Multidecadal Oscillation masks ocean wave climate trends for 75 years in JRA-3Q based global wave hindcast

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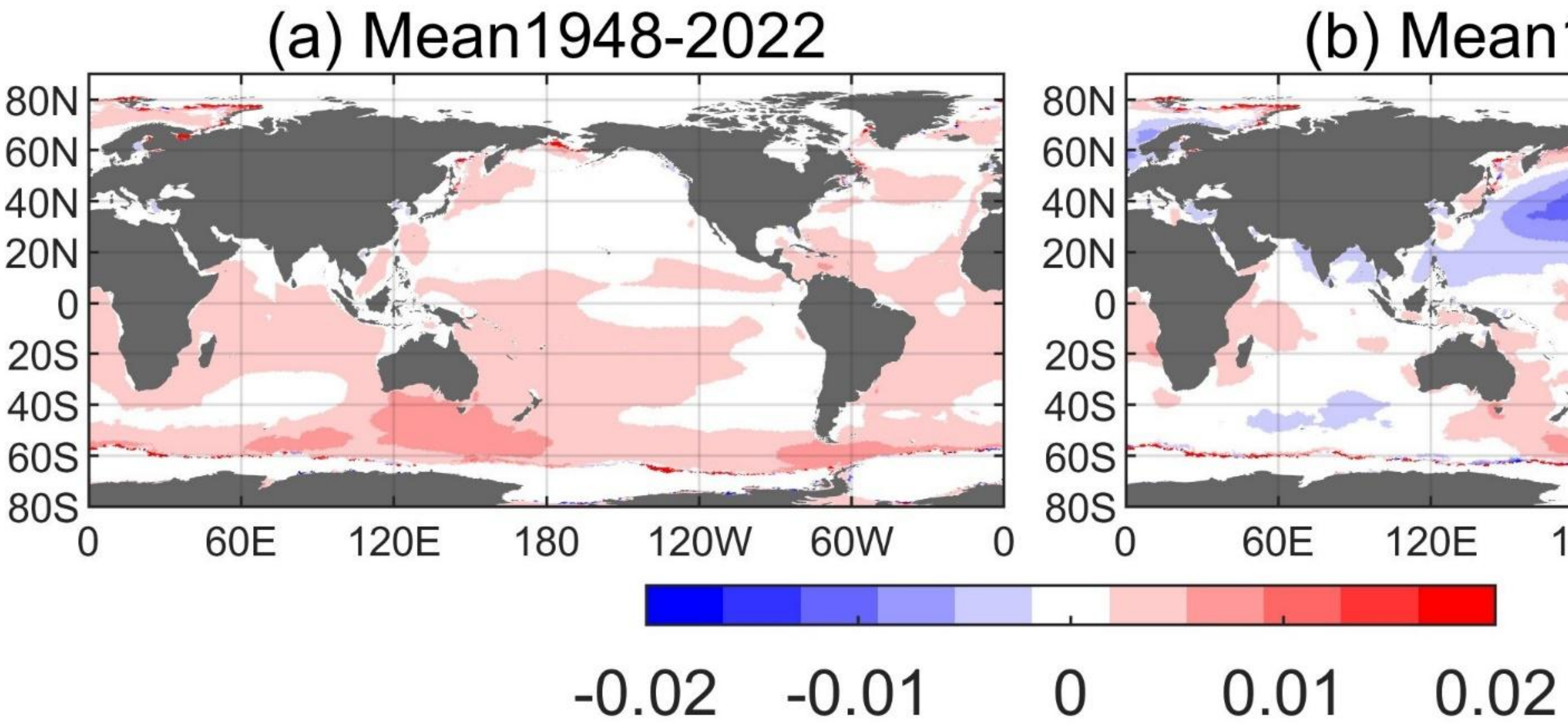

Global wave climate trend by satellite since 1980s

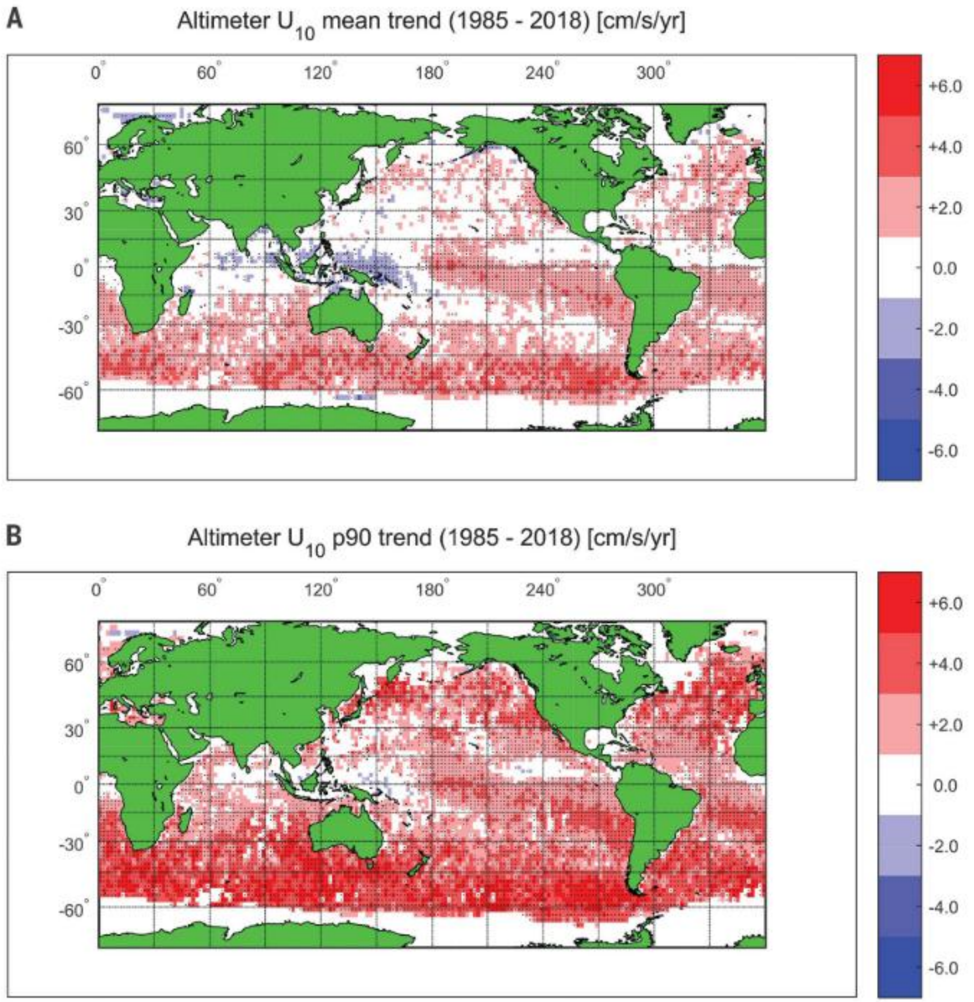

Fig. 1. Global trend in altimeter wind speed over the period 1985–2018. (**A**) Mean trend and (**B**) 90th percentile (p90) trend in altimeter U_{10}. Values that are statistically significant according to the Seasonal Kendall test are marked with a black dot.

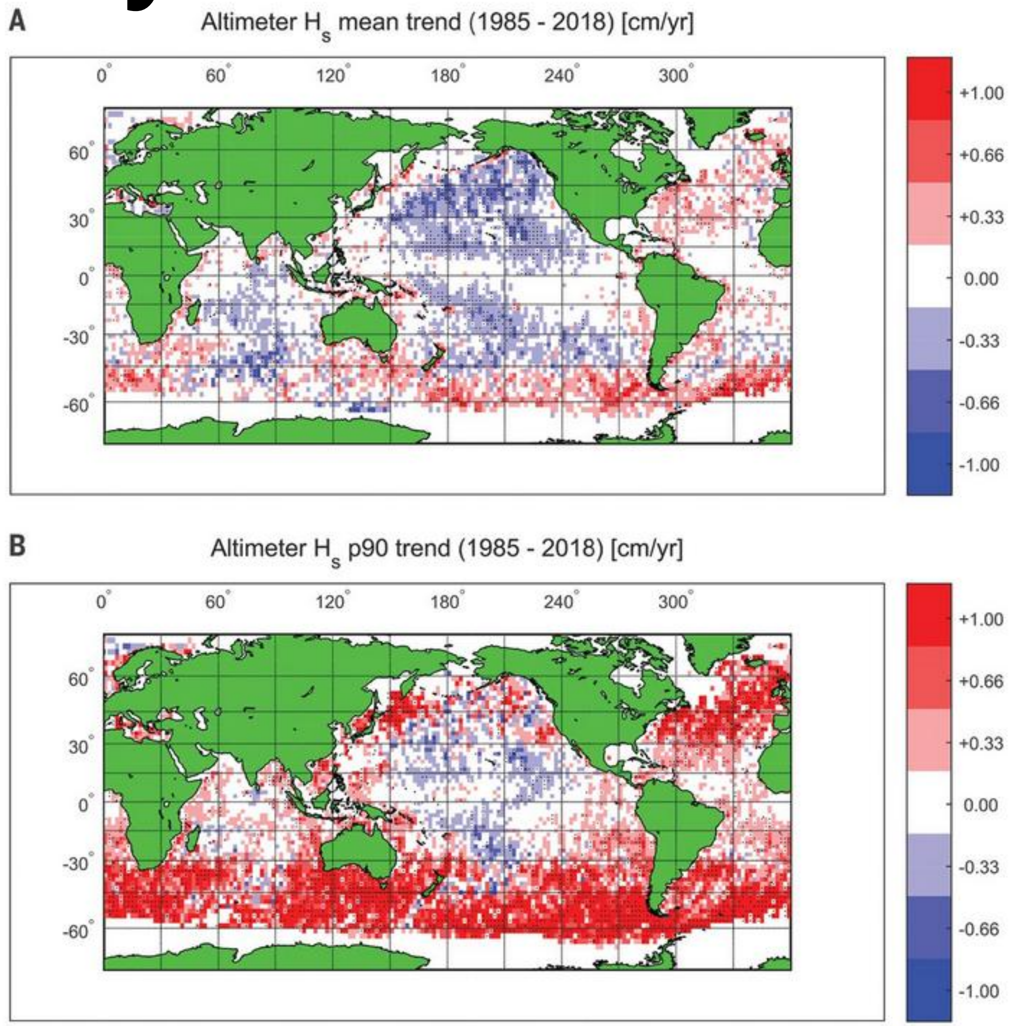

Fig. 2 Global trend in altimeter significant wave height over the period 1985–2018.

