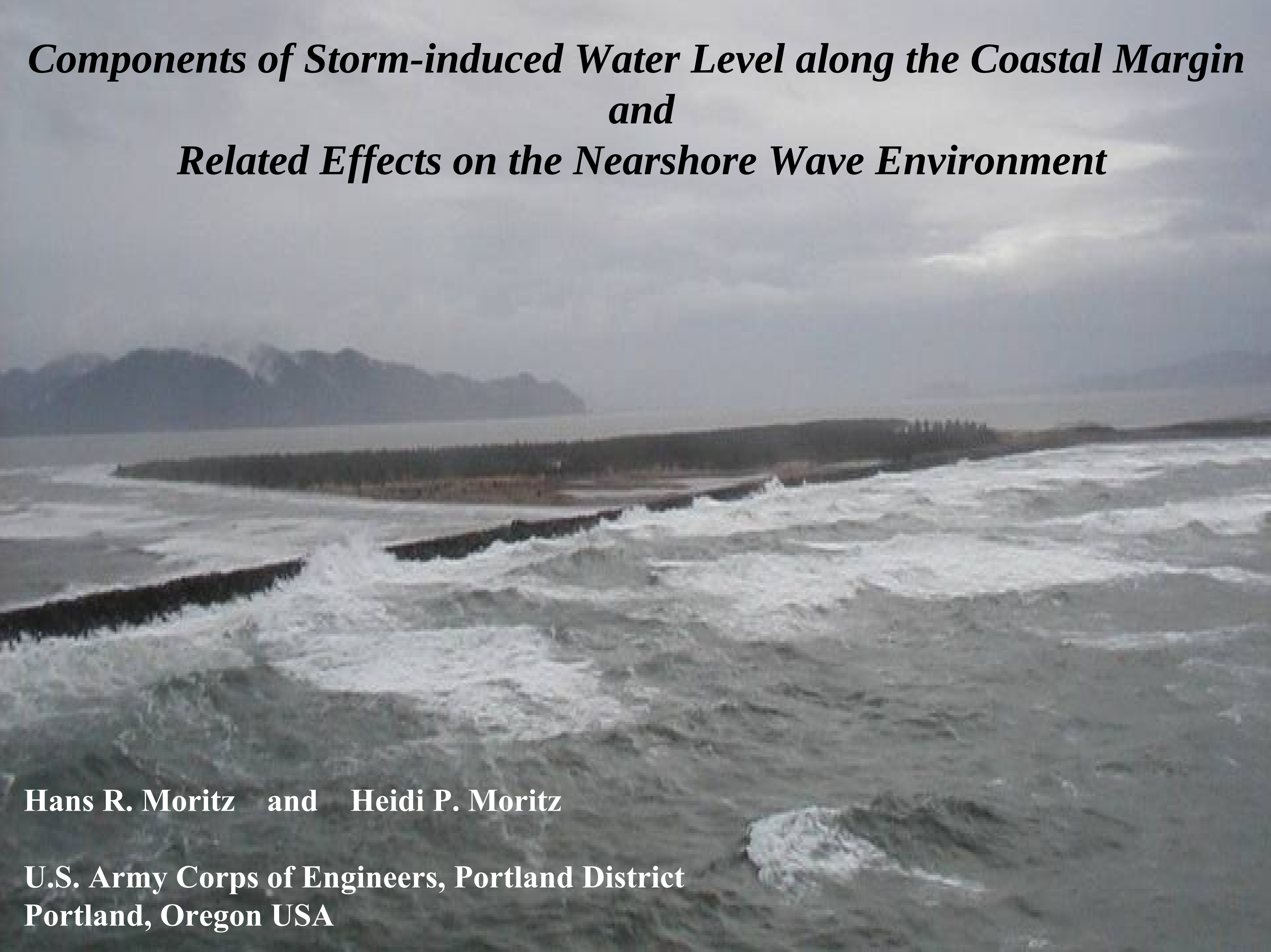
Components of Storm-induced Water Level along the Coastal Margin and Related Effects on the Nearshore Wave Environment



Hans R. Moritz and Heidi P. Moritz

U.S. Army Corps of Engineers, Portland District
Portland, Oregon USA

OUTLINE

Review Water Level Components – as Affected by Storm Wave Action

Examine Observed Infragravity Transients – Produced by Shoaling Bound Waves

Examine Consequences of Infragravity Transients – Effects on Coastal Margin Use

Consider Hypothesis: Storm Surge Enhanced by Infragravity Transients

Conclusions

The storm water level that acts upon the coastal margin is a product of many components (processes).

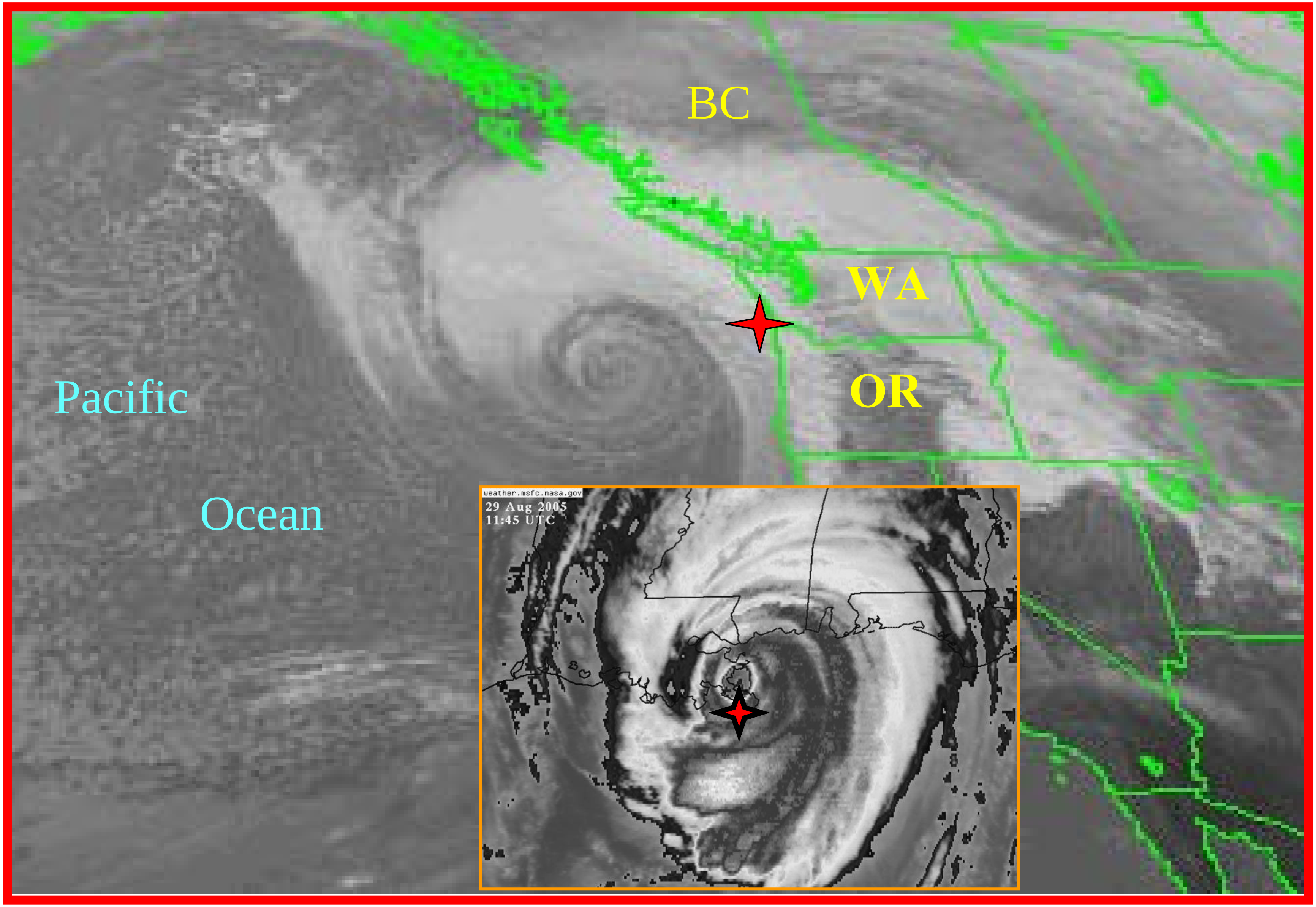
A basic understanding of these components should be attained before initiating significant costal zone planning or implementing the design and construction of coastal infrastructure, at a given location.

Infragravity Transients ($\Delta\eta$) of 1-2 meters and associated rip currents elevate the RISKS to life and property within the active coastal margin.

More work is needed to fully parameterize the estimation of $\Delta\eta$ and use this information to reduce risk along the coastal zone.

Hypothesis: $\Delta\eta$ may be responsible for a considerable fraction of the storm surge which affects coastal margins.

Based on an initial assessment, this “$\Delta\eta$-Surge” warrants further evaluation.

