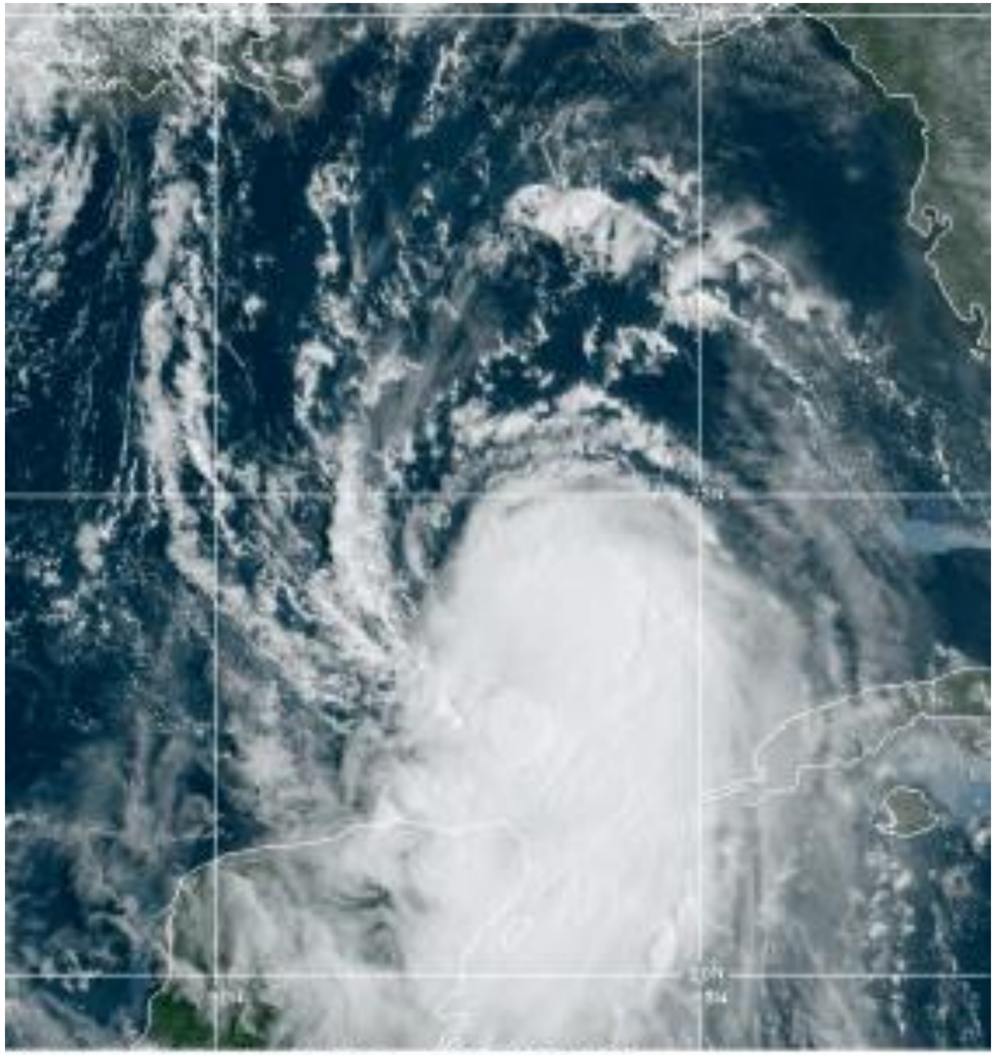
Tropical cyclone derived ocean waves and climate change in the North Atlantic and Eastern North Pacific basins



/NESDIS/STAR GOES-East GEOCOLOR

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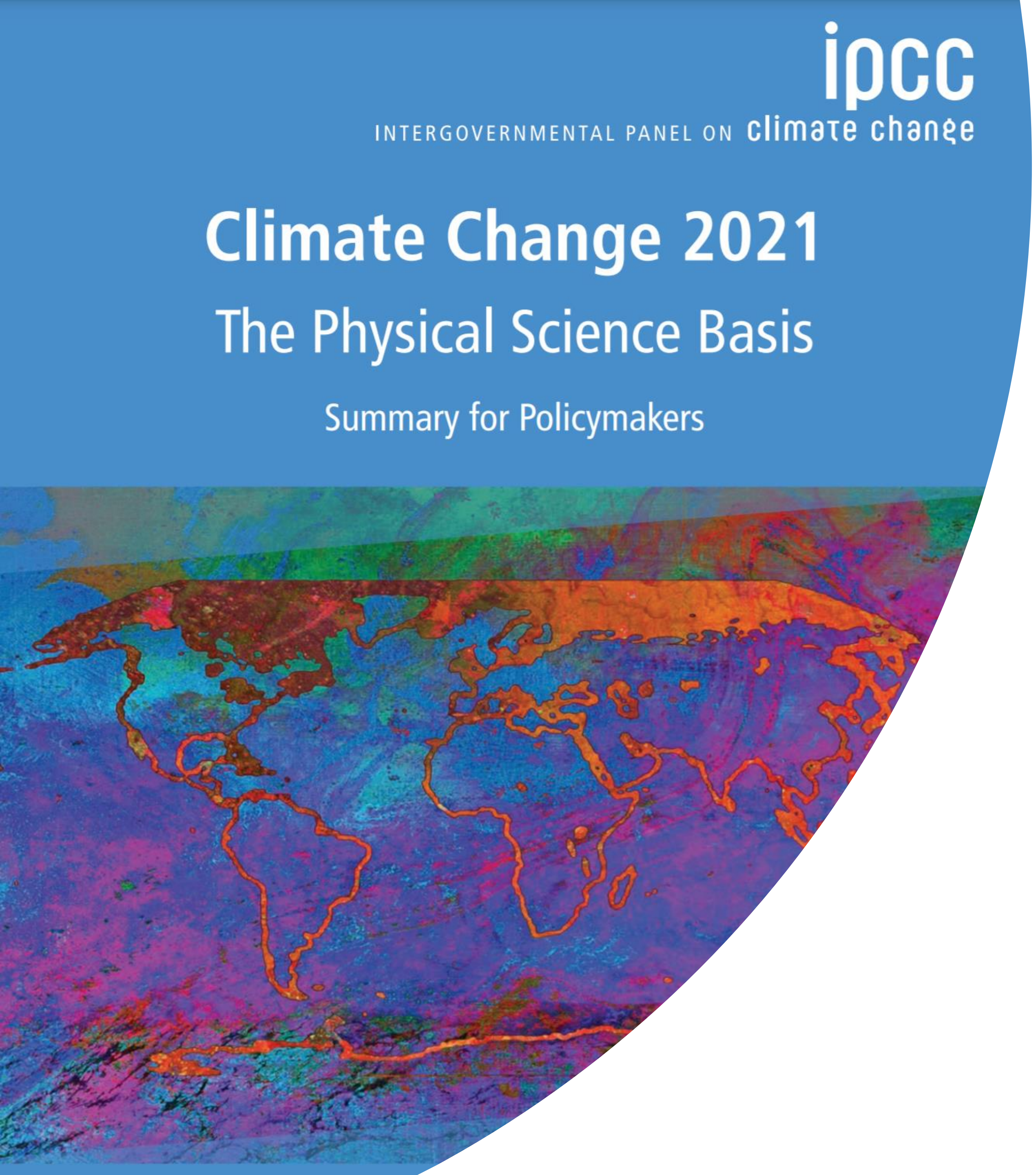
INSTITUTO DE INGENIERÍA UNAM

U.S. DEPARTMENT OF ENERGY

THEISS RESEARCH

STEVENS INSTITUTE OF TECHNOLOGY 1870

UNIVERSITAT ROVIRA i VIRGILI



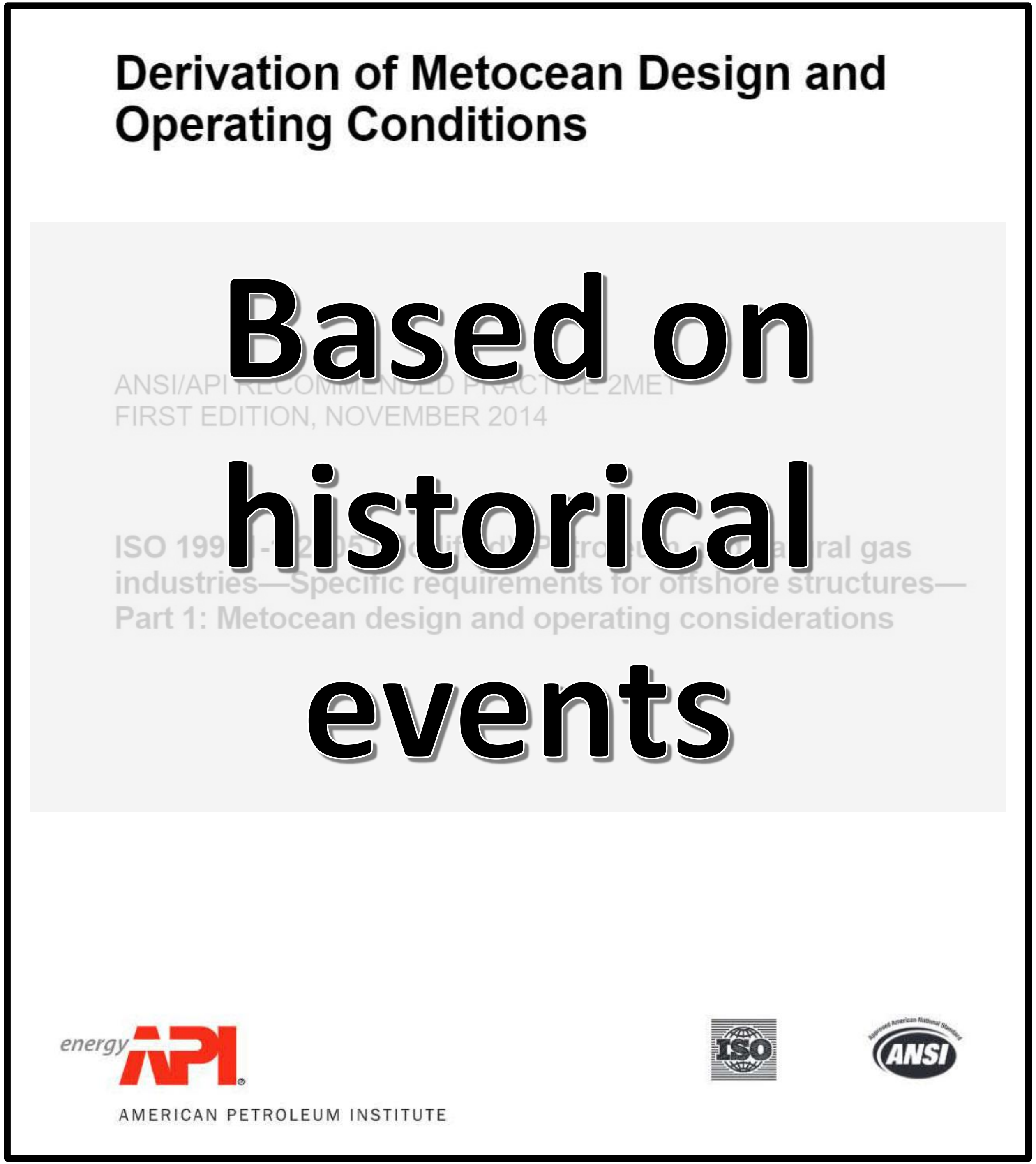
HIGH CONFIDENCE

The **proportion of intense tropical cyclones (Category 4–5)** and **peak wind speeds** of the most intense tropical cyclones are **projected to increase** at the global scale with increasing global warming.

