Workshop on Stochastic Weather Generators

Avignon, September 17-19, 2014

Modeling in the form of met-ocean events of the swell climate in West Africa.

K. A. Kpogo-Nuwoklo[1], S. Arnault[2], M. Olagnon[1] , Z. Guédé[1] and **P. Ailliot[3]**

1-Laboratoire Comportement des Structures en Mer, IFREMER, Brest, France.

2- LOCEAN/IPSL, Université Pierre et Marie Curie, Paris, France.

3-Laboratoire de Mathématiques de Bretagne Atlantique, UBO, Brest, France.

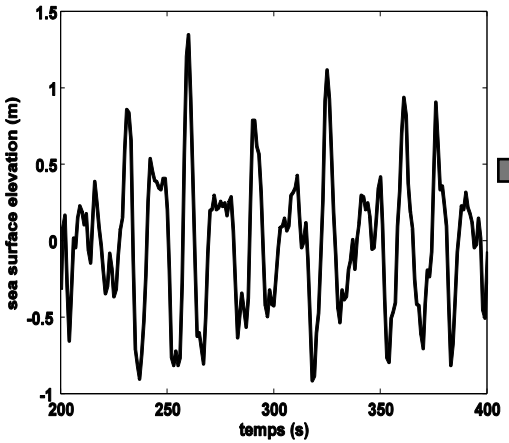
Introduction

➢ **Ocean wave climate is important in many ocean engineering fields : design against fatigue, wave energy harvesting, coastal erosion, …**

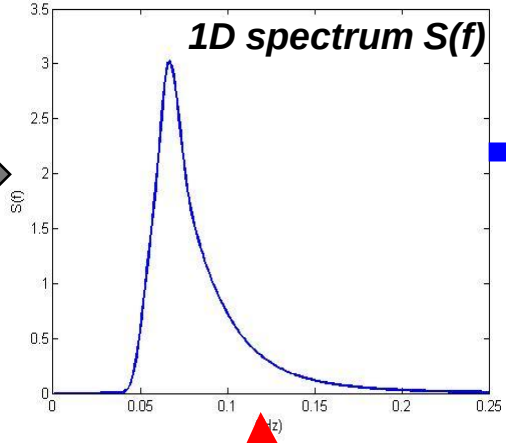
➢ ***Wave climate*** **is defined as the joint distribution of the sea state characteristic parameters averaged over a period of time for a particular location** *(Wiegel, 1964).*

Introduction

- A Sea state is defined for a period (from 20min to 6h) during which its charateristic parameters are supposed to be constant

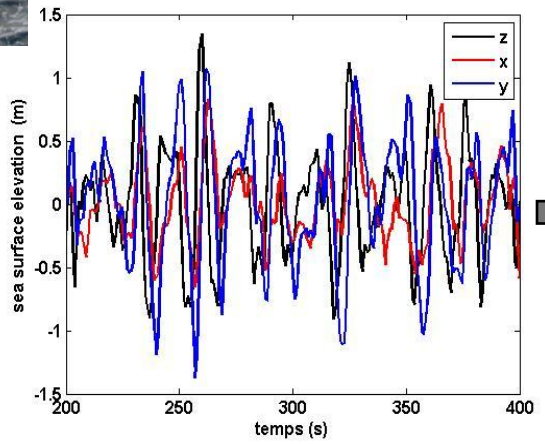


FFT

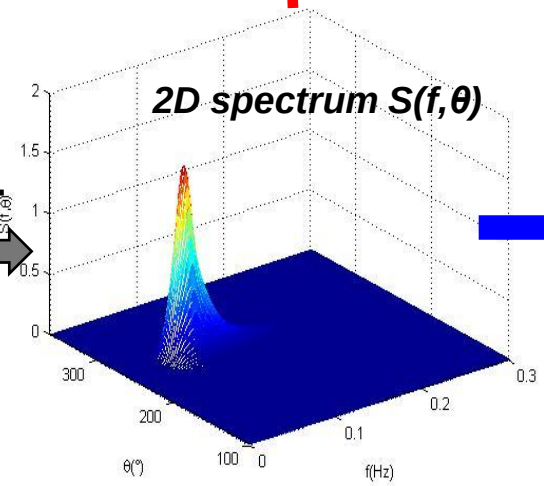


(H_s, T_p)

$$S(f) = \int_0^{2\pi} S(f,\theta)$$



FFT

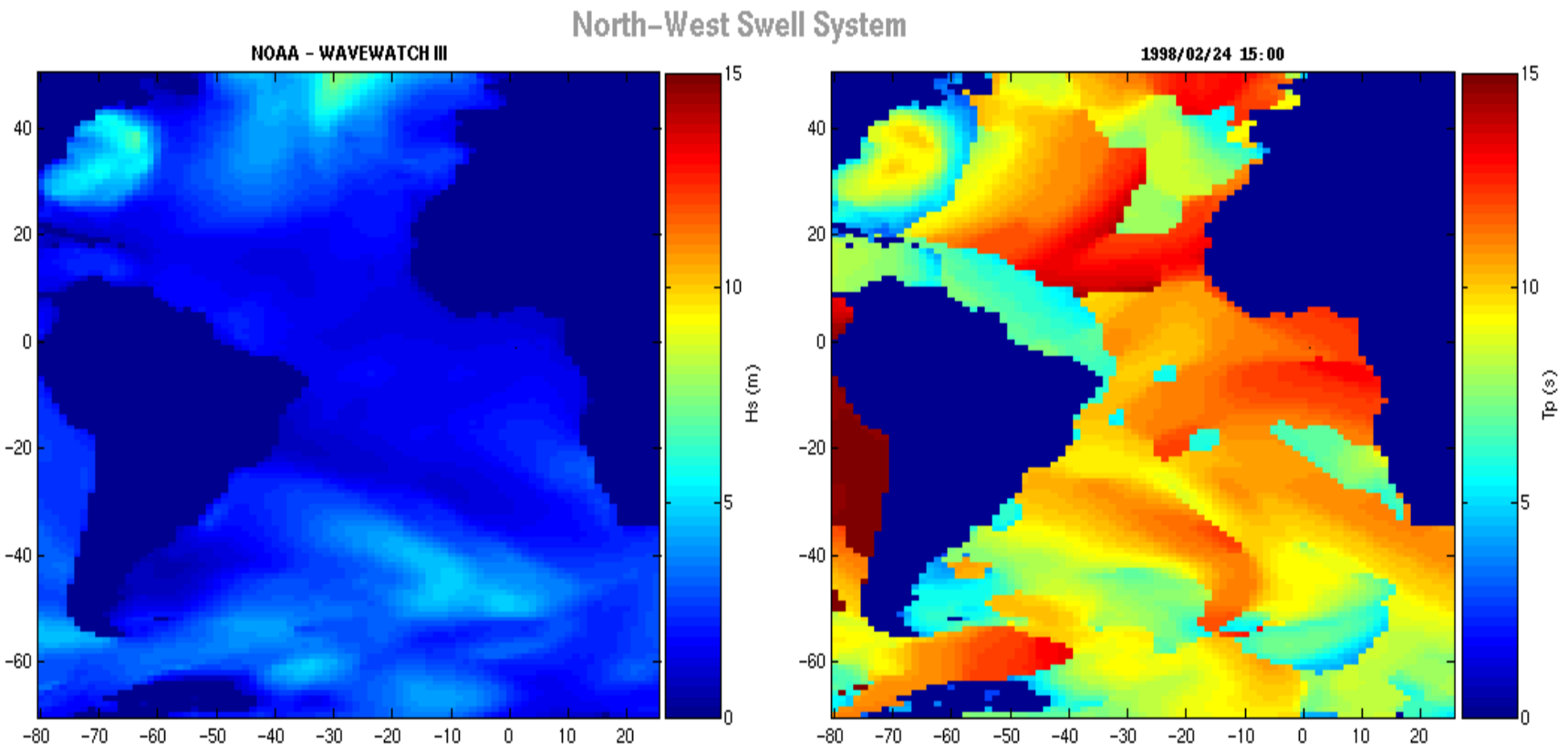


(H_s, T_p, θ_p)

- A sea state is characterized by its spectrum with associated synopsis parameters (H_s, T_p, θ_p) .

