16th International Waves Workshop
2nd International Workshop on Waves, Storm Surges and Coastal Hazards
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Added value of Spectral data against standard Sea State Parameters for Wave Climate studies

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From Significant Wave Height to Multi-Variate to Multi-Dimensional

Hs

- Hm0 (The best parameter to integrate wave climate conditions)
  Great indicator of total wave energy amount

Hs, Tm, Dir

Tp, spr, Pdir…

- Multi-parameter wave climate information from the characteristic Sea-State
  Very useful to understand other properties of the wave spectra

Hs1, T1, Dir1

Hs2, T2, Dir2

Hs3, T3, Dir3

…..

- Sea/Swell; 'Spectral Partitions'
  Valuable information of multimodal spectral behaviour

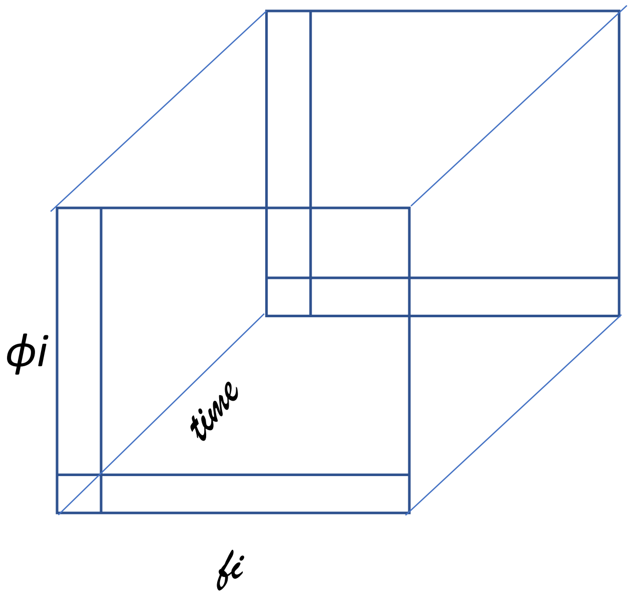
3D Wave Spectrum

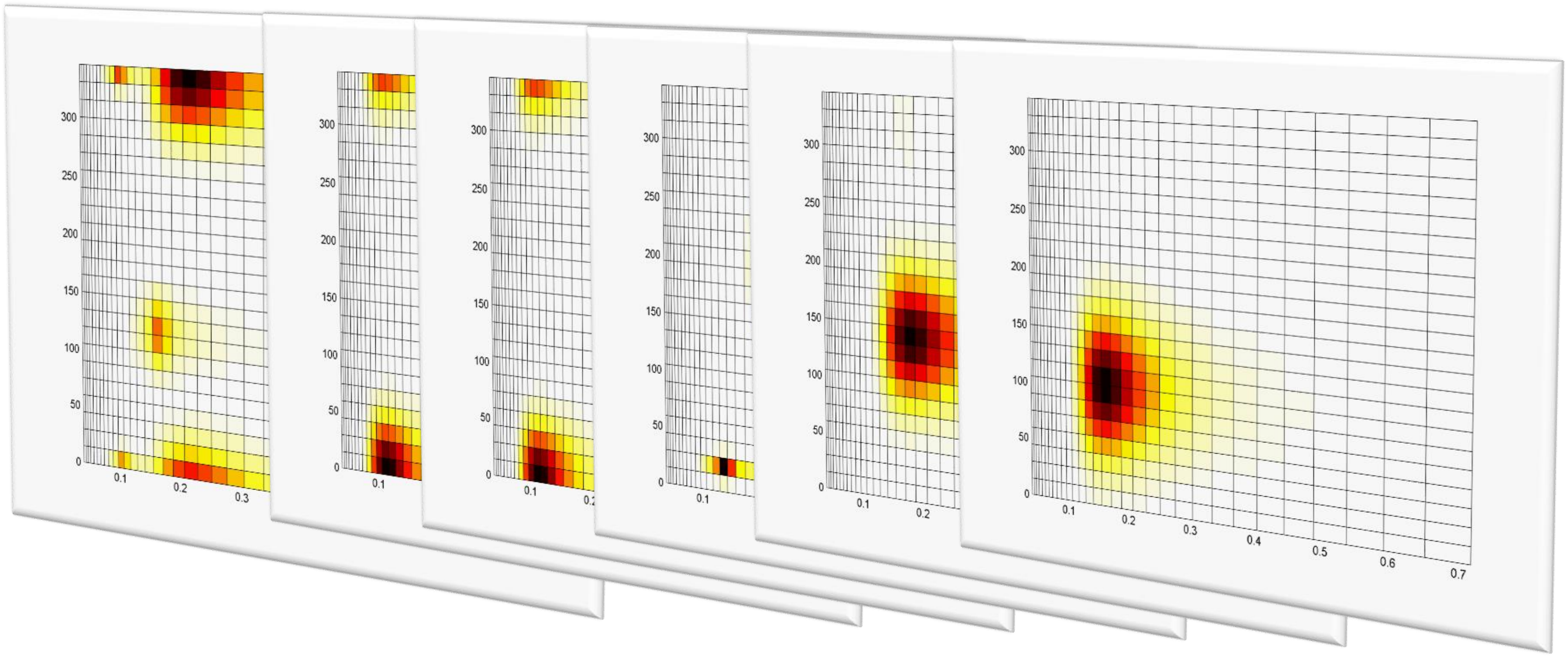
- Frequency & directional energy info
  Full information of wave climate

Technological progress

From Significant Wave Height to Multi-Variate to Multi-Dimensional

Nowadays 3D wave spectra datasets with hourly time resolution and for long time series are available





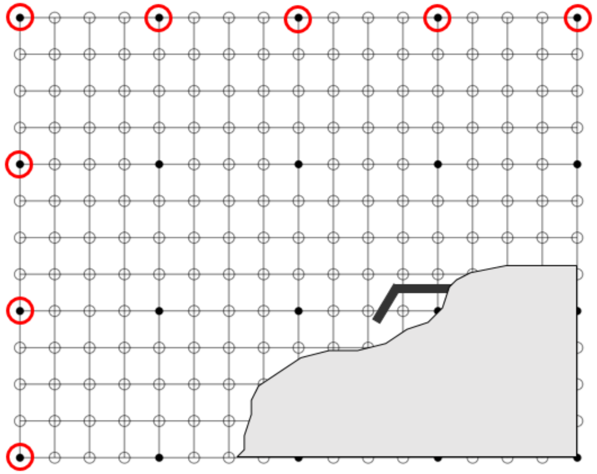
We can use spectral climate data info to:

Complement / Verify / validate …..

provide added info to better understand Wave Climate

Topics:

- **Checking suitability of often used theoretical spectral formulas from sea-states to reconstruct historical spectral climate properties**



Common practice for coastal dynamic downscaling

Spectrum is required as boundary condition of numerical models

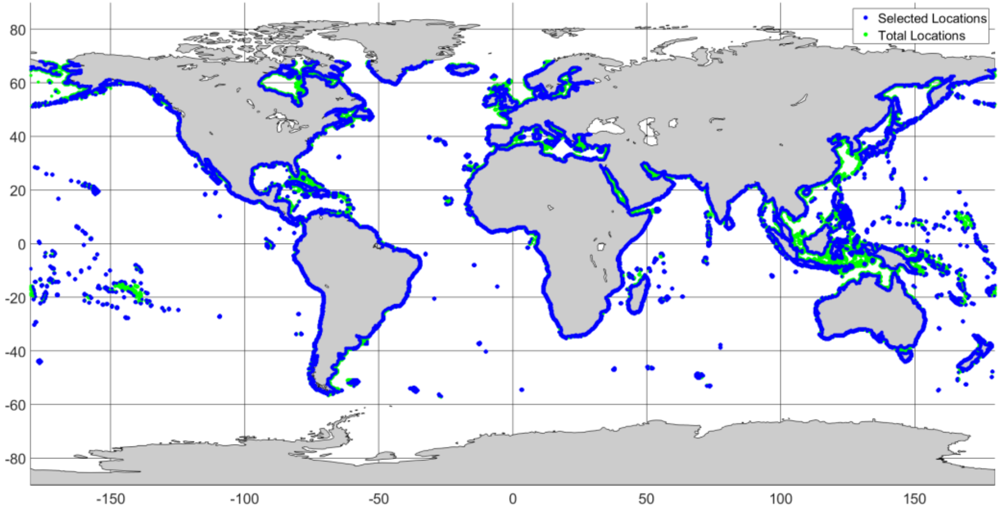
- **Analyze spectral future wave climate changes**

For a better understanding of wave climate conditions (including wave storms)

Description of changes for specific 'wave energy families', Sea/swell

Provide added information to analyse coastal impacts

SUITABILITY OF THEORETICAL SPECTRA TO RECONSTRUCT HISTORICAL CLIMATE PROPERTIES



Data source: ***GOW2*** wave hindcast (36455 spectra locations)

Locations: 11643 locations analyzed (~8000 near the coast and offshore and ~3500 offshore. Depths: from 5 to 4000m