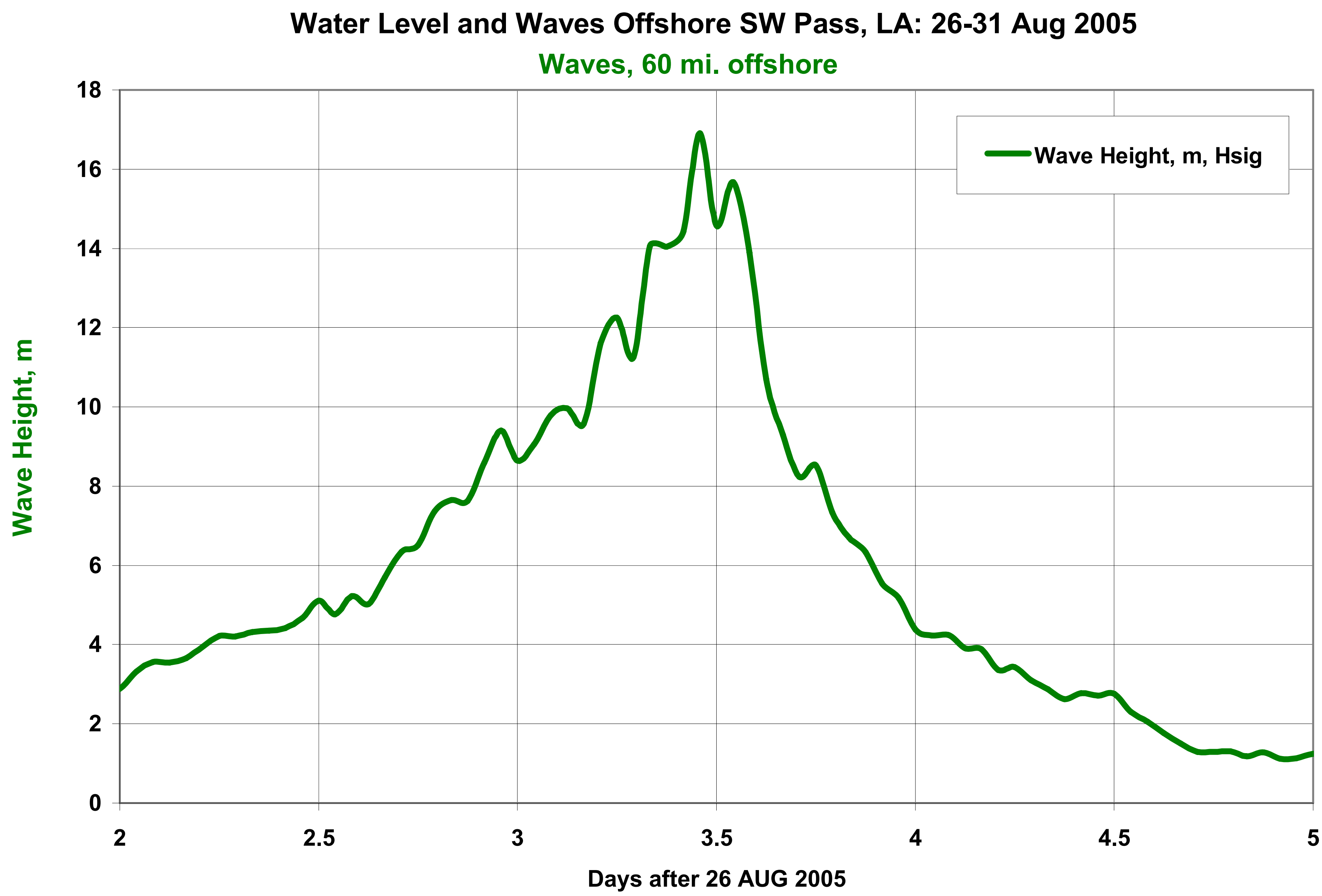


3 MAR 1999 - Extr Trop Low

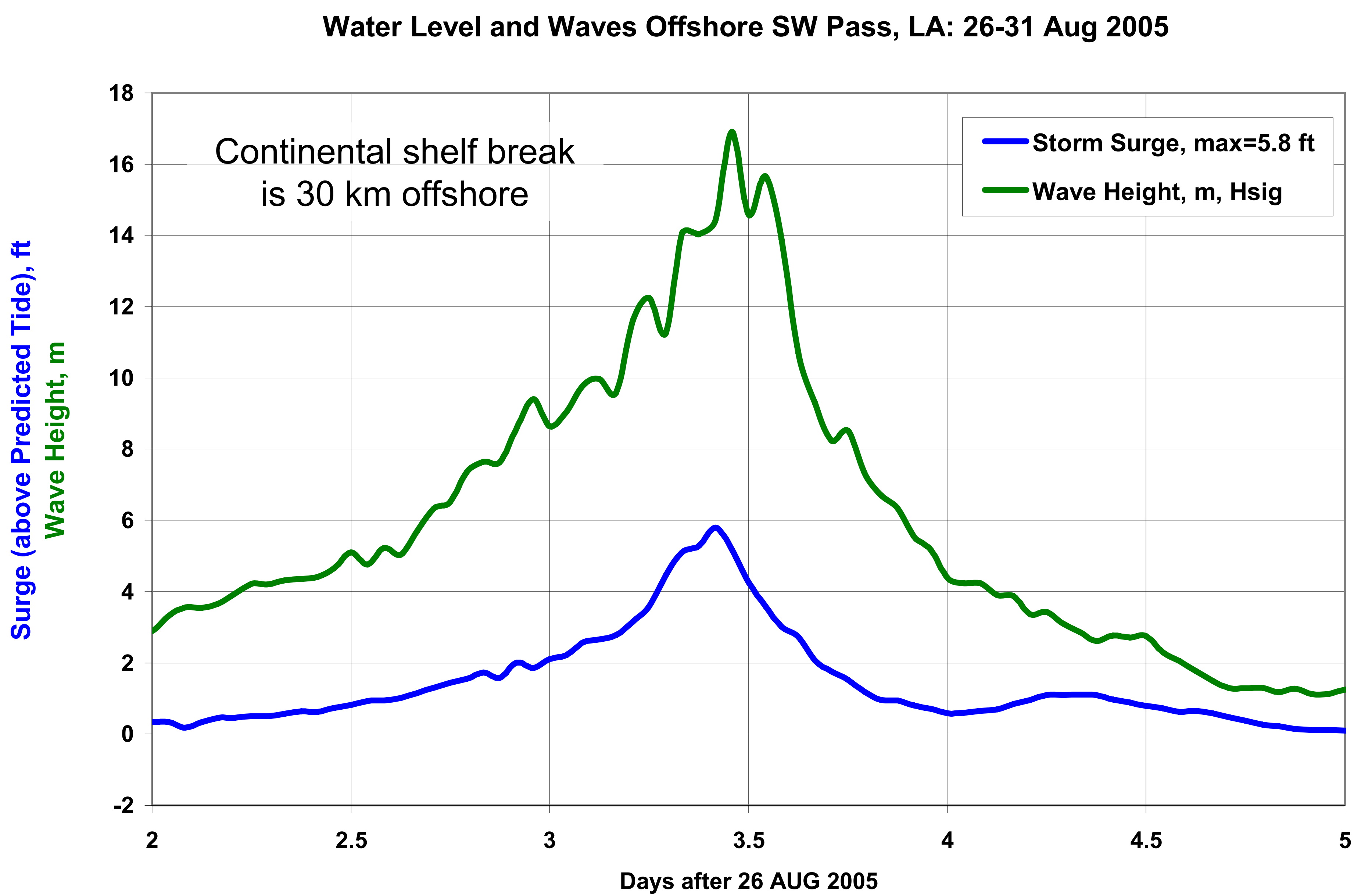
image courtesy of NOAA

29 AUG 2005 - Hurricane

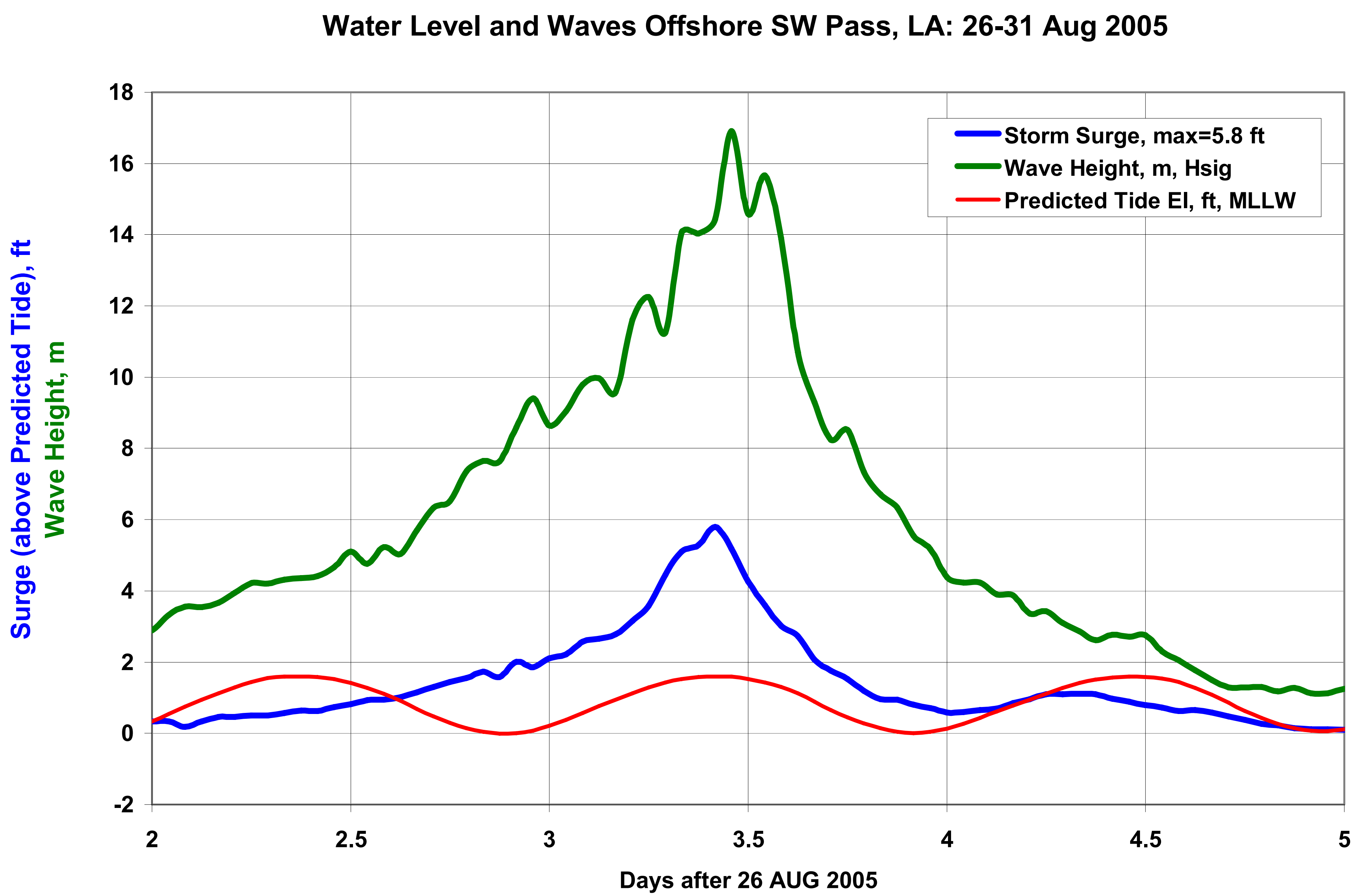
image courtesy of NOAA

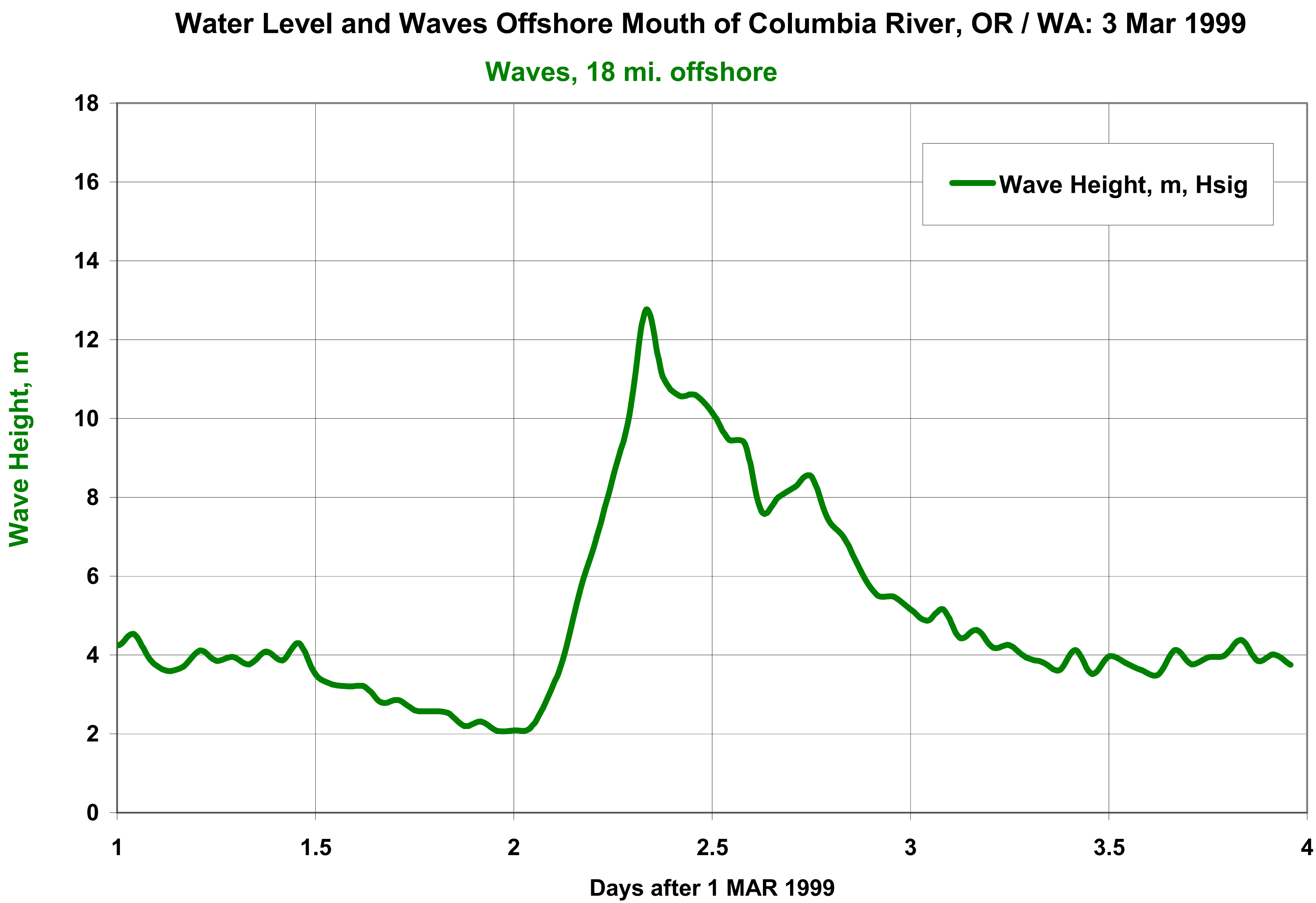


Water Level and Waves Offshore SW Pass, LA: 26-31 Aug 2005
Waves, 60 mi. offshore
Wave Height, m, Hsig
Wave Height, m
Days after 26 AUG 2005
0
2
4
6
8
10
12
14
16
18
2
2.5
3
3.5
4
4.5
5

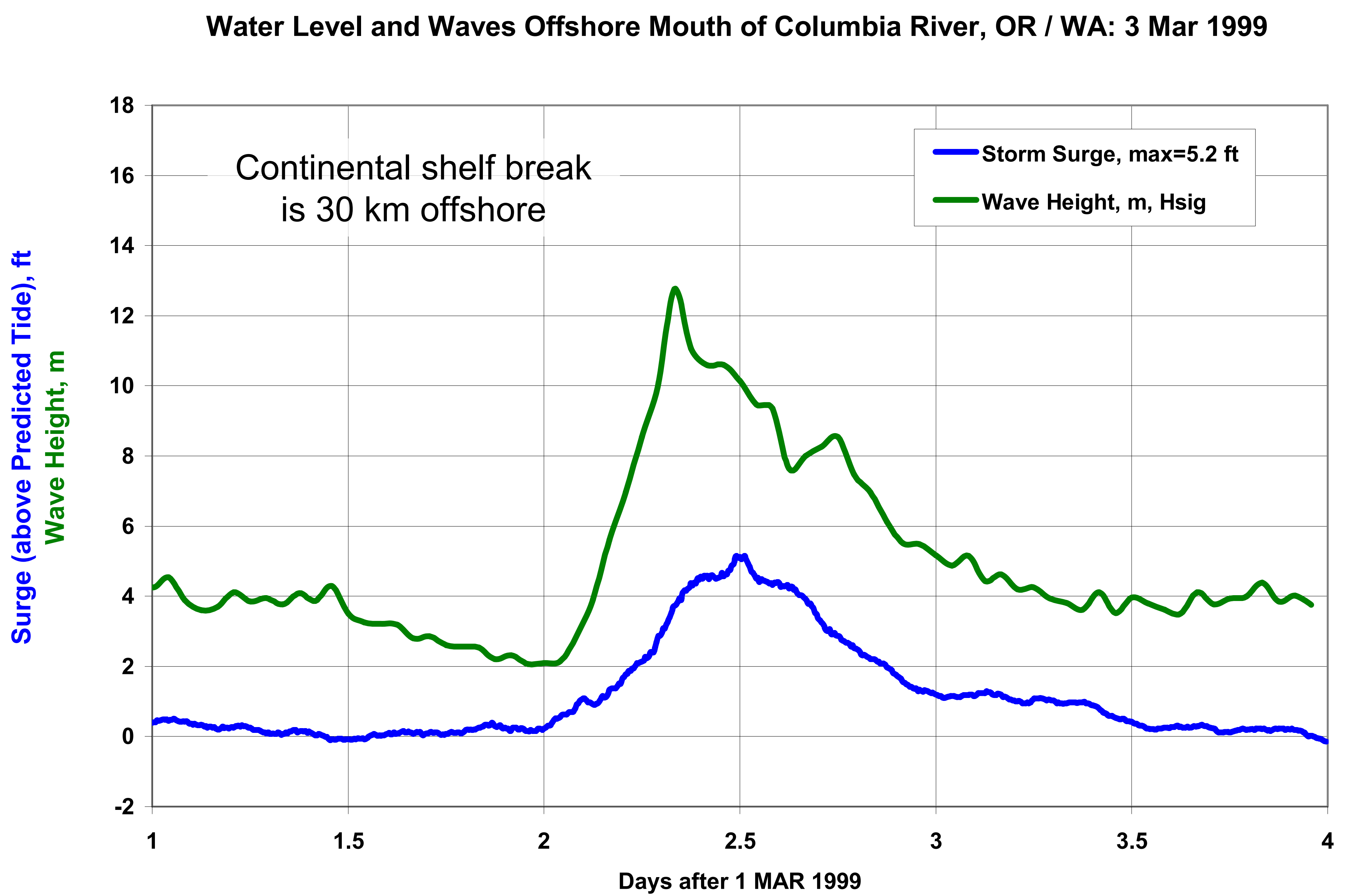


Water Level and Waves Offshore SW Pass, LA: 26-31 Aug 2005
Continental shelf break
is 30 km offshore
Storm Surge, max=5.8 ft
Wave Height, m, Hsig
Surge (above Predicted Tide), ft
Wave Height, m
Days after 26 AUG 2005
18
16
14
12
10
8
6
4
2
0
-2
2
2.5
3
3.5
4
4.5
5


Water Level and Waves Offshore SW Pass, LA: 26-31 Aug 2005
Storm Surge, max=5.8 ft
Wave Height, m, Hsig
Predicted Tide El, ft, MLLW
Surge (above Predicted Tide), ft
Wave Height, m
Days after 26 AUG 2005
18
16
14
12
10
8
6
4
2
0
-2
2
2.5
3
3.5
4
4.5
5

