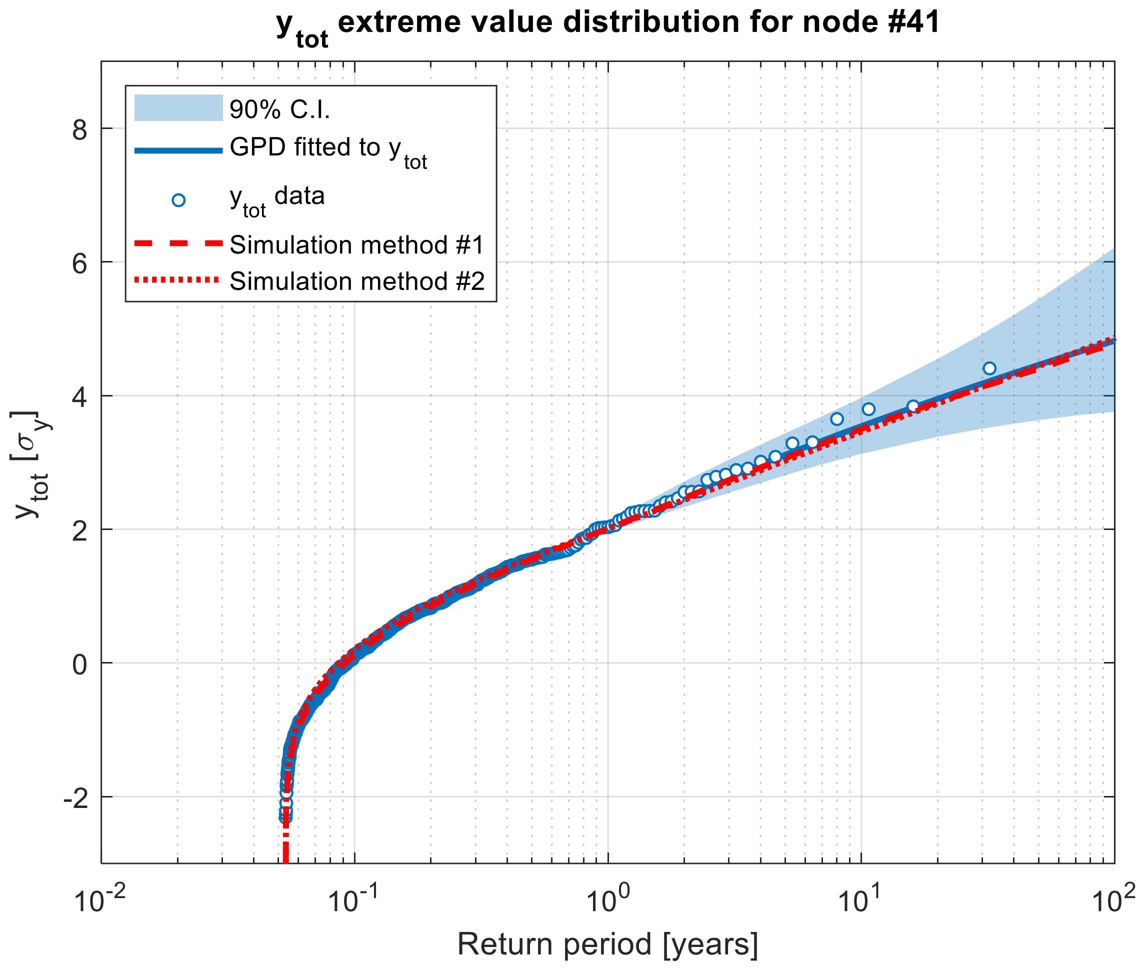


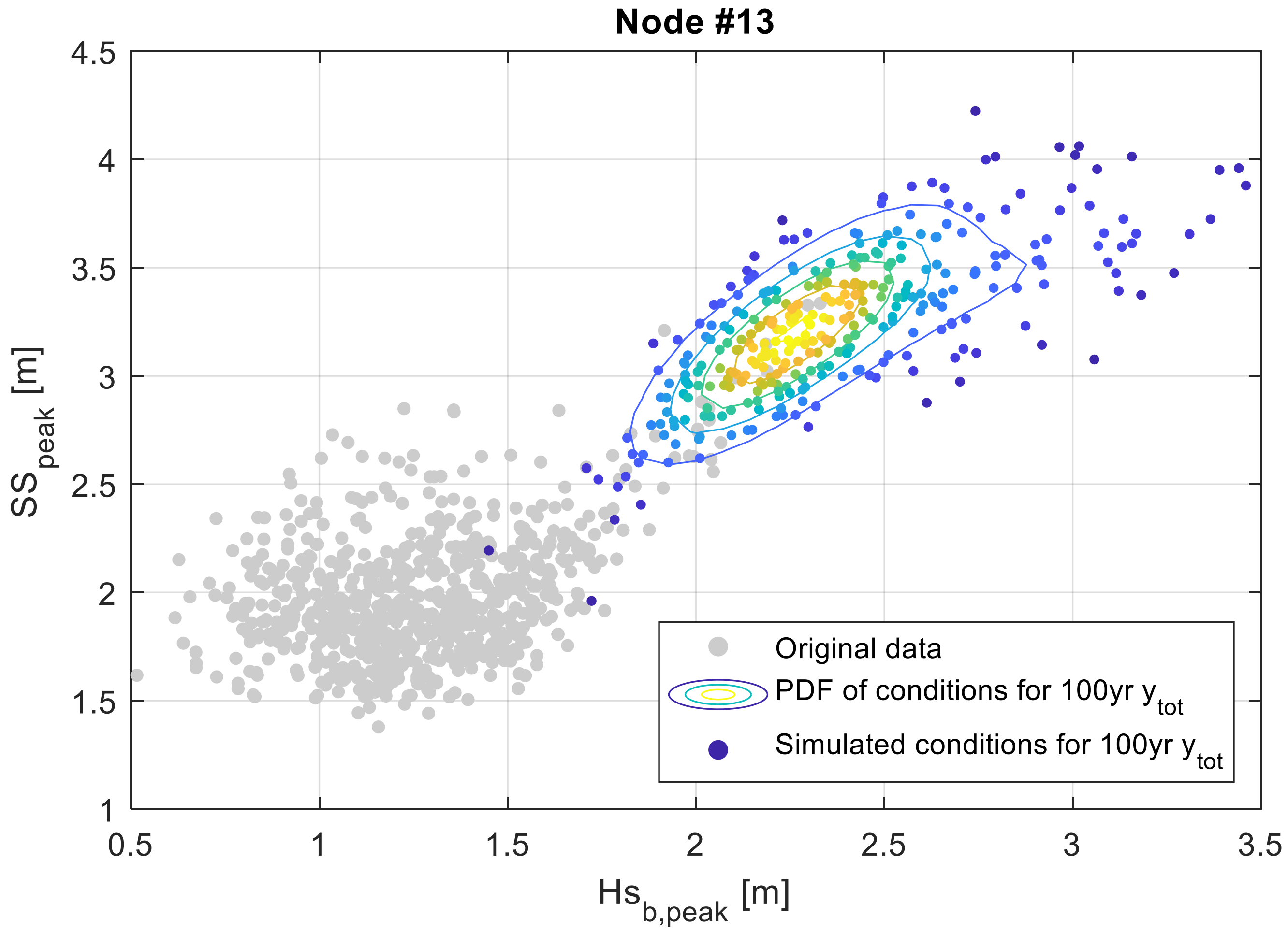