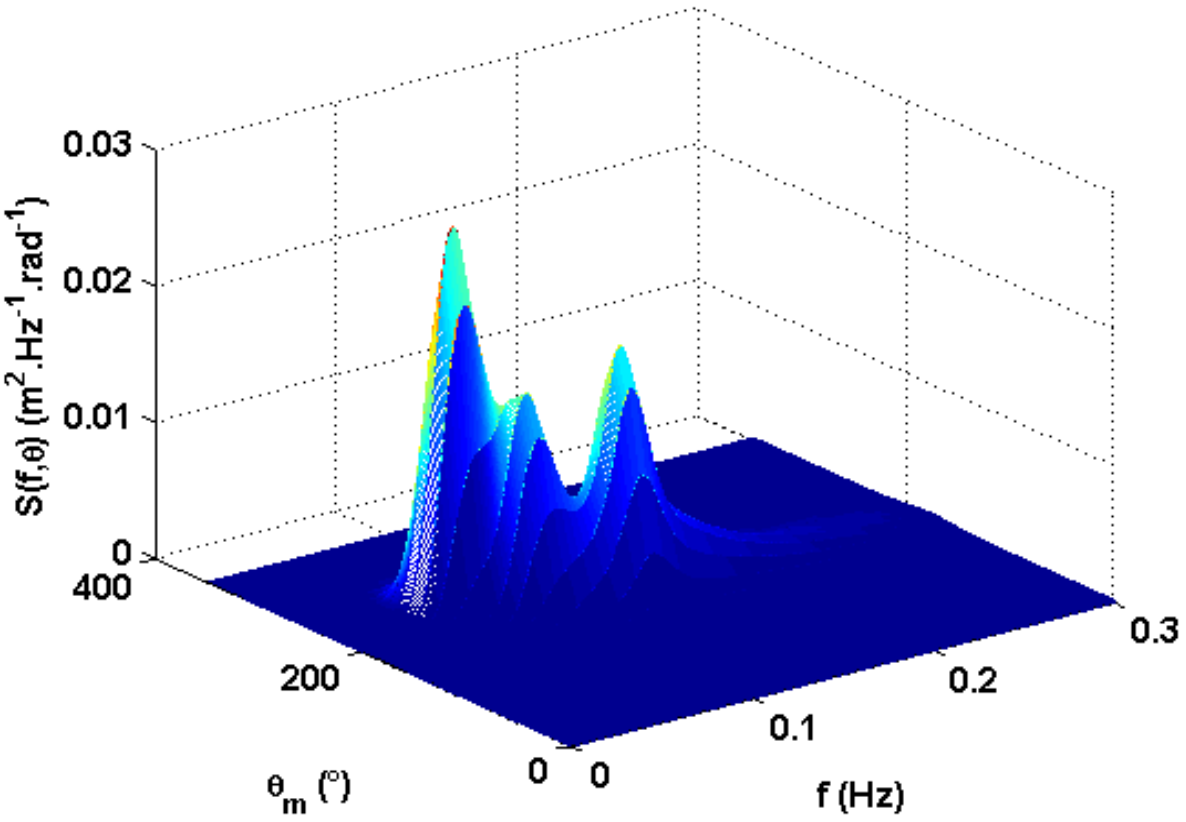
Introduction

- **Complexity of the sea states: example of West Africa**



Introduction

- A Sea state may be a combination of coexisting wave systems.

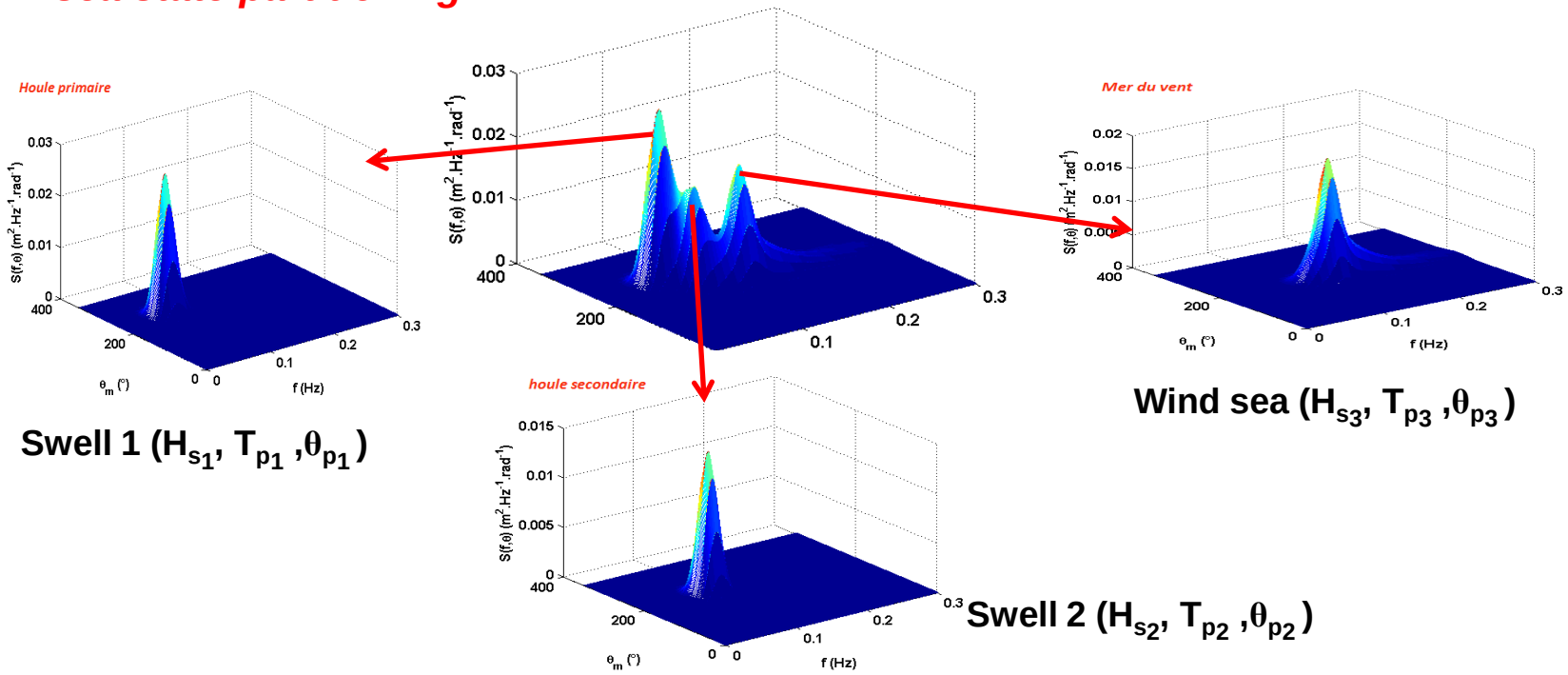


➢ A single set of 3 spectral parameters is not appropriate any more.

Introduction

- **Existing method for an accurate description of the wave climate:**

1- sea state partitioning



Swell 1 (H_{s_1}, T_{p_1} ,θ_{p_1})

Wind sea (H_{s_3}, T_{p_3} ,θ_{p_3})

Swell 2 (H_{s_2}, T_{p_2} ,θ_{p_2})

2- Joint distribution of the wave systems parameters.