Young and Ribal (2019, Science)

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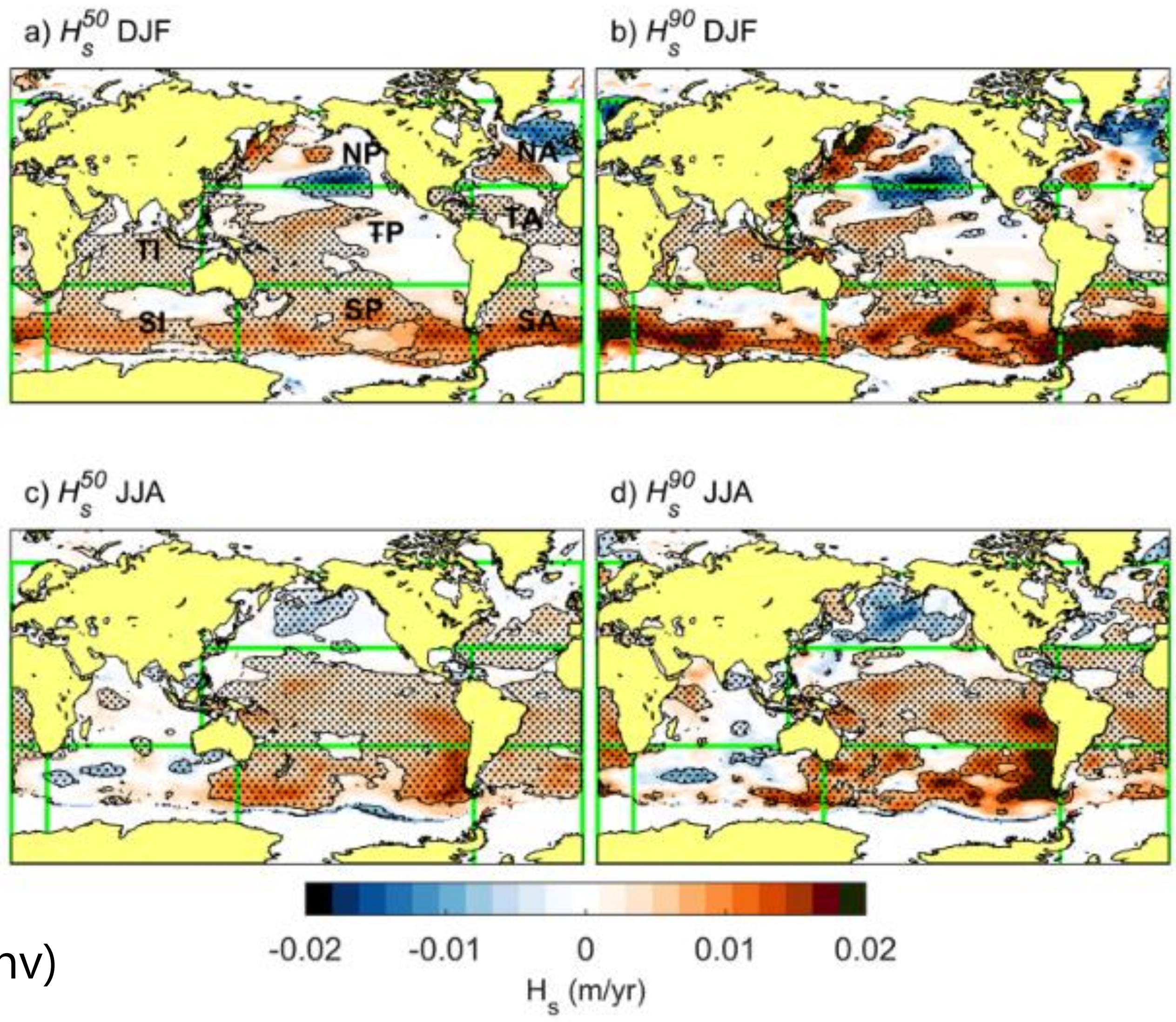
Global wave climate trend by hindcast/reanalysis since 1980s

Table 1 Summary of wind-wave products considered in this analysis.

ID	Centre-dataset Bathymetry Source	Atmospheric reanalysis (levels) Wave variables[a]	Assimilation system and method	Spatial and temporal resolution
1	ECMWF-ERA5[b]	ERA5 (L137)	IFS 41R2- 4DVAR[c]	0.25°/1 h
2	ECMWF-ERAI[b]	ERA-Interim (L91)	IFS 31R2- 4DVAR[c]	0.75°/6 h
3	ECMWF-ERA5H	ERA5 (L137)	IFS 41R2- 4DVAR	0.25°/1 h
4	KU-JRA55 (1980-2012)	JRA55 (L60)	GSM-4DVAR	0.56°/6 h
5	IORAS-MERRA2	MERRA2 (L72)	GEOS-5-3DVAR	0.50° × 0.62°/6 h
6	NOC-ERAI	ERA-Interim (L91)	IFS 31R2- 4DVAR	1.12°/3 h
7	IHC-GOW1.0	NCEP-NCAR (L28)	GDAS/ 3D-VAR	1.90° × 1.87°/6 h
8	IHC-GOW2.0	CFSR/ CFSv2 (L64)	GDAS/CFS- 3DVAR	0.30°/1 h
9	CSIRO-CAWCR	CFSR/ CFSv2 (L64)	GDAS/CFS- 3DVAR	0.30°/1 h
10	IFREMER-CFSR[d]	CFSR/ CFSv2 (L64)	GDAS/CFS- 3DVAR	0.30°/1 h
11	JRC-CFSR	CFSR/ CFSv2 (L64)	GDAS/CFS- 3DVAR	0.30°/1 h
12	JRC-ERAI	ERA-Interim (L91)	IFS 31R2- 4DVAR[c]	0.75°/12 h
13	IORAS-VOS			
14	IMOS (GLOBWAVE/RADS/AVISO/NSOAS and NOAA)[a] (1985-2014)			
15	ECCI (1995-2014)			

The description of each product is provided in Supplementary Notes 1. Time-periods cover 1980-2014 unless stated
first time-point.
[a]T_m is the first moment mean wave period in all products except IFREMER-CFSR for which the second moment m
[b]Coupled System. Assimilated data within each atmospheric reanalysis product are provided within Supplementary
[c]IFS consolidation cycle.
[d]Includes altimetry wind corrections.



Li et al., (2022, Commsenv)
Trend during 1980-2014

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How about before 1980s?
--> 70-year global wave hindcast and trend estimation

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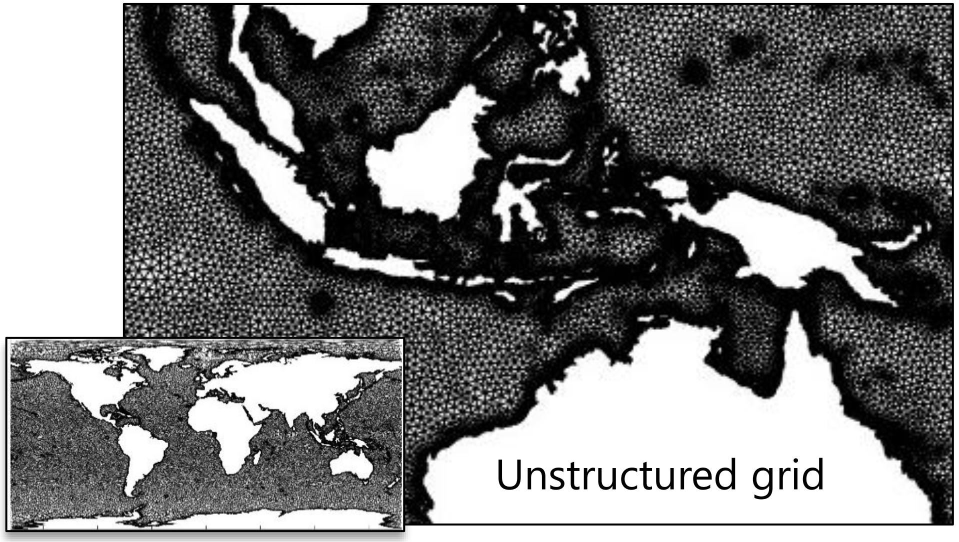
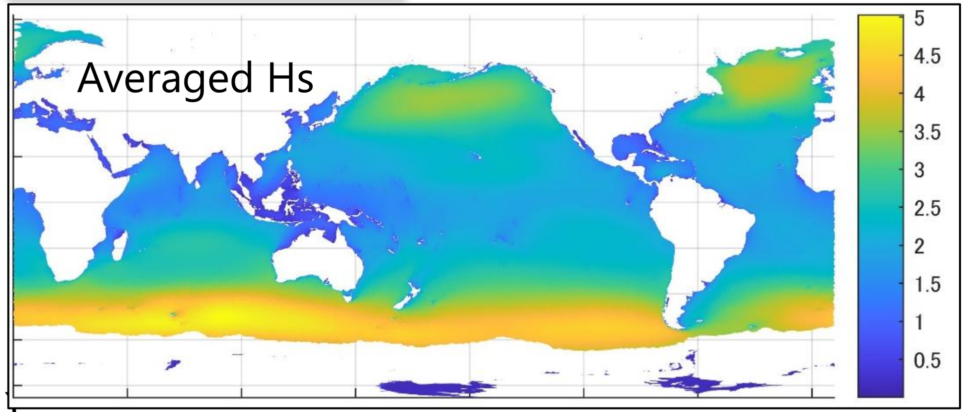
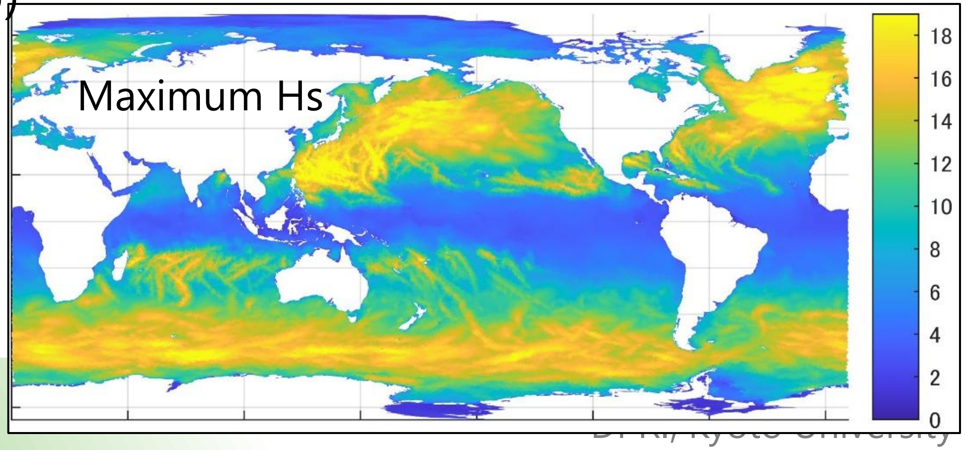
70-year global wave hindcast

