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Revisiting Historical Meteotsunami Events in Lake Huron

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Background

Meteotsunamis are a global phenomena that risk property damage, loss of life, and impacts on navigation [*Candela et al., 1999; Jansa et al., 2007; Vilibic´ et al., 2008; Dragani et al., 2009; Sepic´ et al., 2009; Thomson et al., 2009; Asano et al., 2012; Pasquet and Vilibic´, 2013; Vilibic´ et al., 2014*]. Meteotsunamis are long waves with periods between 2 minutes to 2 hours that are generated by an atmospheric disturbance, similar to a convective storm, which most commonly entails a sharp gradient in pressure and rise in wind stress [*Bechle and Wu, 2014; Sepic´ and Rabinovich, 2014*]. In the Great Lakes, or other enclosed basins, unique dangers exist due to the reflection and interaction of meteotsunami waves. Often meteotsunamis can appear long after the inducing storm has passed, increasing the danger posed to coastal communities.

Meteotsunami Occurrence

Recent work by *Bechle et al.,* [2016] has shown that meteotsunamis occur in each of the Great Lakes, resulting in death and destruction to coastal communities **[Fig. 1]**, with the largest number of detected meteotsunamis recorded in southern Lake Michigan and along the southern shore of Lake Erie. The largest meteotsunami recorded occurred near Chicago, IL in 1954 [*Bechle and Wu, 2014*]. Results suggest that the majority of meteotsunamis in the Great Lakes are driven by complex and linear convection, though the peak occurrence varies by lake, likely due to variability in the resonant characteristics of each lake and the relationships between atmospheric conditions and water depth.

