

Dangerous Great Lakes Nearshore Waves and Currents: Field and Satellite Observations

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...and many others at

Great Lakes Research Center (GLRC)

Michigan Tech Research Institute (MTRI)

and University of Michigan

SOLM / GLBA Meeting

October, 2015

Coastal Framework: Rip Currents Great Lakes vs. Ocean Coasts

- Classic wisdom (Scripps):
 - Sheppard et al., 1941; Sheppard & Inman, 1950
 - Bowen, 1969; Bowen and Inman, 1969
- West Coast research dominated rip current theory
 - Long period swell
 - Surf beat
 - Pocket beaches
 - “Mellow waves”
- Organized incident waves \Rightarrow Organized nearshore flows - Rips

Swell vs. Sea

Great Lakes:
Dominated by locally generated seas



Beaches change quickly...

- Above the water

- On the water and

- Below the water



St Joseph, MI



This is not new knowledge, just new to modern scientists...

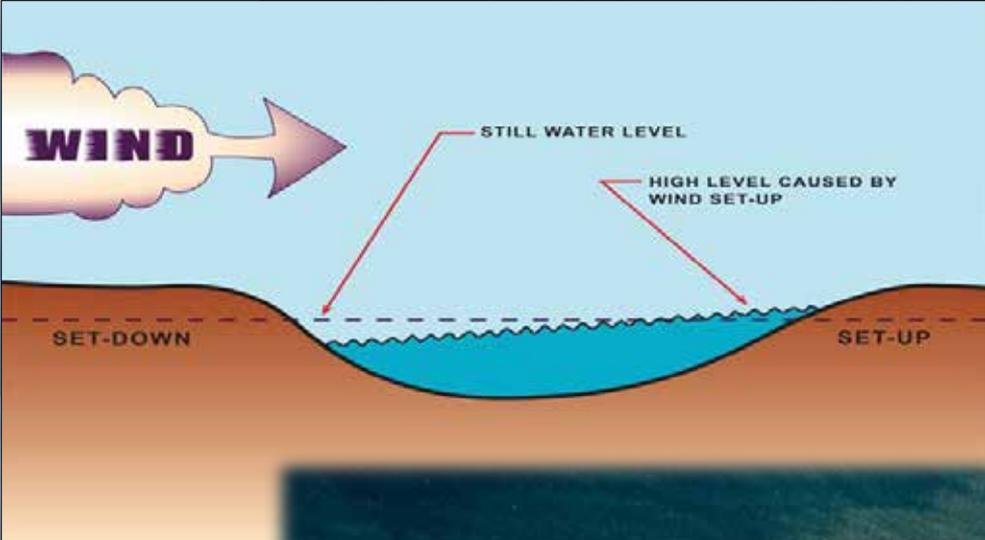
“Rip current monster” is also known as mishibizhii... aka, the “big panther” or the “ojibwe water panther. ”



Great Lakes Dynamics

- Locally generated seas accompanied by very strong and rapidly evolving wind fields
- Small astronomical tides, but large “wind tides”
Seiches
- Producing strong, rapidly evolving: Dangerous Nearshore Currents (DNCs)
 - Longshore currents
 - Rip currents
 - Structural currents
 - Outflow currents (drown river mouths)

Great Lakes Dynamics



Current Related Incidents 2002-2014

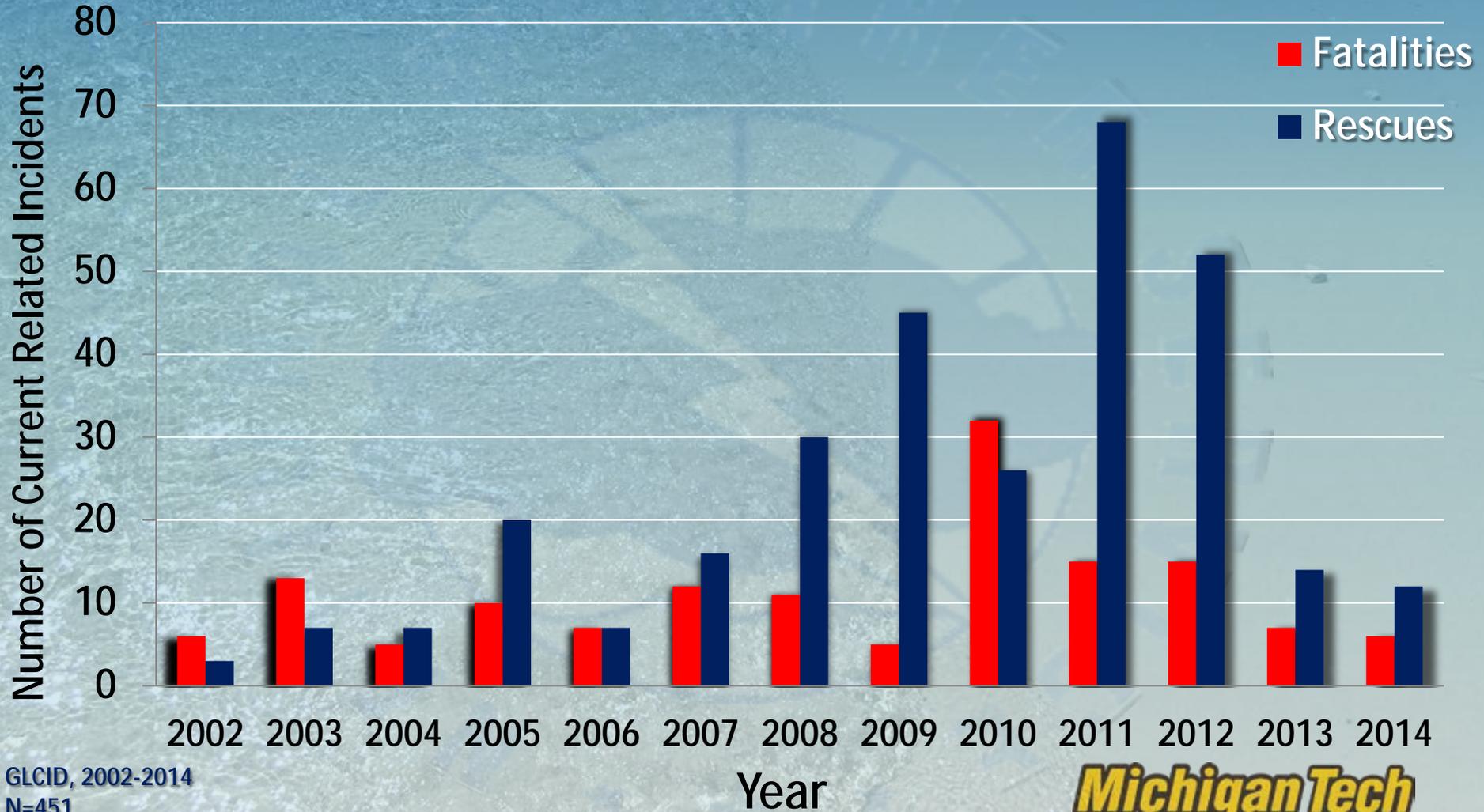
NWS Database

Victims

Conditions

Current Types

Conclusions



GLCID, 2002-2014
N=451

Michigan Tech
Great Lakes Research Center

Dangerous Nearshore Waves and Currents

(MDEQ funded)

Three components:

1. Rip Currents in the Great Lakes: Advancing Forecasting through Perishable Data Recovery
1. Remote Sensing-based Detection and Monitoring of Rip Currents in the State of Michigan
1. Implementation at Michigan State Parks

(1) Rip Currents in the Great Lakes: Advancing Forecasting through Perishable Data Recovery

- Three Test sites
 - Hwy 2 Northern Lake Michigan
 - Grand Haven State Park
 - Holland State Park
- Fall 2012 – Hwy 2 – Equipment Tests
- Spring 2013 (May 13 – 24) & Spring 2014 (May 11- 17)
 - Grand Haven State Park
 - Holland State Park
- Fall 2013 (Sept 16 – 19)
 - Hwy 2 Northern Lake Michigan

The overall research program is designed test two scientific hypotheses:

- **Hypothesis 1:**

- Wind induced seiche in the enclosed basins of the Great Lakes is dynamically similar to tidal height variations on open ocean coasts in intensifying wave generated rip currents.

