Testing TSA & FBI performances with ST4 physics over Global grid

Bash Toulany, Will Perrie and Mike Casey
Bedford Institute of Oceanography

WW3-dev group, March 21, 2018

Introduction:

- A brief history on the Two-Scale Approximation (**TSA**) and the Full Boltzmann Integral (**FBI**) :
  1) Theoretical development by **Resio & Perrie (2008).**
  2) Application to observed wave spectra by **Perrie & Resio (2009).**
  3) First implementation in ww3 was done in v4.18, with academic tests without Sin & Sds **Perrie et al. (2013**) and
  4) First real test cases were done with ST1 & ST2 confirming the need for tuning.
- New advanced physics for SIN4 & SDS4 (switch ST4) by **Ardhuin et al. (2010)** was tested with DIA over global ocean. Tuning was necessary to make ST4 work best with DIA.
- Recently, we have used ST4 was with DIA for modeling North Atlantic Nor'easters, **Perrie et al. (2018).** Tuning also was necessary to make ST4 deliver the best results for North Atlantic storms.

- Using the latest WAVEWATCH III release v5.16, we tested TSA (switch NL4) with ST4 for real storms over the global ocean.
- We simulated several periods in 2014 and 2015 in which significant hurricanes were present, forced by the Global Climate Forecast System Reanalysis winds (CFSR).
- We compared the TSA simulations with two other nonlinear wave-wave interaction formulations available in WW3:
  1) the Direct Interaction Approximation (DIA), the fastest (and most-commonly used) and
  2) the Webb, Resio & Tracey (WRT), the most accurate (but costly and hence least used).

Switches used:

F90 DIST MPI NOGRB NOPA LRB4 NC4 TRKNC **PR3 UQ** FLX0 LN1 **ST4** STAB0 **NL4** BT1 DB1 MLIM IC0 IS0 REF0 WNT2 WNX2 RWND CRT1 CRX1 TR0 BS0 XX0 O0 O1 O2 O3 O4 O5 O6 O7

Grid Domain (GLOBAL):

0.0 E -> 359.5 E
-80.0 S -> 80.0 N
dx = dy = 0.50 deg => 720 x 321 grids
dtg dtxy dtkxy dts = 1800. 600. 600. 300. (sec.)
Depth, mask & obstruction files were all obtained using "gridgen1" on ETOPO1.

Initial Condition:

Use Fetch-limited JONSWAP spectrum (ITYPE = 3)

Wind forcing:

Use the Global CFSR winds at **~0.20 deg**

Longitude range	:	0.00	359.80 (deg)
Latitude range	:	-89.84	89.84 (deg)
Input grid dim.	:	1760	880

No ice forcing, water level or currents

The Simulations:

Instead of running this setup for a whole year, as in (Ardhuin et al. 2010), we chose (given the limited resources) to do several periods from 2014 & 2015 in which significant hurricanes were present. These were selected from the NHC data archive on tropical cyclone reports http://www.nhc.noaa.gov/data/tcr/

Hurricane	kt km/h	Start		End	Duration
Hurricane Arthur	(85=157)	2014-07-01-01	->	2014-07-07-01	(6d)
Hurricane Bertha	(70=130)	2014-08-01-01	->	2014-08-07-01	(6d)
Hurricane Cristobal	(75=140)	2014-08-23-01	->	2014-08-29-01	(6d)
Hurricane Danny	(135=250)	2015-08-18-01	->	2015-08-25-01	(7d)
Hurricane Joaquin	(110=204)	2015-09-29-01	->	2015-10-08-01	(9d)
Hurricane Patricia	(185=343)	2015-10-20-01	->	2015-10-25-01	(5d)

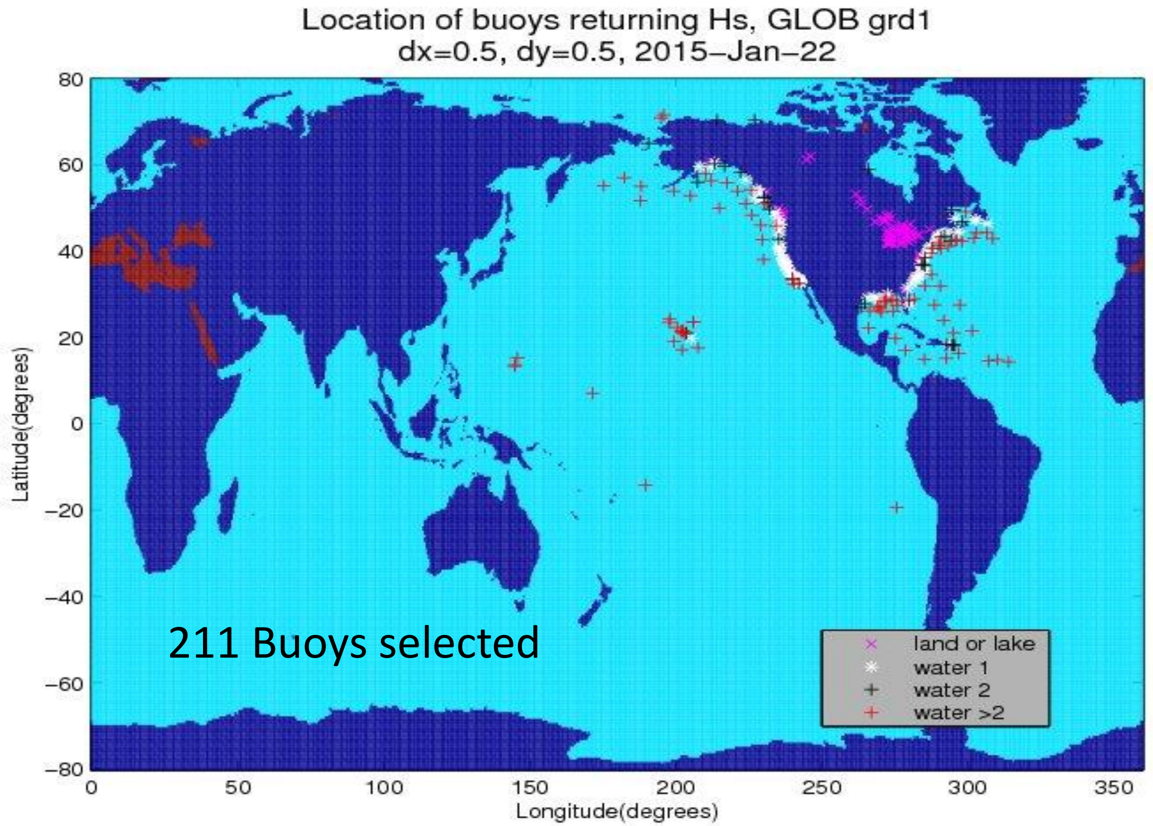
Snl-#	BETAMAX	ZALP	???	
DIA-0	1.43	0.006	----	default
WRT-0	1.43	0.006	----	default
TSA-2	1.65	0.008	-----	mod-2
TSA-4	1.75	0.009	-----	mod-4

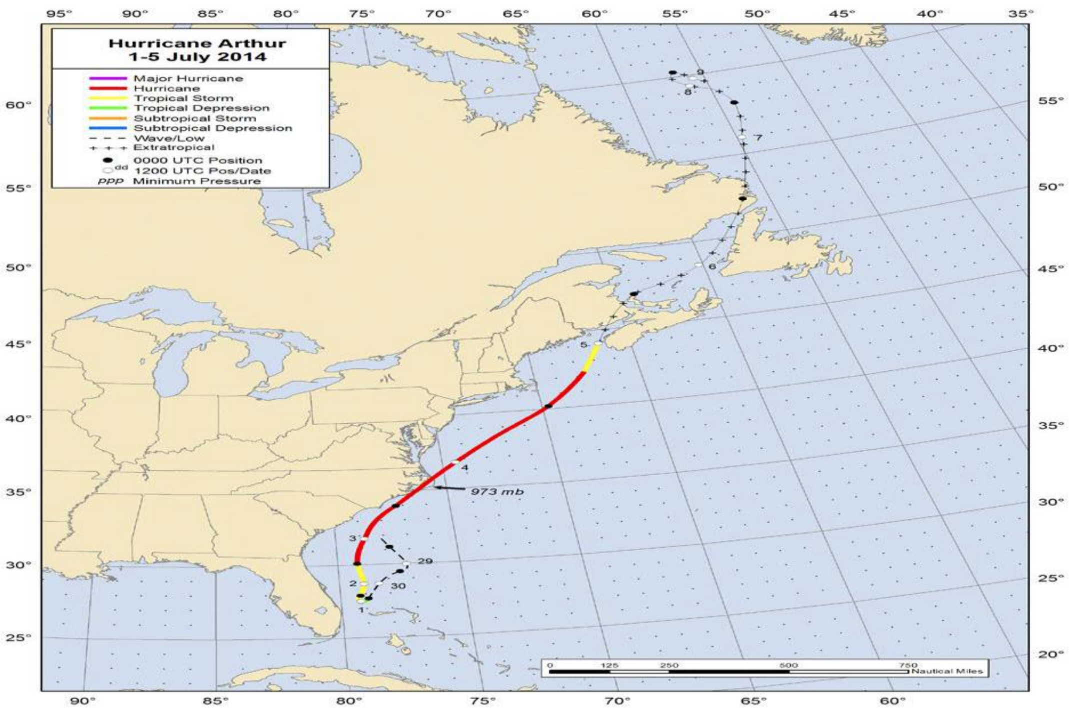
For TSA runs: ALTLP = 2

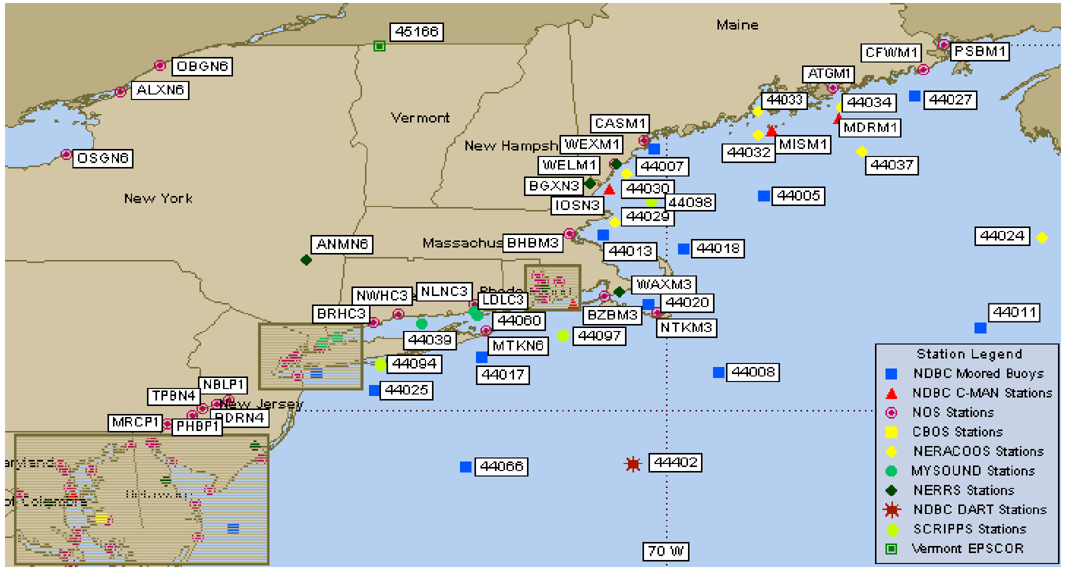
Note: Problem with ww3-v5.16 **NL4** switch in MPI mode implementation. Running **ww3_multi** in MPI mode ran into trouble with all processors wanting to write the same thing, TSA lookup tables **"grd_1.1000_29_36_30_37.dat".** So, to get around this problem, First you have **cancel all the !/MPI lines and all the write statements in SUBROUTINE INSNL4**. Then, run **ww3_shel** in serial mode for 1-point ocean to generate TSA lookup table. Then we can run **ww3_multi** in MPI mode with no problem.

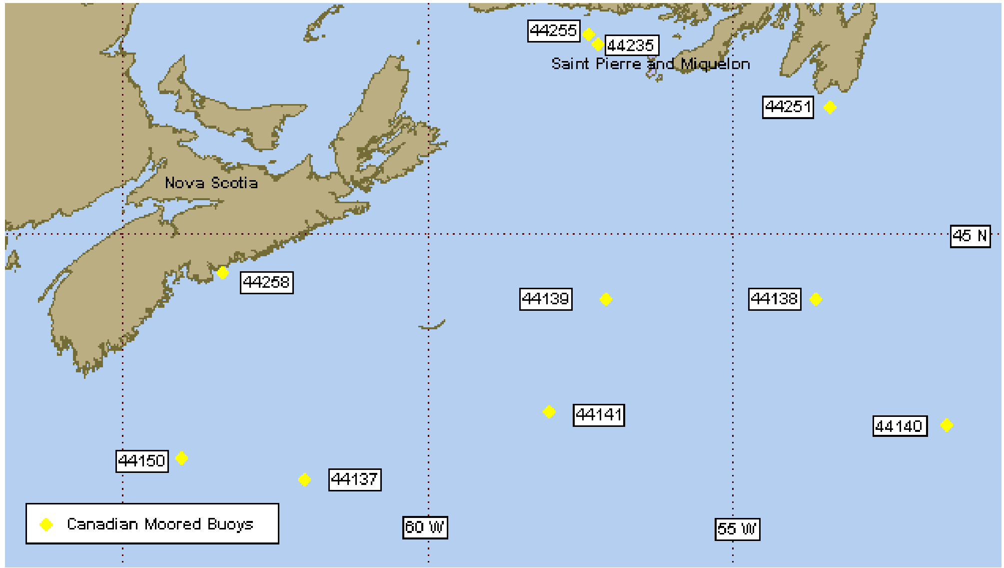
For validation I've used:

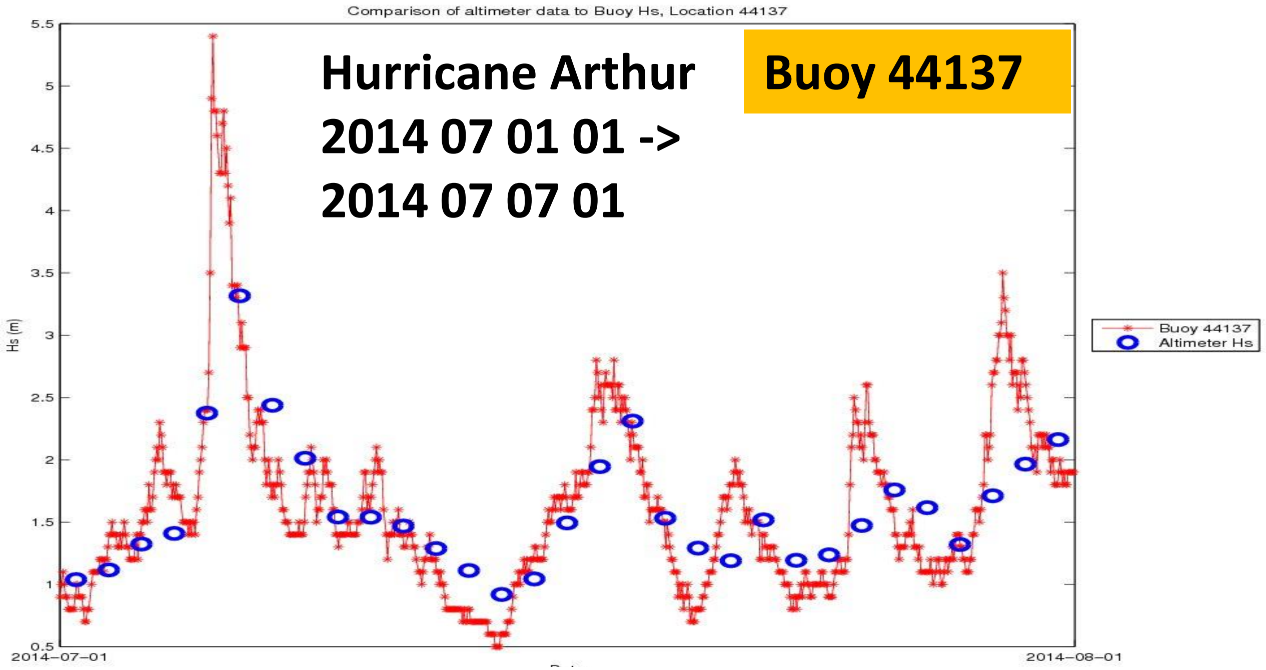
1. all available Buoys (globally): got 211 buoys that are >1 grid point of the coast and
2. AVISO cross-calibrated merged altimeter Significant Wave Height (SWH) data (daily) from
   ftp://ftp.aviso.altimetry.fr/pub/oceano/AVISO/wind-wave/nrt/mswh/merged/

