Tropical Cyclone Generated Rogue Waves

Clarence O. Collins III 10.28.2013 13th Waves Workshop

Collaborators: **Hans Graber & Takuji Waseda**

Acknowledgements: Bjorn Lund, Rafael Ramos, Hitoshi Tamura, Henry Potter, Will Drennan, Neil Williams, Linwood Vincent, Brian Haus, & others

Sponsors: ONR, NSF, & JSPS

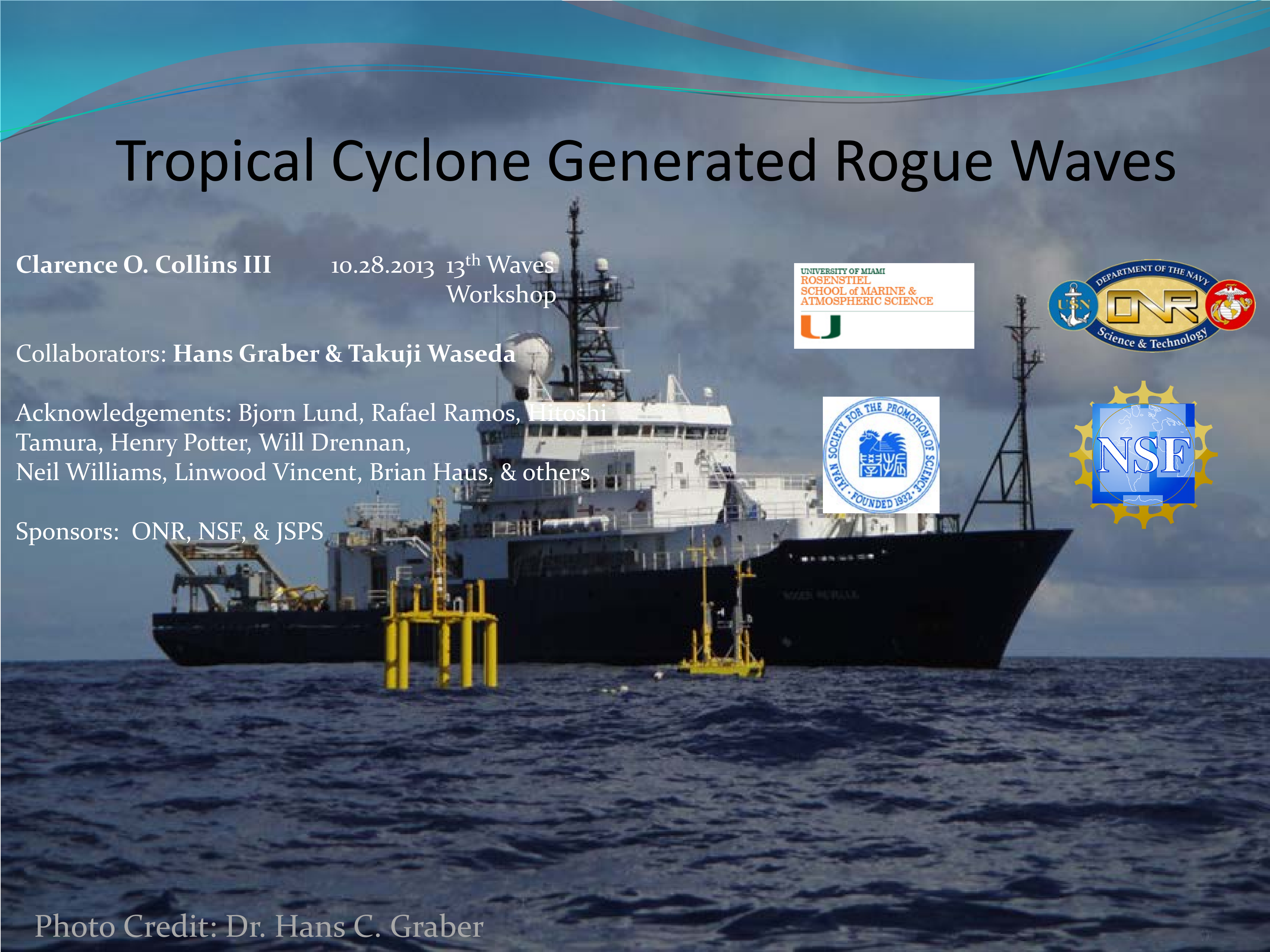


Photo Credit: Dr. Hans C. Graber

Motivation

- Rogue waves are dangerous
- Modern understanding highlights the roll of non-linear energy focusing via modulation instability
- Lack of high quality field data particularly with directional information

Methodology

- 2 pairs of deep sea moored buoys of the coast of Taiwan (ITOP)
- 4 months of data during 2010 Typhoon Season
- zero-crossing and spectral analysis

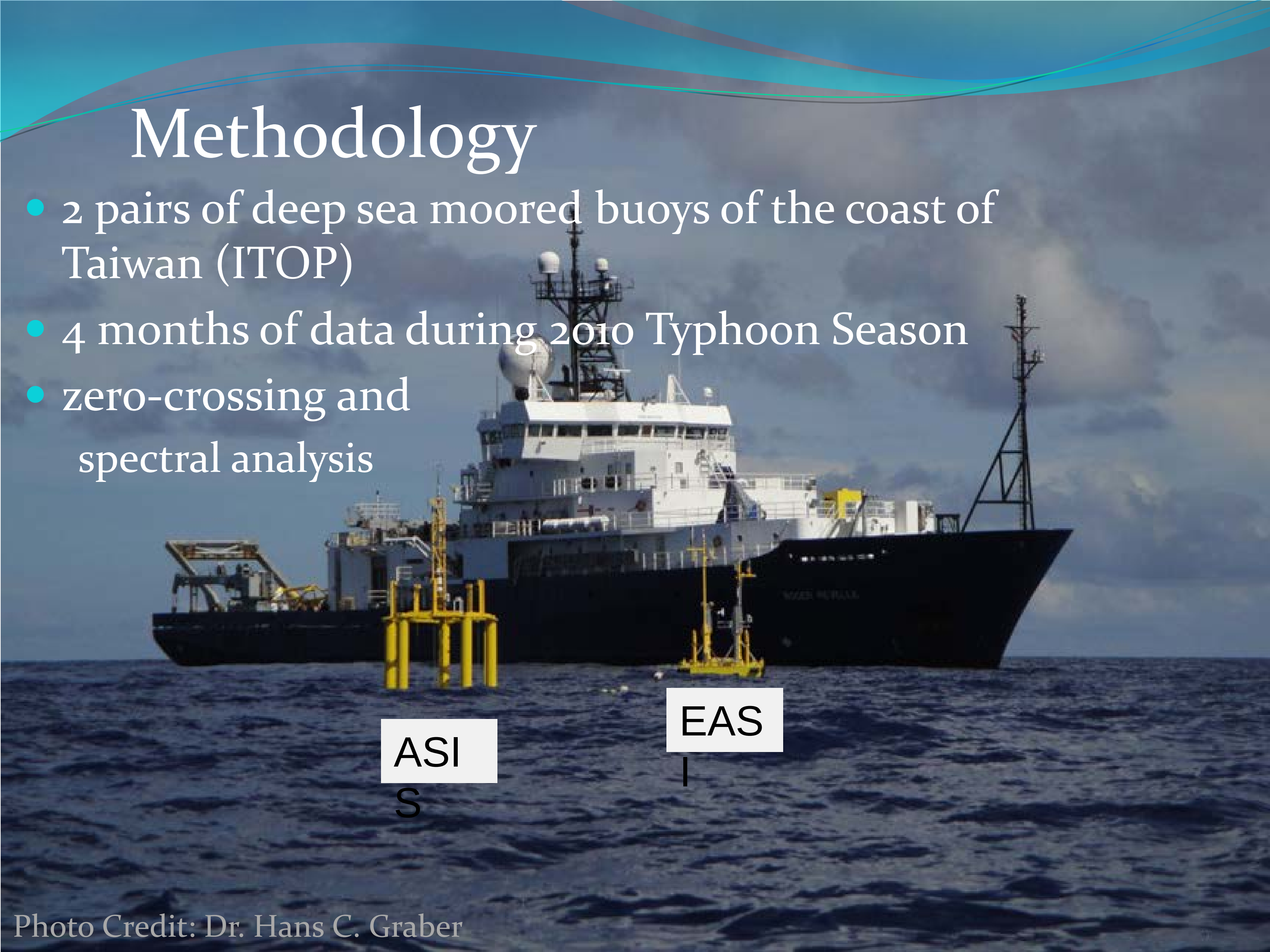
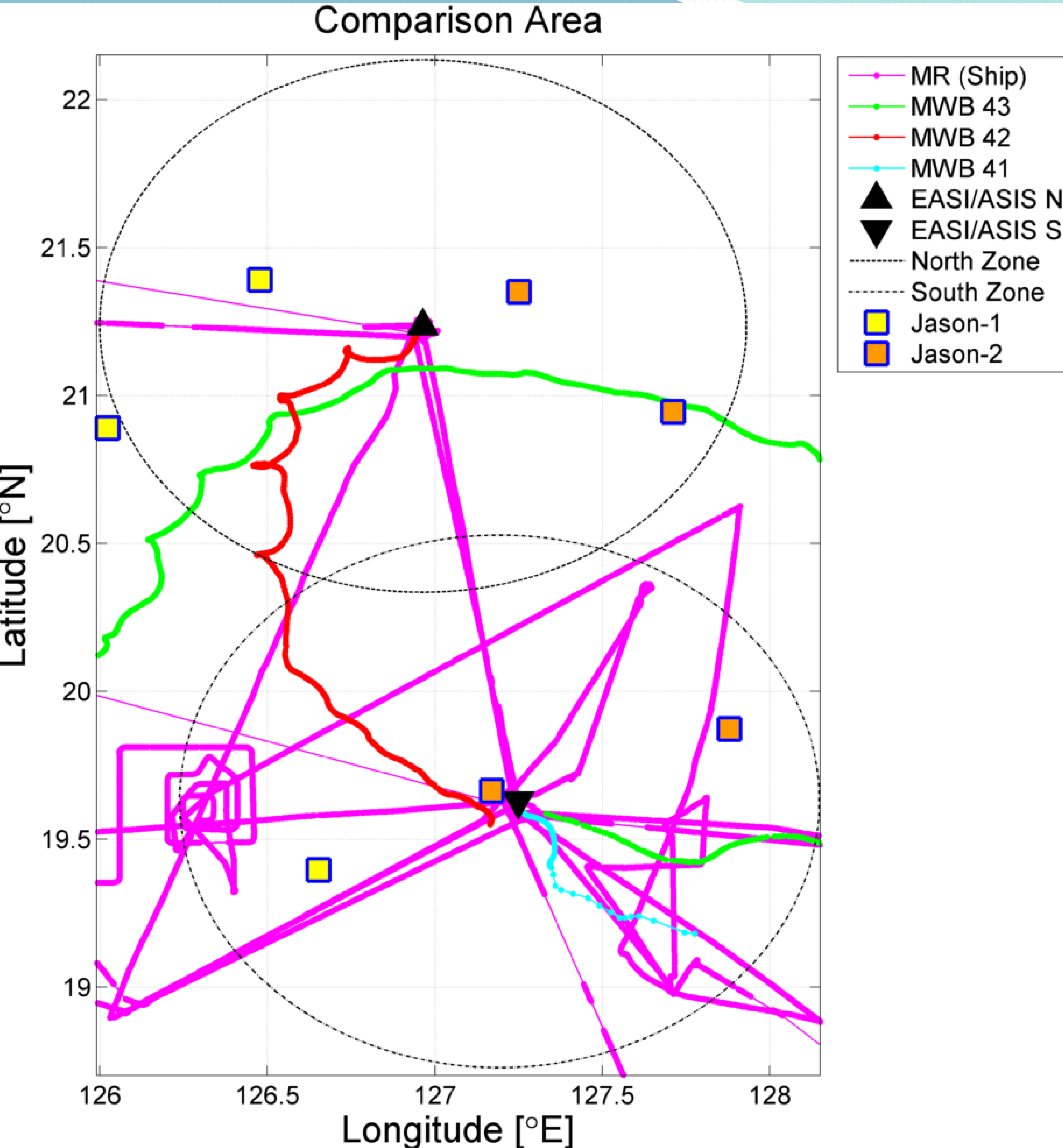
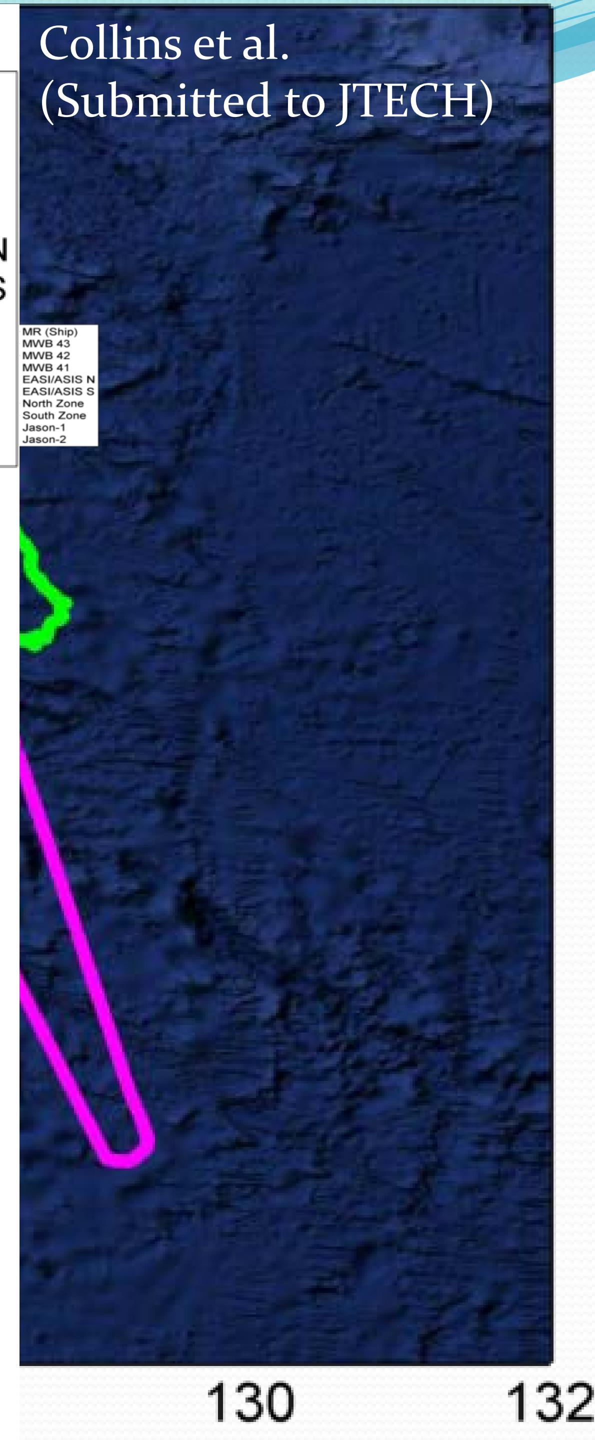