- **Hypothesis 2:**

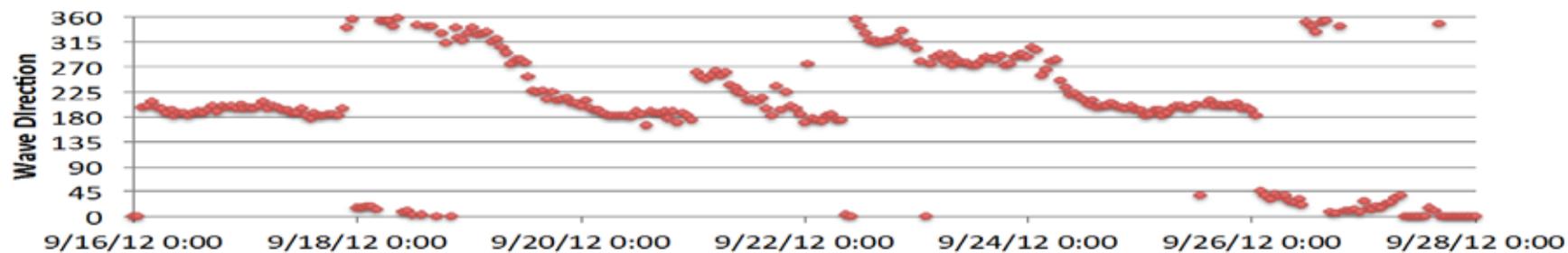
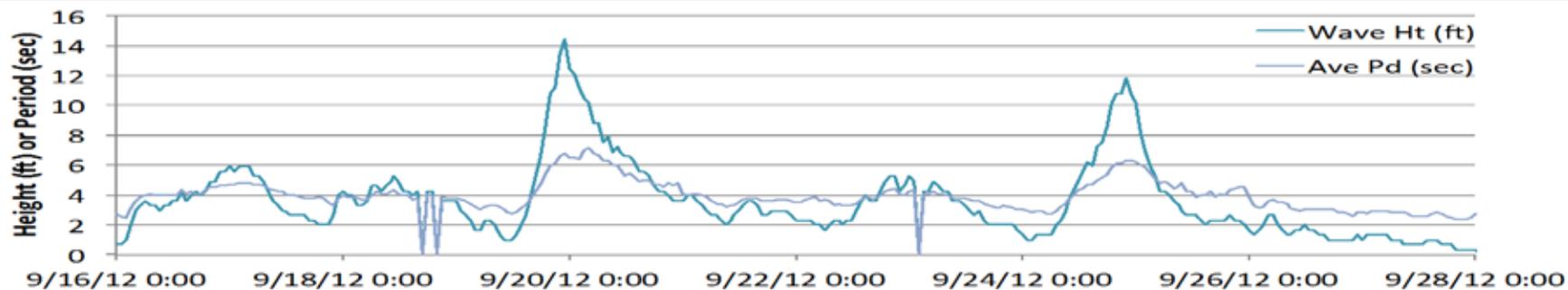
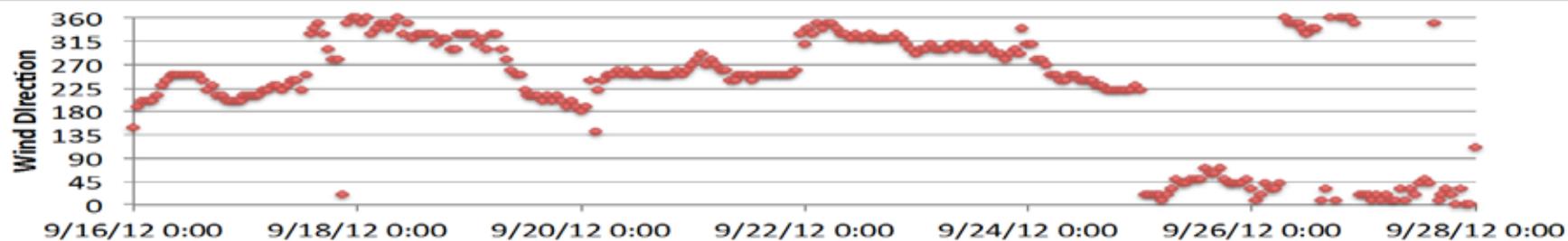
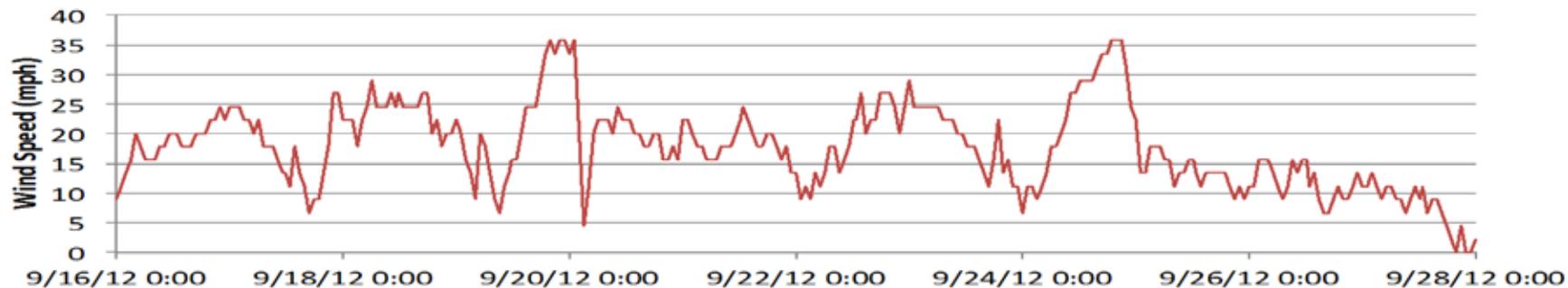
- On barred beaches rip spacing is not related to characteristic dimensions of the incident wave field or pre-existing morphology of the beach and nearshore system.

Fall 2012 – Hwy 2 – Equipment Test

September 24 – 28, 2012

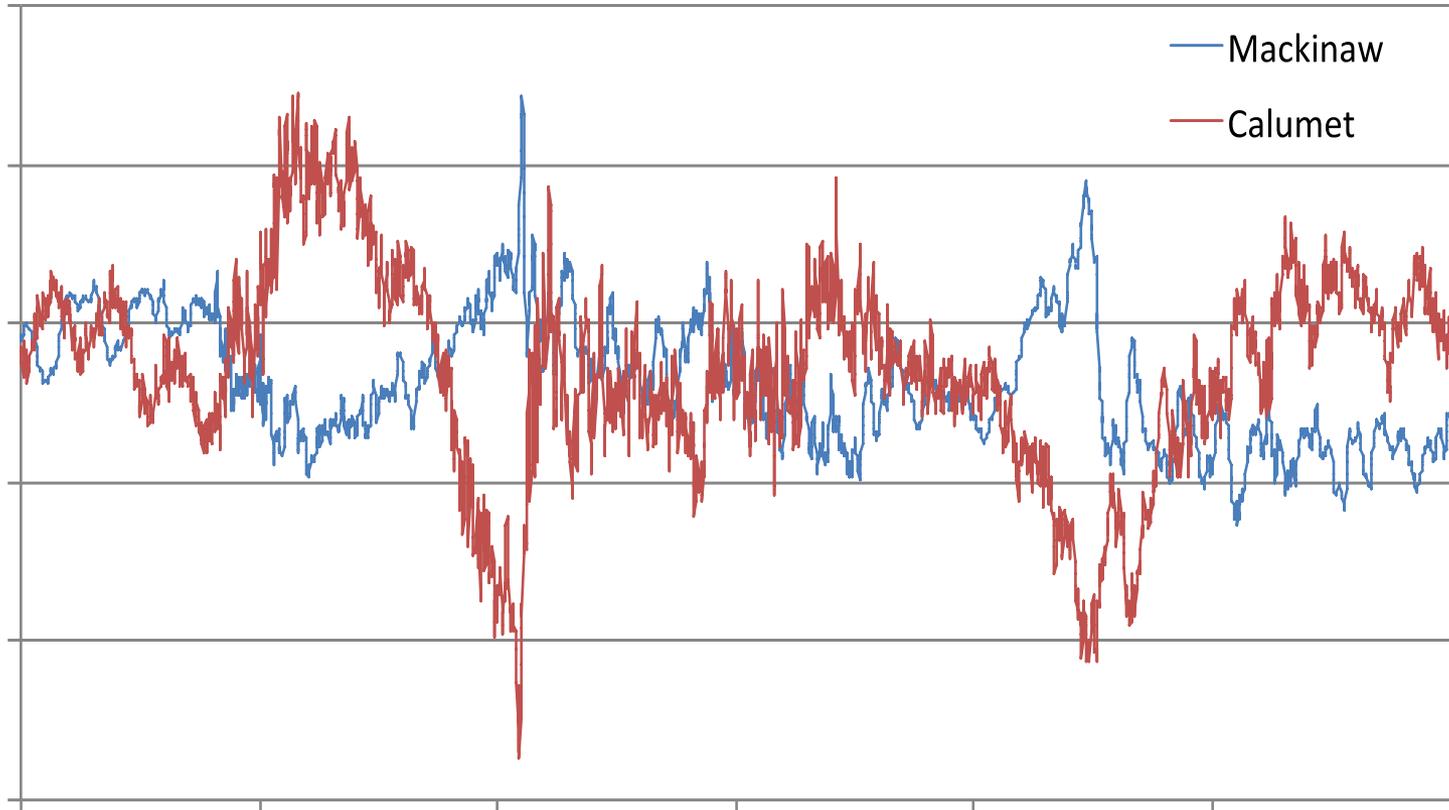


Environmental Conditions: Significant Storms Sept. 19 & 24-25



Environmental Conditions: Significant Storms Sept. 19 & 24-25

an Elevation (ft - IGLD 1985)



Environmental Conditions: Significant Storms Sept. 19 & 24-25

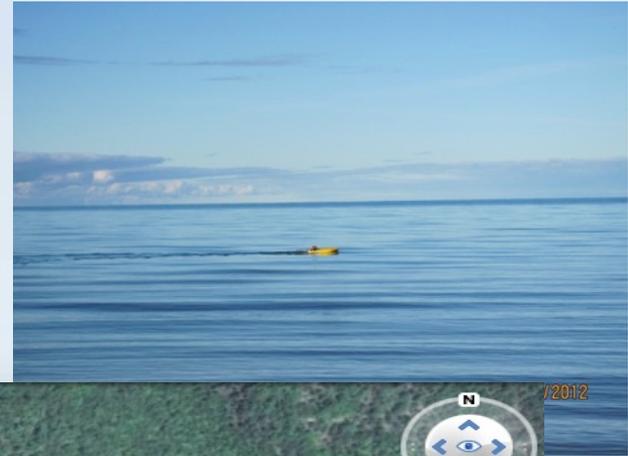


Perishable Data

Bathymetry – Three ways



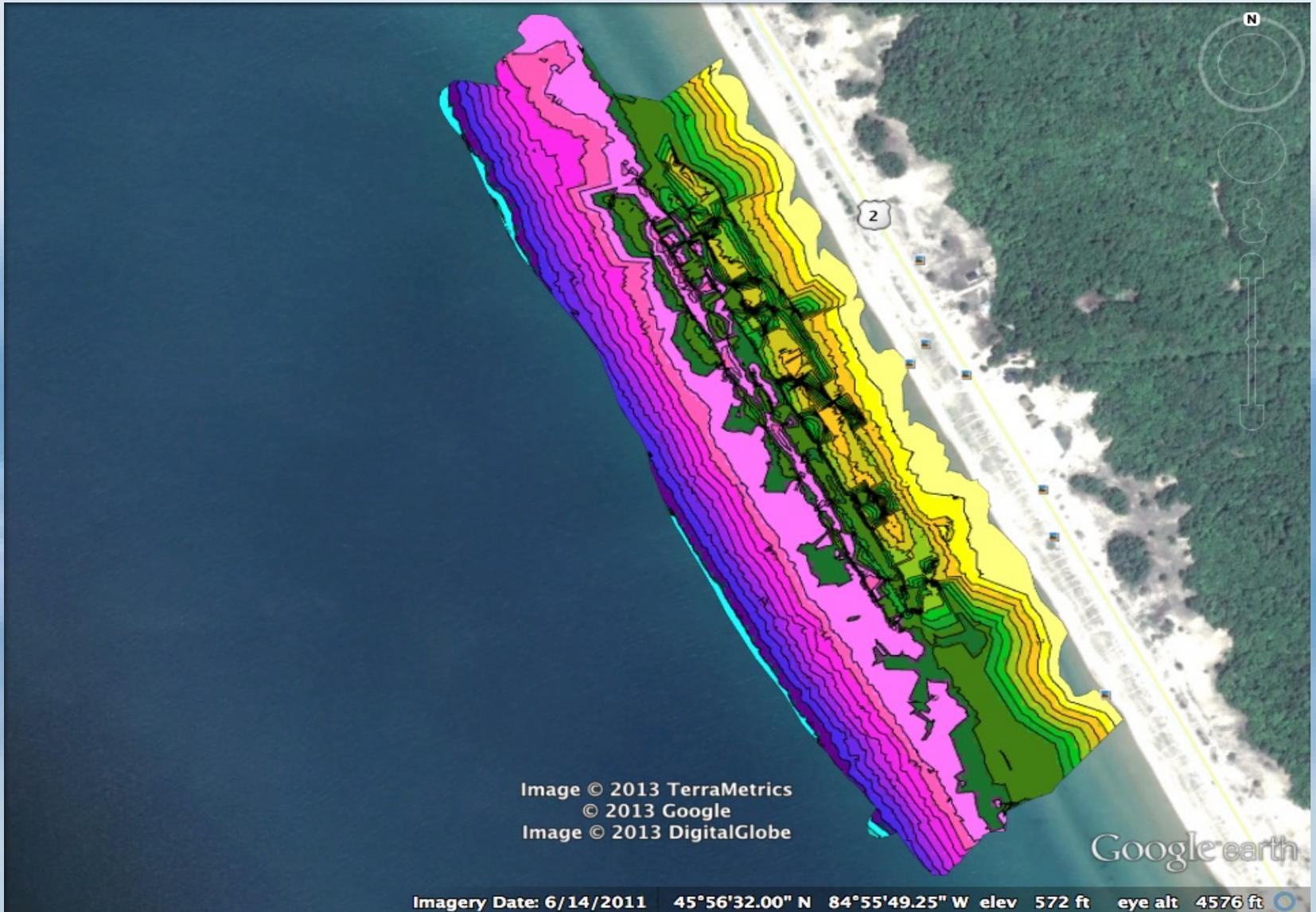
BathyBoat



Autonomous Underwater Vehicle (AUV)