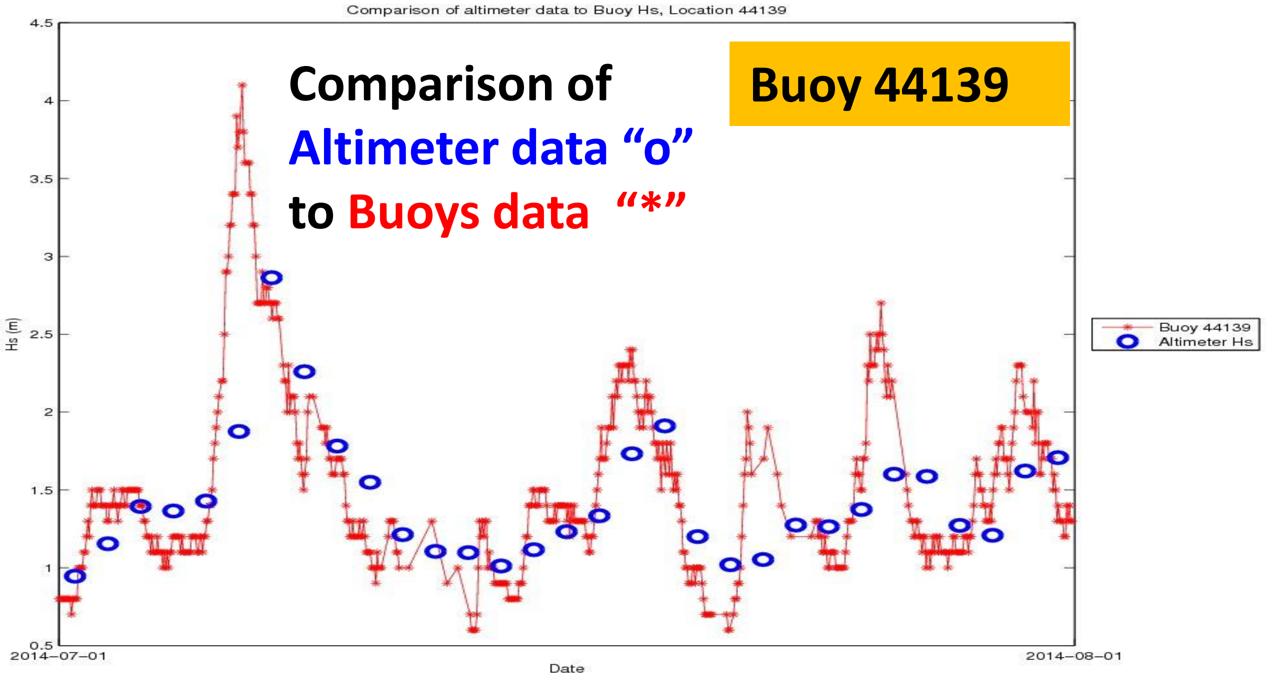

Location of buoys returning Hs, GLOB grd1
dx=0.5, dy=0.5, 2015–Jan–22
Latitude(degrees)
Longitude(degrees)
211 Buoys selected
land or lake
water 1
water 2
water >2

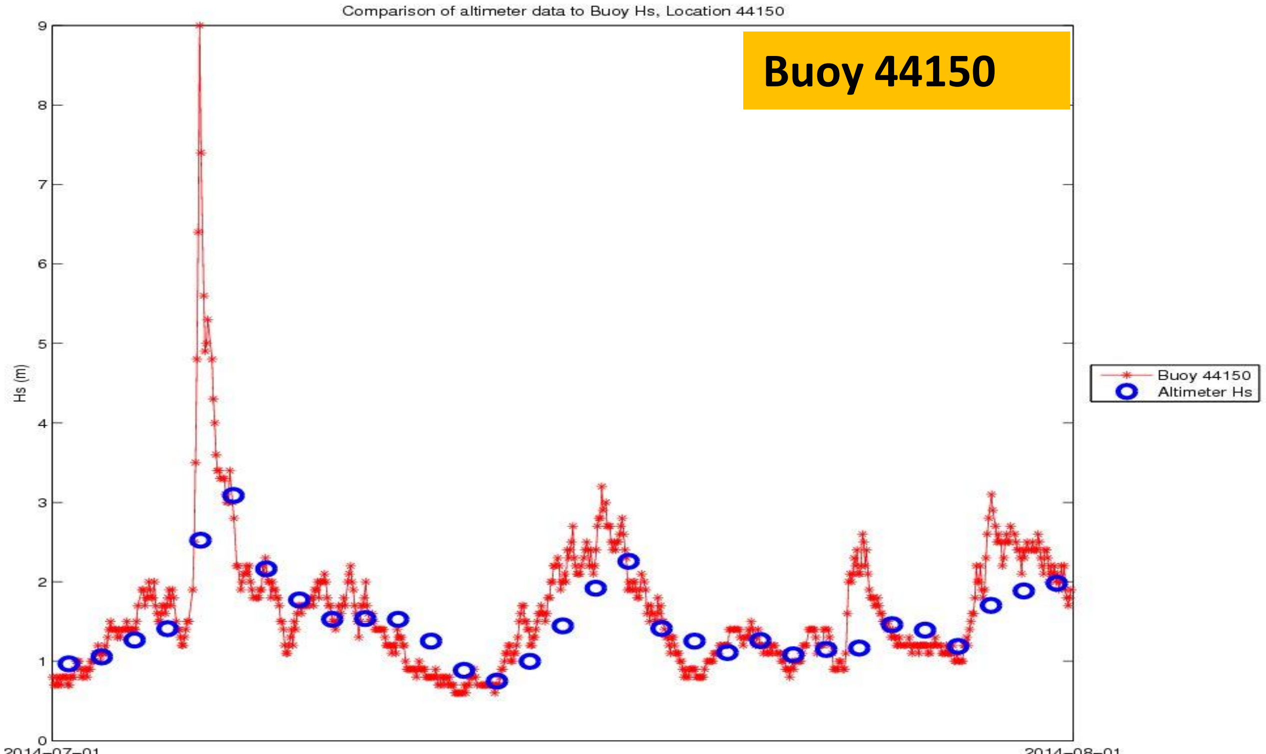

Hurricane Arthur
1-5 July 2014
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low
Extratropical
0000 UTC Position
1200 UTC Pos/Date
Minimum Pressure
973 mb
Nautical Miles

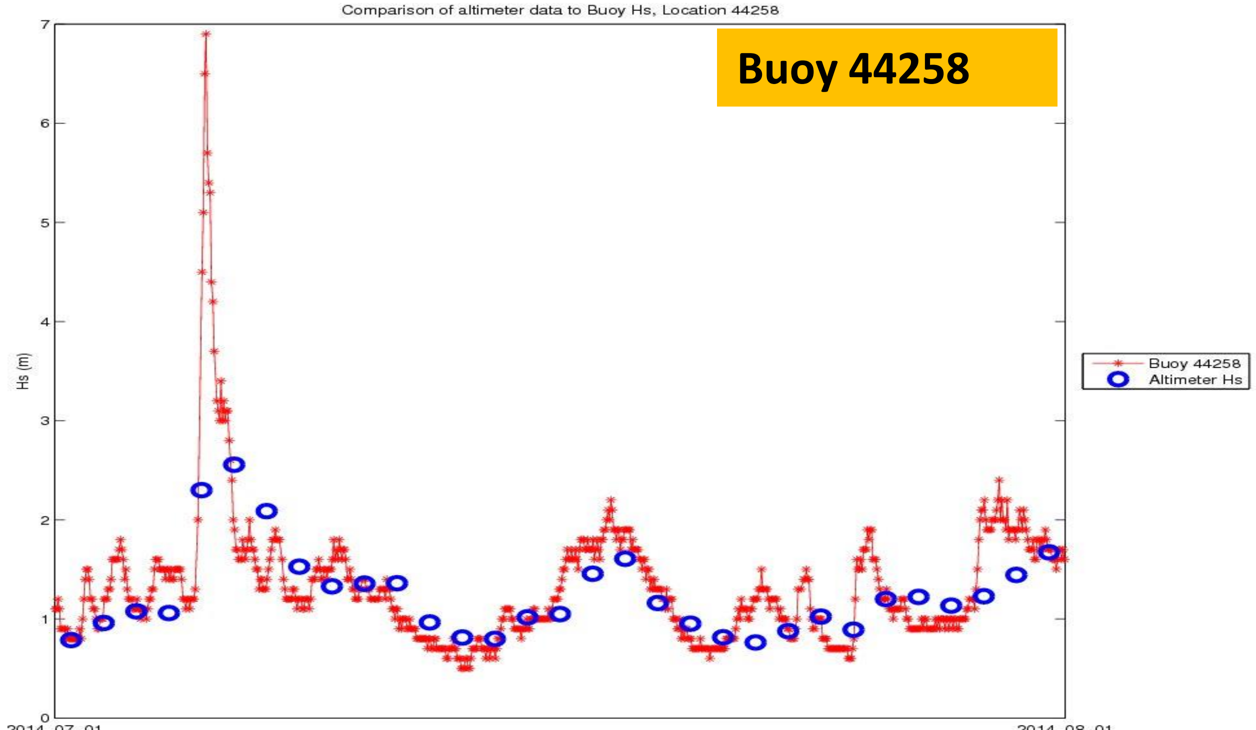

Maine
Vermont
New Hampsh
New York
Massachus
New Jersey
45166
OBGN6
ALXN6
OSGN6
CFWM1
PSBM1
ATGM1
44033
44034
44027
MDRM1
CASM1
44032
MISM1
44037
WEXM1
44007
WELM1
BGXN3
44030
IOSN3
44098
44029
44005
ANMN6
BHBM3
44013
44018
44024
NWHC3
NLNC3
LDLC3
WAXM3
44020
BRHC3
44060
BZBM3
NTKM3
44011
44039
MTKN6
44097
44094
44017
44008
44025
NBLP1
TPBN4
MRCP1
PHBP1
BDRN4
44066
44402
70 W
Station Legend
NDBC Moored Buoys
NDBC C-MAN Stations
NOS Stations
CBOS Stations
NERACOOS Stations
MYSOUND Stations
NERRS Stations
NDBC DART Stations
SCRIPPS Stations
Vermont EPSCOR

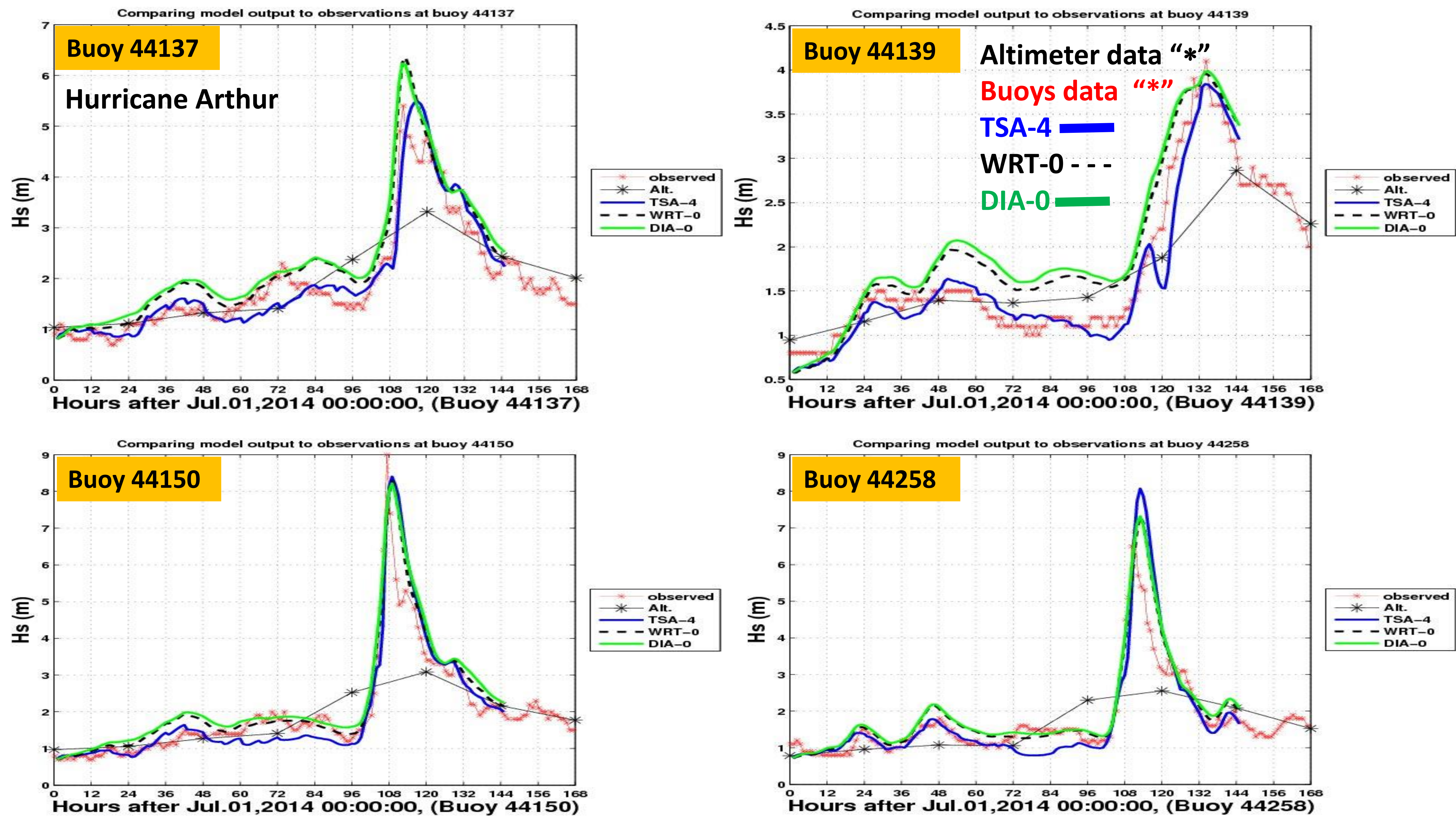

44255
44235
Saint Pierre and Miquelon
44251
Nova Scotia
45 N
44258
44139
44138
44141
44140
44150
44137
Canadian Moored Buoys
60 W
55 W

