

PROJETO  
Metodologia, ferramentas e bases de dados  
para gestão de riscos às mudanças do clima em zonas costeiras:  
*Uma proposta de aplicação para costa brasileira*

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PERIGOS:

**VENTO, ONDAS, NÍVEL DO MAR**

Melisa Menéndez ( [menendezm@unican.es](mailto:menendezm@unican.es) )

➤ VIENTO Y VARIABLES ATMOSFÉRICAS:

- SeaWind (SW)



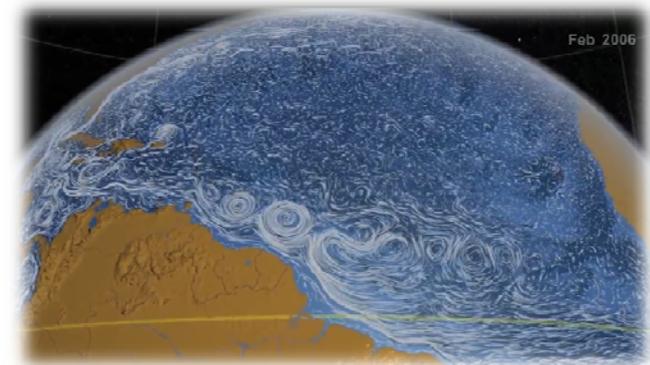
➤ OLAJE:

- Olas en el océano → Global Ocean Waves (GOW)
- Olas en costa → Downscaled Ocean Waves (ROW)

➤ NIVEL DEL MAR Y CORRIENTES:

- Nivel Medio del Mar (MSL)
- Marea astronómica (GOT)
- Marea meteorológica → Global Ocean Surge (GOS)

(GOST)



PROJETO  
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**PERIGOS:**

**ONDAS**

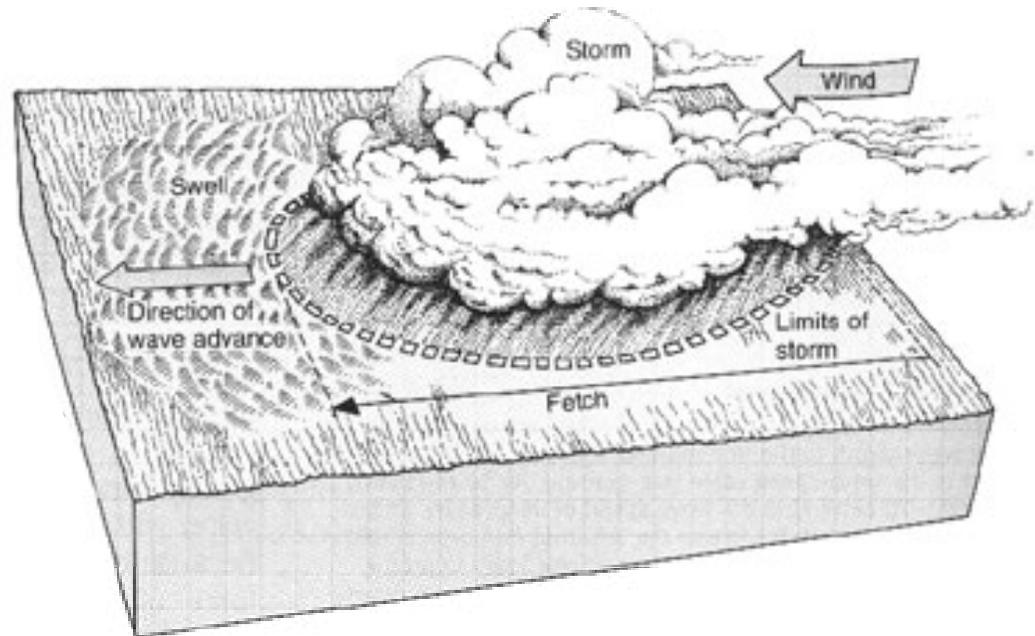
Melisa Menéndez ( [menendezm@unican.es](mailto:menendezm@unican.es) )

## Algunos conceptos preliminares..

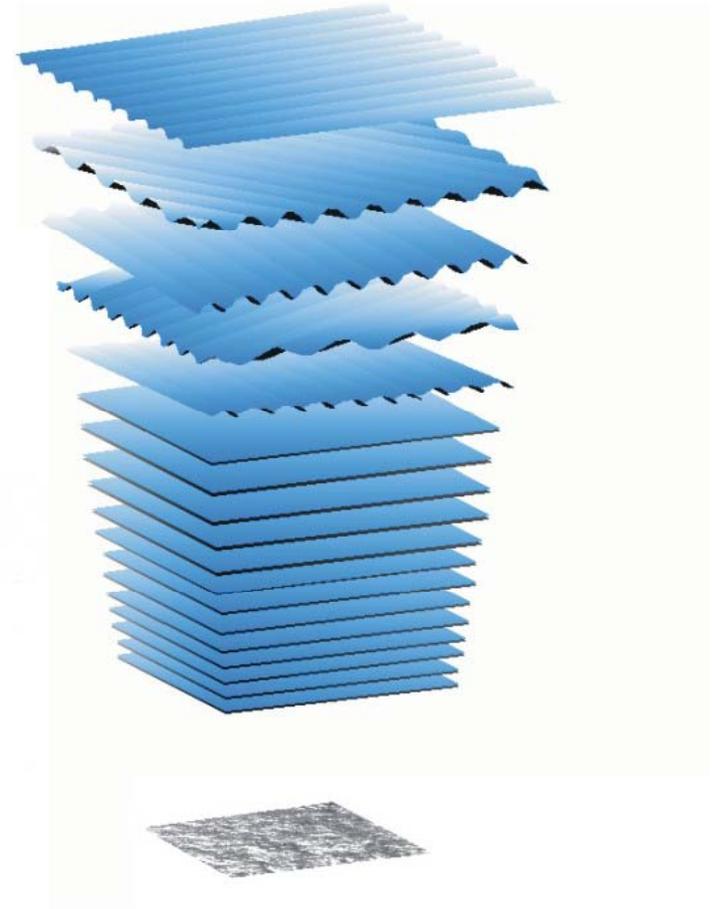
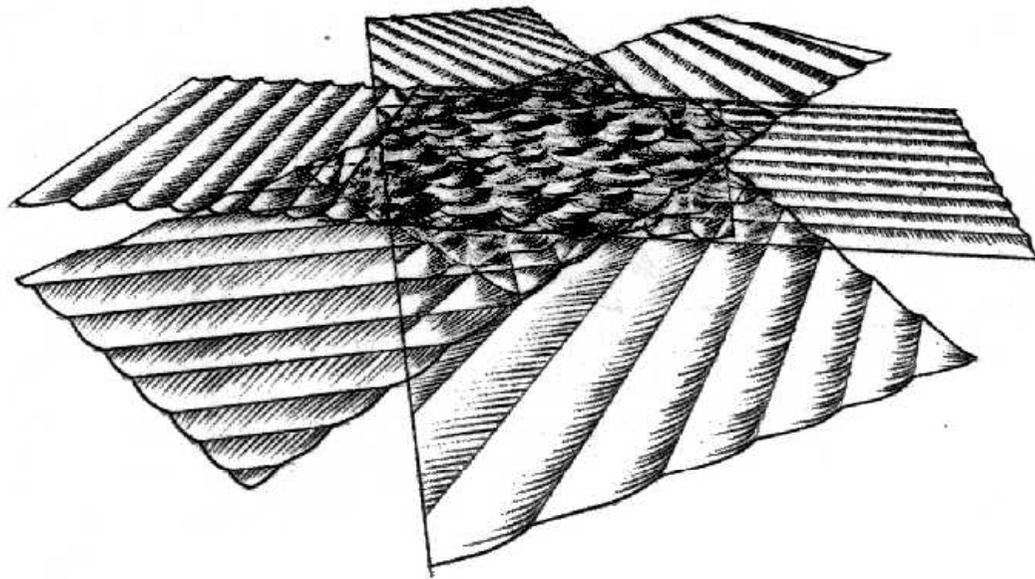
Sea



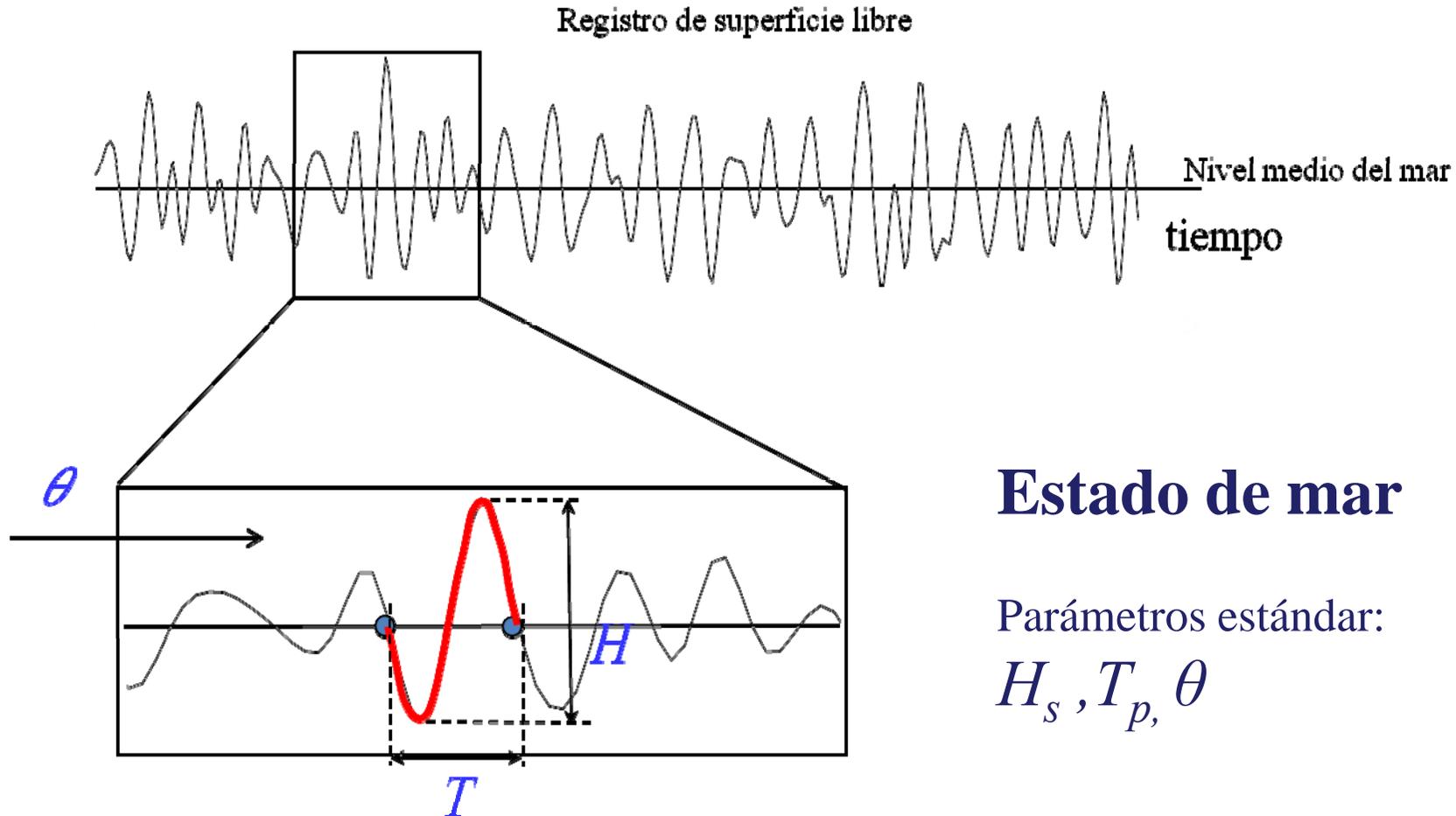
Swell



## Algunos conceptos preliminares..



## Algunos conceptos preliminares..



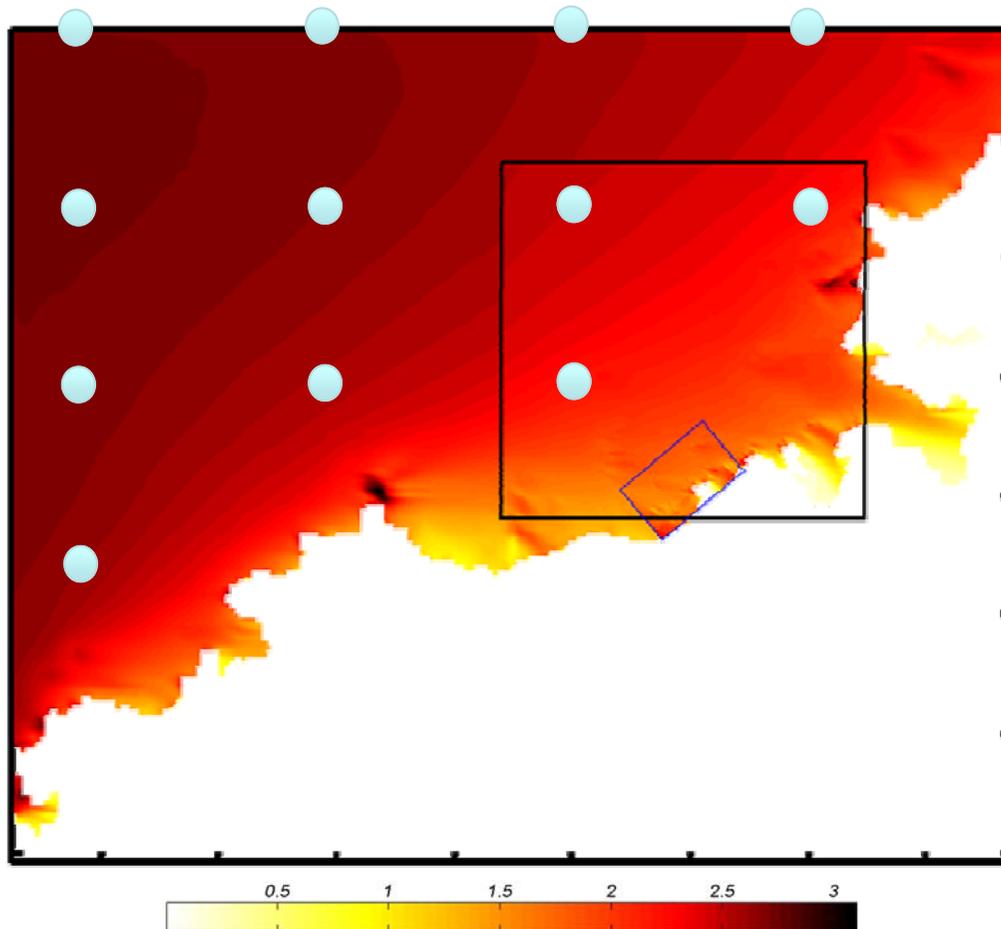
## Estado de mar

Parámetros estándar:

$$H_s, T_p, \theta$$

## Algunos conceptos preliminares..

Métodos para obtener el oleaje costero a partir de olas oceánicas:



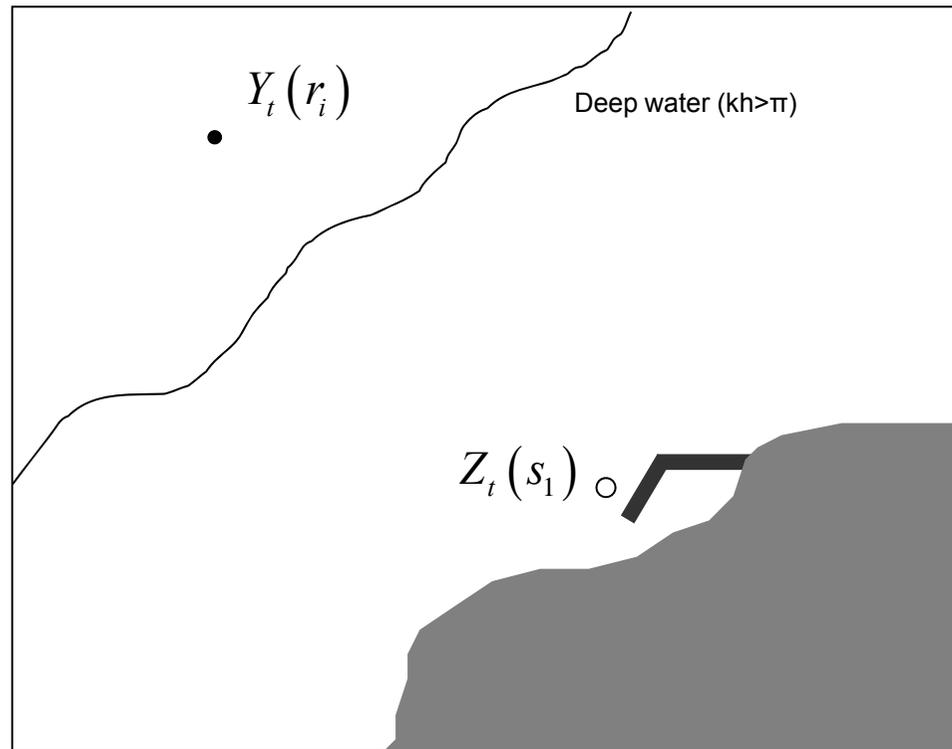
- Dynamical Downscaling
- Statistical Downscaling
- Hybrid Downscaling

# Algunos conceptos preliminares..

Métodos para obtener el oleaje costero a partir de olas oceánicas:

## Statistical Downscaling

$$Y_t(r_i) > Z_t(s_1)$$

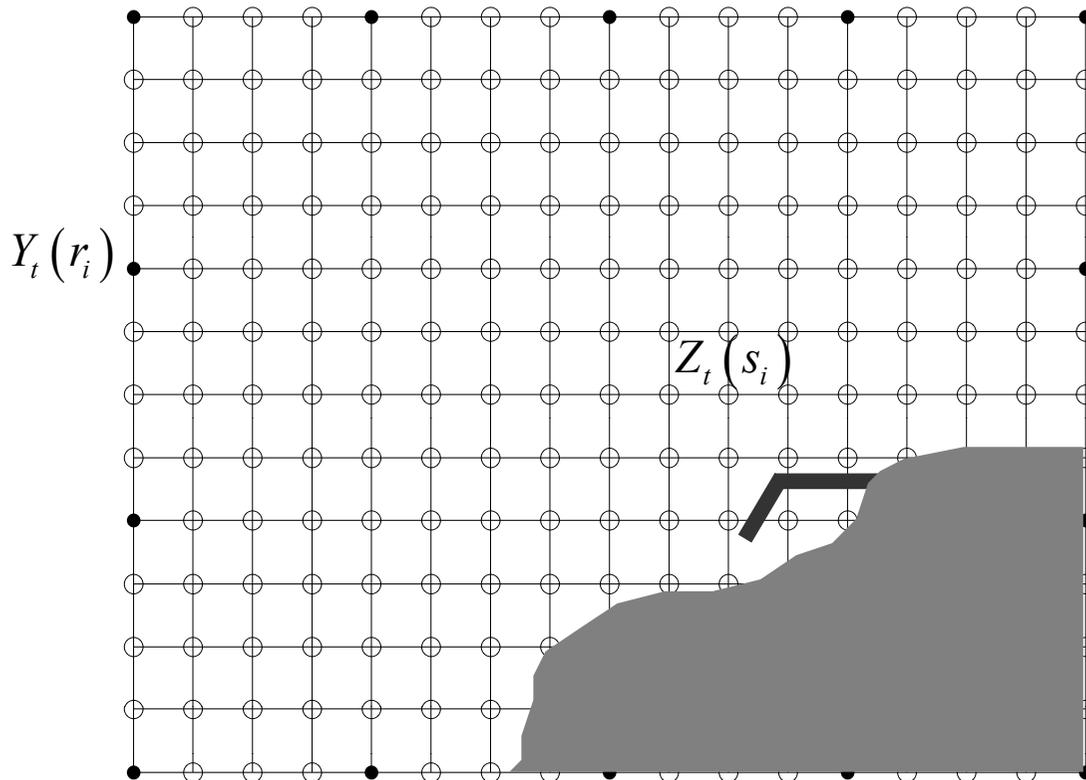


# Algunos conceptos preliminares..

Métodos para obtener el oleaje costero a partir de olas oceánicas:

## Dynamical Downscaling -> ROW

$$Y_t(\{r_1, r_2, \dots, r_R\}) \blacktriangleright Z_t(\{s_1, s_2, \dots, s_S\})$$



$$Y_t = \left( \{r_1, r_2, \dots, r_R\} \right)$$

Oceanographic variables which define wave conditions at deep water at several locations (regional scale)

$$Z_t = \left( \{s_1, s_2, \dots, s_S\} \right)$$

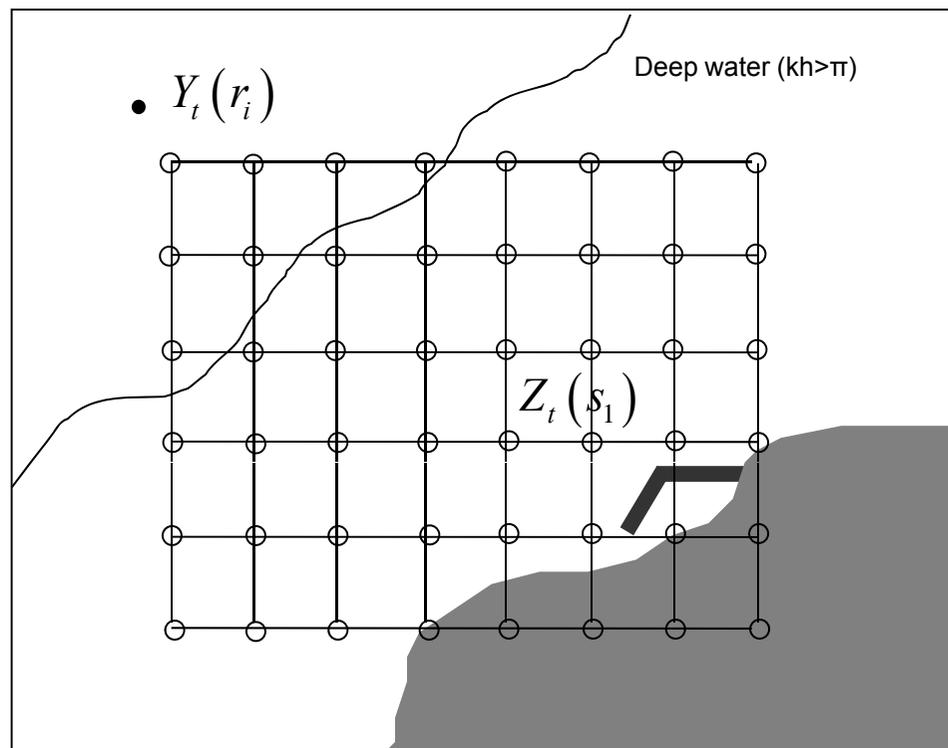
Oceanographic variables which define wave conditions at shallow water at several locations (local scale)

# Algunos conceptos preliminares..

Métodos para obtener el oleaje costero a partir de olas oceánicas:

## Hybrid Downscaling -> **DOW**

$$Y_t(r_1) \triangleright Z_t(\{s_1, s_2, \dots, s_S\})$$



**Dynamical downscaling:**  
Numerical propagation of several sea states conditions at deep water

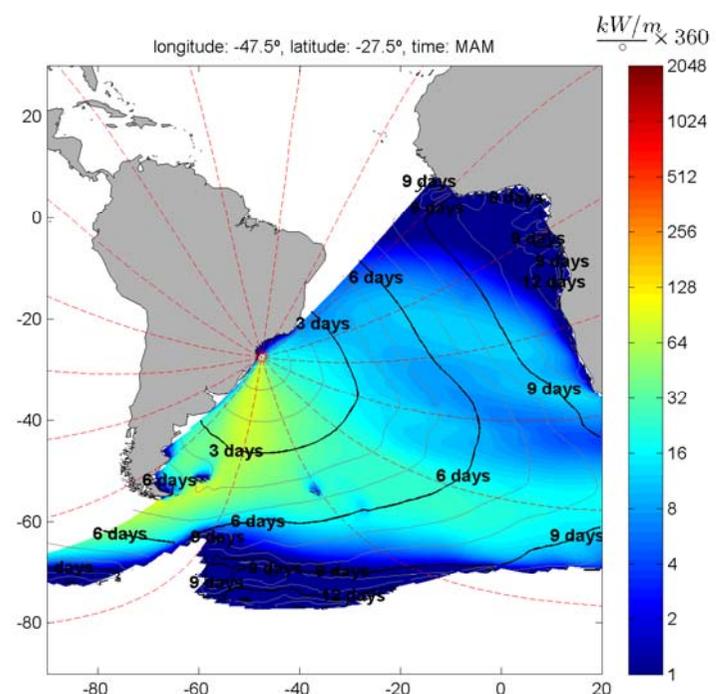
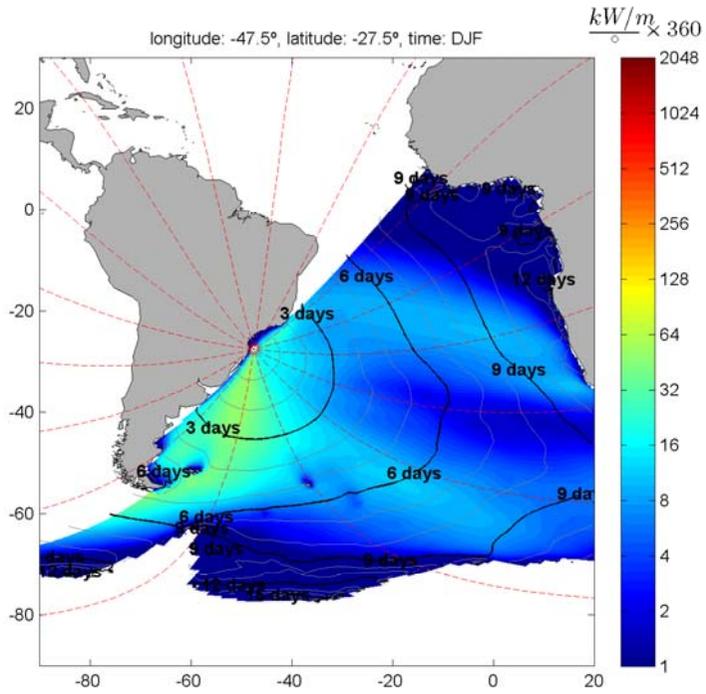
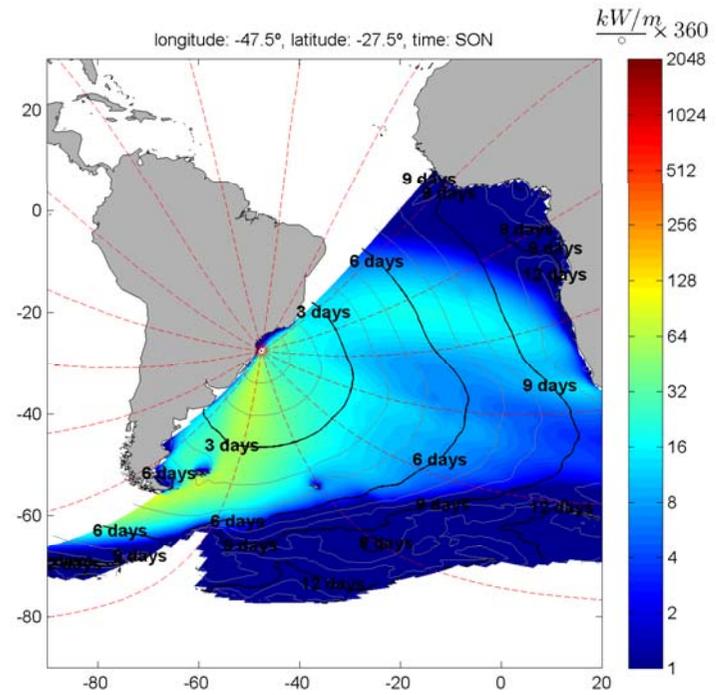
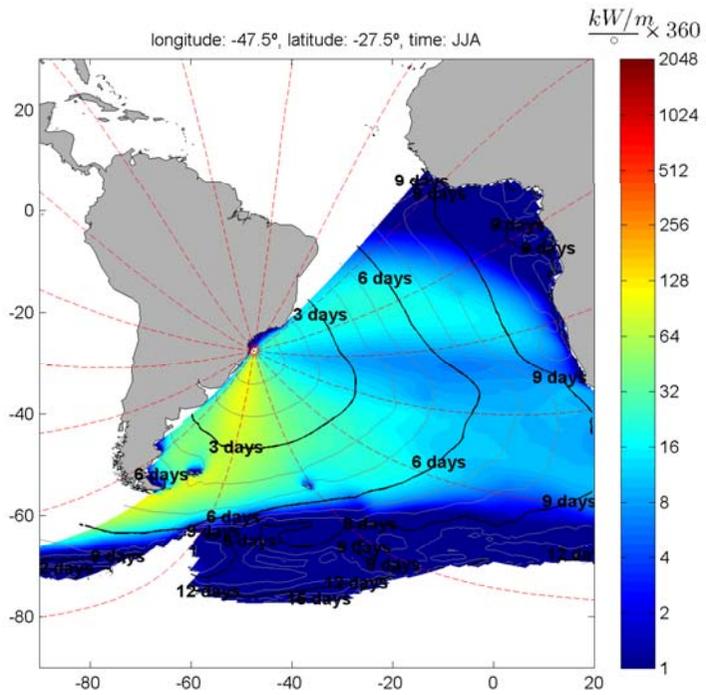
**Statistical downscaling:**  
Transfer functions to extrapolate coastal wave parameters based on the dynamical simulations

## Algunos conceptos preliminares..

### Summary of the different methodologies

- Dynamical downscaling:
  - the most accurate approach
  - high computational demand
- Statistical downscaling:
  - only reproduces the wave parameters, usually the significant wave height, at a specific location at shallow water
  - requires instrumental data at coastal location
- Hybrid downscaling:
  - Simulations of not real wave and wind conditions and transfer functions based on only two or three wave parameters.
  - High computational effort in the case of generating several years of dynamical simulations





## Antecedentes..

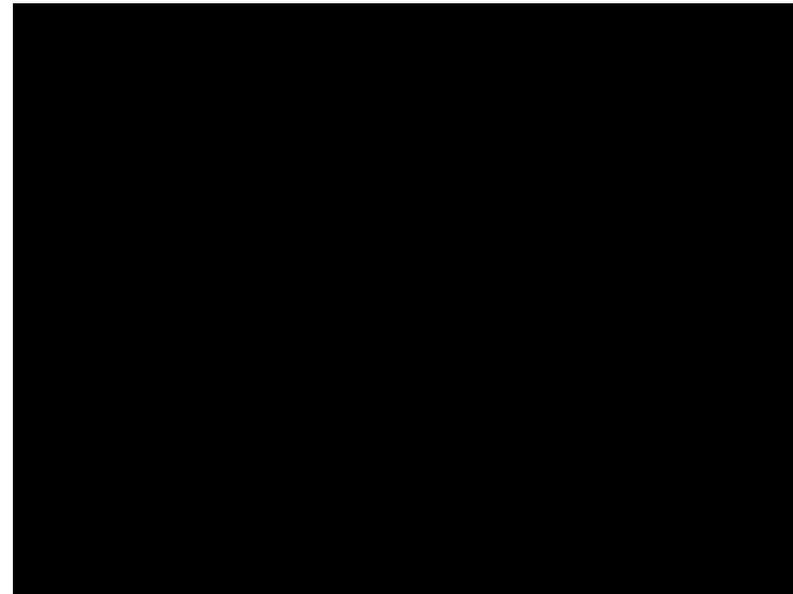
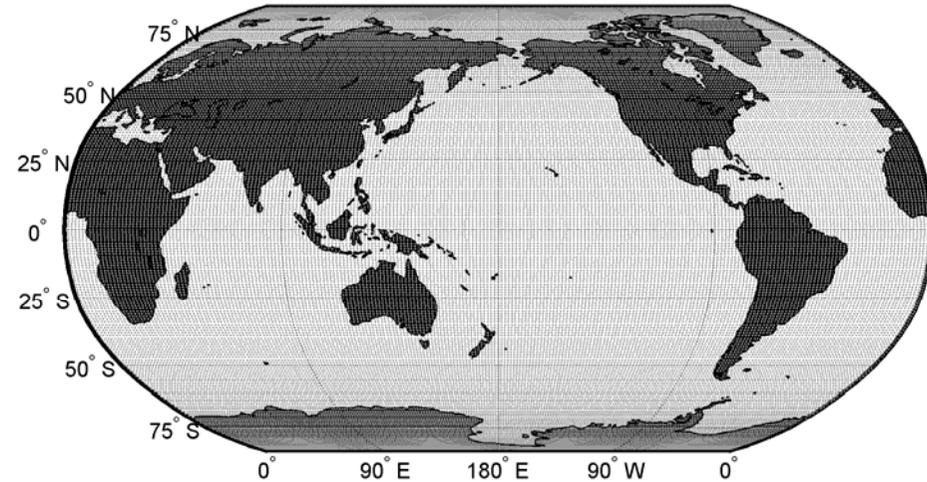


