Observations and simulation of meteotsunamis in southwest Australia

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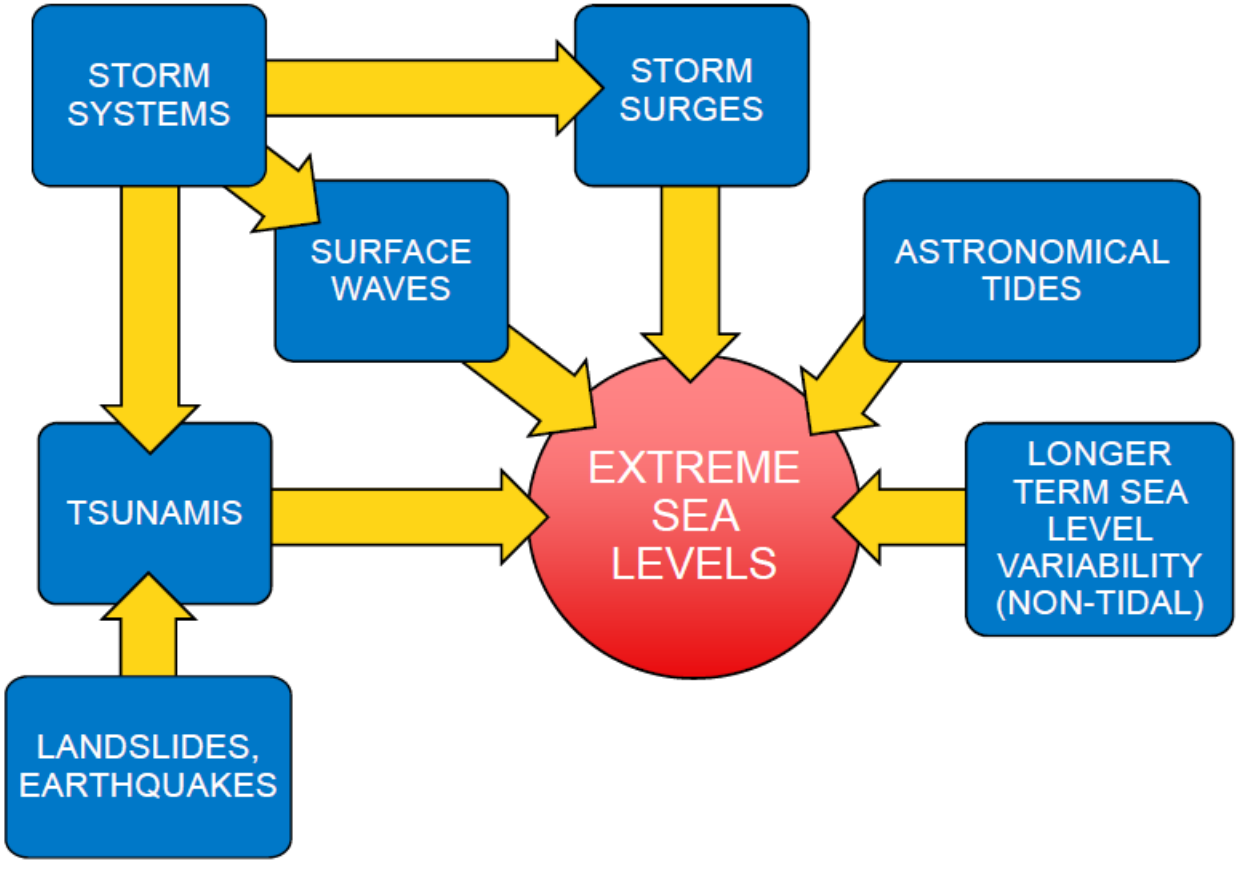
Oceans Graduate School & The UWA Oceans Institute
The University of Western Australia

Coastal Oceanography

Acknowledgements

- Hans Burchard, Ulf Gräwe, Marvin Lorenz, Marlen Kolbe (IOW)
- Department of Transport (WA) – much of the WA data

Extreme sea levels



10 September 2014, 6.27am AEST

Explainer: how weather can trigger dangerous tsunamis

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DISCLOSURE STATEMENT

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European examples

Dramatic moment seven foot tidal wave sweeps away beach chairs, boats and parasols as mini tsunami strikes the Netherlands

- Footage of the mini tsunami was filmed in Zandvoort and Katwijk on Monday
- The phenomenon is called a meteotsunami and is said to be incredibly rare
- No one was hurt at the time although there was some damage reported

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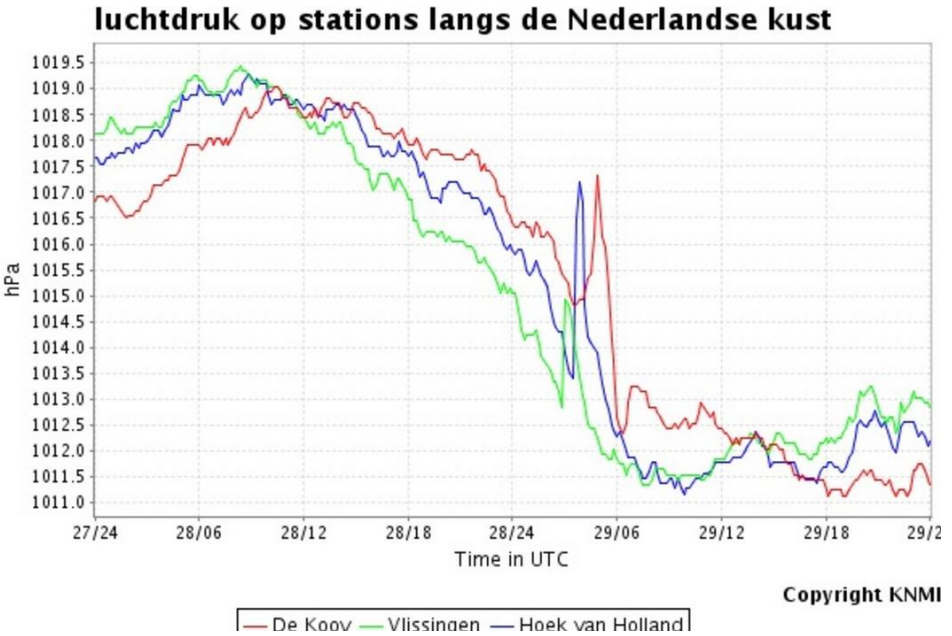


Previous recorded meteotsunamis in the Netherlands occurred in 2004 and 2006.

Seebären

Über den „Seebär“ der westlichen Ostsee vom 16./17. Mai 1888.

Von

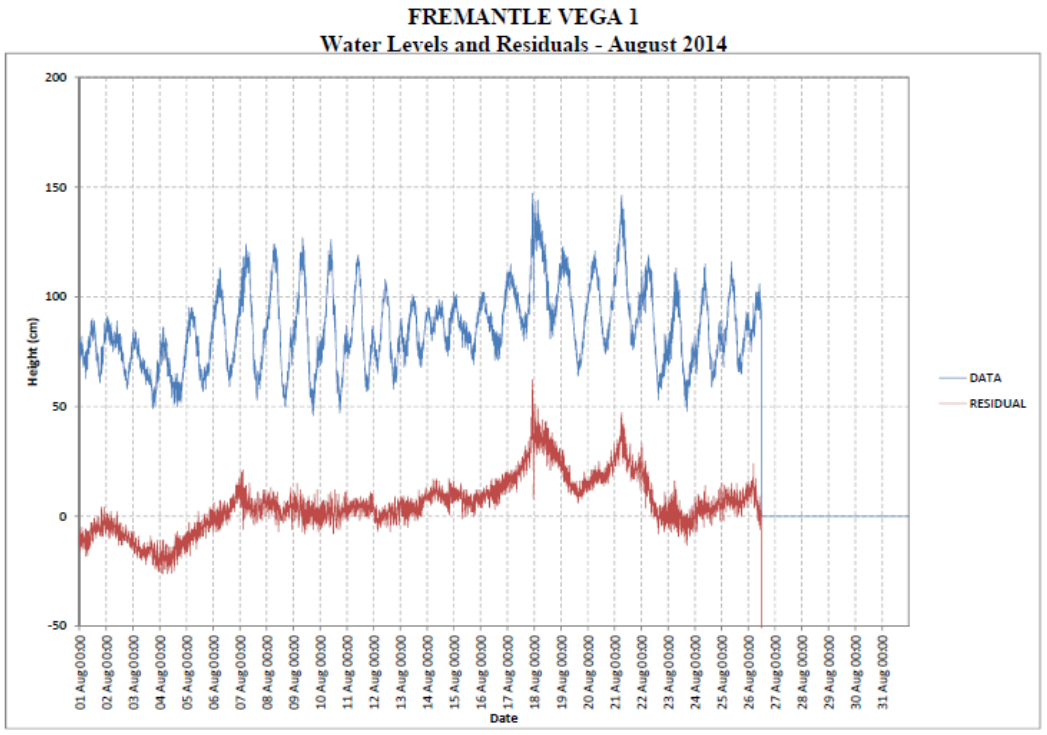
Rudolf Credner, Greifswald.

A. Küsten Vorpommerns, Mecklenburgs und Holsteins.

1. Ahrenshoop, Fischerdorf an der Westküste des Darss, im Dünengebiet der schmalen Landenge gelegen, welche das mecklenburgische Fischland mit dem eigentlichen Darss verbindet (Aussagen des Fischer's Saegert sen. uud des Kapt. Voss in Ahrenshoop). Der Fischer Saegert begab sich gegen 2 Uhr in der Nacht vom 16. zum 17. Mai mit fünf Genossen zum „Nachtzug“ an den Strand. Das Wetter war ruhig, die See fast glatt, von einer leichten Brise kaum merklich bewegt. Der westliche Himmel war von Gewitterwolken bedeckt und blitzte und donnerte es in rascher Aufeinanderfolge. Mit der Herrichtung der Netze beschäftigt wurden die Fischer plötzlich durch ein so rasches Ansteigen des vorher völlig ruhigen Meeres überrascht, dass sie nur mit Mühe noch über den etwa 40 Schritt breiten Vorstrand zu entfliehen und die 3—4 m hohen Dünen zu erklimmen vermochten, nicht ohne dass Saegert bis über die Kniee vom Wasser erreicht wurde. Die vorher unmittelbar am Strande gelegenen Boote und Netze (Waden) wurden 10—20 m weit, z. Th. bis an den Fuss der Düne landeinwärts geschleudert,

Storm Surge or Meteorological Tsunami ?

Inverted barometric factor: 1hPa = 1 cm
+wind: storm surge: 1hPa = 2-4 cm
meteo-tsunami: 1hPa = 20-50 cm



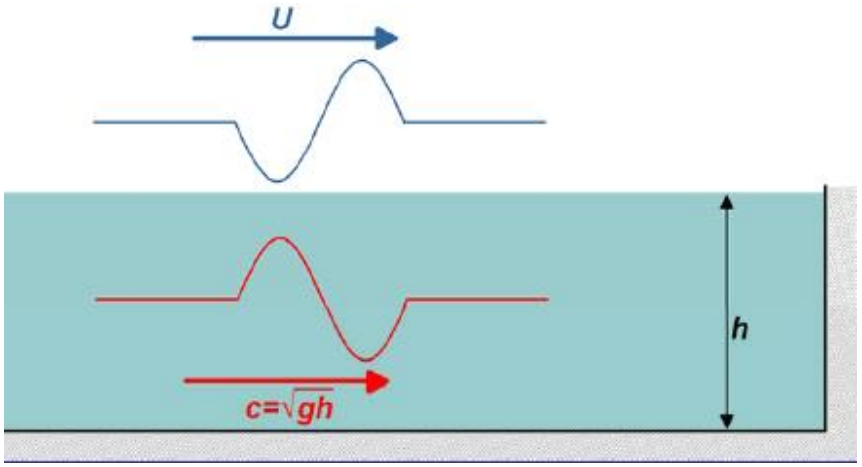
DEPARTMENT OF TRANSPORT - WA
Oceanographic Services

Storm Surge:
Duration > 12 hours, generated by wind + pressure systems either locally or remotely.
Rate of change of water level small.
Relatively weak currents

Meteotsunami:
Duration < 6 hours, generated by local pressure systems.
Rapid change in water level.
Strong currents

Proudman resonance

Solving the governing equations of linearised depth averaged equations (neglecting friction, Coriolis and advection terms) yields the Proudman expression:



$$\frac{\eta}{h} = \frac{\Delta P}{\rho} \frac{1}{U^2 - c^2}$$

Inverted barometric factor $\eta_s = -\frac{\Delta P}{\rho g}$

$$\frac{\eta}{\eta_s} == \frac{1}{1 - {F_R}^2}$$

$If\ F_R \ll 1$ then $\eta = \eta_s$

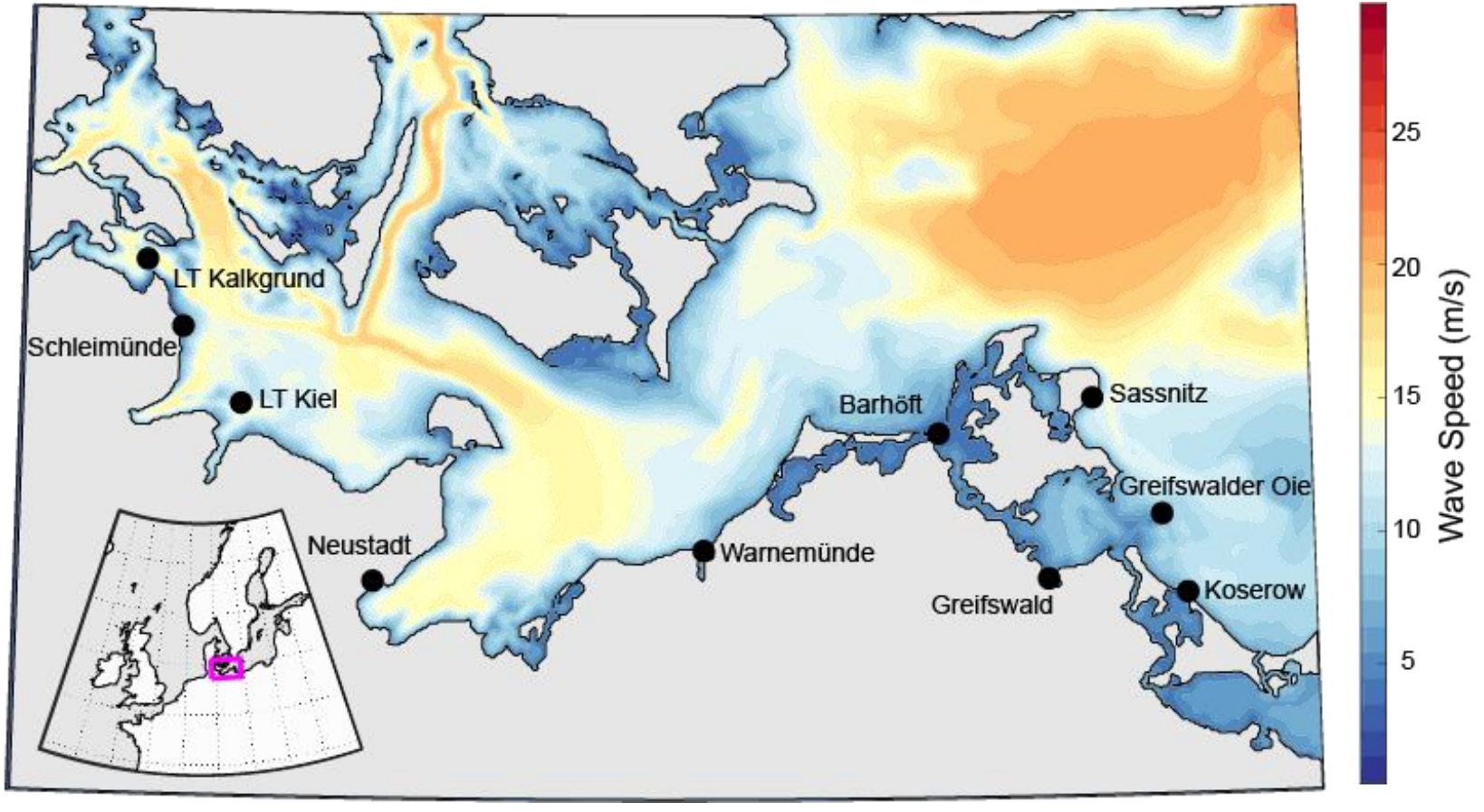
$If\ F_R = 1$ then $\eta = unbounded\ (\varepsilon_{max} \sim 5)$