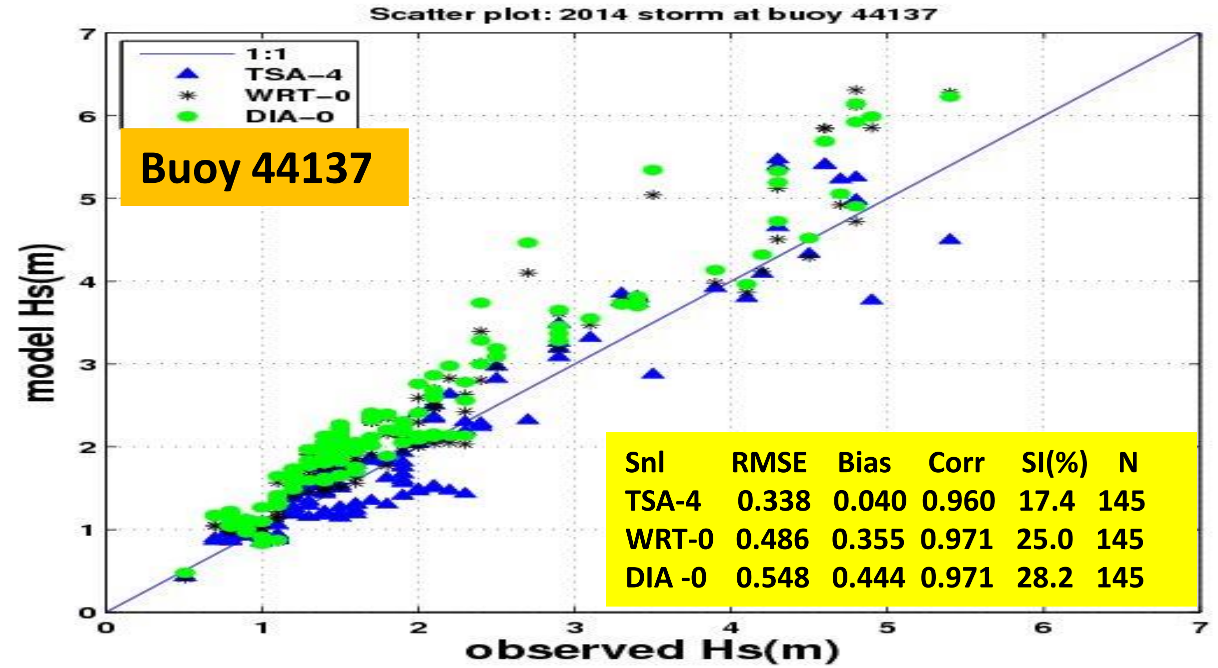

Comparison of altimeter data to Buoy Hs, Location 44137
Hurricane Arthur
2014 07 01 01 ->
2014 07 07 01
Buoy 44137
Buoy 44137
Altimeter Hs
Hs (m)
2014–07–01
2014–08–01

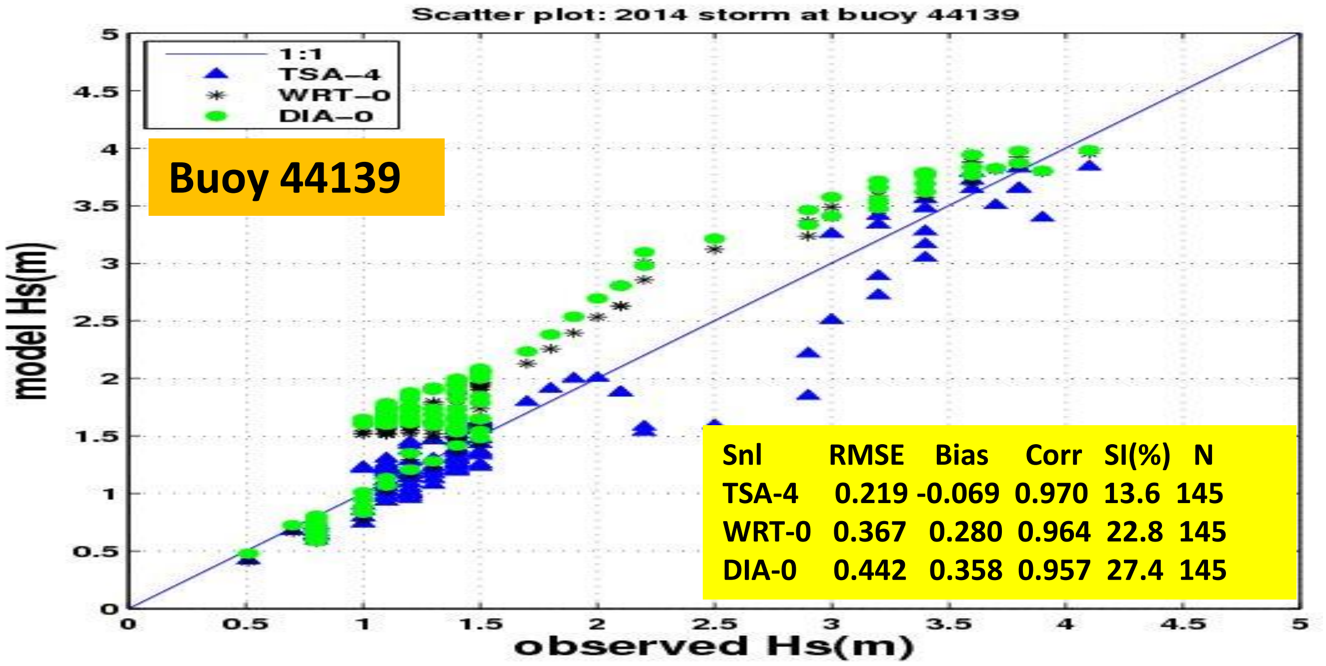

Comparison of altimeter data to Buoy Hs, Location 44139
Comparison of
Altimeter data "o"
to Buoys data "*"
Buoy 44139
Buoy 44139
Altimeter Hs
Hs (m)
Date
2014–07–01
2014–08–01

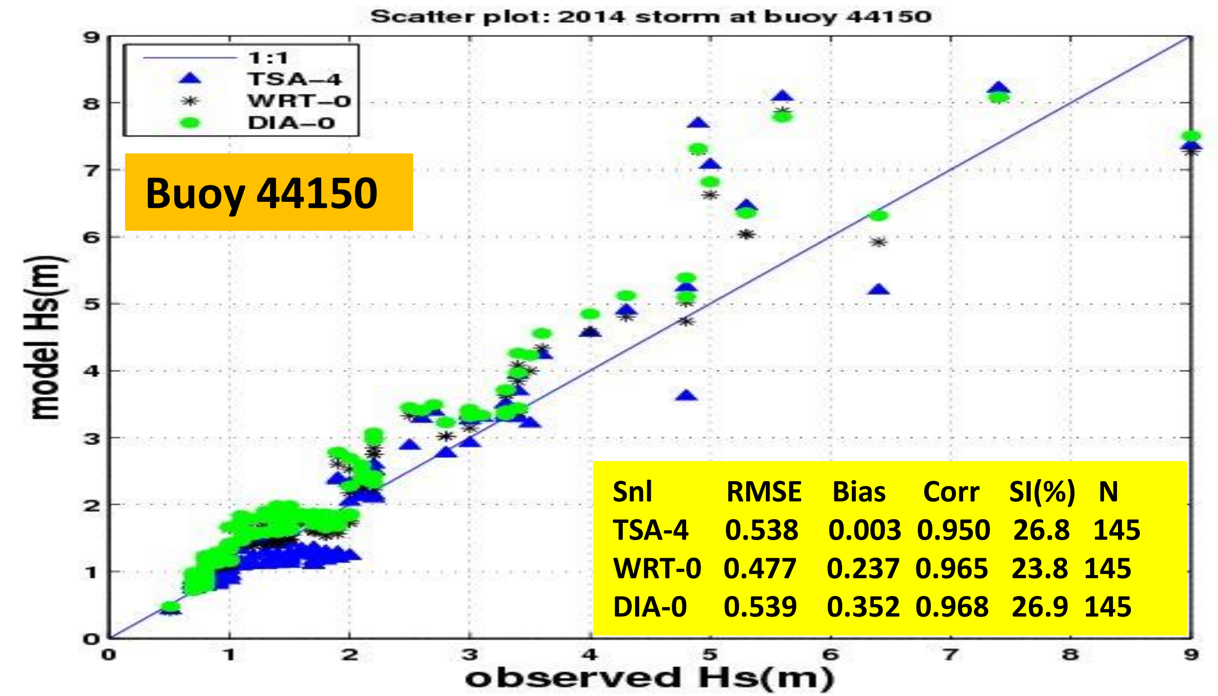

Comparison of altimeter data to Buoy Hs, Location 44150
Buoy 44150
Buoy 44150
Altimeter Hs
Hs (m)

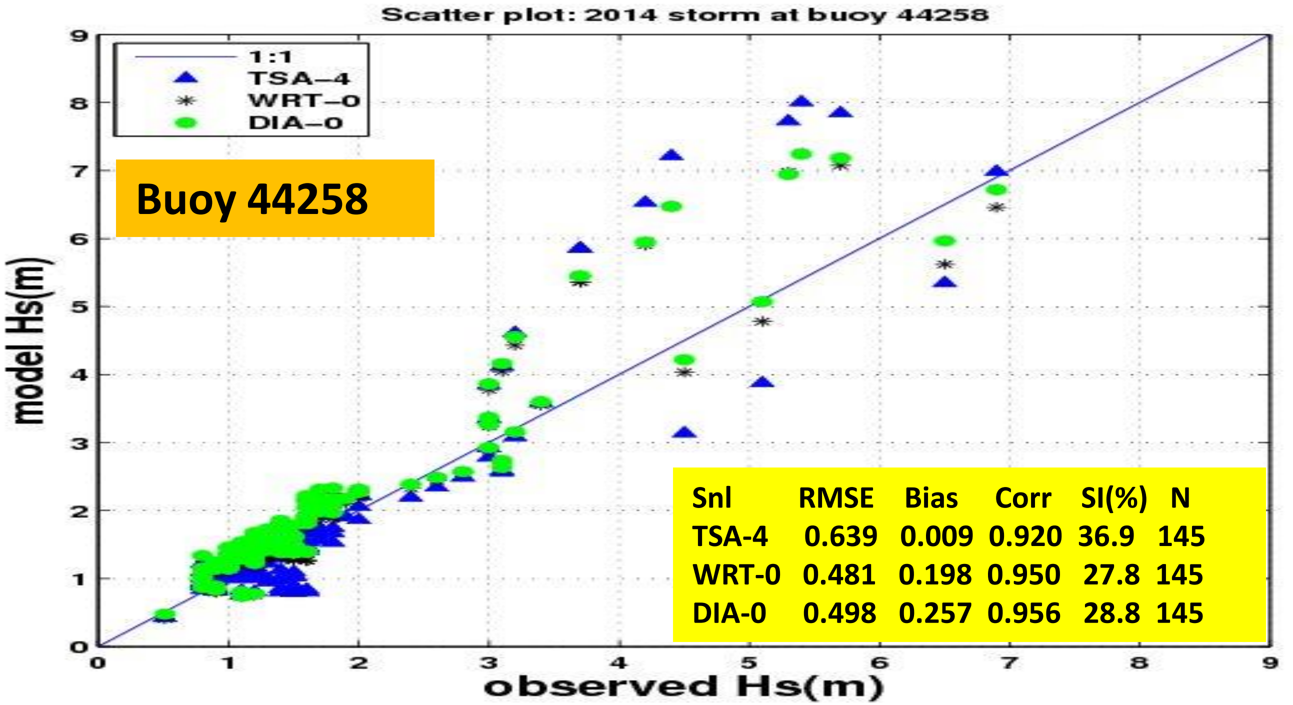

Comparison of altimeter data to Buoy Hs, Location 44258
Buoy 44258
Buoy 44258
Altimeter Hs
Hs (m)


Comparing model output to observations at buoy 44137
Buoy 44137
Hurricane Arthur
Hs (m)
Hours after Jul.01,2014 00:00:00, (Buoy 44137)
observed
Alt.
TSA−4
WRT−0
DIA−0
Comparing model output to observations at buoy 44139
Buoy 44139
Altimeter data “*”
Buoys data “*”
TSA-4
WRT-0 - - -
DIA-0
Hs (m)
Hours after Jul.01,2014 00:00:00, (Buoy 44139)
Comparing model output to observations at buoy 44150
Buoy 44150
Hs (m)
Hours after Jul.01,2014 00:00:00, (Buoy 44150)
Comparing model output to observations at buoy 44258
Buoy 44258
Hs (m)
Hours after Jul.01,2014 00:00:00, (Buoy 44258)


Scatter plot: 2014 storm at buoy 44137
1:1
TSA–4
WRT–0
DIA–0
Buoy 44137
Snl RMSE Bias Corr SI(%) N
TSA-4 0.338 0.040 0.960 17.4 145
WRT-0 0.486 0.355 0.971 25.0 145
DIA -0 0.548 0.444 0.971 28.2 145
model Hs(m)
observed Hs(m)

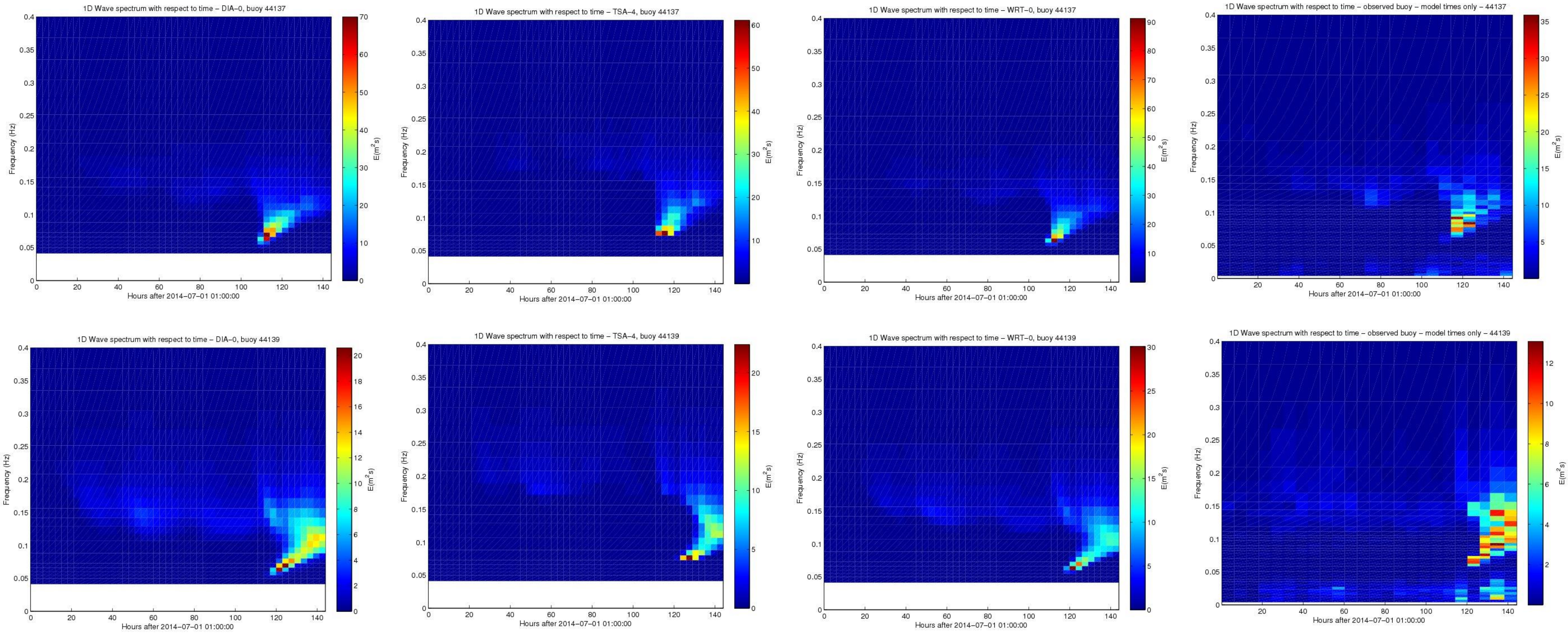

Scatter plot: 2014 storm at buoy 44139
1:1
TSA–4
WRT–0
DIA–0
Buoy 44139
Snl RMSE Bias Corr SI(%) N
TSA-4 0.219 -0.069 0.970 13.6 145
WRT-0 0.367 0.280 0.964 22.8 145
DIA-0 0.442 0.358 0.957 27.4 145
model Hs(m)
observed Hs(m)


Scatter plot: 2014 storm at buoy 44150
1:1
TSA–4
WRT–0
DIA–0
Buoy 44150
Snl RMSE Bias Corr SI(%) N
TSA-4 0.538 0.003 0.950 26.8 145
WRT-0 0.477 0.237 0.965 23.8 145
DIA-0 0.539 0.352 0.968 26.9 145
model Hs(m)
observed Hs(m)