Forzamiento NCEP 1.8° 1948-2008 6h

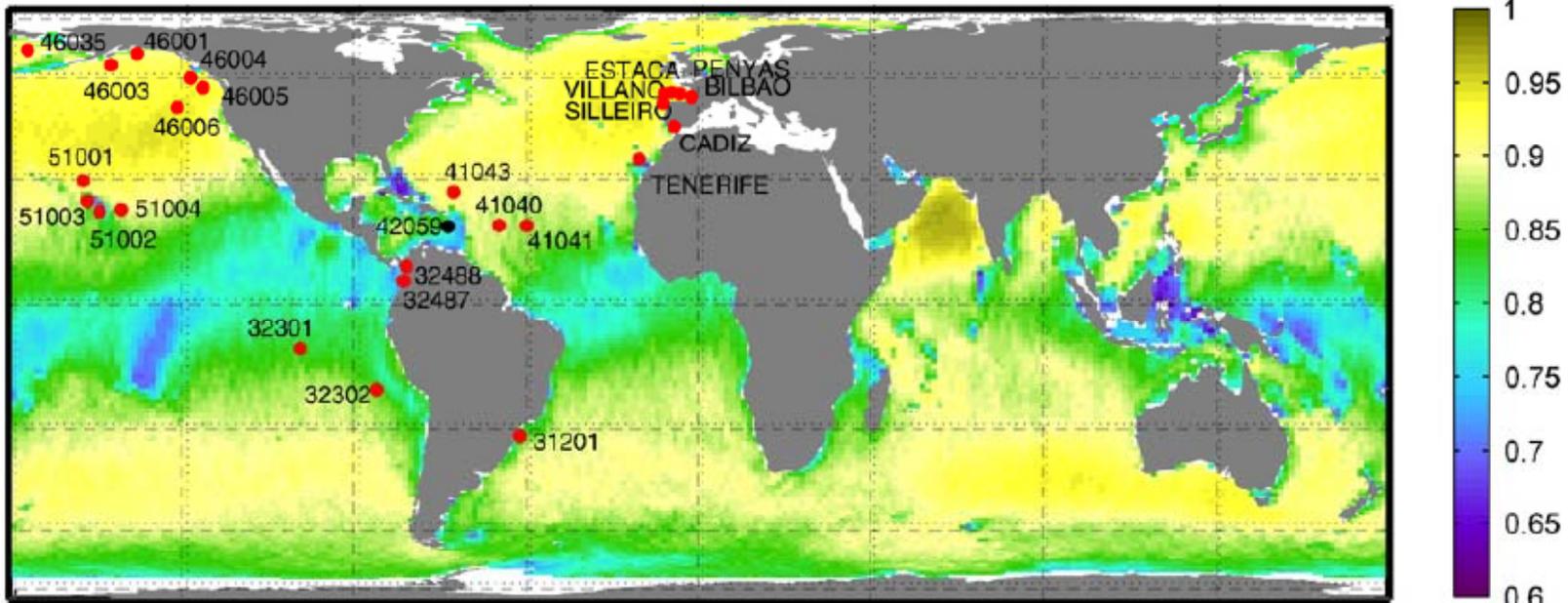
Modelo WW III. V2.22

1°, 1 hora

Parámetros espectrales del estado de mar

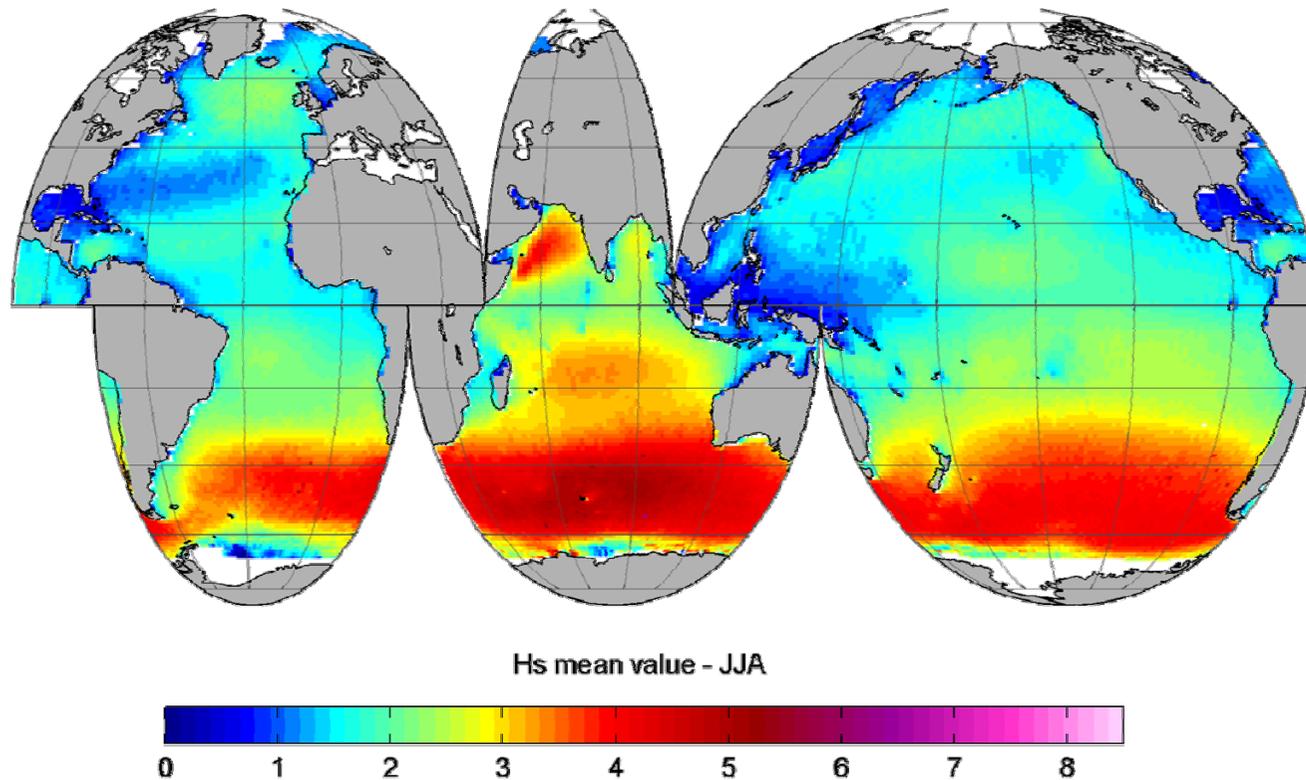


# Antecedentes..



Global map of Pearson correlation coefficient between satellite observations and hindcast results (GOW-1.0) for the period of available altimetry observations (1992–2008). Red dots represent buoy locations.

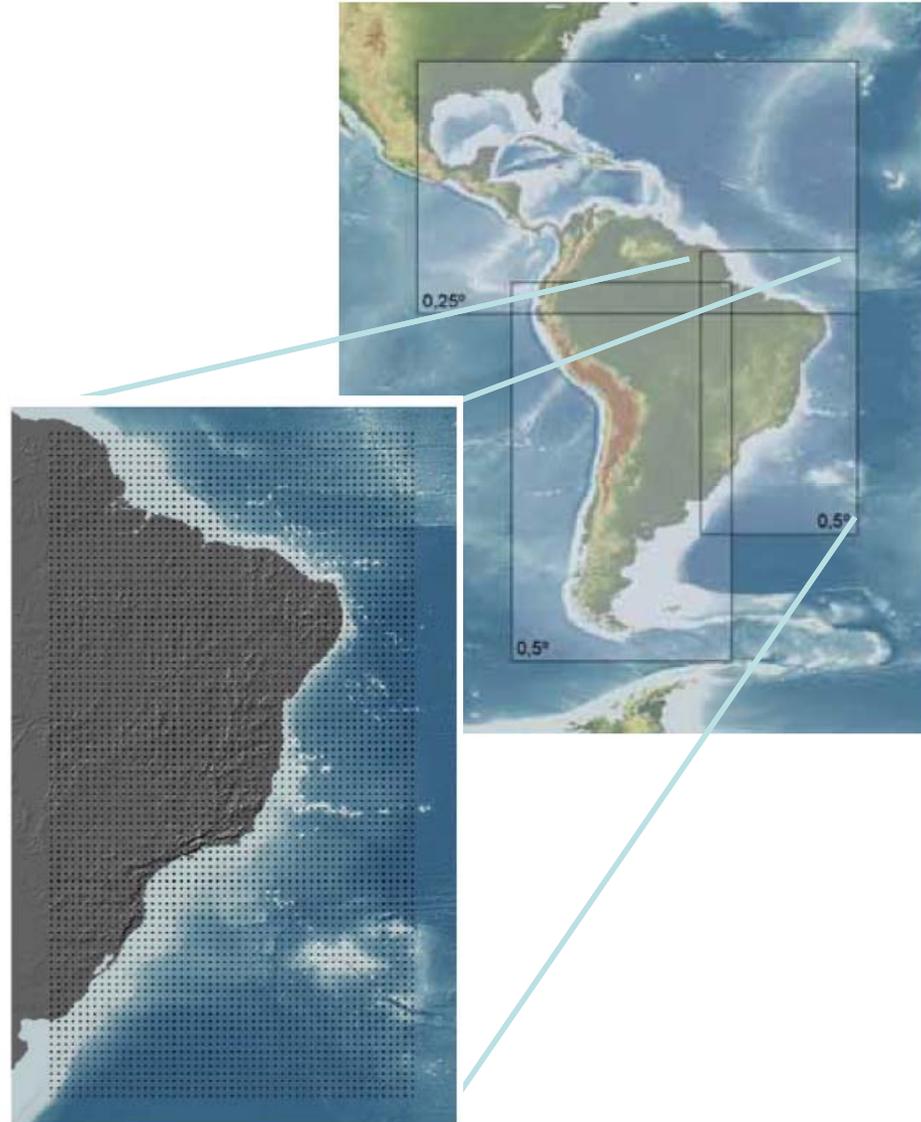
## Antecedentes..



## Antecedentes..



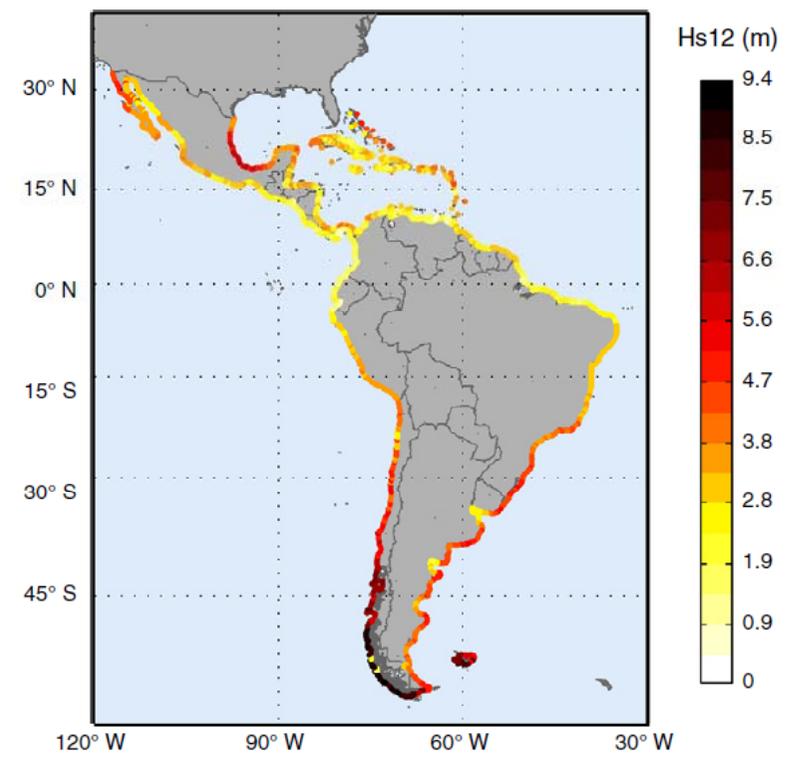
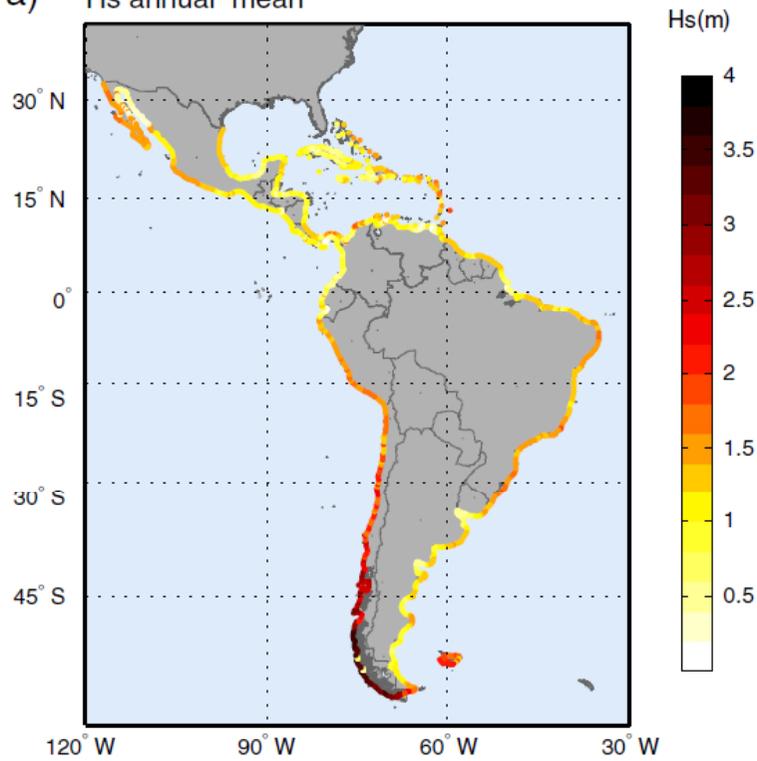
Forzamiento NCEP 1.8° 1948-2008 6h  
Modelo WW III. V2.22  
0.5° , 1 hora  
Parámetros espectrales del estado de mar



# Antecedentes..



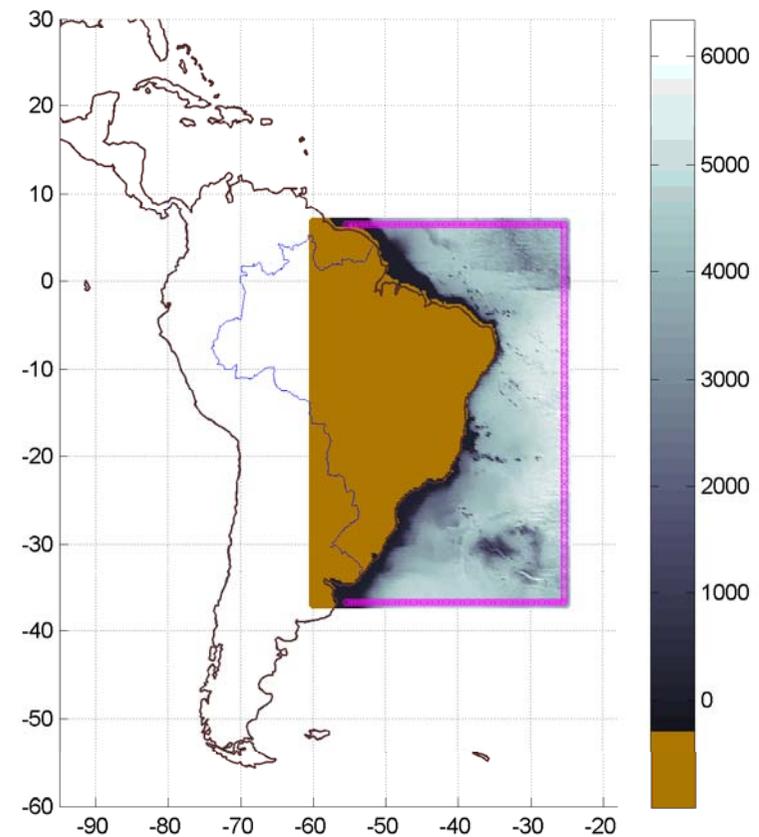
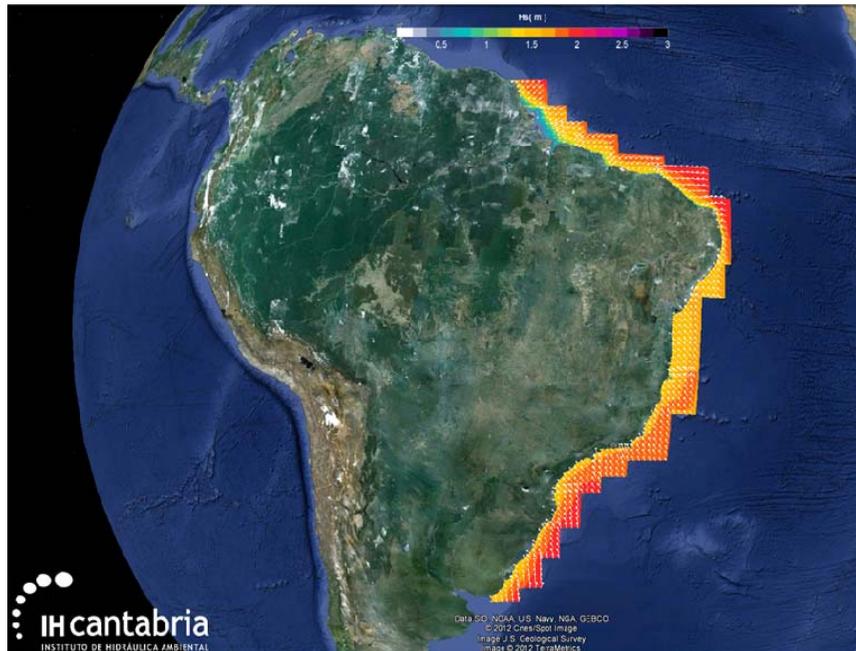
a) Hs annual mean



## Antecedentes..



Forzamiento NCEP 1.8° 1948-2008 6h  
Modelo WW III. V2.22  
0.25° , 1 hora  
Parámetros y espectros del estado de mar



