METEOTSUNAMIS FROM THE SKY

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Source: http://www.meteoweb.eu/wp-content/uploads/2013/03/mareggiata05.jpg

Australian Curriculum – Content Descriptions

Year 7 Unit 1: The **causes, impacts** and **responses** to an **atmospheric** or hydrological **hazard** (ACHGK042)

Year 8 Unit 1: The geomorphic processes that produce landforms, including a case study of at least one landform (ACHGK050) e.g. **Coastal Landforms**

Year 10 Unit 1: Select ONE of the following types of environments as the context for study: land, inland water, **coast,** marine or urban. A comparative study of examples selected from Australia and at least one other country should be included.

- The application of human-environment systems thinking to understanding the **causes** and likely **consequences** of the environmental change being investigated (ACHGK073)
- The application of geographical concepts and methods to the **management** of the environmental change being investigated (ACHGK074)

'Earthquake-generated tsunamis account for approximately 85% of tsunamis. However, the National Oceanic and Atmospheric Administration (NOAA) says that meteorologically-generated tsunami type waves known as meteotsunamis may pose a greater threat to more people. This is because they are not driven by geological forces that only exist in certain locations, but rather by geographical and meteorological forces that can happen in far greater places.'

Source: http://meteotsunami.weebly.com/

Australia and Brazil 2014

In February 2014 a weather induced **meteotsunami** or **meteorological tsunami** caused waves to spill over Cassino Beach in Brazil where parked cars were tossed around. In August 2014 large ocean waves created a meteotsunami at Freemantle port, Western Australia. As a result a cargo vessel broke its moorings and a ship's rope snapped causing it to swing into the bridge and damage a pier.

Meteotsunami or a weather induced tsunami is associated with a sudden change in air pressure over the surface of the ocean's water such as a storm, fast moving front, squall or train of atmospheric gravity waves. At Freemantle the two **hectopascal** (hPa) change in the air pressure created a wave about half a metre high. When the wave entered the harbour there was an increase in the water level and as a result a ship moved over the sandbar and hit the bridge.

What is a meteotsunami?

A meteorological tsunami or meteotsunami resembles a seismic tsunami as it has similar wave formations, physical characteristics, and its destructive waves erode coastlines. However the source of their power differs:

- **geological-seismic tsunami** is generally triggered from the bottom of the ocean such as from earthquakes, landslides and volcanoes.
- **meteotsunami** is generated from the top caused by atmospheric processes.

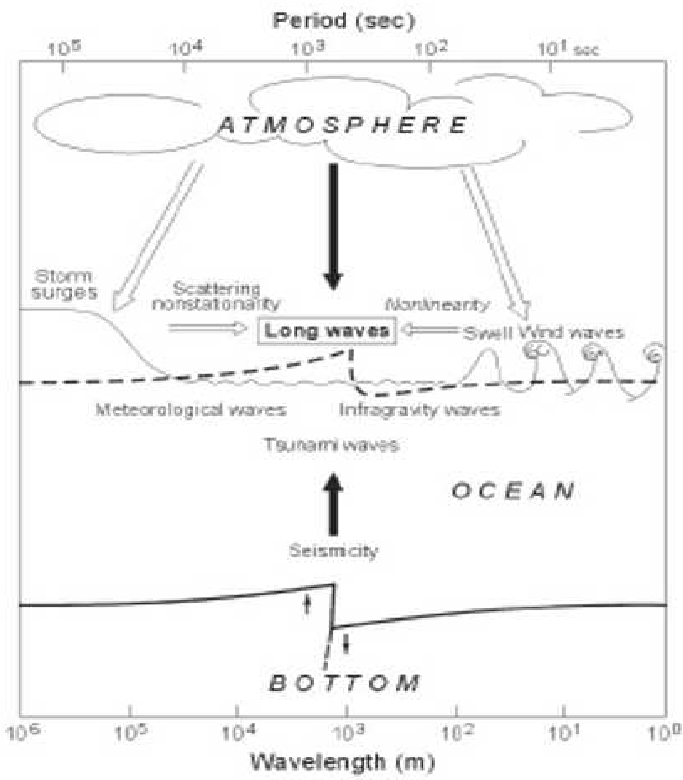
When the two types of tsunamis strike the coast they appear similar. The difference is in their source. Japan experiences both types of tsunamis on its east coast:

- 2011 an undersea earthquake off the Pacific Coast caused a seismic tsunami that reached 40.5 metres in Miyako.
- 1979 a four metre meteotsunami struck Nagasaki Bay.