- Atmospheric reanalysis
  - **JRA-3Q** developed by Japanese Meteorological Agency (Kosaka et at., 2024)
  - 40 km resolution
  - **1947** to present
- Wave model
  - Spectral wave model: WAVEWATCH III
- Domain
  - Unstructured-grid created by Oceanmesh2D (Robert et al., 2019)
  - Global: 50 km resolution
  - Coast: 5 km resolution
  - The Unresolved Obstacles Source Term (Mentaschi et al., 2015)
- Forcing
  - Hourly sea surface wind
  - Daily sea ice concentration (IC0)
- Wave hindcast period
  - 1948 to 2022







Data for comparison

- Satellite remote sensing observation (Ribal and Young, 2019)
  - Obtained from the Australian Integrated Marine Observing System
  - 1985 – 2022
  - Gridded to 0.5°x 0.5°
- In-situ observation
  - US NDBC
    - Buoy
    - 1975 - 2022
  - Japanese NOWPHAS
    - Buoy and ocean bottom mounted sensor
    - 1979 – 2022
- ERA-5 (Hersbach et al., 2020)
  - 1940 – 2022
  - Satellite observation data assimilation since 1991

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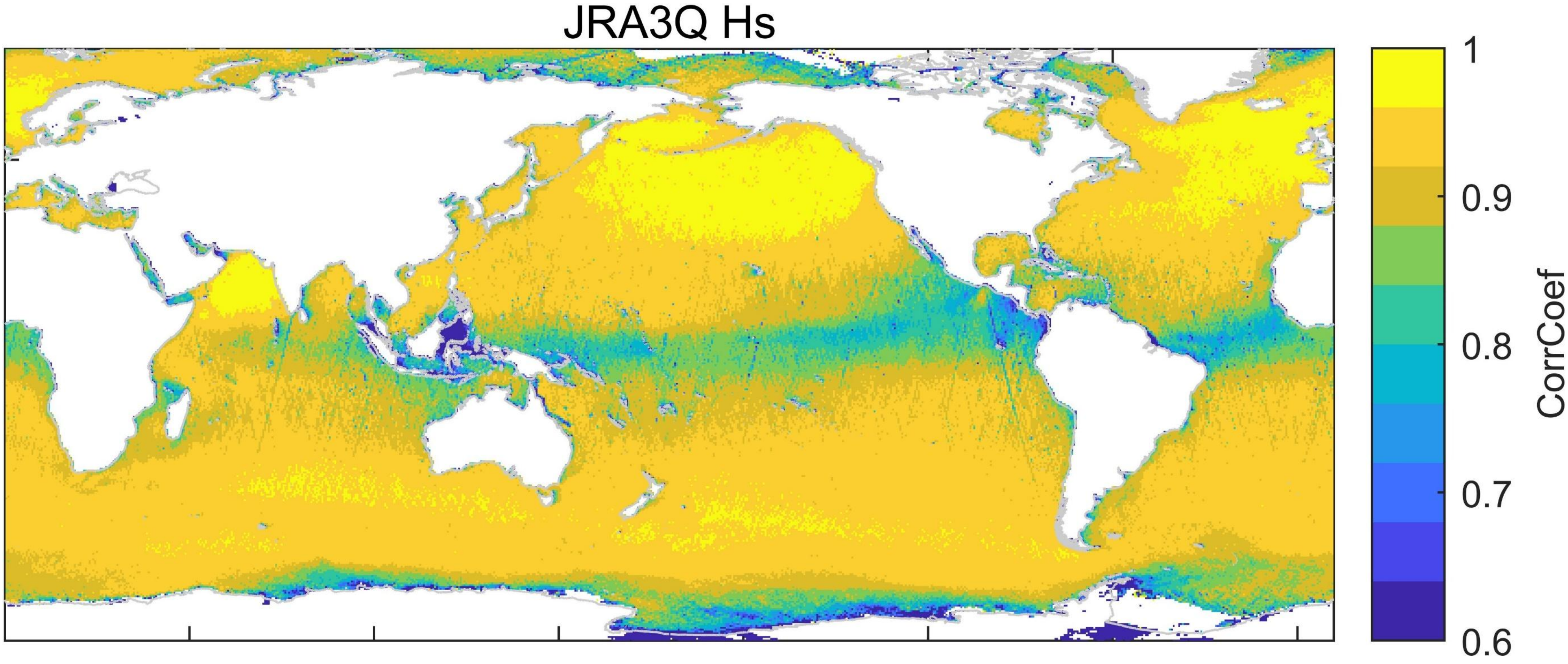
Validation against the satellite observation



Correlation coefficient of hourly significant wave heights between JRA-3Q and satellite observations

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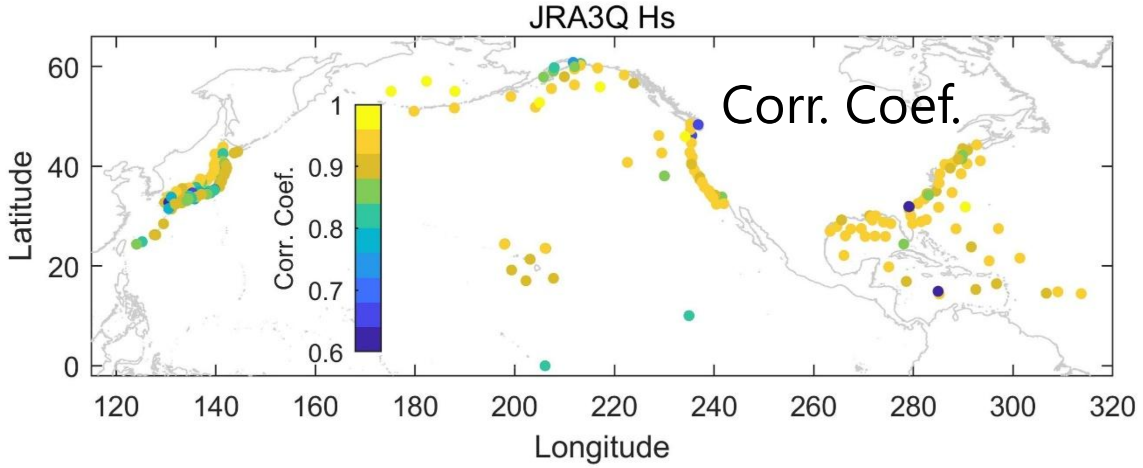
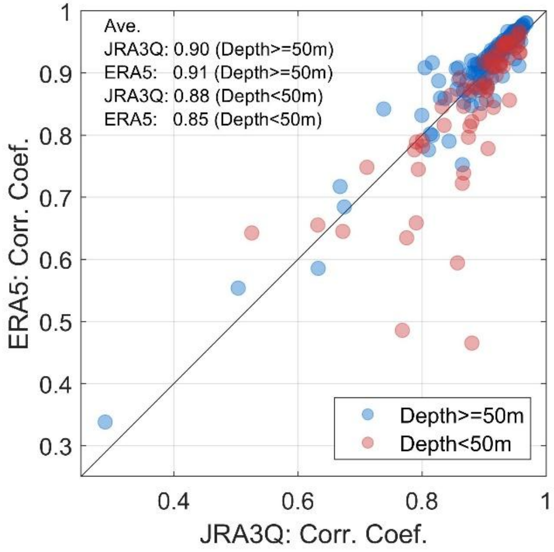
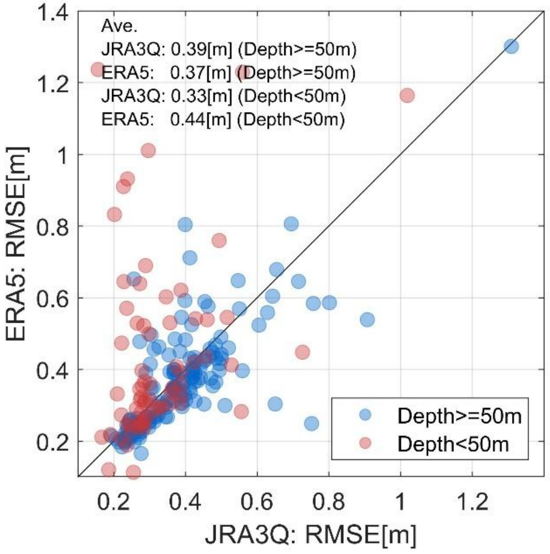
Validation against the in-situ observation with ERA5

