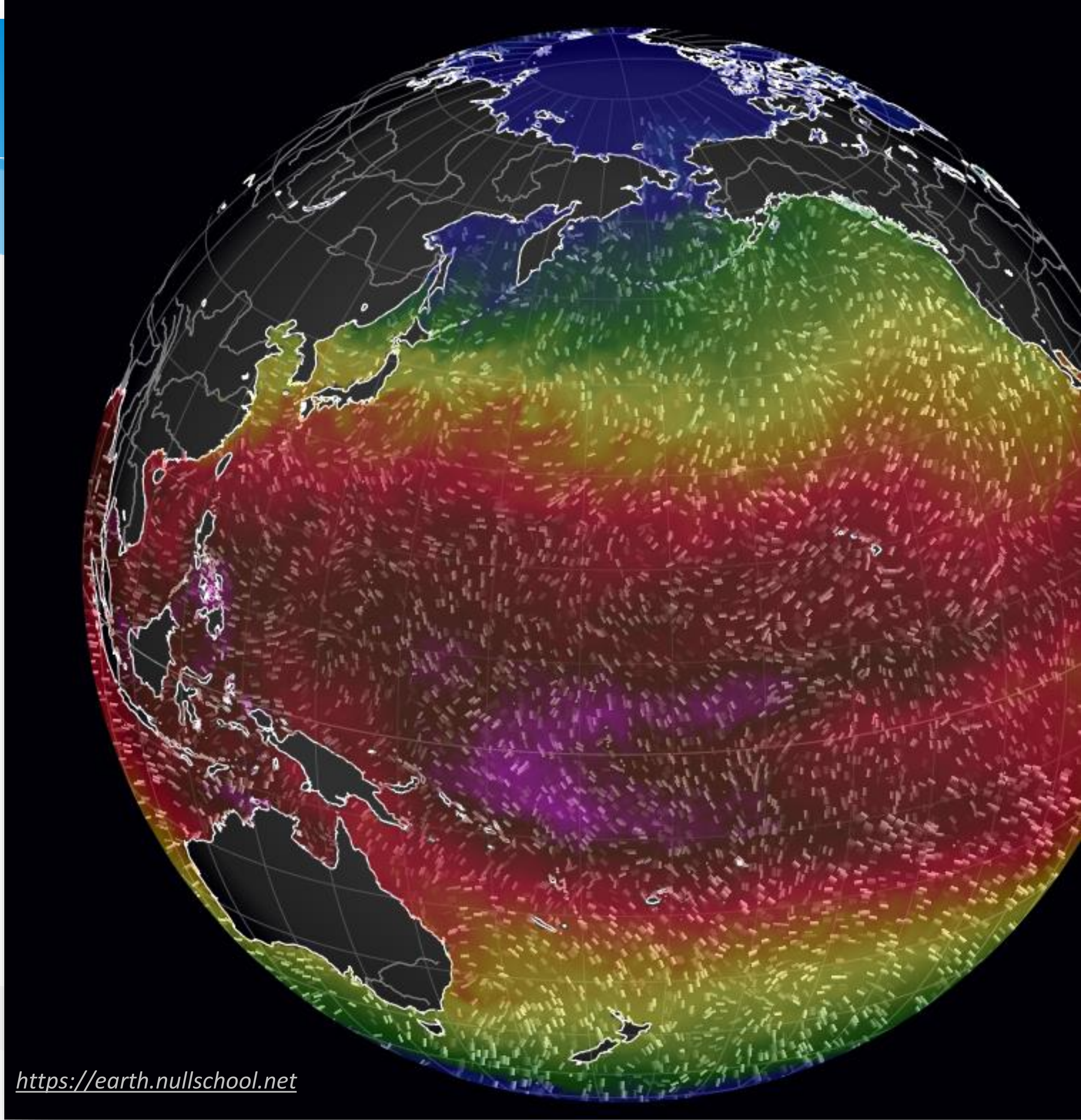
CAN WE FIND…ROBUST SIGNALS OF CHANGE IN THE HISTORICAL GLOBAL WAVE CLIMATE ?



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Ocean Wave Climate

…a project, with research members from around the globe, that provides infrastructure to support a systematic, community-based framework for validation and inter-comparison of wave hindcasts and projections

MOTIVATION

- Ocean scale waves are relevant and important for, among other things:
  - harnessing of wave energy, safety, commerce, and economics (e.g., transport of goods), and in coastal areas drive important processes that determine flooding and erosion.

- Buoy, model, and remotely sensed data are used to understand and describe historical spatial and temporal variations but most global scale or ocean basin studies
  - focus on or are limited to wave heights and periods
  - use single datasets and disparate methods that have led to sometimes contrasting results

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OBJECTIVE

To that end, there is a need to asses how well variability and trends described by current generation datasets compare

Here we aim to

- assess the variance in wave climatology and rates of change across the current generation of hindcast & reanalysis products, and
- evaluate if robust signals of change can be quantified

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APPROACH

Being accomplished via the joint efforts of the COWCliP group, an international collaborative research community of researchers with interests in wind-wave climate variability and change.

10 individual groups contributed and post-processed hindcast or reanalysis global scale datasets in a consistent manner using the same code (provided by Wang and others)

- monthly, seasonal, and annual statistics
- common overlapping time-period 1980-2015 (35 years) (for the most part)

COWCliP meeting in Liverpool, 2017

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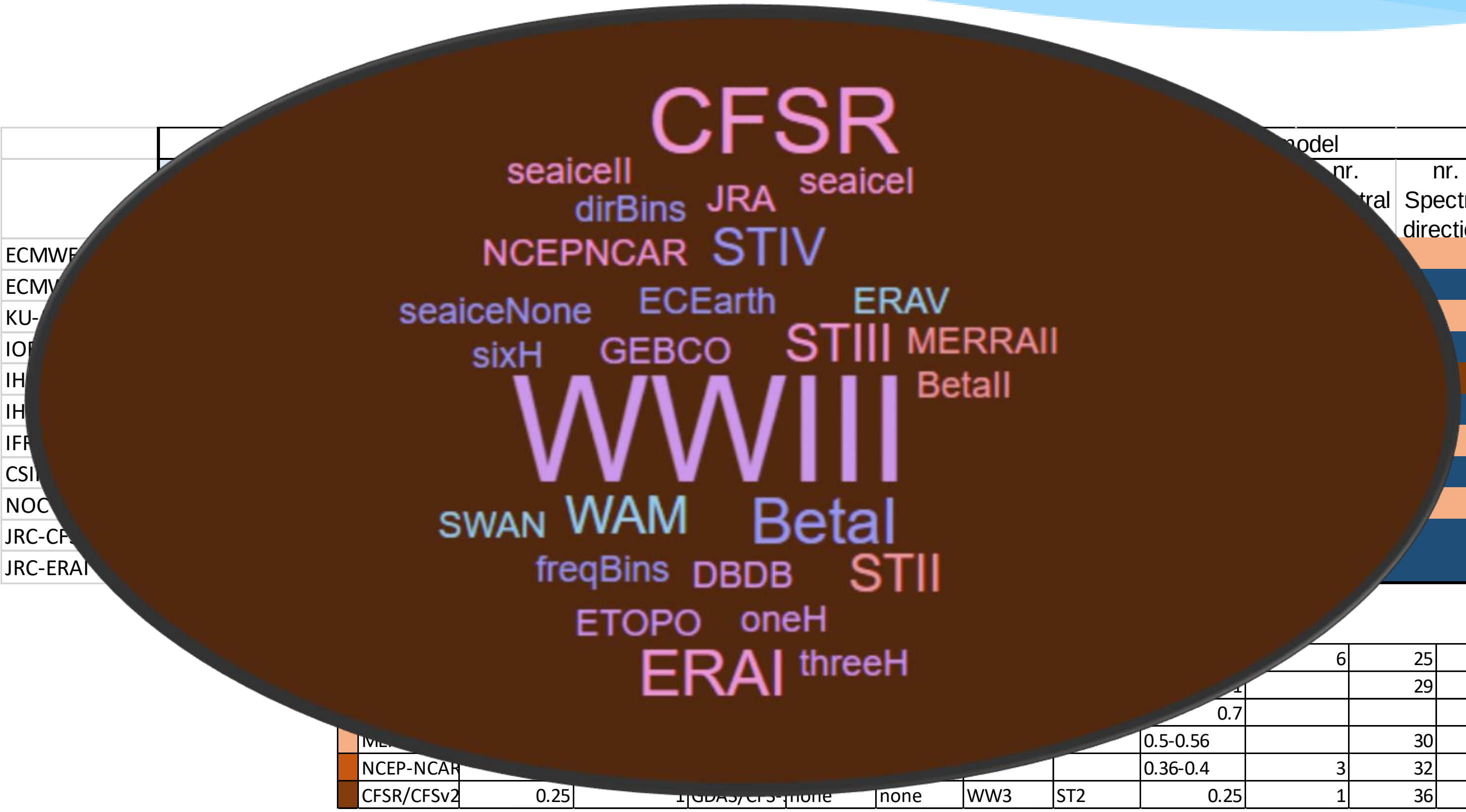
CONTRIBUTED DATASETS

	Label	years
Altimeter		
	GlobWave	1985-2008
Observations		
	Voluntary Observing Ship (VOS) data	1980-2017
Model hindcasts		
1	CFSRMOD	1980-2016
2	CSIRO_1deg	1979-2010
3	CSIRO_glob24m	1979-2017
4	ERAI	1979-2016
5	ERA5	1979-2017
6	GOW1	1980-2015
7	GOW2	1980-2015
8	IORAS-MERRA	1980-2017
9	JRA55_ST2	1979-2004
10	JRA55_ST4	1958-2012
11	JRC_CFSR	1980-2016
12	JRC_ERAI	1980-2015
13	NOC-ERAI	1979-2015

	...model				
		nr. ...tral	nr. Spectral direction	wave altimeter assimilat	bathy source
ECMWF					
ECMW					
KU-					
IOF					
IH					
IH					
IFF					
CSI					
NOC					
JRC-CF					
JRC-ERAI					



								6	25	24	coupled	ETOPO5
									29			ETOPO2
							0.7					
ME...							0.5-0.56		30	36	bias corre	DBDB2v3
NCEP-NCAR							0.36-0.4	3	32			
CFSR/CFSv2	0.25	1	GDAS/CFS-	none	none	WW3	ST2	0.25	1	36	72 none	GEBCO

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CONTRIBUTED DATASETS

Limit the analysis to

- Southern and Northern hemisphere summers and winters
  - DJF and JJA
- Median and 90th percentile statistics (p50 and p90)
- Variables: H_s, T_{m01}, D_m, H_sRo (number of rough days)

