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Exploring spectral wave climate variability using a weather type approach

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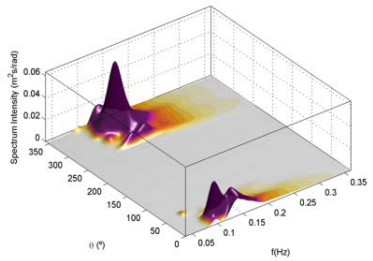


1. INTRODUCTION- Motivation

-Traditional approaches for determining wave climate variability have been broadly focused on aggregated or statistical parameters (Hs,Tm,**θ**m…)

- The overall complexity of the wind-wave fields is contained in the wave spectra, S(f, **θ**)

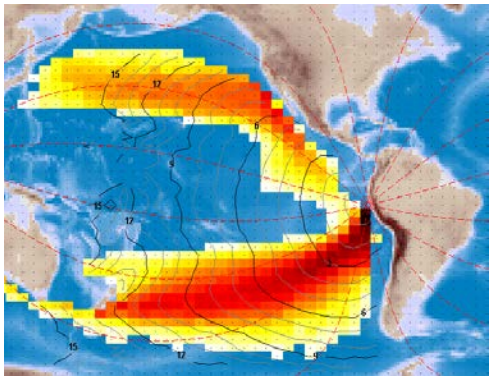
- Future wave climate is addressed usually by changes in Hs, changes in Tm, and changes in **θ**m, but not by changes in pdf(Hs,Tm,**θ**m) or S(f,**θ**)

-- Many coastal impacts depend on Hs,Tm and **θ**m: wave run-up, overtopping, vertical breakwater stability, harbor agitation, …

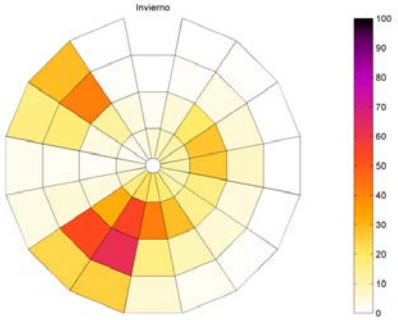
-- Wave propagation in shallow water areas can sometimes be erroneous calculated using spectral parameters (Hs,Tm,**θ**m…)

1. INTRODUCTION- Objetives/Summary

- To propose a framework to model the seasonal-to-interannual variability of directional spectra at a given location
- The framework is based on data mining – clustering techniques
- A statistical downscaling model is proposed to obtain a probabilistic relationship between a large-scale predictor (X) and a local predictand (Y)



$$X \rightarrow Y$$



Large-scale met-ocean predictor

Local directional spectra

- The framework is able to deal with another temporal scales and predictors and predictands (ENSO and Tropical Cyclone activity)

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1. Motivation and Summary
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6. Other applications of SD
7. Conclusions

$$\mathbf{X}_d \xrightarrow{SD} \mathbf{Y}_d$$

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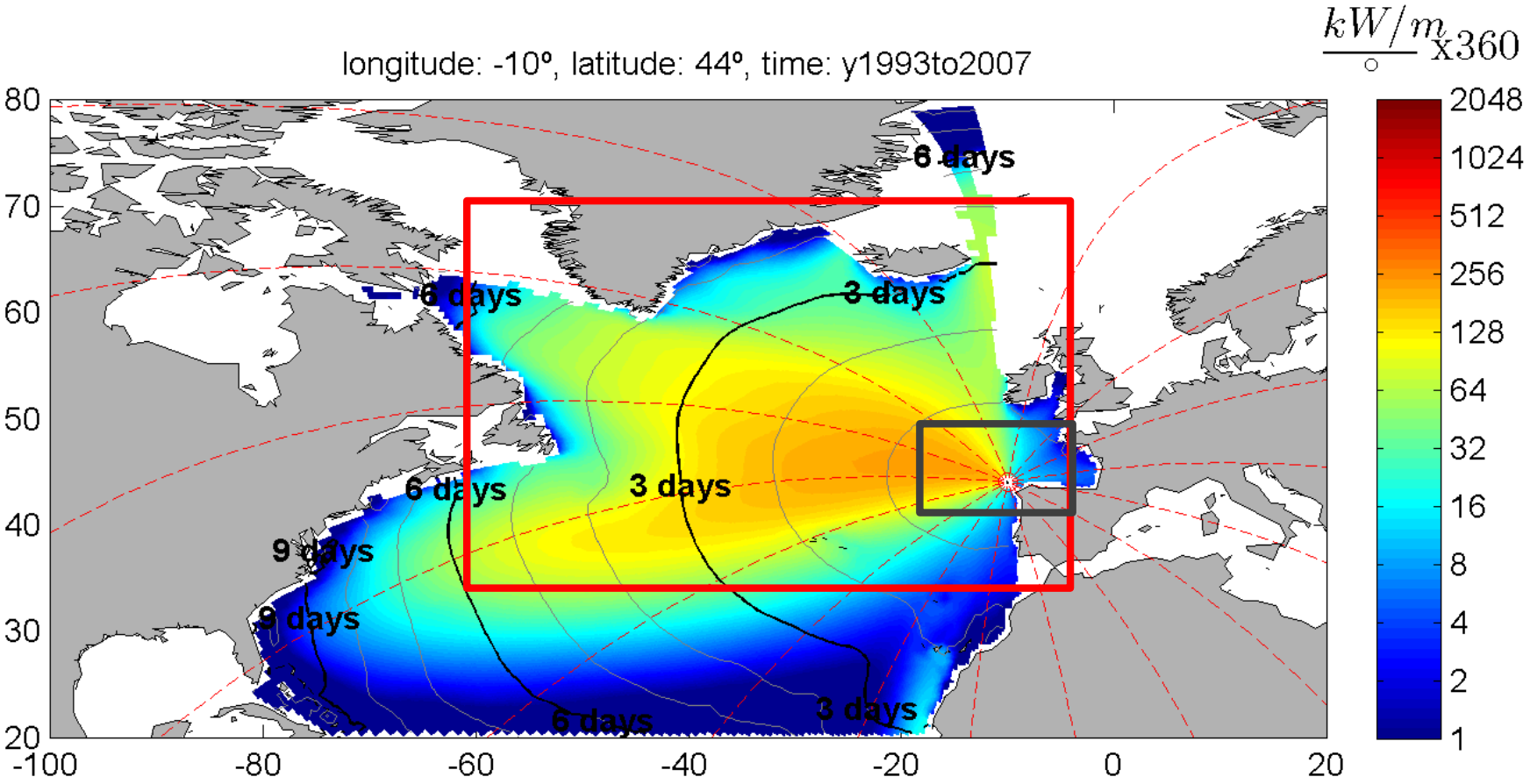
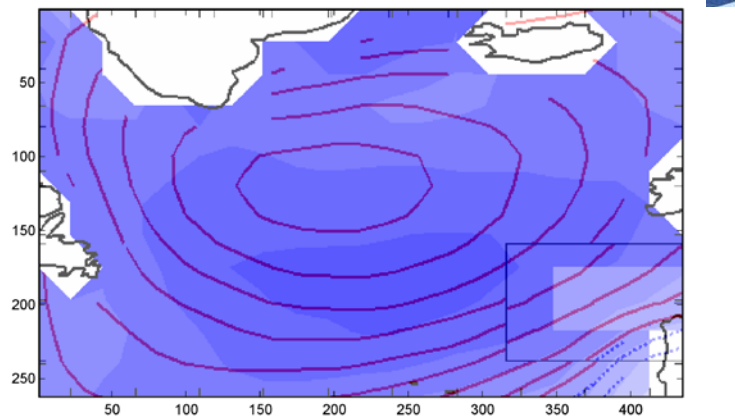
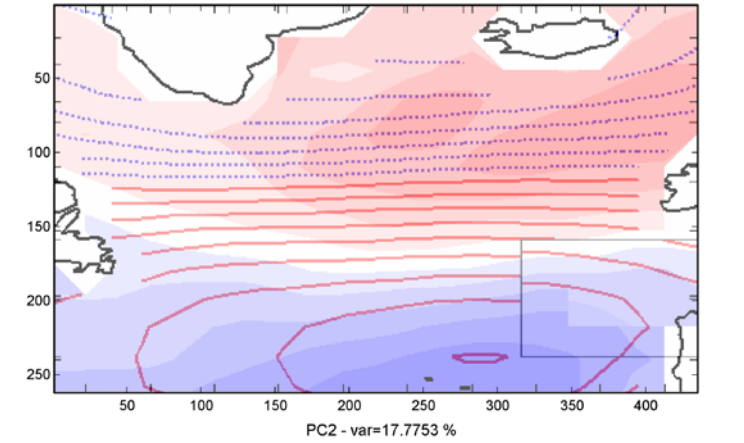
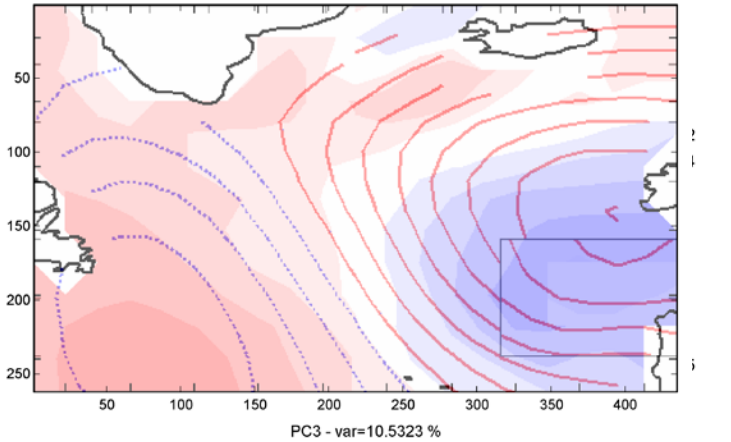
Wave Footprint
(Poster 4, Perez et al)