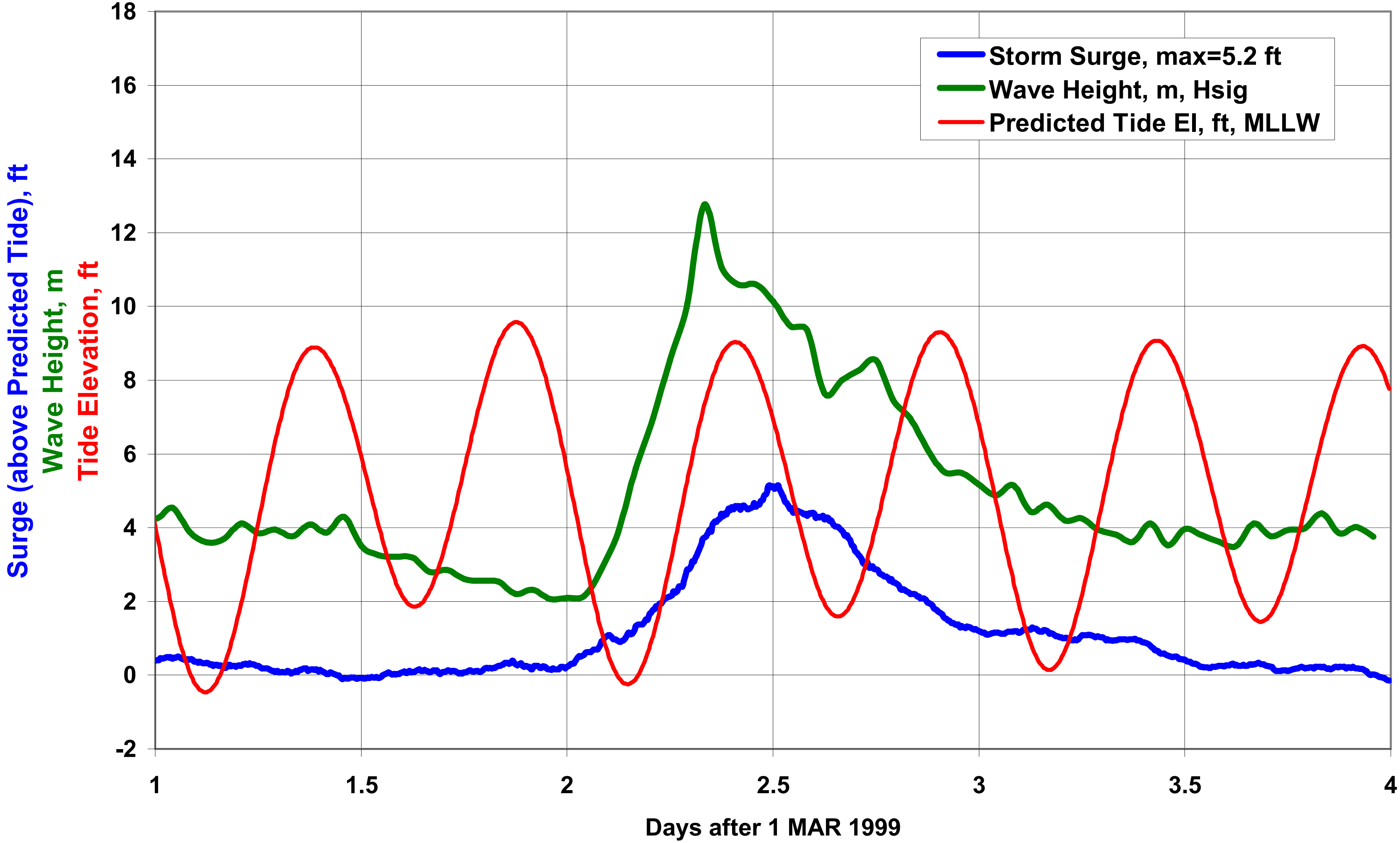


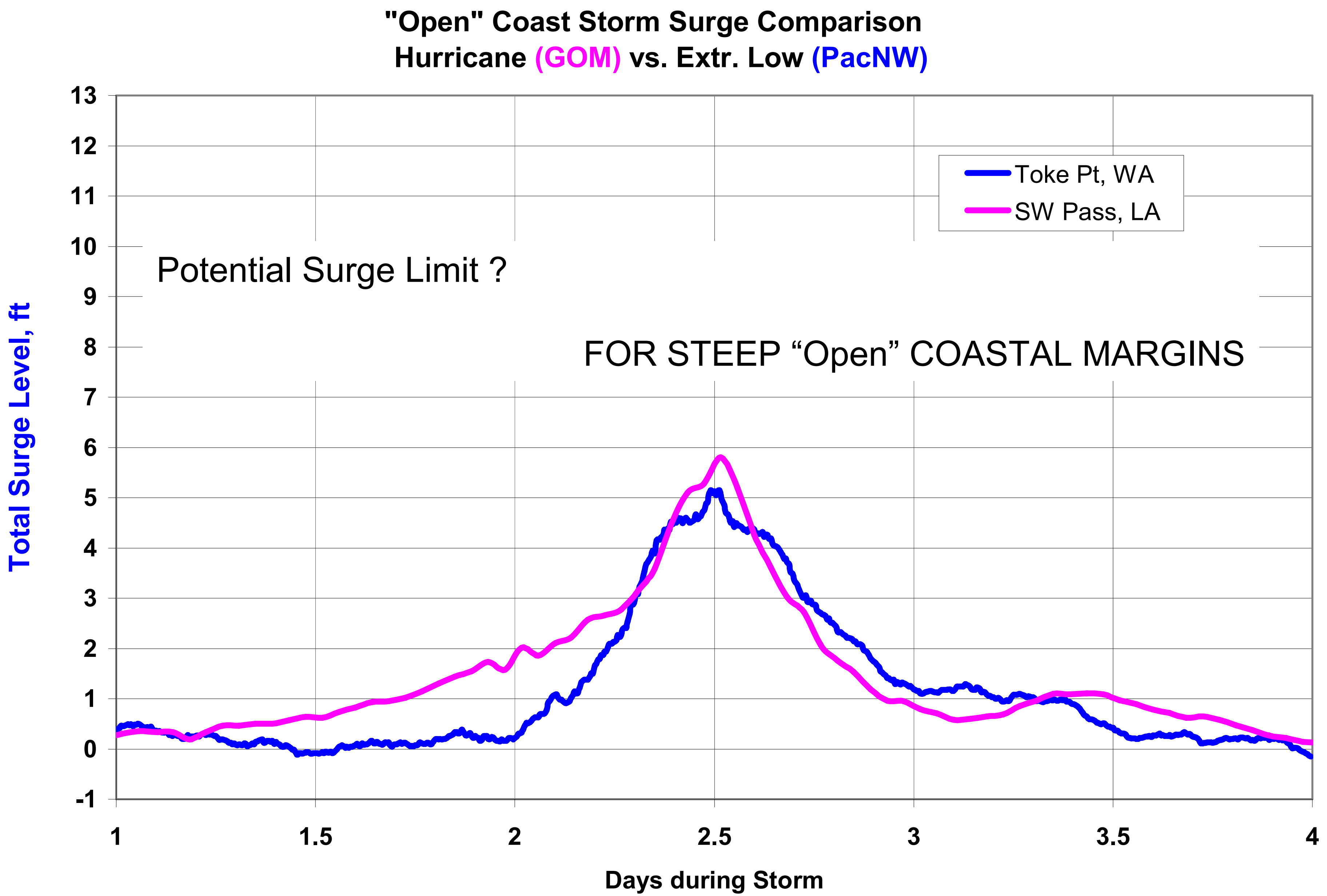
Water Level and Waves Offshore Mouth of Columbia River, OR / WA: 3 Mar 1999
Waves, 18 mi. offshore
Wave Height, m, Hsig
Wave Height, m
Days after 1 MAR 1999
0
2
4
6
8
10
12
14
16
18
1
1.5
2
2.5
3
3.5
4

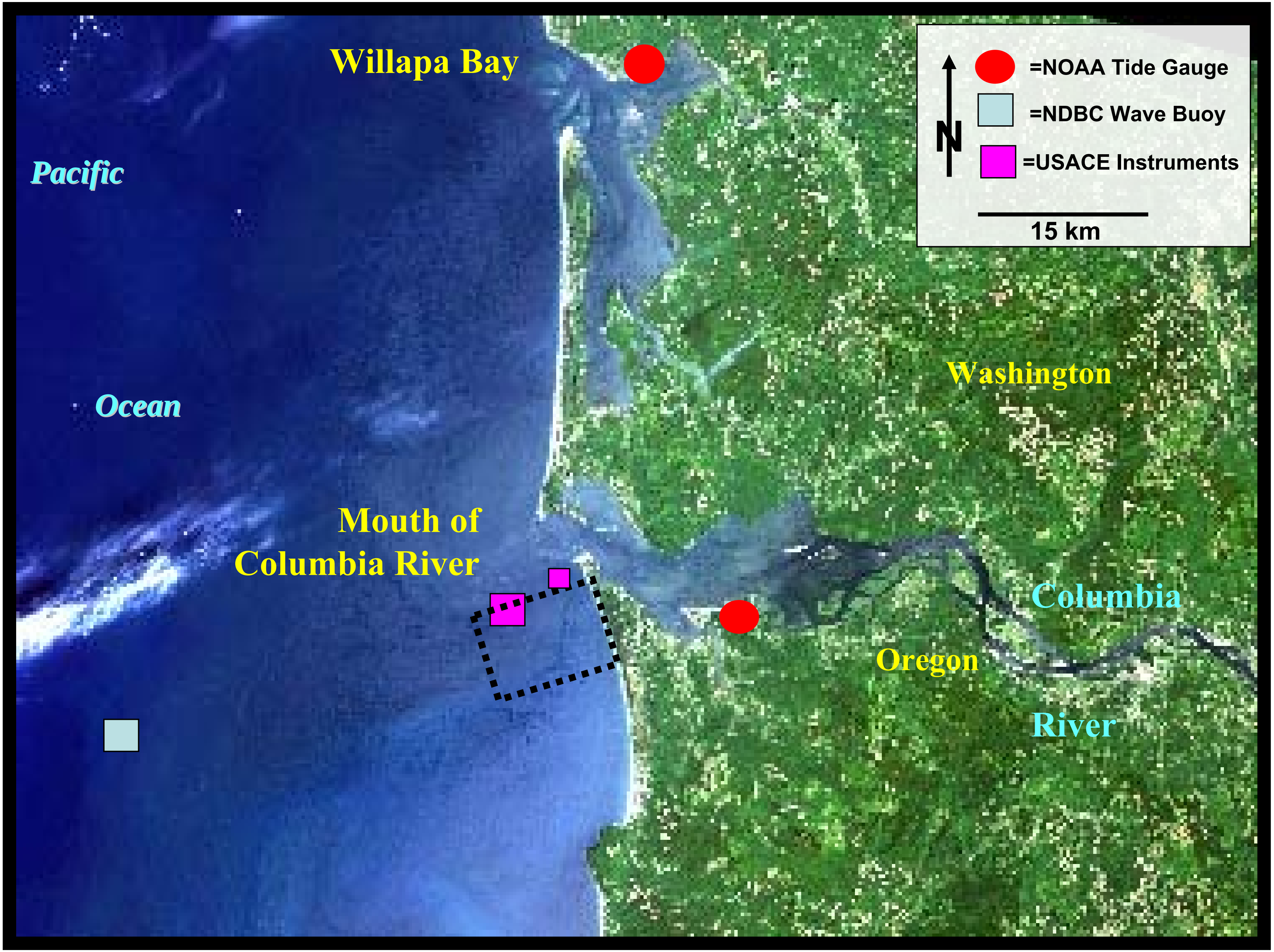


Water Level and Waves Offshore Mouth of Columbia River, OR / WA: 3 Mar 1999
Continental shelf break is 30 km offshore
Storm Surge, max=5.2 ft
Wave Height, m, Hsig
Surge (above Predicted Tide), ft
Wave Height, m
18
16
14
12
10
8
6
4
2
0
-2
1
1.5
2
2.5
3
3.5
4
Days after 1 MAR 1999

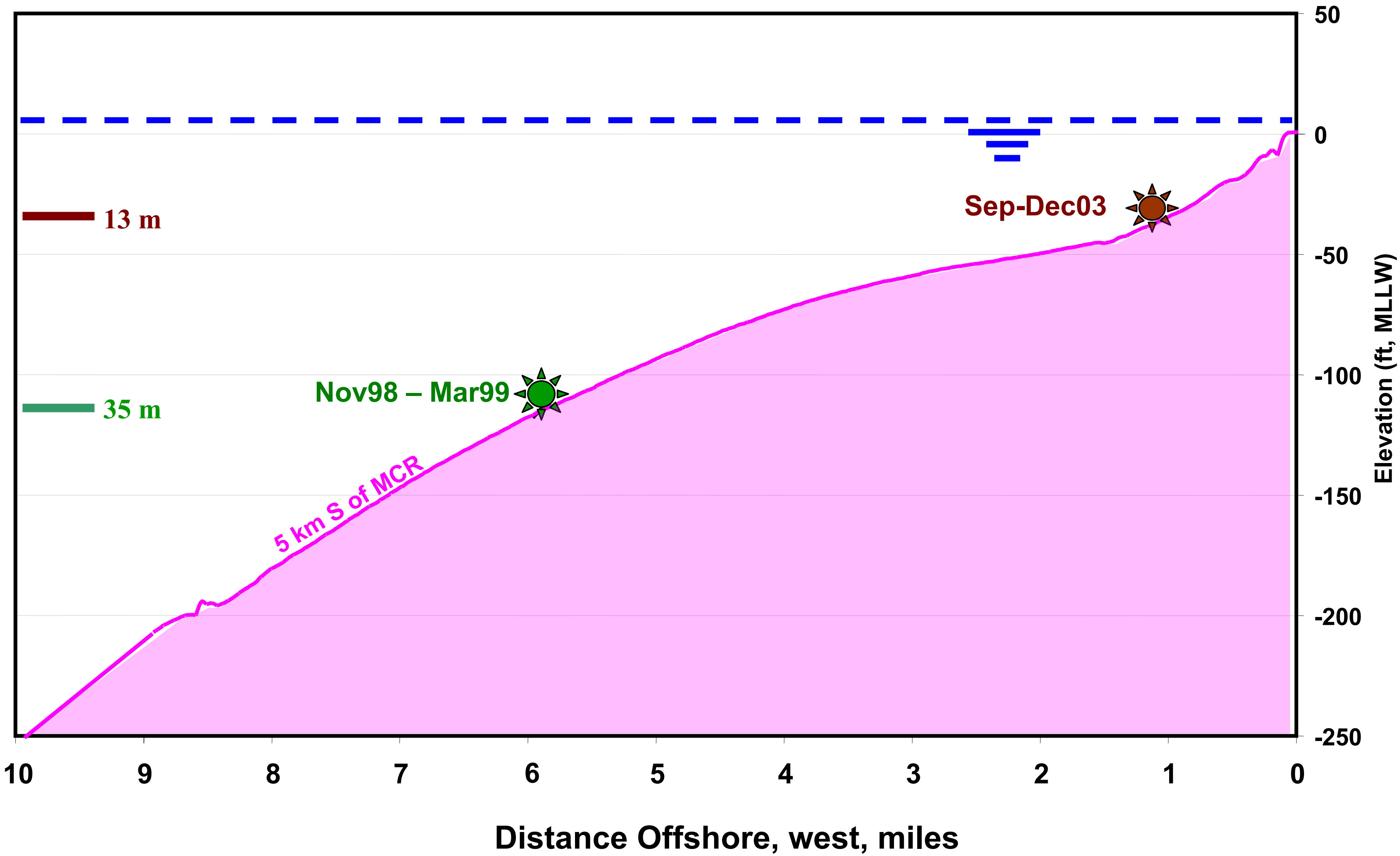
Water Level and Waves Offshore Mouth of Columbia River, OR / WA: 3 Mar 1999

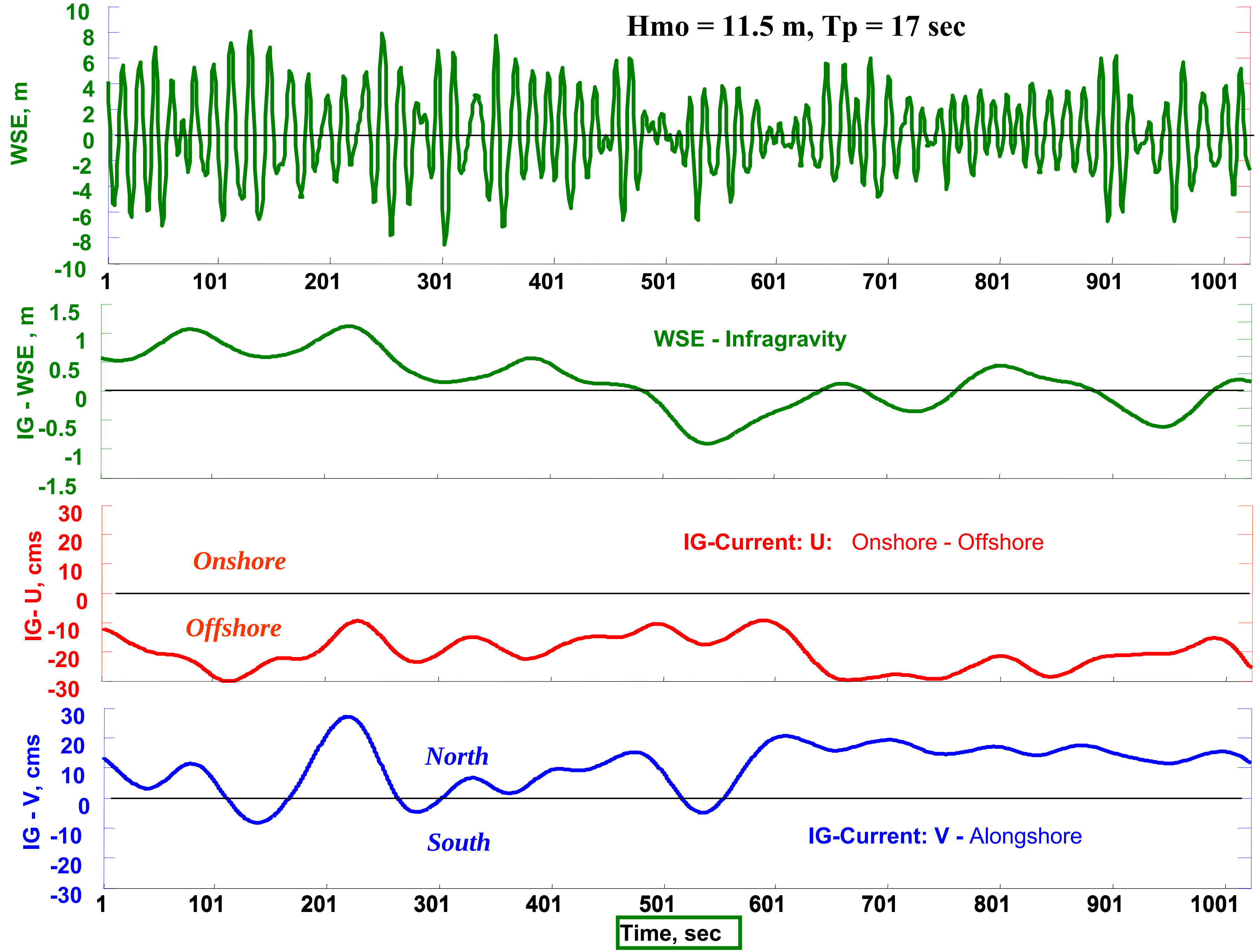



"Open" Coast Storm Surge Comparison
Hurricane (GOM) vs. Extr. Low (PacNW)
Toke Pt, WA
SW Pass, LA
Potential Surge Limit ?
FOR STEEP "Open" COASTAL MARGINS
Total Surge Level, ft
Days during Storm
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
1
1.5
2
2.5
3
3.5
4