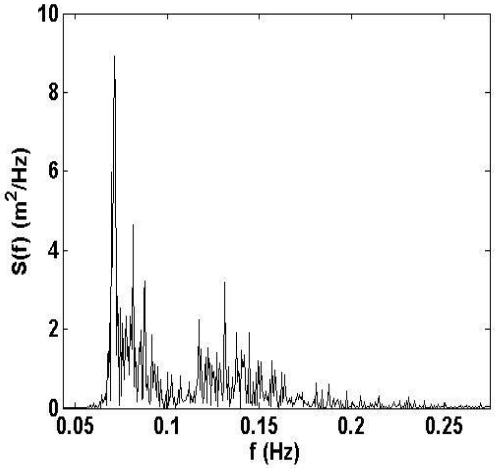
Remarks:

- **The fine description of the sea state involves too many parameters and it may be difficult to derive their joint distribution with confidence.**

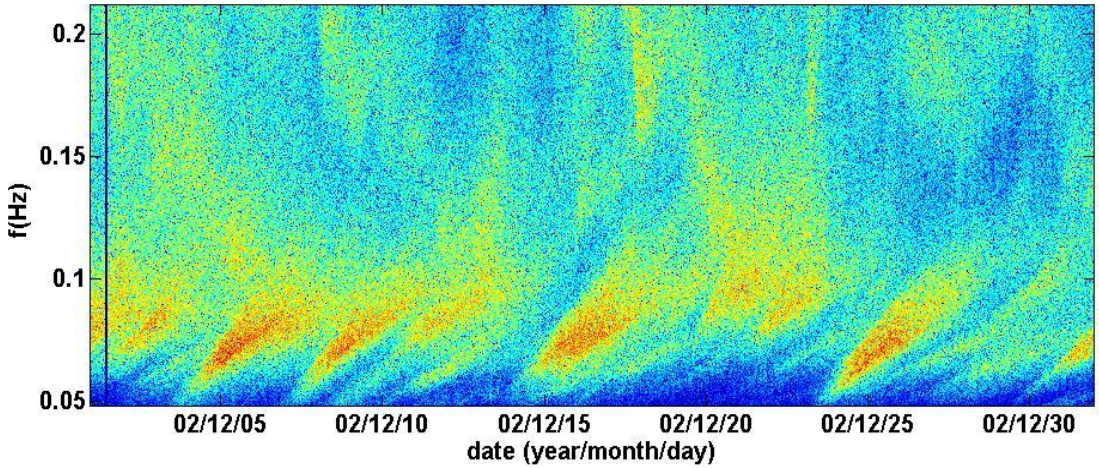
Introduction

❑ **Proposed method:**

Approach based on the modeling of wave systems events in correspondence with the storms that are at their sources.



periodogram

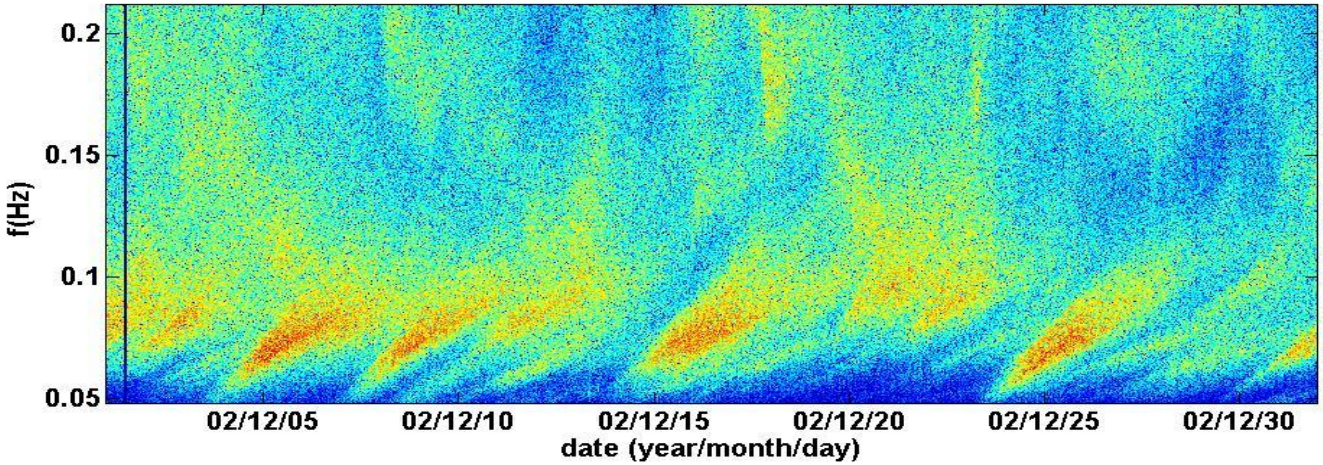


Time-history of the periodograms

➢ **Advantages:**

- **temporal coherence preservation,**
- **simplification of the data structure,**
- **an event has a physical meaning.**

Introduction



❑ **The steps of the proposed method:**

1- extract the swell events

2- find a parametric model of a swell event

3- statistically analyse the model parameters and the inter-arrival times of the swell events

Simulation of realistic swell climate histories of any desired duration for engineers uses.

Outline

1- Extraction of the swell events

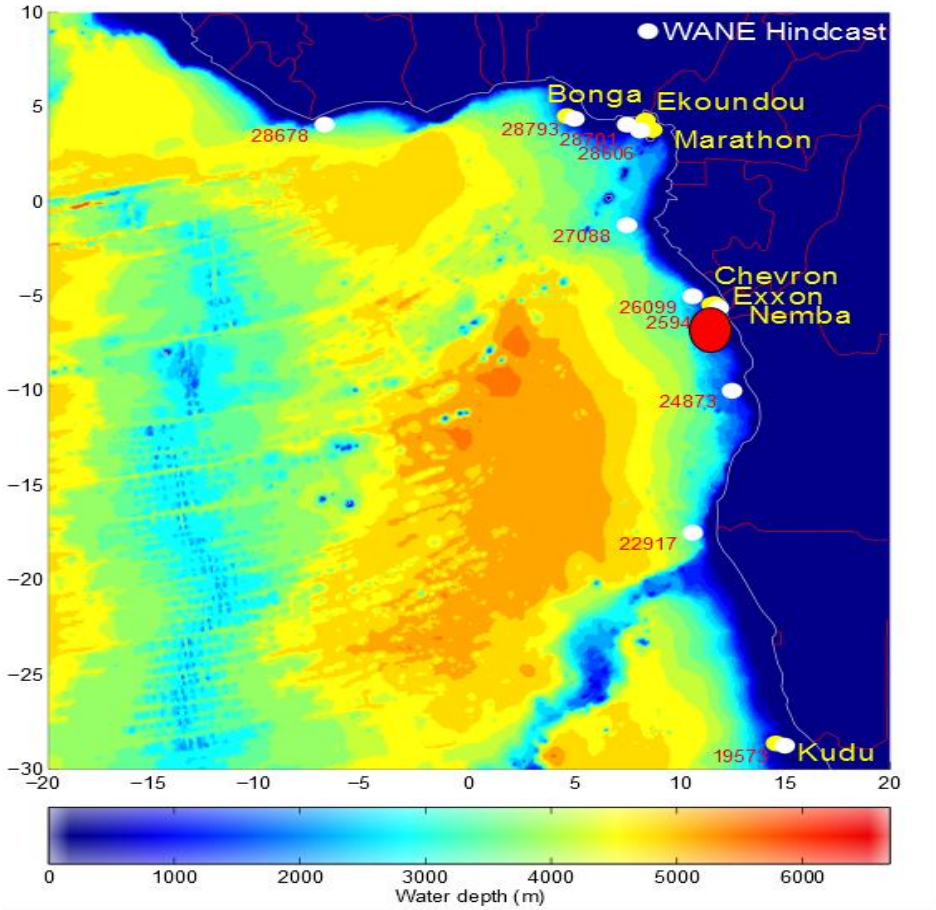
2- Swell event parametric model

3- Multivariate simulation of the parameters of the swell event model

Data

- **in situ sea surface displacement measurements from march 2001 to may 2004 ⟶ half hourly observed directional wave spectra;**