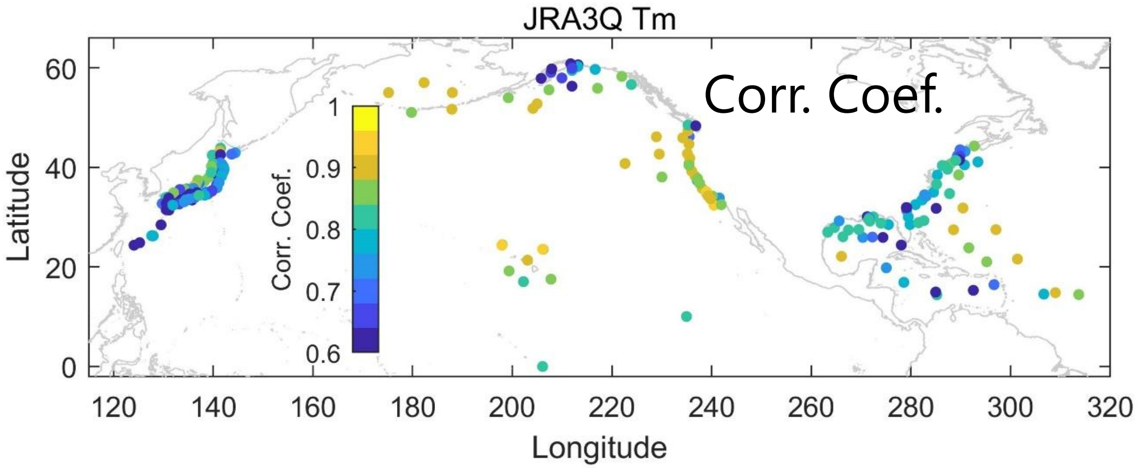
Significant wave height

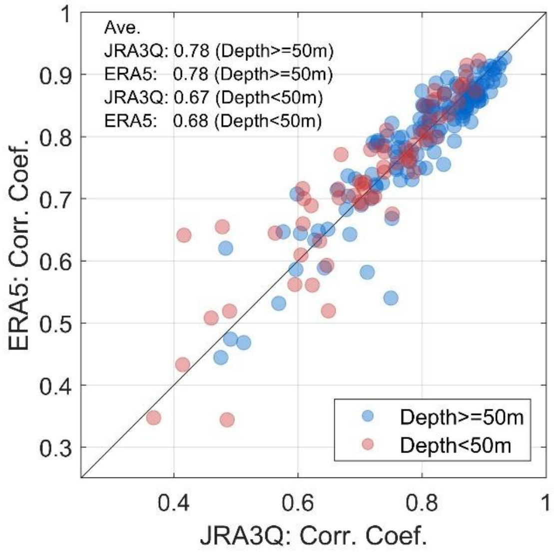


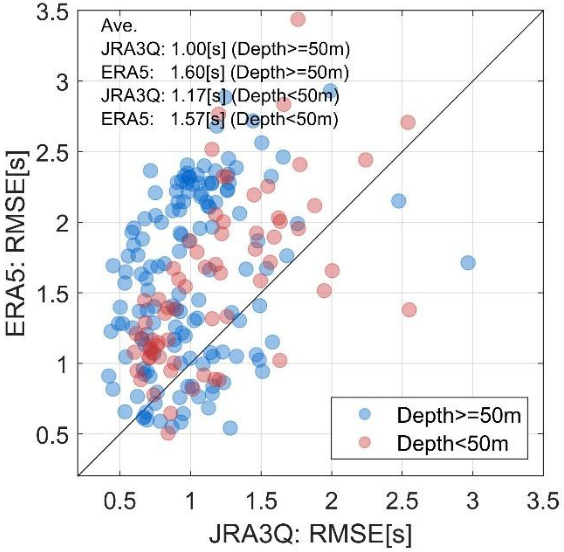




Mean wave period







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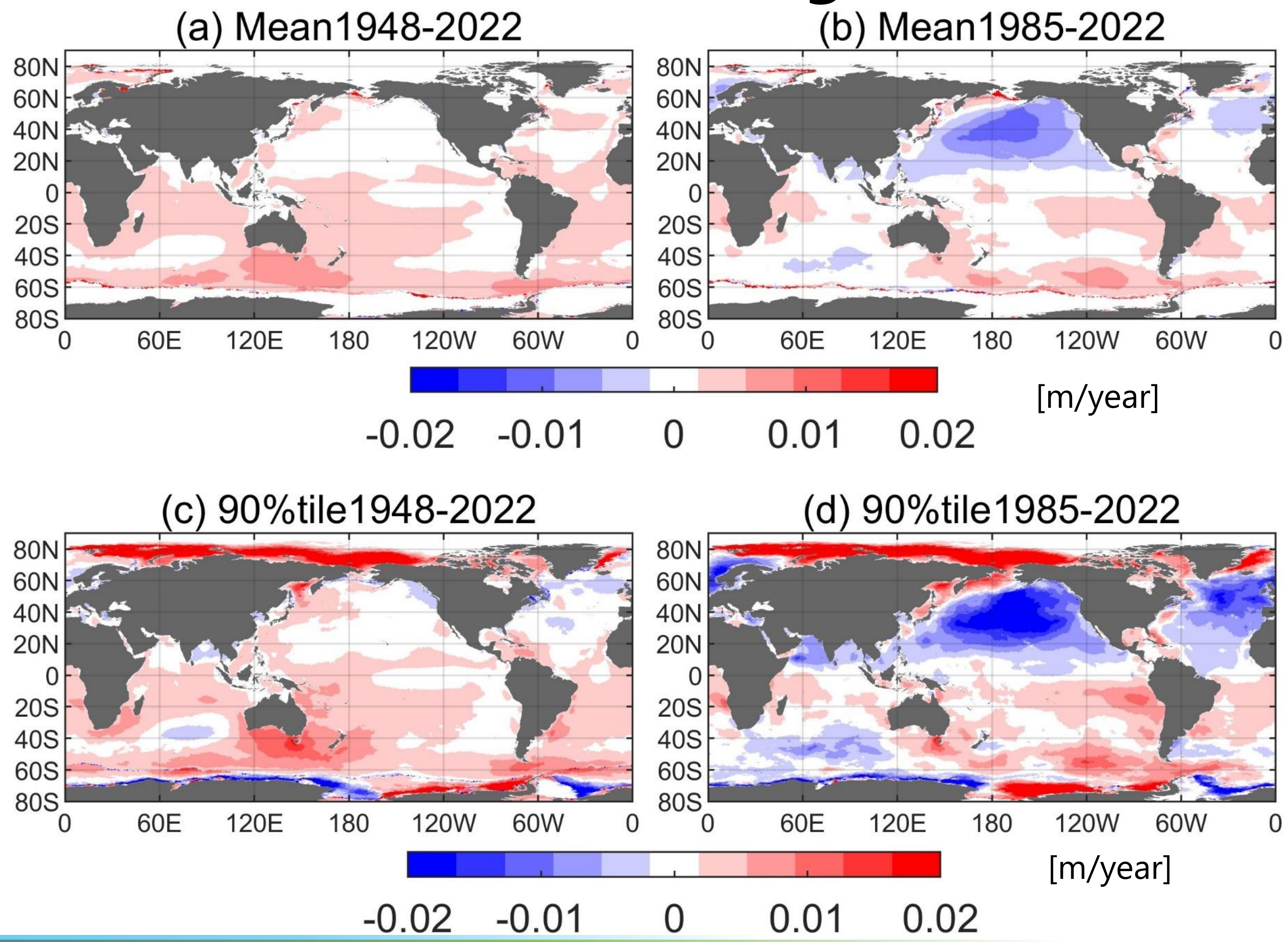
Trends of Hs based on JRA-3Q global wave hindcast

Annual mean
1948 - 2022

Annual 90%tile
1948 - 2022



Annual mean
1985 - 2022

Annual 90%tile
1985 - 2022

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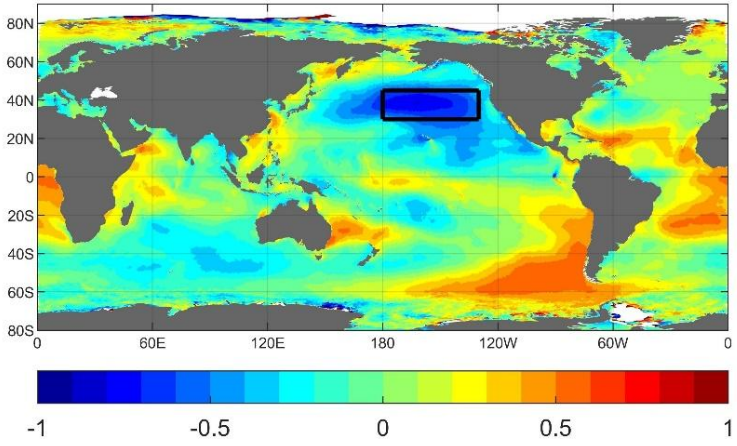
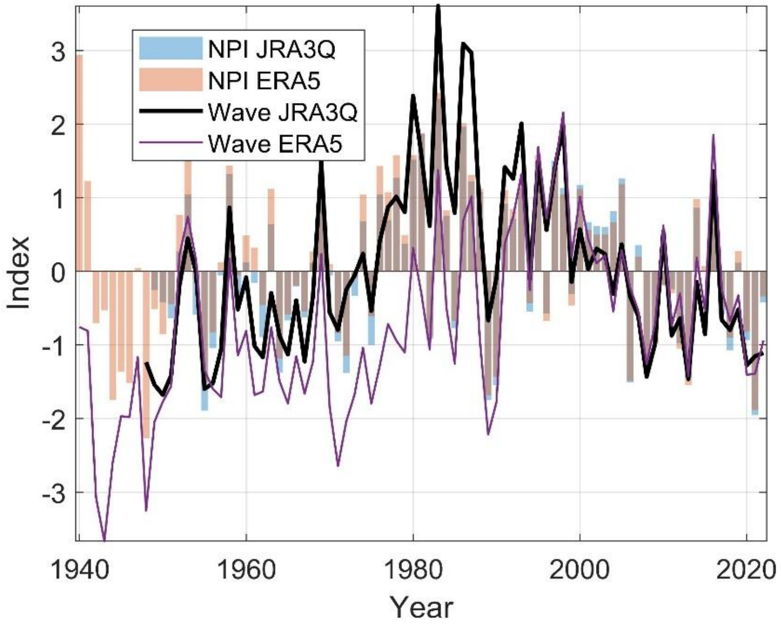
Relationship with climate index

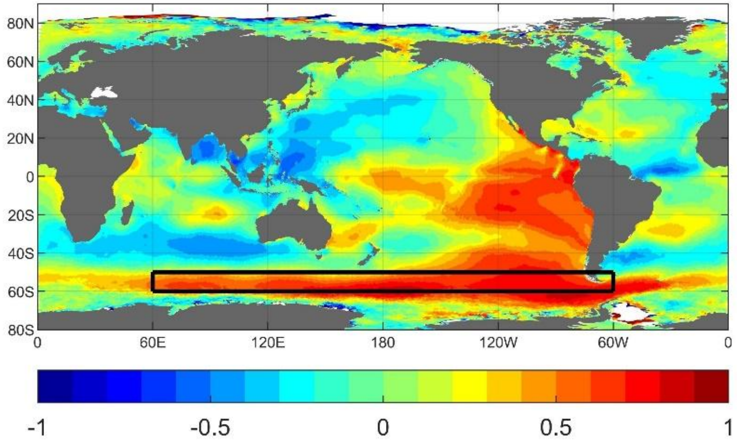
North Pacific Index (NPI)

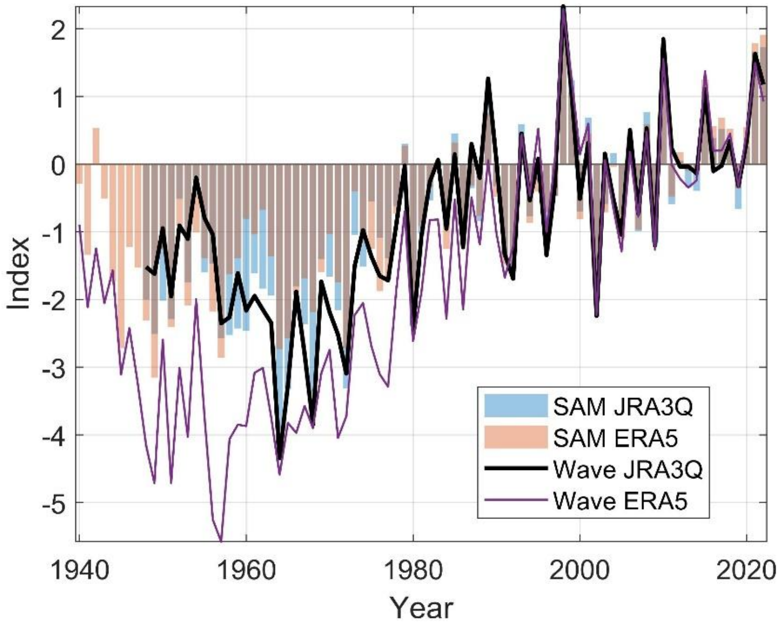




Correlation coefficient of Hs with climate index

Southern Annular Mode (SAM)





ERA-5 has inconsistency between wave and indices before 1980s.

