

HYDRODYNAMIC CONDITIONS AND SEDIMENT MOVEMENT AT PORT OF PORT ORFORD

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Abstract: To evaluate hydrodynamics and waves, investigate sediment movement, and alleviate channel shoaling at Port Orford, numerical modeling simulations are conducted under various hydrodynamic and wave conditions, and different configurations of the breakwater. The channel infilling is examined by identifying the sources and pathways of sediment particles deposited in the port's navigation channel. The current fields show the wind driven flow pattern. Extreme winter storms induce stronger longshore current and can have direct impact on the harbor with incident waves propagating from south-southwest. Particle tracking results indicate that the winter transport regime can motivate rapid channel infilling at Port of Port Orford due to the establishment of sustained sediment transport pathways during storms. Wave actions in coastal areas are more likely to enhance the transport of sediment due to wave-induced sediment resuspension.

Introduction

Port Orford is located on the southern Oregon coast of the USA, about 70 miles north of the Oregon/California state line. The Port of Port Orford is a small boat harbor and has been in operation since 1930. A 750-ft long federal navigation channel (FNC) provides the harbor access from the open coast and a 550-ft federal breakwater has been protecting the port from severe atmospheric and oceanic conditions since its construction in 1969 (Figure 1), yet the breakwater is currently severely degraded in its mid-section. Port operations have been affected by harbor shoaling due to storm induced sediment transport and breakwater degradation.

Without periodic maintenance dredging, vessel access to the Port dock can be restricted to the upper half of the tide cycle when sufficient water depth is available within the Port's channel, which can limit port operations by 50% (for workable time). Timely boat launching/retrieval operations at the Port Orford are critical to safe and successful port operations. As the port is used throughout the year's fishing seasons, the FNC requires operation and maintenance (O&M) dredging every 1-3 years to provide access to the Port dock.

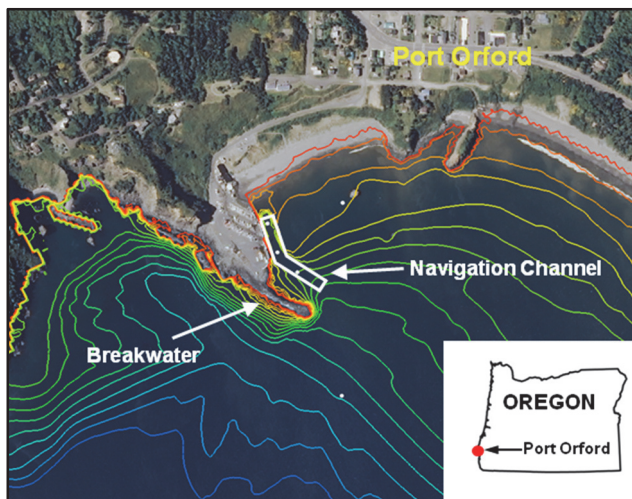


Fig. 1. Port Orford, Oregon.

The navigation issue at Port Orford is the problematic shoaling within the Port's FNC. To address this issue, it is necessary to understand physical conditions surrounding the harbor and to investigate whether the channel shoaling can be reduced by altering the configuration of the breakwater. Based on trends in local and regional shoreline change, dredged material placement practices, and long-term harbor bathymetry change, multiple contributing sediment sources that are affecting shoaling within the Port Orford channel are also needed to be identified and evaluated.

In this study, the U.S. Army Corps of Engineers (USACE) Portland District (NWP) and the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center, performed numerical modeling simulations with the Coastal Modeling System (CMS) (Sanchez et al. 2011; Lin et al. 2011) and the Particle Tracking Model (PTM) (MacDonald et al. 2006). The CMS and PTM simulations by the CHL and NWP are conducted under various hydrodynamic and wave conditions, and different configurations of the breakwater. The sediment movement and channel infilling are examined by identifying the sources and pathways of sediment particles deposited in the port's navigation channel.

Method

CMS and PTM

The flow and wave modeling for Port Orford is conducted using the CMS. The CMS is an integrated suite of numerical models consisting of a hydrodynamic and sediment transport model, CMS-Flow, and a spectral wave model, CMS-Wave (Sanchez et al. 2011; Lin et al. 2011). The CMS can be coupled with a Lagrangian particle tracking model, the PTM, in which a large number of neutral buoyant or sediment particles are released and tracked as they are transported by the flow (MacDonald et al. 2006).

CMS-Flow domain is discretized by a telescoping grid, which is 20.6 km in length along the shore and 16.4 km in width across the shore. The telescoping grid has about 140,000 ocean cells. The fine resolution cells with 10-m spacing are specified around the port and the coarse resolution with 320-m spacing in the offshore area. The average water depth is 3-4 m near the port and increases to 160 m in the CMS offshore boundary. The navigation channel leading to the port has an average depth of 5.8 m (Fig. 2).

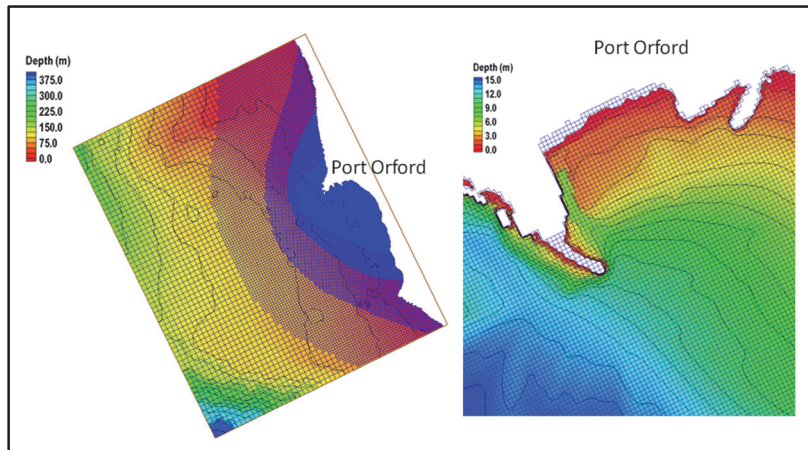


Fig. 2. CMS domain and CMS-Flow telescoping grid.

CMS-Wave domain is within the CMS-Flow domain with a horizontal scale of 12.7×10.1 km and the offshore boundary is facing true south (Fig. 3). Non-uniform rectangular grid is used for the wave model. Similar to the discretization of the flow model, high resolution grids of 8.0×8.0 m are specified surrounding the port and grid cell sizes increase to 200 m away from the port.

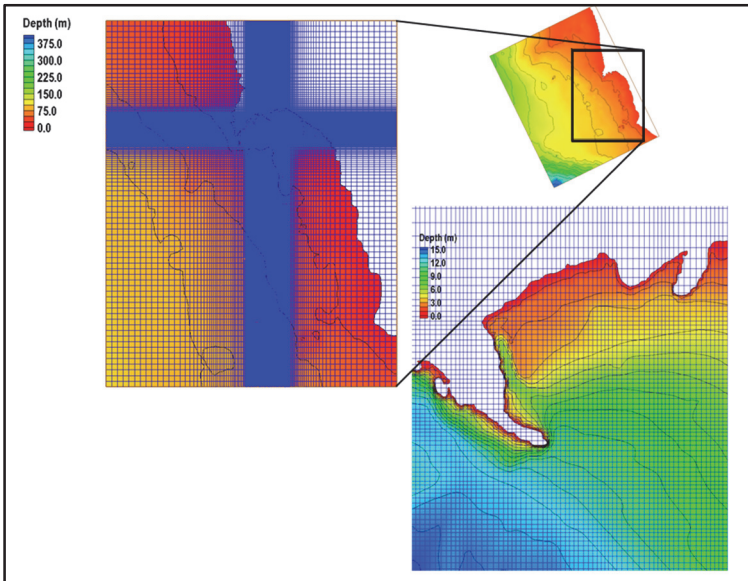


Fig. 3. Nonuniform rectangular CMS-Wave grid.

Three breakwater configurations are specified for the CMS based on the project alternatives described in an early report by Moffatt and Nichol (2011). The first case is to restore the storm damaged breakwater to its original designed configuration, which is maintaining the breakwater at a 167.6 m (550 feet) length and the crest elevation at a 4.9 m (16.1 feet) height relative to MSL (Fig. 4a). The second case is to construct a mid-section notch into the breakwater. The length of the notch is 76.2 m (250 feet) and the crest height is 2.7 m (8.9 feet) below MSL (Fig. 4b). The last case is to remove 121.9 m (400 feet) of the breakwater and the base portion attaching to land will be kept to protect existing dock structure (Fig. 4c). At the original breakwater location the water depth is determined referring to the seabed elevation in the neighboring area.

The PTM is based upon the Lagrangian technique, a modeling framework that moves with the flow (MacDonald et al 2006). Lagrangian modeling is especially appropriate for modeling transport from specified sources. Each particle (or parcel) in a Lagrangian transport model represents a given mass of sediment (not an individual sediment particle or grain), and each parcel has its own unique set of characteristics. As a minimum, a parcel must be defined with certain physical properties (e.g., grain size and specific gravity) and an initial position. A sufficient number of parcels are modeled such that transport patterns are representative of all parcel movement from the sources. The model uses waves

and currents as forcing functions to suspend and transport sediment through advection, which are developed through the CMS.

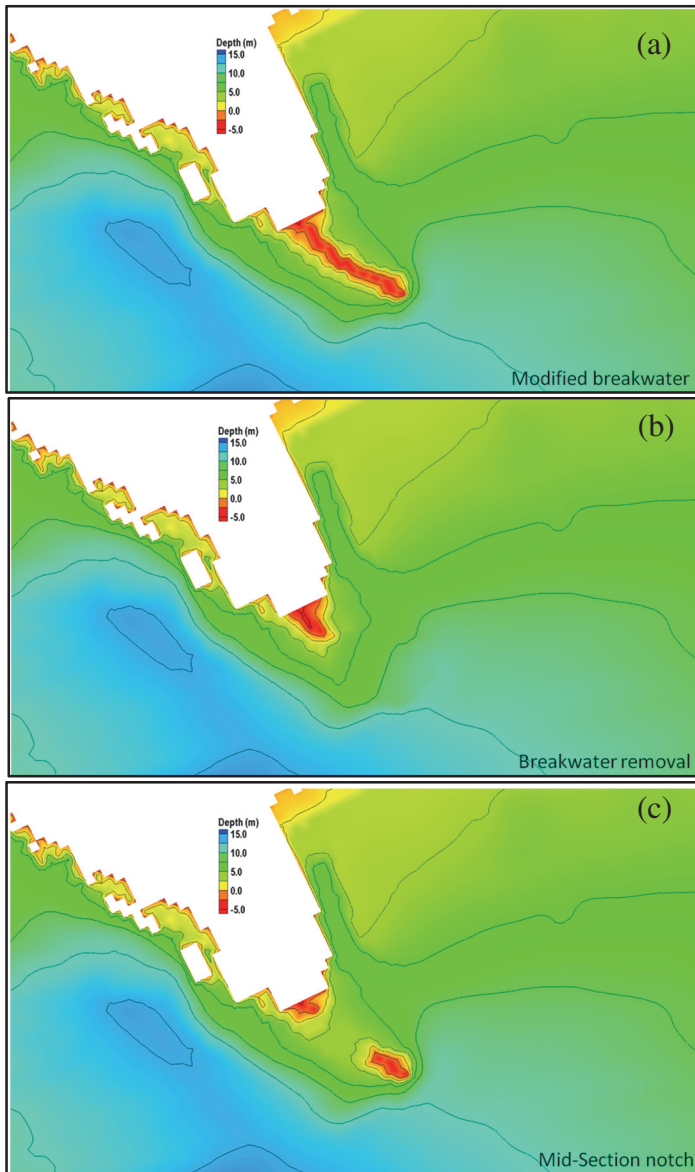


Fig. 4. Three breakwater alternatives. (a) Modified breakwater; (b) Breakwater removal; (c) Mid-section notch.

For this study, the CMS is driven by tides, winds, and waves. The calculated current and wave conditions are applied to drive the PTM to investigate sediment particle movement under three breakwater configurations (the breakwater restoration, the notch construction, and the breakwater removal) in the vicinity of Prot Orford. CMS/PTM simulations are conducted for a winter (6 November – 15 December, 2007) and a summer (June 2010) period, respectively.

Data and Model Forcing

Coastline and bathymetry data for this modeling study are extracted from a bathymetry dataset developed in a modeling study (Moffatt and Nichol, 2011). Fig. 5 shows the distribution of the data sampling locations and the depth contours (in meters relative to mean sea level (MSL)) in the CMS-Flow domain. As shown in Fig. 6, the Google Earth images incorporated in SMS are also used to properly define the coastline and land features in the study area.