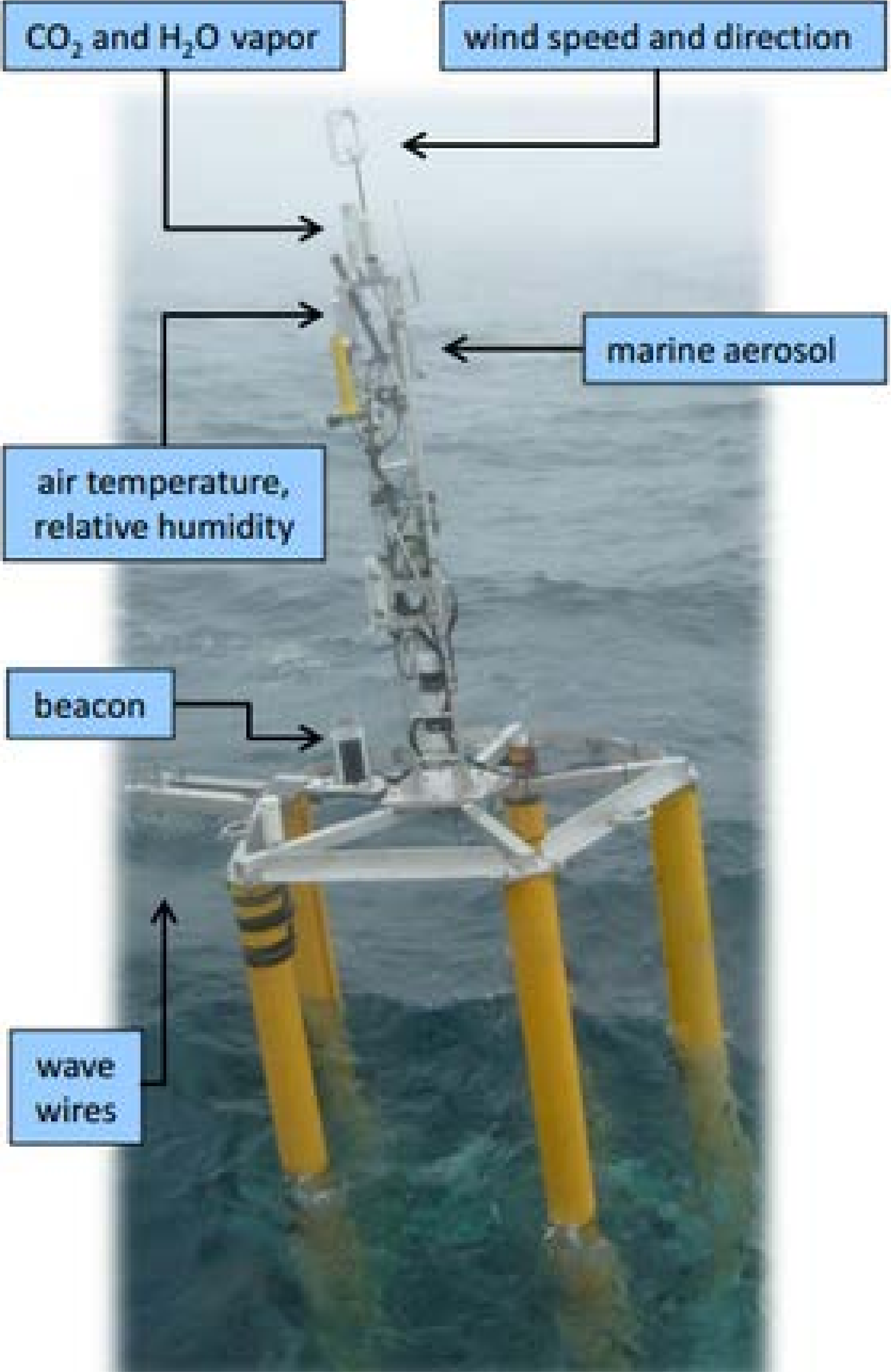
Photo Credit: Dr. Hans C. Graber

Summary

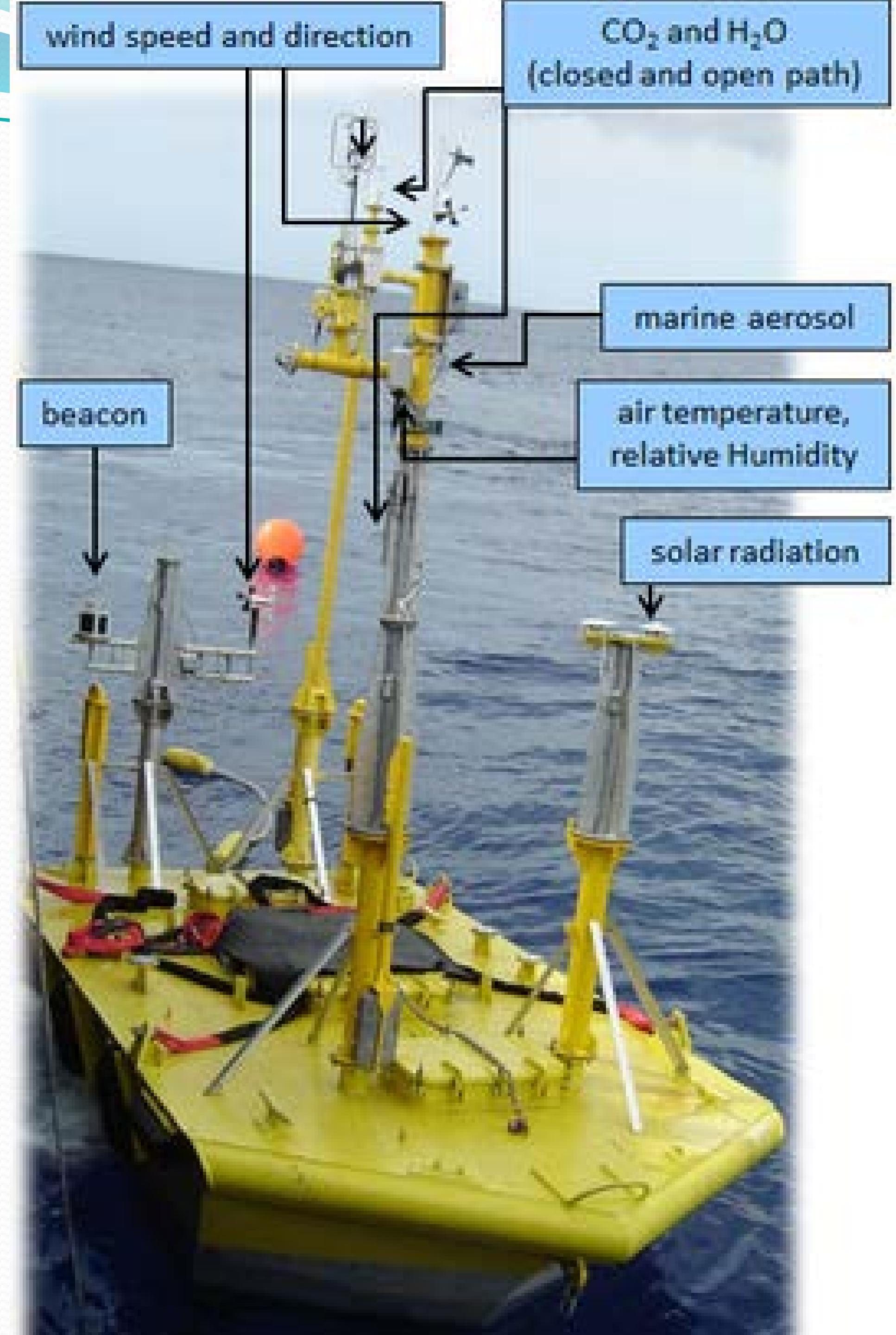
- deep-water dataset for studying rogue waves and waves generated by TCs is presented
  - including directional wave spectra
- Preliminary analysis has found increased observations of rogue waves in the vicinity of TCs
  - maybe related to the increased wave steepness which enhances modulation instability during these storms
- The potential for future efforts using this dataset is great


Comparison Area
MR (Ship)
MWB 43
MWB 42
MWB 41
EASI/ASIS N
EASI/ASIS S
North Zone
South Zone
Jason-1
Jason-2
22
21.5
21
20.5
20
19.5
19
Latitude [°N]
126
126.5
127
127.5
128
Longitude [°E]


Collins et al.
(Submitted to JTECH)
130
132



CO2 and H2O vapor
wind speed and direction
marine aerosol
air temperature, relative humidity
beacon
wave wires



wind speed and direction
CO2 and H2O (closed and open path)
marine aerosol
beacon
air temperature, relative Humidity
solar radiation