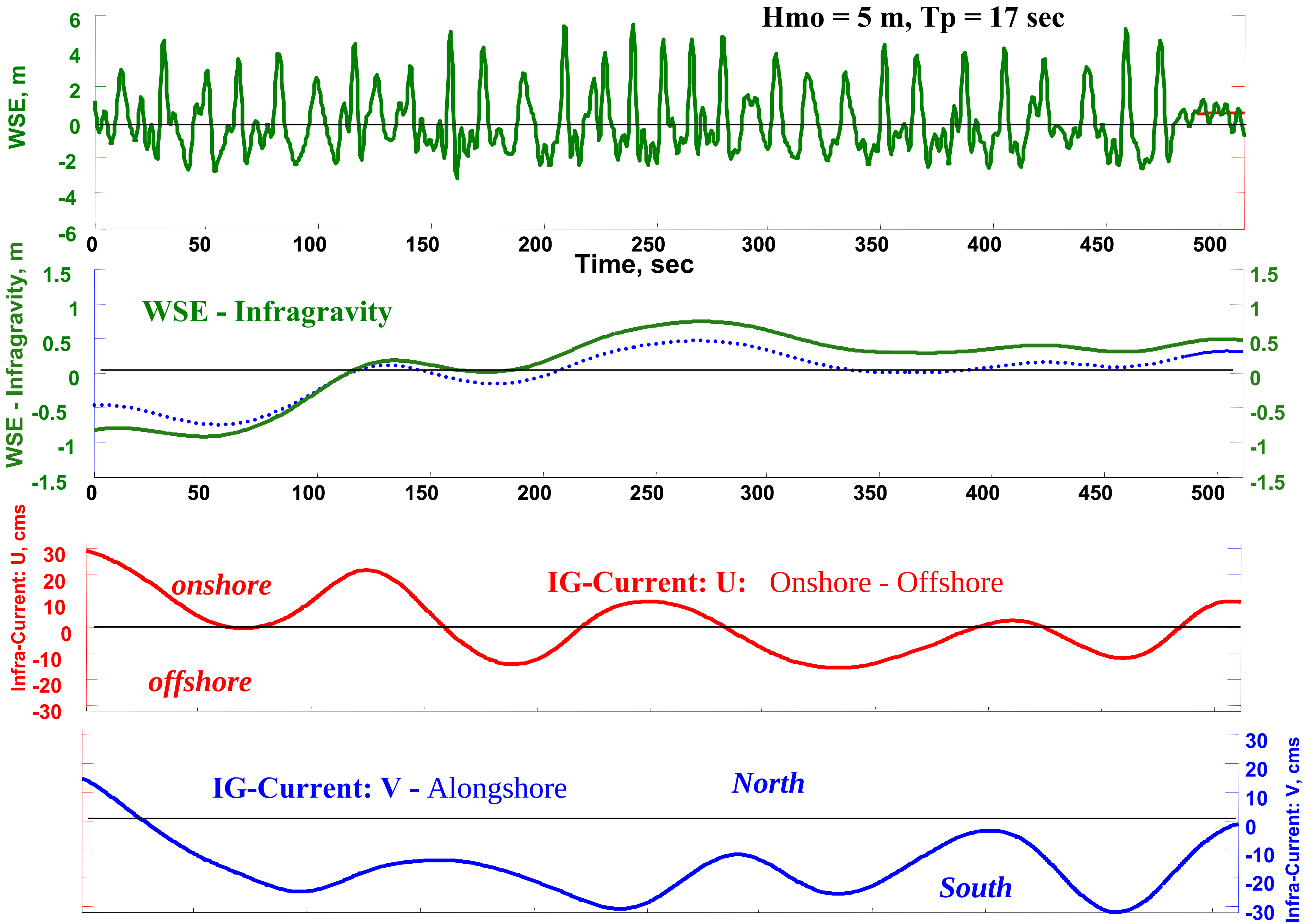

Willapa Bay
Pacific
Ocean
Mouth of
Columbia River
Washington
Oregon
Columbia
River
=NOAA Tide Gauge
=NDBC Wave Buoy
=USACE Instruments
N
15 km

Cross-Shore Profile: 5 km South of Columbia River Mouth

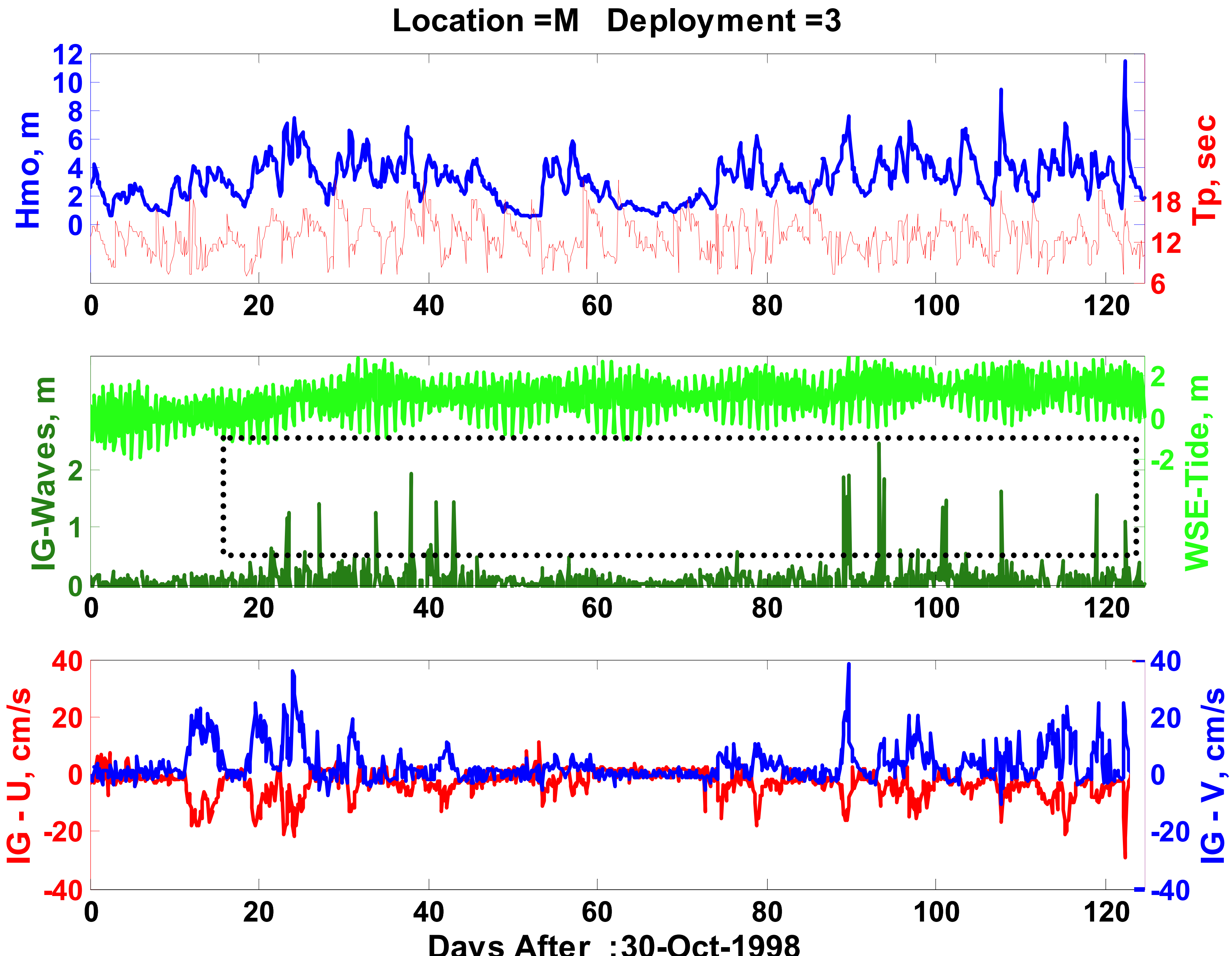




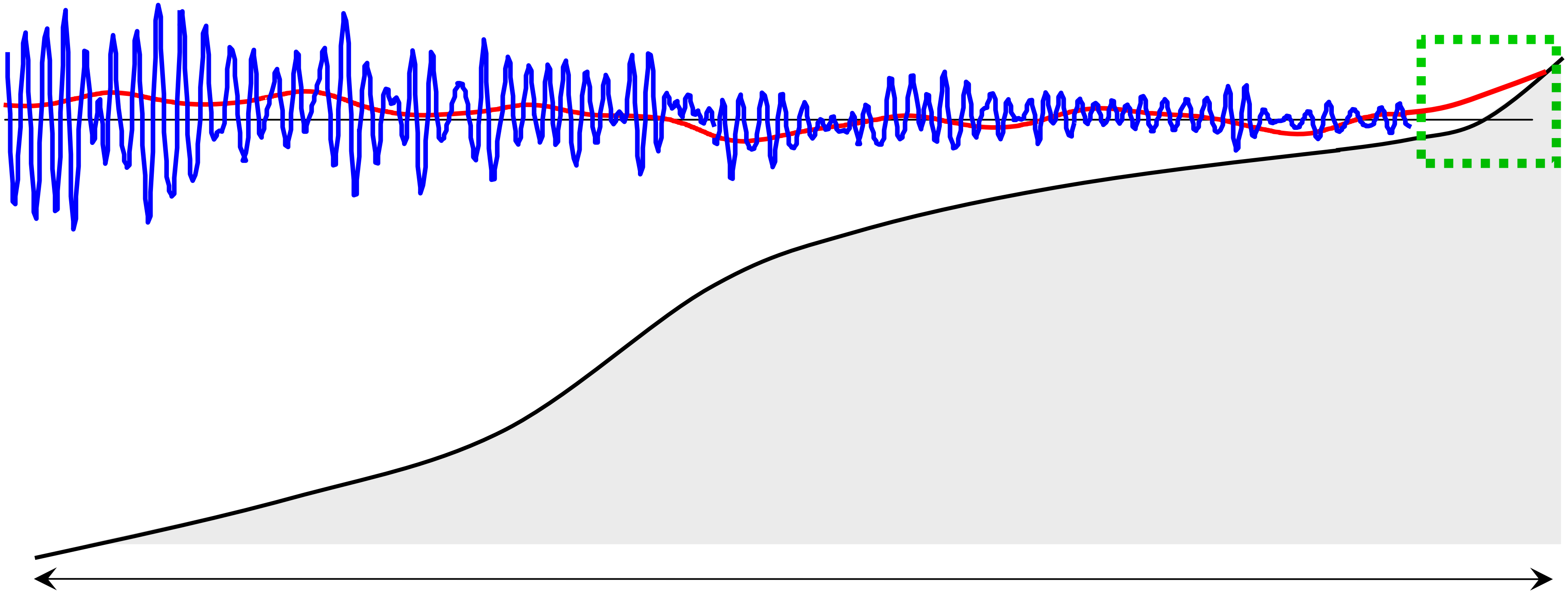
Hmo = 11.5 m, Tp = 17 sec
WSE, m
10
8
6
4
2
0
-2
-4
-6
-8
-10
1
101
201
301
401
501
601
701
801
901
1001
IG - WSE , m
1.5
1
0.5
0
-0.5
-1
-1.5
WSE - Infragravity
IG- U, cms
30
20
10
0
-10
-20
-30
Onshore
Offshore
IG-Current: U: Onshore - Offshore
IG - V, cms
30
20
10
0
-10
-20
-30
North
South
IG-Current: V - Alongshore
1
101
201
301
401
501
601
701
801
901
1001
Time, sec



Hmo = 5 m, Tp = 17 sec
WSE, m
Time, sec
WSE - Infragravity
WSE - Infragravity, m
IG-Current: U: Onshore - Offshore
onshore
offshore
Infra-Current: U, cms
IG-Current: V - Alongshore
North
South
Infra-Current: V, cms


Location =M   Deployment =3
Hmo, m
Tp, sec
IG-Waves, m
WSE-Tide, m
IG - U, cm/s
IG - V, cm/s
Days After :30-Oct-1998

Longwave (IG, η) Propagation in Nearshore and Shoreface



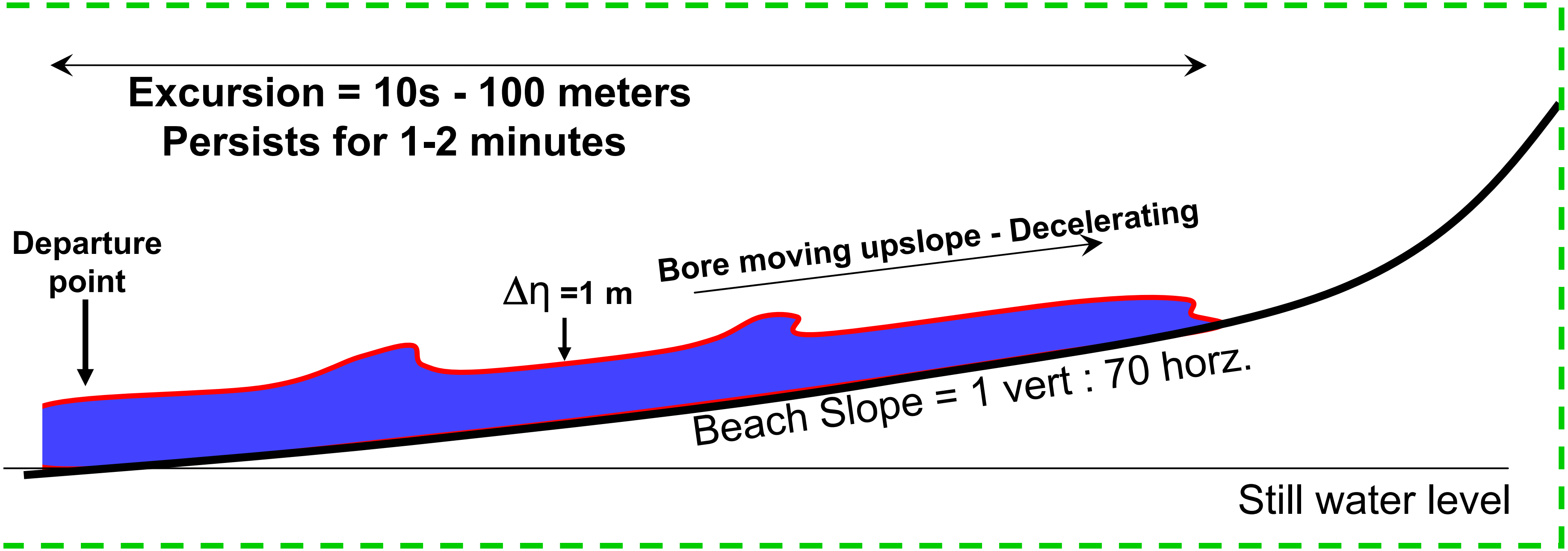
= still water level (non-storm perturbed)

= short waves (sea/swell)

= long (bound) waves - water level transients, η

Longwave Propagation, Nearshore, based on Solitary Wave behavior

Depth-limited Translation speed = $\sqrt{g \times (\text{depth} + \text{wave height})}$



Wave (Bore) Speed at "0" Still Water level – Departure point

Translation speed = $\sqrt{g \times (\text{longwave height}, \Delta\,\eta)}$

= 3 m/sec…….. for $\Delta\eta$ = 1 m

SNEAKER WAVES
An "Unpredictable" Occurrence along the Coastal Margin

Along the Pacific NW coast of the US, several people each year succumb to "sneaker waves"…….

Appear to be associated with transient water levels (Δ η) produced by groups of large waves.