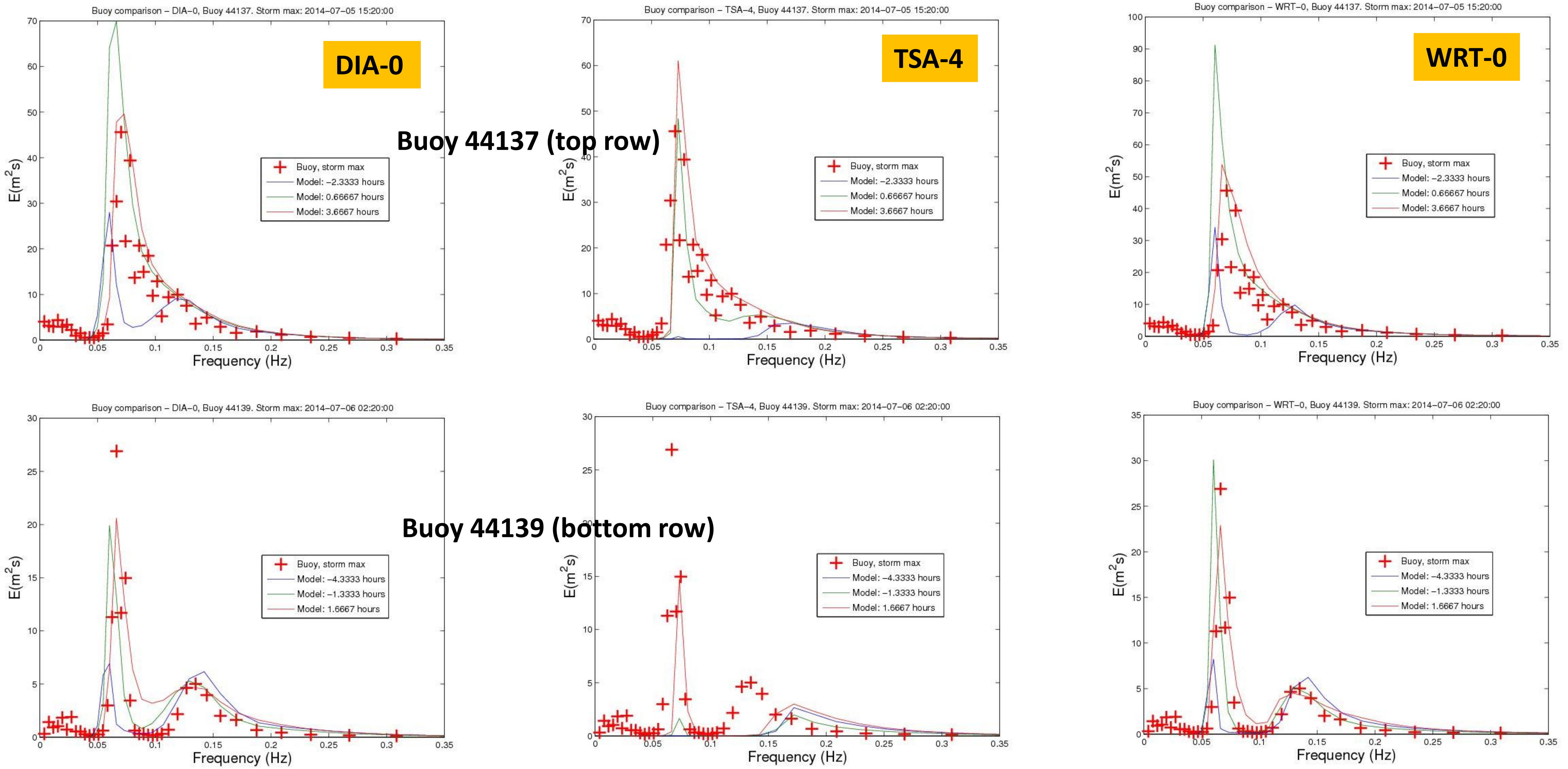

Scatter plot: 2014 storm at buoy 44258
1:1
TSA–4
WRT–0
DIA–0
Buoy 44258
Snl RMSE Bias Corr SI(%) N
TSA-4 0.639 0.009 0.920 36.9 145
WRT-0 0.481 0.198 0.950 27.8 145
DIA-0 0.498 0.257 0.956 28.8 145
model Hs(m)
observed Hs(m)

1D Energy time evolution at Buoy 44137 (top row) & Buoy 44139 (bottom row)

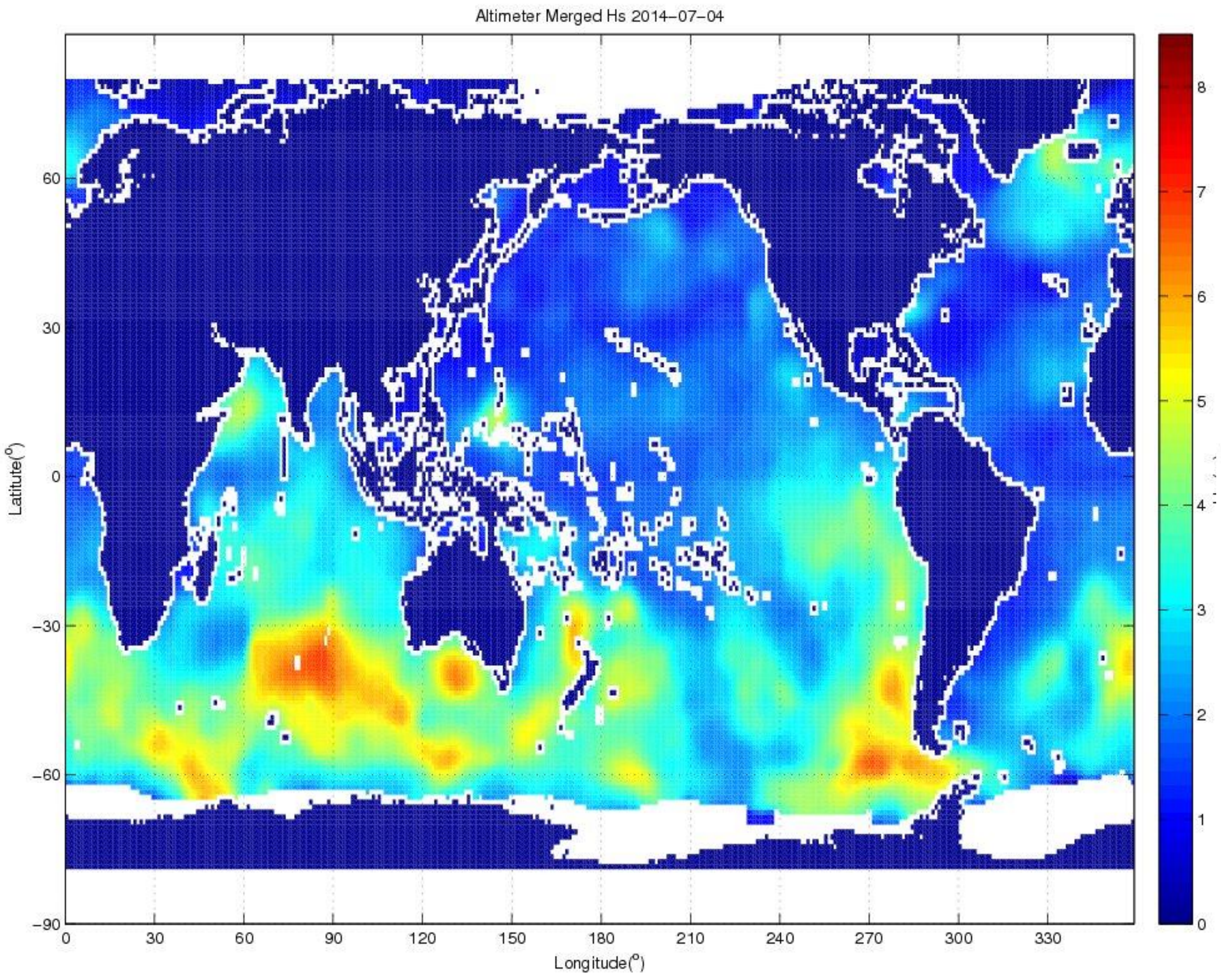
DIA-0 | **TSA-4** | **WRT-0** | **Buoy**



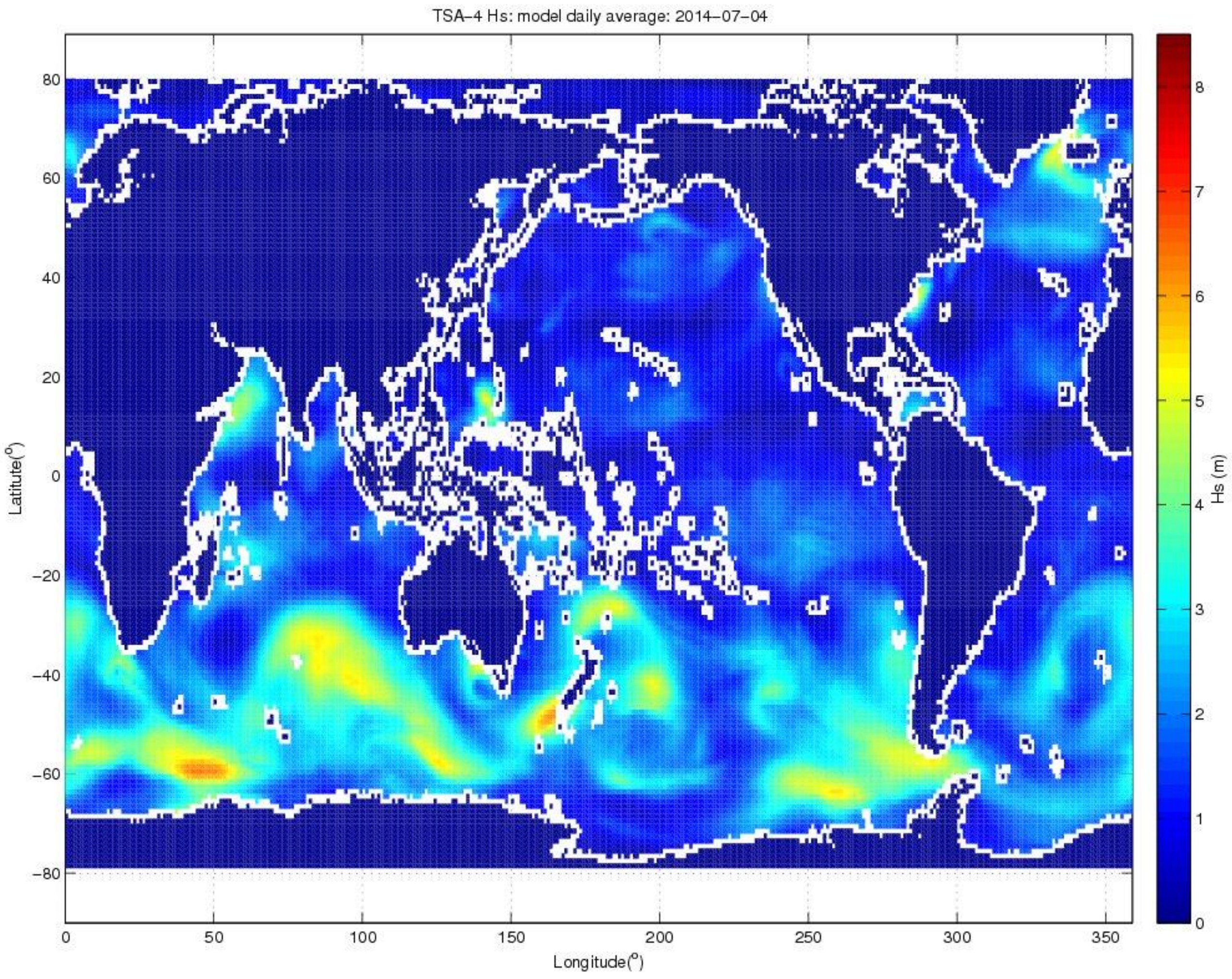
1D Energy comparison at storm peak +/- x hours at Buoy 44137 (top row) & Buoy 44139 (bottom row)



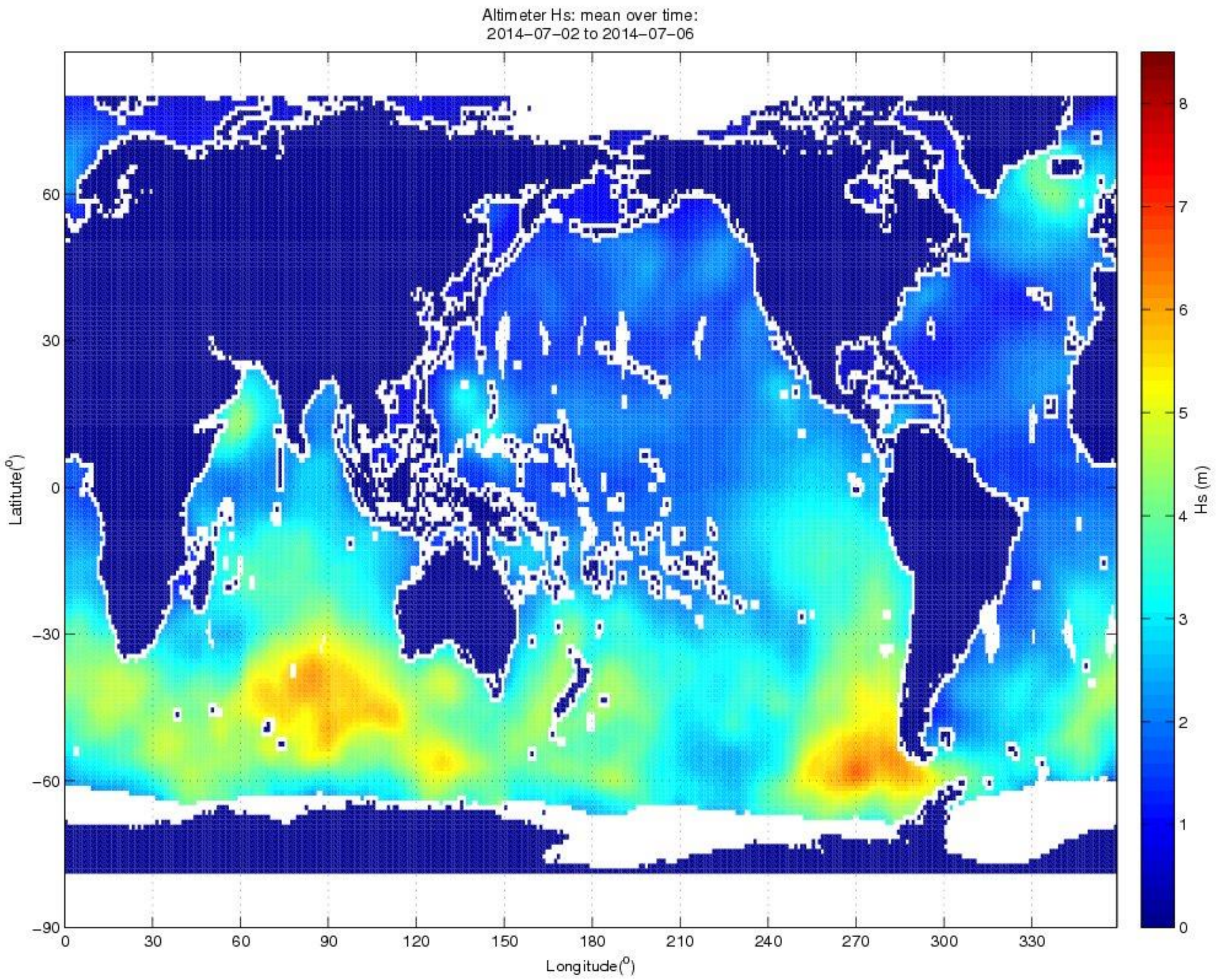
Altimeter daily Hs average for 2014-07-04