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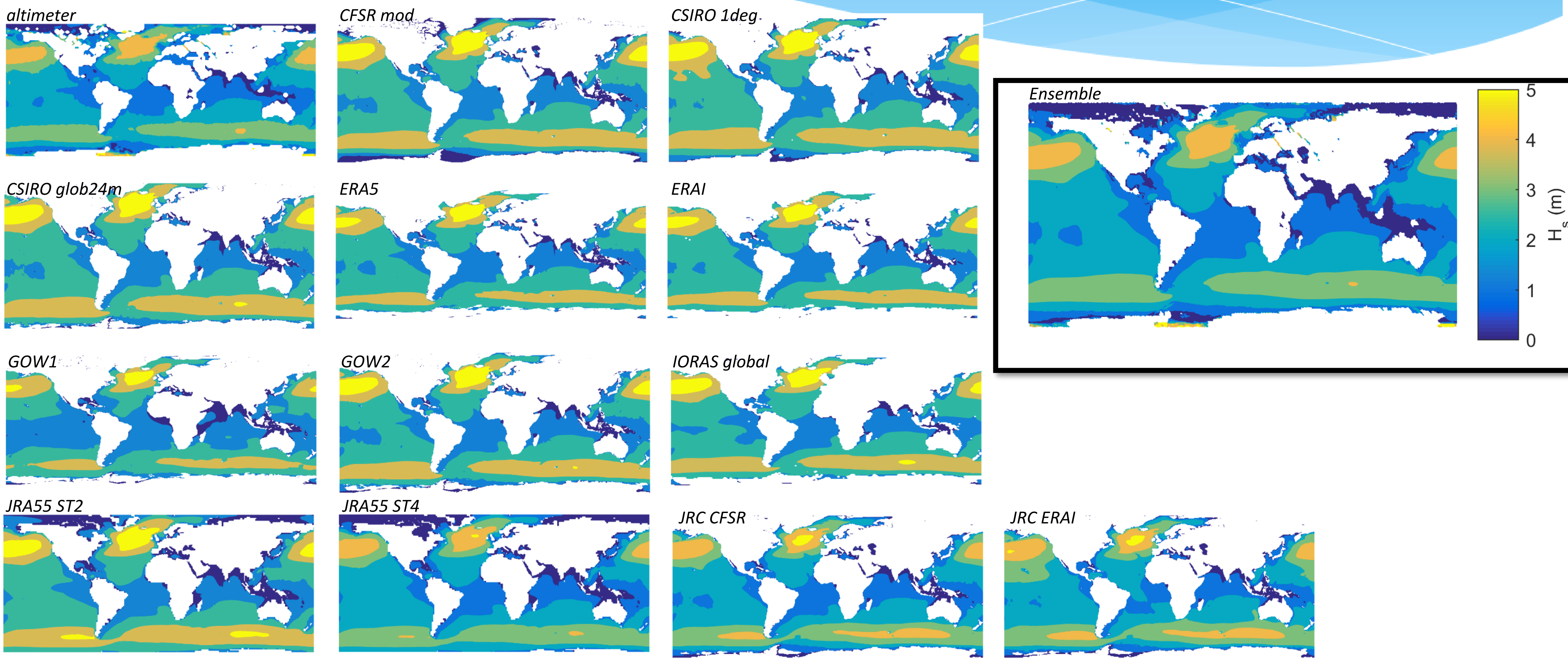
DJF p50 climatology (1985-2015)



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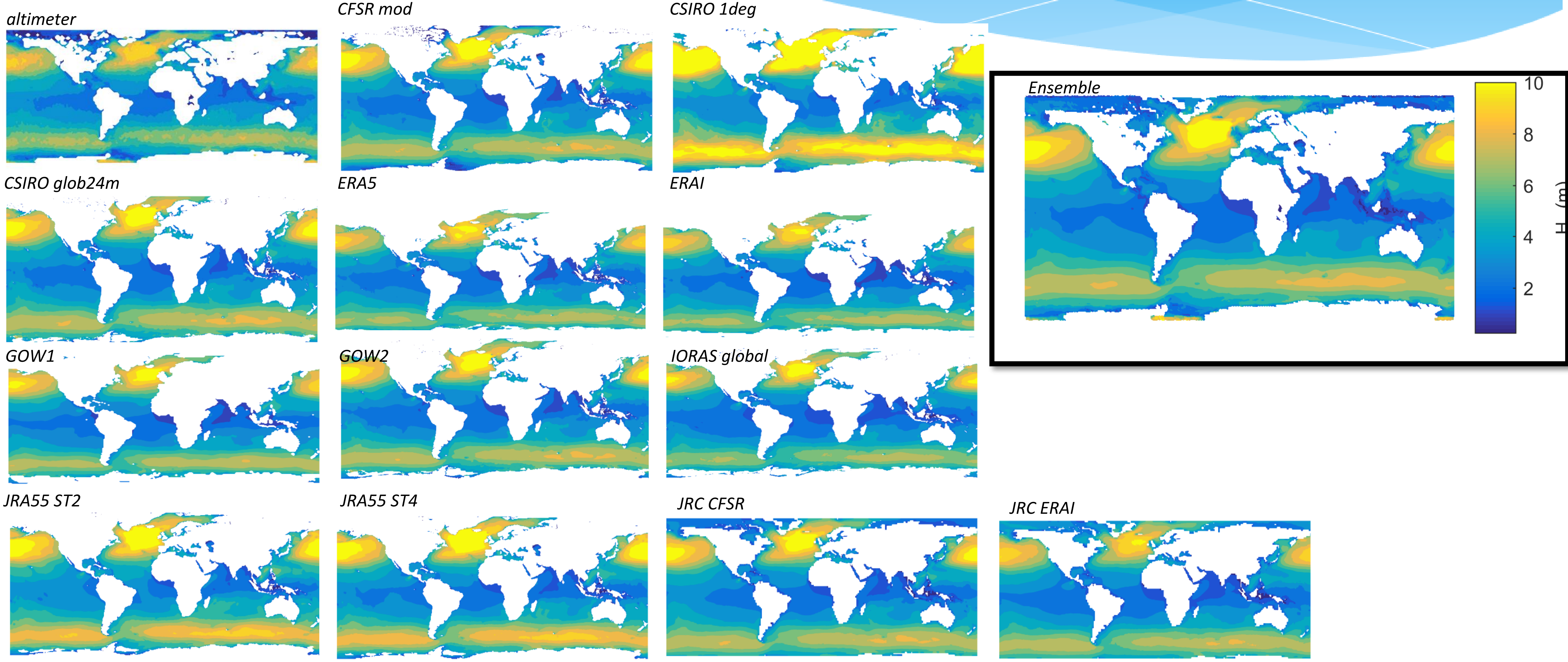
DJF p99 climatology (1985-2015)



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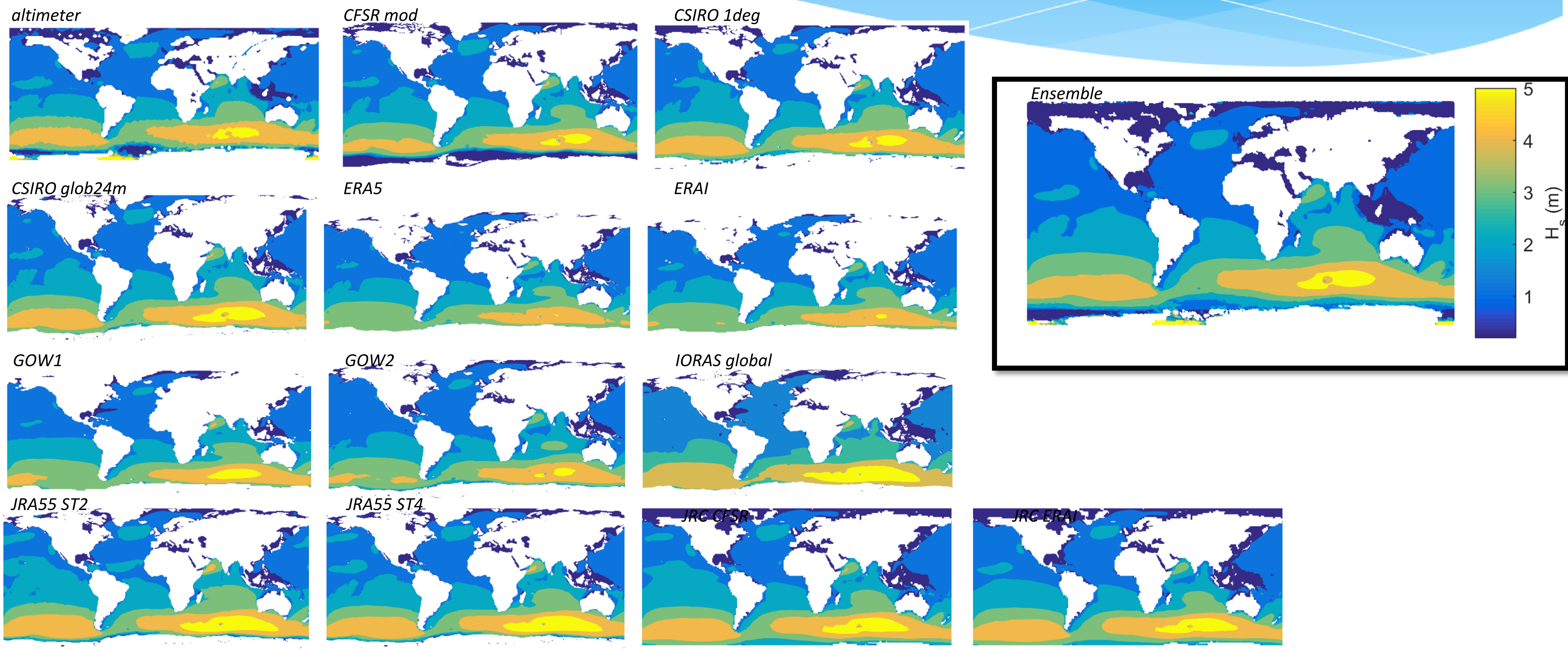
JJA p50 climatology (1985-2015)



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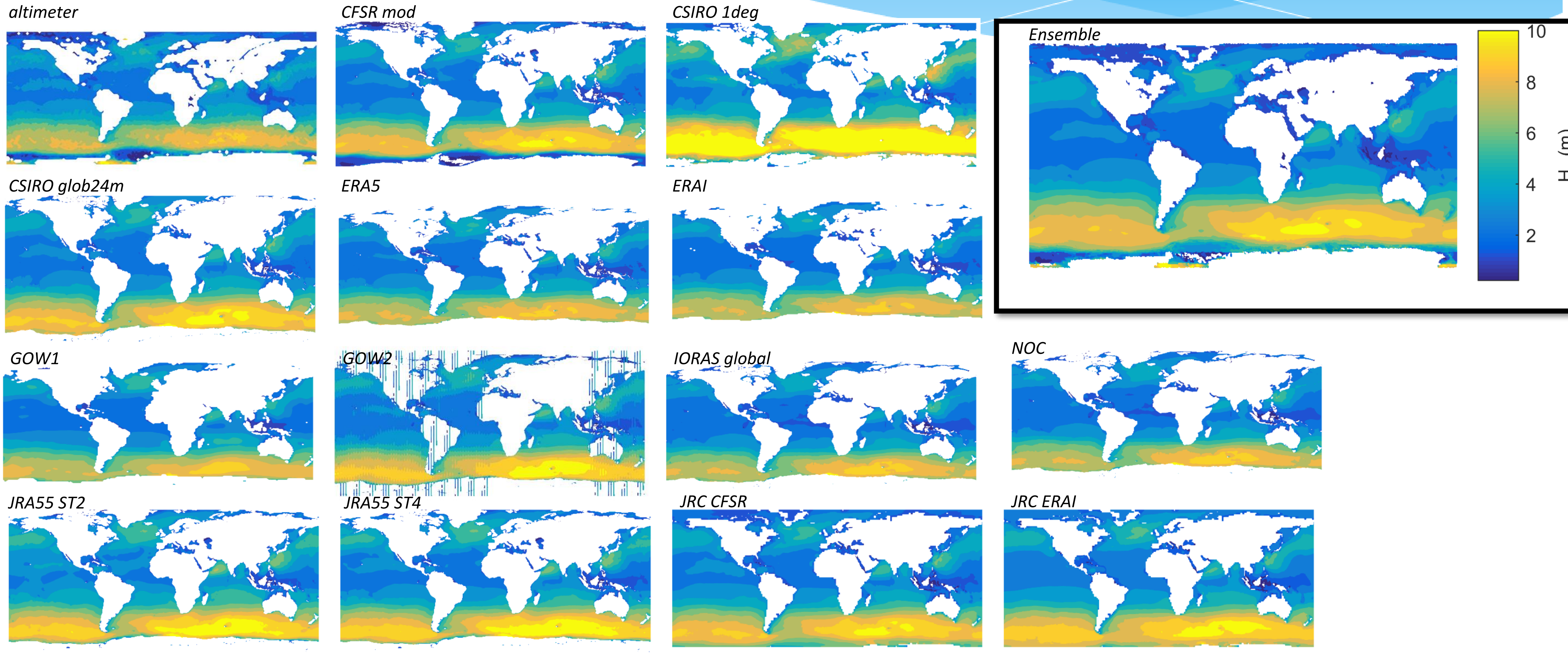
JJA p99 climatology (1985-2015)