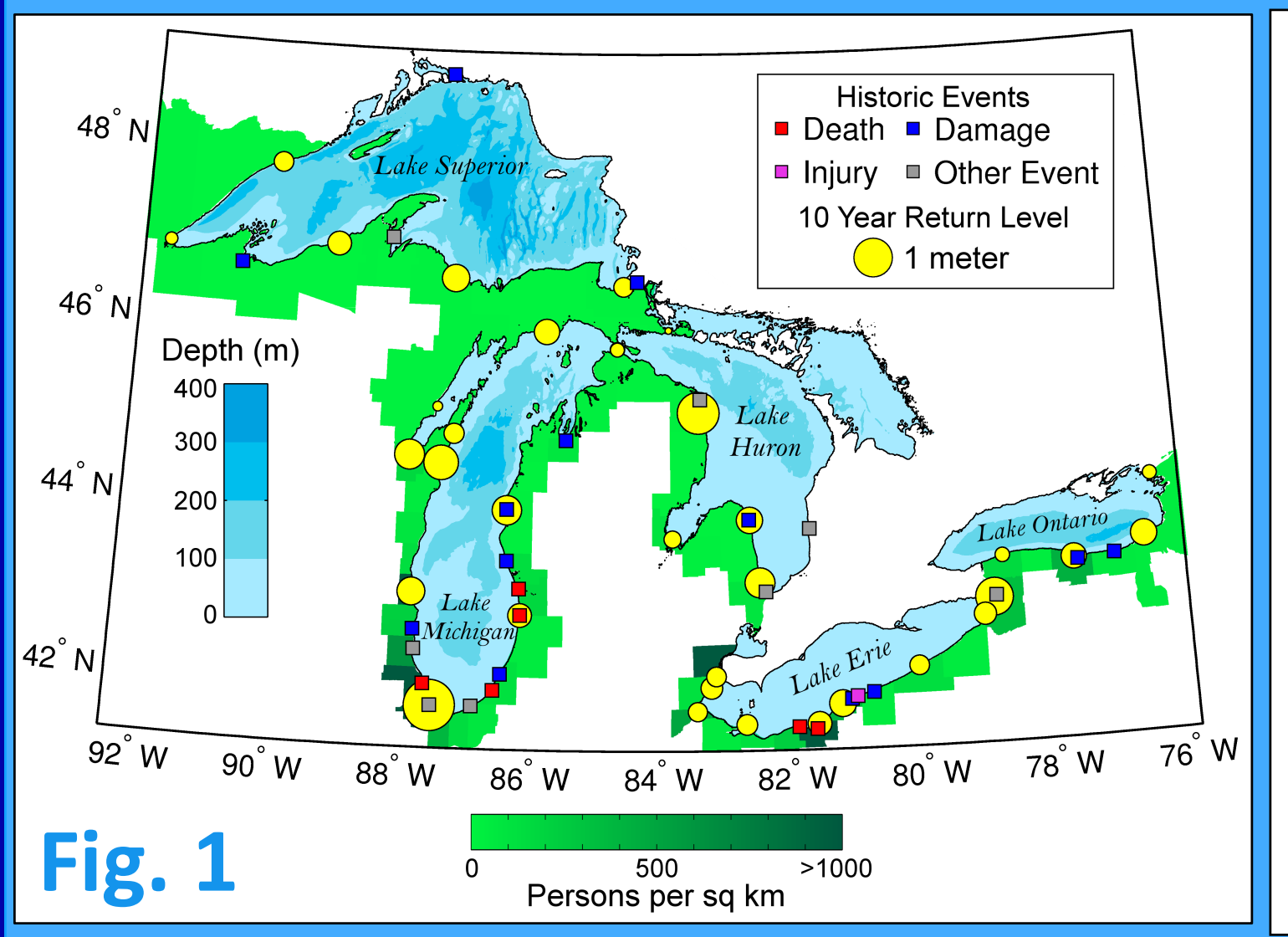


Fig. 1

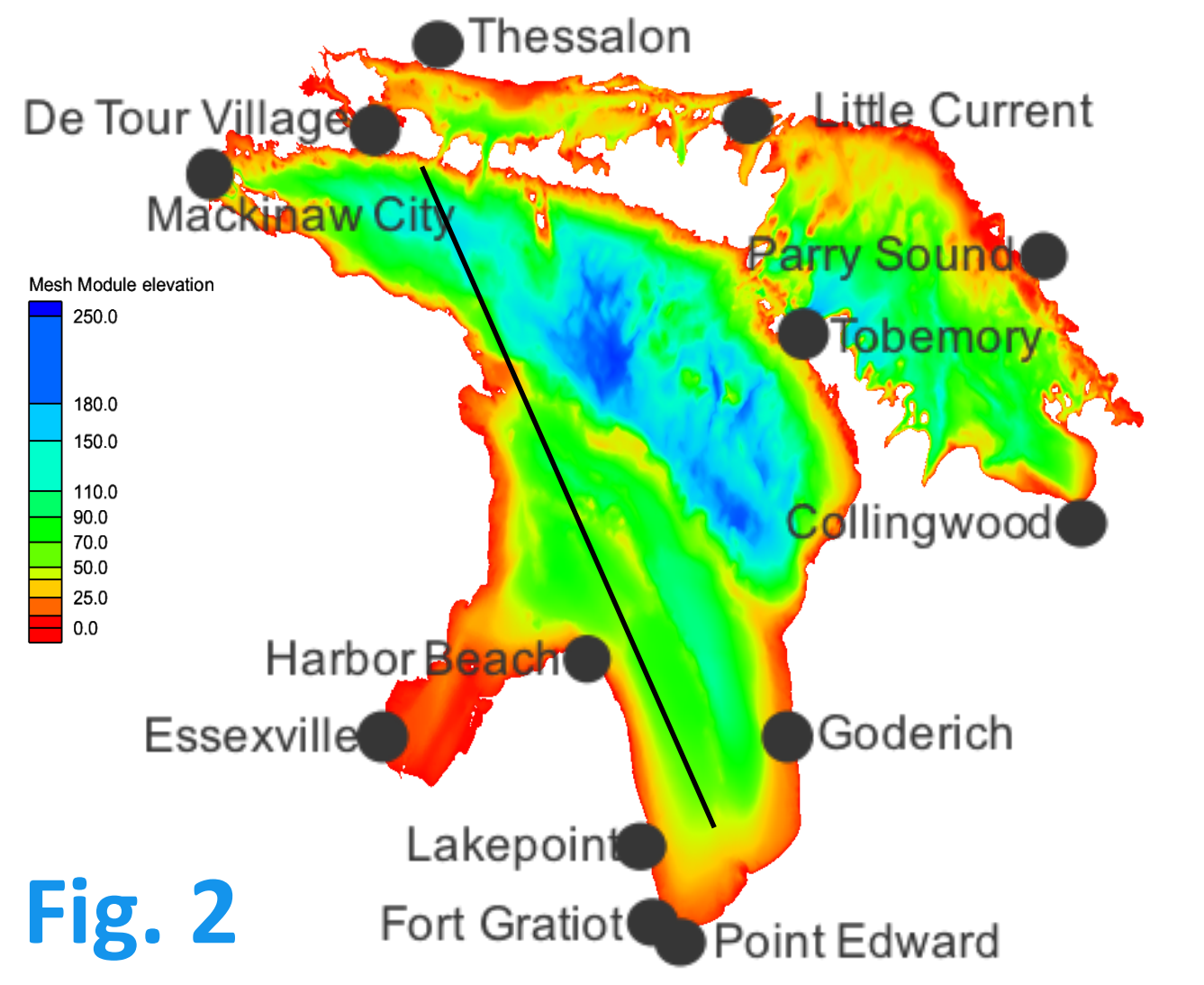


Fig. 2

Lake Huron

- Lake Huron experiences more than 10 events each year (Bechle et al., 2016)
- First event recorded on May 23, 1925 (*Ludington Sunday Morning News*)
- May 5, 1952: 2-foot event caused damage in Mackinaw City and Harbor Beach (*Donn, 1959*)
- August 22, 1971: 1-foot event (*Murty & Freeman, 1973*)
- July 13, 1995: Two derechos result in meteotsunamis that cause 4.6-feet water level change (*Sepic & Rabinovich, 2014*)
- May 31, 1998: a meteotsunami event lead a boat overturned and one drowning in Georgian Bay (*NOAA Storm Prediction Center, 2004*)
- September 23, 2017: a recent meteotsunami was detected, though minor in impact, the wealth of high-frequency observations and improved atmospheric and hydrodynamic models available during this event enable a detailed investigation into the mechanisms behind meteotsunami formation in Lake Huron

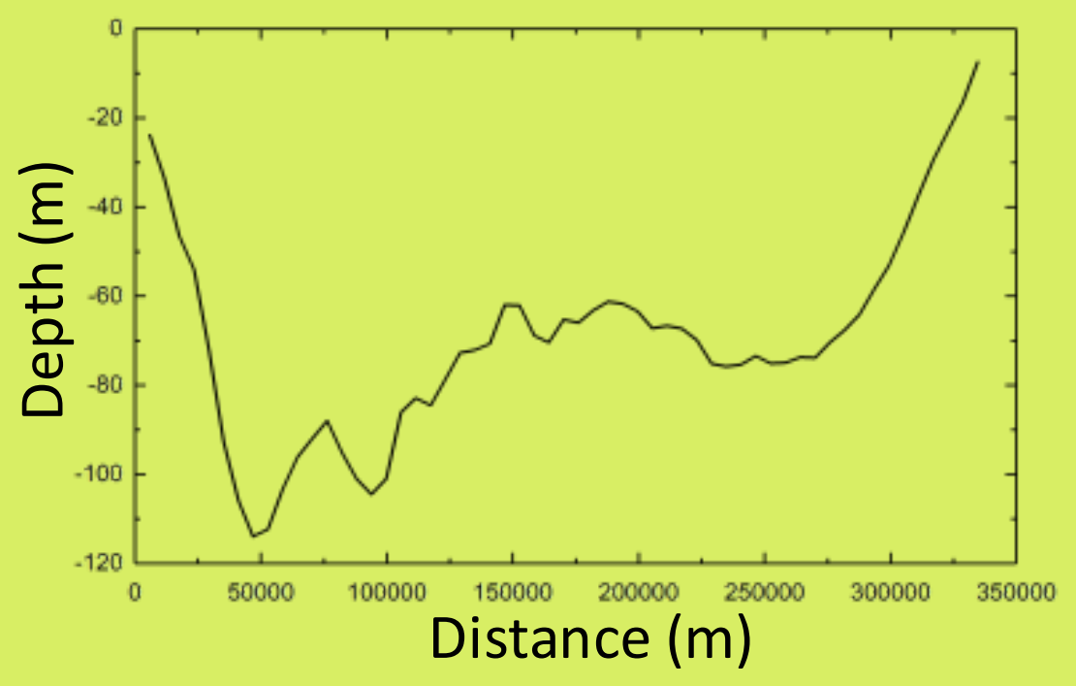
Average Depth for Lake Huron: 59 m

$c = \sqrt{gh} = 24.1\ \mathrm{m/s}$

Cross-section average depth (Fig. 2): 71 m

$c = \sqrt{gh} = 26.4\ \mathrm{m/s}$

Storm Propagation Speed:
$v = 24.1\ \mathrm{m/s}$ (1995) $v = 16.0\ \mathrm{m/s}$ (2017)