Composite Bathymetry



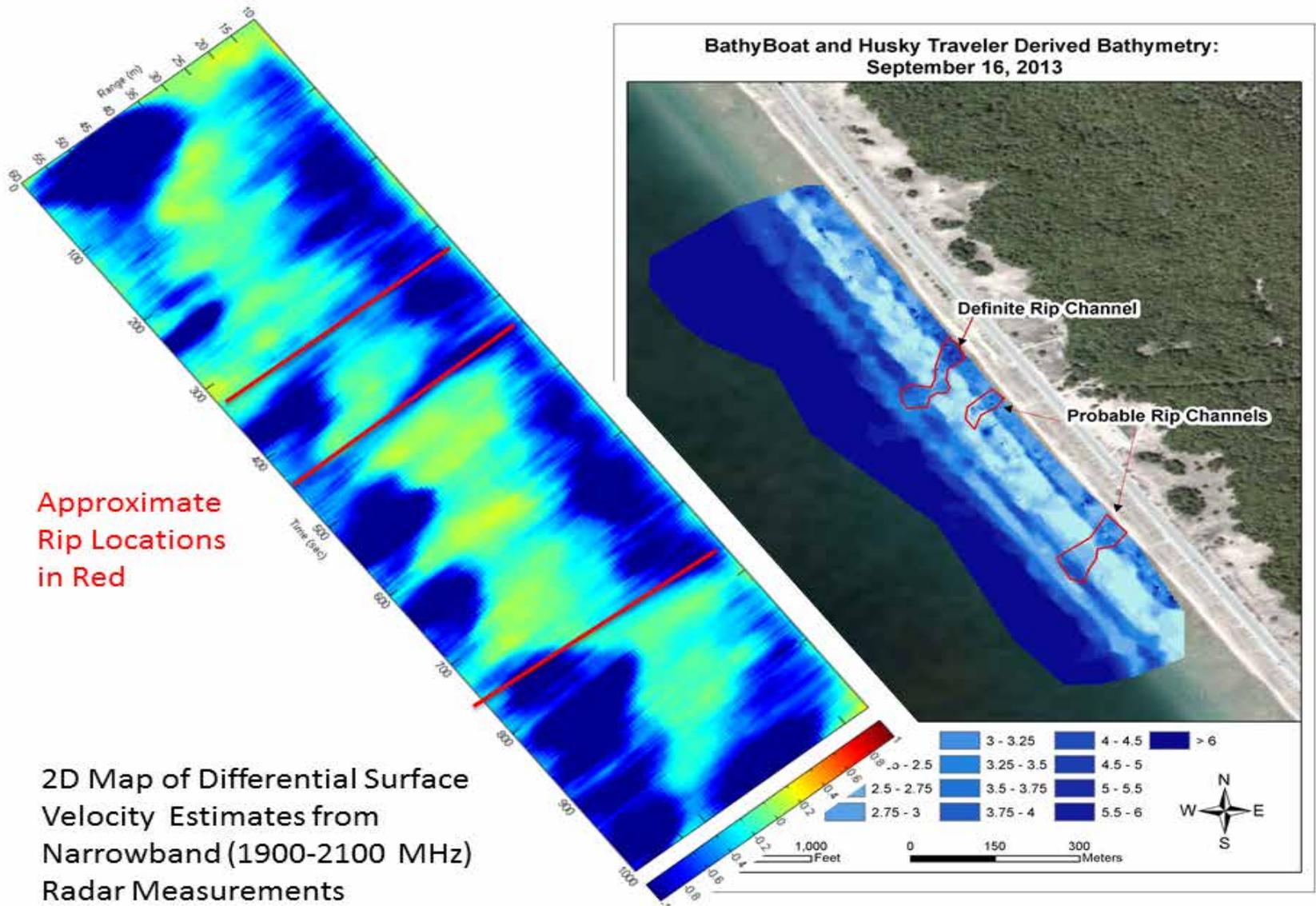
GPS Drifters and New Radar (MTRI)



HWY 2 - Radar Measurements



Promising Radar Results

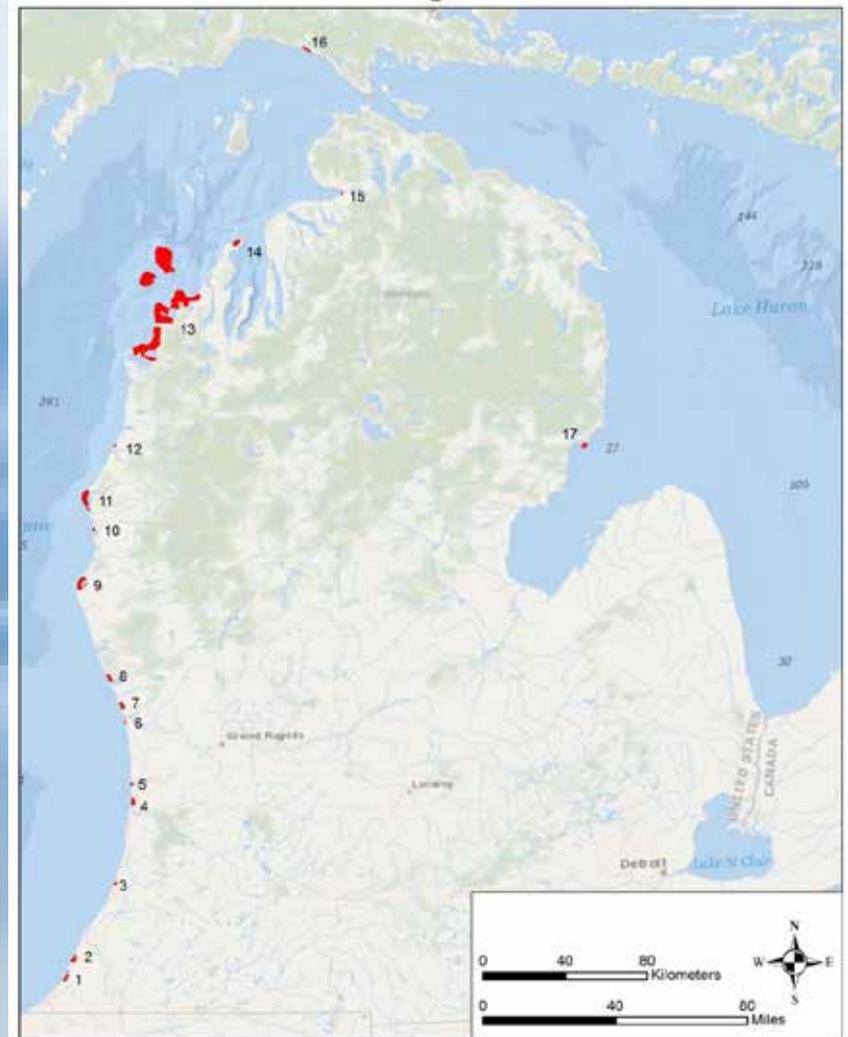


Winter HWY 2



(2) Remote Sensing Project Goals

- Identify areas within Michigan State Park beaches that are prone to rip currents
 - Compile aerial/satellite imagery of State Park beaches
 - Heads-up digitization of rip channels visible in imagery to characterize persistence
- Improve the understanding of the physical features associated with rip current formation



Collected Nearshore imagery for 17 State Parks

	Warren Dunes	Holland	Grand Haven	Hoffmaster	Ludington	Hwy 2 State land near St. Ignace	Tawas Point	Sleeping Bear Dunes	Grand Mere
Images Acquired	11	11	12	13	8	8	11	11	10
Usable images	9	9	10	9	7	7	9	10	8
Images with rip-associated features	7	8	5	8	6	7	3	8	2

	Muskegon	Saugatuck Dunes	Silver Lake	Mears	Petoskey	Leelanau	Van Buren	Orchard Beach
Images Acquired	9	11	8	8	8	8	9	10
Usable images	7	8	7	7	7	7	7	7
Images with rip-associated features	6	3	4	6	7	5	4	5