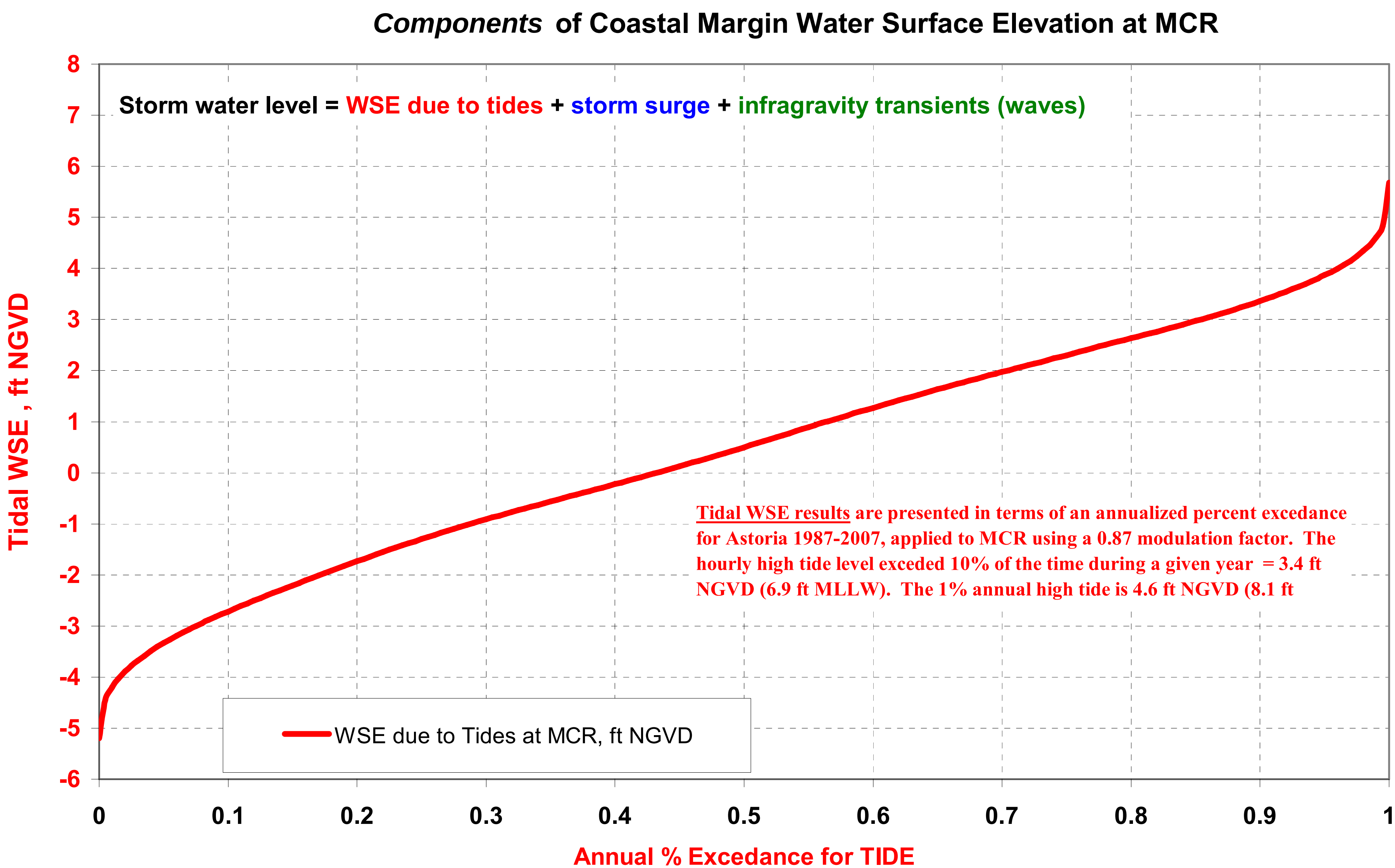
Landward Speed = 2-4 m/sec

Bore height = 0.3 – 1.5 m

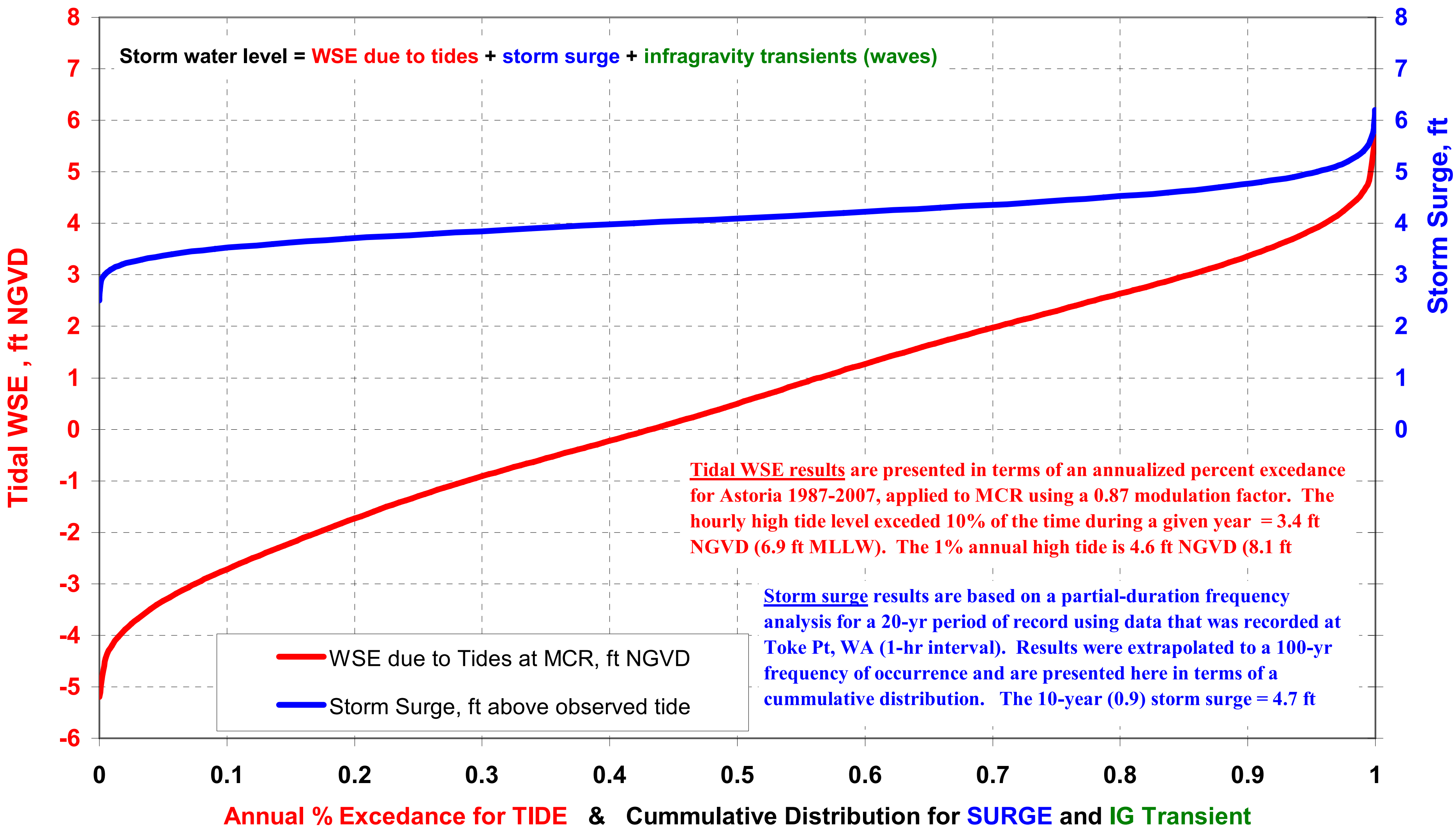
Duration = 1-2 minutes

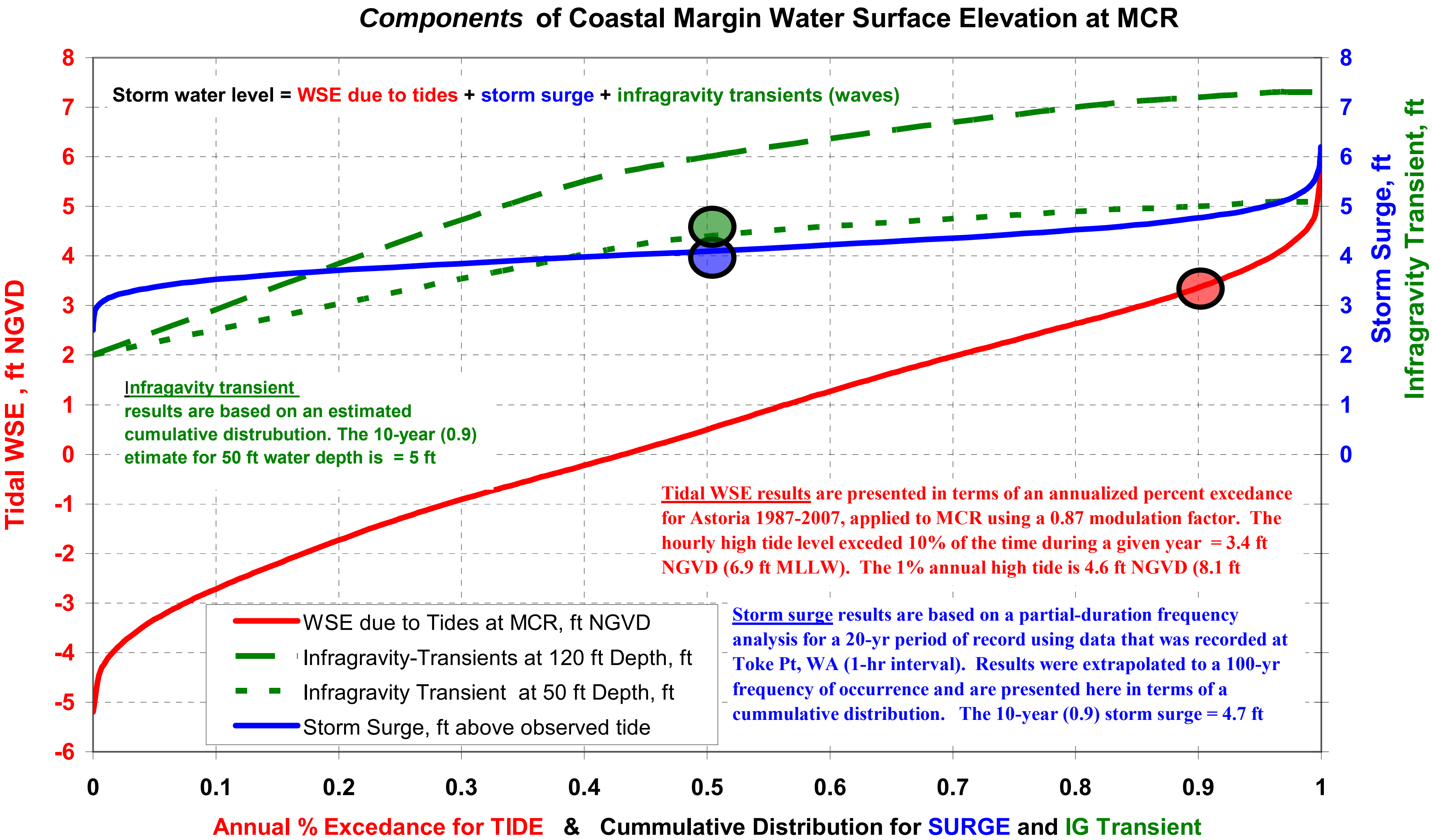
Excursion Distance = 10-100 meters

Return Flow more dangerous than run-up


Components of Coastal Margin Water Surface Elevation at MCR
Storm water level = WSE due to tides + storm surge + infragravity transients (waves)
Tidal WSE, ft NGVD
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Annual % Excedance for TIDE
WSE due to Tides at MCR, ft NGVD
Tidal WSE results are presented in terms of an annualized percent excedance for Astoria 1987-2007, applied to MCR using a 0.87 modulation factor. The hourly high tide level exceded 10% of the time during a given year = 3.4 ft NGVD (6.9 ft MLLW). The 1% annual high tide is 4.6 ft NGVD (8.1 ft

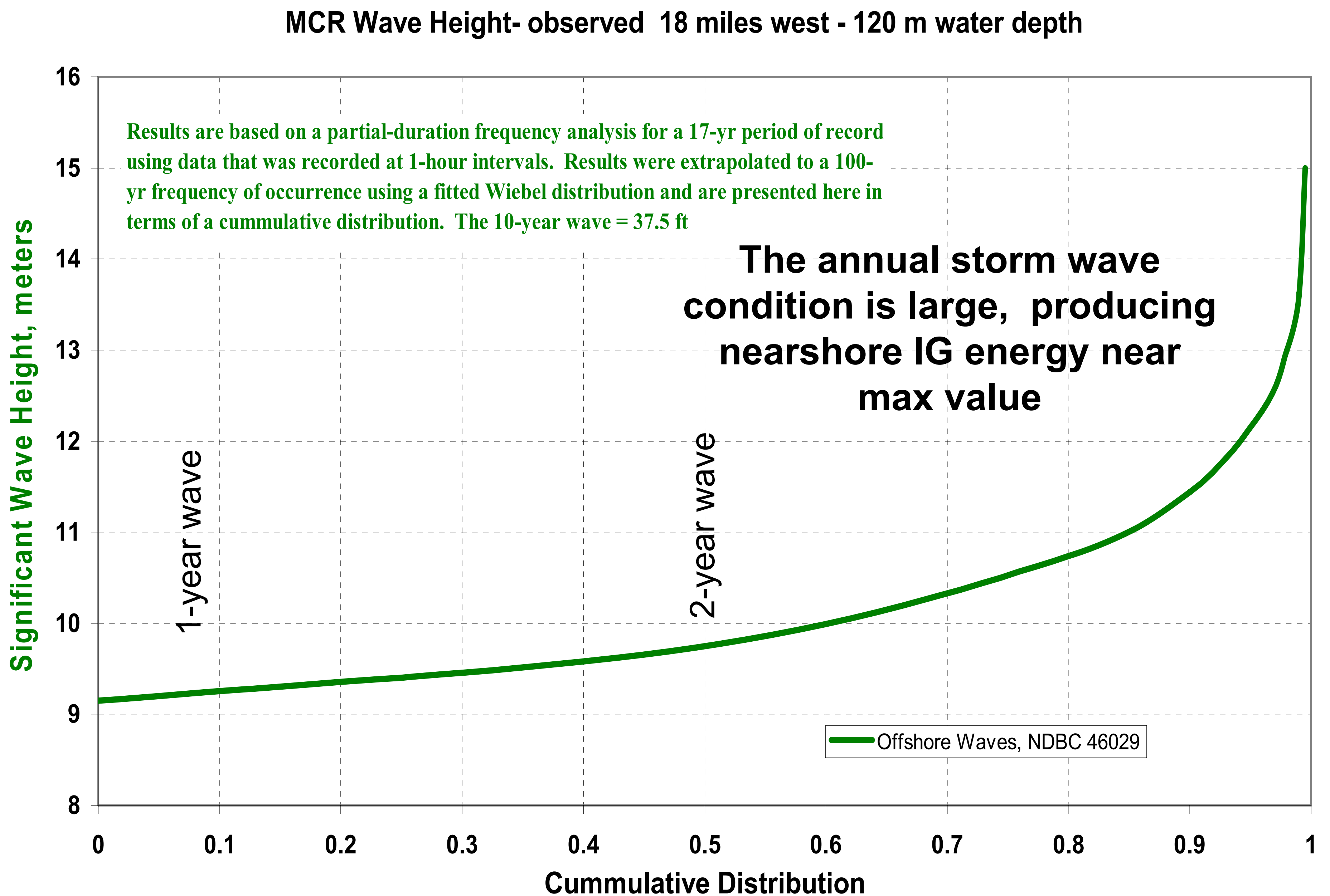
Components **of Coastal Margin Water Surface Elevation at MCR**





2- yr Storm water level, inshore of 50 ft depth **= 3.4 + 4 + 4.5 = 11.9 ft NGVD**

Why is there a lack of variation in storm surge and IG Transient



MCR Wave Height- observed 18 miles west - 120 m water depth
Results are based on a partial-duration frequency analysis for a 17-yr period of record using data that was recorded at 1-hour intervals. Results were extrapolated to a 100-yr frequency of occurrence using a fitted Wiebel distribution and are presented here in terms of a cummulative distribution. The 10-year wave = 37.5 ft
The annual storm wave condition is large, producing nearshore IG energy near max value
1-year wave
2-year wave
Offshore Waves, NDBC 46029
Significant Wave Height, meters
Cummulative Distribution
16
15
14
13
12
11
10
9
8
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Modulation of Water Surface Elevation (Δη, O-min)