Are you still pondering what a meteotsunami is? Here is a description from UNESCO site (http://unesdoc.unesco.org/images/0018/001882/188226e.pdf):

> *"Tsunami-like phenomena generated by meteorological or atmospheric disturbances. These waves can be produced by atmospheric gravity waves, pressure jumps, frontal passages, squalls, gales, typhoons, hurricanes and other atmospheric sources."*
>
> *"Meteotsunamis have the same temporal and spatial scales as tsunami waves and can similarly devastate coastal areas, especially in bays and inlets with strong amplification and well-defined resonant properties."*

Figure 1: Comparing source of atmospheric (meteotsunami) and seismic tsunamis



Source: www.electricyouniverse.com/eye/?level=picture&id=1073

Causes of meteotsunamis

The wave only turns into a tsunami if the wave is travelling at the same speed as the weather front, storm or squall. This is referred to as resonance. The wave may be a few centimetres high in the deep ocean but can rapidly grow to 6 metres high when the water enters a narrow bay or 'V' shaped harbour. This is called amplification.

In Japan meteotsunamis frequently occur along the west coast of Kyushu during winter and early spring. In 2009 at Urauchi Bay a destructive meteotsunami reached 3.1 metres caused capsizing of boats and flooding of houses. The long elongated inlet with a narrow mouth provides calm water conditions for boats and the aquaculture industry. However when a meteotsunami reaches the narrow bay waves increase in height. Forecasting a meteotsunami is important for the local community. As a result researchers are investigating the process of a meteotsunami event and the links between offshore generation (air pressure changes), resonance while it propagates, and finally amplification in the bay.

Lake Superior storm, November 27, 2002.
Source: http://www.glerl.noaa.gov/seagrant/glwlphotos/Superior/images/MNSG/CarlWaves3.jpg

Figure 2: Mechanisms, causes and impacts of meteotsunamis

Main mechanisms	Causes and impacts
Meteorological disturbance	*Atmospheric gravity waves* – energy and air pressure changes are translated to water surfaces. *Sharp air pressure jumps (hPa)* or the differences in air pressure over a short period of time. This frequently occurs during thunderstorms. In June 2014 the meteotsunami along the Adriatic coast at Croatia rose 4 hPa in 20 minutes. *Squalls* – wind gusts of over 25mph for over a minute but nor sustained for over 10 minutes. These winds create wave trains.
Resonance	*Meteorologic disturbance* (e.g. storm or front) must travel at the same speed as the wave speed. In the Western Atlantic, a meteotsunami's deep water speed reached 732 km/h.
Harbour – inundation	*Amplification* of the tsunami waves depends on the shape of the harbour. Greatest amplification occurs in V shaped harbours where a large percentage of damage occurs. The narrow harbours of Spain's Majorca Island and Croatian coast, along the Adriatic Sea, are prone to meteotsunamis.

Figure 3: Formation of a meteotsunami

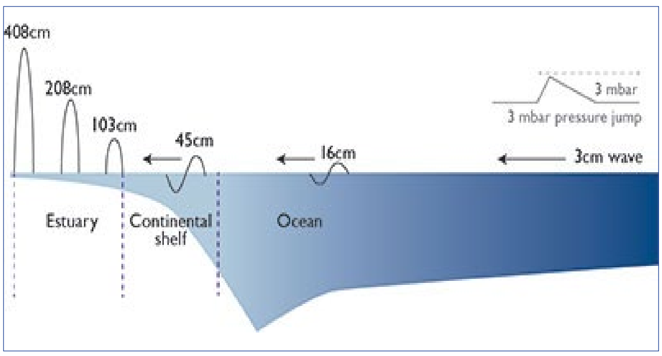


Image source: http://planetearth.nerc.ac.uk/images/uploaded/custom/Figure-1-tsunami.jpg

This Figure 3 diagram illustrates how a meteotsunami is formed from a 3 millibar pressure jump over the ocean. It then causes the movement of a 3cm wave. As the wave travels across the ocean it increases in height (16cm) until it reaches 408cm at the end of a narrow elongated estuary (inlet, bay or river mouth).