Data and Methods

Water level data

- Water level data is available from NOAA/CO-OPS and Fisheries and Oceans Canada **[Fig. 2]**
- 1995: 1-hour intervals data for US gauges and 15-min intervals data for Canadian gauges
- 2017: 6-min intervals data for US gauges and 3-min intervals data for Canadian gauges

Meteorological data

- Meteorological data is available from NOAA and ASOS **[Fig. 3]**
- 1995: 1-hour intervals data at 2 NDBC buoys (green) and 1 or 2 hours intervals data at 5 surface airway stations (**red**)
- 2017: 1-min intervals data at 5 surface weather observation stations and 6-min intervals data at 8 meteorological observation stations (**red**)

Hydrodynamic model

- Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM/SELFE)
- Seamless simulation of 3D baroclinic circulation across creek-lake-river-estuary-shelf-ocean scales
- Finite-element/finite-volume method with Eulerian-Lagrangian algorithm
- Unstructured mesh with mesh size from 100m to 1500m **[Fig. 3]**
- Simulate 1995 and 2017 events with reconstructed meteorological forcing

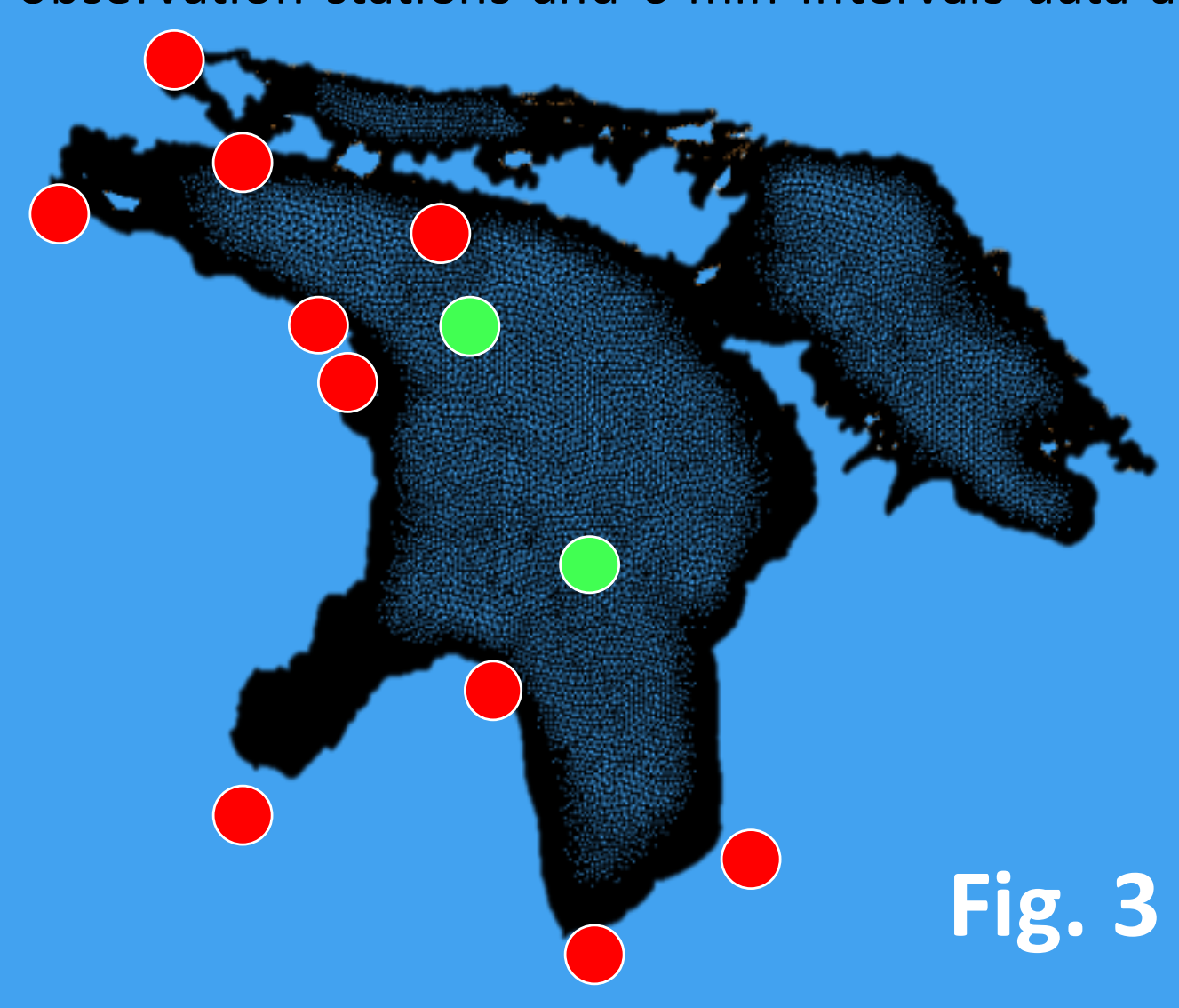


Fig. 3

May 5, 1952

An atmospheric disturbance crossed Lake Huron and Lake Erie with a propagation speed of 16.1 m/s, pressure jump of 4.06 mbar **[Fig. 4]** and increased wind speeds. Resonant coupling to gravity and edge waves induced large fluctuations in water level. At Harbor Beach, water levels surged 2.2 feet with a period of 67 minutes, and continued for several hours. Similar effects were observed in Lake Erie and at other gauges in Lake Huron (*Donn, 1954*).