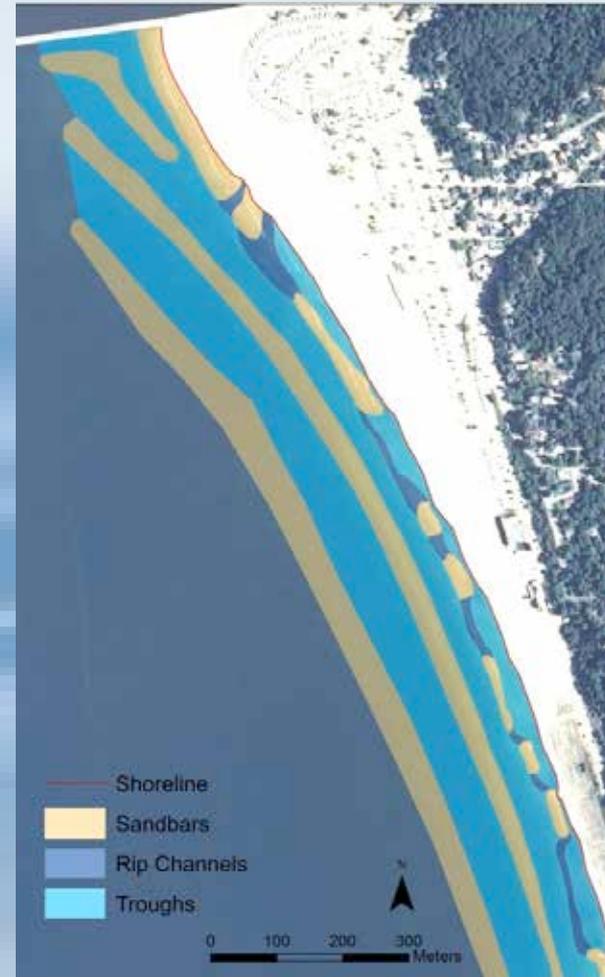
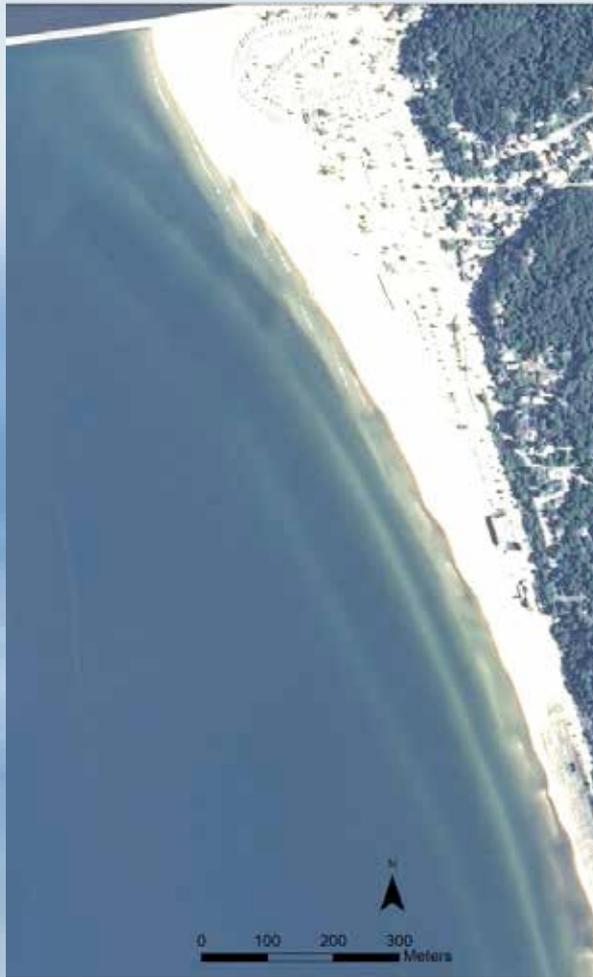
Threat level classification

Frequency of rip feature presence	Threat level
> 50%	High
25 – 50%	Medium
< 25 %	Low
No rip features observed in any image	No Threat

Final products:

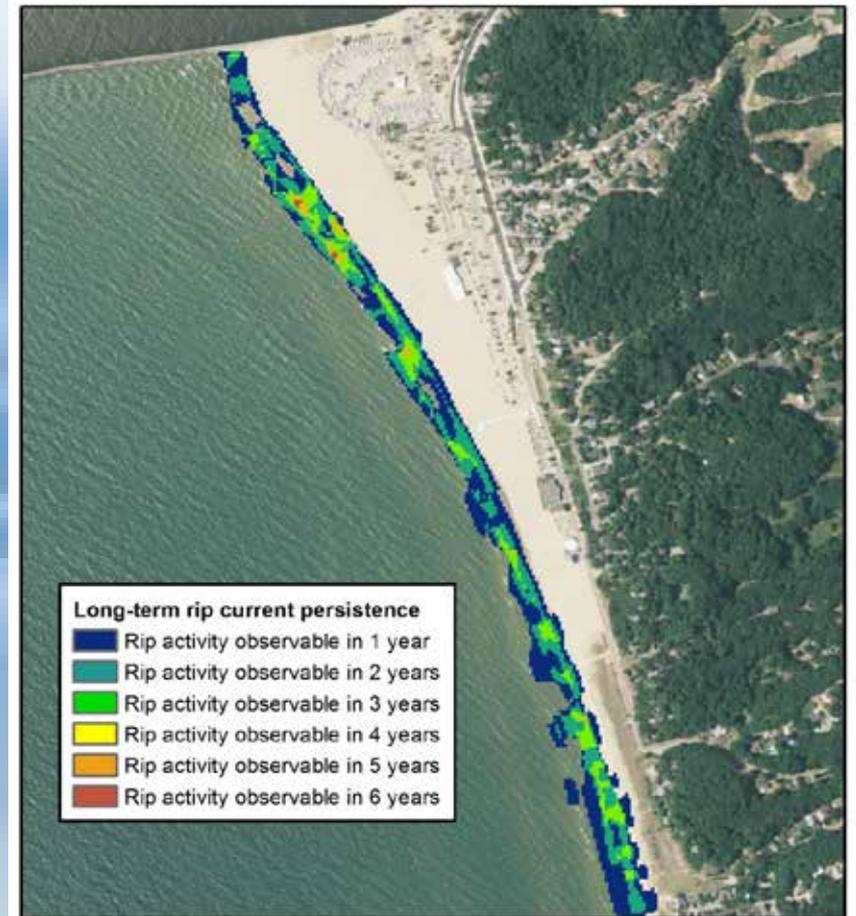
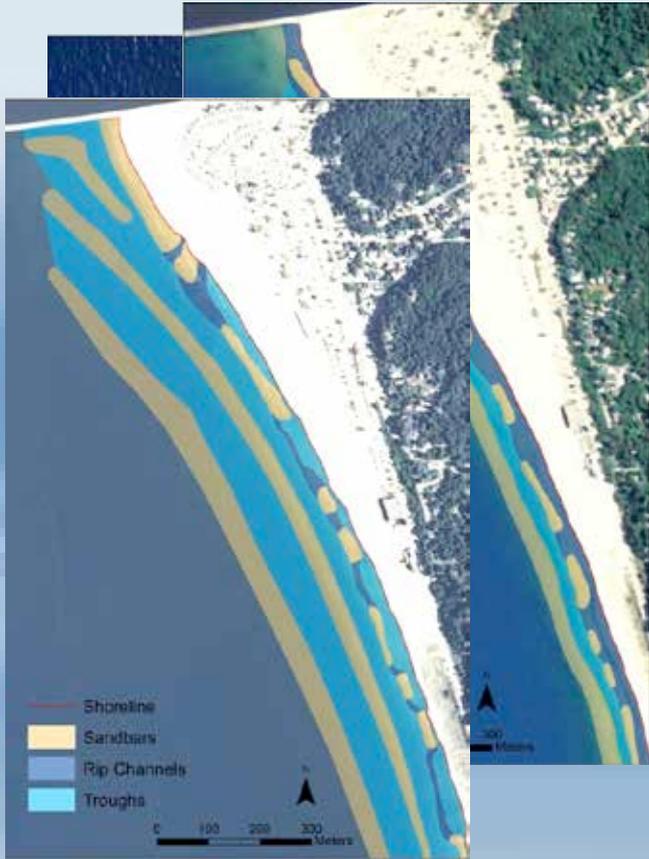
- Heat maps of long-term rip persistence (1998 – 2012)
- Color-coded threat levels

Example: Grand Haven State Park

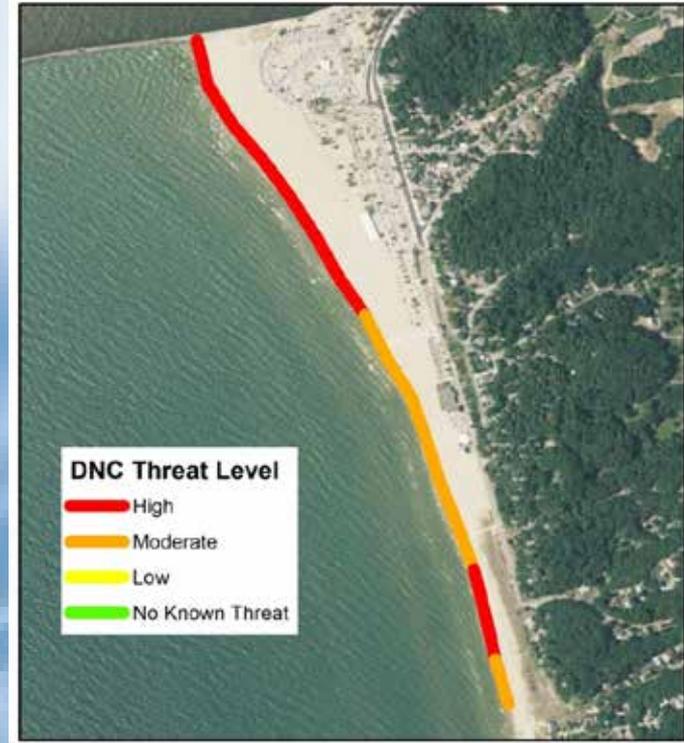
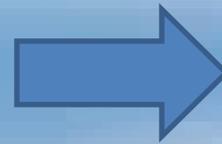
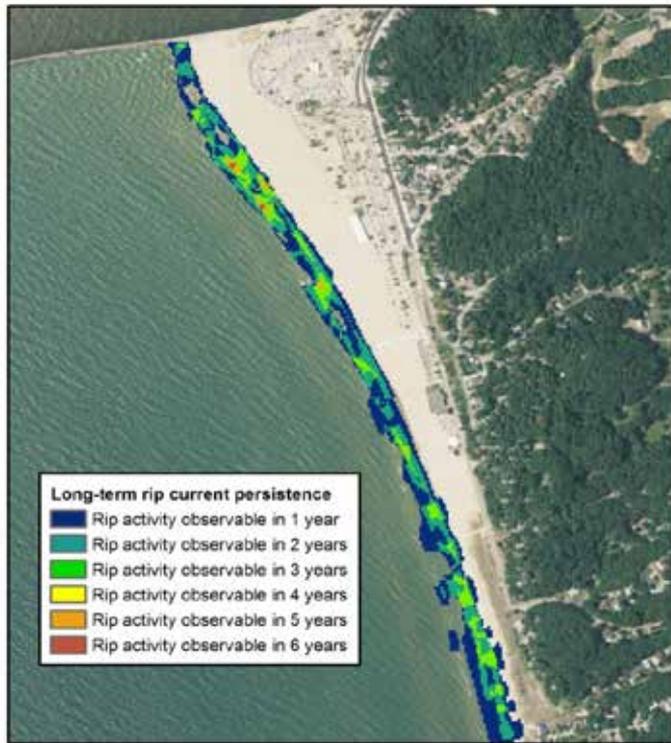


Heads-up digitization of longshore sandbars and rip channels

Compilation of all digitized features into a “heat map” of rip channel locations from 1998-2012