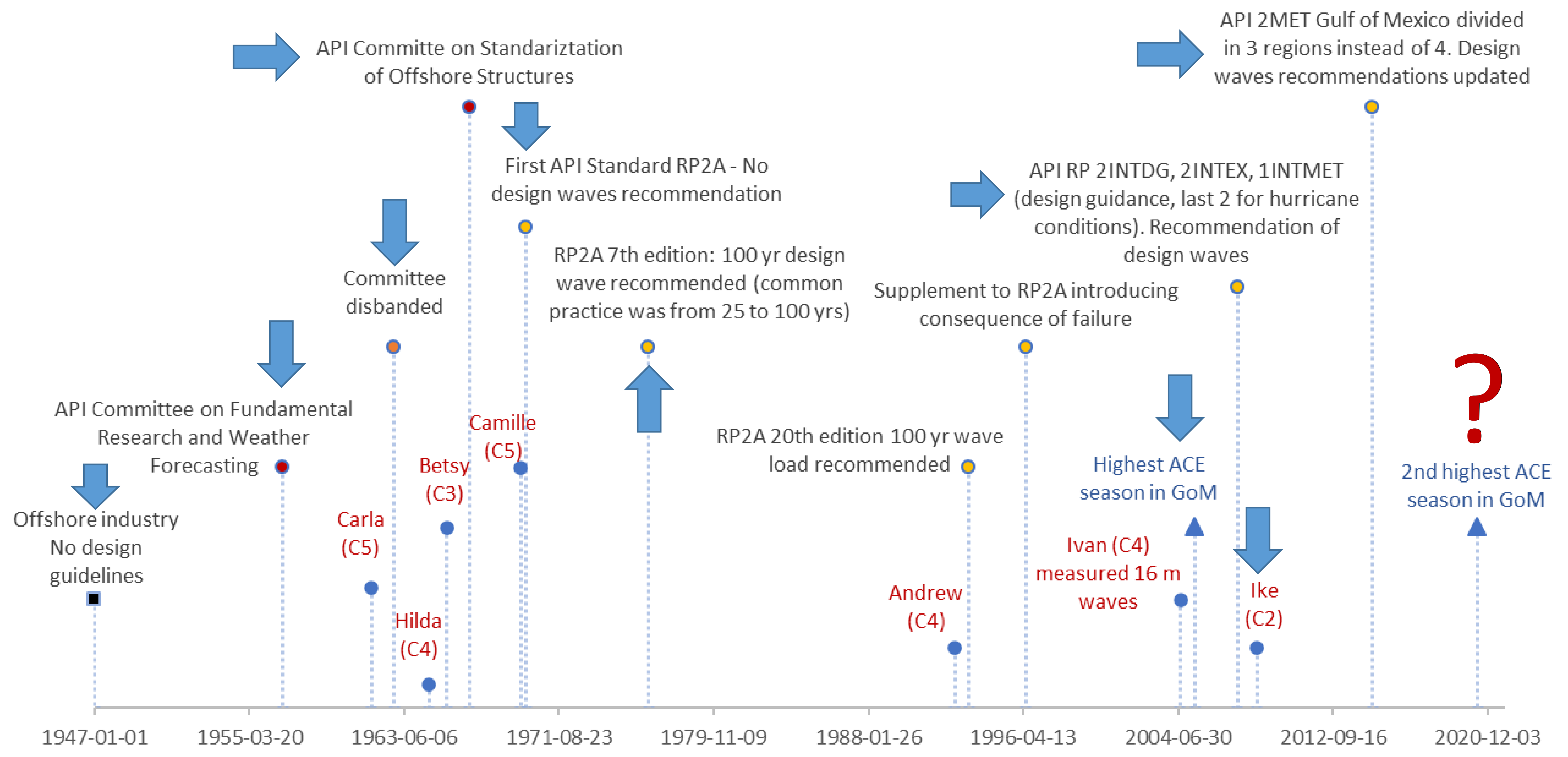
Source: www.offshorevisie.nl/

Ocean waves are a main design parameter for offshore and coastal structures

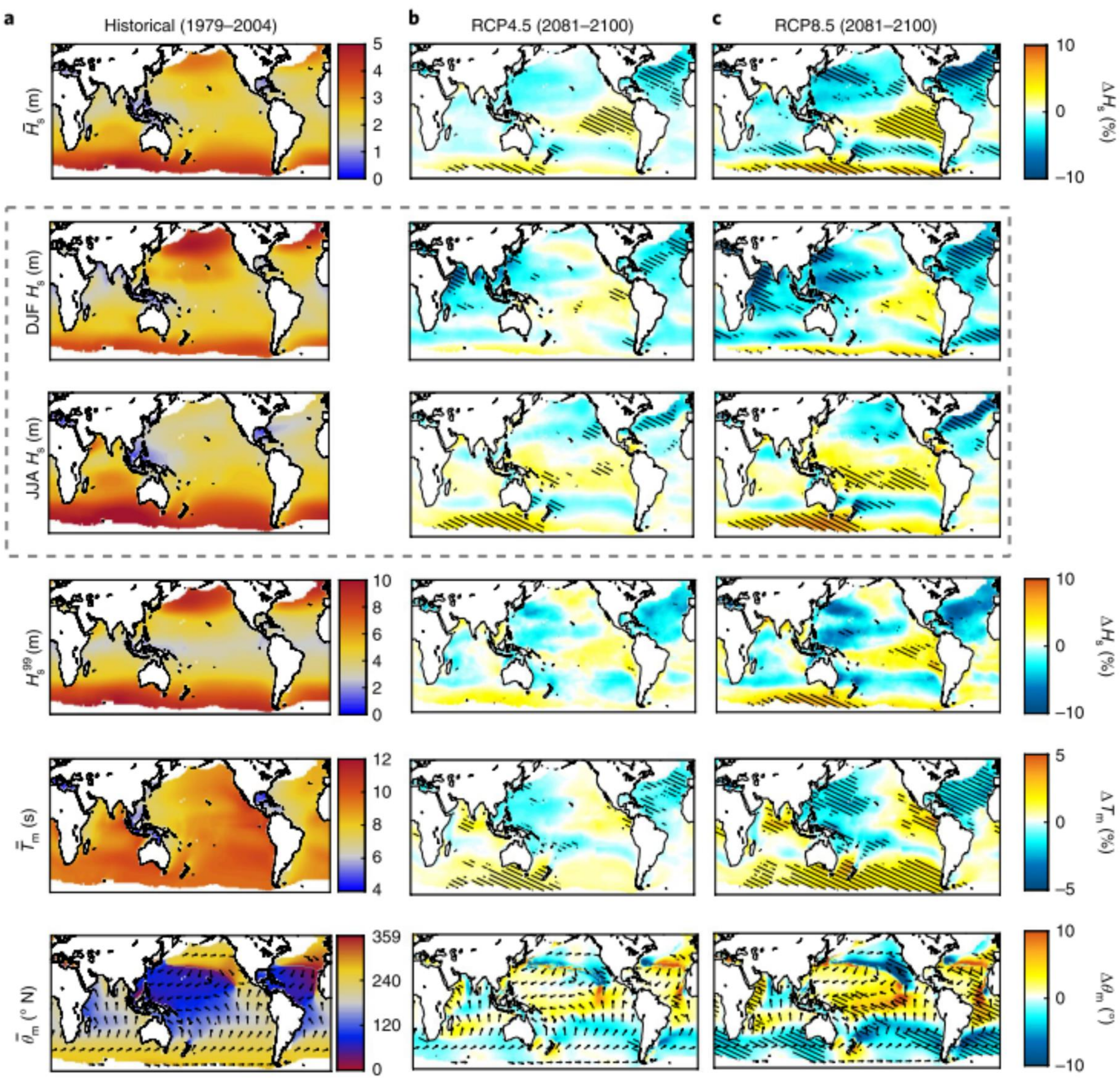
The American Petroleum Institute (API) has provided recommendation for metocean conditions since 1969, with wave data since 1976



Timeline for API guidelines in relation to events damaging oil rigs in the US Gulf of Mexico

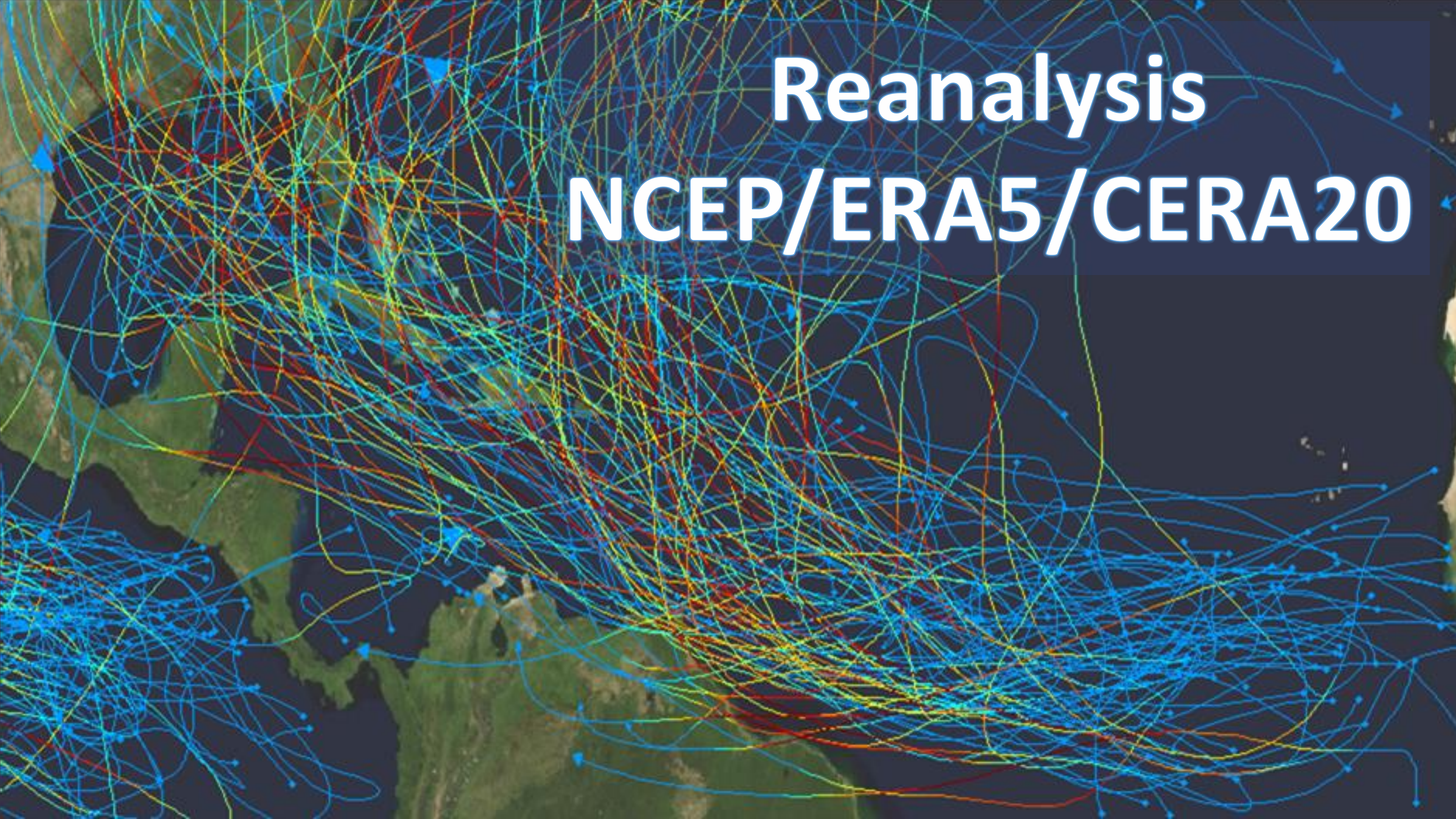


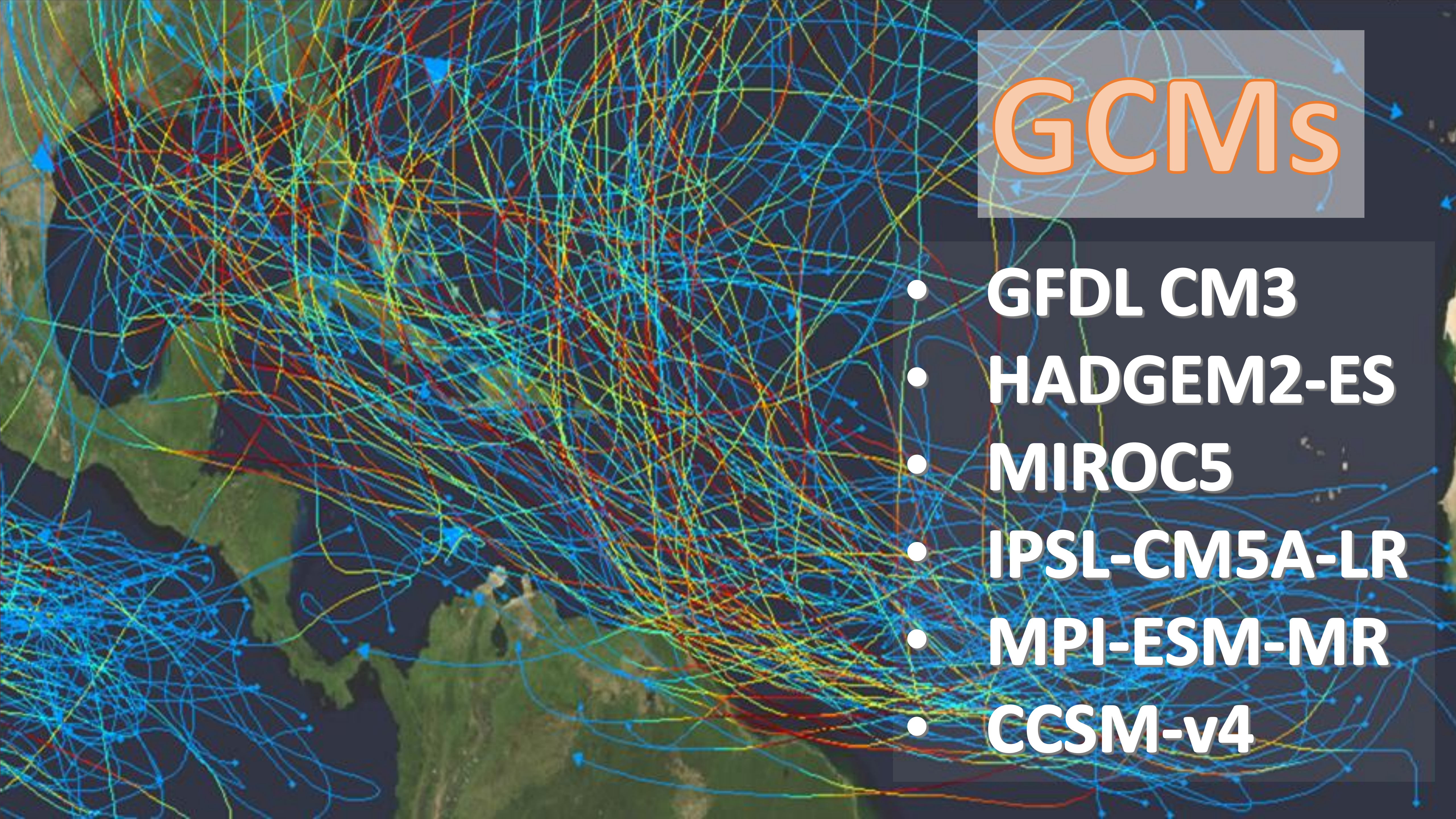
Global wave climate characterization (COWCLIP)



Morim, J., Hemer, M., Wang, X. L., Cartwright, N., Trenham, C., Semedo, A., et al. (2019). Robustness and uncertainties in global multivariate wind-wave climate projections. Nature Climate Change, 9(9), 711–718. doi.org/10.1038/s41558-019-0542-5

- ➢ Use of GCM's winds
  - Underestimation of maximum wind speeds
  - Underestimation of the number of TCs
- ➢ Low resolution for coastal areas and enclosed seas