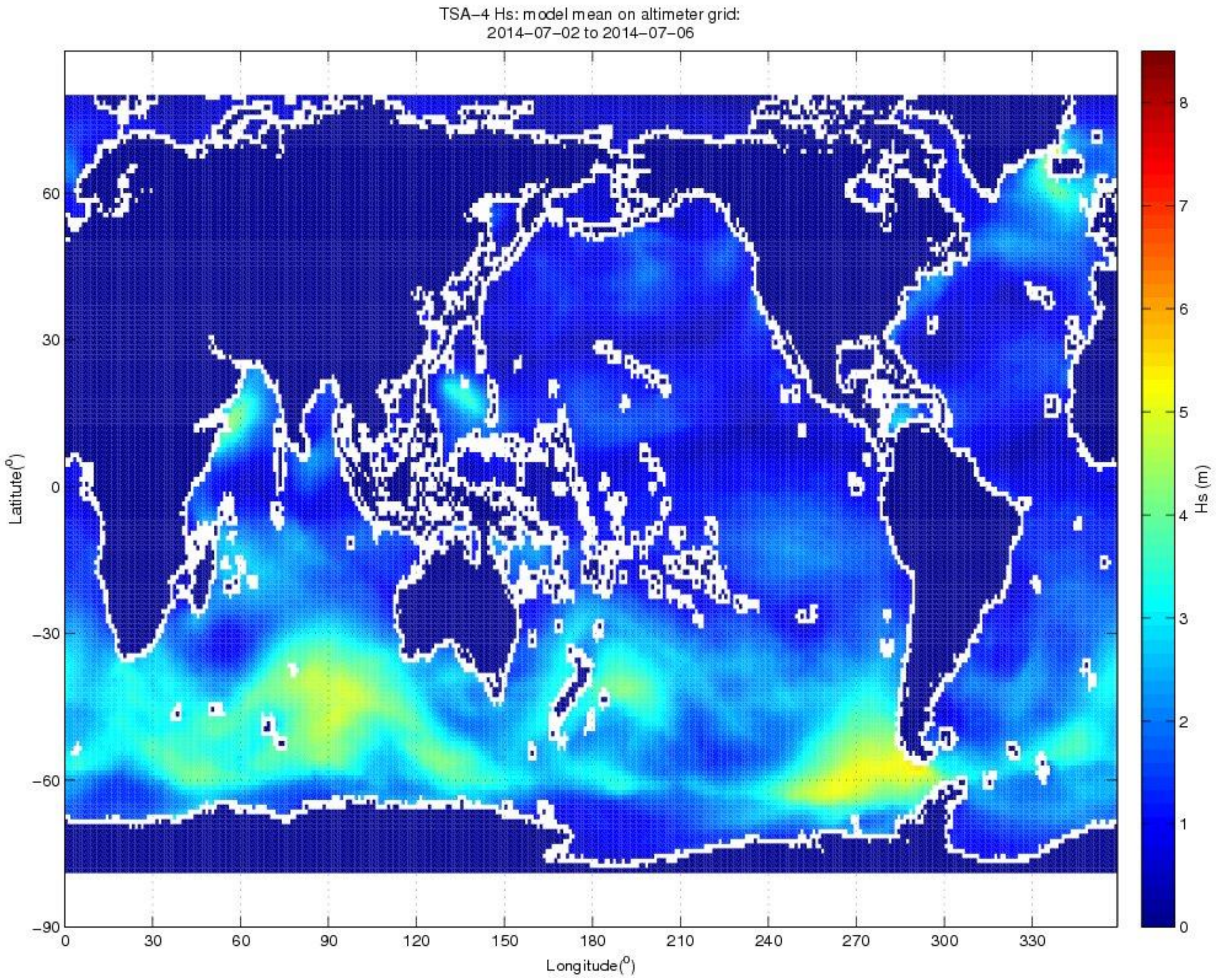
TSA-4 model daily Hs average for 2014-07-04



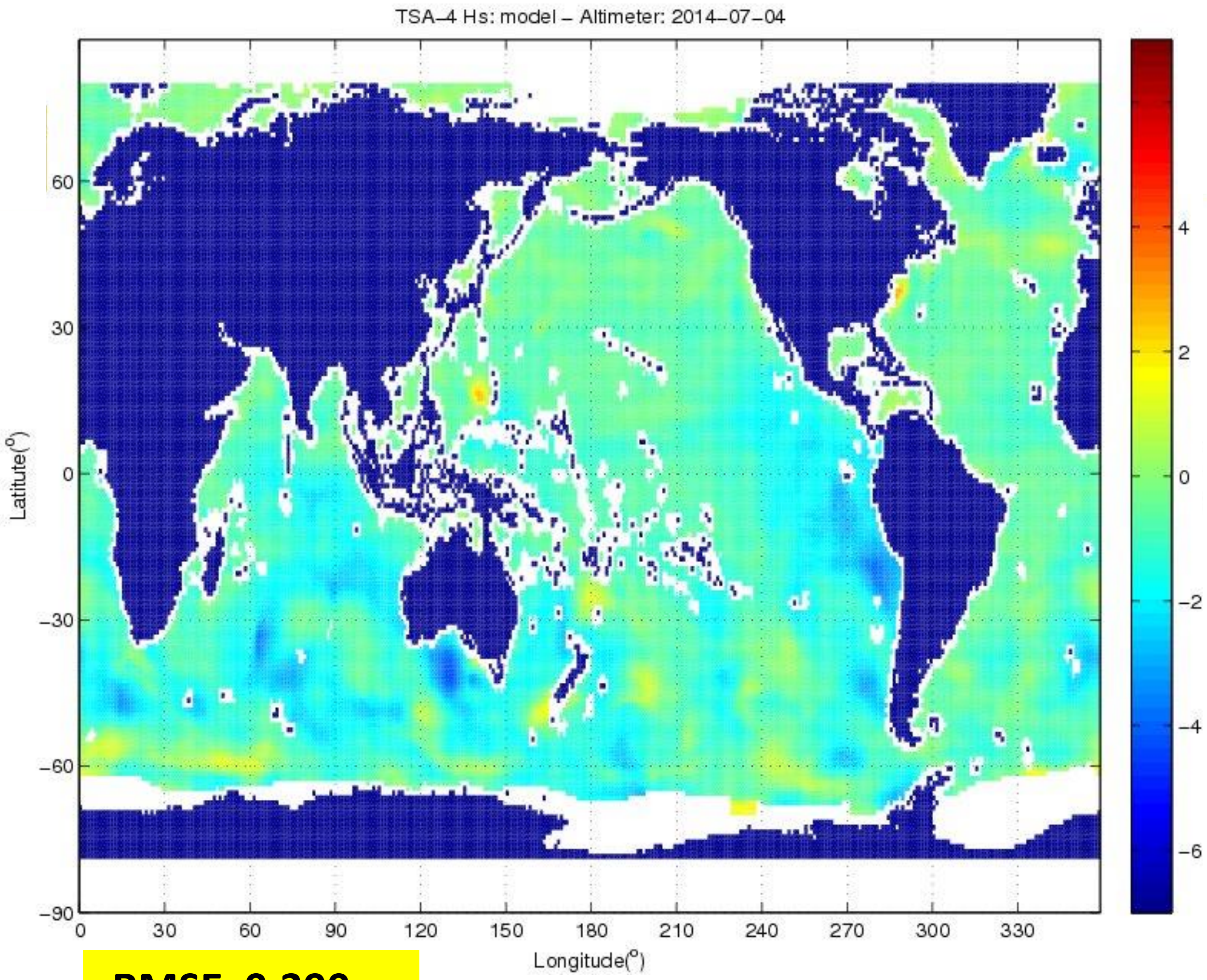
Altimeter Hs average over 5 days
2014-07-02 -> 2014-07-06



TSA-4 Hs average over 5 days
2014-07-02 -> 2014-07-06

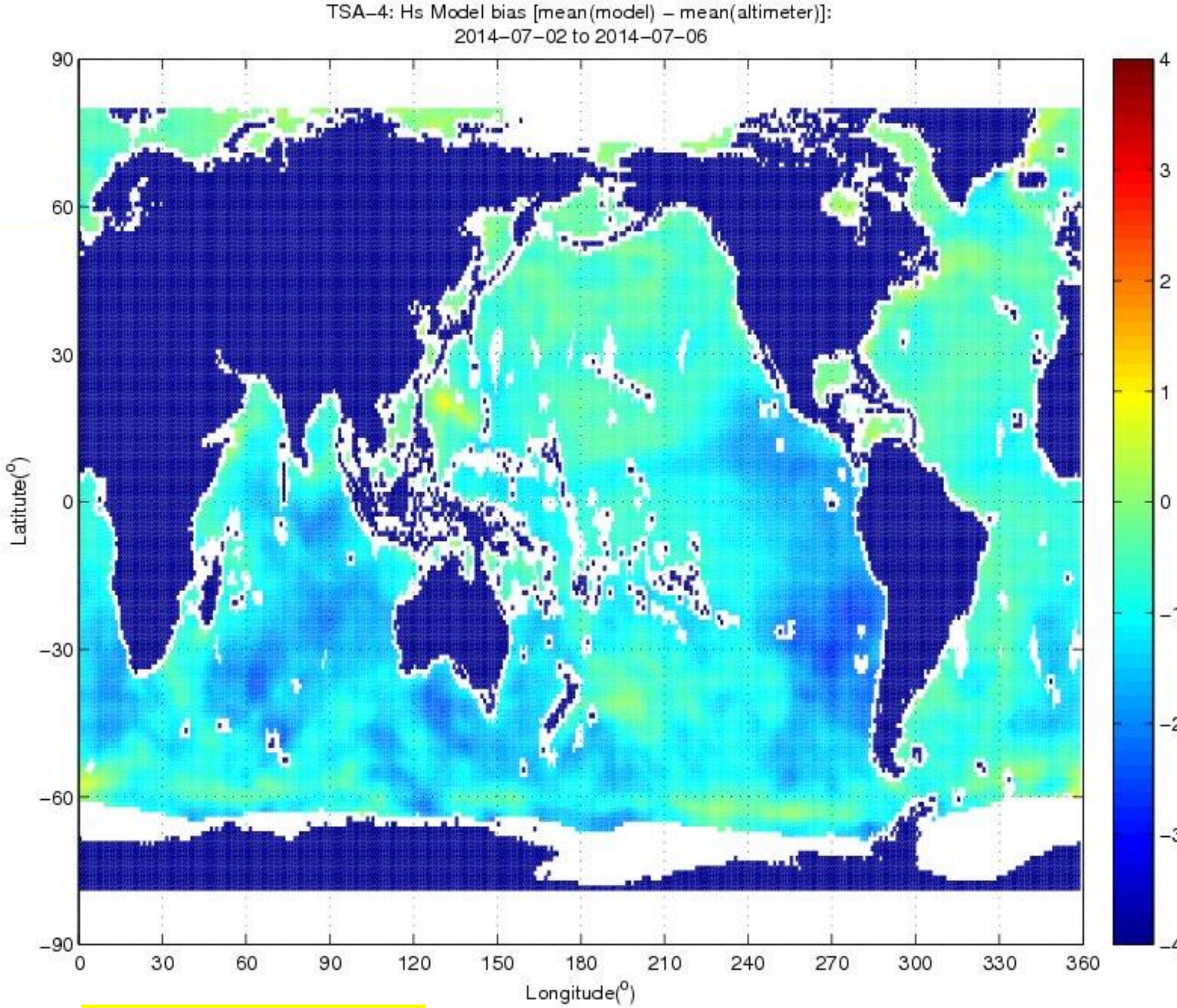


TSA-4: (model-altimeter) over one day
2014-07-04



RMSE 0.390
Bias -0.347
Corr 0.839
N 28199

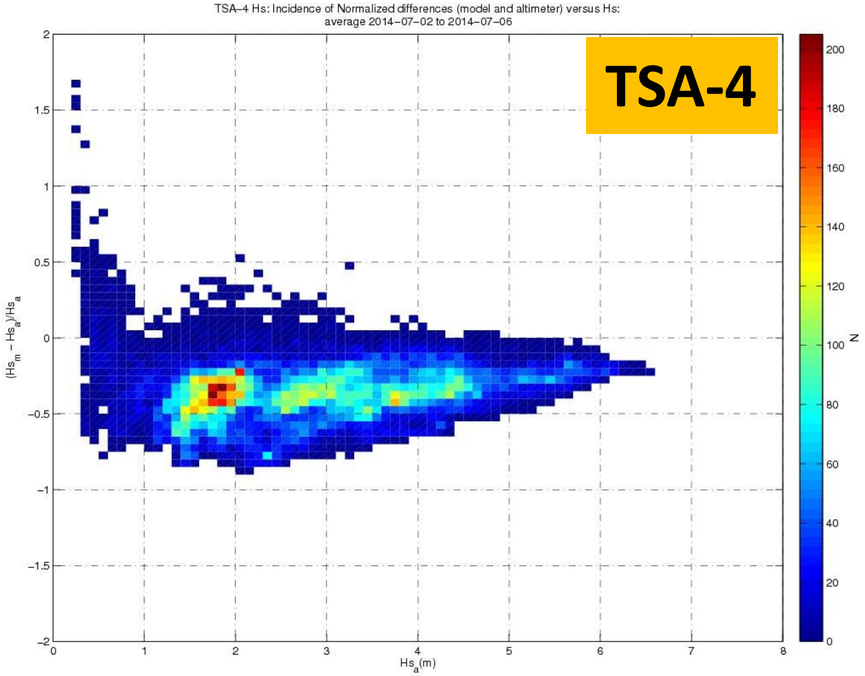
TSA-4: (model-altimeter) over 5 days
2014-07-02 -> 2014-07-06

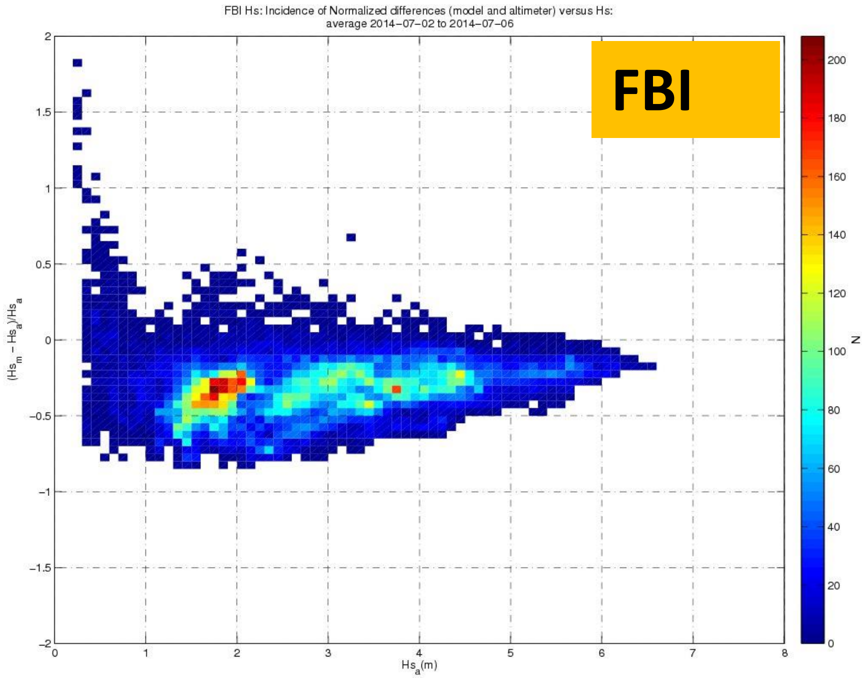


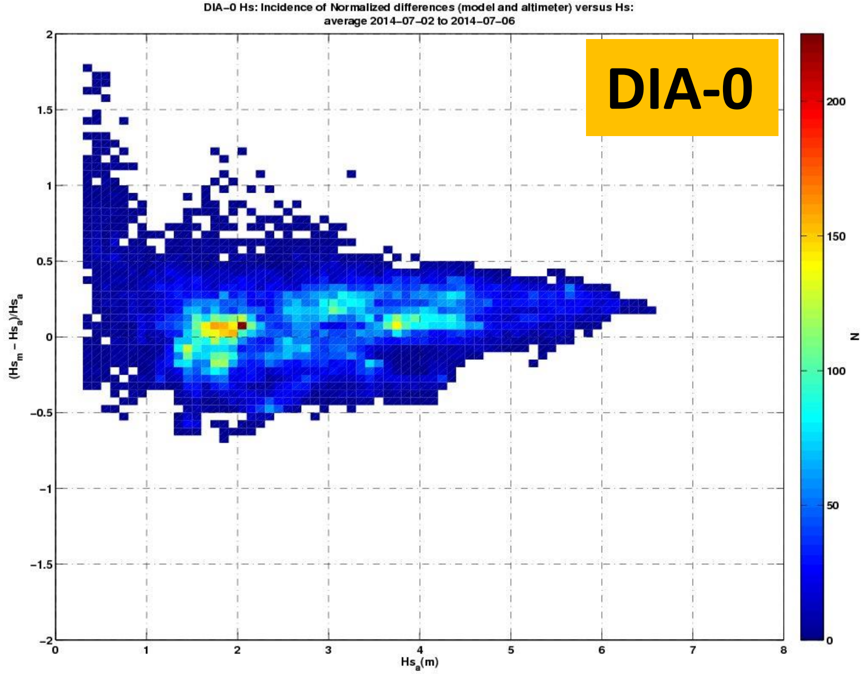
RMSE 0.361
Bias -0.349
Corr 0.910
N 27677