Areas with higher rip channel persistence were assigned higher threat levels



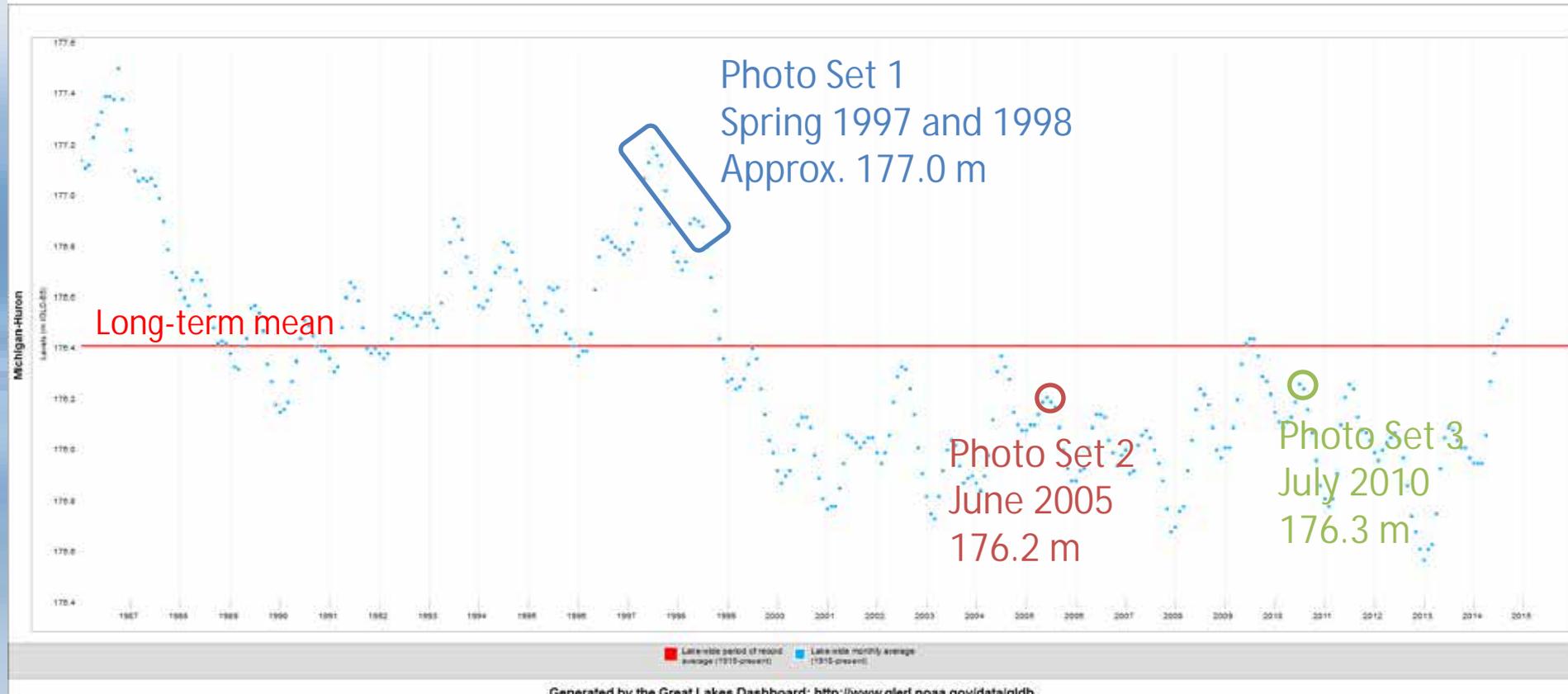
Frequency of rip feature presence	Threat level
> 50%	High
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No rip features observed in any image	No Threat

Lake Michigan rip current patterns

- Rip channel spacing
 - Statewide aerial imagery sets collected at different times were compared to evaluate the effect of changes in lake level on the spacing of rip channels
- Beach slope
 - Beaches where rip channels form frequently were compared to those where they do not in order to look at how beach slope affects rip current formation

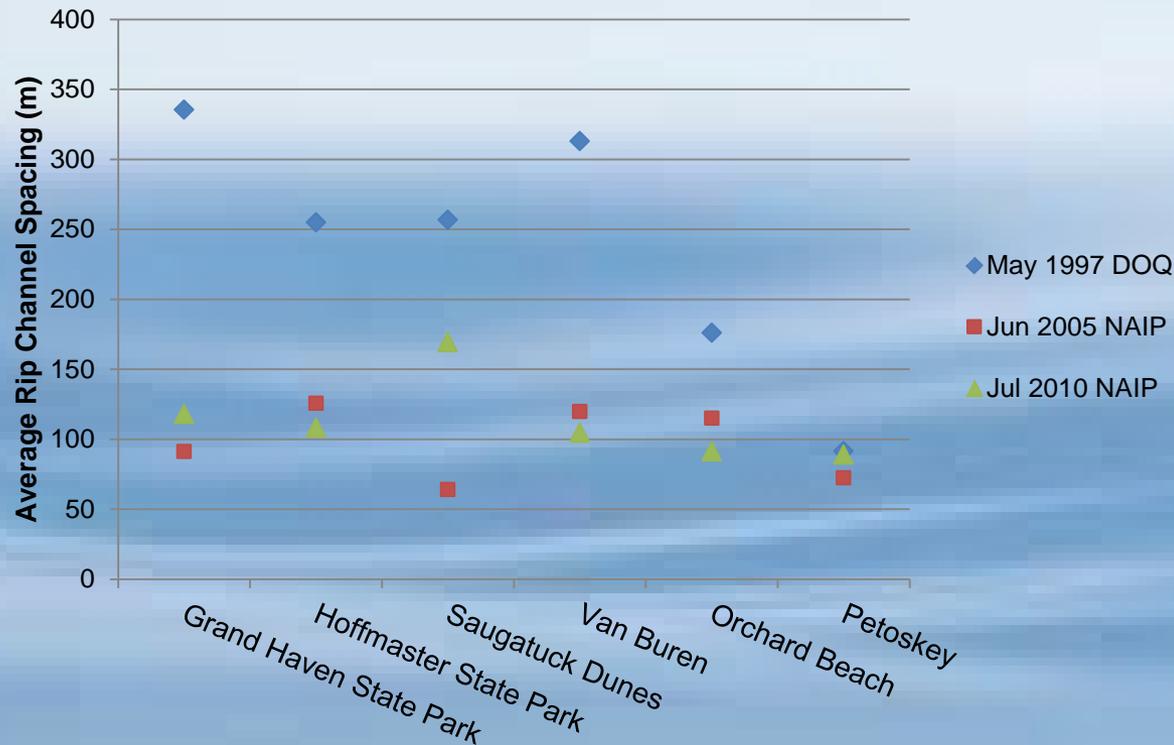
Rip Spacing vs. Changing Lake Level

Michigan-Huron Lake-Wide Water Level
(monthly average, meters above sea level)



Generated by the Great Lakes Dashboard: <http://www.glerl.noaa.gov/data/gldb>

Rip Spacing vs. Changing Lake Level



On average, rip channel spacing across all sites was significantly wider in 1997 (higher water level) than in 2005 ($p = 0.011$) or 2010 ($p = 0.013$) (lower water levels).

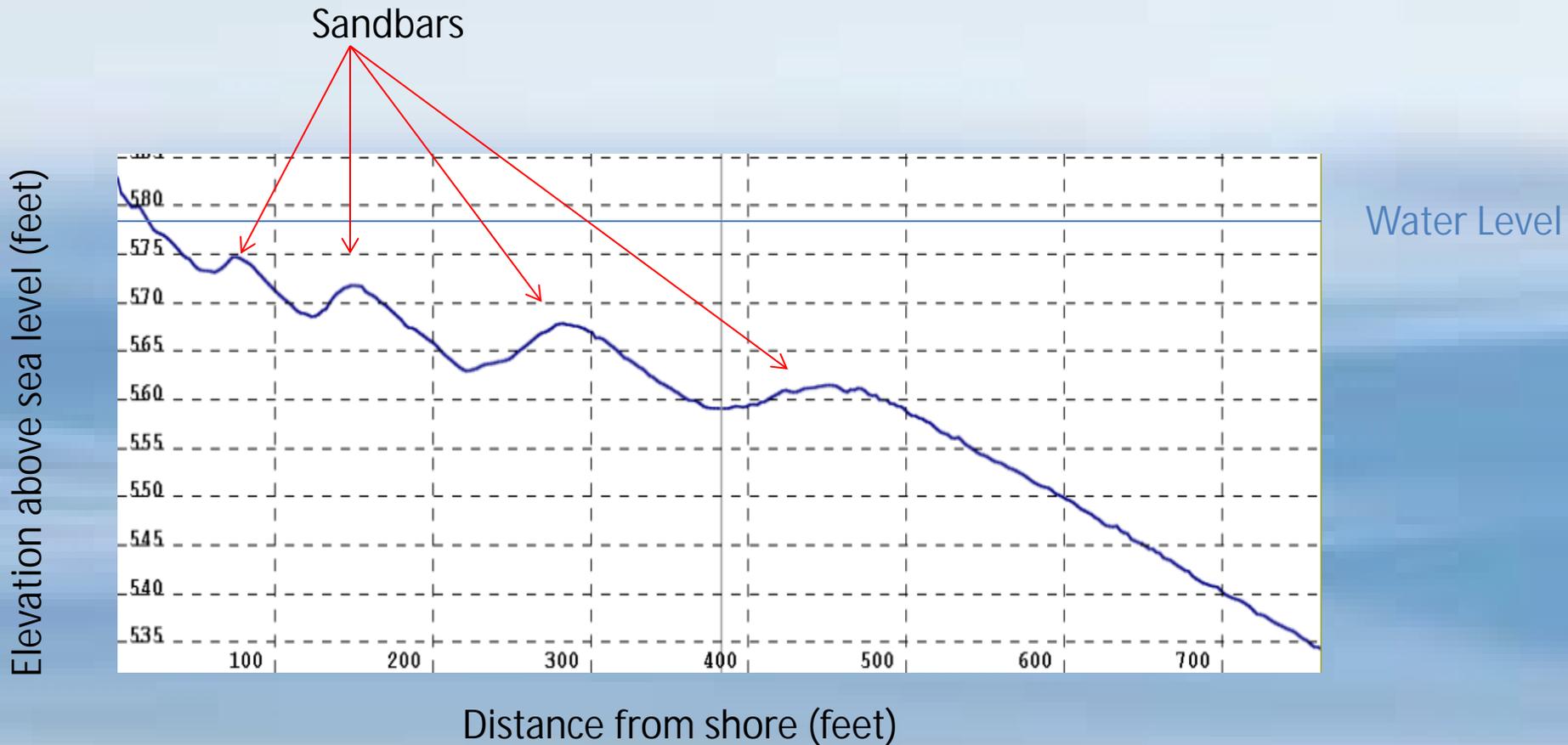
Beach Slope

- On an exposed coastline, the shape of a beach is controlled by the local wave conditions, sediment and geology
- On ocean coasts, it has been observed that beaches with intermediate slopes ($\sim 5\text{-}10^\circ$) are the most dynamic and pose a greater hazard related to nearshore currents than steeper or flatter (reflective or dissipative) beaches.

