Inter-comparison of Operational Wave Forecasting Systems

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Thomas Bruns, ***Deutscher Wetterdienst***, **Germany, (DWD),**

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Fabrice Ardhuin, ***Service Hydrographique et Océanographique de la Marine***, **France, (SHOM)**

Nadao Kohno, ***Japan Meteorological Agency***, **Japan, (JMA),**

Sanwook Park, ***Korea Meteorological Administration***, **Republic of Korea, (KMA),**

Marta Gomez, ***Puertos del Estado***, **Spain (PRTOS).**

Motivations:

- **Following WISE 1995, a routine inter-comparison of wave model forecasts was set-up.**
- **It was intended to provide a mechanism for benchmarking wave forecast products.**
- **Since the early 90's, more wave observations have been available.**
- **Wave forecasting is now routine at many operational centres.**
- **The JCOMM Expert Team on Wind Waves and Storm Surges (ETWS) following ETWS-1(Halifax, 2003) endorsed the expansion of the project.**
- **At ETWS-2 (Geneva 2007), it was agreed to continue and expand this activity.**
- **First results were presented during WAVES97 (Bidlot et al. 1998) and a peer review paper was published (Bidlot et al. 2002).**
- **It is now opportune to review what has been achieved.**

Methodology:

- **Each month, model data (analysis and forecasts) are exchanged for a set of prescribed locations where wave and wind observations are made.**
- **A simple ASCII format is used.**
- **The data sets are combined at ECMWF and quality controlled in-situ observations of wind speed and direction, wave height and wave period are added to the data set.**
- **The combined data sets are made available to all participants.**
- **Summary plots and tables are also produced at ECMWF.**
- **A technical report is available at:**

http://www.wmo.ch/pages/prog/amp/mmop/documents/Jcomm-TR/J-TR-30/J-TR-30.pdf

Conclusions:

- This informal inter-comparison of wind and wave model data has worked well for over 12 years.
- It is time to work on extending this exercise.
- By adding wave spectra?
- By comparing to remotely sensed data (Altimeter(s), SARs)?
- By exchanging model fields (High Resolution Diagnostic Data set (HHDR) approach, objective score approach)?

Participants :

1995:

- *European Centre for Medium range Weather Forecasts* **(ECMWF), global model.**
- ***The Met Office*, UK, (MO), global model.**
- ***Fleet Numerical Meteorology and Oceanography Centre*, USA, (FNMOC), global model.**
- **Meteorological Service of *Canada*, Canada, (MSC), 2 limited area models (N Pac. & N Atl.).**

1996:

- ***National Centers for Environmental Prediction*, USA, (NCEP), global model.**

2001:

- ***Météo France*, France (MF), global model***

2004:

- ***Deutscher Wetterdienst*, Germany, (DWD), global model and limited area models (N Sea & Med.).**

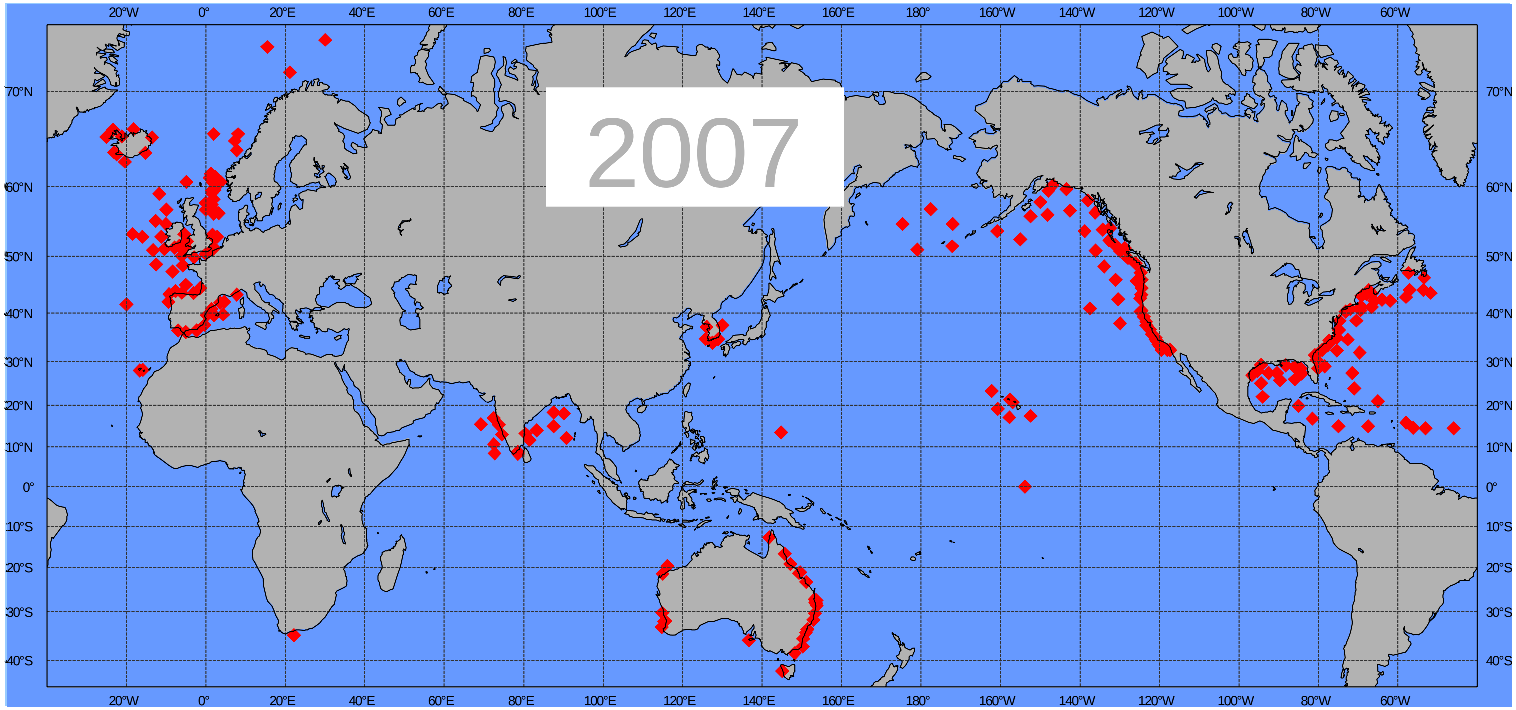
2006:

- ***Bureau of Meteorology*, Australia, (BoM), global model.**
- ***Service Hydrographique et Océanographique de la Marine*, France, (SHOM), global model & N Atl..**
- ***Japan Meteorological Agency*, Japan, (JMA), global model.**

2007:

- ***Korea Meteorological Administration*, Republic of Korea, (KMA), global model.**
- **Puetos del Estado, Spain (PRTOS), limited area models (N Atl. & Med.).**

In-situ observations from buoys and platforms:



Locations where wind and wave data were collocated with ECMWF model.

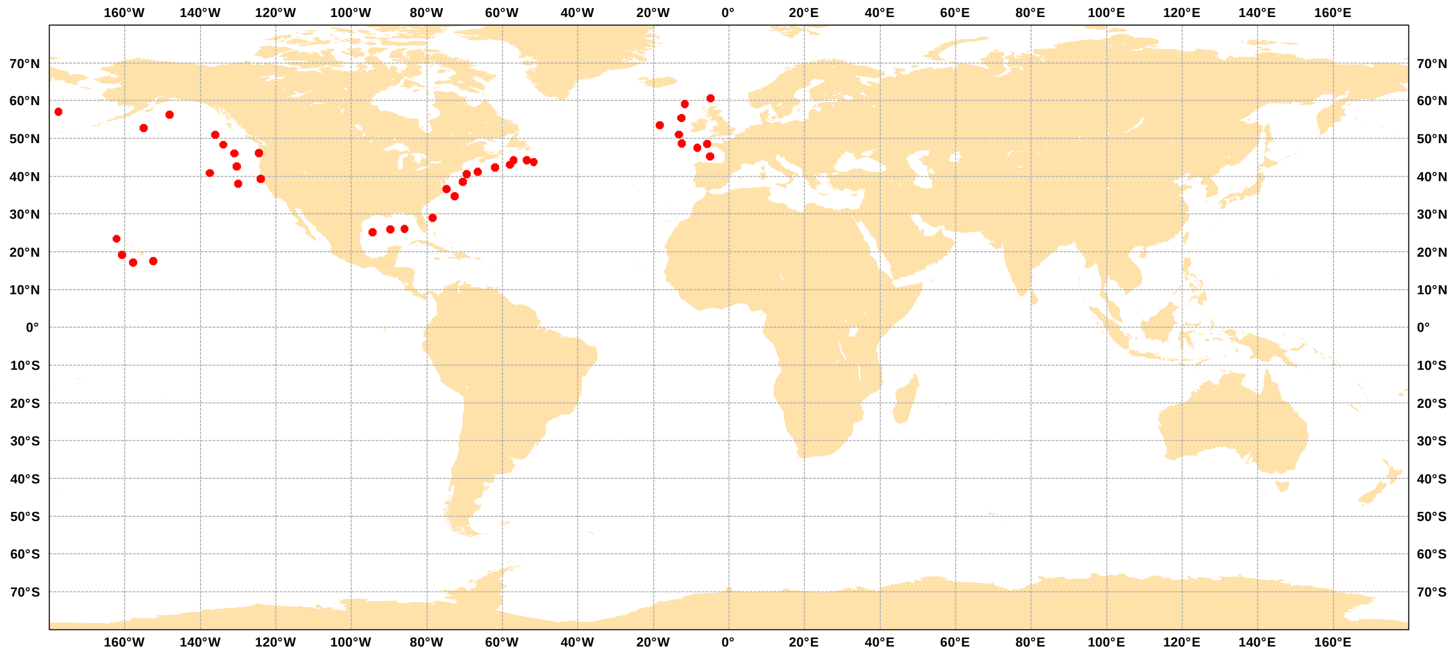
Sources: mostly via the WMO GTS, but also from the South African Weather Service, and recently from BoM, Puertos del Estado, Oceanor, and SHOM.

Quality control and processing of the data done at ECMWF

ECMWF

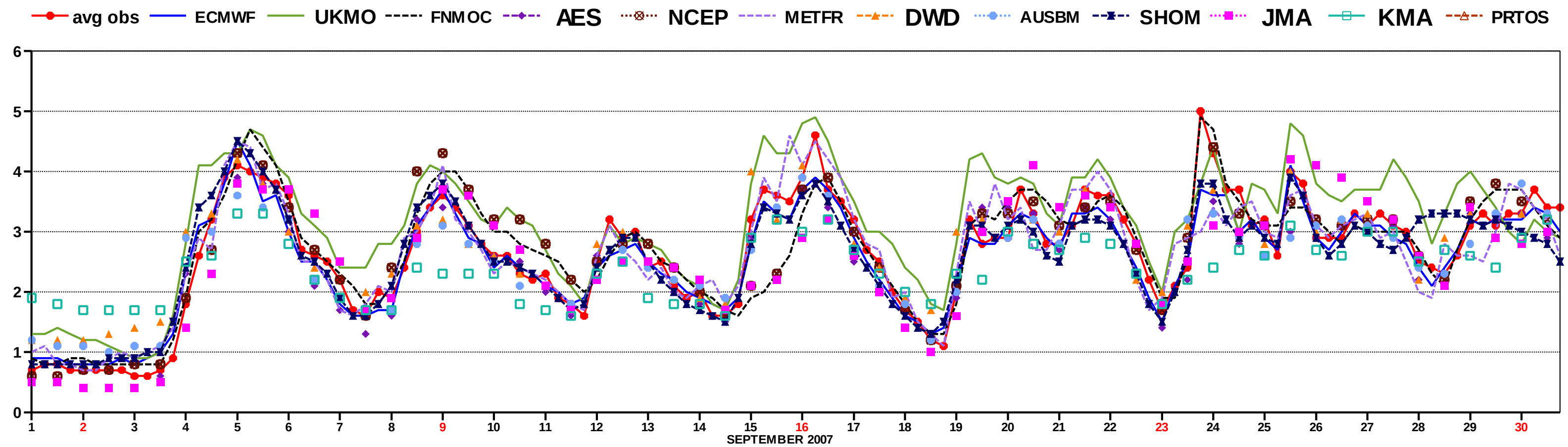
Results based on original list of buoy locations

Wind and wave observations at common locations for all buoys from 200706 to 200708