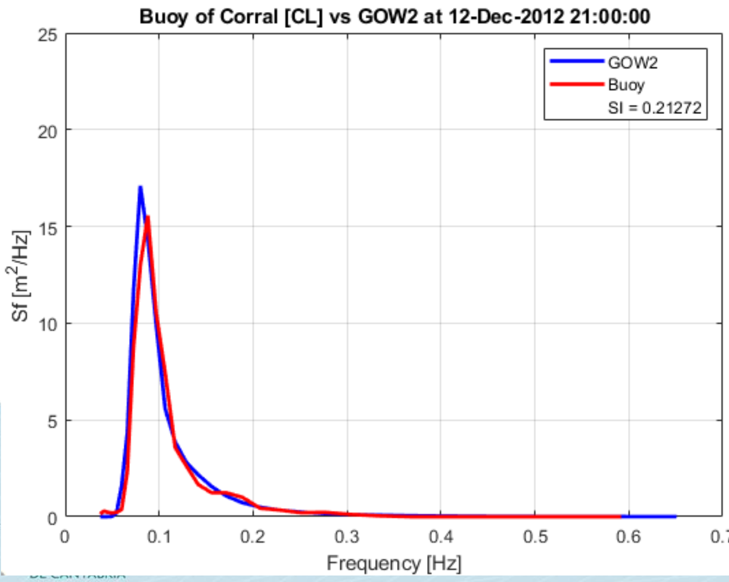
Historical analyzed period: 30yrs: 1989-2018

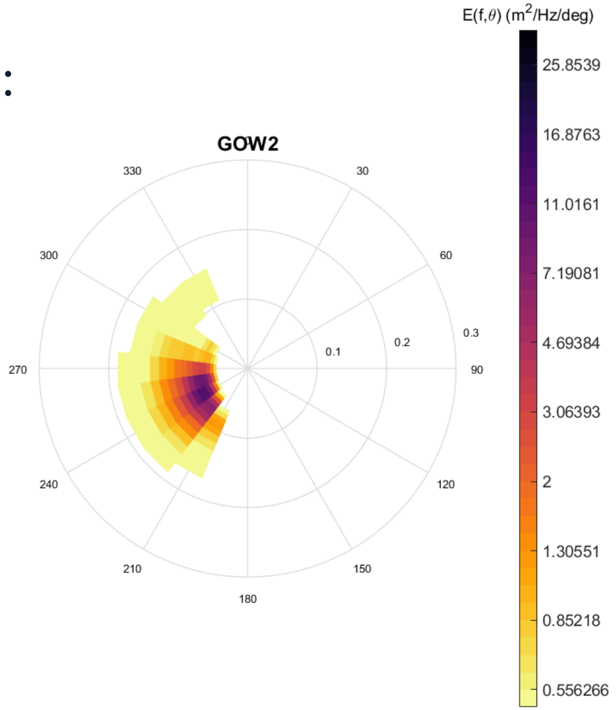
Spatial resolution: 0.25deg

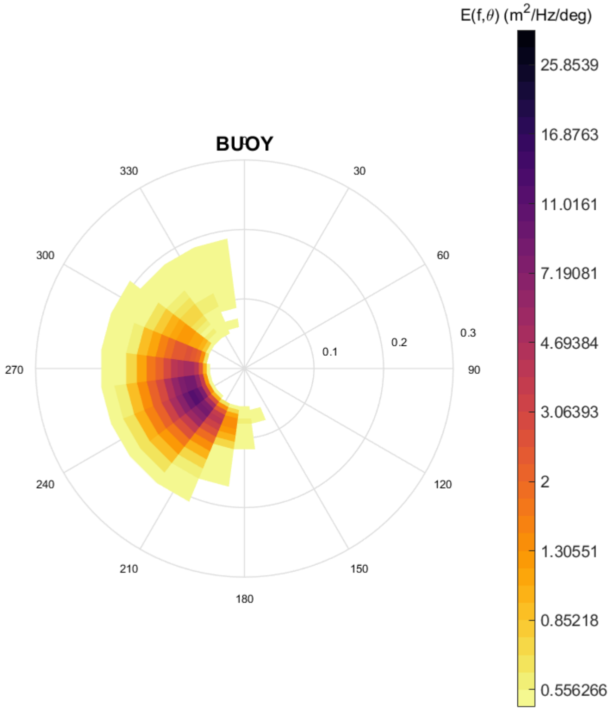
Time resolution: 3hourly

Spectrum resolution: 32 Freq. x 24 directions

Comparison of GOW2 vs. buoy wave spectra:







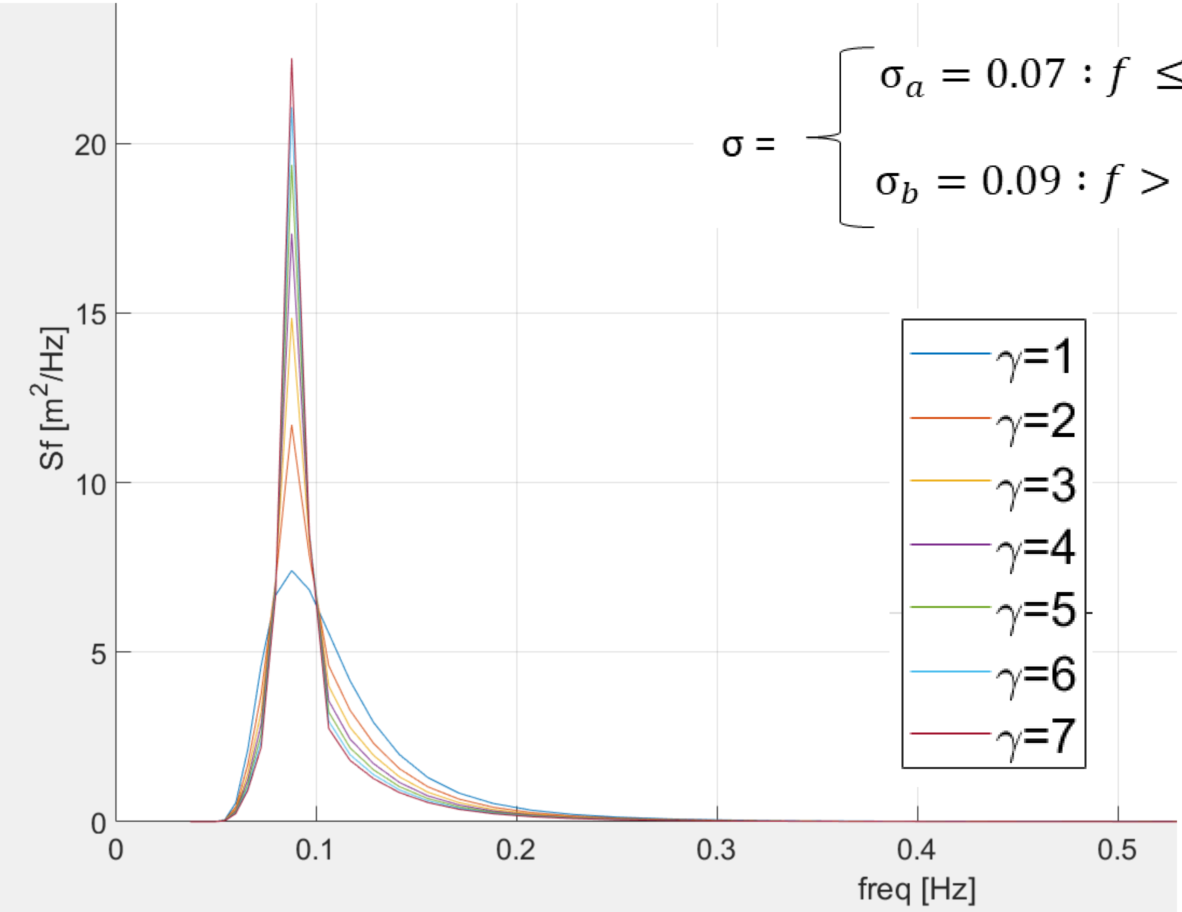
SUITABILITY OF THEORETICAL SPECTRA TO RECONSTRUCT HISTORICAL CLIMATE PROPERTIES

Pierson Moskovitch → JONSWAP SPECTRUM

$$f = \alpha * H_s^2 * T_p^4 * f^{-5} * exp\left(\left(-1.25.* \left(T_p * f\right)^{-4}\right)\right) * \gamma^{exp\left(\frac{\left(-(T_P * f-1)^2\right)}{2*\sigma^2}\right)}$$

$$\alpha = \left(\frac{0.0624}{0.230+0.0336.*\gamma-0.185.*(1.9+\gamma).^{-1}}\right) * (1.094 - 0.01915.* log(\gamma))$$

$$\sigma = \begin{cases} \sigma_a = 0.07 : f \leq f_P \\ \sigma_b = 0.09 : f > f_P \end{cases}$$



- ɣ is estimated for each Sea-state as the minimum RMSE error between the GOW2 spectrum (Sf), and the JONSWAP spectrum (SJ)

$$RMSE = \sqrt{\frac{\Sigma_{i=1}^{n}\left(S_{f_i}-S_{J_i}\right)^2}{n}}$$

- Metrics to evaluate the goodness of Jonswap

Similarity Index (SI)