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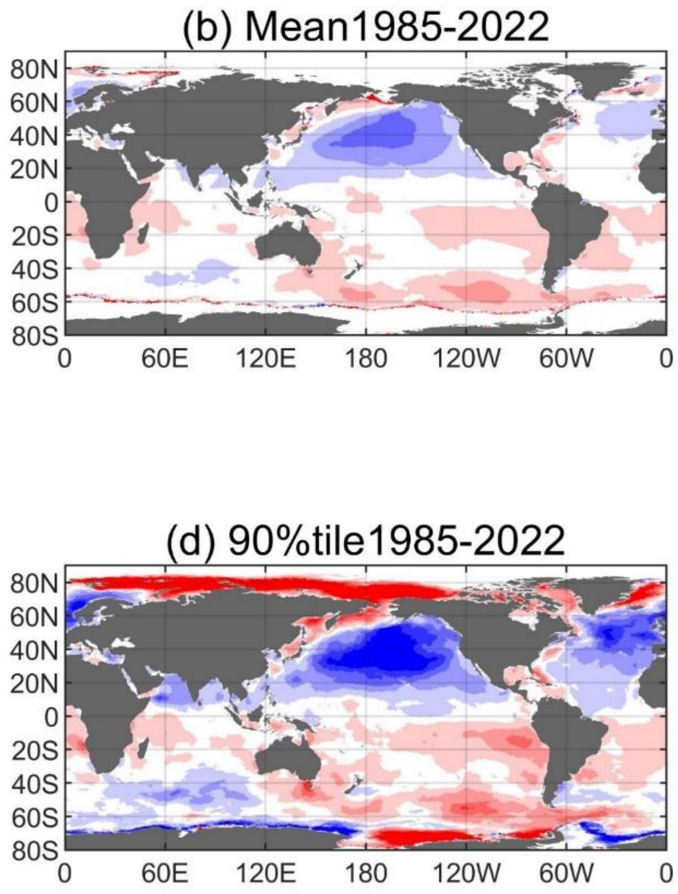
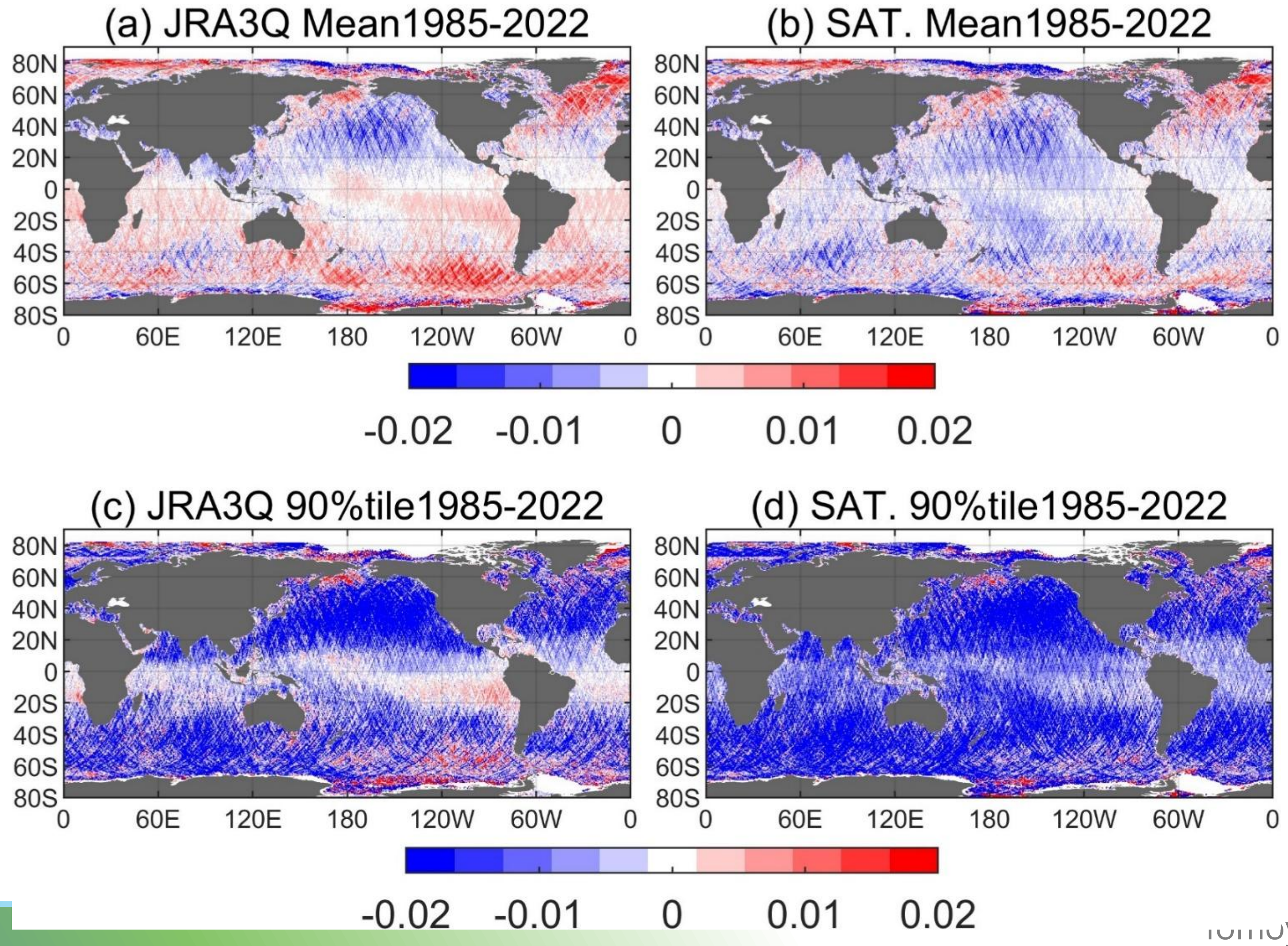
Sampling problem in satellite estimation

JRA-3Q

JRA-3Q
Re-sampled same as satellite

Satellite





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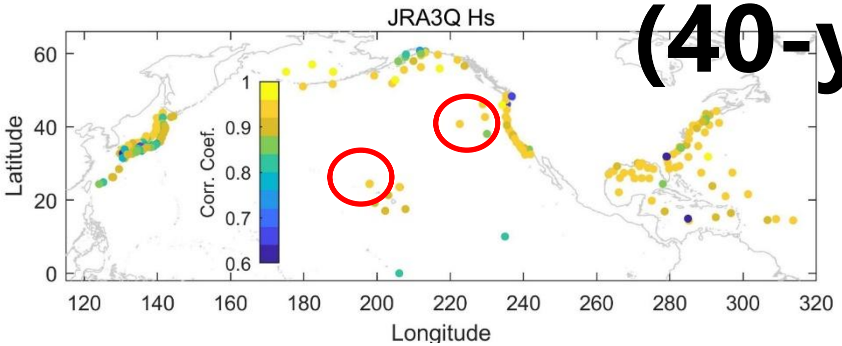
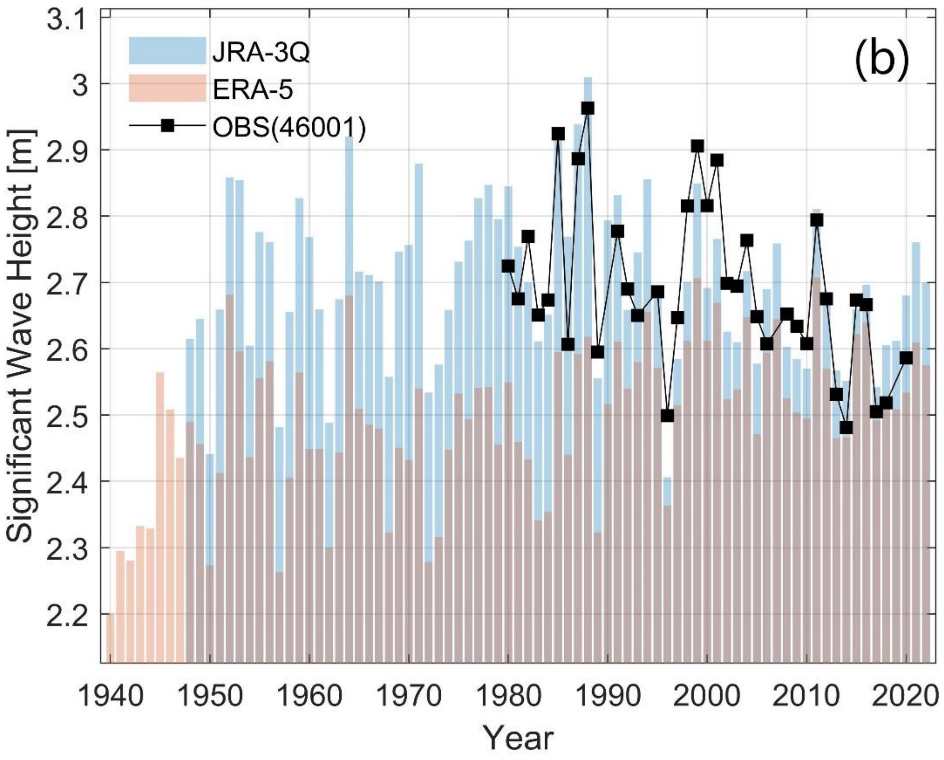
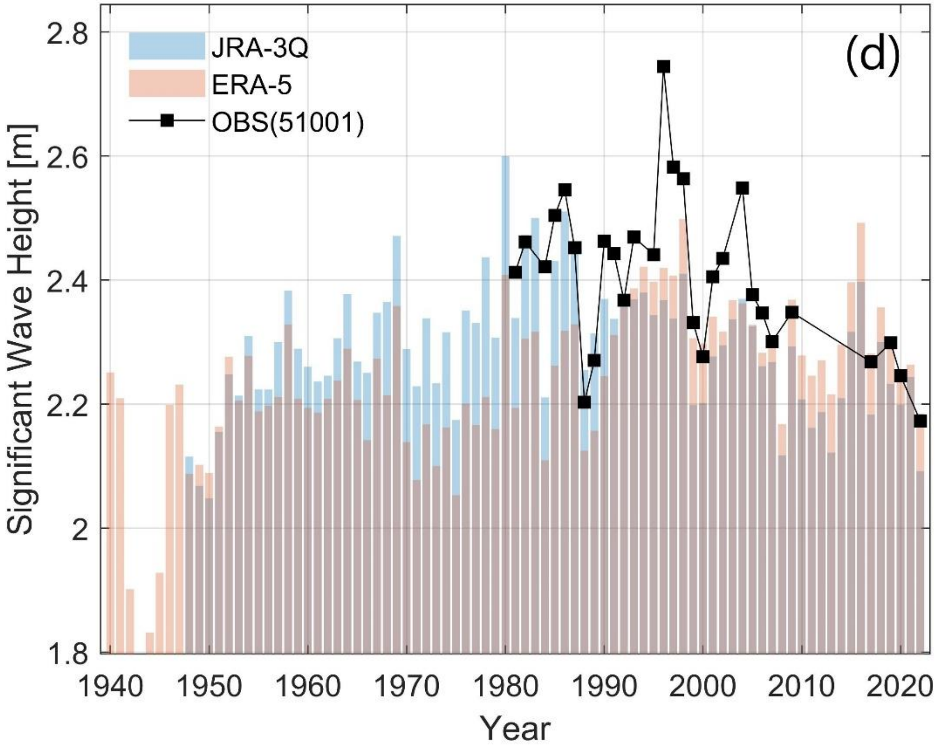
Comparison of trends with buoy estimations (40-year long observations)