Reanalysis
NCEP/ERA5/CERA20


GCMs
GFDL CM3
HADGEM2-ES
MIROC5
IPSL-CM5A-LR
MPI-ESM-MR
CCSM-v4

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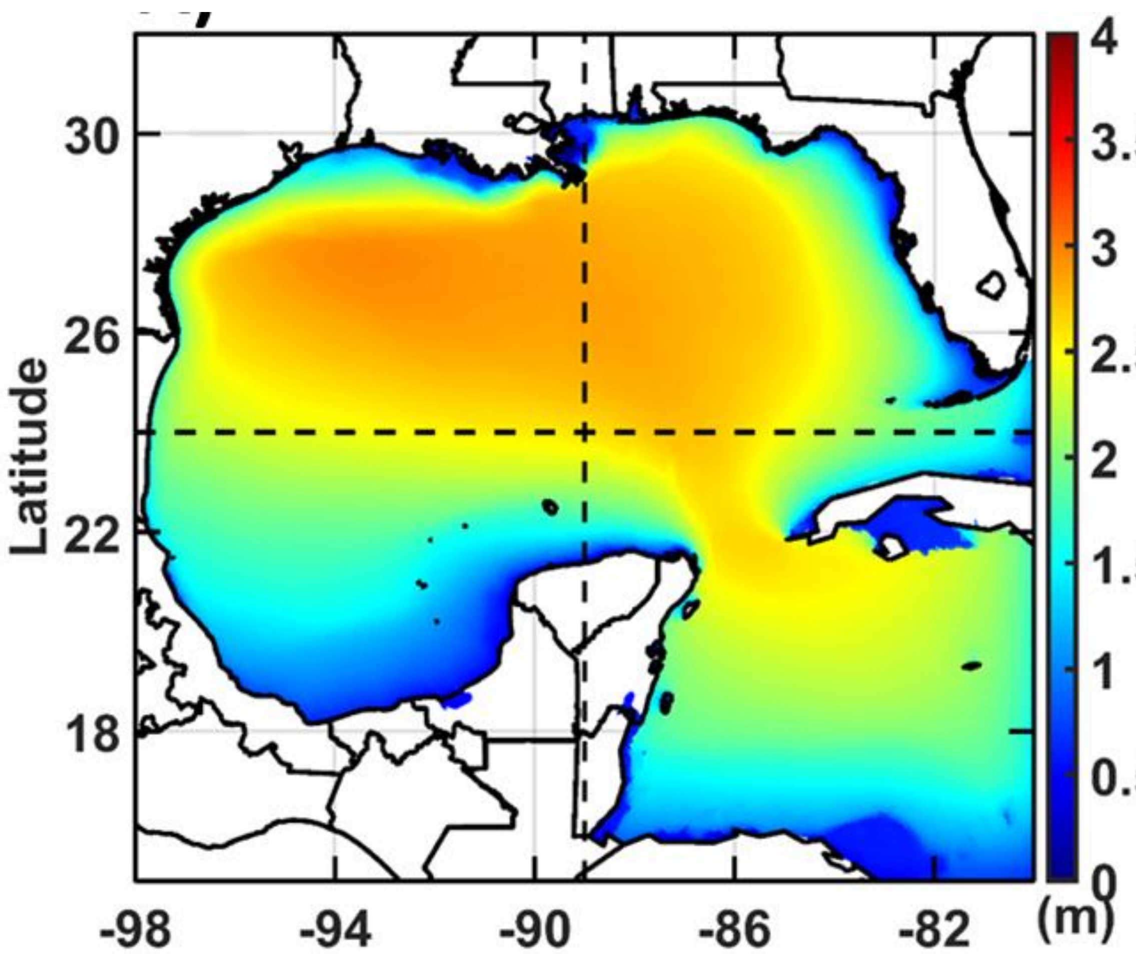
Period	Type	Model	GoM
Present climate	Reanalysis	NCEP	4207
		ERA5	5082
		MERRA2	4139
		CERA20C	4797
	GCM	HADGEM6	3557
		GFDL6	4354
		IPSL6	2587
		MIROC6	4640
		MPI6	6279
		CESM2	4306
Future climate SSP585	GCM	HADGEM6	2015
		GFDL6	4032
		IPSL6	1674
		MIROC6	4149
		MPI6	6019
		CESM2	3360
Total events			65197

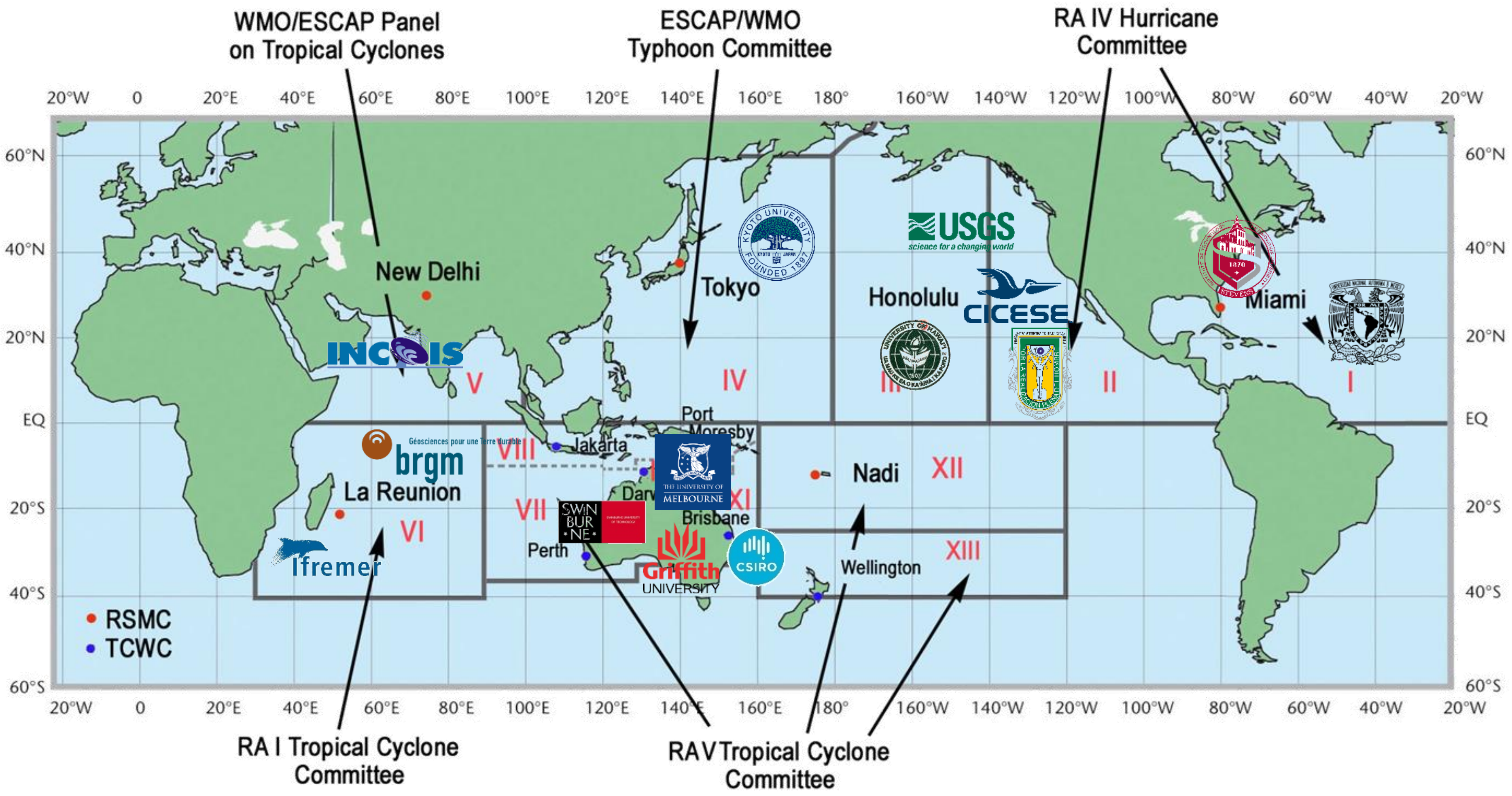


~65000 simulations in 5 days

Collaborative work proposal

PROPOSAL AT COWCLIP MEETING 2021

Basin
North Atlantic
Eastern Pacific
Western Pacific
North Indian
South-West Indian
Australian region
Southern Pacific



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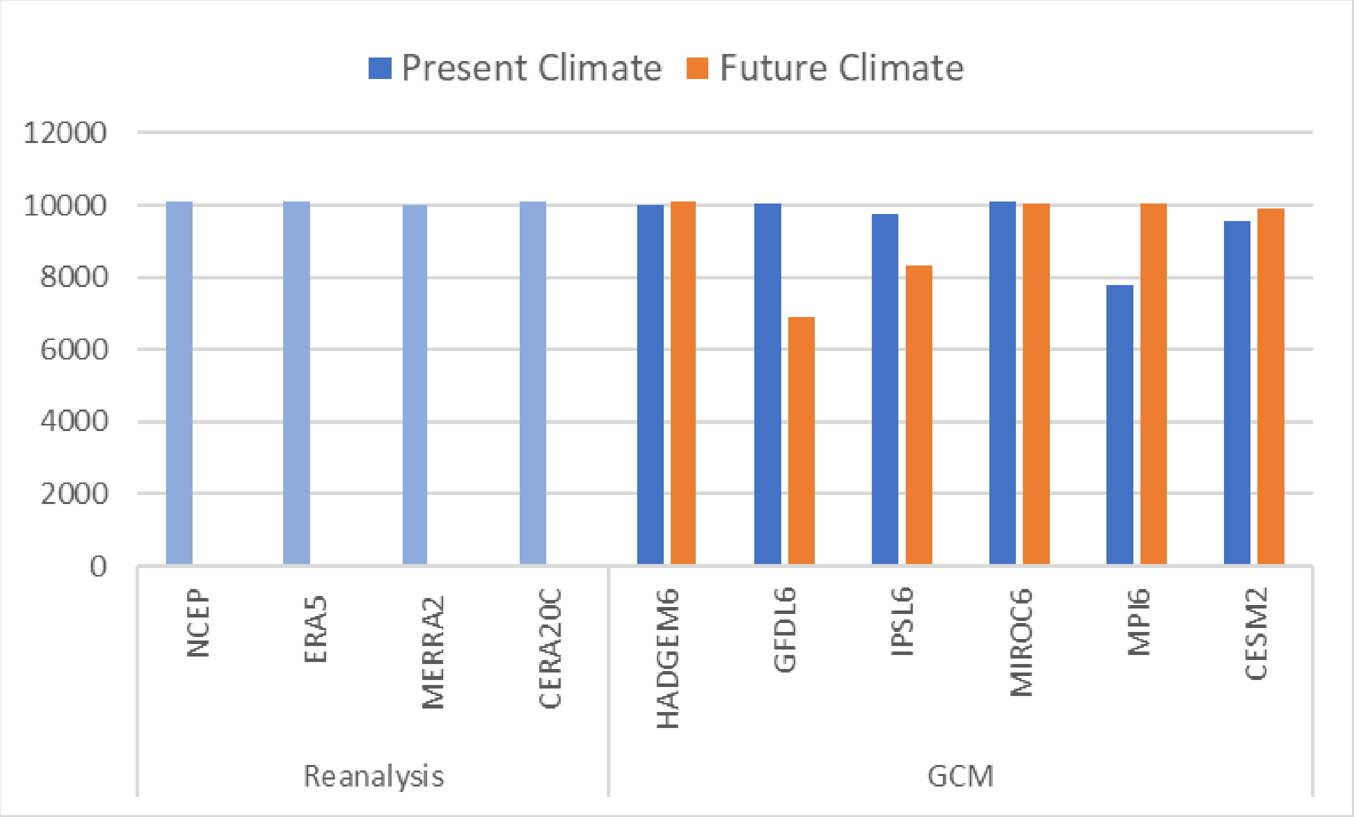
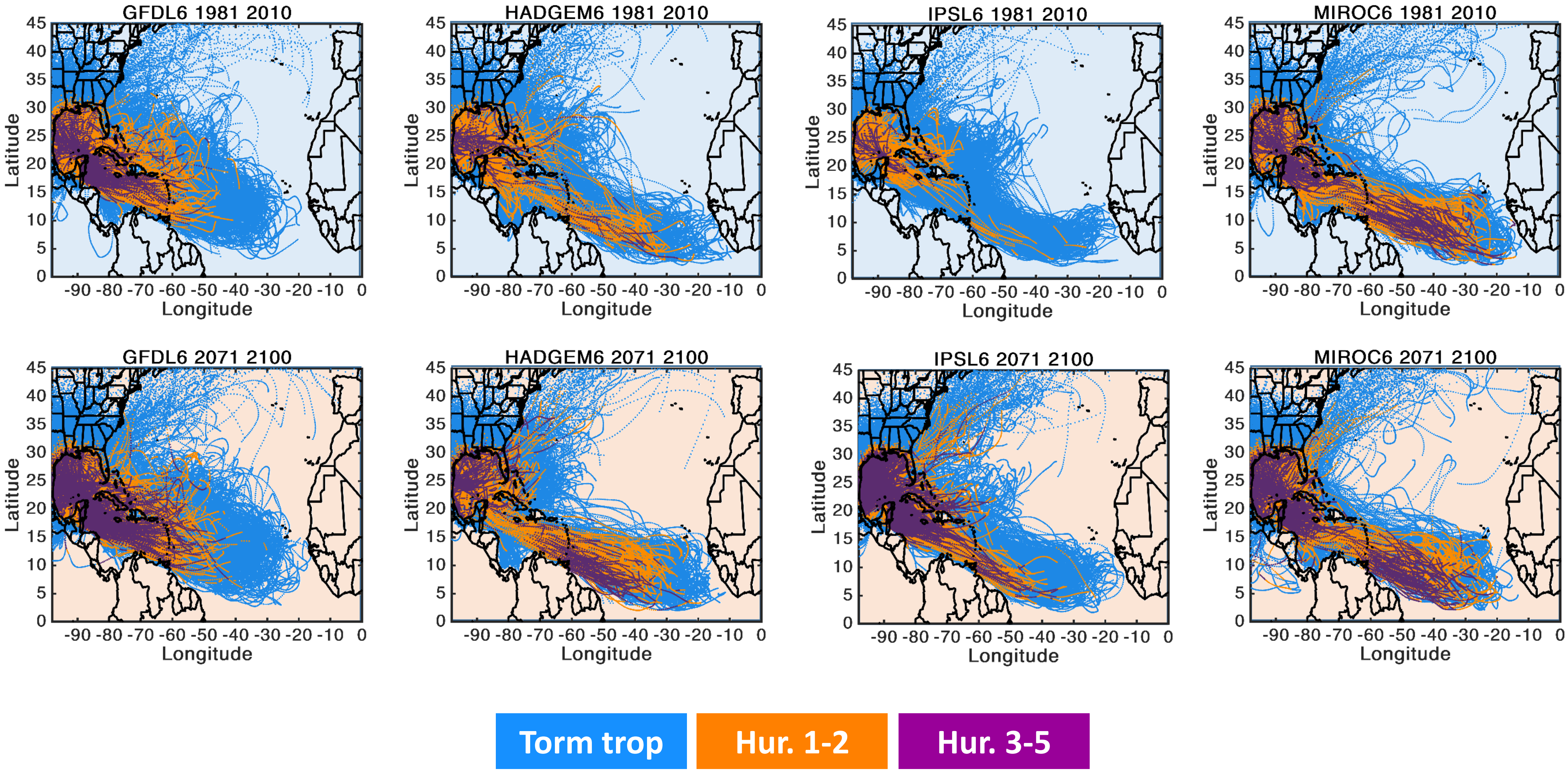
Number of events