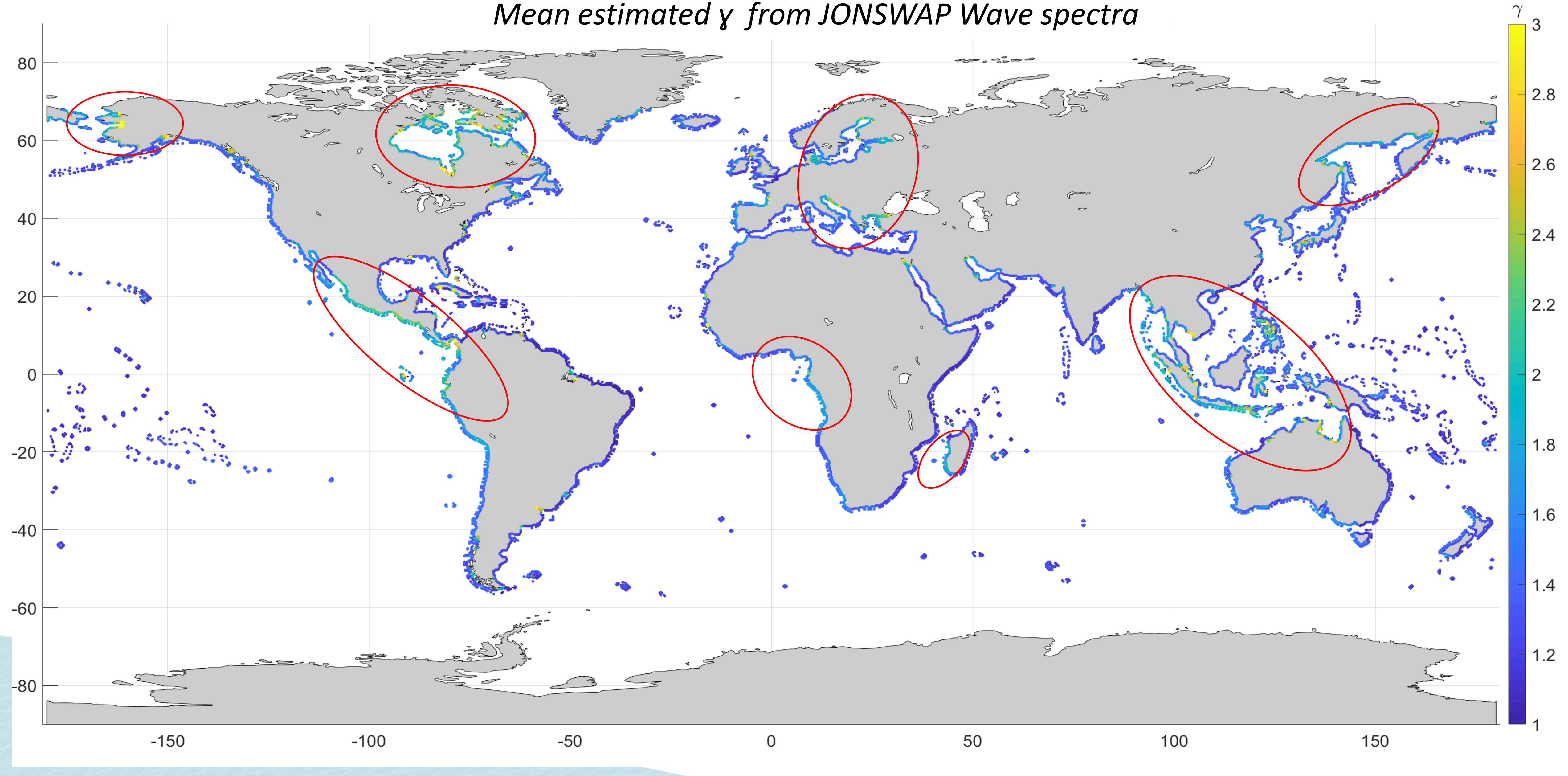
$$SI = \frac{\sqrt{\frac{1}{N}\Sigma_{i=1}^{n}\left(S_{f_i}-S_{J_i}\right)^2}}{\sqrt{\frac{1}{N}\Sigma_{i=1}^{n}S_{f_i}^2}}$$

Skill Score (SS)

$$SS = 1 - \sqrt{\frac{\Sigma_{i=1}^{n}\left(S_{f_i}-S_{J_i}\right)^2}{\Sigma_{i=1}^{n}S_{f_i}^2}}$$

SUITABILITY OF THEORETICAL SPECTRA TO RECONSTRUCT HISTORICAL CLIMATE PROPERTIES

Mean estimated ɣ from JONSWAP Wave spectra



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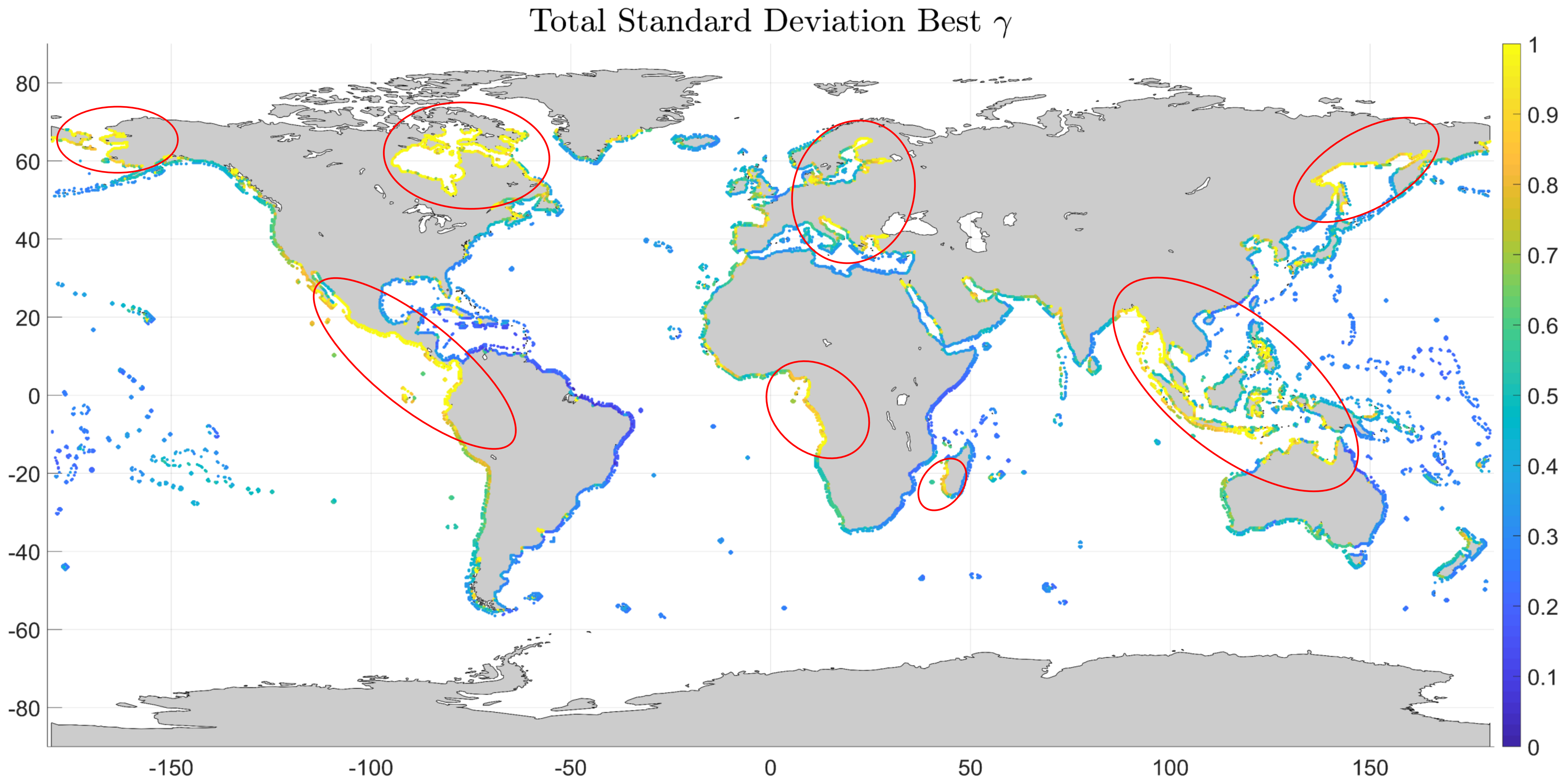

