Wave climate in the North Atlantic Ocean and extreme value analysis

K. Sasmal[1], R. Miratsu[2], T. Kodaira[1], Y. Kita[1], T. Zhu[2], T. Fukui[2], T. Waseda[1]

[1]The University of Tokyo, Kashiwa, Chiba, Japan
[2]Nippon Kaiji Kyokai (ClassNK), Chiyoda, Tokyo, Japan

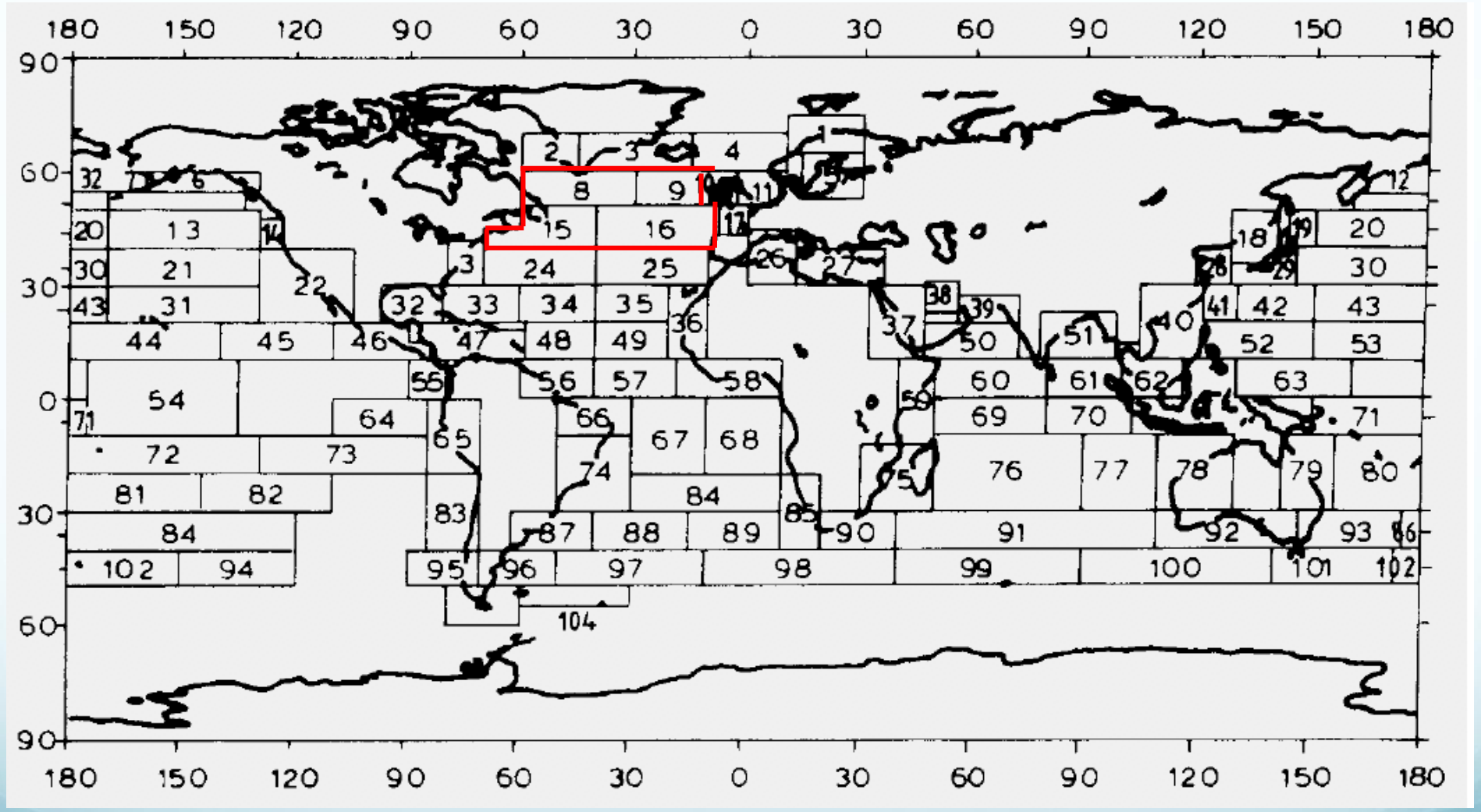
Objectives

- Revisiting the wave statistics of GWS areas 8,9,15 and 16 (40 – 60^{o}N) located in the North Atlantic Ocean. Analyze 25-year (1994-2018) wave data and compare different wave products for extreme waves (JPD and Environmental contours)

  ERA5/ECMWF, IOWAGA/IFREMER, and TodaiWW3-NK

- Validate the model results: model vs. buoy (NDBC and UK Met Office buoys).
- Compare the significant wave height: models vs. altimeter, emphasis is given on extreme waves.
- Impact of model resolution on the result.
- Examine the exceedance probability of significant wave height.
- Identify extreme events and compare maximum wave height and spatial distributions.

Global Wave Statistics (GWS)



- Wave data covers a global grid of 104 sea areas
- Derived from a large number of visual observations

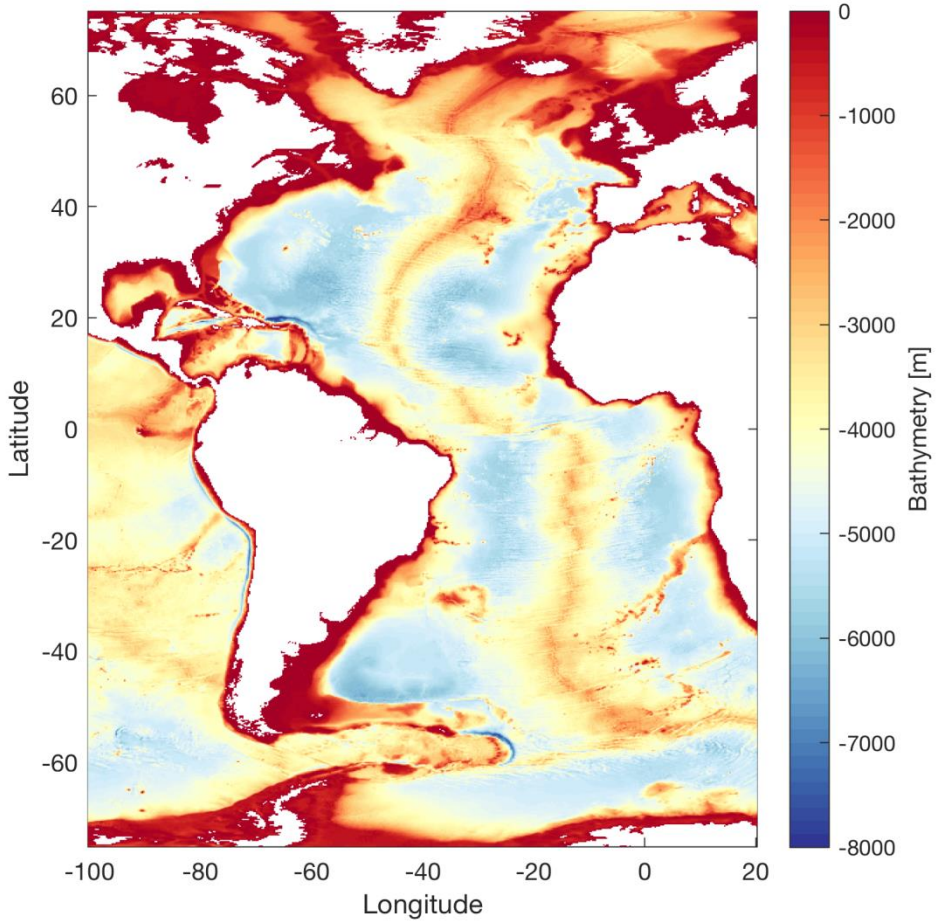
IACS Rec. 34
Global Wave Statistics:
Hogben et al. (1986)

Details of the wave data

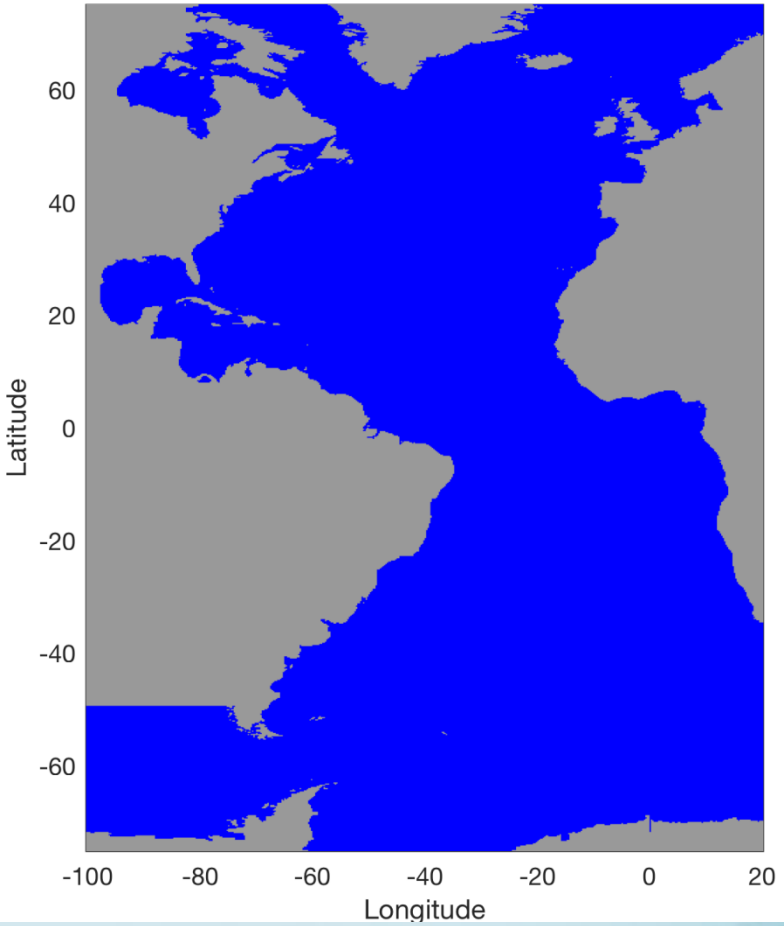
	ERA5/ECMWF	IOWAGA/IFREMER	TodaiWW3-NK
Wave model	ECMWF WAM	WAVEWATCH III	WAVEWATCH III
Horizontal coverage	Global	Global	Atlantic
Model resolution	0.5^0 x 0.5^0	0.5^0 x 0.5^0	0.20^0 x 0.25^0
Temporal resolution	hourly	3-hourly	hourly
Spectral resolution	24 directional bins 30 frequency bins	24 directional bins 31 frequency bins	36 directional bins 35 frequency bins
Wind forcing	ECMWF/IFS	CFSR and ECMWF	CFSR