Period	Type	Model	Total	Simulated	Missing
Present climate	Reanalysis	NCEP	10075	10075	0
		ERA5	10075	10075	0
		MERRA2	10075	10002	73
		CERA20C	10075	10075	0
	GCM	HADGEM6	10070	10006	64
		GFDL6	10060	10060	0
		IPSL6	10068	9752	316
		MIROC6	10074	10074	0
		MPI6	10065	7796	2269
		CESM2	10075	9568	507
Future climate SSP585	GCM	HADGEM6	10074	10074	0
		GFDL6	10064	6897	3167
		IPSL6	10075	8303	1772
		MIROC6	10074	10073	1
		MPI6	10069	10069	0
		CESM2	10073	9921	152
Total events			161141	152820	8321



Goal: ~10K per model

Maximum wind speeds (Present and Future climates)



Methodology

Bathymetry/Mesh

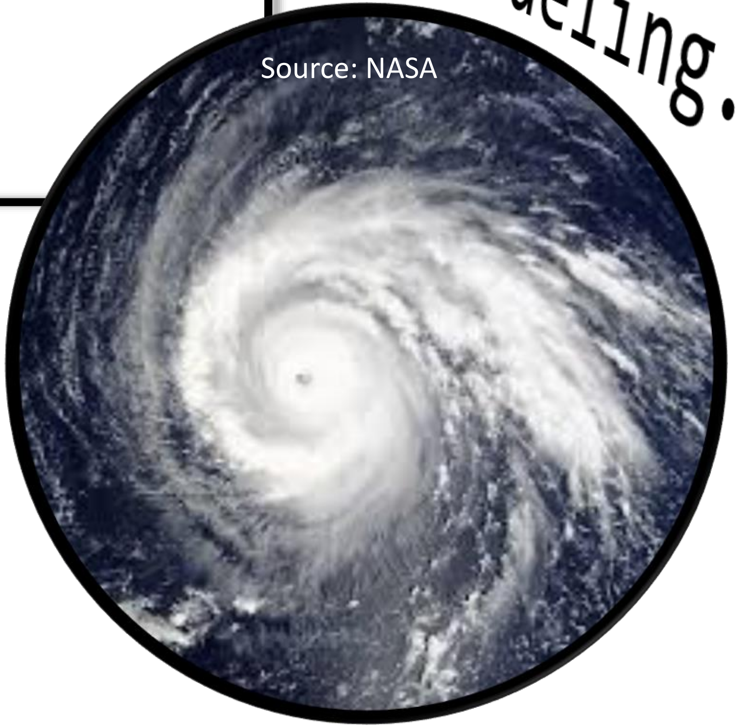
Wind fields
(NCEP, GCMS Present + SSP5 8.5)

Synthetic TCs database

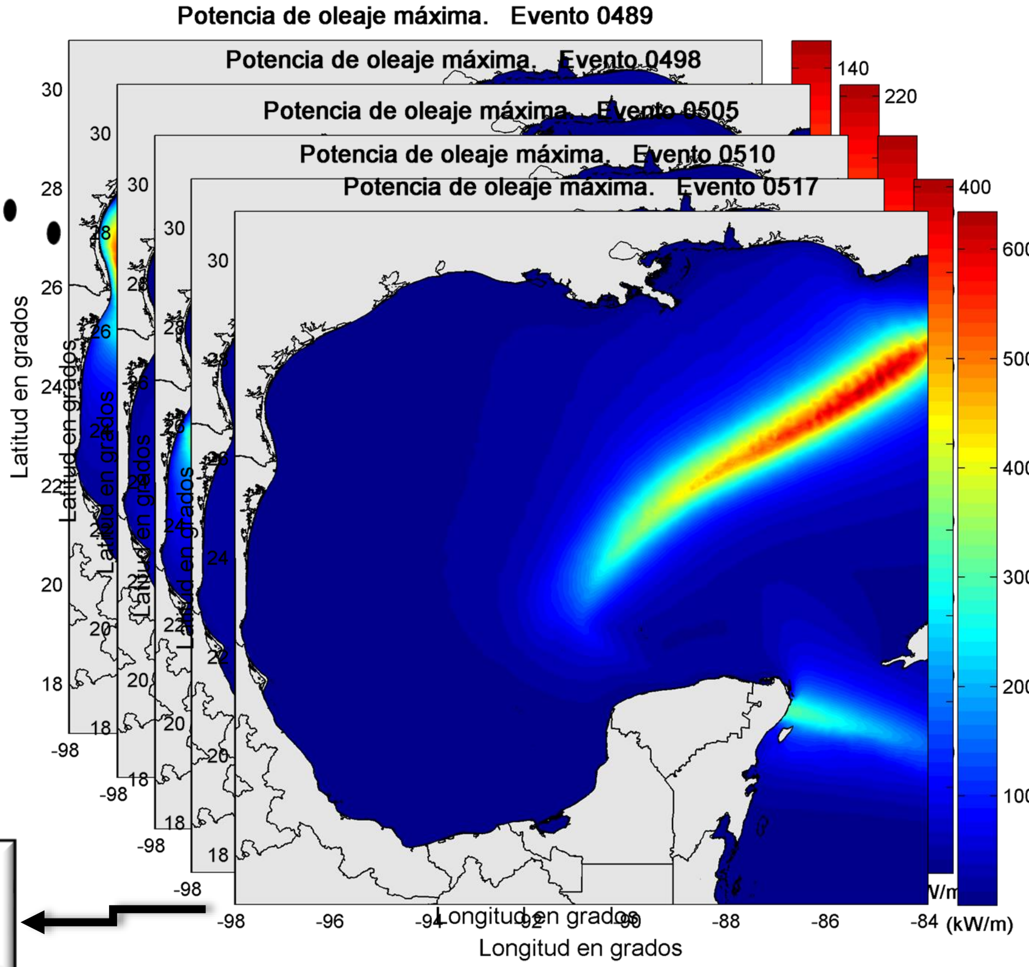
Present climate:
3 Reanalysis + 6 GCMs (GFDL CM3, HADGEM2-ES, MIROC5, IPSL-CM5A-LR, MPI-ESM-MR, CCSM-v4)
Future climate:
6 GCMs – SSP5 8.5

MIKE 21 SW

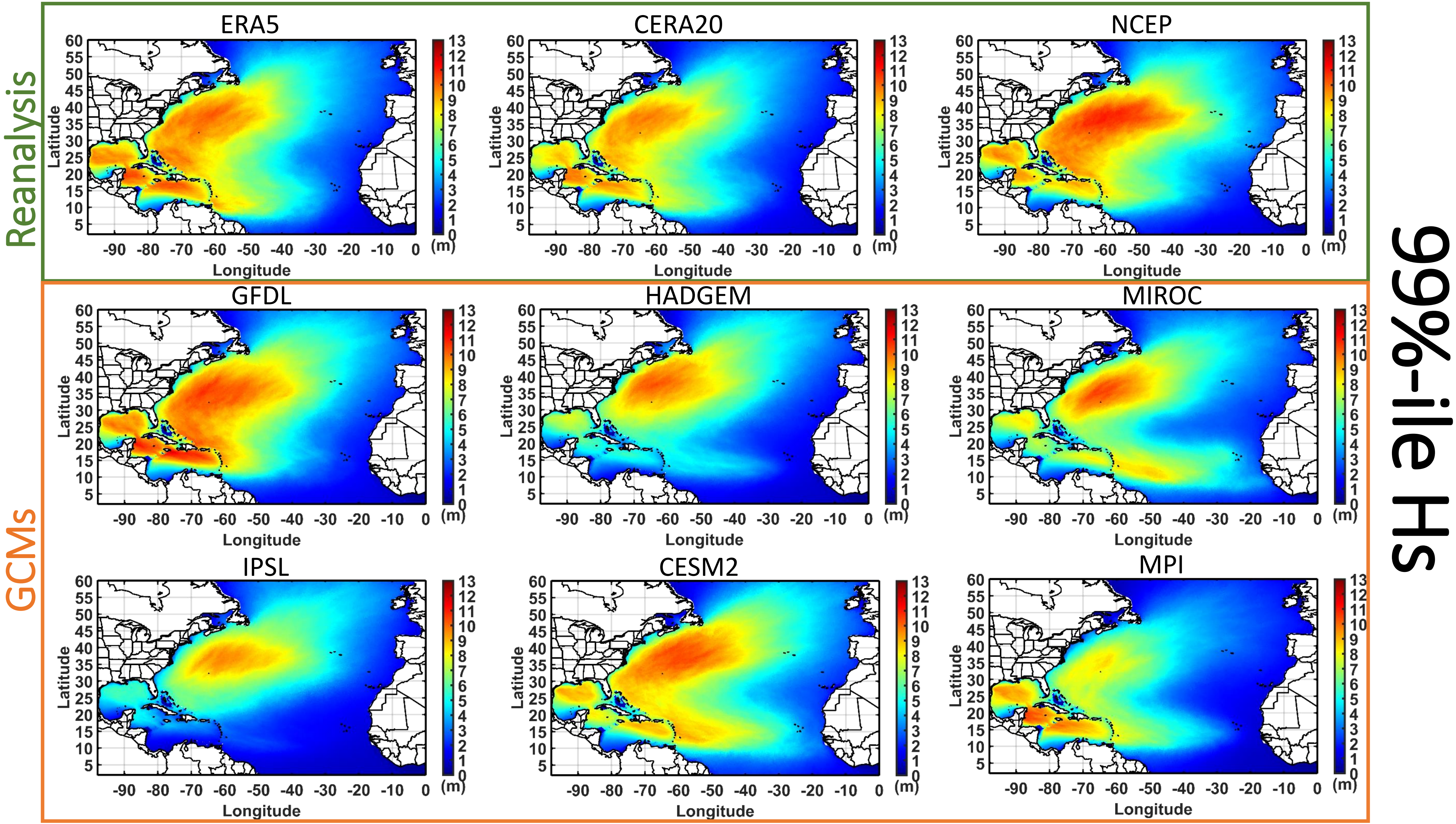
Wave modeling...



Maximum envelopes (Hs, Tp) and Hs associated values (Tp, Dir)

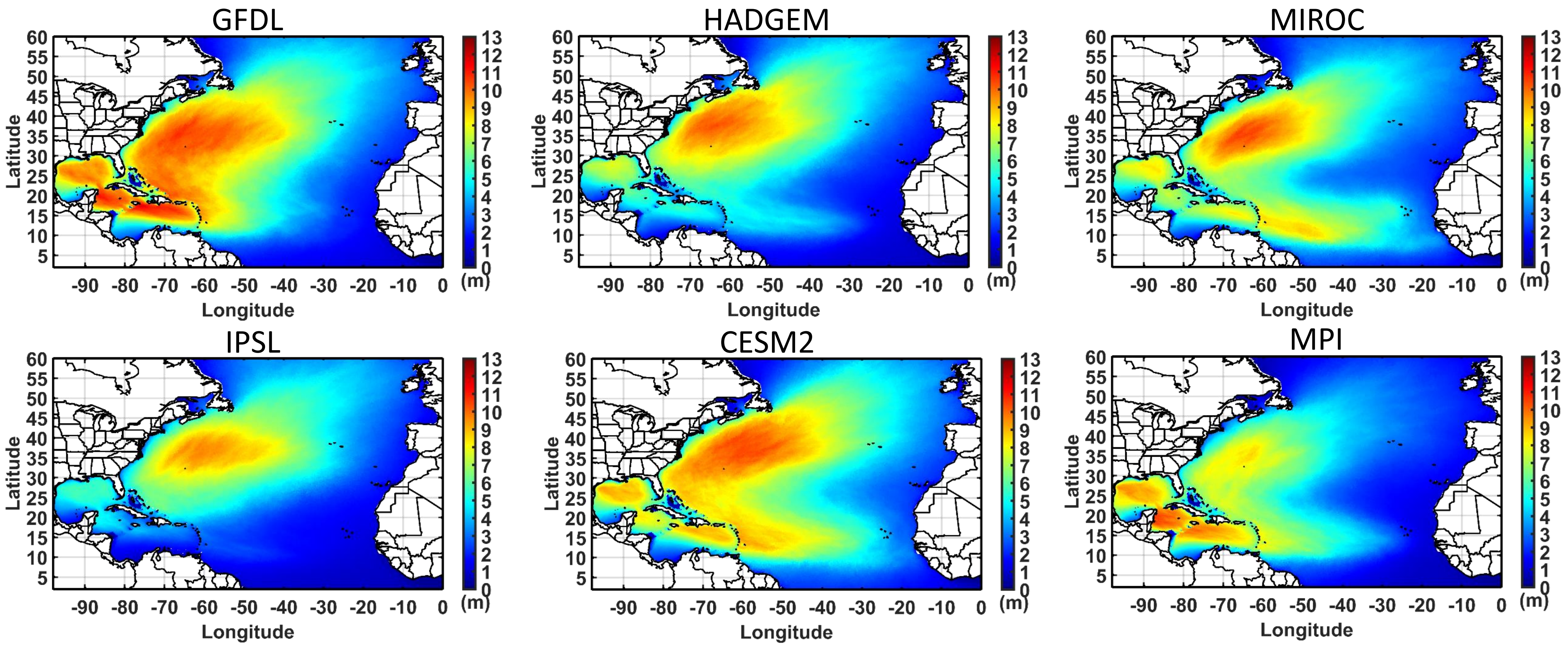


Recommendations for wave design parameters


Reanalysis
ERA5
CERA20
NCEP
GCMs
GFDL
HADGEM
MIROC
IPSL
CESM2
MPI
Latitude
Longitude
(m)
99%-ile Hs