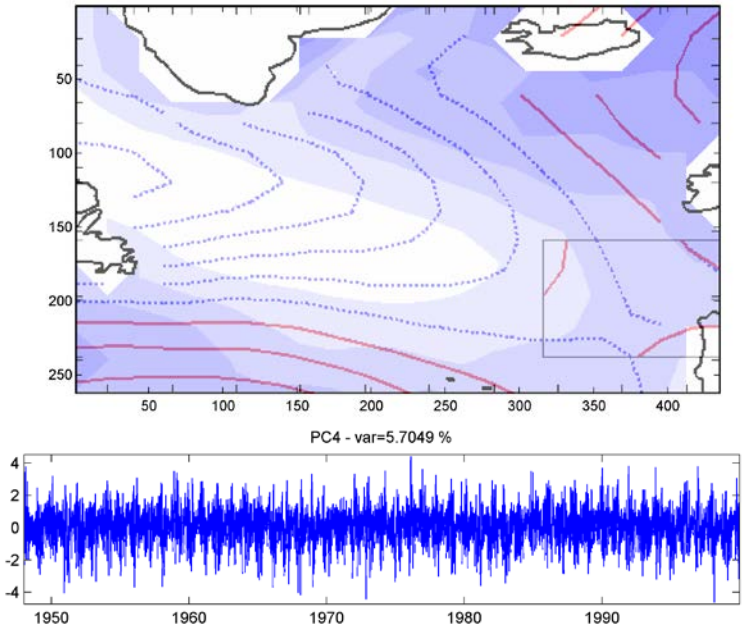


PRINCIPAL COMPONENT ANALYSIS







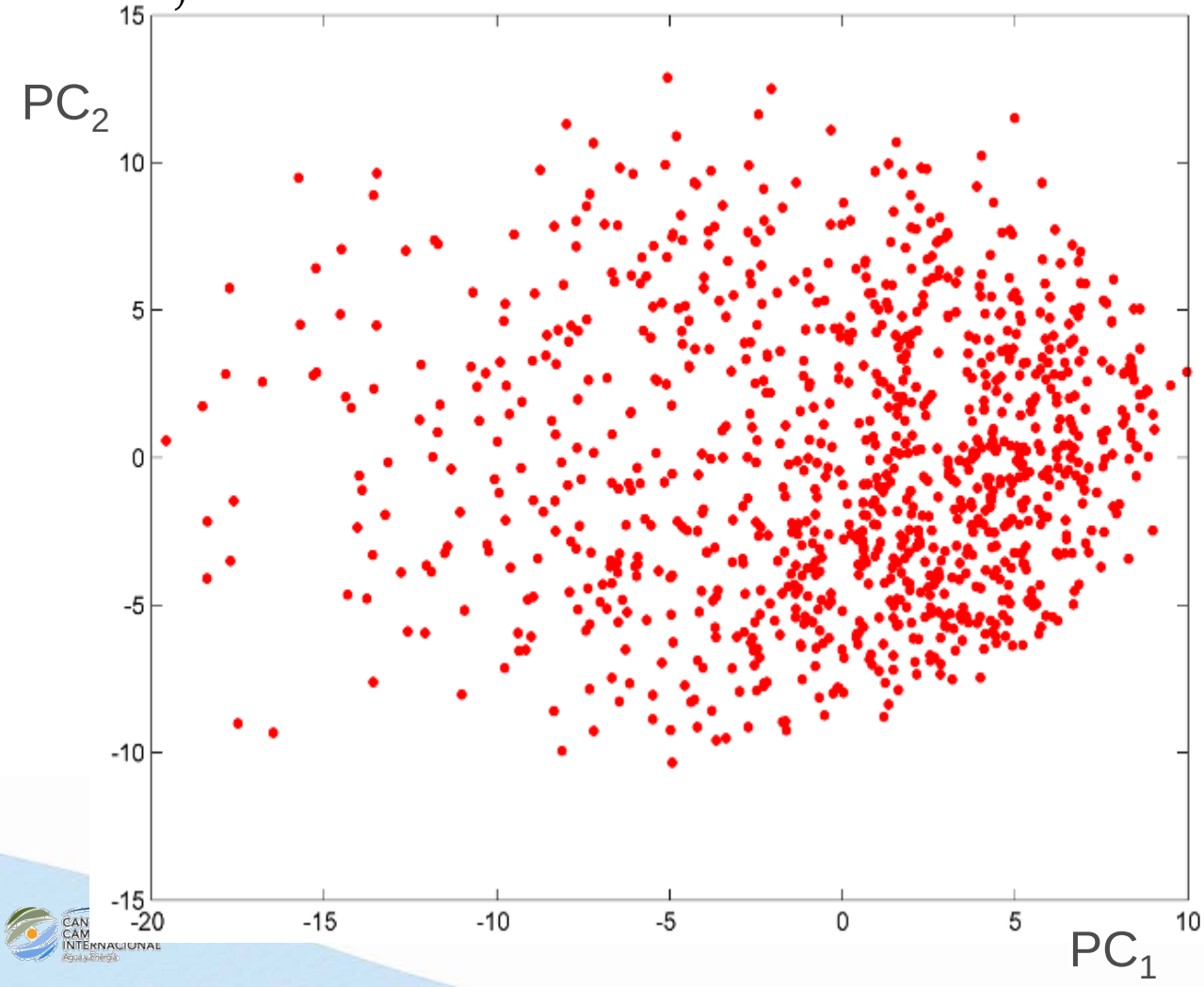


{PC1(t), PC2(t), PC3(t), PC4(t),…}

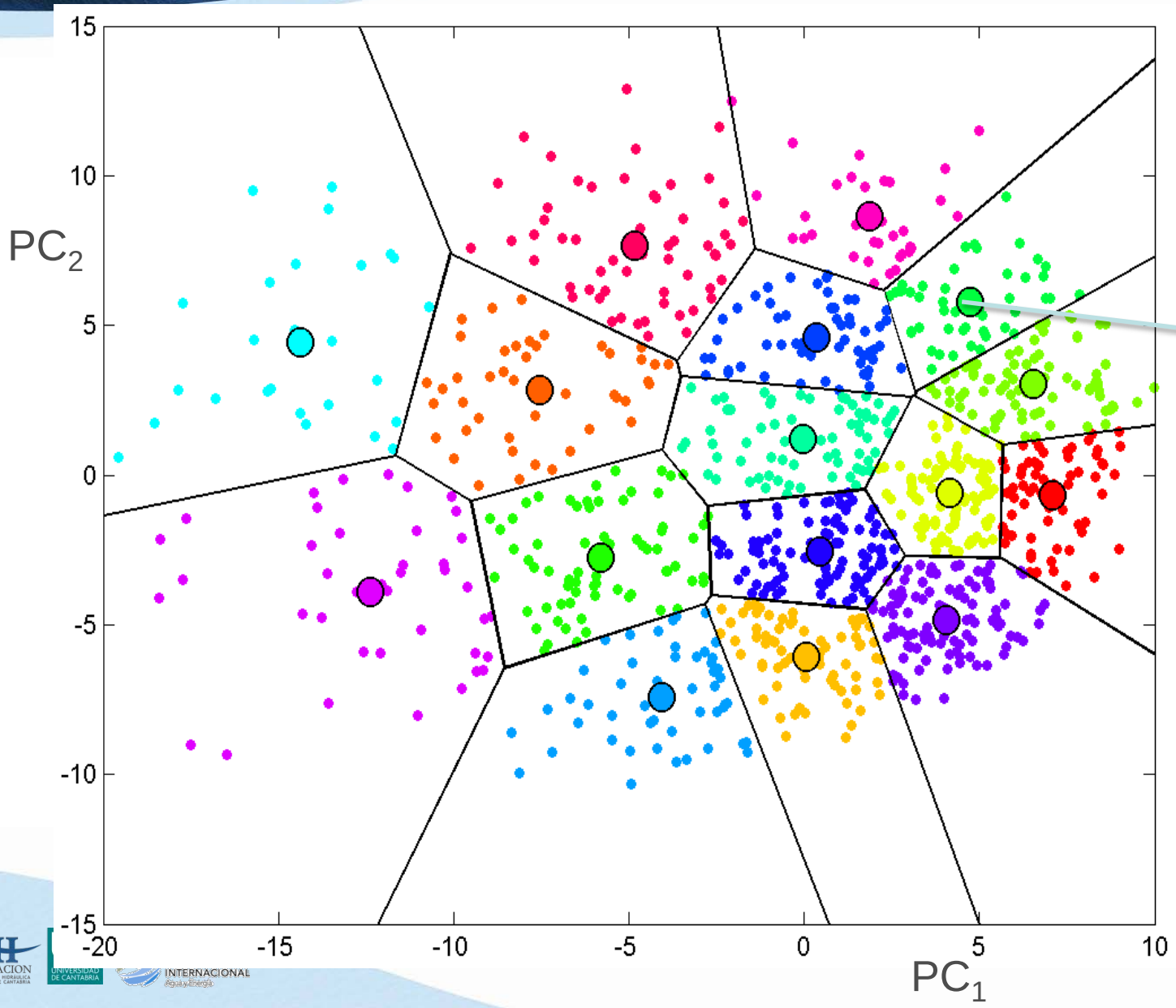
K -means

$\{X_1, X_2, \ldots, X_N\}$ *N* data

$\{v_1^0, \ldots, v_M^0\}$ *M* centroids or prototypes



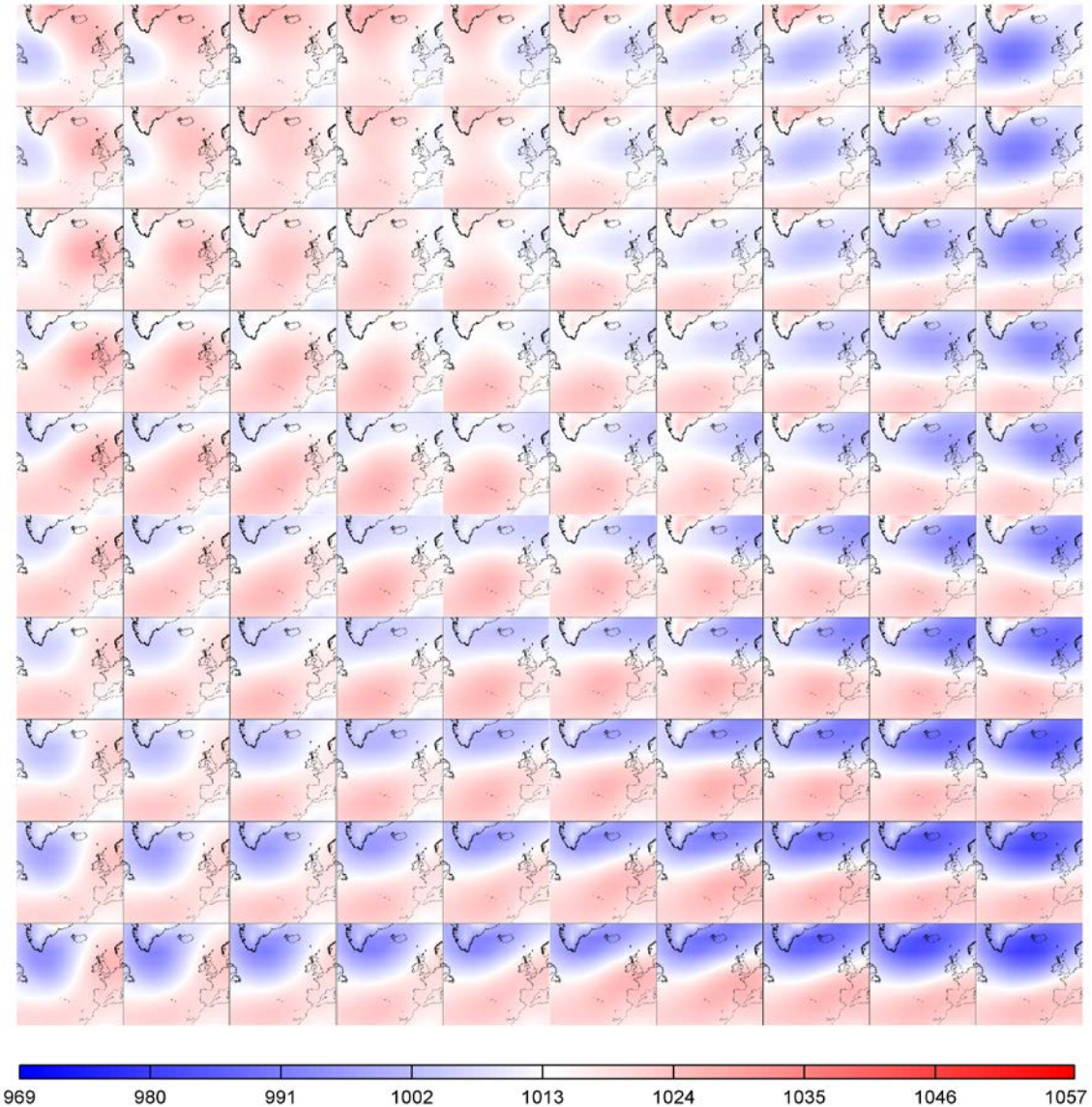
K -means



PC1*,PC2*

❖Synoptic Atmospheric Circulation patterns

$$SLP^*(x) = EOF_1(x)PC_1^* + EOF_2(x)PC_2^* + \ldots$$



N=100

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$$\mathbf{X}_d \xrightarrow{SD} \mathbf{Y}_d$$

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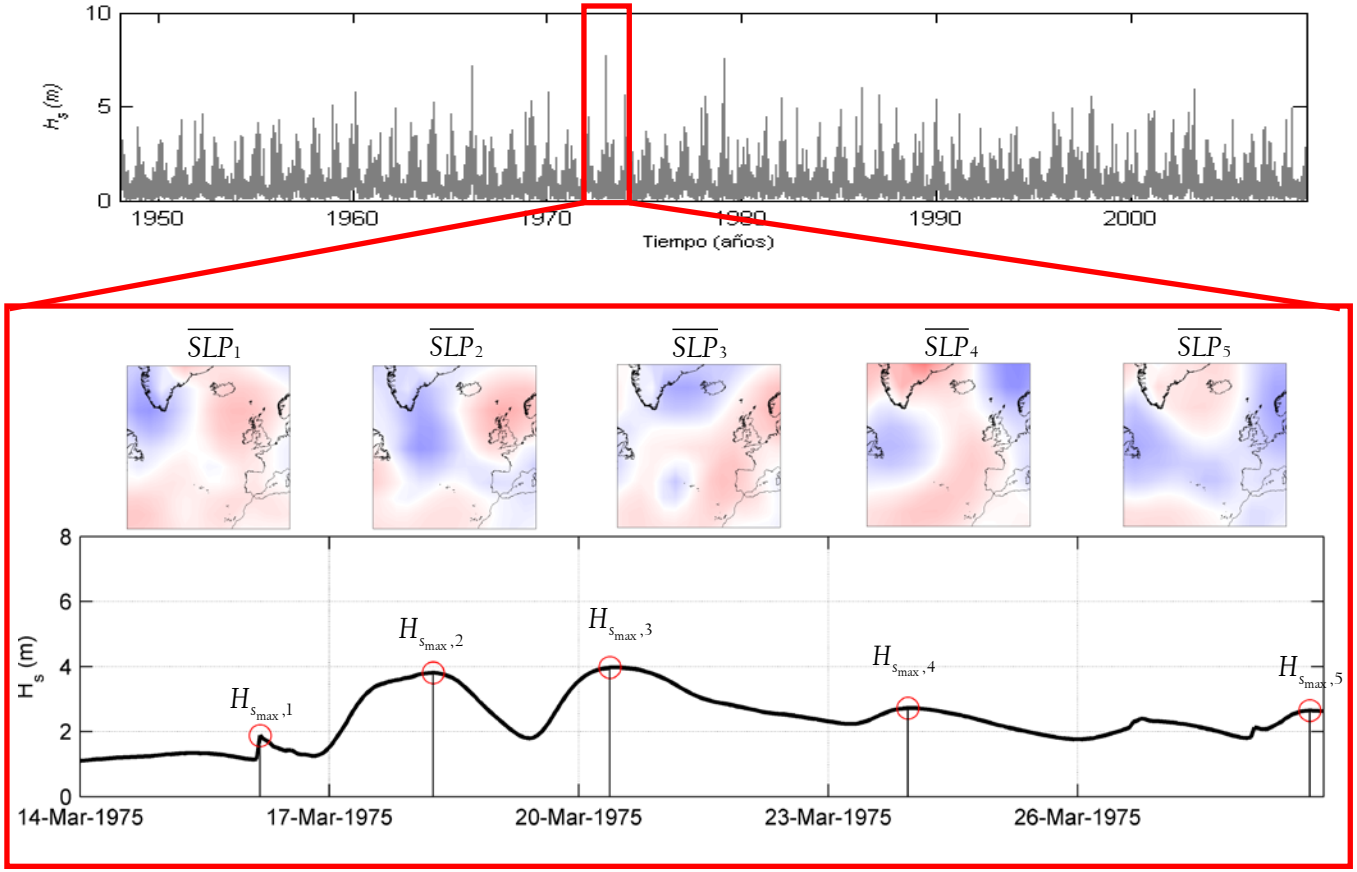
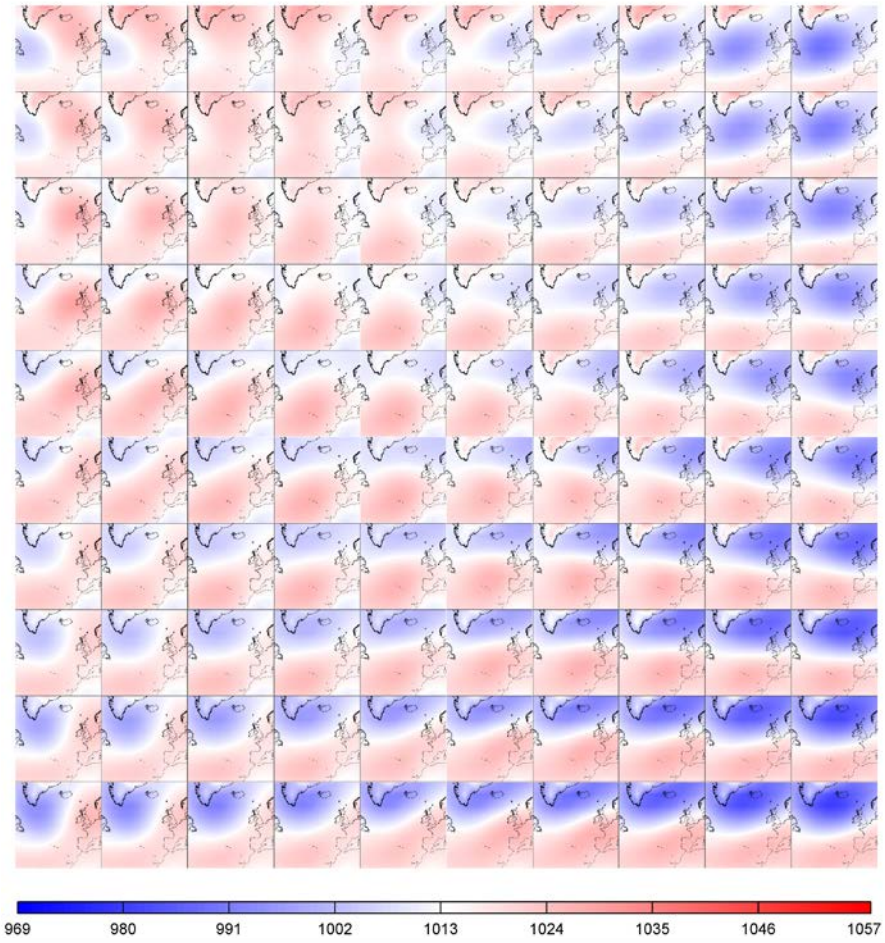
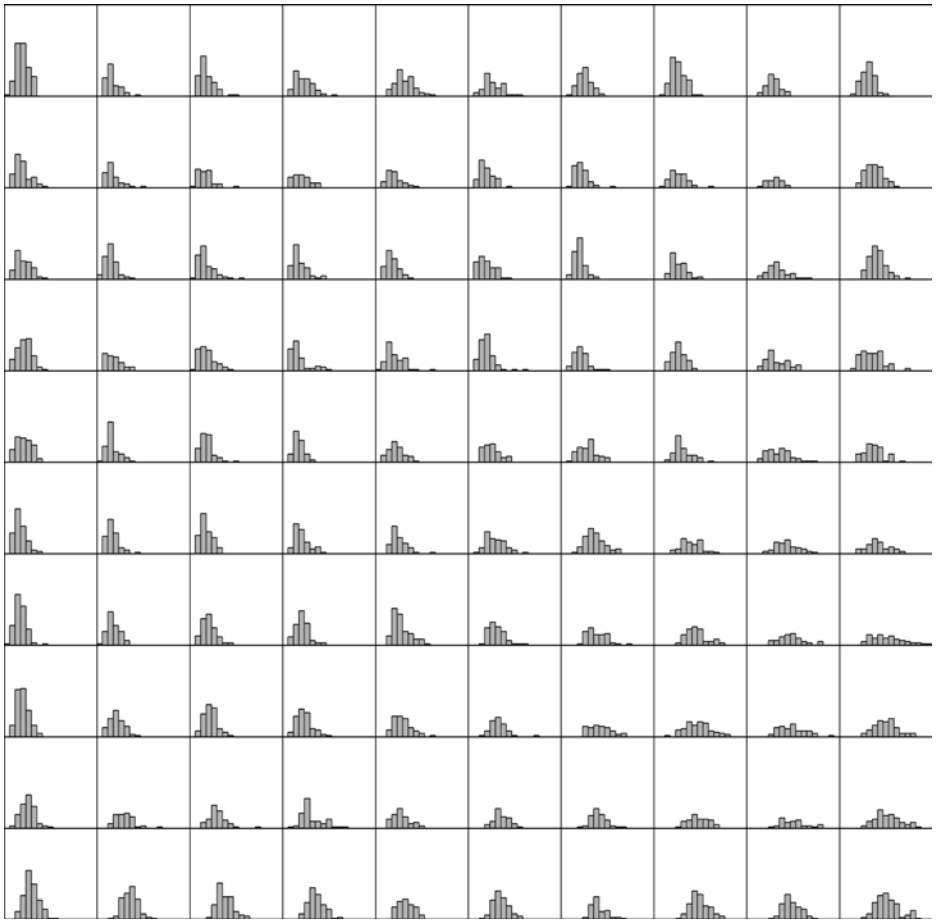
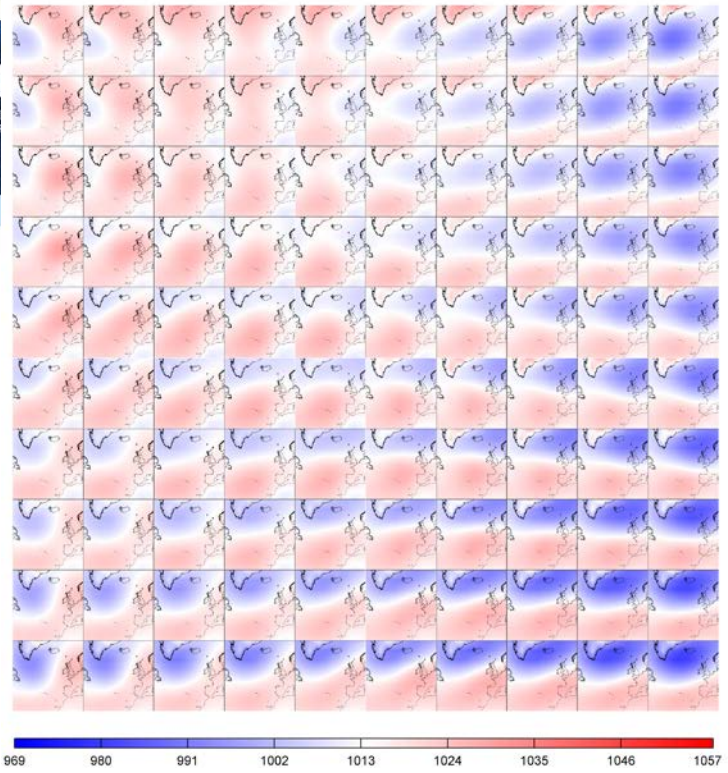
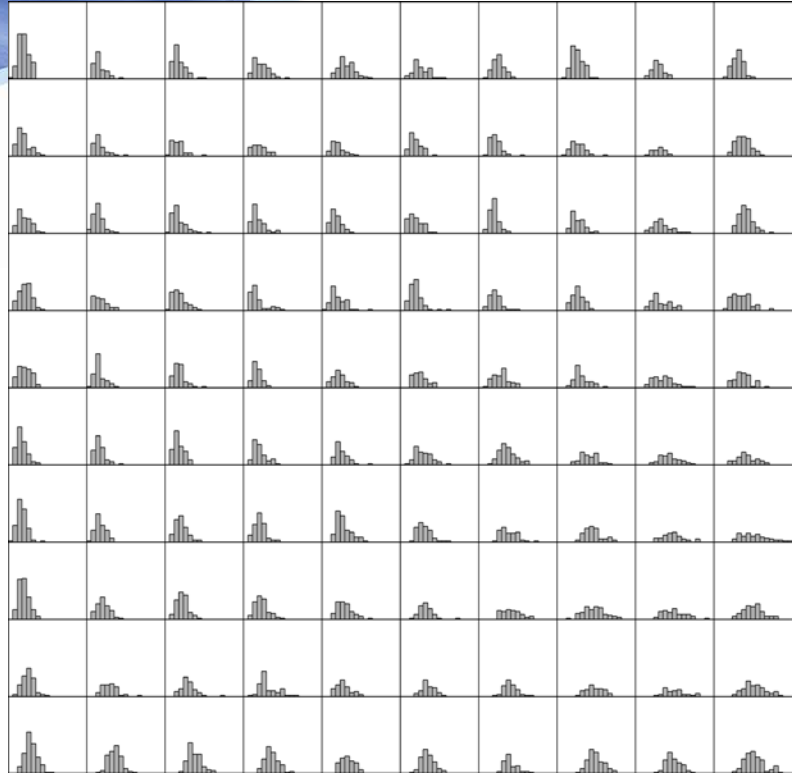