TodaiWW3-NK

Bathymetry: ETOPO1

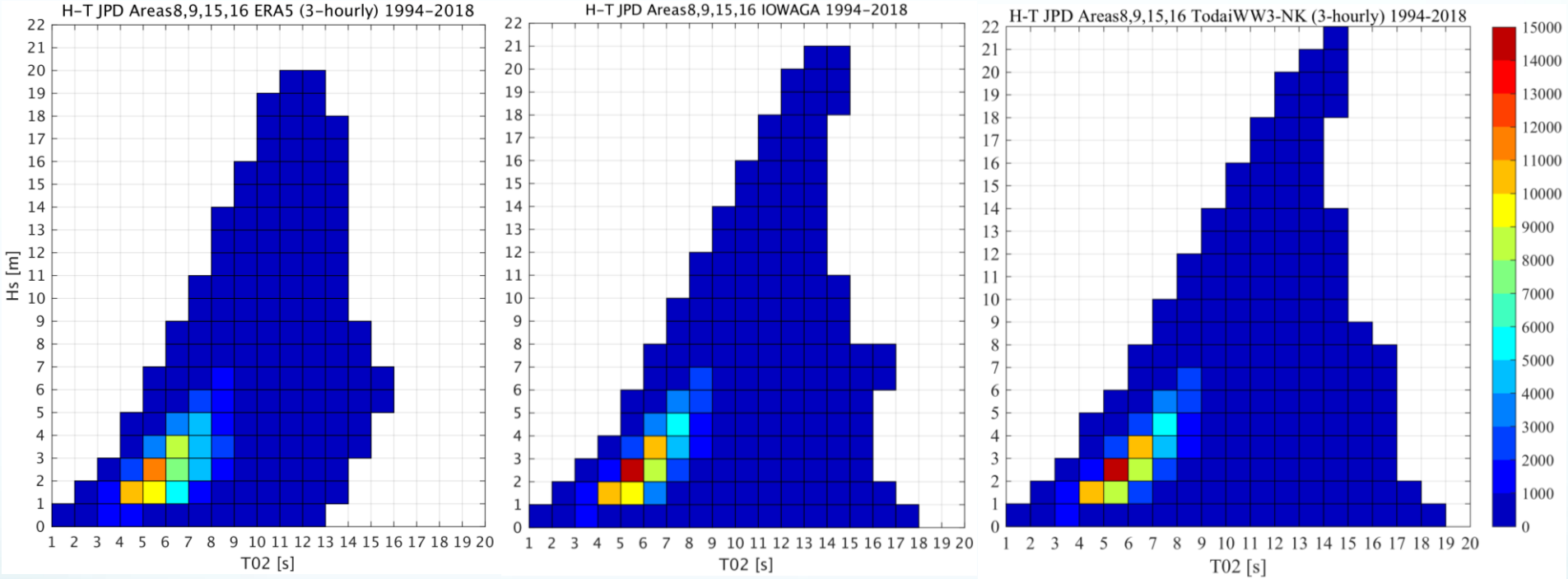


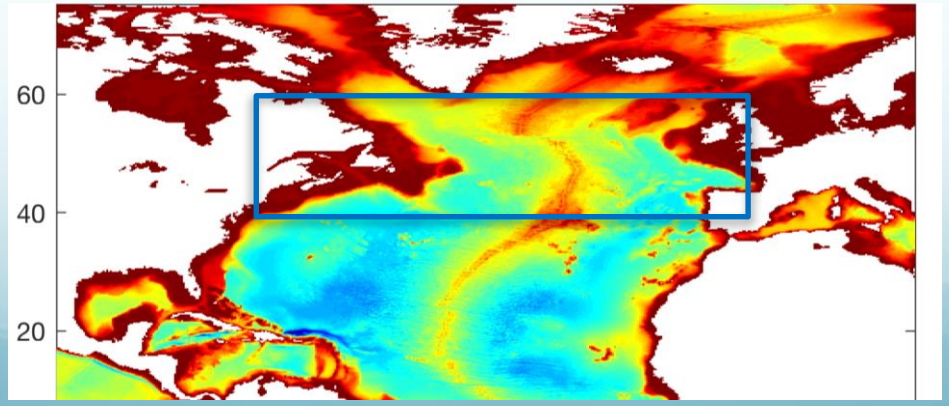
Land/sea masking



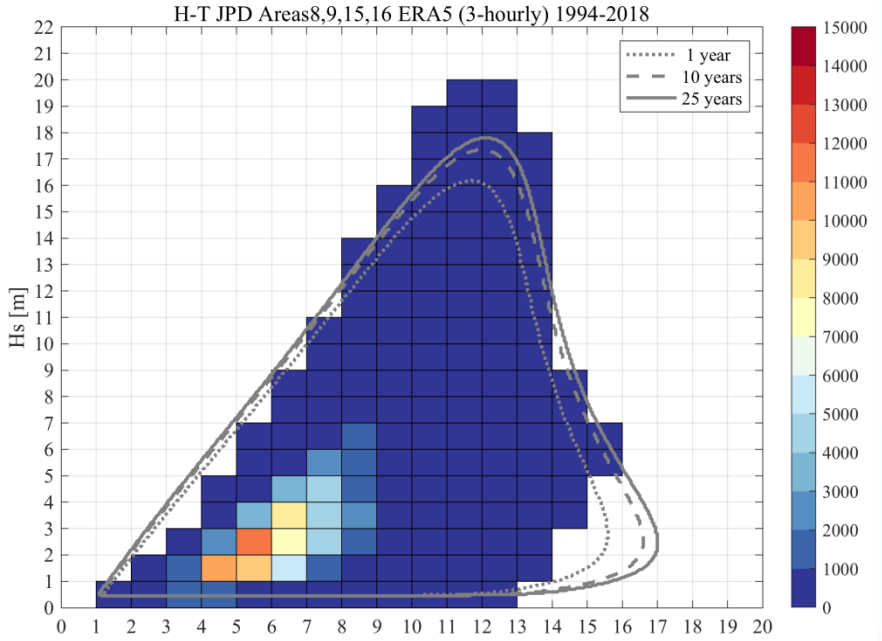
Comparison of JPD diagrams for GWS areas 8,9,15, and 16

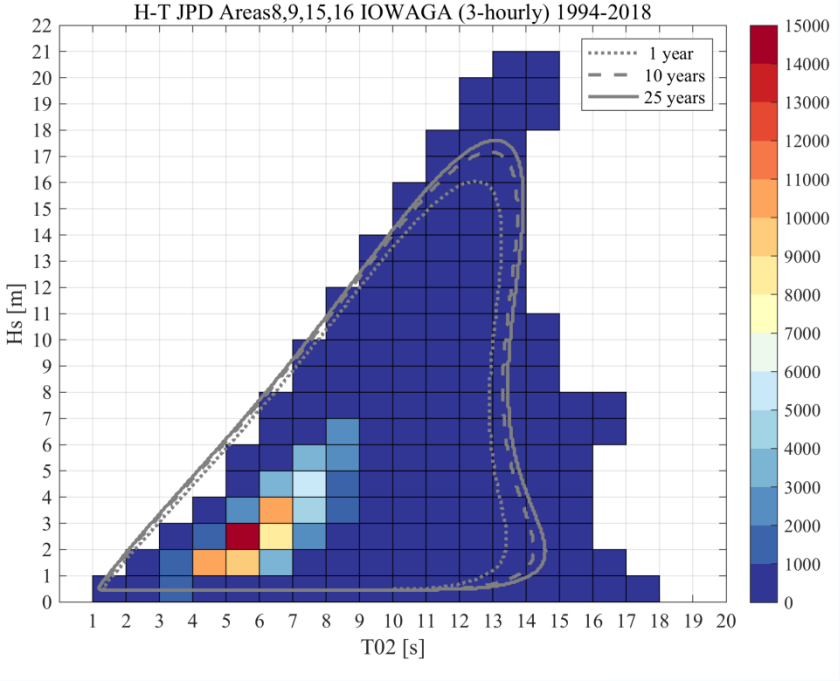
ERA5 IOWAGA TodaiWW3-NK

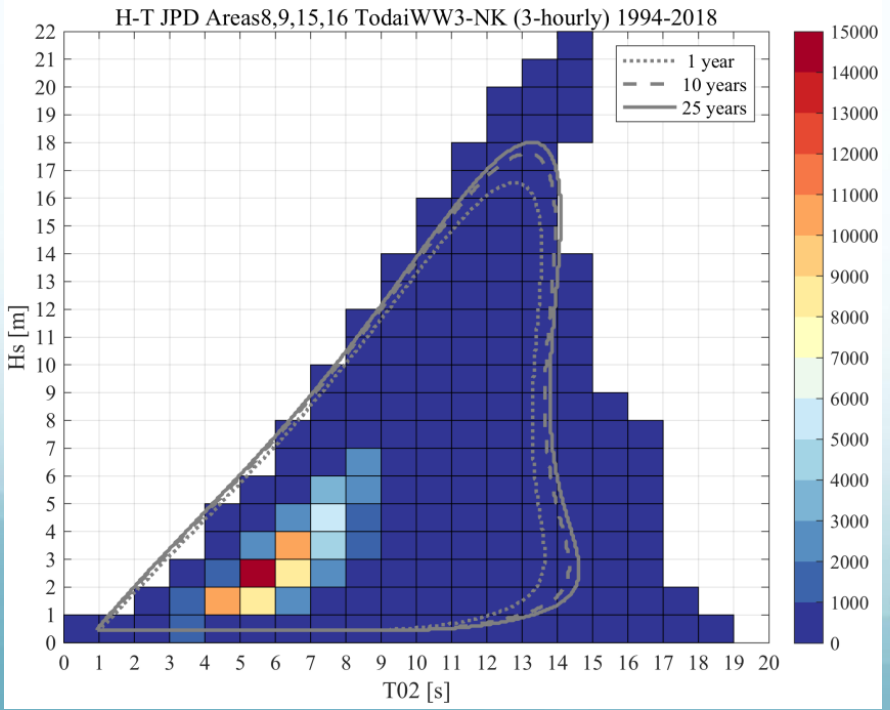




Environmental contour







Values of exceedance probability (ERA5/IOWAGA)

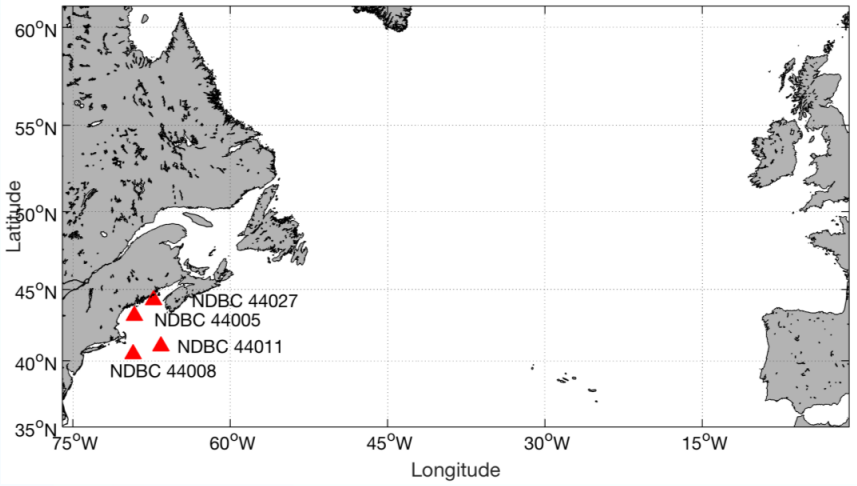
Cases	Return period	Exceedance Prob.
1	1	6.1830e-08
2	10	6.1830e-09
3	25	2.4732e-09

Values of exceedance probability (TodaiWW3-NK)

Cases	Return period	Exceedance Prob.
1	1	1.2596e-08
2	10	1.2596e-09
3	25	5.0386e-10

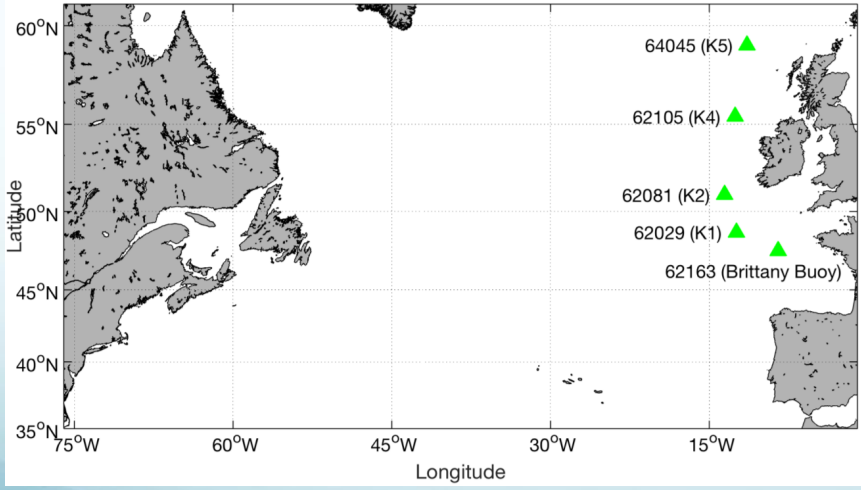
Haselsteiner et al. (2017)
Vanem and Bitner-Gregersen (2012)

Model validation: buoy locations



NDBC buoys

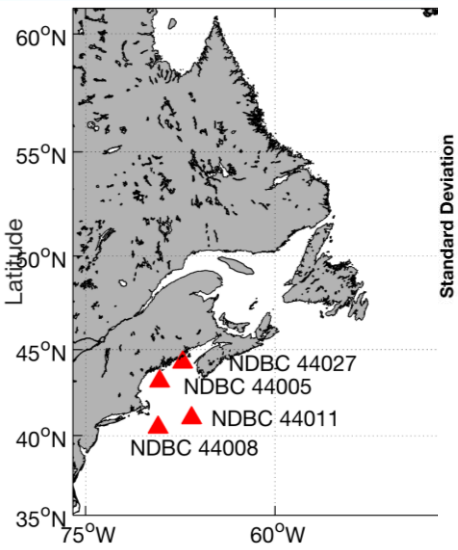
BUOY STATION	LAT	LON	GWS AREA	DEPTH (m)	DURATION OF DATA
44005	43.201N	69.128W	15	180.7	1978-2012, 2014-2018
44008	40.504N	69.248W	15	74.7	1982-2013, 2015-2018
44011	41.070N	66.588W	15	88.4	1984-2013, 2015-2018
44027	44.283N	67.3W	15	185.3	2003-2018