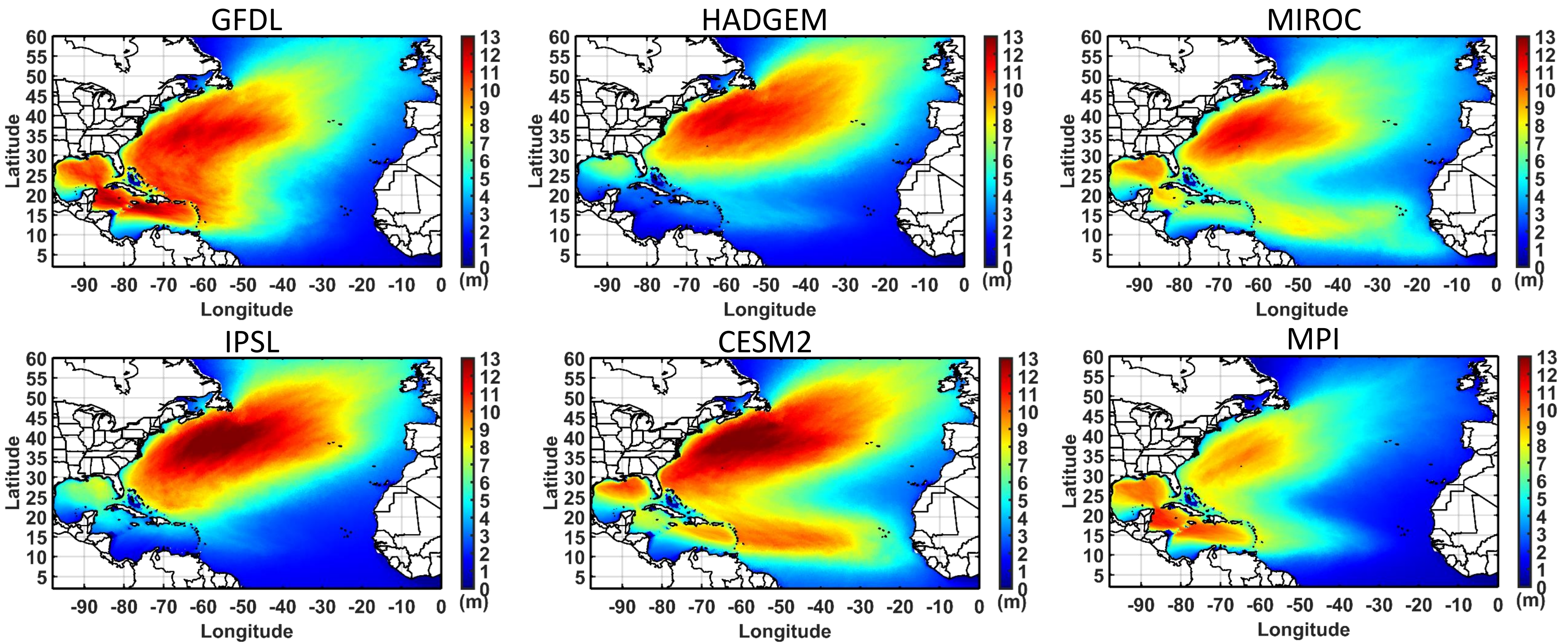
Present Climate
99%-ile Significant wave height

GCMs – Present climate

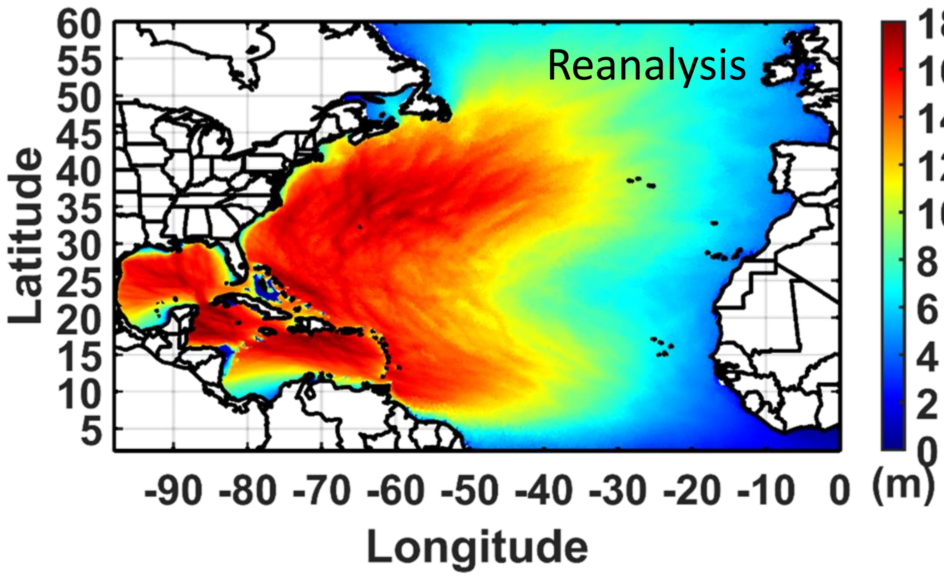


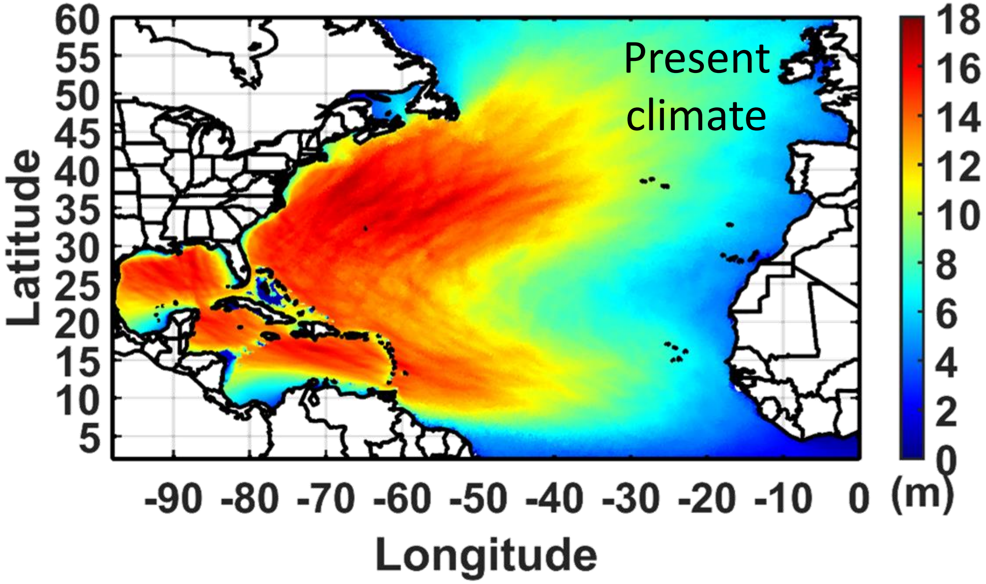
Future Climate
99%-ile Significant wave height

GCMs – Future climate

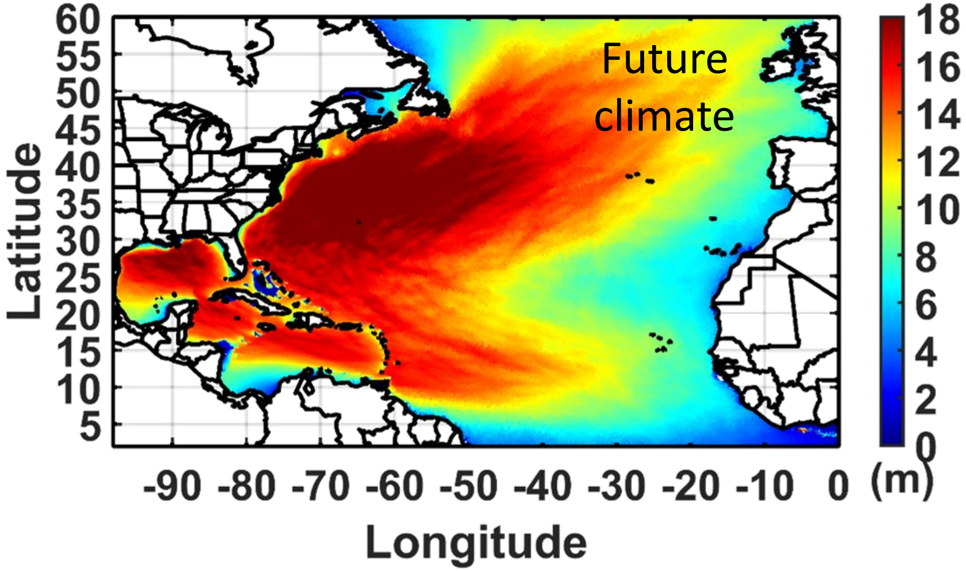


100 year return period significant wave height





Ensamble results for:
Reanalysis (ERA5, MERRA, NCEP)
Present climate (all GCMs)
Future climate (all GCMs)