Image source: http://meteotsunami.weebly.com/meteotsunamis.html

Similarities and differences of tsunamis

A seismic tsunami and a meteotsunami affects coastal environments in similar ways. These hazardous incidents can cause destructive waves resulting in coastal erosion, loss of lives and damage to property. However, seismic tsunamis and meteotsunamis differ in the quantity of energy involved, wave height and the extent of the hazard.

Figure 4: Differences between seismic tsunami and meteotsunami

	Seismic tsunamis	Meteotsunami
Energy	Larger energy input from the initial disturbance	Requires continued energy input from the atmosphere for it to propagate
Amplitude or wave height	Waves tend to be higher	Waves tend to be lower, with the largest waves reaching generally no more than 6 metres
Extent	Can have a global reach such as the 2004 Indian Ocean tsunami and 2011 Japanese Pacific Ocean tsunami	Usually a local phenomenon such as a storm

Spatial distribution of meteotsunamis

Major geophysical tsunamis and meteotsunamis occur infrequently. Despite their rarity small meteotsunamis are so common in some countries they have special names for these freak waves such as ***abiki*** (Japan) and ***šćiga*** (Croatia).

- **Japan**: Nagasaki Bay in Japan lies at the head of a long bay which forms a perfect natural harbour on the island of Kyūshū. Abiki waves often reach 2 metres and in 1979 they reached 4.78 metres.

- **Croatia:** Along the coast of Croatia, on the Adriatic Sea, a meteotsunami reached 6 metres in 1978 and in 2003.

Amplitudes of meteotsunmis are generally small in Chinese coastal waters with the exception of Longkou Harbour which experiences about six events per year with average duration from 2 hours to 4 hours.

Figure 5: Selection of locations exposed to meteotsunamis

Area	Country	Height metres
Nagasaki Bay	Japan	4.8
Pohang Harbour	Korea	0.8
Longkou Harbour	China	3.0
Ciutadella Harbour	Spain	4.0
Gulf of Trieste	Italy	1.5
West Sicily	Italy	1.5
Malta	Malta	1.0

Source: http://en.wikipedia.org/wiki/Meteotsunami

Figure 6: Meteotsunamis with wave heights above 3 metres

Source: http://jadran.izor.hr/tmews/kickoff/Sepic%20-%20 adriatic_%20meteotsunamis.pdf, page 2

Sćiga along the Adriatic Coast

The Croatian Adriatic Coast is vulnerable to numerous meteotsunamis. For example:

- 21 June 1978 waves reached 6 metres.
- 15 June 2006 waves damaged more than 40 boats and cost tens of millions of dollars in Ciutadella Harbour (Menorca Island).
- 25 June 2014 at Vela Luka (Korčula) atmospheric pressure rose 4hPa in 20 minutes. The sea level rose quickly to 1.5 metres and lasted about three hours.

The main characteristics of Adriatic meteotsunamis are:

- Air pressure disturbances. Sharp change in hPa over a period of ten minutes
- Wave direction generally south to west
- Wave heights over two metres
- Occurs at elongated shallow bays

Figure 7: Meteotsunami hits the Adriatic Coast at Vela Luka (Korčula) in June 2014

Source: http://thewatchers.adorraeli.com/2014/06/25/meteo-tsunami-hits-several-cites-along-adriatic-coast-croatia/

Figure 8: Significant Adriatic meteotsunamis

Source: http://jadran.izor.hr/tmews/kickoff/Sepic%20-%20 adriatic_%20meteotsunamis.pdf

Figure 9: Long narrow inlet of Stari Grad is affected by meteotsunamis (Amplification)

Source: http://www.chorvatsko.cz/stdalos/pict/stari_grad_13.jpg

Figure 10: On 15 August 2008 a sea wave flooded the harbour of Mali Lošinj on the island Lošinj in the northern Adriatic. The flood was 50cm-80cm high above the ground and wave height (trough-to-crest) of more than 2 metres.