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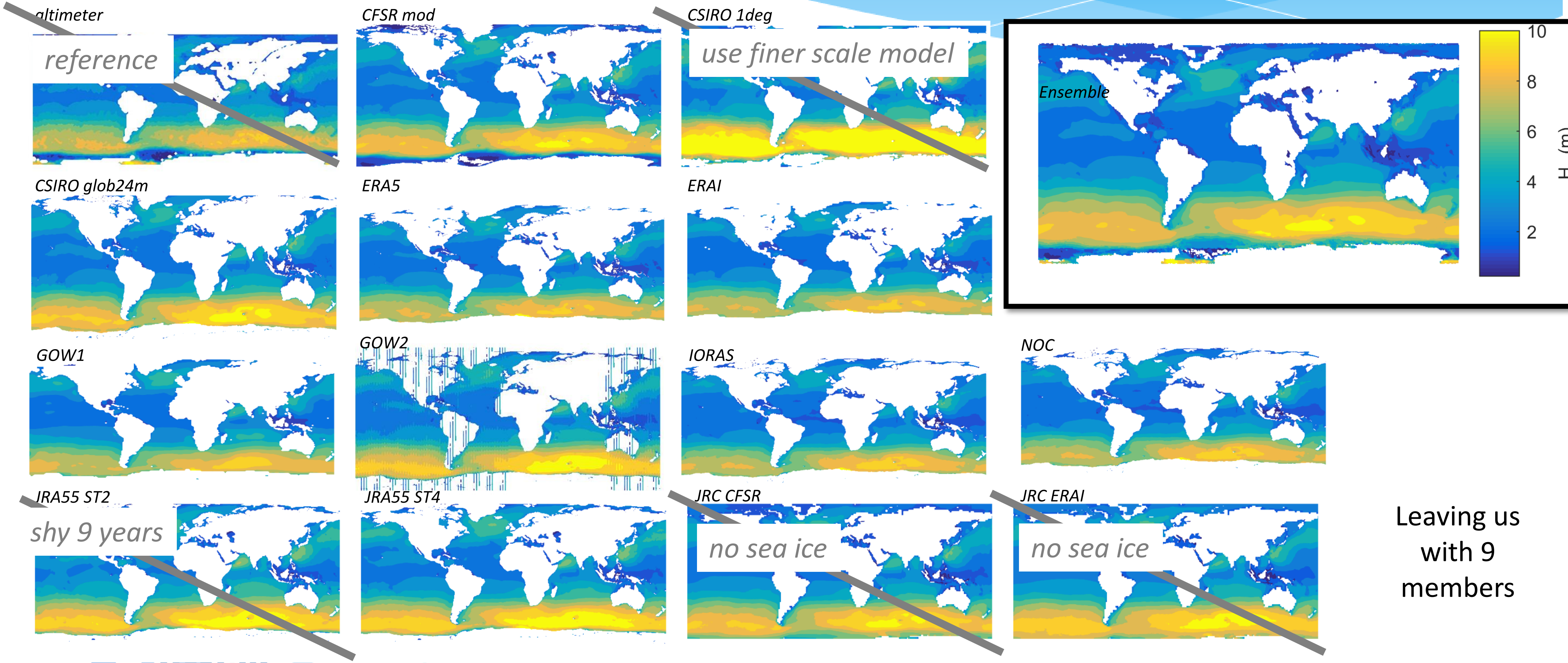
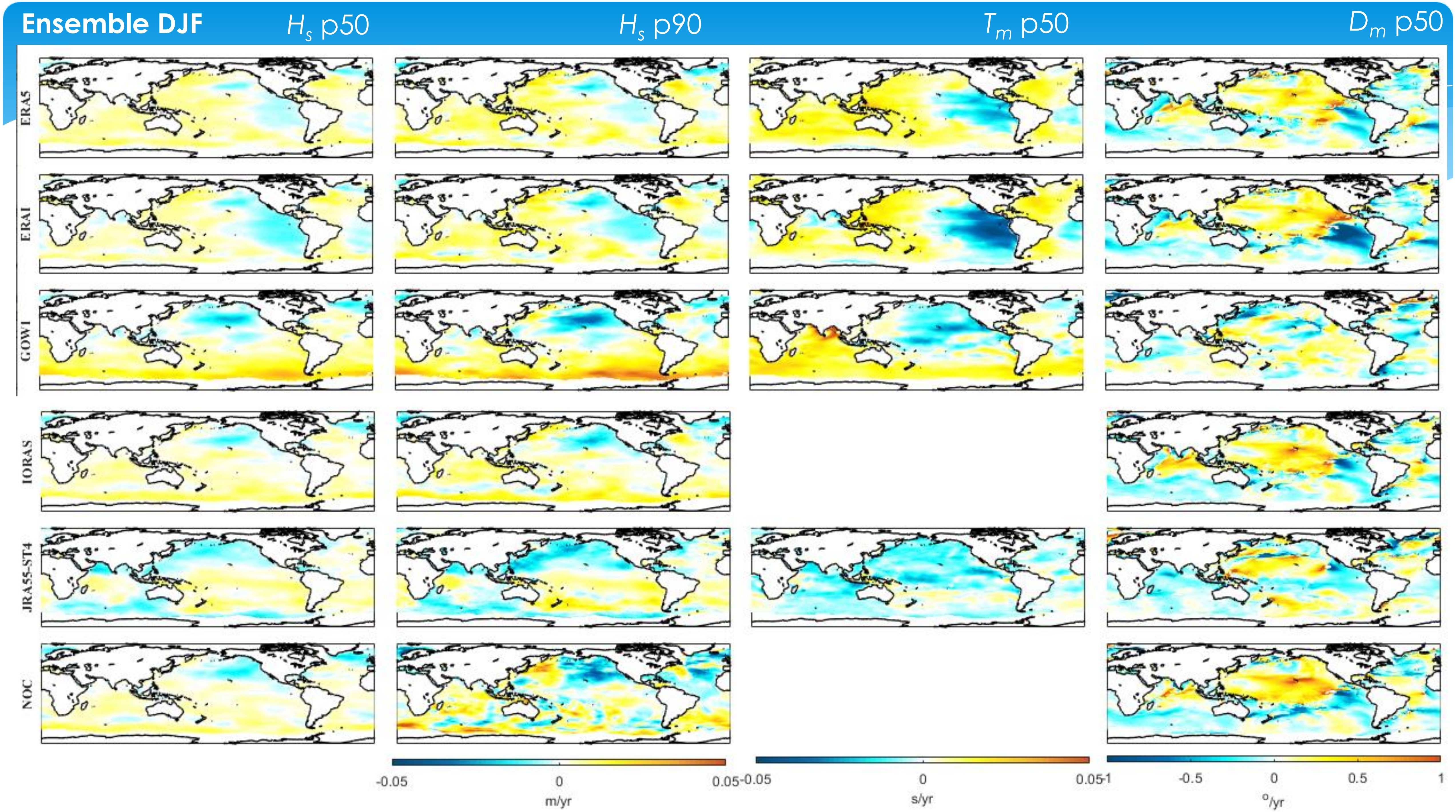
JJA p99 climatology (1985-2015)



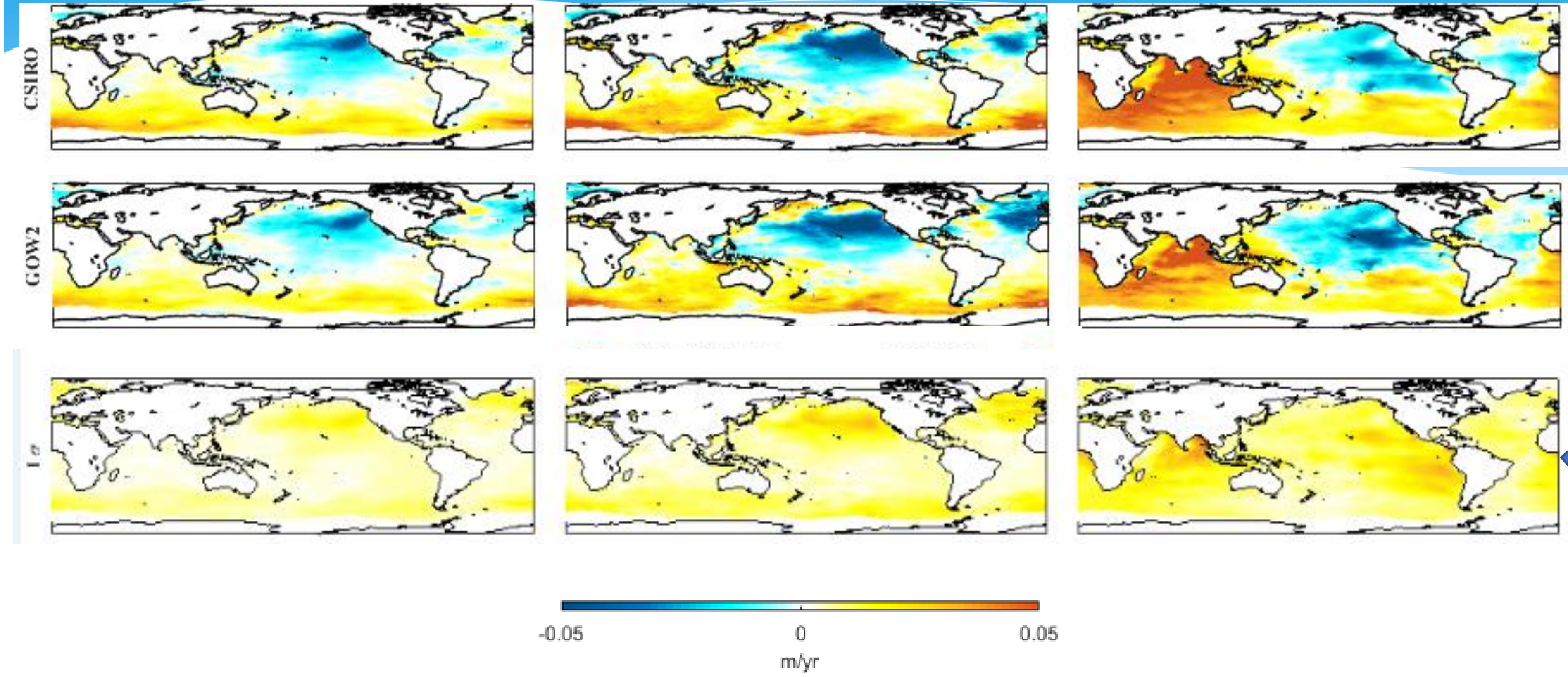
Leaving us with 9 members

Ensemble DJF



Ensemble DJF (CFSR driven)