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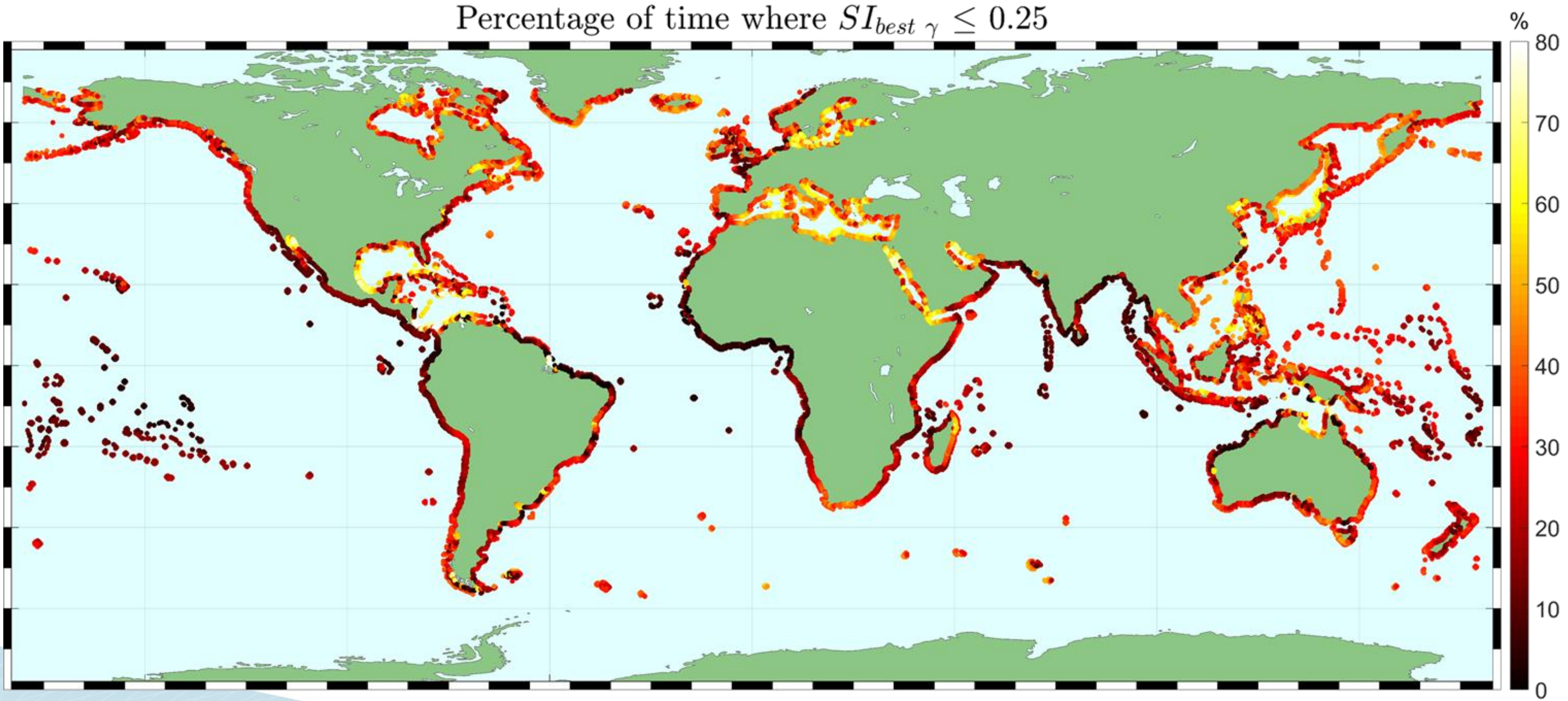

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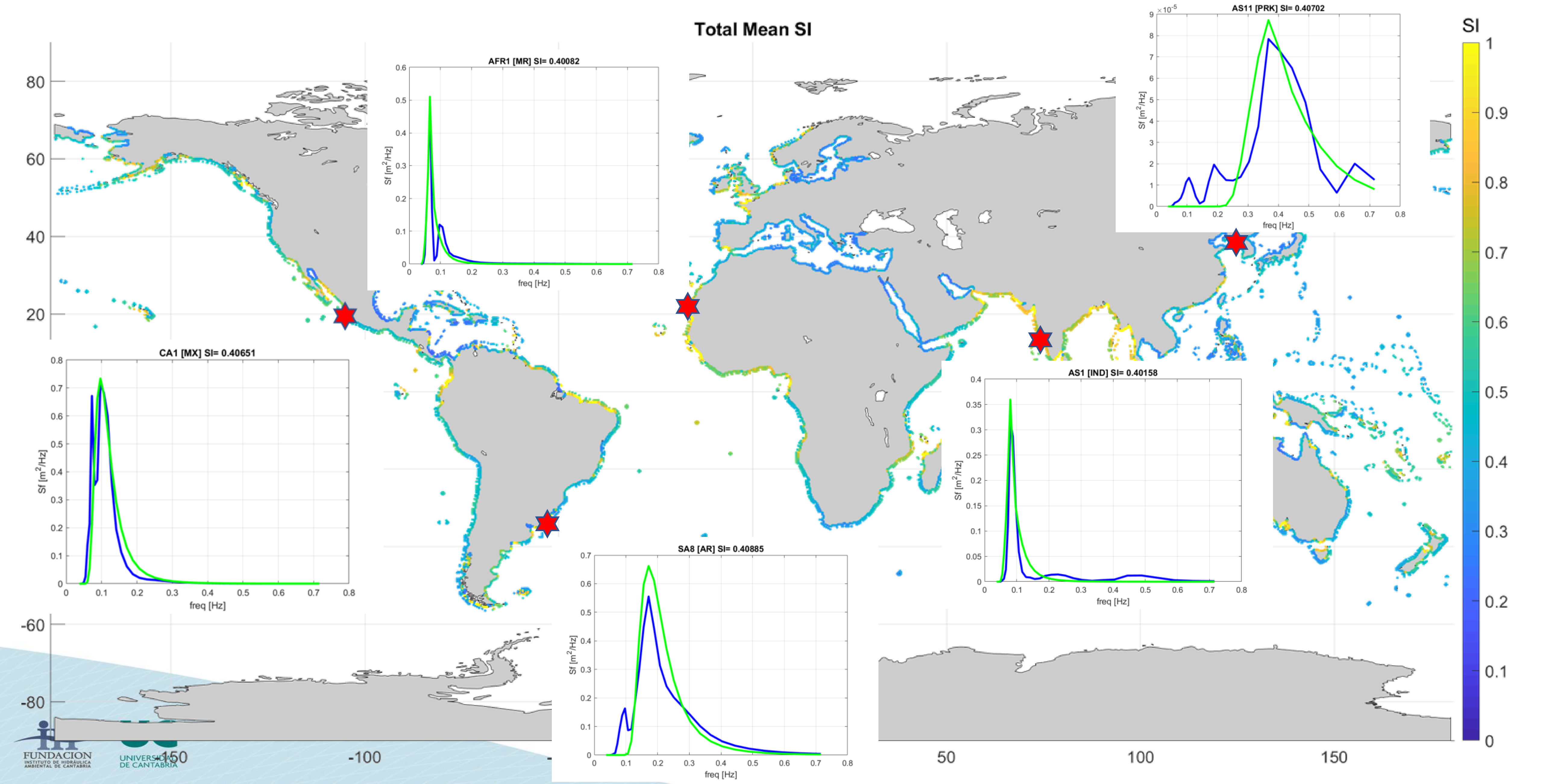

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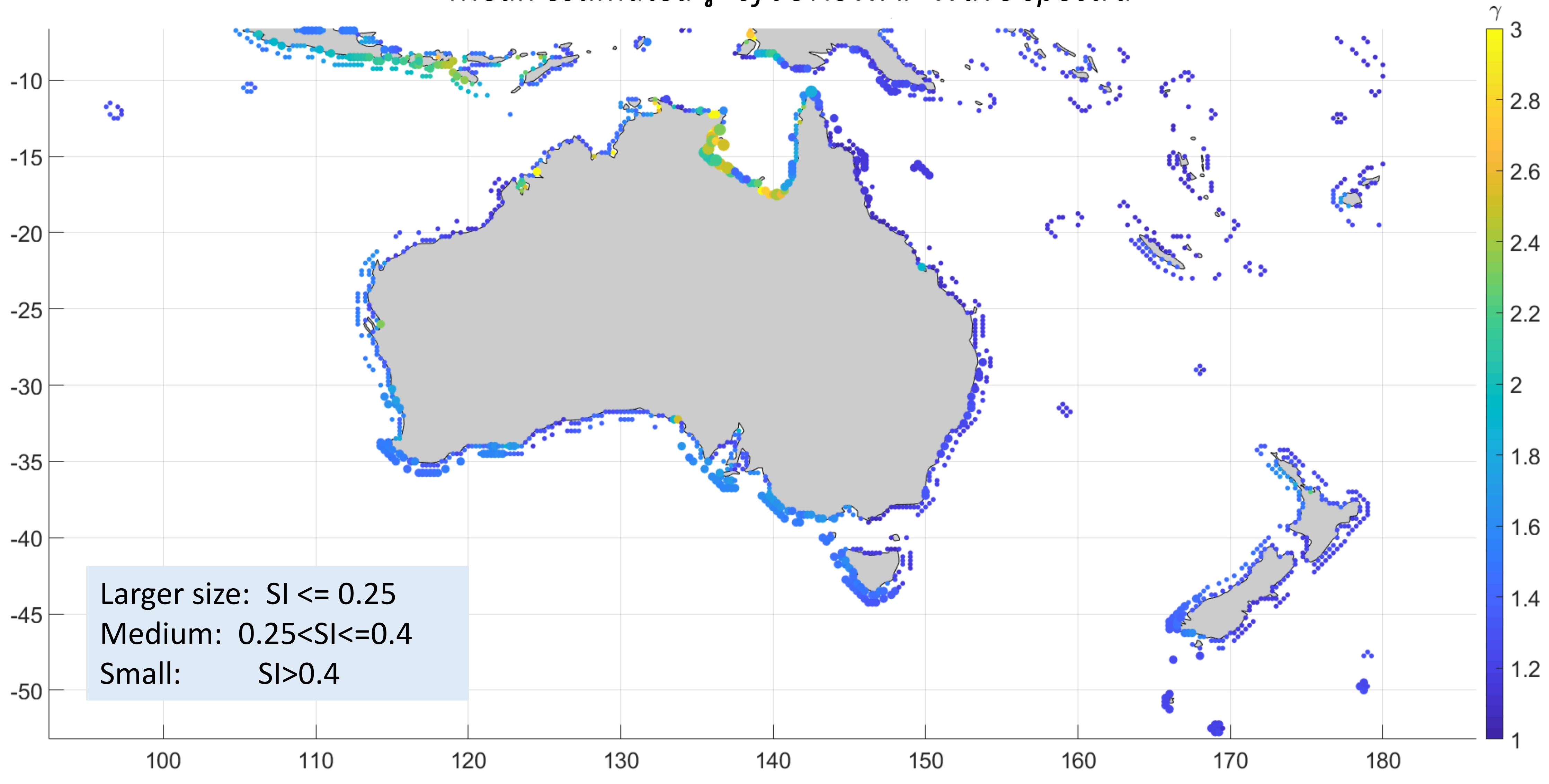
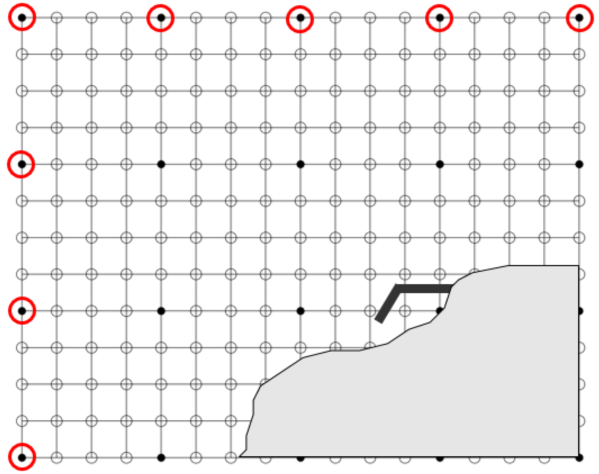