Beach Slope

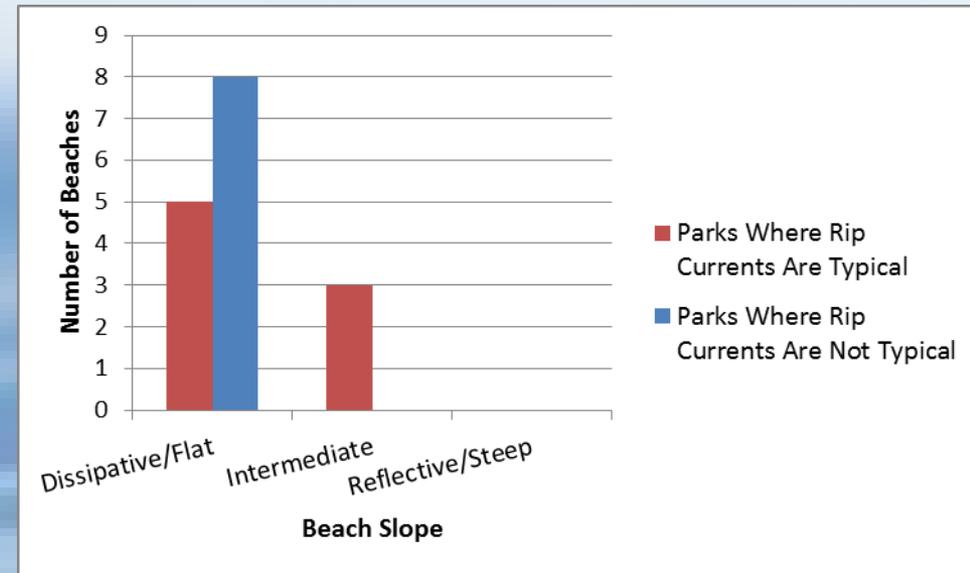
- Recent bathymetric LIDAR data collected along the Great Lakes coasts by USACE over the last decade allows us to compare the slopes of beaches with and without frequent rip current activity
- For each beach, a profile was generated of the change in elevation of the lake bottom moving perpendicularly offshore

Beach Slope



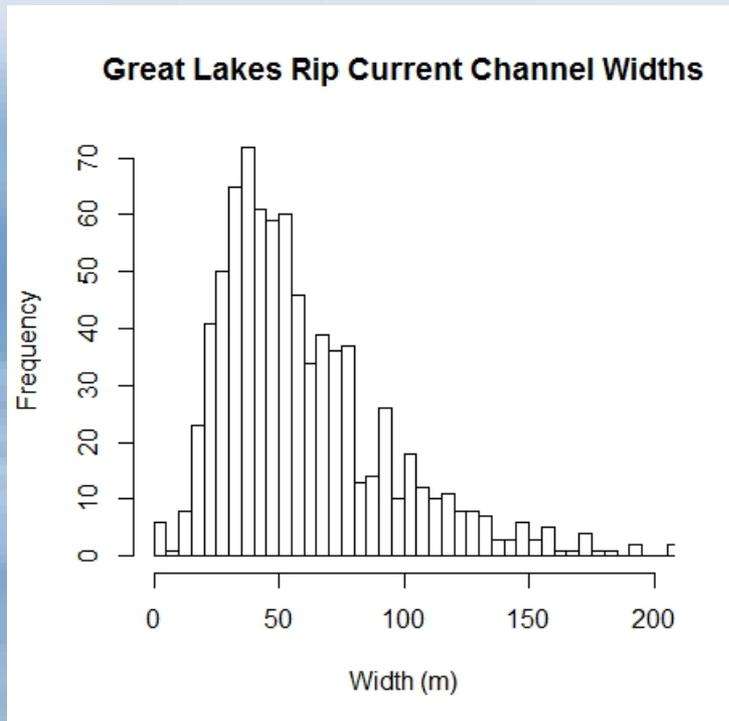
Beach Slope

- 8 State Park beaches where rip currents are a known and frequent hazard were compared to 8 parks where they are not
- Beaches with frequent rip currents tend to be more sloped, but most beaches in both groups are fairly flat
- The three parks with intermediate slopes (Grand Haven, Holland, Petoskey) are some of the most hazardous for rip currents



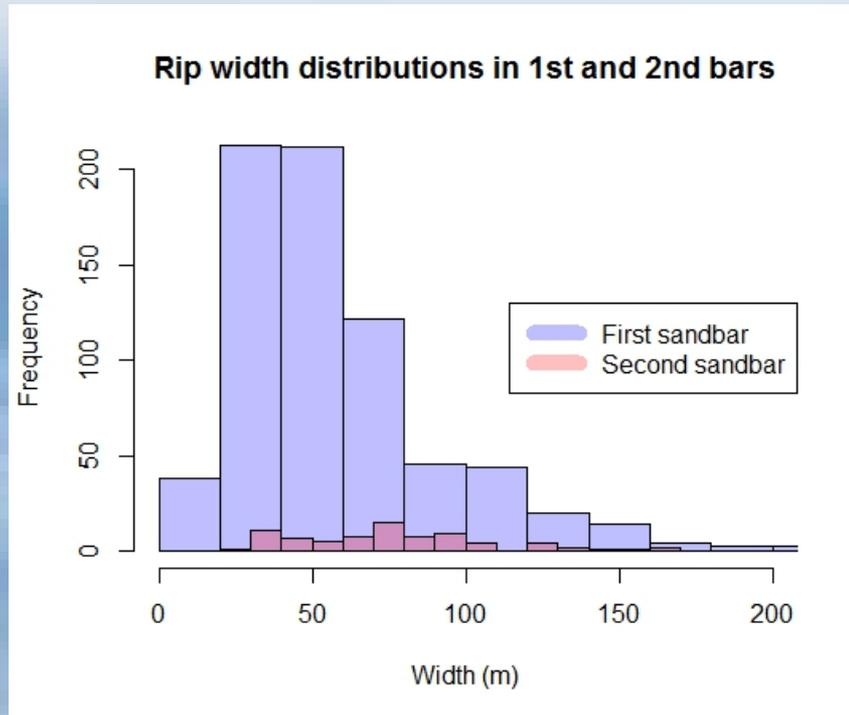
Great Lakes Rip Current Dimensions

- Overall, our dataset of digitized rip current channels (n=916) shows that rip channels in the Great Lakes tend to be 20-100 m wide (median 51 m).



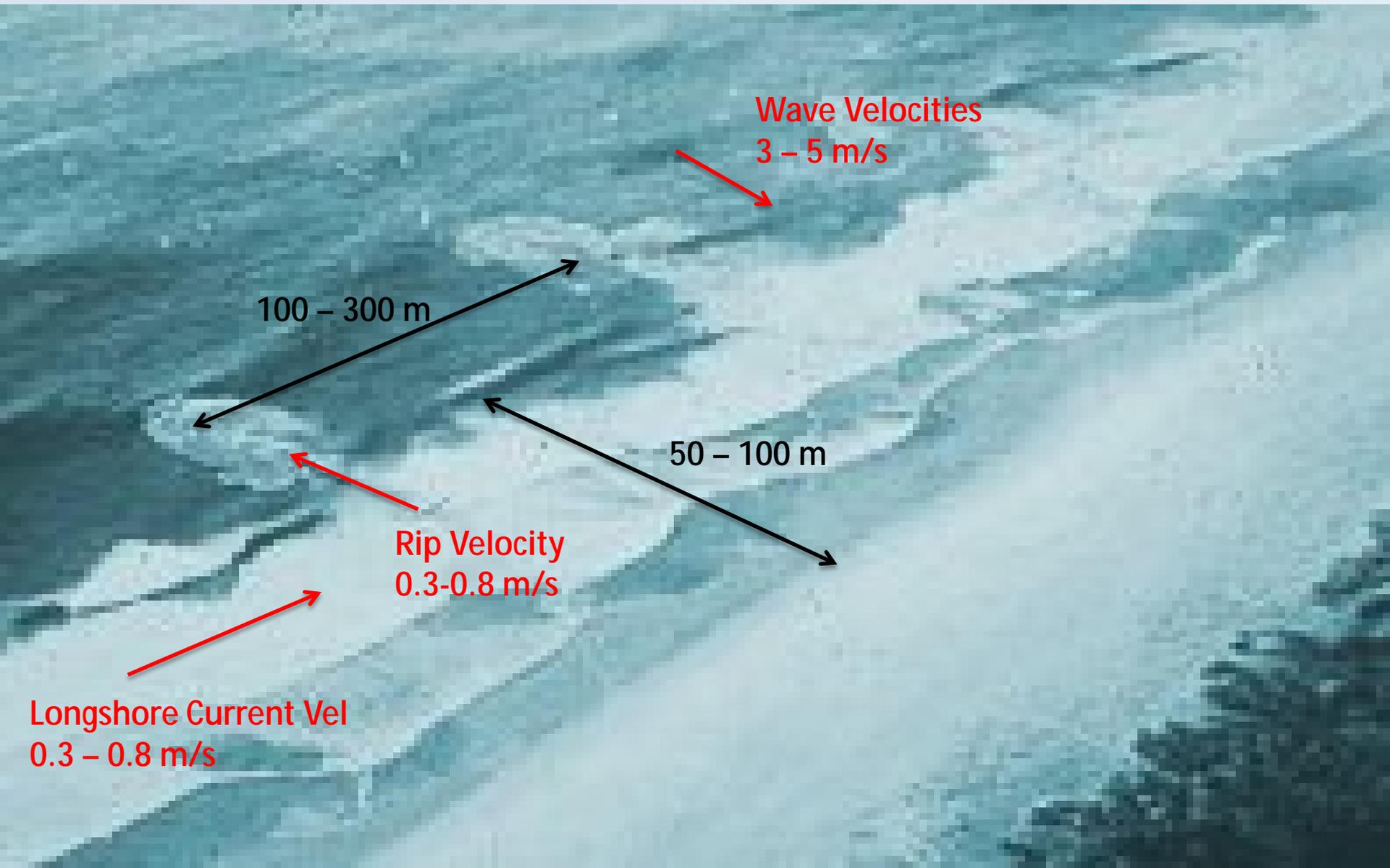
- **Shallow depressions, not deep cuts.**

Great Lakes Rip Current Dimensions



- Rip Channels through the second sandbar were observed much less frequently than in the first sandbar, both because the first sandbar is more active and because water clarity can limit visibility of some second bars