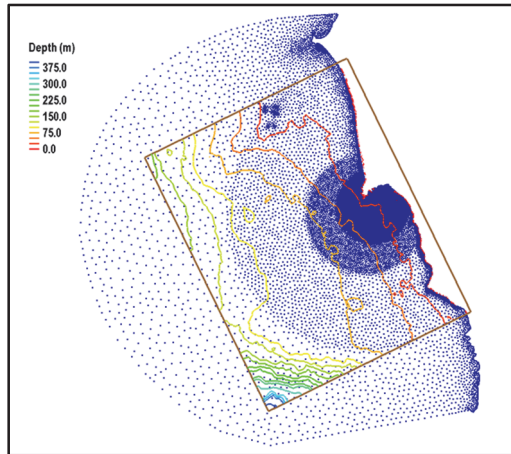


Fig. 5. The distribution of the bathymetry data sampling locations and depth contours within the CMS domain.

Simulations were conducted for a winter (6 November – 15 December, 2007) and a summer (June 2010) period. CMS-Flow was driven with the time-dependent water levels, winds, and waves. Water level data were obtained from NOAA coastal station (9431647) at Port Orford, Oregon (Fig. 6). Fig. 7 is the hourly water surface elevation for the two simulation periods. Water surface elevation at the gauge indicates a mixed, predominately semi-diurnal tidal regime surrounding the study area. The mean tidal range (mean high water – mean low water) is 1.60 m (5.21 ft) and the maximum tidal range (mean higher high water - mean lower low water (MLLW)) is 2.22 m (7.28 ft).

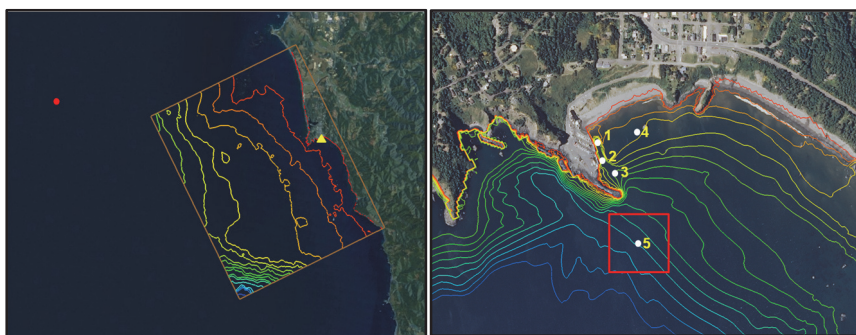


Fig. 6. Locations of NOAA offshore buoy 46015 (red dot) and Port Orford tide gauge 9431647 (yellow triangle), and 5 selected sites (white dots) for CMS result analysis. The red square designates the dredge material placement area.

Wind data were obtained from the National Data Buoy Center (NDBC, <http://www.ndbc.noaa.gov>) Buoy 46015, located approximately 27 km west of Port Orford (Fig. 6). Fig. 8 shows the wind speed and direction for the winter and summer period and distinct seasonal wind patterns can be seen in the figure. The winter storm is characterized by south-southwesterly. The first winter storm in the area appeared on 12 November, 2007 and an extreme storm with a maximum speed of 23.3 m/s between 1 -3 December, 2007. The summer period is relatively calm at this offshore buoy site. The mean wind speed is less than 10 m/s and the dominant wind direction is from north.

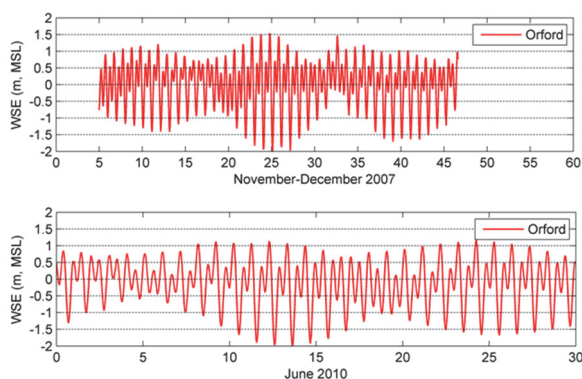


Fig. 7. Water level data for 6 November to 15 December 2007 and June 2010 at Port Orford gauge (9431647).

Incident wave conditions were based on directional wave data collected by NDBC Buoy 46015. The buoy wave data were transformed to the seaward

boundary of the CMS-Wave grid using a simplified wave transformation for shore-parallel depth contours. Wave parameters are shown in Fig. 9. The maximum wave height is 10.6 m during the extreme winter storm. The average wave height is 1.9 m during the summer month. The same wind data described above were also used as atmospheric input to wave modeling for wind and wave interactions.

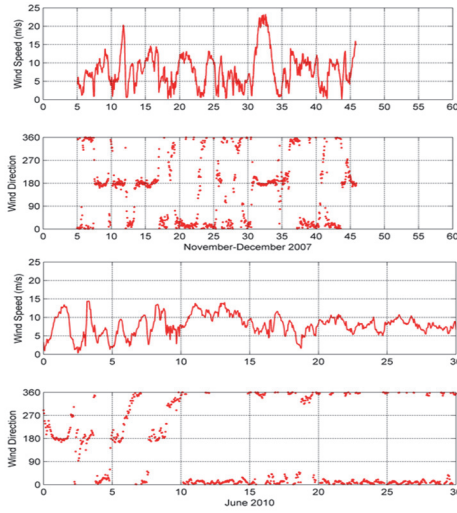


Fig. 8. Wind data for 6 November to 15 December 2007 and June 2010 at NDBC Buoy 46015.

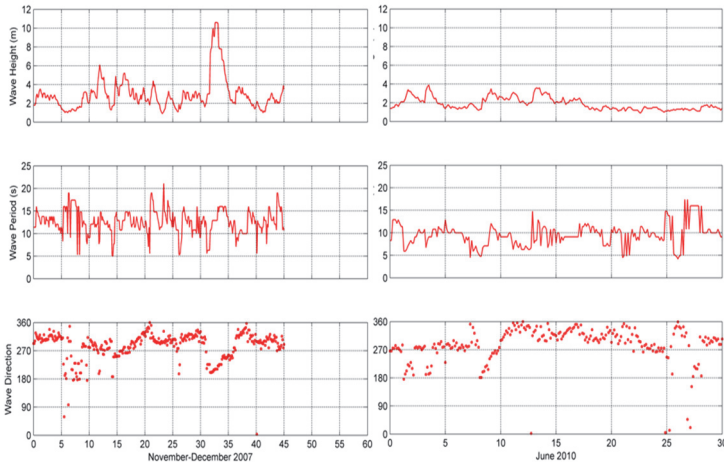


Fig. 9. Wave parameters for 6 November to 15 December 2007 and June 2010 at the CMS seaward boundary.

PTM Sediment Sources and Sinks

In the PTM, eight (8) locations were selected as sediment sources around the immediate project area of Port Orford to address the uncertainty in where the sediment affecting the Port is coming from. Sources represent locations where sediment is eroded from the seabed and introduced into the PTM domain. Sources include nearby beaches, updrift littoral zone, the harbor embayment, the nearshore zone immediately offshore of the harbor, and the CWA-404 dredged material placement site (Fig. 10).

The sediment sources were represented as “lines” along the seabed that sediment parcels were released at pre-specified rates, with each sediment parcel representing a specific mass of sediment (10 kg). Table 1 summarizes the physical aspects of the sediment sources implemented within the PTM, which correspond with the source locations shown in Fig. 10. The sediment sources were defined based on analysis of sediment samples taken from within the FNC. Mean grain size of FNC sediment samples was observed to be 0.45 mm with material classified a poorly sorted coarse sand. Sediment grain size variation about the mean grain size was not reported, and was specified as 0. Based on the total rate of sediment release from all 8 sediment sources, approximately 850 10-kg parcels/day are introduced into the PTM model domain, which is equivalent to 215,000 cy of sediment applied over a collective release area of approximately 105 acres.

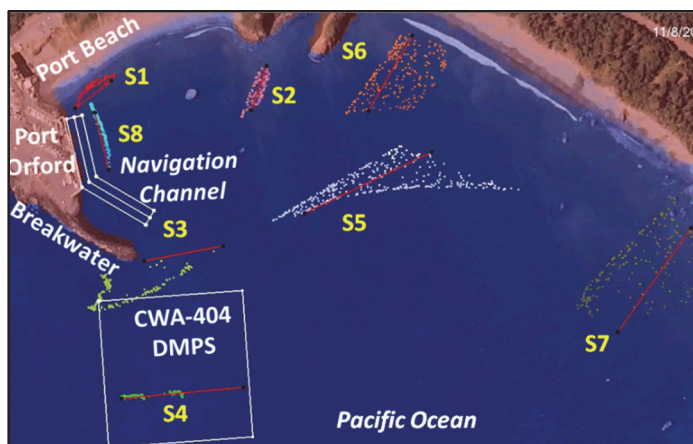


Fig. 10. Sediment sources specified for the Port Orford PTM, for evaluation of shoaling within the navigation channel. S1 represents a local beach sediment source. S2 and S8 represent harbor-embayment sources. S3 and S5 represent nearshore sources. S4 represents sediment sourced from the CWA-404 dredged material placement site. S6 and S7 represent updrift littoral sediment sources.

Table 1. Physical properties of the 8 sediment sources defined within the Port Orford PTM.

Sediment Source	Parcel Mass (kg)	Mass Release Rate (kg/m/sec)	Source Type	Source Size (m, seabed)	Sediment Release bulk vol. cy/sec	Sediment Type	Grain Size D_{50}	Variation Phi-unit
S1	10	0.00001	Line	80 x 1	0.16	coarse sand	0.45	0
S2	10	0.00001	Line	80 x 1	0.16	coarse sand	0.45	0
S3	10	0.00001	Line	140 x 1	0.29	coarse sand	0.45	0
S4	10	0.00001	Line	210 x 1	0.43	coarse sand	0.45	0
S5	10	0.00001	Line	240 x 1	0.49	coarse sand	0.45	0
S6	10	0.00001	Line	150 x 1	0.31	coarse sand	0.45	0
S7	10	0.00001	Line	215 x 1	0.44	coarse sand	0.45	0
S8	10	0.00001	Line	100 x 1	0.21	coarse sand	0.45	0

To evaluate details of sediment shoaling within the FNC, the FNC was split into 6 “sediment traps” within the PTM model as shown Fig. 11. The PTM option was selected to define the sediment traps to allow only one-way deposition. When a PTM sediment parcel enters a sediment trap, the parcel becomes inactive and the parcel’s deposition and source is associated with the sediment trap that it entered. Once a sediment parcel enters and FNC sediment trap, it does not leave the FNC. The one-way deposition may or may not be occurring at the field site FNC, but it allowed for direct assessment of parcel transport pathway and FNC deposition.

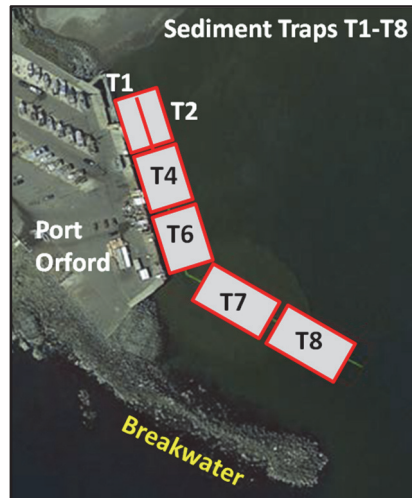


Fig. 11. The FNC was split into 6 different “sediment trap” zones (T1-T8) to evaluate which area of the FNC would be most likely to experience shoaling based on the PTM results.

Results

Current

The Port Orford breakwater protects the harbor from the northwest and southeast waves. However, severe winter storms (southerly waves and wind) can still have direct impact on the harbor and result in significant long-shore sediment movement into the harbor channel. Snapshots of calculated current fields during an extreme winter storm are shown in Fig. 12. Corresponding to the three breakwater configurations, the flow pattern is clearly wind driven, long-shore current being from south to north and turning west in front of the port. Due to the short duration of the winter storm, lasting about 3 days, the maximum current speed is approximately 0.15-0.2 m/s around the breakwater. The current speed is generally smaller than 0.10 m/s inside the harbor area. For the modified breakwater scenario a small current branch was separated from the primary westward current, flowing parallel to the breakwater and into the harbor channel. For the mid-section notch scenario, the flow separation occurred as the primary current passed the head of the breakwater and the secondary flow entered the harbor area through the opened section on the breakwater.