#46001: Mid latitude (40N) in NP



#51001: Lower latitude (25N) in NP

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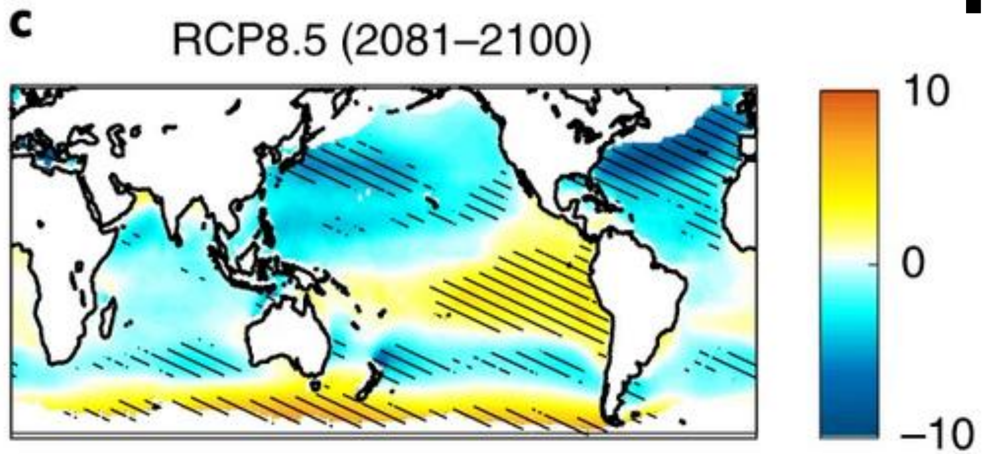
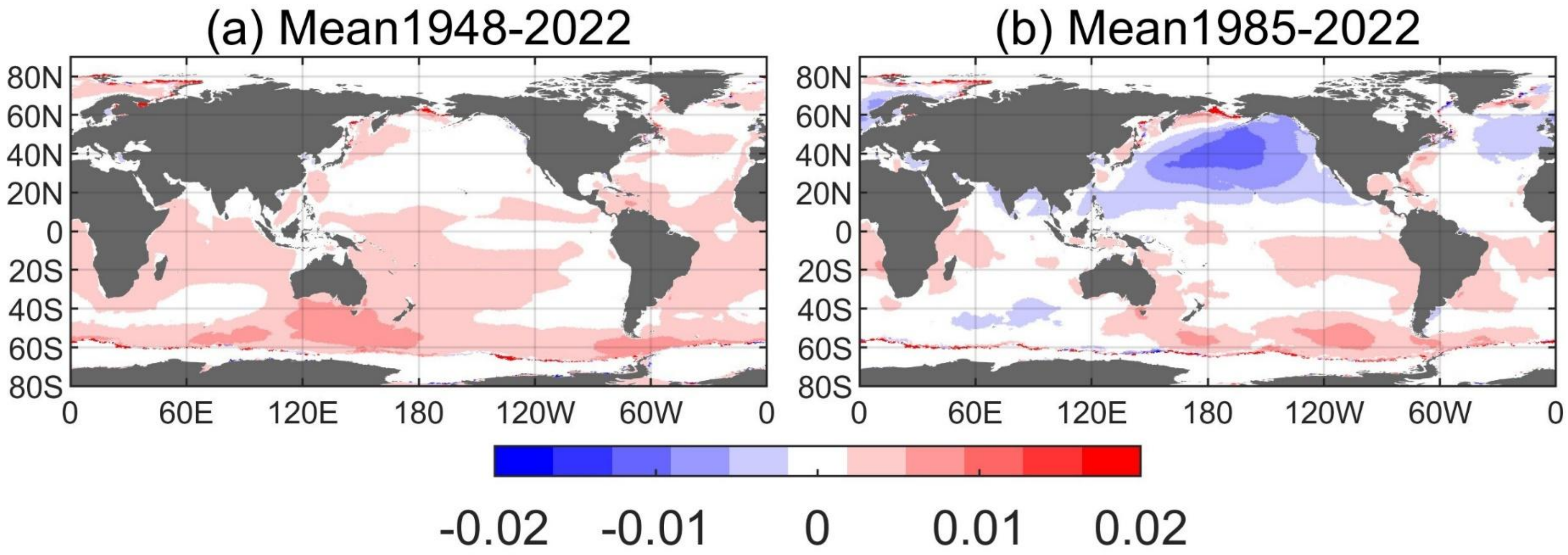
Historical trend is consistent with future wave climate projection ?

Morim et al., (2019, Nature climate change)



Inconsistency:
-> Natural variability?
-> Deficit of climate projection?

This study



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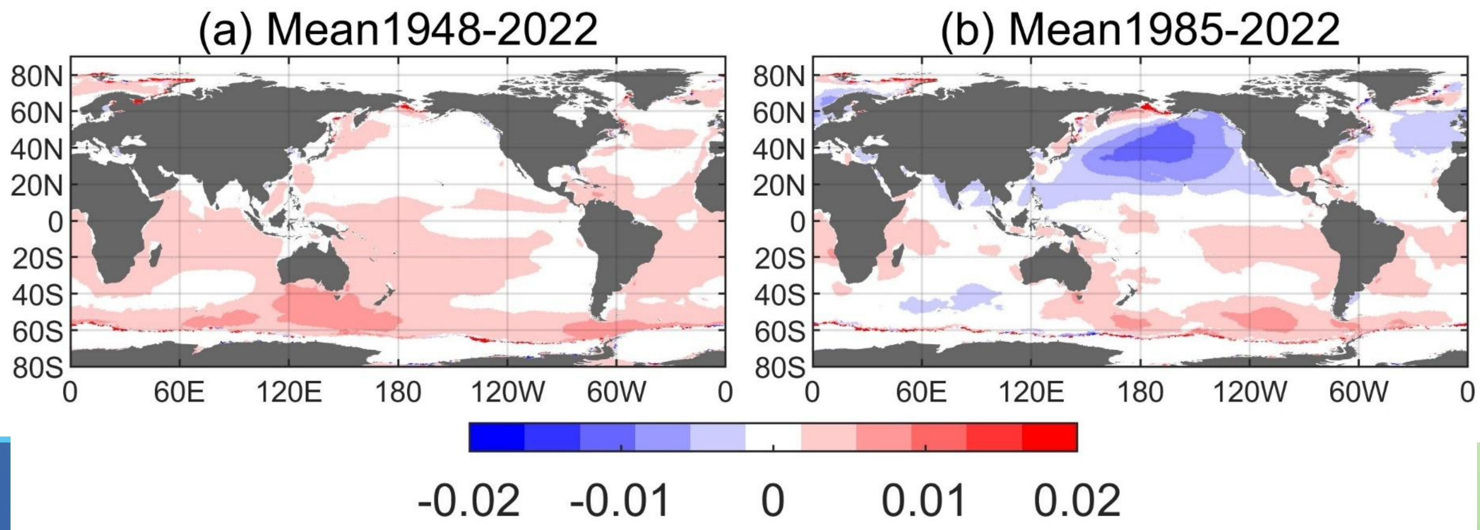
Conclusions

- Global ocean wave hindcasts were conducted using new atmospheric reanalysis and unstructured grid wave model from 1948 to 2022.
- Wave hindcast compared with satellite, buoy, and reanalysis data exhibit good performance particularly along coasts.
- Wave height trends within first and later halves are opposite over North Pacific, indicating large multidecadal variability.
- Resolving the inconsistency between historical trends and future projections is important for increasing confidence in climate projections.



Shimura et al. (under review)
Multidecadal oscillation masks ocean wave climate trends in 75-year global wave hindcast
Preprint is available at ESS OPEN ARCHIVE