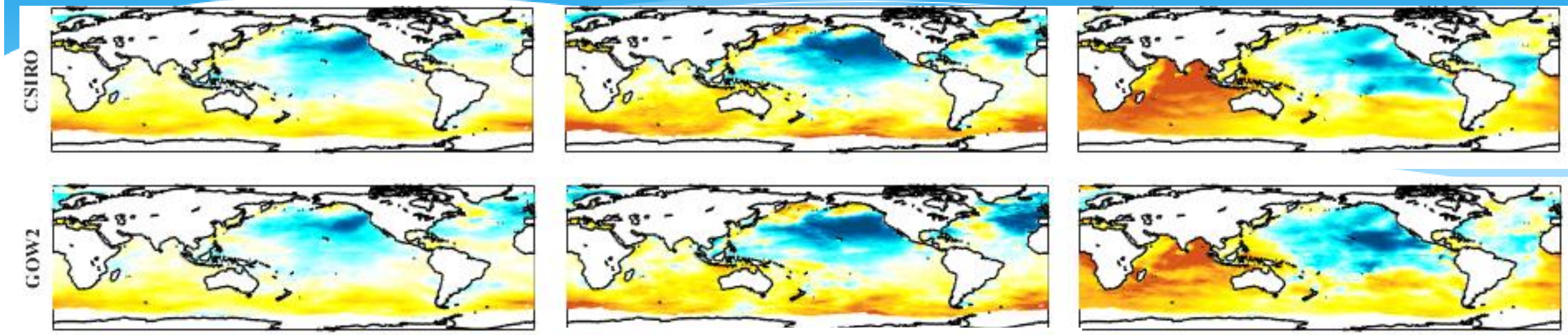
H_s p50 H_s p90 T_m p50



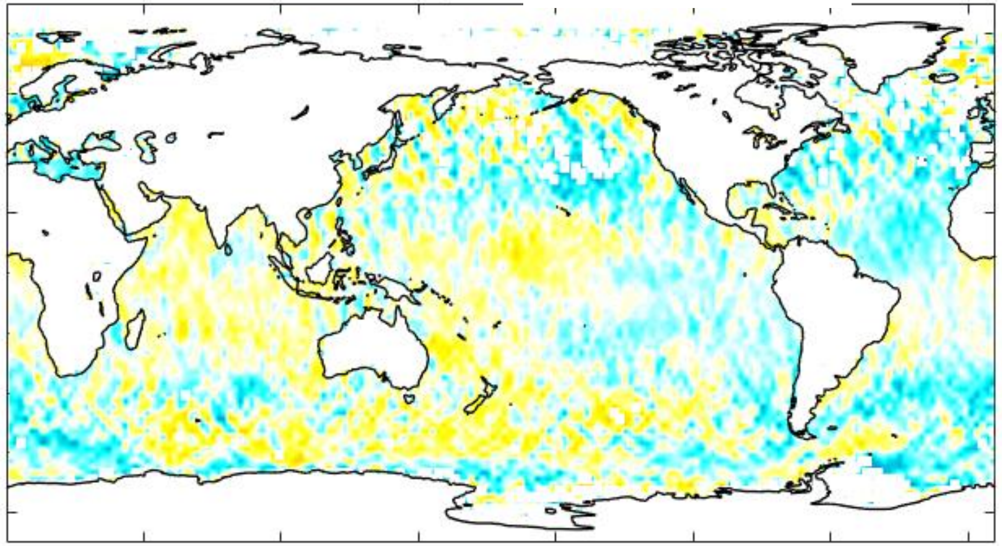
variance

Ensemble DJF (CFSR driven)

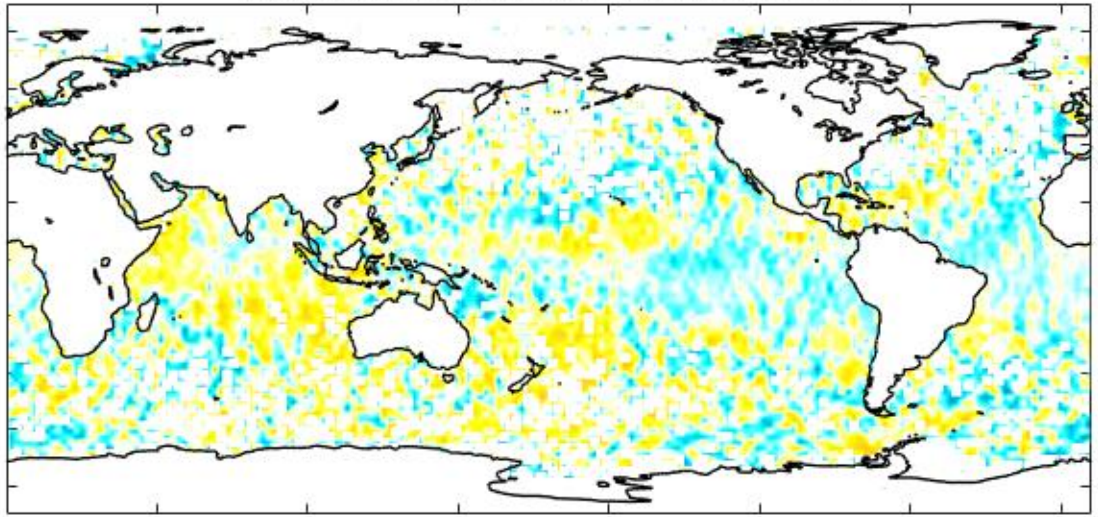
H_s p50 | H_s p90 | T_m p50

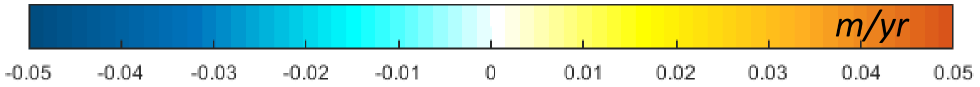


Altimeter trend of Hs p50 DJF (Young & Ribal, 2019)

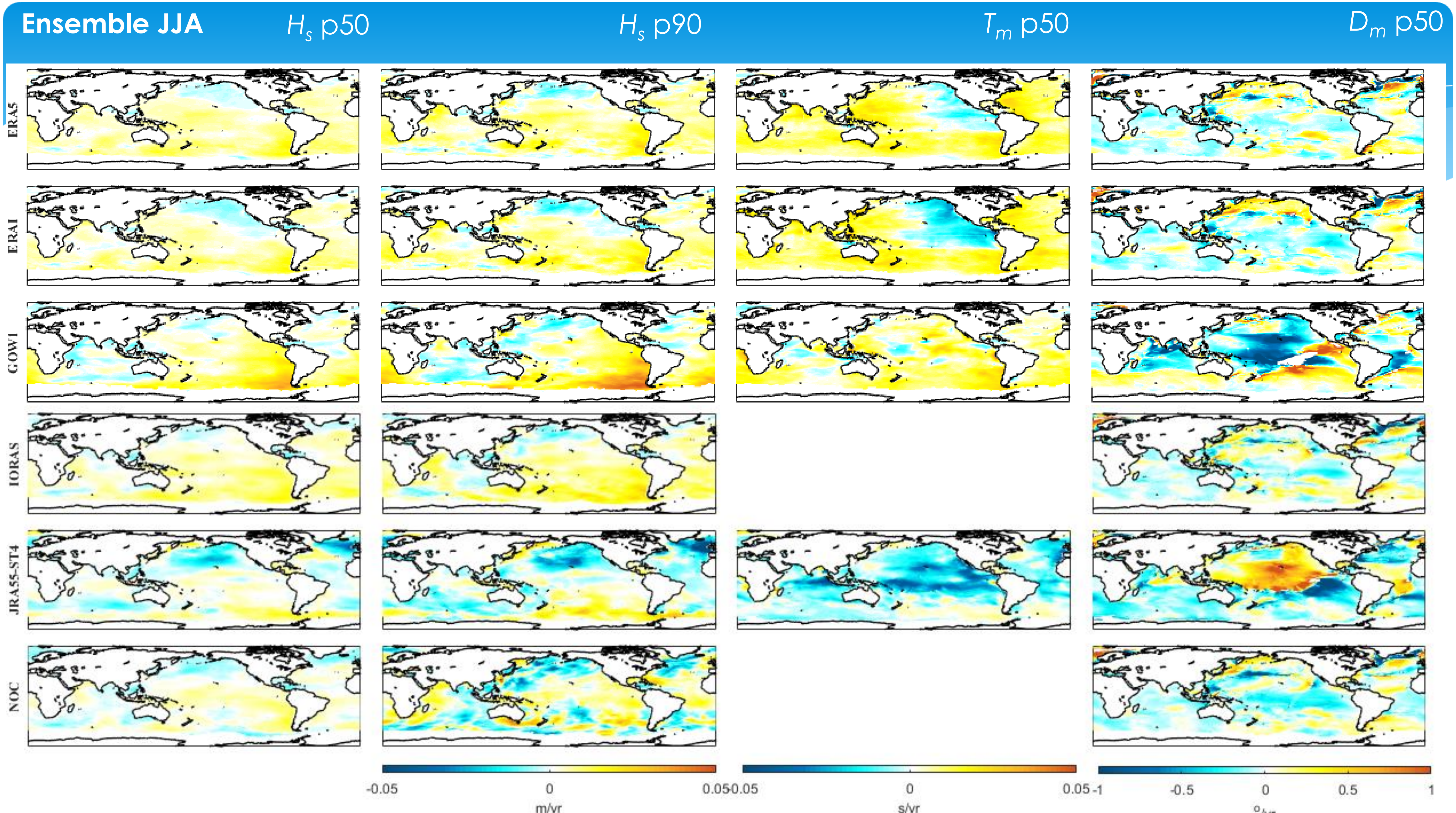


Altimeter Hs p90 DJF (Young & Ribal, 2019)



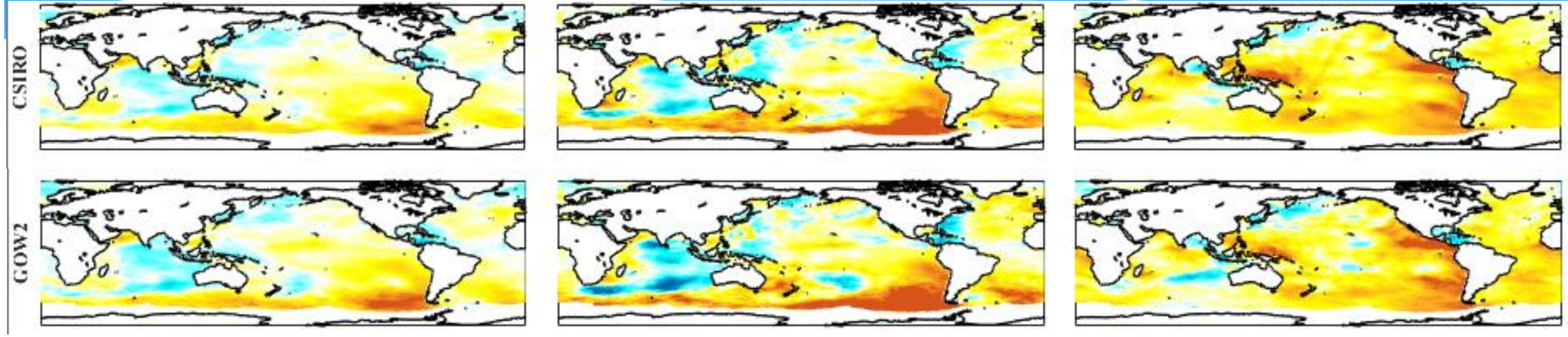


Ensemble JJA

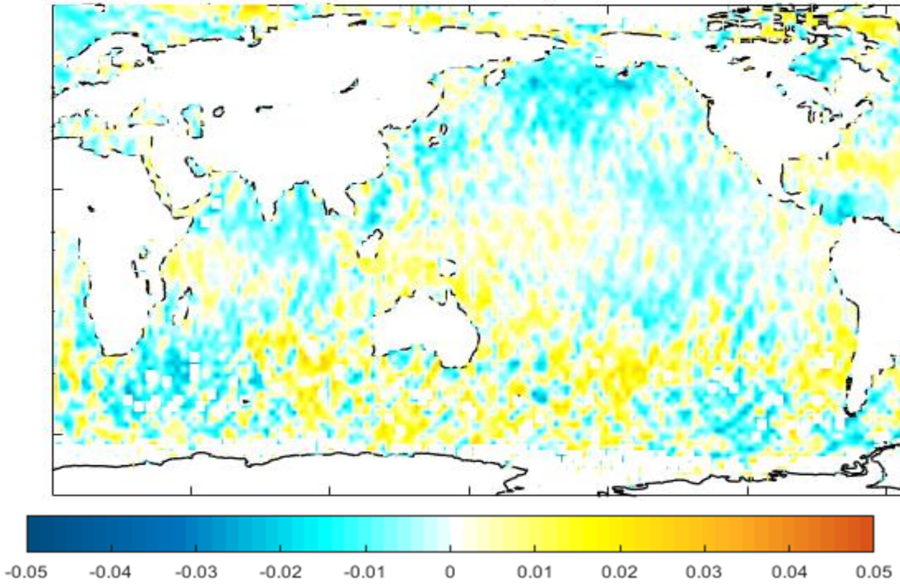


Ensemble JJA (CFSR driven)