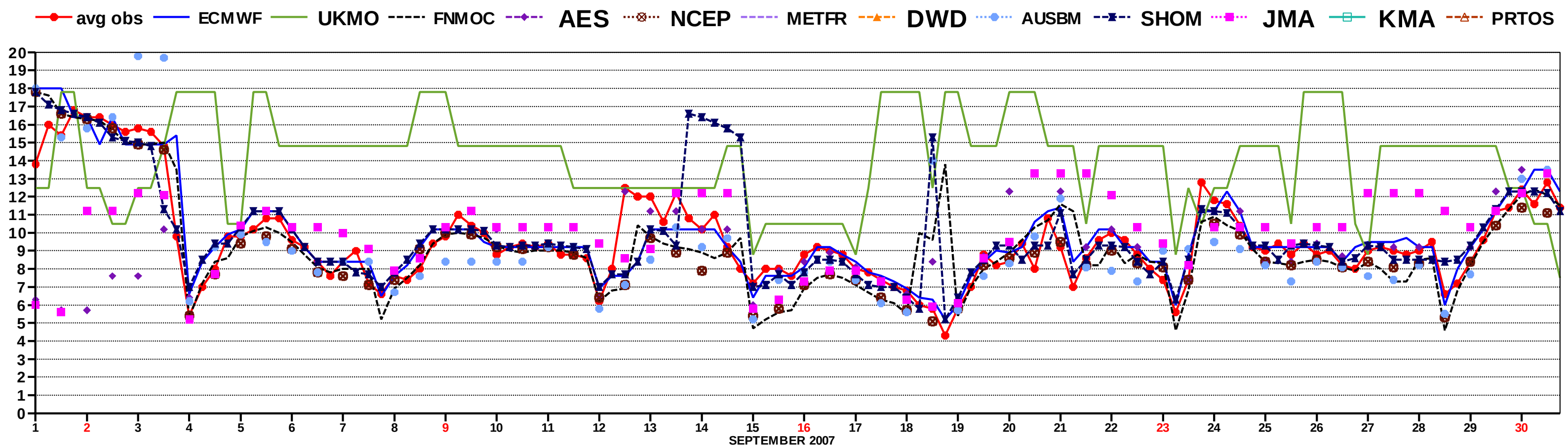


Original list

Analysed significant wave height and averaged buoy data at buoy 46001

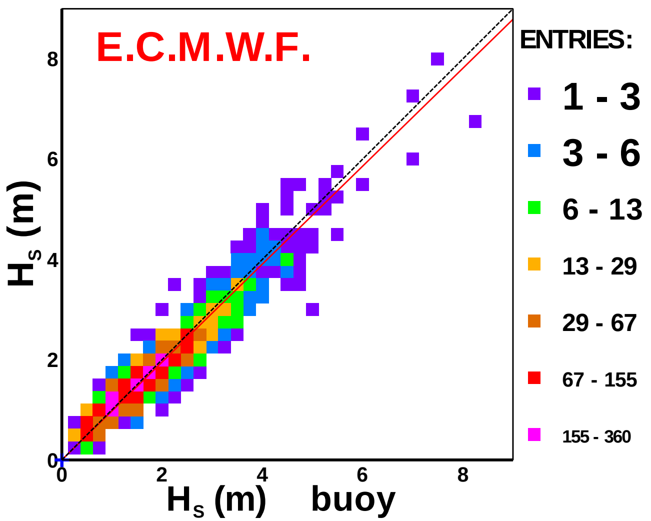


Analysed peak period and averaged buoy data at buoy 46001



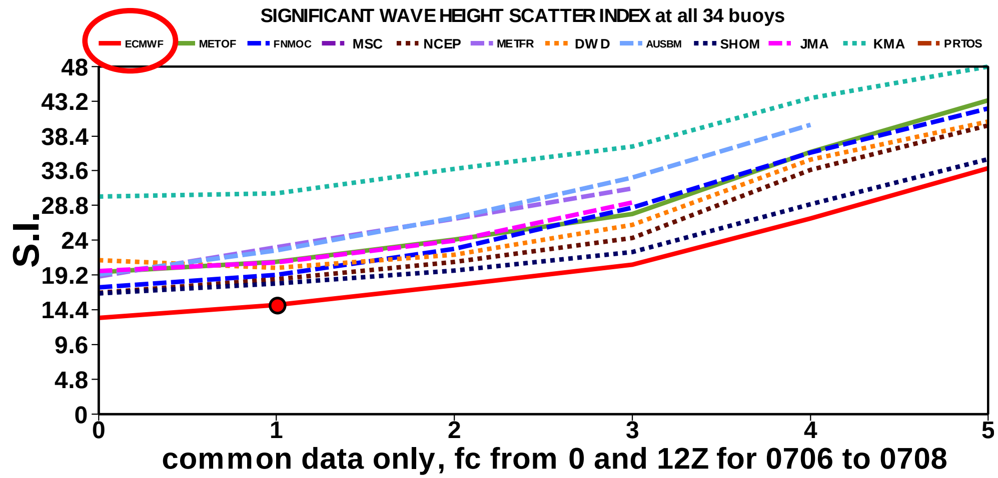
Original list

all buoys 0706 to 0708

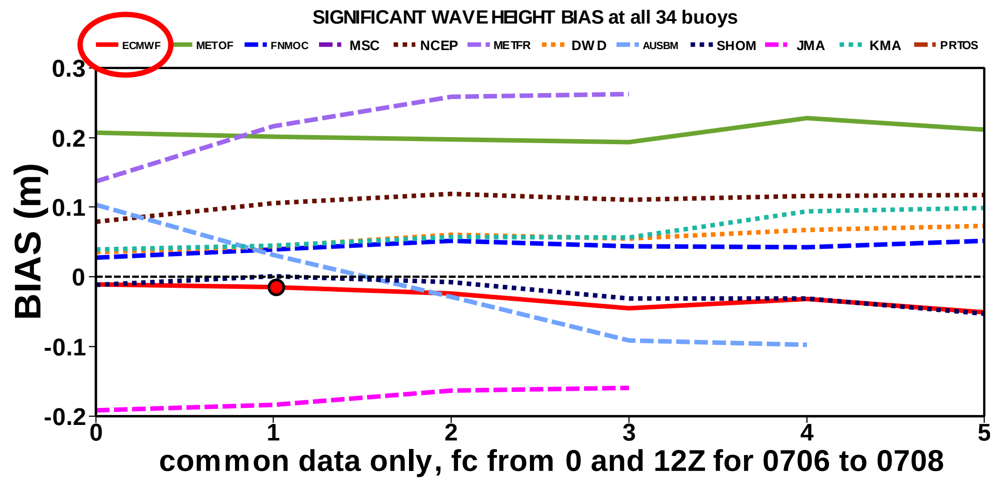


Comparison of forecast(t=t+24) ECMWF wave height with averaged buoy data. fc from 0 and 12Z.

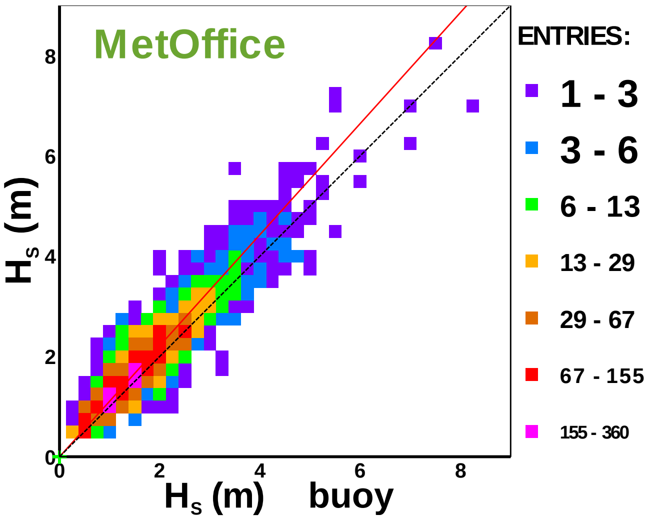
41001	46006
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
44139	62081
44141	62105
46001	62108
46004	62163
46035	64045
46066	64046
46002	
46005	



ENTRIES = 3456
MODEL MEAN = 1.65 STDEV = 0.763
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.874 INTR = 0.195
RMSE = 0.251 BIAS = -0.015
CORR COEF = 0.954 SI = 0.151
SYMMETRIC SLOPE = 0.976



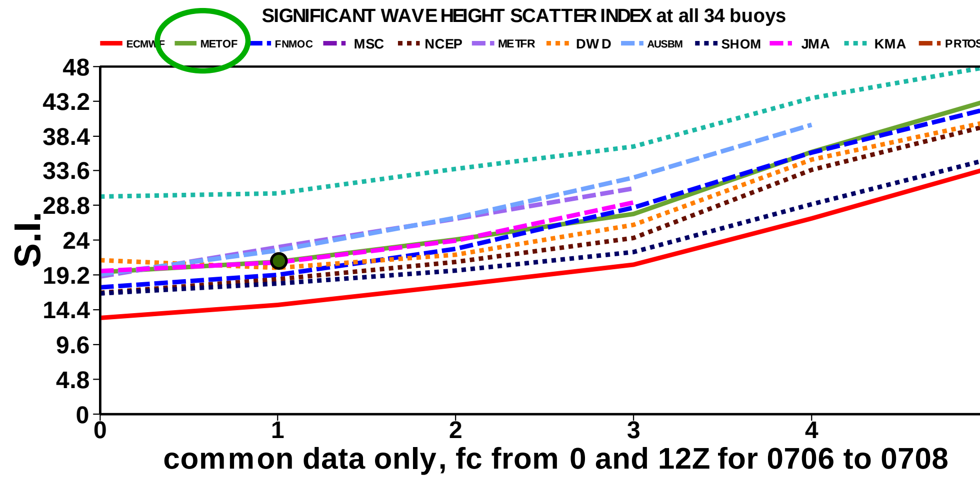
Statistics for all buoys combined

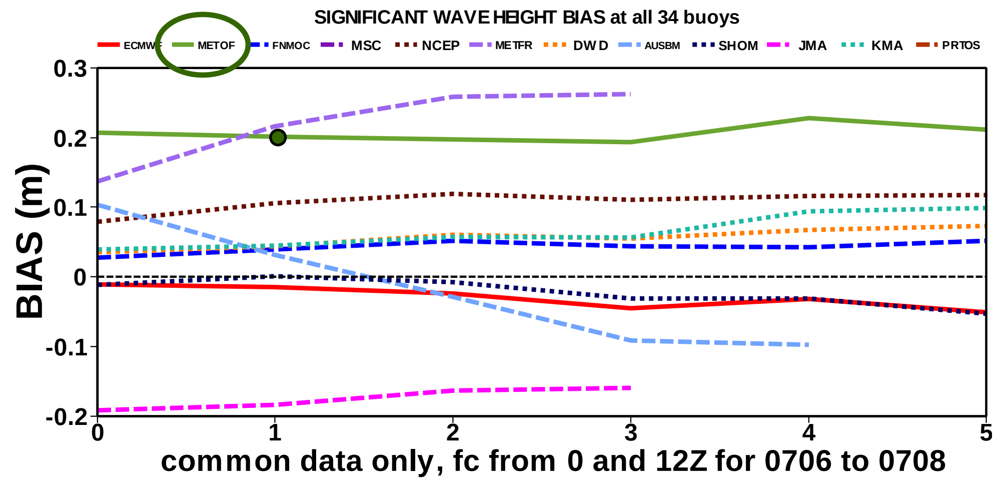


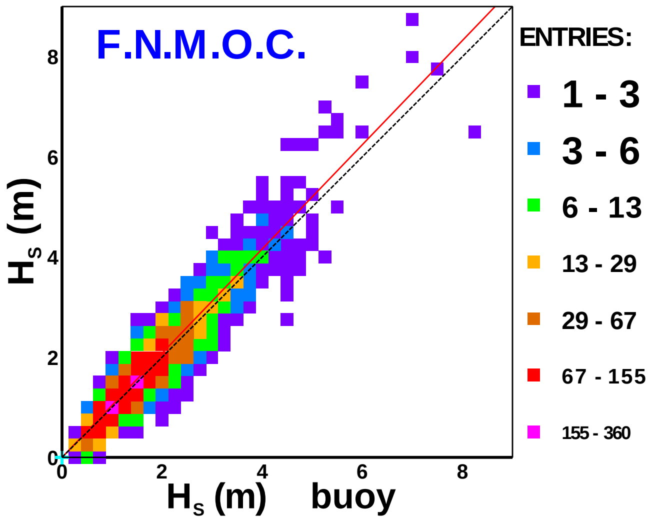
Comparison of forecast(t=t+24)METOF wave height with averaged buoy data. fc from 0 and 12Z.

41001 46006
41010 46036
42001 46059
42002 51001
42003 51002
44004 51003
44008 51004
44011 62001
44137 62029
44138 62052
44139 62081
44141 62105
46001 62108
46004 62163
46035 64045
46066 64046
46002
46005

ENTRIES = 3456
MODEL MEAN = 1.87 STDEV = 0.873
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.960 INTR = 0.267
RMSE = 0.403 BIAS = 0.201
CORR COEF = 0.917 SI = 0.210
SYMMETRIC SLOPE = 1.106

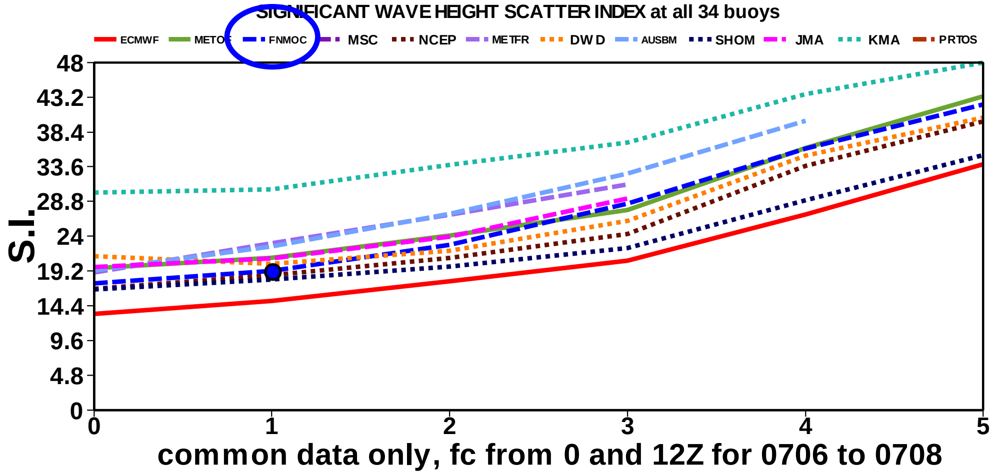




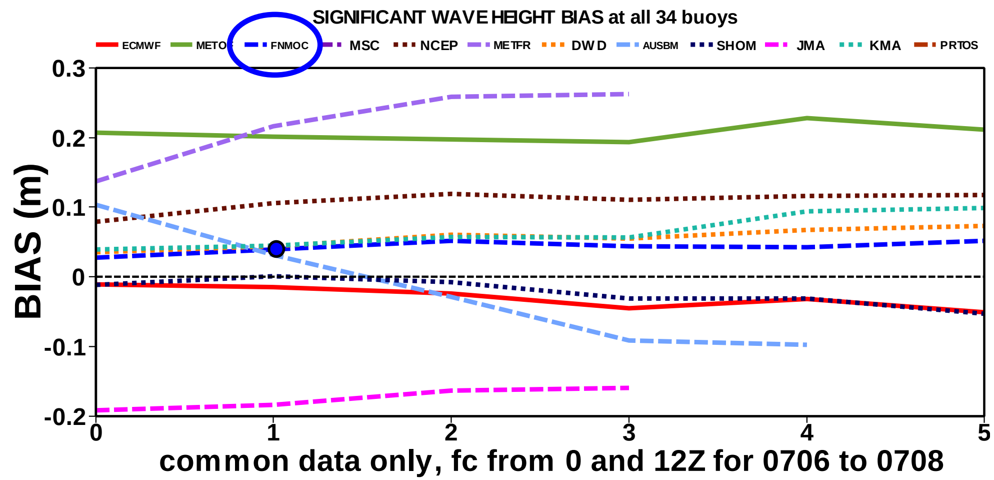


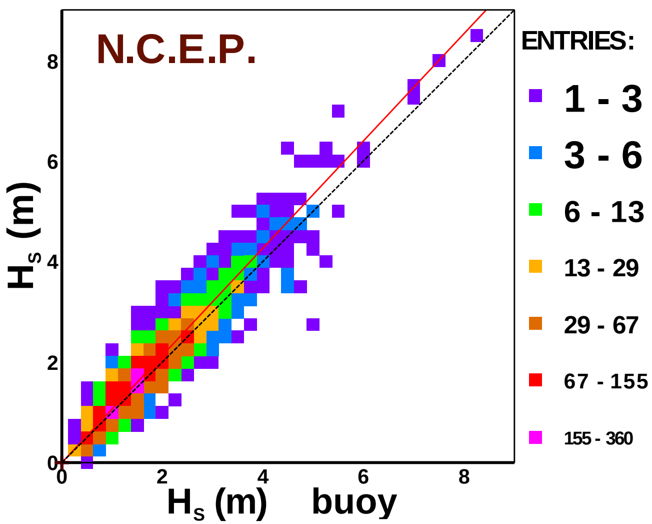
Comparison of forecast(t=t+24) FNMOC wave height with averaged buoy data. fc from 0 and 12Z.