Topics:

- **Checking suitability of often used theoretical spectral formulas from sea-states to reconstruct historical spectral climate properties**



Common practice for coastal dynamic downscaling

Spectrum is required as boundary condition of numerical models

- **Analyzing future spectral wave climate changes**

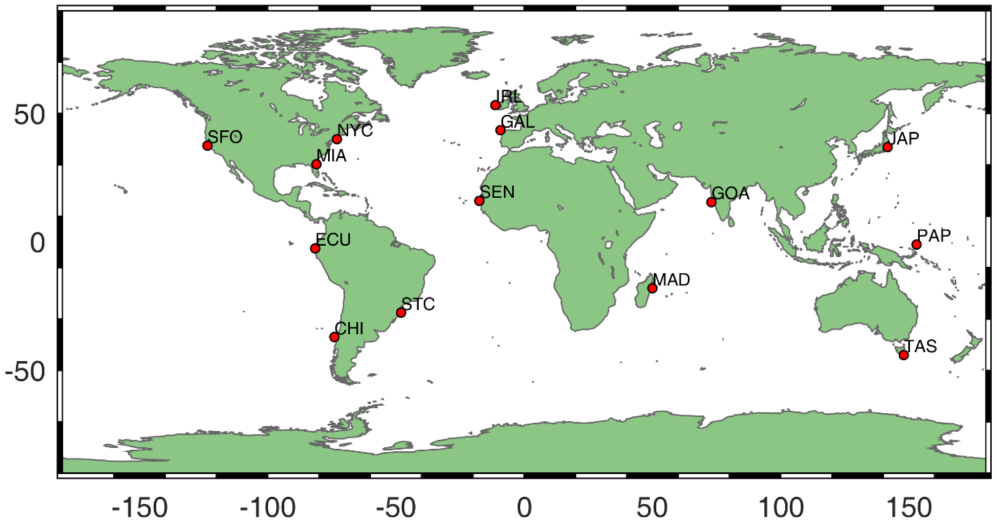
For a better understanding of wave climate conditions (including wave storms)

Description of changes for specific 'wave energy families', Sea/swell

Provide a dded information to analyse coastal impacts

SPECTRAL FUTURE WAVE CLIMATE CHANGES

WAVE DATASET



Data source: 7 Global Wave Climate Simulations

Locations: 14 coastal grid points

Time resolution: hourly

Spectrum resolution: 32 Freq. x 24 directions

Sea-state parameters: H_s, T_p, T_{02}, Dir_m

Climate Projections:

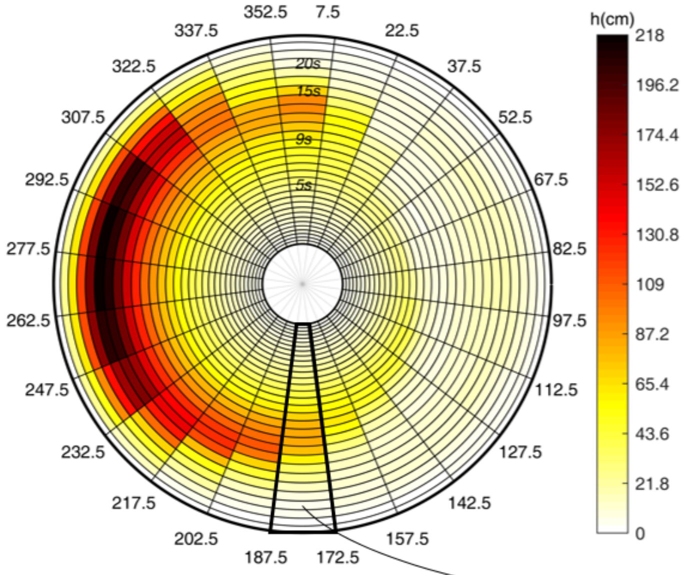
Reference period: 1985-2005

Future period: 2081-2100

Climate Change Scenario: RCP8.5

Members: CNRM, GFDL, CMCC, IPSL, HADGEM, ACCES, CNRM

Forcings: hourly winds & daily Ice coverage

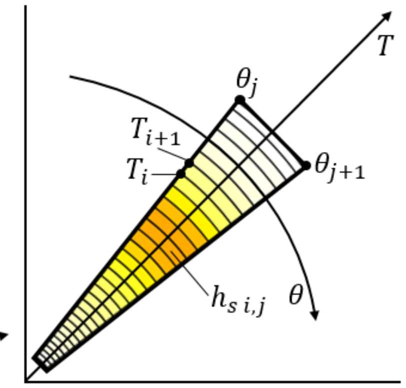


32 Frequencies
24 Directions → 768 Spectral bins

$$m_{0\,i,j} = \int_{f_i}^{f_{i+1}} \int_{\theta_j}^{\theta_{j+1}} S(f,\theta)\, df\, d\theta$$

$$h_{s\,i,j} = 4\sqrt{m_{0i,j}}$$

Equivalent significant wave height per spectral bin

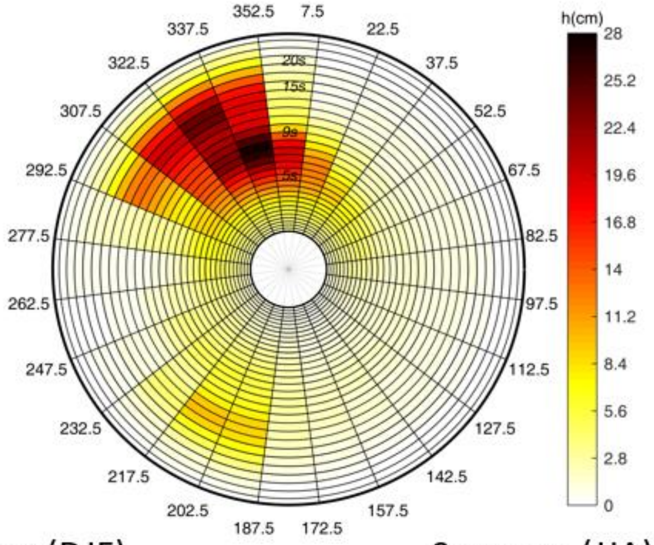


ANALYZE SPECTRAL FUTURE WAVE CLIMATE CHANGES

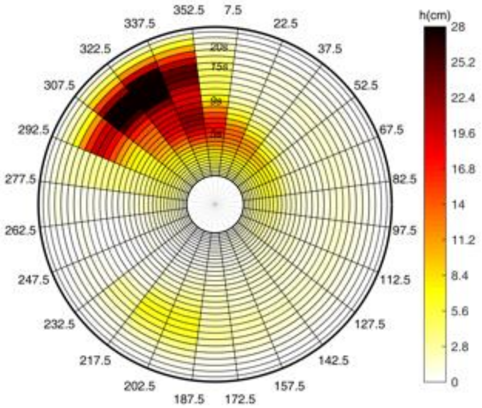
Location: Senegal, Africa

Reference period: 1985-2005

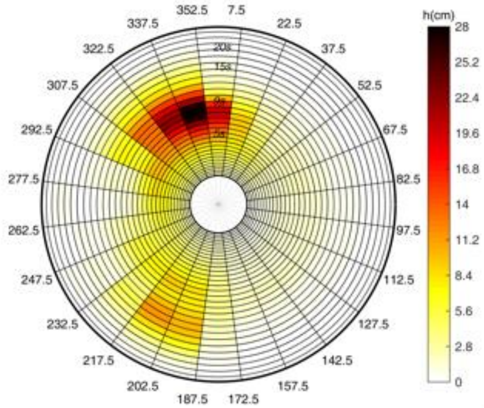
GOW2 wave hindcast



Winter (DJF)