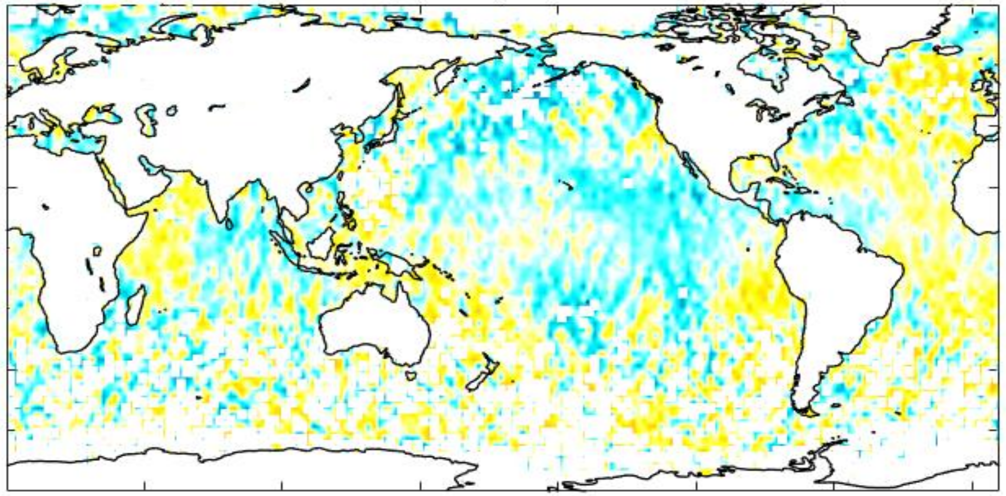
H_s p50 | H_s p90 | T_m p50



Altimeter Hs p50 JJA (Ribaldi & Young, 2019)



Altimeter Hs p90 JJA (Ribaldi & Young, 2019)



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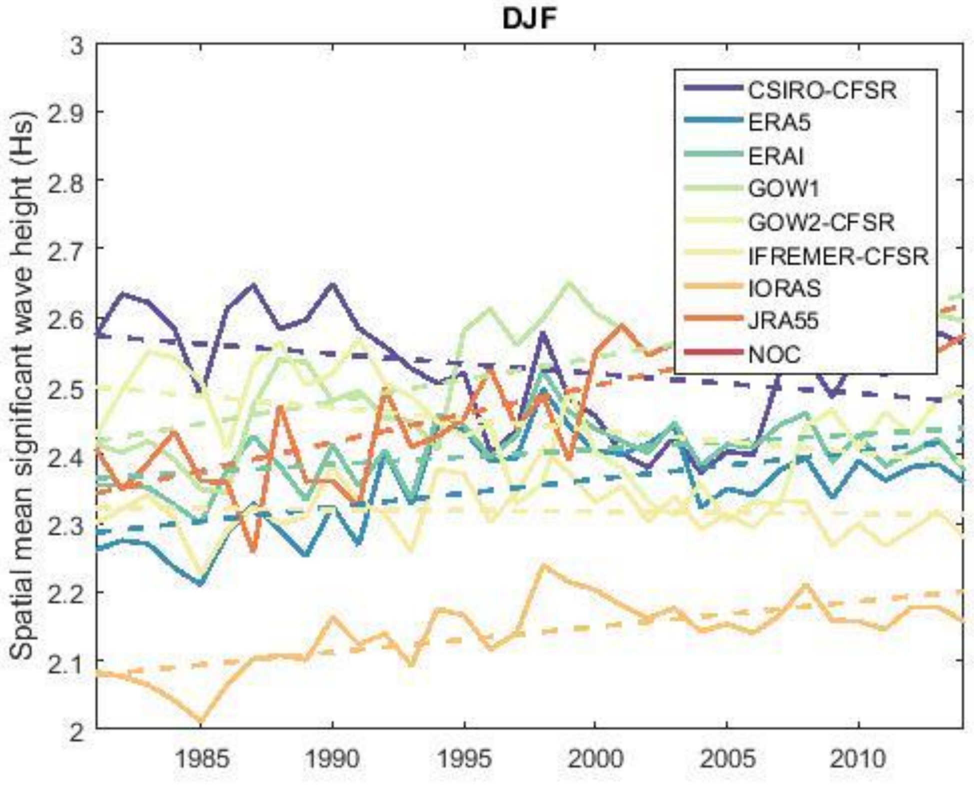
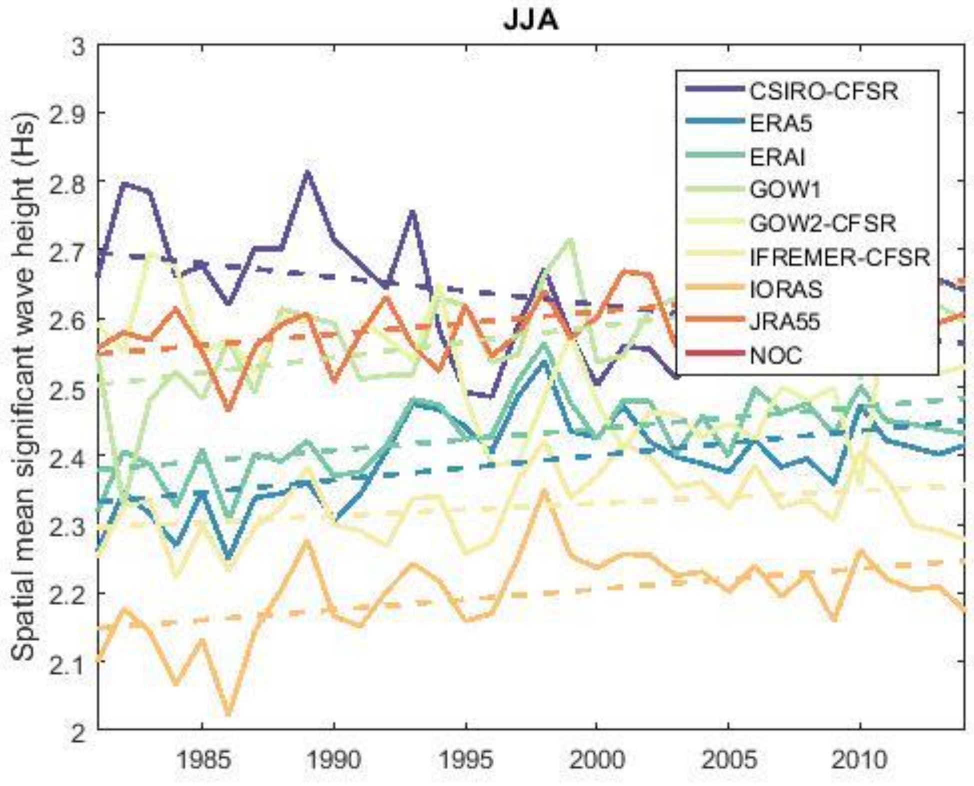
Trends





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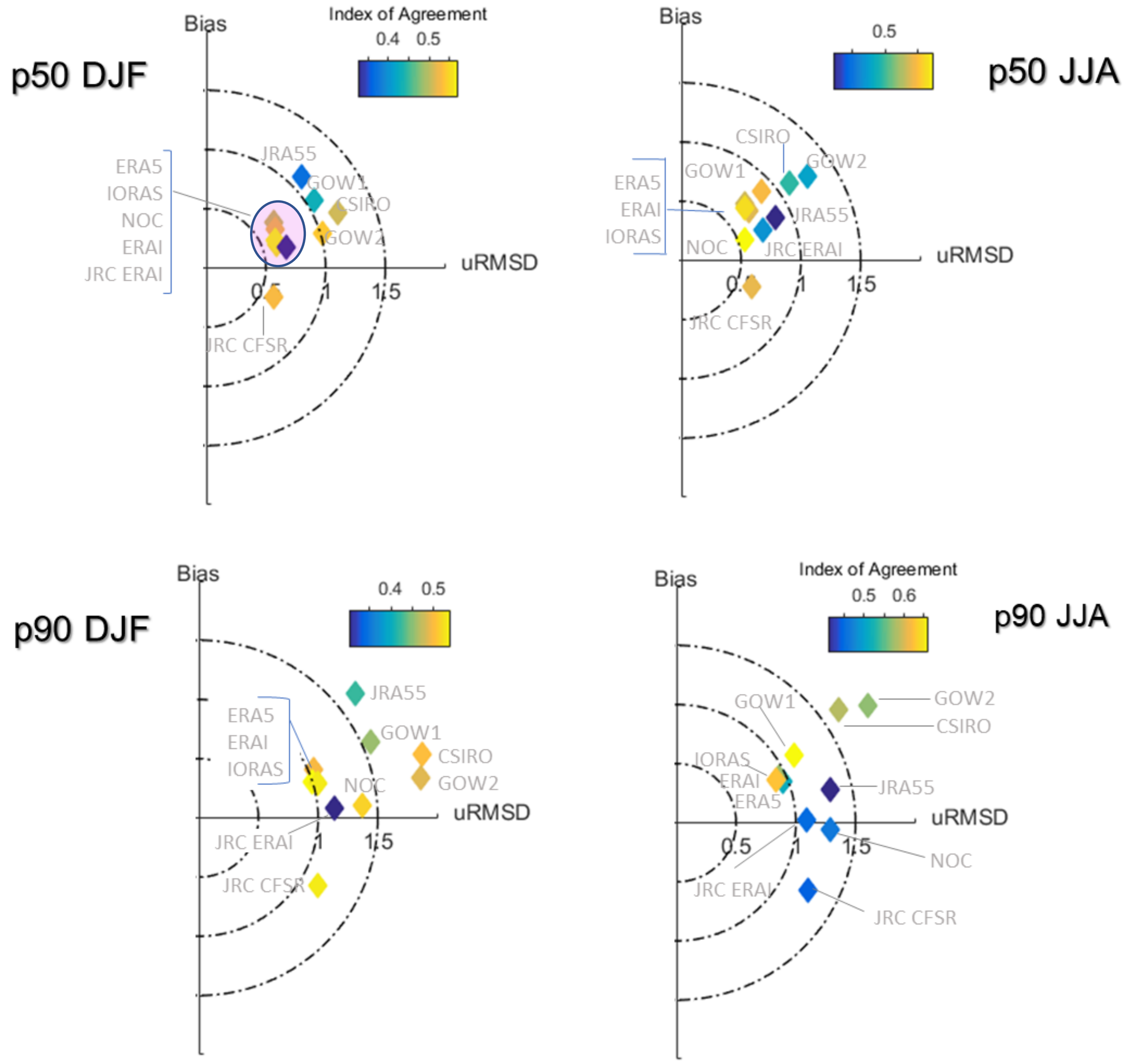
Trends compared to reference altimeter data[1]