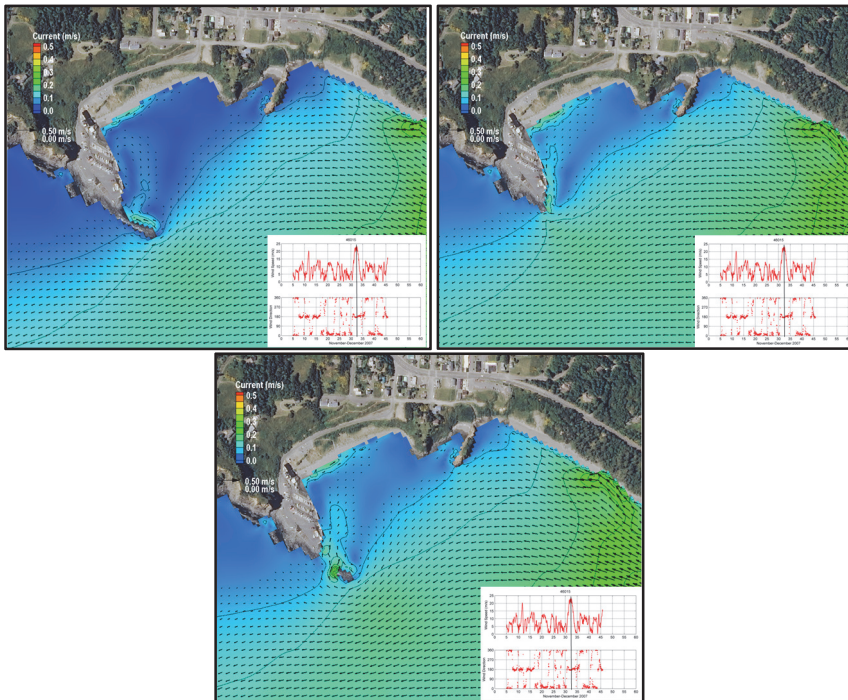


Fig. 12. Calculated current field for different breakwater scenarios on 3 December 2007 at 13:00 GMT.

Comparing to the winter case, the summer month is relatively calm. The summer flow pattern looks very similar to the winter ones (Fig. 11) but the peak current speed during the summer time is generally small around 0.1 m/s.

Waves

Incident waves are propagating from south-southwest during a winter storm period. Fig. 13 shows the snapshots of calculated wave fields during the 2007 extreme winter storm. As approaching the shallow water area, waves refract and wave heights reduce. Corresponding to the winter storm, wave heights are close to 8.0 m offshore. Refracted wave heights in the harbor are reduced but are still close to 2.0 m.

For the summer month, a selected peak southerly wave period shows that wave heights are approximately 2.5 m in the offshore and refracted wave heights in the harbor range between 0.5 m and 1.5 m corresponding to the three breakwater configurations.

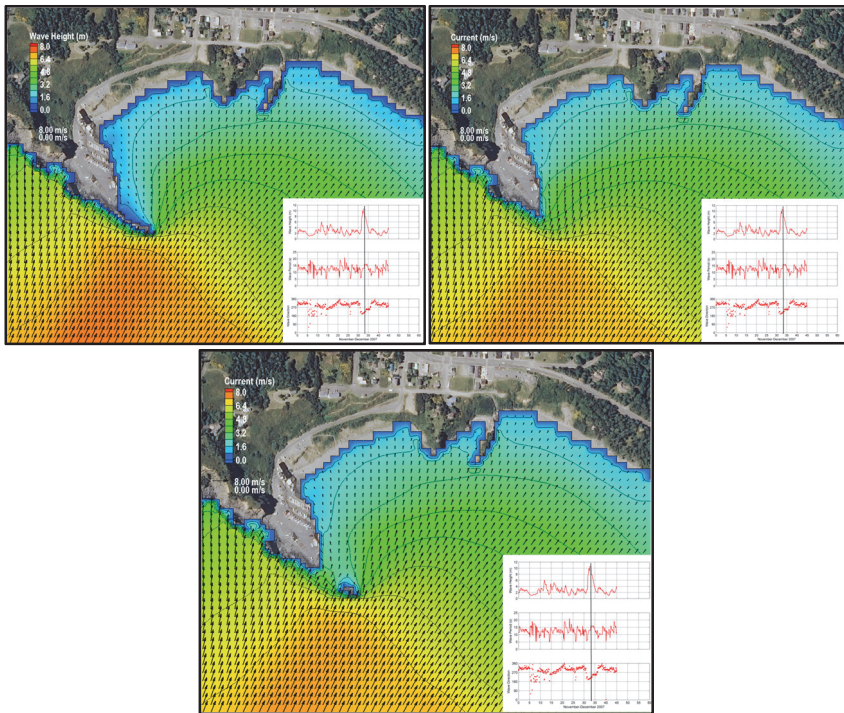


Fig. 13. Calculated significant wave height for different breakwater scenarios on 3 December 2007 at 15:00 GMT.

PTM

Fig. 14 shows PTM results obtained for three different breakwater configurations for the winter 2007 model run when a severe winter storm brought high southerly winds and waves to the Oregon coast. During this storm, offshore winds exceeded 20 m/sec, waves exceeded 10 m, and depth-averaged current exceeded 0.2 m/sec. Note that sandy sediment can be mobilized at a threshold current of 0.05 m/sec with the enhanced agitation of wave action. Eight (8) sediment sources were implemented into the Port Orford PTM model to evaluate the shoaling contribution from all possible sources in the project area. Sediment sources S1, S2, S3, and S8 are directly feeding sediment into the harbor-embayment area shown in the middle panel.

Conclusions

Corresponding to the three breakwater configurations, current fields show the wind driven flow pattern. Extreme winter storms induce stronger current alongshore but not near the harbor. Incident waves are propagating from south-southwest during a winter storm period. For an extreme winter storm, 8-m waves are found in the offshore and refracted wave heights in the harbor are close to 2.0 m. The Port Orford breakwater protects the harbor from the northwest and southeast waves. However, severe winter storms (southerly waves and wind) can still have direct impact on the harbor.

The Port Orford PTM results indicate that the winter transport regime can motivate rapid channel infilling at Port of Port Orford due to the establishment of sustained sediment transport pathways during storms. Wave actions in coastal areas like Port Orford are more likely to enhance the transport of sediment due to wave-induced sediment resuspension.

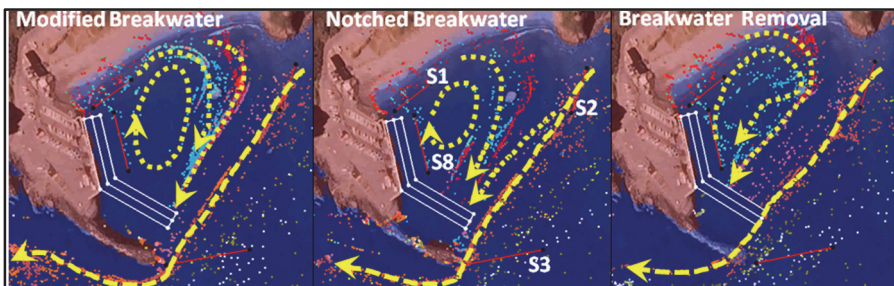


Fig. 14. PTM results for sediment transport at 0000 3 DEC 2007, for three different breakwater configurations.

Acknowledgements

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References

- Lin, L., Demirbilek, Z., Thomas, R., and Rosati III, J. (2011). "Verification and validation of the Coastal Modeling System, Report 2: CMS-Wave." *Coastal and Hydraulics Laboratory Technical Report ERDC/CHL TR-11-10*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- MacDonald, N. J., Davies, M. H., Zundel, A. K., Howlett, J. D., Lackey, T. C., Demirbilek, Z., and Gailani, J. Z. (2006). "PTM: Particle Tracking Model; Report 1: Model theory, implementation, and example applications." *Coastal and Hydraulics Laboratory Technical Report ERDC/CHL TR-06-20*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- Moffatt & Nichol, 2011. "Port Orford breakwater major maintenance report."
- Sanchez, A., Wu, W., Beck, T. M., Li, H., Rosati III, J., Thomas, R. C., Rosati, J. D., Demirbilek, Z., Brown, M. E., and Reed, C. W. (2011). "Verification and Validation of the Coastal Modeling System, Report 3: Hydrodynamics." *Coastal and Hydraulics Laboratory Technical Report ERDC/CHL TR-11-10*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Hydrodynamic Conditions and Sediment Movement at Port of Port Orford



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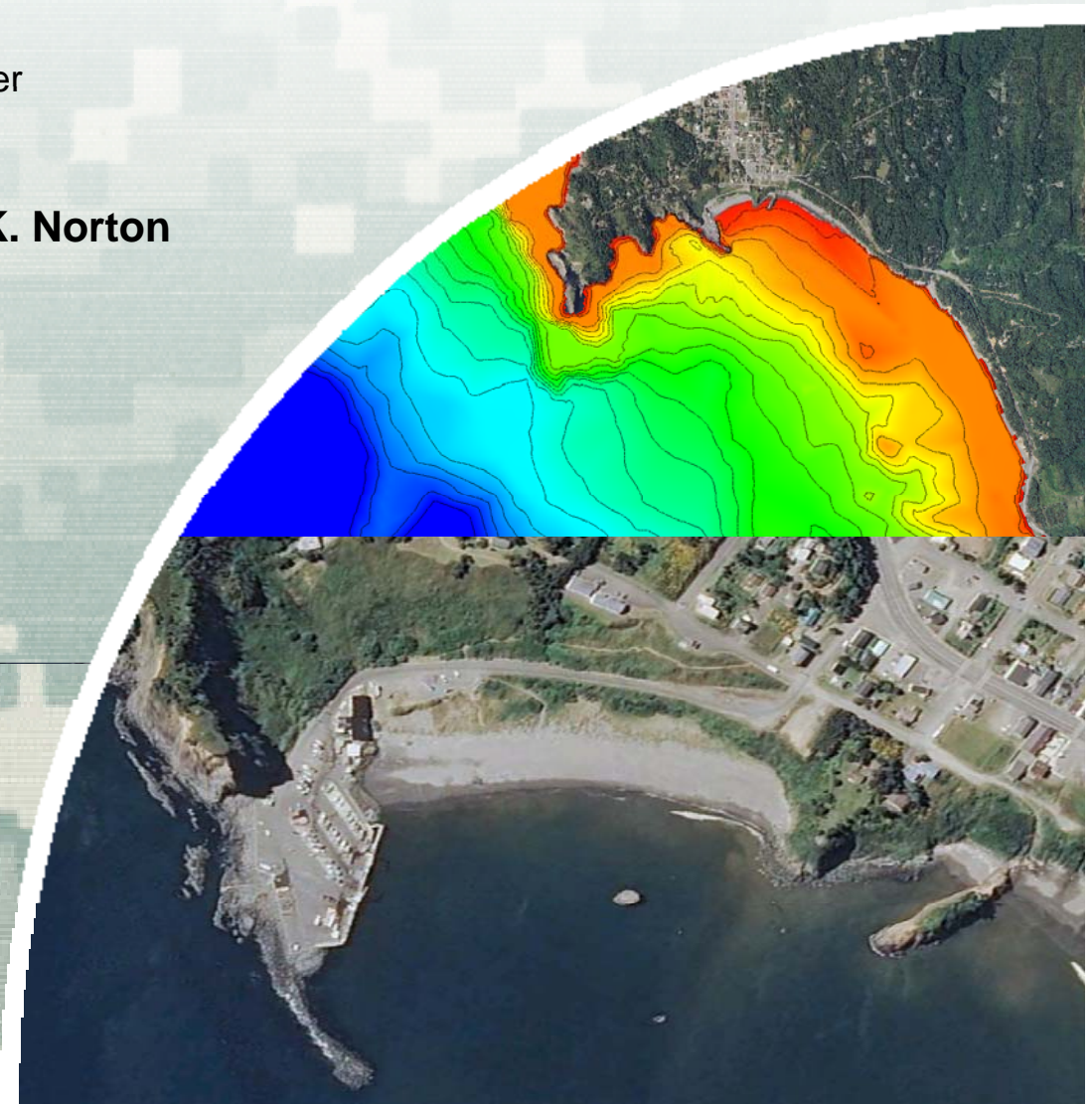
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Portland District