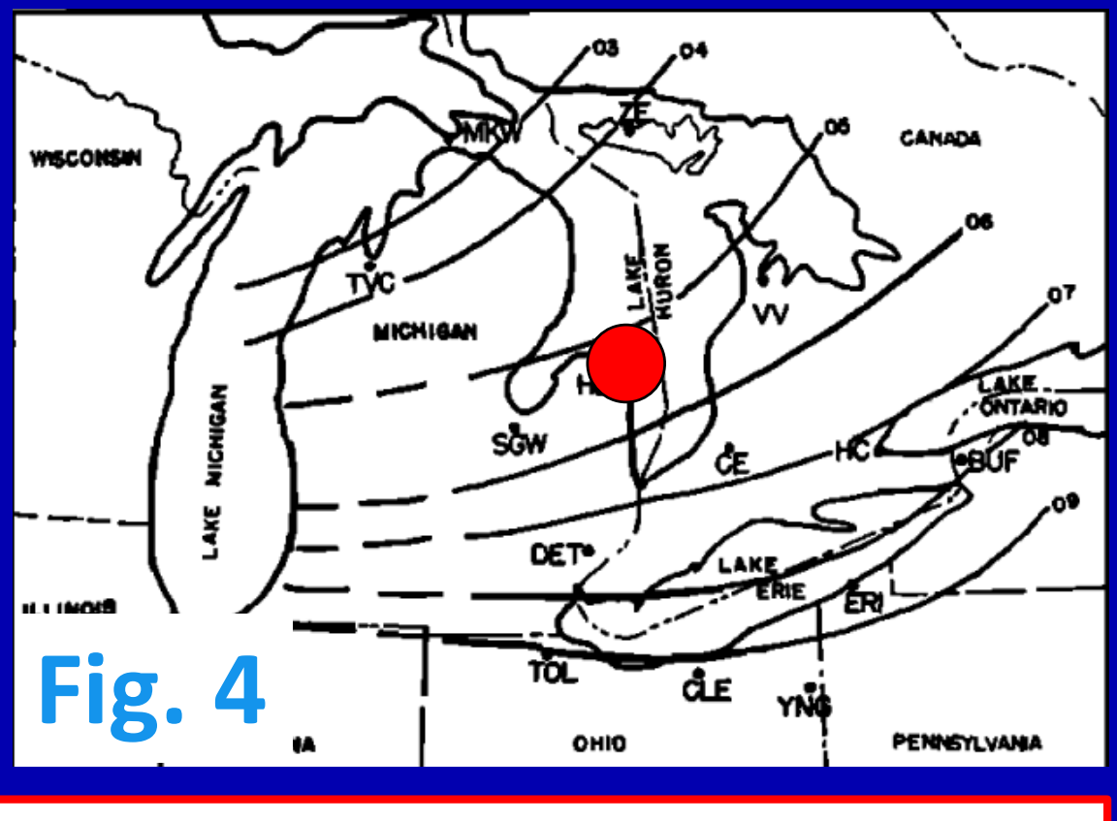
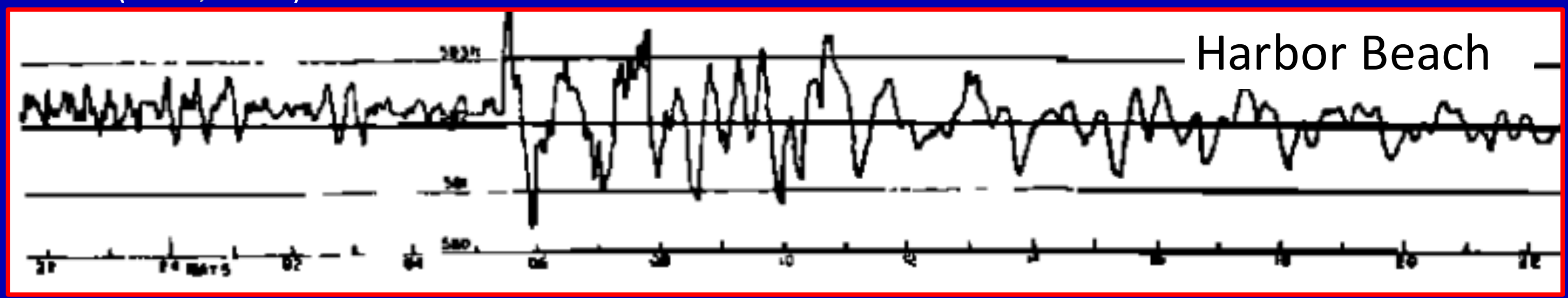


Fig. 4



July 13, 1995

Between July 11th and 15th, four derechos crossed the upper midwest, two of which had significant impacts on Lake Huron **[Fig. 5]**. The first event had a propagation speed of 24.1 m/s, which matches the long wave speed in Lake Huron, thus inducing Proudman Resonance. Wind speeds reached 12 m/s, with a pressure change of 340 Pa (3.4 mbar). Water level observations as a result of the meteotsunami were detected at several gauges **[Fig. 6]**, with greatest magnitudes felt in the southern part of the lake, and with a maximum recorded fluctuation of 4.6 ft (1.4 m) at Lakeport **[Fig. 6c]**.

As a result of the storm, dozens of boats were capsized or destroyed on rocks along the shoreline, and one boater was killed as a result. The US Coast Guard received 152 calls for assistance.

Using observed winds and pressure records, a reconstructed meteorology was applied to the Lake Huron hydrodynamic model **[Fig. 5]**, following the methods used in *Anderson et al.,* [2015]. Results show even a simplified moving disturbance is able to partially resolve the meteotsunami event, including the maximum water level fluctuation in the southern region of the lake **[Fig. 7]**. However, limitations in the idealized atmospheric forcing causes the model to underpredict water withdrawal after the initial surge, as well as fluctuations along Canadian gauges.