41001 46006
41010 46036
42001 46059
42002 51001
42003 51002
44004 51003
44008 51004
44011 62001
44137 62029
44138 62052
44139 62081
44141 62105
46001 62108
46004 62163
46035 64045
46066 64046
46002
46005



ENTRIES = 3456
MODEL MEAN = 1.70 STDEV = 0.918
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 1.032 INTR = -0.014
RMSE = 0.322 BIAS = 0.039
CORR COEF = 0.938 SI = 0.192
SYMMETRIC SLOPE = 1.040

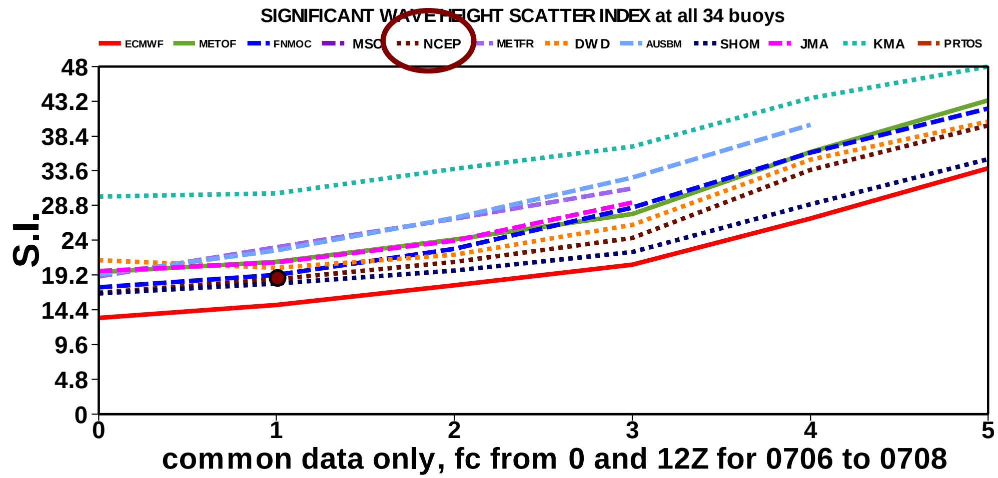


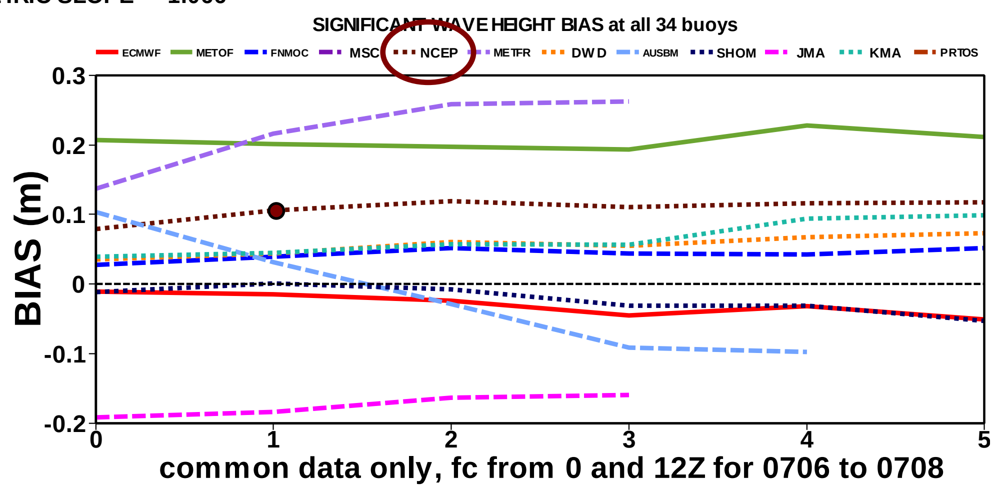


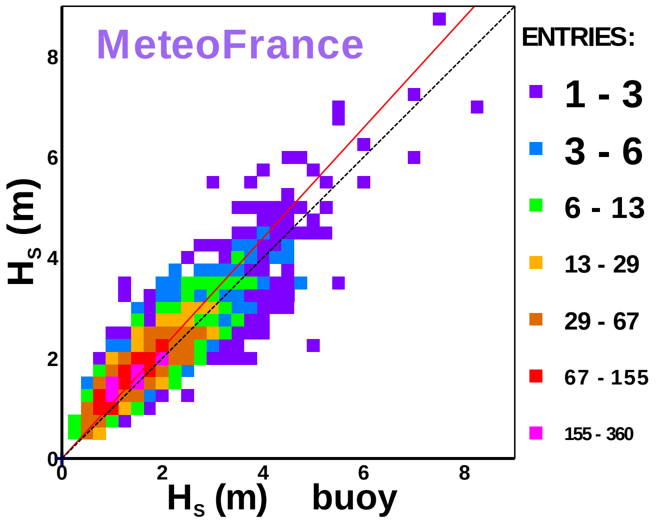
Comparison of forecast(t=t+24) NCEP wave height with averaged buoy data. fc from 0 and 12Z.

41001	46006
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
44139	62081
44141	62105
46001	62108
46004	62163
46035	64045
46066	64046
46002	
46005	

ENTRIES = 3456
MODEL MEAN = 1.77 STDEV = 0.898
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 1.011 INTR = 0.087
RMSE = 0.327 BIAS = 0.106
CORR COEF = 0.939 SI = 0.186
SYMMETRIC SLOPE = 1.066



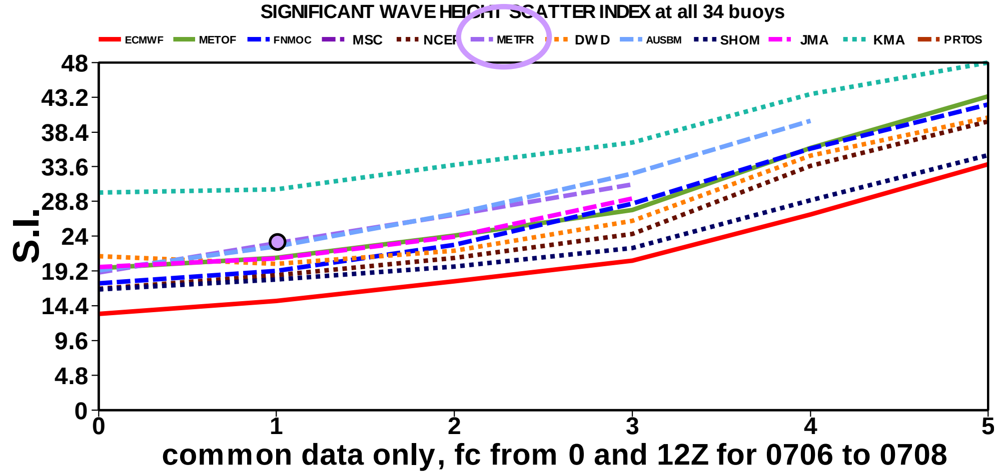


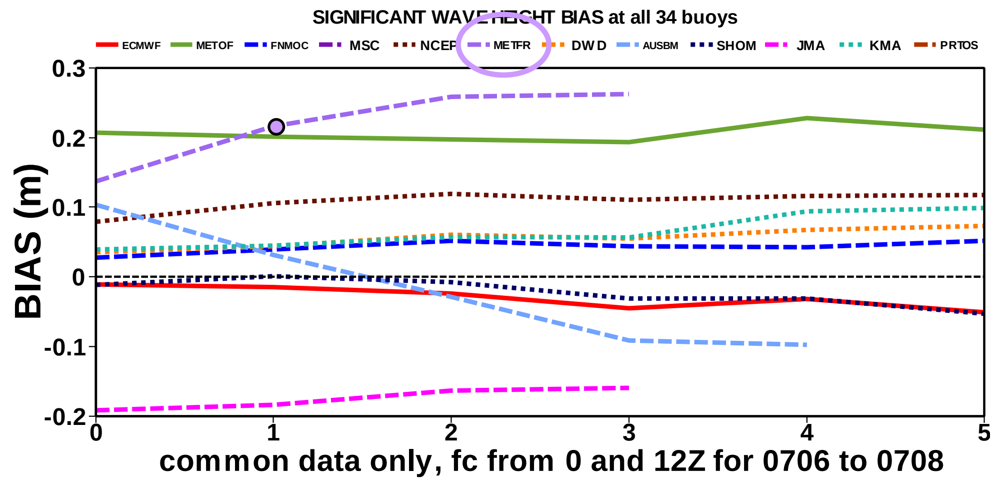


Comparison of forecast(t=t+24) METFR wave height with averaged buoy data. fc from 0 and 12Z.

41001	46006
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
44139	62081
44141	62105
46001	62108
46004	62163
46035	64045
46066	64046
46002	
46005	

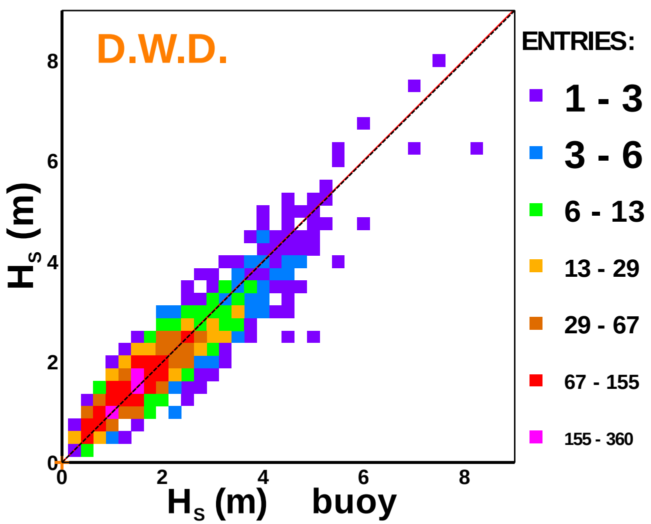
ENTRIES = 3456
MODEL MEAN = 1.88 STDEV = 0.794
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.848 INTR = 0.469
RMSE = 0.441 BIAS = 0.216
CORR COEF = 0.890 SI = 0.231
SYMMETRIC SLOPE = 1.097





ECMWF

all buoys 0706 to 0708



Comparison of forecast(t=t+24) DWD wave height with averaged buoy data. fc from 0 and 12Z.

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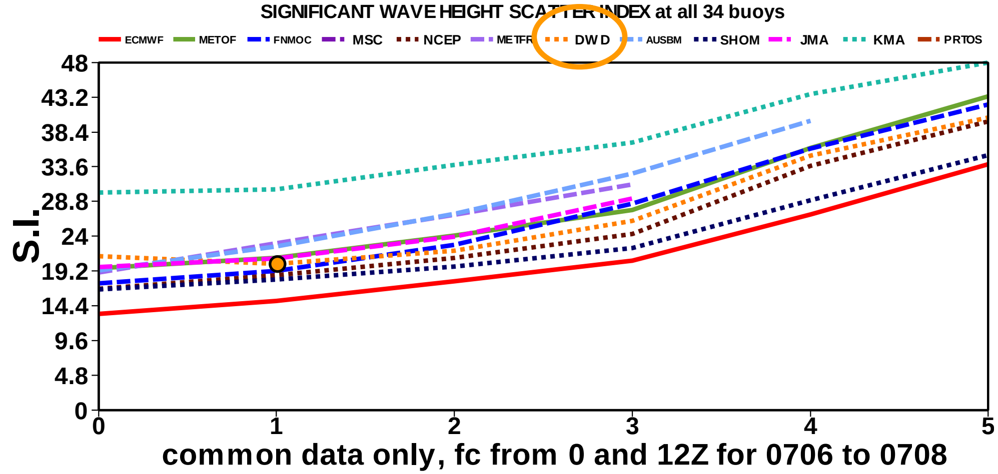
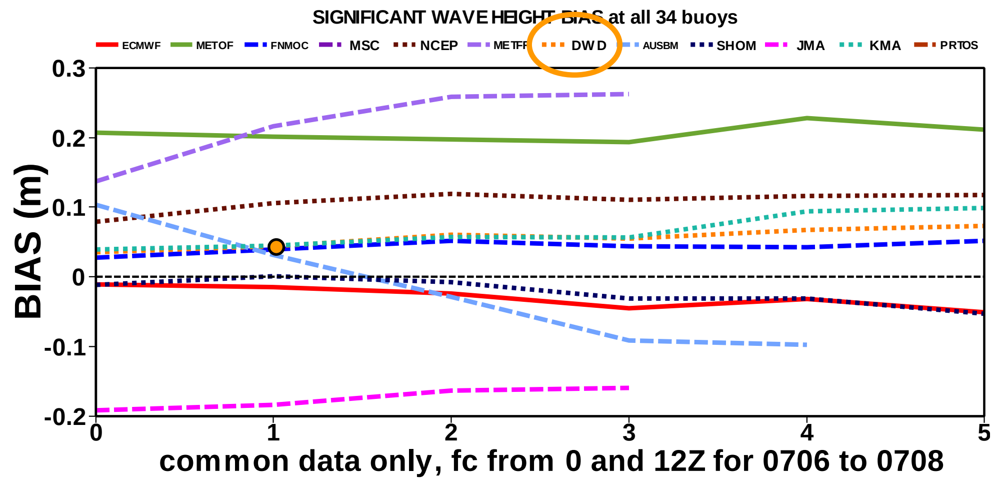
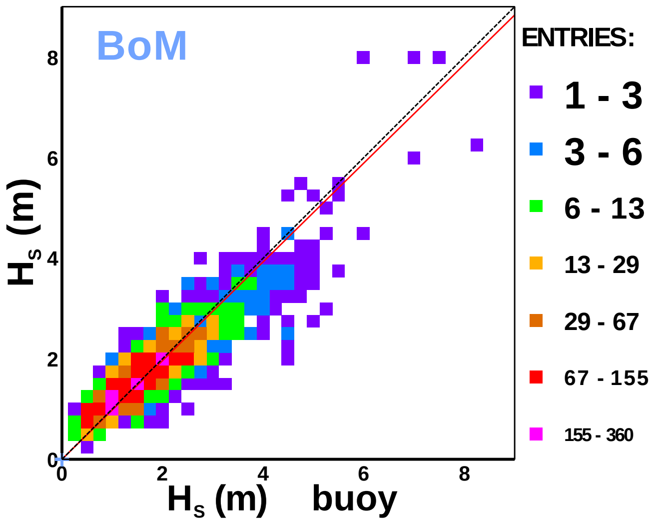
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
44139	62081
44141	62105
46001	62108
46004	62163
46035	64045
46066	64046
46002	
46005	

ENTRIES = 3456
MODEL MEAN = 1.71 STDEV = 0.755
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.829 INTR = 0.329
RMSE = 0.339 BIAS = 0.044
CORR COEF = 0.915 SI = 0.202
SYMMETRIC SLOPE = 1.003