Coastal Sediments 2015
San Diego, California
May 14, 2015



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BUILDING STRONG



Outline

- **Background and objective**

- **Method**

 - Hydrodynamic and particle tracking models

 - Data and model forcing

 - Sources and sinks

- **Results**

 - Currents

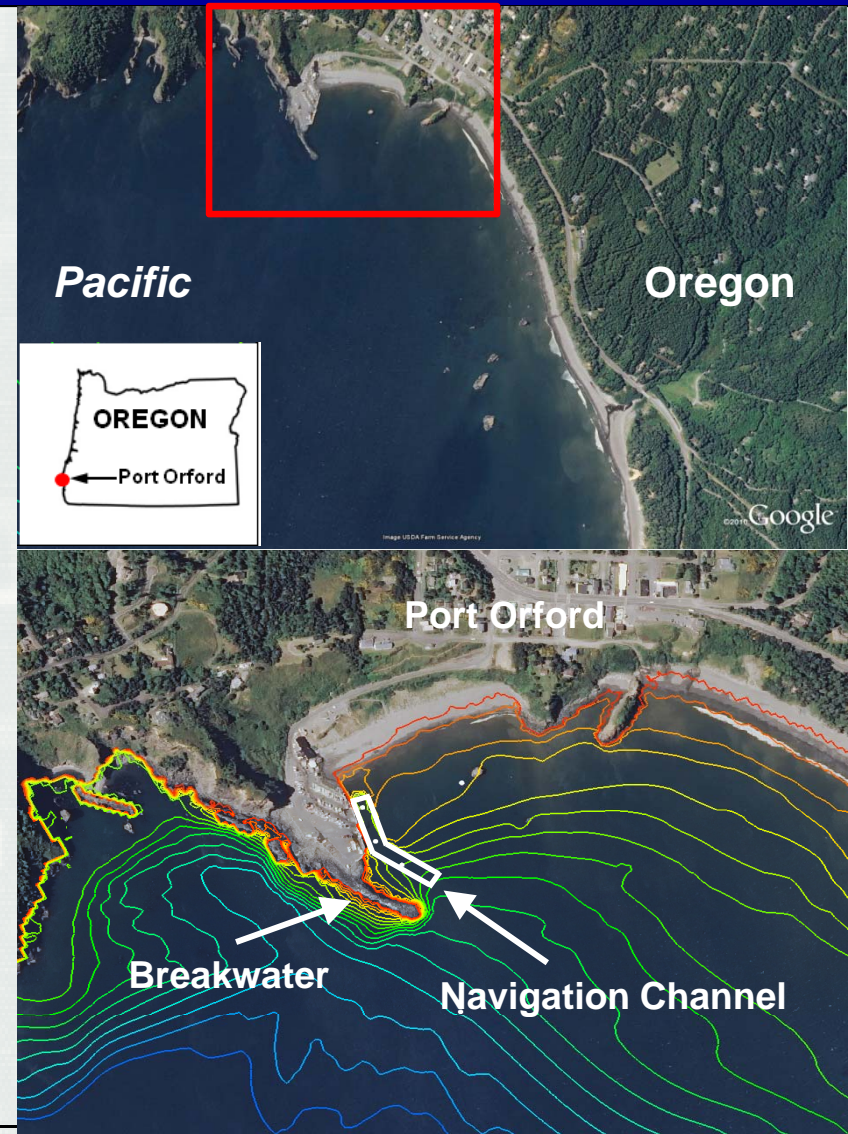
 - Waves

 - Particle tracking

- **Summary**

Background and Objective

- Maintain a federal navigation channel at the Port of Port Orford
- Evaluate alternative breakwater configurations to reduce recurring dredging needs/costs
- Define littoral sediment transport pathways that affect shoaling at Port Orford
- Determine long term solution other than annual dredging maintenance

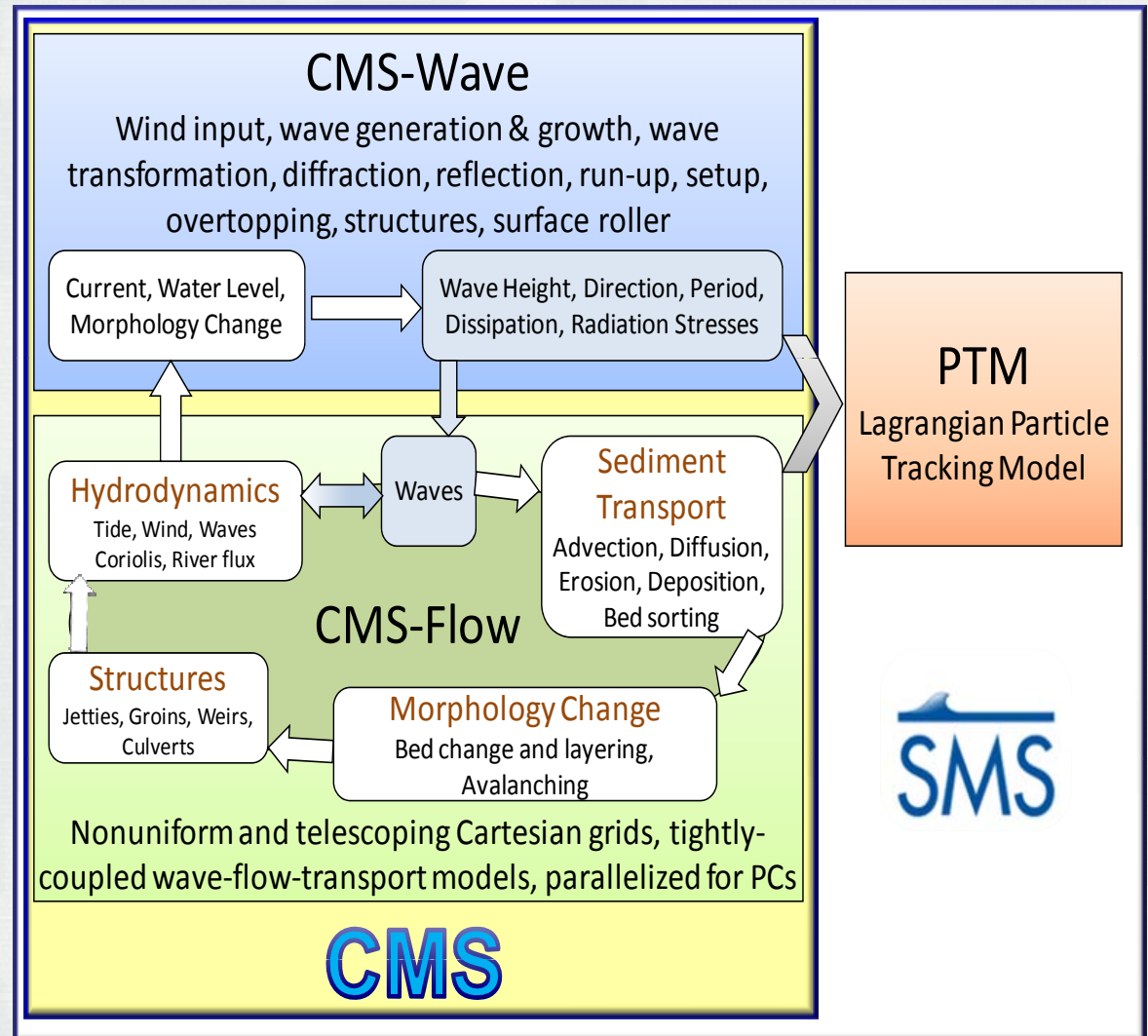


Method

Integrated waves, current, and sediment transport model in the Surface-water Modeling System (SMS)

CMS-Flow and CMS-Wave

Coupled with Particle Tracking Model (PTM)



CMS Configuration

CMS-Flow:

Telescoping

Domain Size: 21 x 16 km

Cell Size: 10 to 320 m

Water Depth: 0 to 400 m

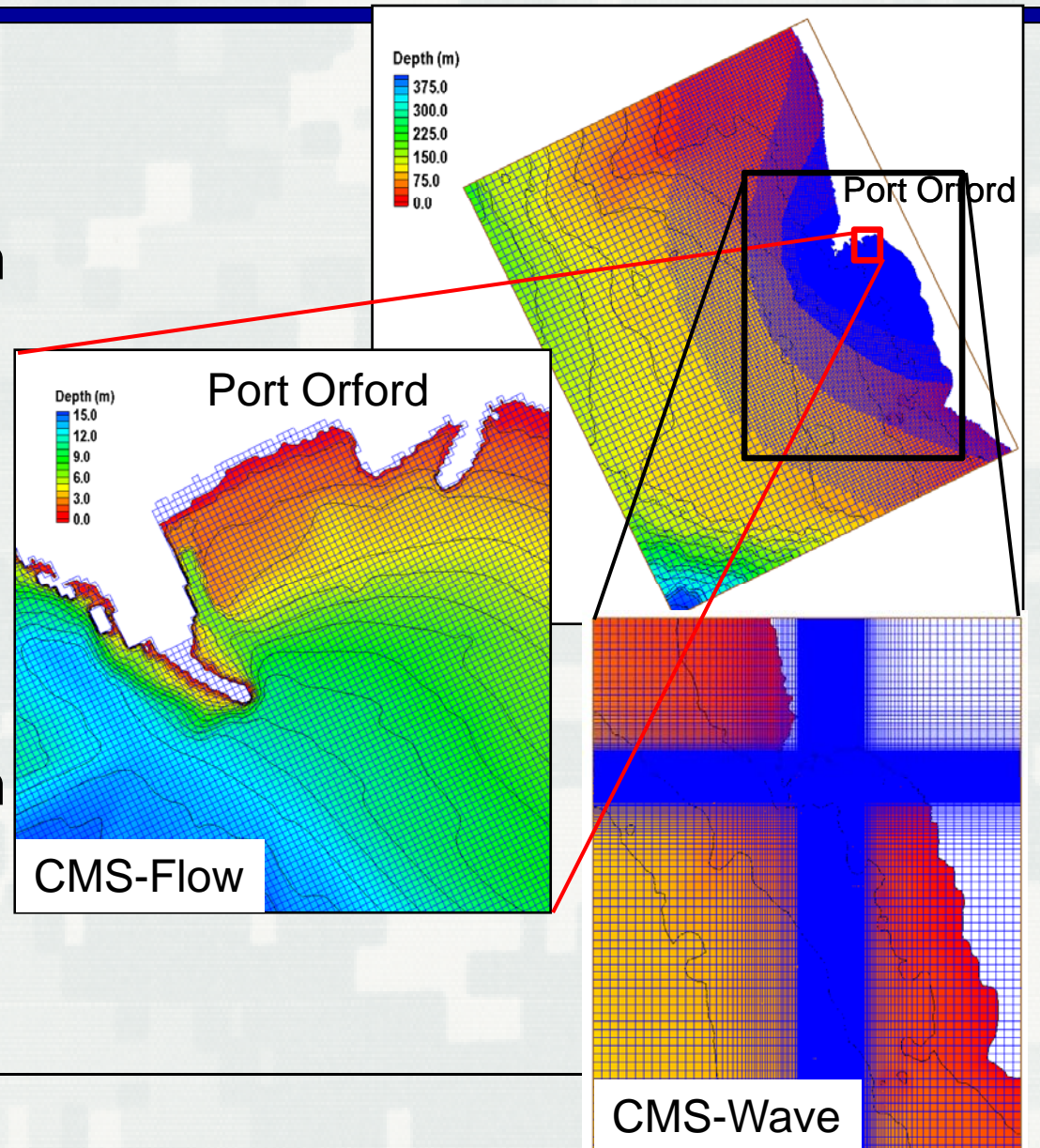
CMS-Wave:

Non-uniform rectangular

Domain Size: 13 x 10 km

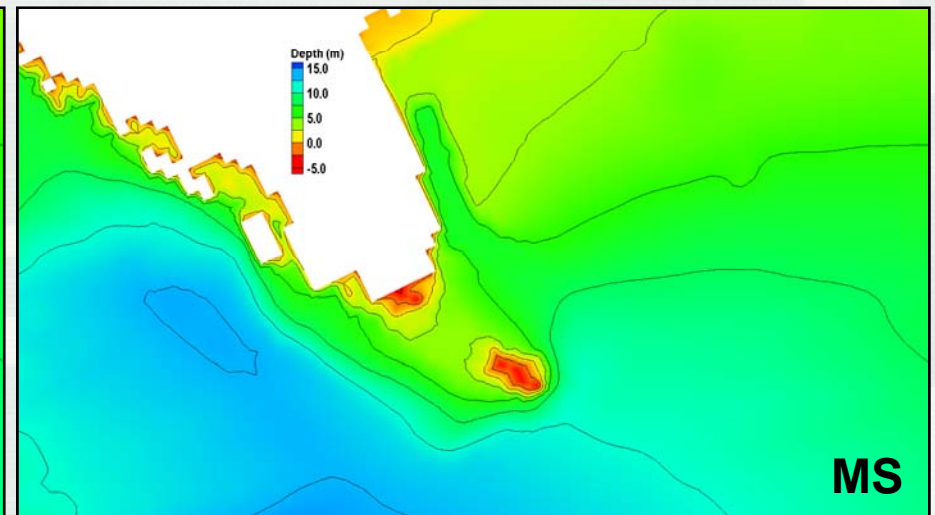
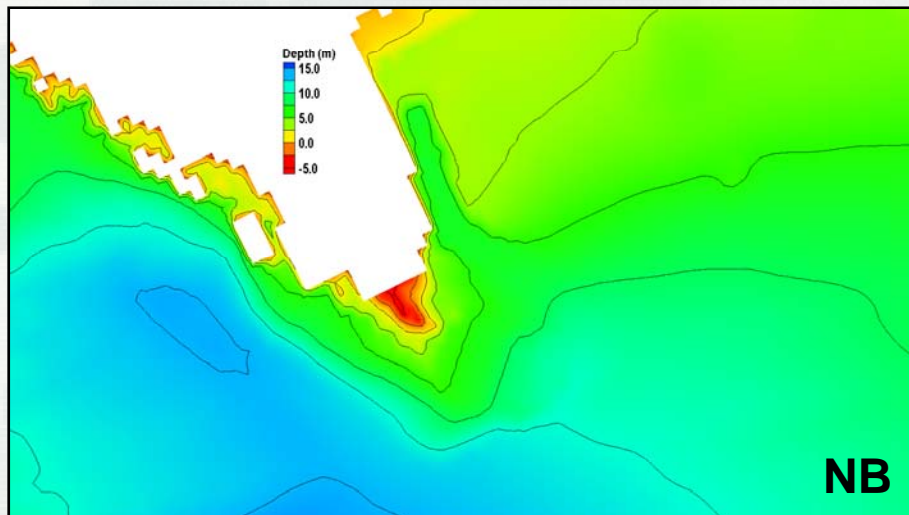
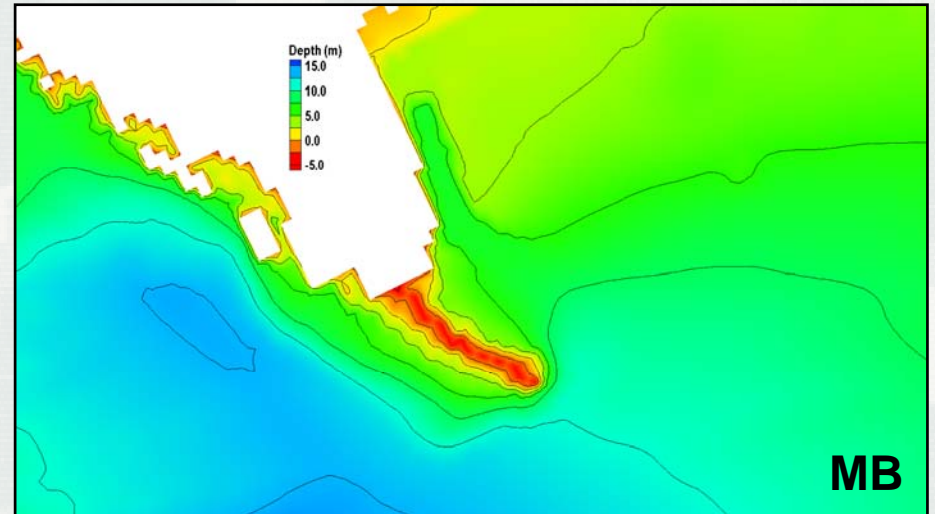
Cell Size: 8 to 200 m

Water Depth: 0 to 90 m



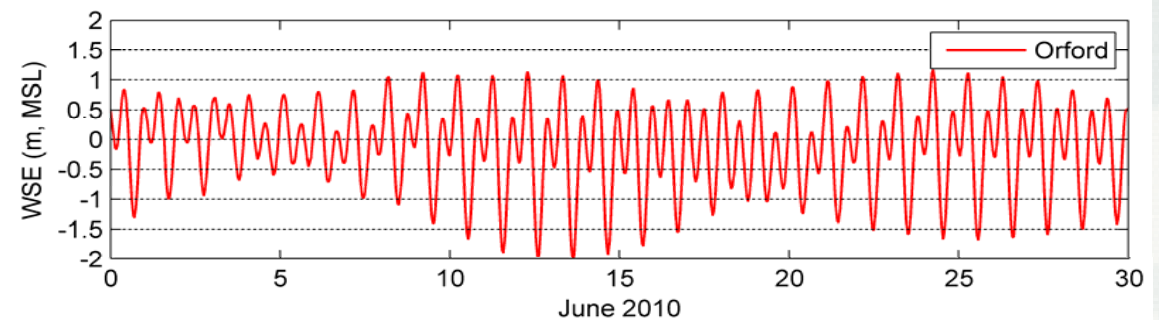
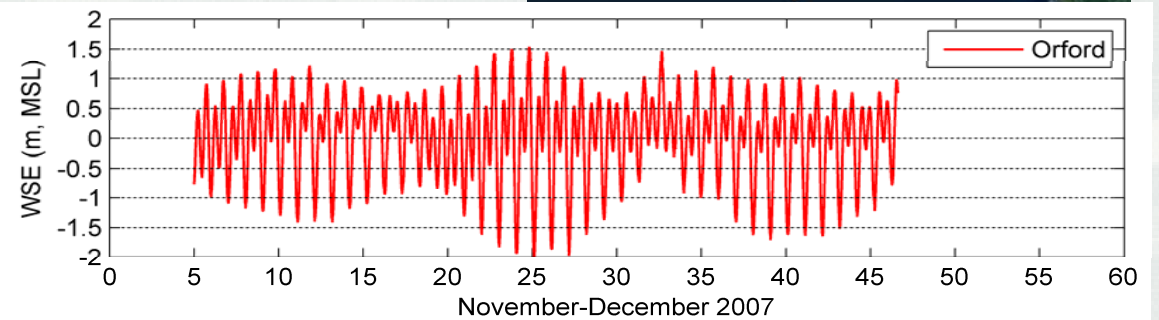
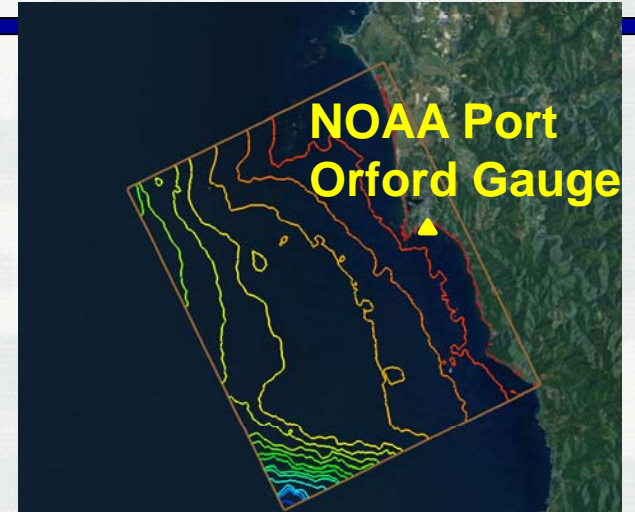
Breakwater Configuration

- Restore breakwater (MB)
Crest elevation: 4.9 m above MSL
- Open mid-section notch (MS)
Length: 76.2 m
Crest elevation: 2.7 m below MSL
- Remove breakwater (NB)



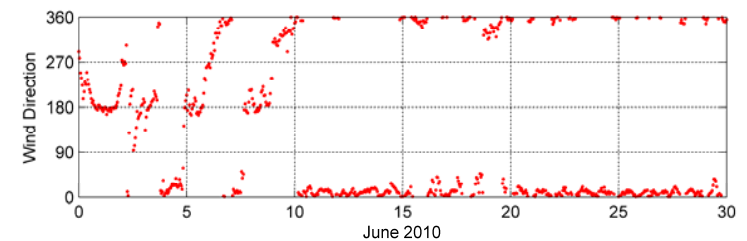
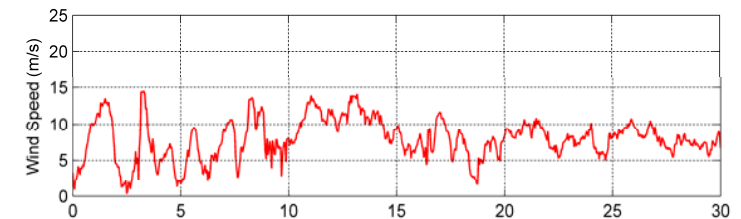
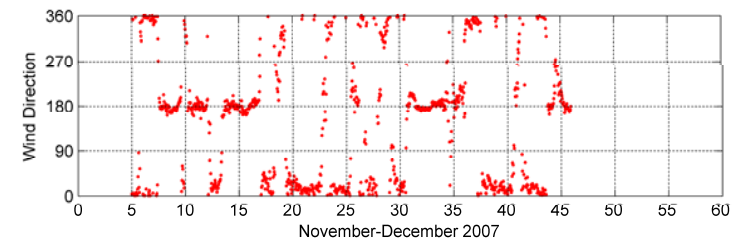
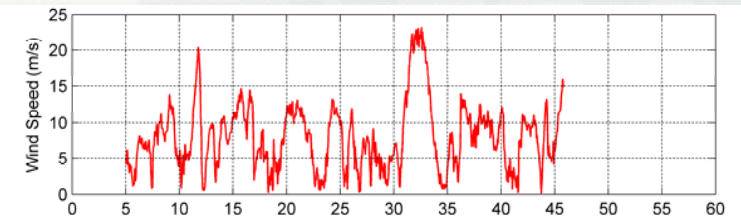
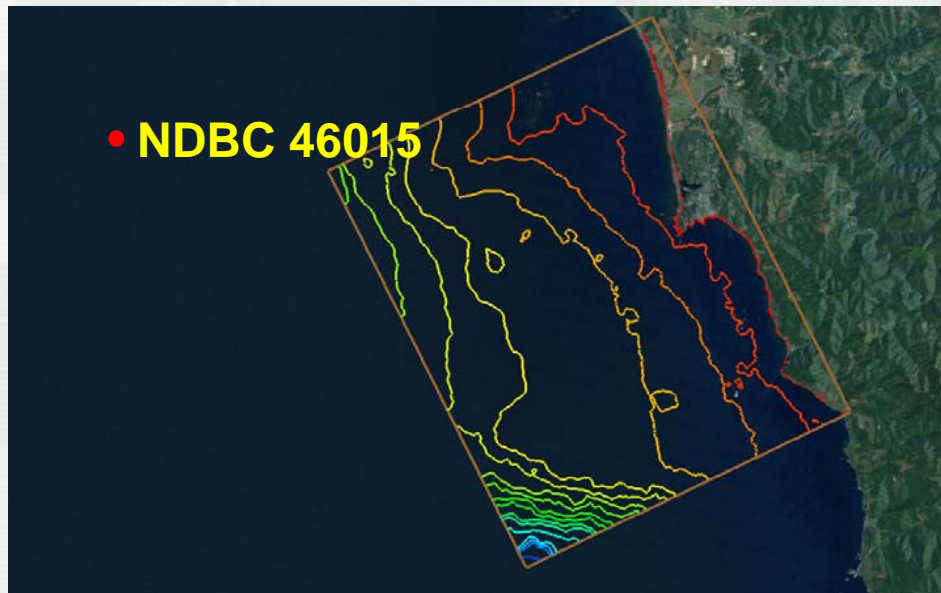
Water Level

- NOAA tide gauge (Port Orford: 9431647)
- 6 November – 15 December 2007 and June 2010
- Mixed, predominately semi-diurnal tide
- Mean tide range:
 $MHW - MLW = 1.6 \text{ m (5.2 ft)}$
- Diurnal tide range:
 $MHHW - MLLW = 2.2 \text{ m (7.3 ft)}$