10
5
0
H_s (m)
1950
1960
1970
1980
1990
2000
Tiempo (años)
$\overline{SLP}_1$
$\overline{SLP}_2$
$\overline{SLP}_3$
$\overline{SLP}_4$
$\overline{SLP}_5$
8
6
4
2
0
H_s (m)
$H_{s_{max},1}$
$H_{s_{max},2}$
$H_{s_{max},3}$
$H_{s_{max},4}$
$H_{s_{max},5}$
14-Mar-1975
17-Mar-1975
20-Mar-1975
23-Mar-1975
26-Mar-1975

$$\mathbf{X}_d \xrightarrow{SD} \mathbf{Y}_d$$

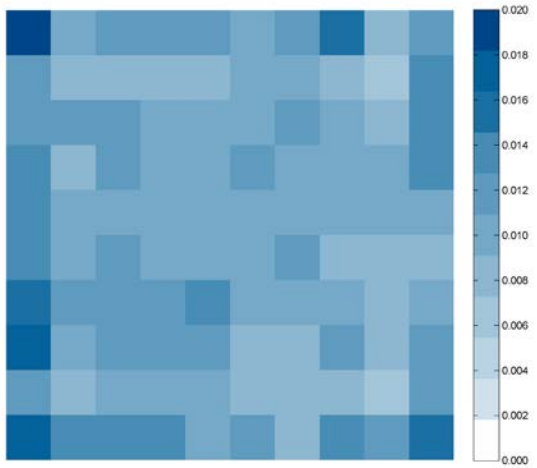








Histograms, $f_i(y)$



Ocurrence probabilities, p_i

$$p_1+p_2+\ldots+p_N=1$$

$$f_S(y)=p_1f_1(y)+p_2f_2(y)+\ldots+p_Nf_N(y)$$

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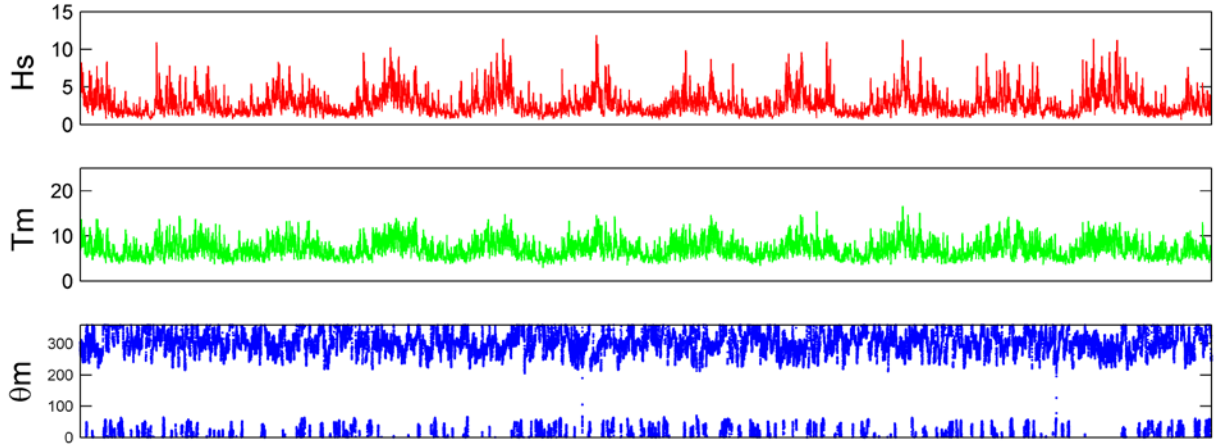
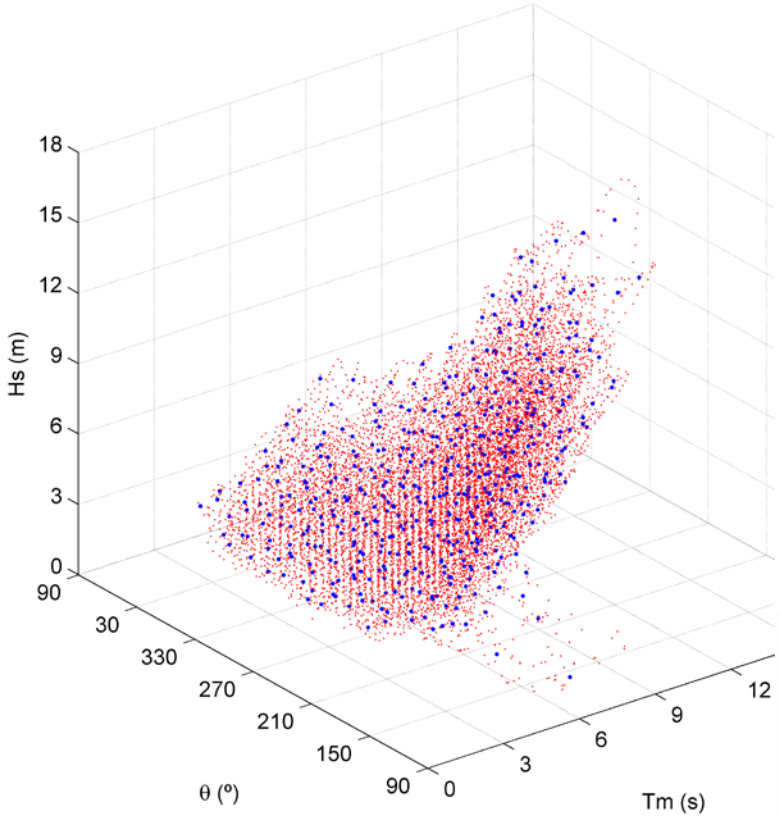
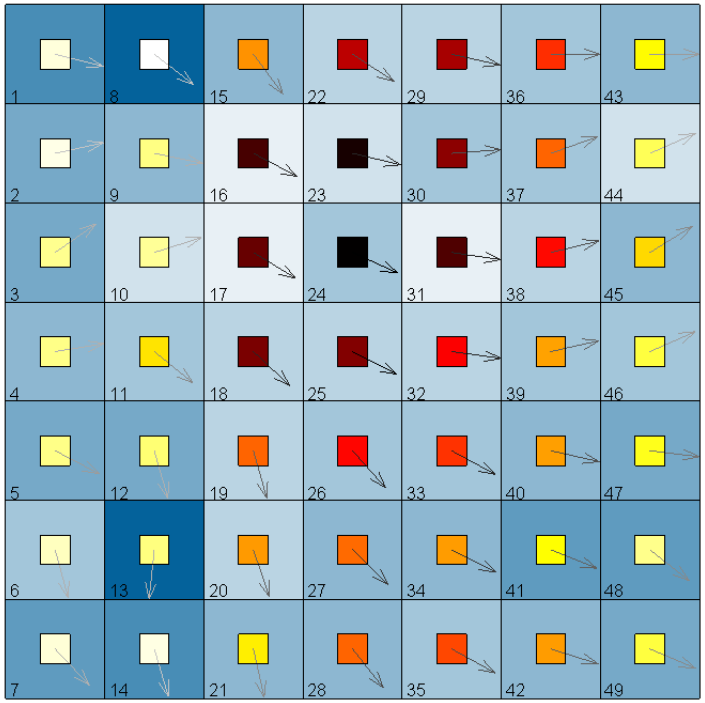
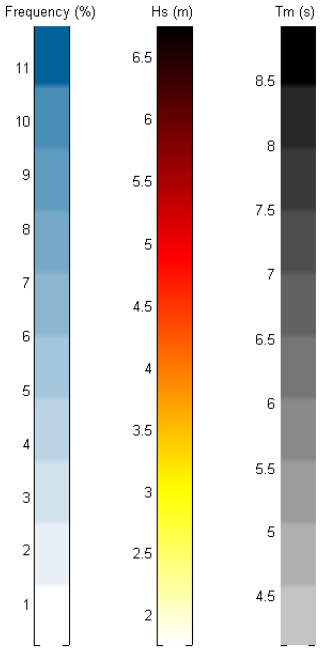


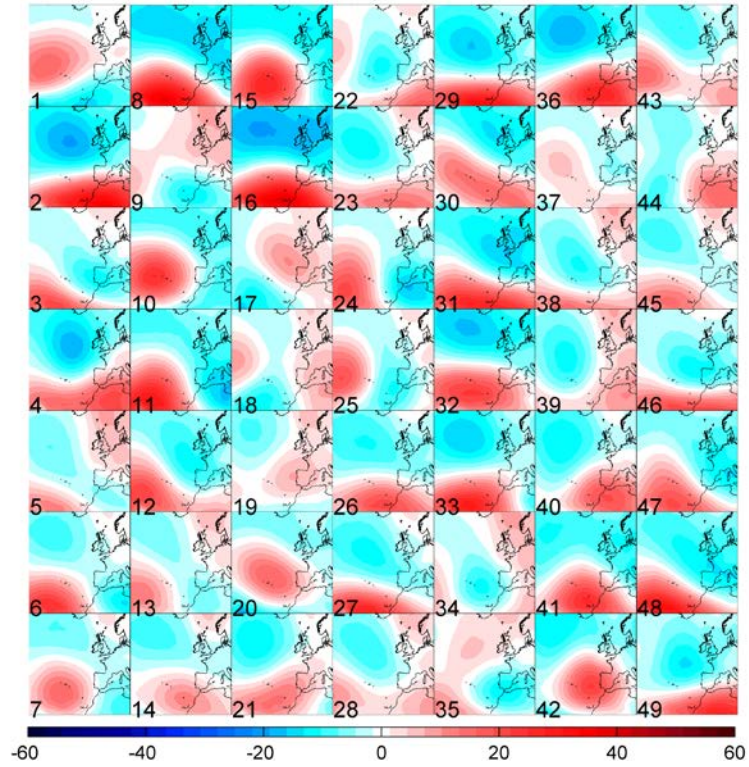


Sea state types



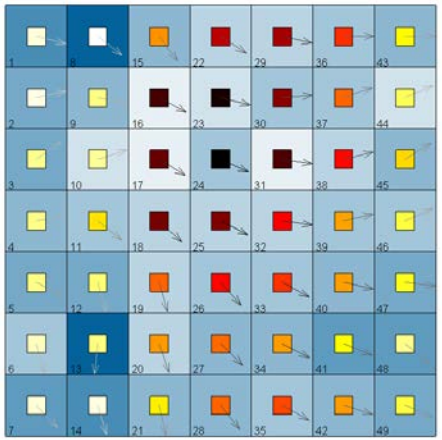


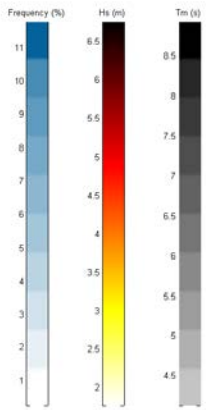
Camus et al 2011 CENG



Circulation (weather) types, CTs

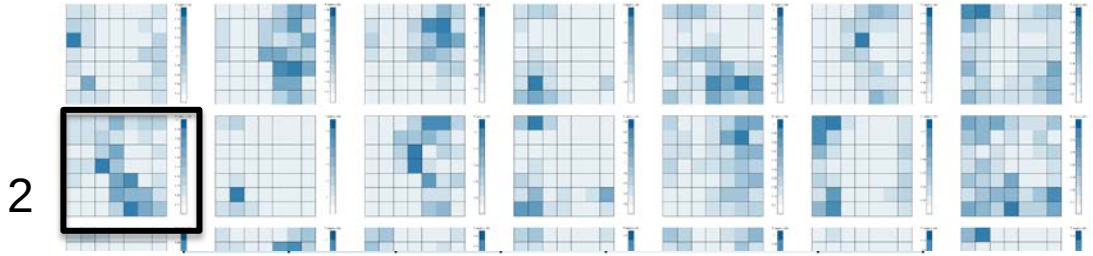
Sea state types, STs

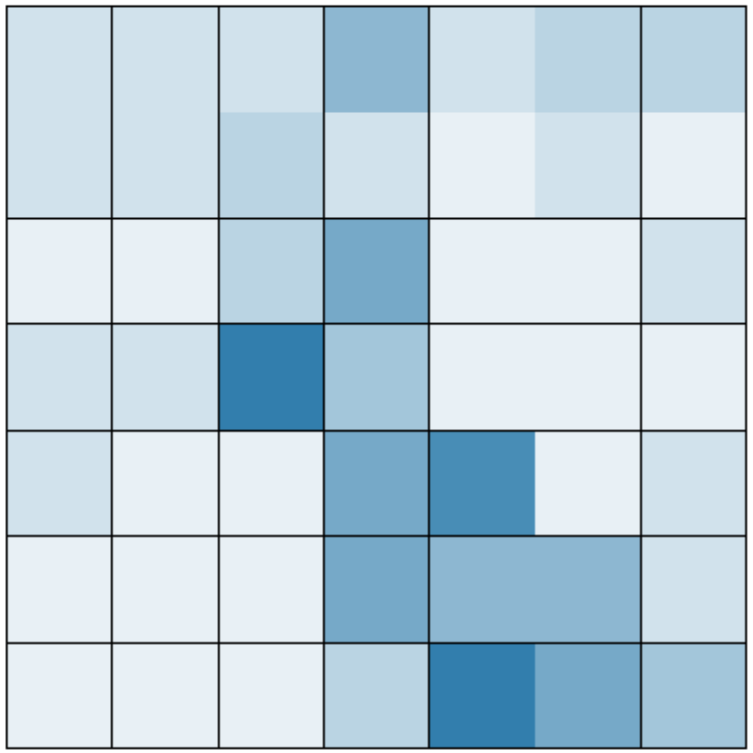


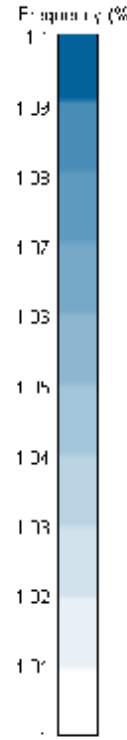


$$\mathbf{X}_d \xrightarrow{SD} \mathbf{Y}_d$$

Look-up table of ocurrence probabilities of ST types /conditioned to CT







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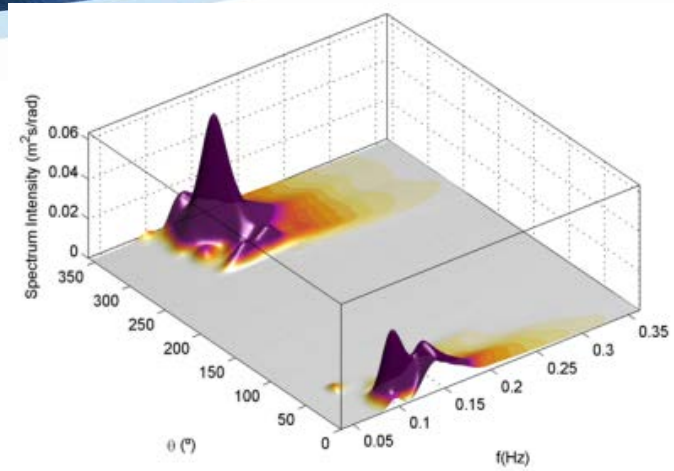
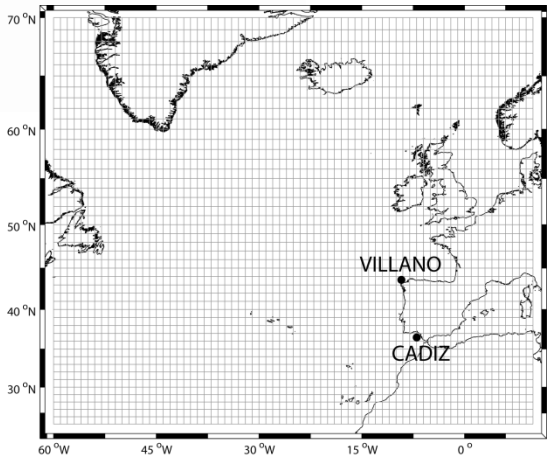
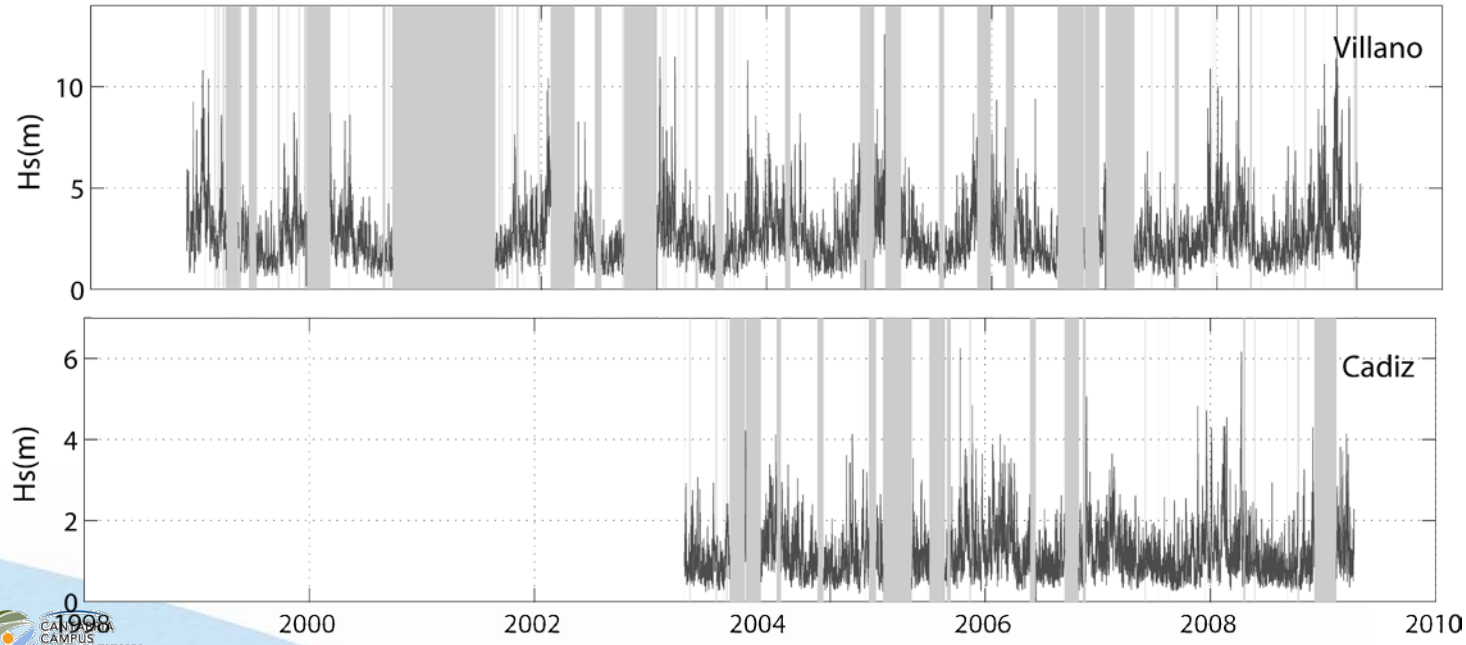
2. DATA



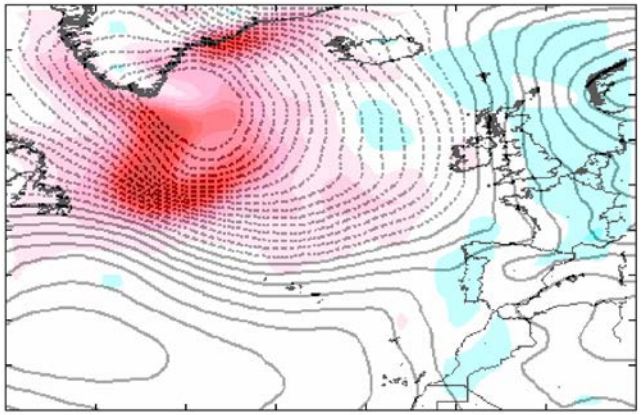


Buoys from Puertos del Estado (Spanish Ministry of Public Works & Infrastructures)



2. DATA

Sea level pressure (SLP): is the geophysical variable used to explain the state of the atmosphere. It is also our **predictor** to investigate the wave climate and its inter-annual variability.