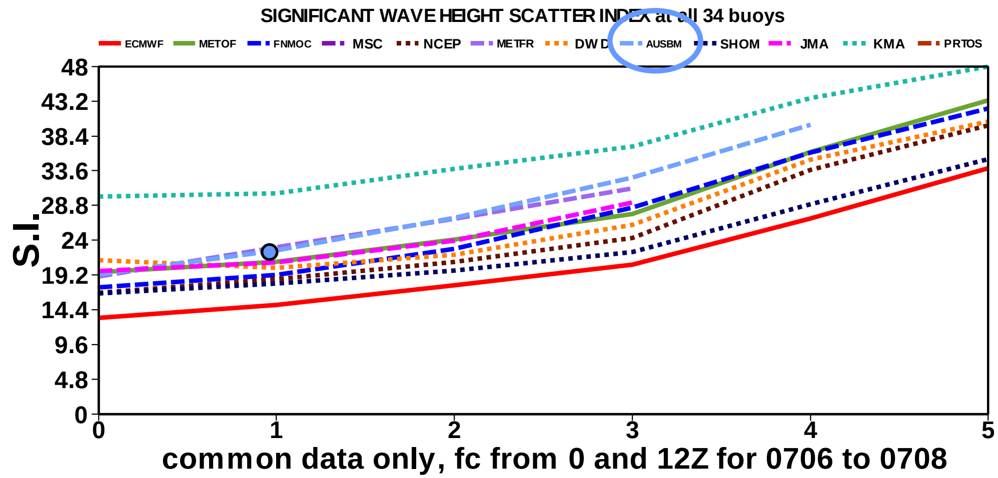


ECMWF

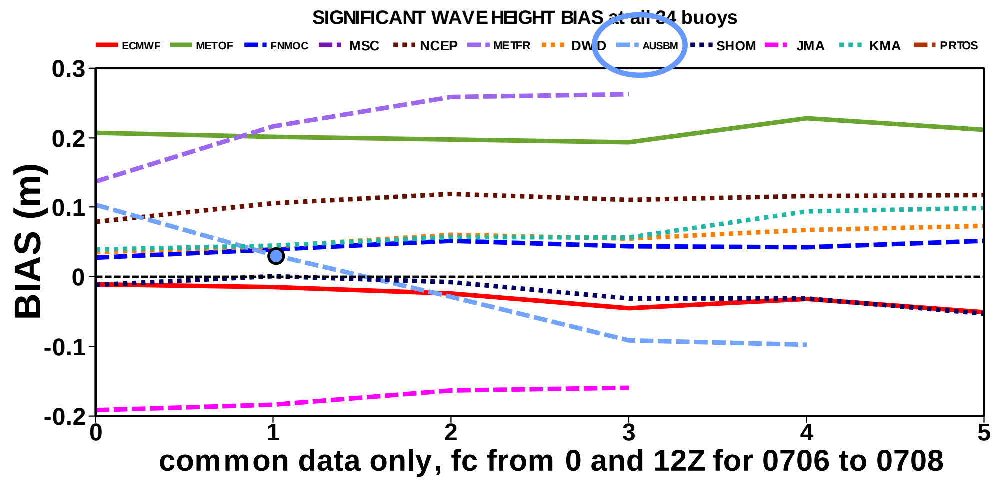


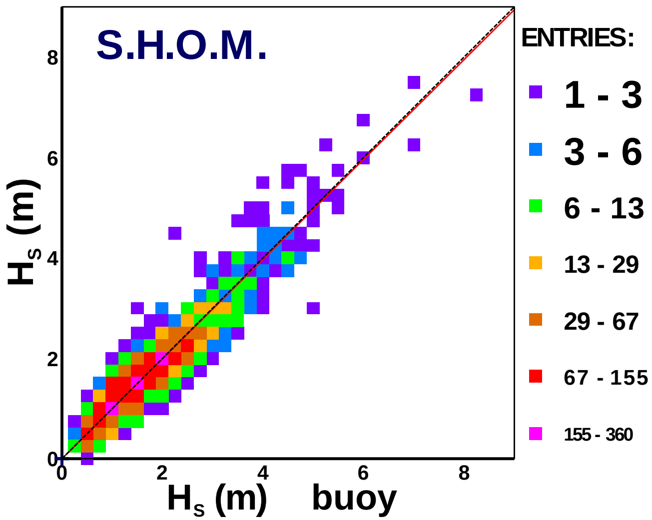
Comparison of forecast(t=t+24) BoM wave height with averaged buoy data. fc from 0 and 12Z.

41001	46006
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
44139	62081
44141	62105
46001	62108
46004	62163
46035	64045
46066	64046
46002	
46005	



ENTRIES = 3456
MODEL MEAN = 1.70 STDEV = 0.683
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.734 INTR = 0.474
RMSE = 0.377 BIAS = 0.031
CORR COEF = 0.896 SI = 0.226
SYMMETRIC SLOPE = 0.982





Comparison of forecast(t=t+24) SHOM wave height with averaged buoy data. fc from 0 and 12Z.

41001	46006
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
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44141	62105
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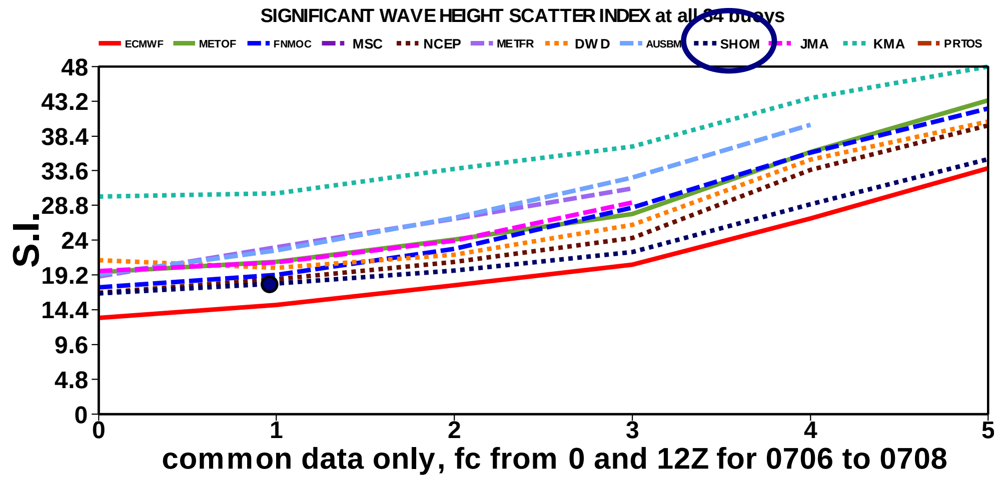
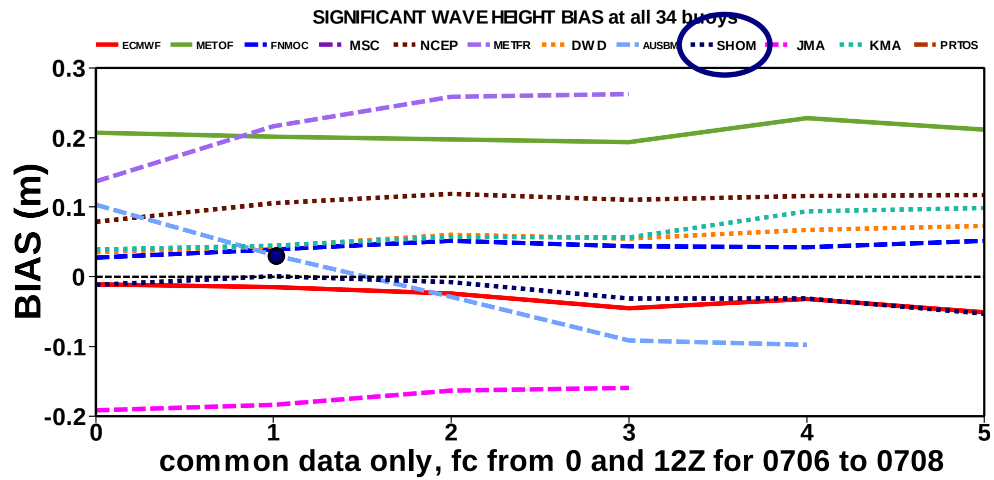
46004	62163
46035	64045
46066	64046
46002	
46005	

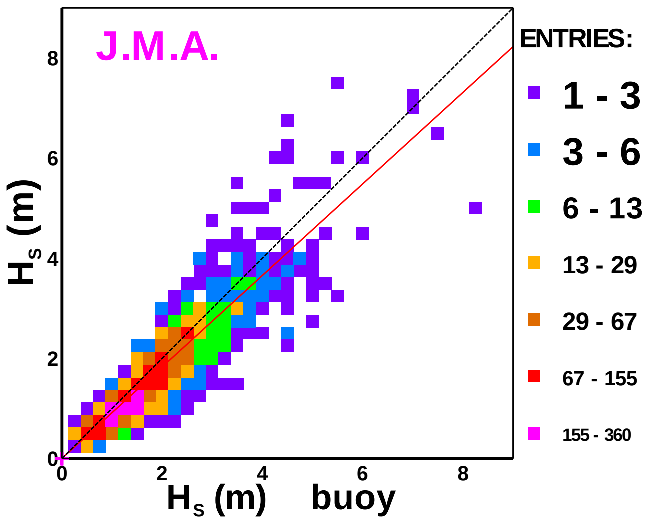


ENTRIES = 3456
MODEL MEAN = 1.66 STDEV = 0.808
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.905 INTR = 0.158
RMSE = 0.300 BIAS = 0.001
CORR COEF = 0.934 SI = 0.180
SYMMETRIC SLOPE = 0.994



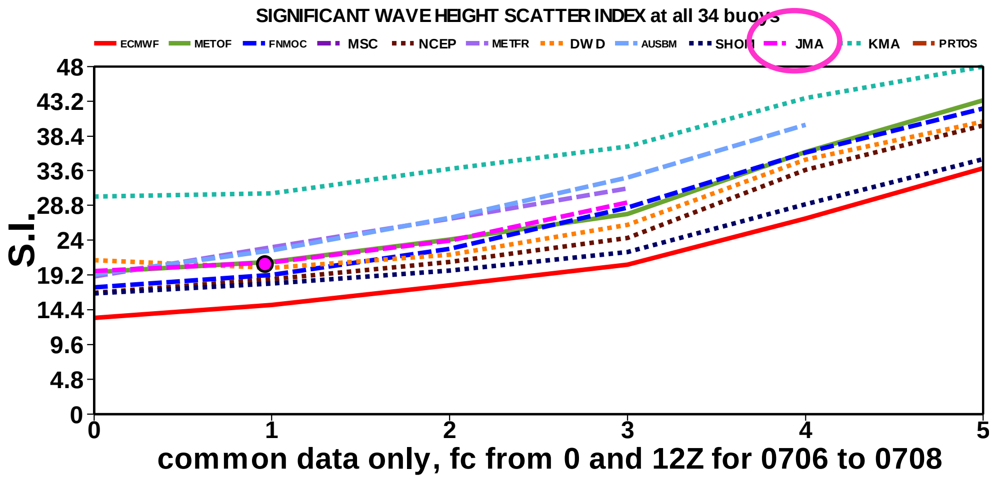
ECMWF

all buoys 0706 to 0708

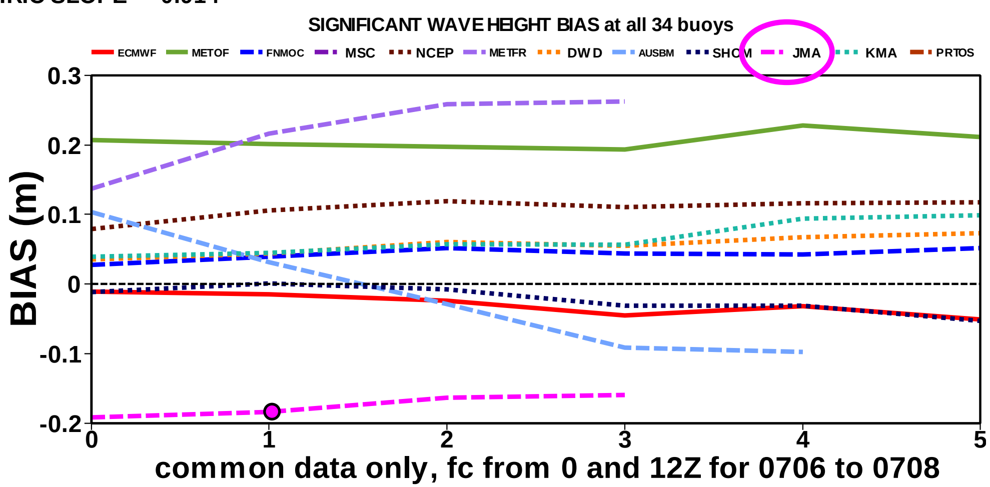


Comparison of forecast(t=t+24) JMA wave height with averaged buoy data. fc from 0 and 12Z.

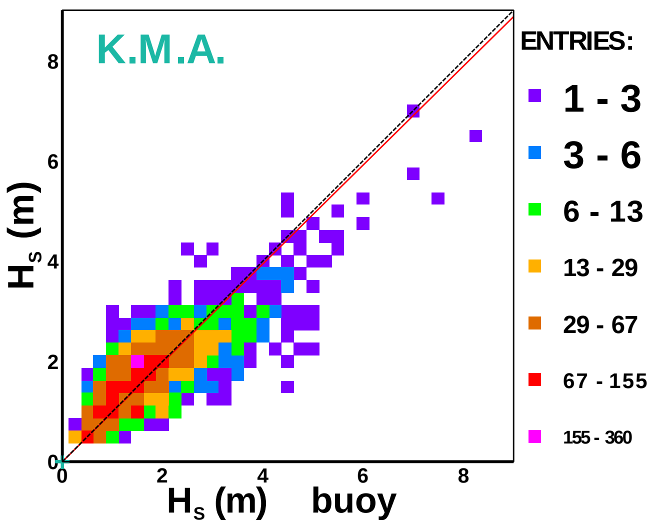
41001	46006
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
44139	62081
44141	62105
46001	62108
46004	62163
46035	64045
46066	64046
46002	
46005	



ENTRIES = 3456
MODEL MEAN = 1.48 STDEV = 0.839
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.919 INTR = -0.049
RMSE = 0.394 BIAS = -0.183
CORR COEF = 0.913 SI = 0.209
SYMMETRIC SLOPE = 0.914



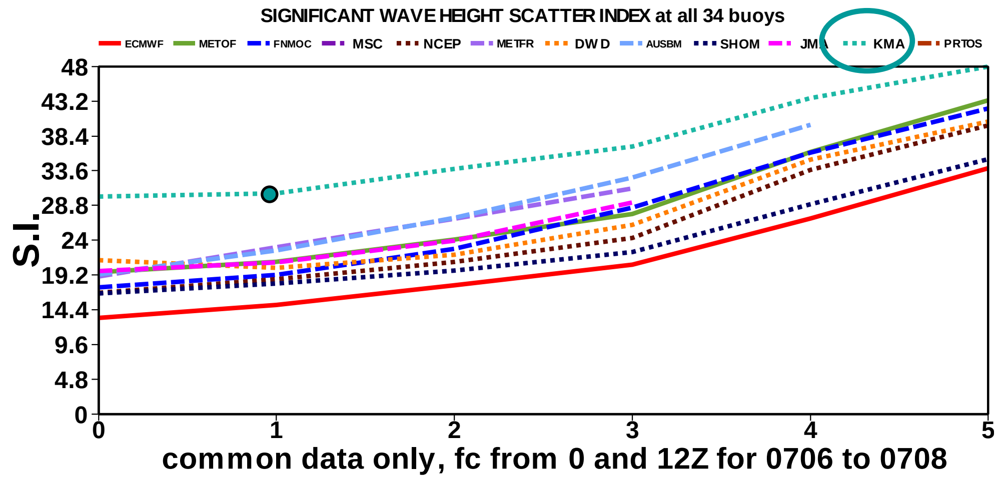
ECMWF

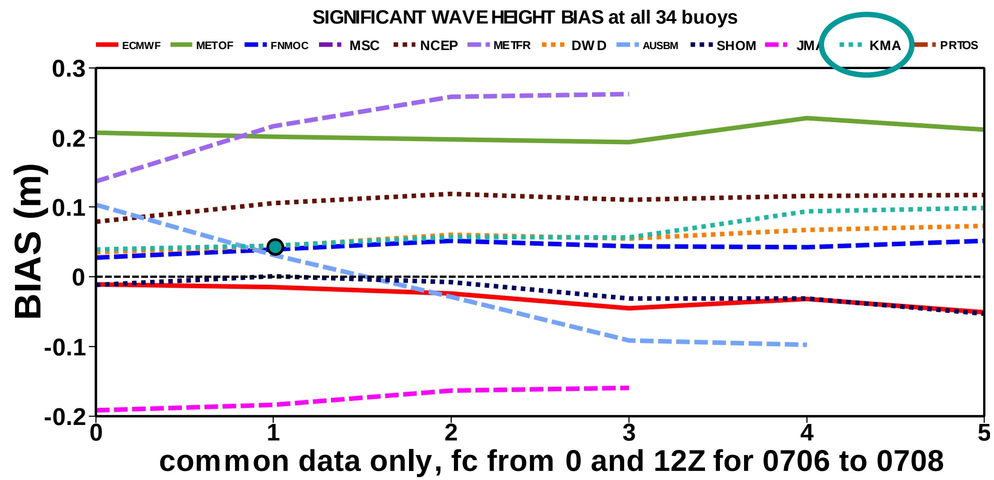


Comparison of forecast(t=t+24) KMA wave height with averaged buoy data. fc from 0 and 12Z.