Wind

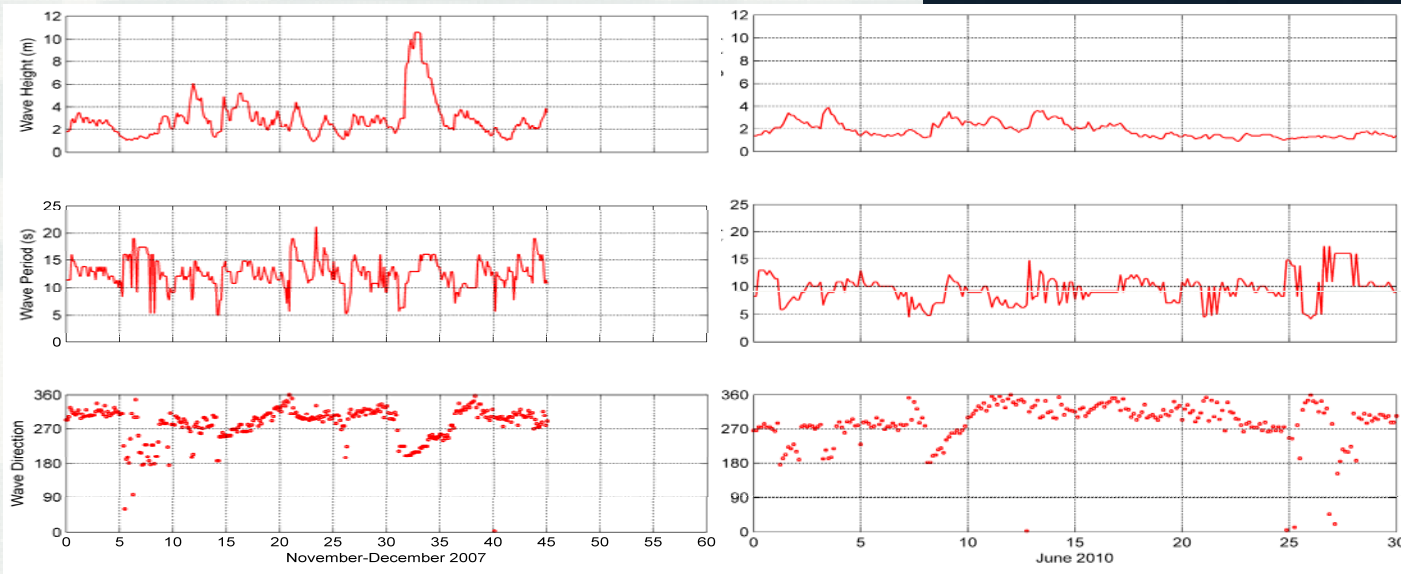
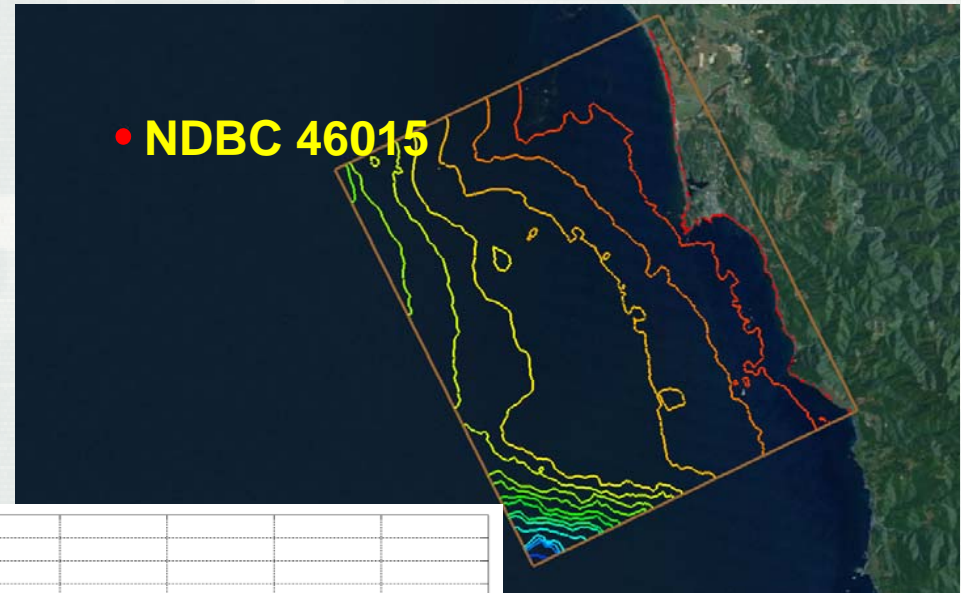
- Wind at NDBC Buoy 46015
- Surface boundary forcing
- Wind direction:
0° North, 90° East, etc.
from which wind blowing



Waves

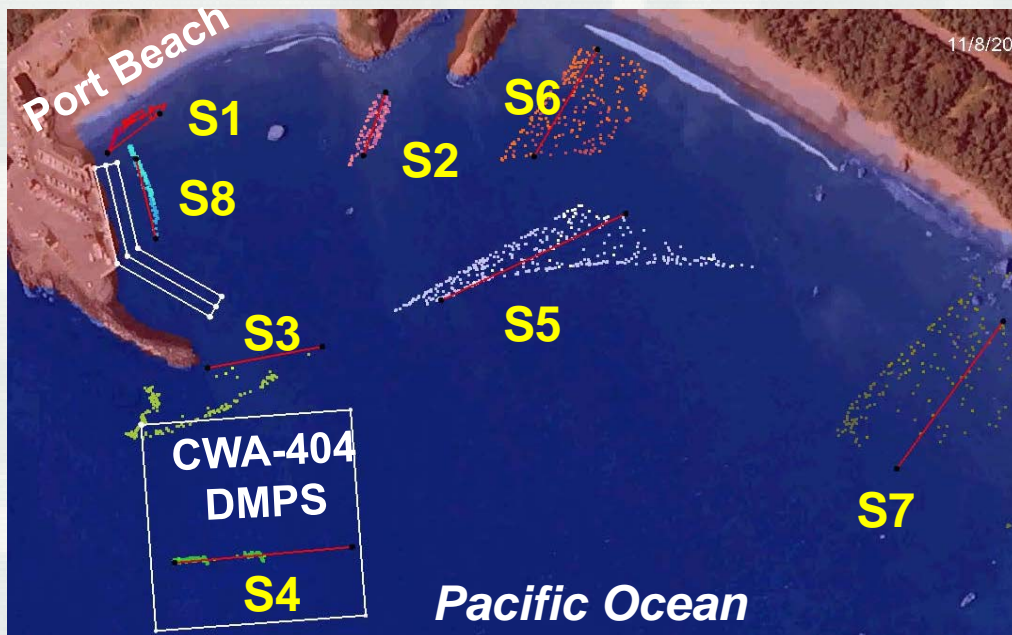
- Wave transformation to seaward boundary

First winter storm and an extreme winter storm



Summer month

Particle Tracking Model (PTM)



Sediment sources

Sediment sinks



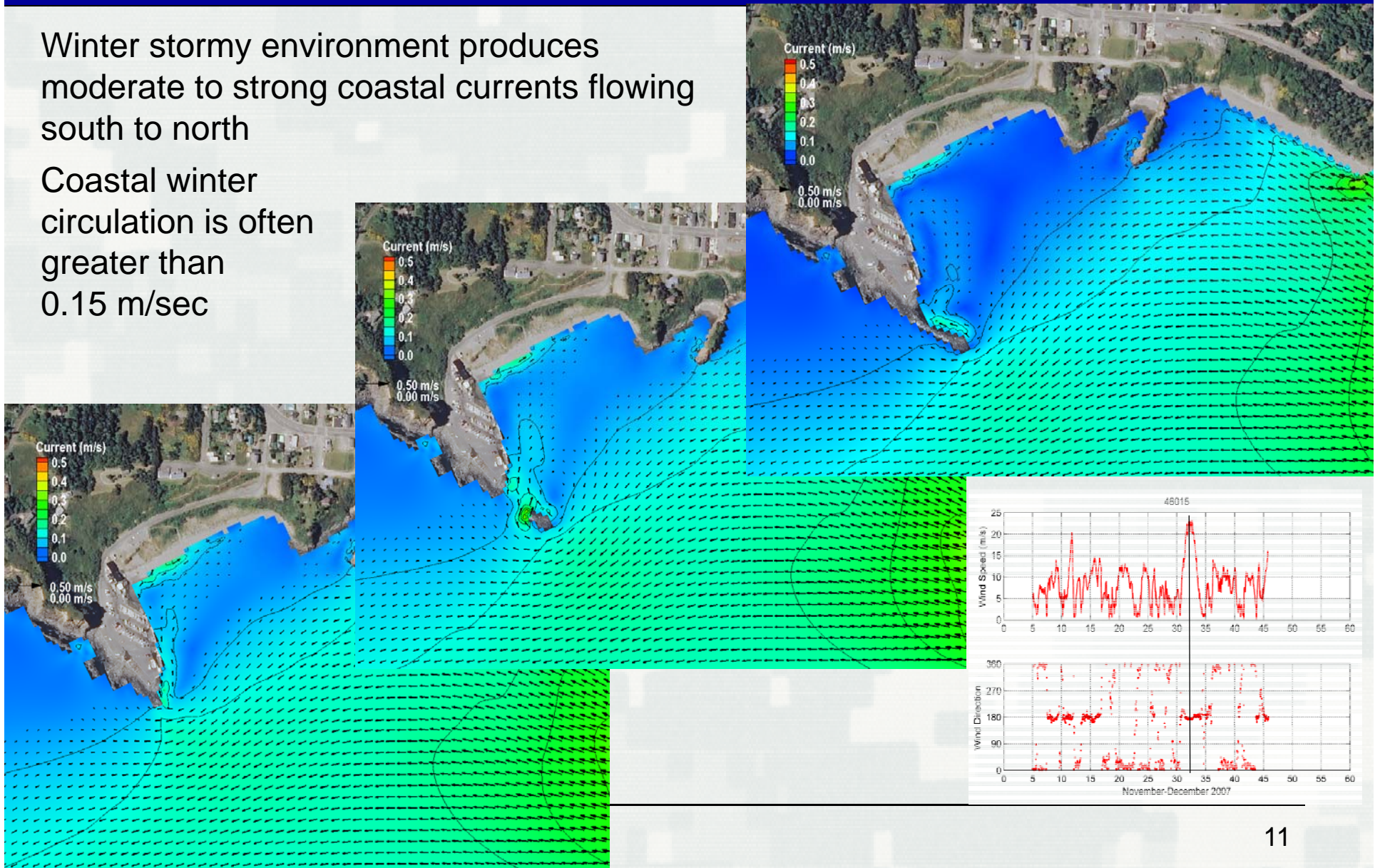
- Specify erosion sediment sources and sediment traps to assess sediment transport pathways
- Evaluate sediment transport for different configurations of the breakwater to alleviate channel shoaling

Current

(Extreme Winter Storm, 3 December, 2007)

Winter stormy environment produces moderate to strong coastal currents flowing south to north

Coastal winter circulation is often greater than 0.15 m/sec

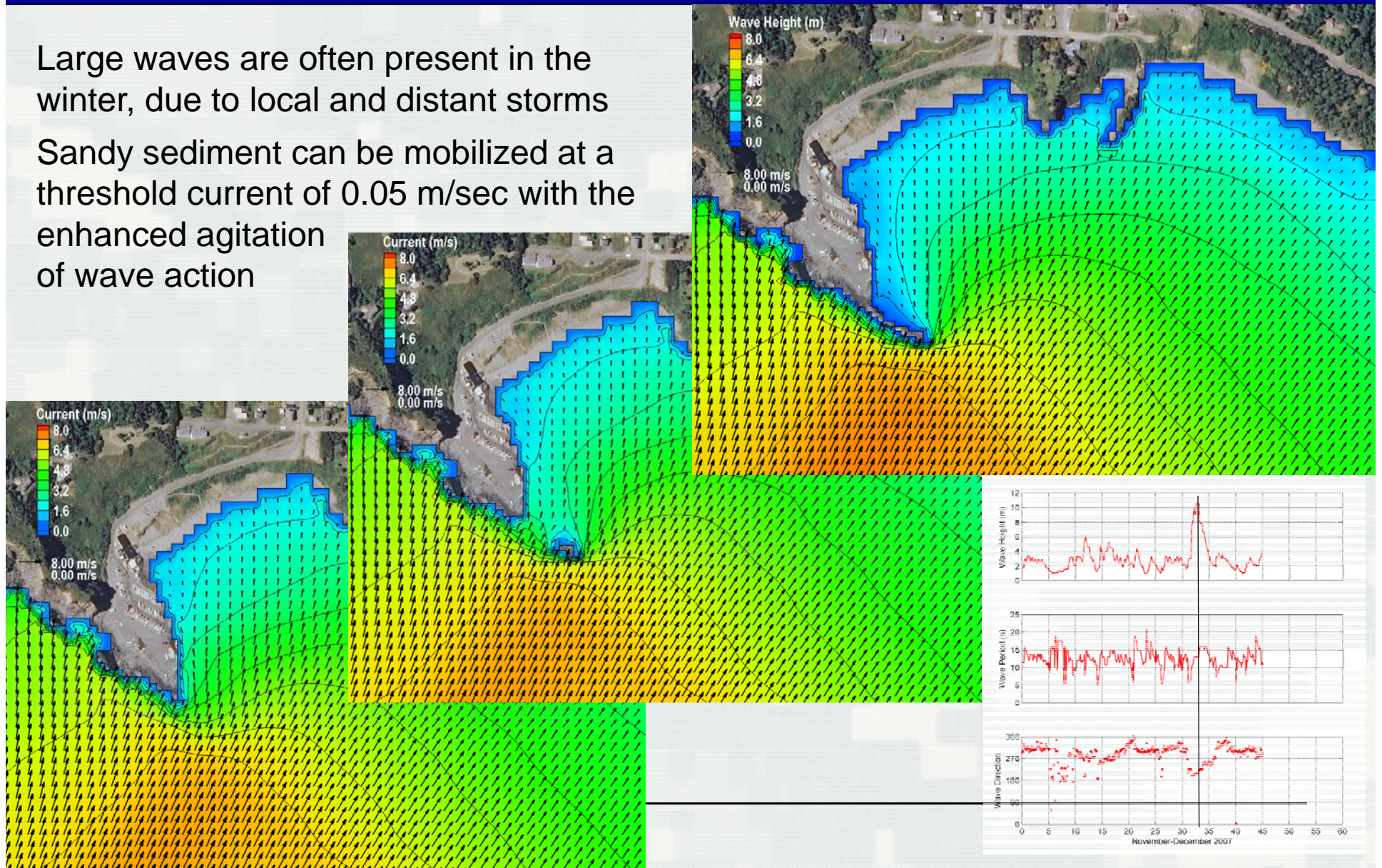


Waves

(Extreme Winter Storm, 3 December, 2010)