(4) Simulate y_0 independently

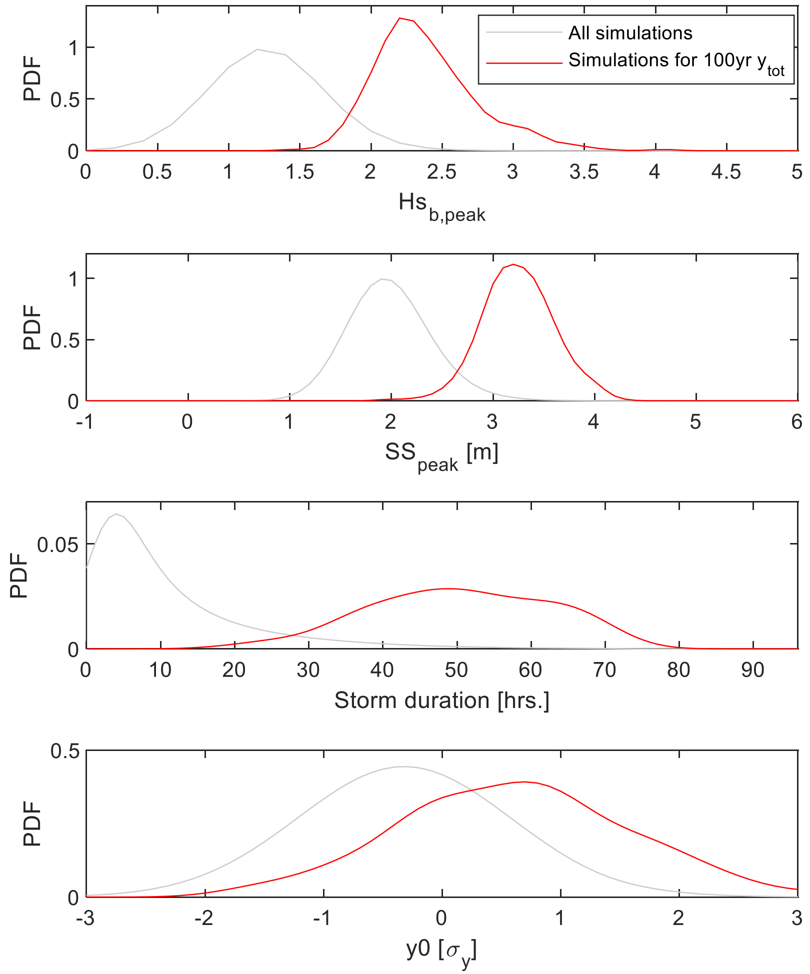
(5) Calculate $y_{tot} = y_0 + y_{event}$