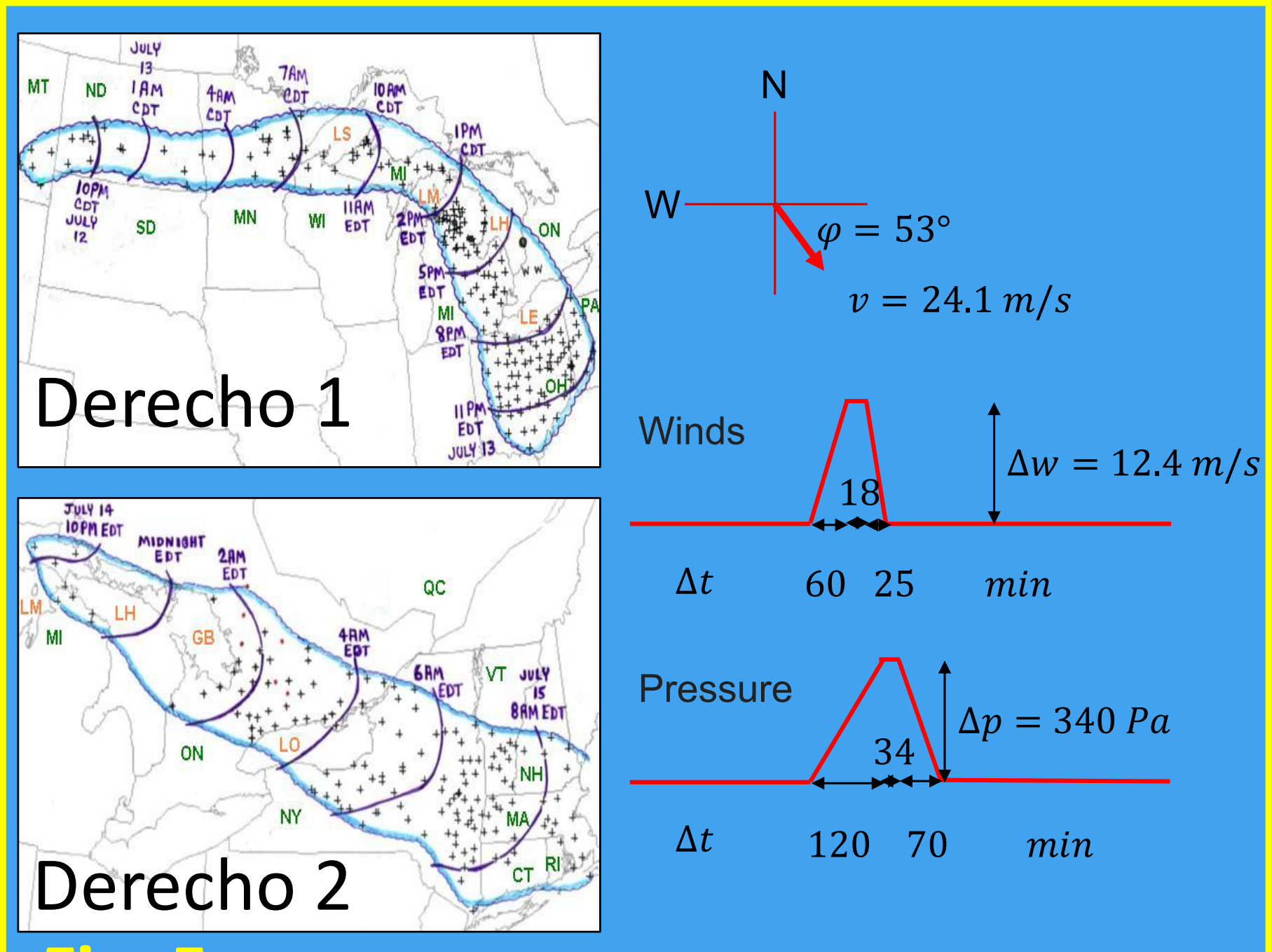


Fig. 5

Derecho pathways in July, 1995 (NOAA Storm Prediction Center, SPC), and illustration of reconstructed meteorology used for hydrodynamic simulation of the event.