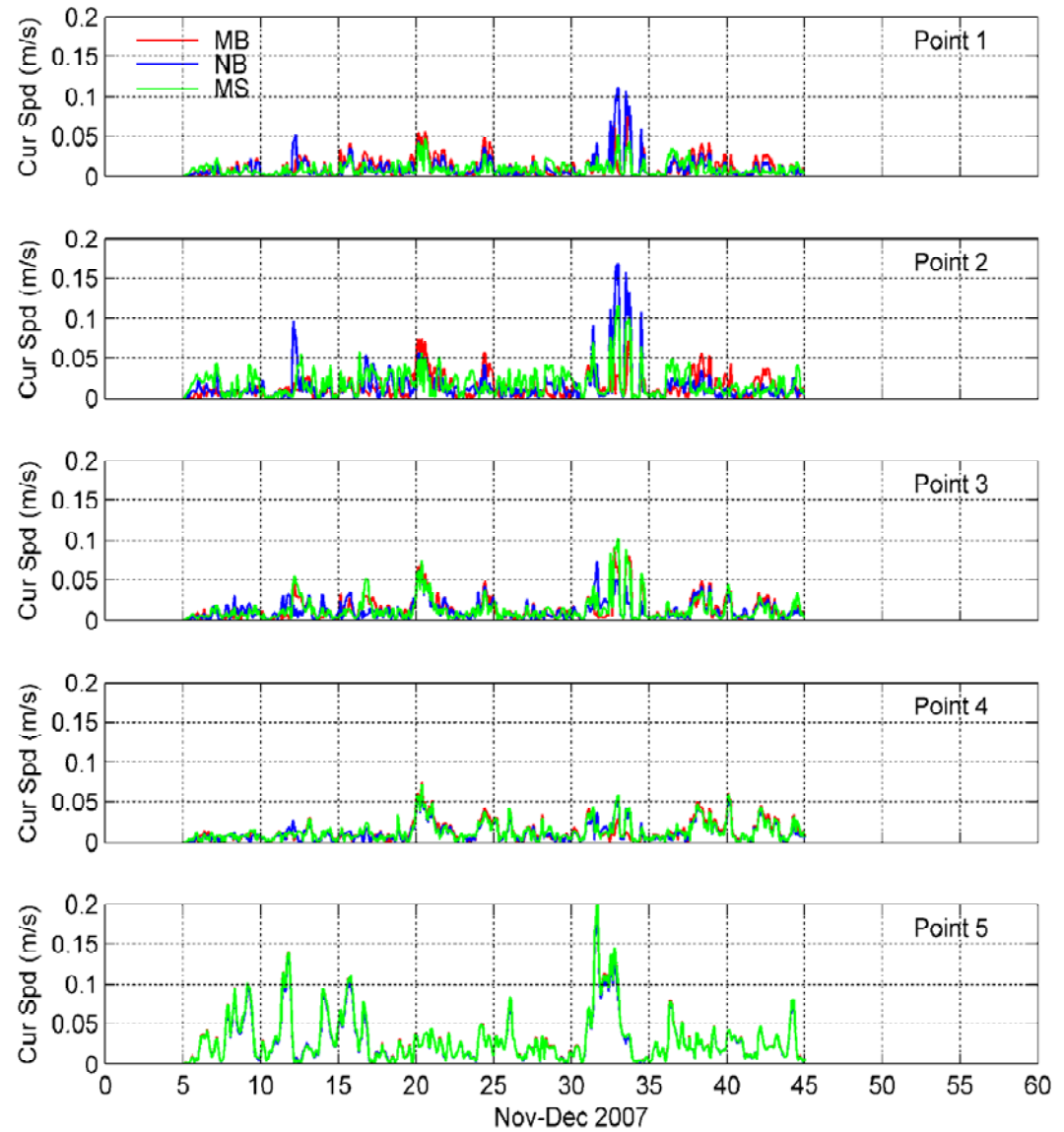
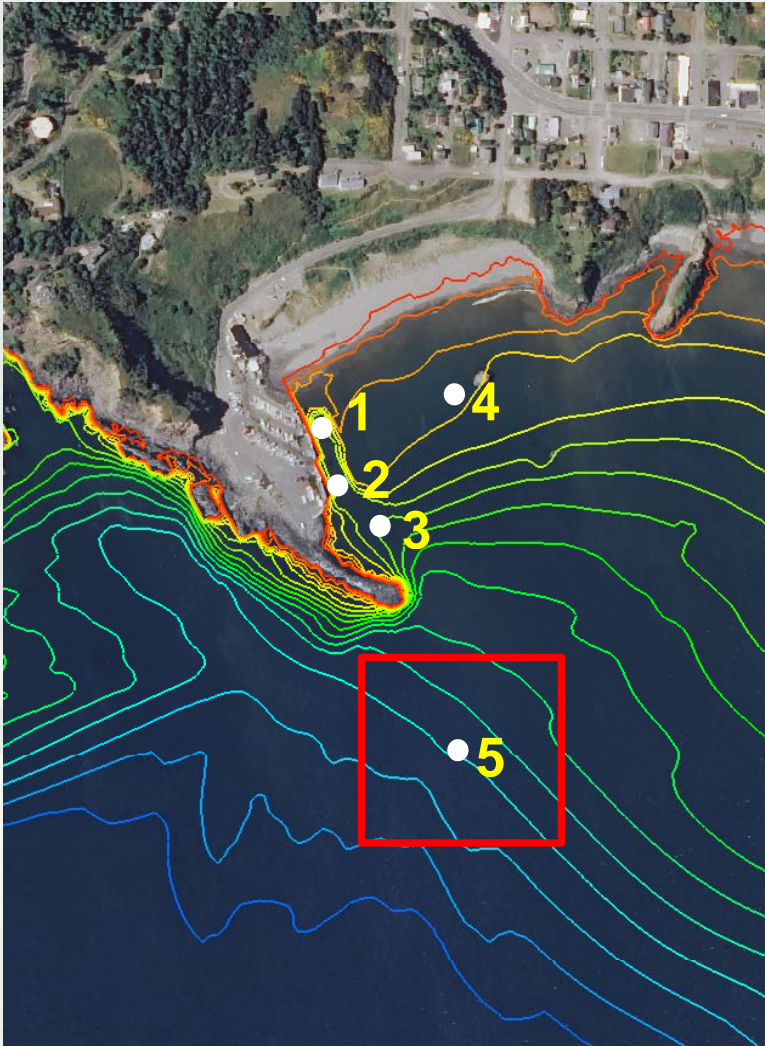
Large waves are often present in the winter, due to local and distant storms

Sandy sediment can be mobilized at a threshold current of 0.05 m/sec with the enhanced agitation of wave action



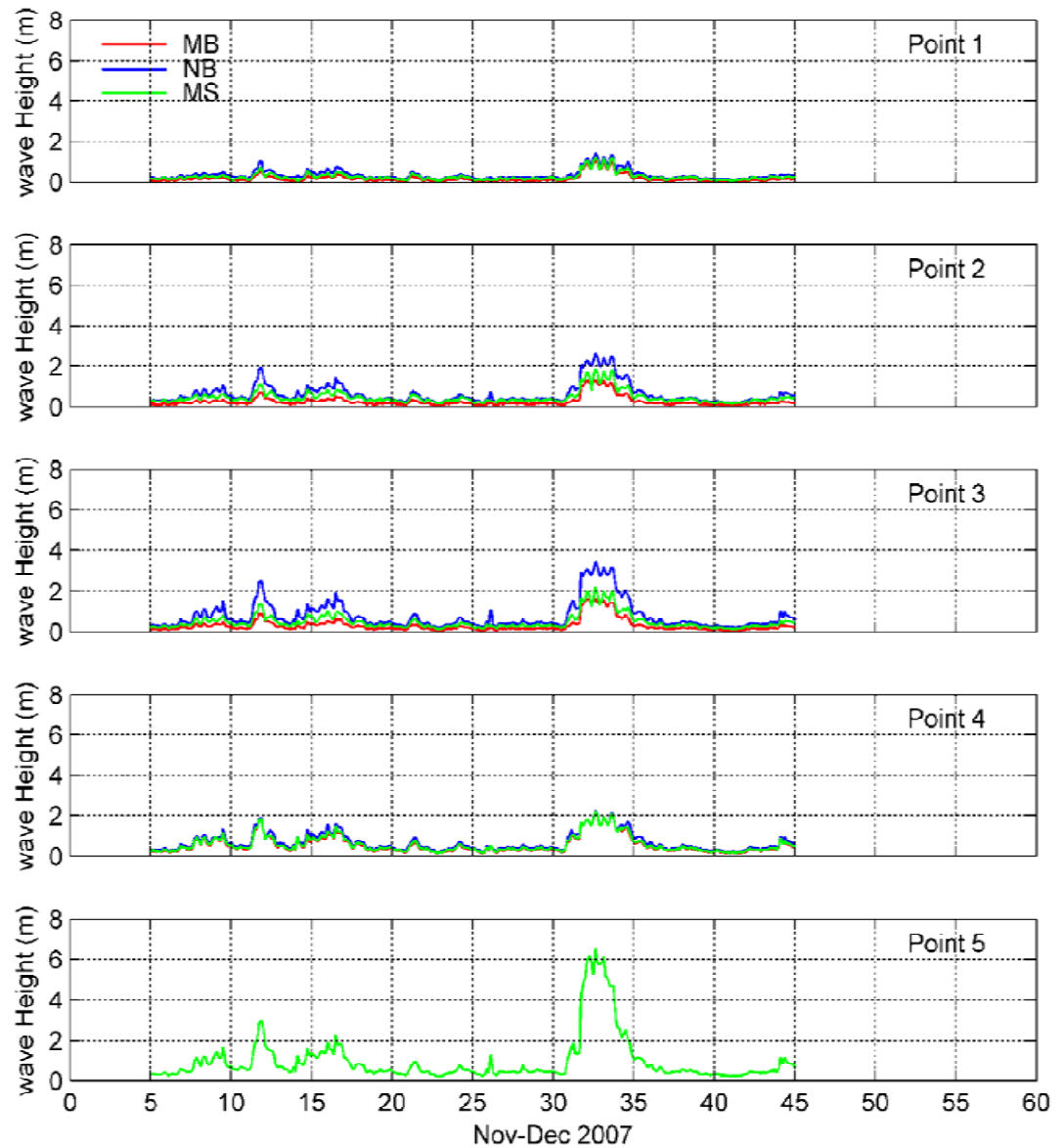
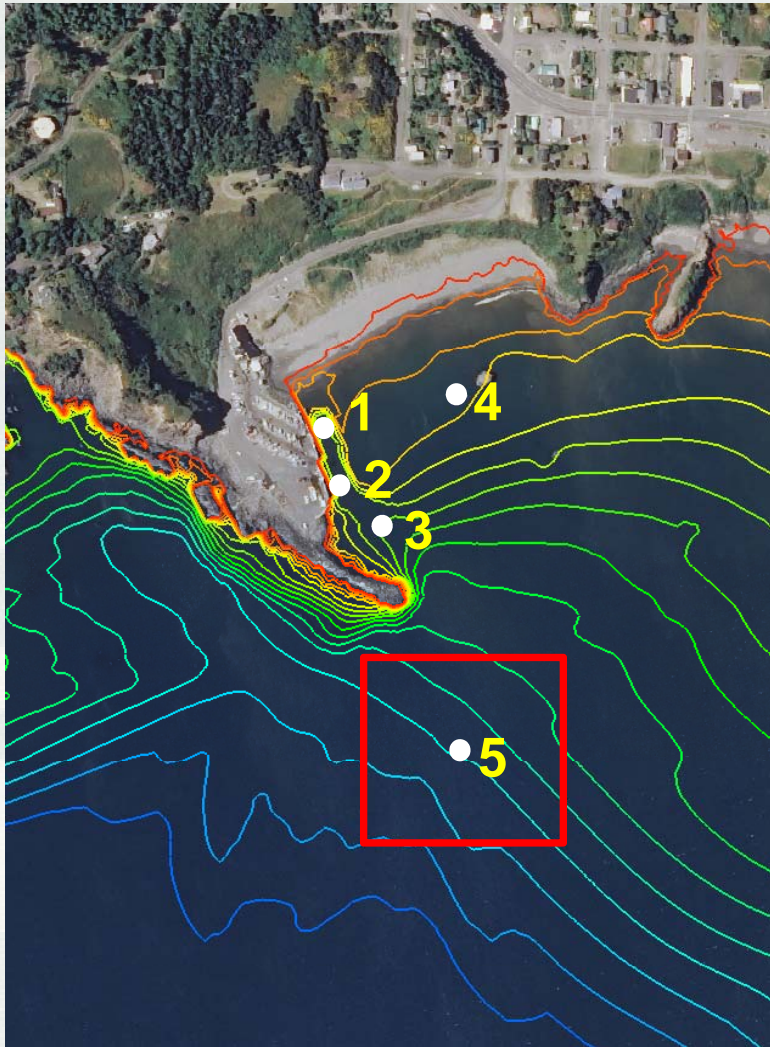
Current at 5 Selected Sites