–Can temporarily increase nearshore water depth

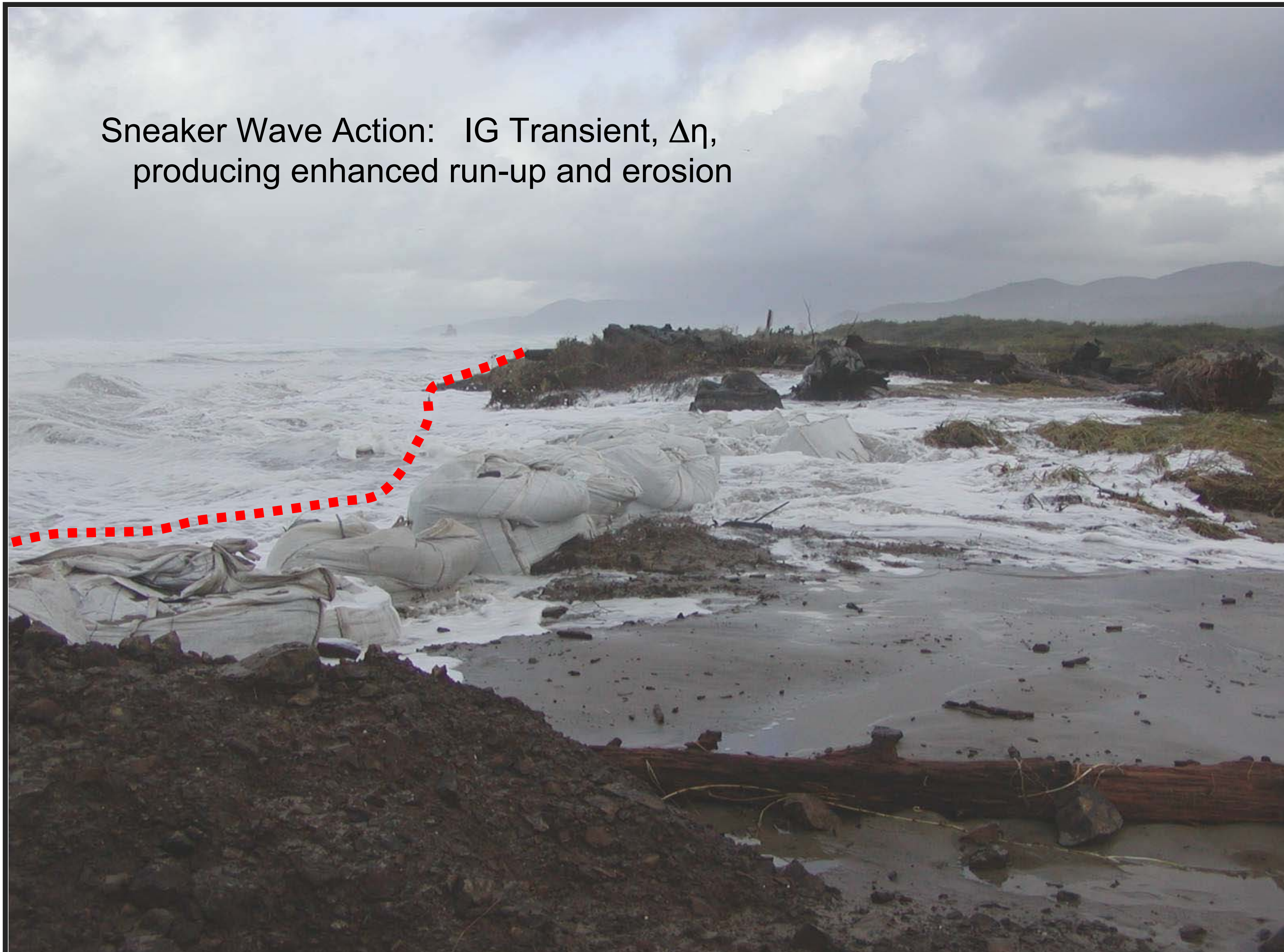
Allowing Larger Waves to attack infrastructure

Columbia River Bar Pilots Photo

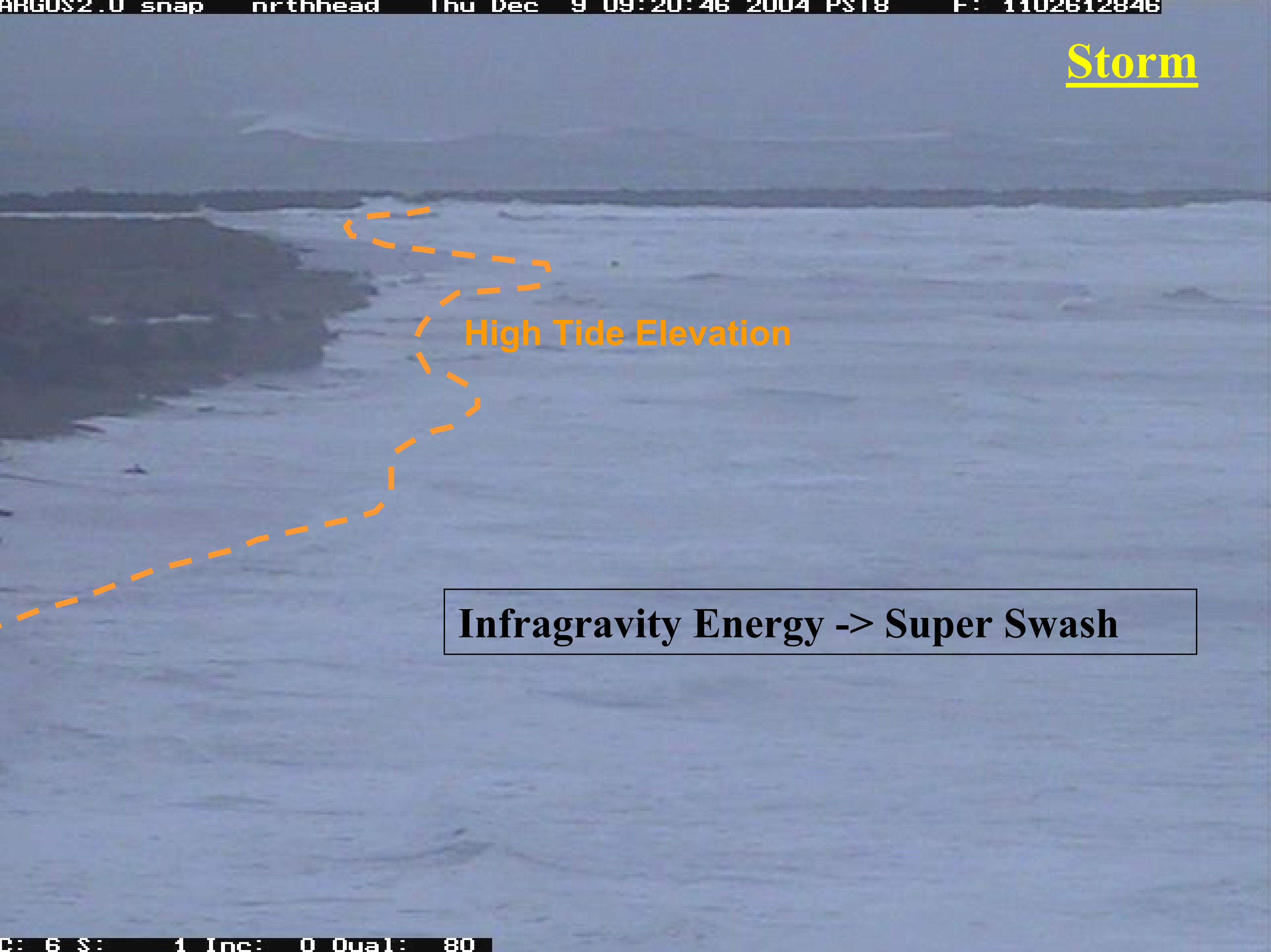
Effect of Transient Water Level, $\Delta\eta$, when Wave Height (H) is depth-limited

$\Delta\eta$ has taken the role of ΔH in the following performance functions

Type of Loading Condition or Hazard Scenario Affected by a Transient Water Level ($\Delta\eta$)	Performance Function for Coastal Infrastructure Loading Increase or Coastal Zone Hazard
Conventional Structures (rigid)	
-- Static Loading (hydrostatic)	$(\Delta\eta)^{2}$
-- Dynamic Loading (wave action)	$(\Delta\eta)^{2}$
-- Overtopping/Interior Protection (waves)	$(\Delta\eta)^{1.5} \times \exp^{-(\text{crest elevation} - (\text{TWSE} + \Delta\eta))}$
Compliant Structures (rubblemound)	
-- Direct Wave Action (armor unit stability)	$(\Delta\eta)^{3}$
-- Lee-side Wave Action (armor unit stability)	$(\Delta\eta)^{3} \times \exp^{-(\text{crest elevation} - (\text{TWSE} + \Delta\eta))}$
Nearshore and Structure Foundation Stability	
-- Sediment Transport Potential (seabed erosion)	$(\Delta\mathbf{u})^{2.x} + (\Delta\eta)^{1.x}$
Wave Run – Up on Shoreface	
-- Run-up Distance	$2\,\Delta\eta \times$ beach slope
-- Run-up Speed	$(2\,\Delta\eta)^{1/2}$
-- Run-up Depth (water depth increase before $\Delta\eta$)	$2\,\Delta\eta$


Sneaker Wave Action: IG Transient, Δη,
producing enhanced run-up and erosion


ARGUS2.0 snap nrthhead Wed Sep 1 08:20:47 2004 PST8 F: 1094055647
North Jetty, 25 ft high
High Tide Elevation
C: 6 S: 1 Inc: 0 Qual: 80


ARGUS2.0 snap nrthhead Thu Dec 9 09:20:46 2004 PST8 F: 1102612846
Storm
High Tide Elevation
Infragravity Energy -> Super Swash
C: 6 S: 1 Inc: 0 Qual: 80

Transient Water Level at the Shoreface

Normal Condition

Storm Condition

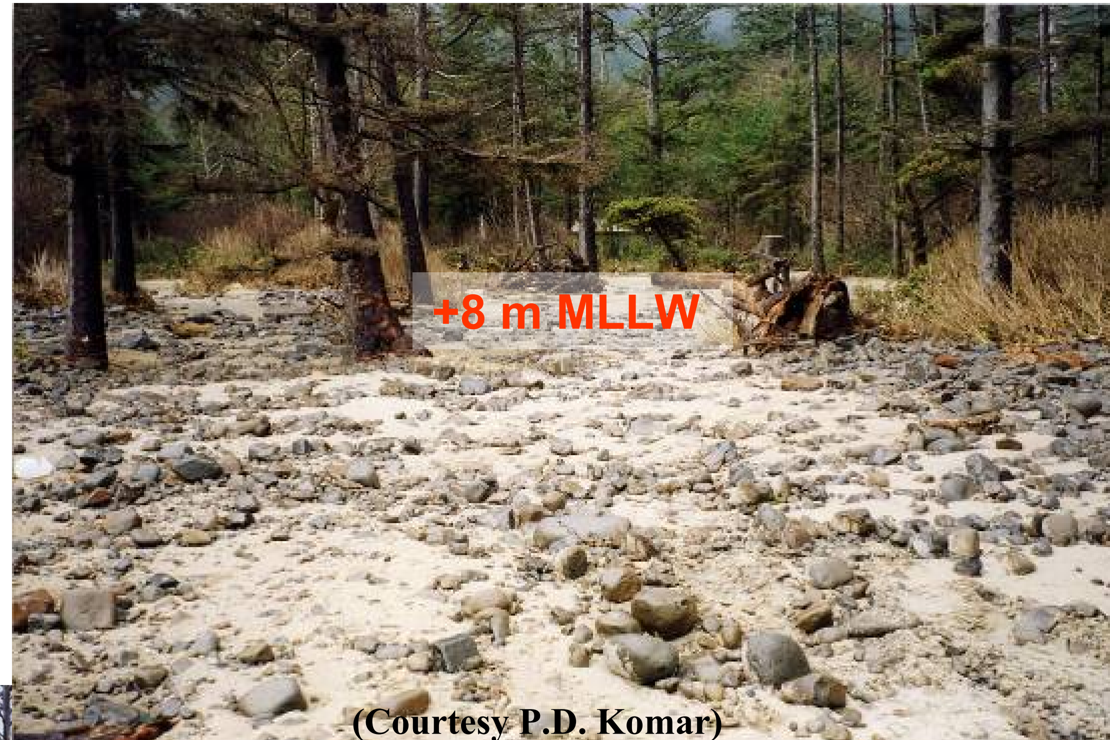

Infragravity Bore produced a 0.5 m Water Level Transient, Δη

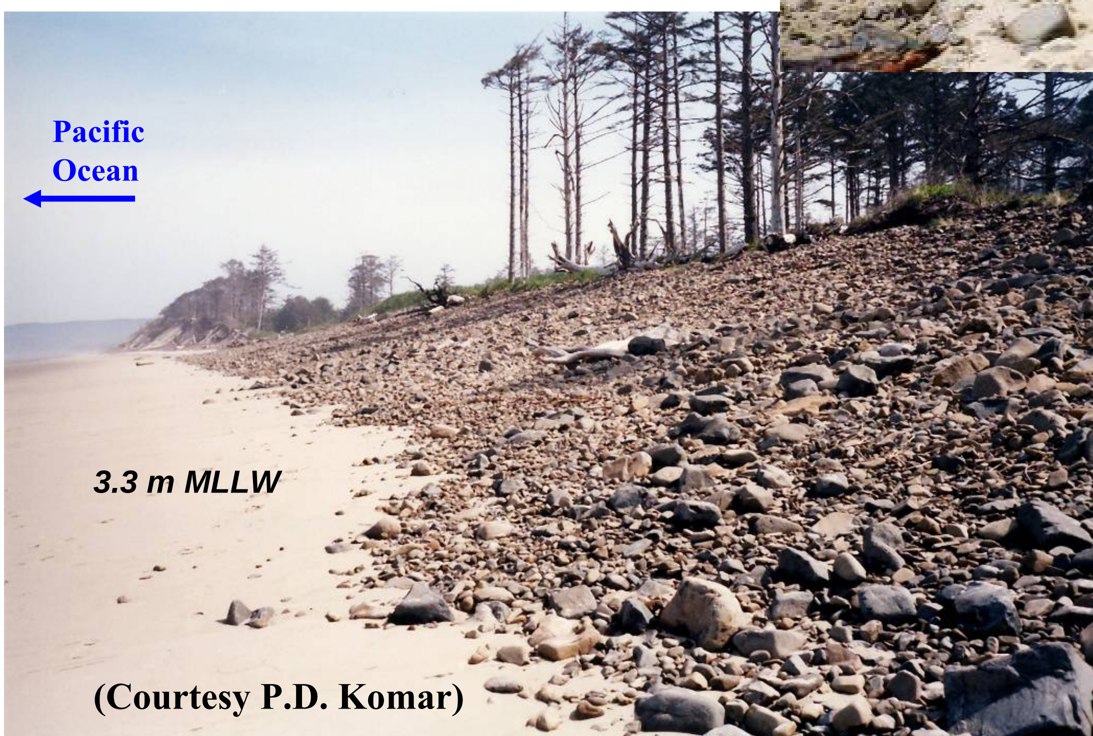
Jetty Root Erosion produced by wave Overtopping

Made possible by a transient increase in water level

Result of Dune being Overtopped by at least 1 meter over dune crest

+ 8.5 m MLLW = Overtopping El.

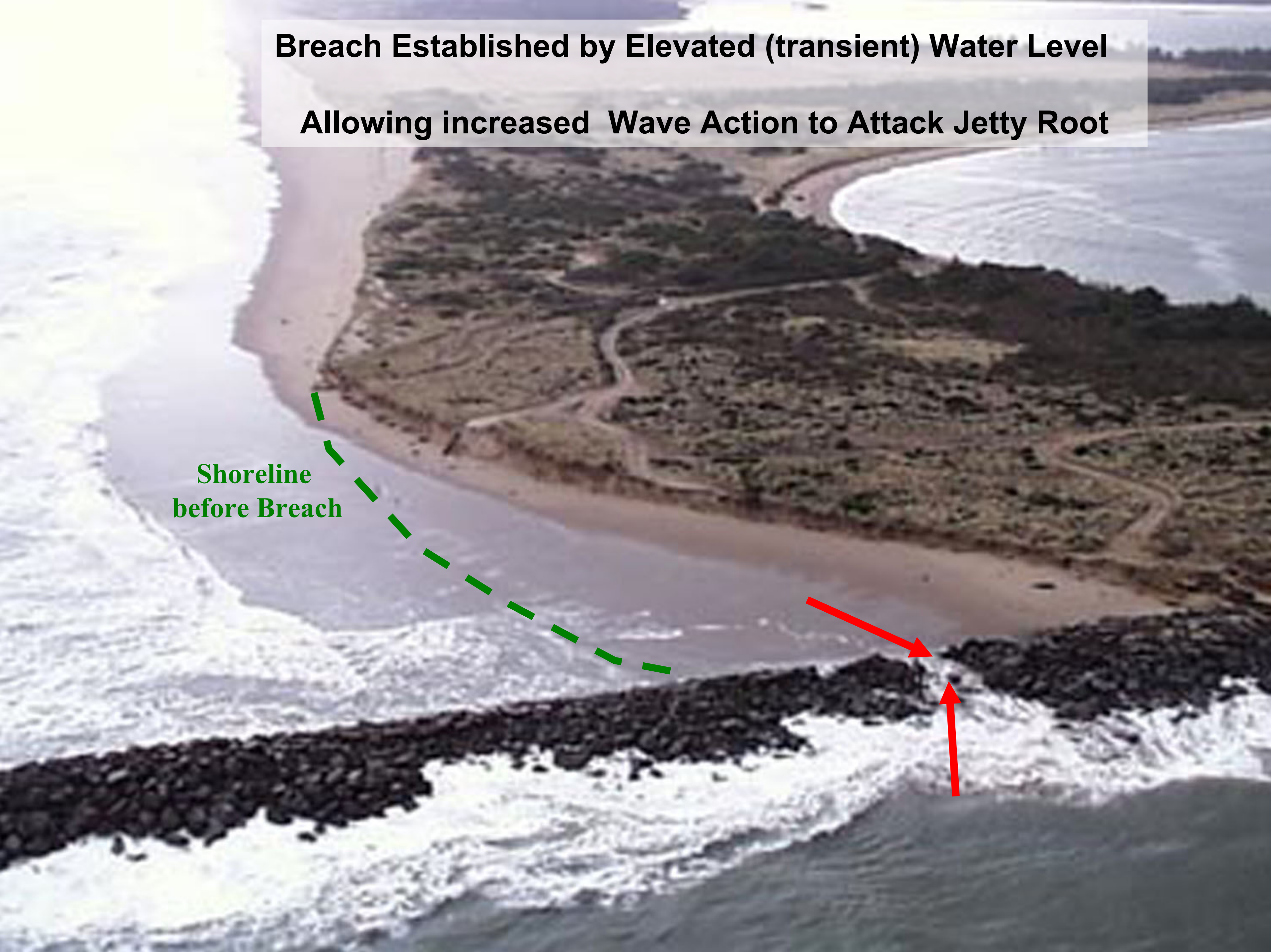




Top of Dune ≈ +7.6 m MLLW

Static Storm Surge Water Level = +4.3 m MLLW

Post MAR99


Breach Established by Elevated (transient) Water Level
Allowing increased Wave Action to Attack Jetty Root
Shoreline before Breach

Levee being overtopped by short waves propagating on top of storm surge during Hurricane Katrina landfall. The degree of overtopping is considerable.

