EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

24 Dec 2018 11:00 UTC

Indonesia - Volcanic Eruption & Tsunami

GLIDE: TS-2018-000423-IDN

GDACS Volcano RED Alert

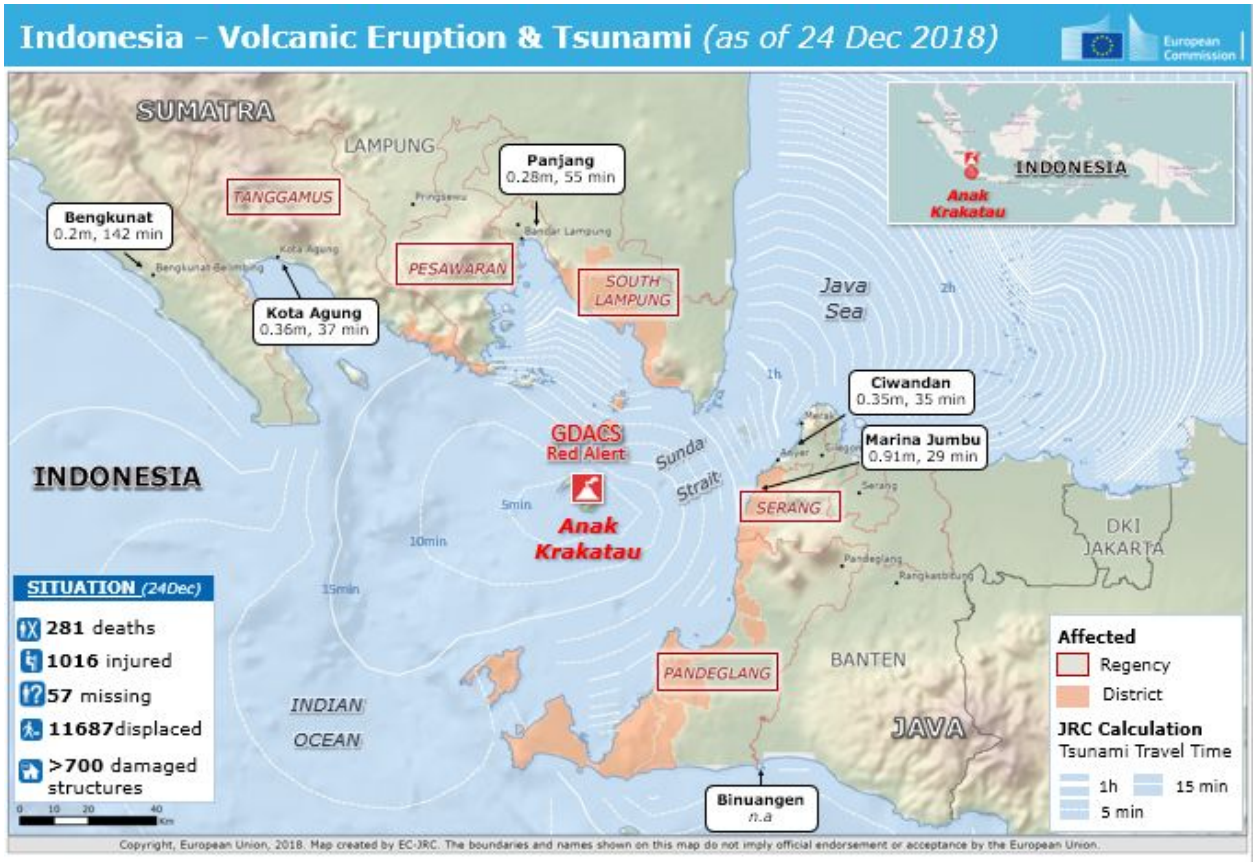

Figure 1 *- Mount Anak Krakatau Volcano and Tsunami*

1 Executive Summary

- On **22 Dec 2018 13:56 UTC** a Tsunami was generated from the area of the **Anak Krakatau** Volcano, with waves propagating in all directions inside the Sunda Strait, the sea portion between the Java and Sumatra islands. The cause of this event seems to have a correlation with the

ongoing Volcanic eruption, particularly active since June 2018, even if no stronger eruption occurred at the time of the Tsunami event.

- The first radar satellite images (Sentinel 1) indicate that a large part of the upper cone of the volcano does not exist any more and that may be the reason for the creation of the Tsunami.
- The Tsunami caused fatalities and extensive damage along the coastal areas of Sunda Strait. As of 24 Dec morning, there were at least **281 deaths,** mostly in **Pandeglang** (Banten province, Java), 57 people missing, 1016 injured, more than 700 structures damaged and 350 boats damaged. Search and rescue operations are still ongoing and these figures are expected to rise.
- The immediate response to the disaster is ongoing and is coordinated by local authorities, National Agency for Disaster Management (BNPB). Staff of the Ministry of Social Welfare and volunteers of National Red Cross (PMI) are also deployed. **At the moment the Indonesian Government indicated that the disaster can be faced with National resources.**
- ECHO partners, including OCHA and international NGOs are monitoring the situation and considering their own response to the situation. IFRC intends to issue a Disaster Relief Emergency Fund (DREF) operation by 25 December at the latest.
- The ERCC has activated the **EU Copernicus Emergency Mapping Service** on 23 December and stays in close contact with the ECHO representatives in the region.

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2. Situation Overview

2.1. Event description

- On **22 Dec 2018 13:56** a Tsunami was generated from the area of the **Anak Krakatau Volcan**o, with wave propagating in all directions. The cause of this event seems to have a correlation with the ongoing Volcanic eruption, active since June 2018, even if no particular stronger eruption occurred at that time. Details about the volcano are provided in Appendix A.
- The consequent tsunami caused extensive damage along the coastal areas of Sunda Strait (Sumatra and Java islands), killed at least **281** people and injured more than **1000**. Search and rescue operations are still on-going (see Section 2.2).