$If\ F_R \gg 1$ then $\eta \approx 0$

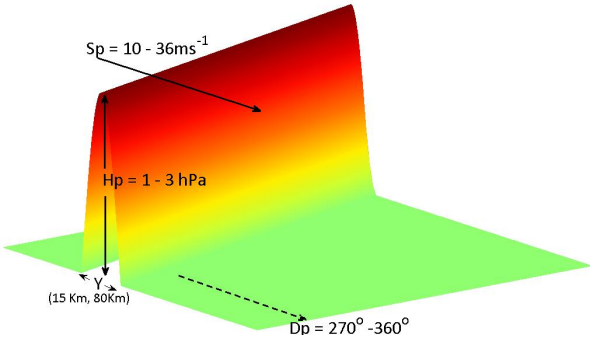
Froude Number $F_R = \frac{U}{c}$

Baltic Sea

2007-2018 sampling at 1 minute



Idealised simulations

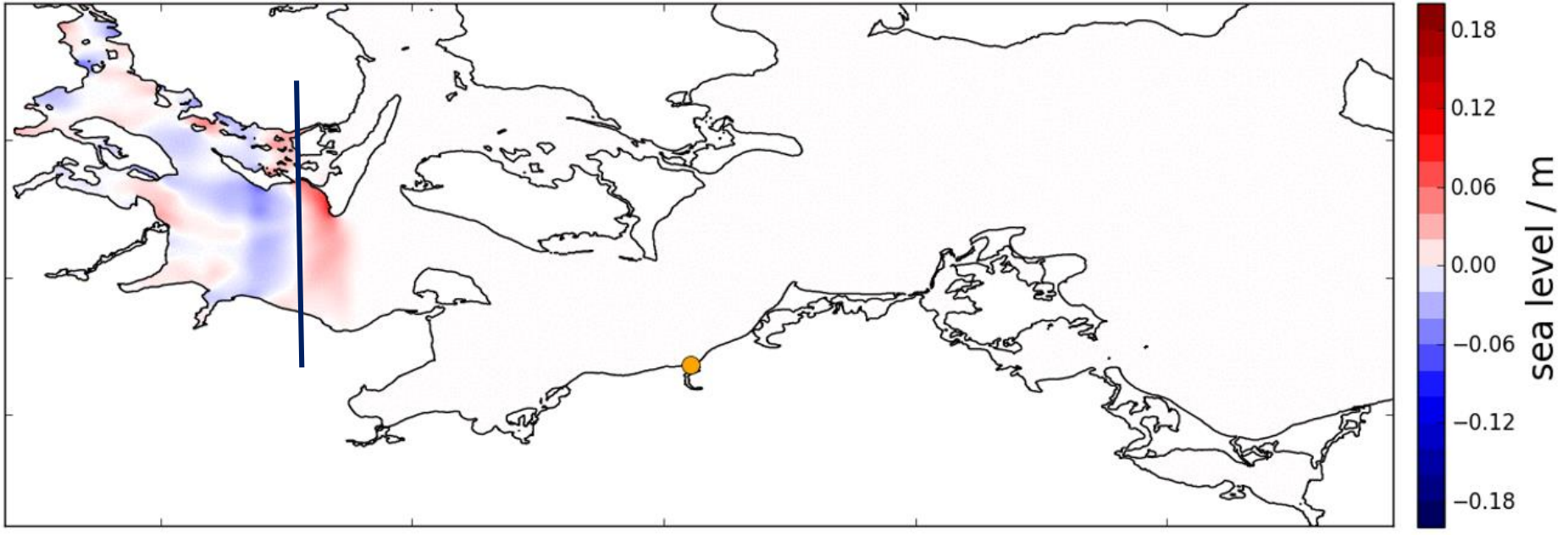


Moving pressure jump: 2 hPa

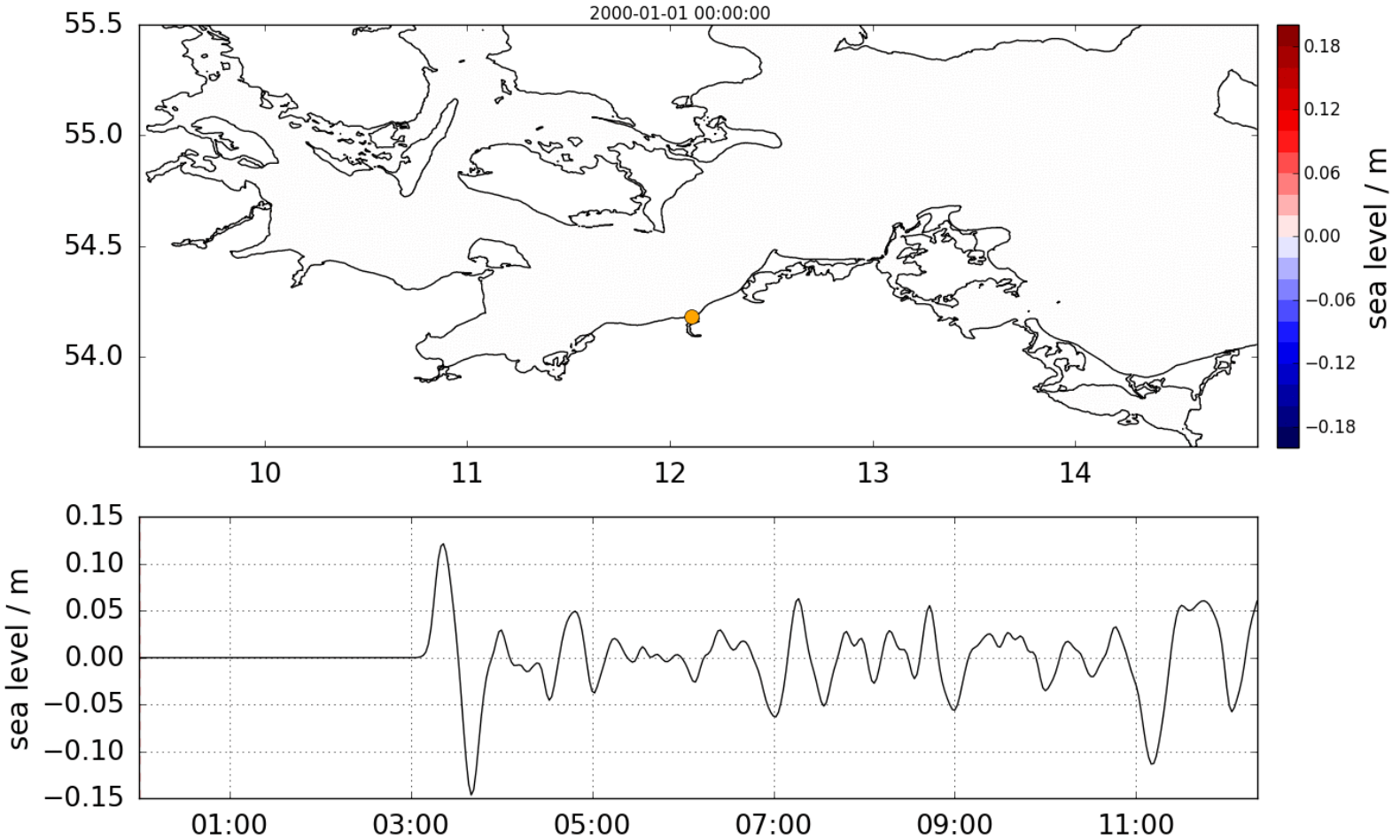
Speed: 20 ms^{-1}

Direction: 270 (west to east)

Marvin Lorenz (IOW)



Idealised simulations



Meteotsunamis

Location	Max height
Croatia	6.0 m
Balearic Islands, Spain	5.0 m
Nagasaki Bay, Japan	4.8 m
Boothbay, Maine, USA	4.0 m
Black Sea	3.2 m
Chicago, Great Lakes (US)	3.0 m
Daytona Beach, Florida	3.0 m
Dwarskersbos, South Africa	2.9 m
Longkou Harbour, China	2.9 m
Odessa, Black Sea	2.0 m
West Australia	1.1 m
New Zealand	1.0 m

Meteotsunamis

Local names for Destructive Events.

"Rissaga", in the Balearic Islands, Spain (Gomis et al., 1993)

"Abiki", in the Nagaski Bay, Japan (Hibiya and Kajiura 1982)

"Marrubio", in Sicily (Candela et al., 1999) – 'Mad Sea'

"Seebär", in the Baltic Sea (Credner, 1889)

"Zeebar", along Dutch coast (??)

"Malghuba", in Malta (Drago, 2008)

"Sciga", in Croatian Coast in Adriatic Sea (Hodzic, 1979/1980).

Also:

Dutch coast, English Channel, Persian Gulf, Florida shelf, Brazil & Argentina Coasts, the Yellow Sea, New Zealand, Australia

Freaky Meteotsunami Tosses Parked Cars Around at Brazilian Beach

8 Comments

TUESDAY, FEBRUARY 11, 2014 CATEGORIES: ACCIDENTS, BRAZIL, OFFBEAT NEWS, REPORTS, VIDEO |

Sunbathers, swimmers and casual visitors at the world's longest beach, the Praia do Cassino (literally Casino Beach) in Rio Grande, Brazil, were captured by surprise this past Sunday when a bizarre natural phenomenon known as a Meteorological Tsunami, Meteotsunami or simply, weather-induced tsunami, hit the area.

THE UNIVERSITY OF WESTERN AUSTRALIA

Bizarre 'Meteotsunami' Stirred Waves in UK

LiveScience By By Tia Ghose, Staff Writer
August 5, 2013 4:55 PM

A tsunami that struck the UK in 2011 was caused by a storm roiling the ocean hundreds of miles away, a new study confirms.

The "meteotsunami" (or weather-induced tsunami) of June 27, 2011, caused swells on a normally calm estuary on a sunny day, left some people knee-deep in water and made other people's hair stand on end in southwest England. Scientists suspected that a storm was to blame for the bizarre waves, but the new study, published in the June issue of the journal Weather, confirms it.

"As far as Britain is concerned this is the first time that a meteotsunami has been recorded," said study co-author David Tappin, a marine geologist at the British Geological Survey. [10 Tsunamis That Changed History]

Rare waves

Weather-induced waves happen when storms blast the ocean surface with a burst of pressure, creating a wave. But this wave only turns into a tsunami if the pressure wave forms a resonance with the weather pattern — meaning the wave is traveling at the same speed as the weather front itself.

The wave may be just a few inches high in the deep ocean. But once the wave hits a narrow inlet or V-shaped harbor, the waterway reflects and amplifies the wave's energy and the blip on the water's surface can rapidly grow to 20 feet (6 m) high, Tappin told LiveScience's OurAmazingPlanet.

Rare weather-induced monster waves have been reported in Majorca, Spain; the Great Lakes in the United States; and the Adriatic Sea. In 1979, a weather-induced tsunami struck Japan at Nagasaki Bay. The 13-foot-high (4 m) wave killed several people. [Album: Monster Waves]

Unusual event

Burnie: Tasmania

Rare 'tsunami' tides hit north

Updated 3 Dec 2009, 11:52am

Abnormal tides reported in northern Tasmania last week are being attributed to a rare atmospheric disturbance, known as a meteo-tsunami.

00:00 00:00

AUDIO: Brendan McMahon describes the meteo-tsunami to reporter Annah Yard. (ABC News)

MAP: TAS

The Weather Bureau took several calls from people in Stanley, Port Sorell and Bridport who noticed particularly high and fast moving tides on November the 22nd.

The bureau says it was caused by a rare rissaga, or meteo-tsunami, but spokesma says it is not known what triggered the event.

"Unlike the conventional tsunami which we've come to know which is produced by a undersea earthquake or some sort of earthquake...this is produced by an atmosphe

"So a deep low pressure system, the passage of a front moving through quite vigoro

Bridport shack owner Tony Power witnessed the event.

He says in a matter of minutes the tide came up to his shack and then went back ou it.

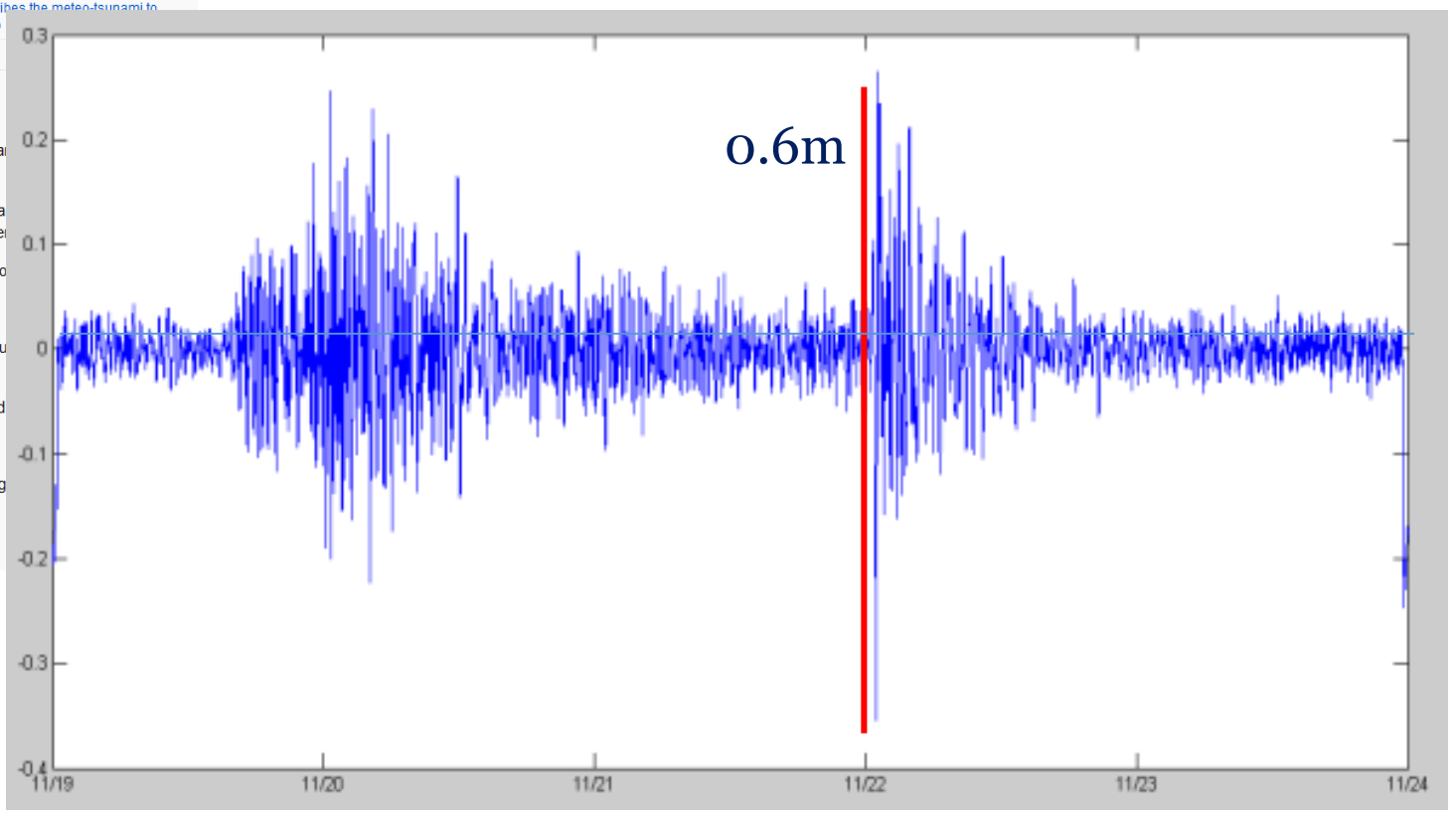
"I reckon within 10 minutes it was up over the sand bar coming towards us," he said

"Fairly forceful, you probably wouldn't have stood up in it.