Source: http://www.zamg.ac.at/etrainwiki/doku.php?id=15_august_2008_-_meteorological_perspective_of_a_meteotsunami_on_island_losinj_in_the_adriatic_sea

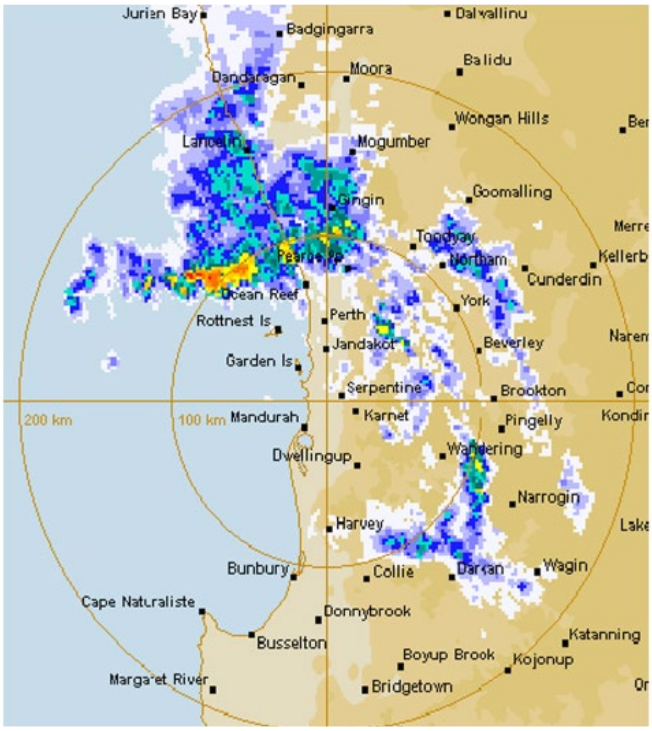
Aerial view of Fremantle – http://en.wikipedia.org/wiki/Fremantle

Western Australia hit by meteotsunamis

Meteotsunamis along the south-west Australian coast were found to coincide with thunderstorms in summer and the path of low-pressure systems during winter. Meteotsunamis are common around Perth and in 2012 a meteotsunami contributed to the highest water levels recorded at Fremantle in 115 years.

In 2013 a thunderstorm affected an area of over 500km from Bunbury to Geraldton. Two pressure jumps of 4 hPa were recorded and waves reached 0.48 metres at Freemantle. Recent modelling has been undertaken for areas considered vulnerable, such as Port Geographe and Bunbury, which have the potential for major inundation. Port Geographe is a low lying marina and residential canal estate development.

Figure 11: Radar rainfall 6am on 7 January 2013 showing the squall line in the Perth region. Warmer colour reflect higher rainfall rates.



Source: http://download.springer.com/static/pdf/100/art%253A10.1007%252Fs11069-014-1263-8.pdf?auth66=1410566662_d690490baaa35f94b4043e4fa66f9b66&ext=.pdf, page 19

Marina, Ciutadella Harbour Spain. Source: Wikimedia Commons

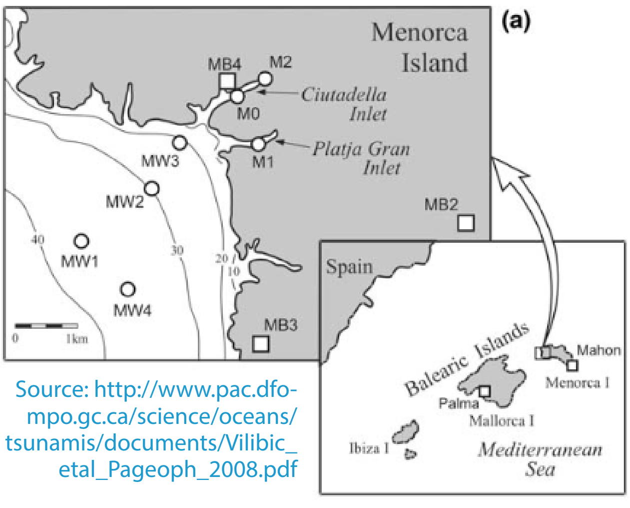
Rissaga in Ciutadella Harbour Spain

Ciutadella is located on the island of Menorca in Spain. The natural elongated inlet is about 1 kilometres long, 100 metres wide and 5 metres deep. The harbour is located at the head of the inlet. Rissaga waves are high and occur more frequently than other places along the coast. Rissaga waves over 2 metres usually occur once in every 5-6 years and heights 3–4 metres once in 15–20 years. These destructive waves cause damage to harbour facilities.