41001	46006
41010	46036
42001	46059
42002	51001
42003	51002
44004	51003
44008	51004
44011	62001
44137	62029
44138	62052
44139	62081
44141	62105
46001	62108
46004	62163
46035	64045
46066	64046
46002	
46005	

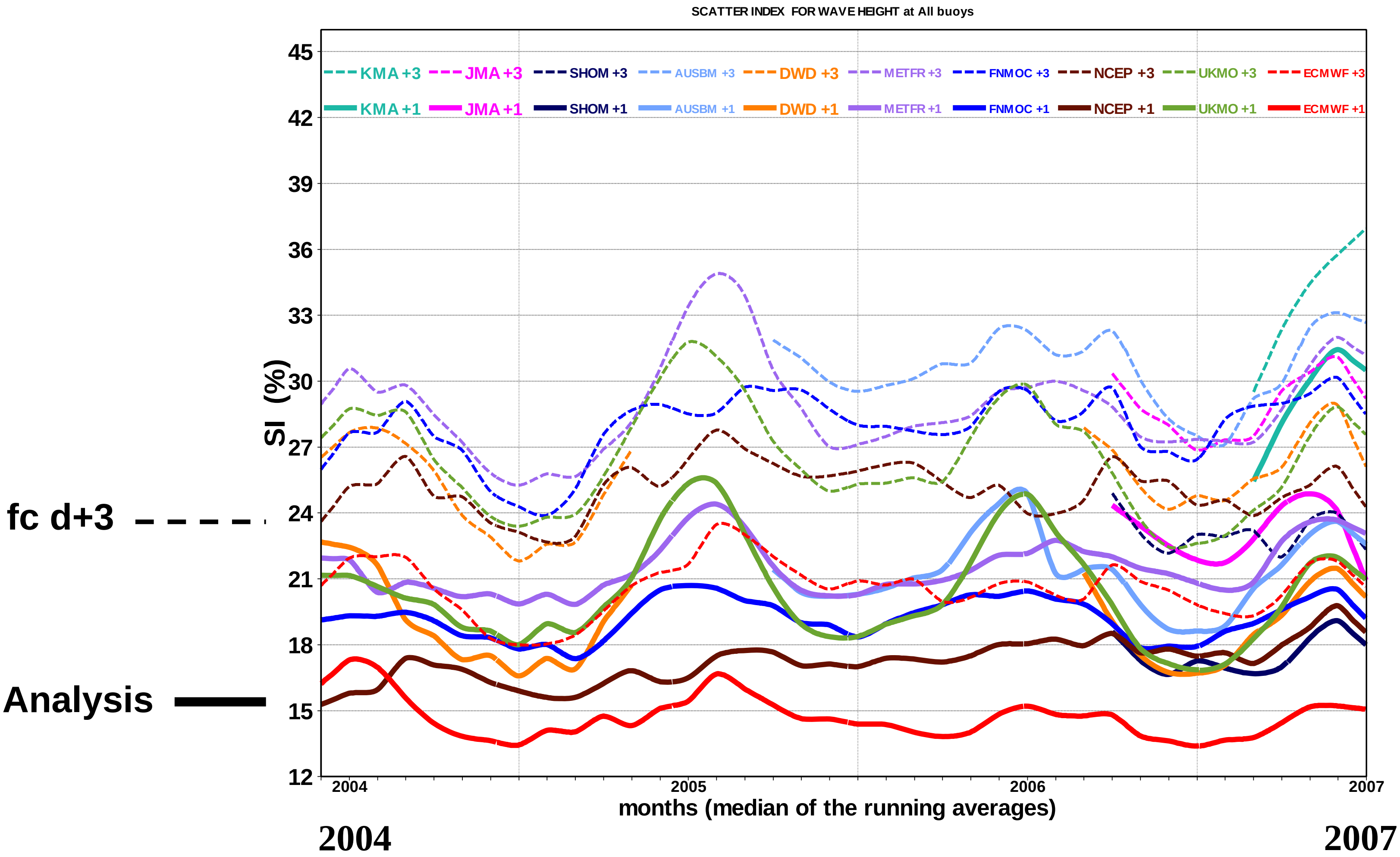
ENTRIES = 3456
MODEL MEAN = 1.71 STDEV = 0.669
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.637 INTR = 0.649
RMSE = 0.510 BIAS = 0.045
CORR COEF = 0.793 SI = 0.305
SYMMETRIC SLOPE = 0.986





ECMWF

Original list: wave height scatter index time series

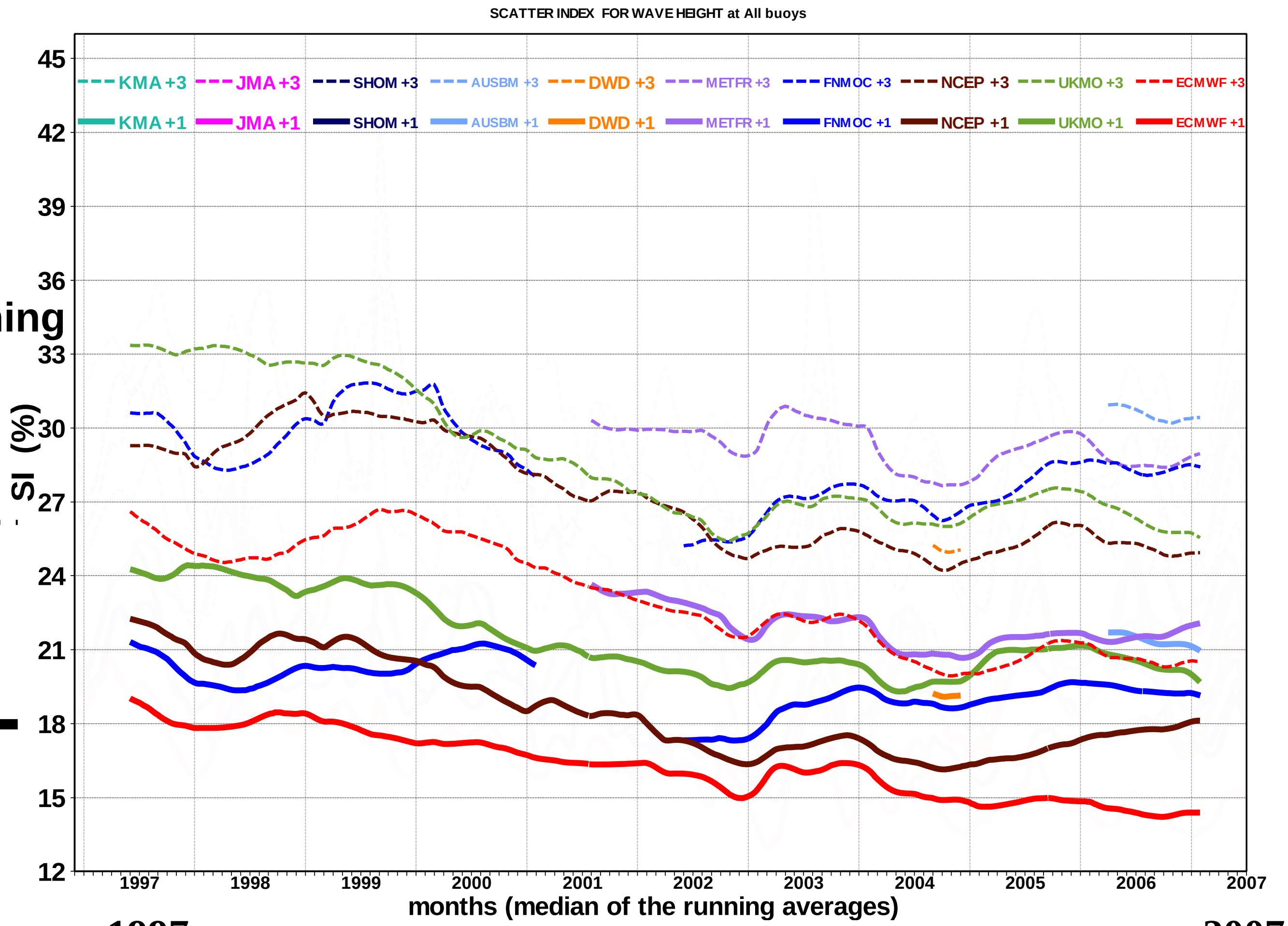


Original list: wave height scatter index time series

12-month running average

fc d+3

Analysis



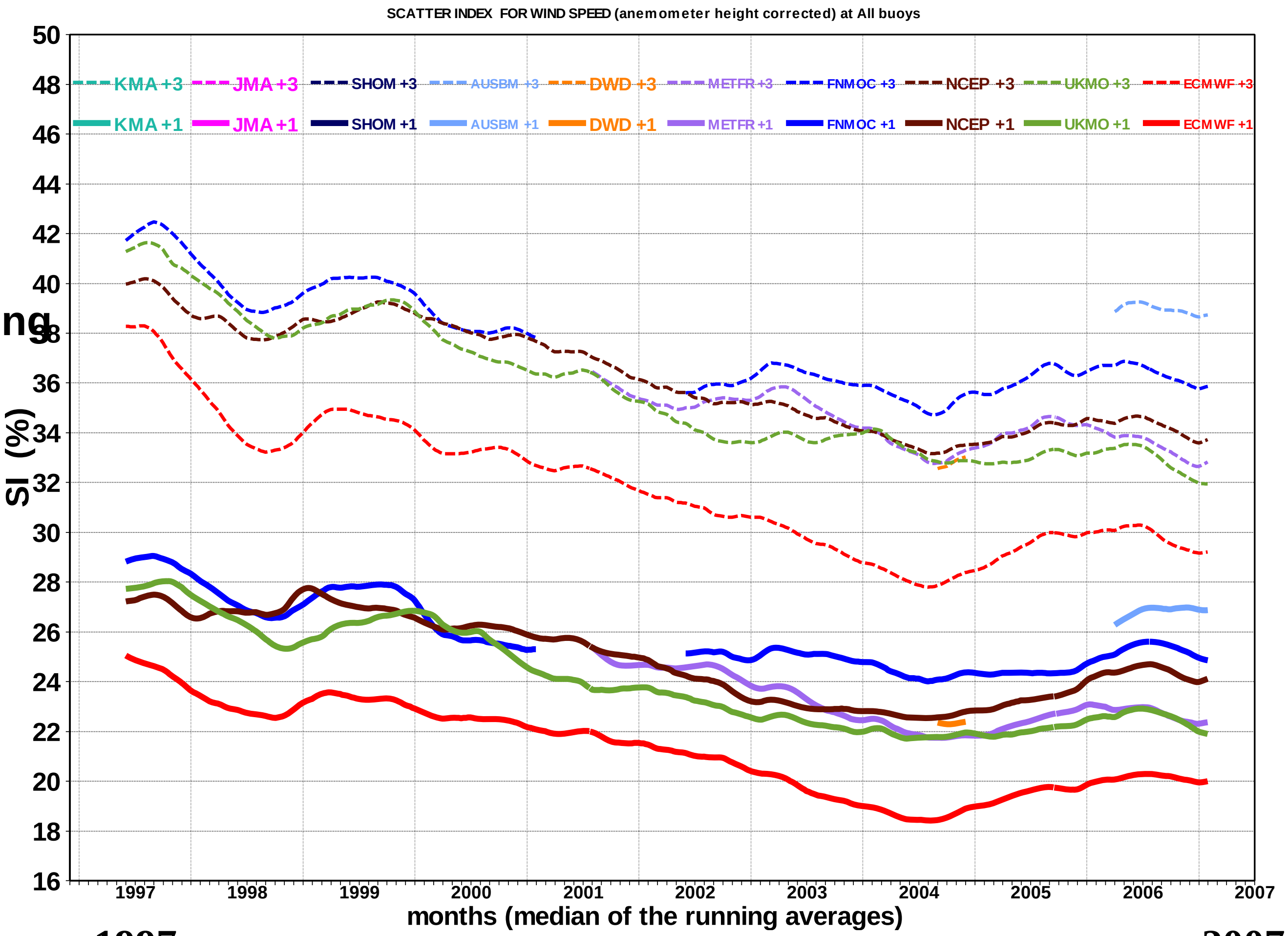
1997 2007

ECMWF

Original list: wind speed scatter index time series

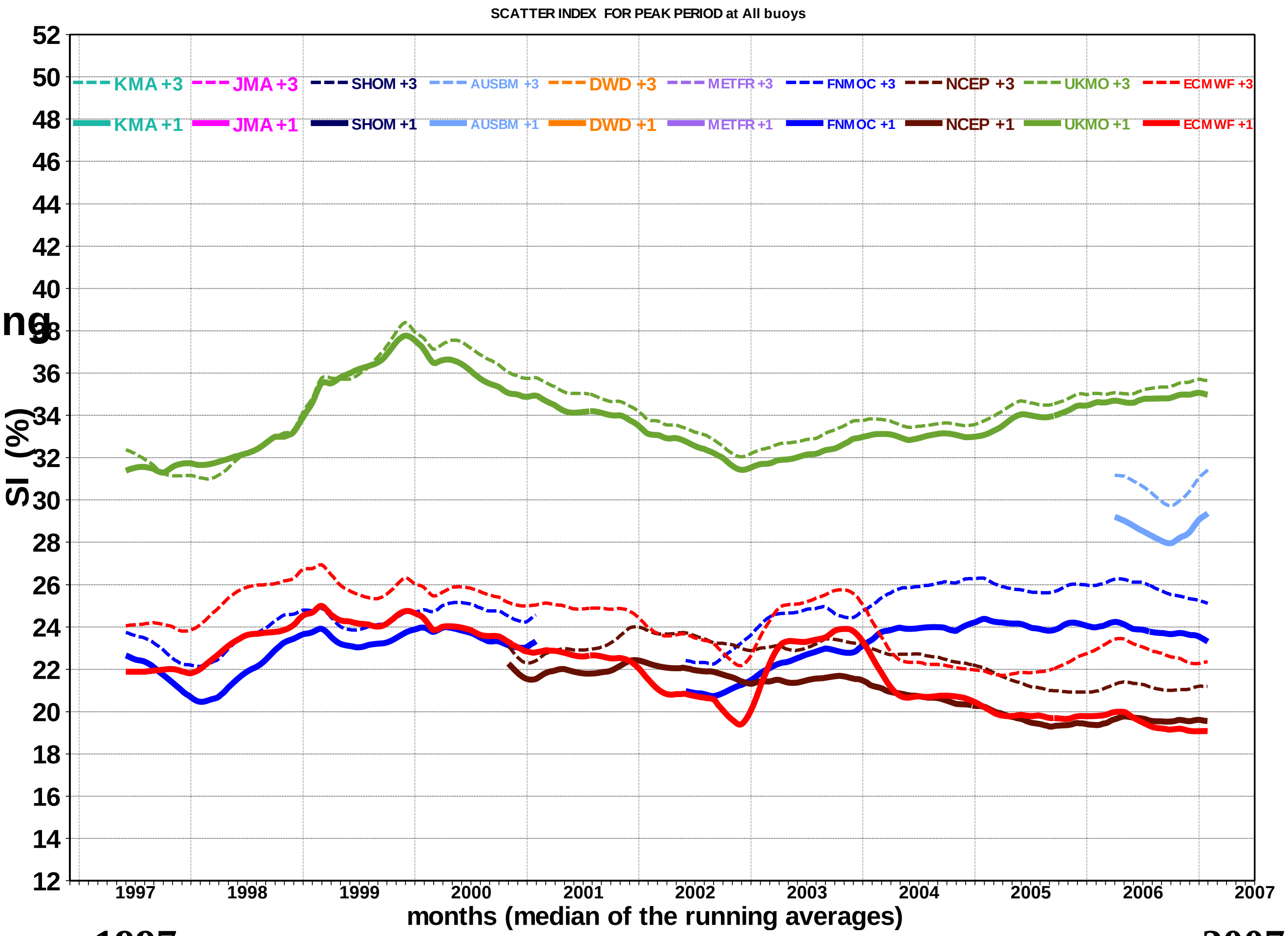
12-month running Average.