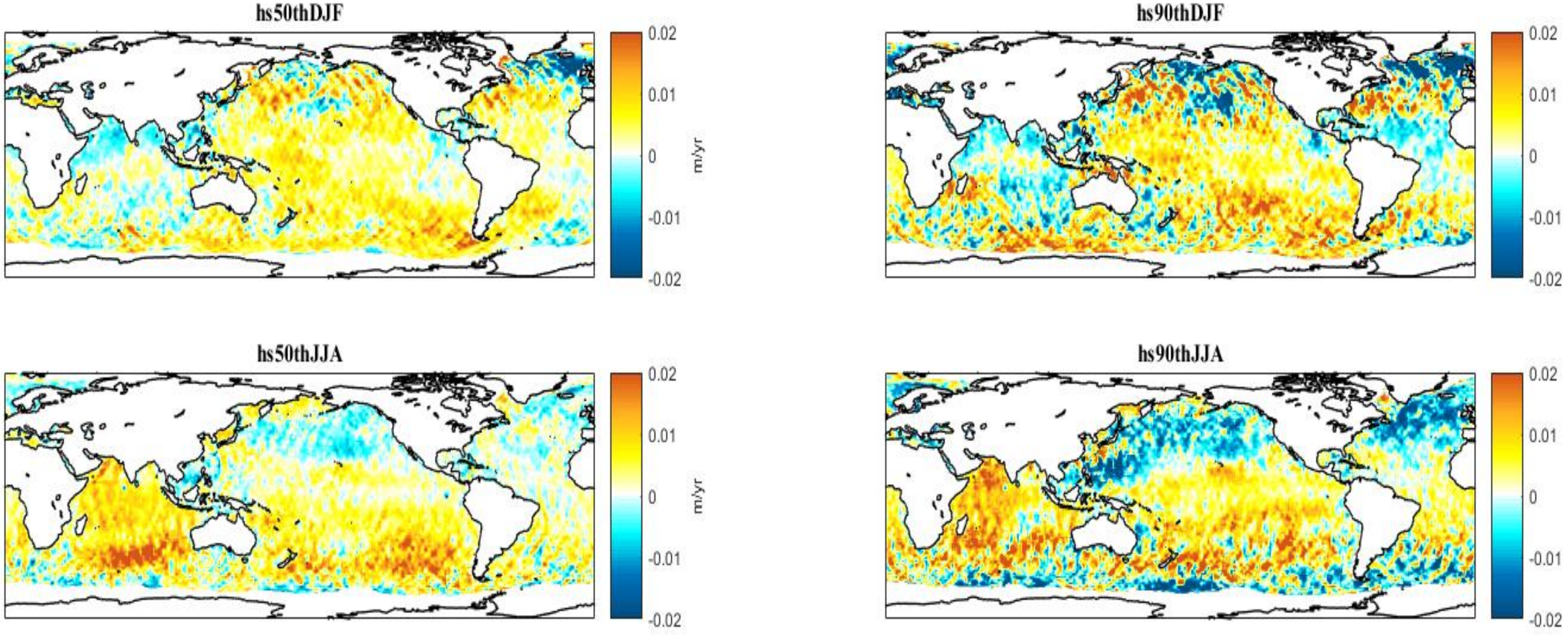
$$bias = \sum_{i=1}^{N} (s_{mod} - s_{sat})^i / N$$

$$uRMSD = \sum_{i=1}^{N} \left[\left(s_{mdl}^i - \bar{s}_{mdl} \right) - \left(s_{sat}^i - \bar{s}_{sat} \right) \right]^2 / N$$

$$IoA = \frac{\sum_{i=1}^{N} \left| s_{mdl}^i - s_{sat}^i \right|^2}{\sum_{i=1}^{N} \left(\left| s_{mdl}^i - \bar{s}_{mdl} \right| + \left| s_{sat}^i - \bar{s}_{sat} \right| \right)^2}$$

[1] Young and Ribal, 2019

Ensemble mean trend minus altimeter



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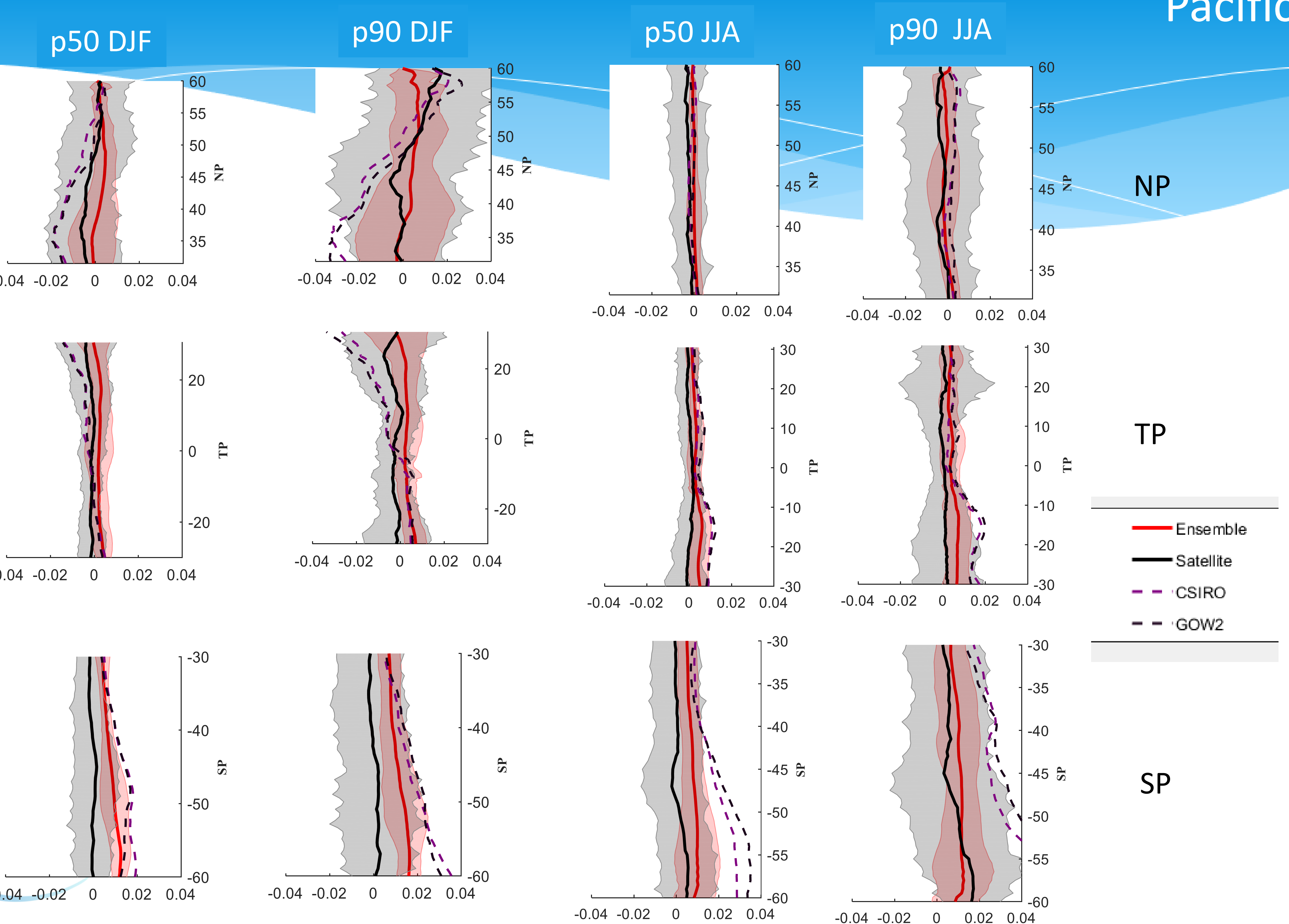
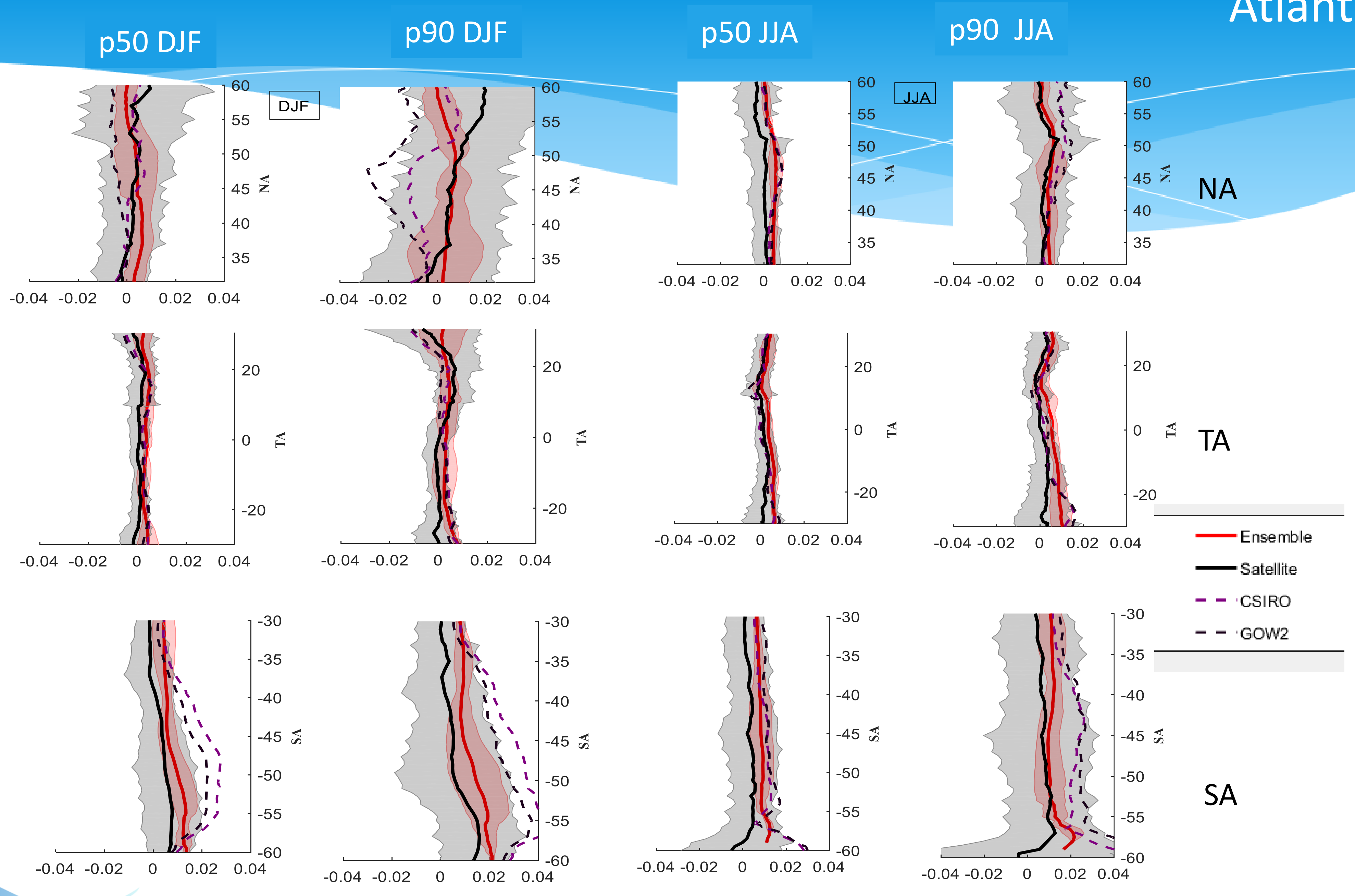
Pacific

- in all cases except NH summer (JJA), the ensemble shows higher trends compared to altimeter
- Greater zonal spatial homogeneity amongst the model ensemble compared to the altimeter data



Atlantic



p50 DJF
p90 DJF
p50 JJA
p90 JJA
DJF
JJA
NA
TA
SA
Ensemble
Satellite
CSIRO
GOW2
-0.04 -0.02 0 0.02 0.04

wave height trends: ensemble mean and robustness

Method A: (ref: 11,12,13)
Large change with high model agreement:
multi-model mean trend > exceeds two standard deviations of internal variability AND at least 90% of the models agree on the sign of change

Small signal or low agreement of models:
multi-model mean trend > exceeds standard deviation of internal variability

Method B1: (variant of method A)
80% of the models show a trend < two standard deviations of variability (calculated from interannual variations within each model; ie use all model data)
(no distinction between large and small model agreement)

Method B2: (ref: Hemer et al 2013; Wang et al, 2014; and others)
Multi-model ensemble mean > inter-model standard deviation