Data Processing

- "Right Hand Rule" Coordinate System

"Strapped Down" MP

Heave – z_b

Surge - x_b

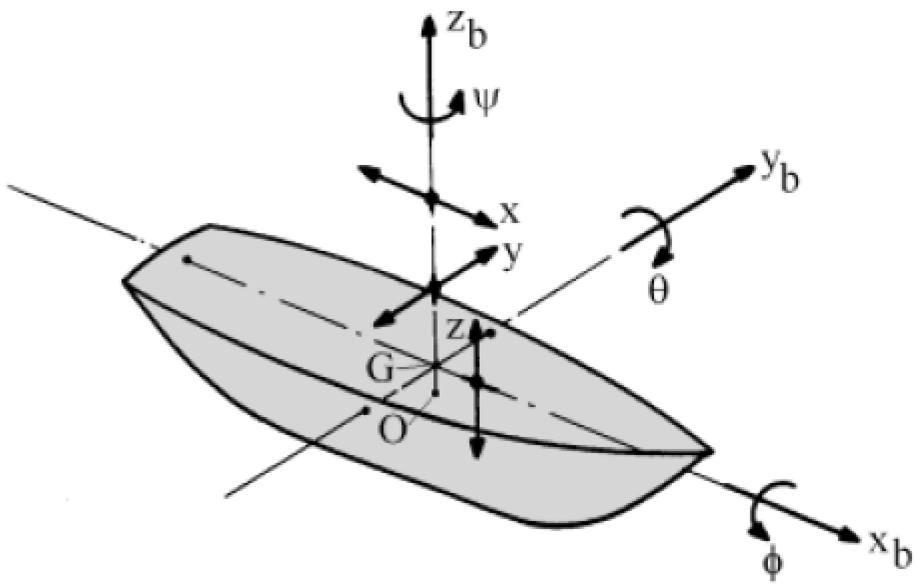
Sway - y_b

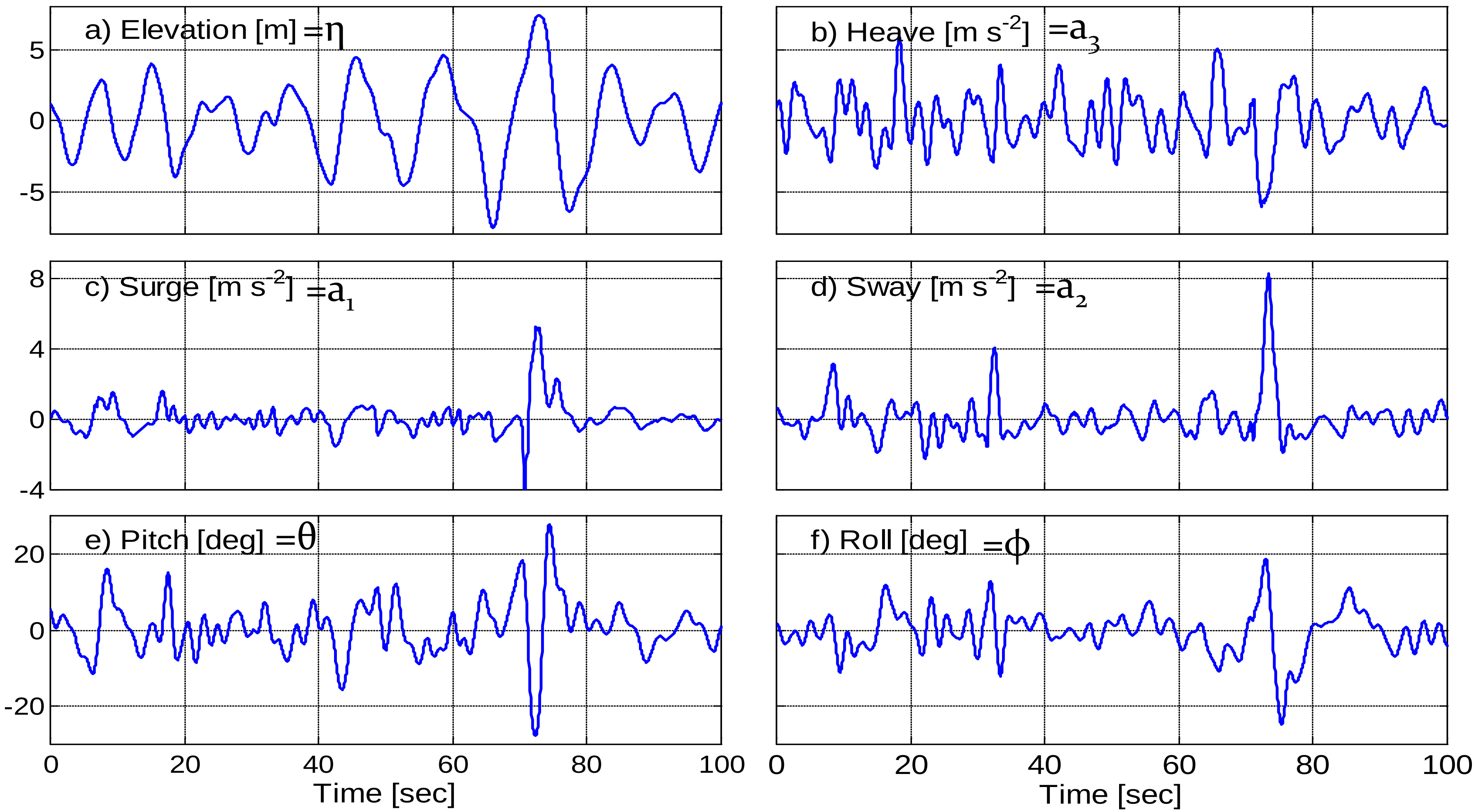
Pitch - θ

Roll - ϕ

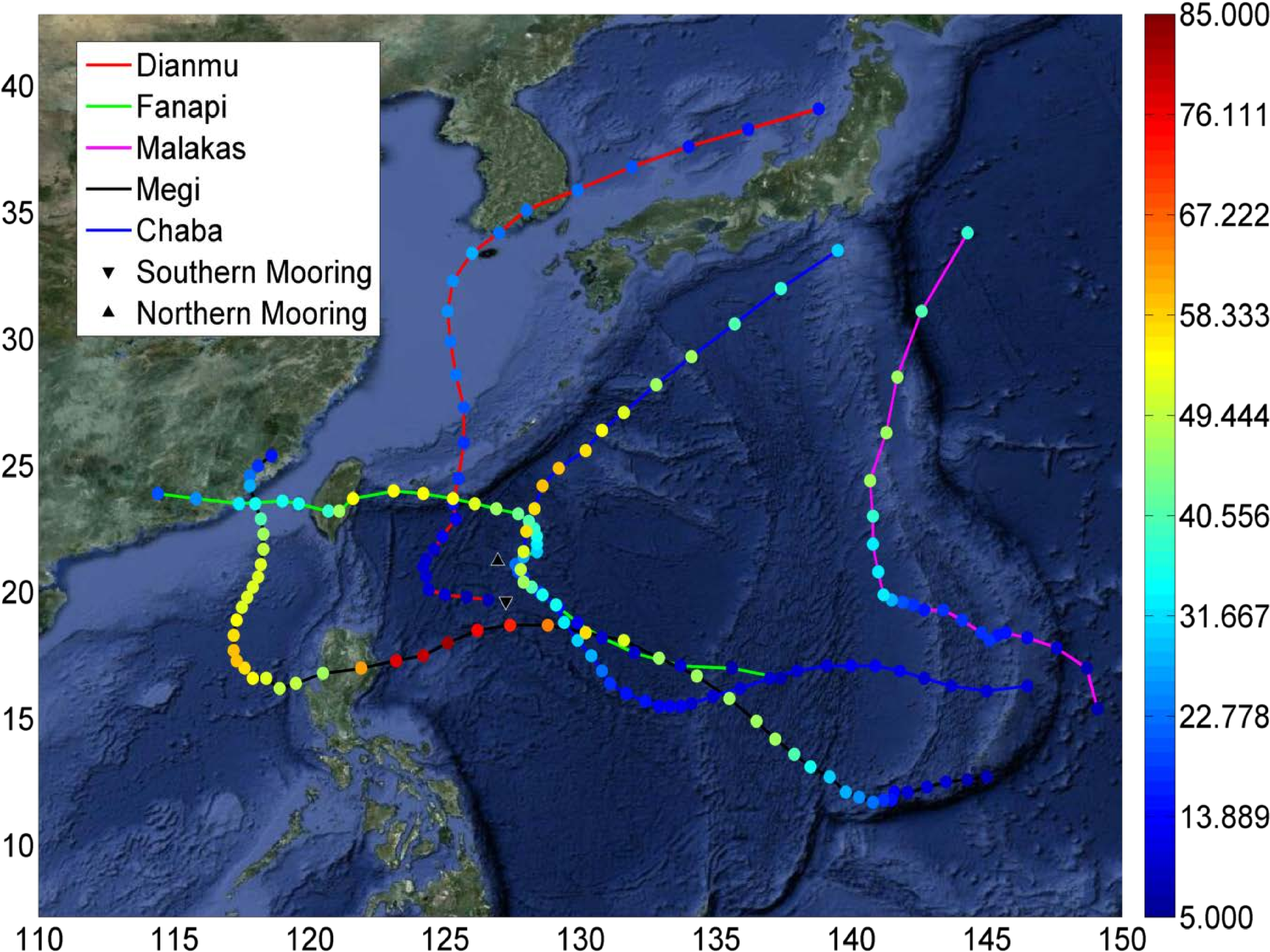
Yaw - ψ

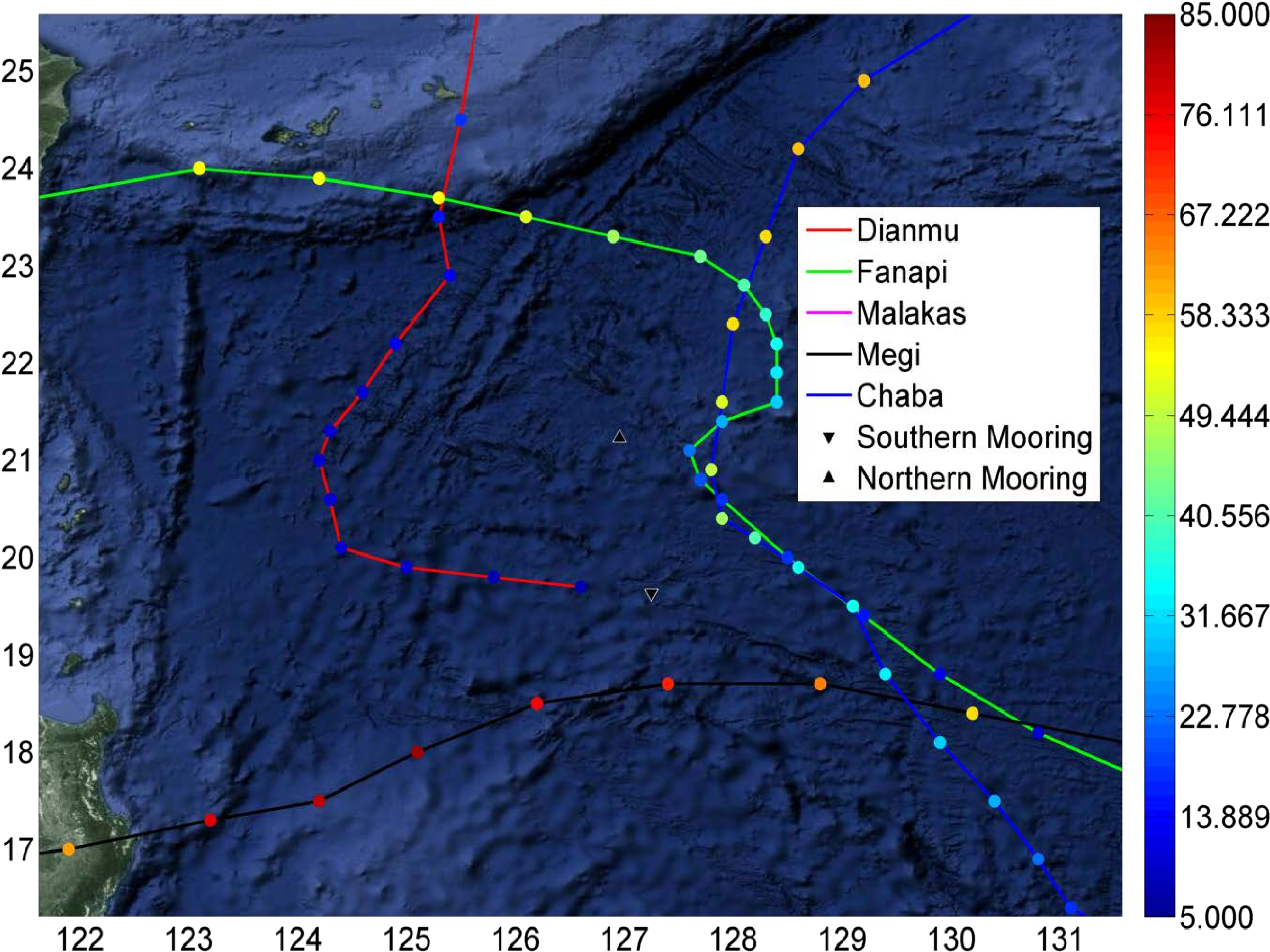
(Heading)

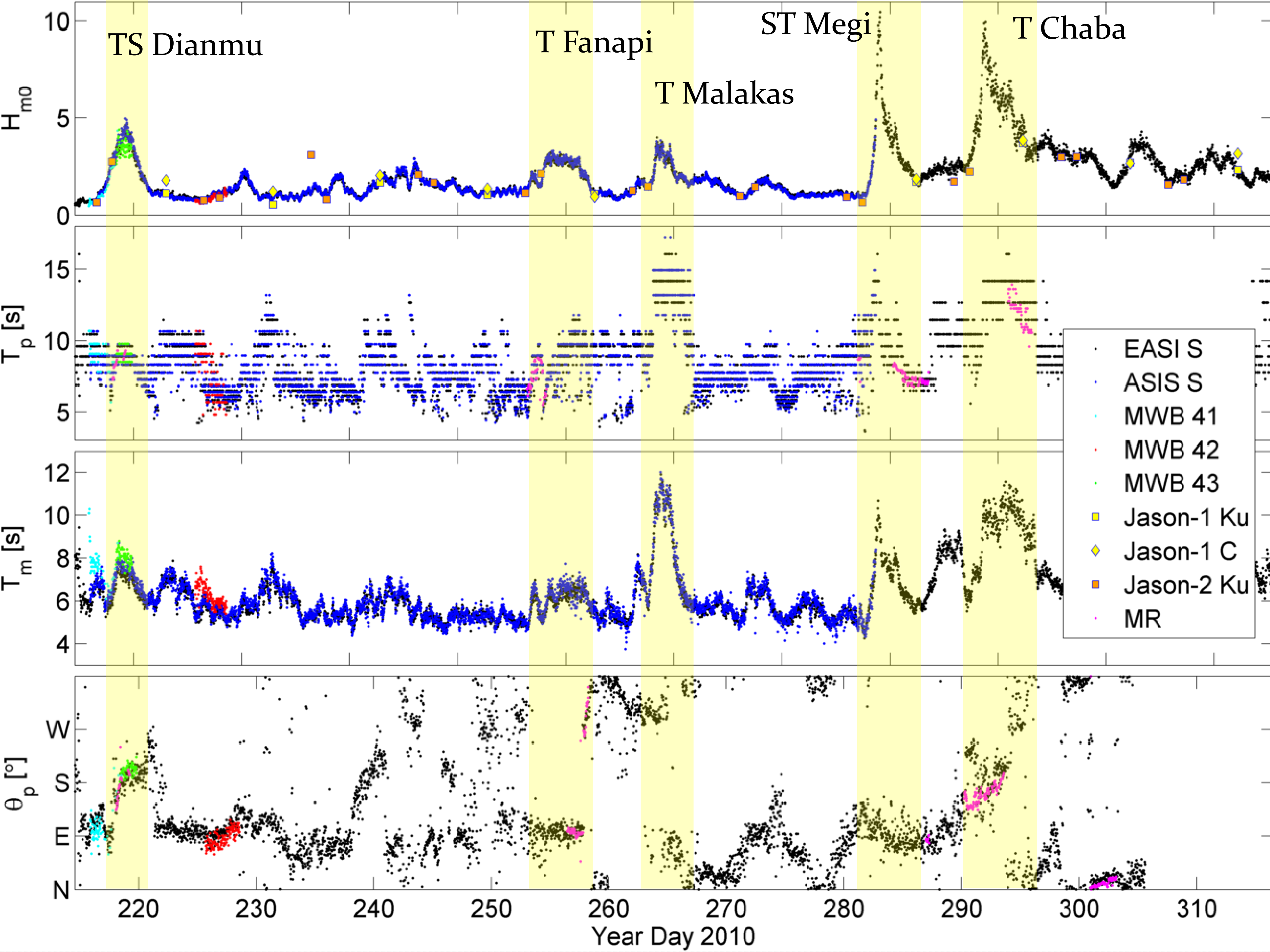




$$\eta = \iint (-a_1 \sin\theta + a_2 \cos\theta \sin\phi + a_3 \cos\theta \cos\phi - g)\, dt\, dt$$


Dianmu
Fanapi
Malakas
Megi
Chaba
Southern Mooring
Northern Mooring
40
35
30
25
20
15
10
110
115
120
125
130
135
140
145
150
85.000
76.111
67.222
58.333
49.444
40.556
31.667
22.778
13.889
5.000


Dianmu
Fanapi
Malakas
Megi
Chaba
Southern Mooring
Northern Mooring
85.000
76.111
67.222
58.333
49.444
40.556
31.667
22.778
13.889
5.000
25
24
23
22
21
20
19
18
17
122
123
124
125
126
127
128
129
130
131



TS Dianmu
T Fanapi
T Malakas
ST Megi
T Chaba
H m0
T p [s]
T m [s]
θ p [°]
W
S
E
N
EASI S
ASIS S
MWB 41
MWB 42
MWB 43
Jason-1 Ku
Jason-1 C
Jason-2 Ku
MR
Year Day 2010

Definitions

- We use down-crossing analysis
- H is apparent wave height
- H_c (H_t) is hieght of apparent wave crest (trough)
- $H_{m0} = 4\sqrt{m_0} = 4\sqrt{\int_0^\infty S(f)df}$

Rogue Waves

- **AKA – Freak, Abnormal, Killer,**

- $H \geq 2H_{m0}$ **(Sometimes** H_s **or** $H_{1/3}$**)**
- **Or** $H_c \geq 1.25H_{m0}$

- **Rare (1 in 3000 waves), but most observations are consistent with 2nd order theory**

- **There are some observations which require an explanation outside of 2nd order theory**

Rogue Wave Generation Mechanisms

- Energy Focusing
- Spatial Focusing via Interactions:
  - Currents (Gulf Stream, Kuroshio, Agulas)
  - Bathymetry (Refraction and Defraction)

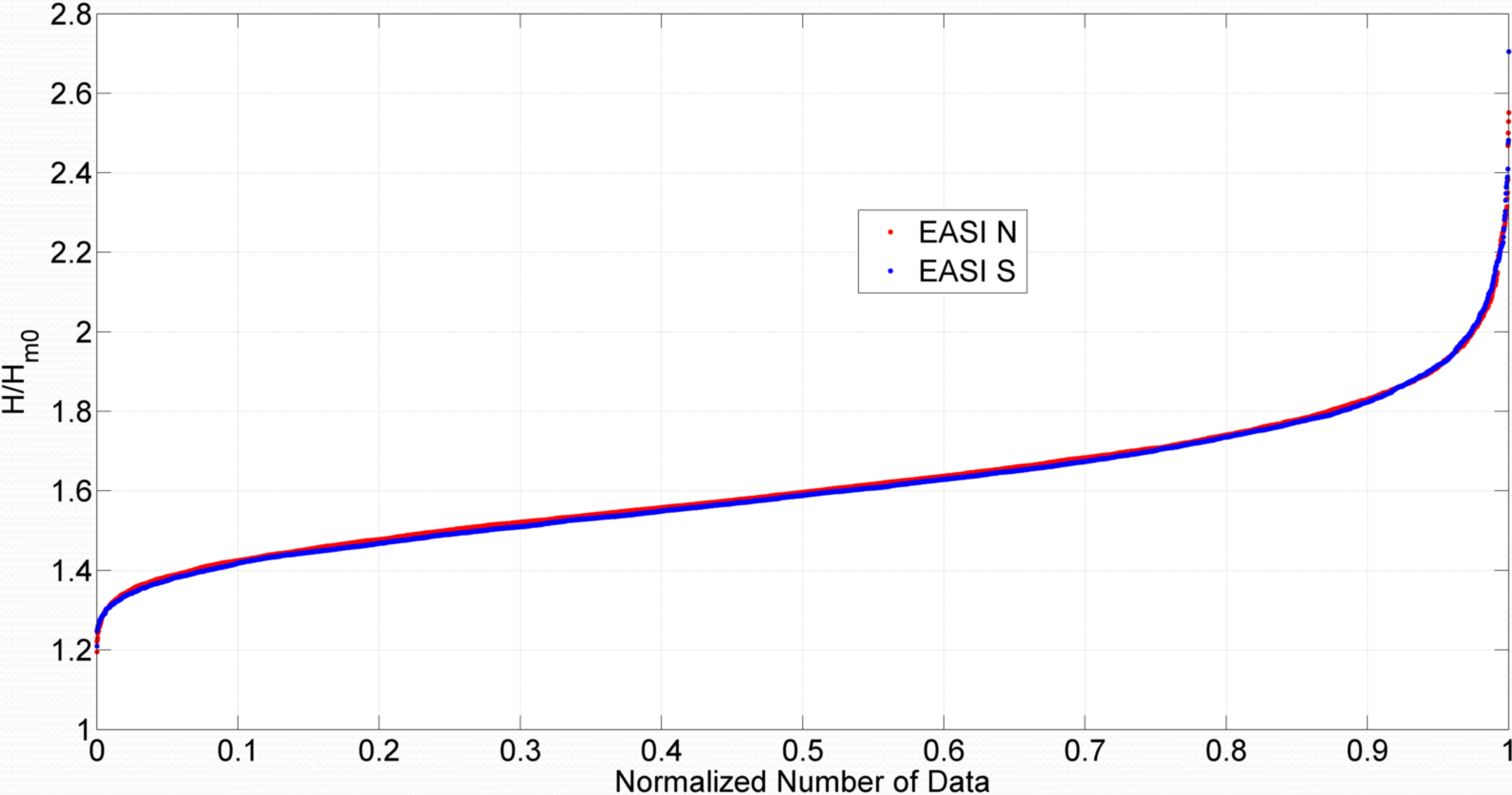
- Dispersive Focusing (linear, first order)
- Adjusted Statistics via Geometric Non-Linearity (2^{nd} order)