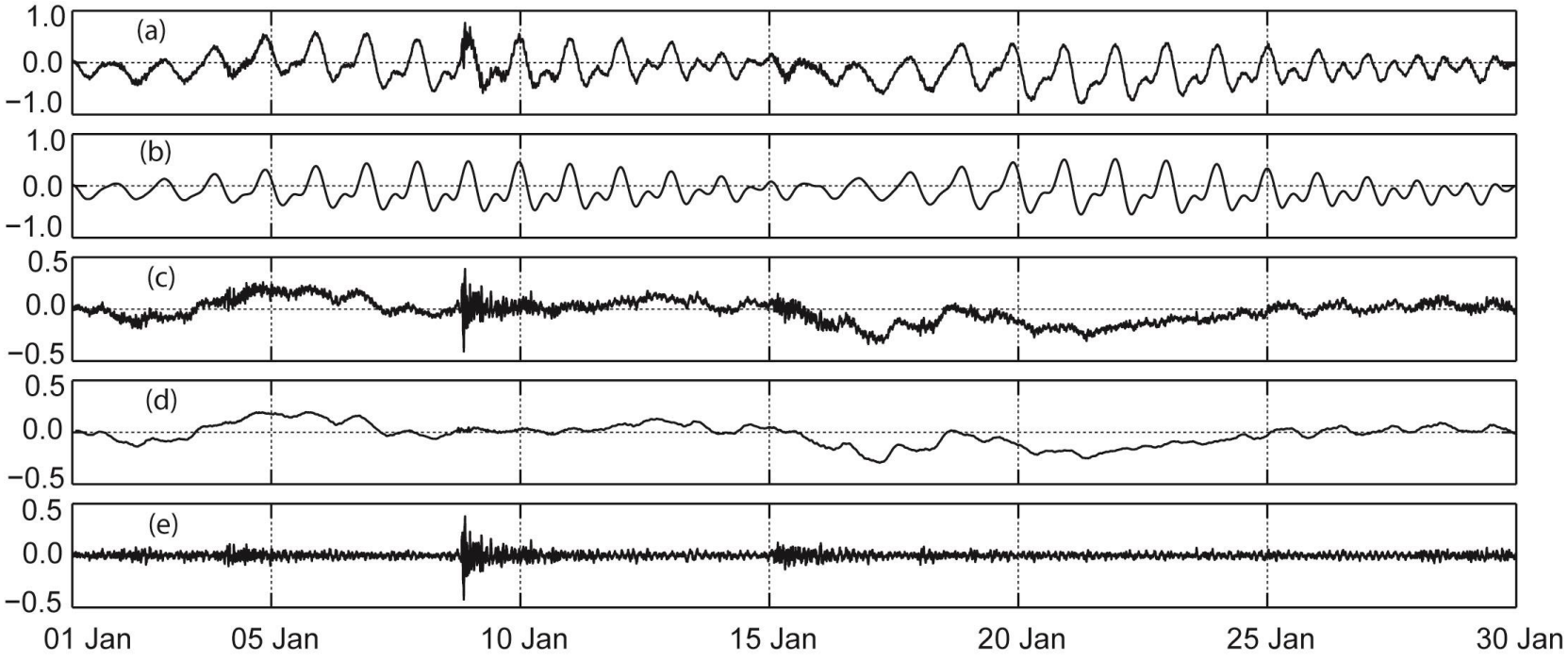
"It was pretty strange and eerie because you sort of didn't know how far it was going

"We didn't know whether to retreat to higher ground."

Topics: phenomena, tas, bridport-7262, port-sorell-7307, stanley-7331



Data Analysis



Measured

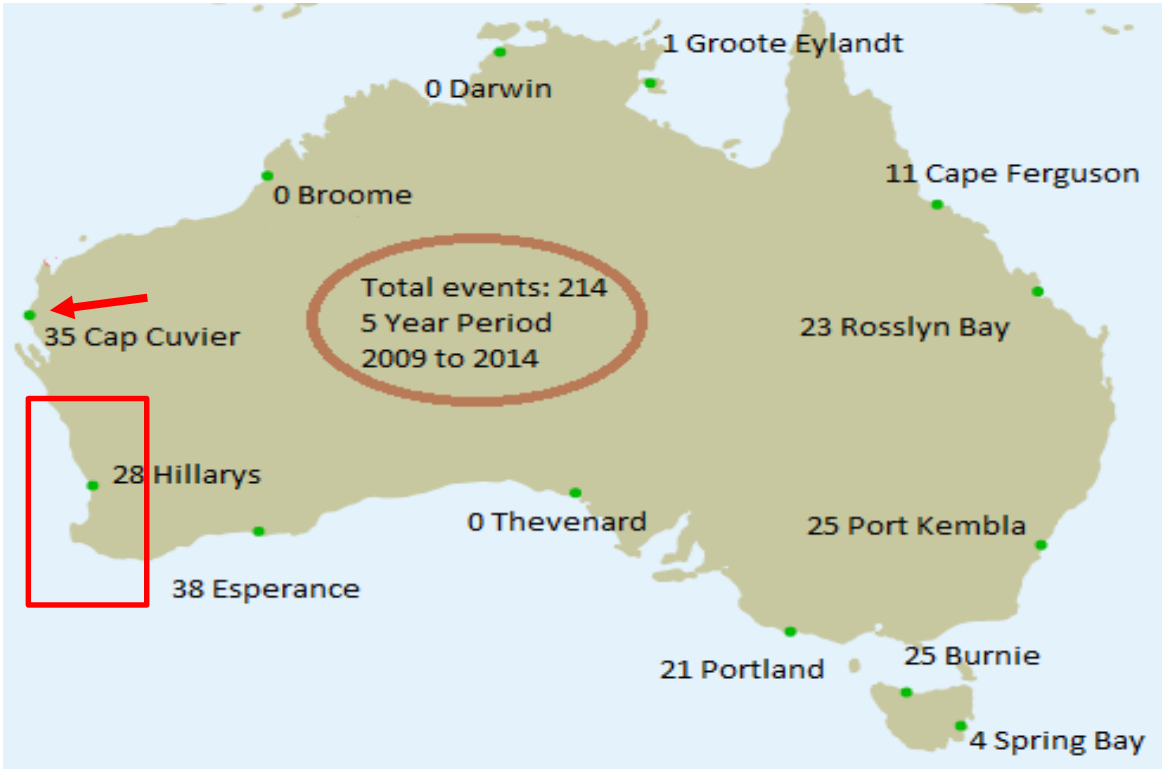
Tidal component

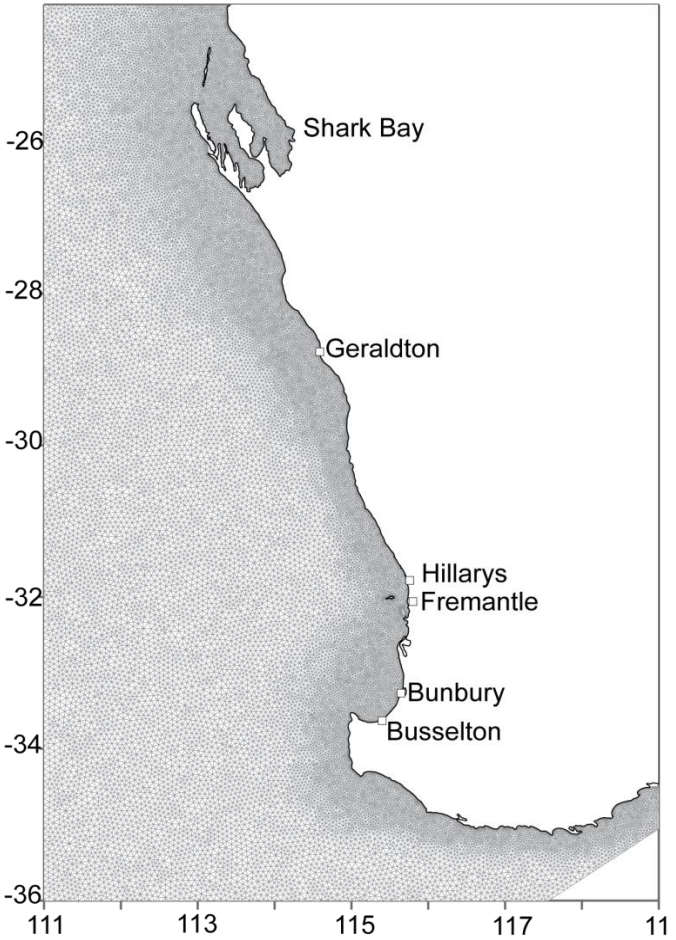
Residual

Weather band

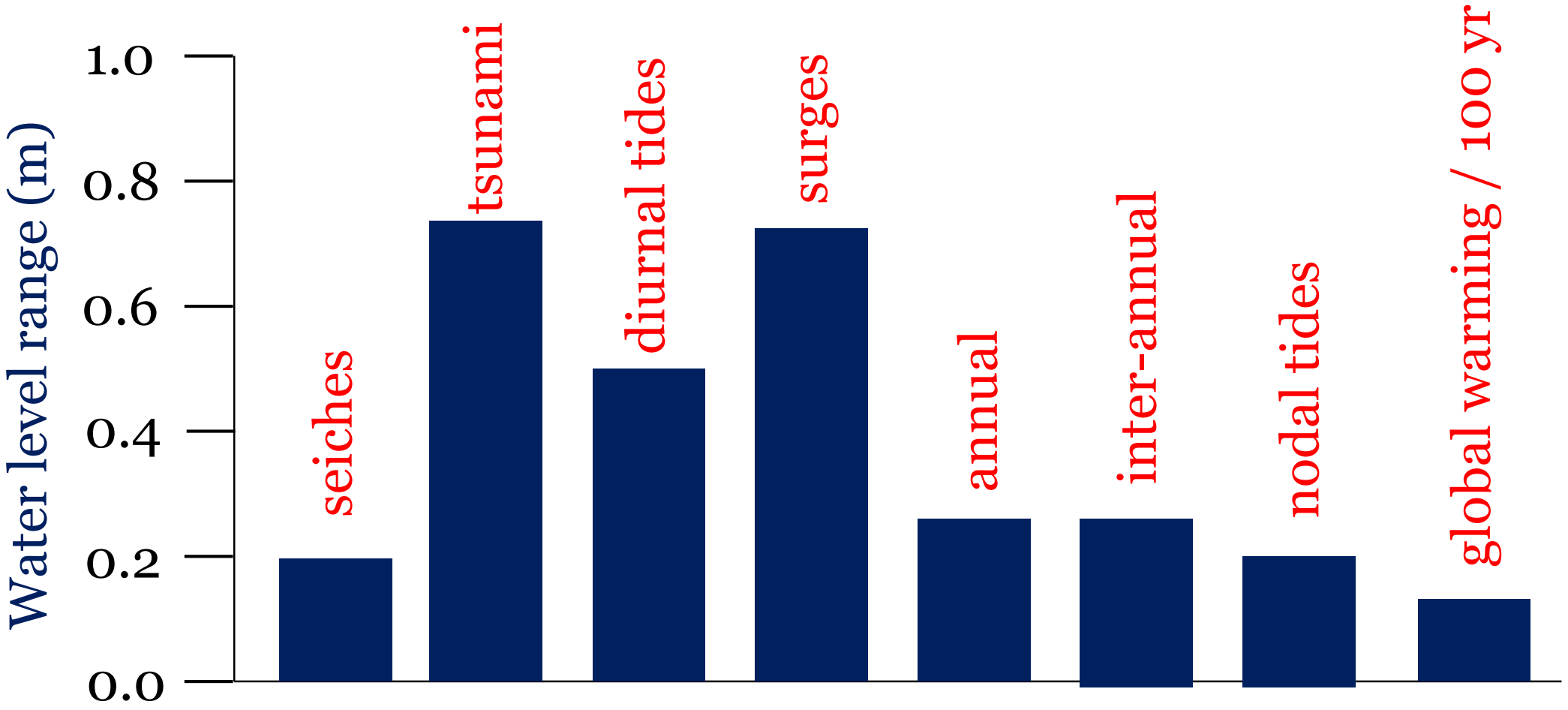
< 6 hr period

Meteotsunami events around Australia





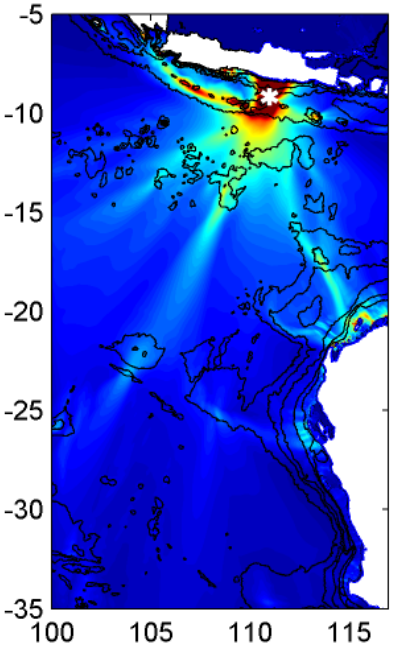
Processes contributing to water level variability at Fremantle