- As in the case of Palu event of 28 Set 2018, still in Indonesia, no Warning was issued, as the Indonesian Tsunami EWS do not cover Volcanic-triggered tsunami. The population was therefore hit by an unexpected wave, and also due to the night time of the arrival

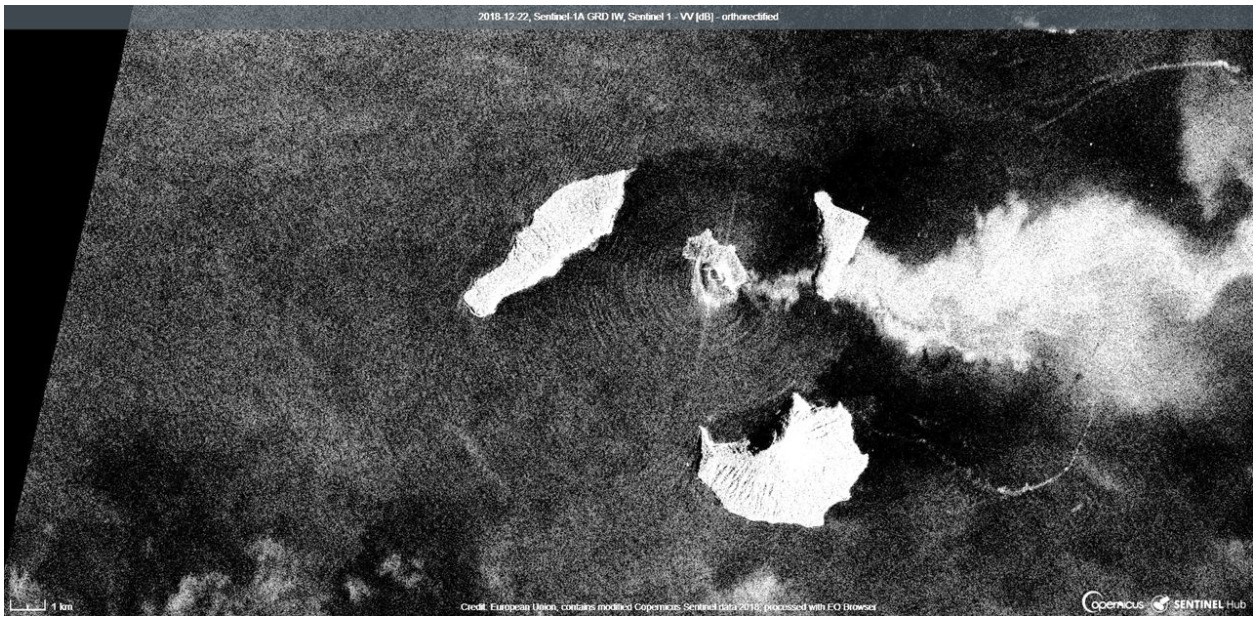
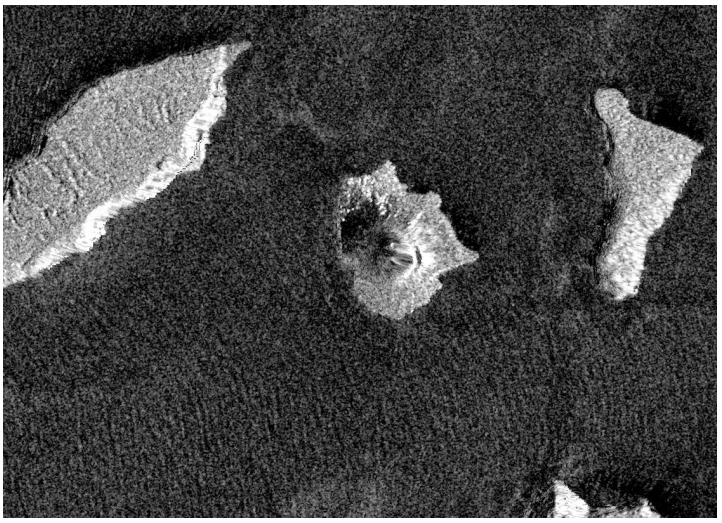
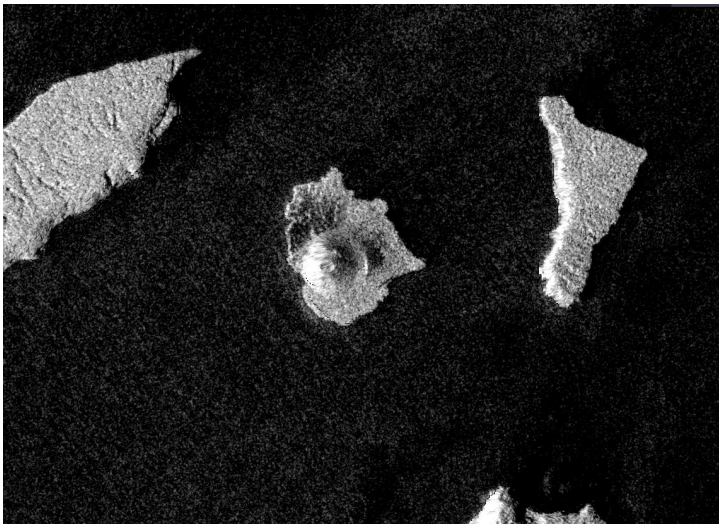


***Figure 2** - Mount Anak Krakatau Volcano - Sentinel-1, acquired on 22 December 2018 at 22:34. The image clearly shows concentric rings around the Volcano; given the time those were not the first waves that started at 13:58 UTC*