- **Non-linear (4^{th} order) Focusing via Modulation Instability (E.g. B-F type)**

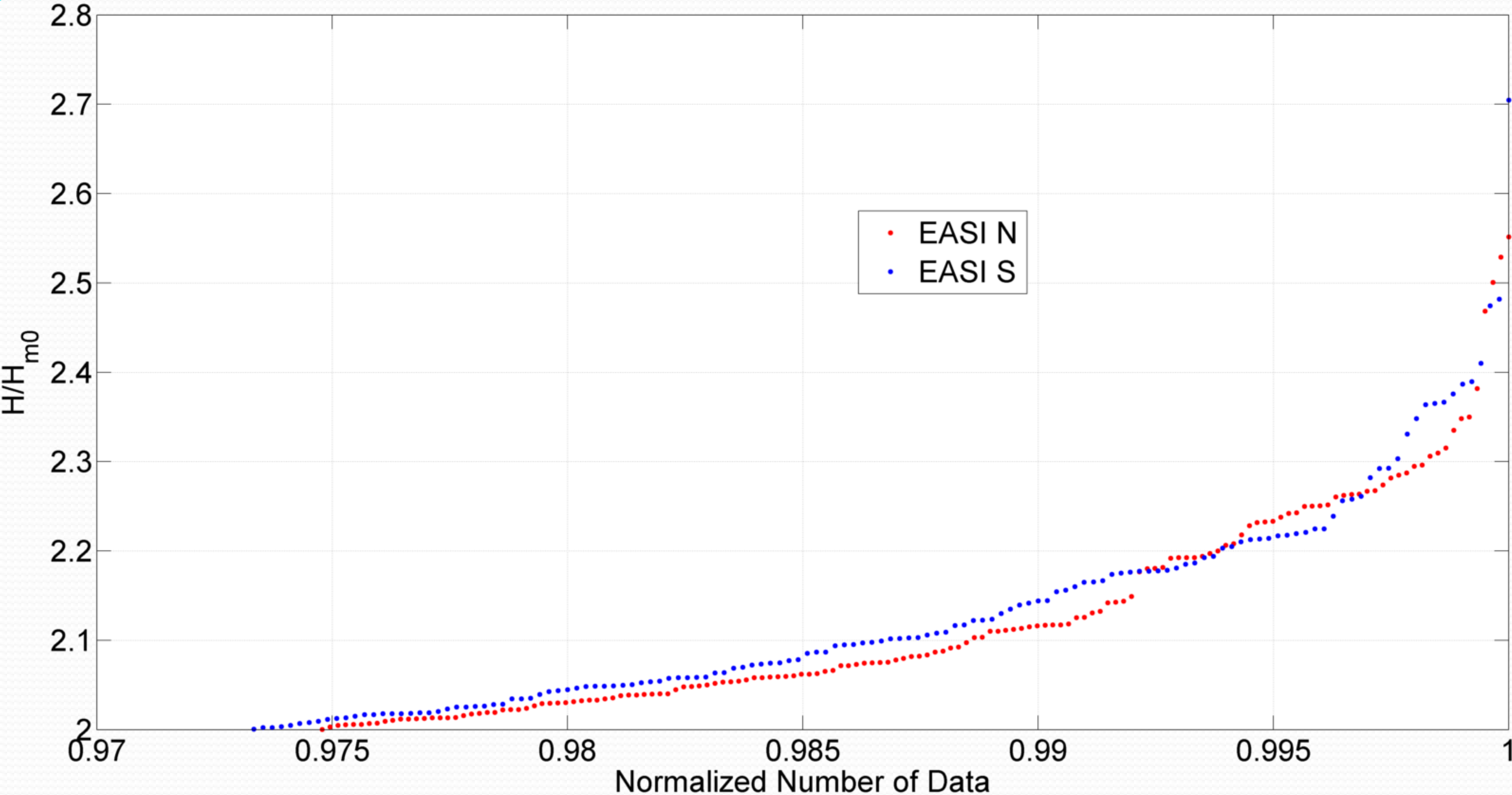
General Consensus

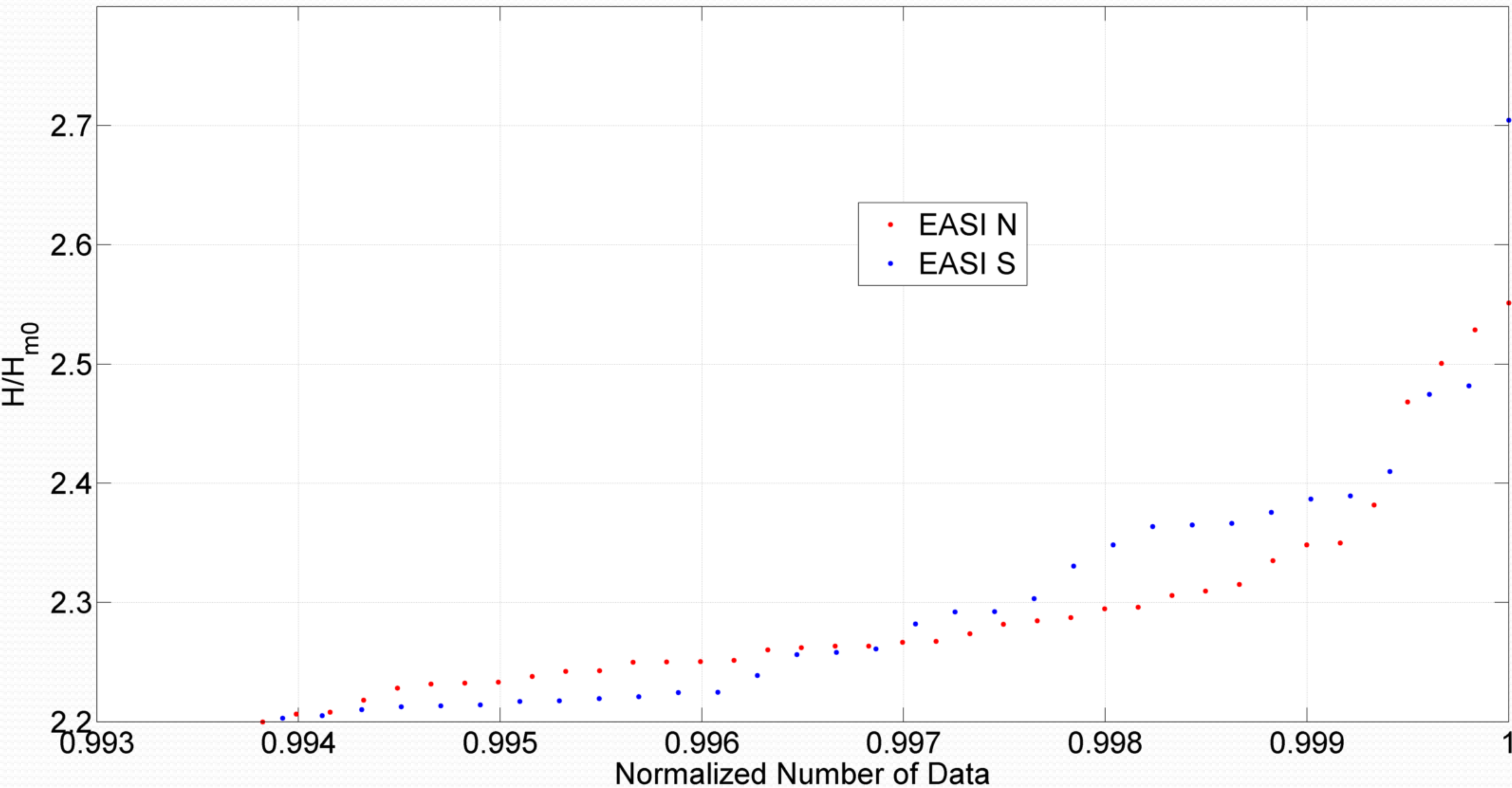
The Modulation Instability is More Active as:

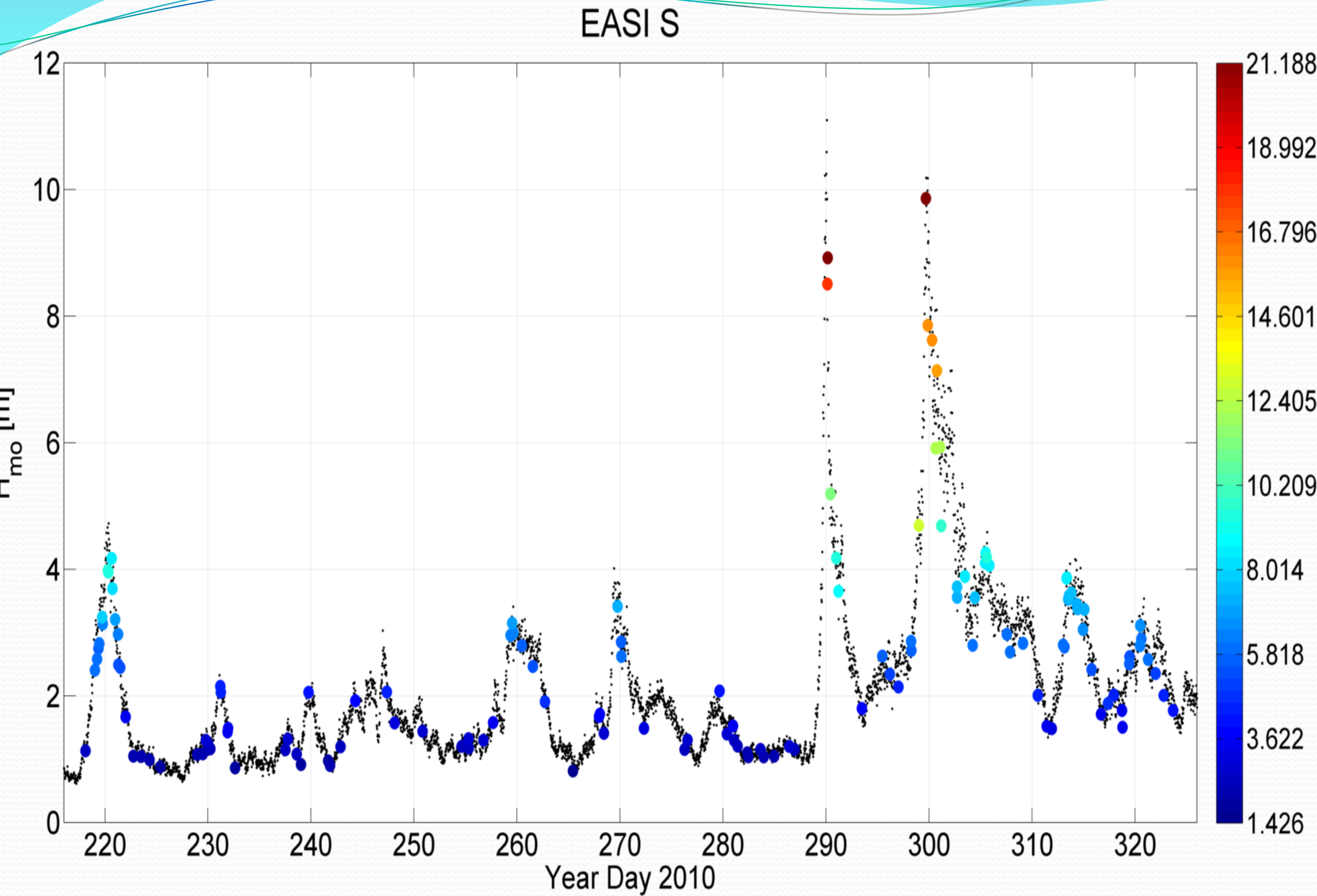
- Steepness Increases (Non-Linearity)
- Spectral Width Decreases (Narrow-Band/Peaked) (Onorato et al. 2001)
  - Related to Kurtosis in the Narrow-Band Approximation (Janssen 2003; Mori and Janssen 2006)
- Directional Spread Decreases (Waseda et al. 2009; Onorato et al. 2009)



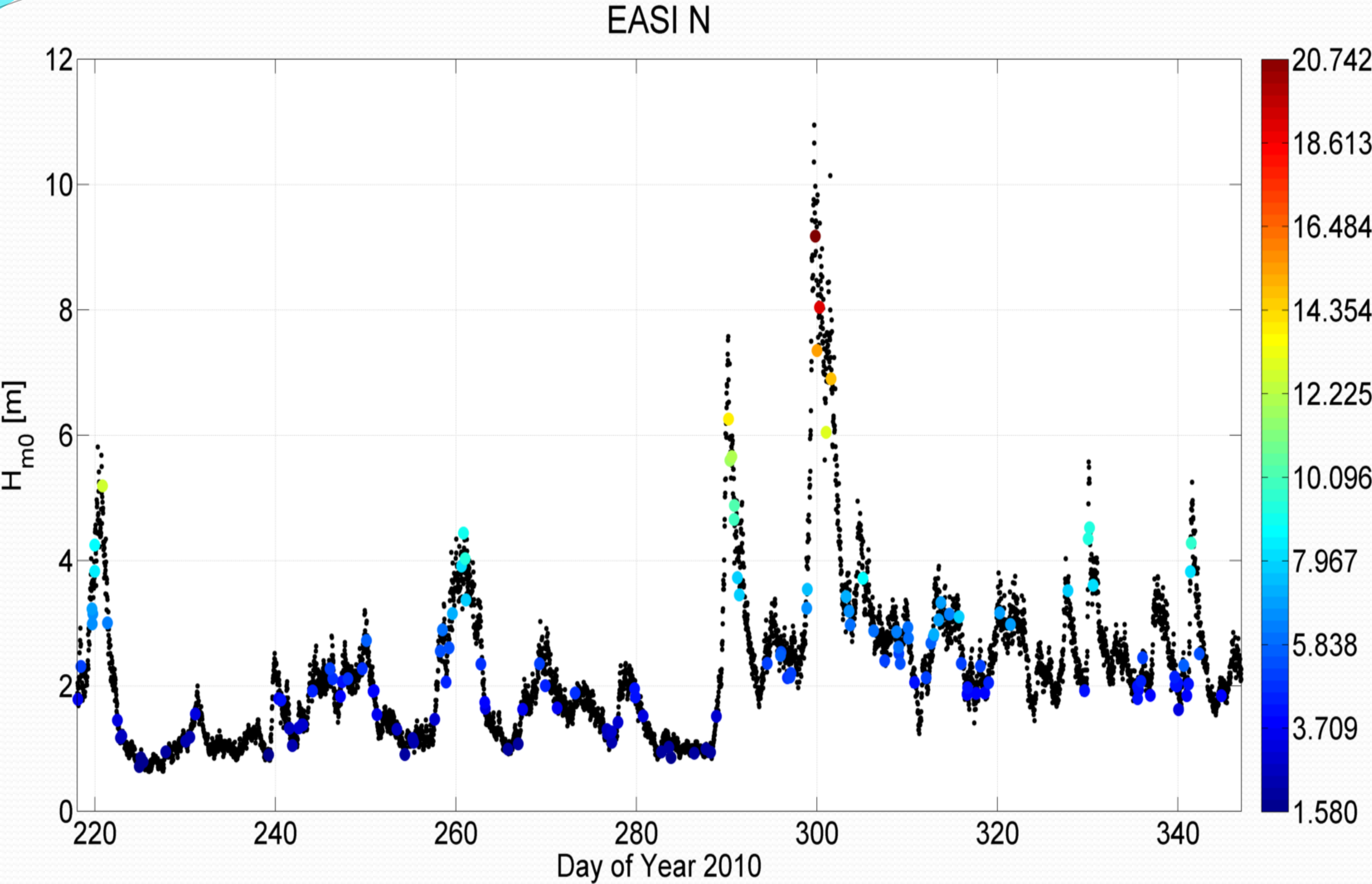
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
H/H_m0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Number of Data
EASI N
EASI S