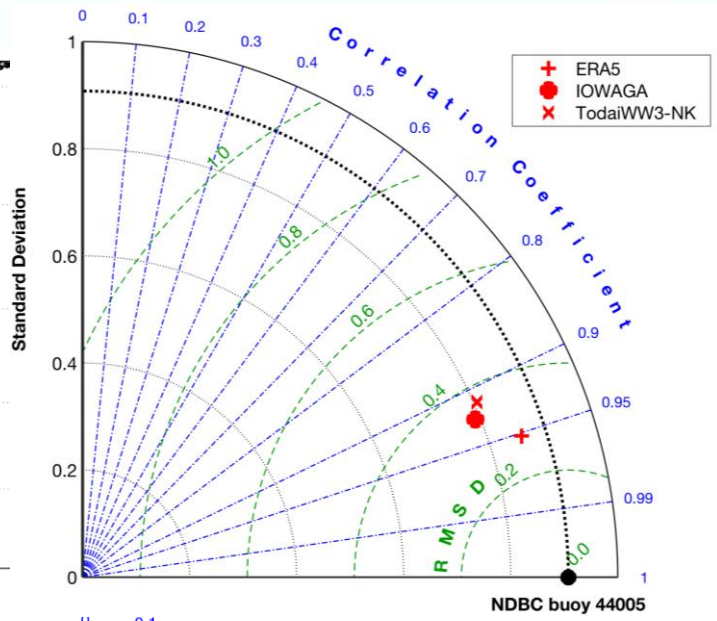


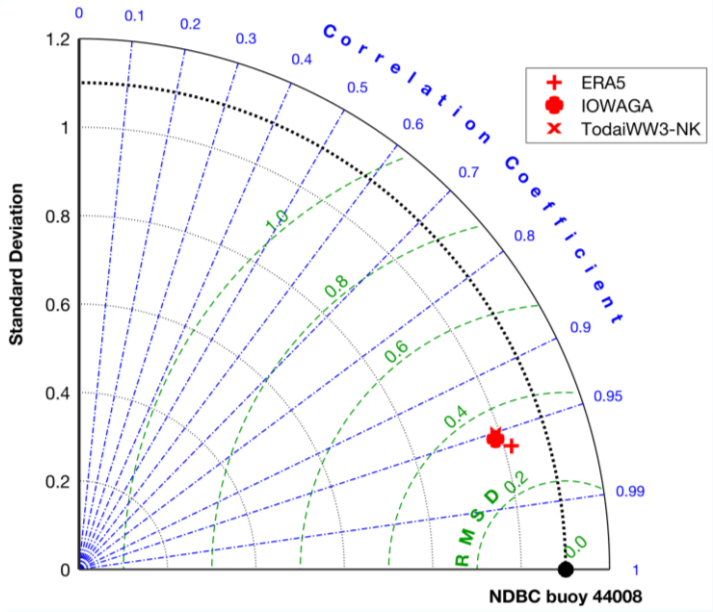
UK Met Office buoys

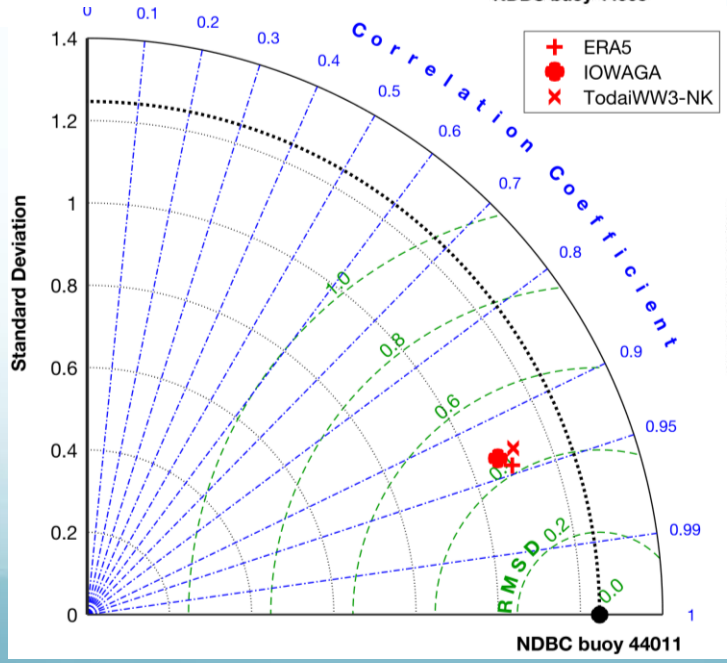
BUOY STATION	LAT	LON	GWS AREA	DEPTH (m)	DURATION OF DATA
62081 (K2)	51.00 N	13.55 W	9		1991 - 2018
62105 (K4)	55.420 N	12.570 W	9		1993 - 2018
64045 (K5)	59.070 N	11.420 W	9		1994 - 2018
62029 (K1)	48.720N	12.430 W	16		1991 - 2018
62163 (Brittany Buoy)	47.550 N	8.470 W	16		1995 - 2018

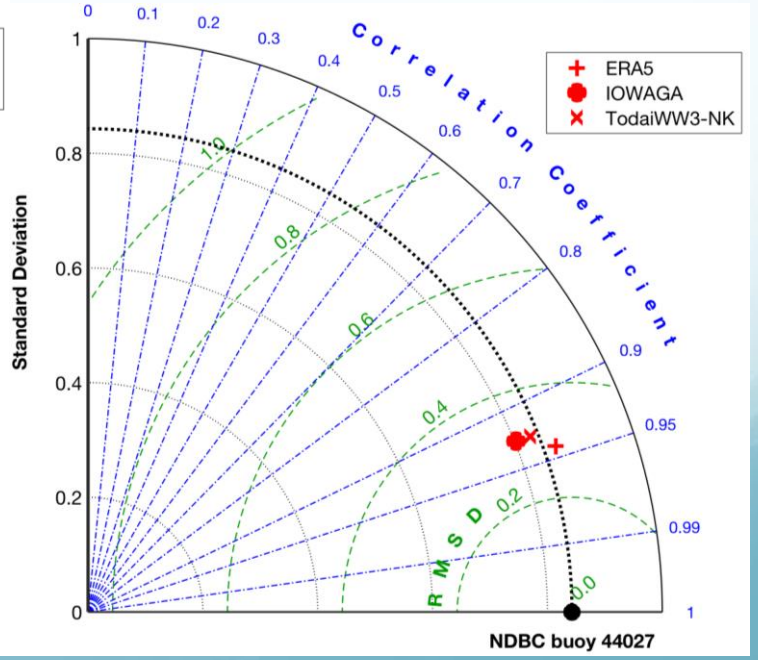
Model validation for Hs (NDBC buoys)



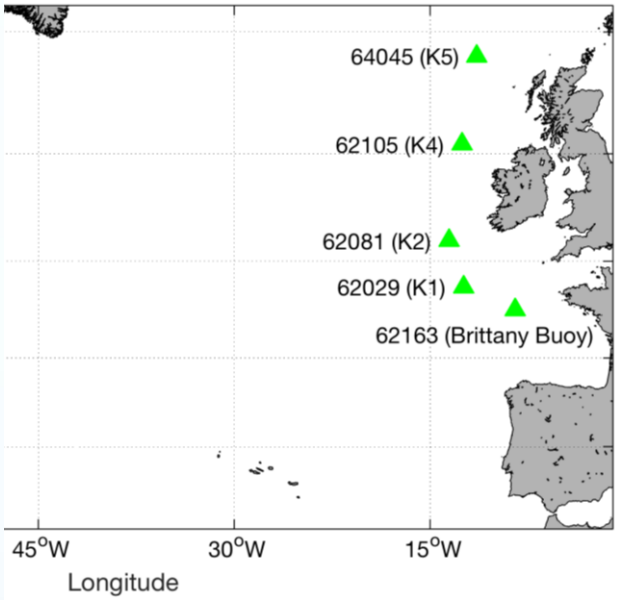


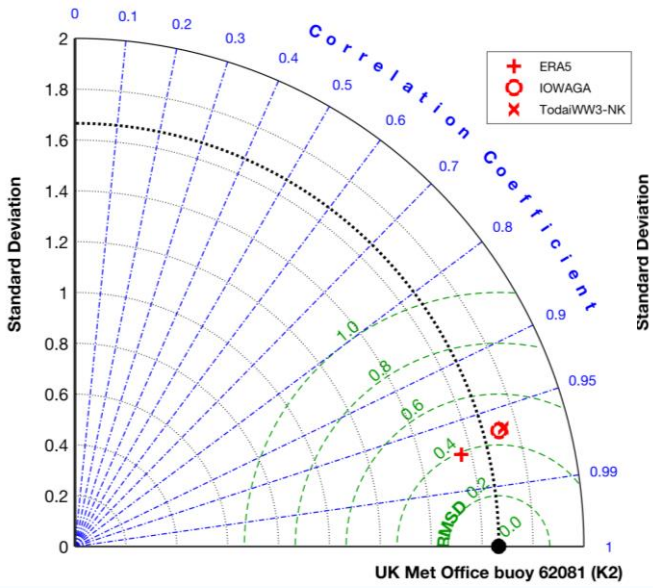


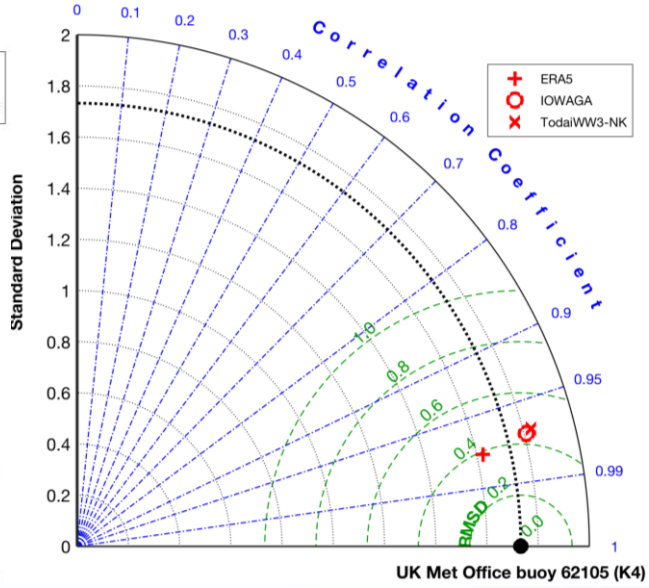


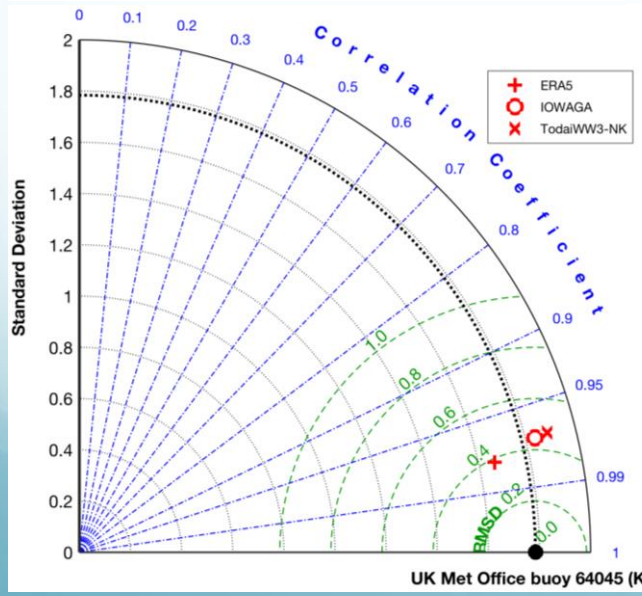


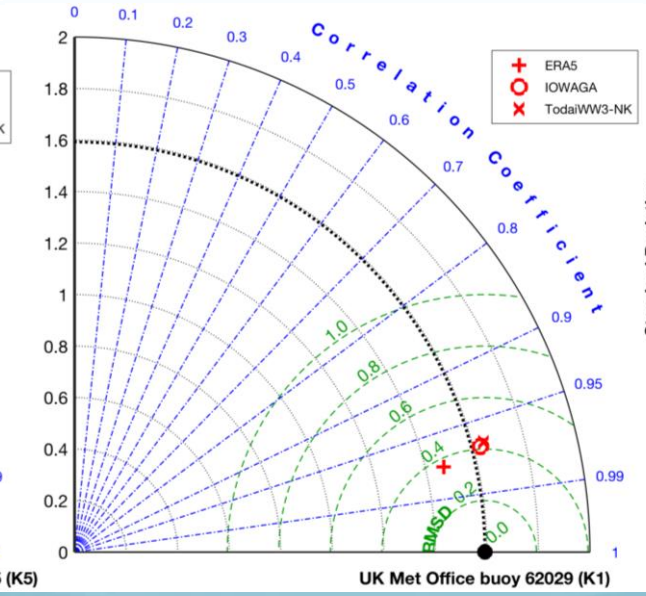
Model validation for Hs (UK Met Office buoys)

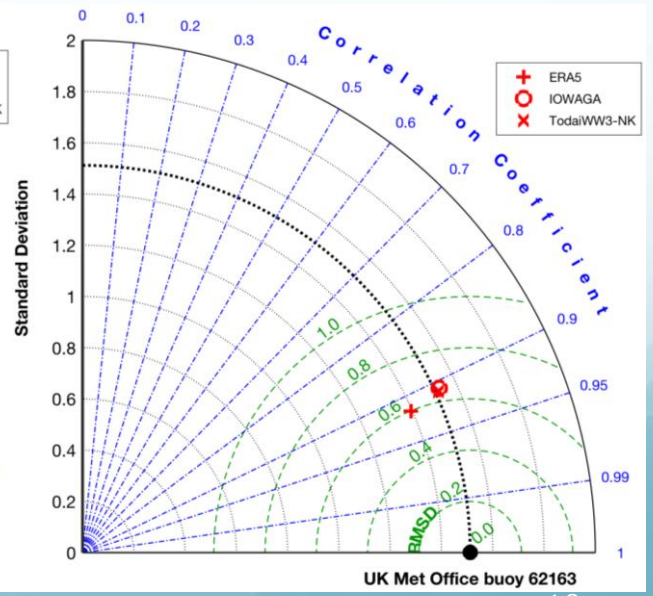




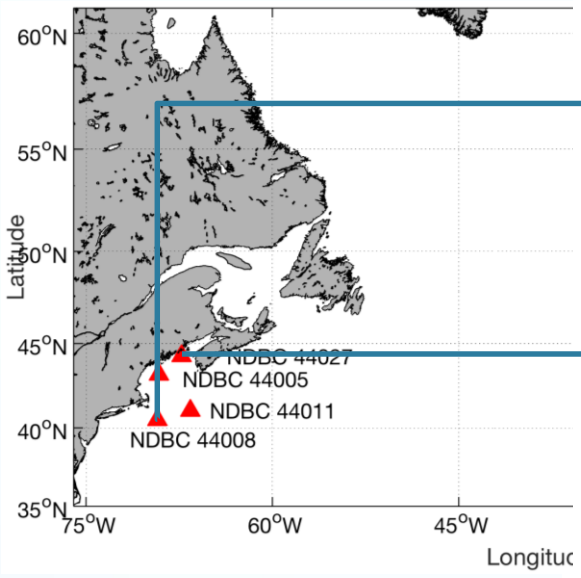








Statistics of Hs: model vs. buoy

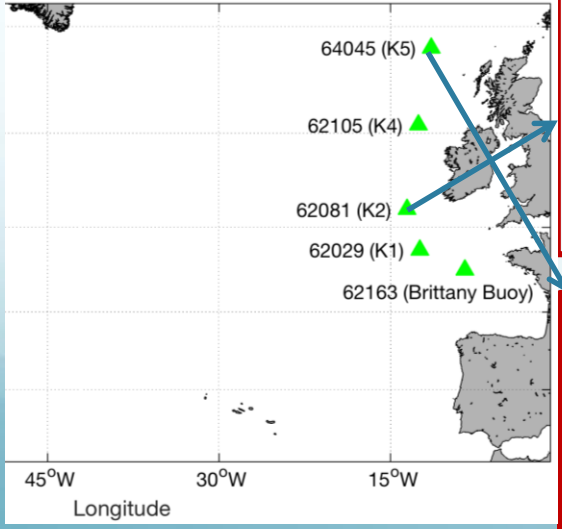


NDBC 44008

Statistics	Model		
	ERA5	IOWAGA	TodaiWW3-NK
CC	0.96	0.95	0.95
BIAS	0.03	0.05	0.05
RMSE	0.30	0.34	0.35
STD	1.01 (1.10)	0.98 (1.10)	0.99 (1.10)
SI	0.17	0.19	0.20