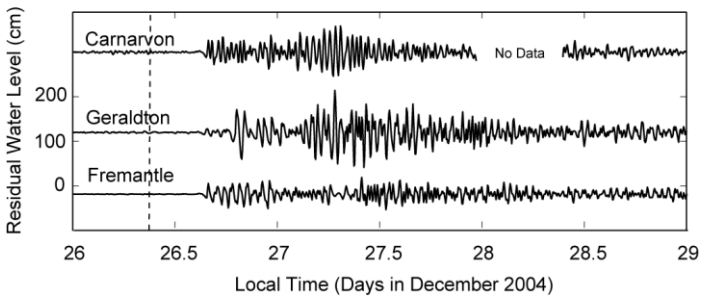


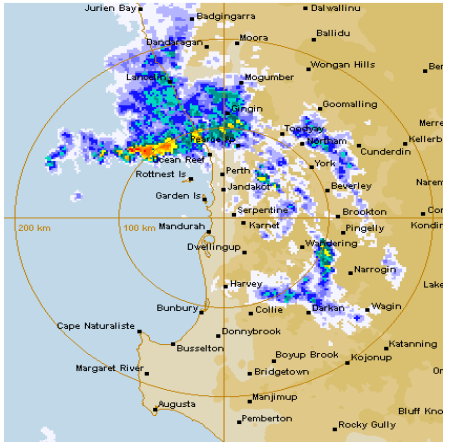
Tsunamis: Seismic and Meteorological

THE UNIVERSITY OF WESTERN AUSTRALIA

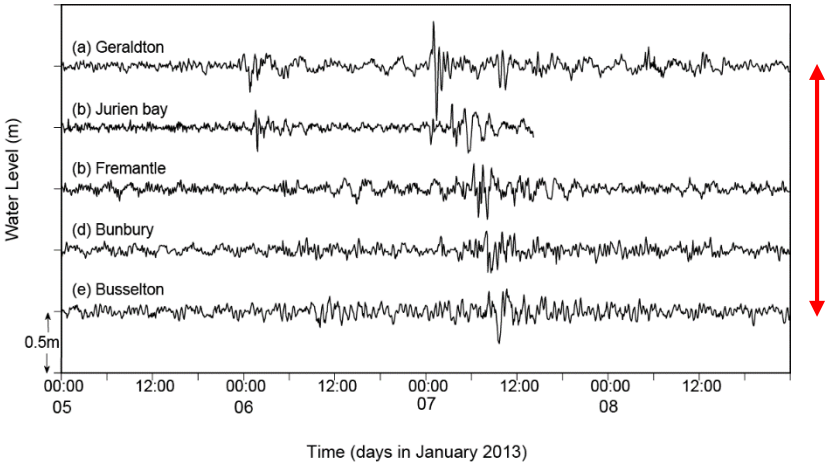
Max: 0.60m







Max: 0.72m



600 km

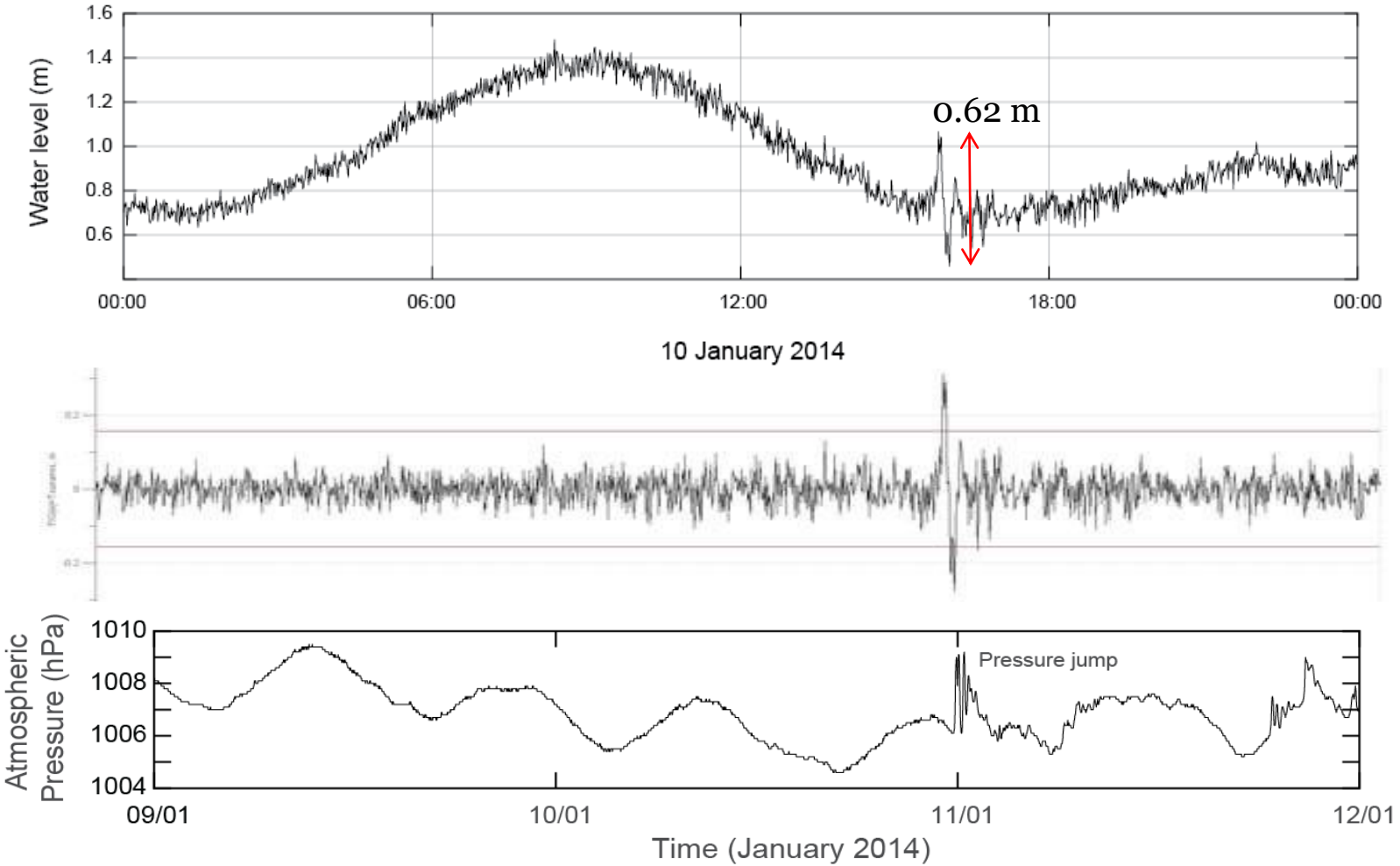
Thunderstorms

Occur during the warmer season (October – April) and develop mostly in the afternoon.

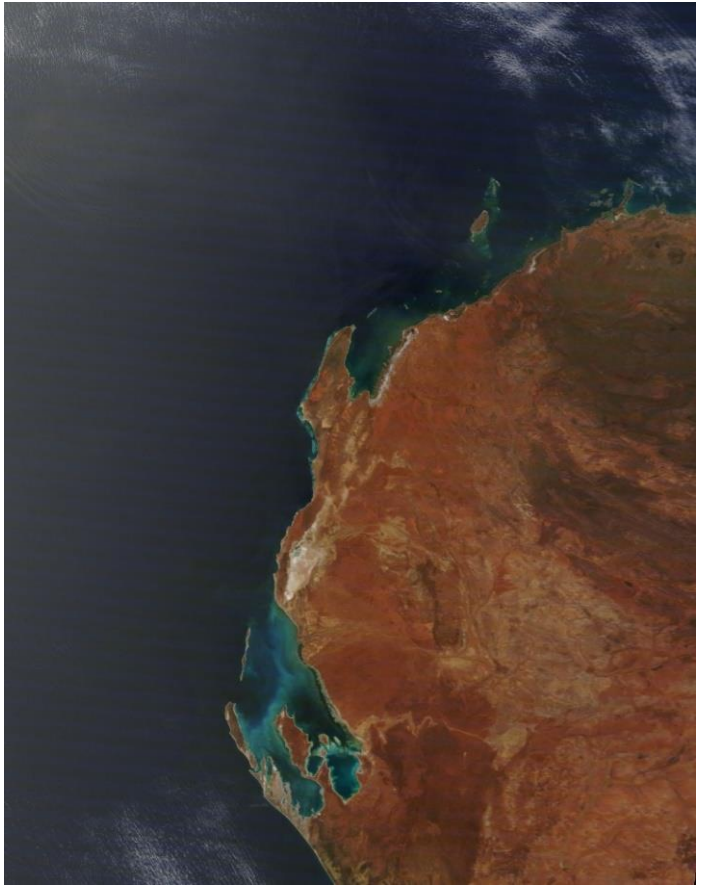
Most storm events are highly localised.

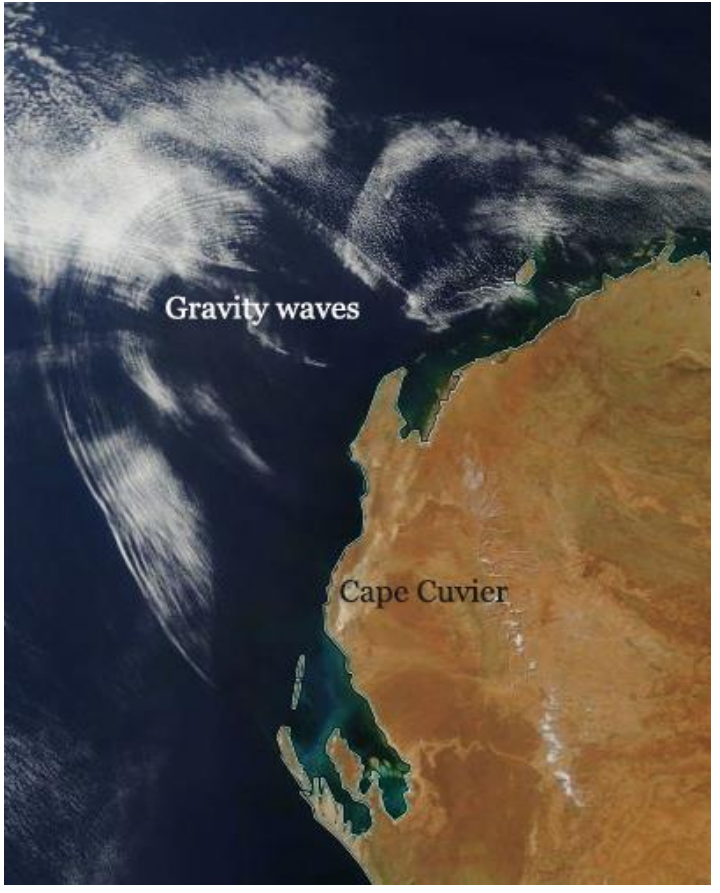
They move at 20-40 km/h, and last only a few hours whilst some multiple events may affect a larger area (~600km).

Cape Cuvier - WA



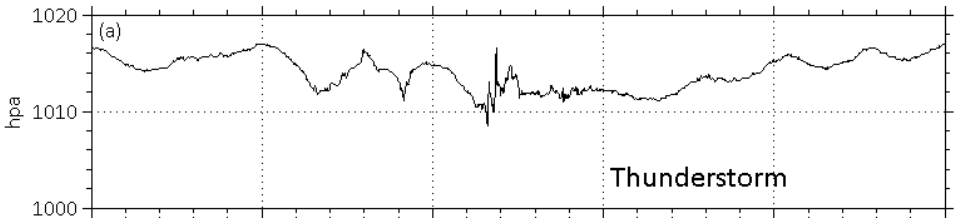
Cape Cuvier - WA

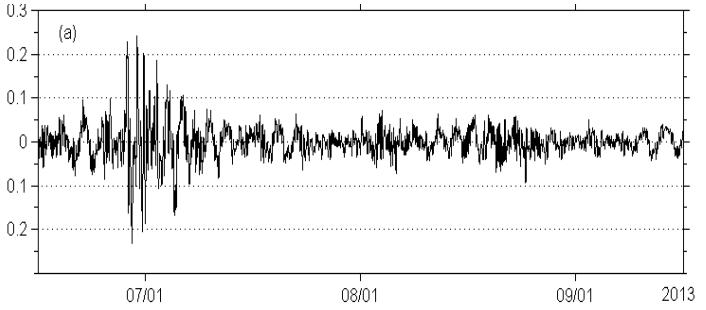




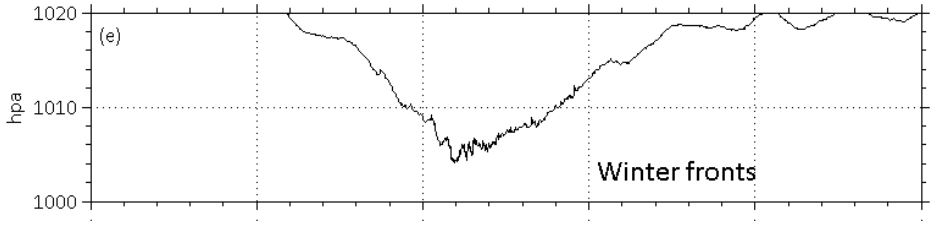
Meteotsunami events: Hillarys

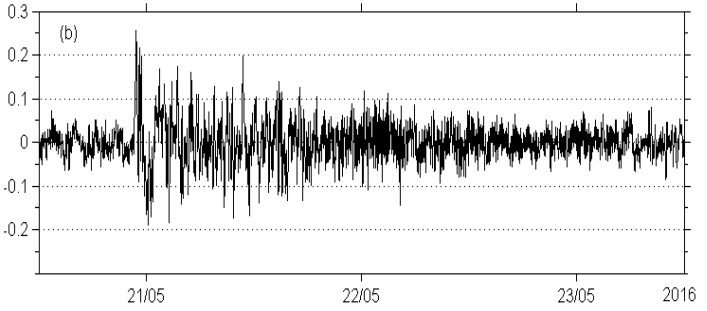
Thunderstorm



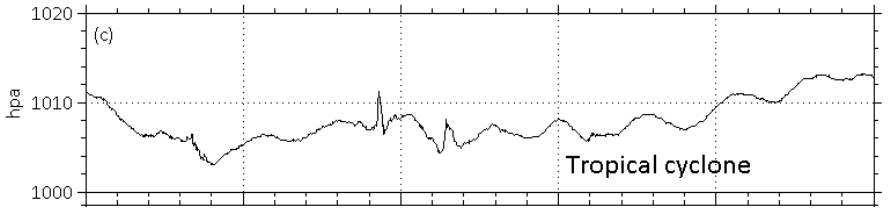


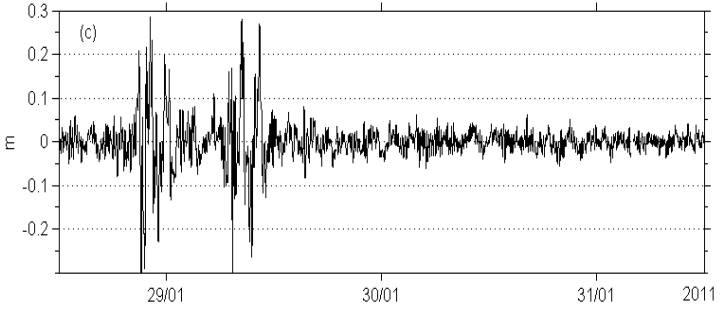
Cold Front





Tropical Cyclone





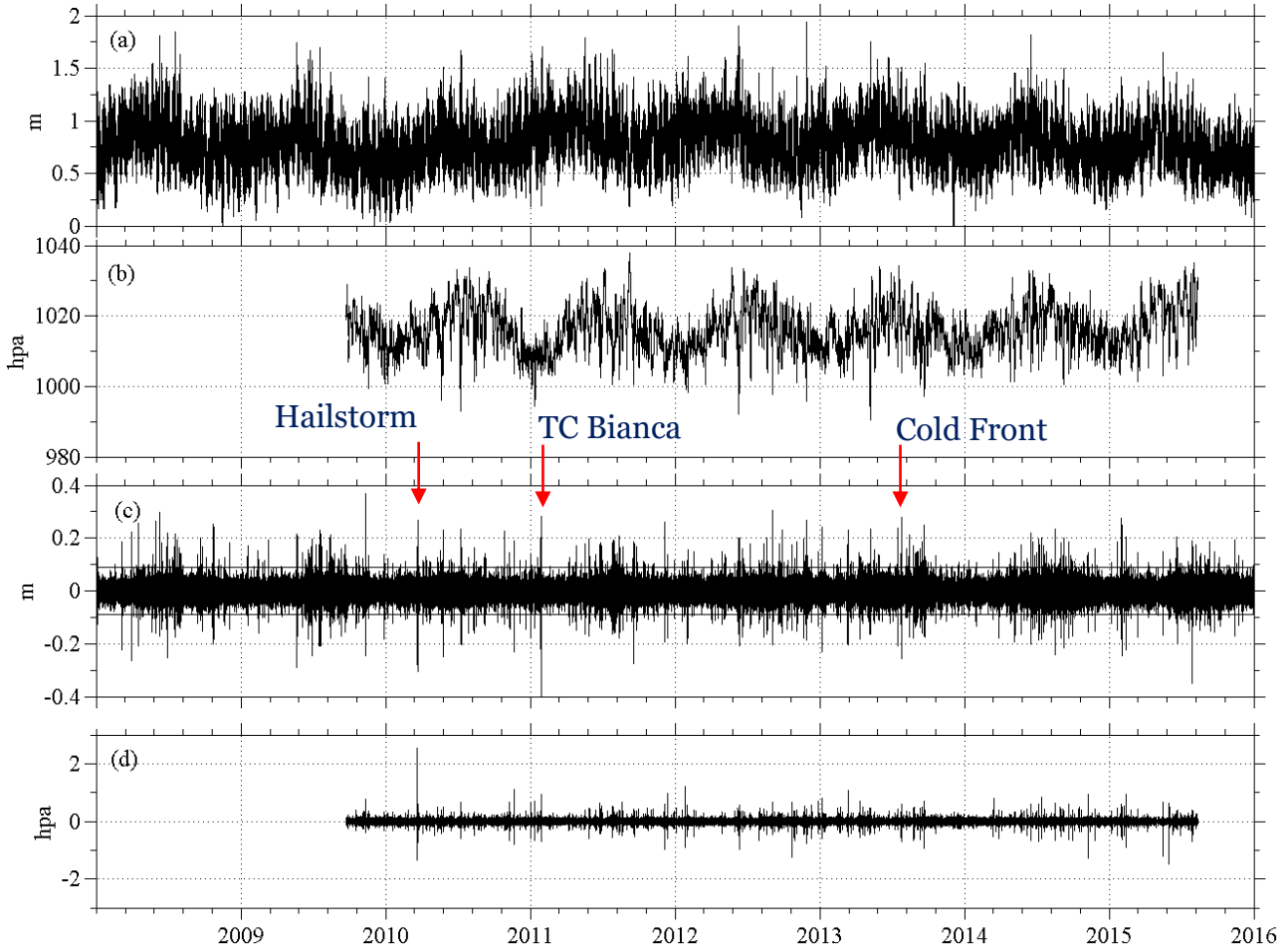
Meteotsunami events: Hillarys

Water level (measured)