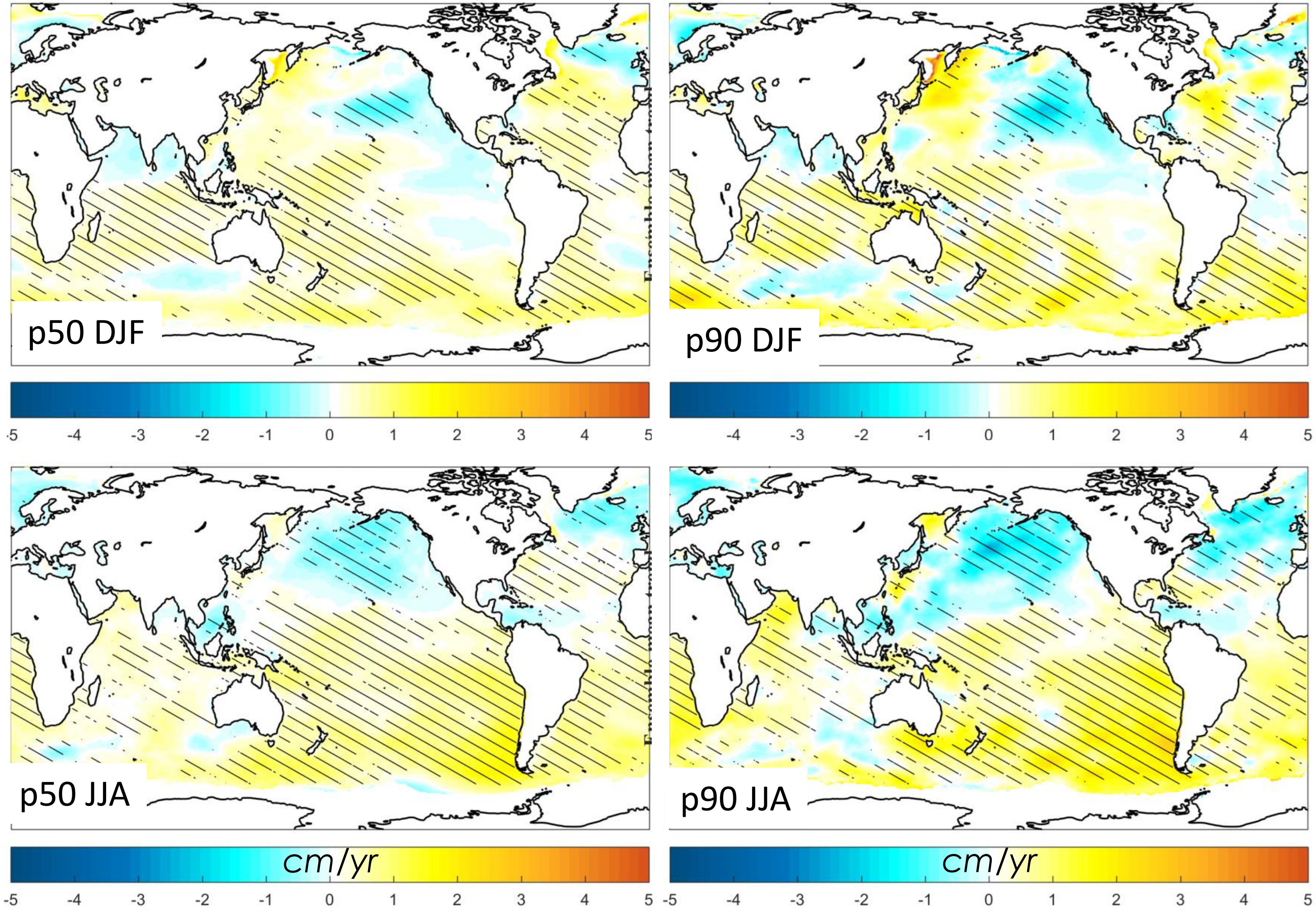
Method C: (ref: Knutti and Sedláček, 2013)
Large change with high model agreement:
Dimensionless robustness measure considers natural variability and agreement on magnitude and sign of change. Uses a signal to noise ratio and ranked probability skill score.

Small signal
Regions where at least 80% of the models individually show no significant change
are hatched and interpreted as 'changes unlikely'

Method D: (ref: Tebaldi et al., 2011; Neelin et al., 2006)
Robust large change:
more than 50% of the models show significant trends and at least 80% of those agree on the sign of change

Unreliable large change:
more than 50% of the models show significant trends but less than 80% of those agree on the sign of change

Method E: (ref: Mentaschi et al 2017; Alferi et al 2015; Vousdoukas et al 2016)
Robust change with high model agreement:
Dimensionless coefficient of variation <1, where the CV is the intermodel standard deviation divided by the ensemble average.



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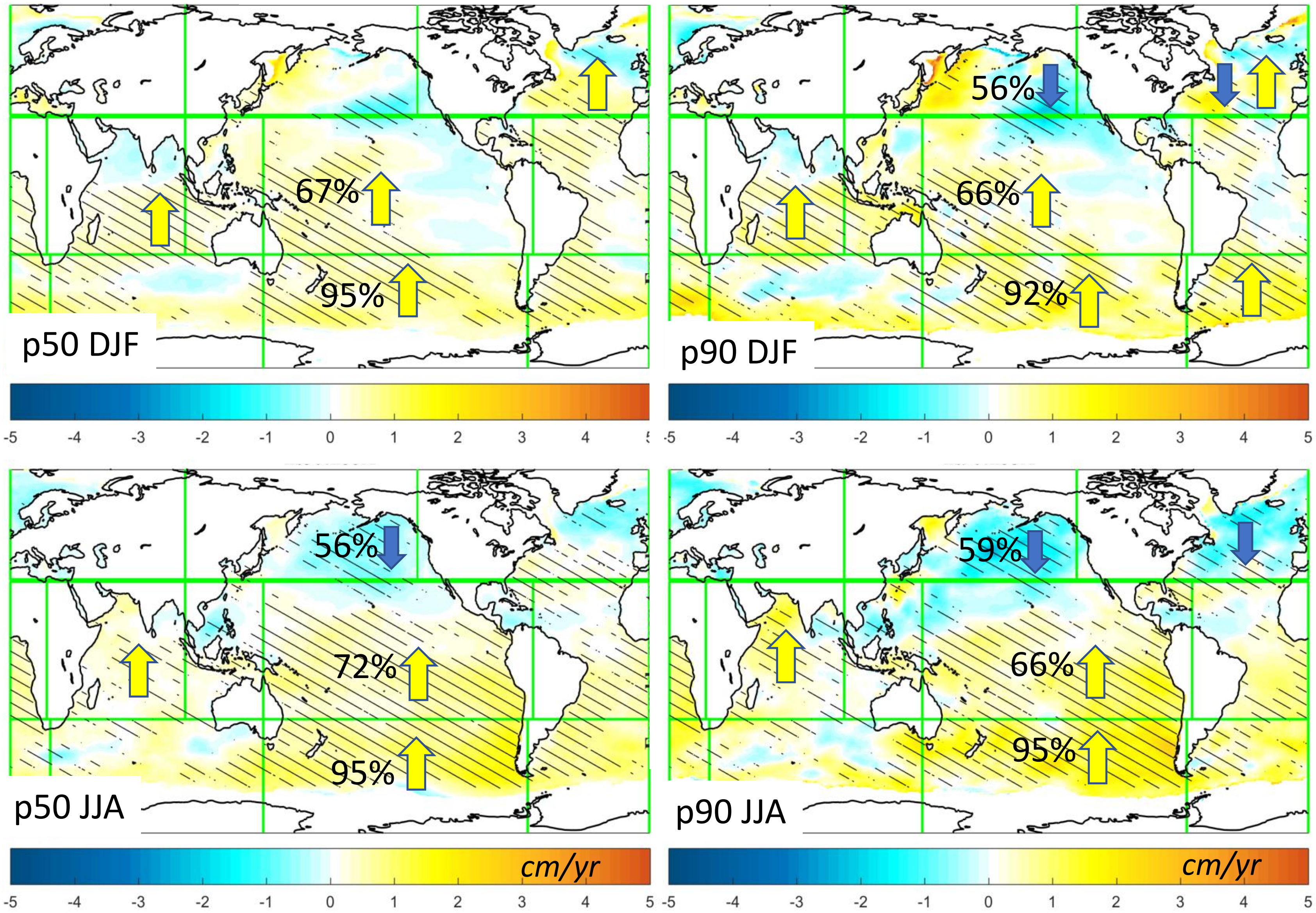
wave height trends: ensemble mean and robustness

Percent area of robust change signal

.. and (avg. rate of change [cm/yr or s/yr])

Region	DJF p50 Hs		DJF p90 Hs	
NP	45 (0.40)		38 (1.02)	
	22 (-0.44)		29 (-0.70)	
NA	39 (0.56)		37 (0.67)	
	16 (-0.39)		18 (-0.36)	
SP	95 (0.54)		92 (0.70)	
	<0.1 (-0.08)		3 (-0.15)	
SA	83 (0.63)		89 (0.98)	
	6 (-0.13)		1 (-0.08)	
TA	52 (0.26)		48 (0.28)	
	11 (-0.10)		15 (-0.12)	
TP	67 (0.30		66 (0.39)	
	19 (-0.15)		21 (-0.34)	
TI	51 (0.30)		52 (0.49)	
	12 (-0.15)		11 (-0.22)	
SI	82 (0.38)		69 (0.62)	
	15 (-0.17)		27 (-0.26)	

Region	JJA p50 Hs		JJA p90 Hs	
NP	13 (0.17)		11 (0.52)	
	56 (-0.44)		59 (-0.90)	
NA	33 (0.18)		13 (0.25)	
	24 (-0.36)		44 (-0.60)	
SP	95 (0.85)		95 (1.24)	
	1 (-0.20)		1 (-0.11)	
SA	86 (0.66)		84 (0.85)	
	1 (-0.18)		3 (-0.24)	
TA	56 (0.44)		54 (0.67)	
	6 (-0.14)		8 (-0.17)	
TP	72 (0.39)		66 (0.55)	
	15 (-0.19)		21 (-0.33)	
TI	54 (0.24)		48 (0.42)	
	9 (-0.20)		15 (-0.28)	
SI	81 (0.43)		73 (0.60)	
	13 (-0.19)		21 (-0.21)	