End

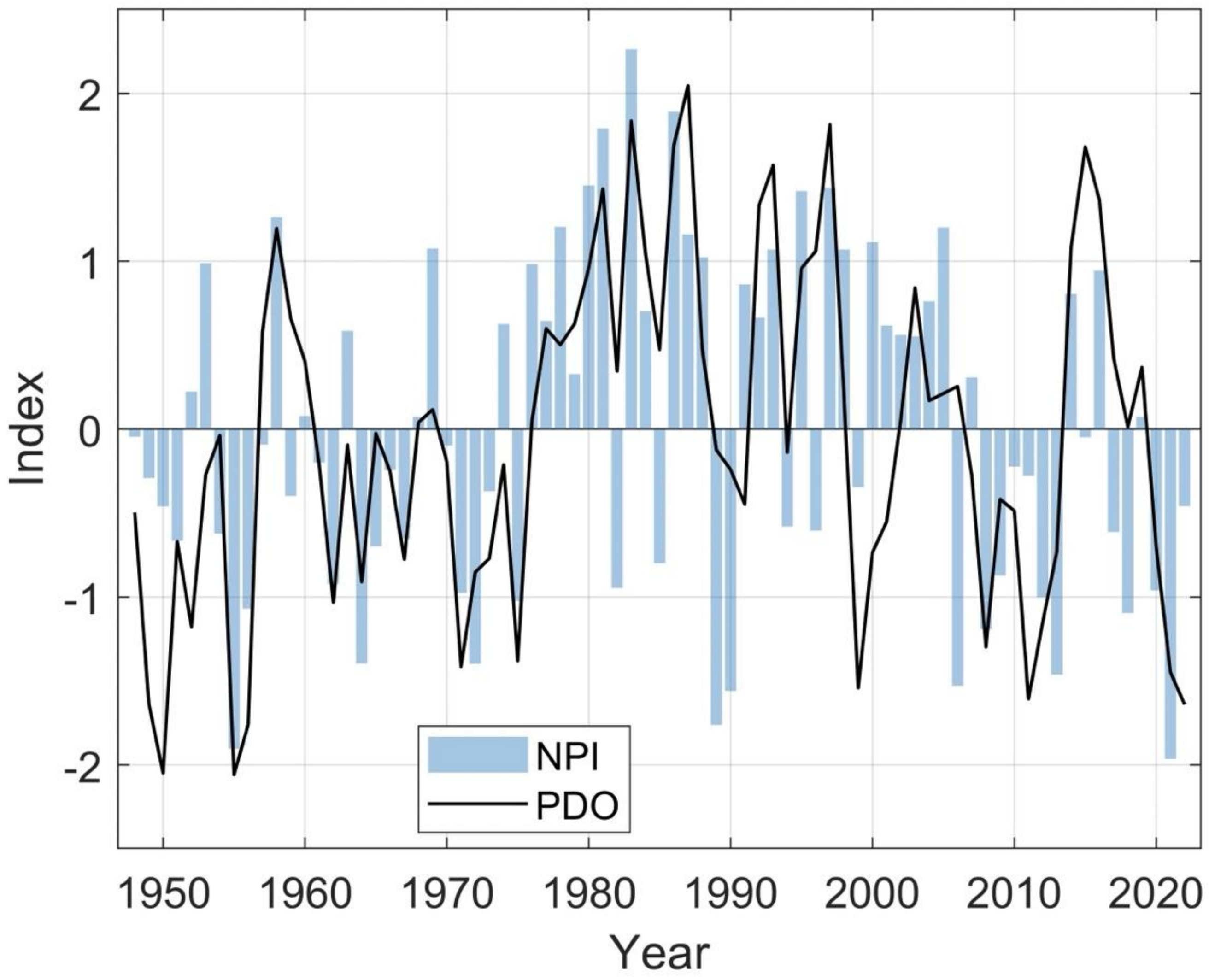


Figure S2. Time series of NPI and PDO. This figure shows the inverse-sign NPI for easy comparison between NPI and PDO. The values were normalized using the mean and standard deviation from 1990 to 2022. The PDO index was obtained from Japan Meteorological Agency.

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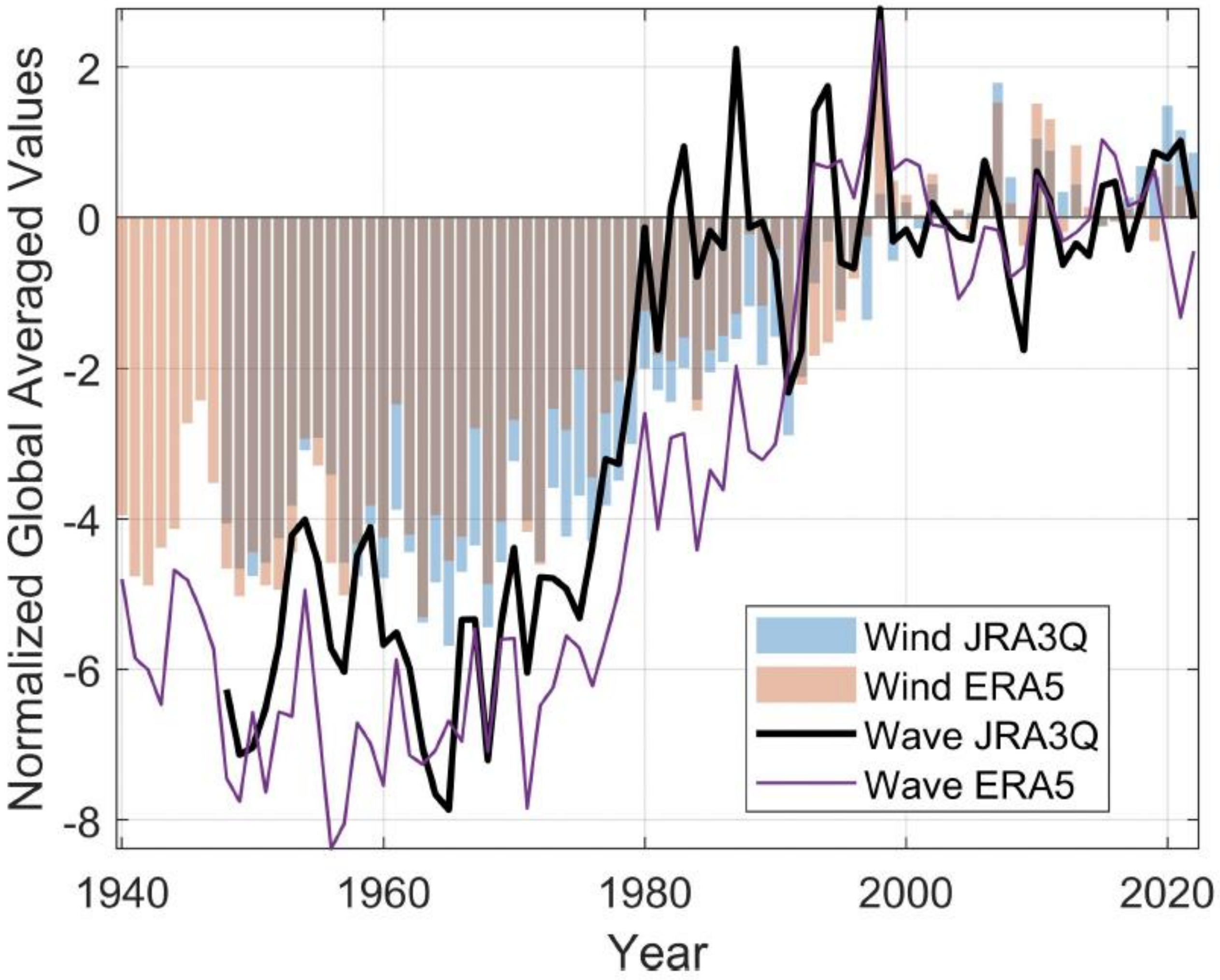

Figure 5. Timeseries of globally averaged wave heights and wind speeds. The values are normalized by the mean and standard deviation in the period from 1990 to 2022.

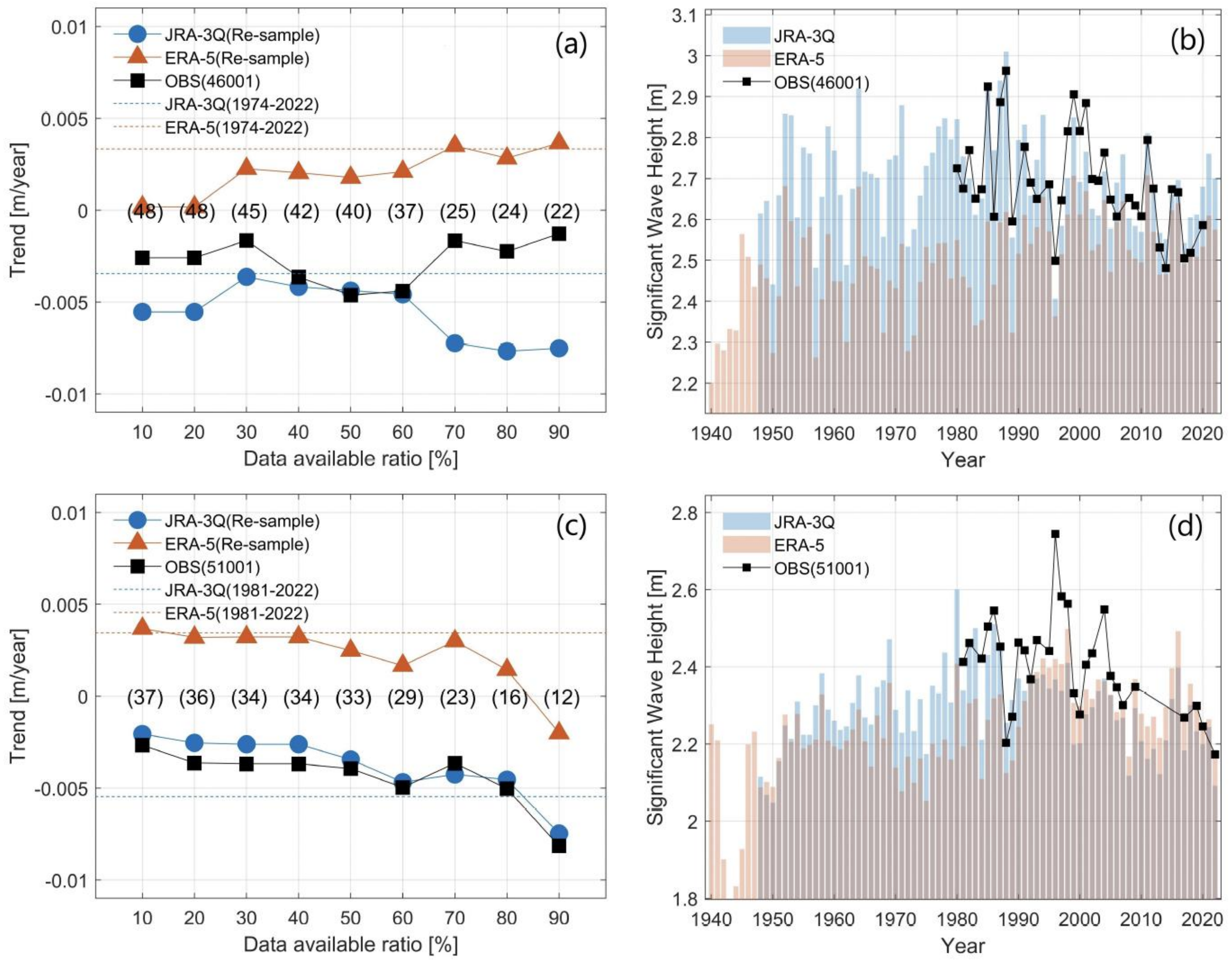

Figure 7. Comparison of trends in annual averages of significant wave heights across JRA-3Q, ERA-5, and NDBC buoys: (a) estimated trends depend on data availability ratio in time series of annual average wave heights for JRA-3Q, ERA-5, and the buoy observations at NDBC #46001 location; numbers in brackets represent years considered for trend estimation. (b) Time series of annual average wave heights for JRA-3Q, ERA-5, and the buoy observations at #46001 location. Buoy values are plotted based on a minimum data availability ratio of 60%, while all available data were used for JRA-3Q and ERA-5. (c, d) Same as (a, b) but for NDBC #51001 location.