NDBC 44027

Statistics	Model		
	ERA5	IOWAGA	TodaiWW3-NK
CC	0.94	0.93	0.93
BIAS	0.18	0.12	0.06
RMSE	0.34	0.34	0.32
STD	0.86 (0.84)	0.80 (0.84)	0.83 (0.84)
SI	0.27	0.26	0.25



UK Met Office 62081 (K2)

Statistics	Model		
	ERA5	IOWAGA	TodaiWW3-NK
CC	0.97	0.96	0.96
BIAS	-0.12	0.06	0.07
RMSE	0.41	0.46	0.47
STD	1.56 (1.66)	1.72 (1.66)	1.74 (1.66)
SI	0.12	0.14	0.14

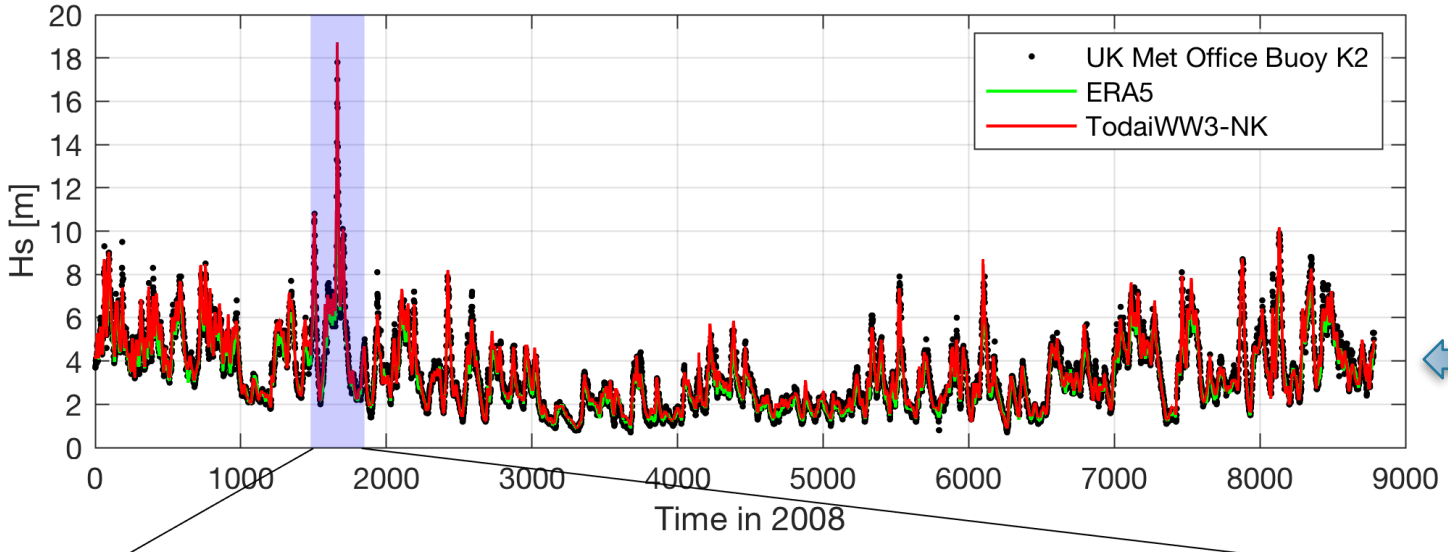
UK Met Office 64045 (K5)

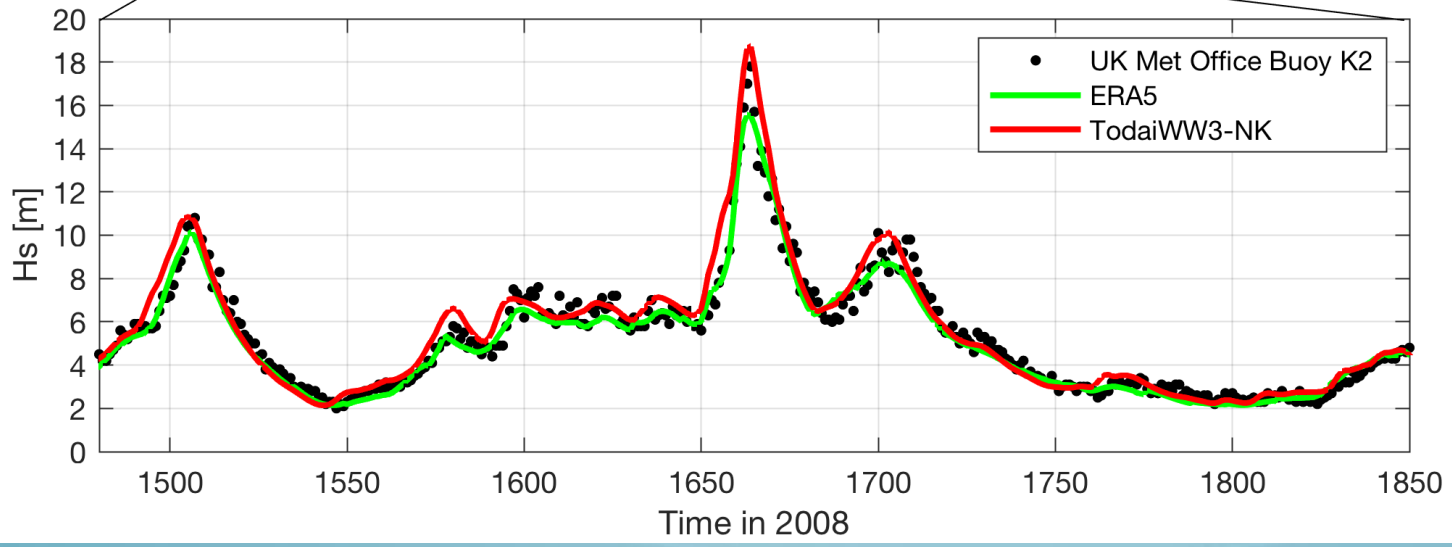
Statistics	Model		
	ERA5	IOWAGA	TodaiWW3-NK
CC	0.97	0.96	0.96
BIAS	-0.15	-0.0075	0.03
RMSE	0.41	0.44	0.47
STD	1.66 (1.78)	1.83 (1.78)	1.88 (1.78)
SI	0.11	0.12	0.13