Atmos. Pressure (measured)

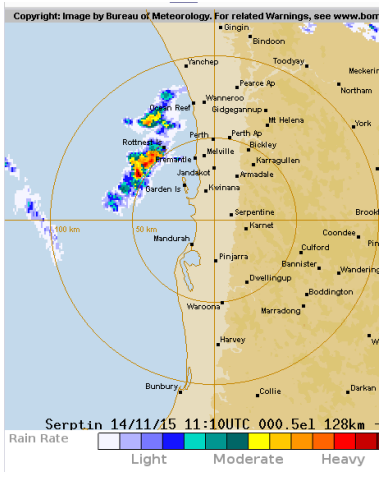
Water level (< 6hr period)

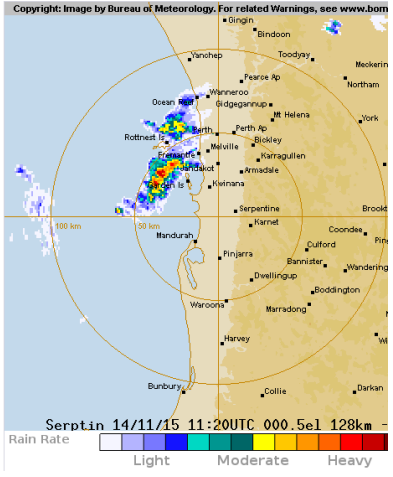
Atmos. Pressure (< 6hr period)

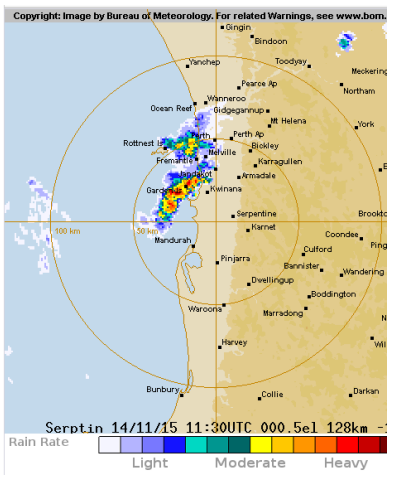


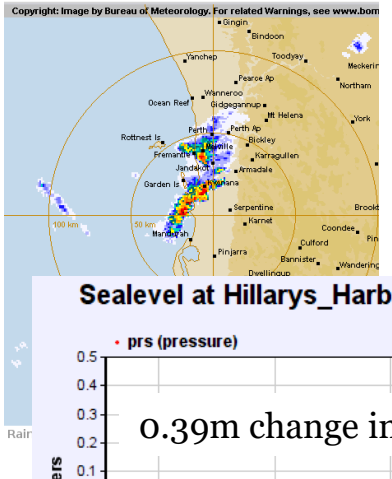
Meteotsunami

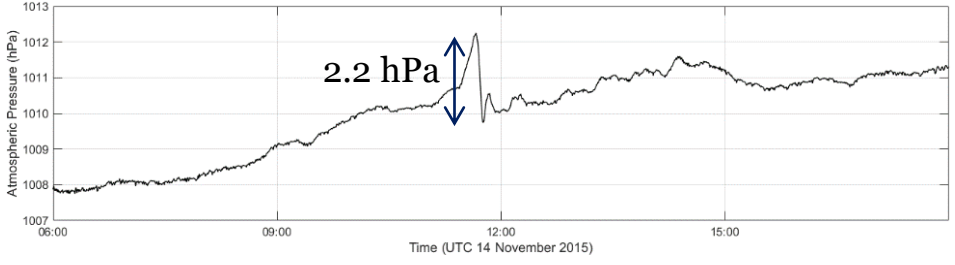
Perth region: 14 November 2015: 1145 UTC

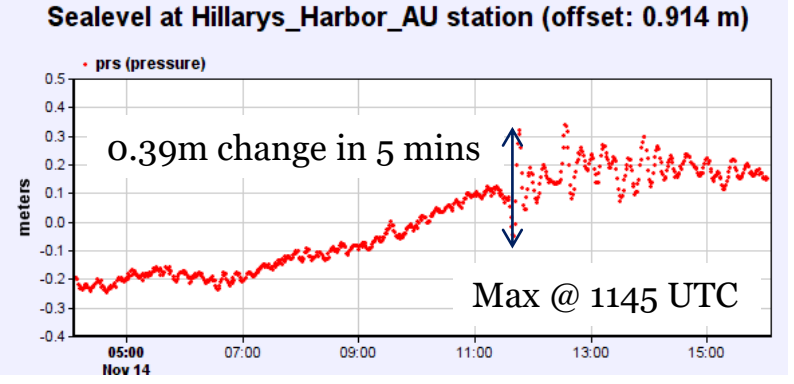


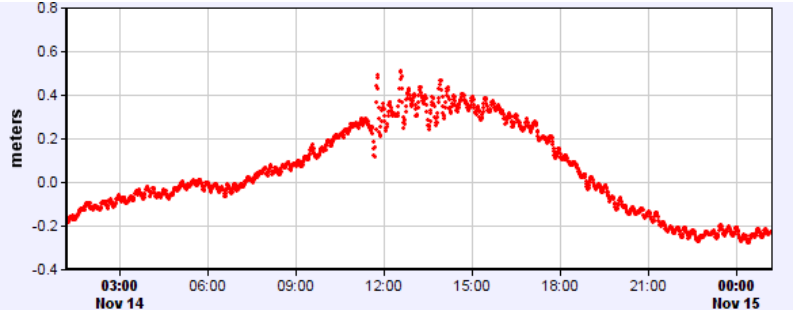




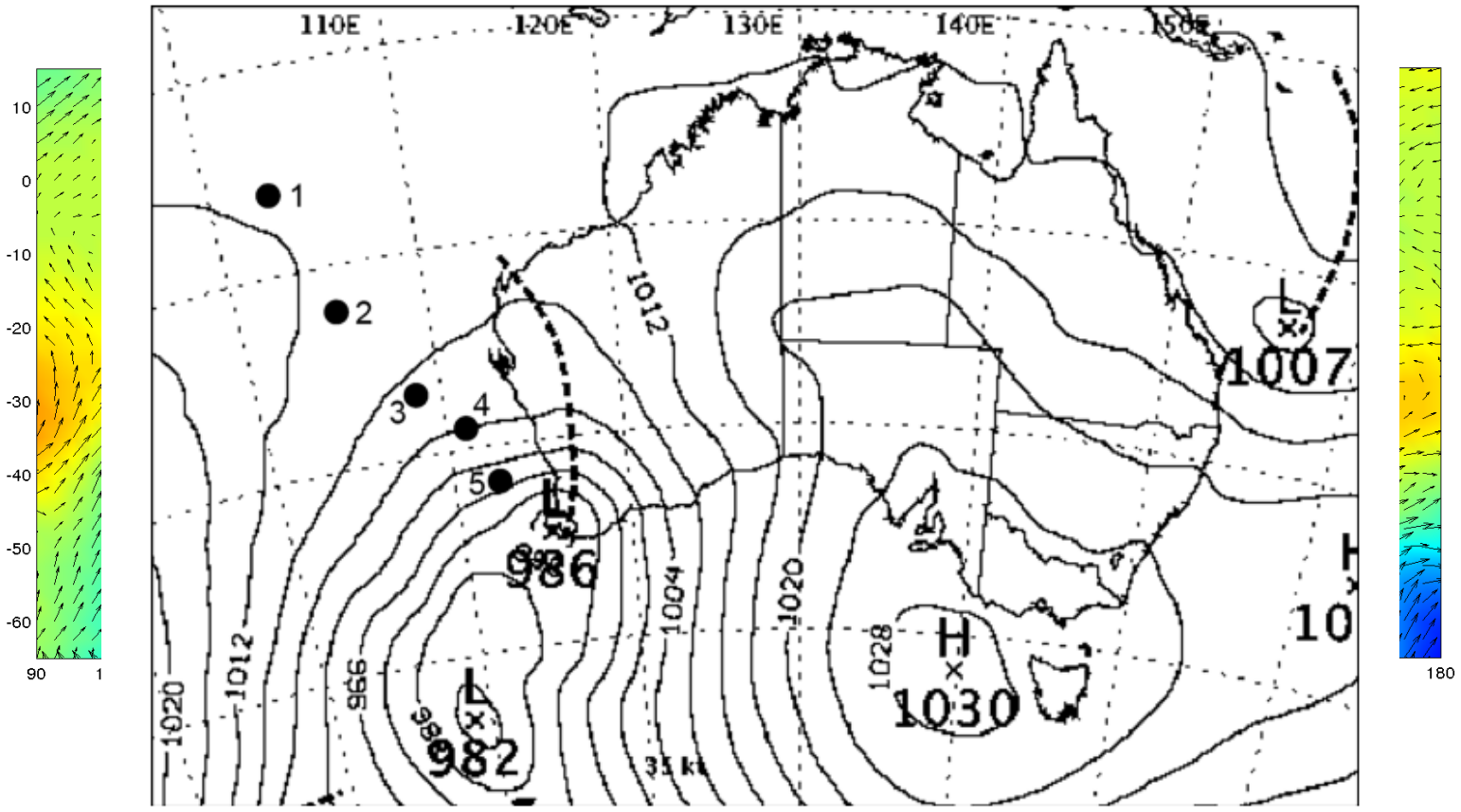




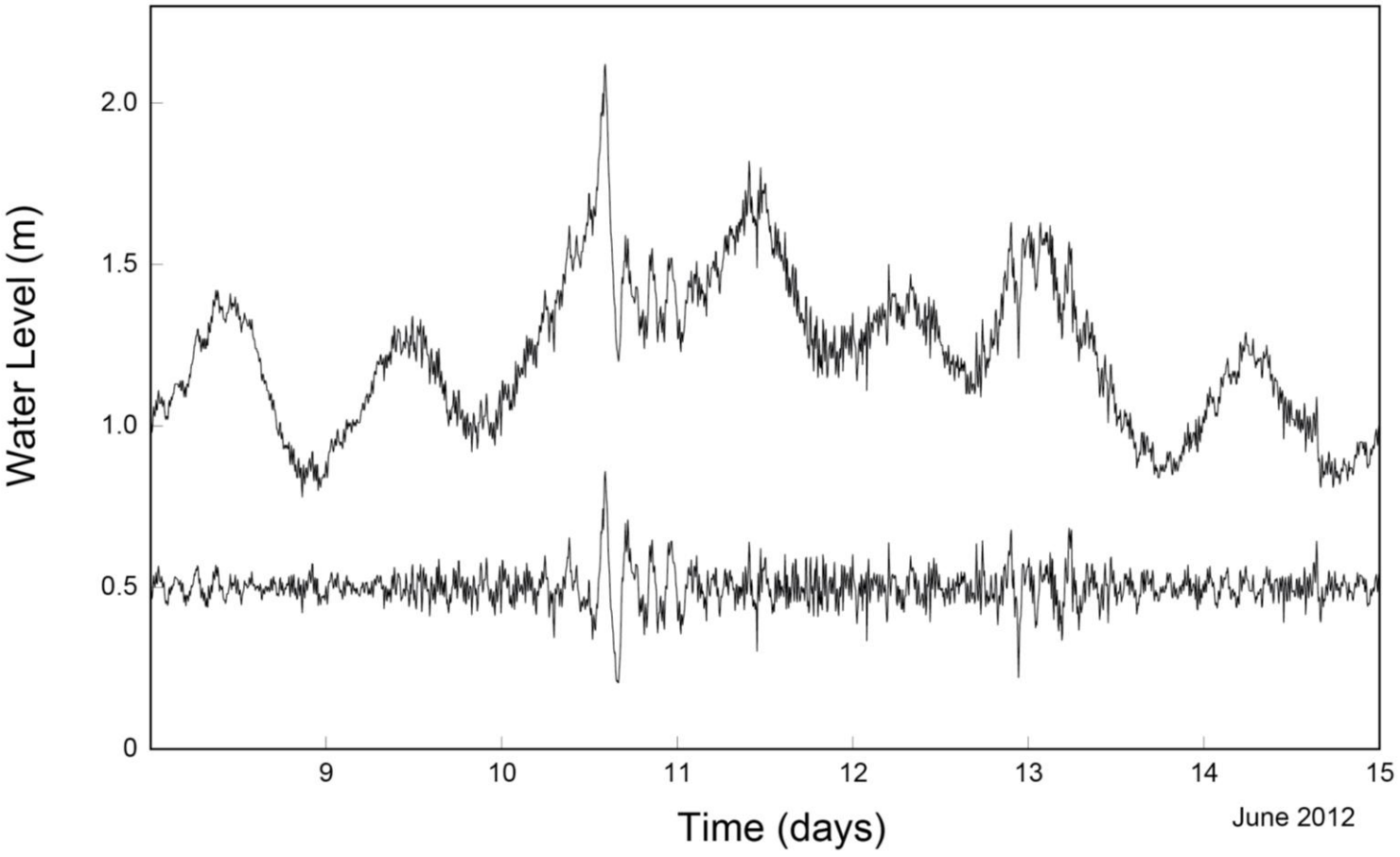




Storm tracks: 10-11 June 2012



Water level: June 2012



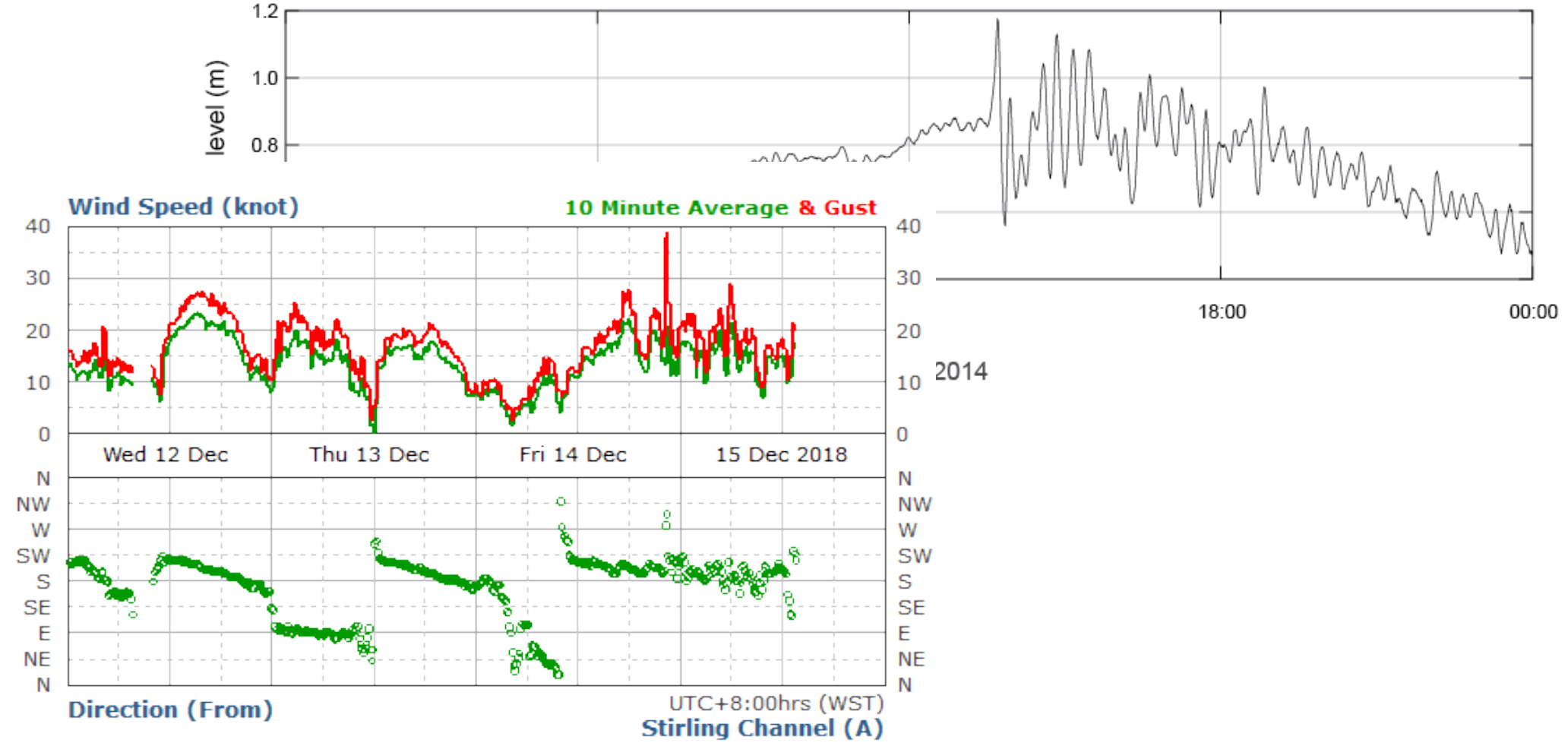
Highest water level recorded in 115 years