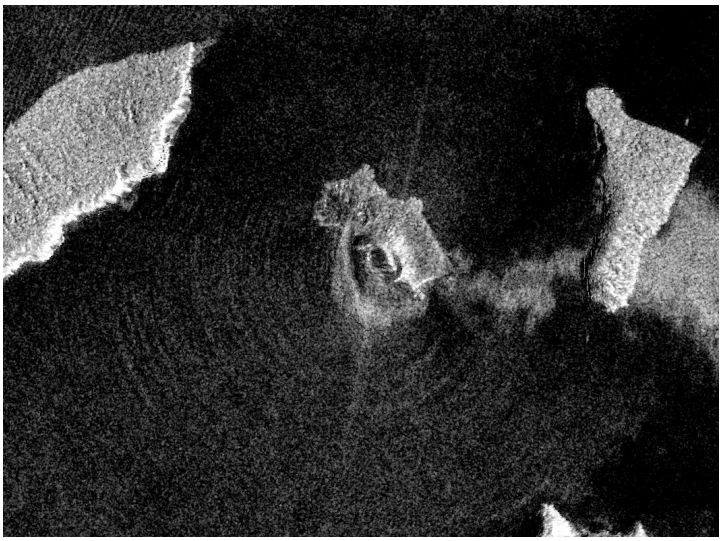
https://apps.sentinel-hub.com/eo-browser/?lat=-6.11666&lng=105.39562&zoom=13&time=2018-12-22&preset=6_VV_DB_ORTHORECTIFIED&datasource=Sentinel-1%20GRD%20IW



15 Dec 2018



19 Dec 2018



22 Dec 2018

Figure 3 *- Sentinel 1 Images, timeline*

Another view of the same image above, more detailed, allows to better understand the size of the collapse.

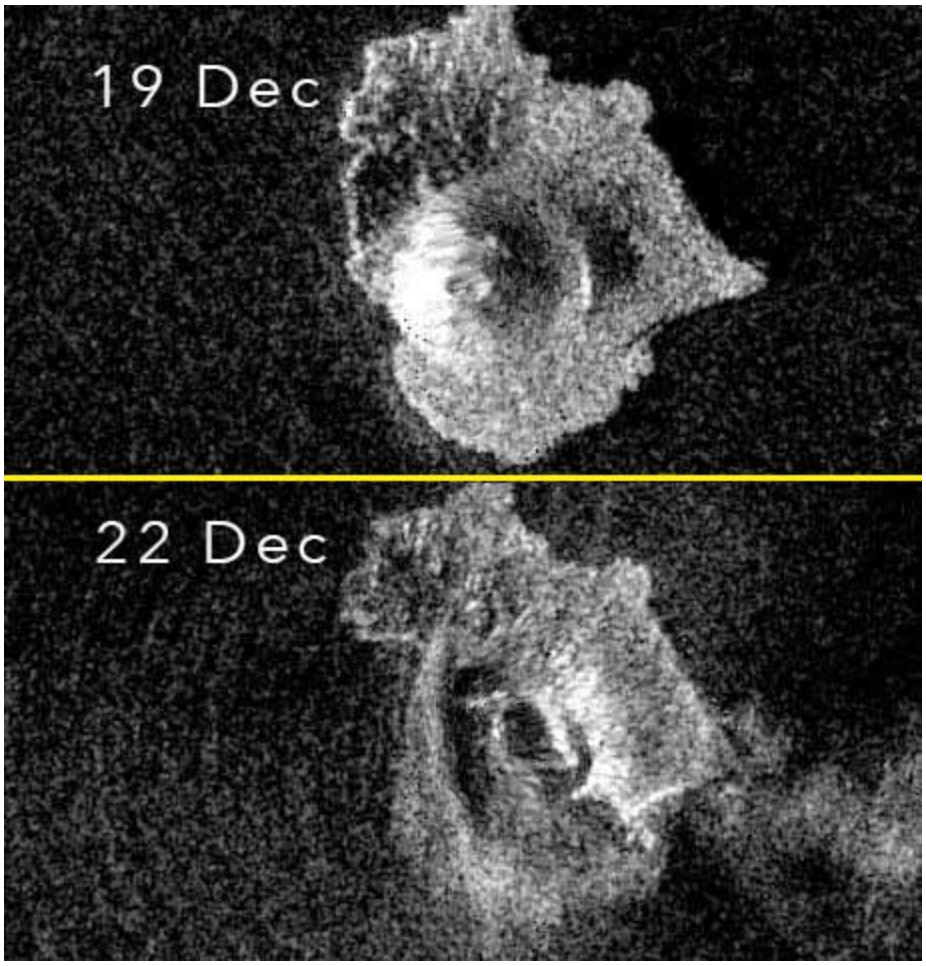


Figure 4 *- Pre and post event satellite image (Sentinel 1), showing that a large part of the volcano cone has been modified and has probably relocated*

2.1.1. Tsunami Event

On 22 December 2018, around around 21:27 local time (14:27 UTC) a tsunami hit the coastal towns on Indonesia's Sunda Strait (between Sumatra and Java islands, Indonesia); travel time considerations from the Krakatoa volcano (see later) allow to set the start of the event at about **22 Dec 2018 13:58 UTC**. Tragically the tsunami hit several popular tourist destinations during peak holiday season. Many holidaymakers were caught off guard as there had been no earthquake to warn that a wave may be on the way. The worst affected area was the Pandeglang region of **Banten** province in Java, which encompasses the Ujung Kulon National Park and popular beaches. The updated list of damages and human toll is indicated in the Humanitarian Situation chapter.

There is an hypothesis that the tsunami, occurred in the strait linking the Indian Ocean and Java Sea (Sunda Strait), may have been connected with the activity of the Anak Krakatau volcano. BMKG, the Indonesian National Meteorology, Climatology, and Geophysical Agency, is conducting field surveys and

coordinating with the Indonesia Volcanology Agency (PVMBG). Based on preliminary reports from PVMBG, whether the tsunami has anything to do with eruption activities is still being investigated (source AHA flash update n.1).