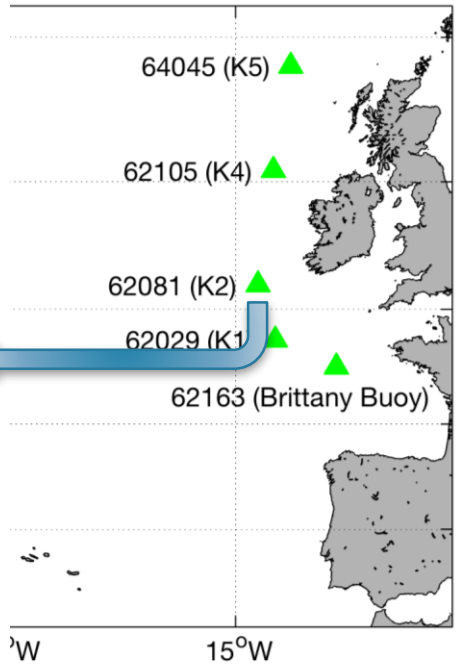
Comparison with buoy (K2) data for 2008

Hourly data

Buoy Hs,max = 17.8 m

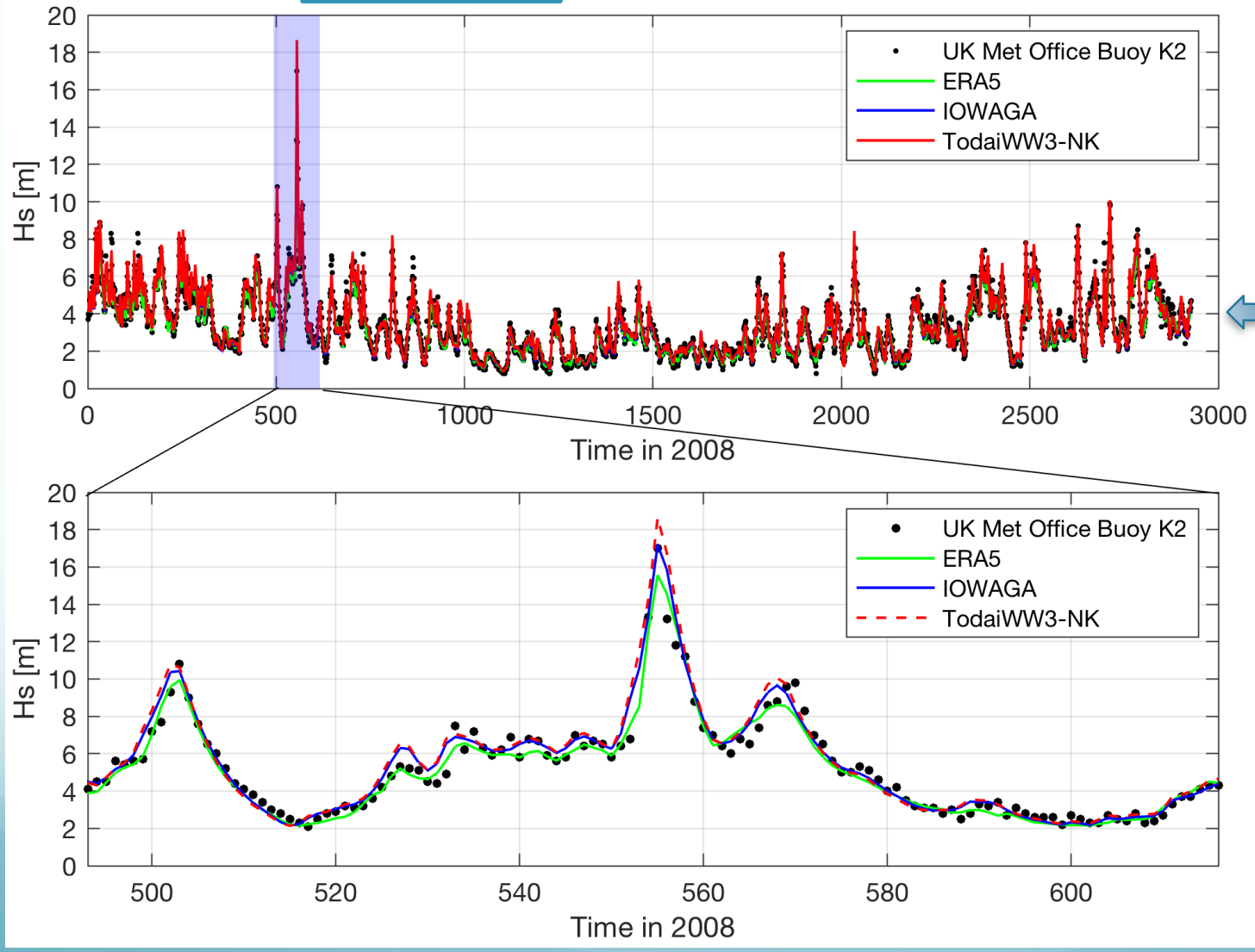


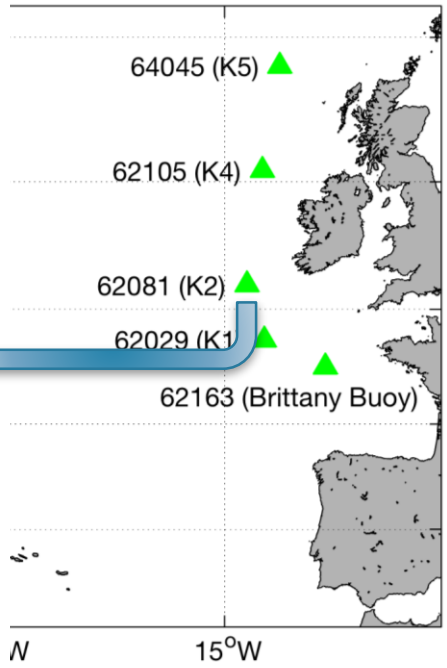




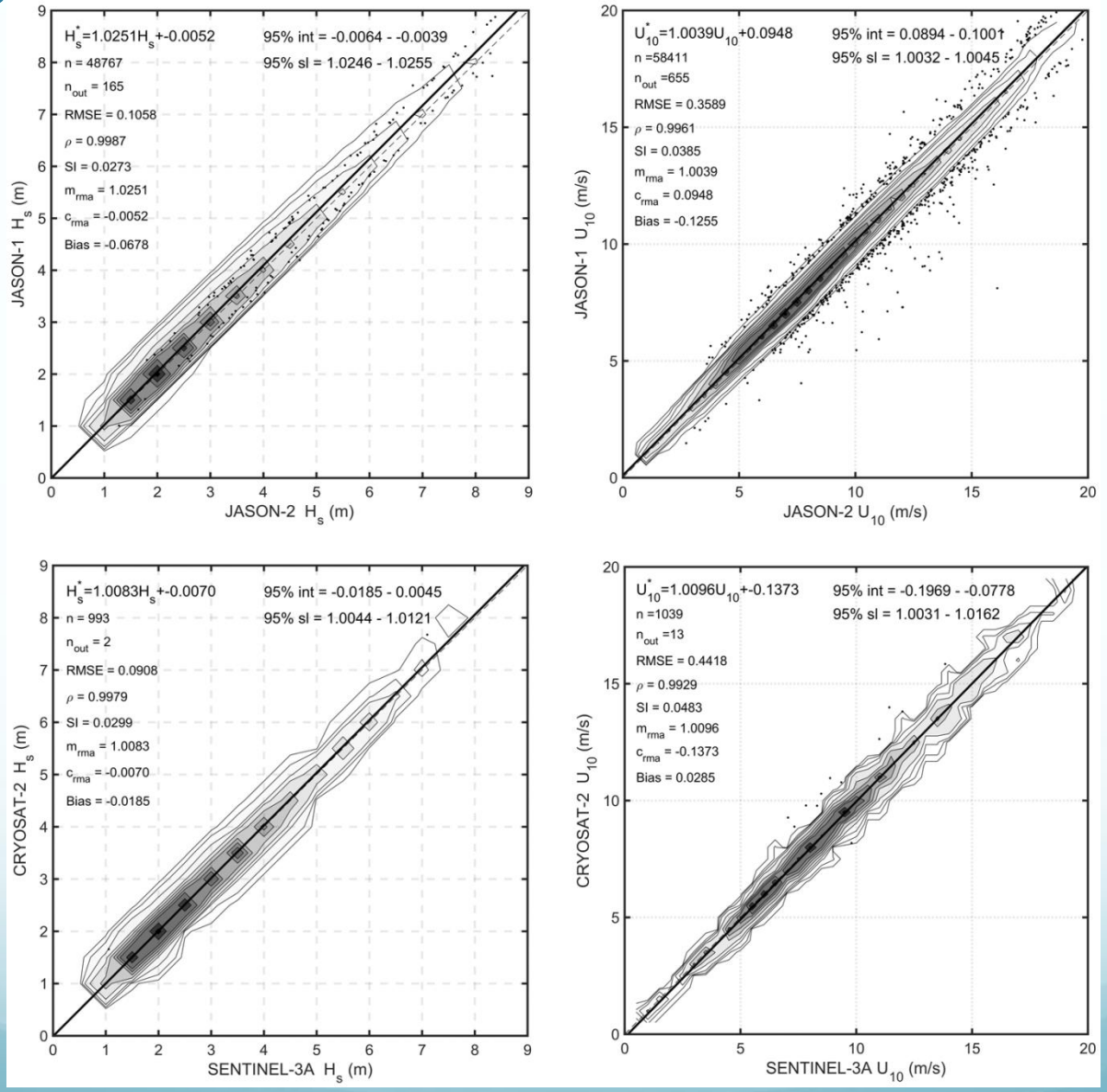
Comparison cont.

3-hourly data



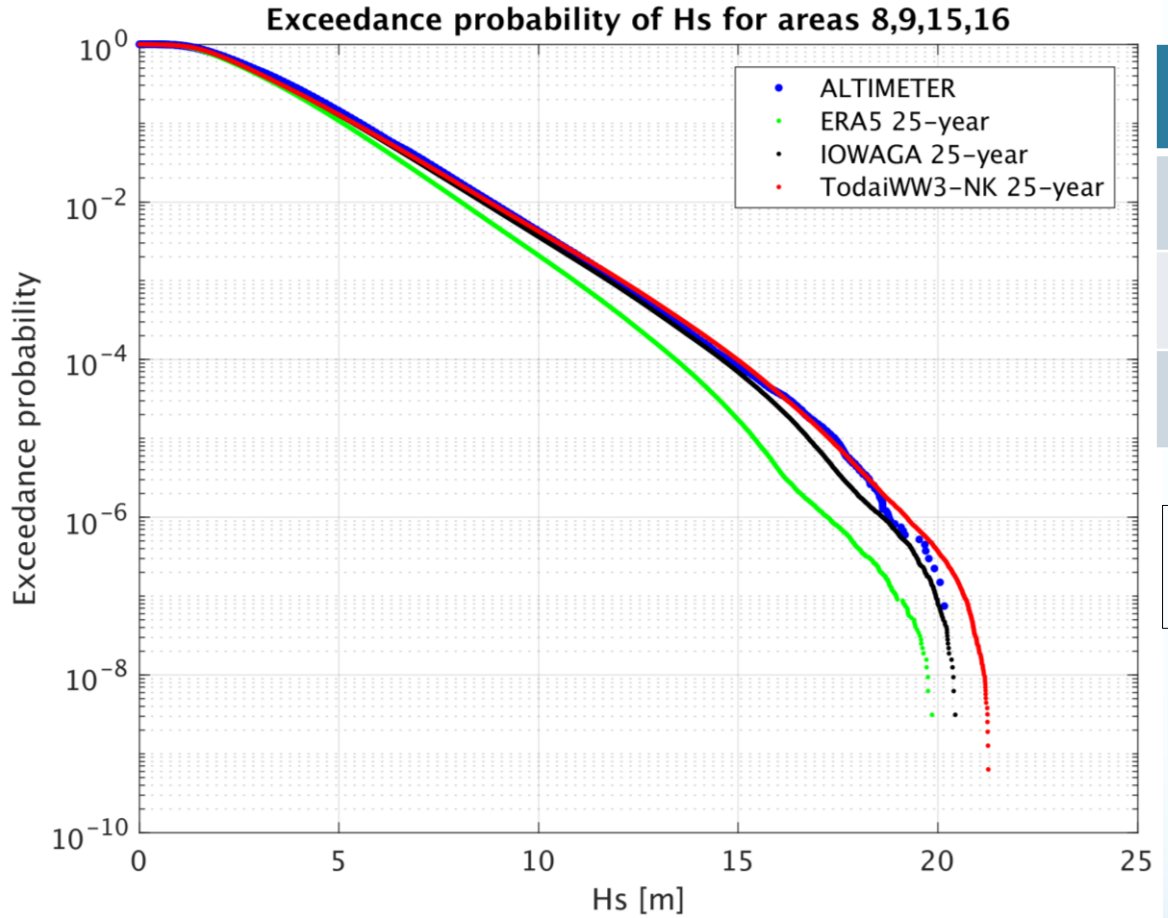


Cross-validation between the altimeters for significant wave height and wind speed.



Source: Ribal and Young (2019)

Comparison with altimeter data

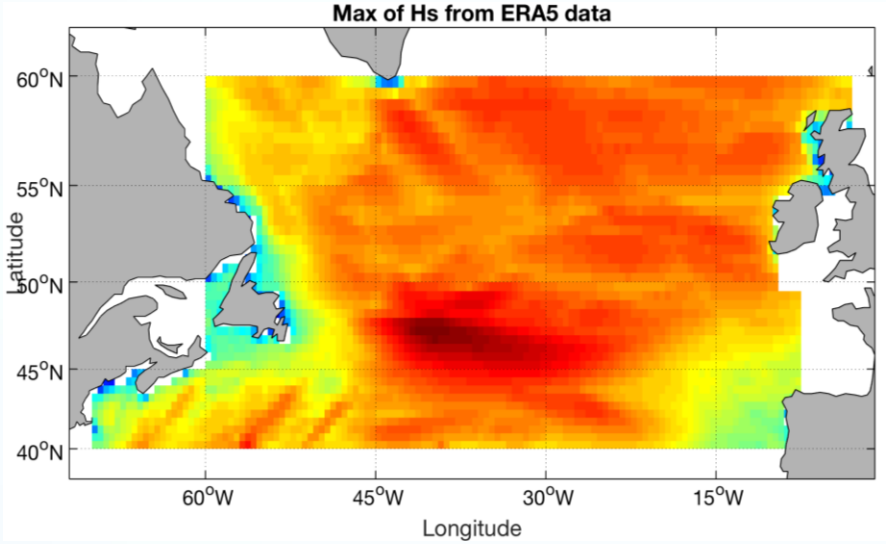


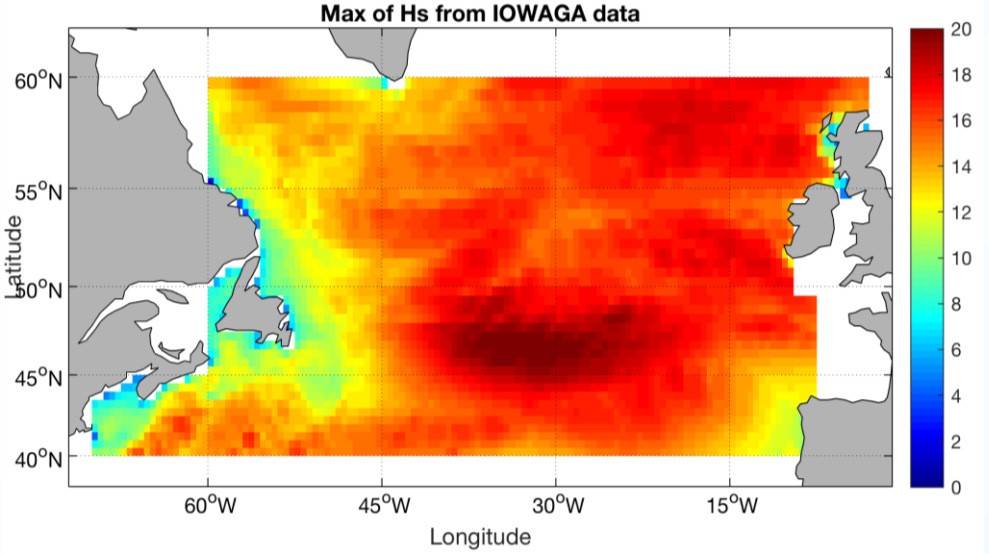
Altimeter	Repeat days	Freq. band	Duration
TOPEX	10	Ku C	1994-2004
JASON-1	10	Ku C	2005-2012
JASON-2	10	Ku C	2013-2018

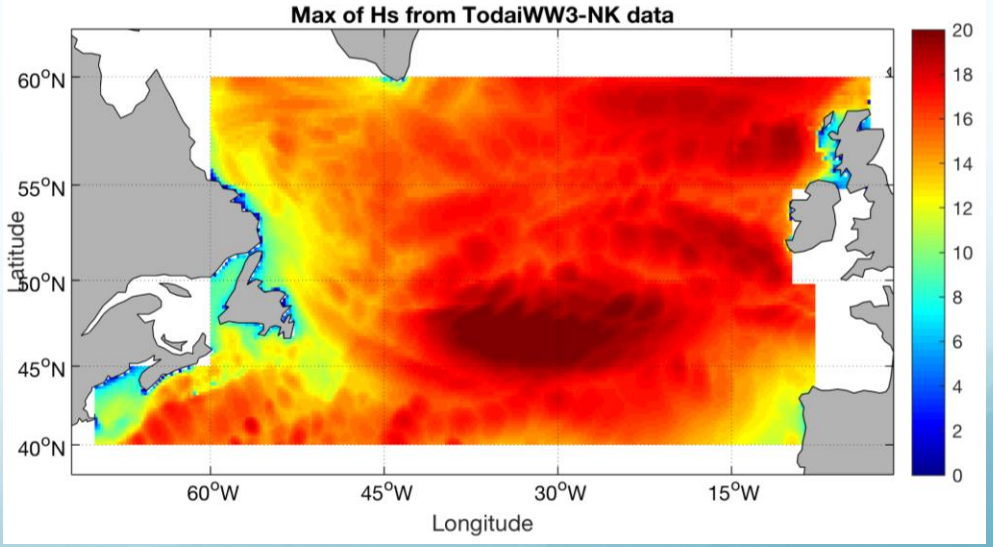
Altimeter data is obtained from Ribal and Young (2019)

Wave data from the models and altimeters are extracted for the GWS areas 8,9,15 and 16. The duration of the data is 25 years (1994-2018).