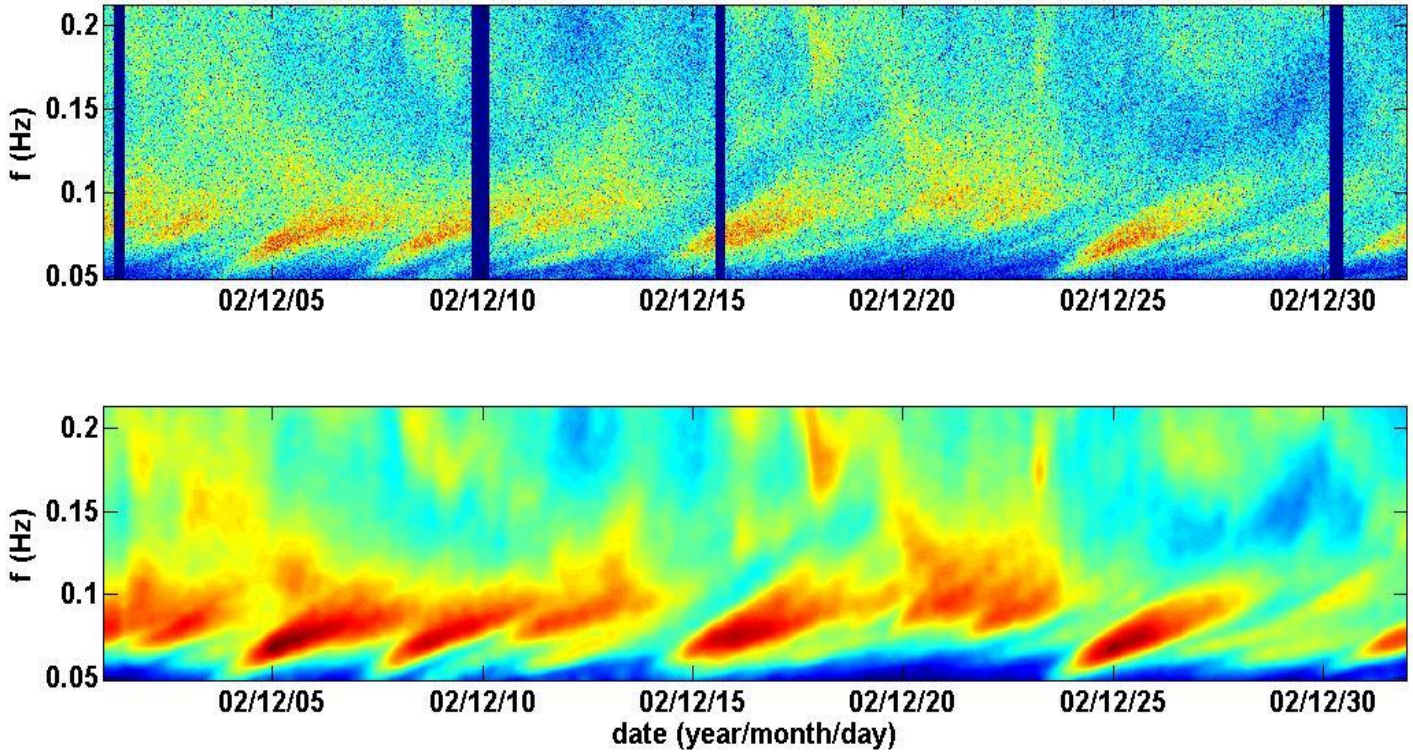
- **Hindcast 3 hourly directional wave spectra from January 1991 to December 2012.**



1-Extraction of the swell events

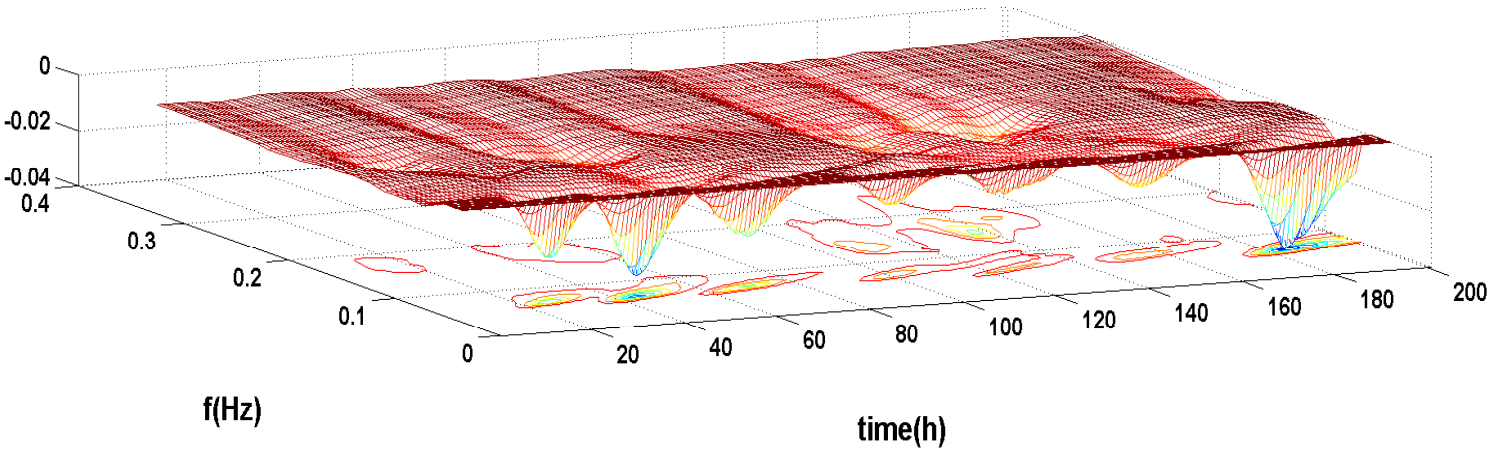
1-Extraction of the swell events

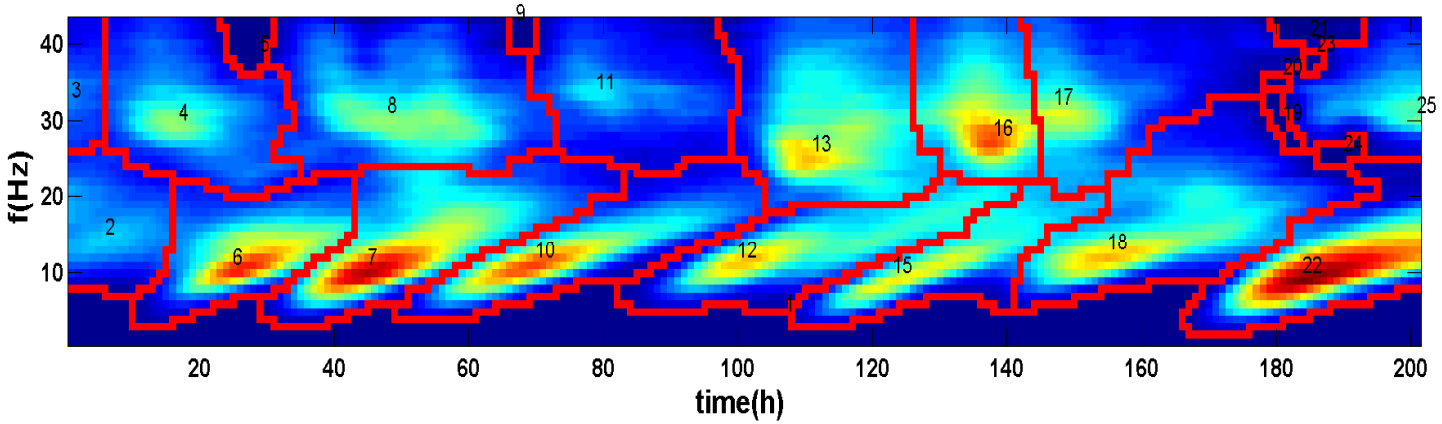
- **Smoothing of the time-history of the empirical spectra computed from buoy using Kriging or a 2 dimensional Kernel Density Estimator.**