In the case of a volcano originated Tsunami the reasons for the waves creation of may be various:

- Collapsing of the caldera and elimination or strong reduction of the visible part of the volcano (example Santorini, Greece)
- Creation of landslides or submarine landslides that then trigger tsunami waves
- Detachment of a section of the mountain which falls under water causing the wave (example: Stromboli 2002): sudden displacement of water caused by a volcanic explosion, by a volcano's slope failure, or more likely by a phreatomagmatic explosion and collapse/engulfment of the volcanic magmatic chambers

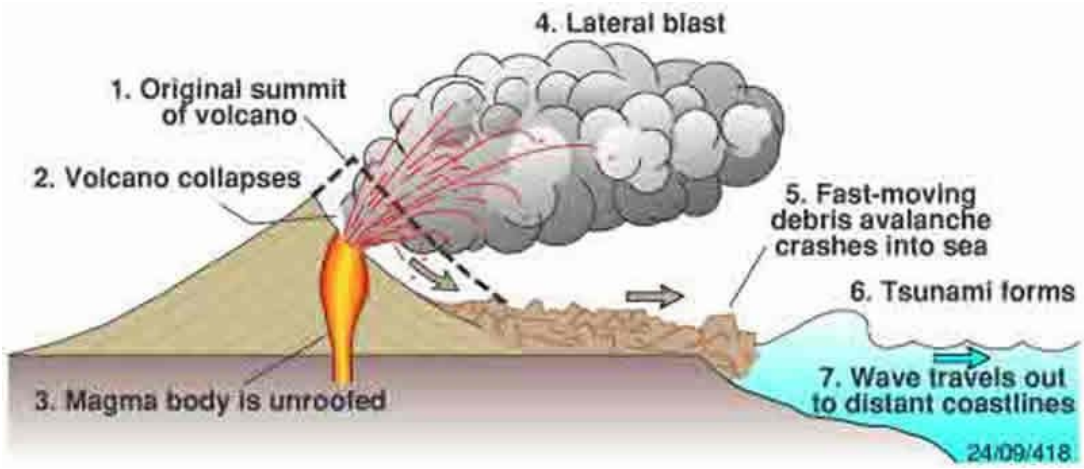
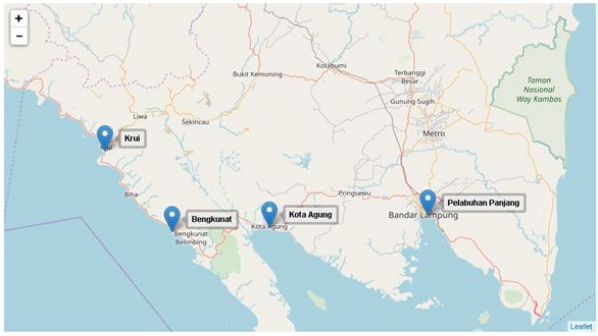


Figure 5 *- Illustration of the waves creation from a volcanic explosion (UNESCO Tsunami Information Center)*[1]

A number of tide gauge located in the Sunda Strait. Several of them produced a signal as a result of the Tsunami event.

1 http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1159:how-do-volcanic-eruptions-generate-tsunamis&catid=1340&Itemid=2059



http://tides.big.go.id:8888/dash/prov/Lampung.html

http://tides.big.go.id:8888/dash/prov/Banten.html

Figure 6 *- Tide gauges available in the area*

The gauges have measured Tsunami waves ranging between **0.28 m and 0.9 m**, as shown below. Considering that the travel time from Krakatau volcano to Marina Jumbu is in the order of 30 min, according to Giachetti et al. 2012[2], the estimated origin time of the event is **22 Dec 2018 13:56** (+- 2 min).

The arrival time of the waves was the following:

Tide Gauge	**Arrival Time (UTC)**	**Time difference[3] (min)**	**Max Height (above the tide, m)**
Estimated Time of the event	22/12/2018 13:58	0	n.a.
Marina Jumbu	22/12/2018 14:27	29	**0.91**
Ciwandan	22/12/2018 14:33	35	**0.35**
Kota Agung	22/12/2018 14:35	37	**0.36**
Panjang	22/12/2018 14:53	55	**0.28**
Bengkunat	22/12/2018 16:20	142	**0.20**
Binuangen	Not detected		

Table 1 *- Arrival time of the waves measured by the tide gauges..*

The paper of Giachetti et al, in 2012 was estimating similar consequences for the occurrence of the volcano flank collapsing:

> *Numerical modelling of a rapid, partial destabilization of Anak Krakatau Volcano (Indonesia) was performed in order to investigate the tsunami triggered by this event. Anak Krakatau, which is largely*

[2] T. Giachetti, R. Paris, K. Kelfoun and B. Ontowirjo -"*Tsunami hazard related to a flank collapse of Anak Krakatau Volcano, Sunda Strait, Indonesia*" - Geological Society, London, Special Publications, 361, 79-90, 3 January 2012

[3] Respect to the Estimated time of the event, e.g. 22/12/2018 13:58

built on the steep NE wall of the 1883 Krakatau eruption caldera, is active on its SW side (towards the 1883 caldera), which makes the edifice quite unstable. A hypothetical 0.280 km3 flank collapse directed southwestwards would trigger an initial wave 43 m in height that would reach the islands of Sertung, Panjang and Rakata in less than 1 min, with amplitudes from 15 to 30 m.