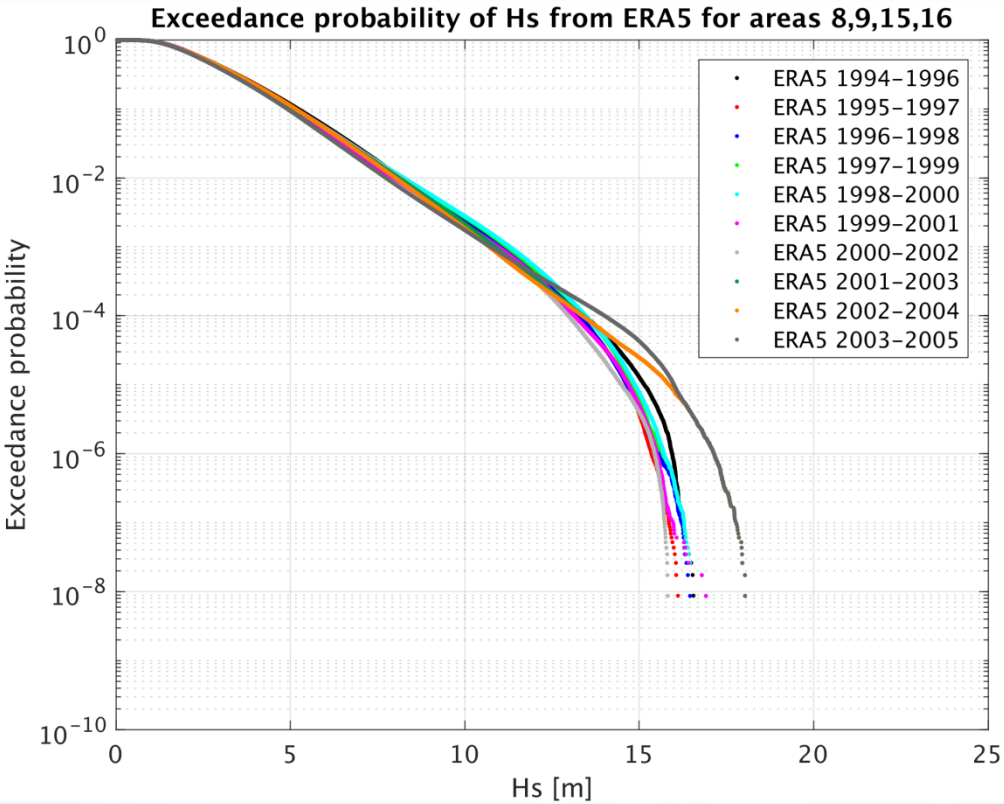
25-year (1994-2018) maximum of Hs

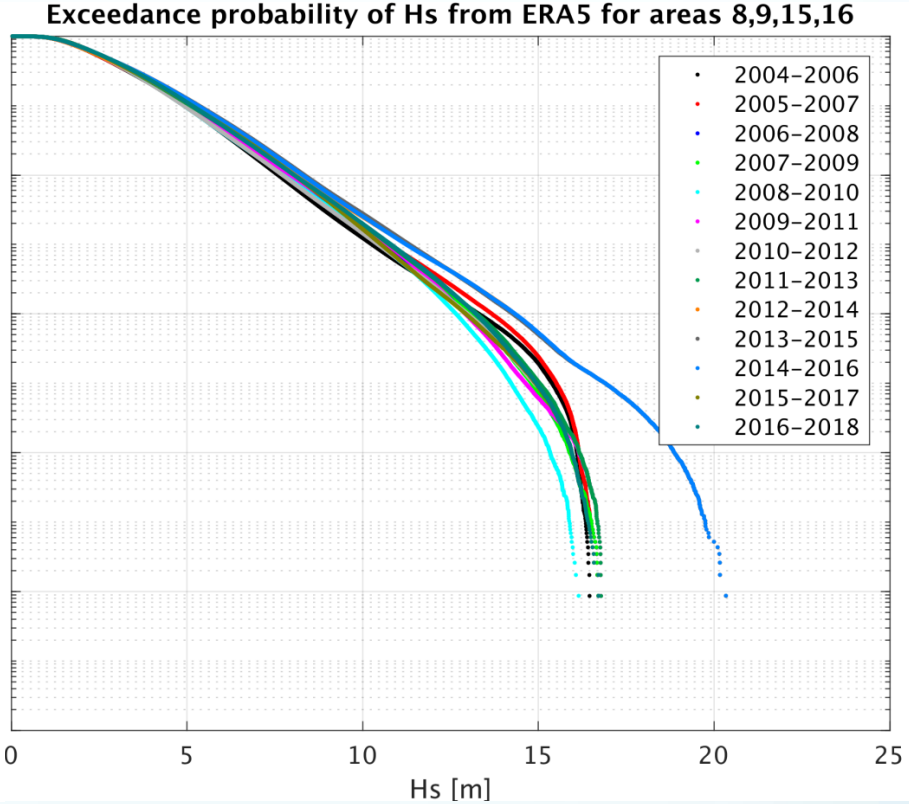






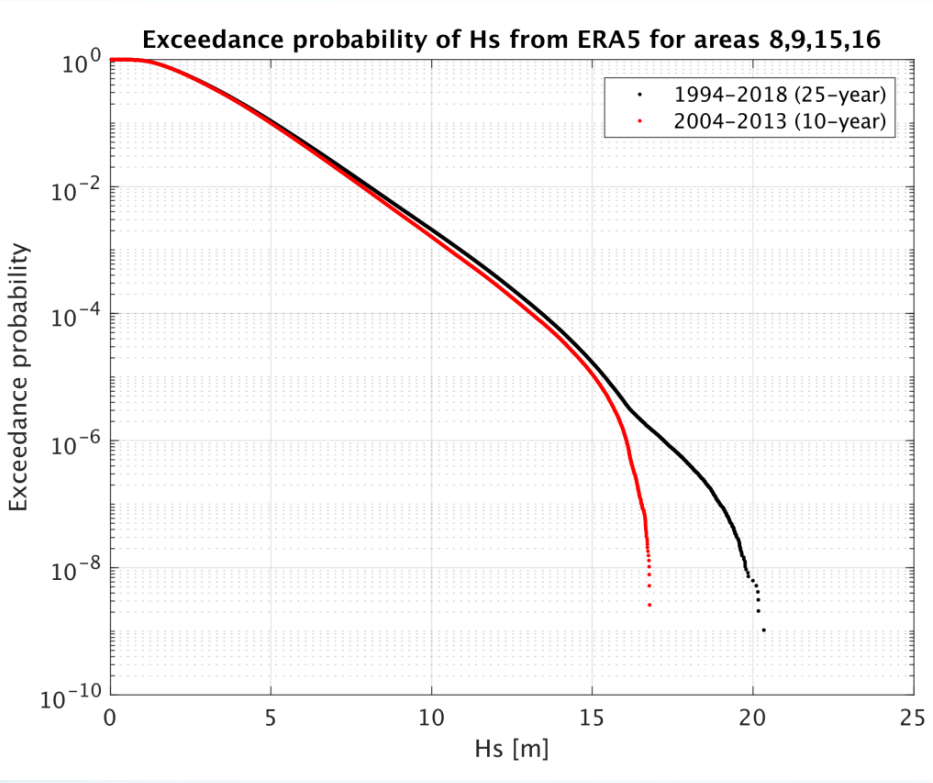
Exceedance probability for different 3 years subset

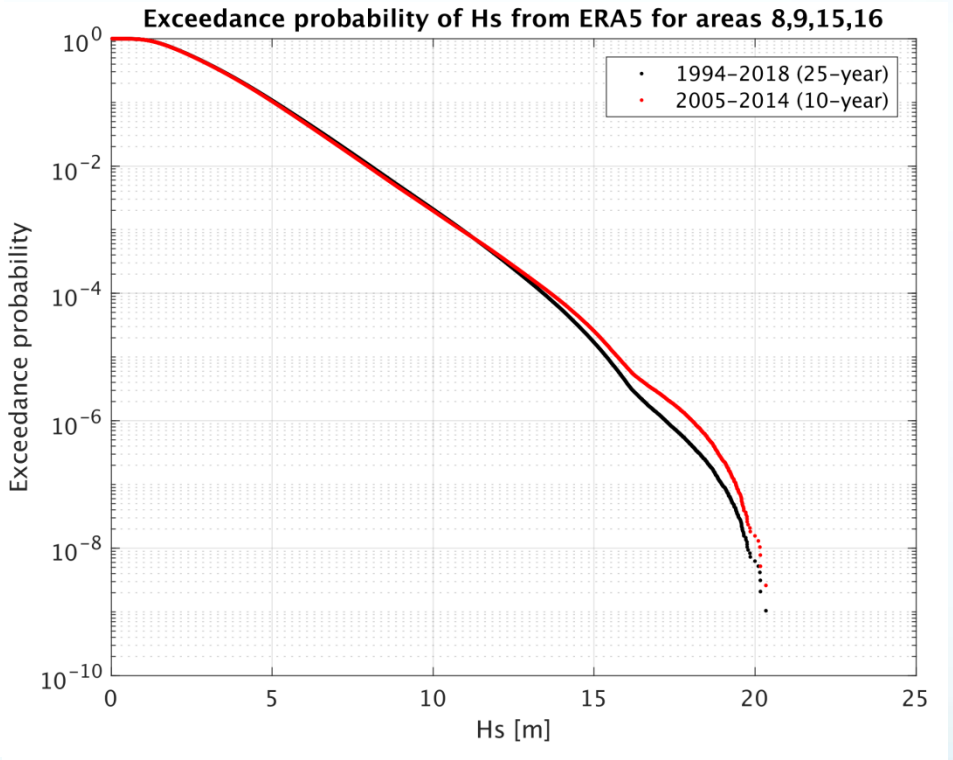




Wave data sets from the ERA5are extracted for the GWS areas 8,9,15 and 16.

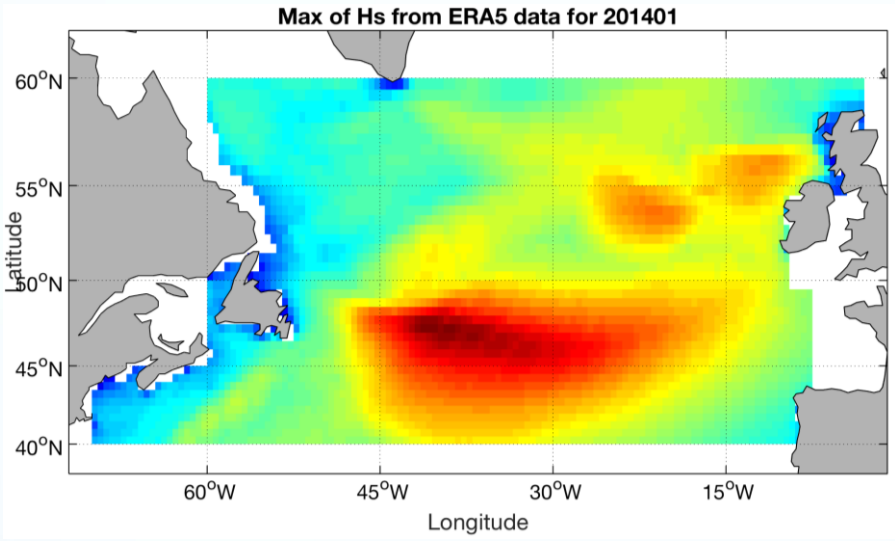
Comparison of exceedance probability of Hs

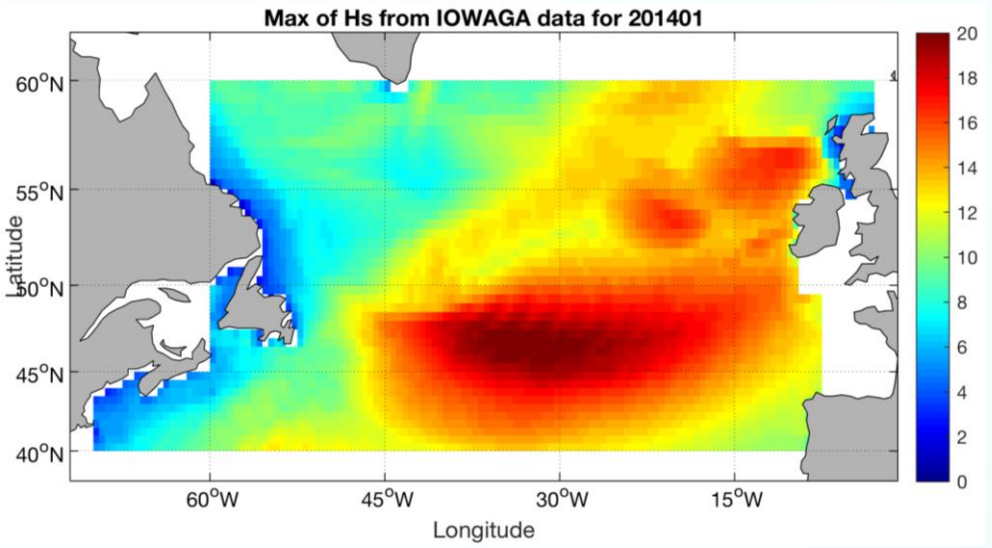


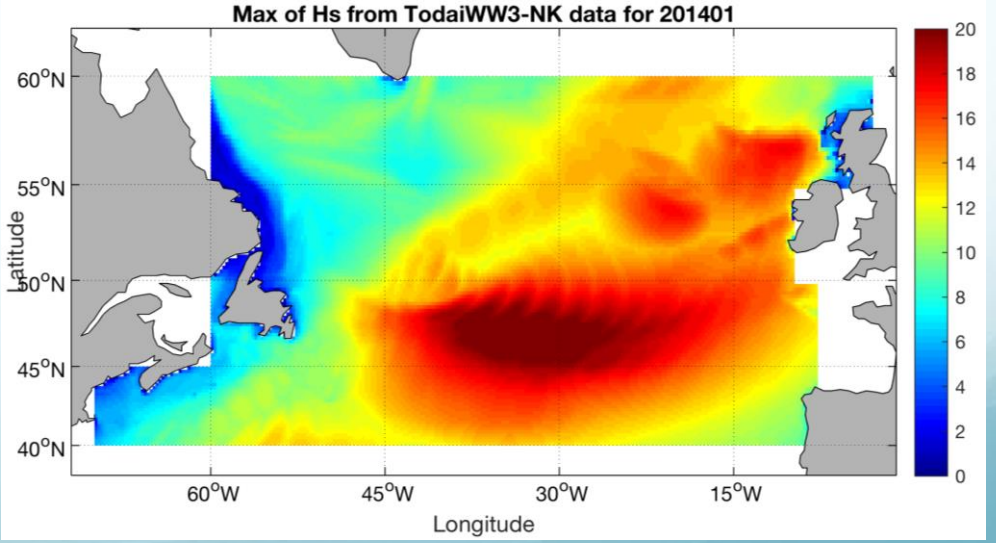


Wave data sets from the ERA5are extracted for the GWS areas 8,9,15 and 16.