'Rissaga is the local name for sea level oscillations characterised by their large amplitude (1 m, in usual cases) and short period (around 10 min) observed in Ciutadella harbour. Rissaga events typically occur several times a year (mainly in summer) and they usually produce only minor problems to the harbour functionality. A rissaga event is very similar to a tsunami: there are one or two large sea level oscillations, but they are accompanied, before and after, by smaller amplitude oscillations. The total duration of an event can range between a few hours and a couple of days.'

http://www.kweather.ph/#!meteotsunami/c4nb

Figure 12: Map of the Balearic Islands showing the Ciutadella inlet



Source: http://www.pac.dfo-mpo.gc.ca/science/oceans/tsunamis/documents/Vilibic_etal_Pageoph_2008.pdf

Figure 13: Ciutadella Harbour – before and after a meteotsunami photo sequence.

On the 15 June 2006 in the port of Ciutadella on the island of Menorca in Spain, the water level suddenly dropped four metres. The mooring lines of almost all the boats snapped. The normal tide difference in the port is around 20cm. Some minutes later the vessels fell prey to te returning water, which came in three metres higher than before. More than forty boats were sunk or seriously damaged.

Source: http://www.afloat.com.au/images/magazine-articles/MAGAZINE/2010/0210/0210p59-port-of-Ciutadella-water-drop.jpg

Right: Puert de Ciutadella. Source: Wikimedia Commons

Yealm River inlet, Devon UK Source: Wikimedia Commons

Britain experiences meteotsunamis

On 27 June 2011 a meteotsunami struck SW England between Penzance and Portsmouth; approximately 320 kilometres of coastline were affected. The meteotsunami was caused by a summer storm in the Bay of Biscay more than 480 km away from Yealm River estuary. The storm moved into the English Channel at a time when tides were higher.

'On June 27, 2011 – a sunny day – the normally placid estuary at the mouth of the Yealm River in southwest England reported waves up to 0.8 m high. On the tidal island of St. Michael's Mount in Cornwall, people crossing the causeway connecting the island to the mainland quickly found themselves knee-deep in water.'

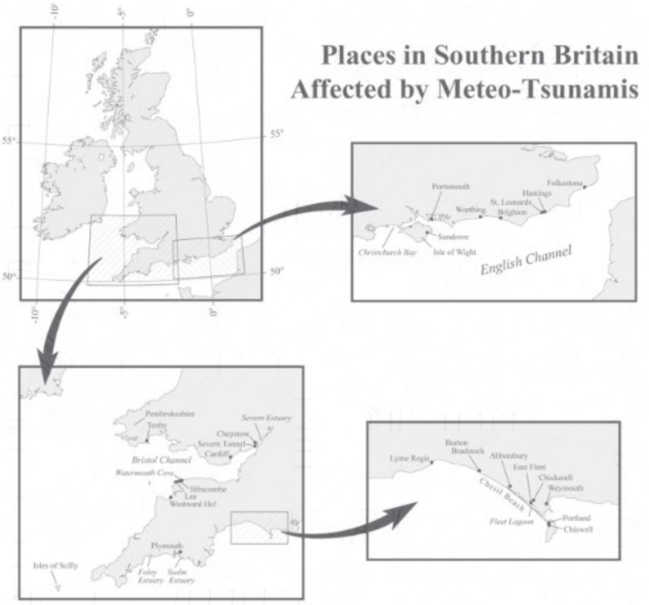
Source: http://news.discovery.com/earth/weather-extreme-events/uk-tsunami-caused-by-storm-130806.htm

St Michael's Mount causeway Source: Wikimedia Commons

'UK tide gauges take measurements every15 minutes, compared to the continuous recording of our nearest European neighbours. The UK also has highly-developed operational models to forecast storm surges and tides, but we need to link them to high-resolution weather forecast models. All possible; it just costs money. If meteotsunamis are going become more common, and perhaps more damaging, this could be money well spent.'