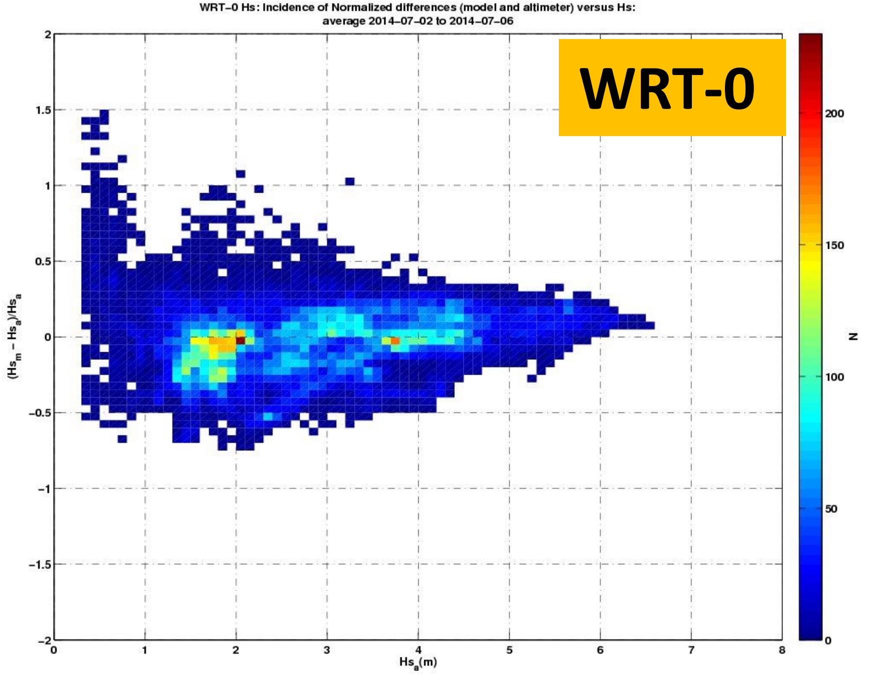
For Hurricane Arthur

Incidence of Normalized Differences vs alt. Hs over 5 days 2014-07-02 -> 2014-07-06









Hurricane Arthur

TSA-4-statistics

yyyy-mm-dd	NRMSE	Bias	R	N
2014-07-01	0.612	-0.565	0.673	28135
2014-07-02	0.481	-0.443	0.793	28146
2014-07-03	0.424	-0.384	0.826	27991
2014-07-04	0.390	-0.347	0.839	28199
2014-07-05	0.358	-0.301	0.835	28064
2014-07-06	0.332	-0.274	0.871	28188
2014-07-07	0.337	-0.272	0.871	28046
total (d2-6)	0.361	-0.349	0.910	27677

FBI-2-statistics

yyyy-mm-dd	NRMSE	Bias	R	N
2014-07-01	0.603	-0.553	0.669	28135
2014-07-02	0.458	-0.409	0.790	28146
2014-07-03	0.392	-0.341	0.833	27991
2014-07-04	0.355	-0.303	0.848	28199
2014-07-05	0.324	-0.253	0.846	28064
2014-07-06	0.300	-0.225	0.879	28188
2014-07-07	0.306	-0.224	0.881	28046
total (d2-6)	0.322	-0.306	0.917	27677

DIA-0-statistics

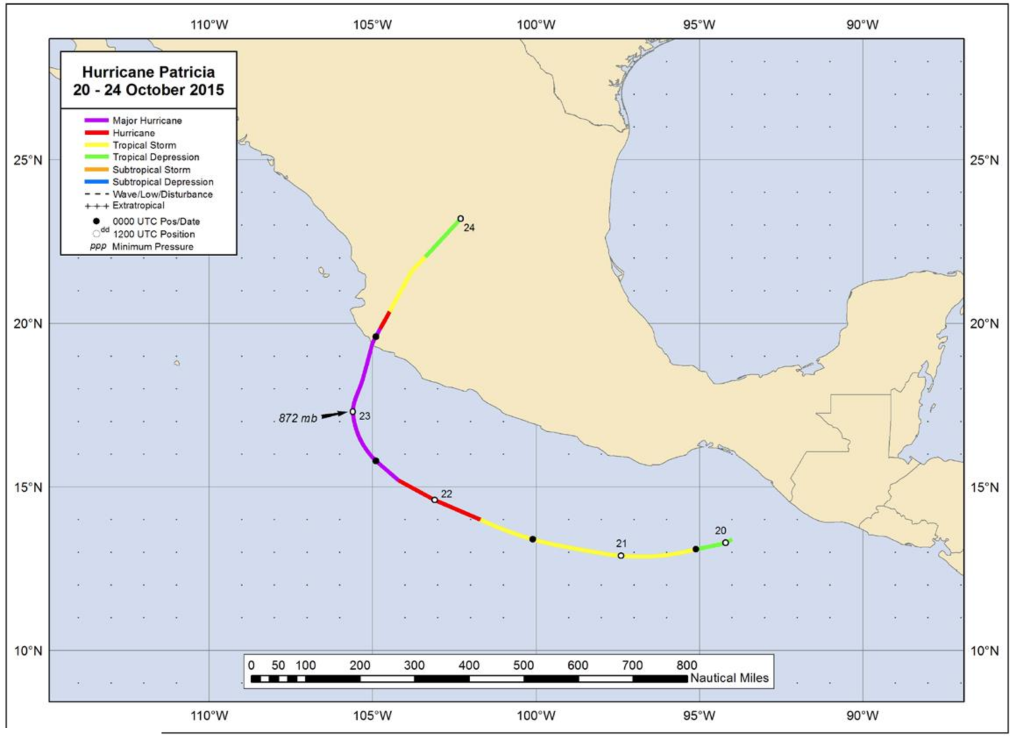
yyyy-mm-dd	NRMSE	Bias	R	N
2014-07-01	0.507	-0.422	0.686	28135
2014-07-02	0.327	-0.103	0.819	28146
2014-07-03	0.306	0.047	0.862	27991
2014-07-04	0.306	0.123	0.870	28199
2014-07-05	0.359	0.194	0.865	28064
2014-07-06	0.393	0.232	0.888	28188
2014-07-07	0.397	0.239	0.902	28046
total (d2-6)	0.223	0.099	0.938	27677

WRT-0-statistics

yyyy-mm-dd	NRMSE	Bias	R	N
2014-07-01	0.541	-0.471	0.678	28135
2014-07-02	0.348	-0.202	0.808	28146
2014-07-03	0.288	-0.066	0.853	27991
2014-07-04	0.263	0.008	0.865	28199
2014-07-05	0.297	0.079	0.860	28064
2014-07-06	0.319	0.116	0.888	28188
2014-07-07	0.327	0.123	0.899	28046
total (d2-6)	0.177	-0.013	0.935	27677

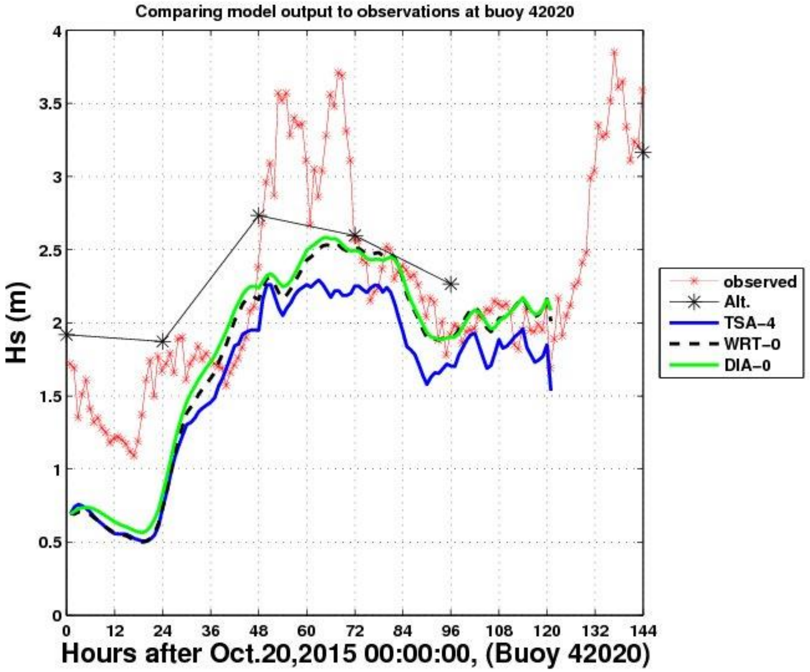
Hurricane Patricia
2015 10 20 01
-> 2015 10 25 01

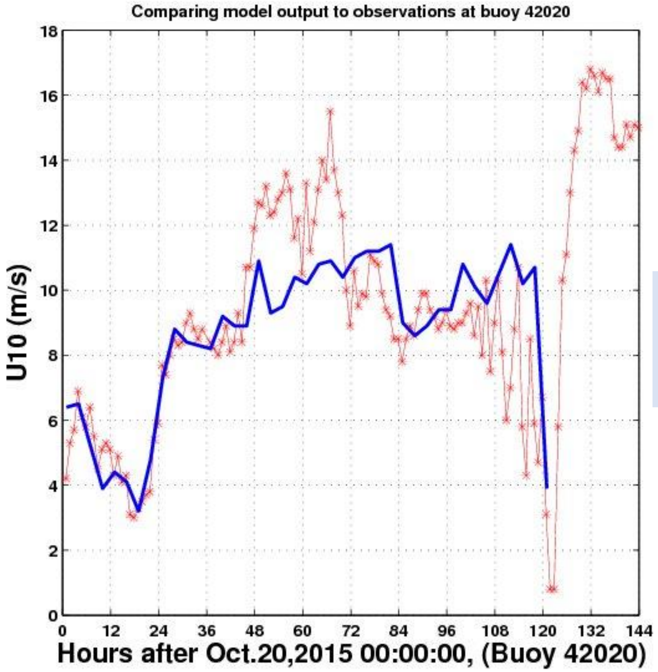
max winds 185kt=343km/h
on 2015 10 23 12



Only few buoys available. All buoys are to left of the track and close to the coast. Need to find some altimeter tracks in that area.