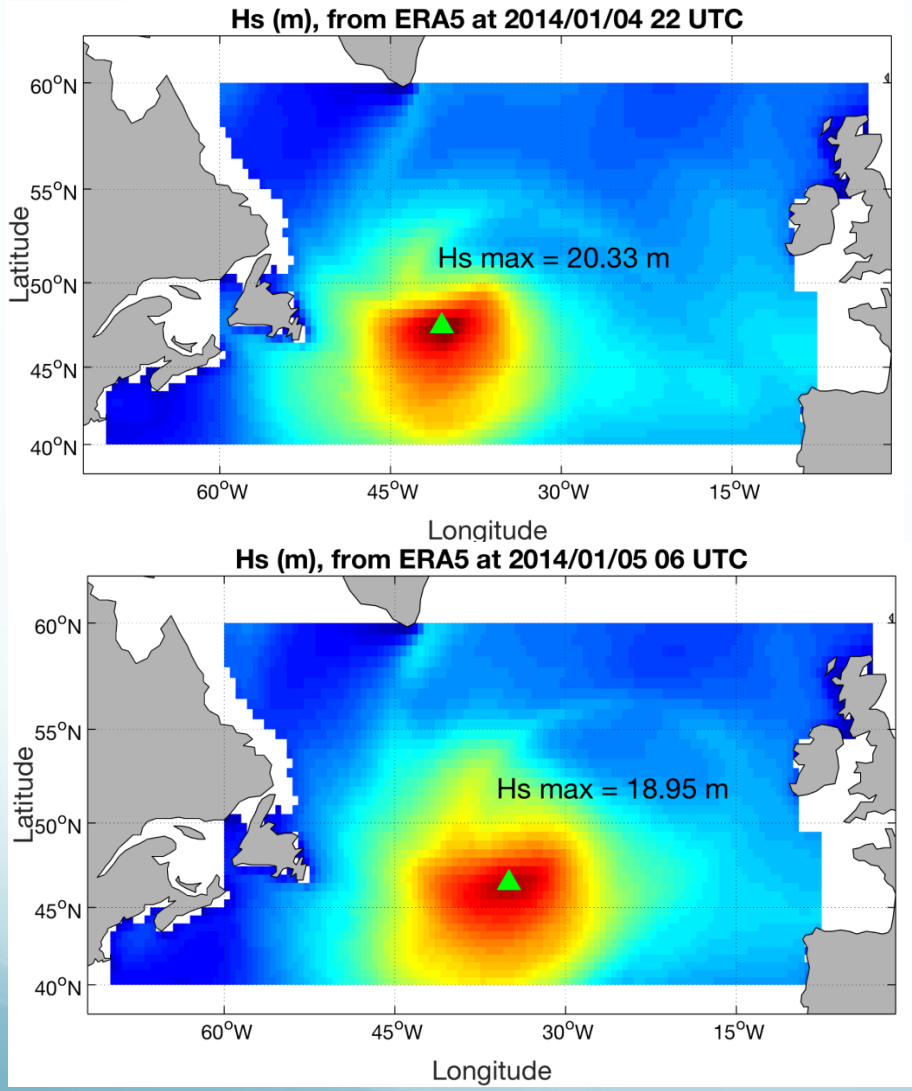
Extreme event in 2014/01

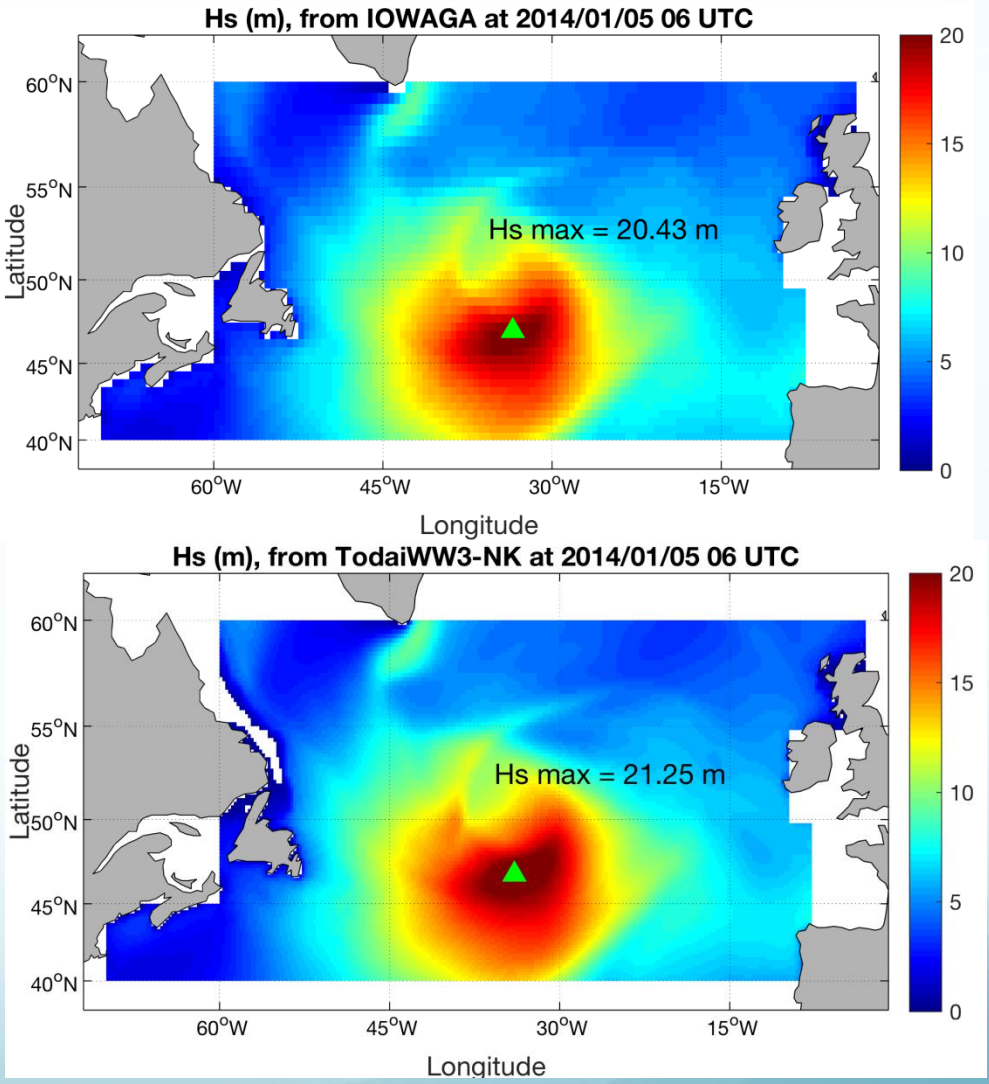




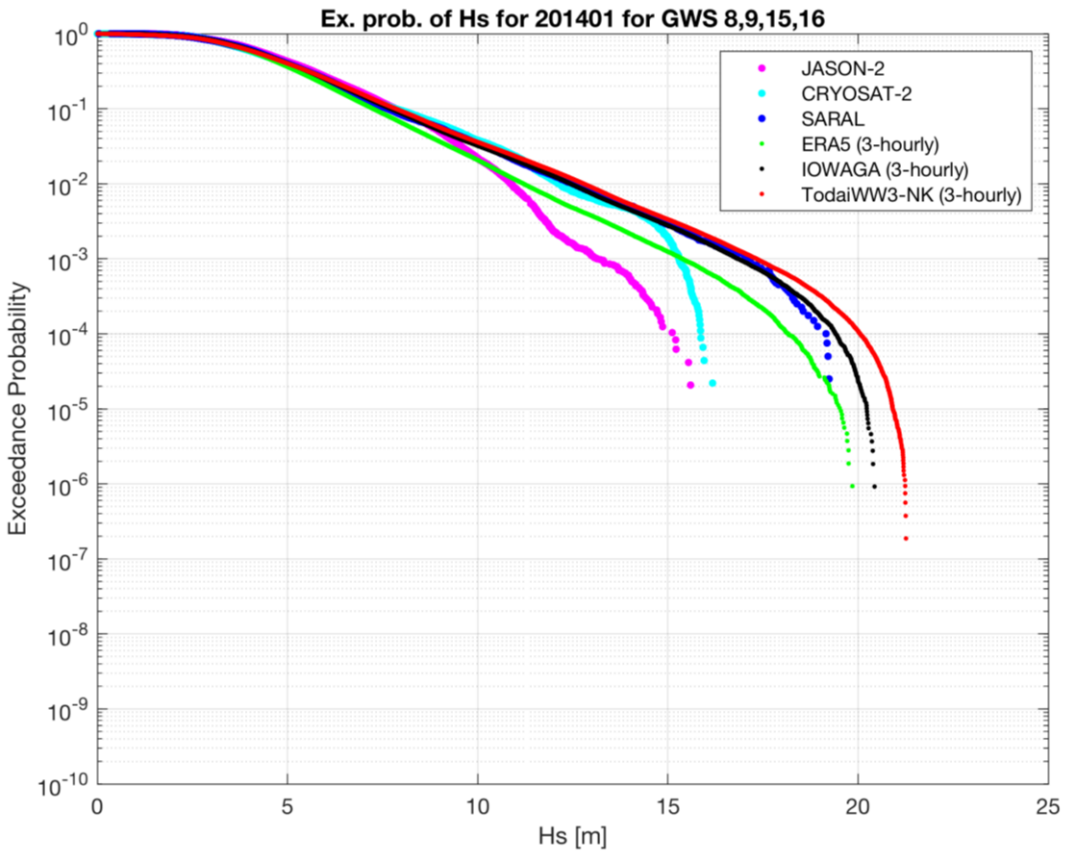


Extreme event in 2014/01





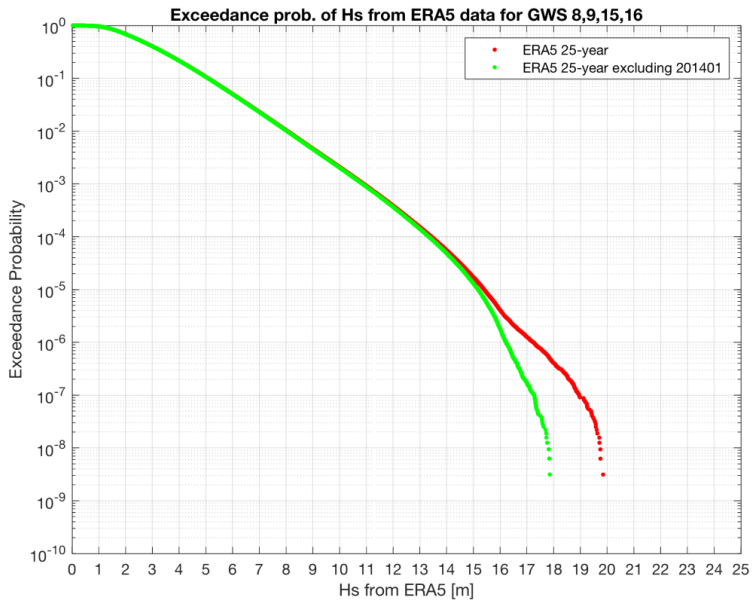
Comparison of Exceedance probability of Hs for 2014/01