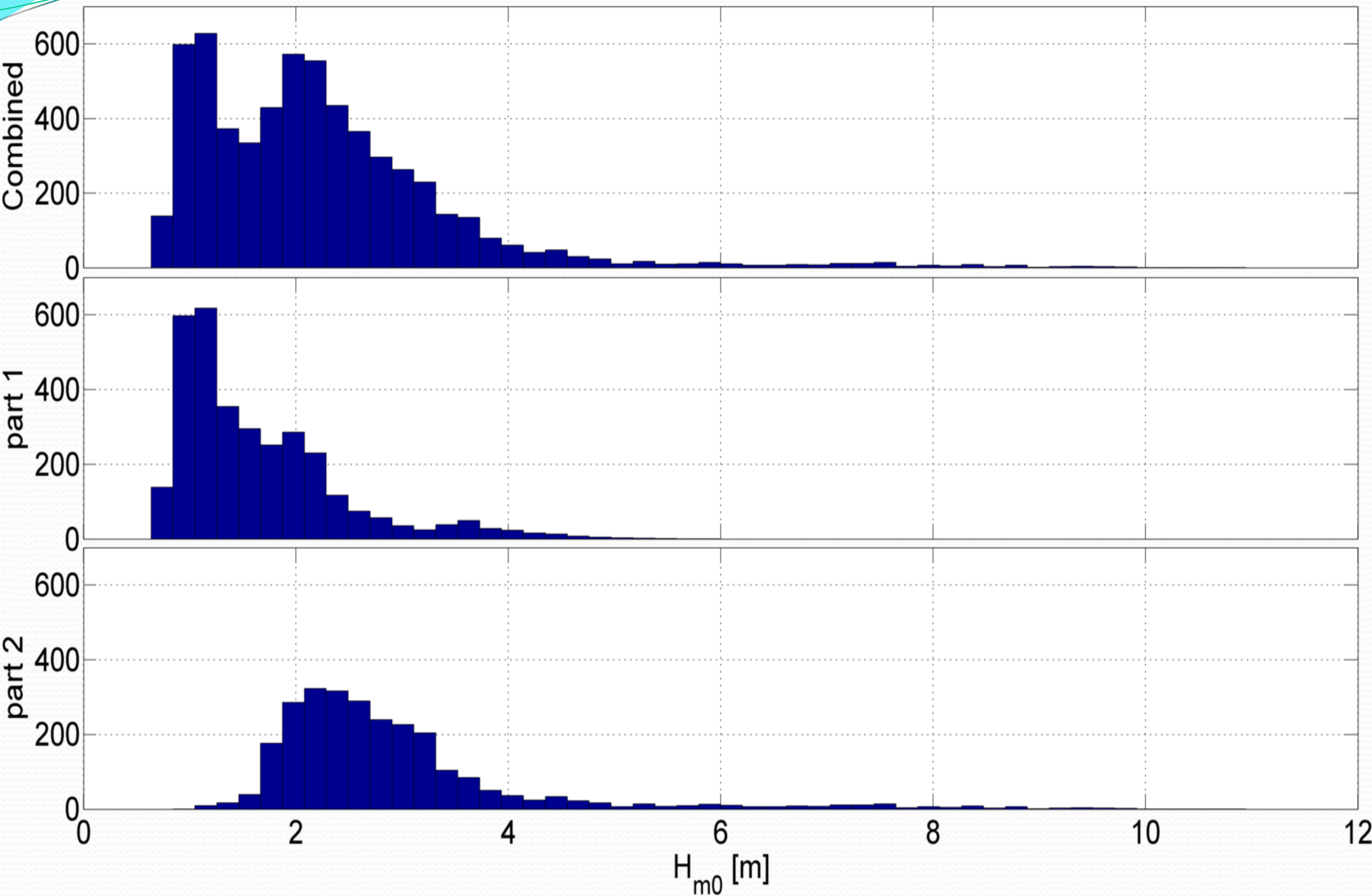

2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
H/H$_{m0}$
0.97
0.975
0.98
0.985
0.99
0.995
1
Normalized Number of Data
EASI N
EASI S


EASI N
EASI S
2.7
2.6
2.5
2.4
2.3
2.2
0.993
0.994
0.995
0.996
0.997
0.998
0.999
1
Normalized Number of Data
H/H_{m0}

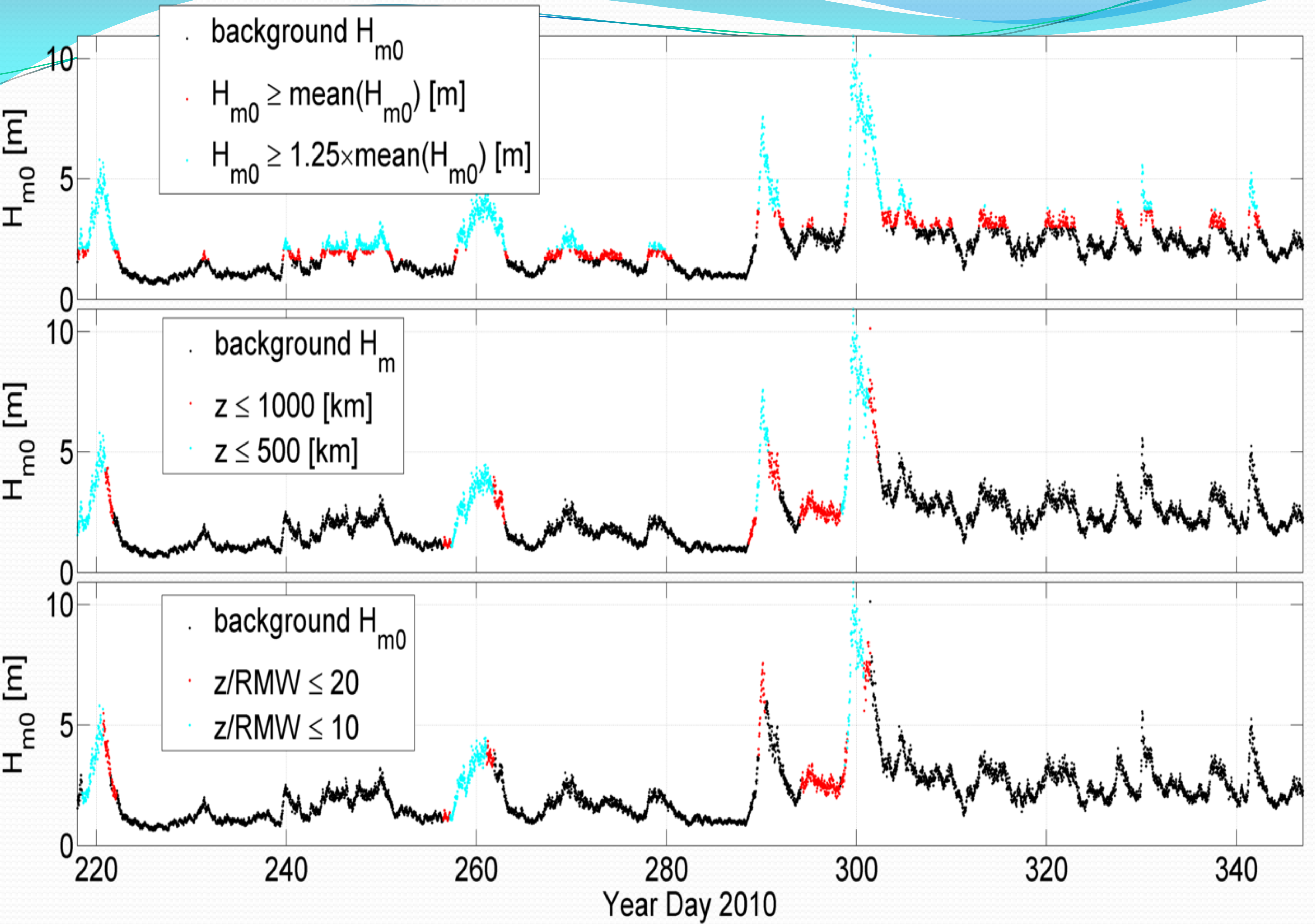


EASI S
12
10
8
6
4
2
0
220
230
240
250
260
270
280
290
300
310
320
Year Day 2010
21.188
18.992
16.796
14.601
12.405
10.209
8.014
5.818
3.622
1.426


EASI N
12
10
8
6
4
2
0
H$_{m0}$ [m]
220
240
260
280
300
320
340
Day of Year 2010
20.742
18.613
16.484
14.354
12.225
10.096
7.967
5.838
3.709
1.580



Combined
part 1
part 2
0
200
400
600
0
2
4
6
8
10
12
H_{m0} [m]



background H_{m0}
$H_{m0} \geq mean(H_{m0})$ [m]
$H_{m0} \geq 1.25 \times mean(H_{m0})$ [m]
background H_m
z ≤ 1000 [km]
z ≤ 500 [km]
background H_{m0}
z/RMW ≤ 20
z/RMW ≤ 10
H_{m0} [m]
0
5
10
220
240
260
280
300
320
340
Year Day 2010

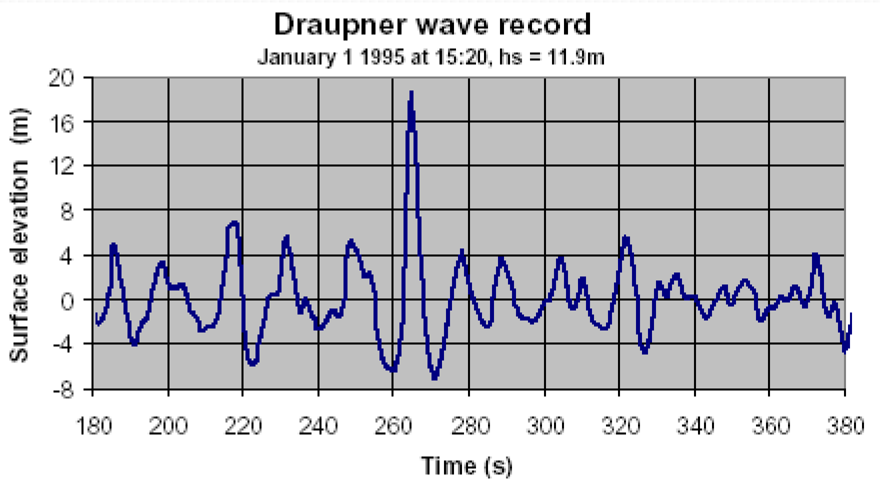
Storm	# of Rogues	# of Waves	OP [10^{-4}]
Dianmu	28	106814	2.62
Fanapi	18	137964	1.30
Malakas	7	126486	0.55
Megi	13	60998	2.13
Chaba	31	153573	2.02
Combined TC	97	585826	1.66
non-TC	208	2752171	0.76
Combined TC*	**90**	**459349**	**1.96**
non-TC*	**215**	**2878657**	**0.75**
Total	305	3338006	0.91

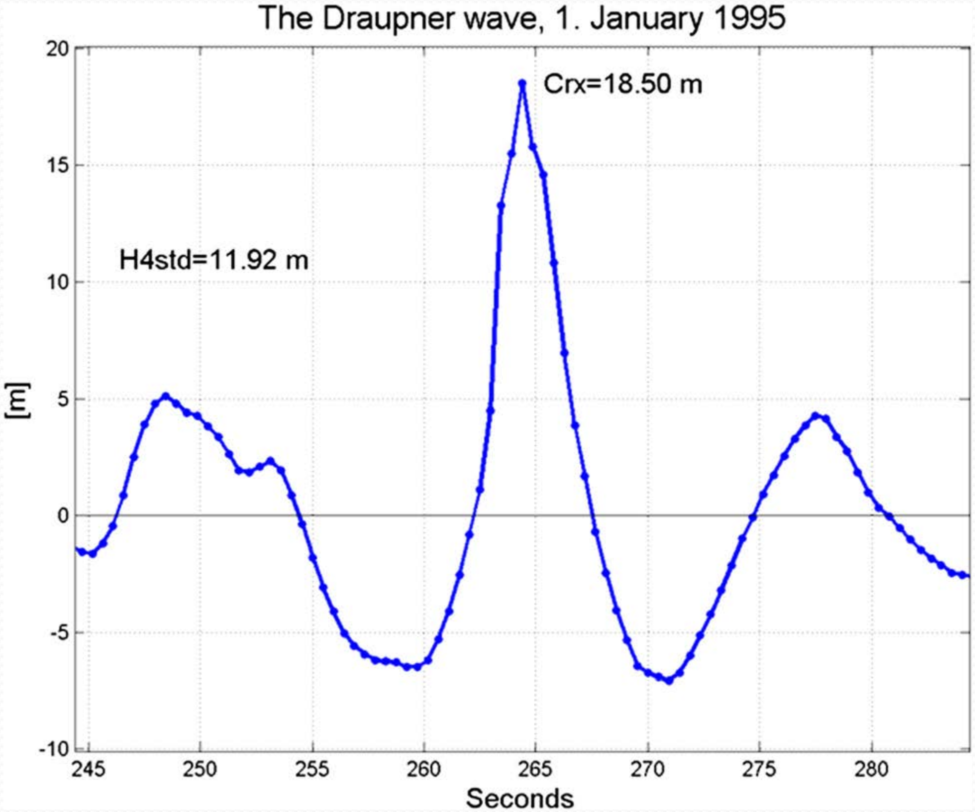
Buoy	S_S	σ_p [°]	ν [Hz]	IWA
EASI-N TC*	**0.052**	34.84	0.72	**0.80**
EASI-N non-TC*	**0.036**	37.41	0.70	**0.59**
EASI-S TC*	**0.050**	34.89	0.73	**0.74**[†]
EASI-S non-TC*	**0.032**	39.67	0.71	**0.45**[†]

Comparison Against Other Famous Rouges

- **Considering only Extreme Rogue Waves:**
  - $H \geq 2.0H_{m0}$ & $H \geq 15\ m$
- **The New Year's Wave (Draupner)**
- **The Andrea Wave**