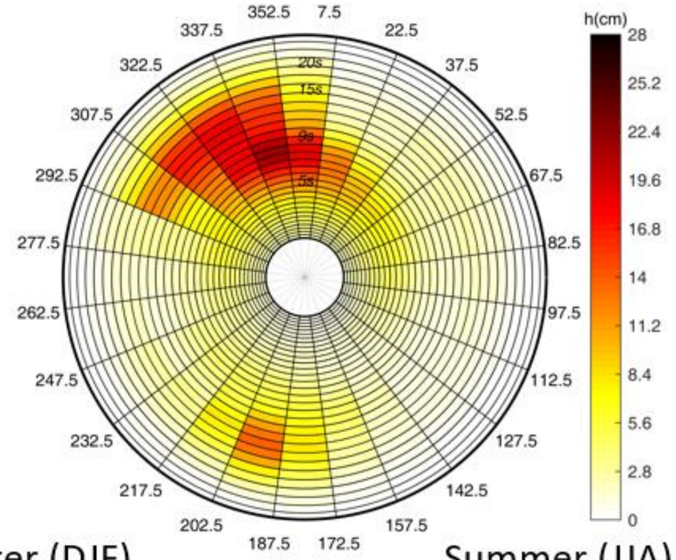


Summer (JJA)



Mean equivalent H_s per component: h_{sm}

Mean ensemble



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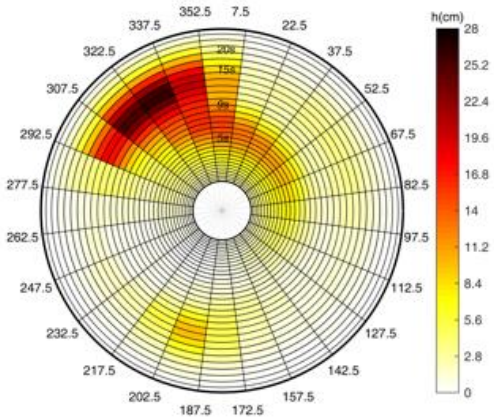

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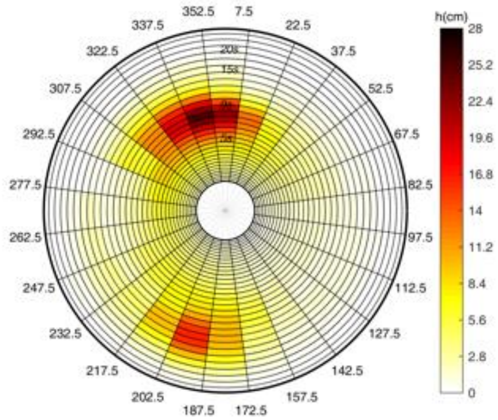
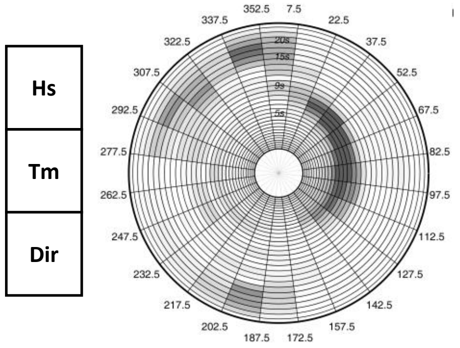
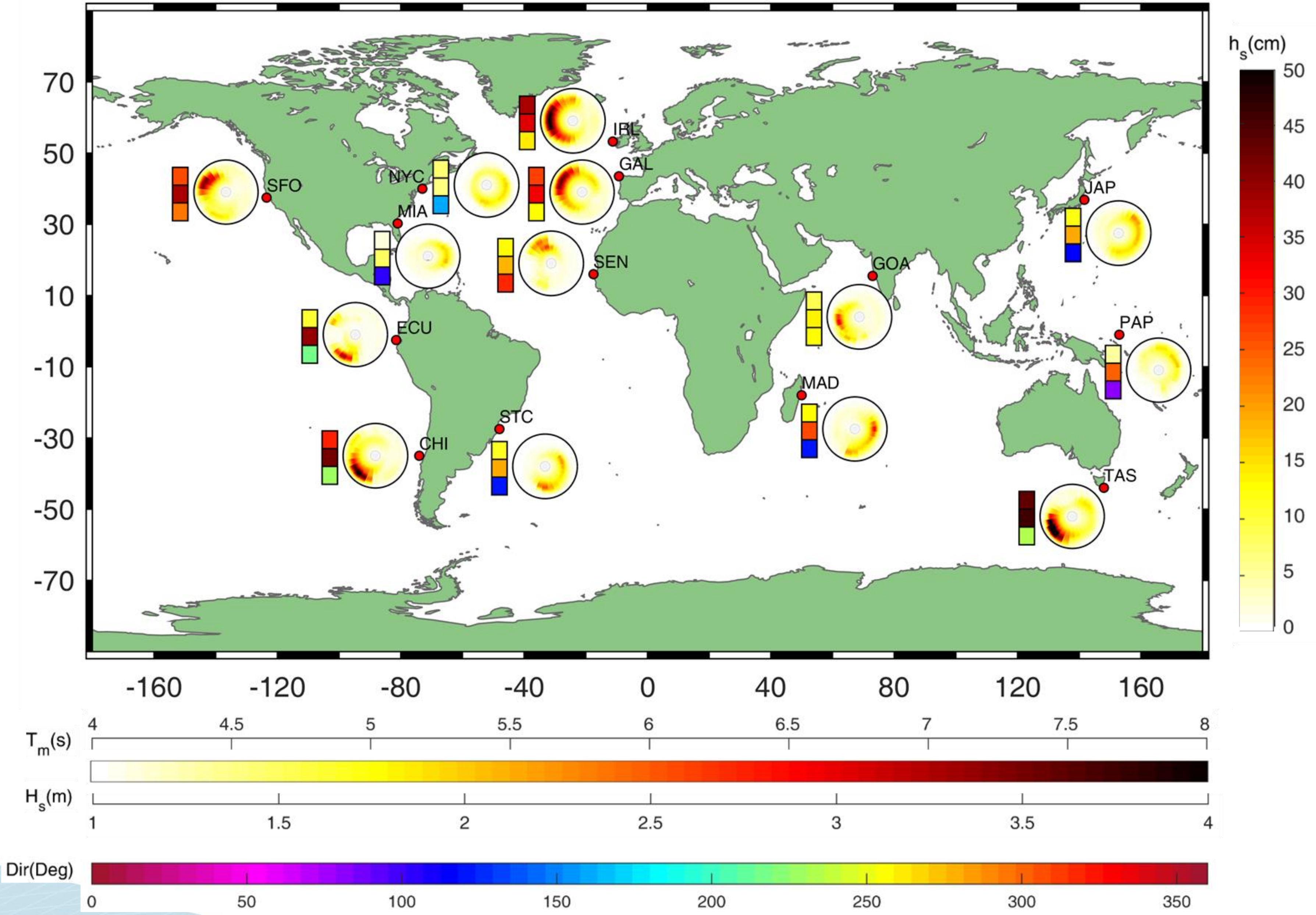