NCEP Climate Forecast System Reanalysis (CFSR)

31 years (**1979 to 2009**)
6-hourly fields
0.5° longitude x 0.5° latitude (grid)
Conventional and satellite observations included

3. METHODOLOGY- The discrete wave spectrum

- Wave spectra provide significantly more information, being **possible to differentiate** between **distant and local wave generation areas** (Bromirski et al., 2004).

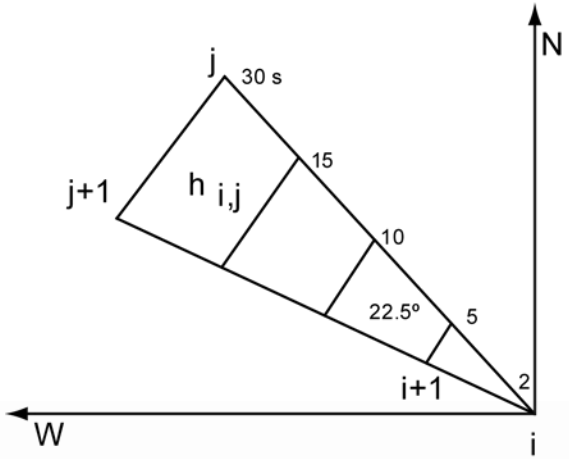
- When **grouped by bins** or packages the wave **energy distribution becomes Gaussian**, which is a precondition when a PCA analysis is conducted.

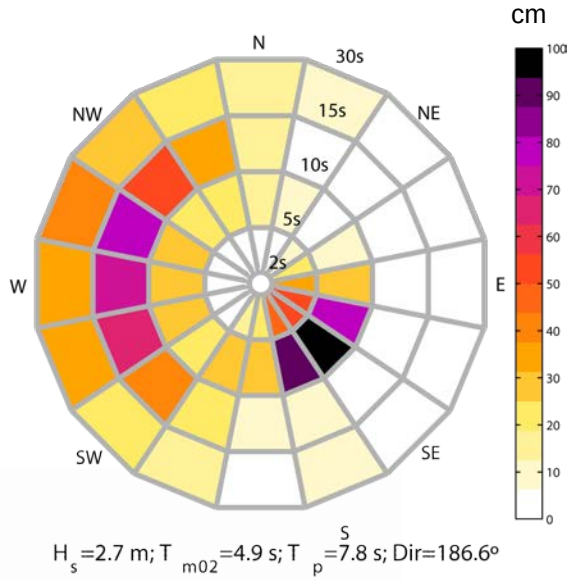
- **More easily interpretable by visual inspection.**

$$m_{oi,j} = \int_{f_i}^{f_{i+1}} \int_{\theta_j}^{\theta_{j+1}} \overline{S(f,\theta)} df d\theta$$

$$h_{i,j} = 4.004\sqrt{m_{oi,j}}$$

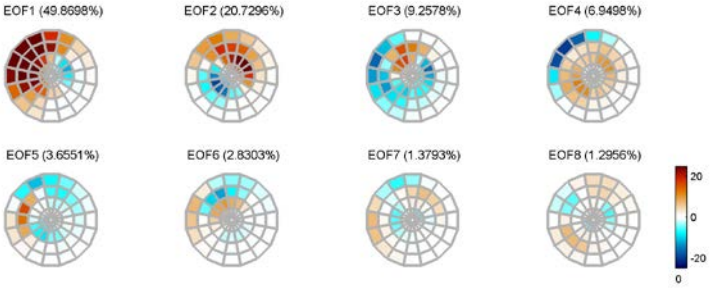
$$H_s^2 = \sum_i \sum_j h_{i,j}^2$$

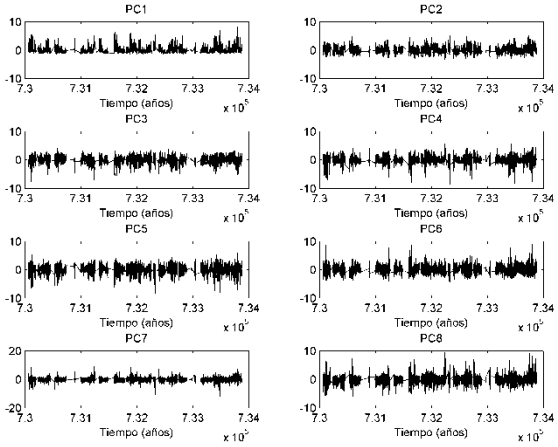


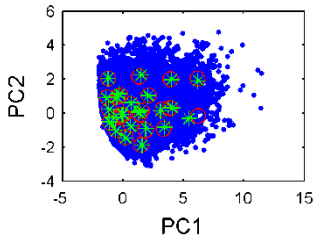


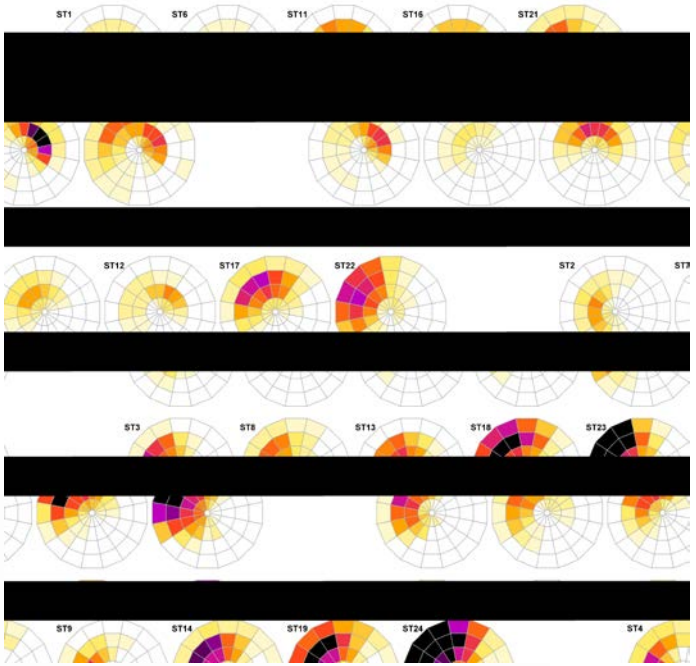
3. METHODOLOGY- Clustering

a) Dimension reduction: EOFs of daily averaged wave spectra
b) Classification: K-means of the temporal modes









3. METHODOLOGY- Spectral types analysis

- Westerly swells
- Easterly windseas
- Mixed seas
- Calms

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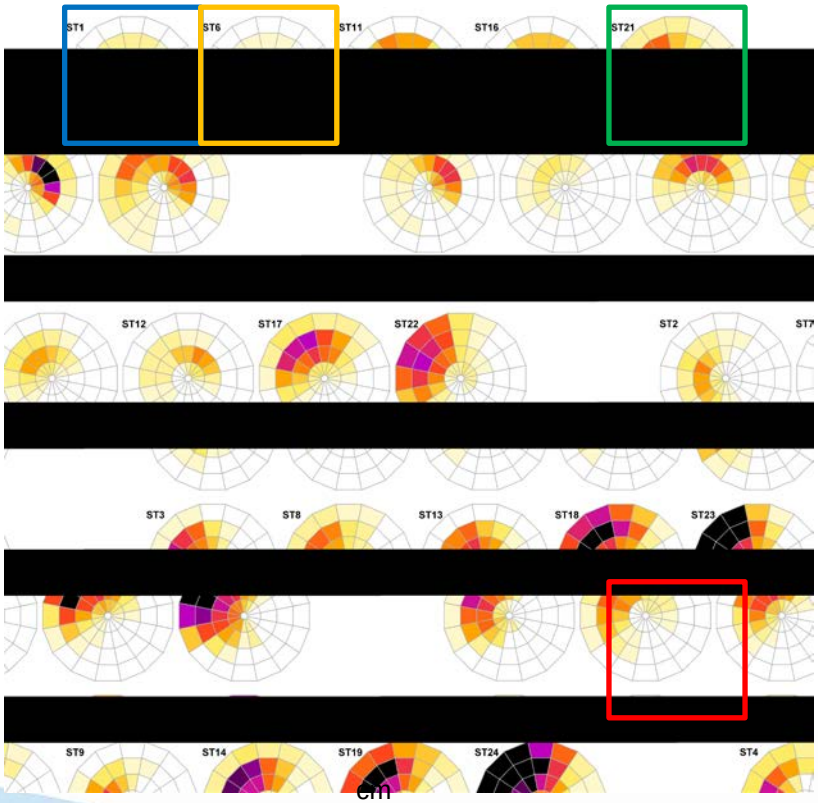
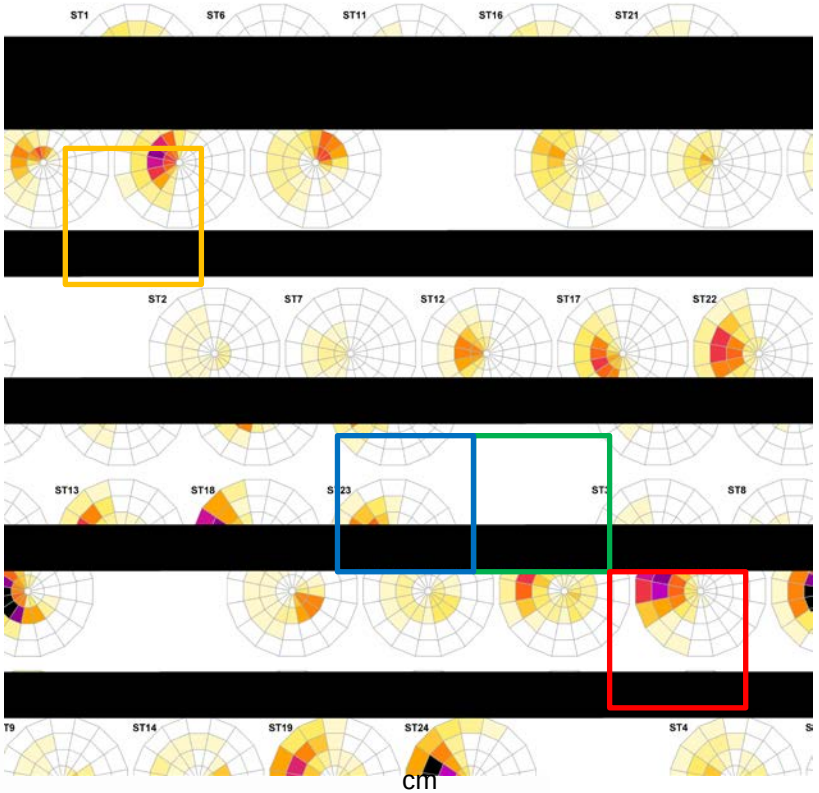


cm

Cádiz



cm

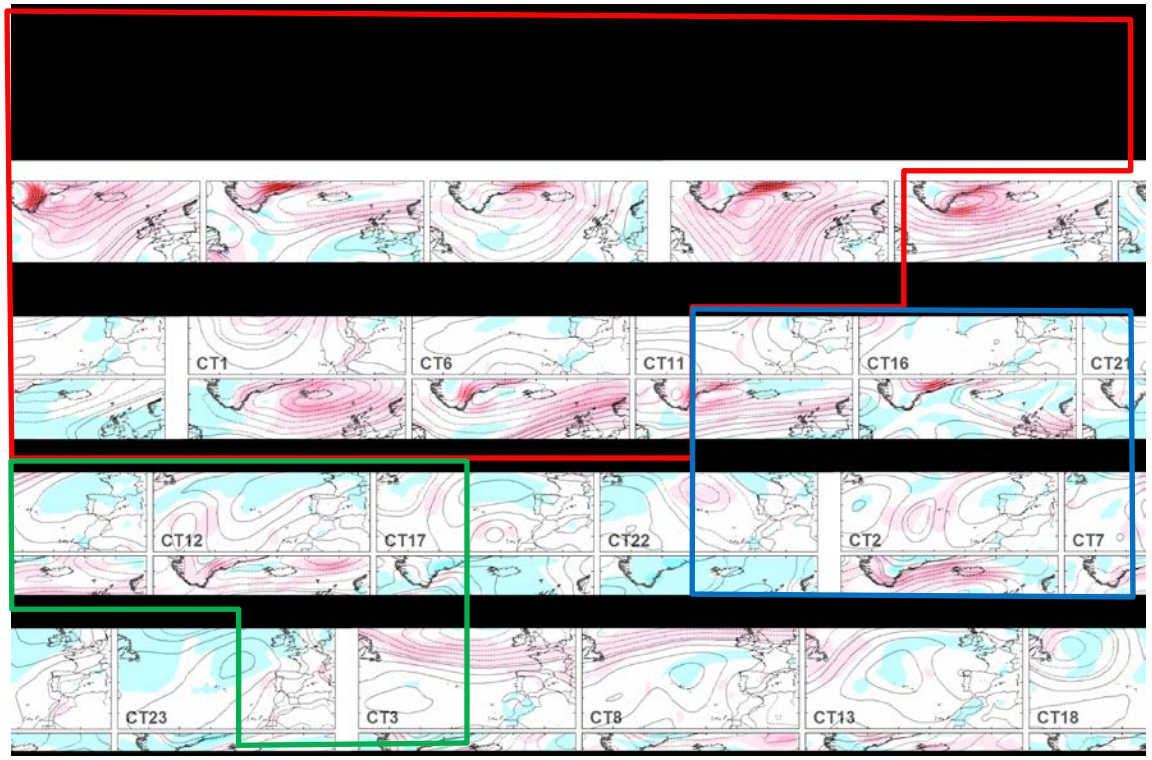
3. METHODOLOGY- Circulation types analysis

a) Dimension reduction: EOFs of the 3-days running averages of SLP squared gradients