# Antecedentes..



Downscaling híbrido  
- Estadístico + Dinámico

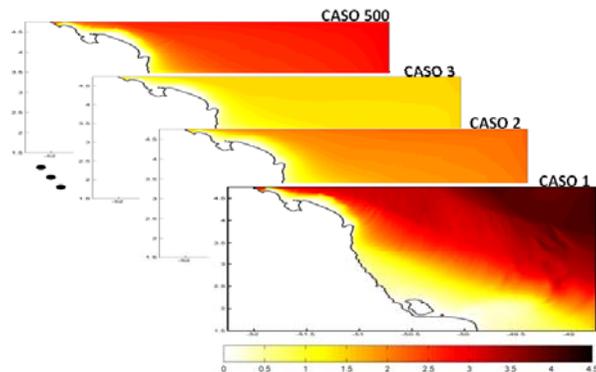
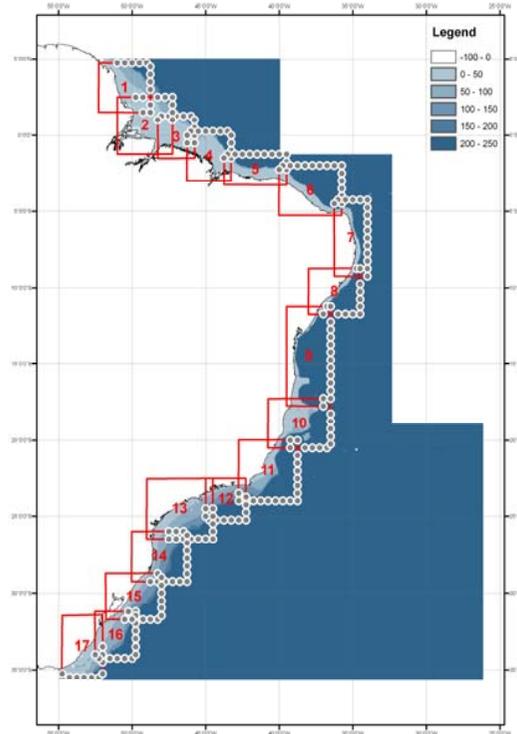
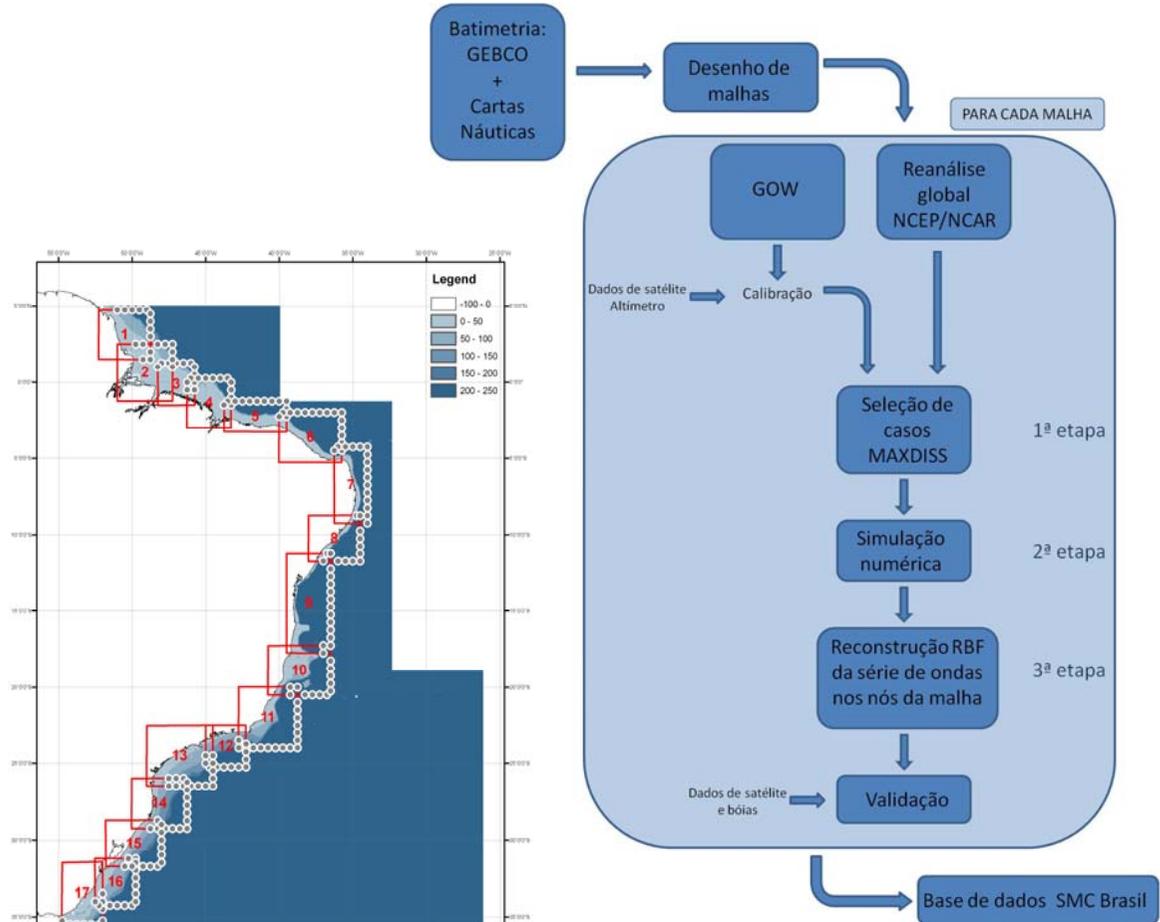


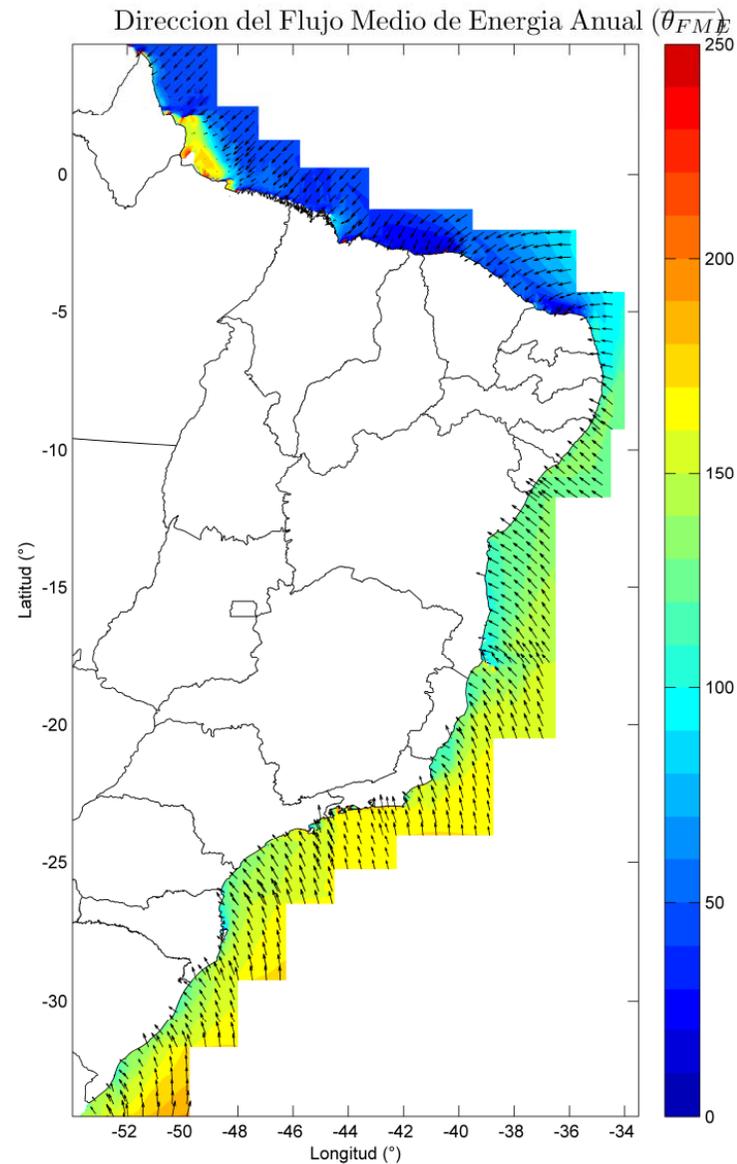
Figura 4.12 - Esquema de la librería de casos de  $H_2$  generada a partir de los 500 casos seleccionados a nivel medio de marea.



## Antecedentes..



Downscaling híbrido  
- Estadístico + Dinámico



## Objetivo

El objetivo principal de esta parte del trabajo es la **generación de una base de datos de oleaje histórica de alta resolución espacio-temporal (datos horarios a una resolución entre 200 m y 1 km) que cubra el estado de Santa Catarina en Brasil: ROW**

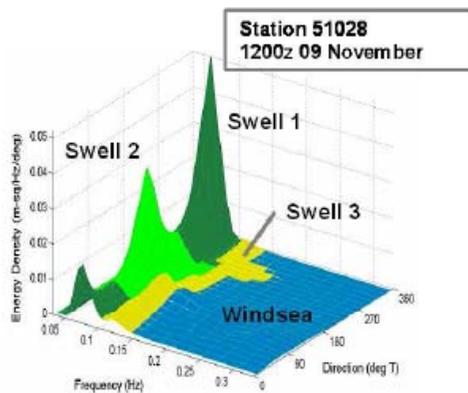
### Objetivos específicos:

- 1) Análisis de las bases de datos de oleaje y disponibles
- 2) Corrección y/o validación de la base de datos reanálisis utilizada como forzamiento en el modelo de propagación.
- 2) Elaboración de una batimetría lo más detallada posible que permita transferir correctamente el oleaje desde aguas profundas hasta la costa.
- 3) Diseño de las mallas de cálculo que serán utilizadas en el modelo de propagación.
- 4) Pre-procesado de los forzamientos de oleaje y viento.
- 5) Ejecución del modelo durante el dominio temporal disponible en la base de datos de aguas profundas.
- 6) Post-procesado de las salidas del modelo a formato netCDF.
- 7) Validación espacio-temporal con la información instrumental disponible.

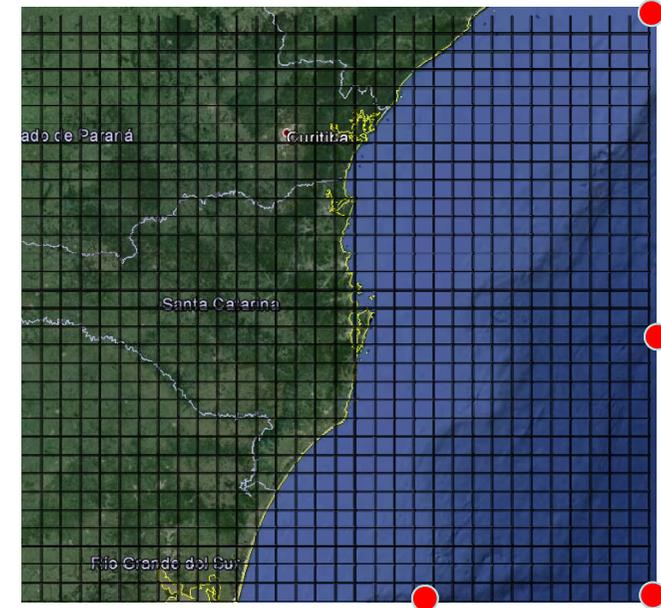
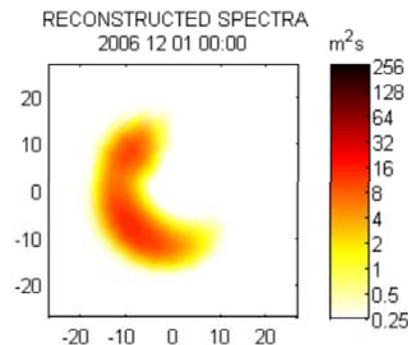
## Regional Wave Reanalysis (ROW)

### Mejoras con respecto a anteriores Reconstrucciones de Oleaje:

- Contornos: Base de datos GOW2 (nuevo forzamiento CFSR, nuevo modelo WWIII,..)
- Calibración de Espectros GOW2 con nueva base de altimetría multi-mission (1992-2013).
- ROW (reconstrucción dinámica en continuo) vs. DOW (downscaling híbrido)
- Forzamiento del Oleaje: SeaWind (alta resol. espacial), capacidad para reproducir 'Seas'.
- Simulación dinámica SWAN (nueva versión)
- ROW con Activación de fricción por fondo.



- Mínimo Resol: 1Km
- Periodo: 1979-2010
- Resol. temporal: horaria

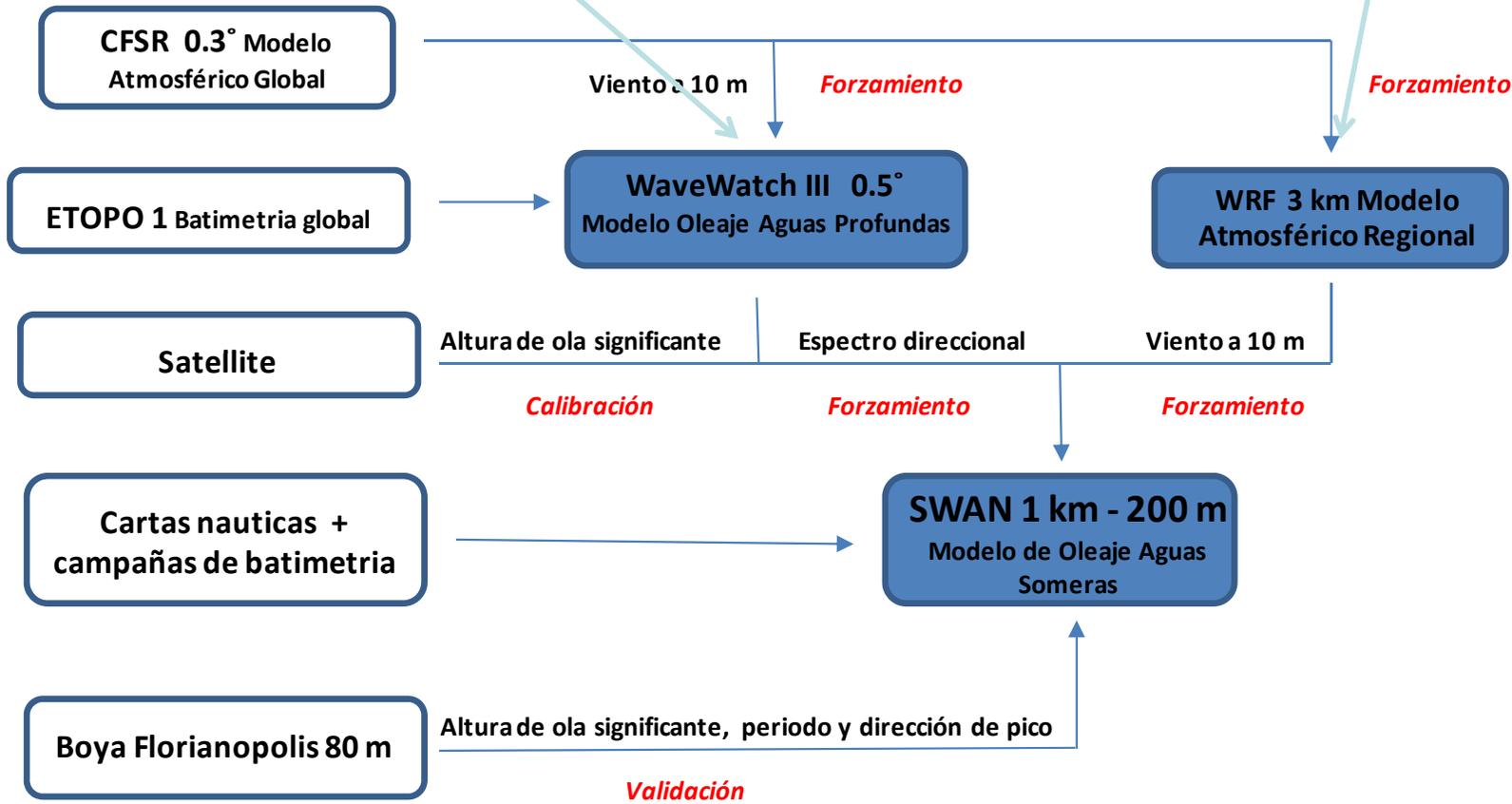


*Ejemplo de Dominio espacial de estudio.*

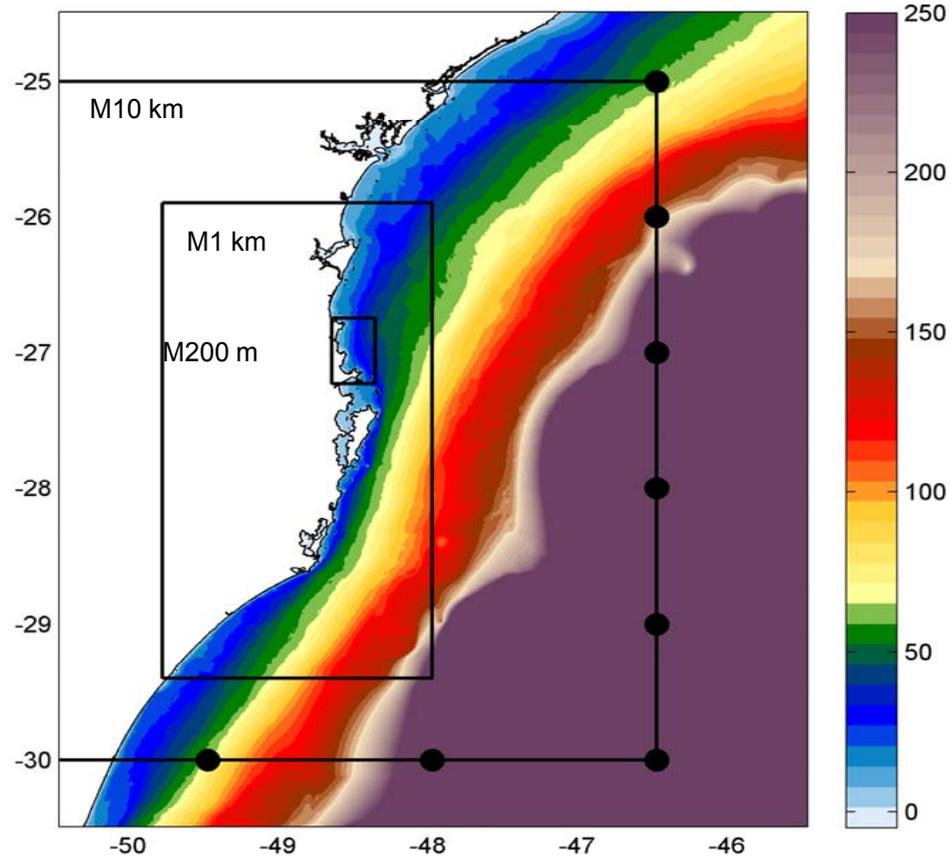


Forzamiento CFSR y CFSv2, 0.3/2° 1979-2015  
WaveWatch III v4.18 (2014)  
1°, 1 hora  
parámetros, particiones y espectros