Source: http://planetearth.nerc.ac.uk/features/story.aspx?id=1537

Figure 14: Places in southern Britain affected by meteotsunamis at a variety of scales



Source: http://jadran.izor.hr/~vilibic/meteotsunami/Haslett_Bryant_GeoRev_2009.pdf, page 3

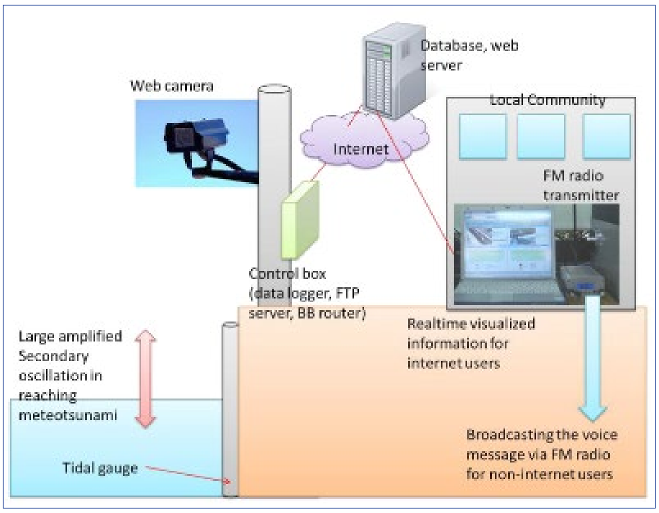
Yealm Estuary from Warren Pt, Devon UK
Source: Wikimedia Commons

Response – management

Despite their worldwide occurrence, the phenomenon is not well known. Awareness of meteotsunamis has risen recently says Paul Whitmore, director of the National Tsunami Warning Centre in Palmer, Alaska. He stated that '*while there is great interest in predicting meteotsunamis before they strike, the interplay between the atmosphere, the ocean and the shape of a harbour makes it difficult to accurately estimate a wave's size at present.*'

To understand the process of the formation of a meteotsunami and to prepare warnings prior to the event, requires a combination of meteorological and oceanographic data such as synoptic maps and the Global Spectral Model.

Figure 15: Sketch of the monitoring and information systems for harbour oscillation due to meteotsunamis.



Source: http://www.iiirr.ucalgary.ca/files/iiirr/A7-4_.pdf, page 7

Geofacts

- Large meteotsunamis have wave heights over 0.4 metres.
- A meteotsunami differs from other types of sea level oscillations of meteorological origin such as storm surges.
- Rogue waves are large meteorological waves infamous for sinking ships in the deep ocean. This differs from a tsunami which are of low amplitude in the open sea.
- The abiki phenomenon in Japan often occurs during days experiencing mild weather in winter.

Geolinks

- Freemantle 2014 – http://www.abc.net.au/news/2014-09-06/ship-hits-fremantle-bridgejpg/5724662
- Meteotsunamis – http://meteotsunami.weebly.com/
- Meteotsunami Panama City Beach Florida March 29, 2014 and video – http://www.extremestorms.com/meteo_tsunami.htm
- Formation of Abiki waves – http://www.electricyouniverse.com/eye/?level=picture&id=1062
- Global Spectral Modelling.– http://www.springer.com/earth+sciences+and+geography/atmospheric+sciences/book/978-0-387-30254-6
- University paper on tsunamis. – http://www.theplasmaverse.com/pdfs/meteorological-tsunamis-destructive-atmosphere-induced-waves-observed-in-the-worlds-oceans-seas-seiches-abiki-milghuba.pdf

Video

- Storm causes container ship to break its moorings and crash into Freemantle rail bridge – http://www.abc.net.au/news/2014-09-06/meteo-tsunami-caused-ship-crash-into-fremantle-bridge/5724654
- Rissaga Al Port De Ciutadella (2006) –h ttp://www.youtube.com/watch?v=7pBMbNGSQn4