1-Extraction of the swell events

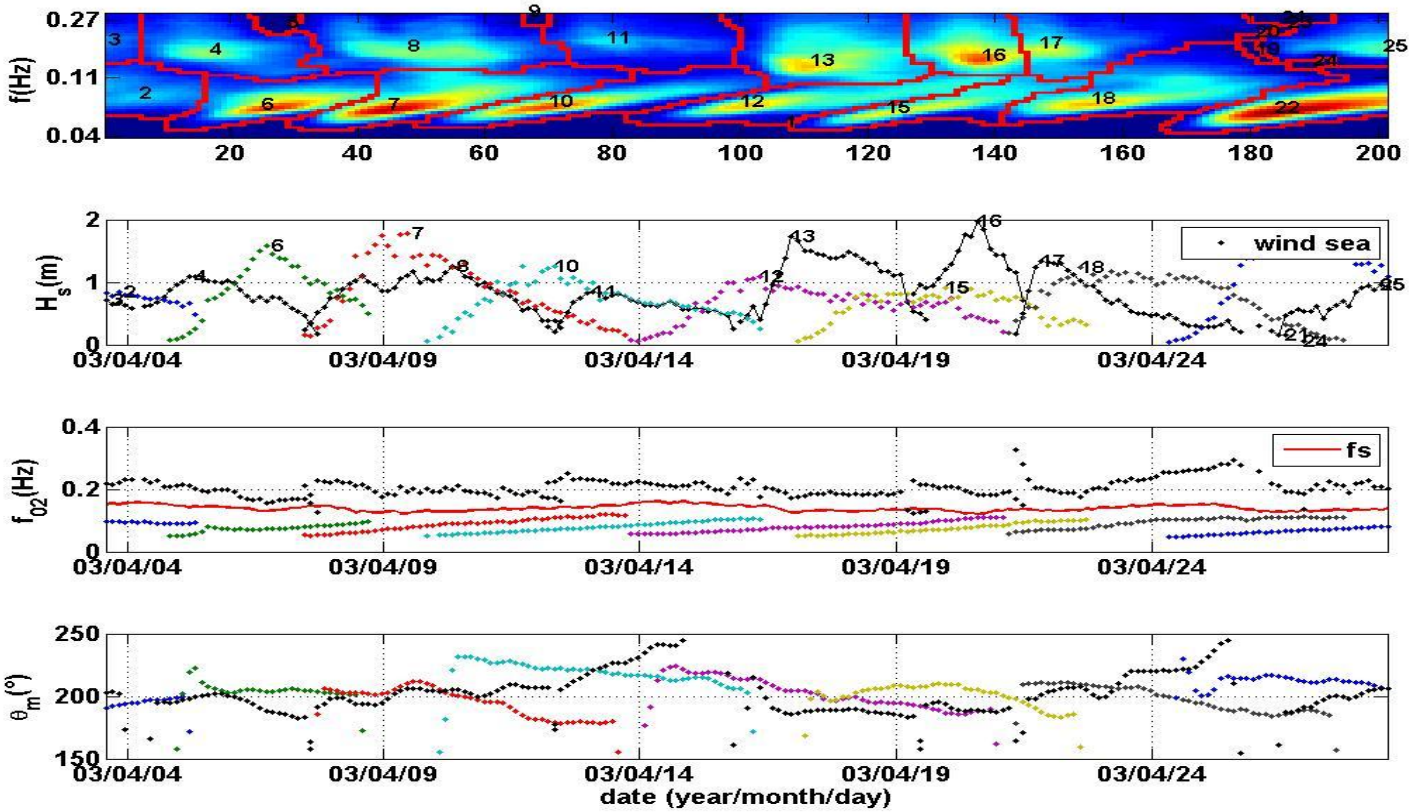
- **The extraction is carried out by using the Watershed algorithm.**





1-Extraction of the swell events

- Estimation of wave-system parameters and selection of swell events

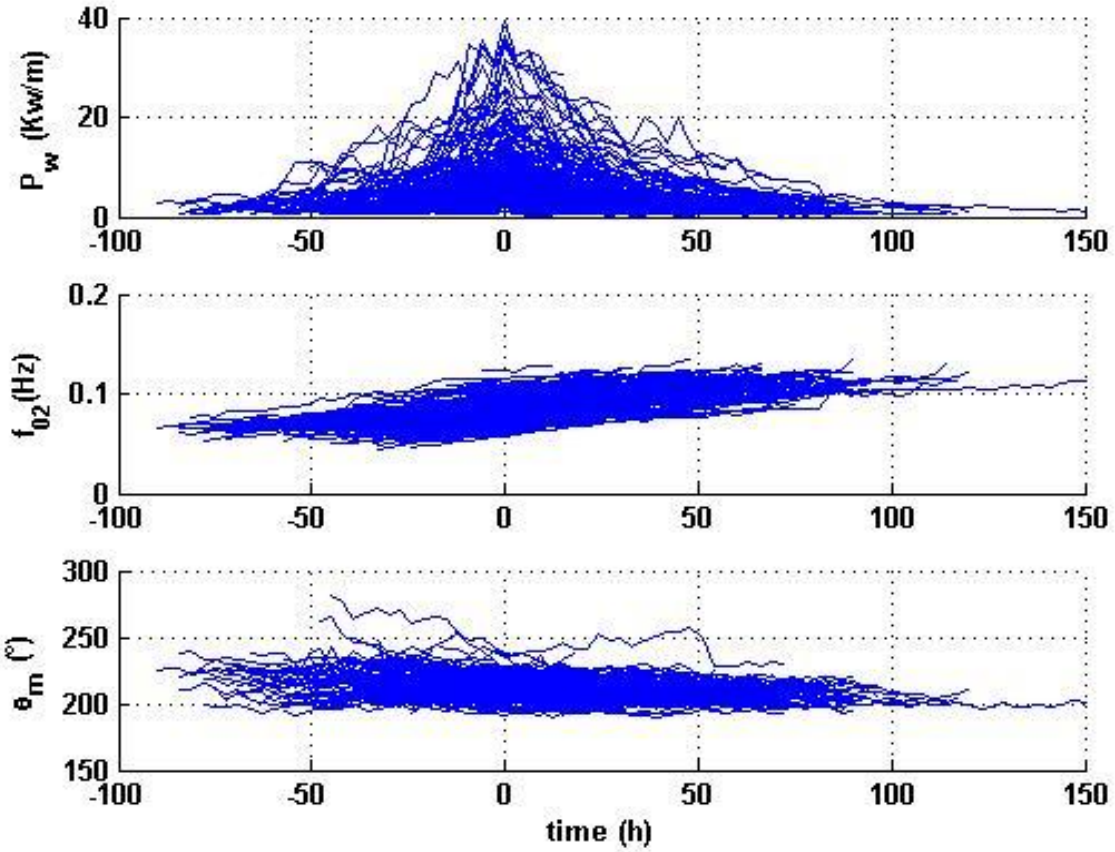


- 201 swell events are extracted from 3-year in-situ data when the number of extracted swell events from hindcast data is 80 per year in average.