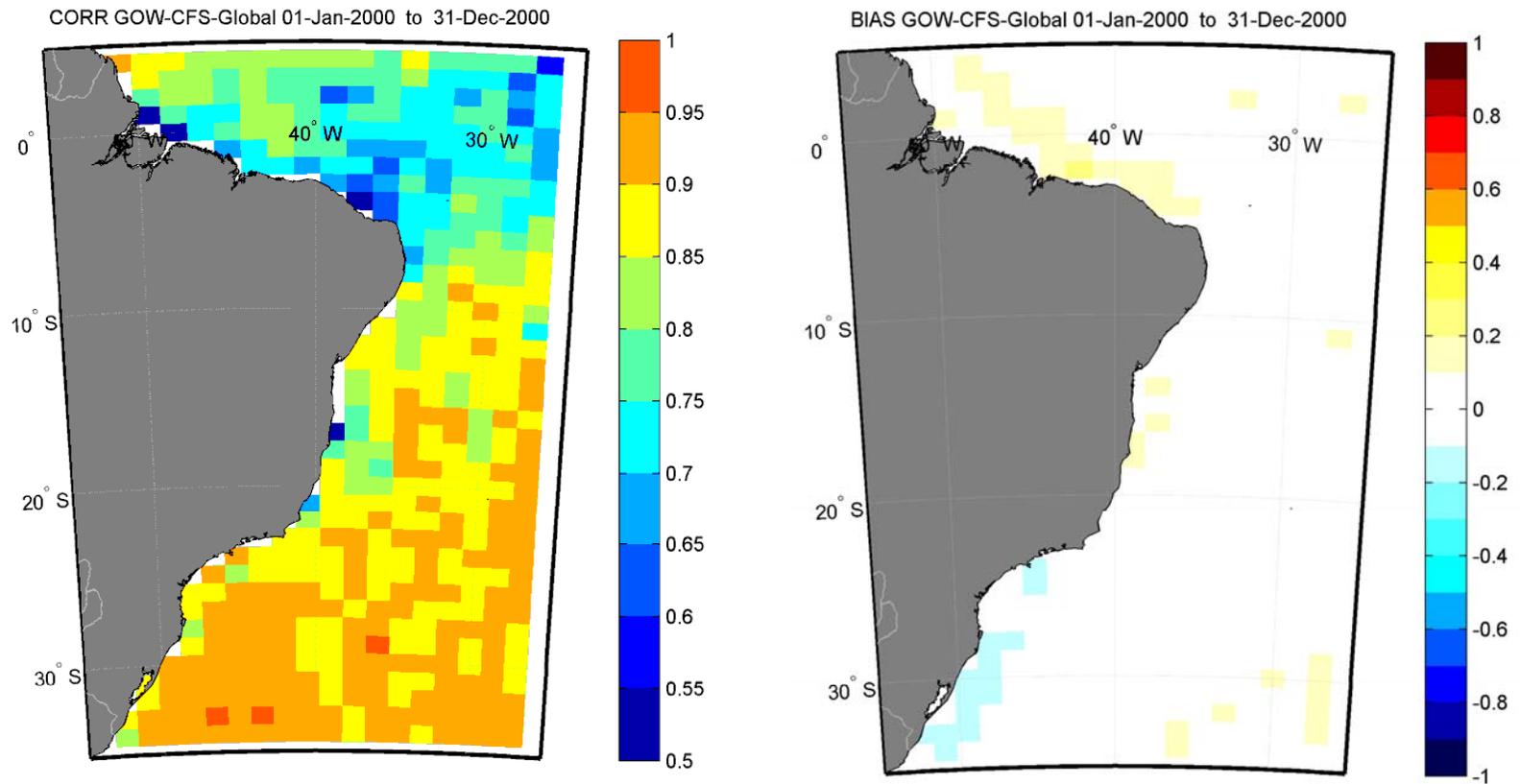
SEAWIND-Sta Catarina



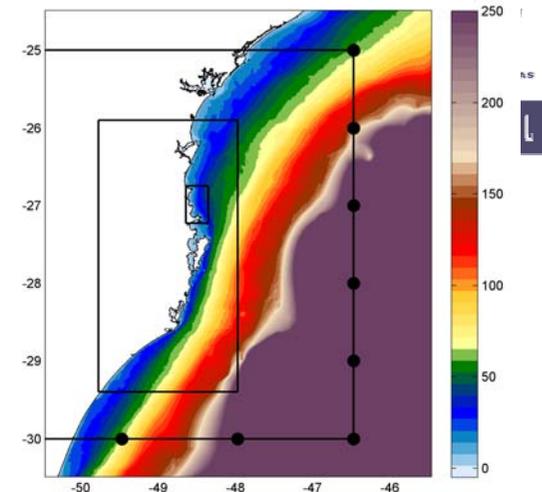
## Dominios espaciales



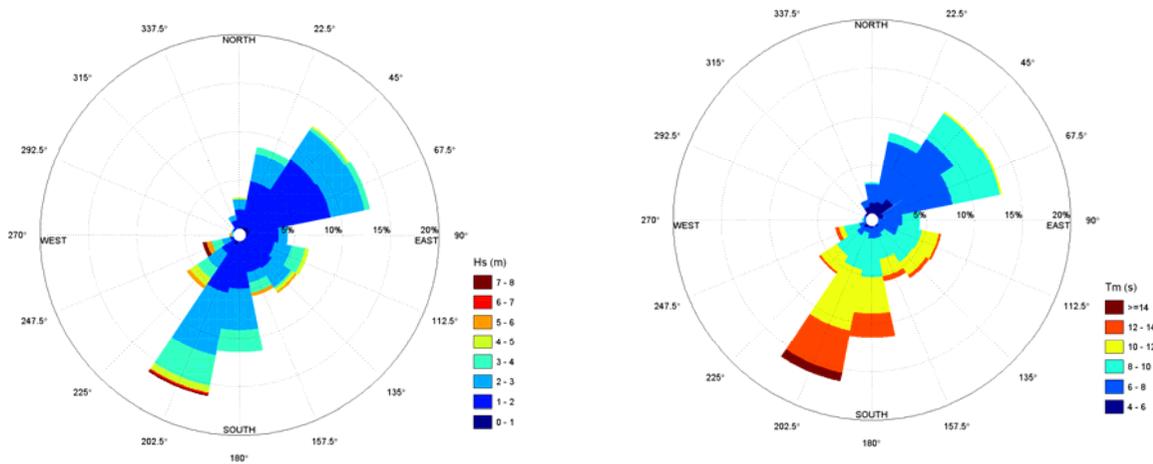
## Validación oleaje GOW



Comparación de GOW con datos de satélite en el litoral Brasileño.  
De izquierda a derecha: correlación de Pearson y sesgo.



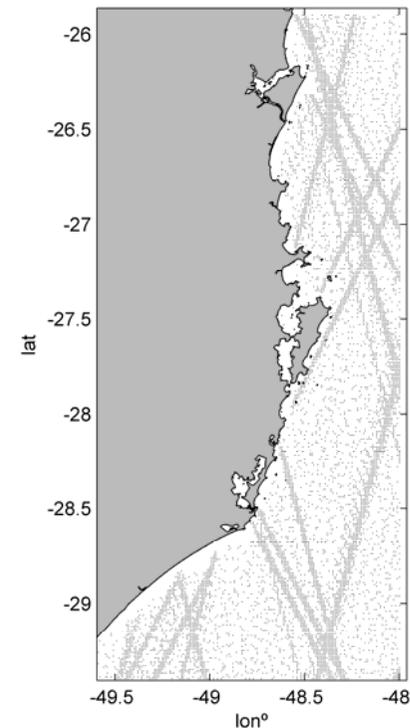
## Corrección oleaje GOW en contornos



Rosas direccionales de  $H_s$  (izquierda) y  $T_p$  (derecha) de los estados de mar seleccionados.

GOW 1.5:

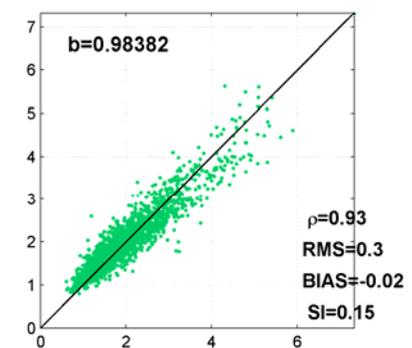
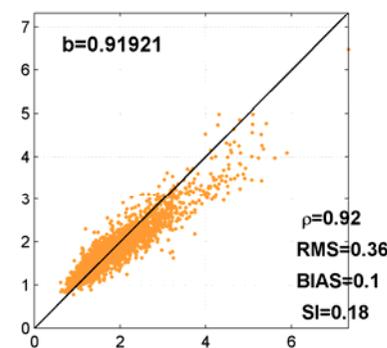
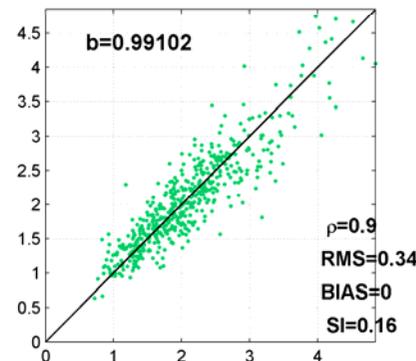
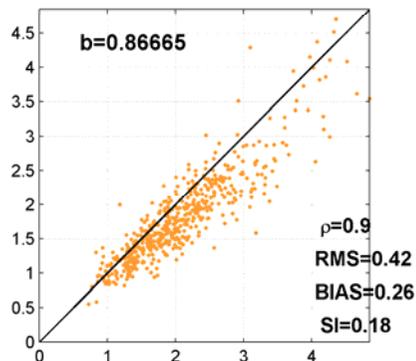
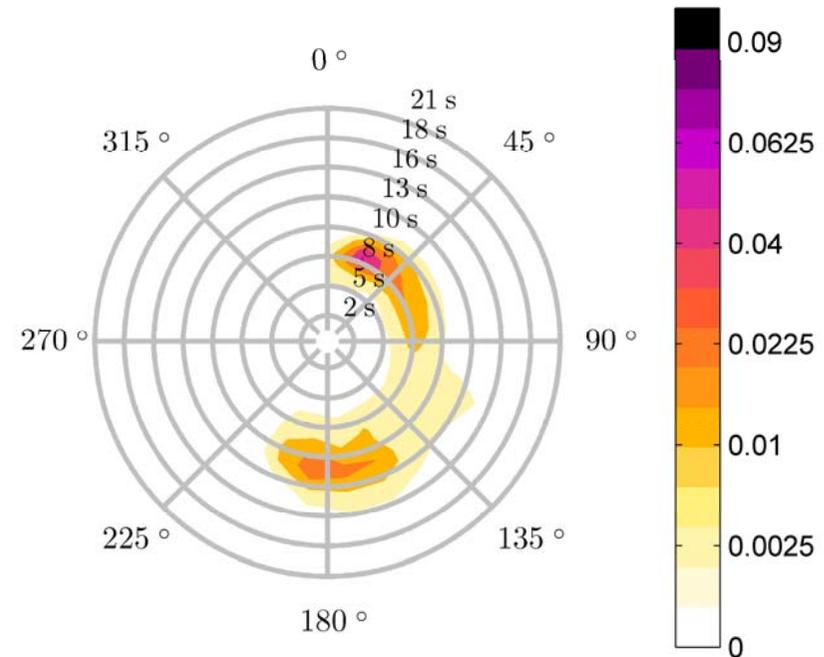
cada estado de mar queda definido por 12 variables  $\{H_{s1}, H_{s2}, H_{s3}; T_{p1}, T_{p2}, T_{p3}; \theta_1, \theta_2, \theta_3; \gamma_1, \gamma_2, \gamma_3\}$ , siendo  $\gamma_i$  la dispersión direccional de cada componente



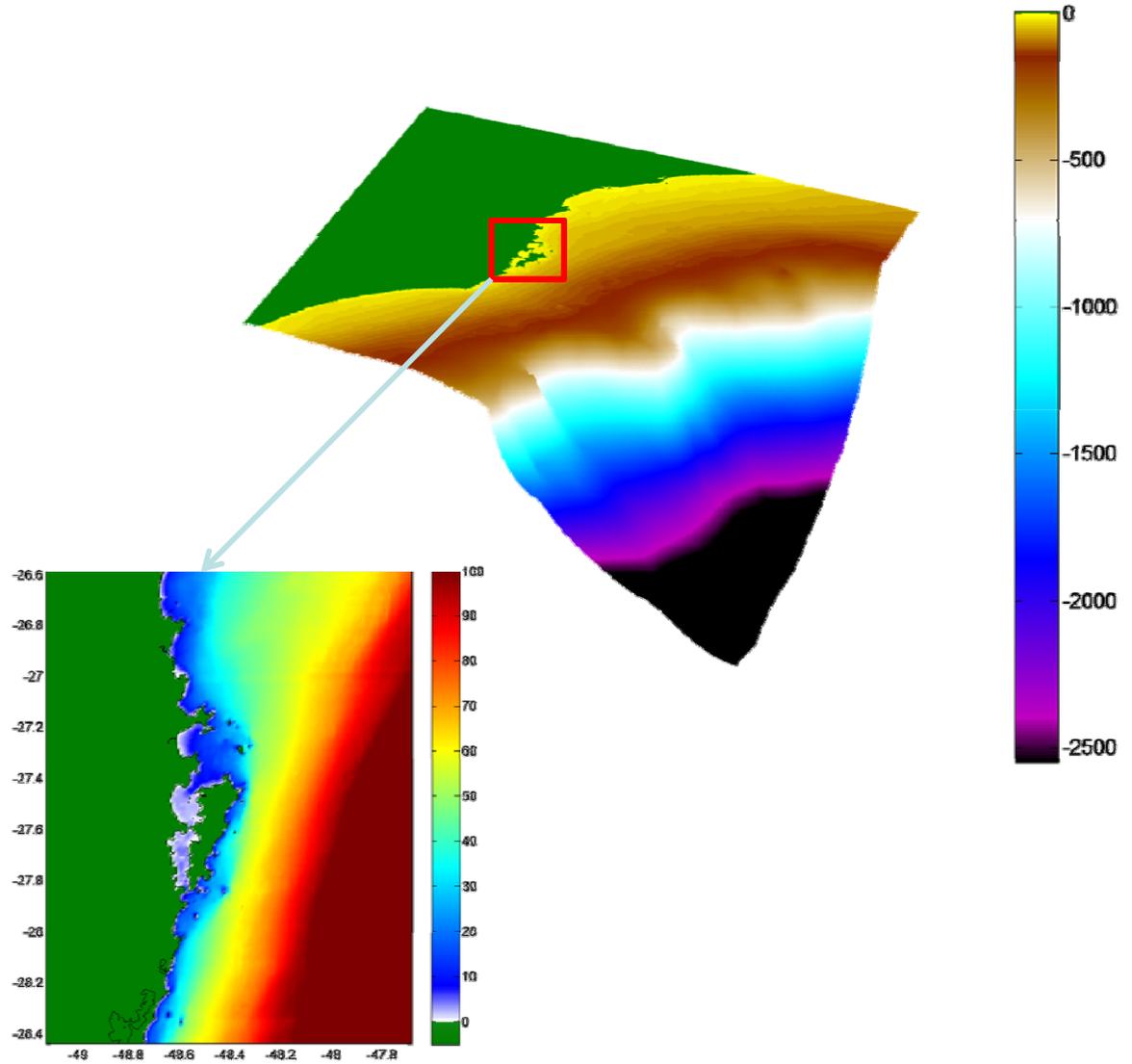
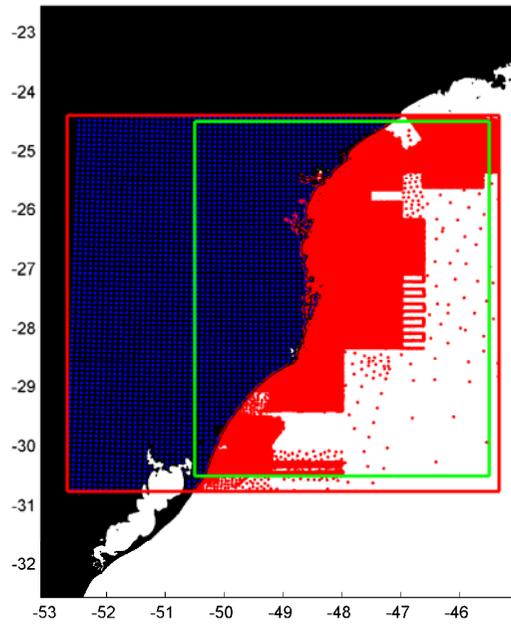
## Corrección oleaje GOW en contor