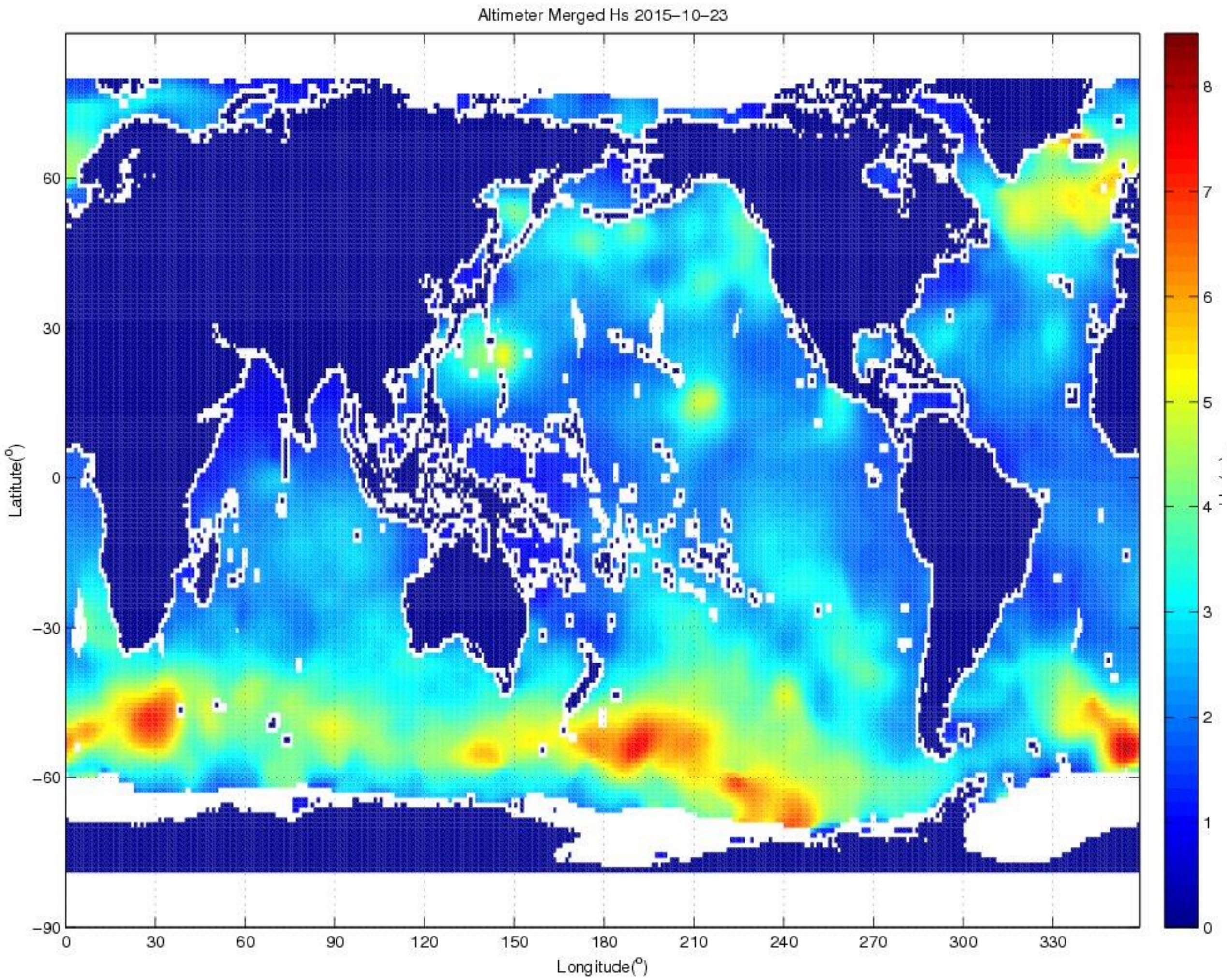
Buoy 42020



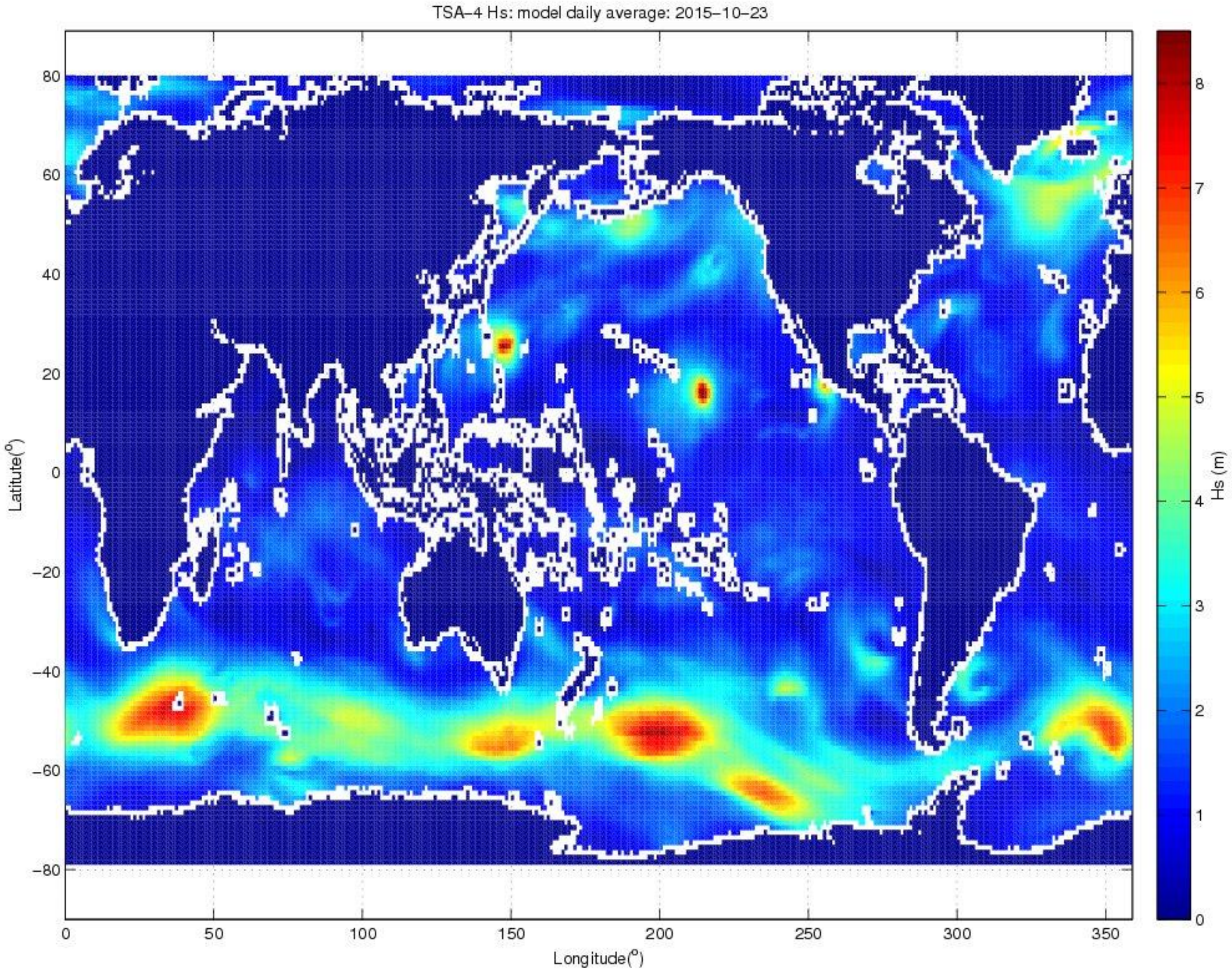


model
Obs.

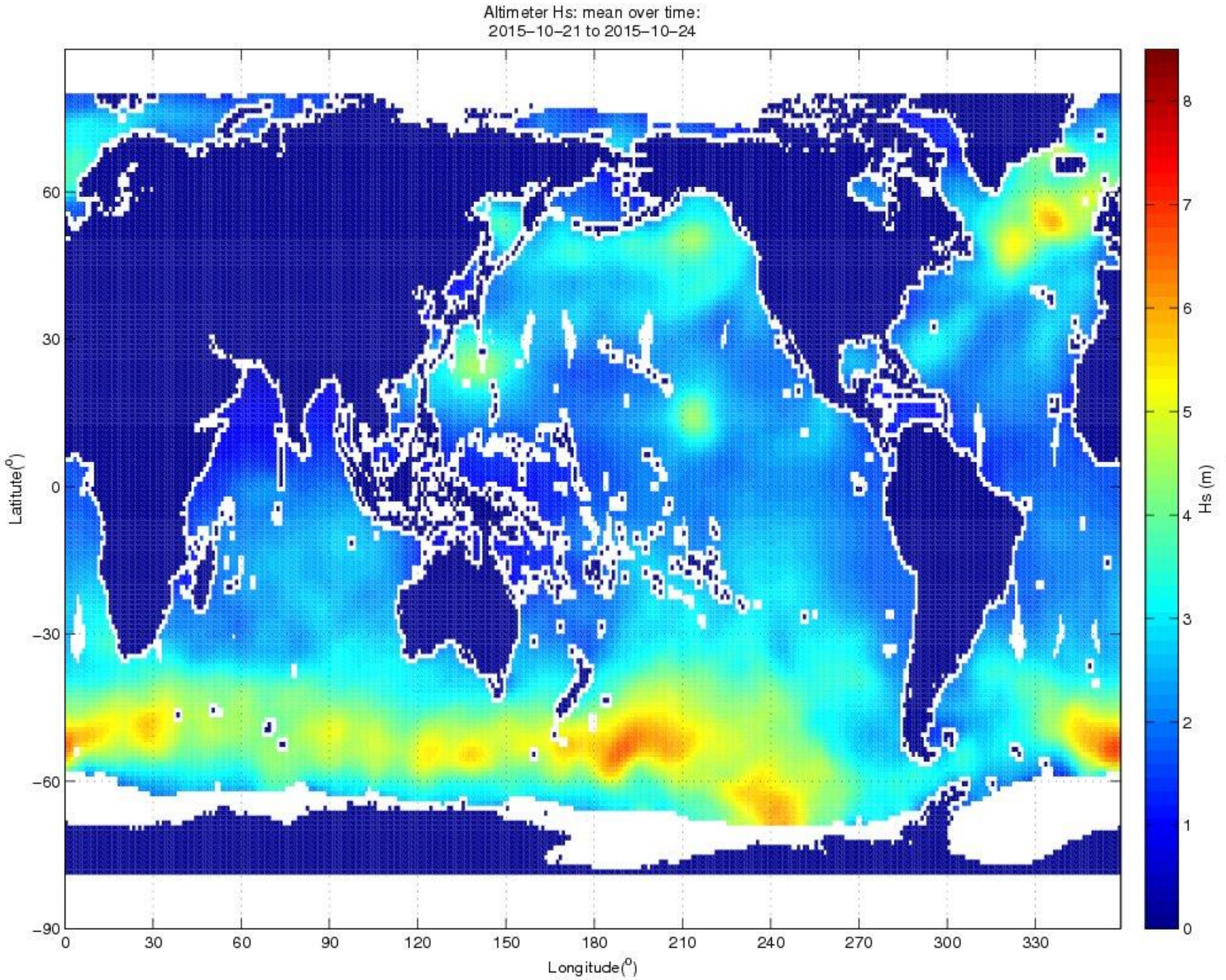
Altimeter daily Hs average for 2015-10-23



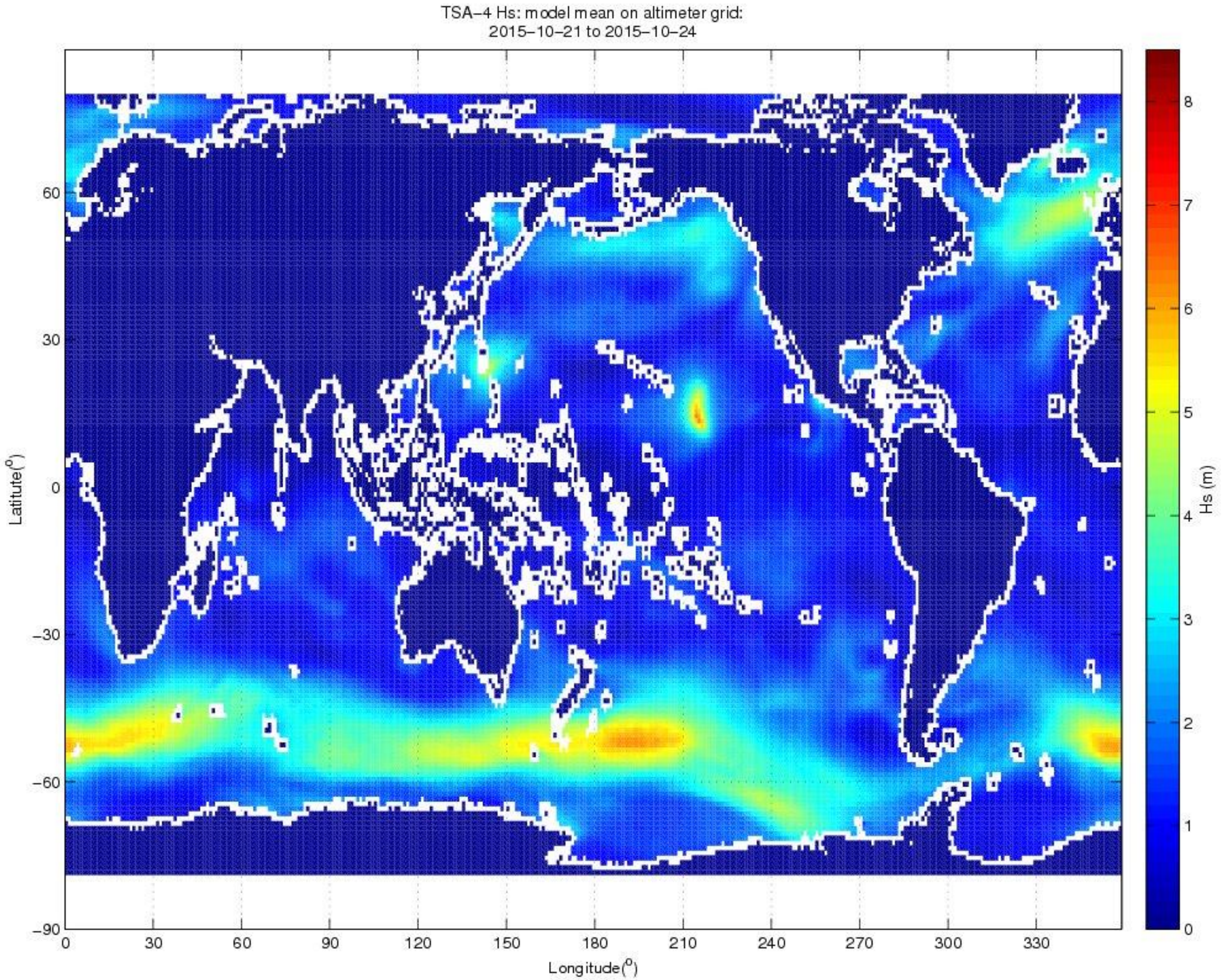
TSA-4 model daily Hs average for 2015-10-23



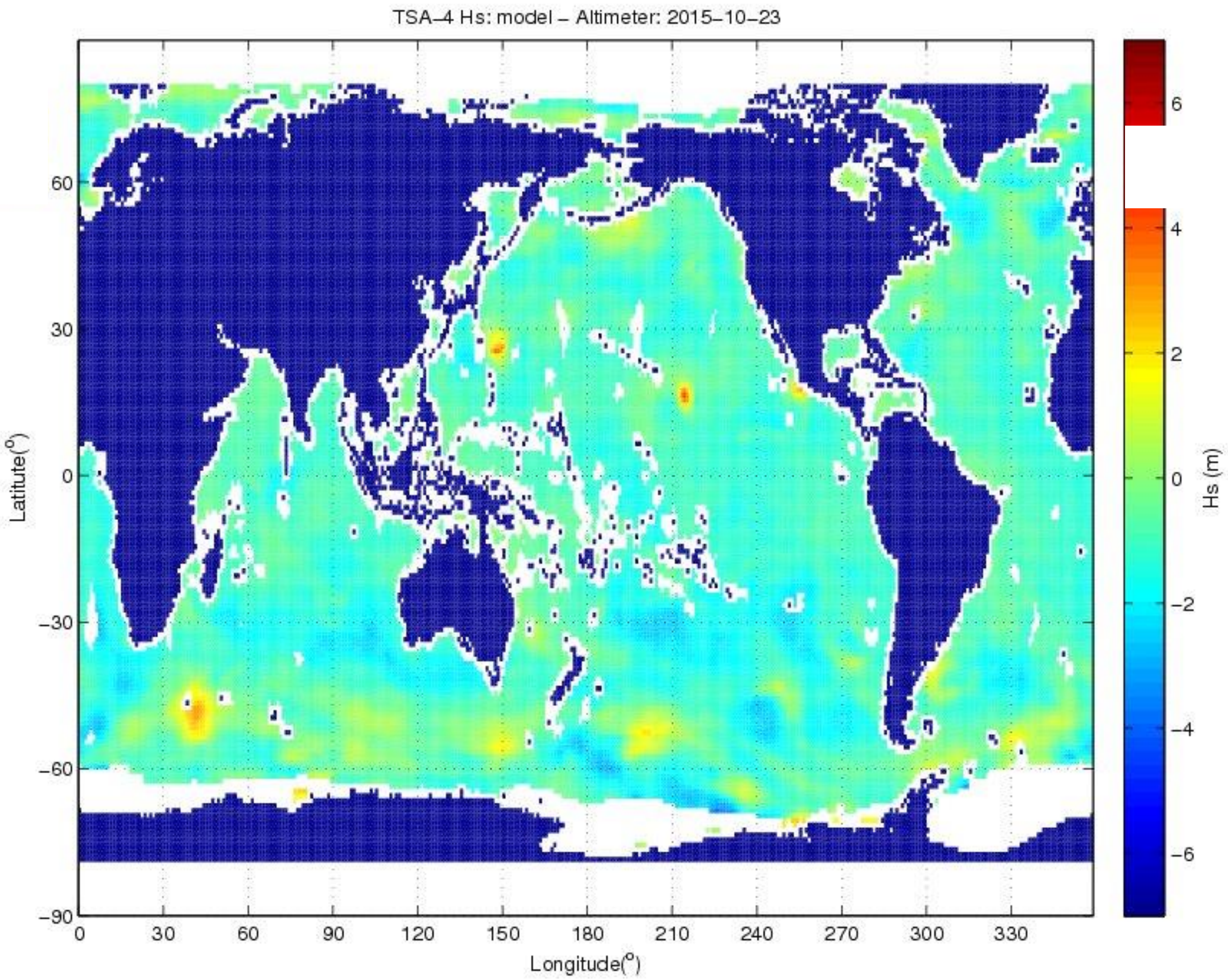
Altimeter Hs average over 4 days
2015-10-21 -> 2015-10-24