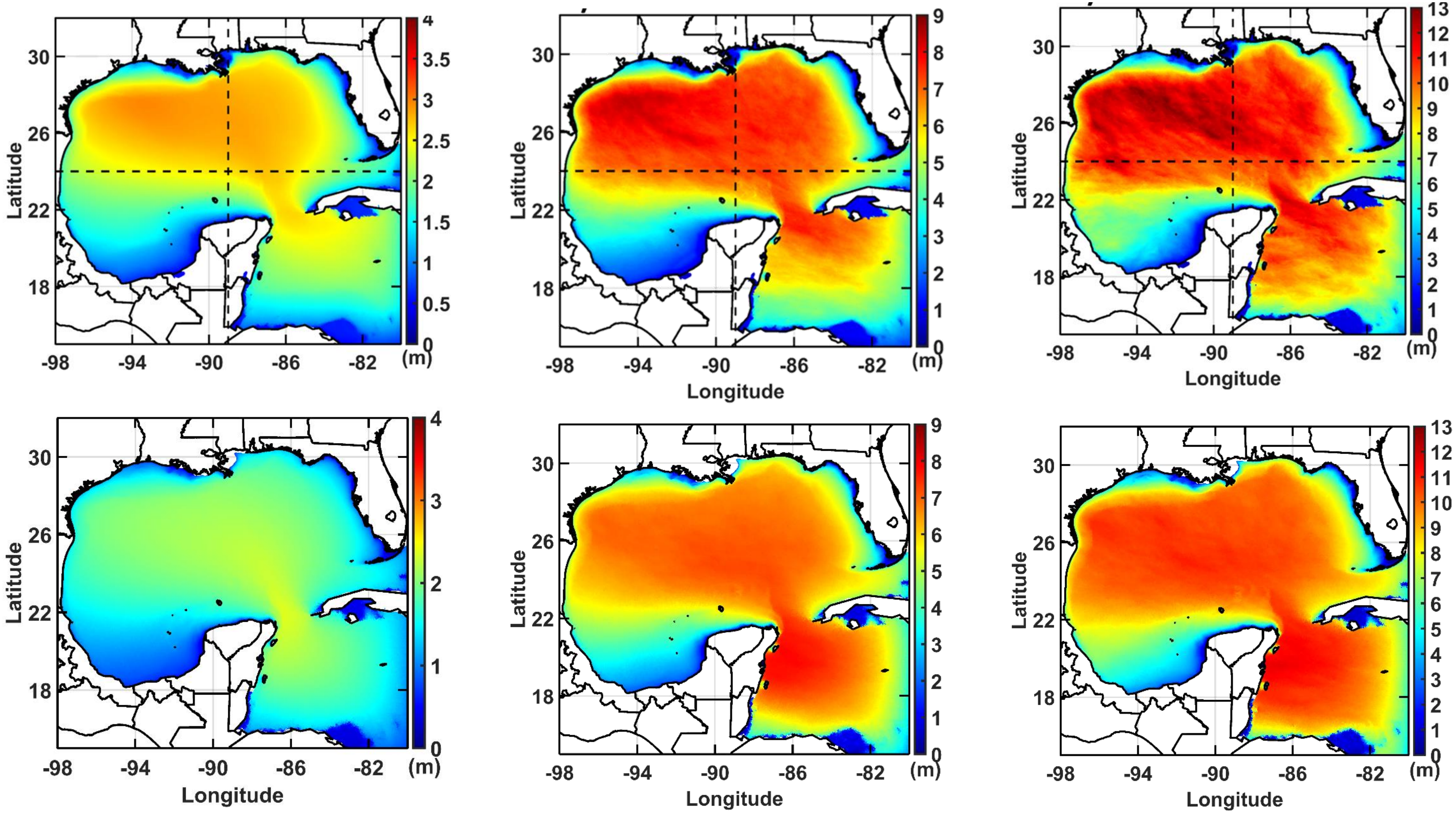


Hs derived from reanalysis

Hs mean | Hs 90%-ile | Hs 99%-ile

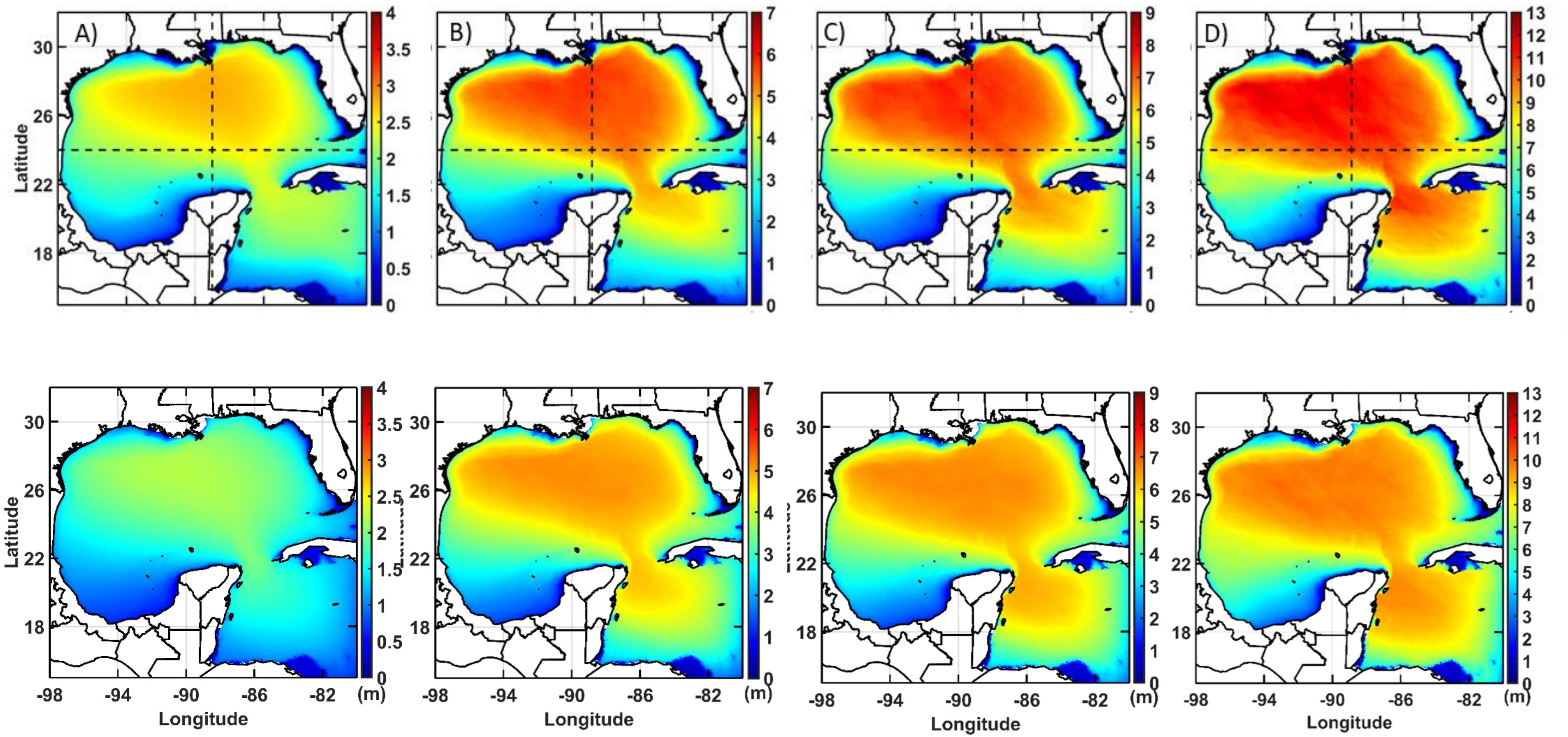
NCEP

Ensemble ERA5, MERRA, NCEP



Hs for GCM derived events ensemble – Present climate

	Hs mean	Hs 90%-ile	Hs 95%-ile	Hs 99%-ile
CMIP5				
CMIP6				

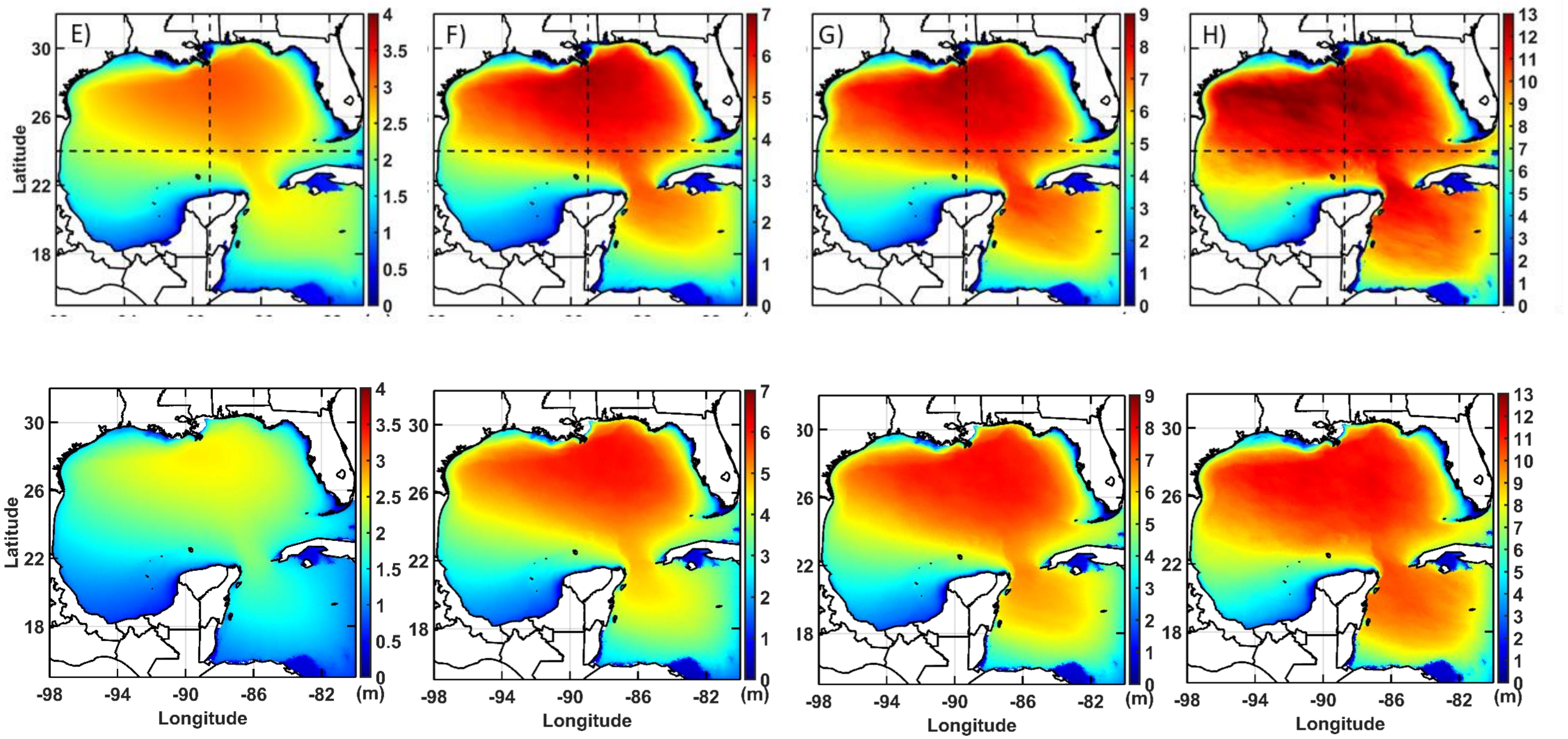


Hs for GCM derived events ensemble – Future climate

Hs mean | Hs 90%-ile | Hs 95%-ile | Hs 99%-ile

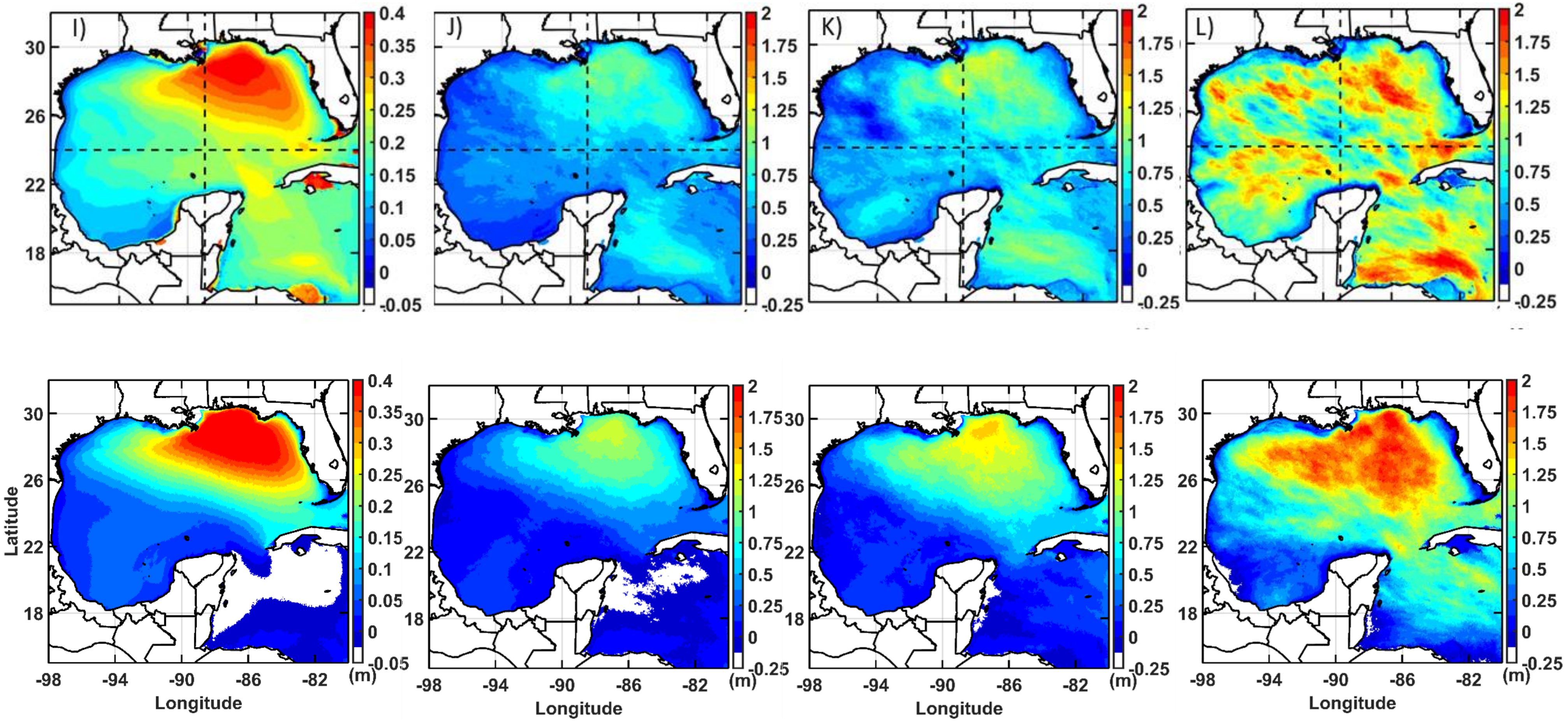