- Two main spectral components in the area NNE seas + S swells
- Different corrections are needed when comparing with satellite data
- Method:
  - Identifying pure sea-swell states (one component at least 80% of the total energy)
  - Separate directions
  - Linear regression fit ( $b_{NNE}$  y  $b_S$ )

m<sup>2</sup>/Hz/deg

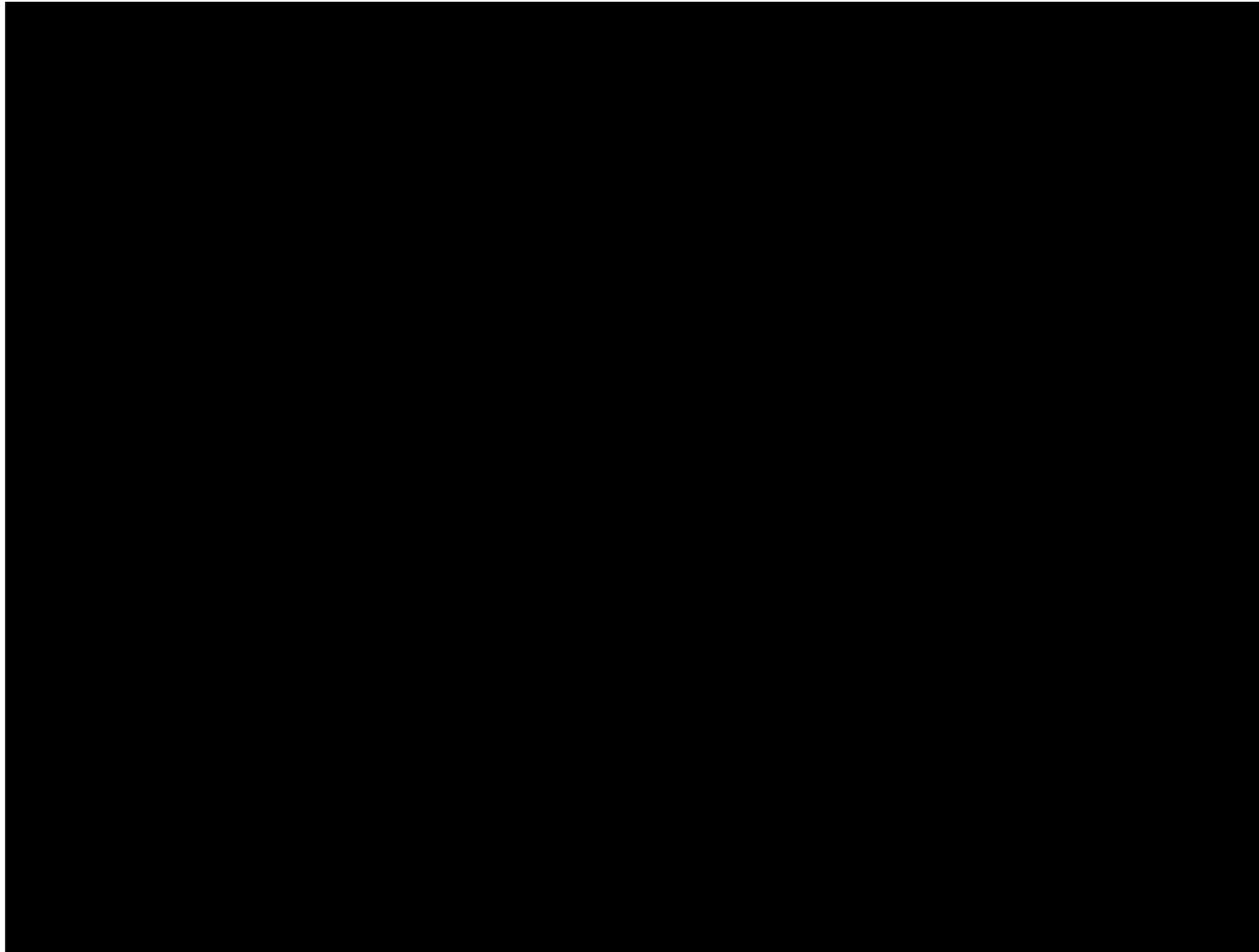


# Batimetria



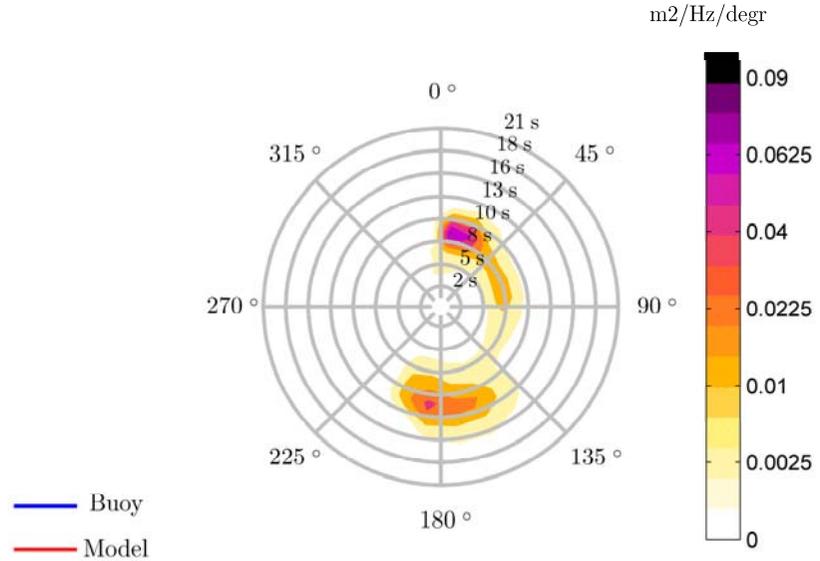
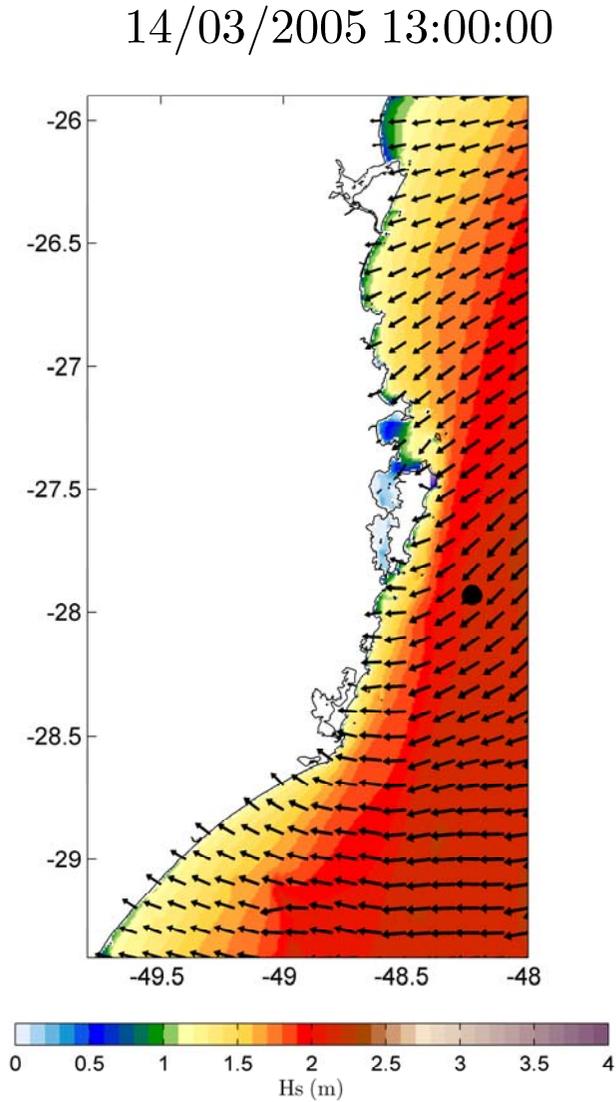


## Validación

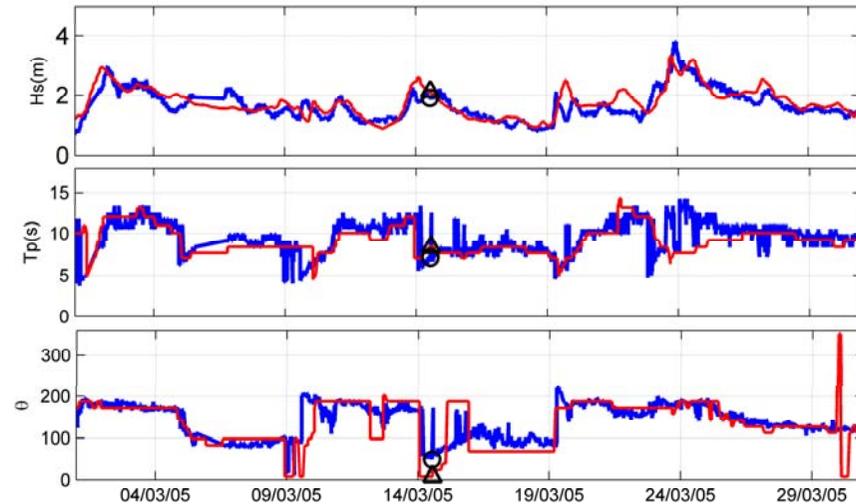


# Validación

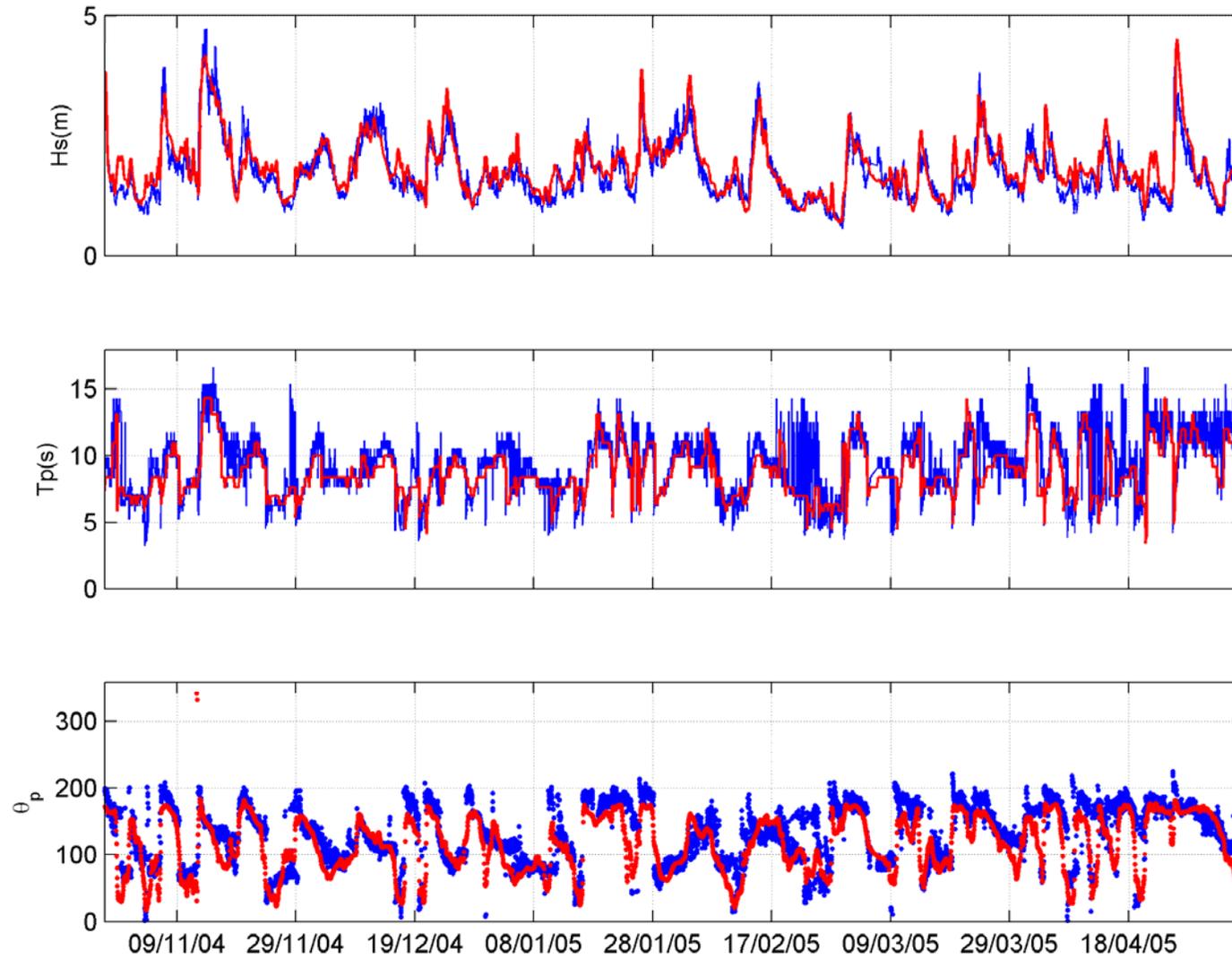
14/03/2005 13:00:00



— Buoy  
— Model



# Validación



## Simulación ROW-Santa Catarina: Resultados

### • Variables guardadas:

- Parámetros espectrales del estados de mar en malla 1Km y 200m

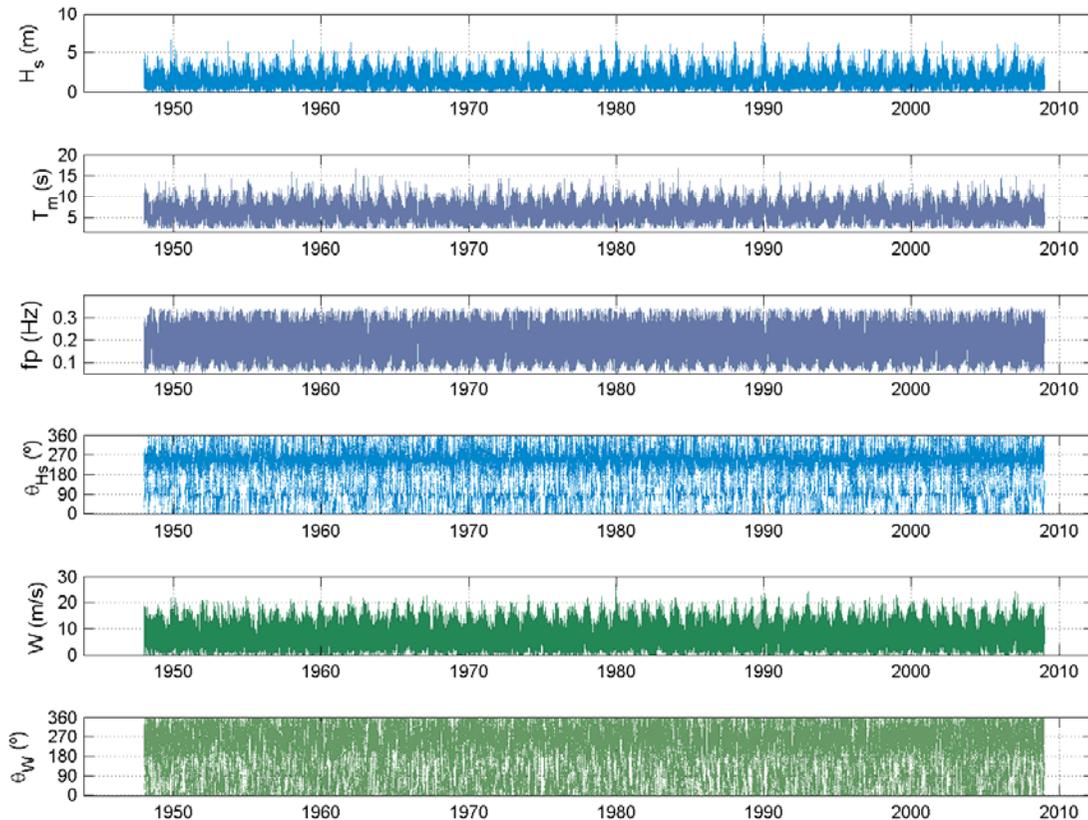
### • Resolución temporal: horaria.

• Periodo histórico: 1979-2010, total de 32 años.