Typical Great Lakes Rip Dimensions and Velocities



Wave Velocities
3 - 5 m/s

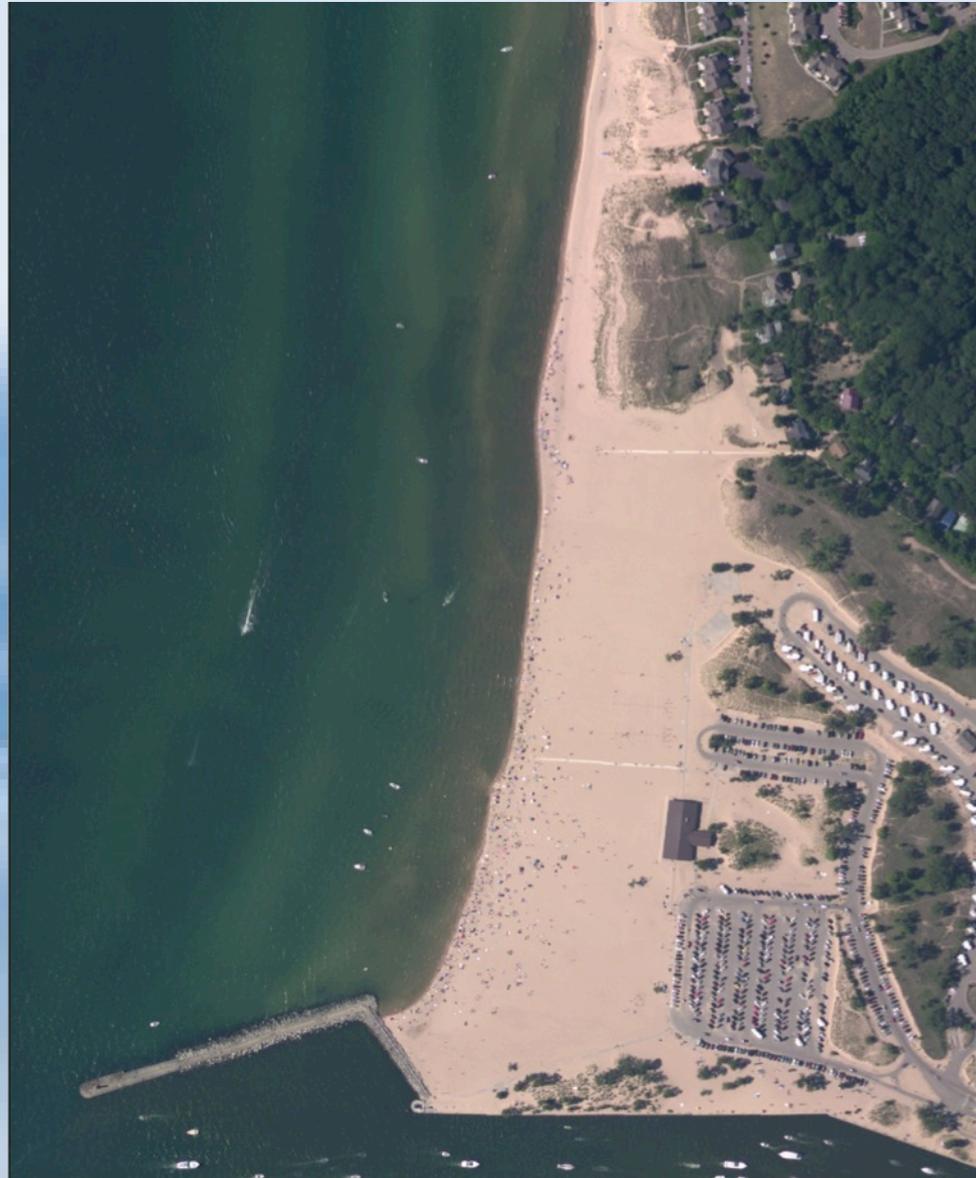
100 - 300 m

50 - 100 m

Rip Velocity
0.3-0.8 m/s

Longshore Current Vel
0.3 - 0.8 m/s

Holland State Park, Summer 2011



0 50 100 200 300 Meters

0 50 100 200 300 Yards



Results...



Michael vs. Drifters



Michael Phelps:

Career Best 100 m Freestyle

-47.51 s à 2.1 m/s

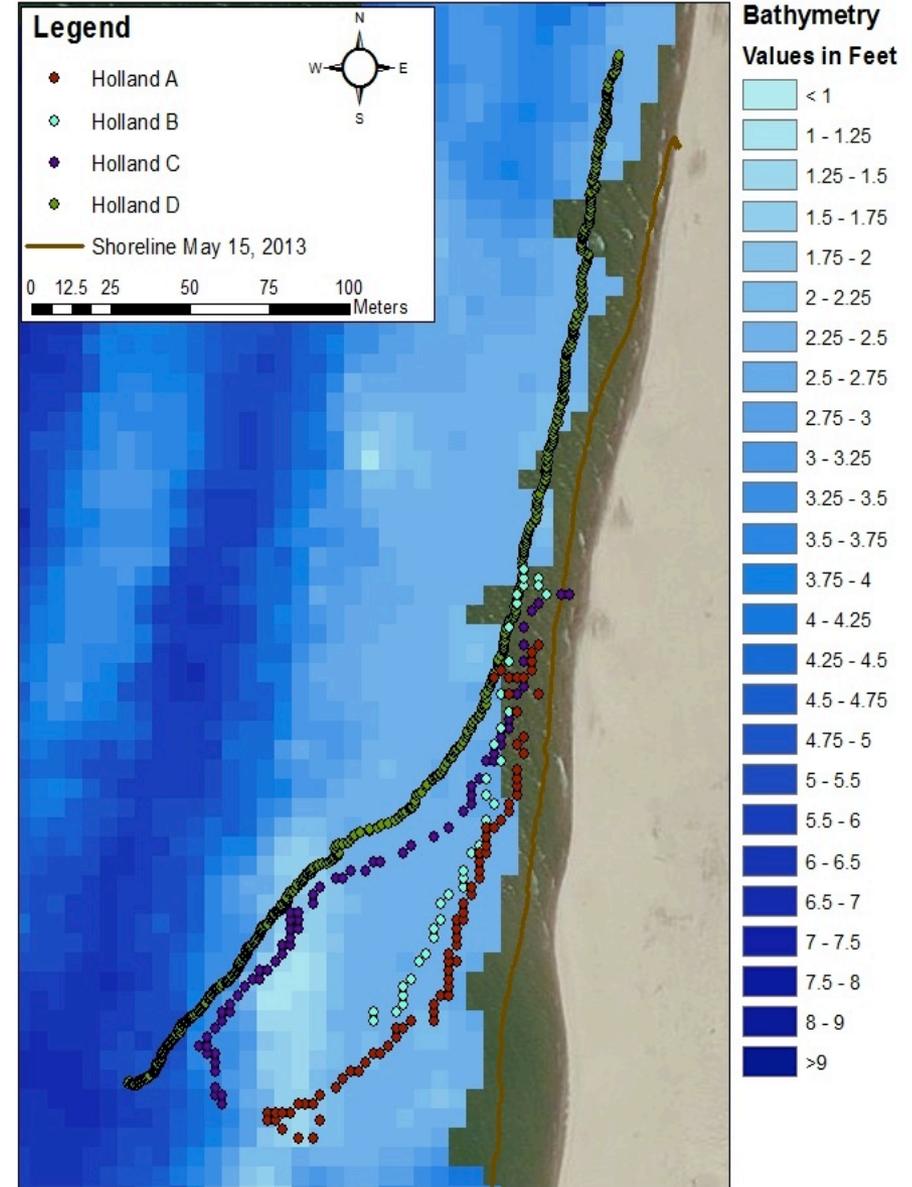
4.7 mph

6.9 fps (~ 1 body length/second)

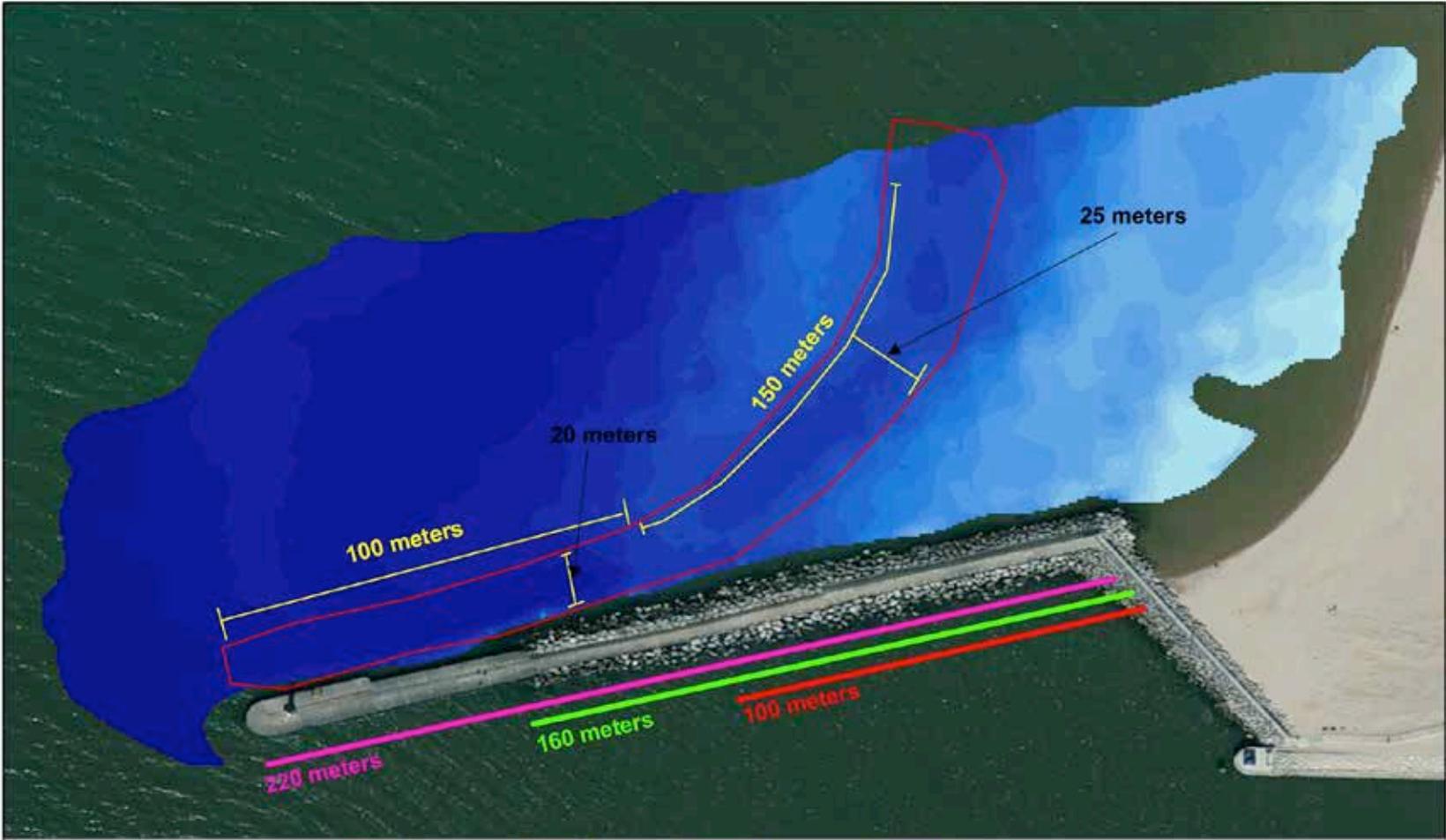
- Holland State Park – Drifter Floats beach with no bathymetric features indicating rip current activity, drifters travelled consistently along the shoreline.