Under such conditions, infrastructure behind the level can be damaged or incapacitated.

This level of overtopping can lead to catastrophic failure of coastal flood protection.

Hypothesis:
Storm Surge Is Affected by Infragravity Transients ($\Delta\eta$)

A component of storm surge evolves as a series of landward propagating longwaves ($\Delta\eta$), which introduce water and momentum into the nearshore.

Each successive longwave transient ($\Delta\eta$) is superimposing additional water/momentum on the previous surge transient.

As the water level increases, depth limited storm waves ride on top of the long waves to add destructive power to the storm surge event.

If an efficient path (conveyance) for return flow can not be established, the water level (surge) will increase unit conveyance is established such that added shoreward momentum (vol flux) = return flow

Verify: 1) By Review of Surge Event Photography.
2) Apply Bouss-2D Model, forced by Infragravity BC

Arrival of Hurricane Katrina storm surge,
as it came over US Hwy 90 at Gulfport, MS approximately two hours before storm peak made landfall.

Surge propagating landward in terms of individual bores, long wave transients ($\Delta\eta$), with shortwaves traveling on top

Photography provided by Mike Theiss – UlitmateChase.com

Hurricane Katrina storm surge @ Gulfport Beachfront Hotel during storm landfall at Gulfport, MS.

The surge arrived at the hotel location in terms of long wave pulses, with short waves traveling on top of the long wave transients ($\Delta\eta$).

The level of the water outside of the hotel is 2-3 ft higher than inside the hotel due to surge transients, $\Delta\eta$.

An eyewitness account: **"I suddenly envisioned what a tsunami must look like, and realized that I was in a situation similar to that. I watched as the waves were coming in from the Gulf of Mexico.**

They were very long, two-to-three foot tall waves that didn't crash, but just moved in--the classic storm surge".

Eyewitness testimony and photography provided by ***Mike Theiss – UlitmateChase.com***

Before and during a storm surge event at Port Hedland, Australia, 1939

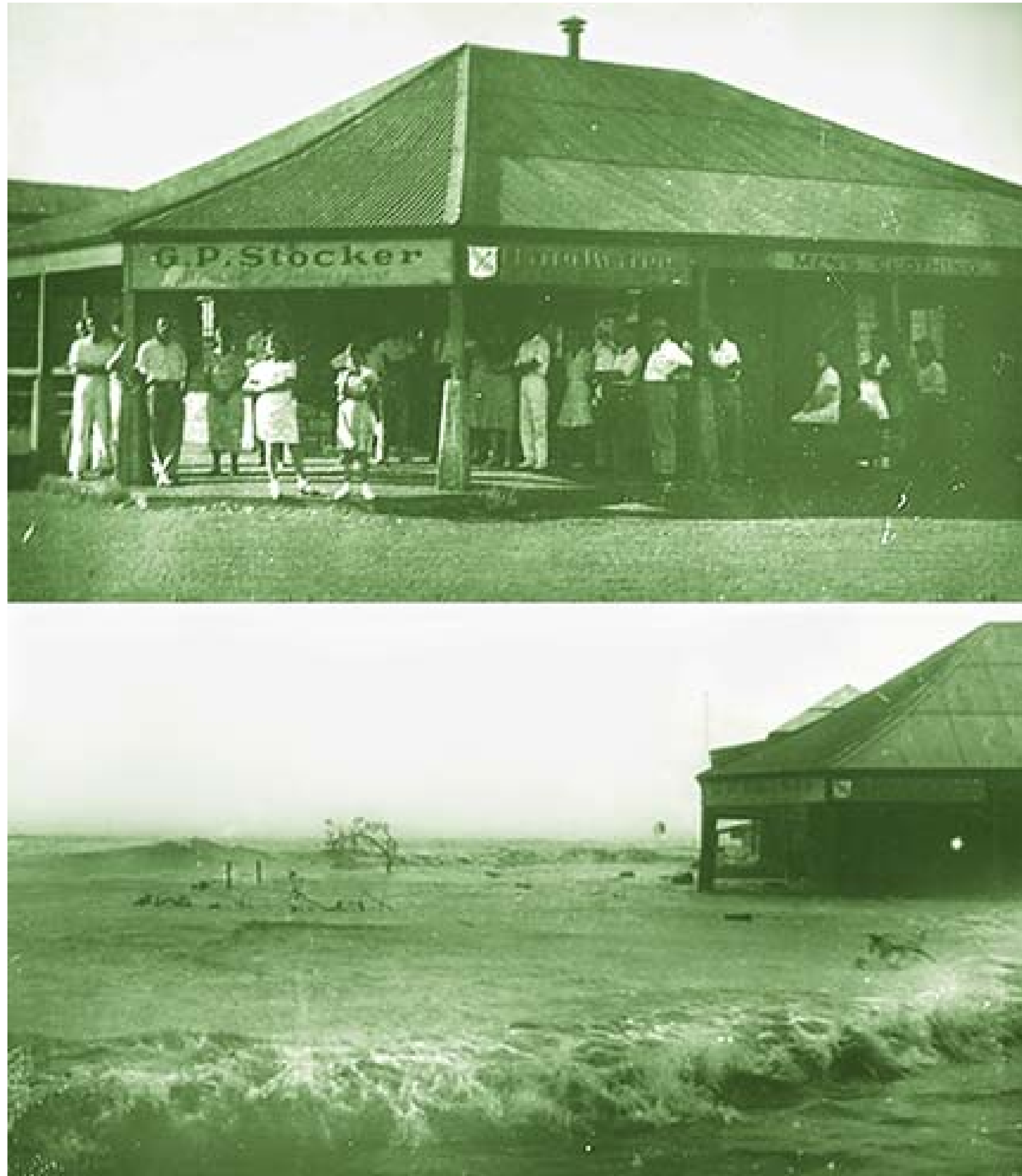


Photo courtesy of Australia Bureau of Meteorology

Bouss-2D Patch Test

BOUSS-2D is a comprehensive numerical model based on time-domain solution of Boussinesq-type equations.

The fully non-linear equations are solved through the surf zone to allow evaluation of wave shoaling-diffraction-bottom friction-breaking, wave-wave interaction, and generation-dissipation of IG motion.

The model was applied using a nearshore domain for an area 5 km south of MCR

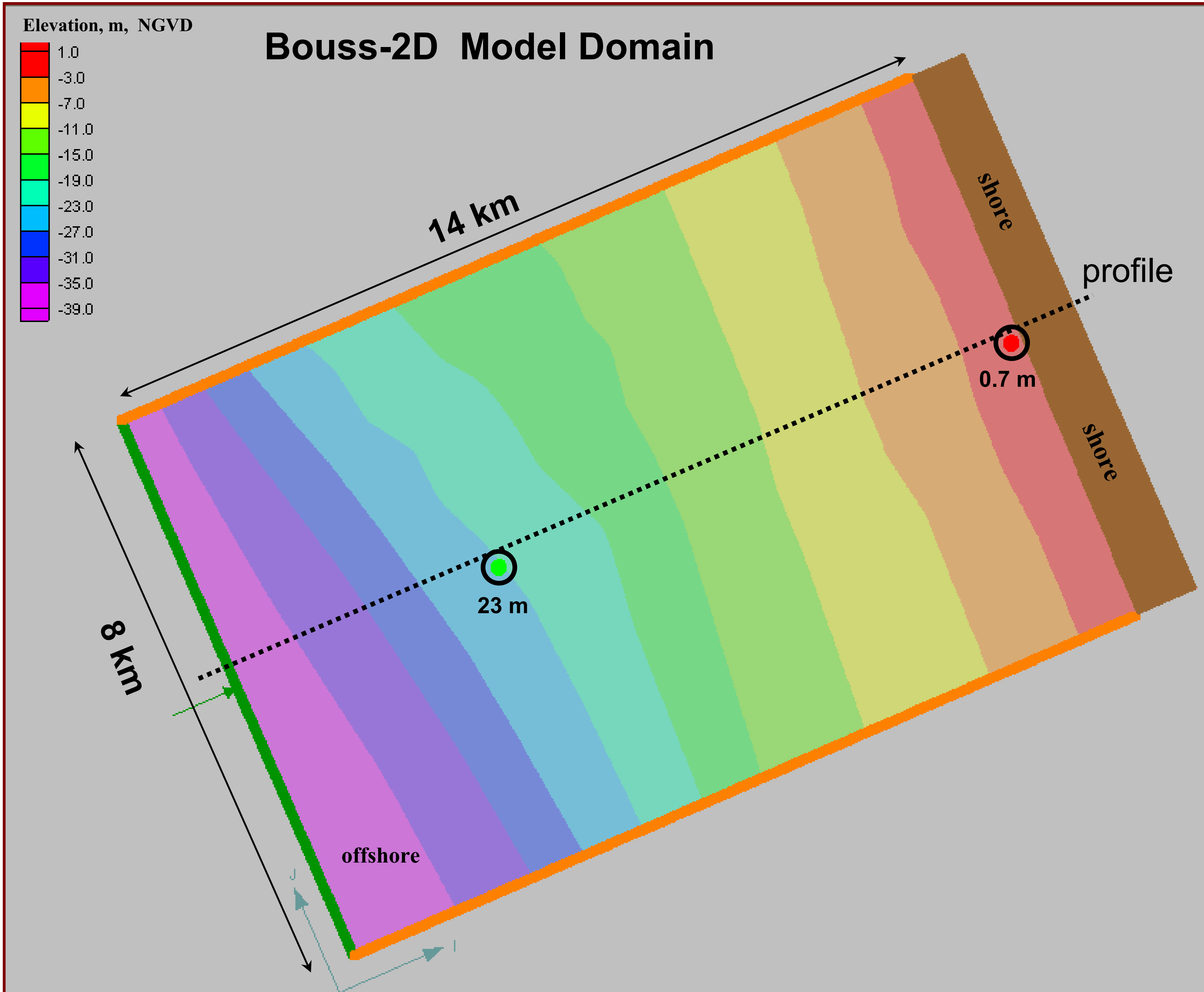
The model domain covered an area of 14 km (onshore-offshore) x 8 km (alongshore).

Water depth within the model domain varied between -38 m (below NGVD) at the offshore boundary to 6 m (above NGVD) at the shore. The domain was descretized using 20x20 m cells.

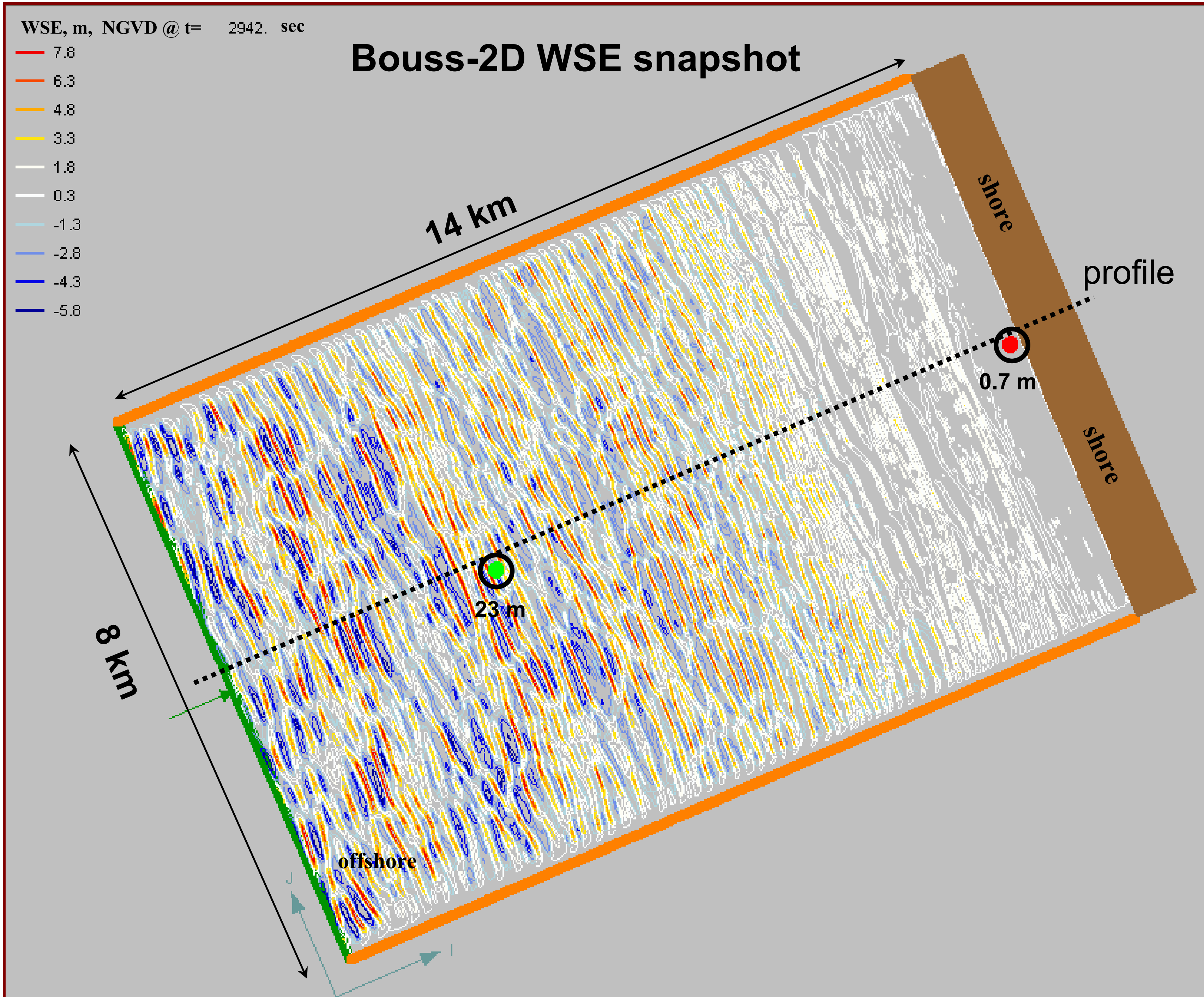
The storm wave-field simulated within the domain was generated using a irregular multi-directional bi-modal spectrum (Ochi-Hubble, Tp1 = 160 sec, Hs1=2 m, nn1=2, Tp2 = 17 sec, Hs1=12.3 m, nn2=3).