Wind speed



1997 **2007**

Original list: peak period scatter index time series



12-month running Average.

Peak period

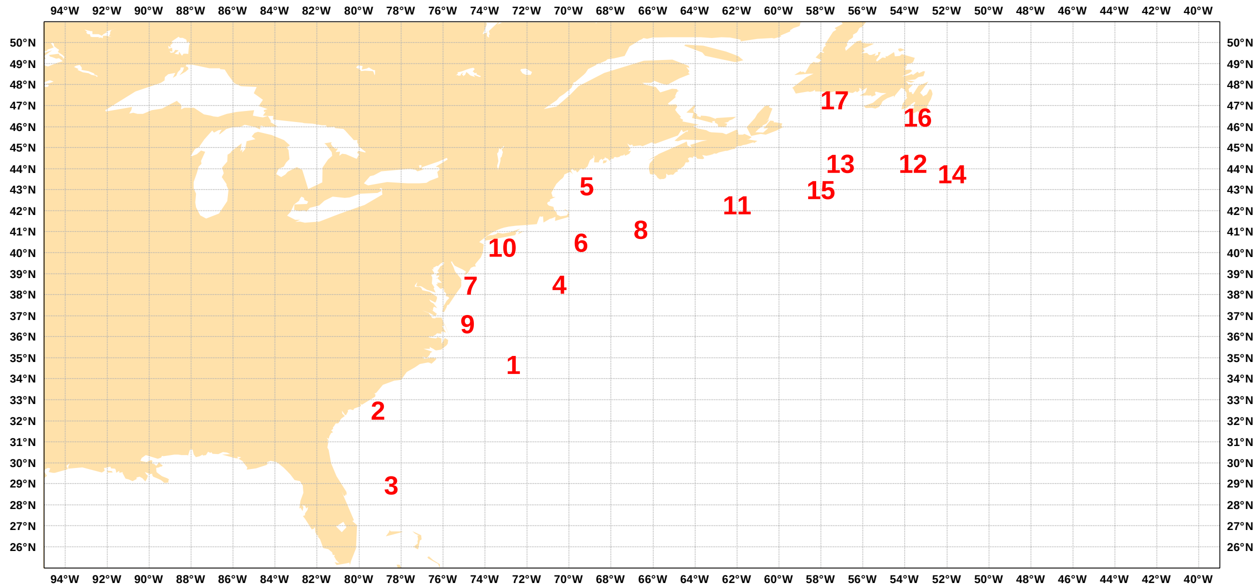
1997 **2007**

Sub-areas:

North West Atlantic

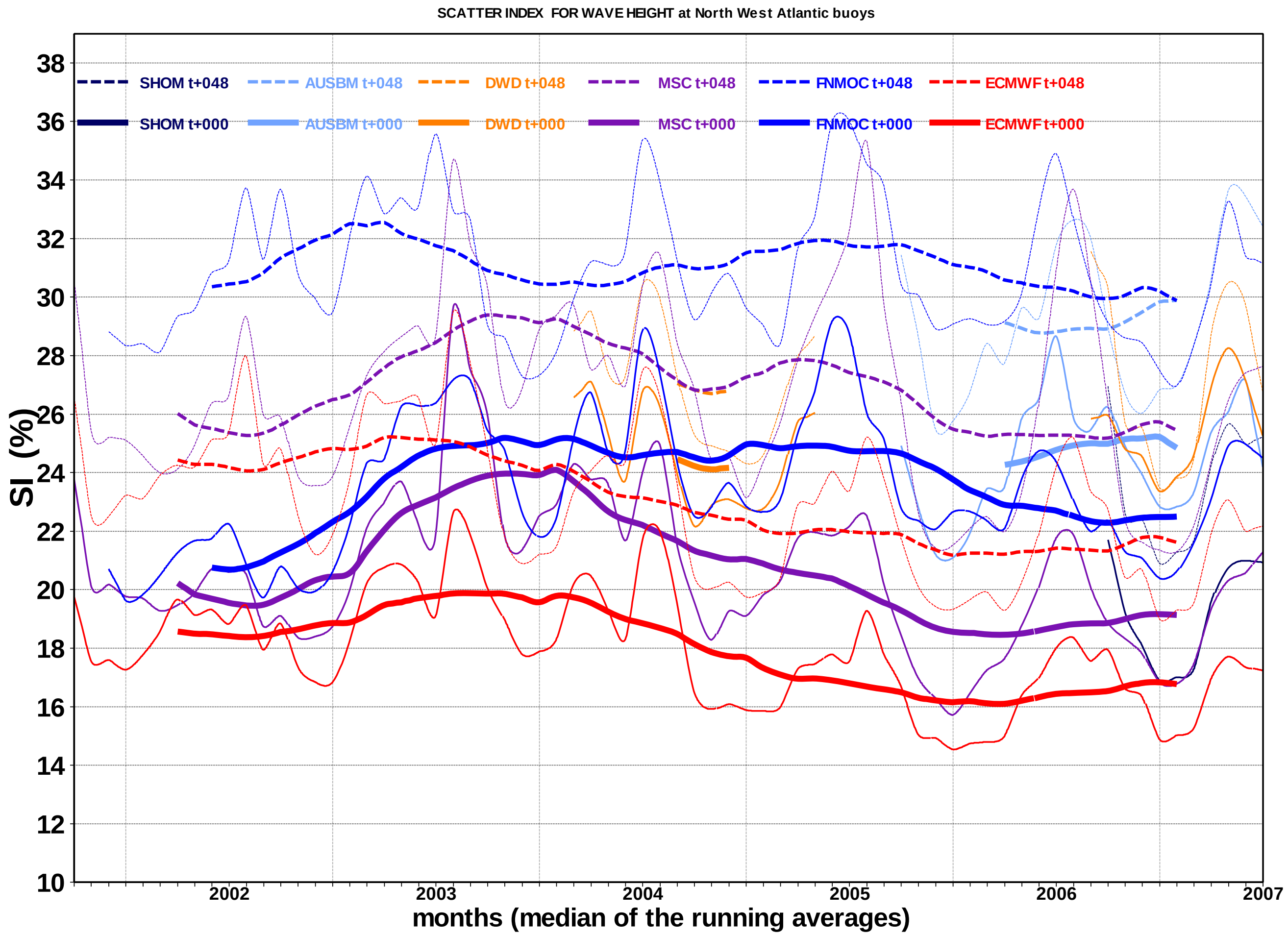
Number of common observations for North West Atlantic buoys (NWATL) from 200706 to 200708 (wind, Hs, Tp)

1	41001	178	177	177	US East Coast, E Hatteras
2	41004	101	100	100	US South-East Coast, Edisto
3	41010	178	179	179	US East Florida , Cape Canaveral East
4	44004	180	179	179	US North East Coast, Hotel
5	44005	55	129	129	US North East Coast, Gulf of Maine
6	44008	180	180	180	US North-East Coast, Nantucket
7	44009	180	179	179	US North-East Coast, Delaware bay
8	44011	180	180	180	US North-East Coast, Georges Bank
9	44014	179	176	176	US East Coast, Virginia Beach
10	44025	0	179	179	US North East Coast, Long Island
11	44137	178	118	118	Nova Scotia, East Scotia slope
12	44138	64	178	178	Newfoundland, SW Grand Bank
13	44139	178	177	177	Newfoundland, Banquerau
14	44140	179	117	117	Newfoundland, Tail Of The Bank
15	44141	180	180	180	Nova Scotia, Laurentian Fan
16	44251	71	143	143	Newfoundland, Nickerson Bank
17	44255	180	179	0	Newfoundland, NE Bugeo Bank



ECMWF

North West Atlantic

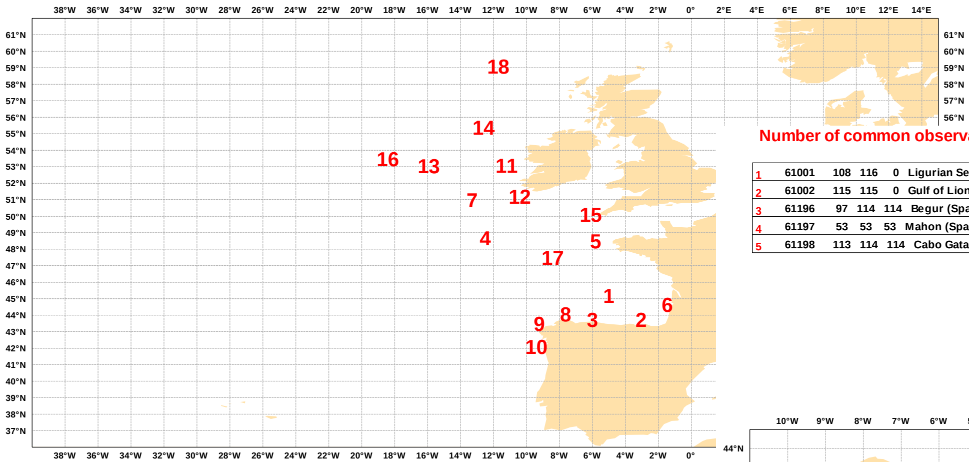


2002 **2007**

Euro Atlantic

Number of common observations for North East Atlantic buoys (NEATL) from 200708 to 200709 (wind, Hs, Tz)

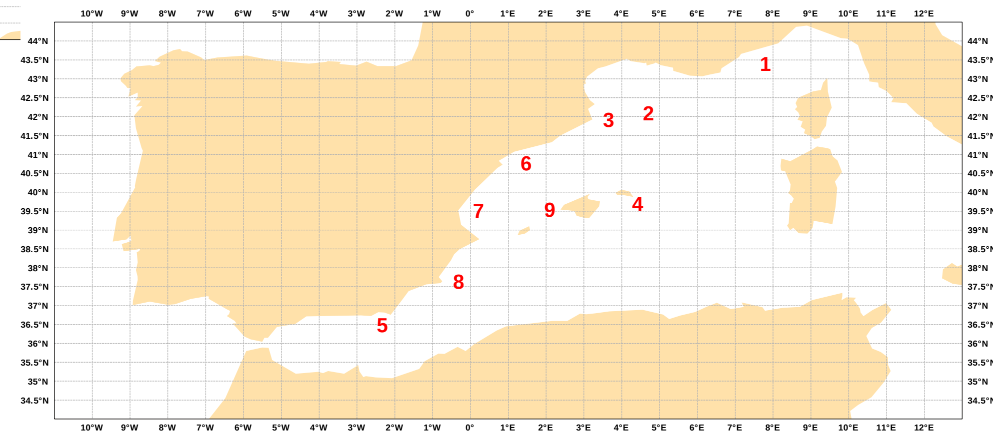
1	62001	118	118	0	Gulf of Biscay, Gascogne	10	62084	115	115	115	Silleiro Spain)
2	62024	65	115	115	Bilbao (Spain)	11	62090	1	0	0	West Ireland (M1), Aran Islands
3	62025	115	115	115	Cabo de Penas (Spain)	12	62092	118	118	118	South West Ireland (M3), Mizen Head
4	62029	168	168	0	UK Celtic Sea shelf break (K1)	13	62095	118	118	0	West Ireland (M6), West Coast
5	62052	113	118	0	CETMEF Ouessant (Brest)	14	62105	0	134	117	UK East Atlantic (K4)
6	62064	0	117	117	SHOM (Cape Ferret)	15	62107	118	118	118	Isle of Scilly (7 stones)
7	62081	169	169	117	UK East Atlantic (K2)	16	62108	0	168	118	UK East Atlantic (K3)
8	62082	94	94	94	Estaca de Bares (Spain)	17	62163	69	118	118	UK Celtic Sea shelf break (Brittany)
9	62083	89	89	89	Villano-Sisargas (Spain)	18	64045	0	118	118	UK North-East Atlantic (K5)



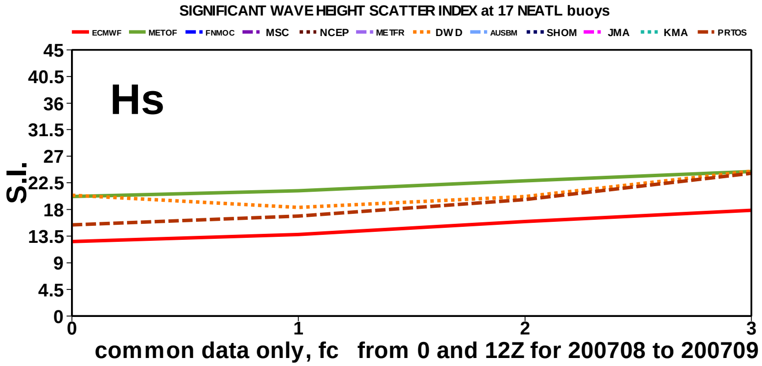
Western Mediterranean Sea

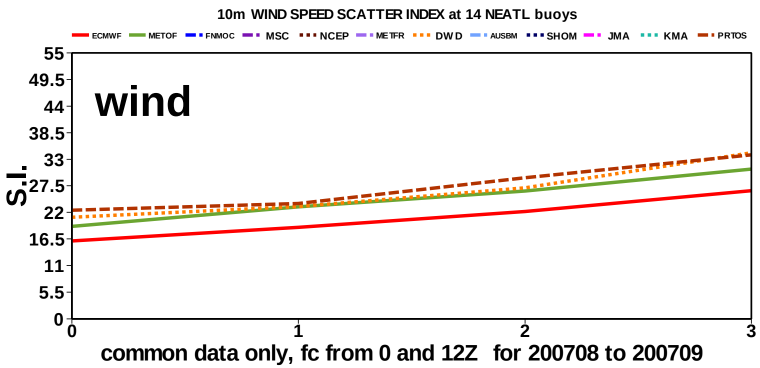
Number of common observations for Western Mediterranean Sea (WMED) from 200708 to 200709 (wind, Hs, Tz)