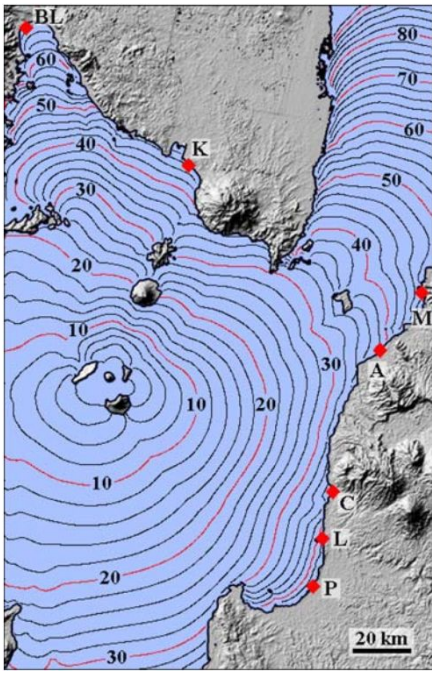


Figure 7 *- Travel time (Giachetti et al 2012)*

Figure 8 *- Location and Arrival time at Sunda Strait Tide Gauges*

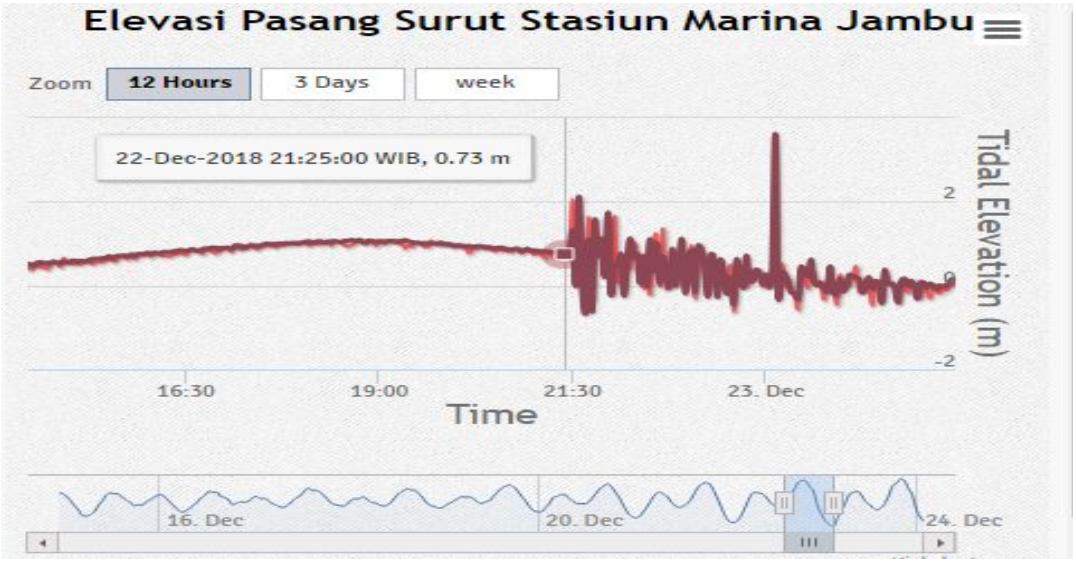


Figure 9 *- Tide Gauge signal in Marina Jumbu, where the highest measurement was detected*

It is important to note that the measurement of 90 cm of wave at a certain tide gauge does not prevent to have 1.8-2.0 m or more in another location, as it was clearly demonstrated in the case of Tsunami in Palu, where a maximum measured sea level of about 2.6 m was then showing 5-6 m or more on other shores.

The effect of the Tsunami has been devastating with beaches and shore completely flattened. Detailed survey by BMKG is ongoing, with flights over the area as well as bathymetric surveys.

No tsunami early warning worked in the Sunda Strait on 12/22/2018 night. The existing Tsunami EWS is based on seismic signals which in this case was not present. The tide gauge network did not include tide gauge on the islands around the volcano; Tsunami buoy networks in Indonesian waters have not been operating since 2012.

Therefore no alert was possible until the wave reached the coast. The absence of any warning system and no anticipated seismic signal caused the tsunami potential to be undetected beforehand. As no sign of the arrival of the tsunami was available the people did not have time for evacuation and this explains the large number of fatalities. Nevertheless Tsunami Hazard maps for this event have been produced by BMKG (Appendix B).

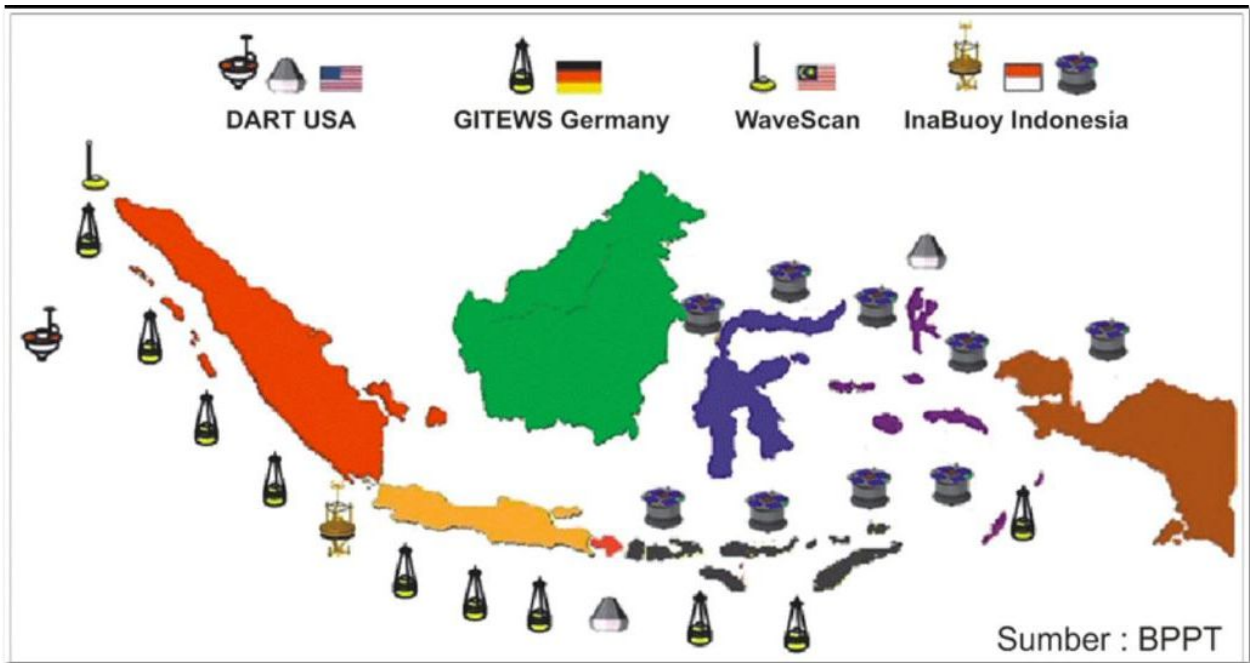


Figure 10 *- The status of the Tsunami EWS (source: BPPT, shared on Twitter by @Sutopo_PN, BNPB)*