SPECTRAL FUTURE WAVE CLIMATE CHANGES

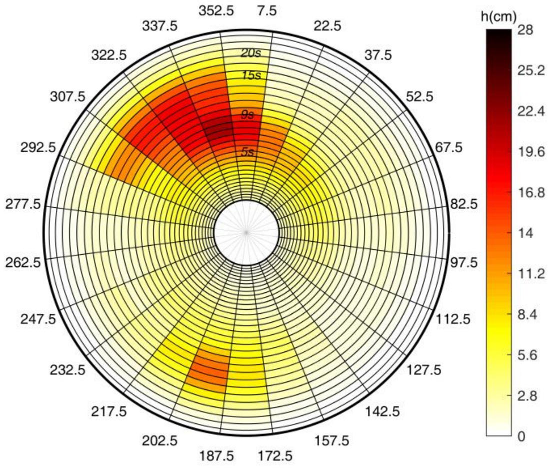
Reference period: 1985-2005

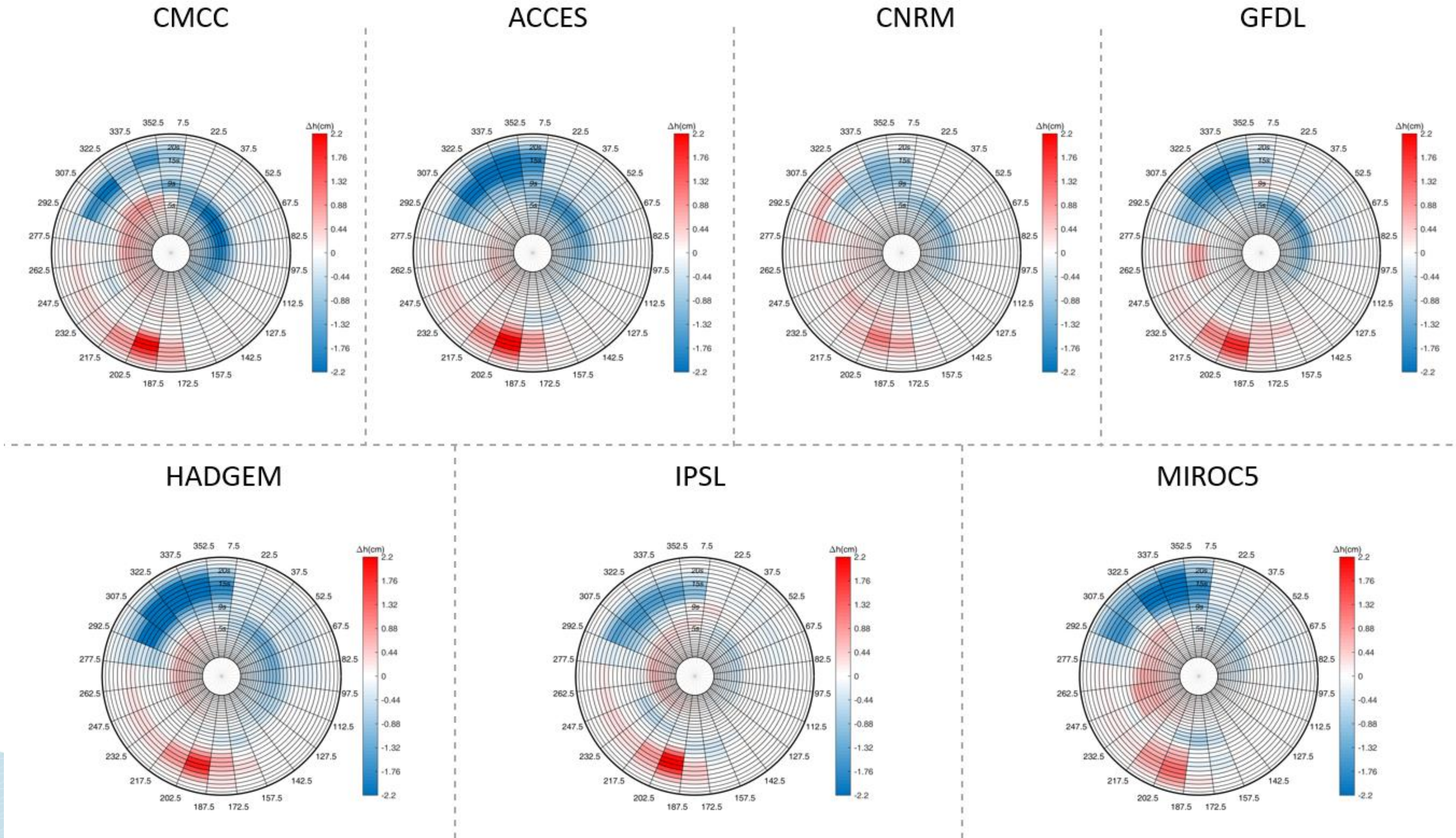




ANALYZE SPECTRAL FUTURE WAVE CLIMATE CHANGES

Location: Senegal Offshore
Projected changes: 2081-2100
RCP8.5 scenario





ANALYZE SPECTRAL FUTURE WAVE CLIMATE CHANGES

Location: Senegal Offshore
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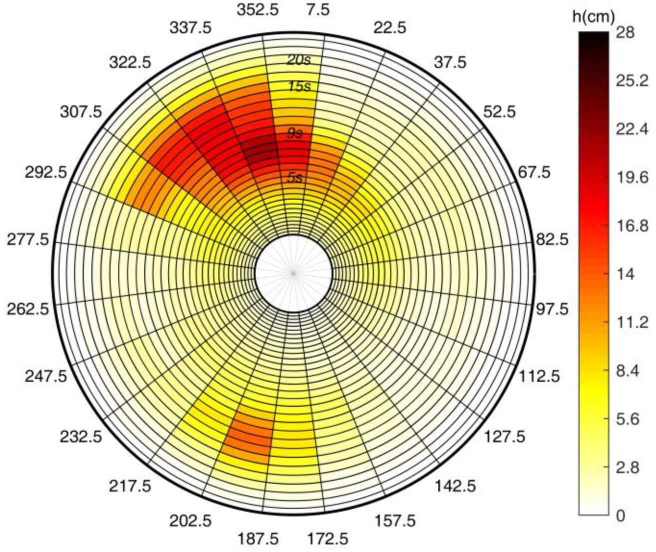
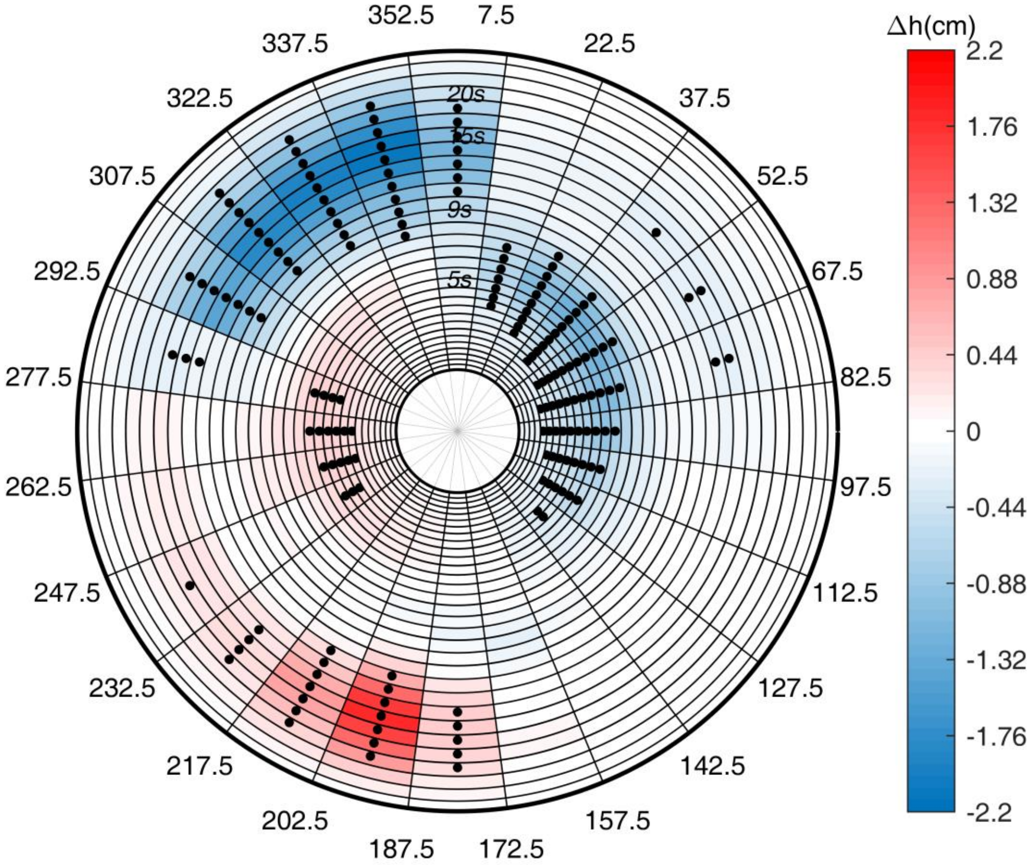
H_s	T_m	Dir_m
-3,89 cm	-0,05 s	2.97º