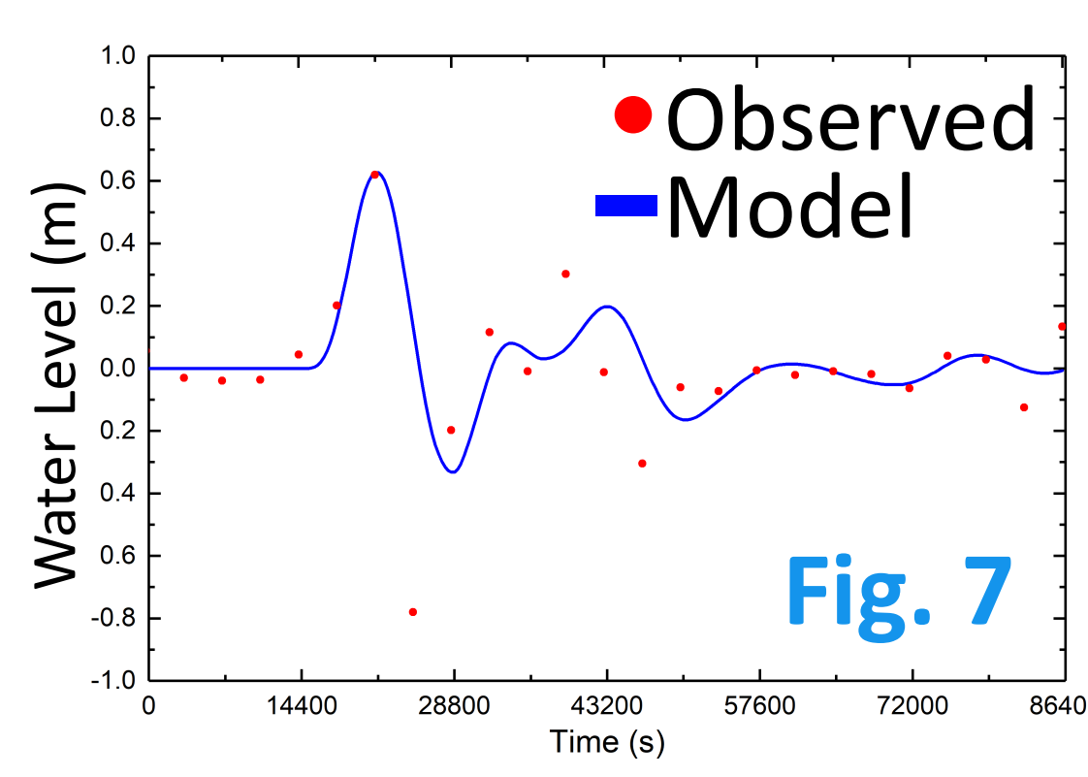


Fig. 7

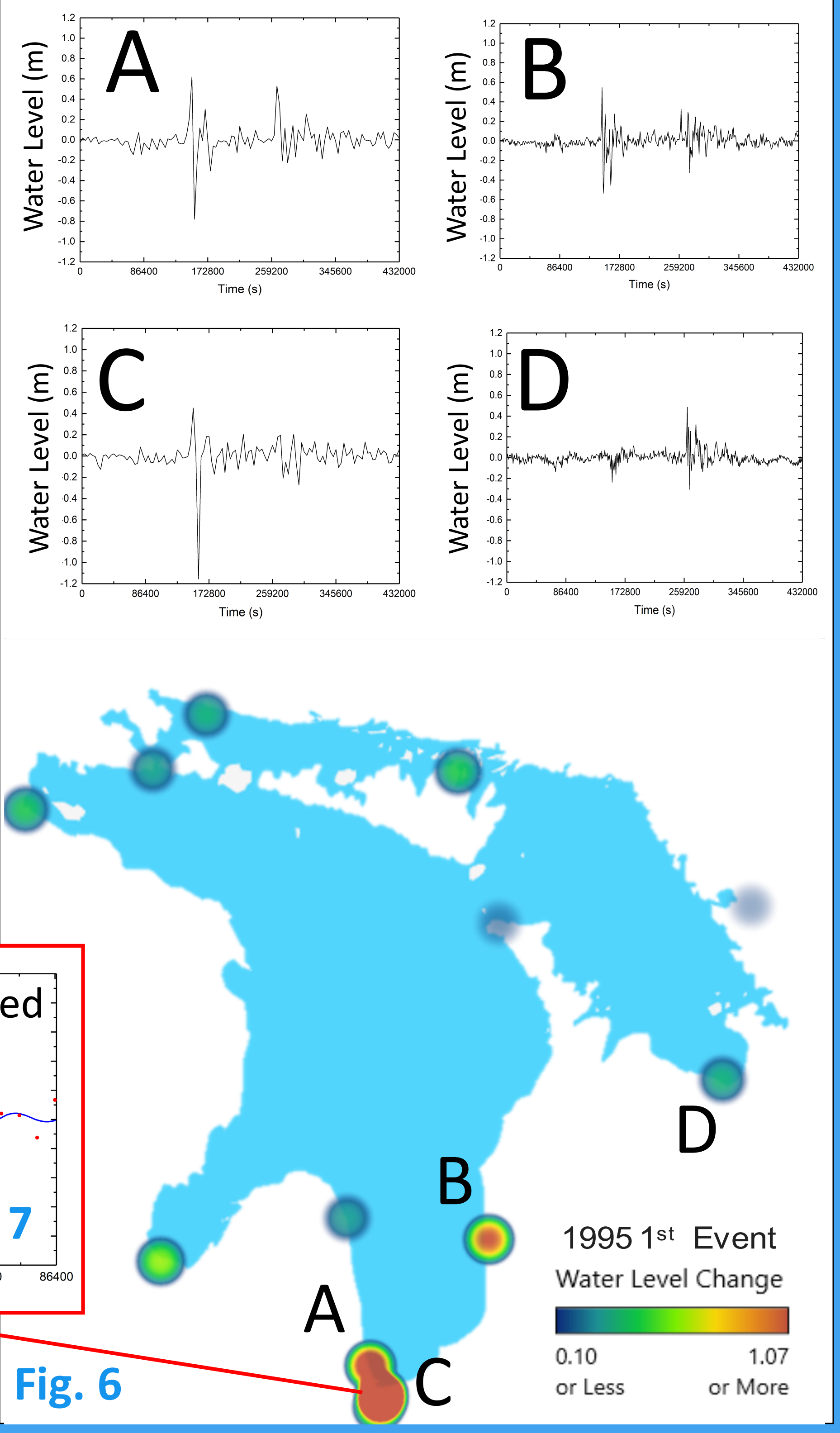


Fig. 6

September 23, 2017

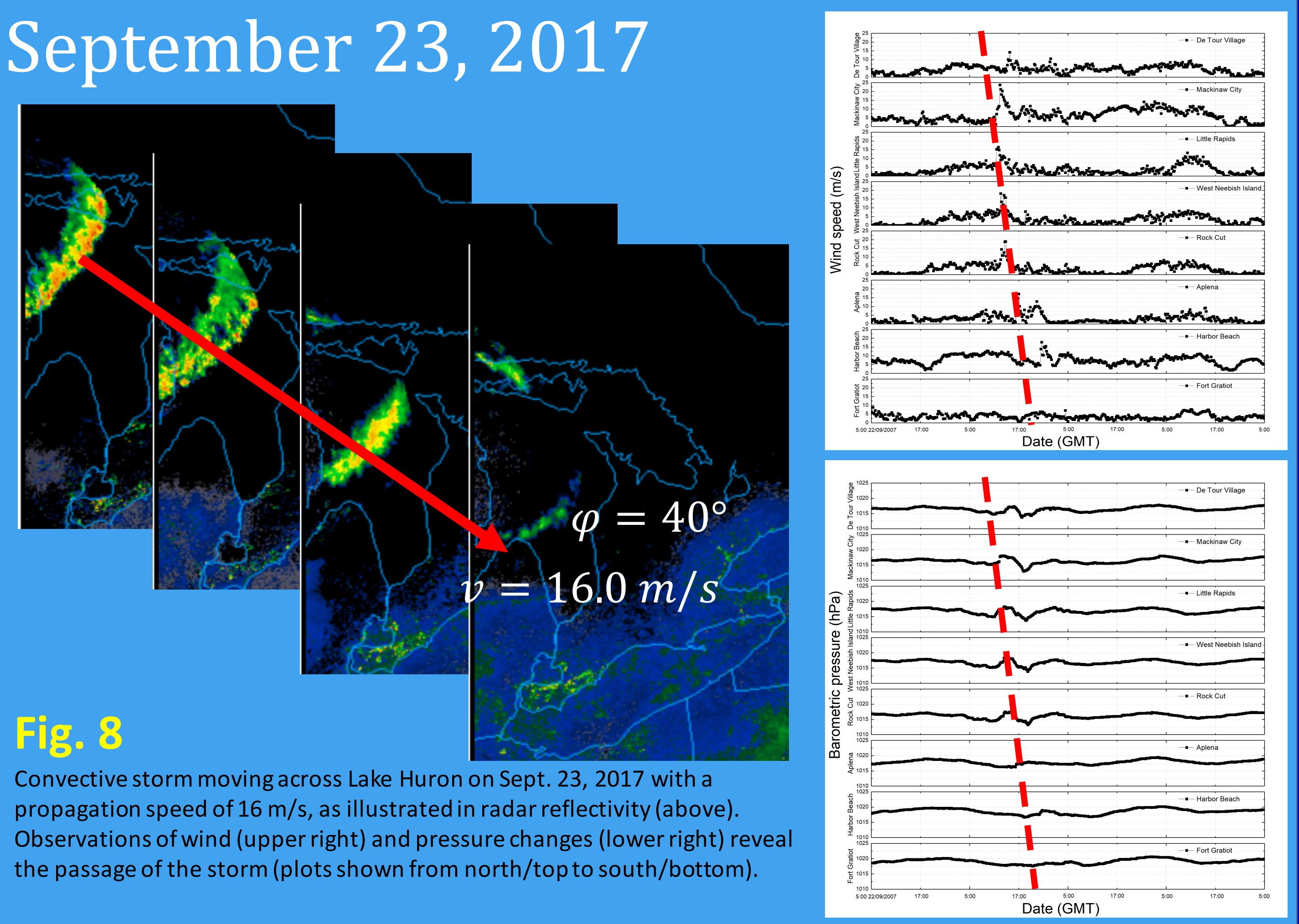


Fig. 8

Convective storm moving across Lake Huron on Sept. 23, 2017 with a propagation speed of 16 m/s, as illustrated in radar reflectivity (above). Observations of wind (upper right) and pressure changes (lower right) reveal the passage of the storm (plots shown from north/top to south/bottom).