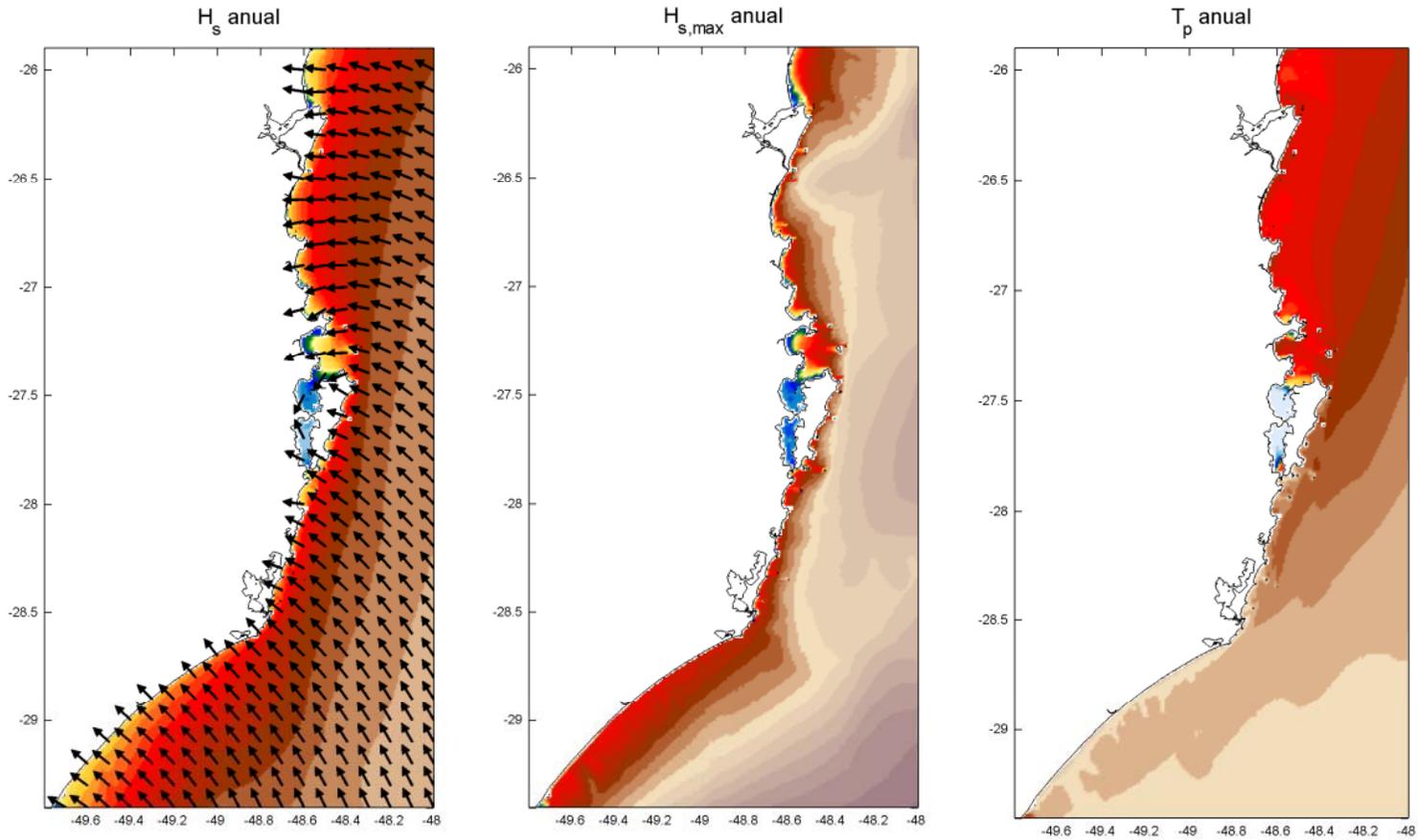
### • Volumen de datos generados:

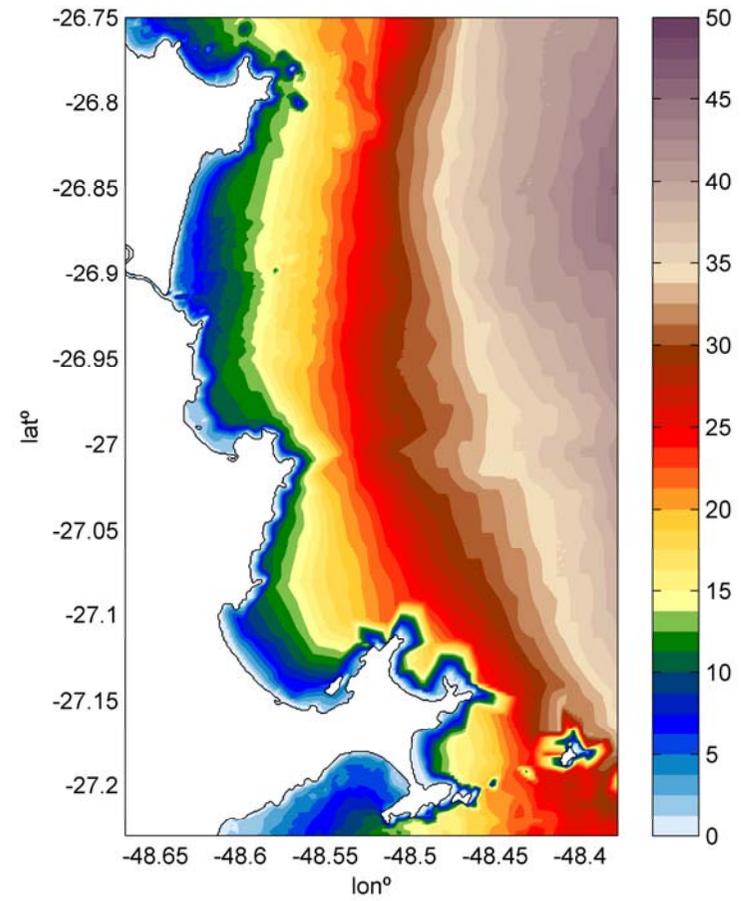
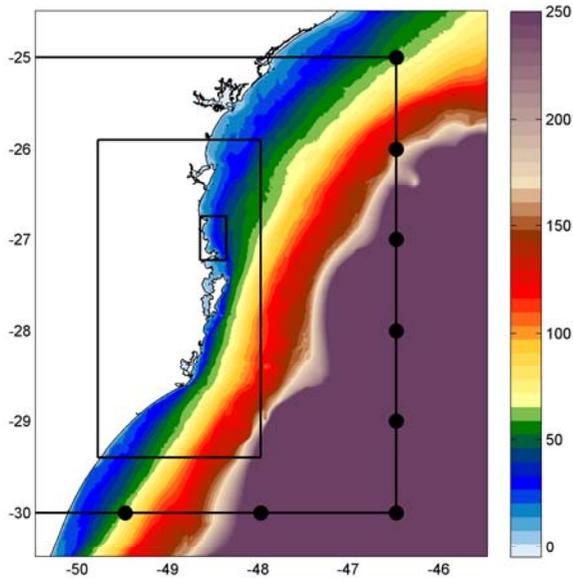
750 GB

Ficheros NetCDF mensuales

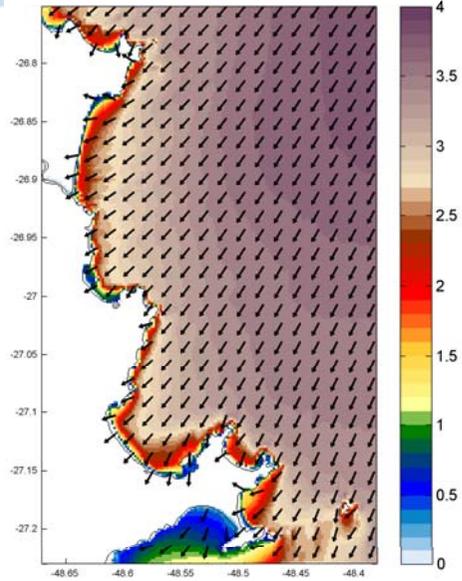


## Análisis climático: climatologías

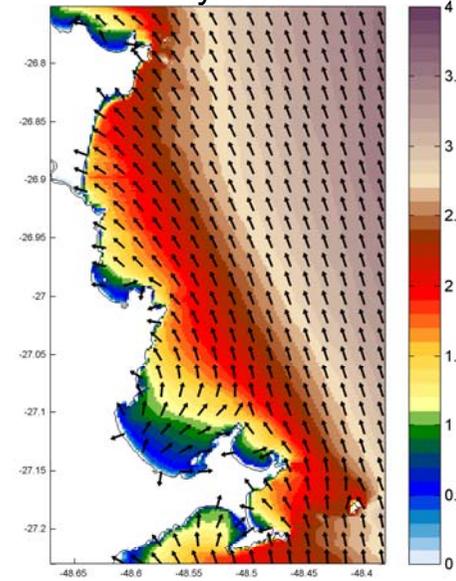




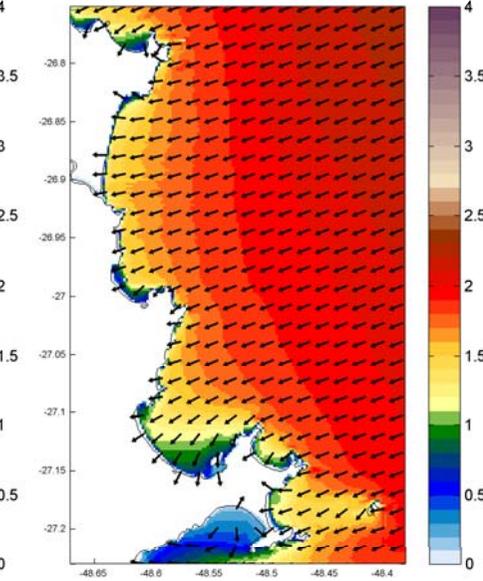
5 de Julio de 1983



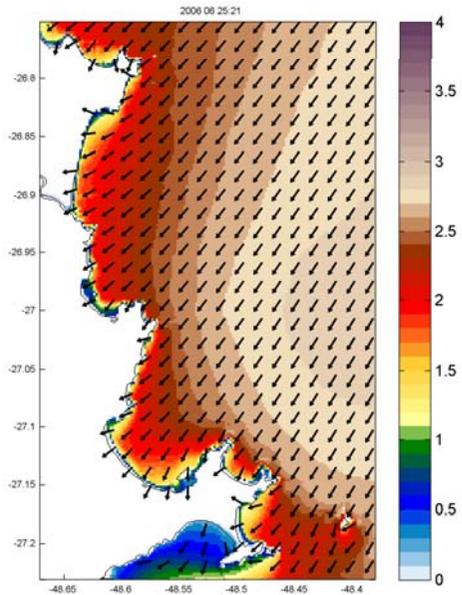
6 de Mayo de 2001



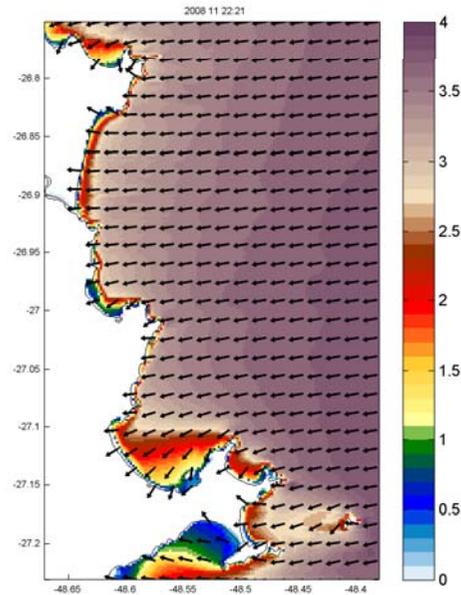
29 de Marzo de 2004



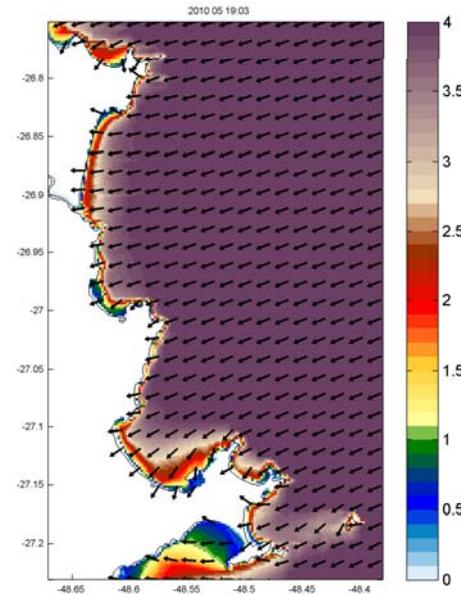
25 de Junio de 2006



22 de Noviembre de 2008

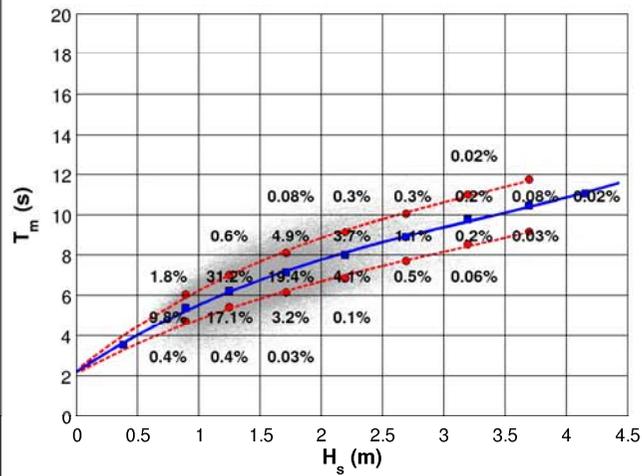
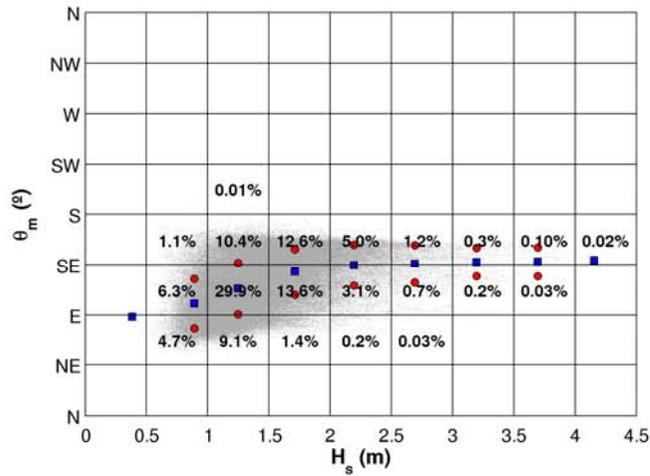
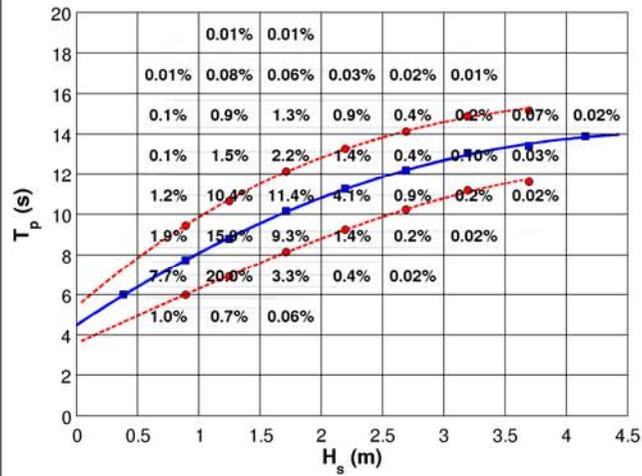


19 de Mayo de 2010





# Caracterización del oleaje Local



■ —  $\mu$   
● - -  $\mu \pm \sigma$

$$\mu(x|H_s) = a_0 + a_1 H_s + a_2 H_s^2 + a_3 H_s^3$$

$$\sigma(x|H_s) = a_0 + a_1 H_s + a_2 H_s^2 + a_3 H_s^3$$

$$x = \{T_p, T_m, \theta_m, \kappa, \sigma_\theta\}$$

$T_p$	$a_0$	$a_1$	$a_2$	$a_3$
$\mu(T_p H_s)$	4.494	4.042	-0.452	0.005
$\sigma(T_p H_s)$	0.910	1.276	-0.461	0.048

$T_m$	$a_0$	$a_1$	$a_2$	$a_3$
$\mu(T_m H_s)$	2.194	4.056	-0.797	0.081
$\sigma(T_m H_s)$	0.087	0.781	-0.173	0.013

**Caracterización clima marítimo OLEAJE**  
Tablas de encuentros  
ROW Santa Catarina (1979-2010)

Lon=48.7°O; Lat=28.5°S

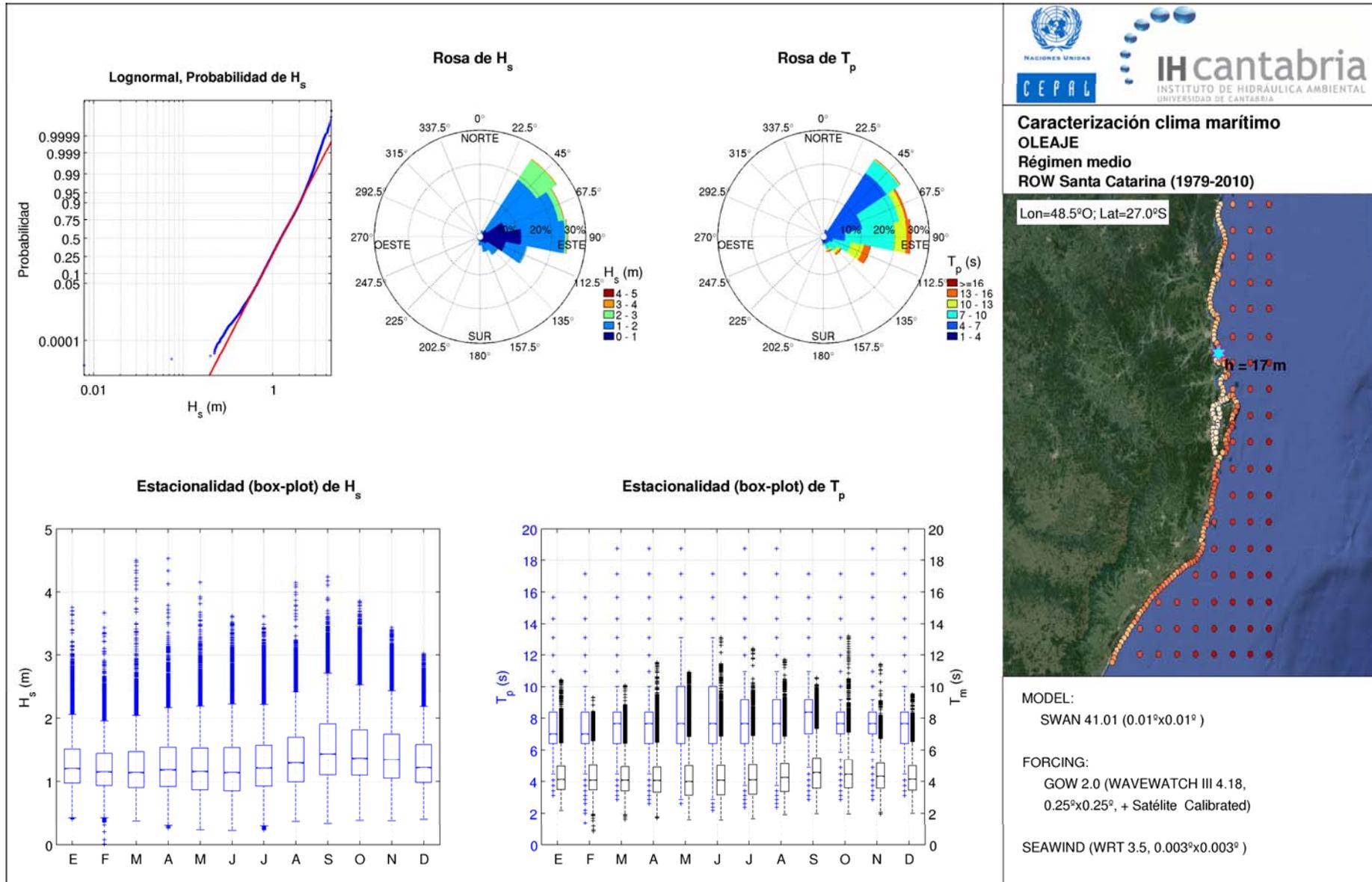
h = 20 m

MODEL:  
SWAN 41.01 (0.01°x0.01°)