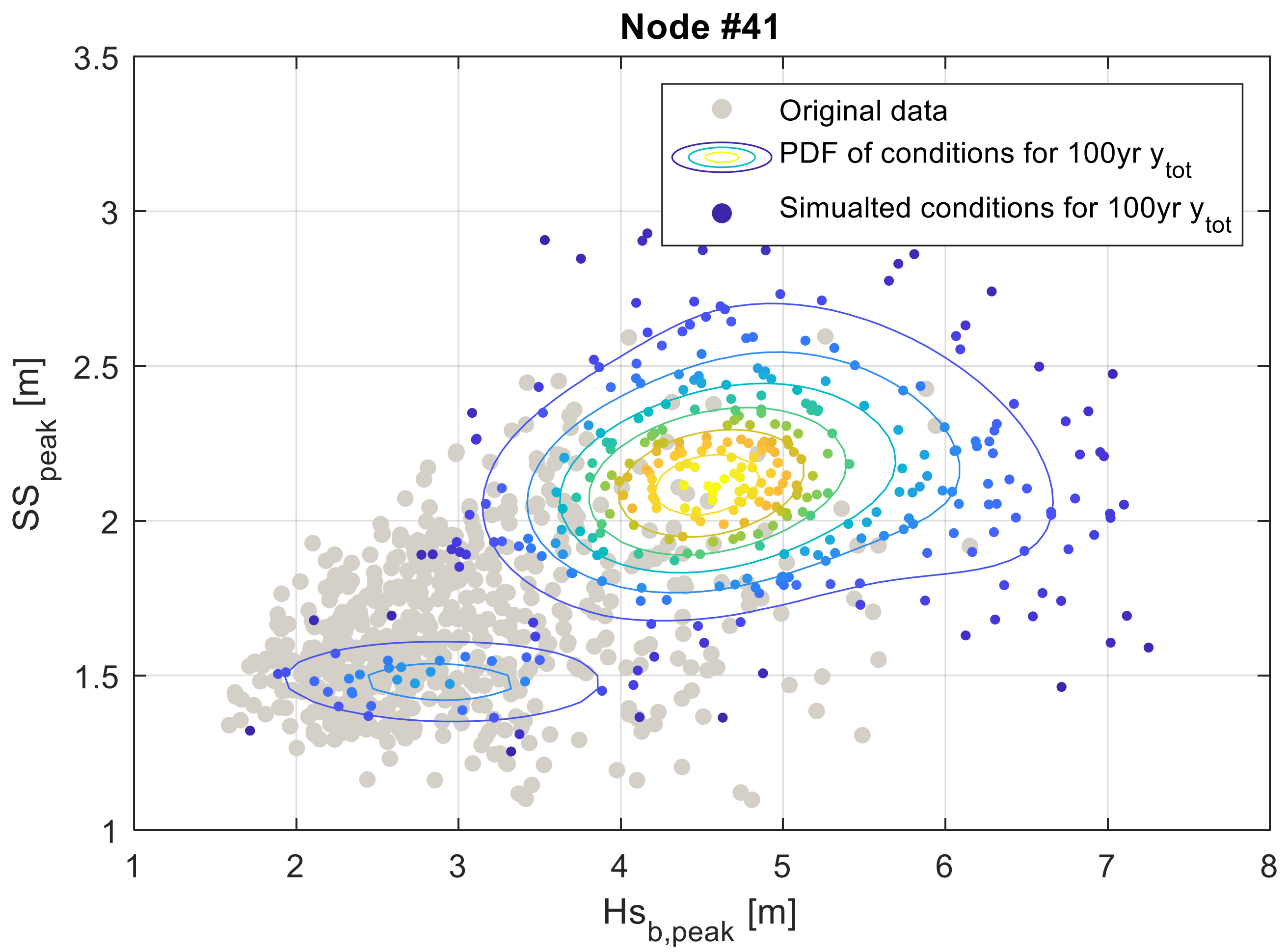
Simulation method #2 (event approach)