2.1.2. Volcano Situation

In 2018, Mt. Anak Krakatau erupted since **29 June 2018**, in the form of strombolian eruptions. Precursors of the 2018 eruption began with the earthquake tremors on 18-19 June 2018 and on June 29, 2018 the volcano erupted with a large ash flow. Most eruptions of material fell around the body of Mt. Anak Krakatau or less than 1 km from the crater, but since July 23 incandescent material that fell around the coast was observed, so the danger radius of G. Krakatau was extended from 1km to 2km from the crater.

Recent activities, December 22, as usual in the previous days, the eruption of Mt. Anak Krakatau occurred. Visually, eruptions with high smoke ranged from 300 - 1500 meters above the top of the crater. Earthquake tremors are recorded continuously with overscale amplitude (58 mm). At 22 Dec 2018 9:03 UTC, an eruption occurred, and after more than 12 hours later the tsunami occurred.

When the tsunami occured, the alert level of the volcano was **Level II** and the status of the volcano was the following (source: PVMBG - Indonesia Volcanology Agency[4], translated from Indonesian to english :

> The eruption of Mt. Anak Krakatau, Lampung on December 21, 2018 at 8:51 UTC with an ash column height of ± 400 m above the peak (± 738 m above sea level). The ash column is observed in black with thick intensity leaning northward.
>
> This eruption is recorded on a seismogram with a maximum amplitude of 58 mm and a duration of ± 2 minutes 12 seconds.
> At present Anak Krakatau is in **Level II** Status (Waspada) with recommendations:
> - People / tourists are not allowed to approach the crater within a 2km radius of the crater

The Volcano Observatory Notice for Aviation (VONA) was the following, issued on 21 Dec 2018 at 08:57 UTC:

> Last Issued:
>
> 20181221/0857Z
>
> Current Aviation Color Code:
>
> ORANGE
>
> Volcanic Activity Summary:
>
> Eruption with ash clouds at 08:47 UTC (15:47 local time). The eruption lasted for 776 seconds.
>
> Volcanic Cloud Height:

[4] http://www.vsi.esdm.go.id/index.php/gunungapi/aktivitas-gunungapi/2561-informasi-erupsi-g-anak-krakatau

Best estimate of ash-cloud top is around 2682 FT (838 M) above sea level, may be higher than what can be observed clearly. Source of height data: ground observer.

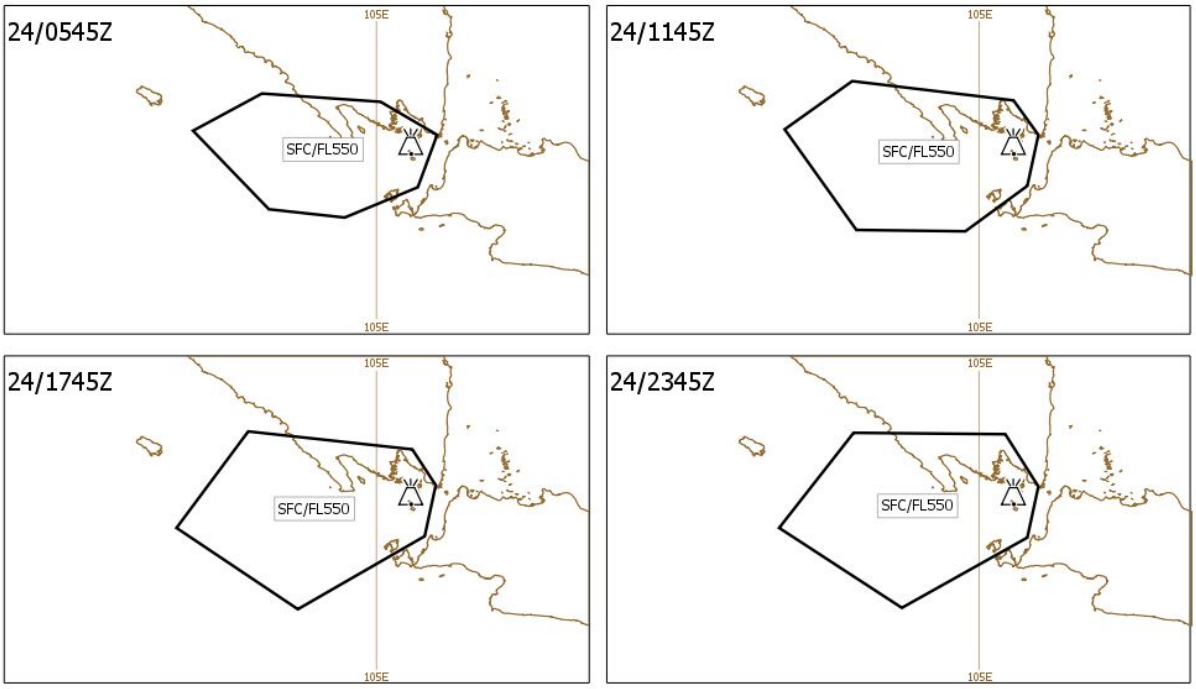
Other Volcanic Cloud Information:

Ash cloud is moving to north

Remarks:

Eruption recorded on seismogram with maximum amplitude 58 mm and maximum duration 87 second.