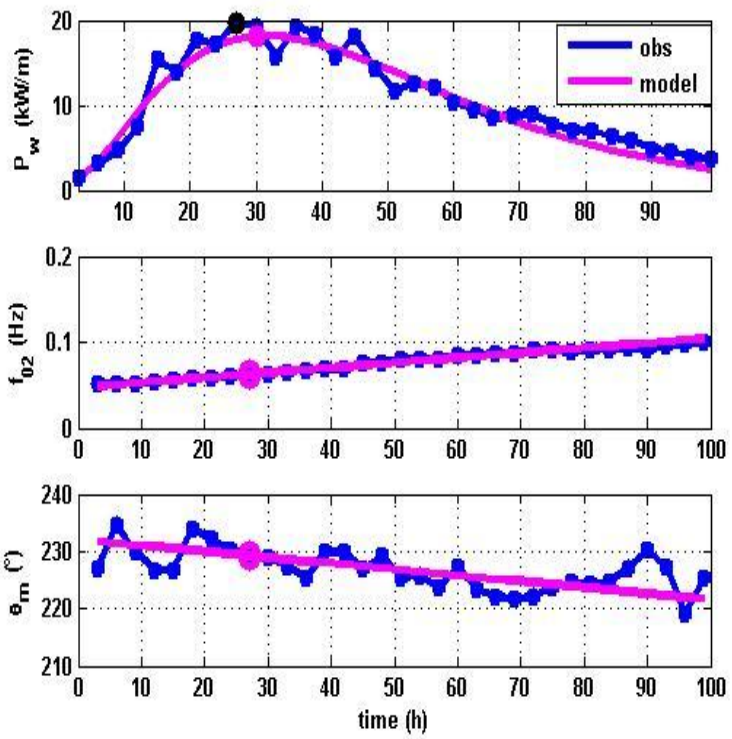
2- Swell event parametric model

2- Swell event parametric model

- **The model involves 3 sea state parameters:**
  - **wave power (P_w)**
  - **zero up-crossing frequency (f_{02})**
  - **mean direction (θ_m)**



2- Swell event parametric model

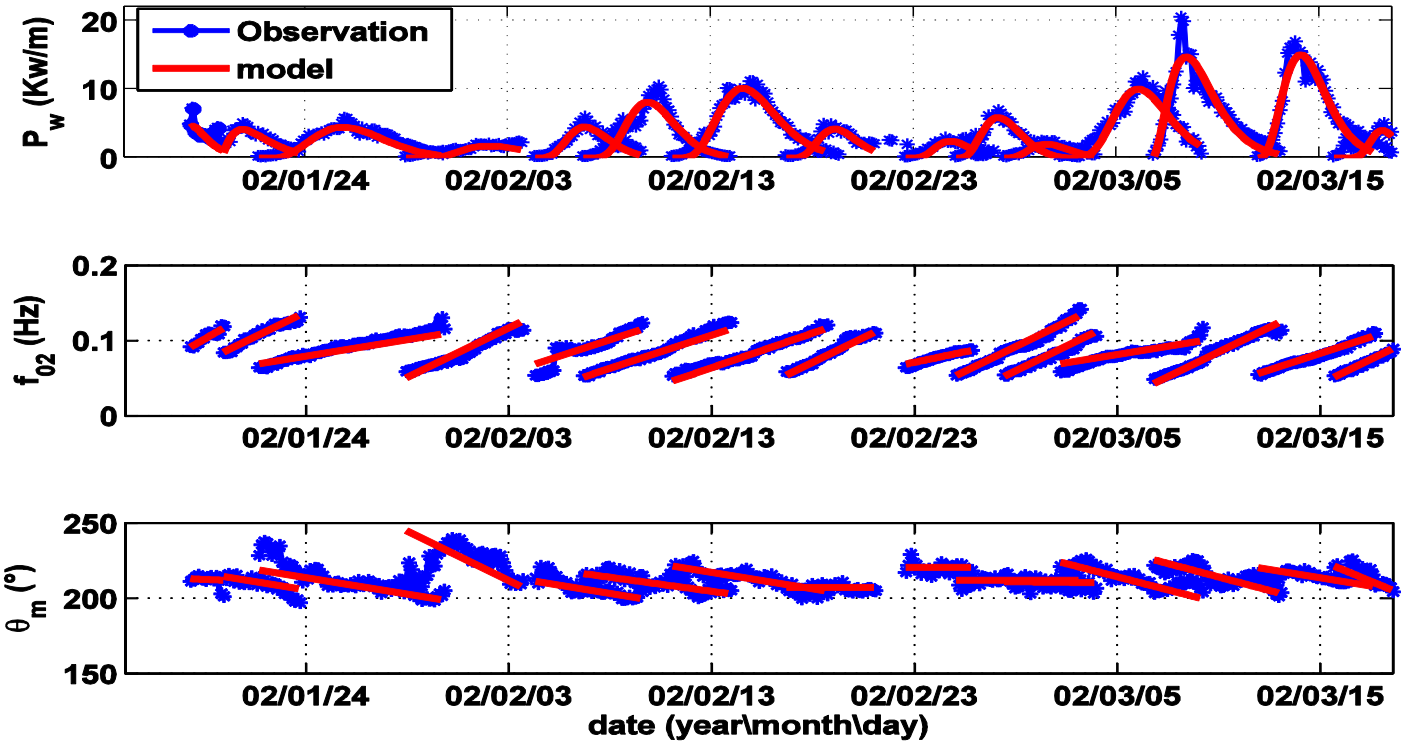


- The swell event model uses a set of 7 parameters

	model parameters	signification
Wave power $P_w(t) = \frac{E_0}{\tau^\alpha \Gamma(\alpha)} t^{\alpha-1} \exp\left(\frac{-t}{\tau}\right)$	$E_0 = \int P_w(t)\, dt$	total energy of the swell event
	α	shape parameter
	τ	Characteristic duration
zero crossing frequency $f_{02}(t) = \frac{g}{4\pi d} t + \frac{1}{T_{max}}$	d	traveled distance
	T_{max}	maximum observed period of the event
mean direction $\theta_m(t) = \omega t + \theta_0$	ω	direction slope, i.e. mean angular speed of the source storm relative to obs. point
	θ_0	direction of the first-arrival swell in the event