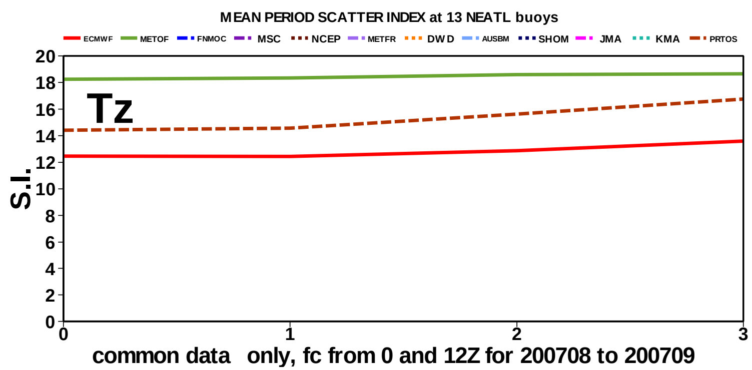
1	61001	108	116	0	Ligurian Sea (Cote d'Azure)	6	61280	114	14	14	Tarragona (Spain)
2	61002	115	115	0	Gulf of Lion	7	61281	91	91	91	Valencia (Spain)
3	61196	97	114	114	Begur (Spain)	8	61417	114	114	114	Cabo de Palos (Spain)
4	61197	53	53	53	Mahon (Spain)	9	61430	114	111	111	Dragonera (Spain)
5	61198	113	114	114	Cabo Gata (Spain)						



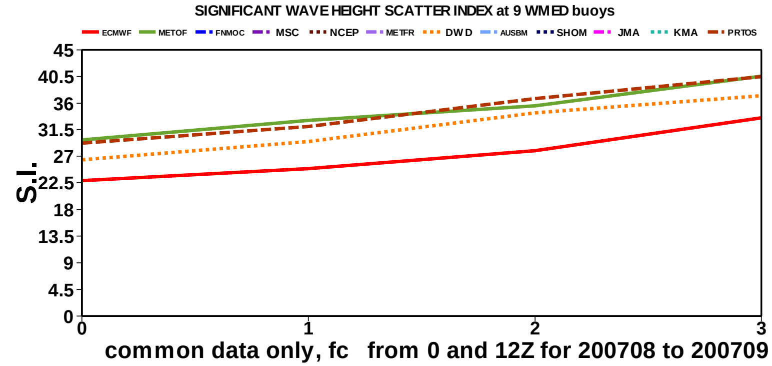
Euro Atlantic

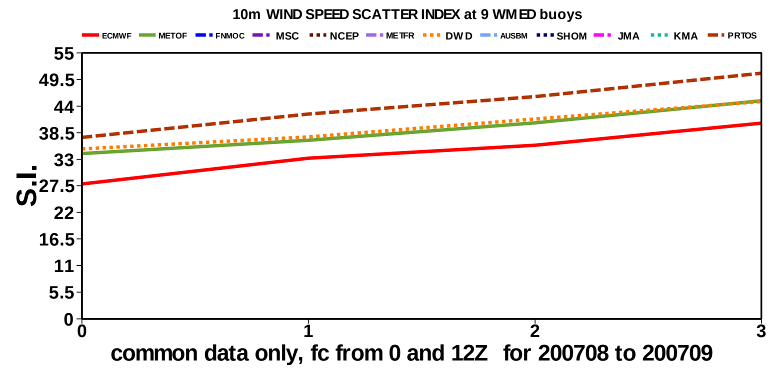


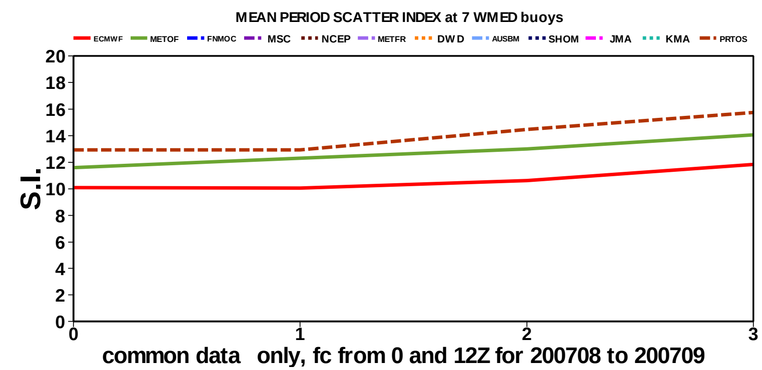




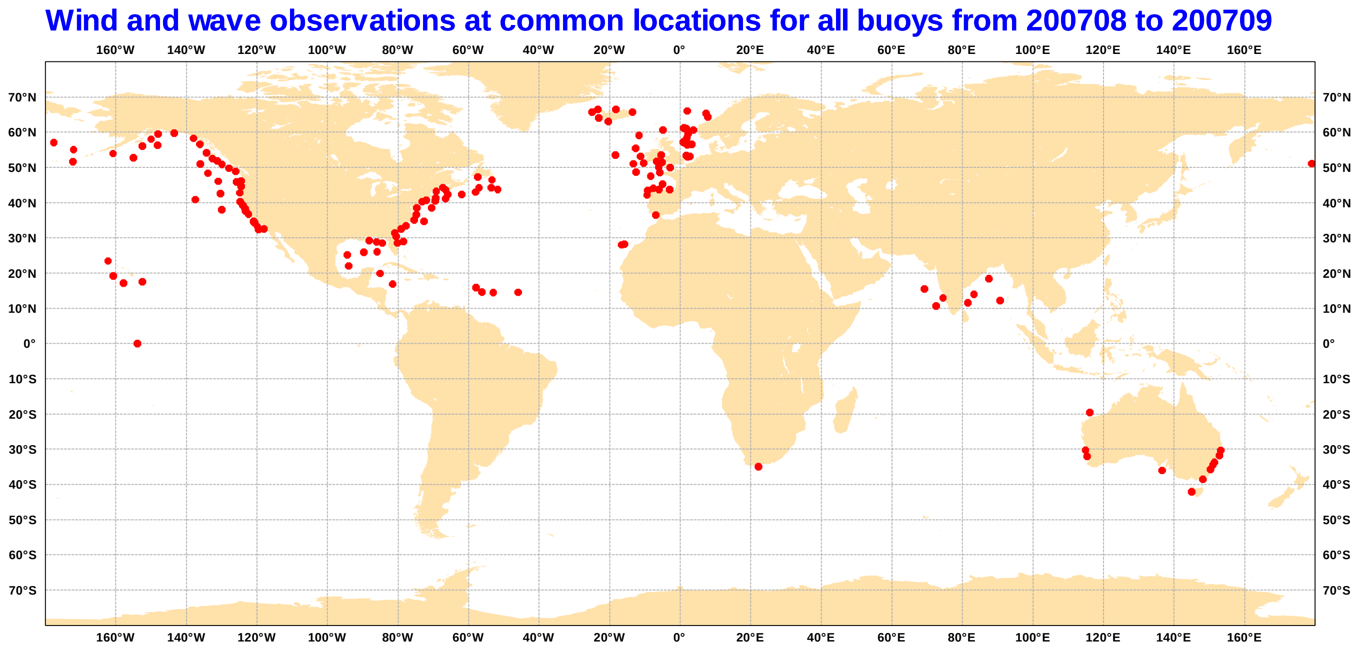
Western Mediterranean Sea





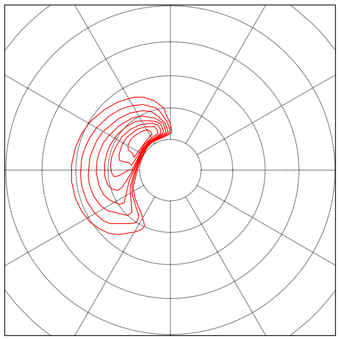


Latest list

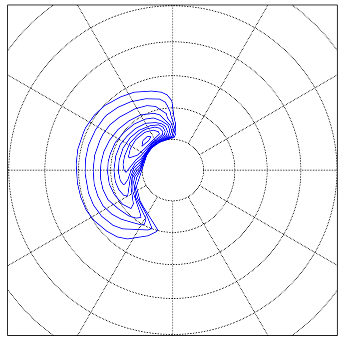

Wind and wave observations at common locations for all buoys from 200708 to 200709
160°W
140°W
120°W
100°W
80°W
60°W
40°W
20°W
0°
20°E
40°E
60°E
80°E
100°E
120°E
140°E
160°E
70°N
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S
70°S

Extension: wave spectra ?

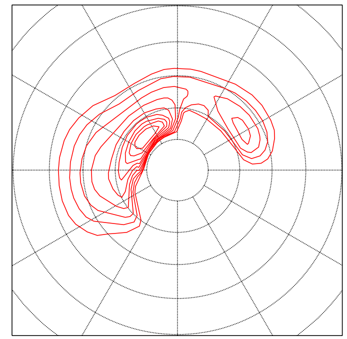
Normalised 2-D spectrum for
ey8s 1045 AN alpha= 0.1
21:00Z on 17.08.1969
at xxxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 13.54 m, fm= 0.085 Hz, fp= 0.067 Hz
Qp= 1.156, Dir. Spread = -nan



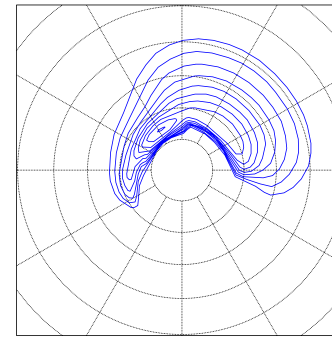
Normalised 2-D spectrum for
ey8s 1045 AN alpha= 1.0
21:00Z on 17.08.1969
at xxxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 16.20 m, fm= 0.079 Hz, fp= 0.067 Hz
Qp= 1.300, Dir. Spread = -nan



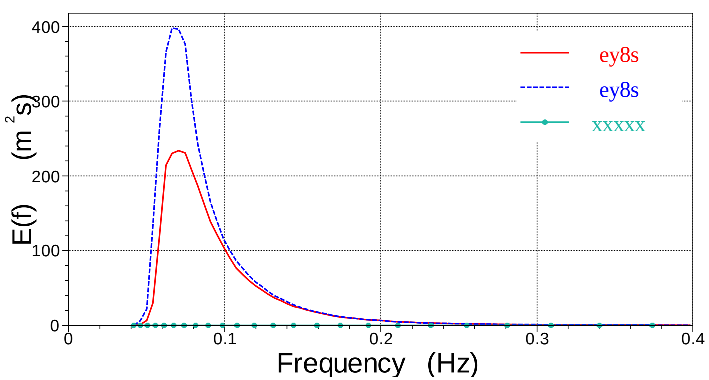
Normalised 2-D spectrum for
ey8s 1045 AN alpha= 0.1
00:00Z on 18.08.1969
at xxxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 8.32 m, fm= 0.096 Hz, fp= 0.074 Hz
Qp= 0.968, Dir. Spread = 0.647



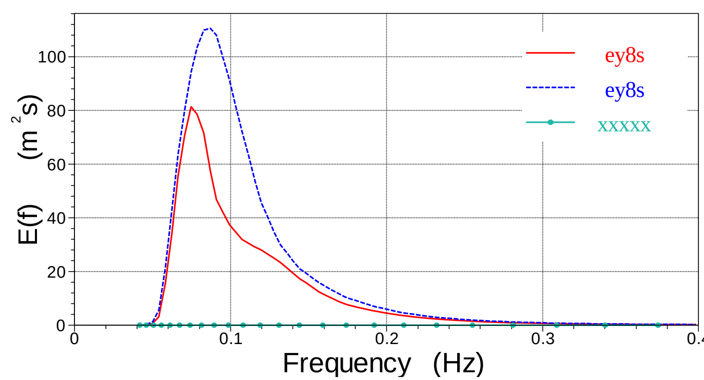
Normalised 2-D spectrum for
ey8s 1045 AN alpha= 1.0
00:00Z on 18.08.1969
at xxxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 10.41 m, fm= 0.097 Hz, fp= 0.090 Hz
Qp= 0.853, Dir. Spread = -nan



ey8s: Hs= 13.54 m, fm= 0.085 Hz, fp= 0.067 Hz
U10=43.27 m/s, u*= 3.17 m/s, windsea direction = 295°
ey8s: Hs= 16.20 m, fm= 0.079 Hz, fp= 0.067 Hz
U10=43.27 m/s, u*= 3.18 m/s, windsea direction = 299°
buoy: Hs= 0.00 m, fm= 0.000 Hz, fp= 0.000 Hz
wind speed = 0.00 m/s, wind direction (ocean. convention) = 0°

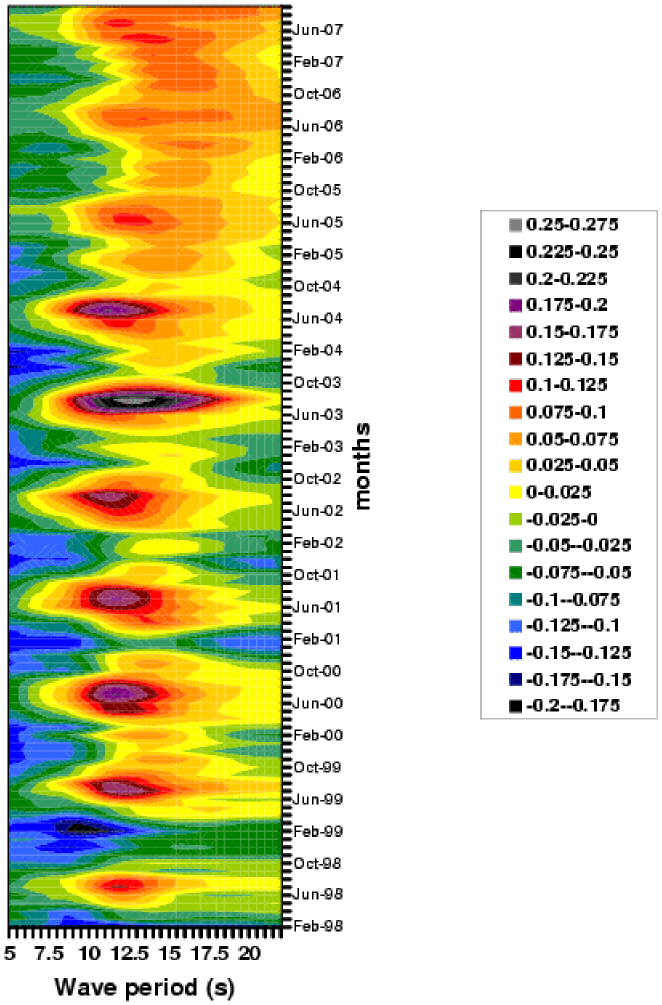


ey8s: Hs= 8.32 m, fm= 0.096 Hz, fp= 0.074 Hz
U10=32.30 m/s, u*= 1.66 m/s, windsea direction = 7°
ey8s: Hs= 10.41 m, fm= 0.097 Hz, fp= 0.090 Hz
U10=32.30 m/s, u*= 2.60 m/s, windsea direction = 26°
buoy: Hs= 0.00 m, fm= 0.000 Hz, fp= 0.000 Hz
wind speed = 0.00 m/s, wind direction (ocean. convention) = 0°