In the last week, 7 Volcanic Ash Advisories (VAAC) were received by Darwin. From an aviation color code ORANGE, since the 23 Dec at 14:00 UTC the code was increased to RED. Below the last issued on 24 Dec 2018 at 05:45 UTC.
(Source: http://www.bom.gov.au/aviation/volcanic-ash/darwin-va-advisory.shtml)



VOLCANIC ASH ADVISORY

DTG:	20181224/0545Z	ADVISORY NR:	2018/376
VAAC:	DARWIN	INFO SOURCE:	HIMAWARI-8
VOLCANO:	KRAKATAU 262000	AVIATION COLOUR CODE:	RED
PSN:	S0606 E10525	ERUPTION DETAILS:	CONTINUOUS ERUPTION TO FL550 EXT W TO W AT 24/0520Z.
AREA:	INDONESIA	RMK:	CONTINUOUS S02/ICE RICH VOLCANIC ERUPTION OBSERVED TO FL550 MOV W. ASH CLOUD LACKS A SPECTRAL-BASED ASH SIGNATURE BUT THE ANOMALOUS CLOUD EMERGING FROM THE VOLCANO IS UNAMBIGUOUSLY VOLCANIC.
SUMMIT ELEV:	813M	NXT ADVISORY:	NO LATER THAN 20181224/0845Z

Figure 11 *- The geographical area of the last VAAC - RED code issued on 24 Dec 2018 at 05:45 UTC*

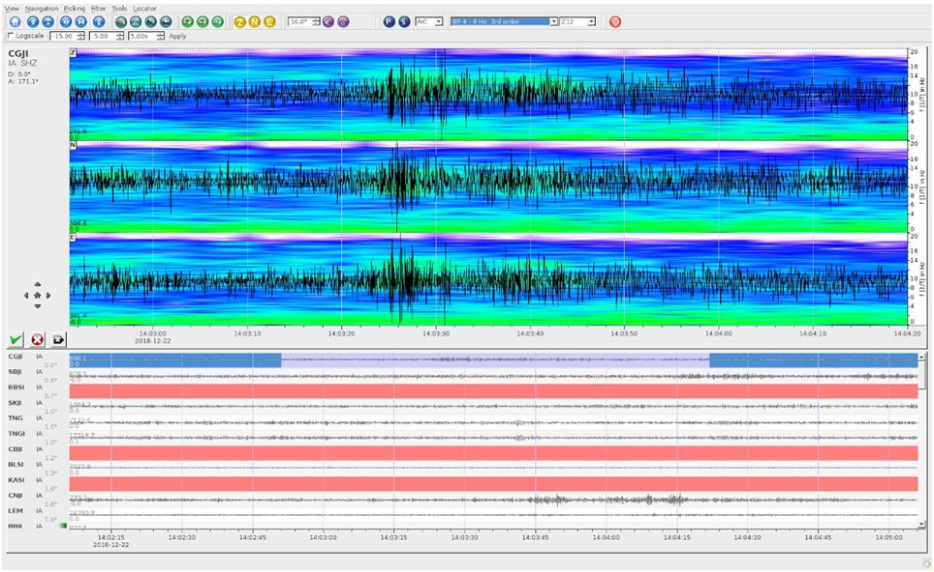


Figure 12 *- - The seismogram of the Anak Krakatau eruption on the 22 Dec 2018 9:03 UTC.*

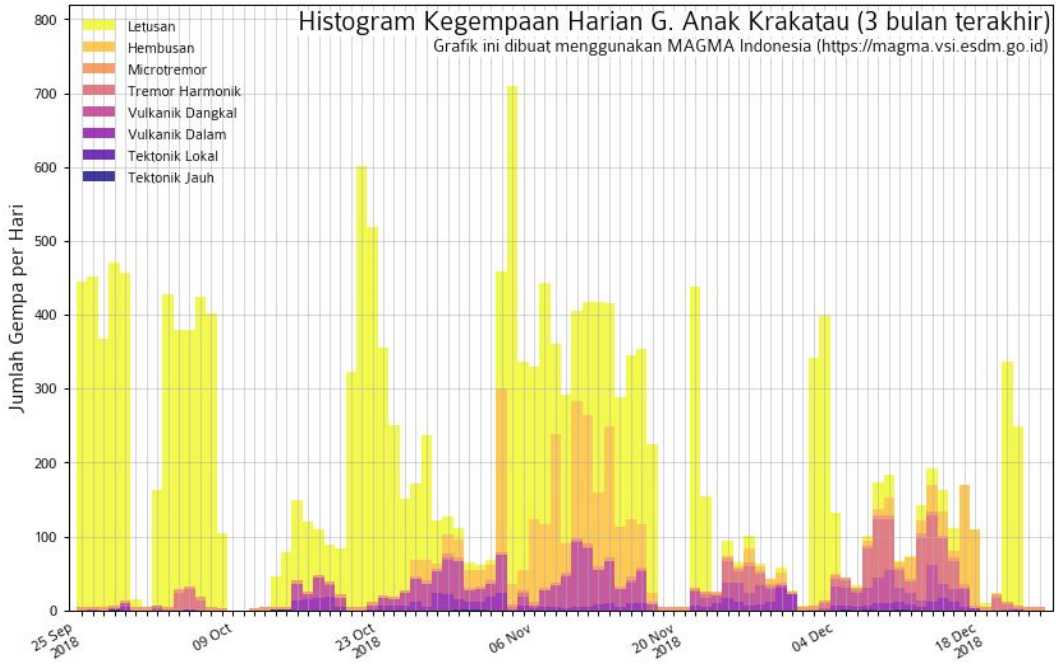


Figure 13 *- Graph showing the continuous volcanic activity over the last 3 months.*

2.2 Humanitarian impact and response

2.2.1 Impact

The updated humanitarian impact (as of 24 December at 2:16 UTC, BNPB) is shown in the table below. Search and rescue operations are still on-going, the full scale of damages and humanitarian needs are not yet known.