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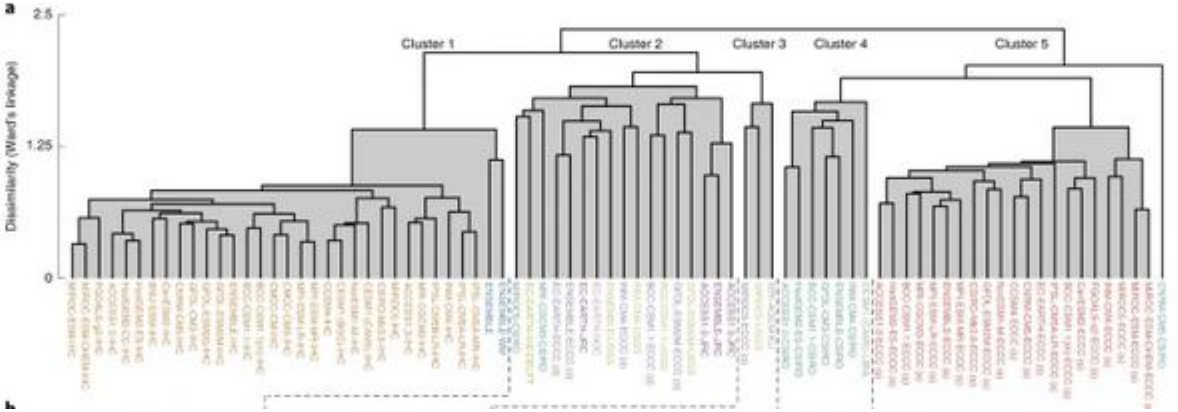
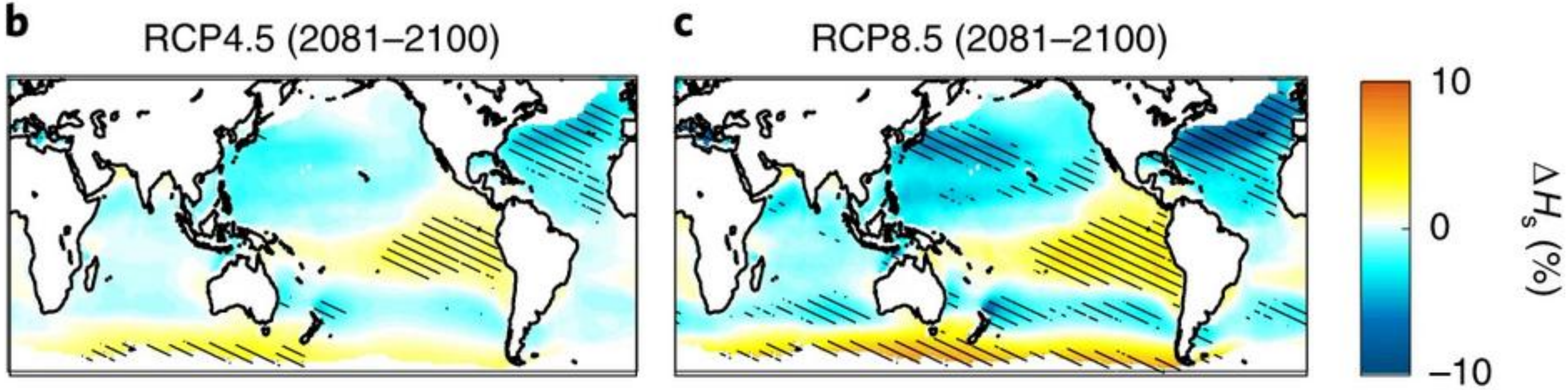
Historical trend is consistent with future wave climate projection ?



- 21 international research groups
  - AUS: CSIRO, USA: USGS, CA: ECCC, UK: NOC, JA: KU-DPRI etc.
- 148 ensemble member
- Future projection of wave height, period, direction and the uncertainty
- RCP4.5 and 8.5 scenarios



Morim et al., (2019, Nature climate change)

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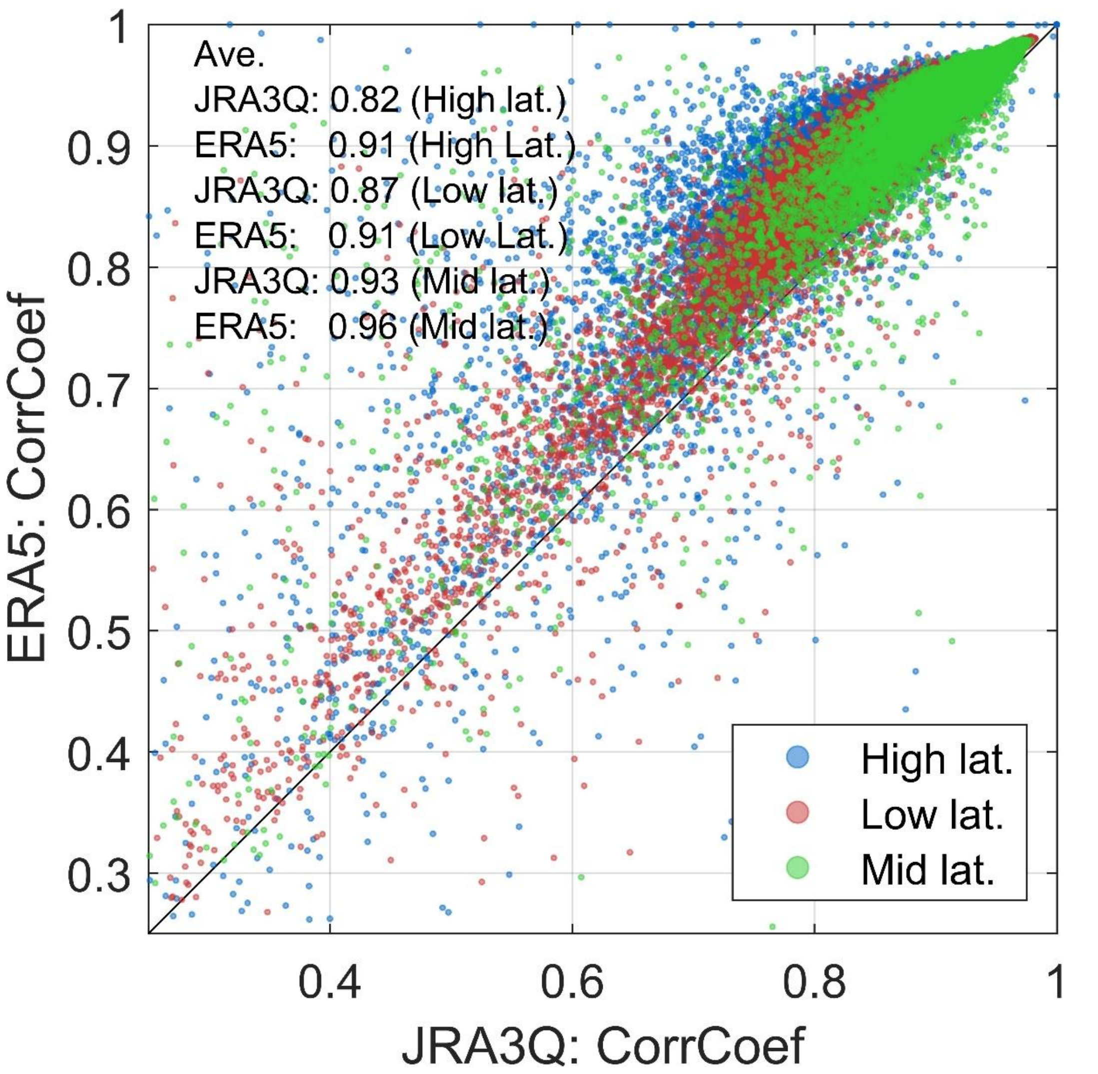
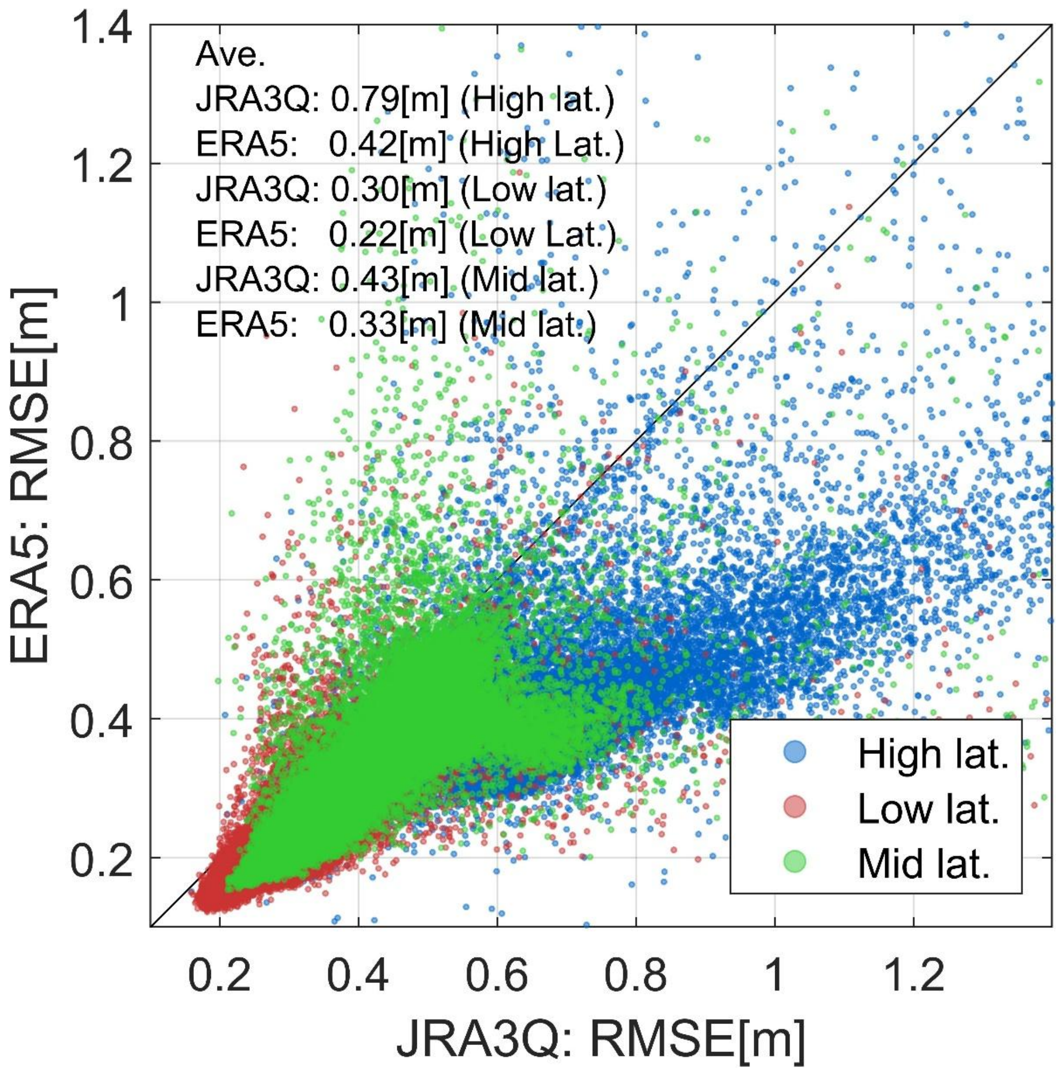
Validation against the satellite observation with ERA5





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