b) Classification: K-means of the temporal modes

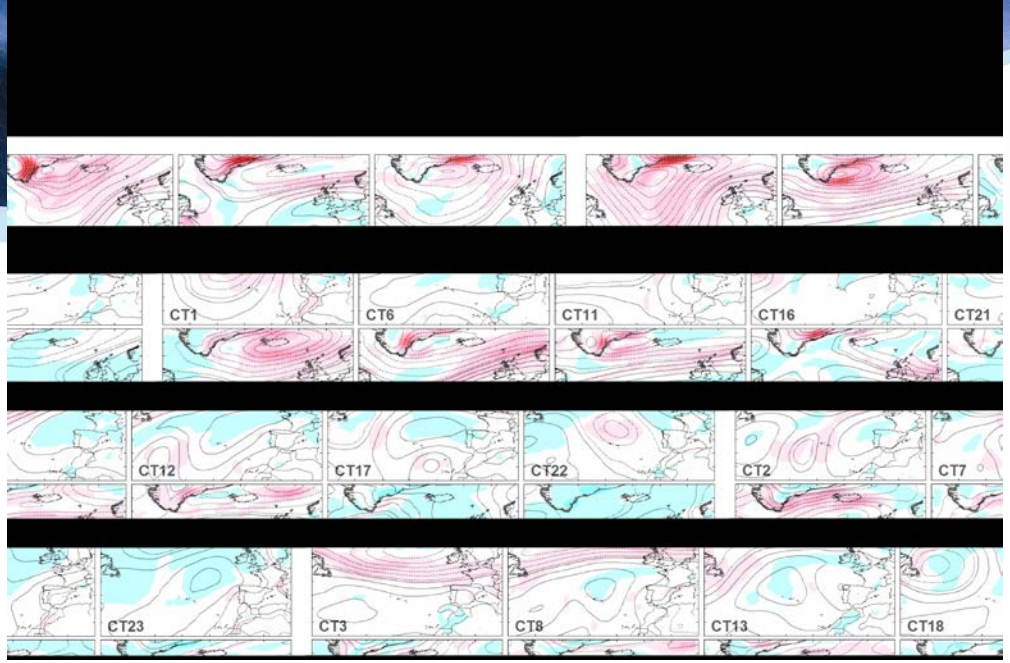
Asymmetries of +NAO estates

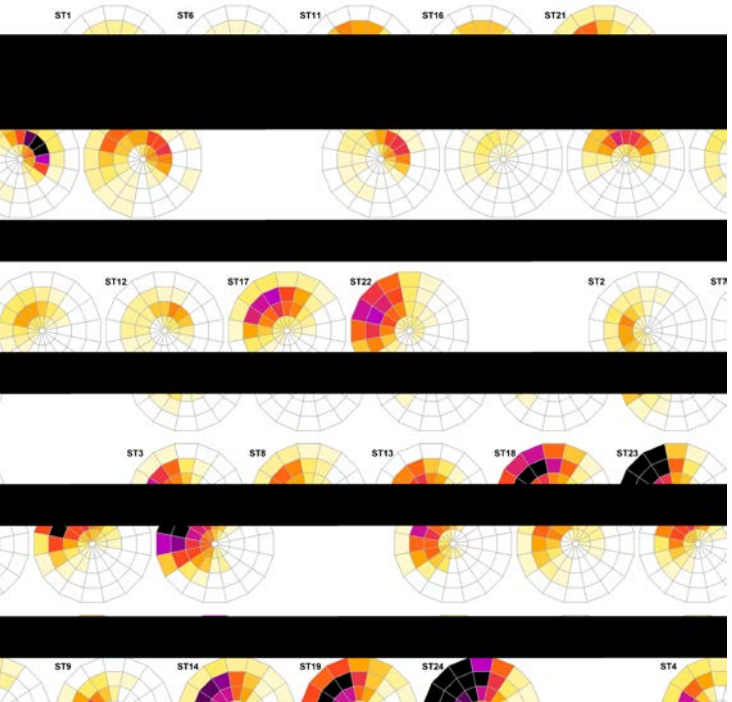
Anomalous southerly lows

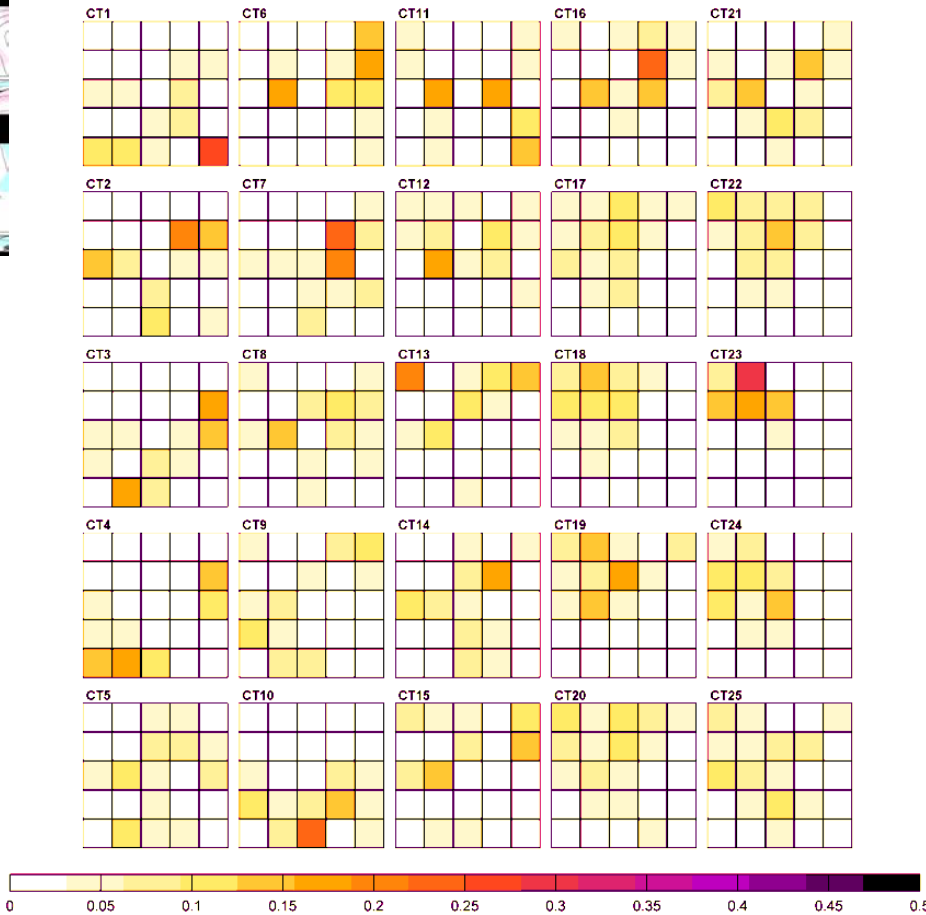


Anticyclone dominance

3. METHODOLOGY- Exploring relations







3. METHODOLOGY- Validation

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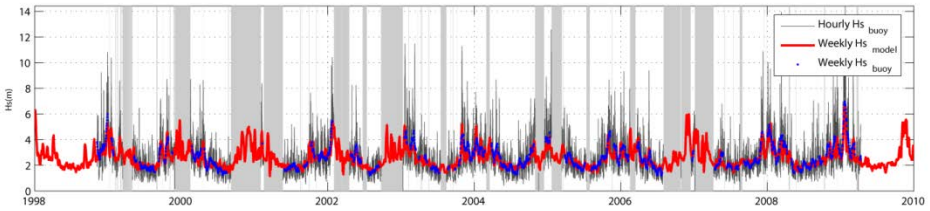

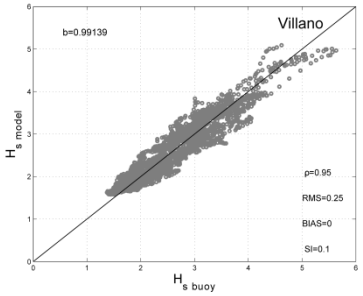

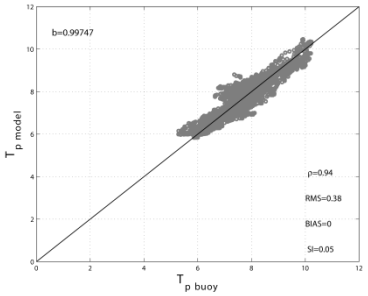

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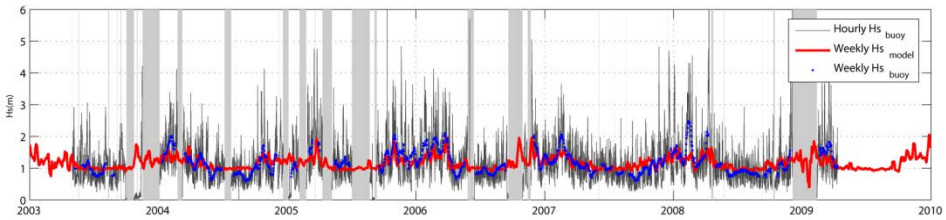

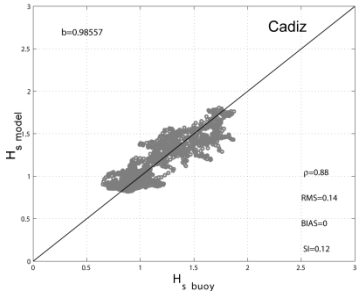

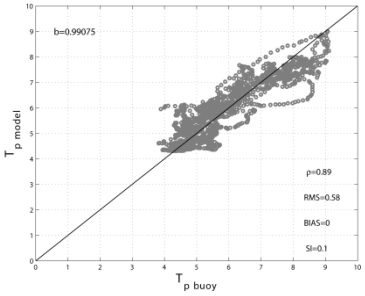

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$$\mathbf{X}_m \xrightarrow{SD} \mathbf{Y}_m$$

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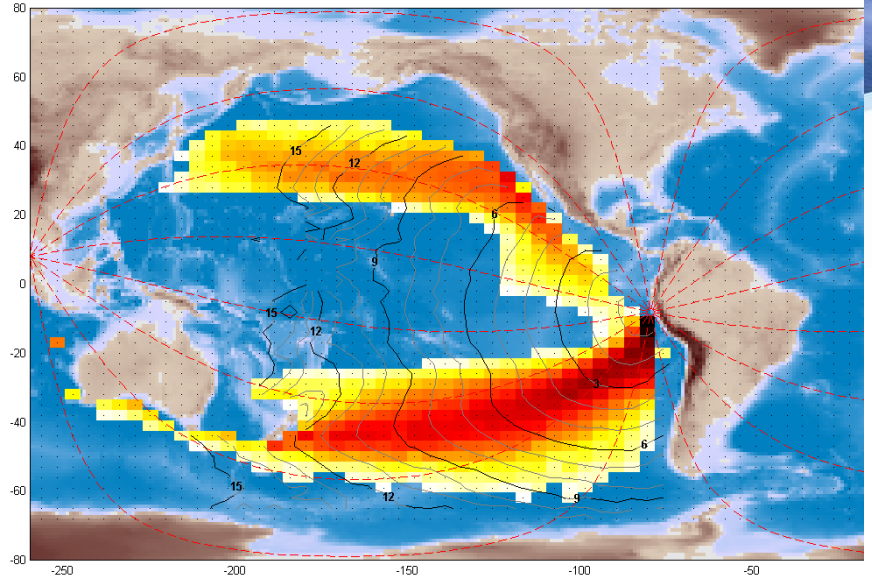
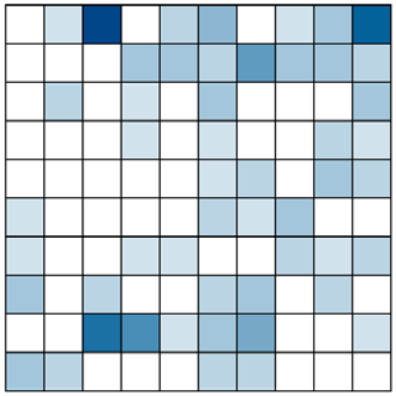
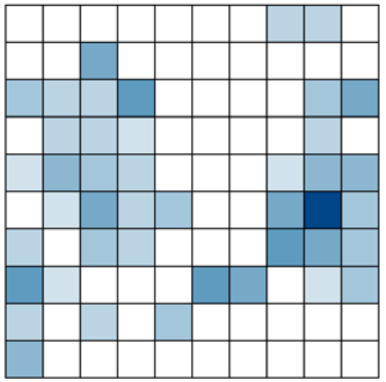
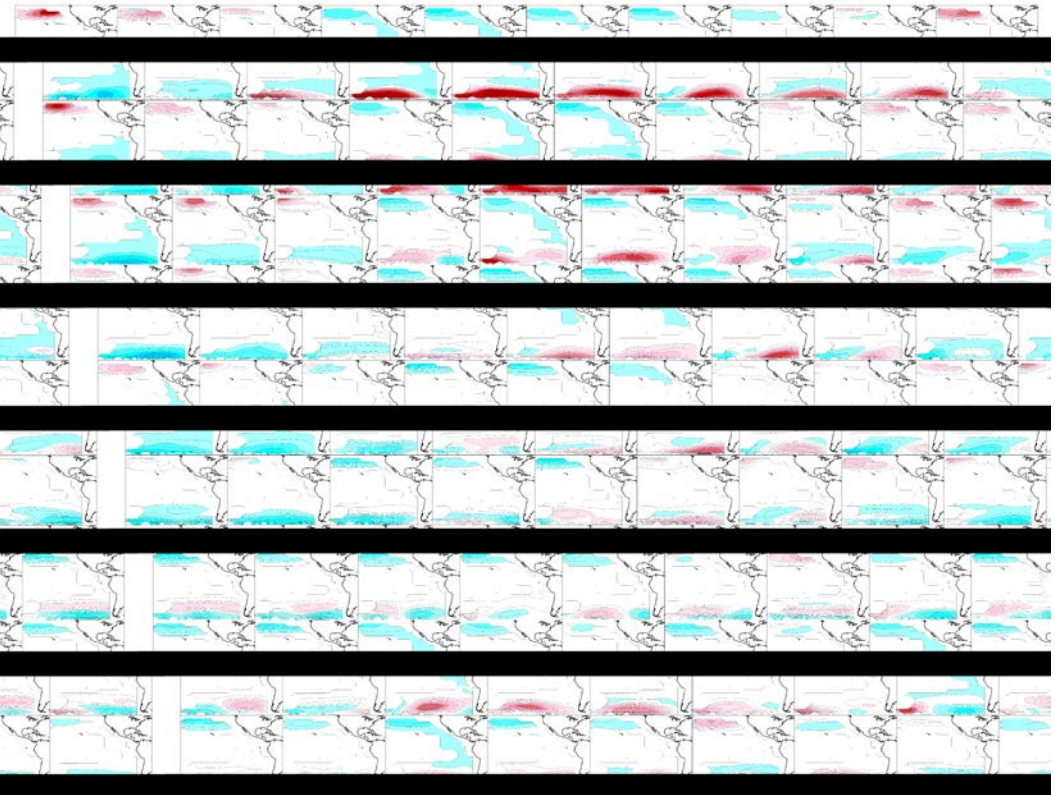