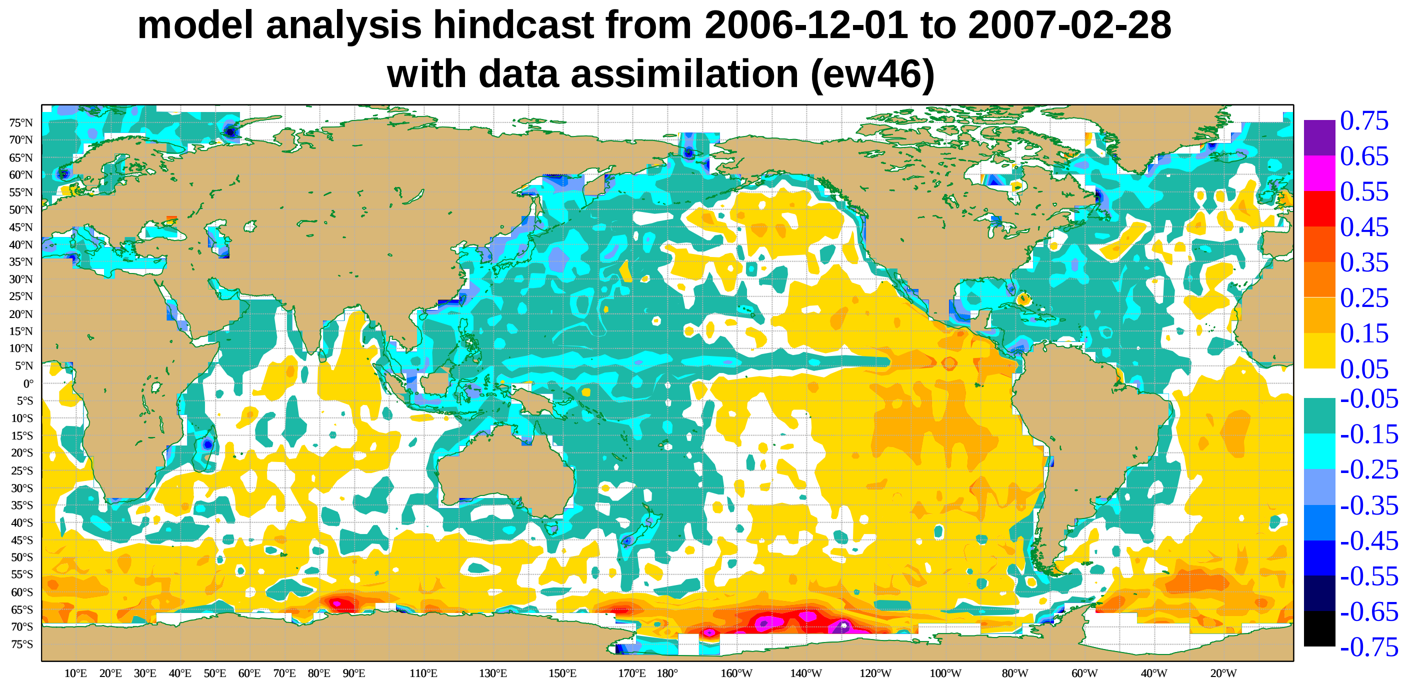


Extension: wave spectra ?

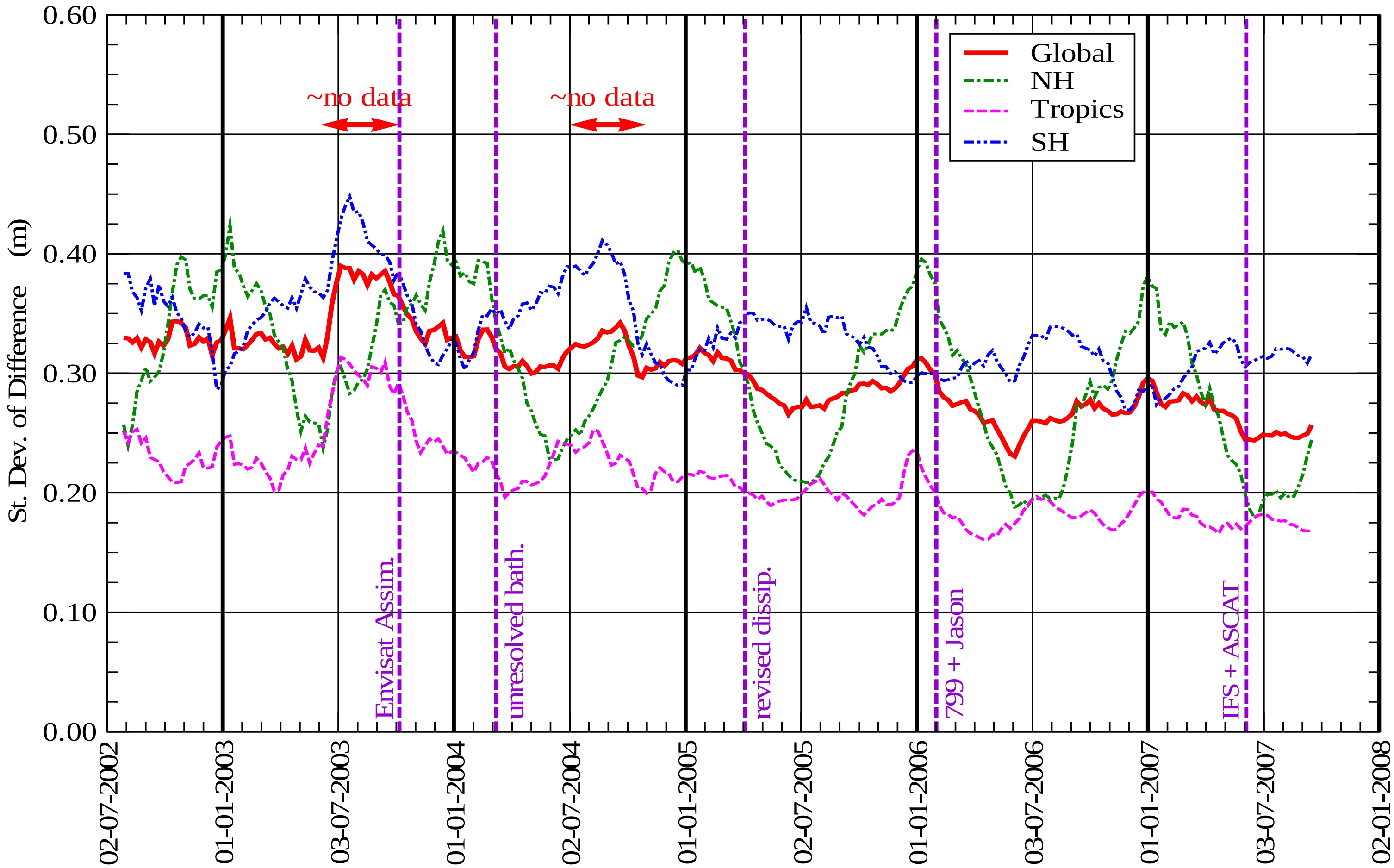
Equivalent wave height bias (model-buoy)
at all US and Canadian buoys.
Operational analysis



Extension: comparison with altimeter Hs ?



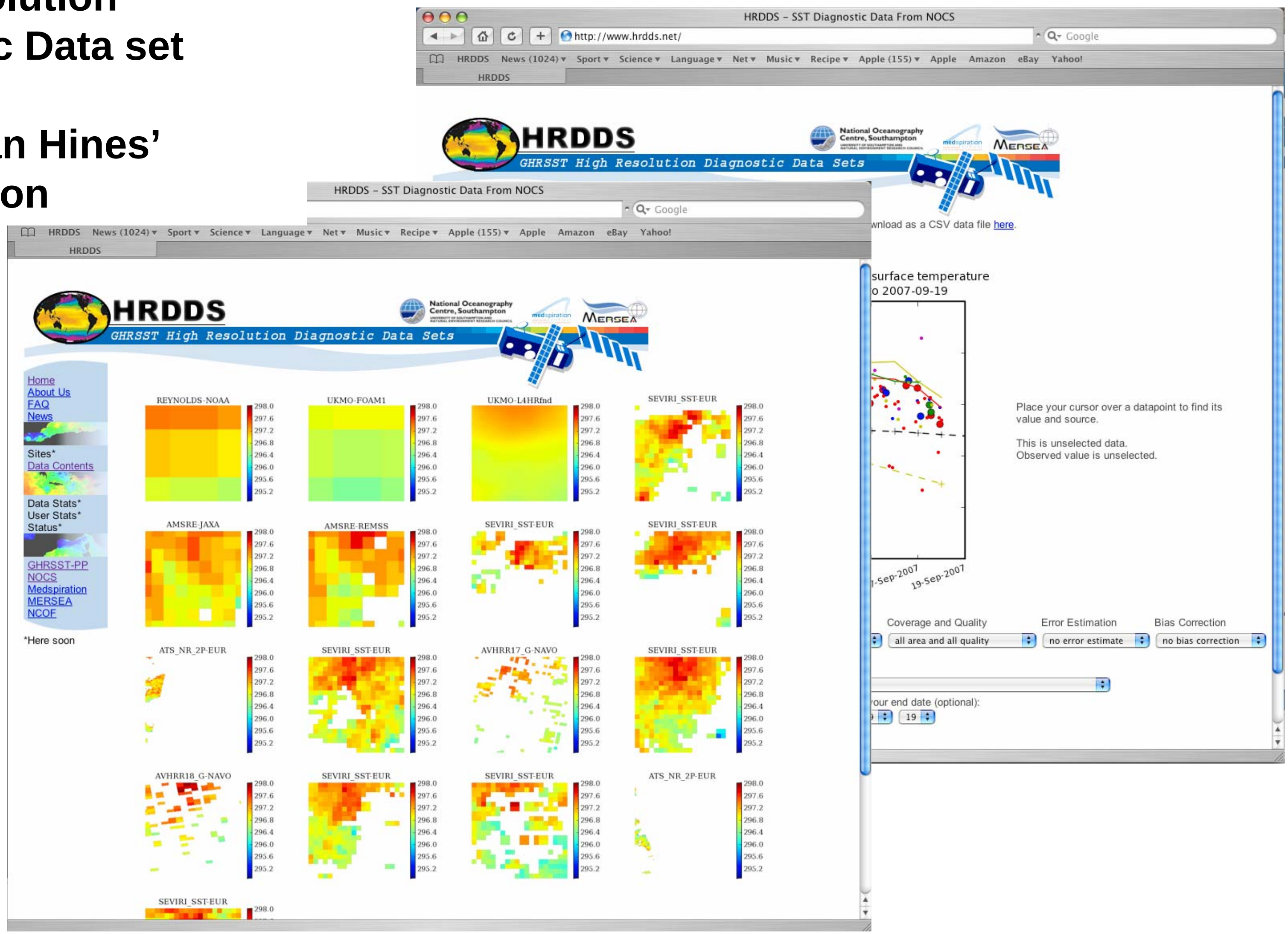
Extension: comparison with altimeter Hs ?



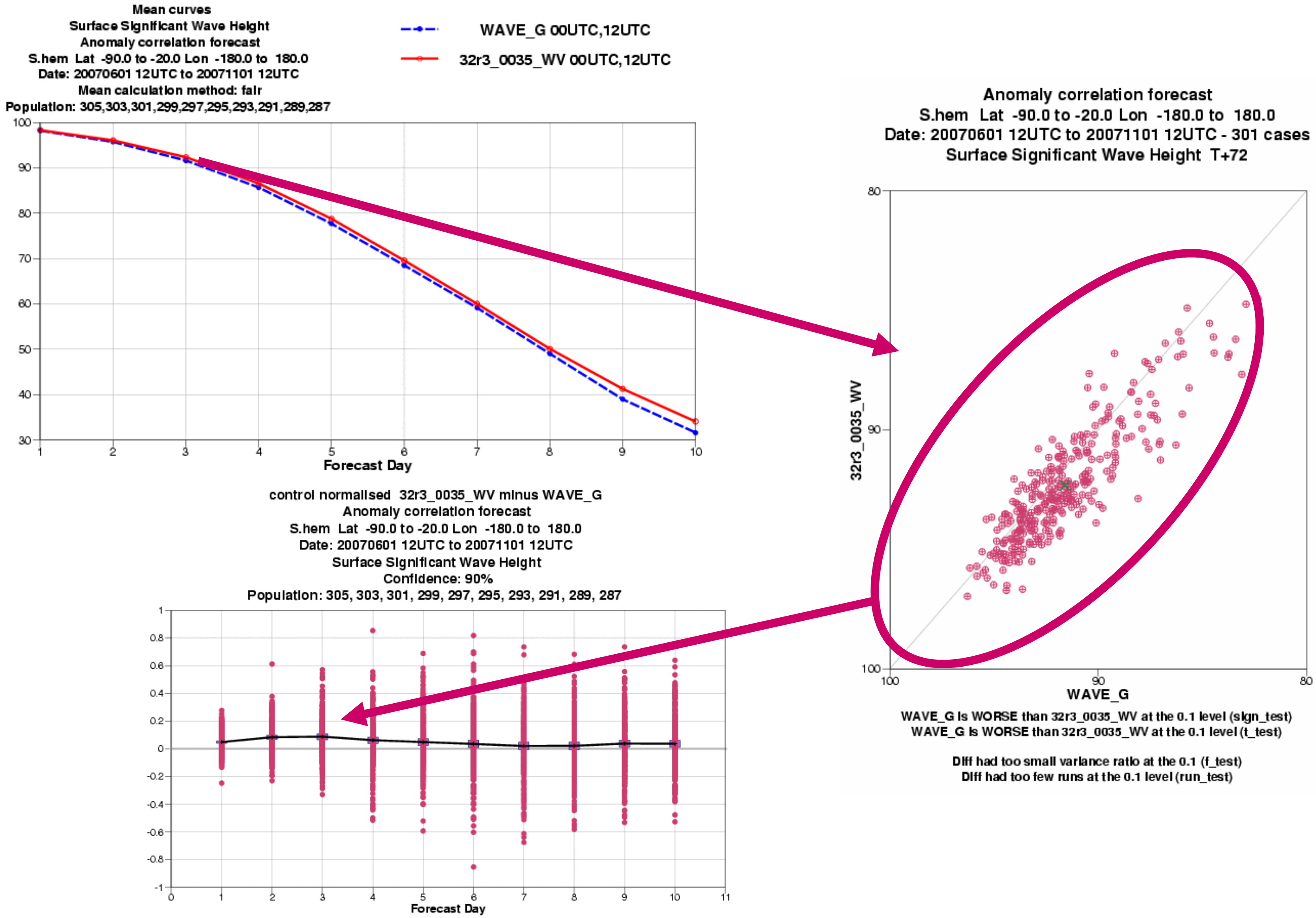
ENVISAT RA-2 SWH St. Dev. Diff. with respect to WAM

Extension: field comparison ?

High Resolution Diagnostic Data set (HRDDS)
(see Adrian Hines' presentation



Extension: field comparison: scores as in atm. forecasting



Conclusions:

- This informal inter-comparison of wind and wave model data has worked well for over 12 years.
- It is time to work on extending this exercise.
- By adding wave spectra?
- By comparing to remotely sensed data (Altimeter(s), SARs)?
- By exchanging model fields (HHDR approach, objective score approach)?