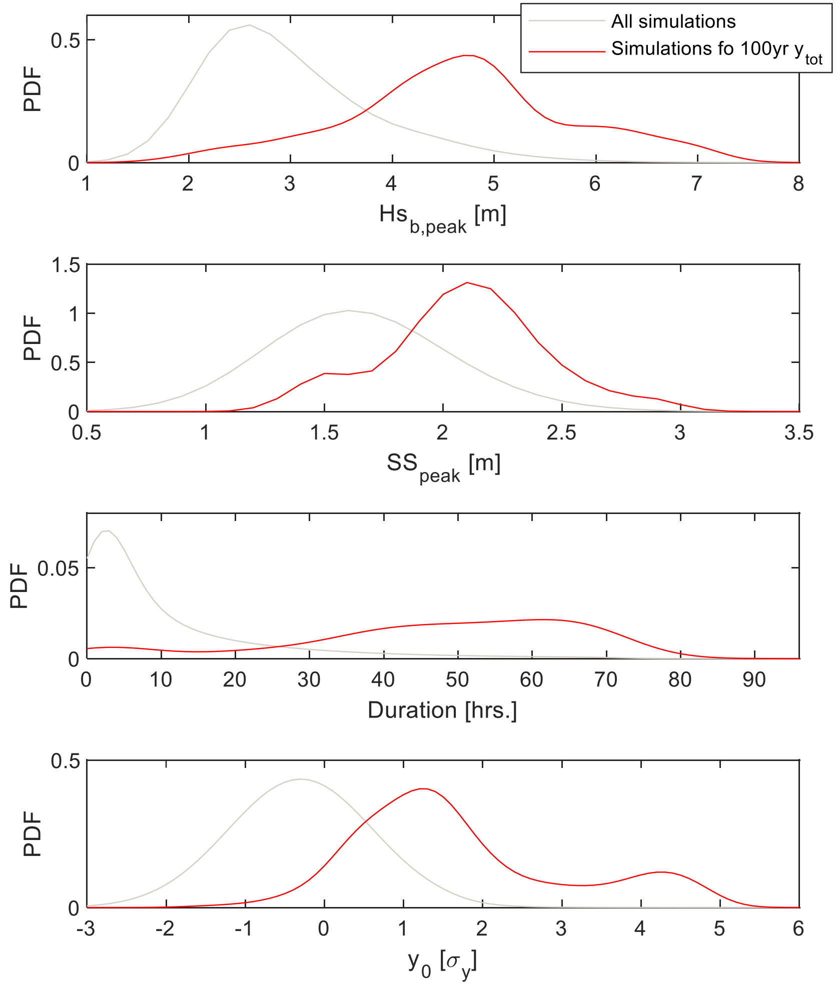

y_{tot} extreme value distribution for node #13
90% C.I.
GPD fitted to y_{tot}
y_{tot} data
Simulation method #1
Simulation method #2
y_{tot} [σ_y]
Return period [years]


y_{tot} extreme value distribution for node #41
90% C.I.
GPD fitted to y_{tot}
y_{tot} data
Simulation method #1
Simulation method #2
y_{tot} [σ_y]
Return period [years]