2- Swell event parametric model

➢ **Fitting the proposed model to the observed swells**



time-history of swell events

❑ **Now, our goal is to develop a generator of swell events parameters**

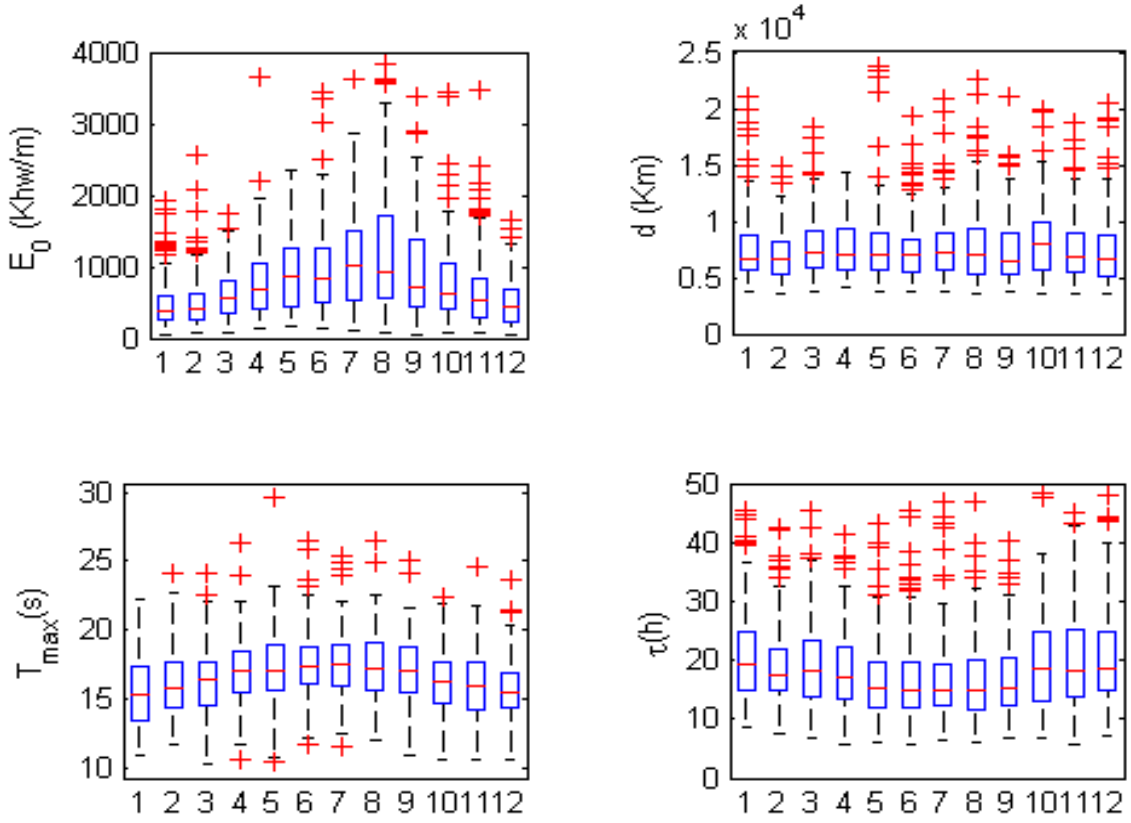
3- Multivariate simulation of the parameters of the swell events model

Checking some statistical features of the swell events parameters:

- **seasonality**
- **correlation between the parameters of a swell event**
- **correlation between a swell event and its subsequent, and correlation between events and their inter-arrival time.**

3- Multivariate simulation of the parameters of the swell events model

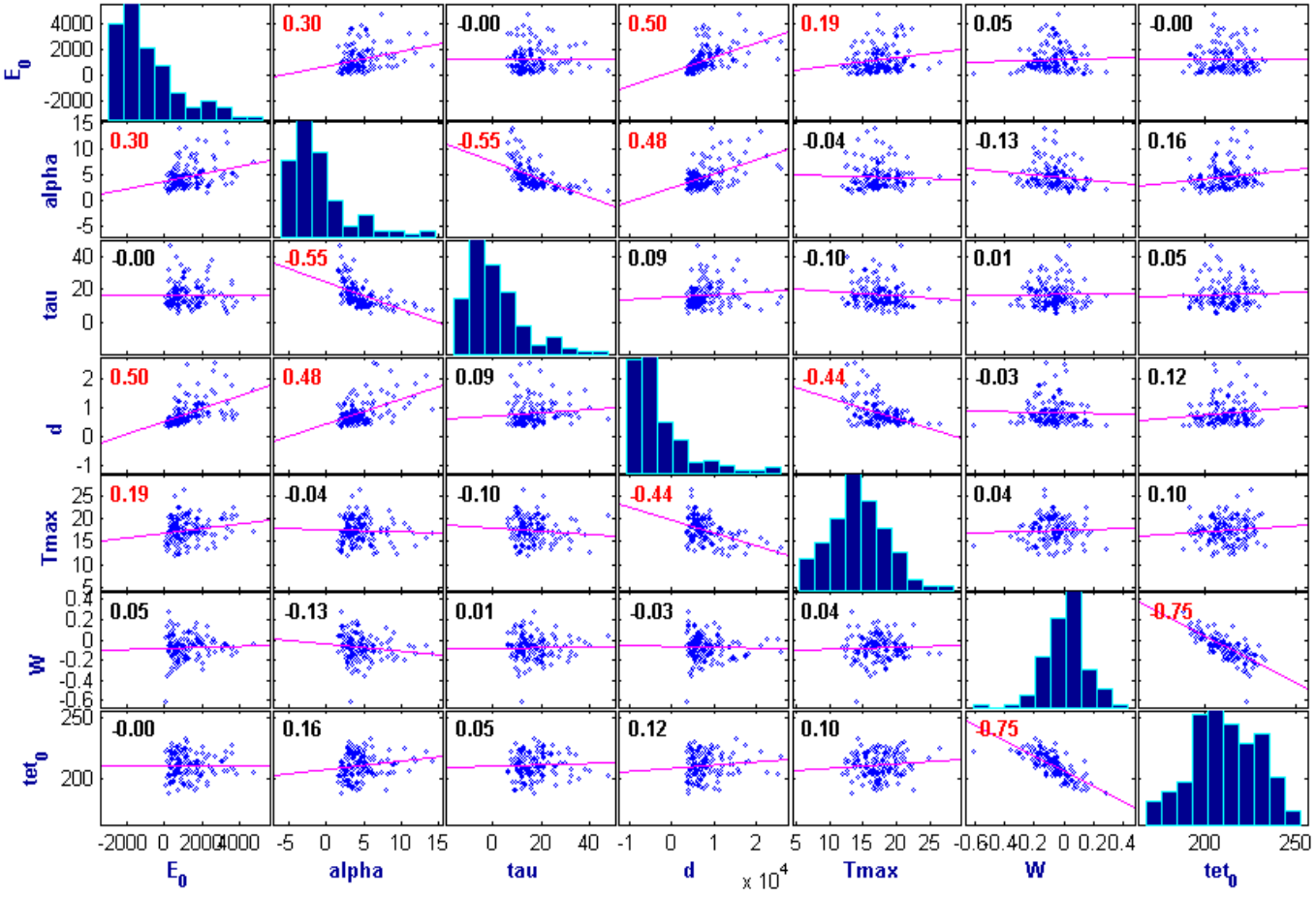
➢ **Seasonality: strongest events occur during Winter in the South Hemisphere**



Monthly distributions of the swell events parameters

3- Multivariate simulation of the parameters of the swell events model

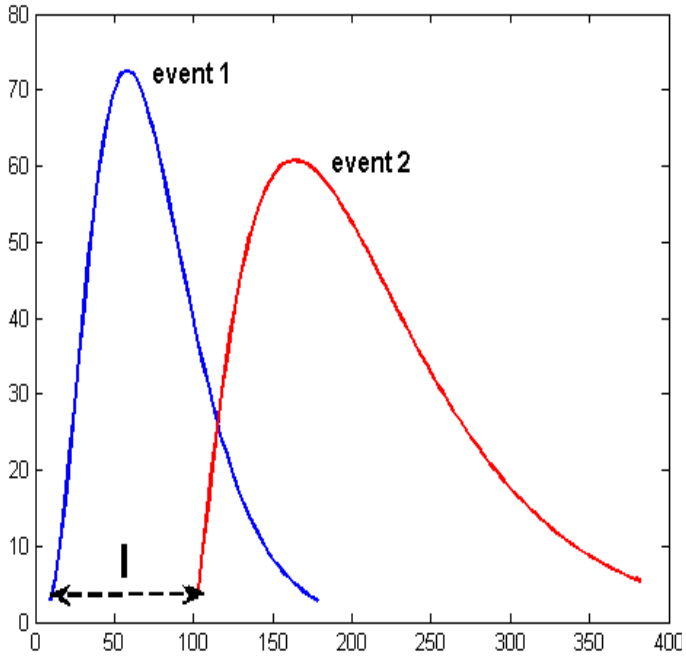
➢ **correlation between the parameters of a swell event**