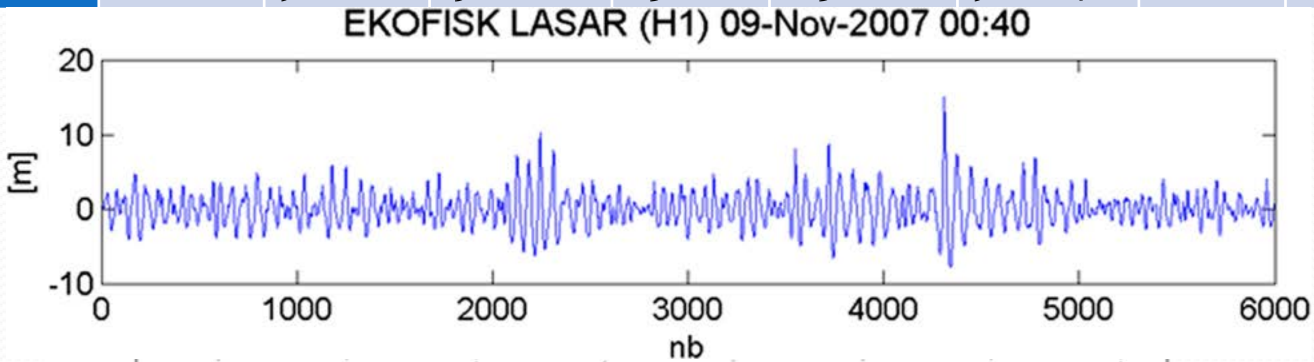
Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
Draupner	25.0	11.9	18.5	2.1	1.55	1.1.1995	LPS	NS



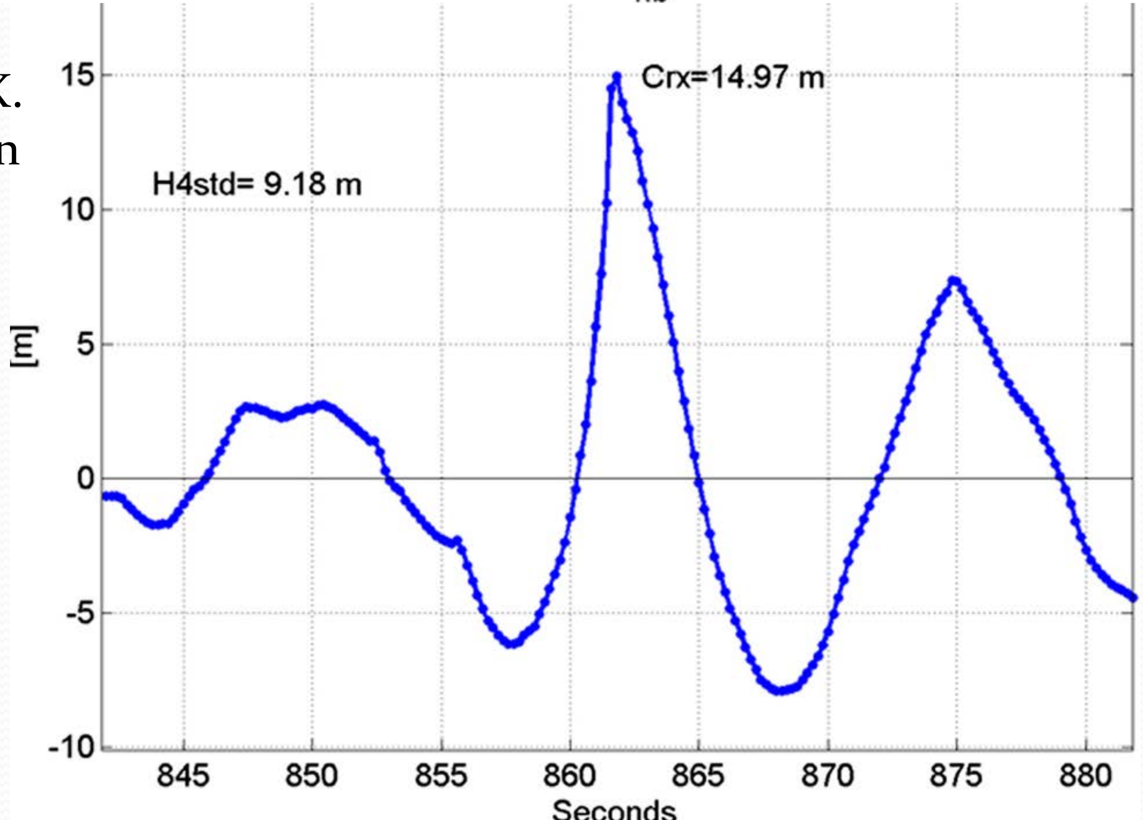


Haver, S. (2004)

Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
Andrea	21.1	9.2	15.0	2.3	1.63	9.11.2007	LPS	NS



Magnusson A.K. & M.A. Donelan (2013)



Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
Draupner	25.0	11.9	18.5 (6.5)	2.1	1.55	1.1.1995	LPS	NS
EASI S (2)	21.2	8.9	13.8 (7.4)	2.37	1.55	290.16	Megi	PS
EASI S (3)	21.1	9.9	12.5 (8.6)	2.14	1.27	299.68	Chaba	PS
Andrea	21.1	9.2	15.0 (6.1)	2.3	1.63	9.11.2007	LPS	NS
EASI N (1)	20.7	9.2	11.8 (9.0)	2.26	1.28	299.82	Chaba	PS
EASI N (3)	18.7	8.0	9.5 (9.2)	2.34	1.18	300.25	Chaba	PS
EASI S (1)	17.6	8.5	8.4 (9.2)	2.07	0.98(1.08)	290.11	Megi	PS
EASI S (4)	15.7	7.9	10.8 (5.0)	2.02	1.38	299.86	Chaba	PS
EASI S (5)	15.6	7.6	10.1 (5.5)	2.05	1.33	300.29	Chaba	PS
EASI N (2)	15.1	7.3	6.7 (8.4)	2.06	0.91(1.15)	299.99	Chaba	PS

Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
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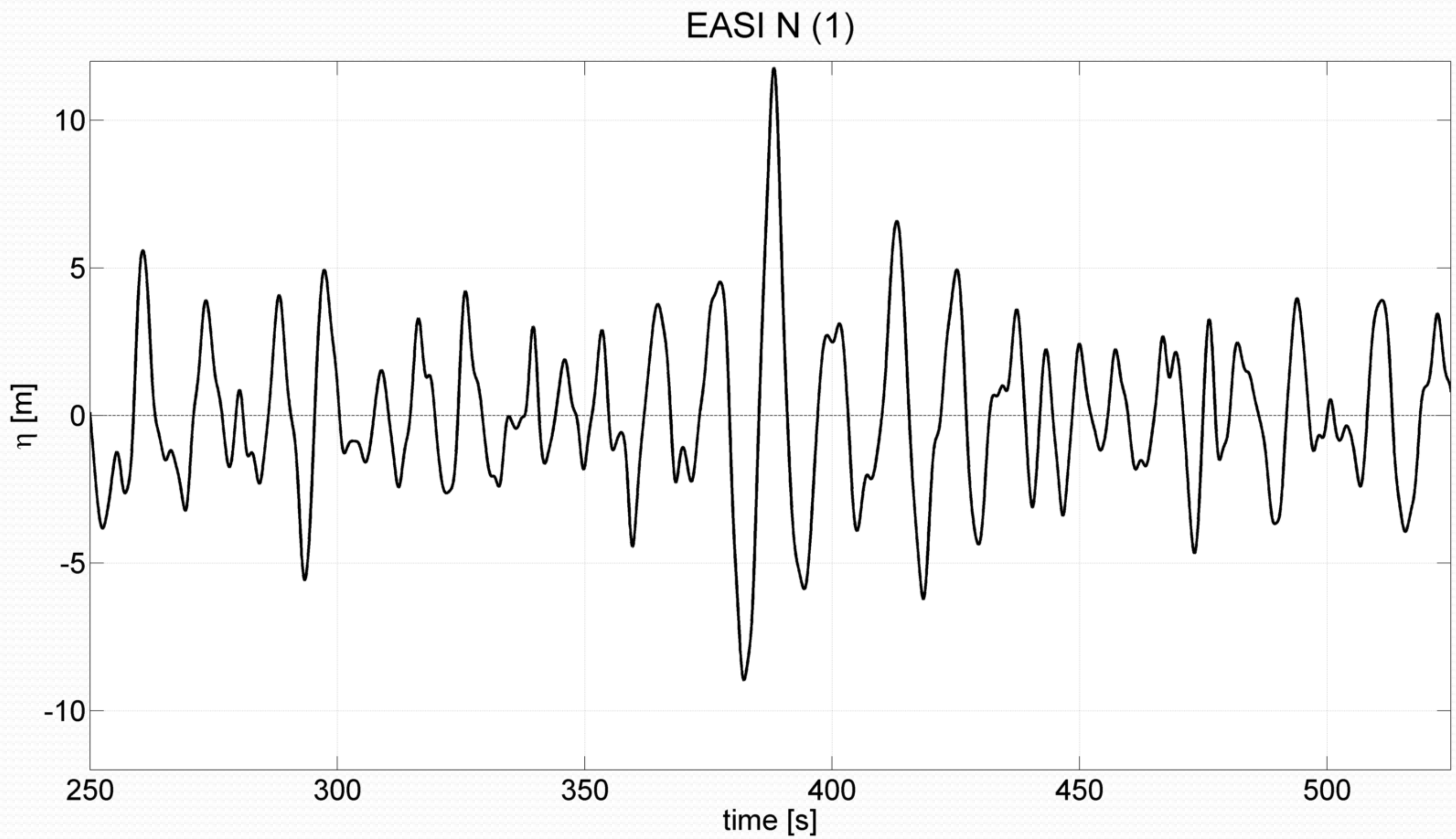
EASI S (4)	15.7	7.9	10.8 (5.0)	2.02	1.38	299.86	Chaba	PS

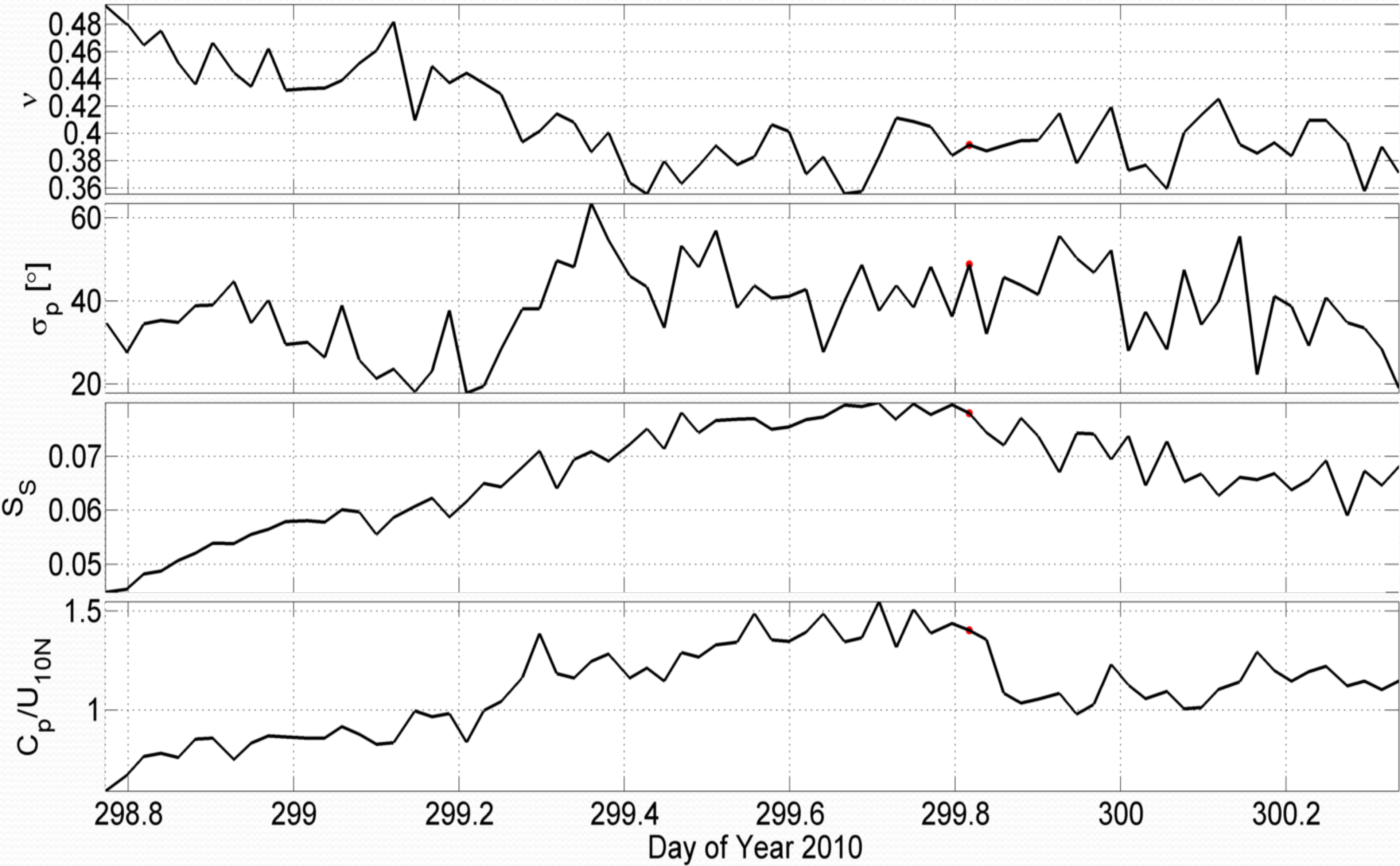
Summary

- deep-water dataset for studying rogue waves and waves generated by TCs is presented
  - including directional wave spectra
- Preliminary analysis has found increased observations of rogue waves in the vicinity of TCs
  - maybe related to the increased wave steepness which enhances modulation instability during these storms
- These waves are at least as interesting as the famous Draupner wave, perhaps more so given the high level of H/H_{mo}
- The potential for future efforts using this dataset is great
  - What would the community like to see, please offer analysis suggestions

Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
EASI N (1)	20.7	9.2	11.8 (9.0)	2.26	1.28	299.82	Chaba	PS