A convective storm crossed Lake Huron on Sept. 23, 2017, traveling southeast with a propagation speed of 16 m/s **[Fig. 8]**. The wind speed associated with the storm reached 9 m/s, accompanied by a pressure change of 1.9 mbar (190 Pa). Although not sufficient to induce Proudman Resonance, edge waves were produced that traveled southward along the shoreline. High-frequency water level oscillations were detected at several US and Canadian gauges **[Fig. 9]**, with the largest fluctuation detected at Lakeport in the southern region of the lake.

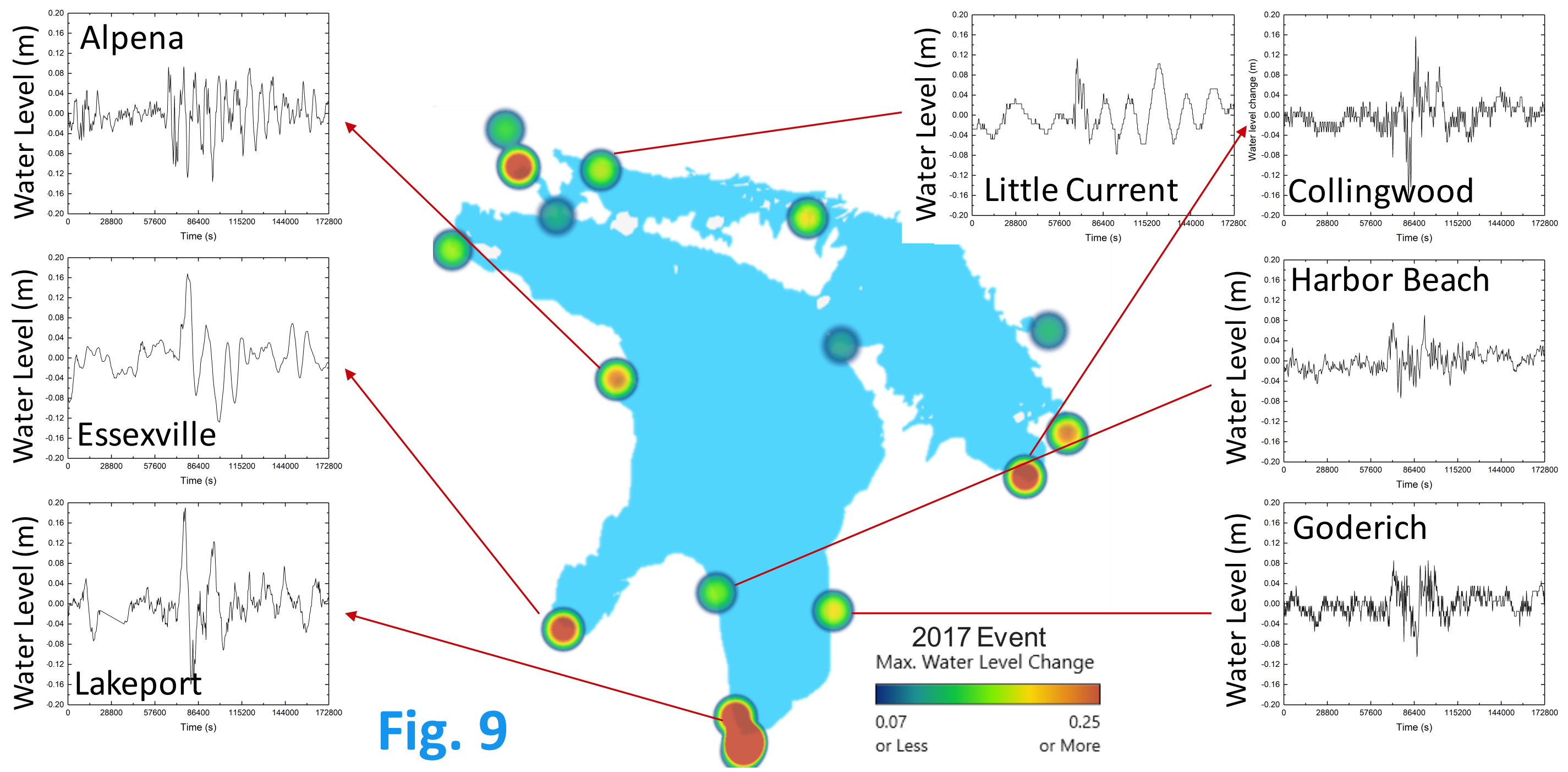


Fig. 9

Model results show good agreement with both the amplitude and period of the water level fluctuations at key gauges **[Fig. 10]**. A study of water level response at several coastal gauges as a function of storm direction and propagation speed reveals varied sensitivity to the storm characteristics dependent on the gauge location **[Fig. 11]**. Peak water level fluctuation is induced by atmospheric disturbances moving from SE and E for most of the lake, with exception in Georgian Bay (eastern region).