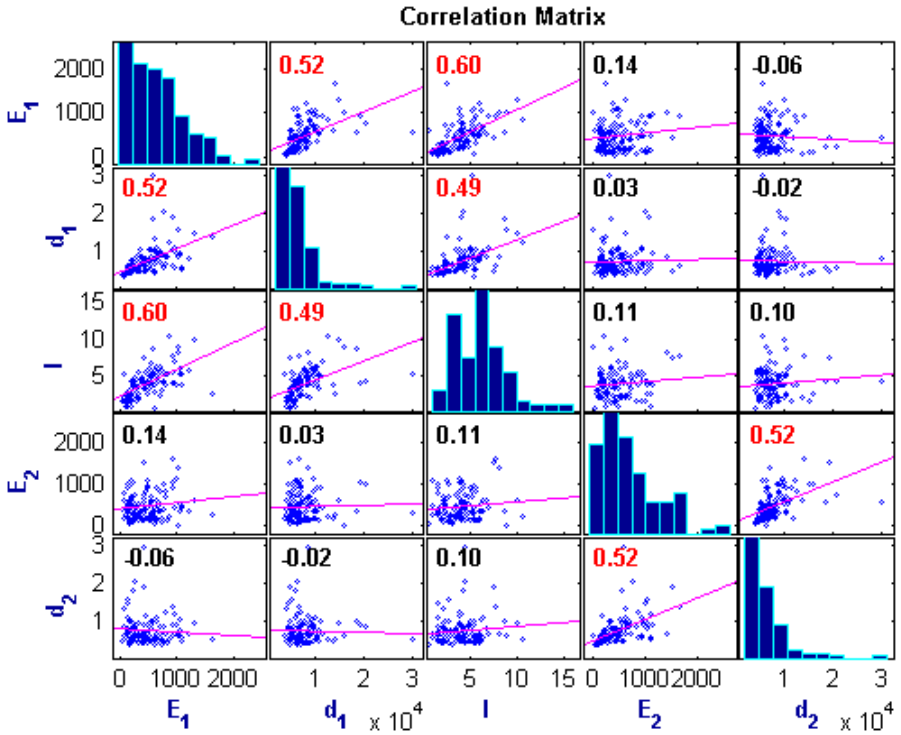


• **The directional parameters (ω, θ_0) are found to be statistically uncorrelated from the others.**

3- Multivariate simulation of the parameters of the swell events model

➢ **Correlation between a swell event and its subsequent, and correlation between events and their inter-arrival time.**





• **Excluding seasonality, events can be considered as independent**

• **The inter-arrival time is found to depend only on the previous event**

3- Multivariate simulation of the parameters of the swell events model

➢ **Proposed monthly simulation diagram:**

1. Joint probability distribution of (E_0, d) and (ω, θ_0) using gaussian copula to model their dependence .

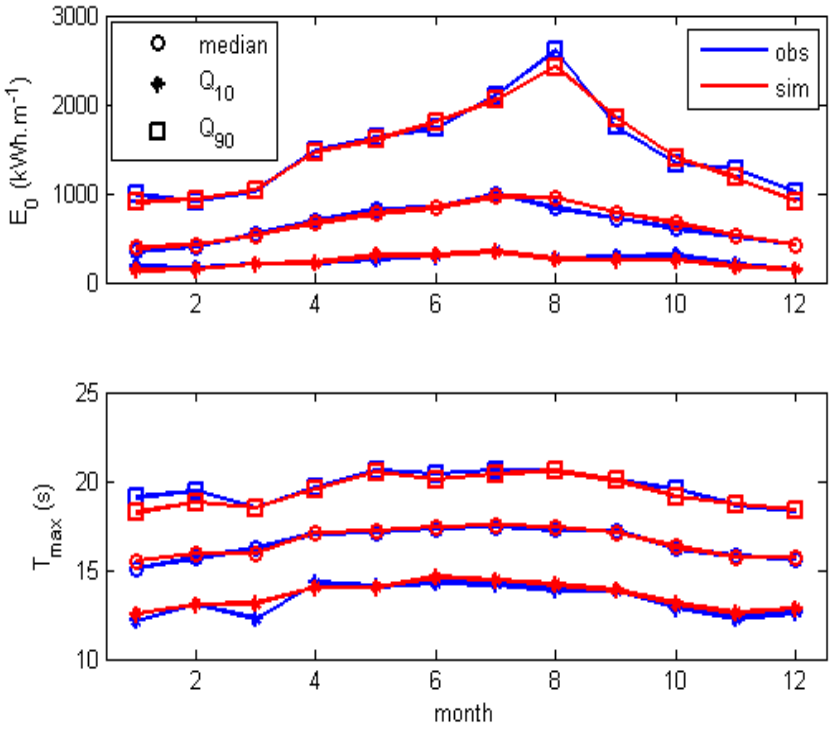
2. Probabilities distributions of α, τ, I, T_{max} given the joint probability of (E_0, d) using GLM model.

3- Multivariate simulation of the parameters of the swell events model

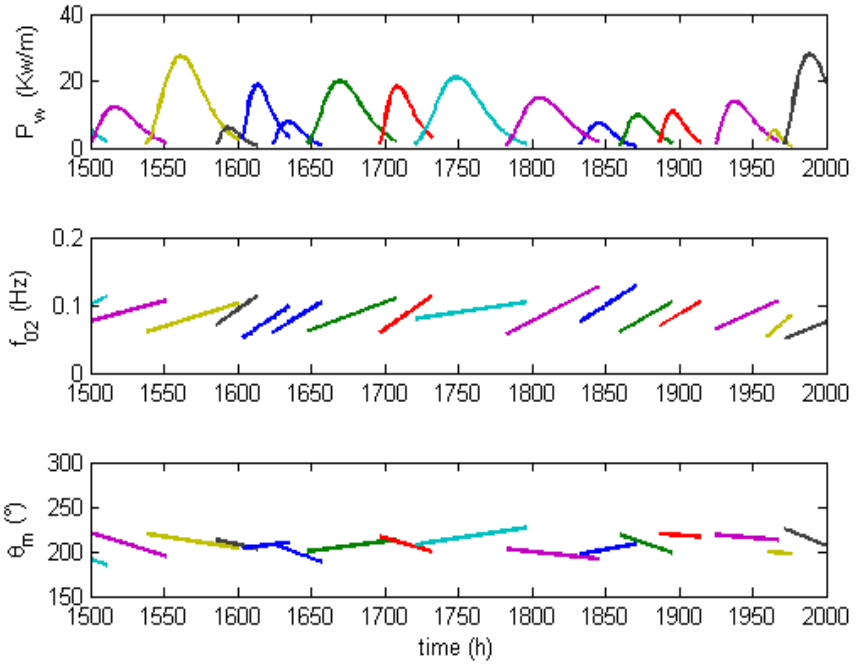
➢ **Proposed monthly simulation diagram:**

1. Joint probability distribution of (E_0, d) and (ω, θ_0) using gaussian copula to model their dependence .

2. Probabilities distributions of α, τ, I, T_{max} given the joint probability of (E_0, d) using GLM model.



➢ **Example of reconstructed swell**



Conclusion

- A new approach based on swell event is proposed to model the swell climate. It is a satisfactory way to preserve the temporal coherence of swells.
- A swell event parametric model is also proposed and it is found to fit well the observed swell events.
- The analysis of the swell events parameters shows seasonality and the study of the dependence allows us to propose a monthly mutivariate simulation diagram of these parameters.

Perspectives

- we still working on the simulation of monthly multivariate swell events parameters in order to derive realistic histories of swell events.
- Use some applications such as fatigue, wave energy harvesting or the estimation of coastal shore erosion to validate the simulated swell climates.

Thank you!