Geoactivities

Knowledge and Understanding

1. Define what is meant by a meteotsunami.
2. Research the meaning of the following terms: air pressure, hectopascals, atmospheric gravity waves and amplification.
3. Answer True or False to the following questions:
   a. Meteotsunamis account for approximately 15% of all tsunamis.
   b. Meteotsunami are also called meteorological tsunamis.
   c. Special names for meteotsunamis include abiki (Japan).
   d. Meteotsunamis are not common around Perth.
   e. To sustain a meteotsunami a storm needs to move at the same speed as the movement of the water wave.
   f. The largest meteotsunamis occur where the water is funnelled into narrow bays.

g. Japan experiences both types of tsunamis.
h. A rogue wave is the same as a tsunami.
i. Narrow harbours found around Spain's Majorca Island and Croatia's Adriatic Sea, are prone to meteotsunamis.
j. Sharp air pressure jumps (hPa) is the differences in the air pressure over a short period of time.
k. A meteotsunami is a long-period wave that possesses tsunami like properties but is meteorological in origin.
l. The maximum period for a meteotsunami does not exceed several hours, while a storm surge may last several days.

Inquiry and skills

4. Refer to Figure 1: Describe the links between the atmosphere and the ocean.
5. Refer to Figure 2: List the main causes of a meteotsunami as an oral report.
6. Refer to Figure 3: Explain how a small change in air pressure generates large waves.
7. Refer to Figure 4: A small tsunami that struck the south coast of England on 27 June 2011 was most likely caused by weather conditions and not a submarine landslide or earthquake. Distinguish between the two types of tsunamis.
8. Refer to Figure 5:
   a. Using the internet name the places experiencing meteotsunamis above 3 metres.
   b. Research one place in Asia. Include cause and impacts of meteotsunamis.
9. Refer to Figure 6: Locate these ten places on a world map and the name of the surrounding oceans or seas that influence the meteotsunami.
10. Refer to Figures 7 and 8:
    a. Where is Vela Luka (Korčula) located?
    b. Describe the impacts of a meteotsunami in Vela Luka (Korčula).
    c. In groups discuss the main characteristics of meteotsunamis along the Croatia's Adriatic Coast
11. Refer to Figures 9 and 10: In groups investigate the meteotsunami in June 2003 in Stari Grad or August 2008 in Mali Lošinj. Include causes and impacts. Include maps and photographs http://jadran.izor.hr/tmews/kickoff/Sepic%20-%20adriatic_%20meteotsunamis.pdf; http://www.zamg.ac.at/etrainwiki/doku.php?id=15_august_2008_-_meteorological_perspective_of_a_meteotsunami_on_island_losinj_in_the_adriatic_sea

Meteotsunami, Florida March 2014.
Source http://www.extremestorms.com/meteo_tsunami.htm

12. Refer to Figure 11: Describe the meteotsunami incident in the Freemantle port in 2014. Suggest strategies to reduce the adverse impacts of meteotsunamis on the port and its residents.
13. Refer to Figured 12 and 13: Refer to the internet and YouTube and explain the changes to Ciutadella Harbour and its impacts on the coastal community.
14. Refer to Figure 14: List the places in southern Britain that are more vulnerable to meteotsunamis.
15. Refer to Figure 15: Describe the monitoring and information systems used to measure harbour oscillations due to meteotsunamis.
16. Research what is meant by the following tsunamis: meteorological, local, microtsunami, ocean-wide tsunami, paleotsunami and regional.
17. Explain how a meteotsunami is an underrated hazard.
18. In groups research one of the following acronyms and how they aim to reduce the adverse impacts of tsunamis on environments and people. GLOSS, GOOS, ICG, GTS, ICG/CARIBE-EWS, ICG/IOTWS, ICG/PTWS, IOC, ICG/ITSU, ITIC, ICG/NEAMTWS, IUGG, JMA, PTWC, WCATWC, RTSP, TBB, TER, TNC, TWFP. TWP, WDS AND MGDC. This website will help http://unesdoc.unesco.org/images/0018/001882/188226e.pdf
19. List the differences between a storm surge and a meteotsunami and present findings as a two column table http://www.kweather.ph/#!meteotsunami/c4nb
20. Discuss the causes, impacts and responses to meteotsunamis using Web 2.0 tools. Include photographs, satellite images, diagrams and statistics.