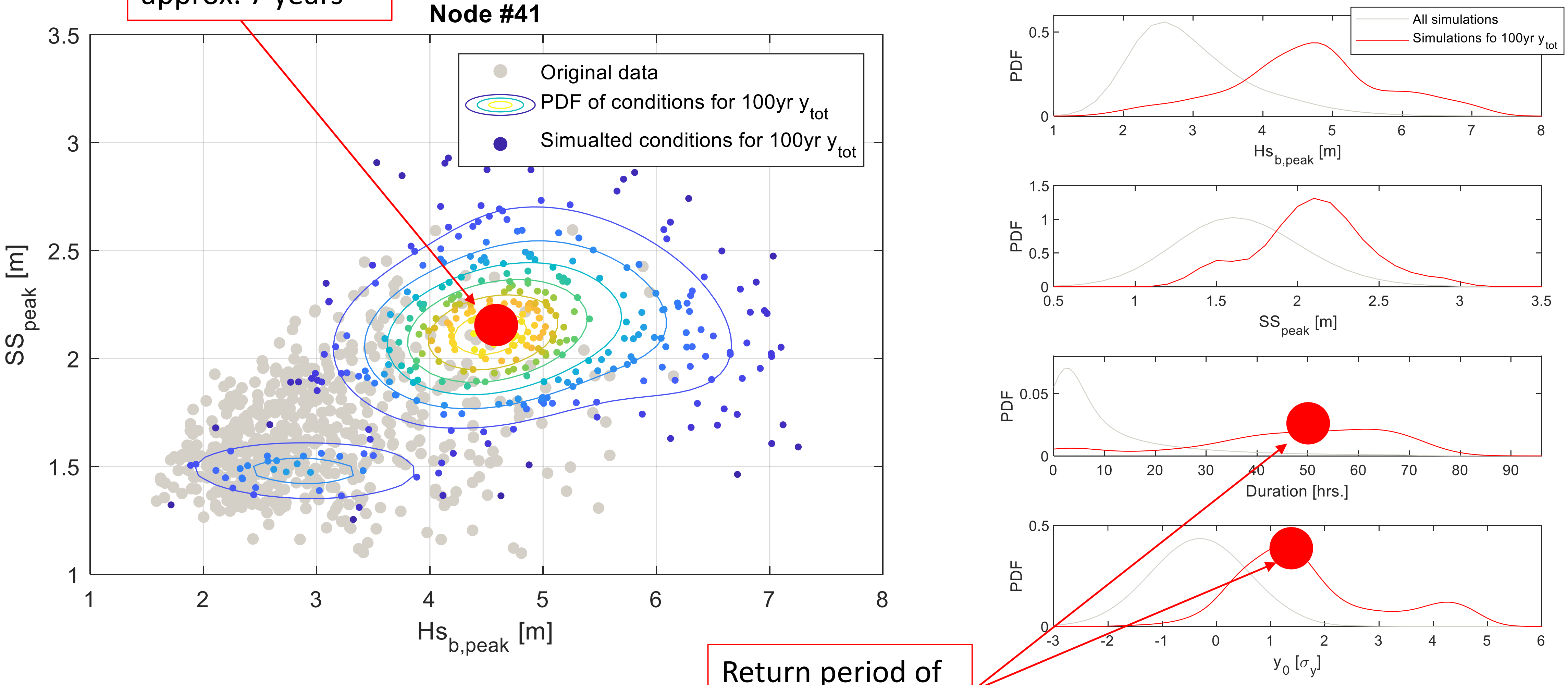

Node #13
Original data
PDF of conditions for 100yr y_{tot}
Simulated conditions for 100yr y_{tot}
SS_{peak} [m]
$Hs_{b,peak}$ [m]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1
1.5
2
2.5
3
3.5


All simulations
Simulations for 100yr y_{tot}
PDF
$Hs_{b,peak}$
SS_{peak} [m]
Storm duration [hrs.]
y0 [σ_y]