TSA-4 Hs average over 4 days
2015-10-21 -> 2015-10-24

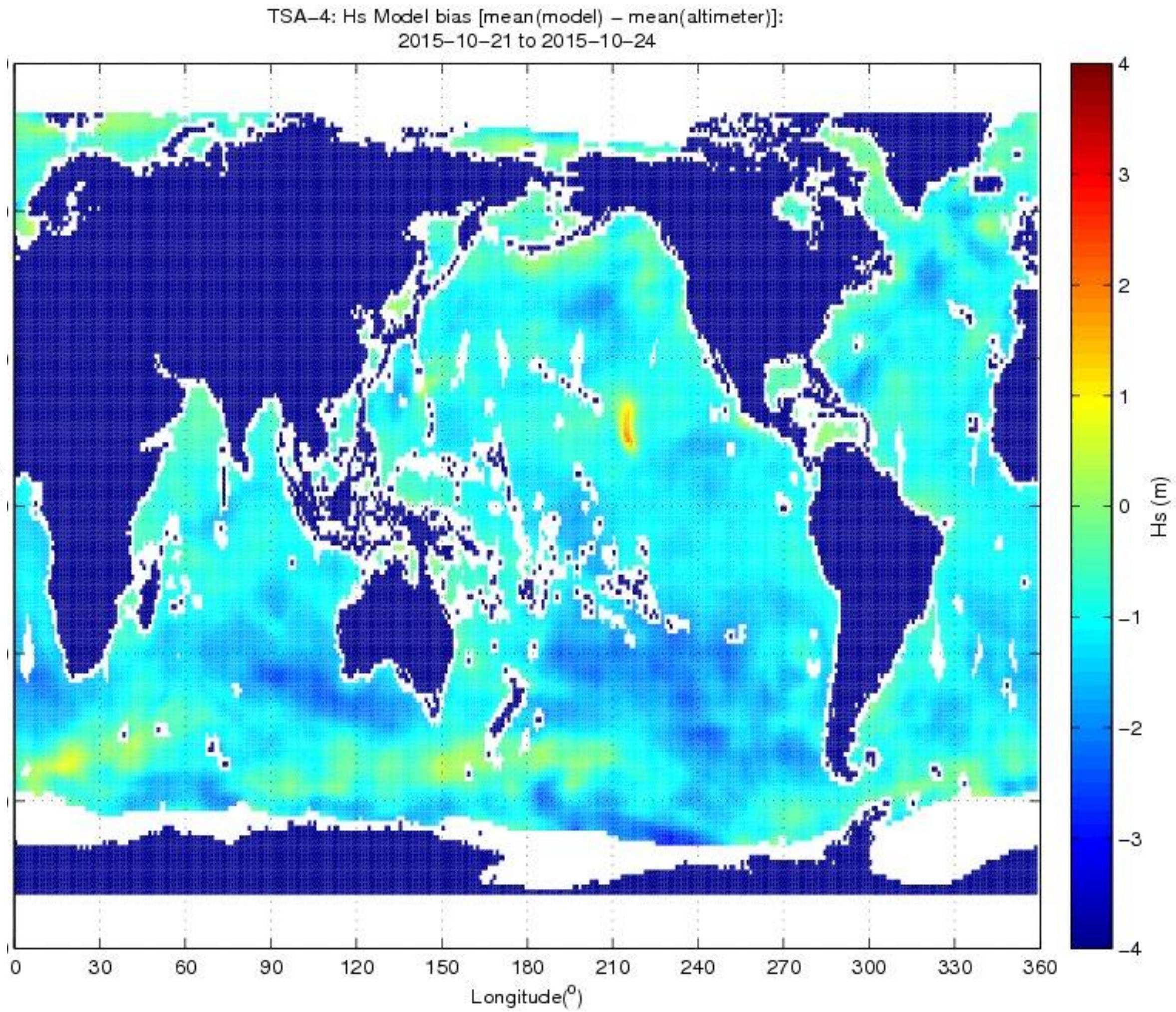


TSA-4: (model-altimeter) over one day
2015-10-23



RMSE	0.376
Bias	-0.340
Corr	0.882
N	27893

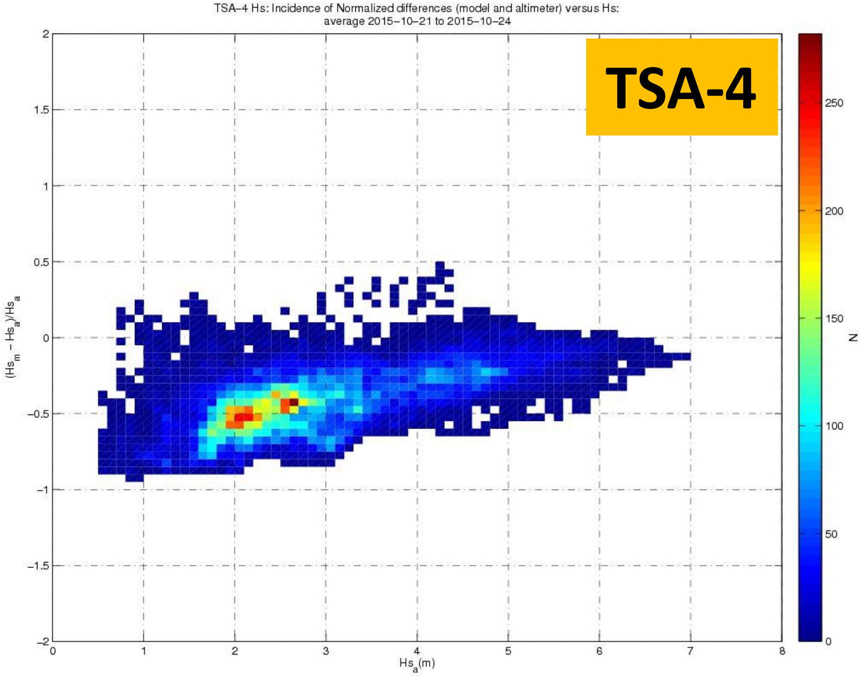
TSA-4: (model-altimeter) over 4 days
2015-10-21 -> 2015-10-24

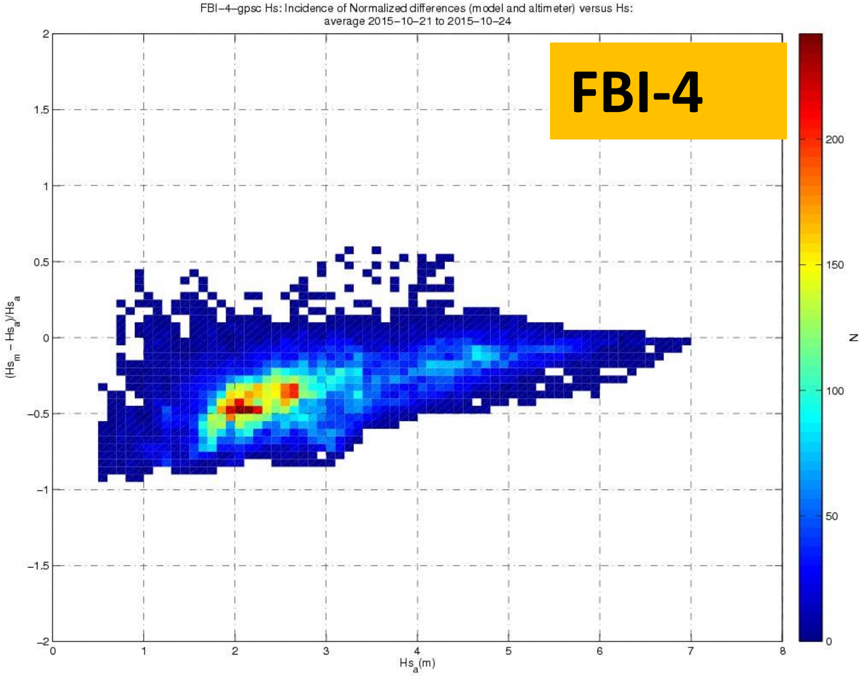


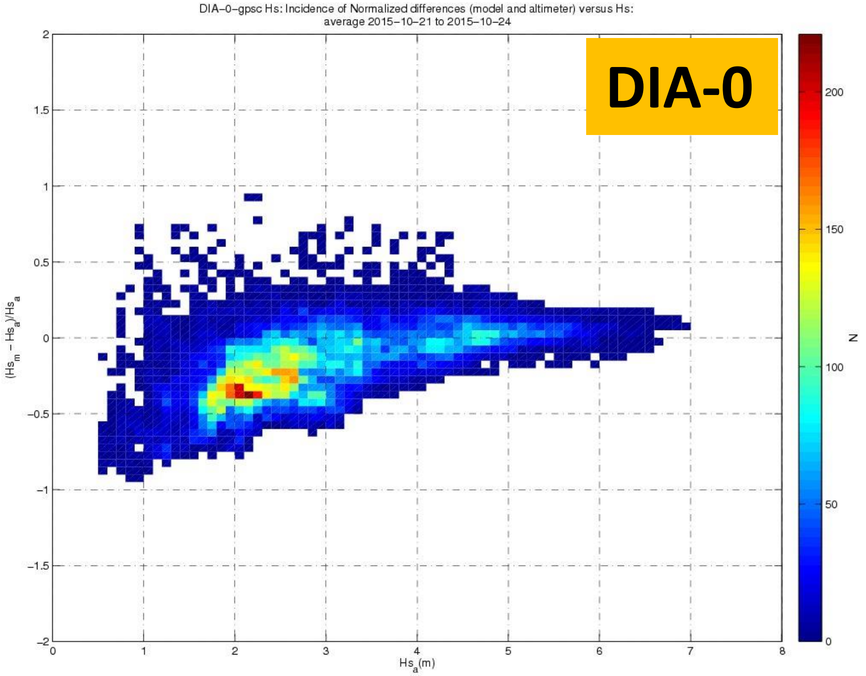
RMSE	0.380
Bias	-0.374
Corr	0.919
N	27577

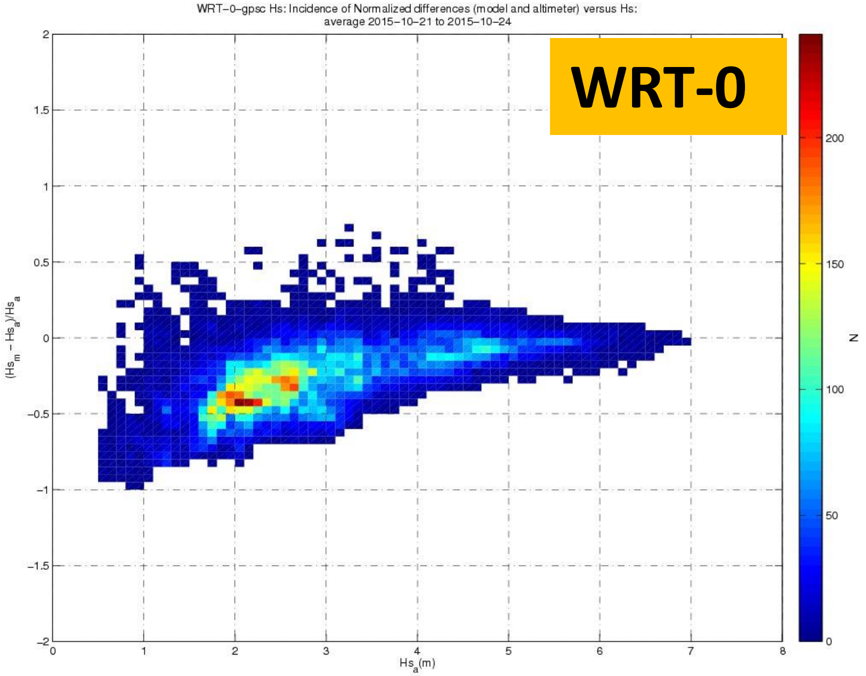
For Hurricane Patricia

Incidence of Normalized differences vs Hs over 5 days 2014-07-02 -> 2014-07-06









Hurricane Patricia

TSA-4-statistics

yyyy-mm-dd	NRMSE	Bias	R	N
2015-10-20	0.612	-0.585	0.667	28022
2015-10-21	0.489	-0.460	0.785	27906
2015-10-22	0.416	-0.383	0.856	28079
2015-10-23	0.376	-0.340	0.882	27893
2015-10-24	0.355	-0.309	0.874	28098
2015-10-25	0.351	-0.302	0.881	27808
Total (d2-5)	0.380	-0.374	0.919	27557

FBI-4-statistics

yyyy-mm-dd	NRMSE	Bias	R	N
2015-10-20	0.593	-0.559	0.658	28022
2015-10-21	0.451	-0.402	0.778	27906
2015-10-22	0.368	-0.312	0.862	28079
2015-10-23	0.327	-0.263	0.889	27893
2015-10-24	0.311	-0.230	0.873	28098
2015-10-25	0.308	-0.223	0.879	27808
Total (d2-5)	0.324	-0.303	0.924	27557

DIA-0-statistics

yyyy-mm-dd	NRMSE	Bias	R	N
2015-10-20	0.562	-0.521	0.668	28022
2015-10-21	0.370	-0.275	0.798	27906
2015-10-22	0.278	-0.142	0.882	28079
2015-10-23	0.239	-0.069	0.916	27893
2015-10-24	0.236	-0.017	0.890	28098
2015-10-25	0.229	-0.011	0.902	27808
Total (d2-5)	0.207	-0.128	0.945	27557

WRT-0-statistics

yyyy-mm-dd	NRMSE	Bias	R	N
2015-10-20	0.591	-0.558	0.664	28022
2015-10-21	0.414	-0.353	0.792	27906
2015-10-22	0.310	-0.231	0.879	28079
2015-10-23	0.258	-0.161	0.912	27893
2015-10-24	0.242	-0.111	0.890	28098
2015-10-25	0.236	-0.105	0.900	27808
Total (d2-5)	0.252	-0.216	0.941	27557

Comparing Efficiency:

Running on my engineering workstation Dell Precision T7910 Dual_Xeon_E5_2660v4 using only 24 processors.

Snl#	Cpu-time (hrs)	Ratio/DIA-time
DIA-0	1.65 h	1.0
TSA-4	44.14 h	26.5
FBI-4	49.80 h	30.2
WRT-0	182.52 h	110.7

Conclusions:

1. Early results are encouraging: on efficiency, the cost of running TSA is about **25 x** that of DIA and **5 x** faster than WRT; on accuracy, the normalized-root-mean-squared error and the bias from TSA are comparable to those of WRT.

2. Tuning done for TSA/FBI was not enough, although, in the right direction. More tuning needs to be done. Note: for the Northeast tuning of some ST4 parameters was also necessary to achieve the best accuracy and lower the rmse, [see Perrie et al. (2018)].

3. In Ardhuin et al. (2010) tuning was done to more ST4 parameters and DIA coupling coefficient
→So what other parameters need to be tuned for TSA/FBI? Is simple adjustments to "bmax, Ccu, rcu, and su" is enough to get better results? And large-scale applications may require retuning of the wind source function, performed by a readjustment of "bmax".

Still to do:

- Fix MPI directives around TSA/FBI in "w3snl4md.ftn". This also may improve TSA speed.
- Need to make longer simulations. Add ice forcing?
- Get more buoys data to get better global coverage and better solid statistics.
- More 1D and 2D energy spectra comparison between model & buoys need to be done.
- Check CFSR winds over the west coast of Mexico & California during Hurricane Patricia.

References:

(1) Resio, D. T. and W. Perrie, 2008: A two-scale approximation for efficient representation of nonlinear energy transfers in a wind wave spectrum. Part I: Theoretical development. J. Phys. Oceanogr., 38(12), 2,801–2,816

(2) Perrie, W. and D. T. Resio, 2009: A two-scale approximation for efficient representation of nonlinear energy transfers in a wind wave spectrum. Part II: Application to observed wave spectra. J. Phys. Oceanogr., 39(10), 2,451–2,476.

(3) Ardhuin, F., W. E. Rogers, A. V. Babanin, J. Filipot, R. Magne, A. Roland, A. van der Westhuysen, P. Queffeulou, J. Lefevre, L. Aouf and F. Collard, 2010: Semiempirical dissipation source functions for ocean waves. Part I: Definition, calibration, and validation. J. Phys. Oceanogr., 40, 1,1917–1,1941.

(4) Perrie, W., B. Toulany, D. Resio, J.-P. Auclair, 2013: A two-scale approximation for wave-wave interactions in an operational wave model. Ocean Modelling. 70, 38-51. doi.org/10.1016/j.ocemod.2013.06.008

(5) Perrie, W., B. Toulany, A. Roland, M. Dutour-Sikiric, C. Chen, R. Beardsley, J. Qi, Y. Hu, M. Casey, H. Shen, 2018: Modeling North Atlantic Nor'easters With Modern Wave Forecast Models. Journal of Geophysical Research: Oceans, 123. https://doi.org/10.1002/2017JC012868