Tp1 was implemented based on the observations of long wave energy at MCR in water depth 35 m

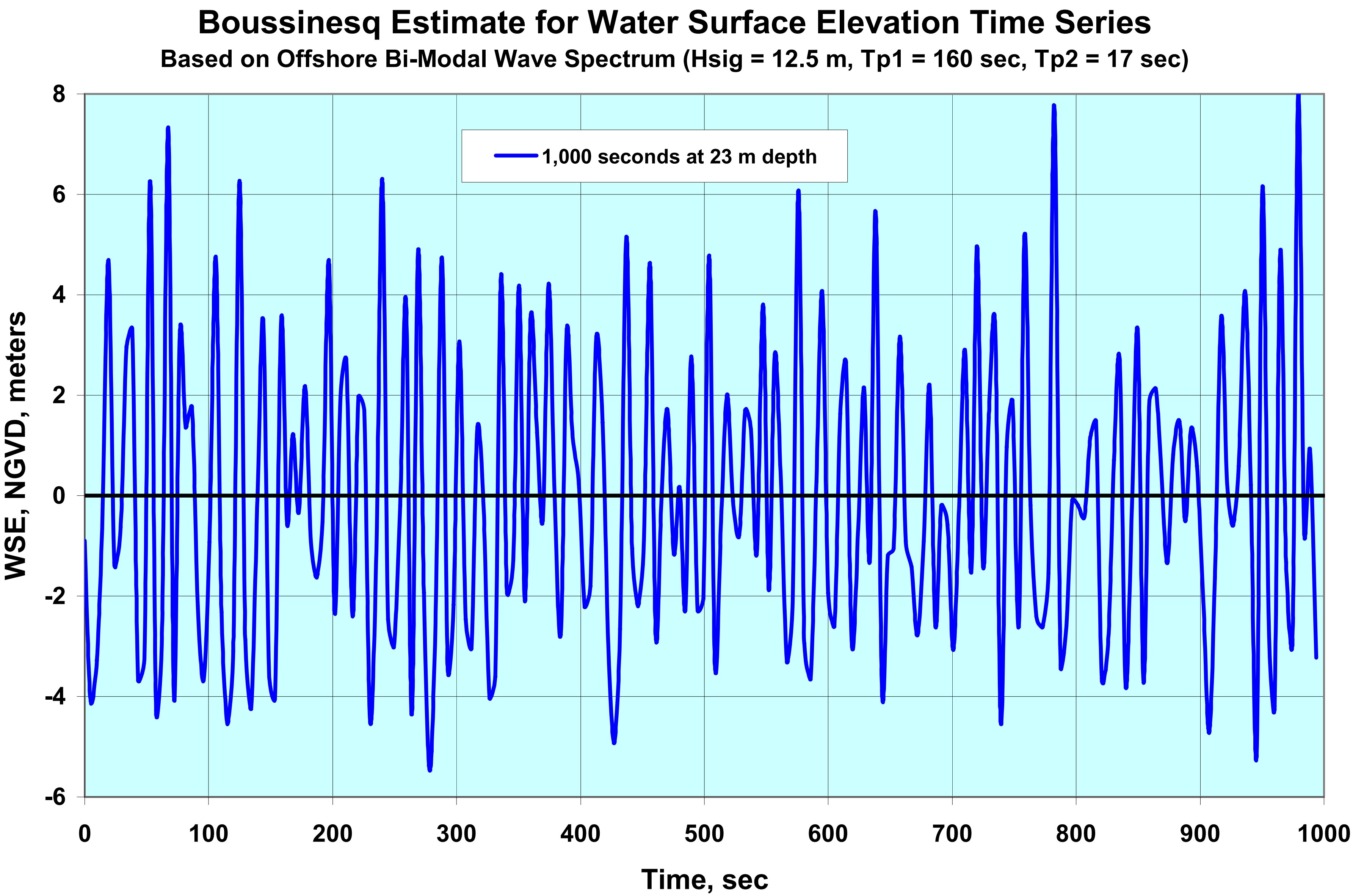
The model was run for 3,000 s using a 0.4 sec time step. Output was obtained during t=2,000-3,000 sec.

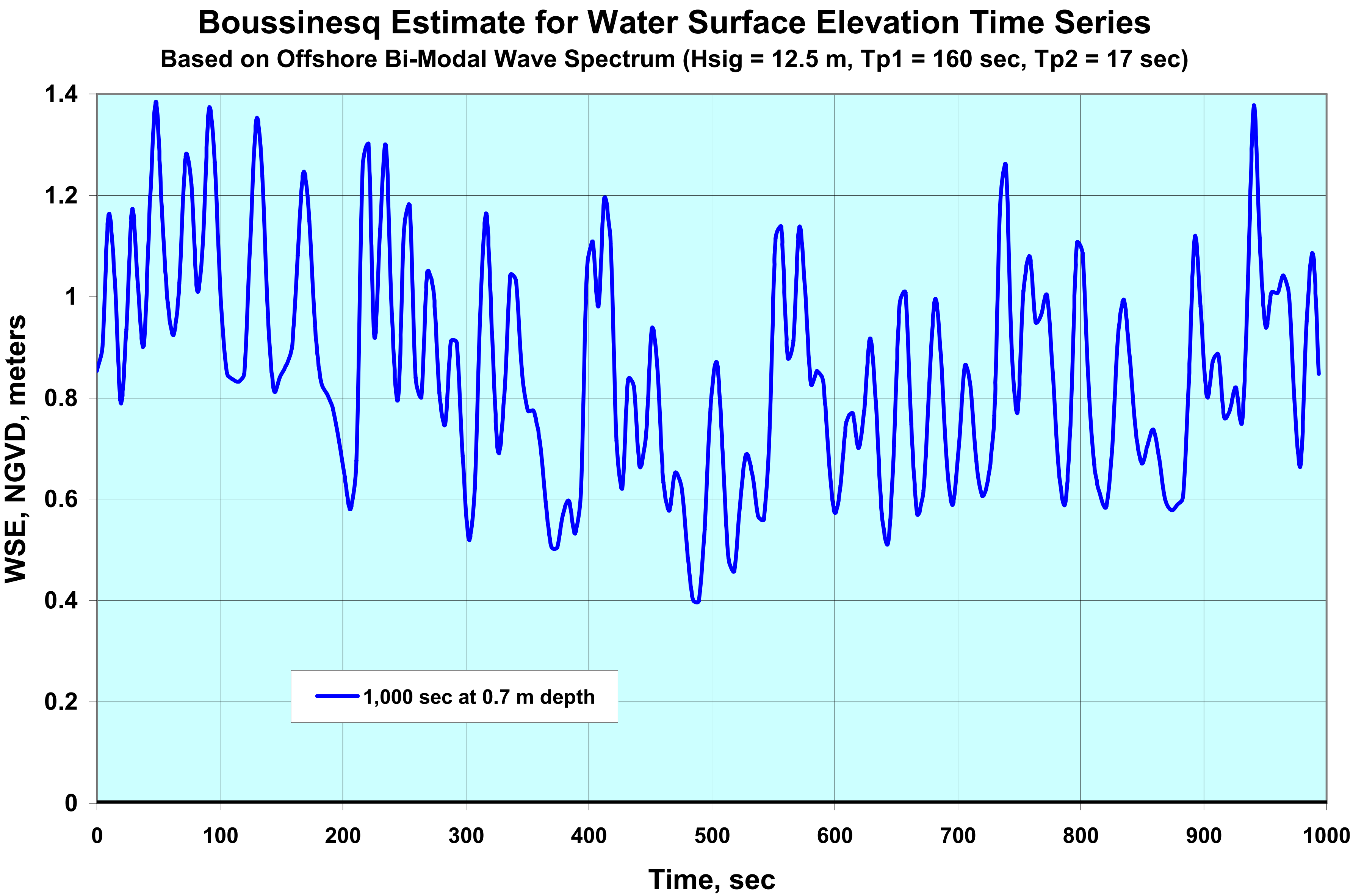


Bouss-2D Model Domain
Elevation, m, NGVD
1.0
-3.0
-7.0
-11.0
-15.0
-19.0
-23.0
-27.0
-31.0
-35.0
-39.0
14 km
8 km
shore
shore
profile
0.7 m
23 m
offshore
J
I

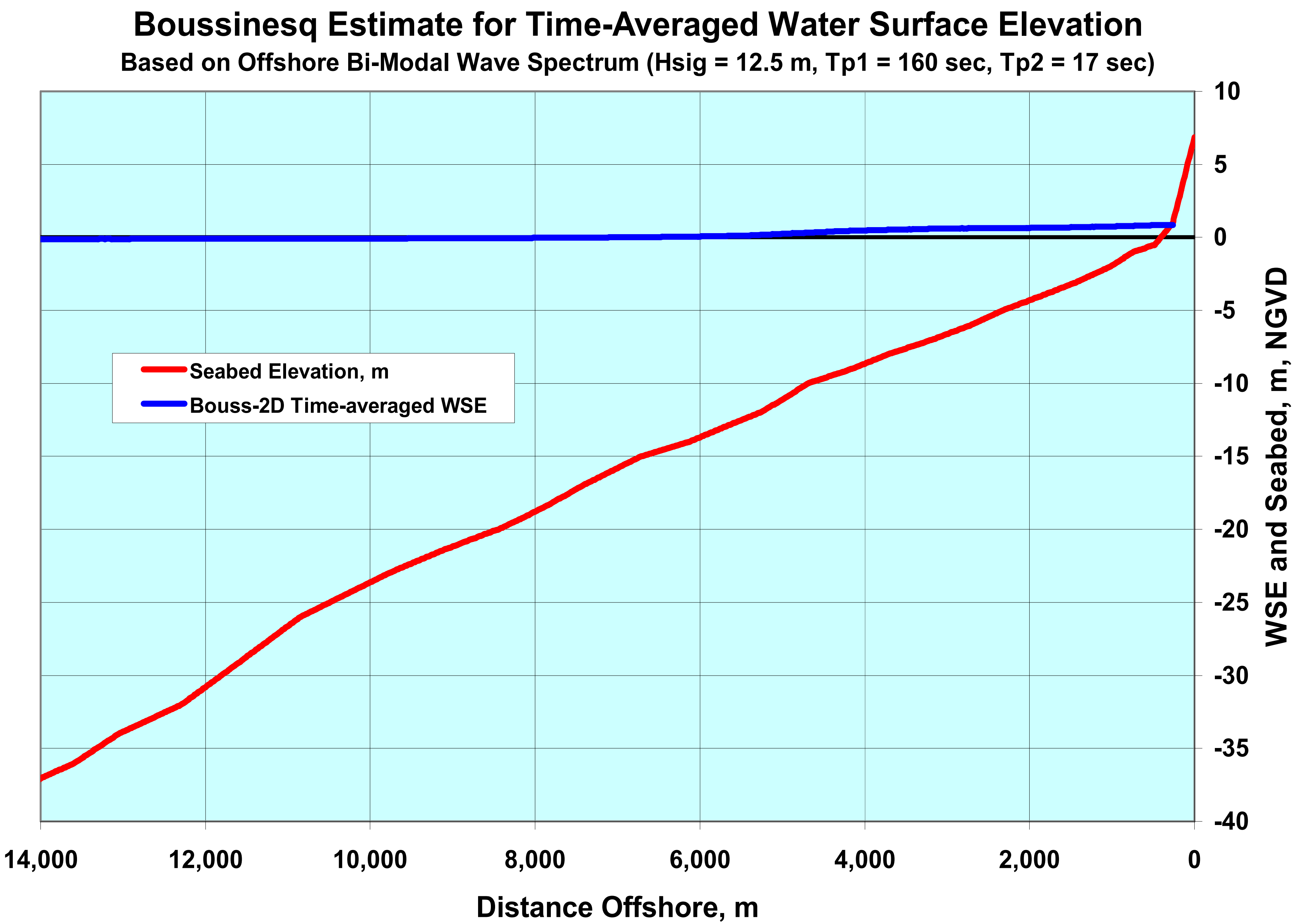


WSE, m, NGVD @ t= 2942. sec
7.8
6.3
4.8
3.3
1.8
0.3
-1.3
-2.8
-4.3
-5.8
Bouss-2D WSE snapshot
14 km
8 km
shore
shore
profile
0.7 m
23 m
offshore

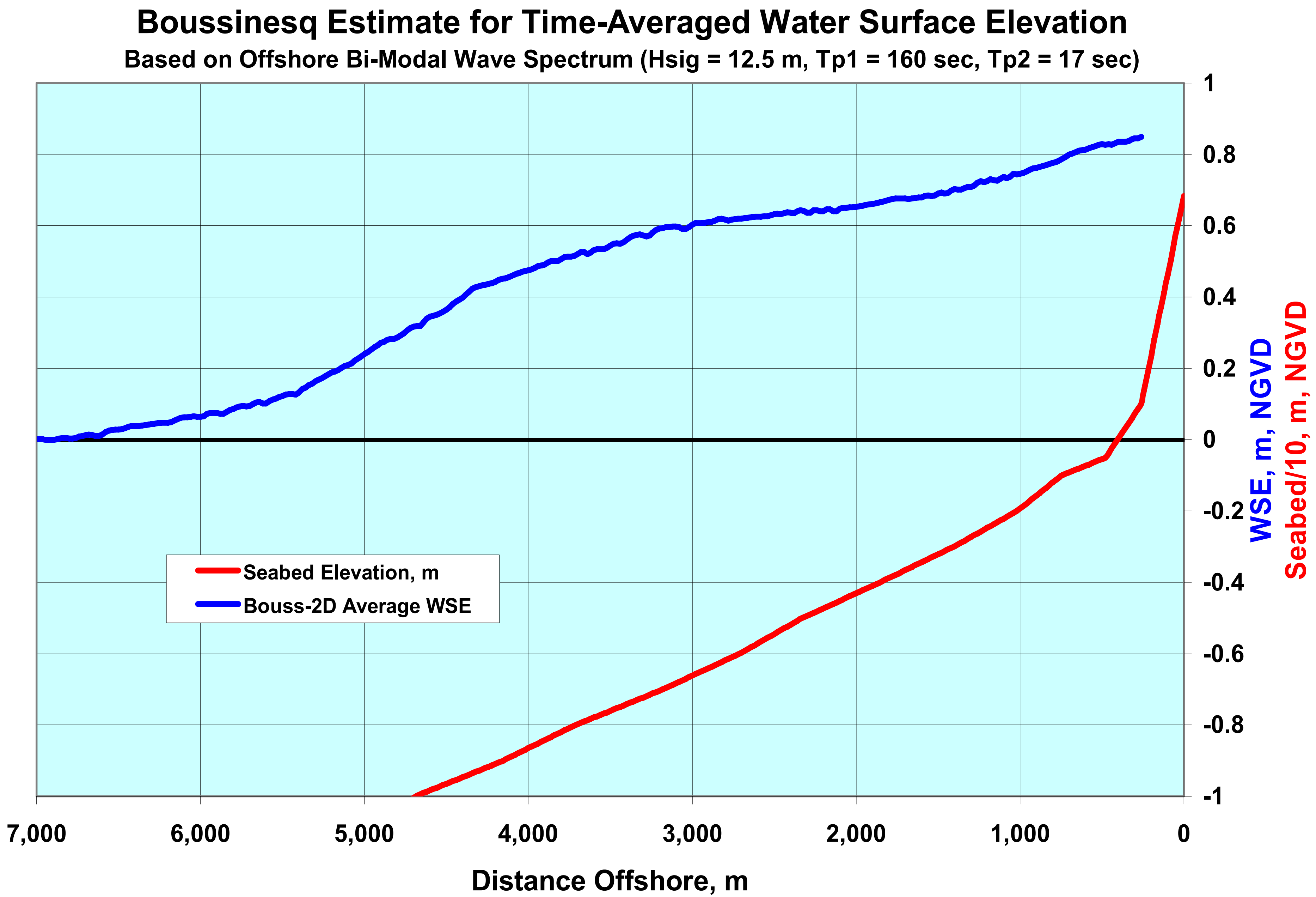

Boussinesq Estimate for Water Surface Elevation Time Series
Based on Offshore Bi-Modal Wave Spectrum (Hsig = 12.5 m, Tp1 = 160 sec, Tp2 = 17 sec)
1,000 seconds at 23 m depth
WSE, NGVD, meters
Time, sec
8
6
4
2
0
-2
-4
-6
0
100
200
300
400
500
600
700
800
900
1000



Boussinesq Estimate for Water Surface Elevation Time Series
Based on Offshore Bi-Modal Wave Spectrum (Hsig = 12.5 m, Tp1 = 160 sec, Tp2 = 17 sec)
WSE, NGVD, meters
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
1000
Time, sec
1,000 sec at 0.7 m depth



Boussinesq Estimate for Time-Averaged Water Surface Elevation
Based on Offshore Bi-Modal Wave Spectrum (Hsig = 12.5 m, Tp1 = 160 sec, Tp2 = 17 sec)
Seabed Elevation, m
Bouss-2D Time-averaged WSE
WSE and Seabed, m, NGVD
Distance Offshore, m
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0



Boussinesq Estimate for Time-Averaged Water Surface Elevation
Based on Offshore Bi-Modal Wave Spectrum (Hsig = 12.5 m, Tp1 = 160 sec, Tp2 = 17 sec)
Seabed Elevation, m
Bouss-2D Average WSE
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Distance Offshore, m
WSE, m, NGVD
Seabed/10, m, NGVD

Conclusions

The storm water level affecting "open" coastal margins can be composed of many processes (components).

Infragravity (IG) Transients, forced by groups of storm waves, may have a significant effect on the coastal margin.

IG Transients ($\Delta\eta$) of 1-2 meters and associated rip currents elevate the RISK to life and property within the active coastal margin.

More work is needed by the wave science/engineering community to fully parameterize the estimation of transient water level behavior, and use this information to improve our utilization of the coastal zone.

Hypothesis: $\Delta\eta$ may be responsible for a considerable fraction of the storm surge which affects coastal margins.

The wave science/engineering community should consider further evaluation of this potentially important storm surge process.