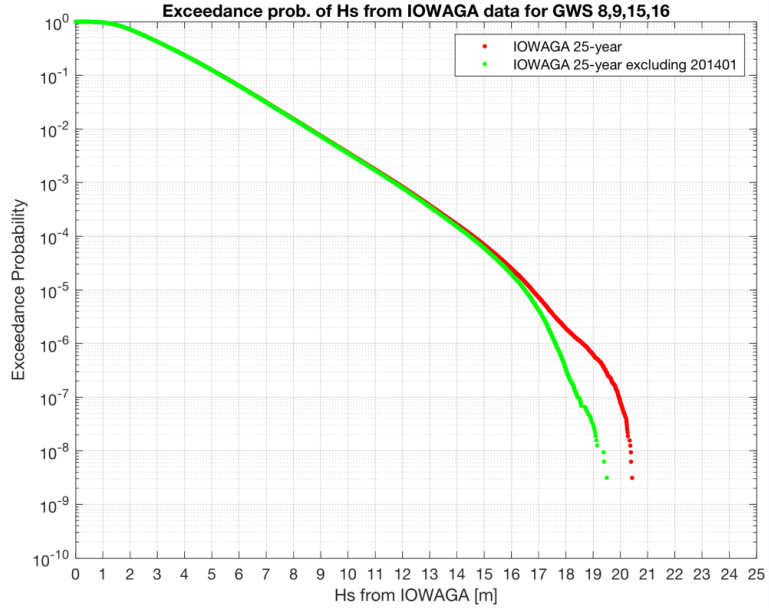


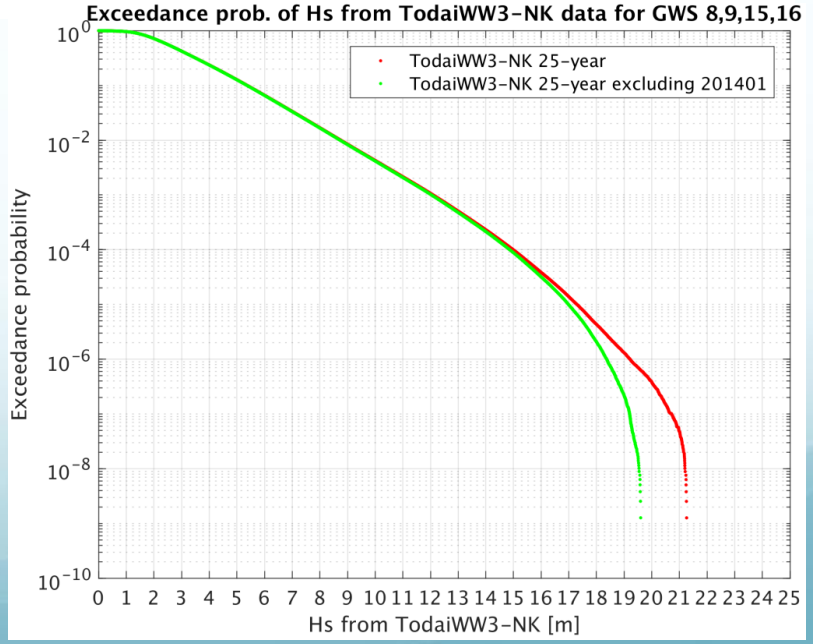
Altimeter	Repeat days	Freq. band	Duration
JASON-2	10	Ku C	2014/01
CRYOSAT-2	30	Ku	2014/01
SARAL	35	Ka	2014/01

Ribal and Young (2019)

Comparison of 25 years statistics with and without 2014/01

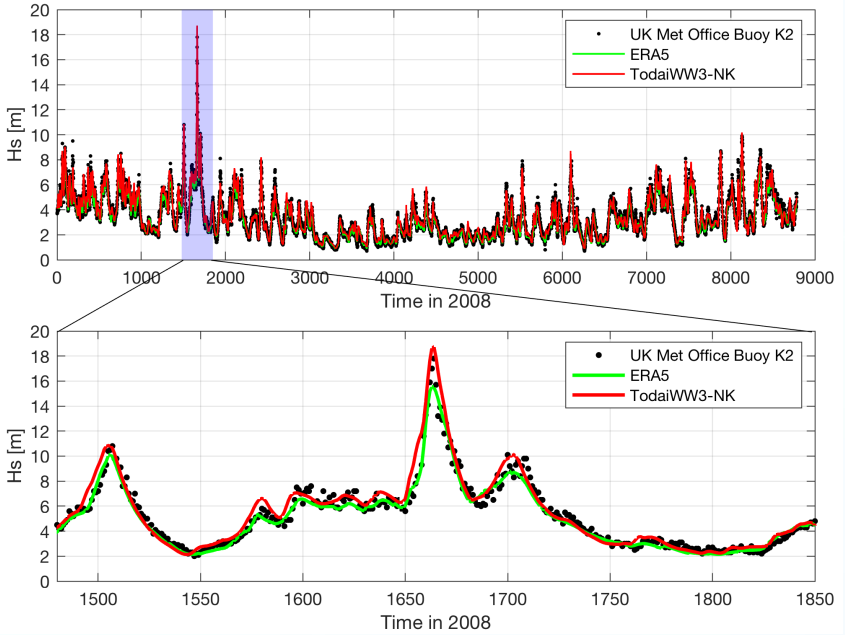


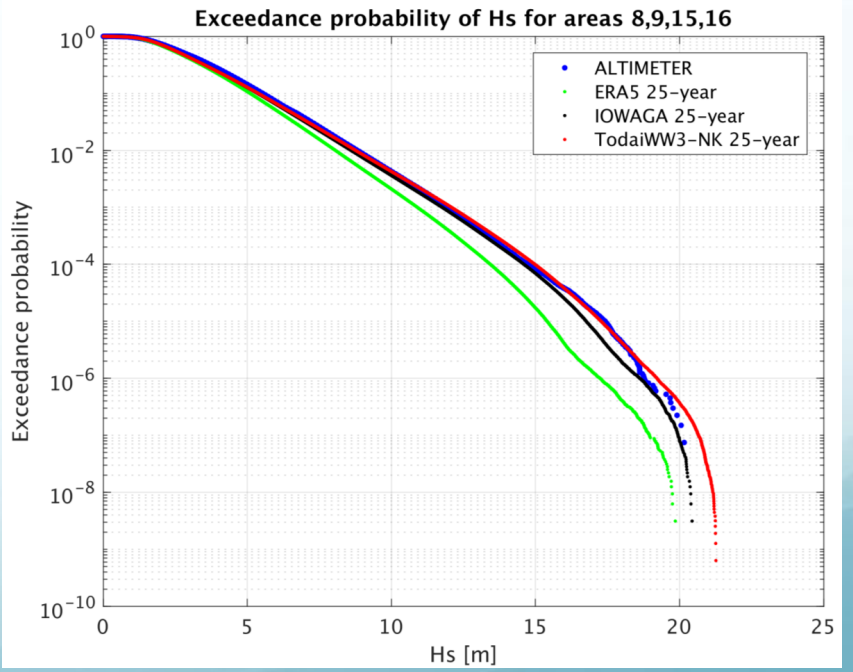




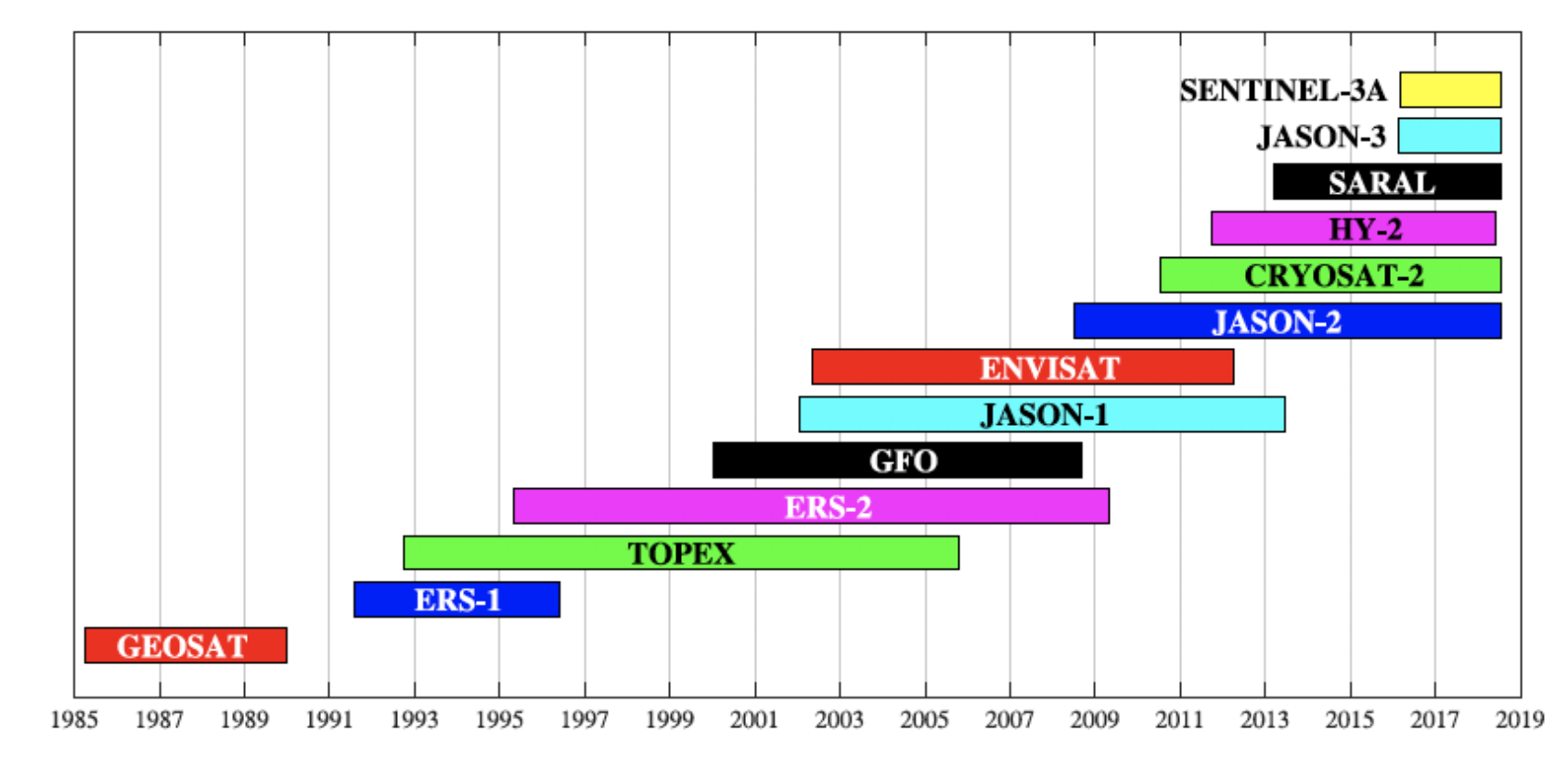
Summary

- Comparison between ERA5, IOWAGA, and TodaiWW3-NK data are shown (JPD diagrams, environmental contours, exceedance probability) by using 25-year wave data for the GWS 8,9,15, and 16 areas.
- Model results are validated against NDBC and UK Met Office buoys and show good agreement for significant wave height at coastal as well as offshore locations.
- UK Met Office buoy K2 measured significant wave height of 17.8 m during 2008/03. For this extreme event, TodaiWW3-NK performs better than ERA5.
- The agreement between models and altimeter for the exceedance probability of Hs is noteworthy at higher waves (18 - 20 m).
- Impact of the model resolution is also illustrated in case of extreme event.
- Within the 25-year analysis period, the largest wave event occurred during 2014/01. Hs,max reached above 20 m (ERA5 and IOWAGA) and above 21 m (TodaiWW3-NK).
- When these extreme events are excluded from the data, tail of the 25-year statistics reduces significantly.





Thank you for your attention



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Altimeter	Exact repeat mission (days)	Inclination	Altitude (km)	Freq. (GHz)	Freq. Band	Latitude coverage	Initial Date	Final Date
GEOSAT	23/17	108°	800	13.5	Ku	−73 to 72	31/03/1985	31/12/1989
ERS-1	35/168	98°	784	13.8	Ku	−81.5 to 81.5	01/08/1991	02/06/1996
TOPEX	10	66°	1336	13.575 5.3	Ku C	−66 to 66	25/09/1992	08/10/2005
ERS-2	35	98°	784	13.8	Ku	−81.5 to 81.5	29/04/1995	11/05/2009
GFO	17	108°	800	13.5	Ku	−73 to 72	07/06/2000	07/09/2008
JASON-1	10	66°	1336	13.575 5.3	Ku C	−66.15 to 66.15	15/01/2002	21/06/2013
ENVISAT	35	98°	784	13.6 3.2	Ku S	−82 to 82	14/05/2002	08/04/2012
JASON-2	10	66°	1336	13.575 5.3	Ku C	−66.15 to 66.15	04/07/2008	Ongoing
CRYOSAT-2	30	92°	717	13.575	Ku	−88 to 88	14/07/2010	Ongoing
HY-2A	14	99.3°	963.6	13.58 5.25	Ku C	−81 to 80	01/10/2011	06/06/2018
SARAL	35	98.538°	~800	35.75	Ka	−81.49 to 81.49	14/03/2013	Ongoing
JASON-3	10	66°	1336	13.575 5.3	Ku C	−66.15 to 66.15	12/02/2016	Ongoing
SENTINEL-3A	27	98.65°	814.5	13.575 5.41	Ku C	−78 to 81	01/03/2016	Ongoing

Table 1. Summary of altimeter operating characteristics for the thirteen altimeter missions, including exact repeat mission period (time until satellite repeats the same ground track), orbit parameters, antenna properties, latitude coverage, and operational time for which data is available.

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Details of TodaiWW3-NK

- NOAA WAVEWATCH III 6.07
- 0.20 x 0.25 (Lat x Lon) spatial resolution
- 35 frequency bins, 36 directional bins
- ST4 (Ardhuin et al., 2010)
- CFSR/NCEP hourly wind
- CFSR/NCEP daily sea ice concentration
- Computation period: 1994-2018
- Spin-up time: 1 month