Coastal flooding: Riverside Drive

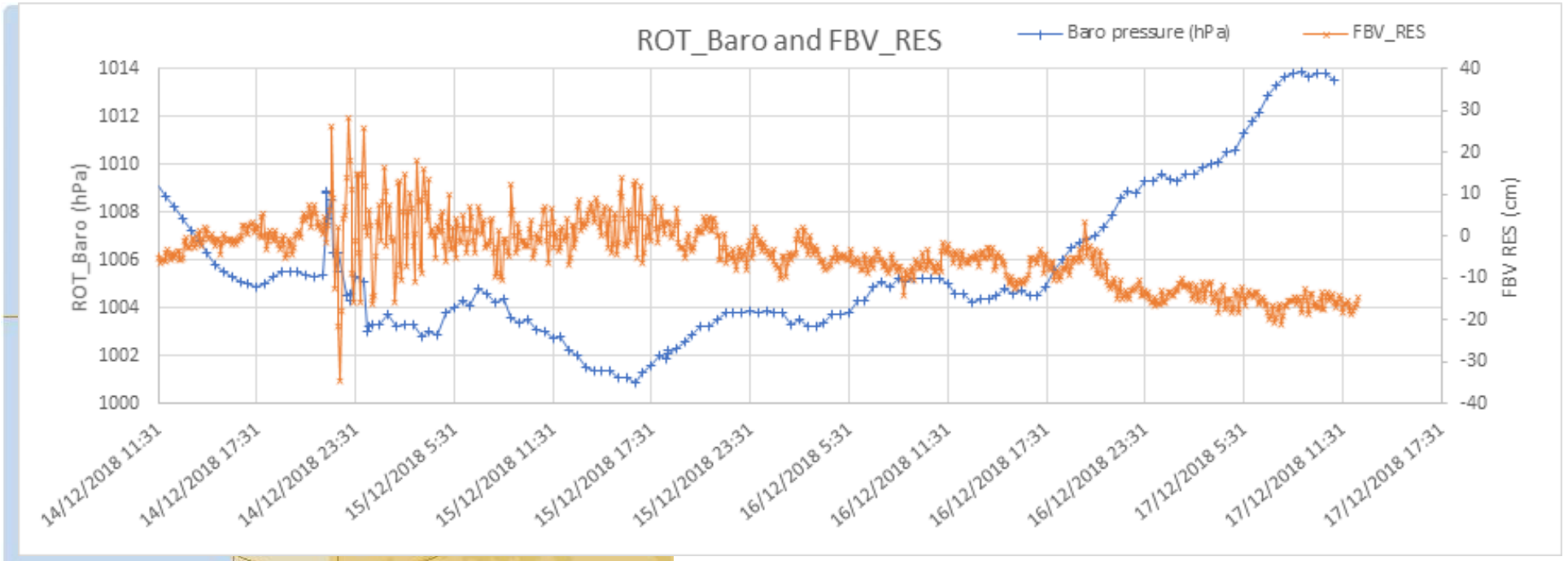
Flooded Riverside Drive closed

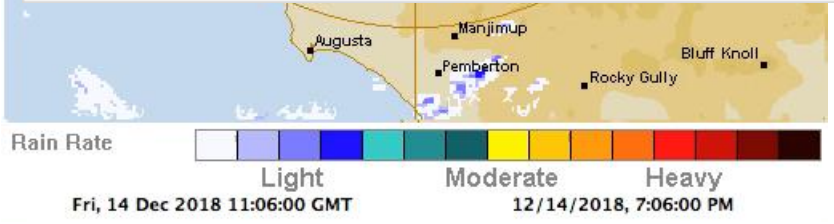
KATIE ROBERTSON • PERTHNOW • JUNE 11, 2012 8:45AM