CMIP5
RCP 8.5

CMIP6
SSP5-8.5

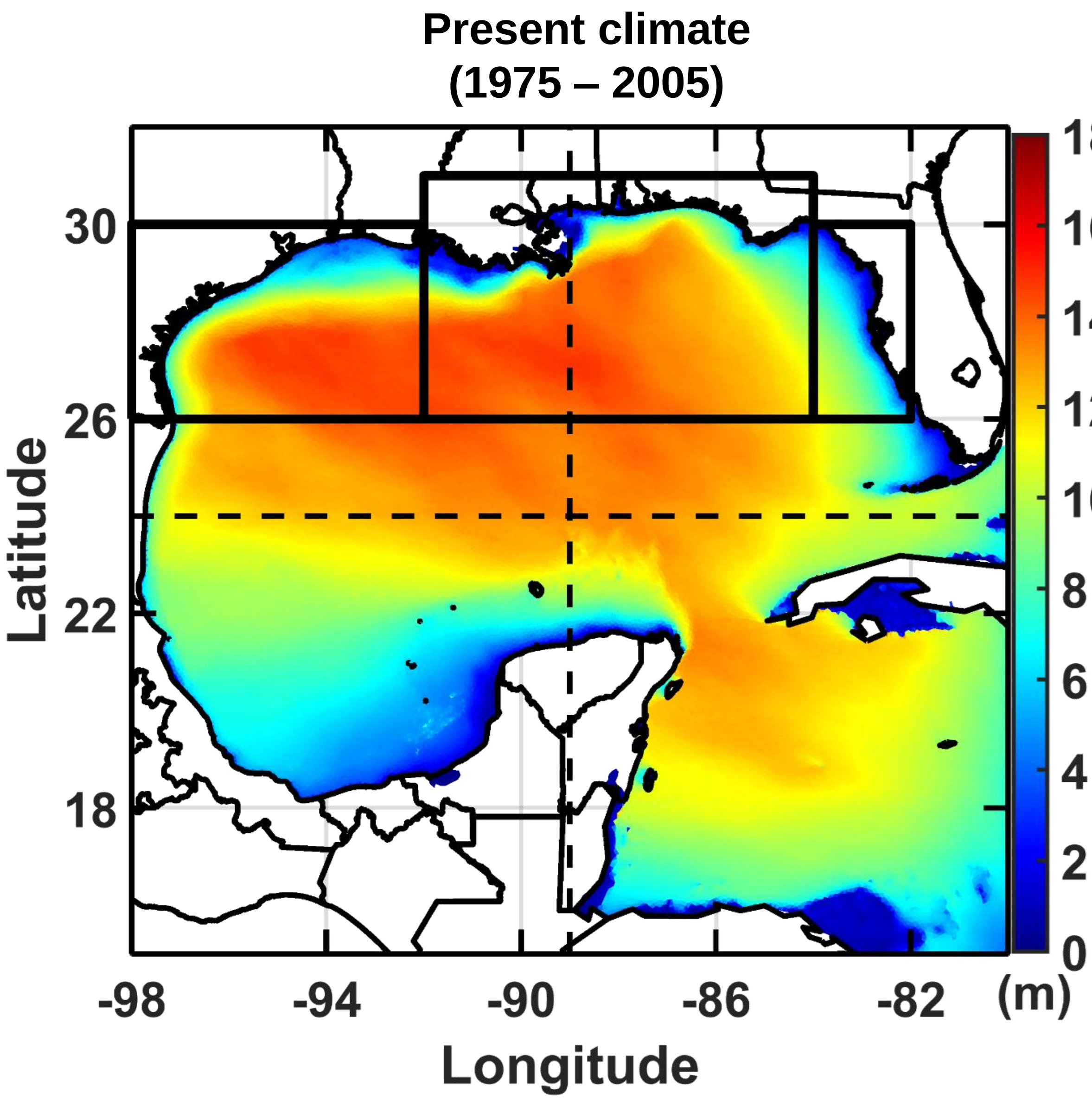


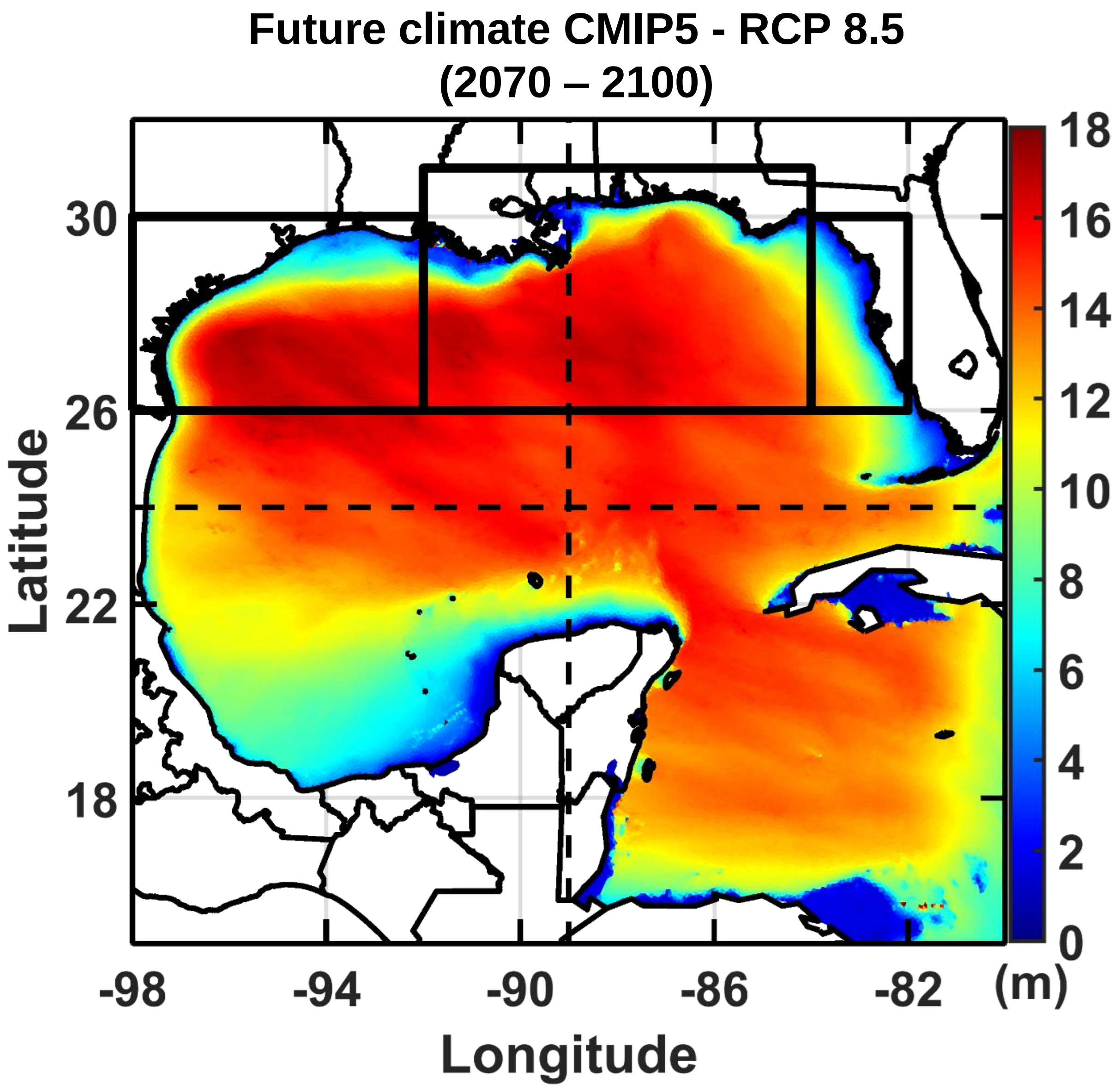
Increase in Hs for the future climate (based on ensemble)

	Hs mean	Hs 90%-ile	Hs 95%-ile	Hs 99%-ile
CMIP5 RCP 8.5				
CMIP6 SSP5-8.5				



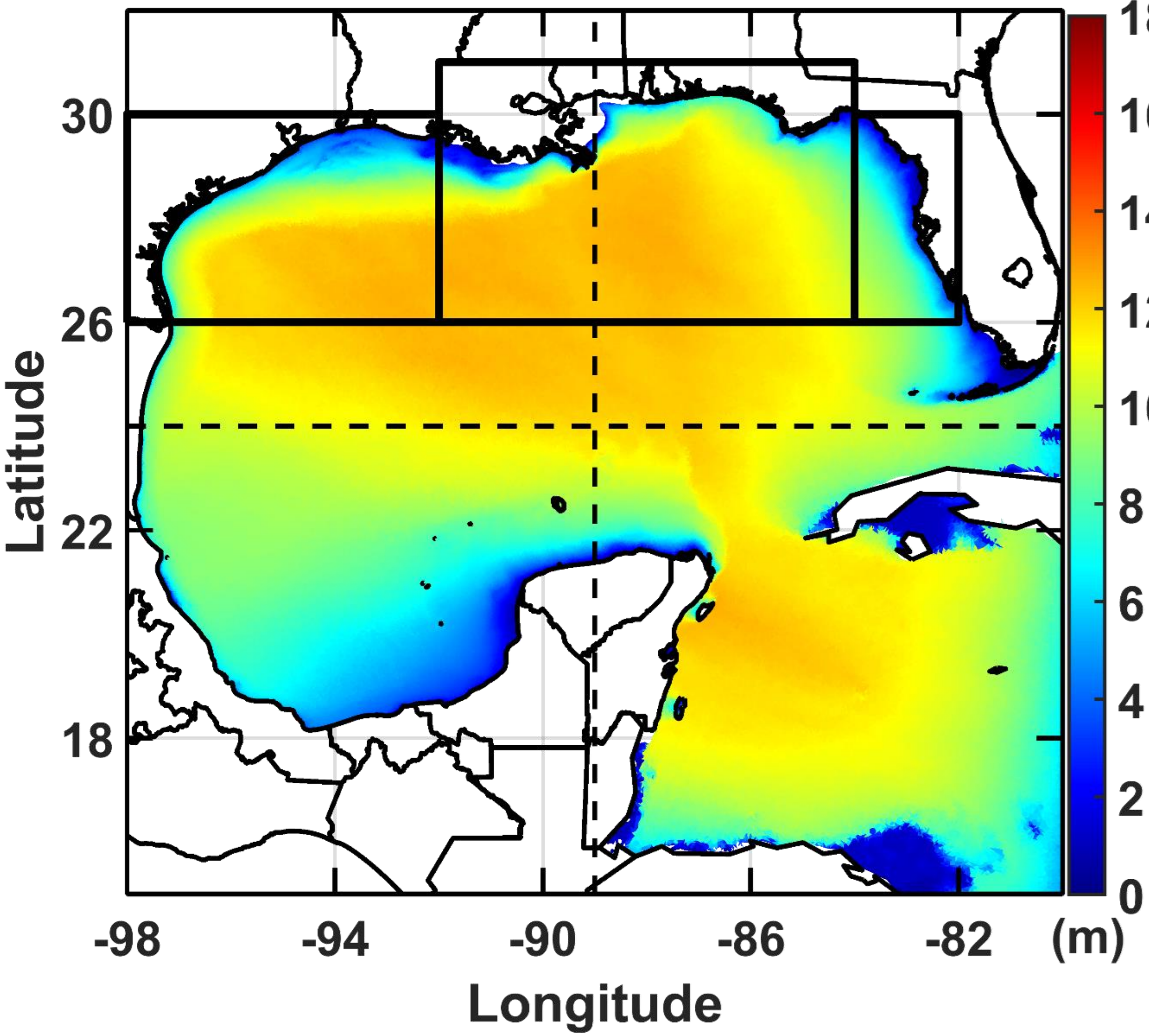
100 Years return period significant wave height – CMIP5



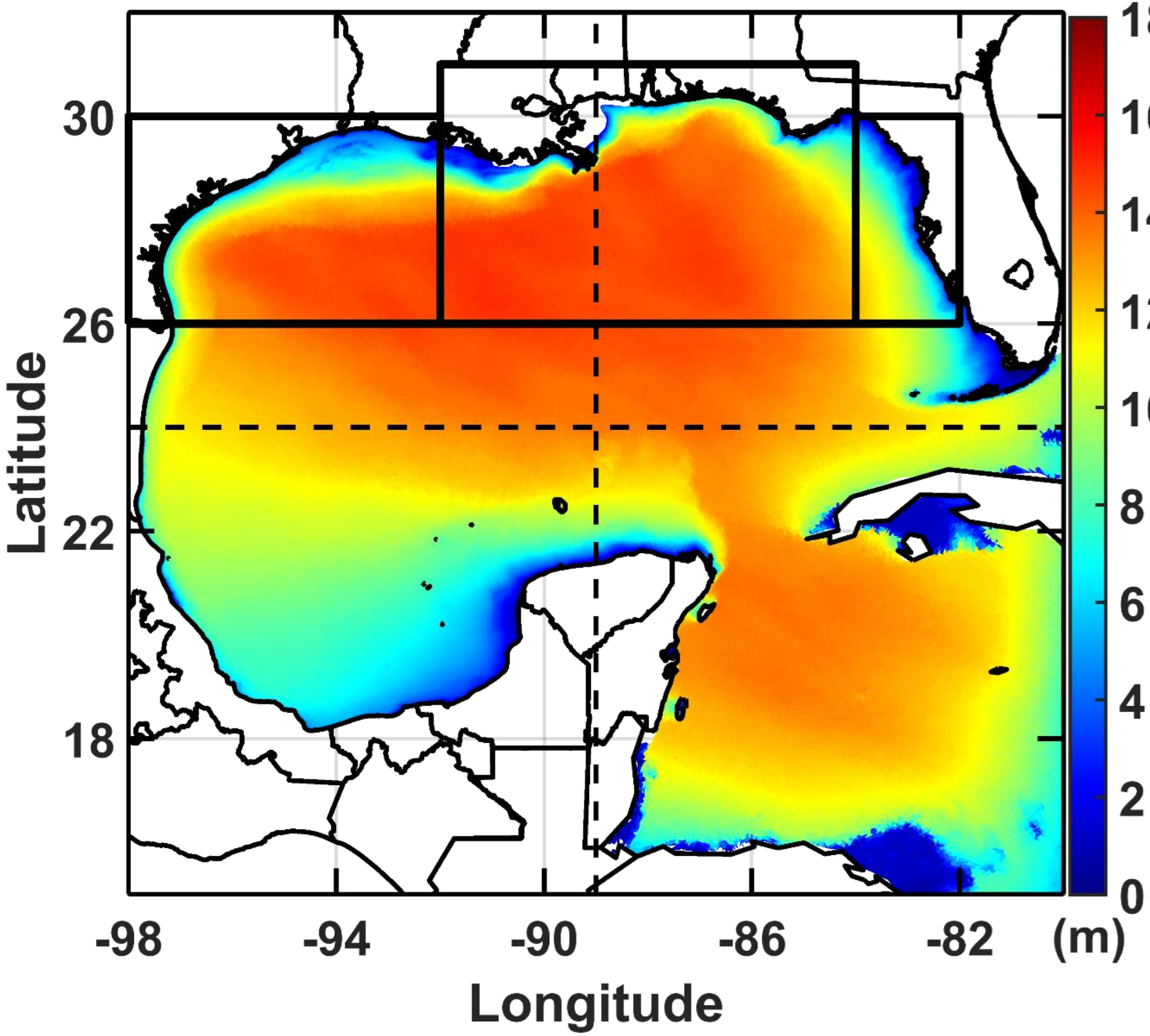


100 Years return period significant wave height – CMIP6

Clima actual
(1975 – 2005)