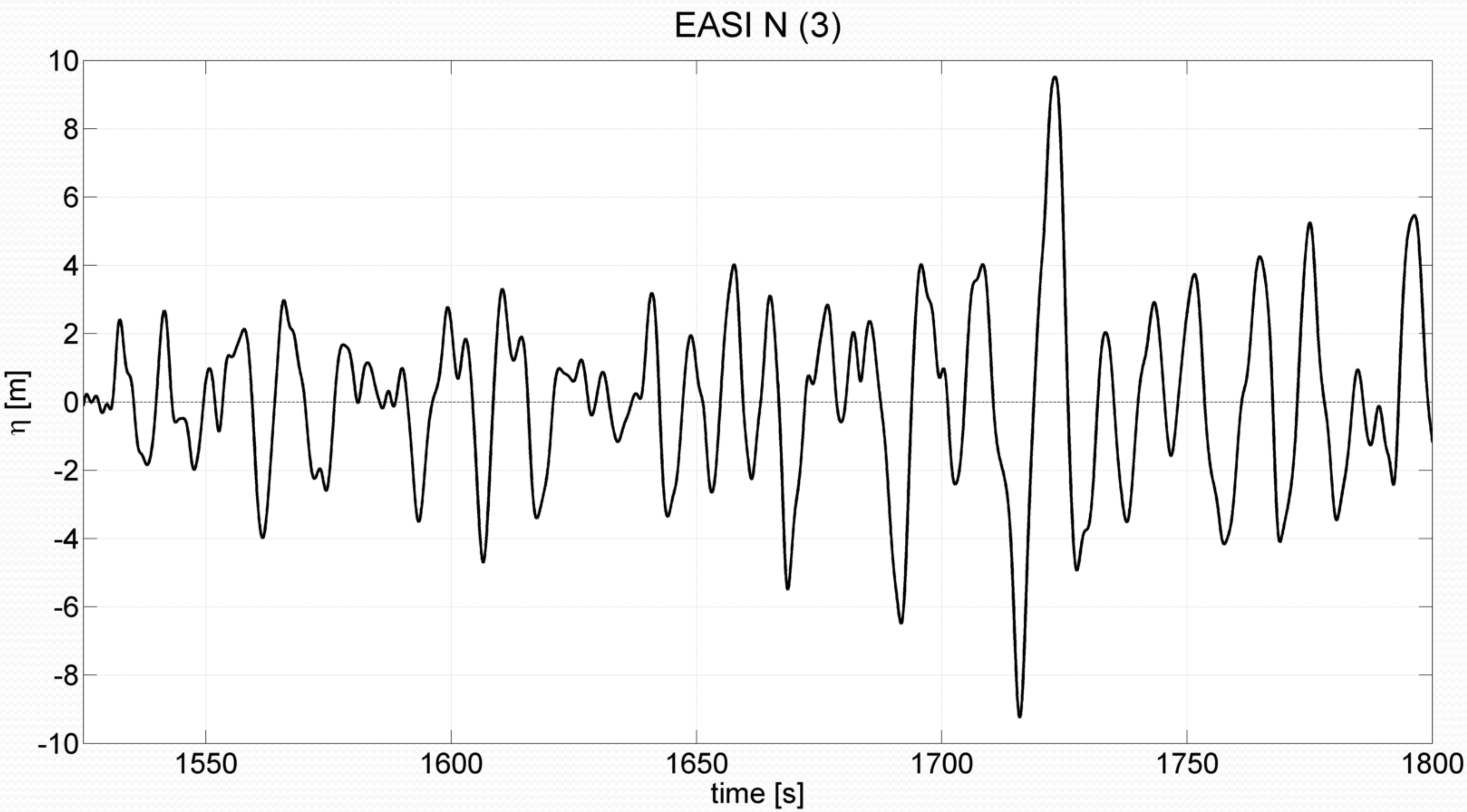


EASI N (1)

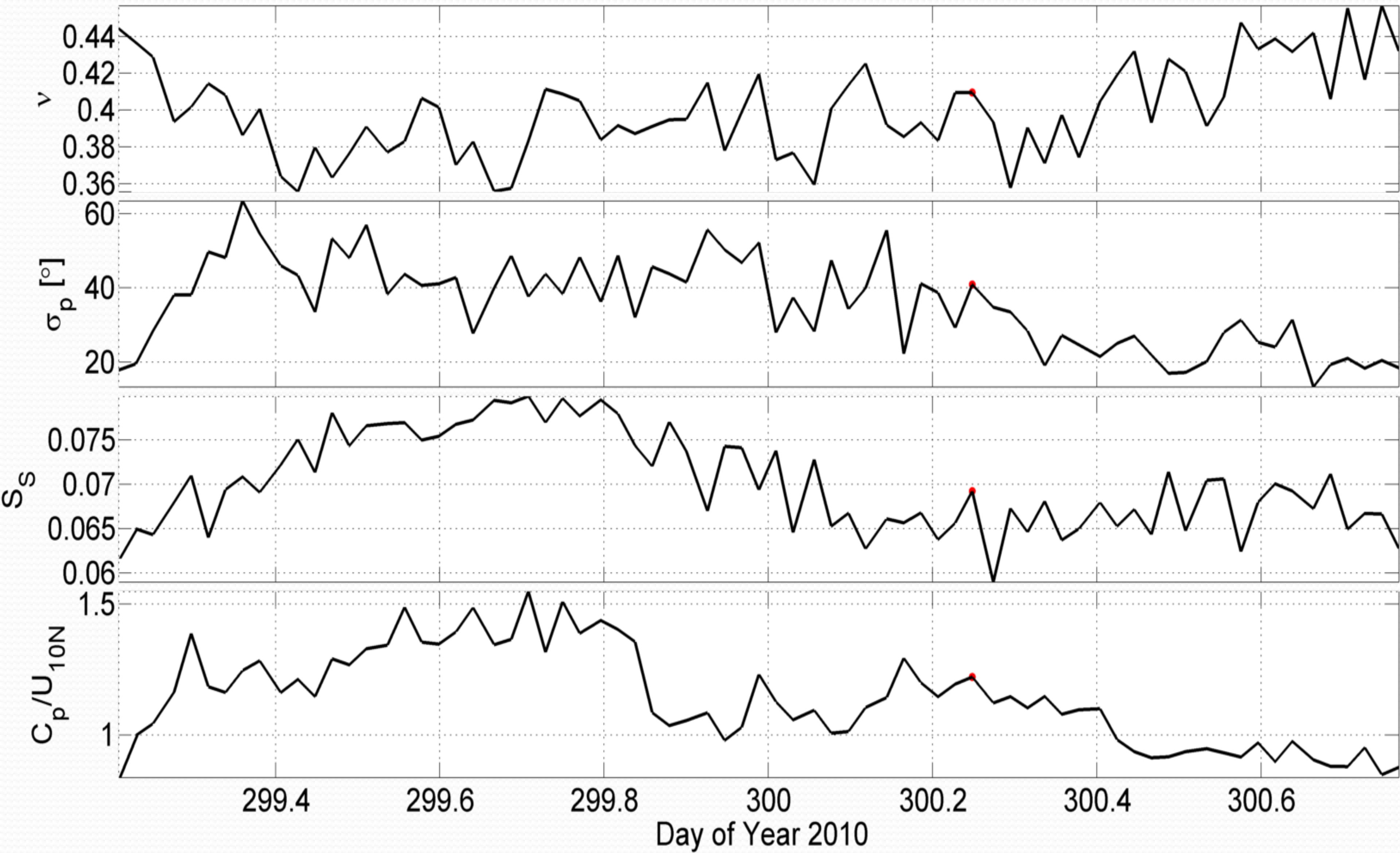


ν
0.48
0.46
0.44
0.42
0.4
0.38
0.36
σp [°]
60
40
20
SS
0.07
0.06
0.05
Cp/U10N
1.5
1
298.8
299
299.2
299.4
299.6
299.8
300
300.2
Day of Year 2010

Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
EASI N (3)	18.7	8.0	9.5 (9.2)	2.34	1.18	300.25	Chaba	PS

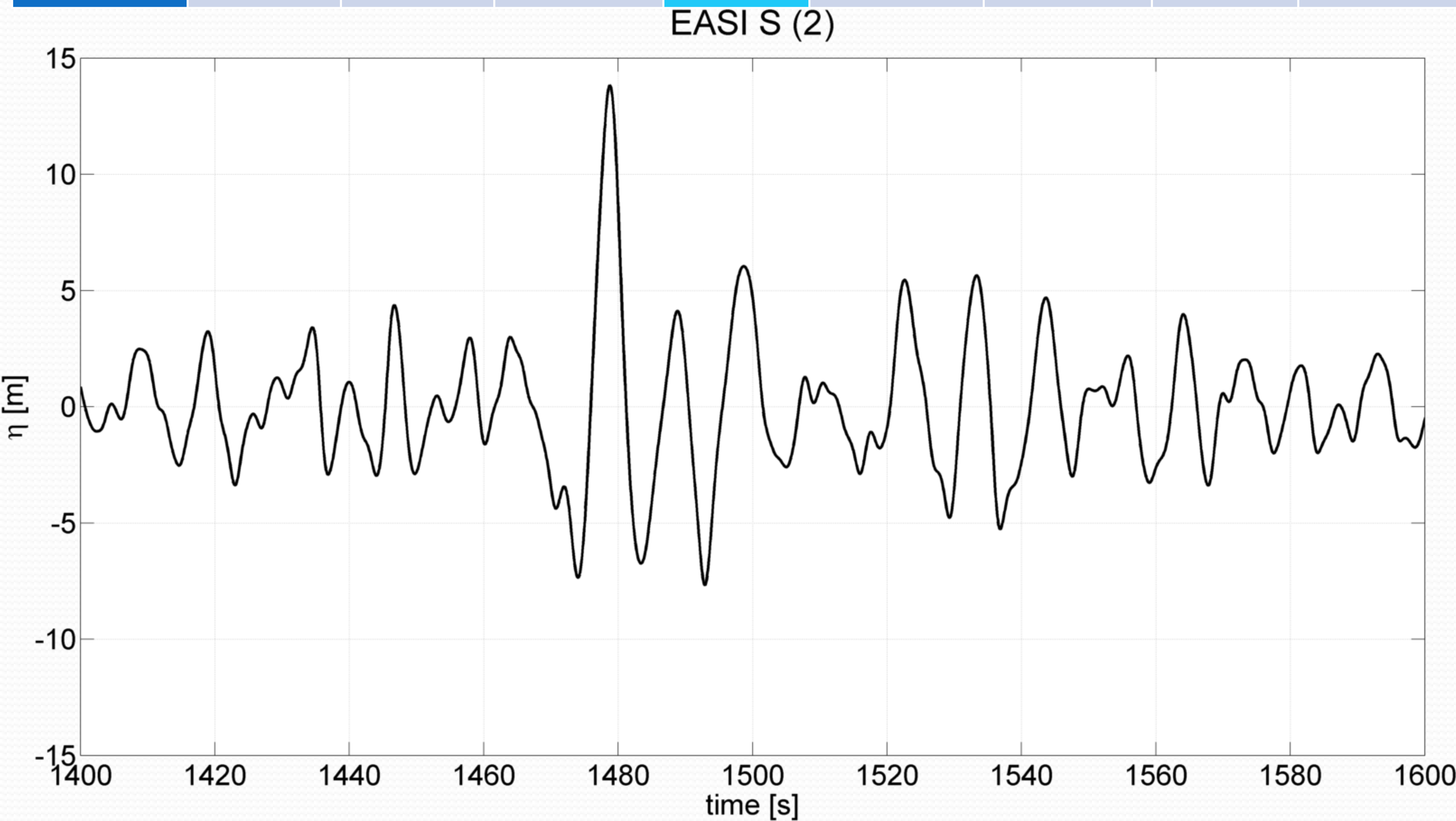


EASI N (3)

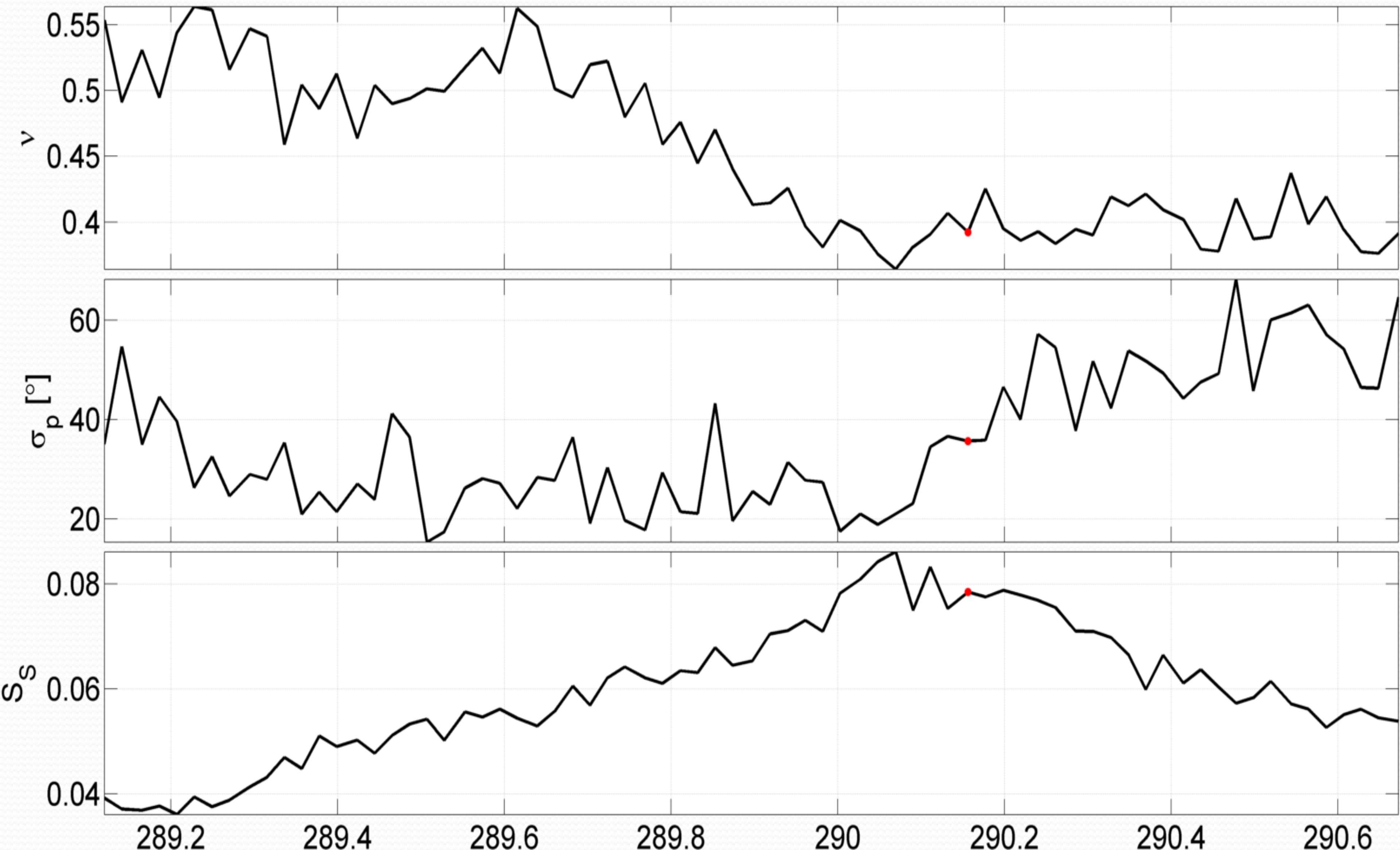


ν
0.44
0.42
0.4
0.38
0.36
σ_p [°]
60
40
20
S_S
0.075
0.07
0.065
0.06
C_p/U_{10N}
1.5
1
299.4
299.6
299.8
300
300.2
300.4
300.6
Day of Year 2010

Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
EASI S (2)	21.2	8.9	13.8 (7.4)	2.37	1.55	290.16	Megi	PS



EASI S (2)



0.55
0.5
0.45
0.4
ν
60
40
20
σp [°]
0.08
0.06
0.04
SS
289.2
289.4
289.6
289.8
290
290.2
290.4
290.6

Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
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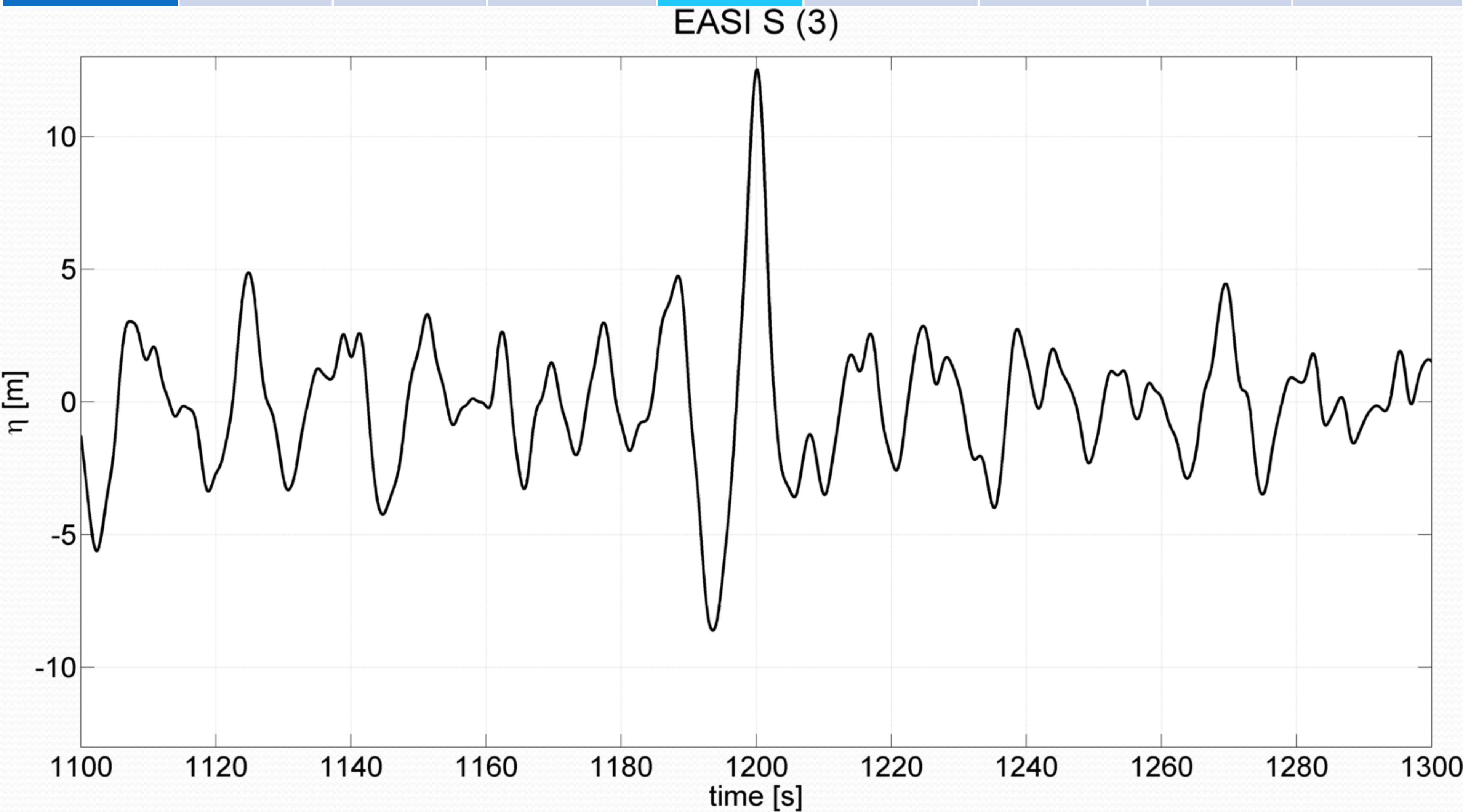
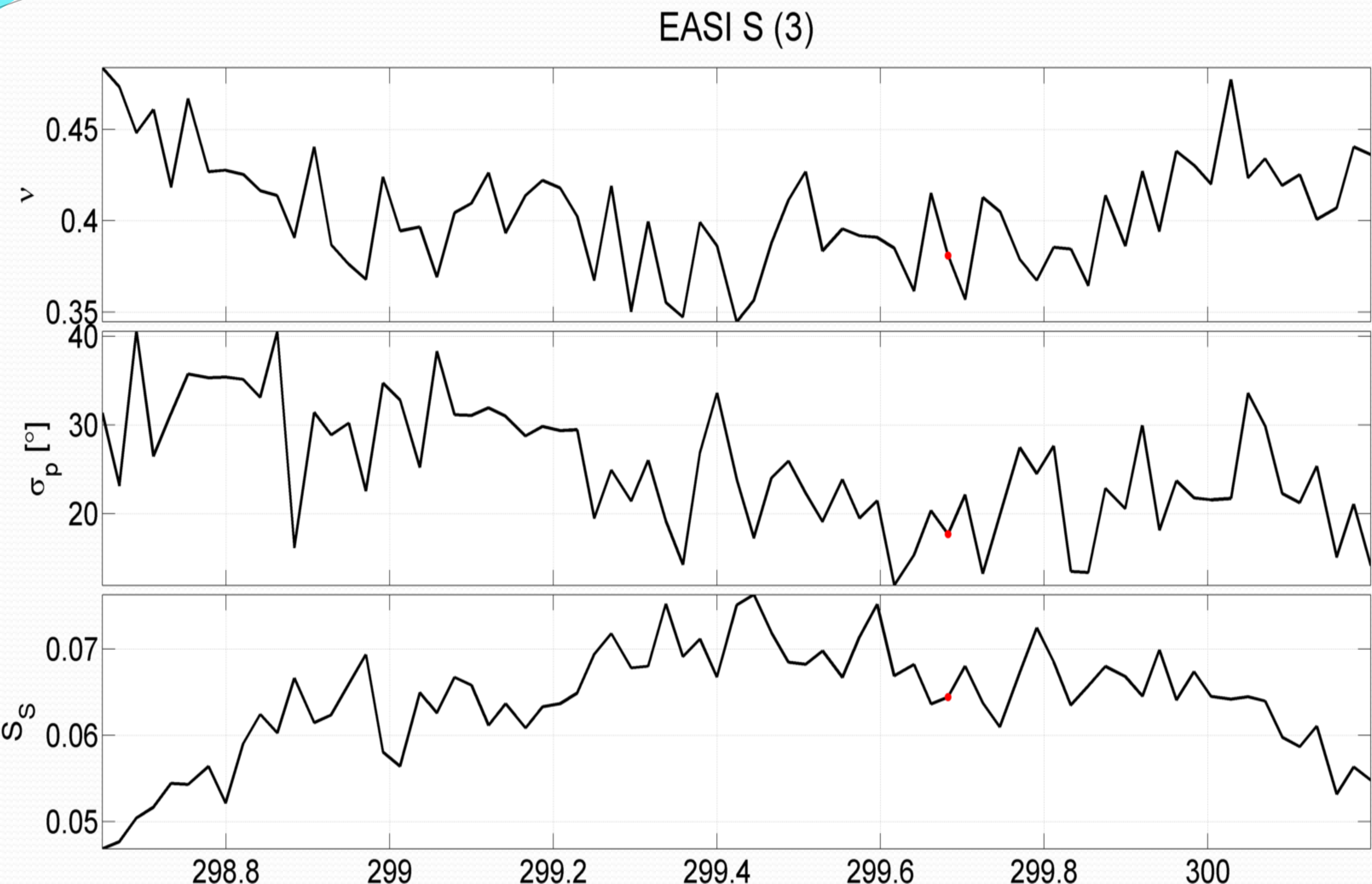
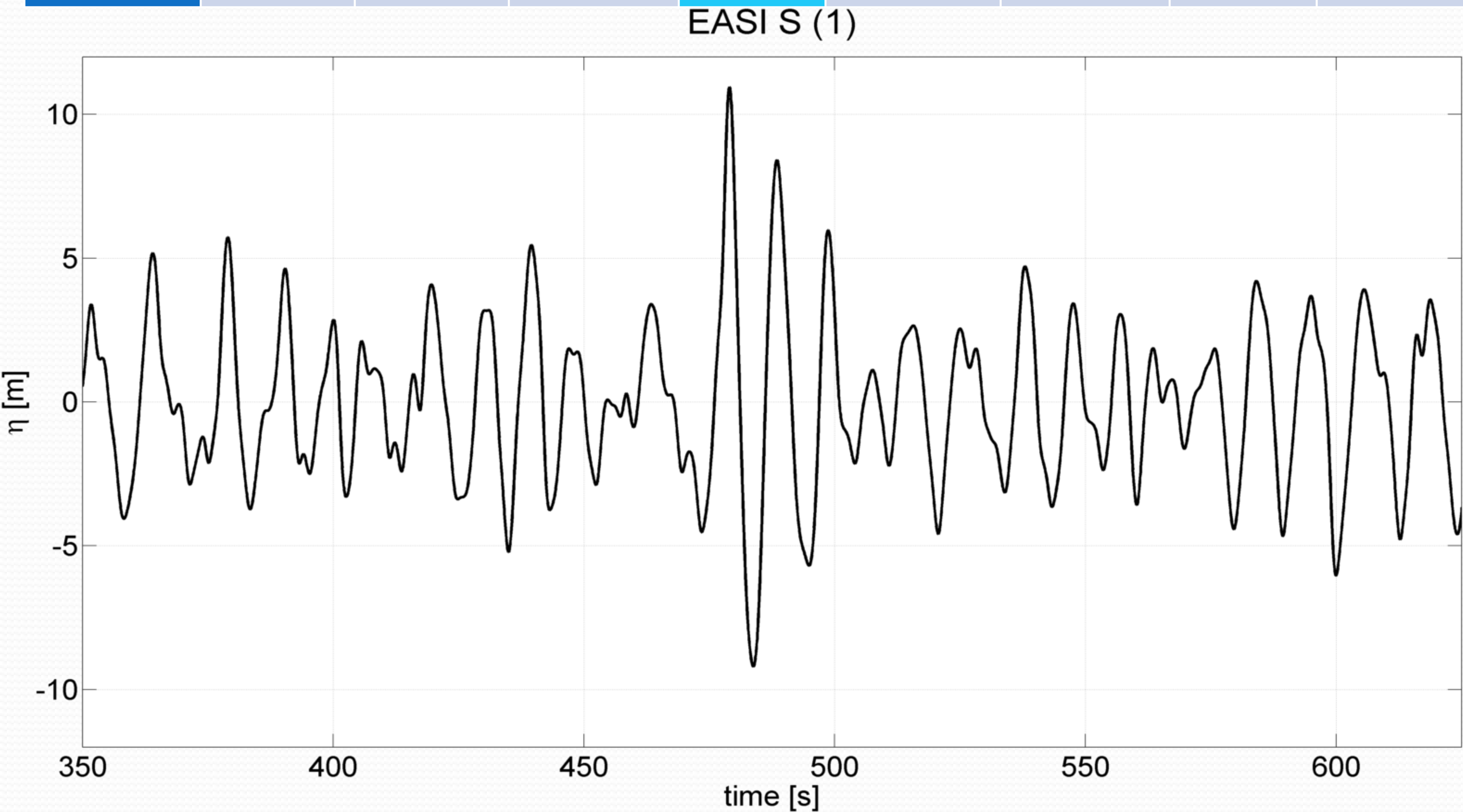
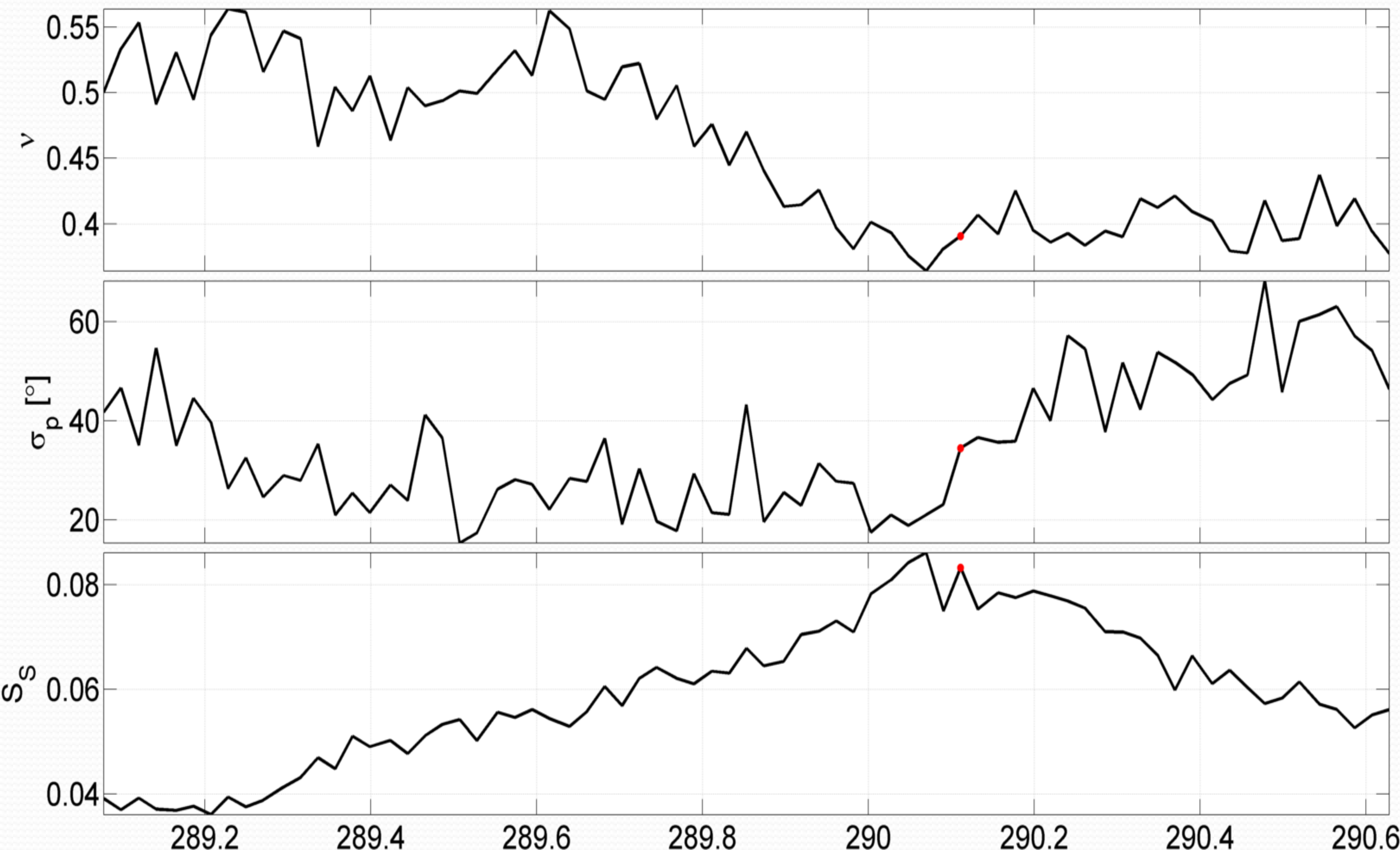



EASI S (3)
ν
0.45
0.4
0.35
40
30
20
σ_p [°]
S_S
0.07
0.06
0.05
298.8
299
299.2
299.4
299.6
299.8
300

Platform	H [m]	H_{mo} [m]	H_c (H_t)	H/H_{mo}	H_c/H_{mo}	Date	Storm	Location
EASI S (1)	17.6	8.5	8.4 (9.2)	2.07	0.98(1.08)	290.11	Megi	PS



EASI S (1)



ν
0.55
0.5
0.45
0.4
σp [°]
60
40
20
SS
0.08
0.06
0.04
289.2
289.4
289.6
289.8
290
290.2
290.4
290.6

Conclusions

- We present a promising dataset, to hopefully fill the need for high quality in-situ measurements of rogue waves
- These waves are at least as interesting as the famous Draupner wave, perhaps more so given the high level of H/H_{mo}
- Measurements show occurrences of rogue waves in-line with current B-F theory

- Future Work
  - Need to research the existence of these unusual waves more systematically
  - Look at the waves in context of the evolution of the directional spectrum [both measured and modeled (Hitoshi Tamura)]
  - In context of the Typhoons (qudrants, wind speed and direction, crossing seas?)