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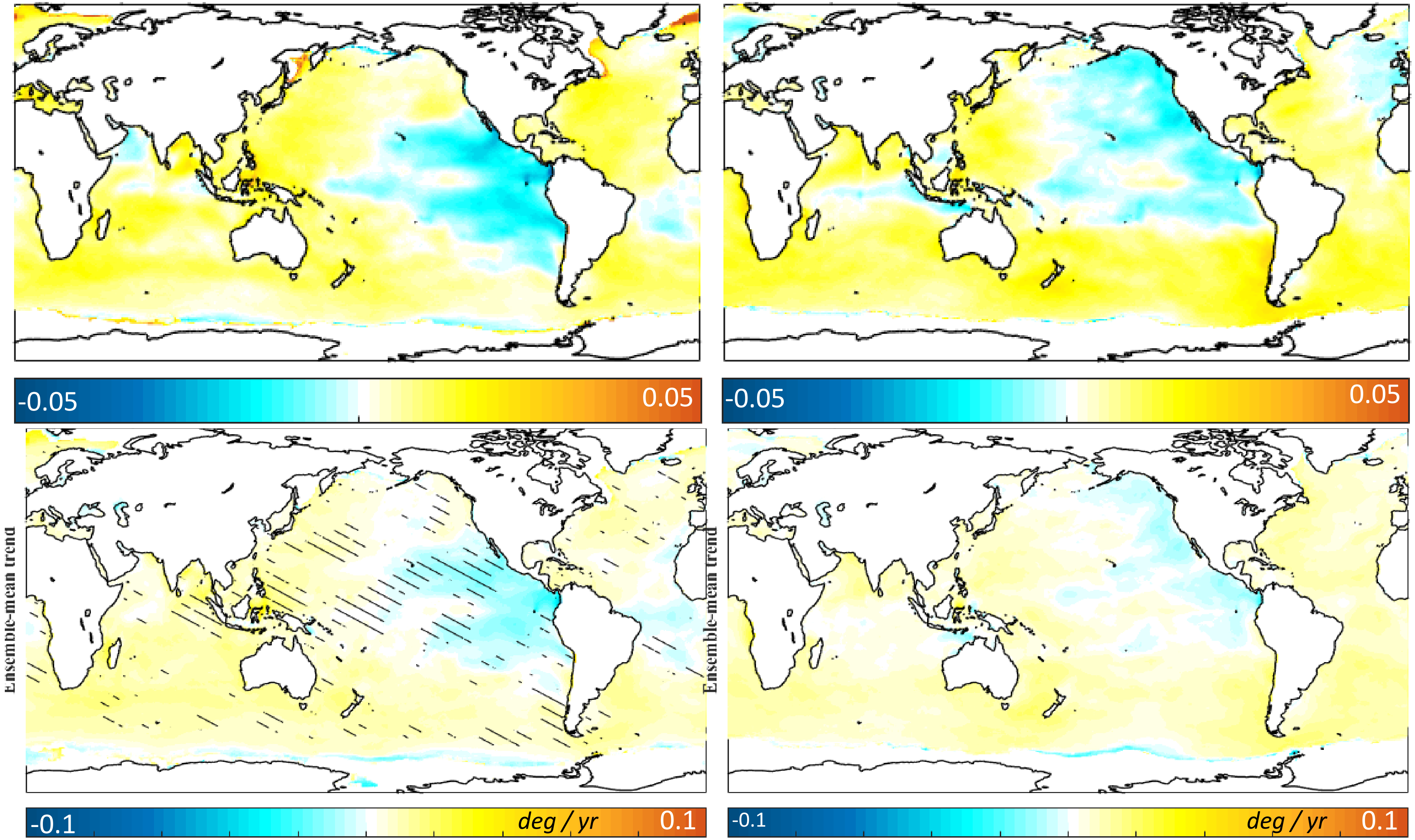
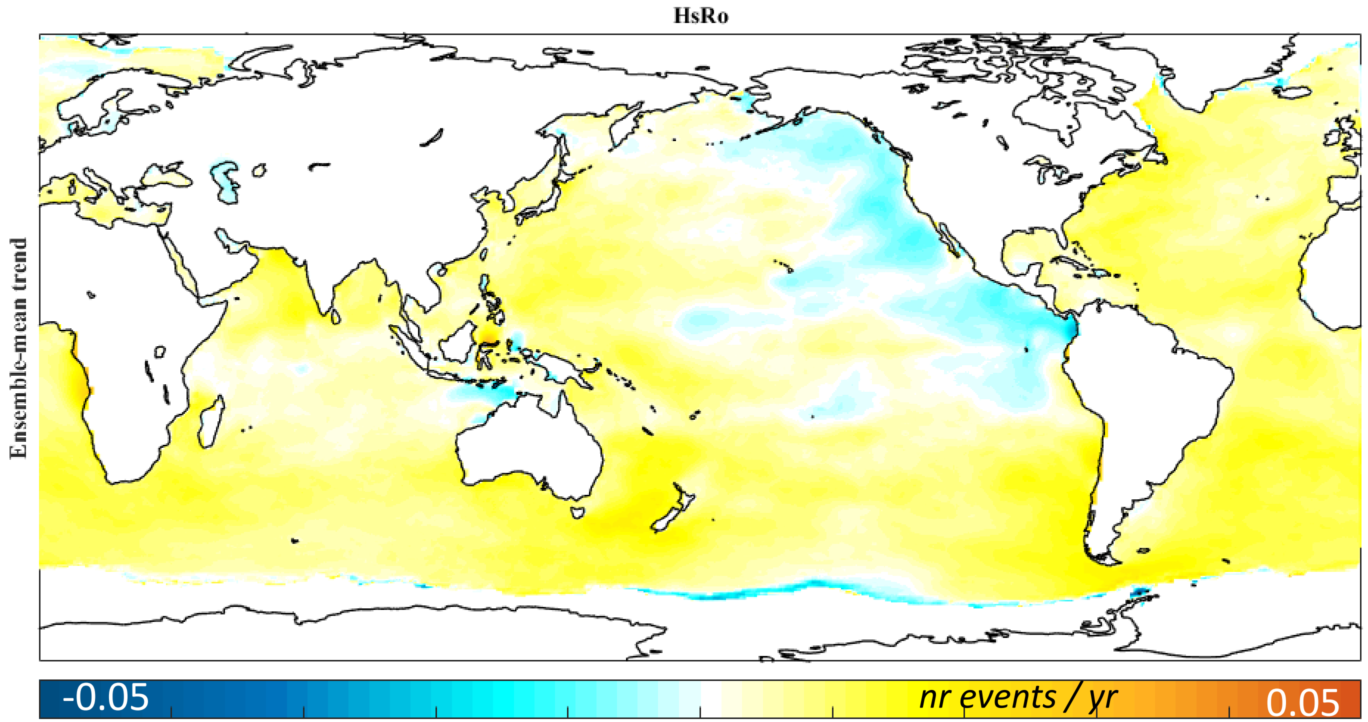
p50 DJF

p50 JJA

Tm ensemble mean trend

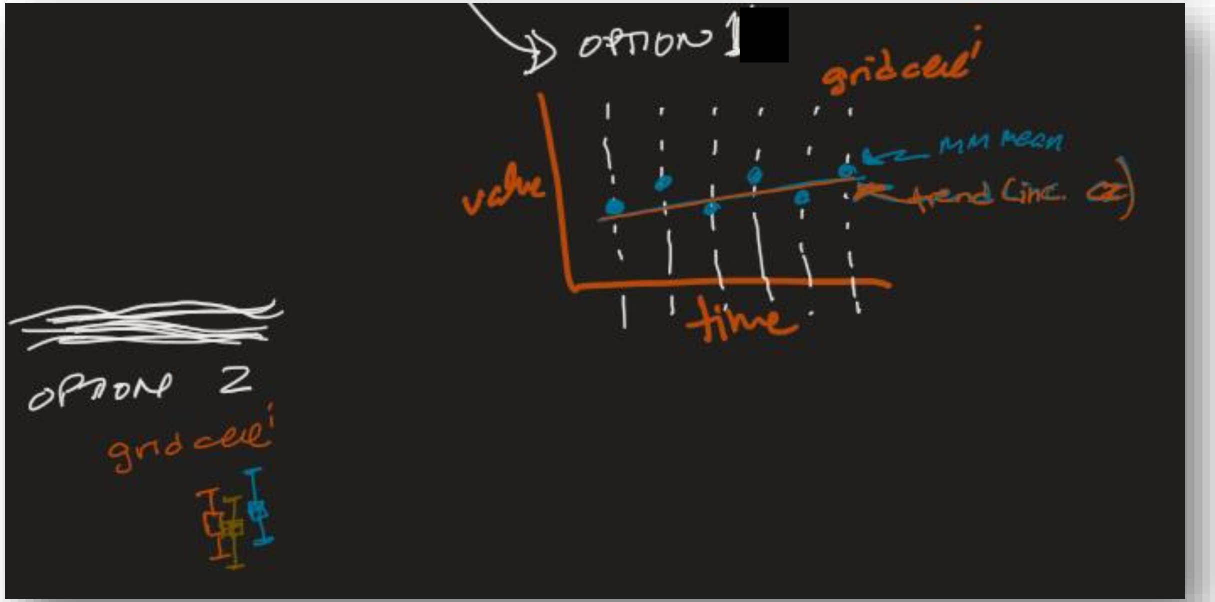
Dm ensemble mean trend





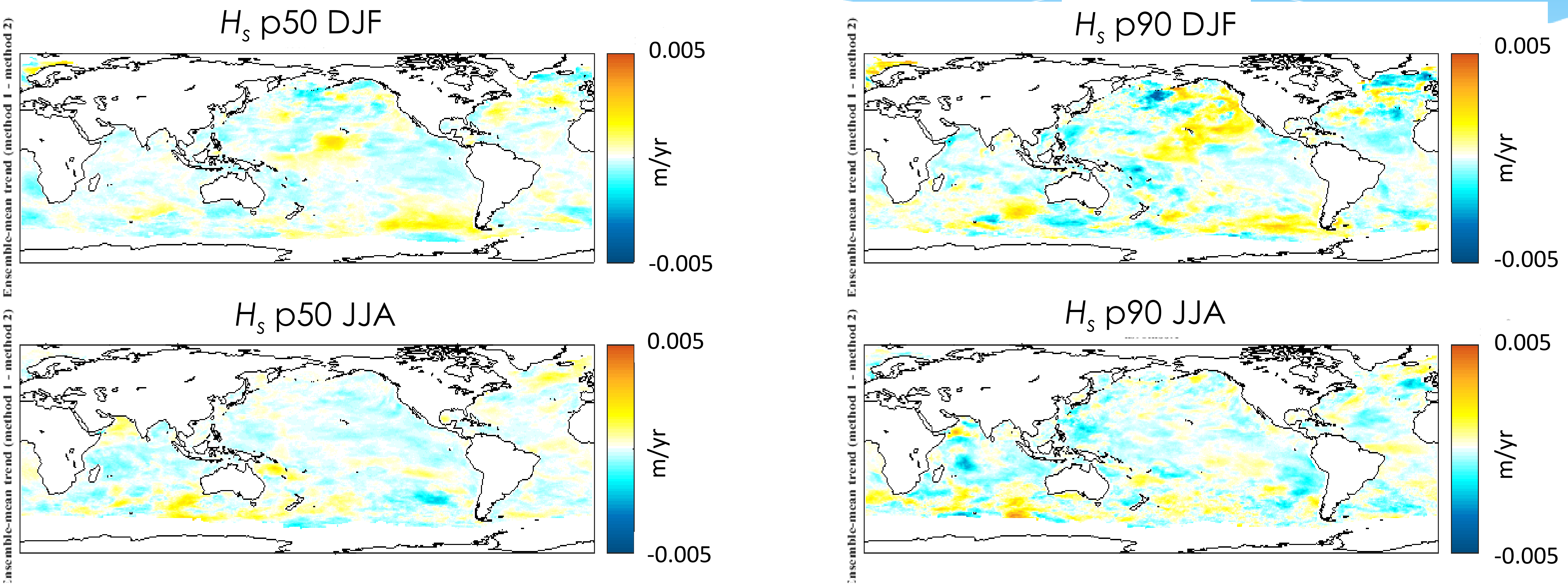
ensemble mean trend in annual frequency of rough days

Method of computing the ensemble



How to compute the ensemble mean… does it matter?

Method of computing the ensemble



method 1 – method 2

Summary

- Difficult to robustly quantify inter-model variability introduced by different model settings from the contributed datasets
  - But the winds clearly have the strongest influence [ITWS ("it's the winds stupid!", Vince Cardone)]
  - CFSR winds have a step change in ~1994, which strongly influences trends
- Method of computing the ensemble can make a difference of ~10%
- Robust signals of change are identifiable across dynamically downscaled models (excepting models influenced by step-changes in atmospheric forcing)
  - Robust signals of upward trending Hs are noted across much of the globe
  - Strong agreement among models that Hs is increasing in both summer and winter and for medians and extremes across >90% of the Southern Ocean at a rate of ~1cm/yr
  - Strong confidence that >60% of the Indian and Central Pacific Oceans are experiencing increasing Hs
  - There is high confidence that the North Sea and Eastern North Pacific have experienced decreasing Hs and direction changes
- It is noted however that rates of change are biased positive compared to altimeter Hs trends

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Thank you

Special thanks to all the COWCliP collaborators