(6 November – 15 December, 2007)



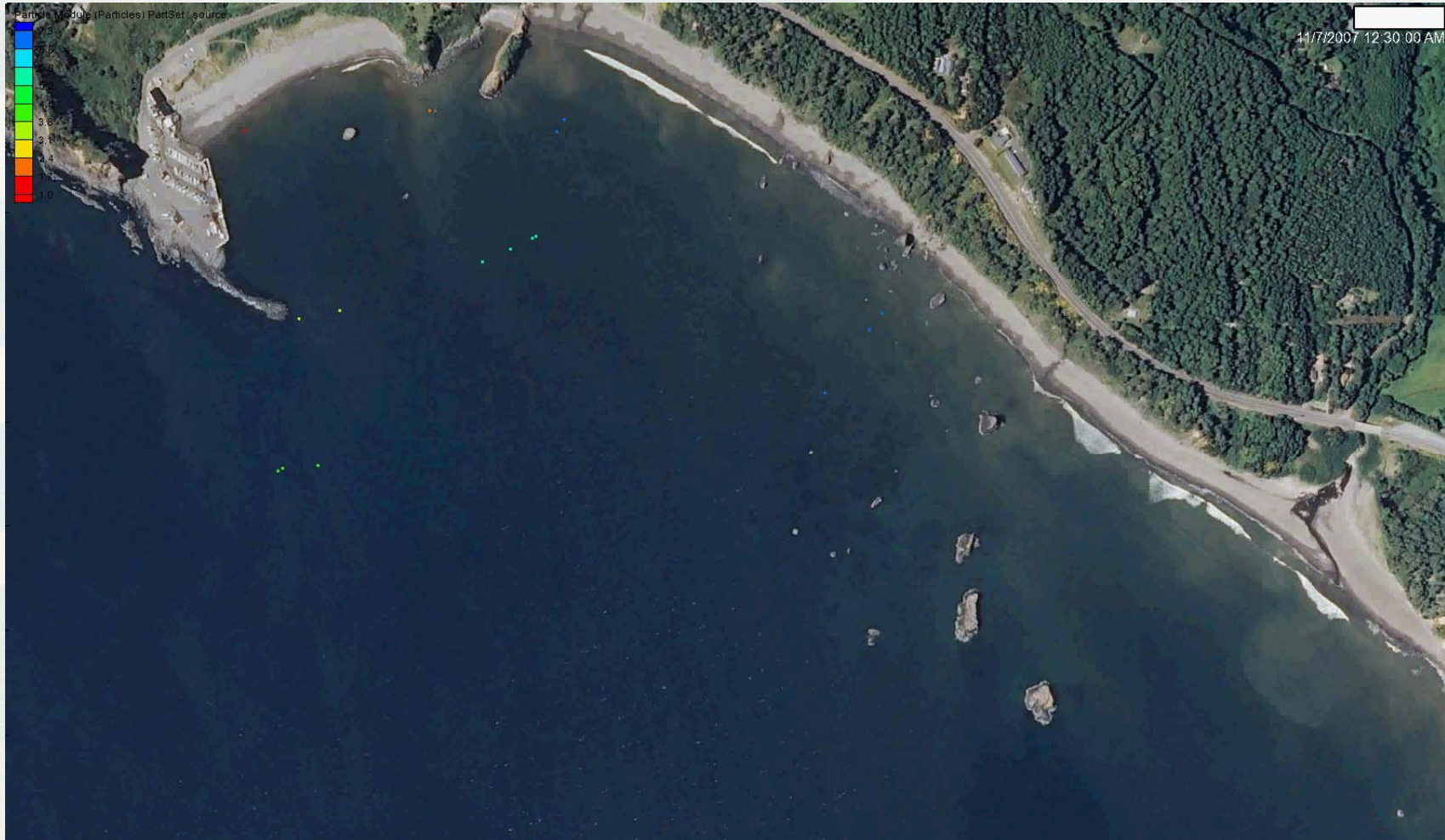
Waves at 5 Selected Sites

(6 November – 15 December, 2007)



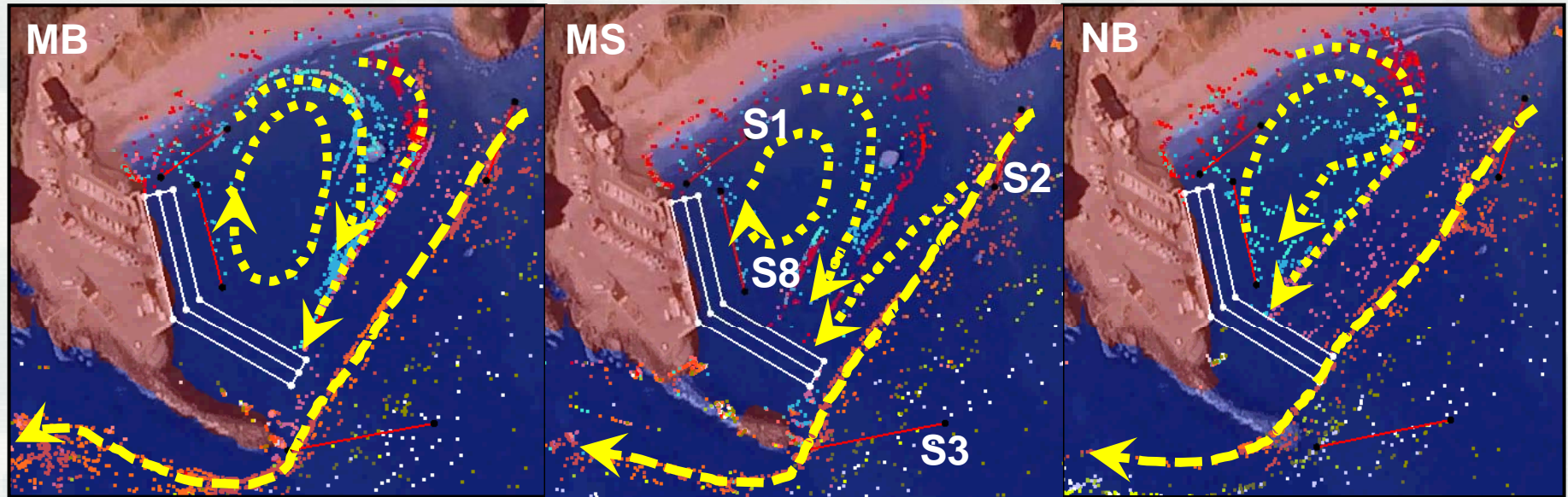
Particle Parthways

(6 November – 15 December, 2007)



Sediment Pathways

(3 December 2007)



S1 - Local Beach

S2 - Harbor-Embayment

S3 - Nearshore

S4 - CWA-404-DMPS

S5 - Nearshore

S6 - Updrift Littoral

S7 - Updrift Littoral

S8 - Harbor-Embayment

Mean grain size: 0.45 mm

Total sediment release: 850 (10-kg) parcels/day

MB: S1, S2, S8, and S6 contribute to most of the channel shoaling

MS and NB: additional sediment from source S7

NB: S1, S2, S5, S6, S7, and S8 contribute to channel shoaling

Sediment Accumulation in the Channel

(6 November – 15 December 2007)

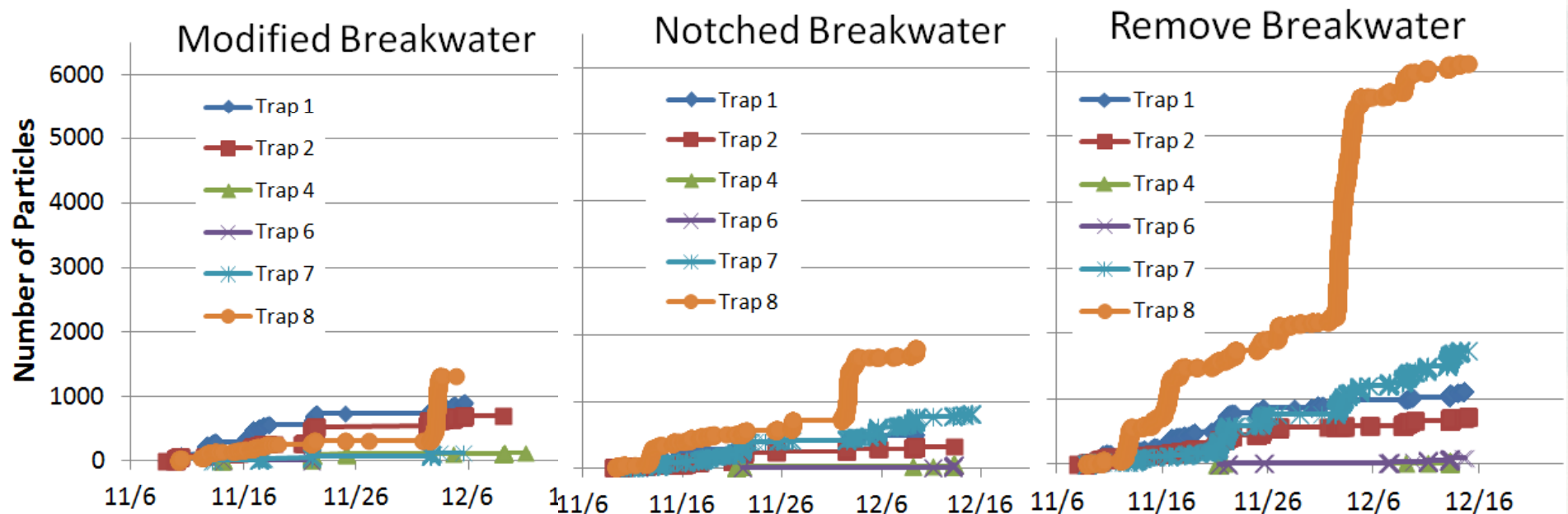
Times and locations of sediment parcels contributing to shoaling within the channel

MB: S1, S2, S8, and S6 contribute to most of the FNC shoaling

MB and MS have the same amount of shoaling within the channel

NB: 200% more shoaling than the others

Rapid infill of the channel due to winter storms (persist for 1-3 days)



Summary

- Coastal area around Port Orford is located in a wave dominated environment. Depth averaged current is weak ($\sim < 0.1$ m/s). Large long-shore current occurs south of the area during southerly waves.
- Wave height is greater than 2.0 m (6.5 ft) in front of the dock during an large winter storm (southerly waves).
- Restored breakwater can effectively protect the harbor from southerly waves. Without the breakwater, the refracted wave heights can be more than doubled in the harbor.
- Wave actions are more likely to enhance the transport of sediment due to wave-induced sediment resuspension.
- Rapid channel infilling occurs at Port of Port Orford due to the establishment of sustained sediment transport pathways during winter storms (southerly waves). The infilling is more severe for the breakwater removal case.

An aerial photograph of a coastal town and bay. The town is built on a hillside overlooking a large body of water. The text is overlaid in the center of the image.

Thank You!
Questions?

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