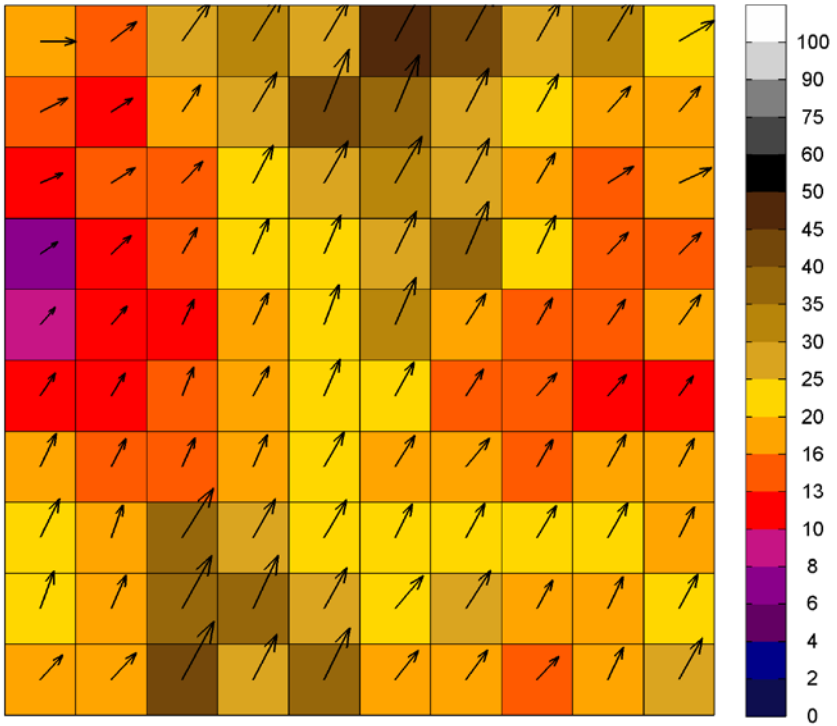


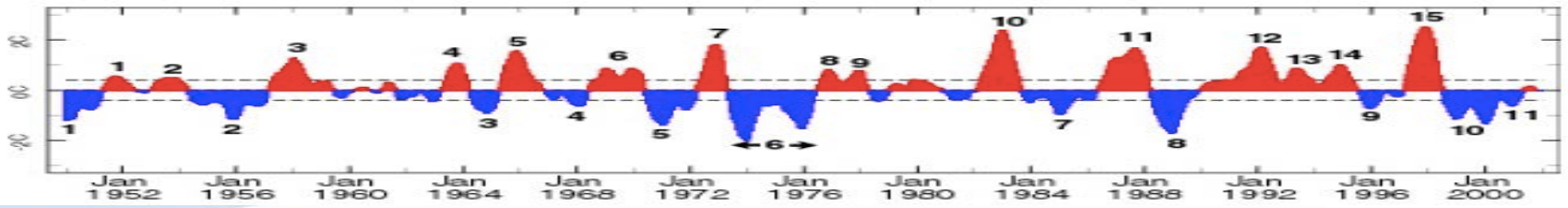
1998, El Niño year



1992



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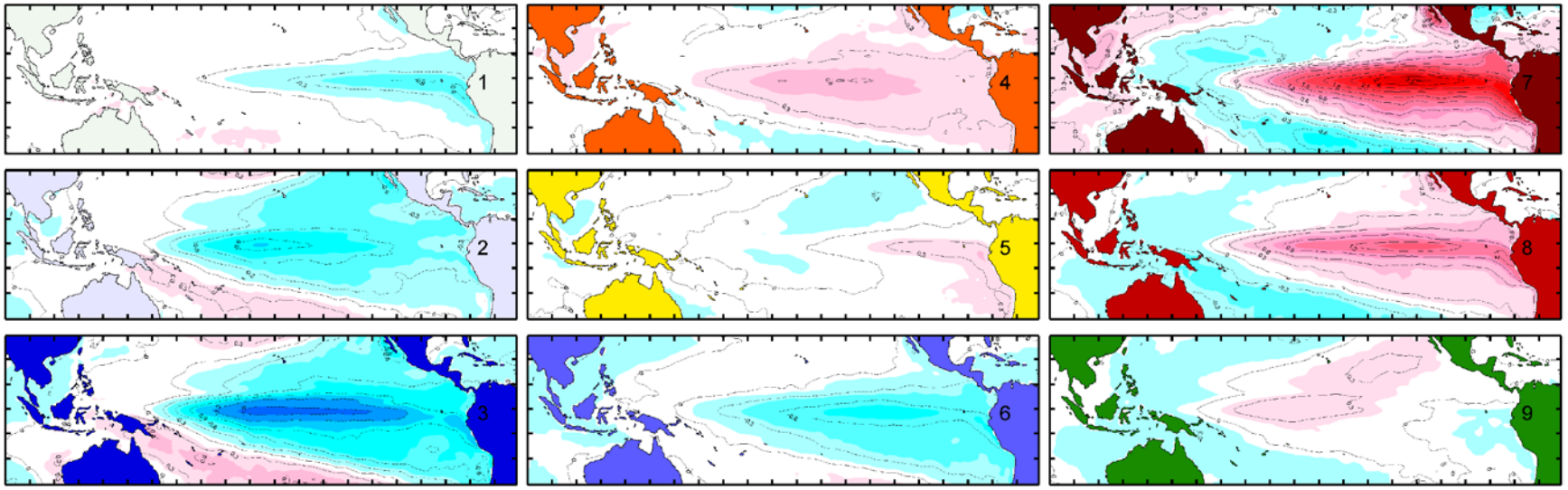
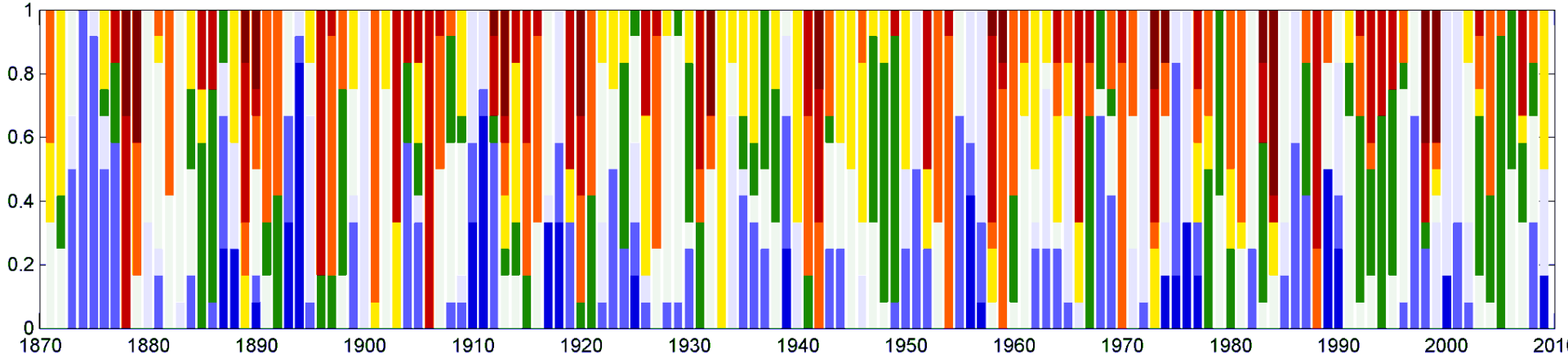
Jan 1960
Jan 1964
Jan 1968
Jan 1972
Jan 1976
Jan 1980
Jan 1984
Jan 1988
Jan 1992
Jan 1996
Jan 2000


1
2
3
4
5
6
7
8
9


Niña+
Niña-
Modoki
Niño-
Niño+


1
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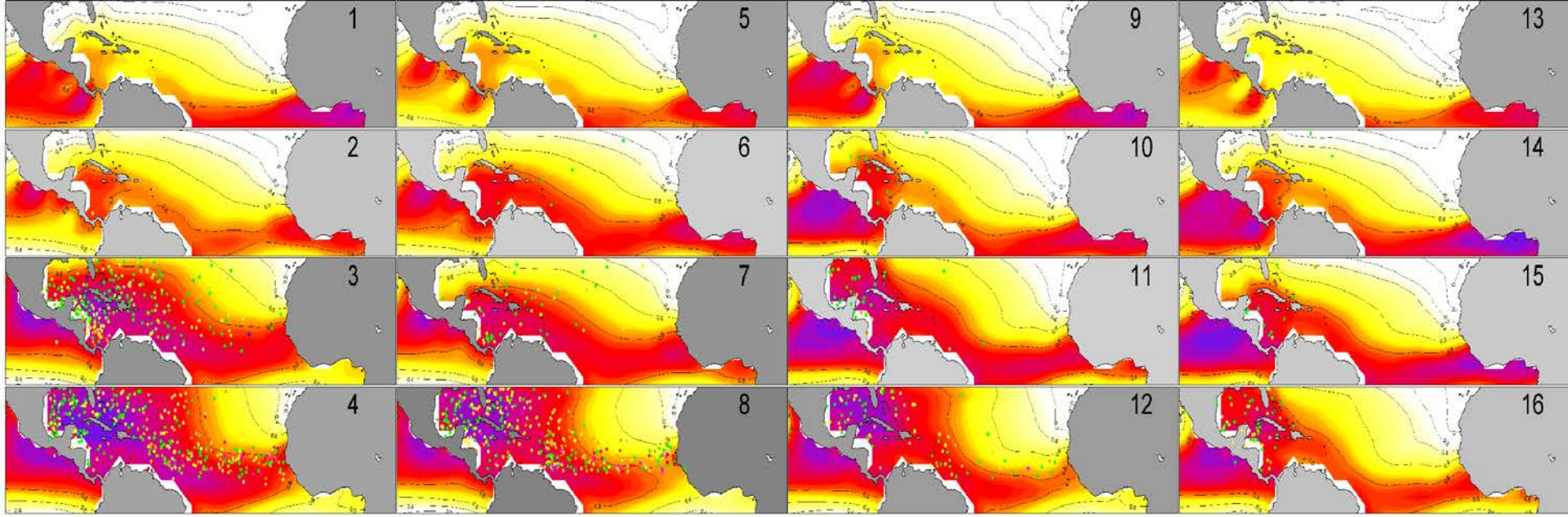
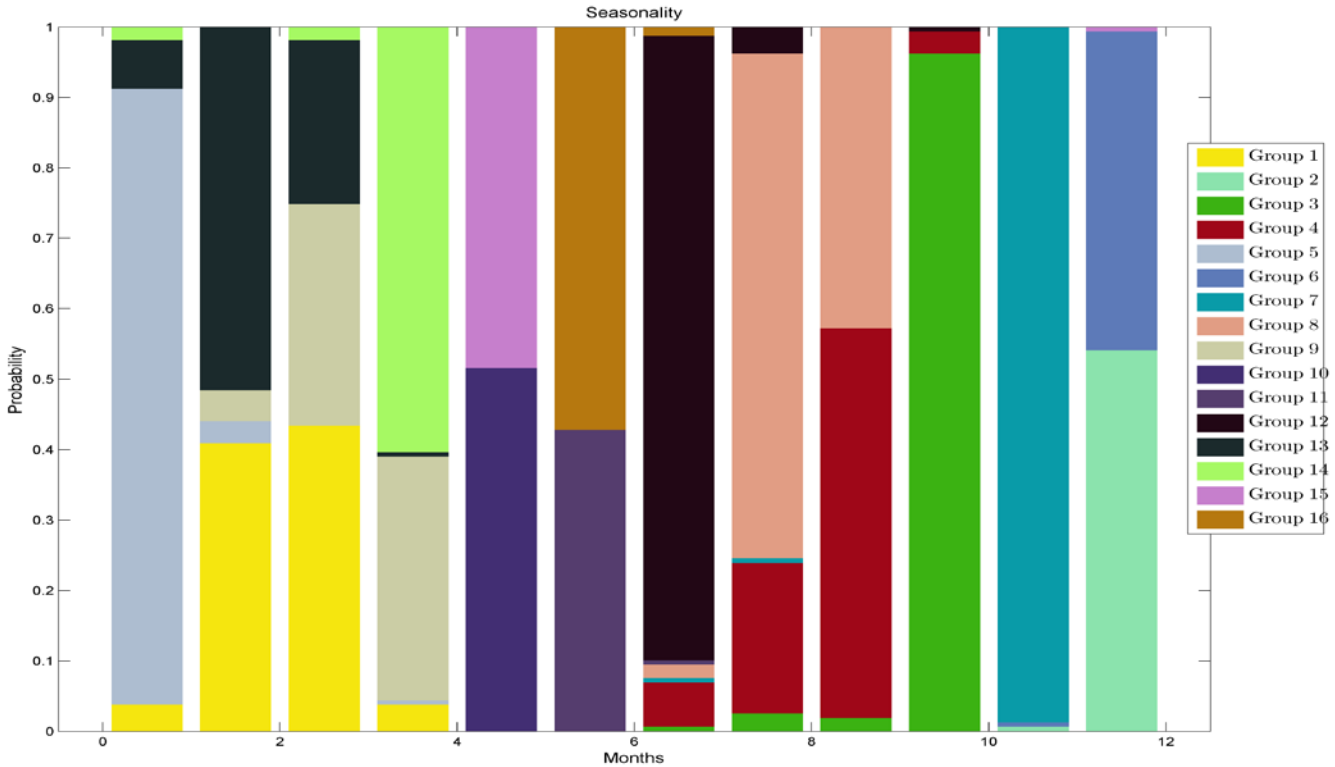
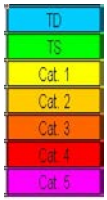
0
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000







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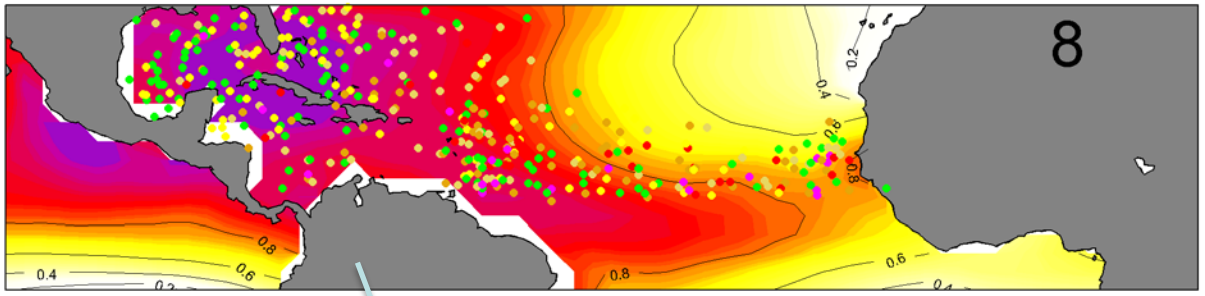
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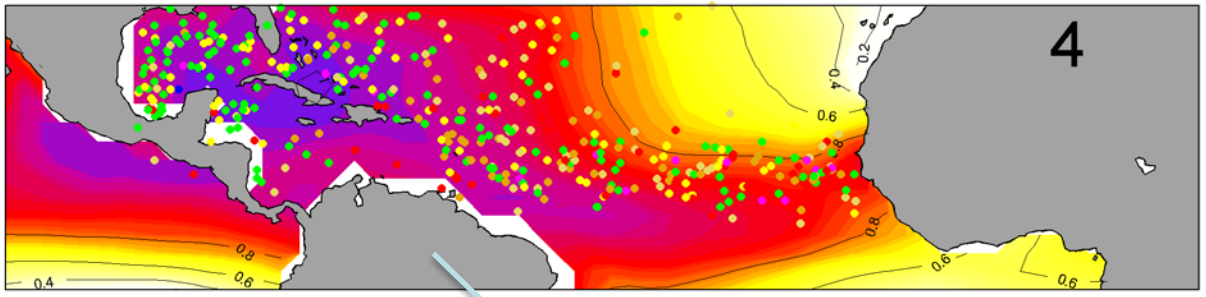
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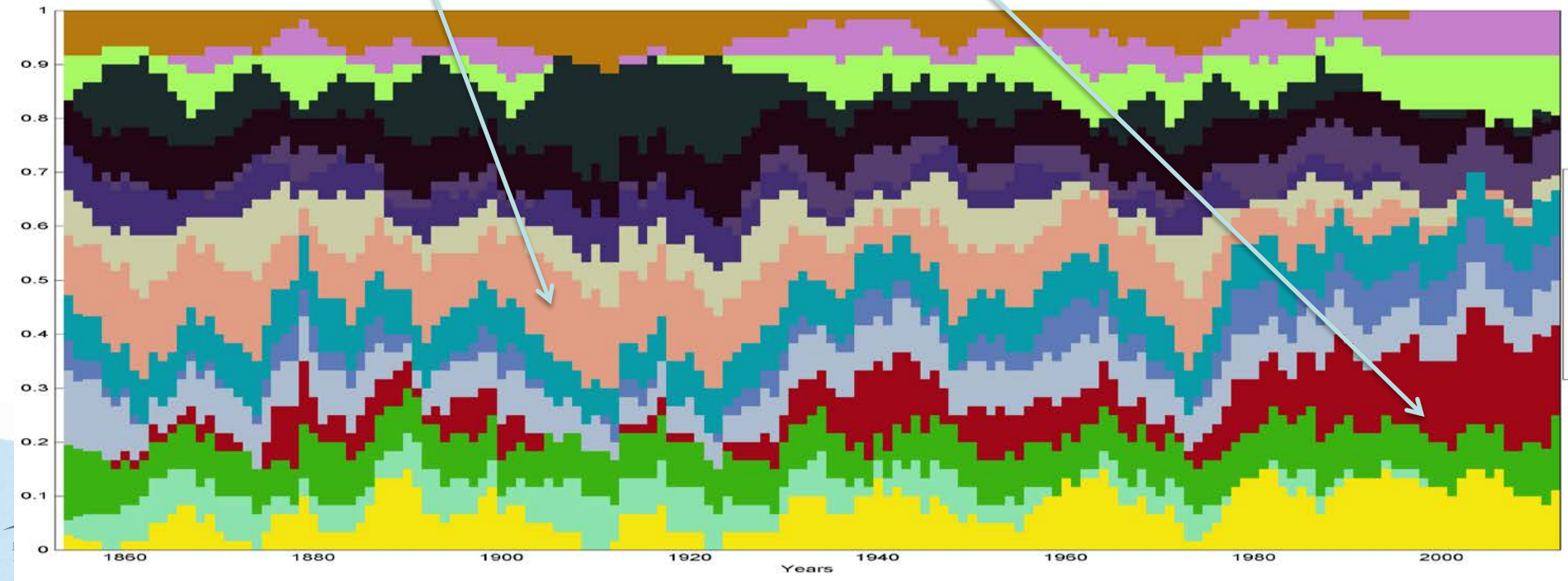
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1860
1880
1900
1920
1940
1960
1980
2000
Years

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$$\mathbf{X}_m \xrightarrow{SD} \mathbf{Y}_m$$

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gabitinho

7. CONCLUSIONS

• An useful **descriptive graphical tool that helps understanding the effect of the atmosphere circulation pattern on the directional wave spectra** has been presented.

•The method is based on the **combination of instrumental wave data** of two deep waters buoys **and the CFSR atmospheric reanalysis**, that by mean of clustering statistical methods allows to **define a probabilistic relationship between the CTs and the STs**.

• ***K-means* algorithm** has demonstrated **excellent skills when working with the wave spectra**. It provides more information about the wave conditions than the traditional used aggregated or statistical wave parameters.