Mean Ensemble change estimated from 7 GCMs members of $\mathbf{h}_{\mathbf{sm}}$

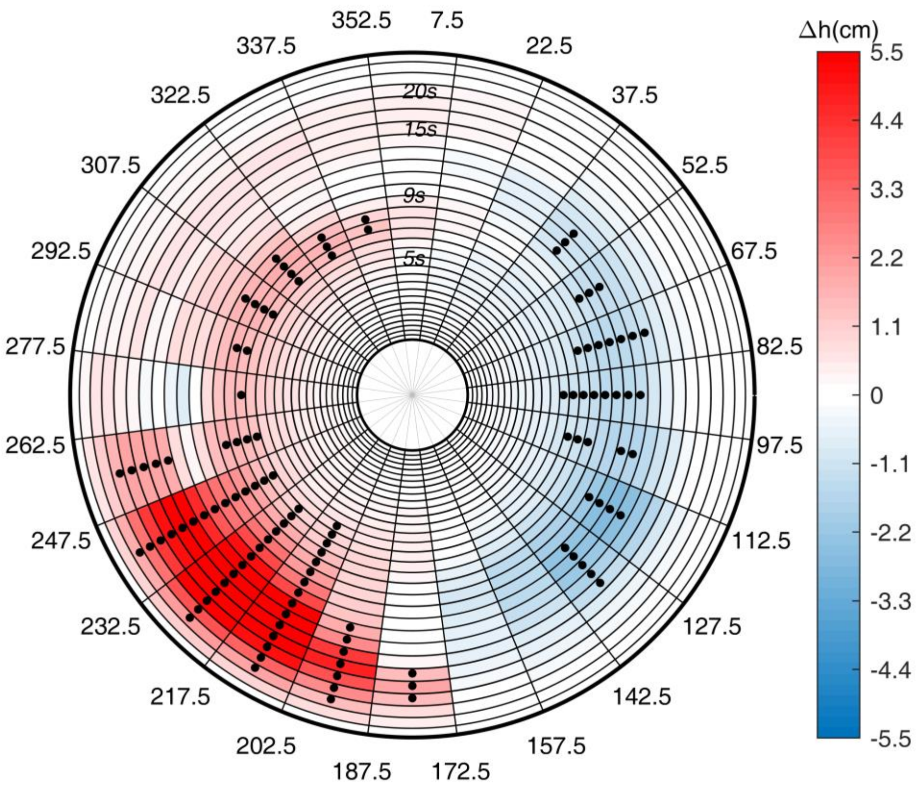


- indicates similar change for 5 of the 7 members

ANALYZE SPECTRAL FUTURE WAVE CLIMATE CHANGES

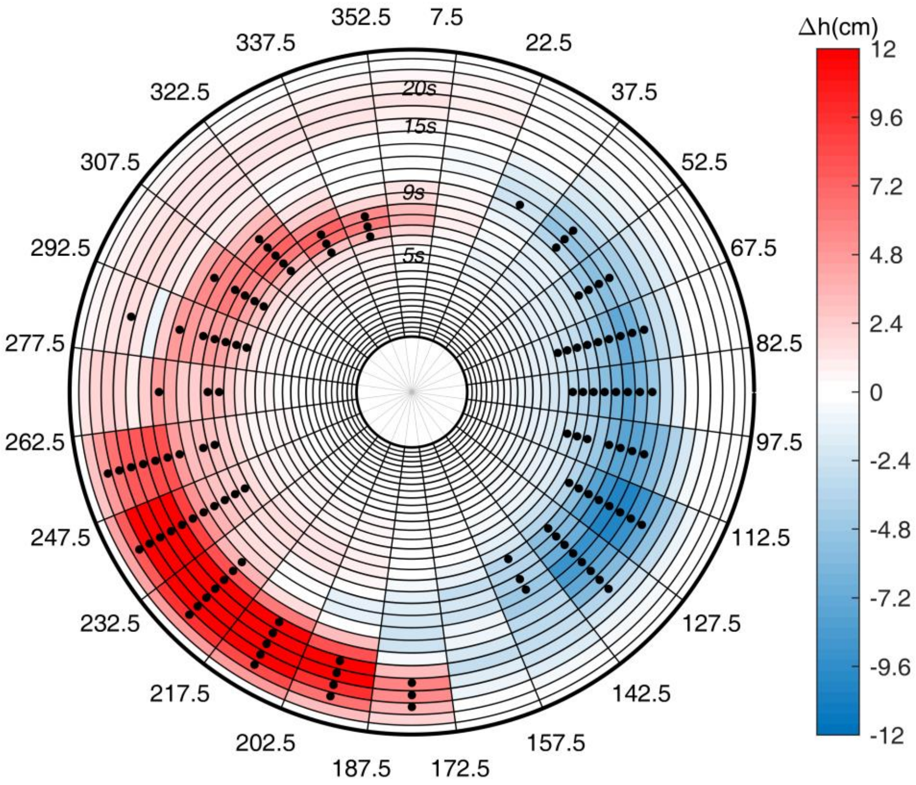
Location: Tasmania Offshore

Mean ensemble. Variable: h_{sm}



H_s	T_m	Dir_m
12.88 cm	0,10 s	1.54º

Mean ensemble. Variable: h_{s99}

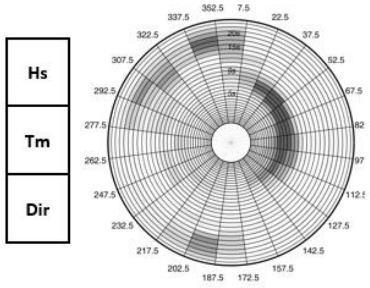


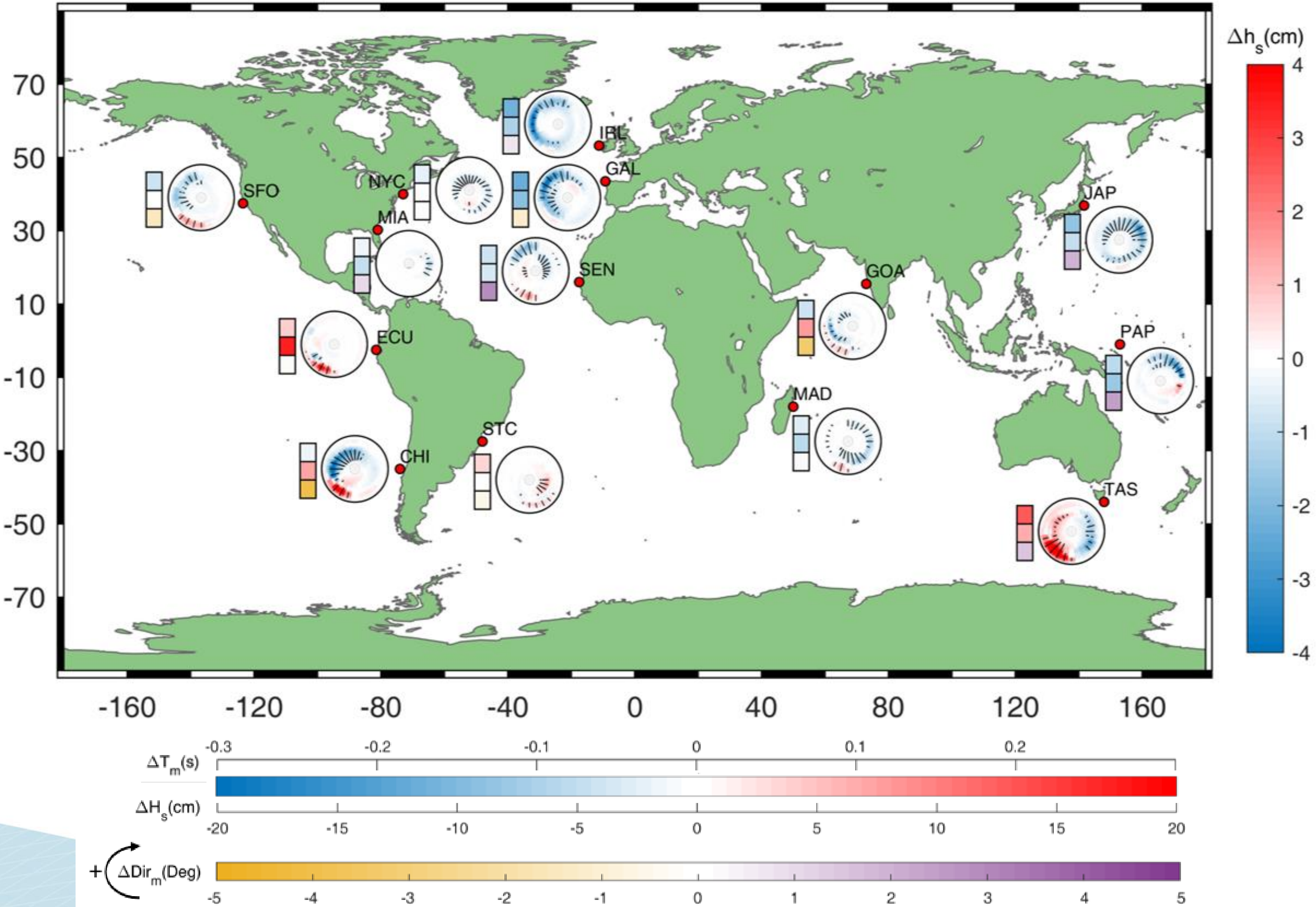
H_s	T_m	Dir_m
38.68 cm	0,08 s	0.89º

- • indicates similar change for 5 of the 7 members

ANALYZE SPECTRAL FUTURE WAVE CLIMATE CHANGES

Projected changes: 2081-2100
RCP8.5 scenario





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Conclusions

- Analysis of wave spectra data can provide novel insights of the Wave Climate characteristics
- Jonswap ɣ=3.3 is not appropriate to reconstruct spectrum data.
- Jonswap spectrum (using best estimated ɣ) works for some regions
- Analysis of climate changes from the bulk sea-state parameters can hide relevant changes of specific sea/swells, even of the opposite sign (increase/decrease)

On-going work

- Study of the reason why Jonswap is not appropriate (multimodal spectrum, sea/swells conditions, etc) and its climate variability
- Climate characterization of wave spectral 'families'
- A broader study of climate changes in wave spectra worldwide

Thank you for your attention!!