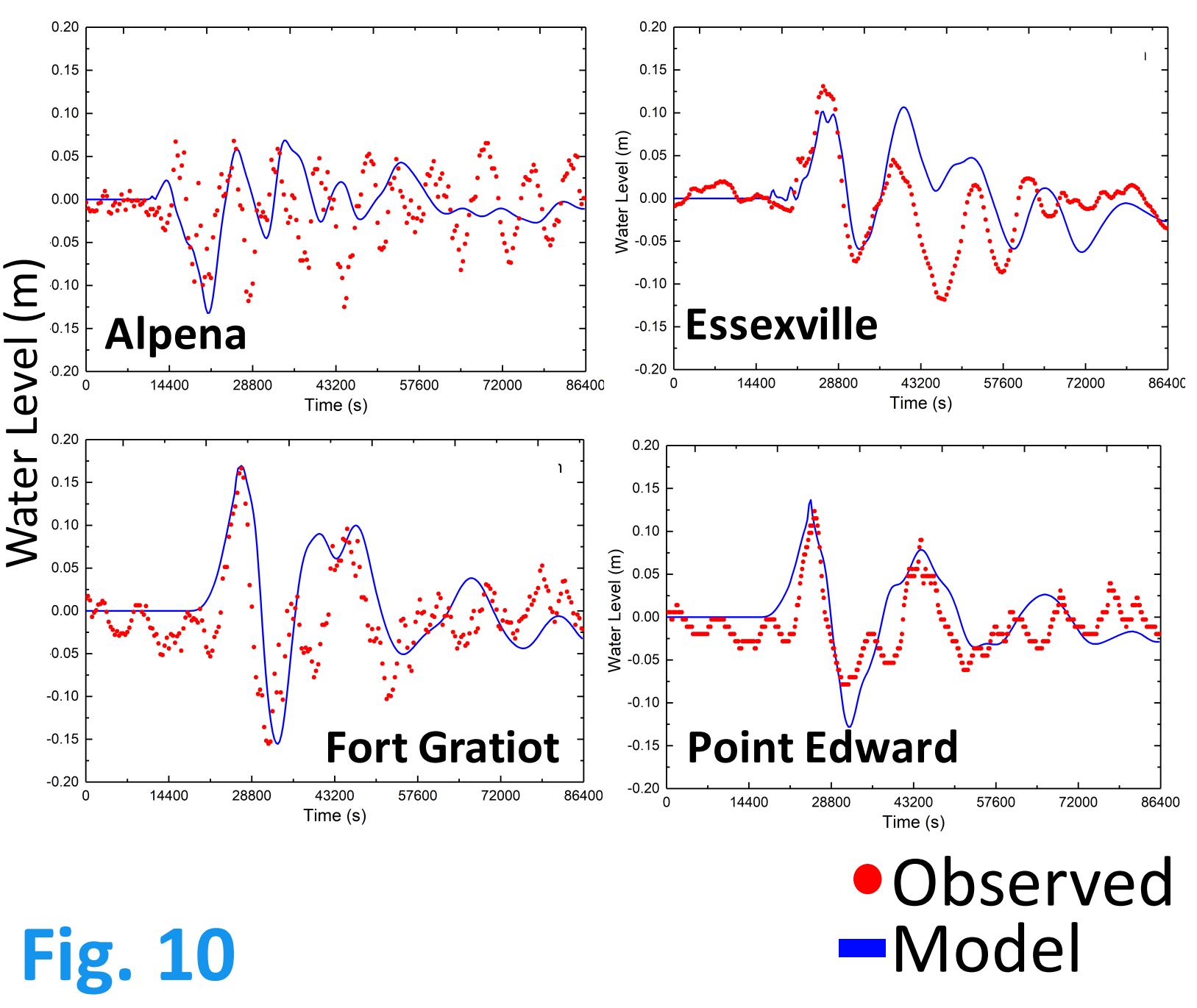


Fig. 10

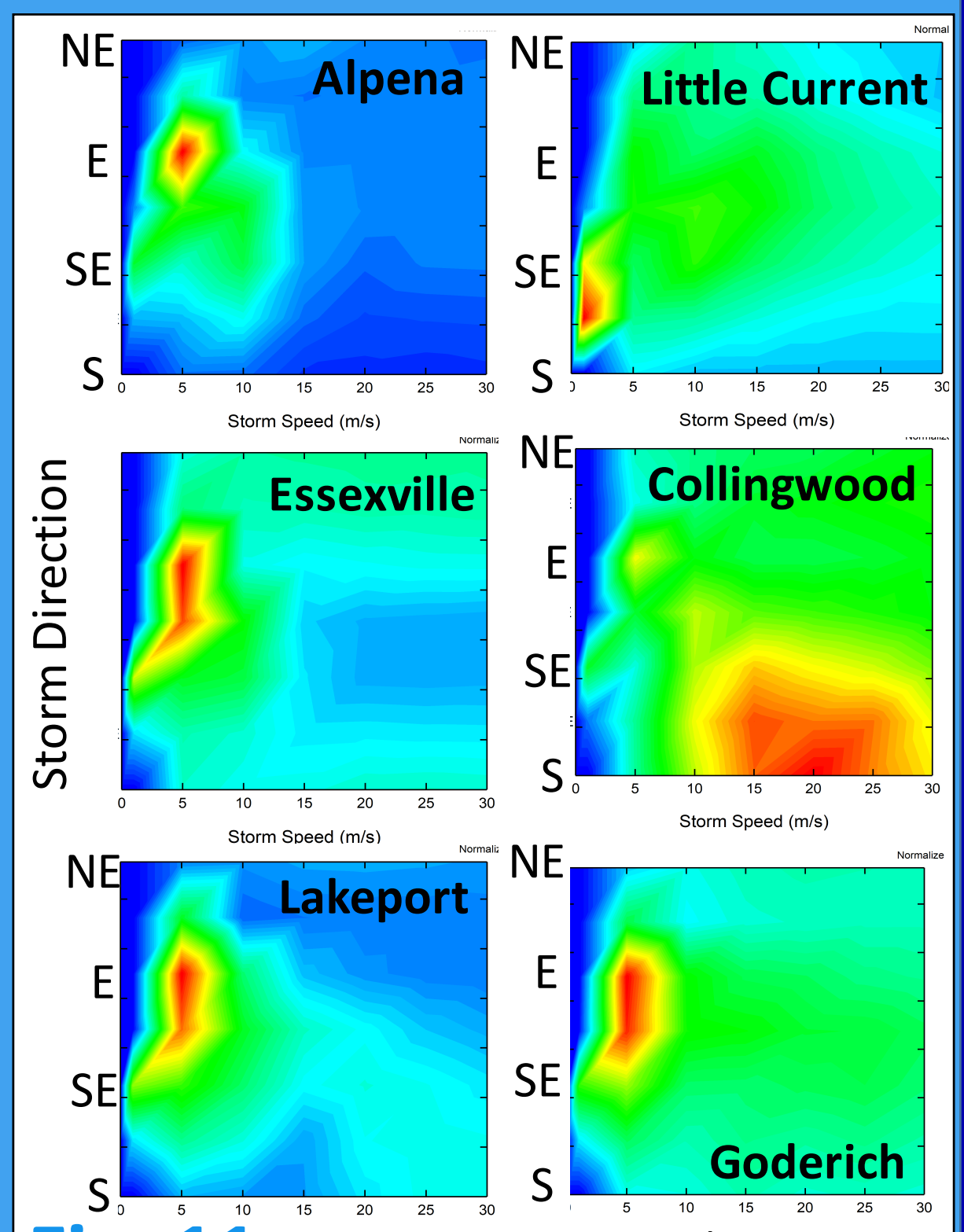


Fig. 11

Conclusions

- Meteotsunamis occur in all Great Lakes, connected to rip current incidents
- Lake Huron experiences >10 events per year
- Historic meteotsunamis reveal largest impacts in southern Lake Huron
- Huron is most sensitive to storms propagating at 24-26 m/s from the SE or E
- Great Lakes meteotsunamis driven by complex and linear convective storms
- High-res models capture the mechanisms behind meteotsunami formation