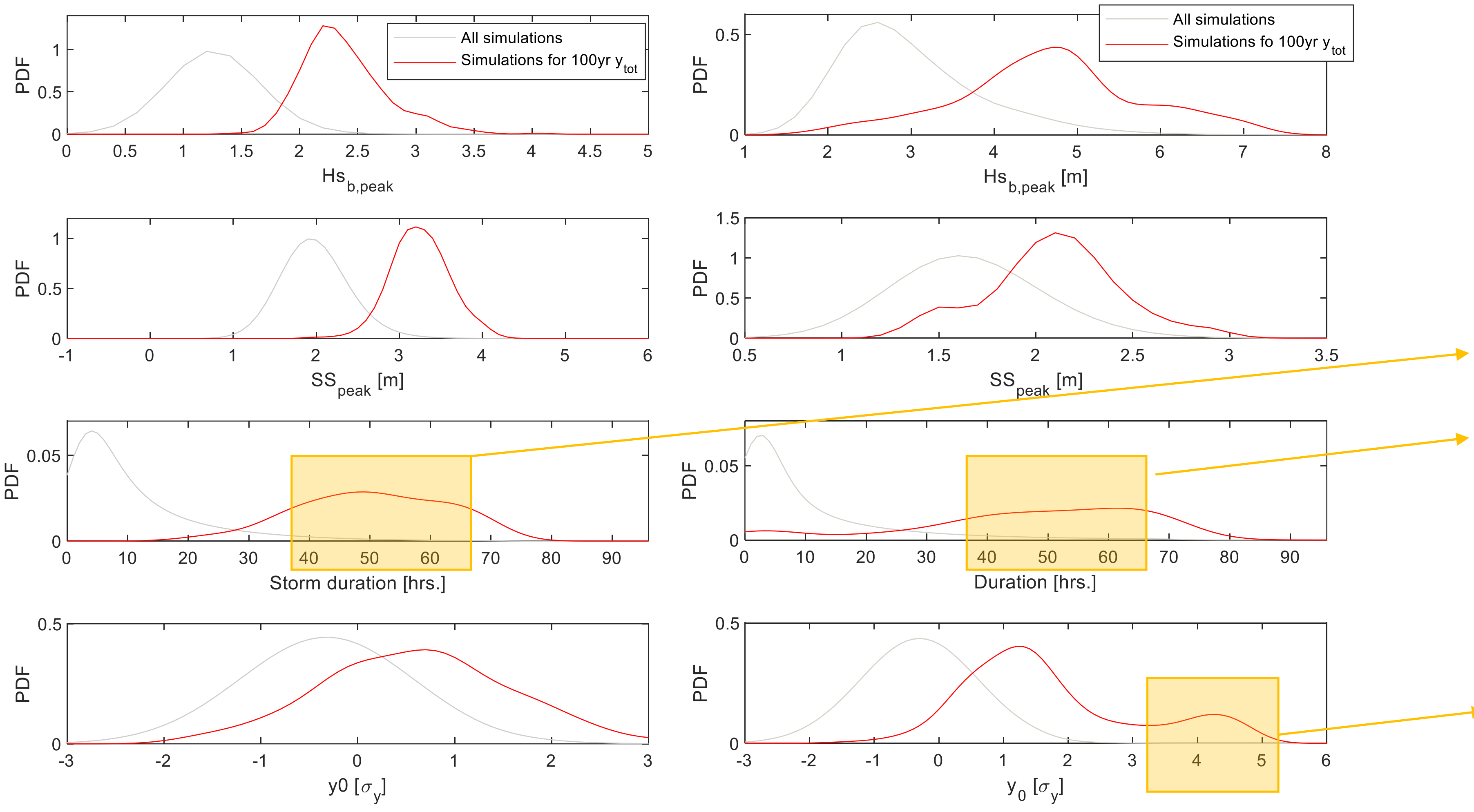

Node #41
Original data
PDF of conditions for 100yr y tot
Simualted conditions for 100yr y tot
SS peak [m]
Hs b,peak [m]
3.5
3
2.5
2
1.5
1
1
2
3
4
5
6
7
8


All simulations
Simulations fo 100yr y tot
PDF
Hs b,peak [m]
SS peak [m]
Duration [hrs.]
y 0 [σ y]

Return period of approx. 7 years



Return period of approx. 2 years



Duration seems to be quite important→ more research on possible storm durations and their distribution.

Storm grouping and recovery times more relevant for node #41 than for node #13.

CONCLUSIONS:

- **Two regions** with distinctive behavior in terms of erosion are clearly distinguished.
- There is **high correlation** along the coast and storms producing the **most intense erosion events are very likely affecting the whole coast**.
- In the *inner part of the Rio de la Plata* estuary extreme erosion seems to be caused by combination of **extreme values of the drivers** acting on a **slightly retreated initial shoreline**.
- In the *middle and outer coast of the estuary and in the Atlantic coast* extreme erosion seems to be caused by **not so extreme values of the drivers** acting on a already **retreated initial shoreline**.

- Regarding the proposed approach: **simulation method #2** is promising as a tool for statistical modelling extreme erosion events that **avoids complex statistical model for storms interarrival times and temporal evolution** of the drivers…
- … but, the duration of the storms deserves a deeper look, since it has a great influence on the results.

WHAT'S NEXT:

- **Calibrate** the erosion/accretion model with the information generated with the cameras system (almost 2 years but with missing data), and install new system(s) in other region(s). Explore use of satellite data for calibration.
- Use **Regional Frequency Analysis** (RFA) o Region of Influence (ROI) approaches to gain robustness in the different distributions and regression.

Thank you!

LatWaves 2020

March 18-20, 2020

4th Latin American Symposium on Water Waves

Montevideo, Uruguay

https://www.fing.edu.uy/imfia/congresos/latwaves/