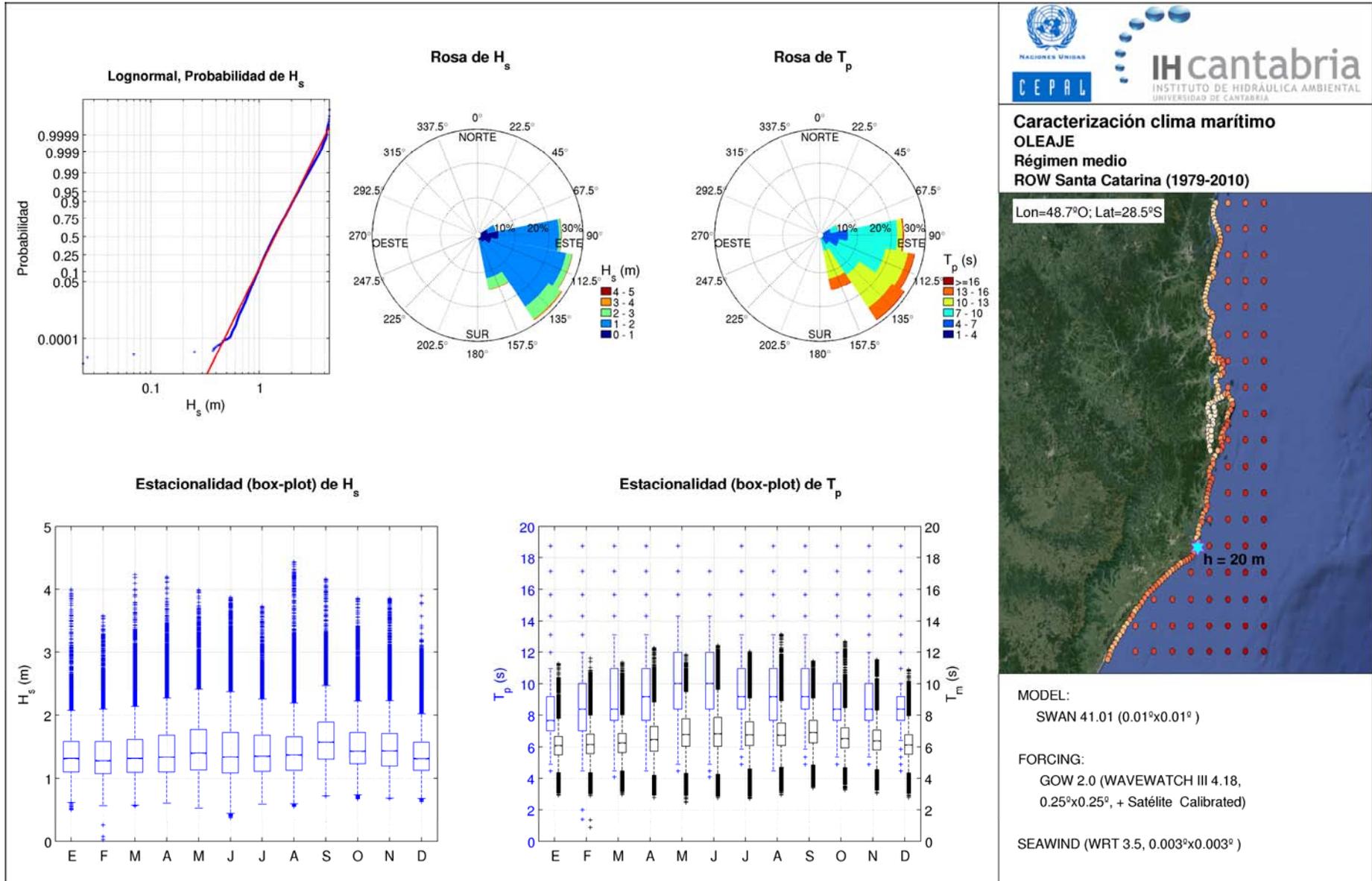
FORCING:  
GOW 2.0 (WAVEWATCH III 4.18,  
0.25°x0.25°, + Satélite Calibrated)

SEAWIND (WRT 3.5, 0.003°x0.003°)

# Caracterización del oleaje Local

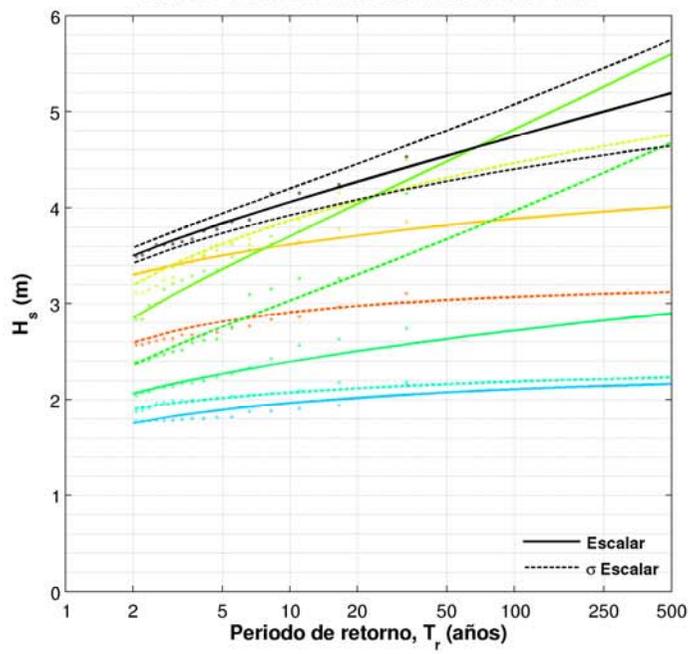


# Caracterización del oleaje Local



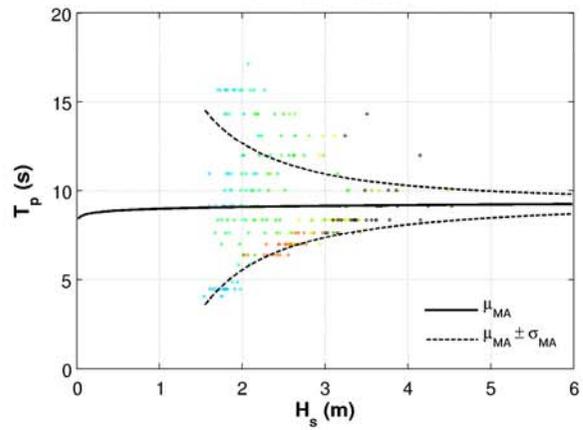
# Caracterización del oleaje Local

Régimen extremal ajustado con la técnica POT a un modelo Pareto-Poisson en términos de la función GEV



Sector	u	λ	σ	μ	ψ	ξ	c <sub>0</sub>	c <sub>1</sub>	c <sub>2</sub>	c <sub>3</sub>
N										
NNE	1.816	5.188	0.572	2.494	0.285	-0.423	-11.427	12.568	-4.561	0.549
NE	2.822	4.781	0.295	3.220	0.218	-0.194	-6.377	6.212	-1.988	0.211
ENE	2.467	3.188	0.539	3.035	0.444	-0.167	-1.661	1.839	-0.609	0.066
E	2.136	3.500	0.434	2.686	0.443	0.018	1.153	-0.707	0.125	-0.000
ESE	1.780	4.125	0.311	2.237	0.334	0.051	0.819	-0.663	0.162	-0.004
SE	1.597	5.562	0.252	1.988	0.206	-0.118	-0.099	0.467	-0.354	0.078
SSE	1.543	6.062	0.226	1.858	0.132	-0.297	-8.092	12.591	-6.502	1.118
S	1.374	4.656	0.260	1.695	0.165	-0.294	-4.262	7.004	-3.787	0.679
SSW										
SW										
WSW										
W										
WNW										
NW										
NNW										
Escalar	2.929	4.625	0.305	3.392	0.300	-0.011	1.837	-1.001	0.137	0.002

Máximos Anuales



$$\mu_{MA}(T_p|H_s) = aH_s^b$$

$$\sigma_{MA}(T_p|H_s) = aH_s^b$$

T <sub>p</sub>	a	b
μ <sub>MA</sub> (T <sub>p</sub>  H <sub>s</sub> )	8.995	0.016
σ <sub>MA</sub> (T <sub>p</sub>  H <sub>s</sub> )	11.505	-1.702



**Función de distribución Pareto-Poisson**

$$F(H_s; u, \lambda, \sigma, \xi) = \exp(-\lambda(1 + \xi(\frac{H_s - \mu}{\sigma}))^{-1/\xi})$$

$$H_s(T_r; u, \lambda, \sigma, \xi) = u - \frac{\sigma}{\xi}(1 - (\lambda T_r)^\xi)$$

**Función de distribución GEV**

$$F(H_s; \mu, \psi, \xi) = \exp(-(1 + \xi(\frac{H_s - \mu}{\psi}))^{-1/\xi})$$

$$H_s(T_r; \mu, \psi, \xi) = \mu - \frac{\psi}{\xi}(1 - (\frac{T_r}{T_c})^{-\xi})$$

$$\sigma(H_s; c_0, c_1, c_2, c_3) = c_0 + c_1 H_s + c_2 H_s^2 + c_3 H_s^3$$

**Caracterización clima marítimo OLAJE**  
Régimen extremal direccional ROW Santa Catarina (1979-2010)



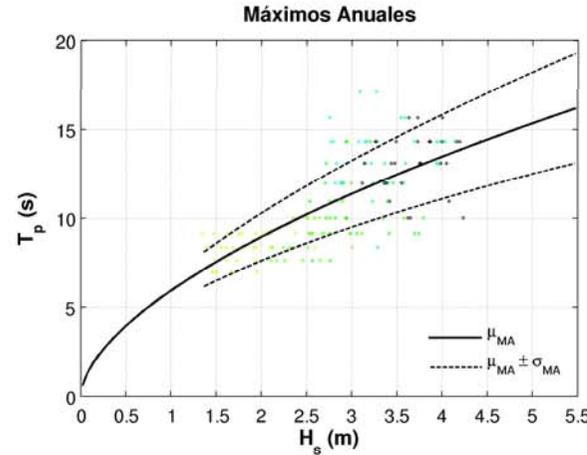
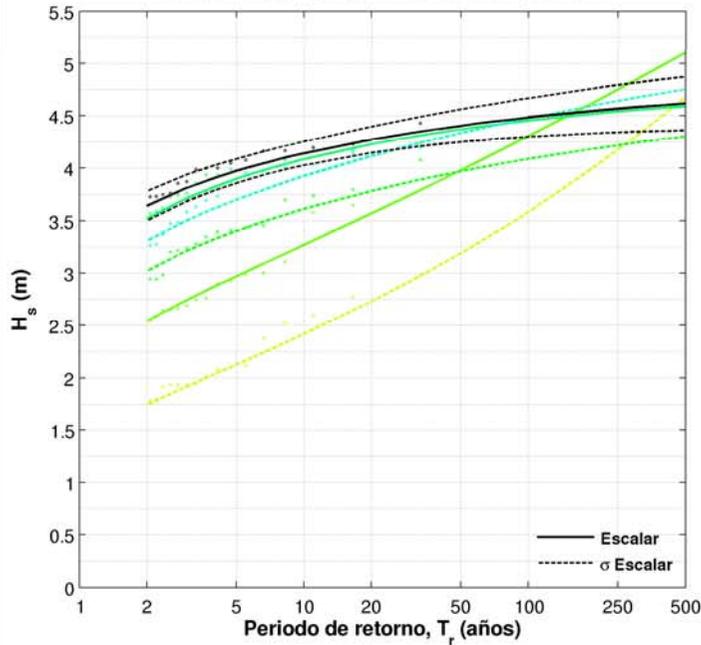
MODEL:  
SWAN 41.01 (0.01°x0.01°)

FORCING:  
GOW 2.0 (WAVEWATCH III 4.18,  
0.25°x0.25°, + Satélite Calibrated)

SEAWIND (WRT 3.5, 0.003°x0.003°)

# Caracterización del oleaje Local

Régimen extremal ajustado con la técnica POT a un modelo Pareto-Poisson en términos de la función GEV



$$\mu_{MA}(T_p|H_s) = aH_s^b$$

$$\sigma_{MA}(T_p|H_s) = aH_s^b$$

$T_p$	a	b
$\mu_{MA}(T_p H_s)$	5.955	0.588
$\sigma_{MA}(T_p H_s)$	0.743	0.840



Sector	u	$\lambda$	$\sigma$	$\mu$	$\psi$	$\xi$	$c_0$	$c_1$	$c_2$	$c_3$
N										
NNE										
NE										
ENE	1.307	3.594	0.234	1.640	0.287	0.159	0.642	-0.725	0.262	-0.014
E	2.083	2.594	0.334	2.411	0.355	0.063	1.211	-0.831	0.166	-0.001
ESE	2.422	2.688	0.507	2.874	0.412	-0.211	-4.323	4.367	-1.405	0.149
SE	2.871	2.625	0.593	3.367	0.441	-0.307	-16.059	13.134	-3.522	0.313
SSE	2.673	3.062	0.480	3.165	0.402	-0.159	-1.644	2.046	-0.729	0.083
S										
SSW										
SW										
WSW										
W										
WNW										
NW										
NNW										
Escalar	3.086	2.656	0.498	3.511	0.378	-0.282	-19.987	16.036	-4.239	0.371

## Función de distribución Pareto-Poisson

$$F(H_s; u, \lambda, \sigma, \xi) = \exp(-\lambda(1 + \xi(\frac{H_s - u}{\sigma}))^{-1/\xi})$$

$$H_s(T_r; u, \lambda, \sigma, \xi) = u - \frac{\sigma}{\xi}(1 - (\lambda T_r)^\xi)$$

## Función de distribución GEV

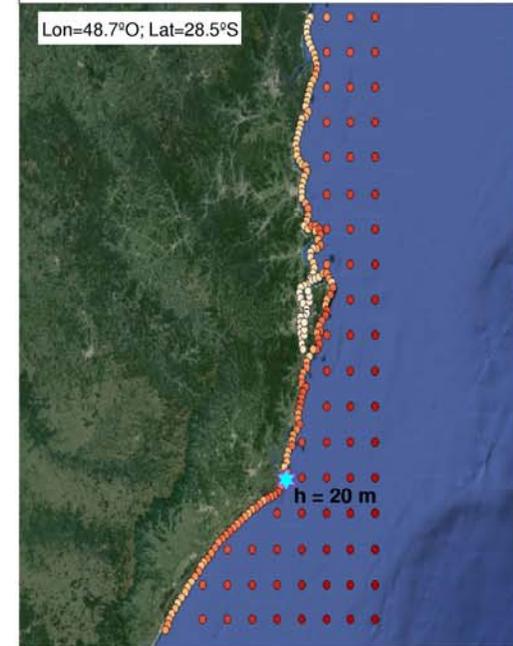
$$F(H_s; \mu, \psi, \xi) = \exp(-(1 + \xi(\frac{H_s - \mu}{\psi}))^{-1/\xi})$$

$$H_s(T_r; \mu, \psi, \xi) = \mu - \frac{\psi}{\xi}(1 - (\frac{1}{\lambda T_r})^\xi)$$

$$\sigma(H_s; c_0, c_1, c_2, c_3) = c_0 + c_1 H_s + c_2 H_s^2 + c_3 H_s^3$$

## Caracterización clima marítimo OLEAJE Régimen extremal direccional ROW Santa Catarina (1979-2010)

Lon=48.7°O; Lat=28.5°S



## MODEL:

SWAN 41.01 (0.01°x0.01°)

## FORCING:

GOW 2.0 (WAVEWATCH III 4.18,  
0.25°x0.25°, + Satélite Calibrated)

SEAWIND (WRT 3.5, 0.003°x0.003°)