Site	Holland A	Holland B	Holland C	Holland D
Average Velocity (m/s)	0.45	0.50	0.20	0.30
Maximum Velocity (m/s)	1.71	3.00	2.00	1.41
Distance From Shore: Start (m)	53.64	29.94	64.22	86.00
Distance From Shore: End (m)	3.21	3.51	0.00	16.31
Travel Time (min)	8.25	7.22	15.65	21.47

Holland State Park May 14th, 2013



Holland State Park, Summer 2011



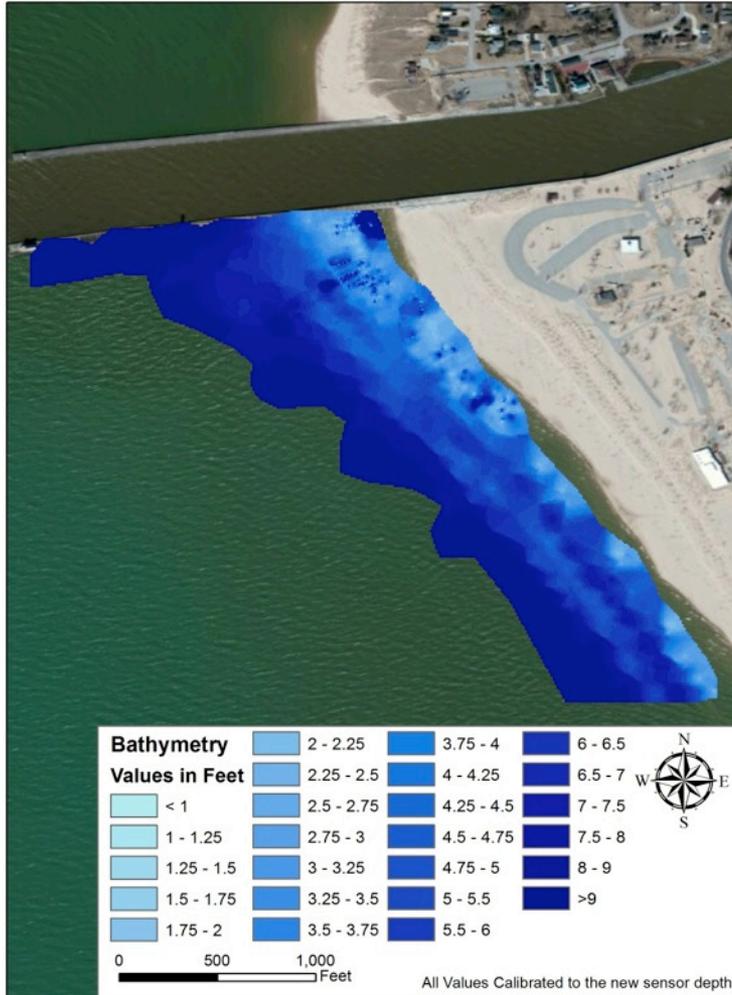
Holland State Park		2 - 2.5	4 - 5	7 - 7.5	12 - 16
Depth(ft)		2.5 - 3	5 - 5.5	7.5 - 8	16 - 20
	< 1	3 - 3.5	5.5 - 6	8 - 9	
	1 - 1.5	3 - 4	6 - 6.5	9 - 10	
	1.5 - 2	4 - 4.5	6.5 - 7	10 - 12	

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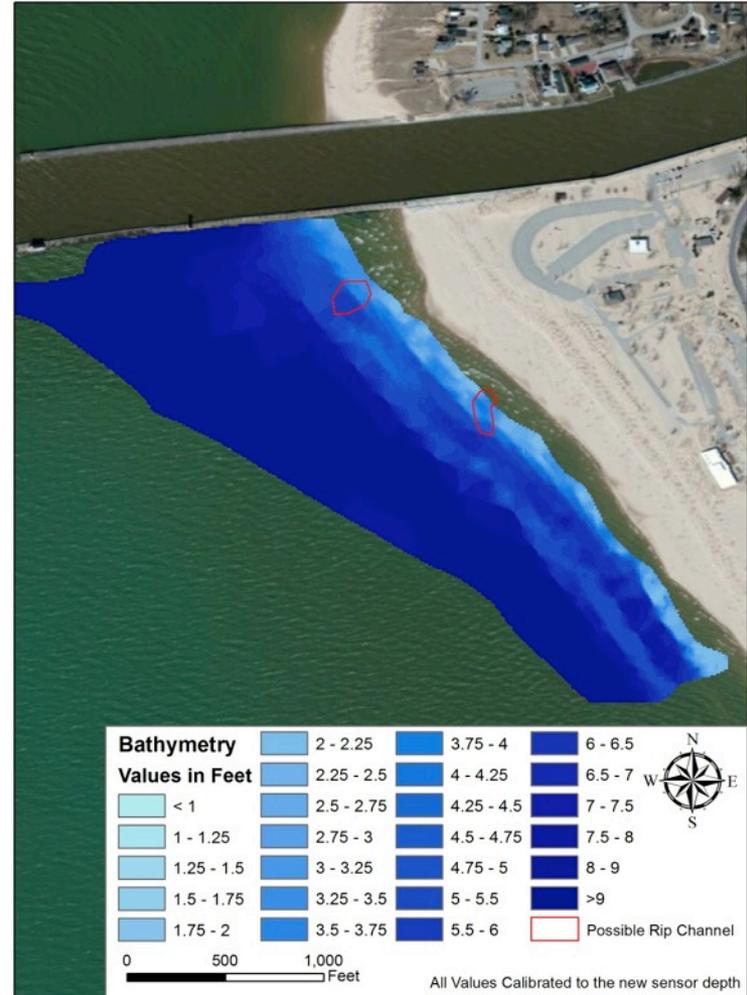


Pre and Post – Storm Bathymetry Grand Haven State Park

Husky Traveler and BathyBoat Derived Bathymetry:
Grand Haven State Park May 13, 2013



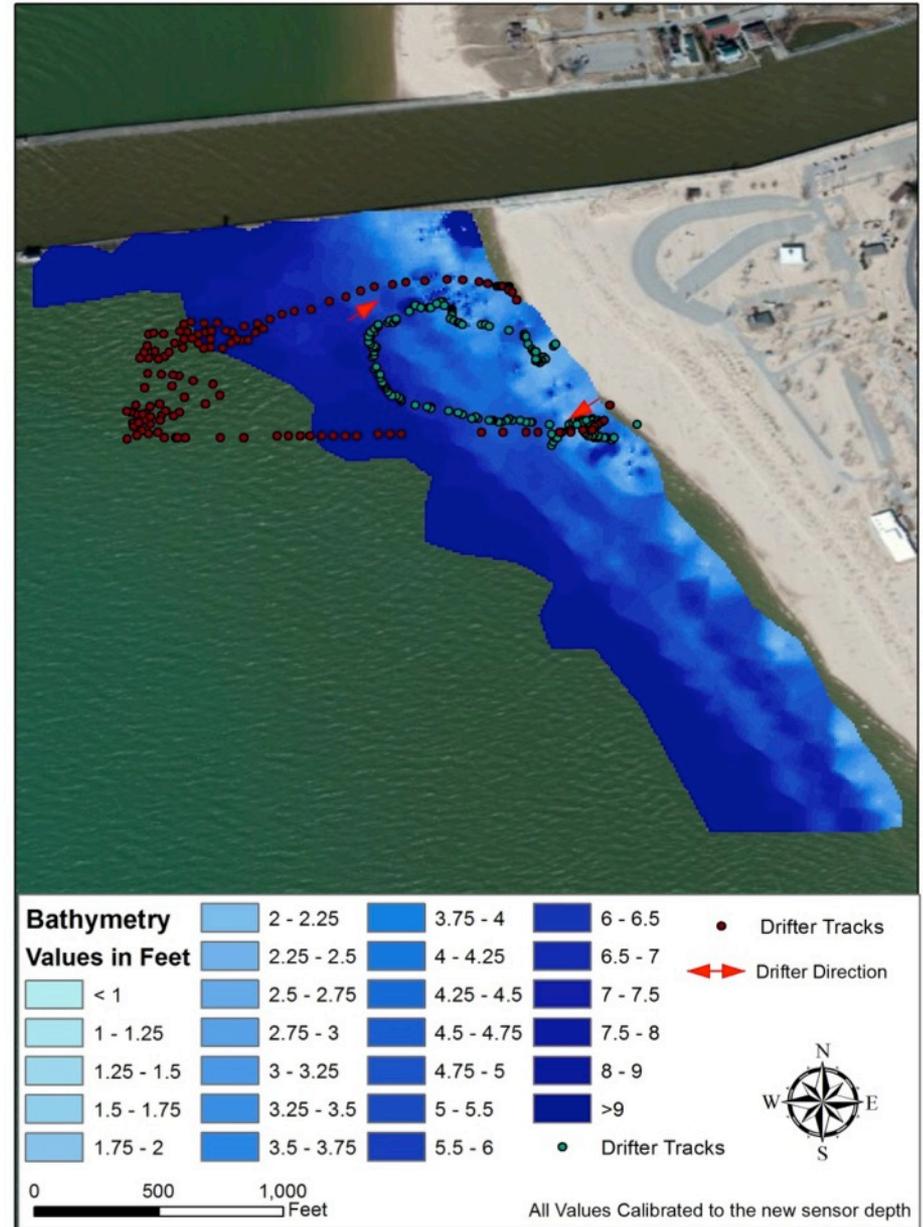
Husky Traveler Derived Bathymetry:
Grand Haven State Park May 16, 2013



Drifter Tracks and Velocities

- At the Grand Haven State Park beach, both drifters were carried quickly offshore, floated slowly north and were pushed back towards the beach
- Average drifter velocity in the rip current was 0.3 m/s, maximum was 3.6 m/s
- The two drifters were carried 175 m and 400 m offshore and took approximately an hour to return to the shoreline.

Derived Bathymetry with Drifter Tracks:
Grand Haven State Park May 15, 2013



Multiple Straight Bars



Takeaways....

- Almost all Great Lakes sand beaches have DNCs
- DNCs Develop Rapidly with increasing wave height
- Nearshore bottom is continually readjusting to waves and currents
- Rip channels can migrate down the beach (Safe \rightarrow Unsafe)
- DNCs persist long after waves subside