•This approach can be applied to different time scales and to different predictors and predictands (ENSO, TCs)

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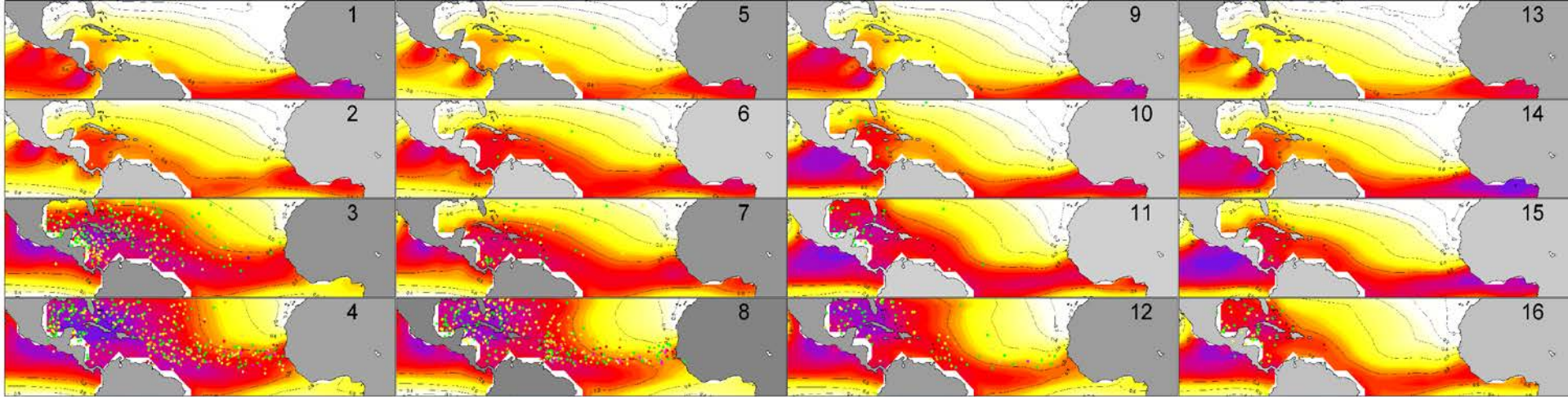
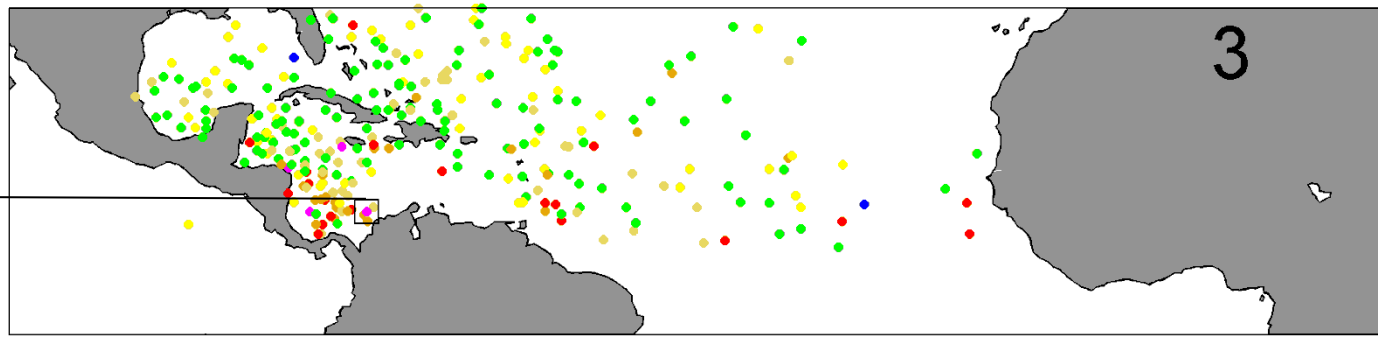
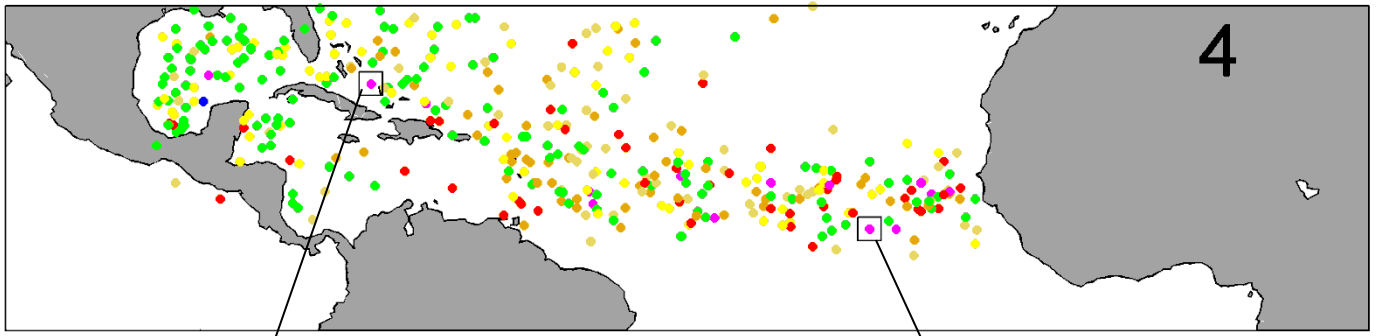
Exploring spectral wave climate variability using a weather type approach

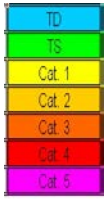
Antonio Espejo, **Fernando J. Méndez**, Iñigo J. Losada, Paula Camus
Environmental Hydraulics Institute "IH Cantabria", Universidad de Cantabria, Spain



Mitch 1998





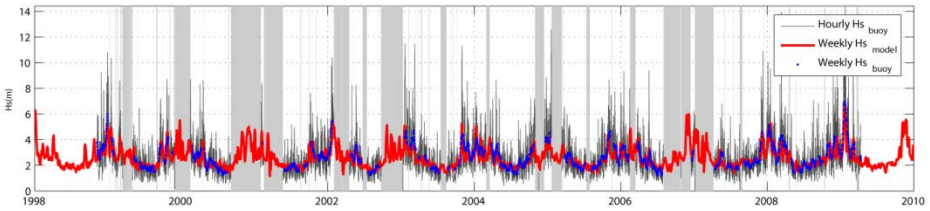


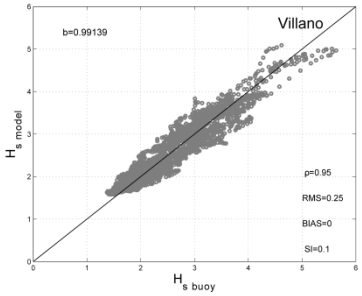
Katrina 2005

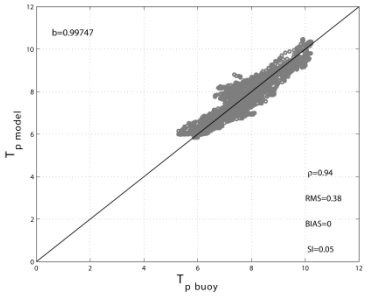
Ivan 2004

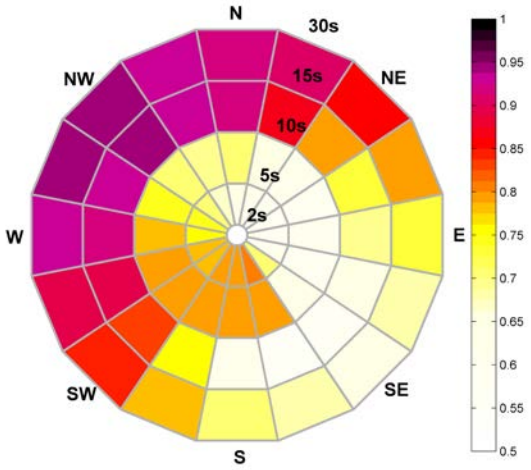
3. METHODOLOGY- Validation

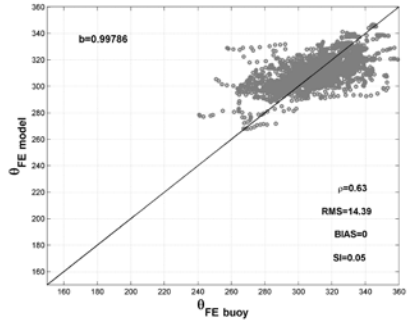
Villano





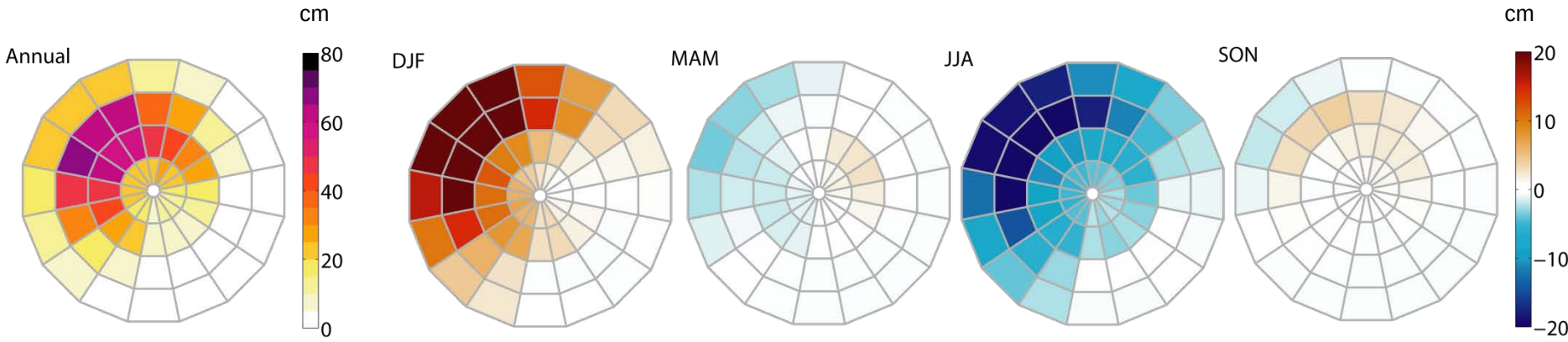




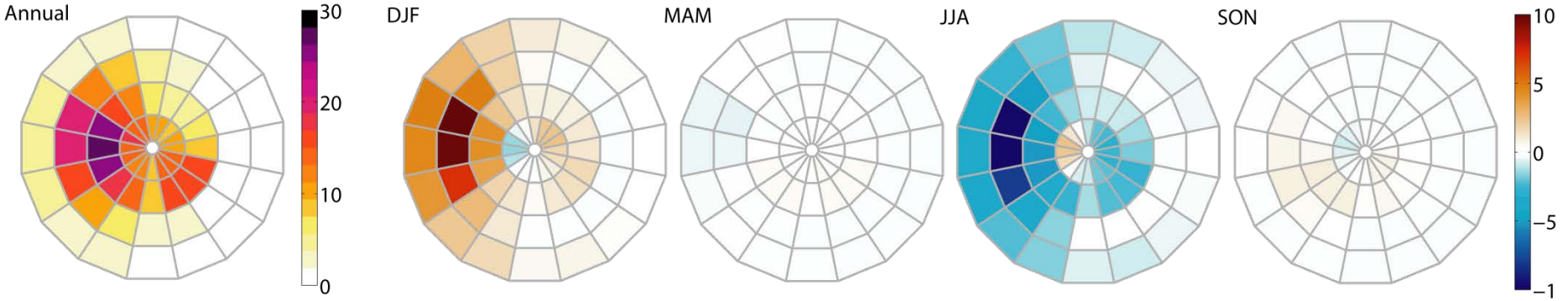


4. RESULTS- Seasonality

Villano



Cádiz

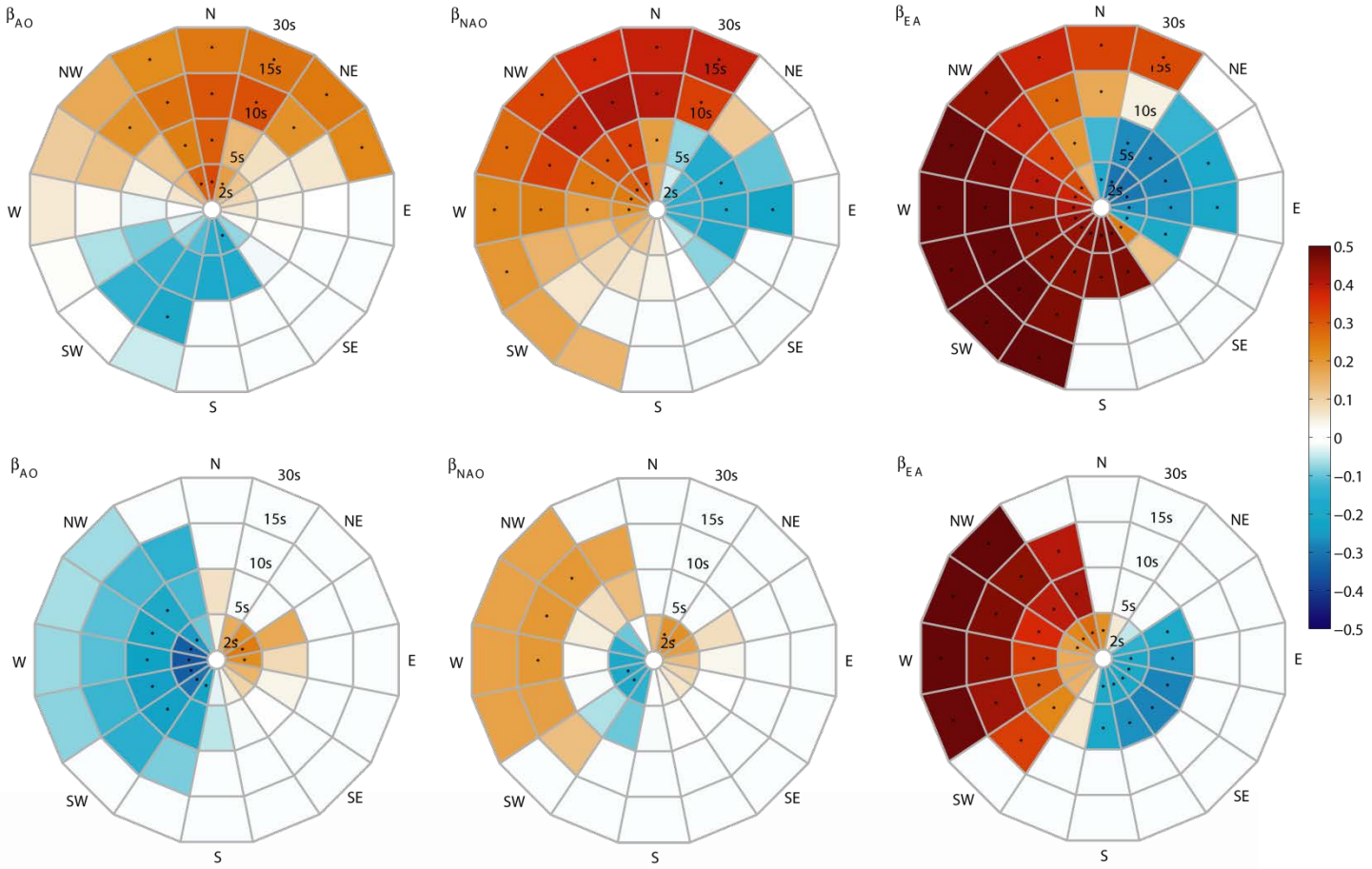


4. RESULTS- Inter-annual variability

(Thompsom and Wallace, 1998) (Barnston and Livezey, 1987)

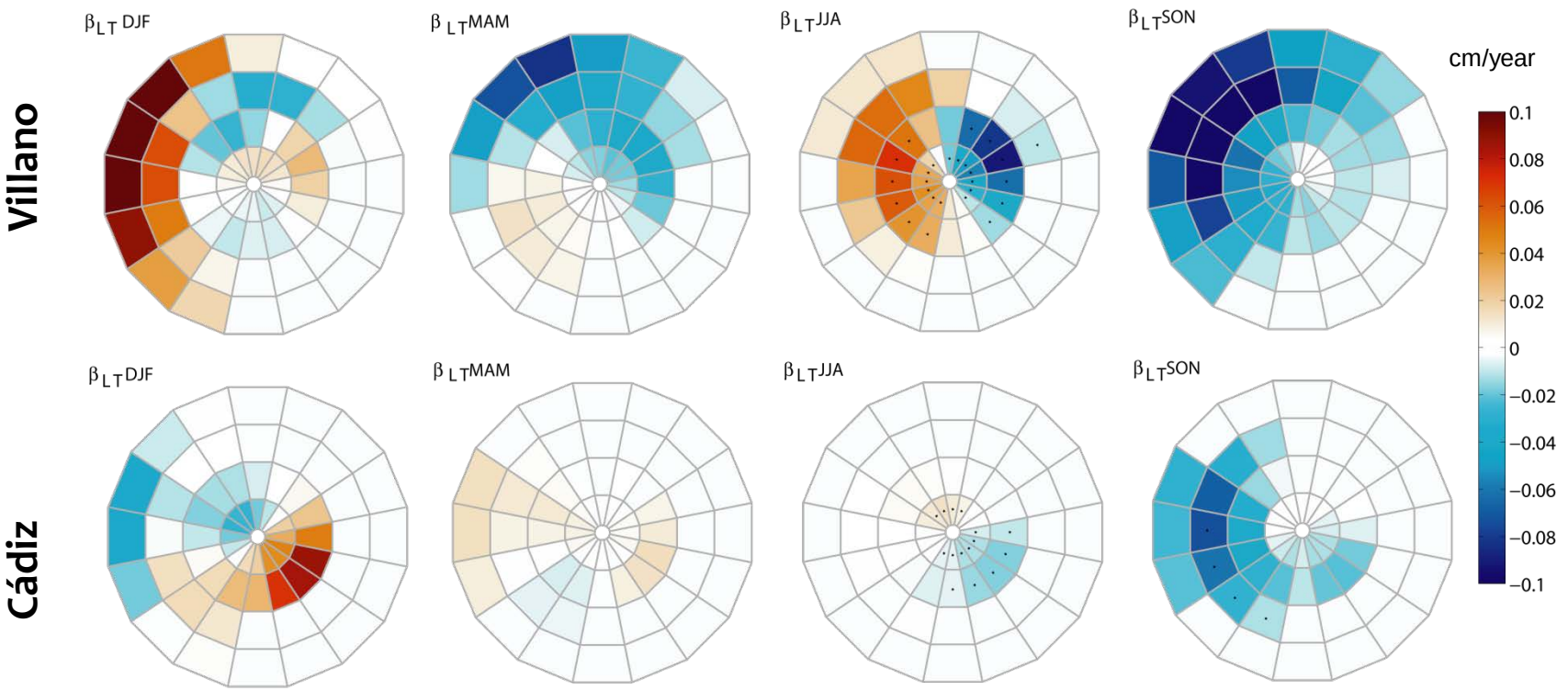
Villano

Cádiz



(Charles et al., 2011; Le Cozannet et al., 2011)