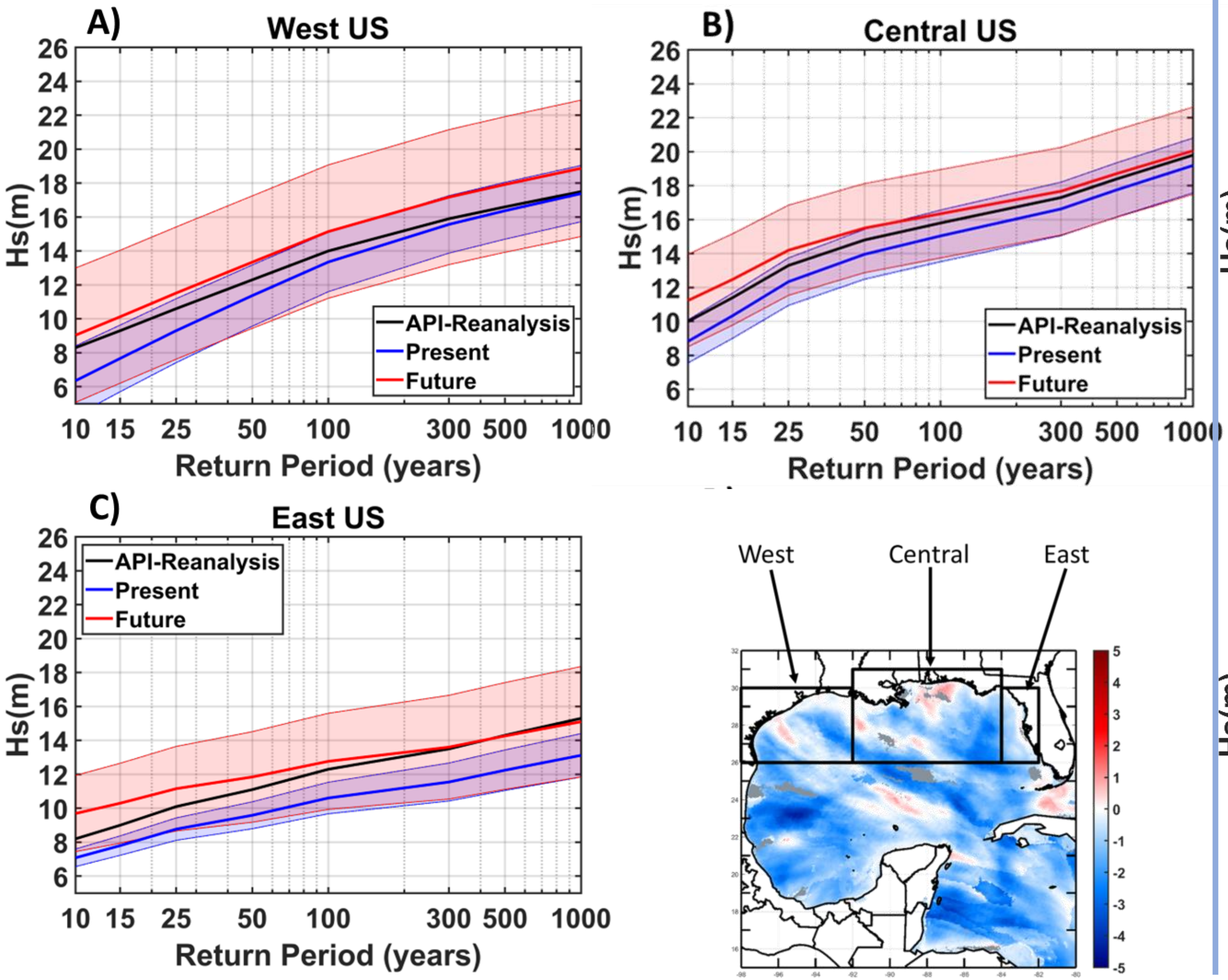


Clima futuro CMIP6 – SSP5 8.5
(2070 – 2100)

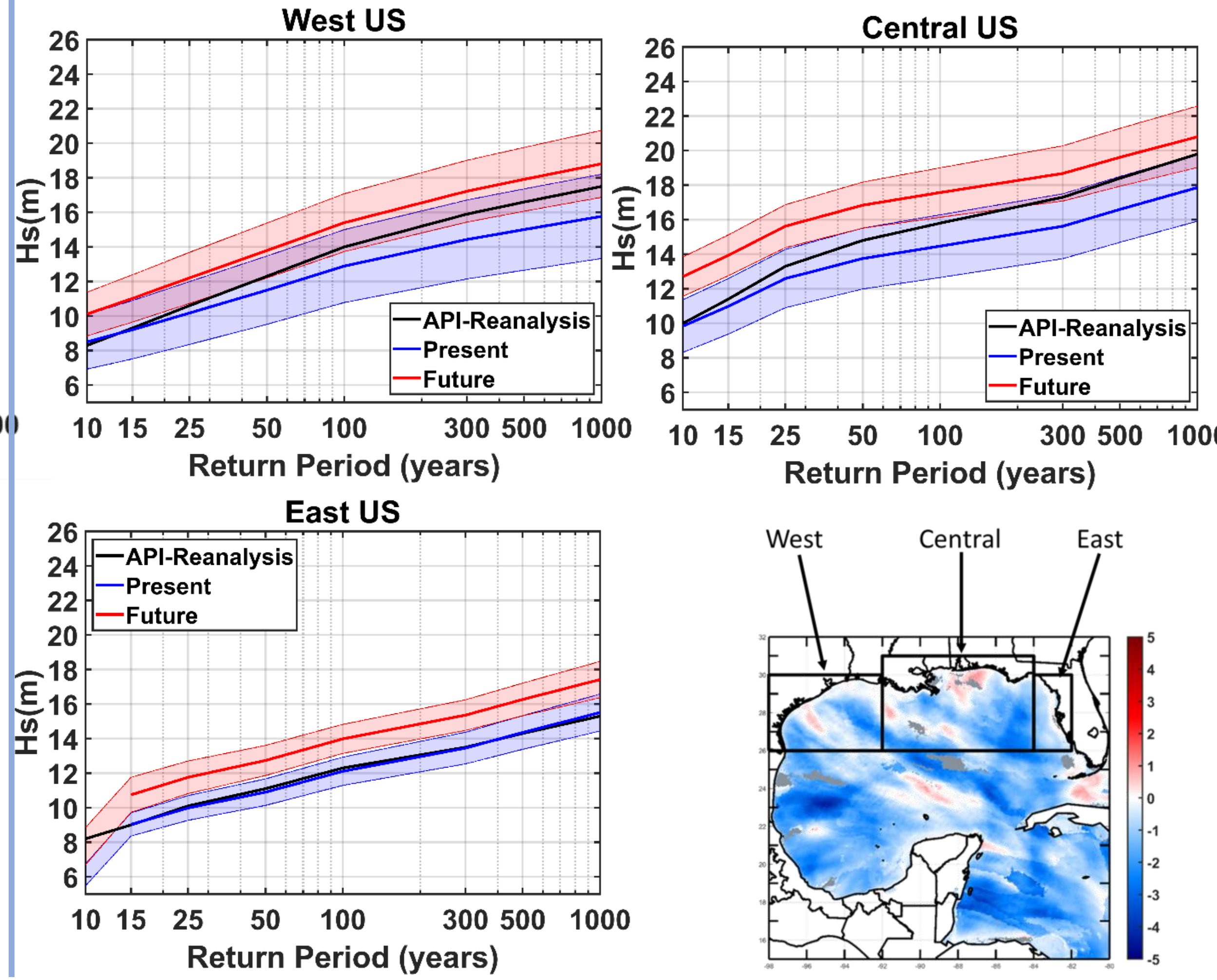


Return periods for the API defined areas in the north GoM

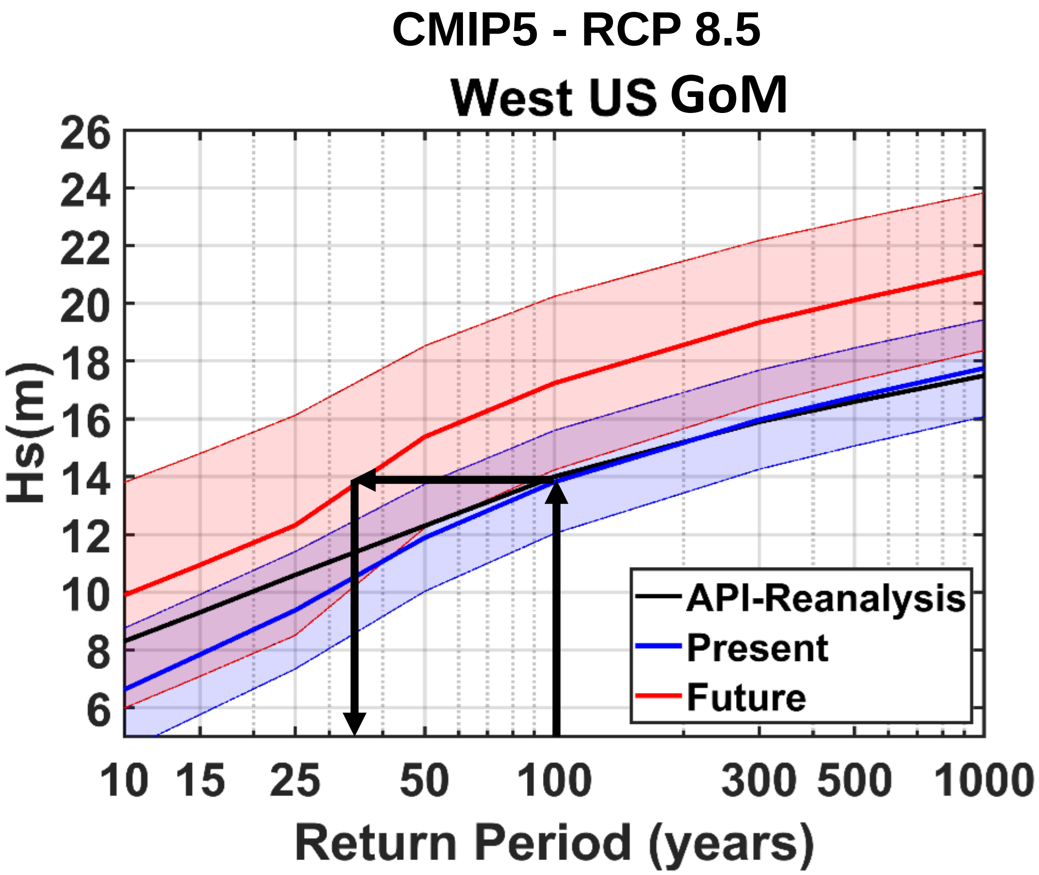
CMIP5 - RCP 8.5

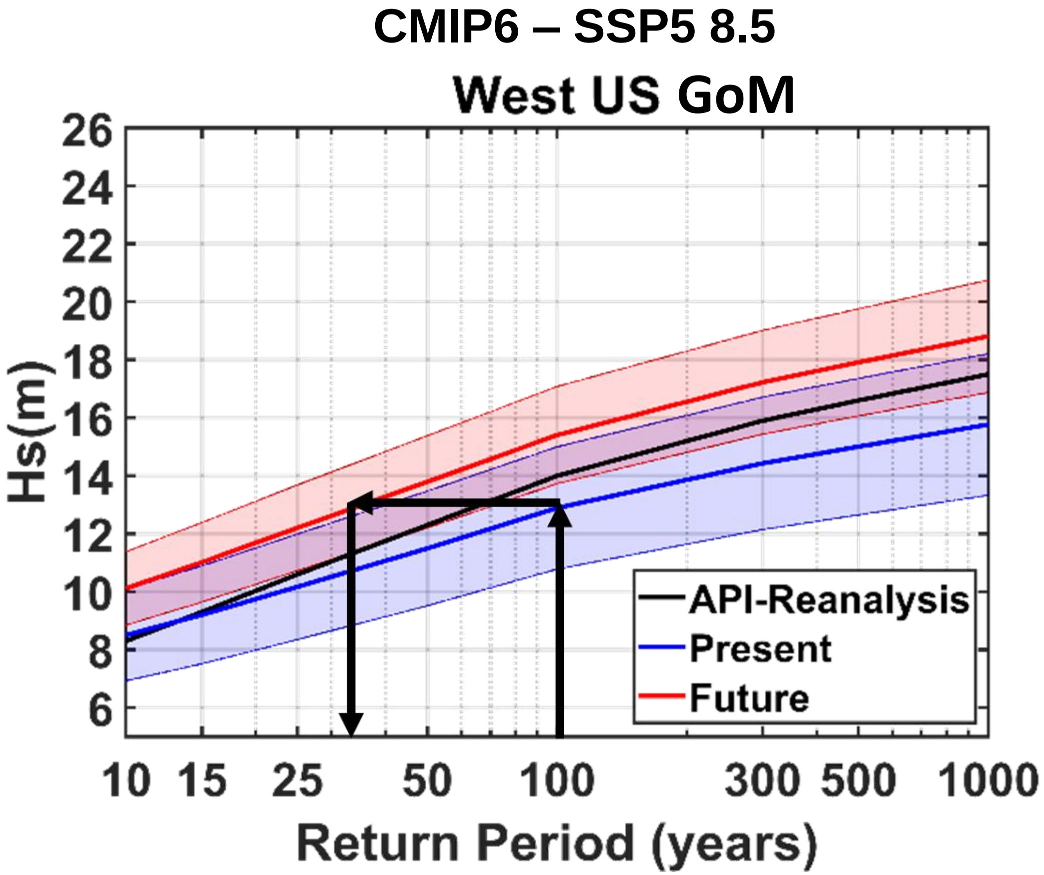


CMIP6 – SSP5 8.5



Change in design parameters due to CC – failure implications





… for both cases (CMIP5 & CMIP6) the **100 year return period** in the **present climate** corresponds to **~30 year return period** in the **future climate**. Based on that, the probability of the design event to ocurr during the lifetime of a structure a increases from **26%** to **64%**

Conclusions

Estimates of extreme wave heights using historical tropical cyclone events are imprecise due to the limited time of available information.

The use of synthetic tropical cyclone events allows for a robust statistical characterization of the extreme wave climate.

Using non-stationary wave climates is essential to reduce the probability of failure in maritime structures.

Synthetic tropical cyclones enable the characterization of future climate to determine design conditions for different return periods, including non-stationary climates.

Programa de Maestría y Doctorado en Ingeniería

ING. CIVIL

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