Fremantle: 14 December 2018



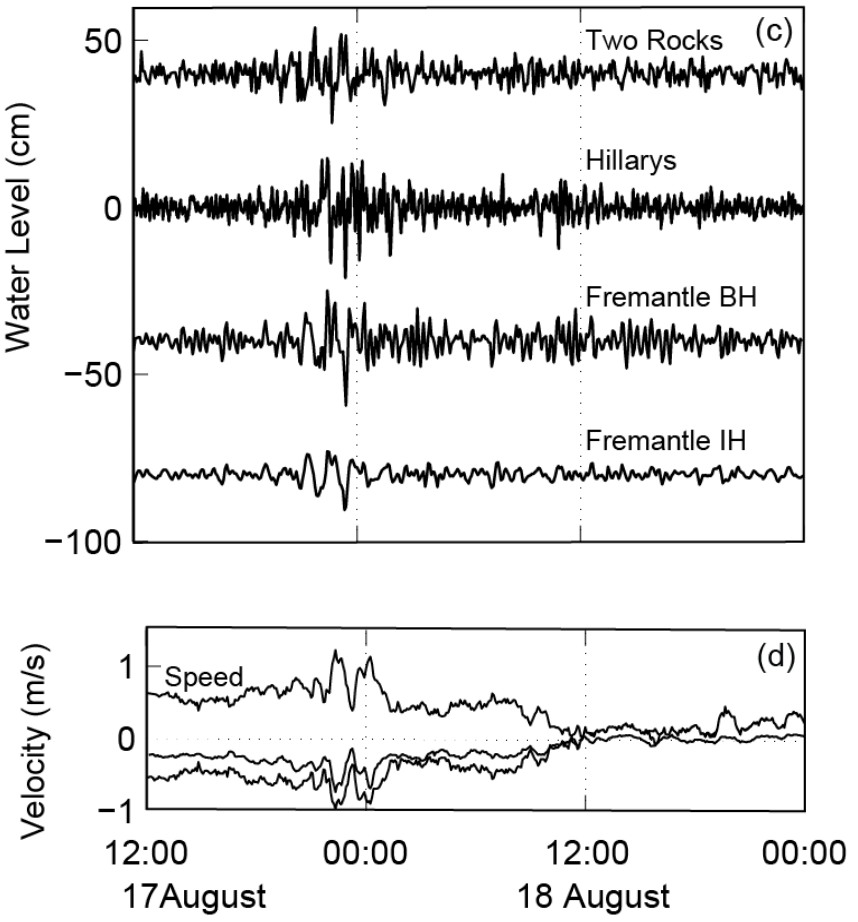
Fremantle: 14 December 2018



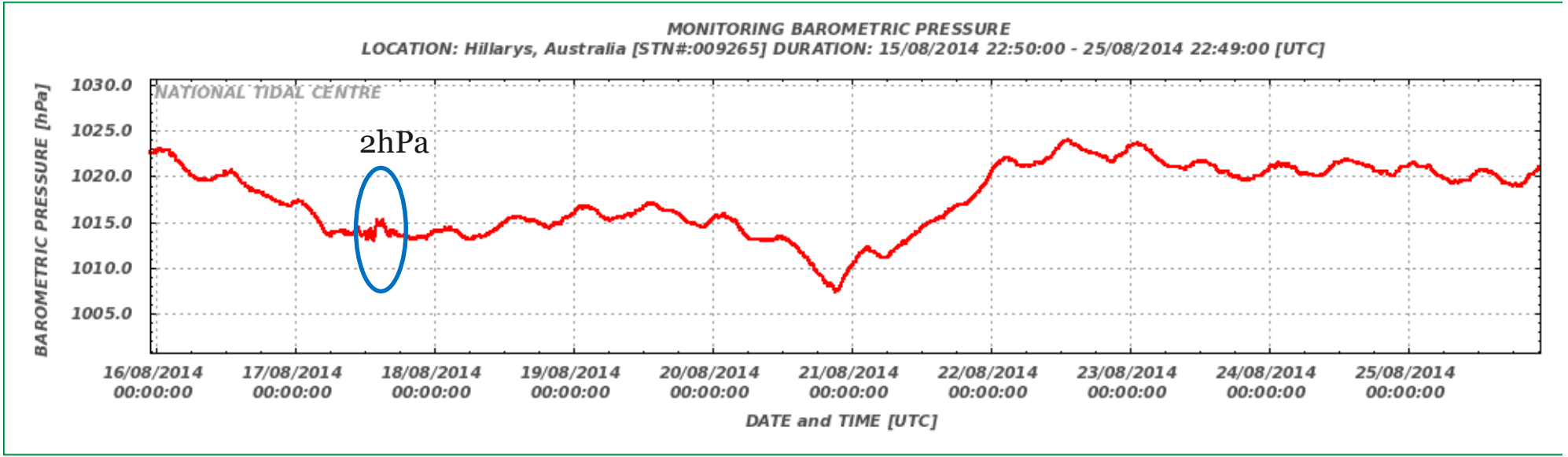


3.4 hPa pressure jump in 15 minutes
peak to trough max. wave height 0.61 m

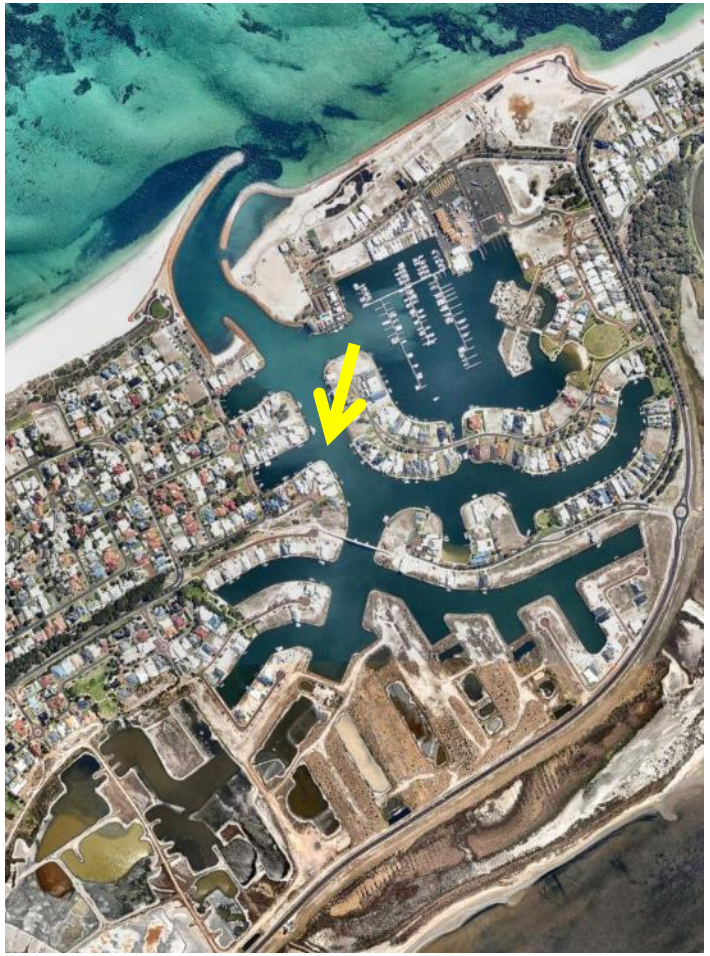
Event of 17 August 2014

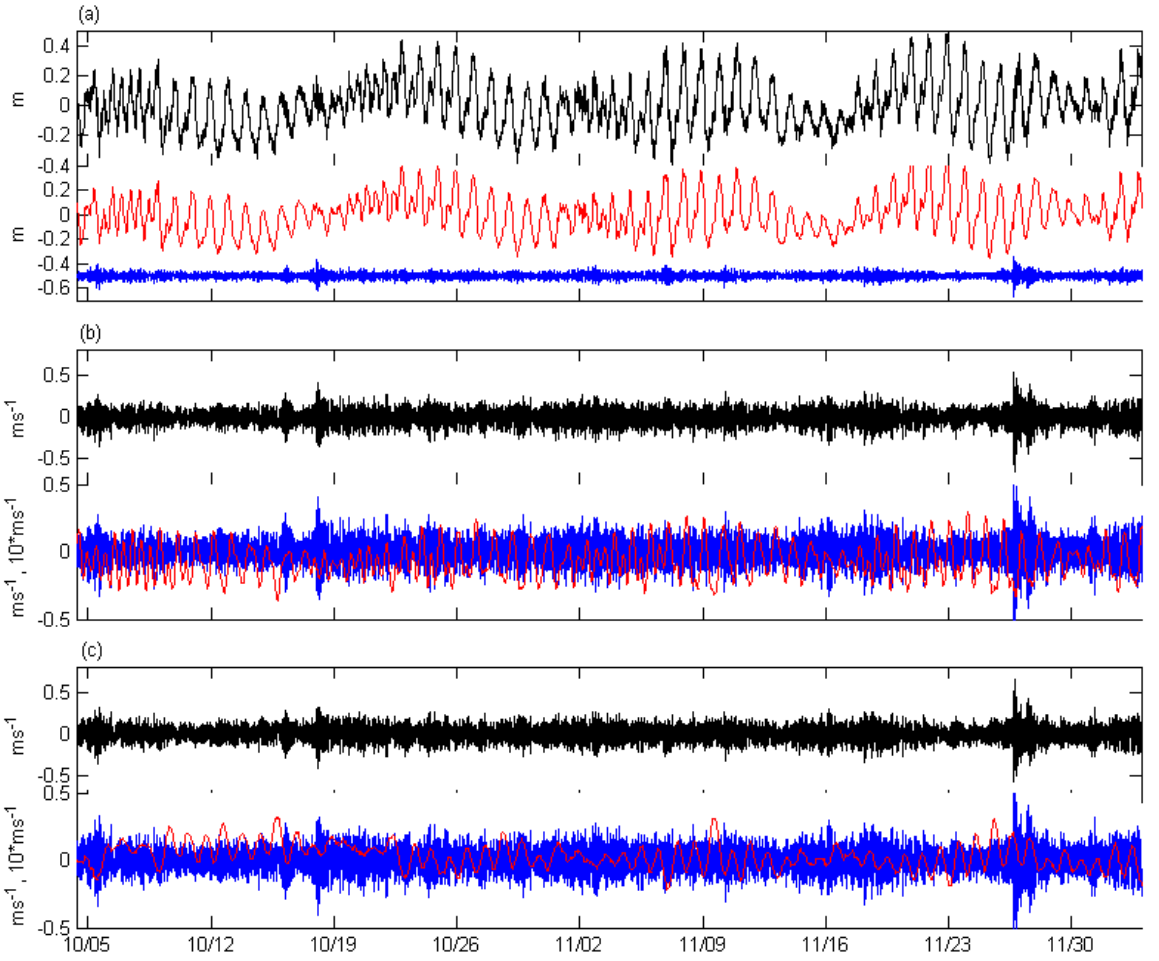


Event of 17 August: air pressure

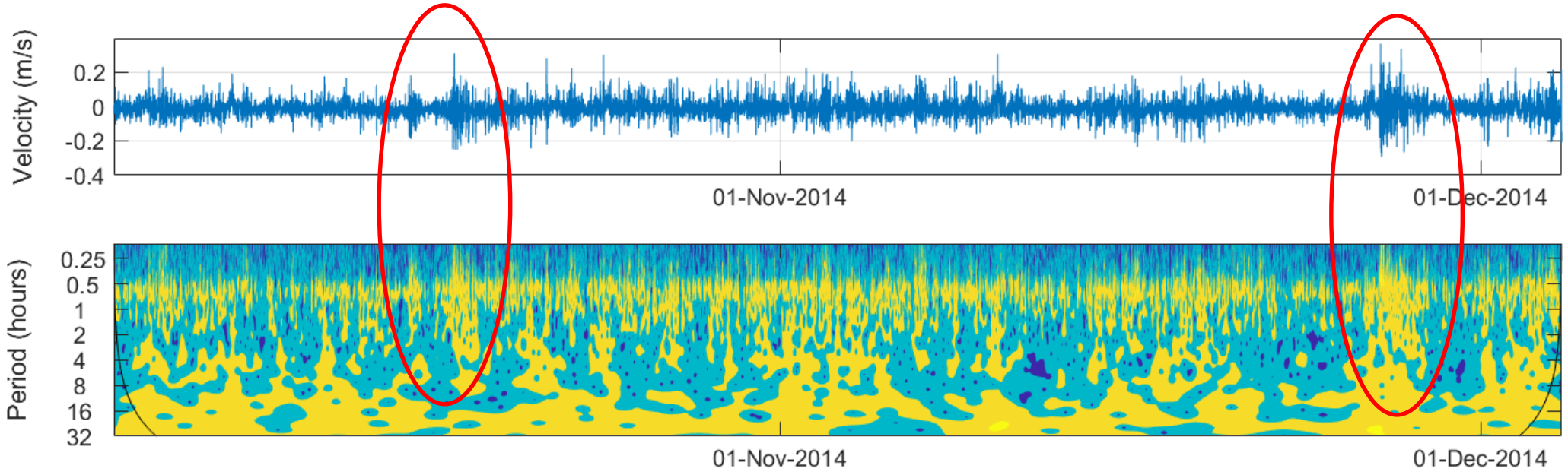


Port Geographe

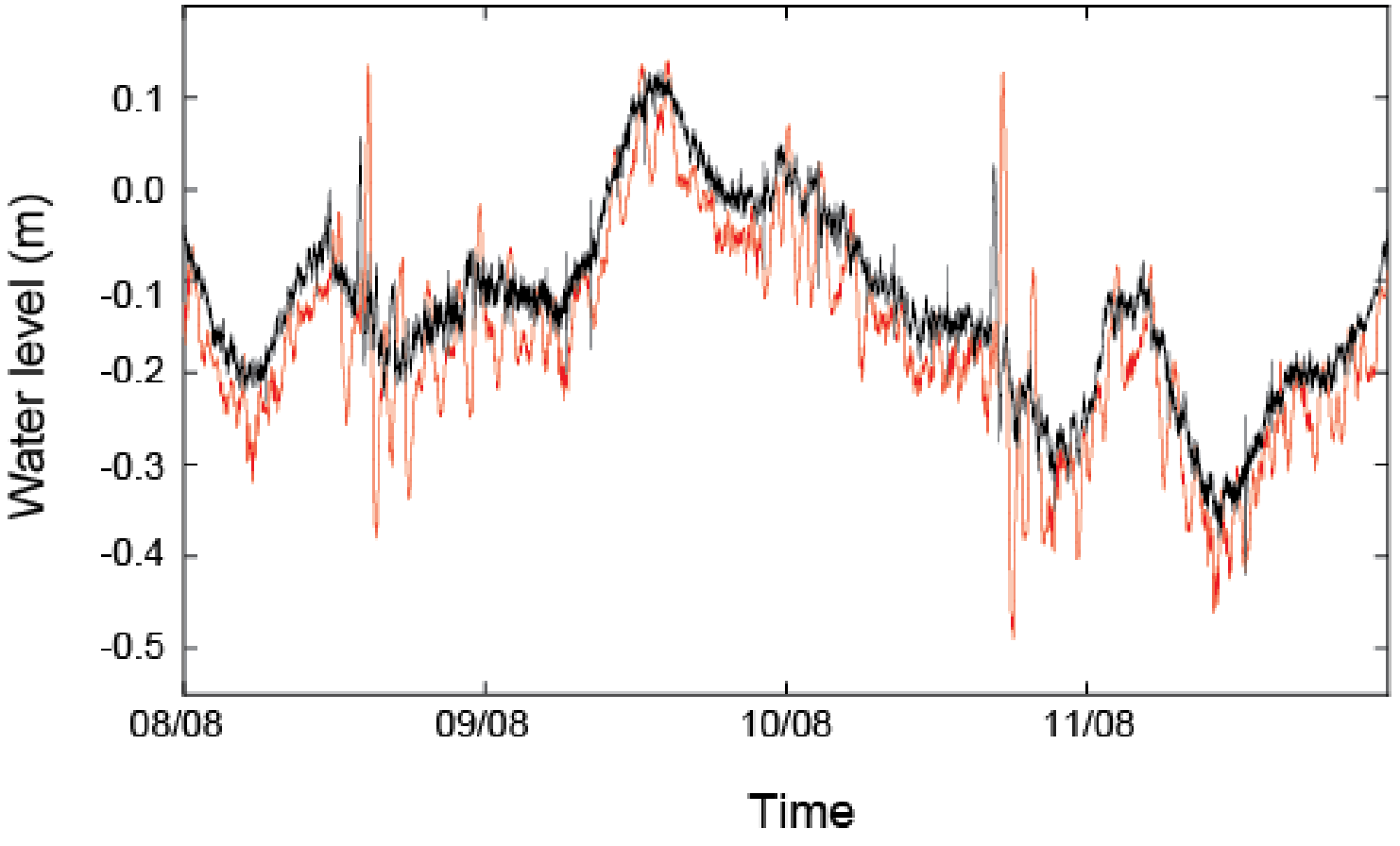




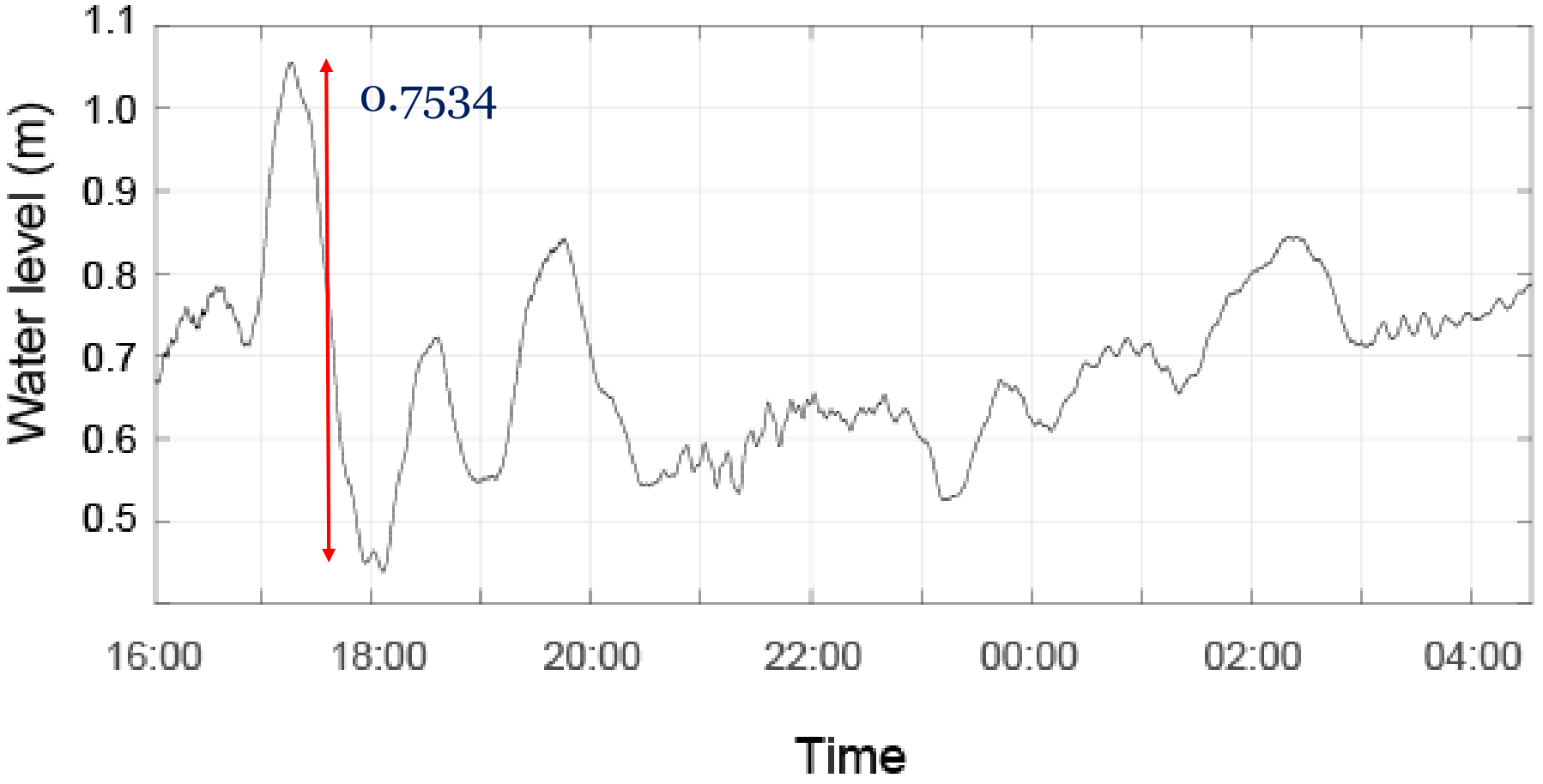
Port Geographe



Warnemünde & Warnow

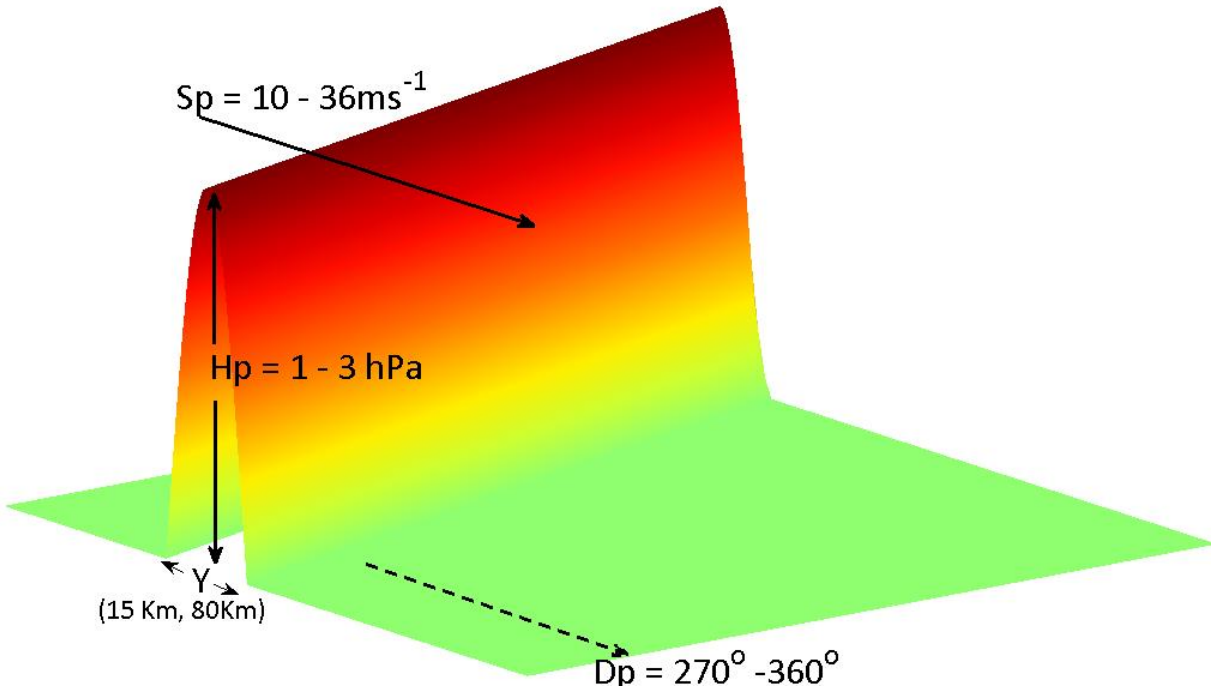


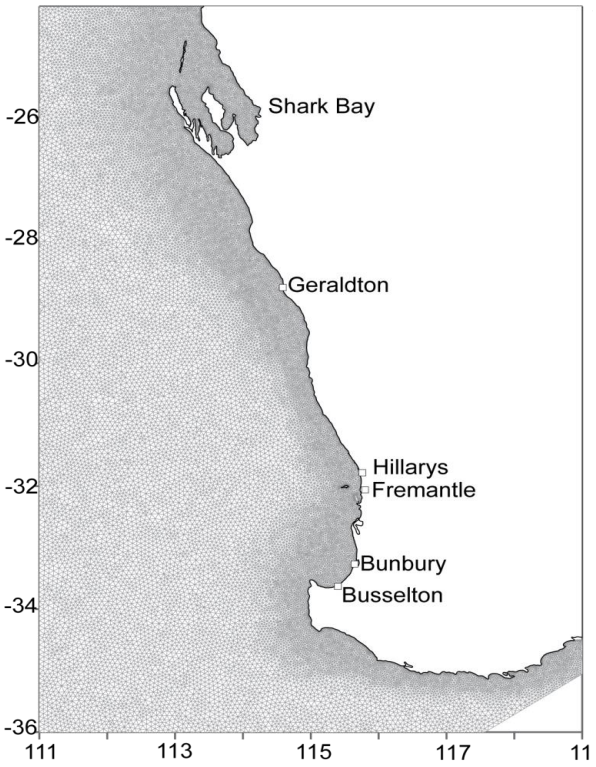
Warnow


1.1
1.0
0.9
0.8
0.7
0.6
0.5
Water level (m)
0.7534
16:00
18:00
20:00
22:00
00:00
02:00
04:00
Time

Numerical simulations

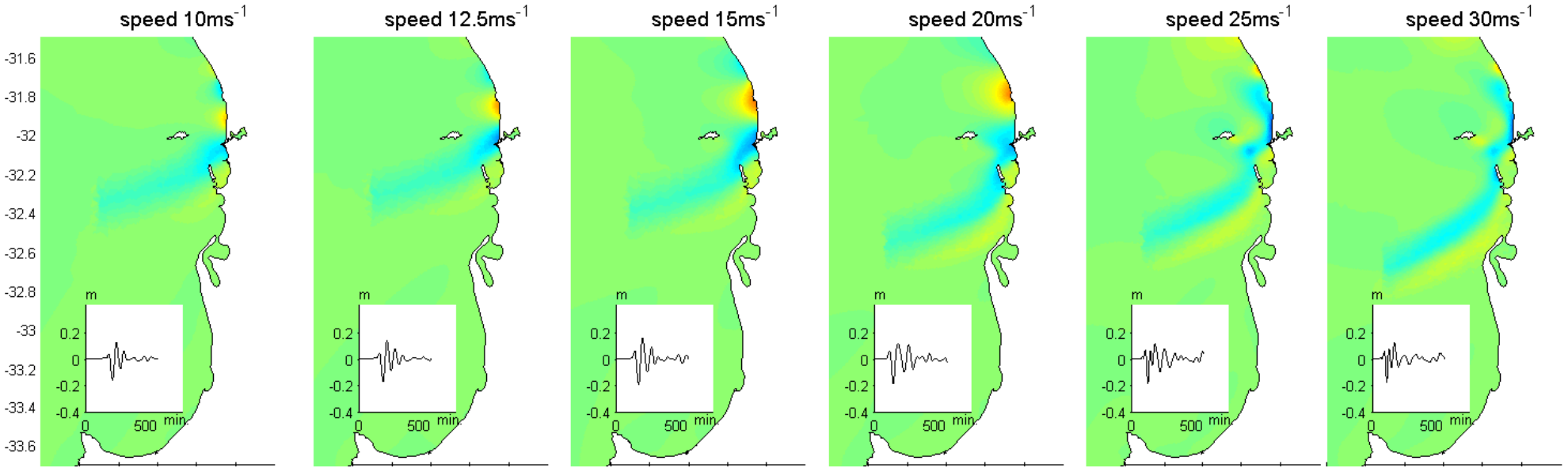
MIKE21 – 2D depth mean; unstructured grid
Forcing by propagating pressure jump, no wind