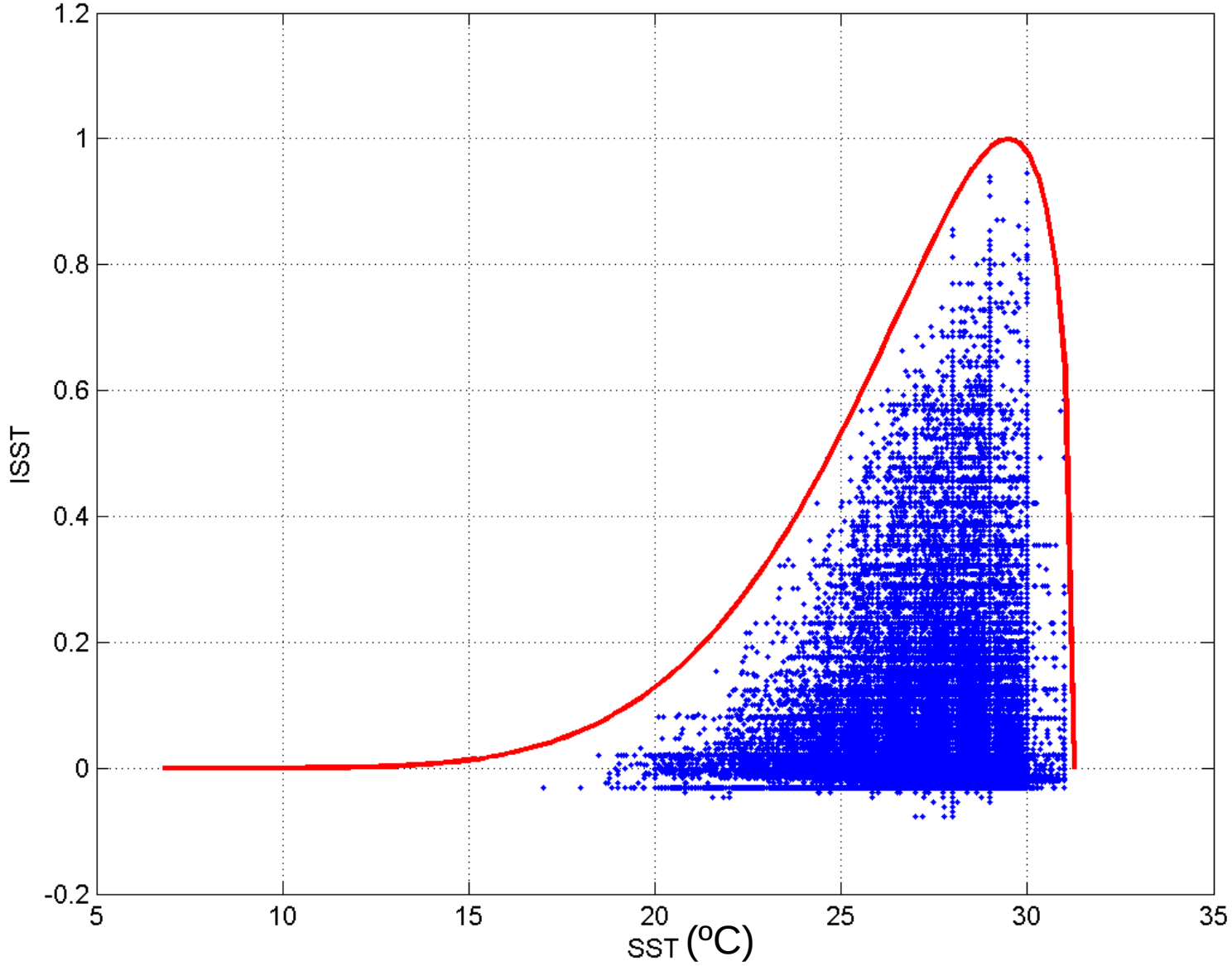
4. RESULTS- Long-term trends



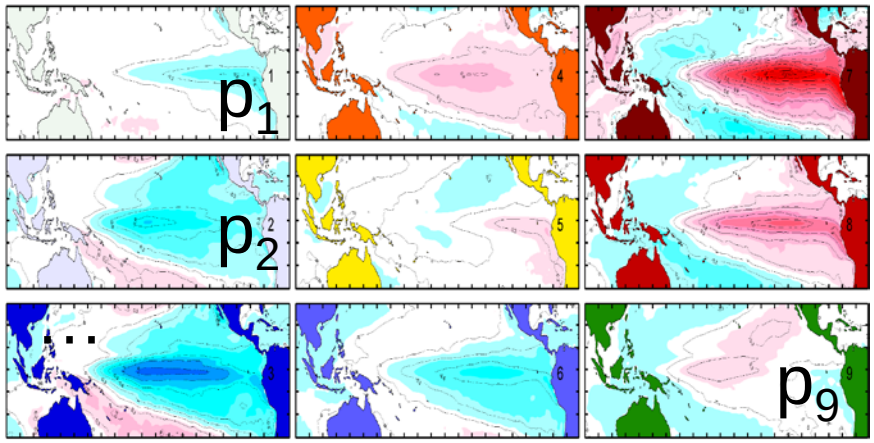
(Charles et al., 2011; Le Cozannet et al., 2011; Wang and Swail, 2002; Woolf et al., 2002; and Dupuis et al., 2006)

Sea Surface Temperature Index por TC activity

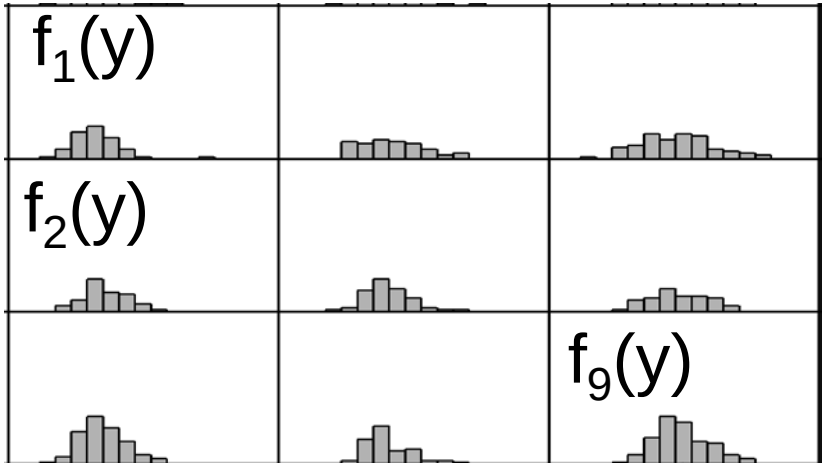
$$SST \rightarrow I_{SST}(SST)$$



$X=(ET_1, ET_2, \ldots, ET_9)$



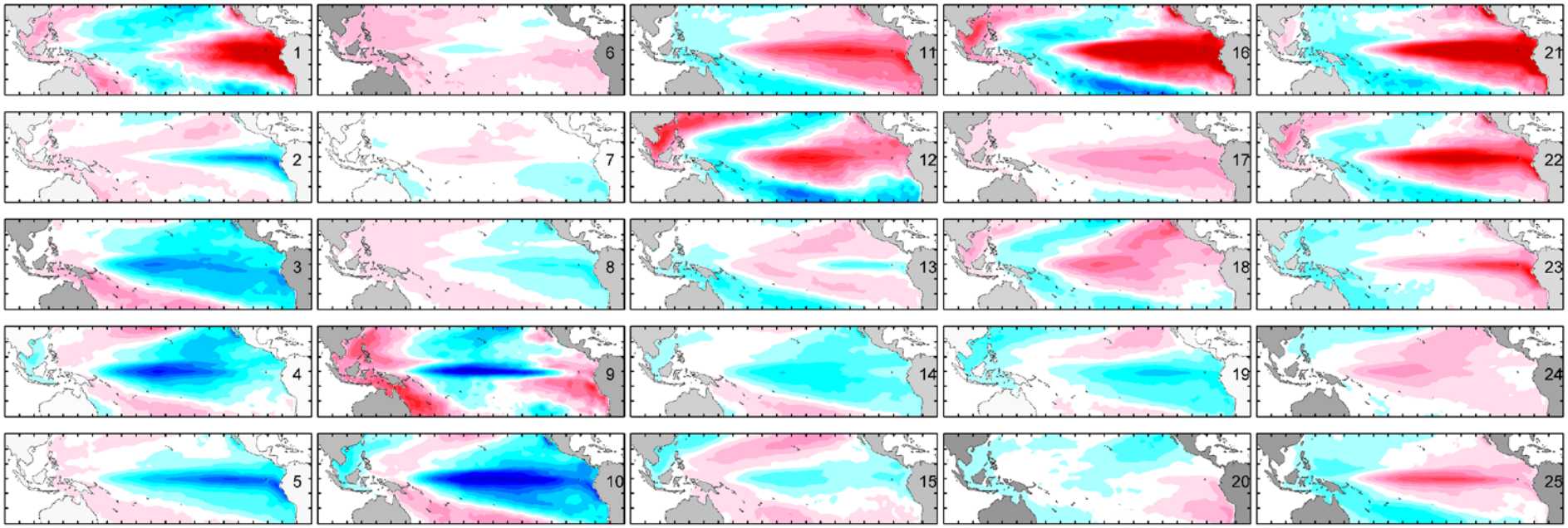
Y

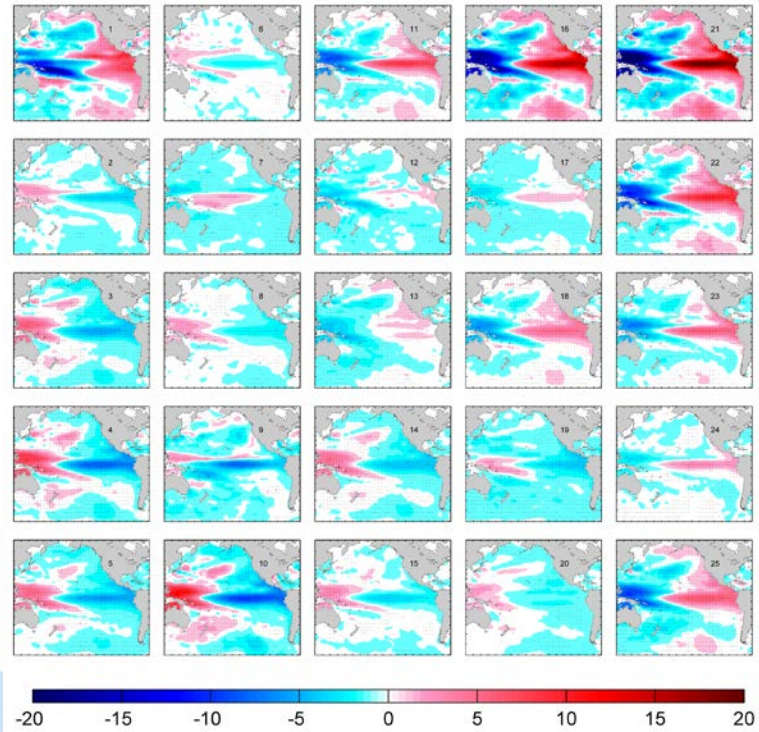


p_i=ocurrence probability of ET_i

$p_1+p_2+\ldots+p_9=1$

$f_S(y)=p_1f_1(y)+p_2f_2(y)+\ldots+p_9f_9(y)$





ENSO types

SLA composites (cm)
Church et al 2004

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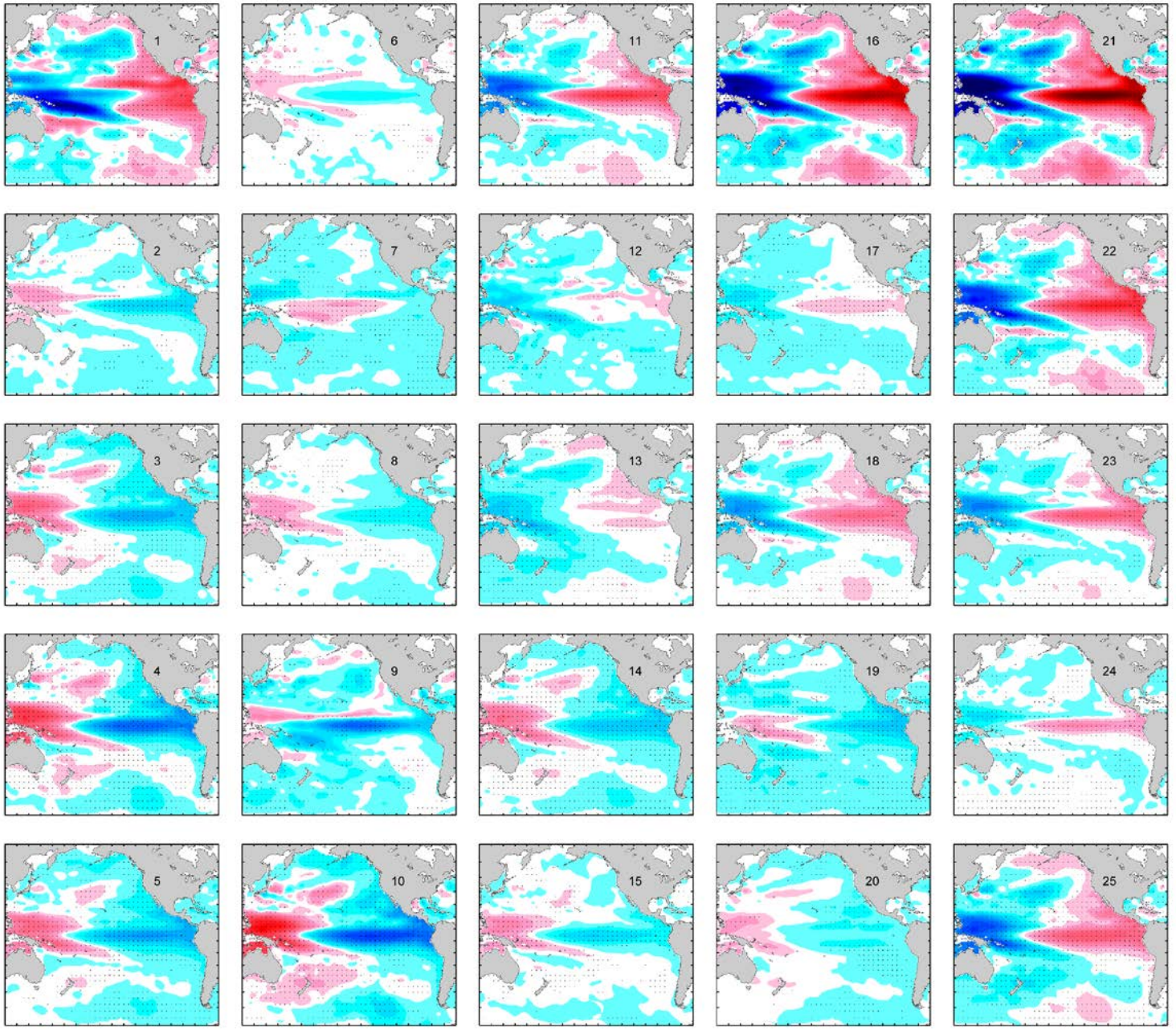
CANTABRIA CAMPUS INTERNACIONAL Agua y Energía

SLA composites (cm)



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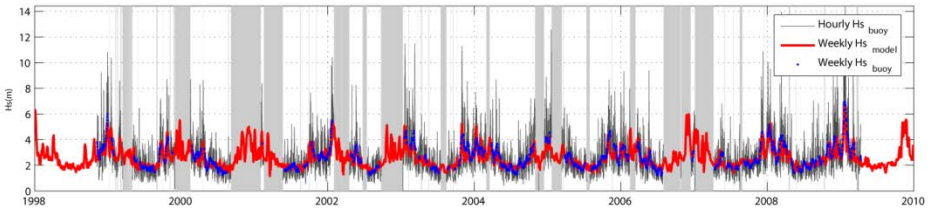

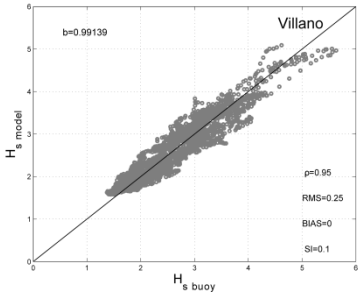

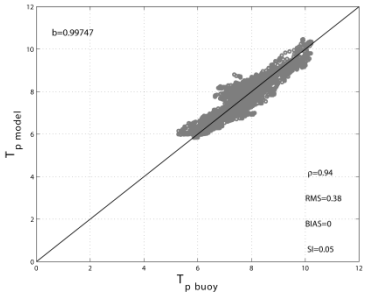

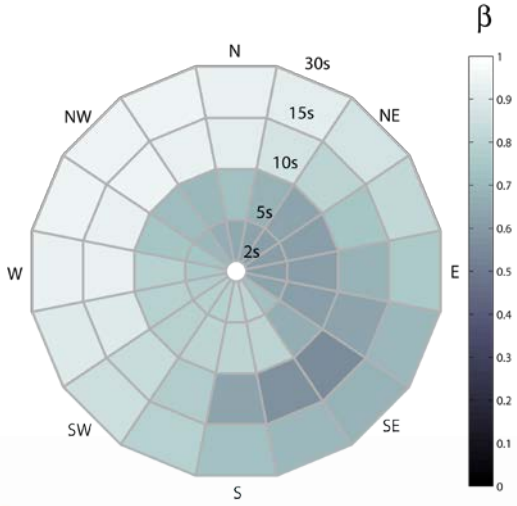

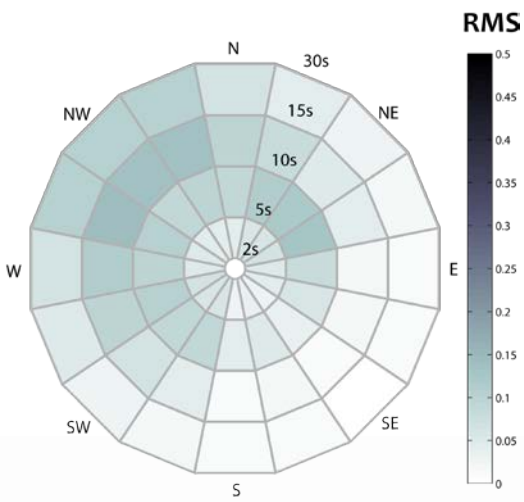

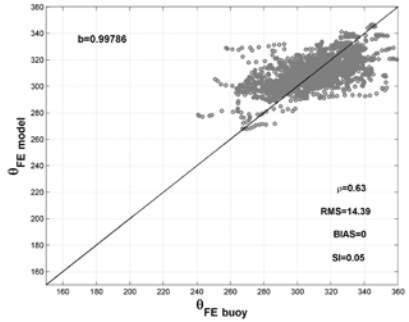

5. CONCLUSIONS

• **Seasonal variations** of the discrete wave spectra gather up **the Iceland low and Azores high winter-summer dominance**.

•**Inter-annual variability** results go further **revealing much more aspects than traditional approaches** based on aggregated or statistical wave parameters, as for example enclosing frequencies and directions in which the analyzed climate pattern have significant effects.

•**Long-term trends** results show **increased summer medium period westerly energy** at Villano and a **decrease of the easterly short period waves** at both locations. **No significant trends have been found in other seasons.**