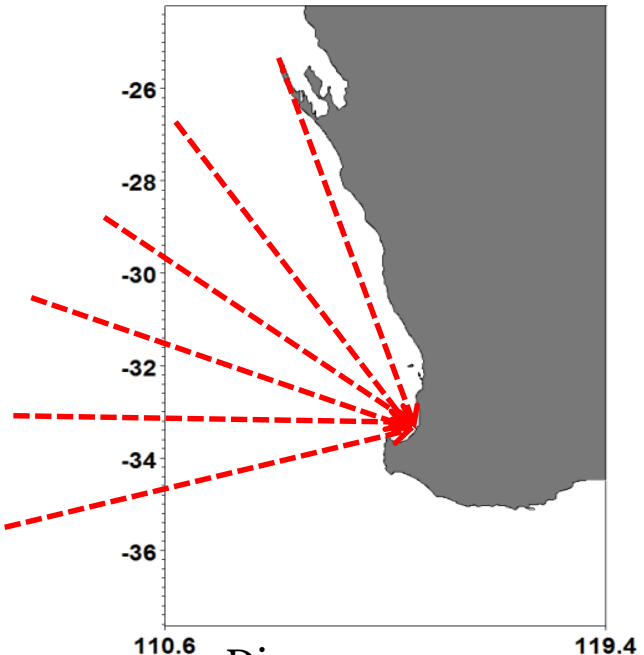


Idealised simulations

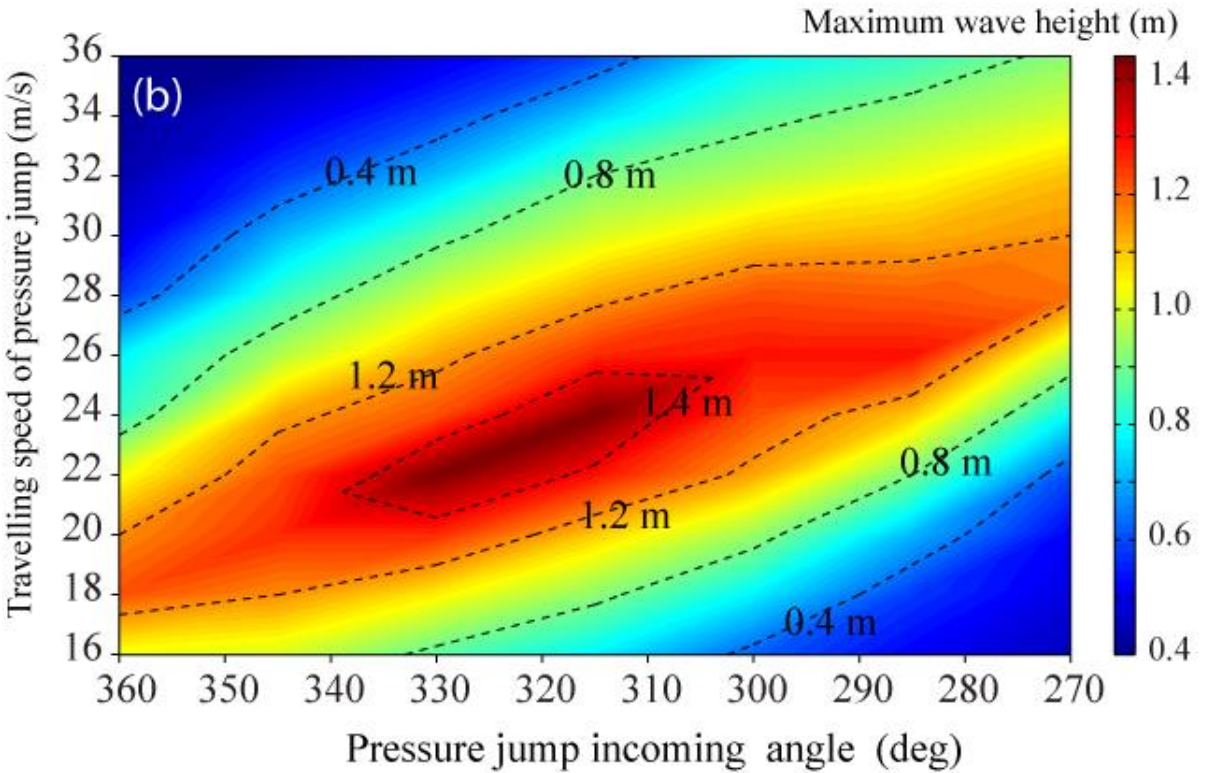
Meteotsunamis generated by moving pressure jumps with different speeds.
Pressure jump= 3hPa. Pressure jump wavelength = 40 km.



Sensitivity to the Pressure jump propagation speed and direction



Dir=0-90,
V= 16 – 36 ms^{-1}



Travelling Different Speed Pressure Jump in different directions with magnitude of 3 hPa

Idealised simulations

THE UNIVERSITY OF WESTERN AUSTRALIA

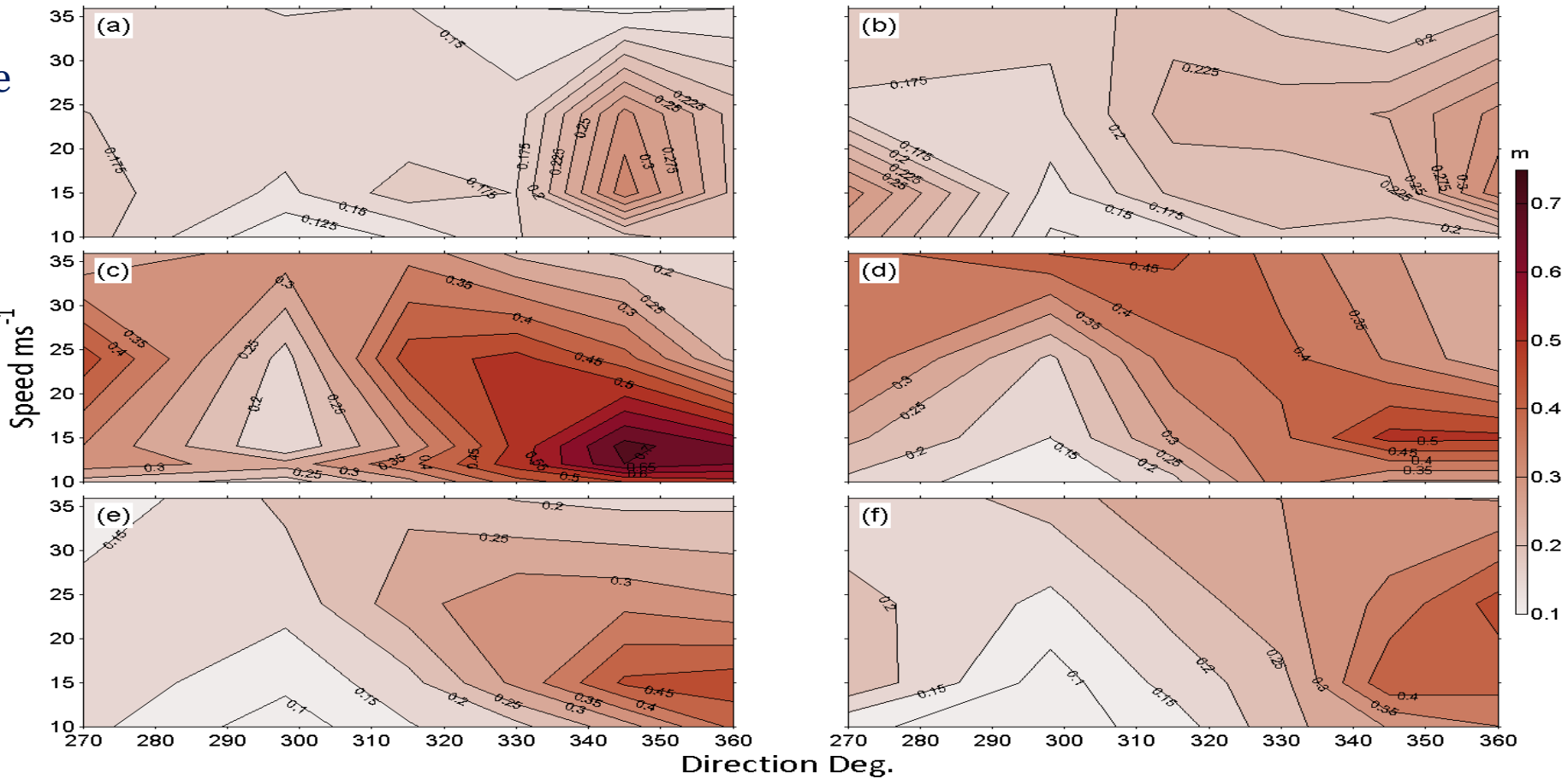
WL = 40 km

WL = 80 km

Fremantle

Bunbury

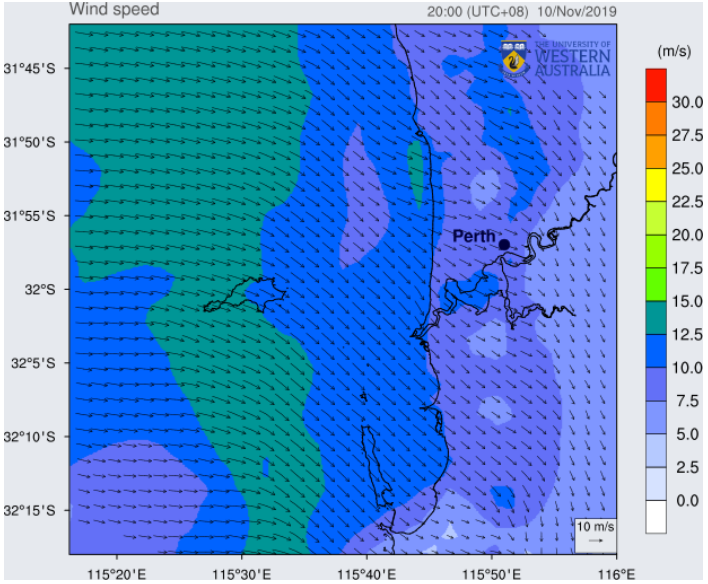
Busselton



Can we predict them ?

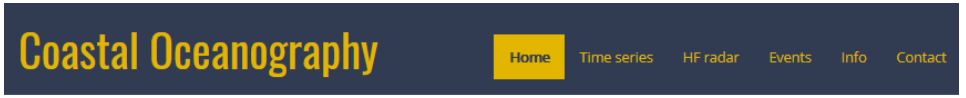
Coupled Atmosphere ocean model

Ocean model : OK
Atmospheric model ??

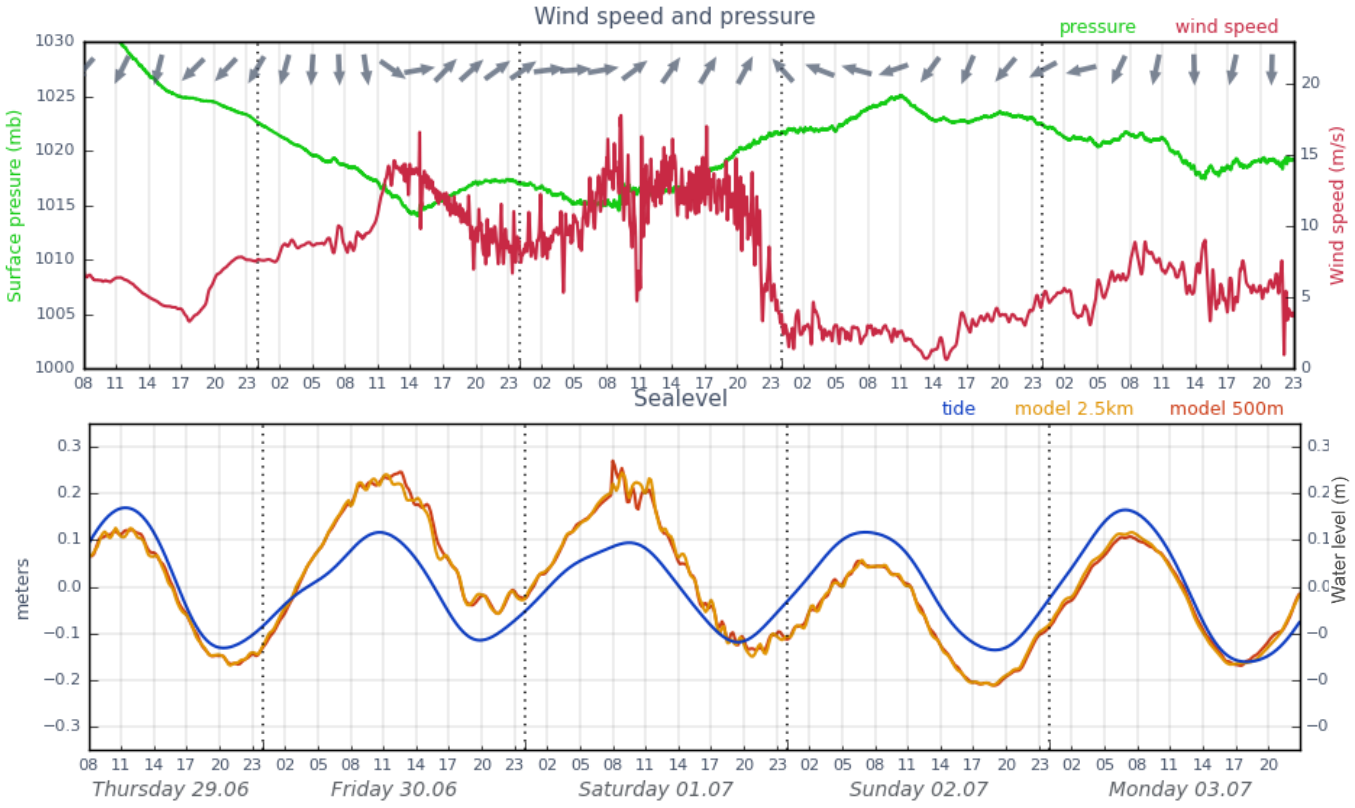


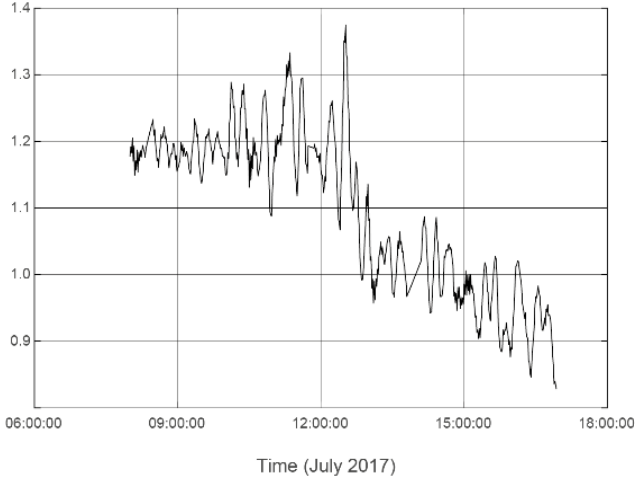
Need to predict pressure jump, travel speed & direction, location

Predictions



coastaloceanography.org





Summary

- Meteo-tsunamis are a regular occurrence along south-west Australian coastline. A 'HOT-SPOT' ?
- Max. amplitudes of 1 m have been measured, higher than seismic tsunamis and storm surges
- Contributed to the highest water level in 115 years at Fremantle in June 2012
- Occurs during thunderstorms, cold fronts and tropical cyclones
- Generating Mechanism: Proudman/Greenspan resonance enhanced by shoaling across the continental slope/shelf
- In the south-west pressure jumps travelling at 10-20 ms^{-1} from compass direction 345°-355° with a wavelength ~40 km creates the largest wave heights