Several tourist areas have been affected and since it is the tourist season there was a large number of tourist in the coastal area of Pandeglang, as well as on several other areas (e.g. Tanjung Lesung Beach, Sumur Beach, Teluk Lada Beach, Panimbang Beach, and Carita Beach, see IFRC report)

Indonesia - Situation *(as of 24 Dec)*	
Deaths	**At least 281 deaths** → *207 Pandeglang, 12 Serang, 60 South Lampung, 1 Tanggamus, 1 Pesawaran* Search and rescue operations are ongoing, casualties are expected to rise
People missing	**57 Missing** → *7 Pandeglang, 28 Serang, 22 South Lampung*
People Injured	At least **1016 injured** → *755 Pandeglang, 230 South Lampung, 30 Serang, 1 Pesawaran*
People displaced	*11687 displaced (mostly in Pandeglang)*
Damaged houses/ infrastructures	> 700 structures damaged (611 houses, 69 hotels, 60 restaurants / food stalls) > 350 boats/ships damaged 71 vehicles damaged
Areas mostly affected	**Coasts of Sunda Strait (Java and Sumatra),** **5 affected districts/regencies, with *Pandeglang the area mostly affected*** → *Banten province (Java): Pandeglang and Serang regencies* → *Lampung province (Sumatra): South Lampung, Tanggamus and Pesawaran regencies* *The coastal areas along the coast from Carita Beach, Panimbang Beach, Teluk Lada Beach, Sumur Beach, and Tanjung Lesung Beach were severely damaged. 10 sub-districts in Pandeglang were affected by the tsunami. Most victims were found at Mutiara Hotel Carita Cottage, Tanjung Lesung Hotel and Sambolo Village.*

***Table 2** - Indonesia - Situation (as of 24 Dec at 2:16 UTC), Sources: BNPB, AHA Flash Rep, IFRC*

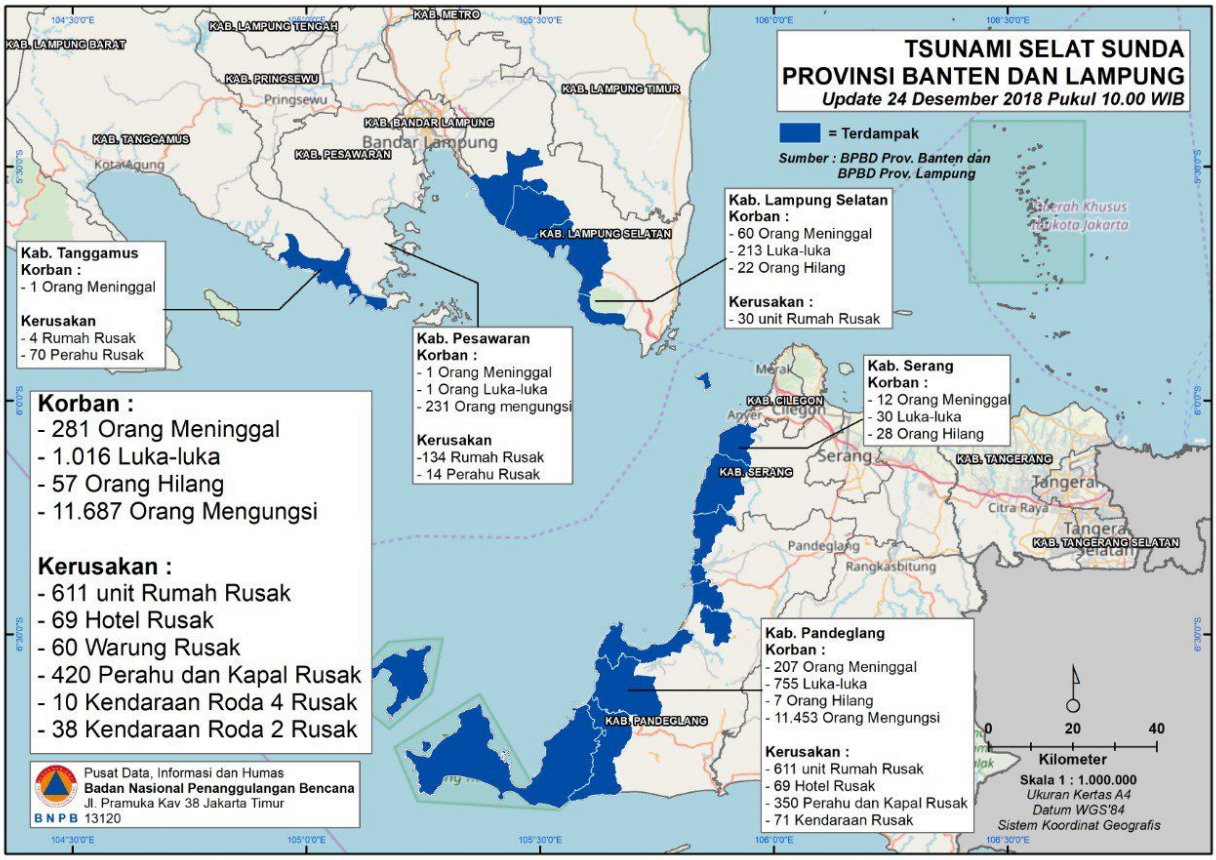


Figure 14 *- Situation map as of 24 December 2018, 03:00 UTC (source: BNPB's spokesperson's twitter account) (LEGEND: Orang Meninggal=victims; luka-luka=injured; orang hilang=missing person; orang mengungsi=people fled; rumah rusak=damaged houses; hotel rusak=damaged hotels; warung rusak=damaged shop; perau dan kapal rusak=boats/ships damaged; kendaraan roda=damaged vehicles)*

2.2.2 Response

Aid agencies were quick to deploy their teams to the area, located just a few hours drive from the Indonesian capital, Jakarta.

Response by the provincial disaster management agency (BPBD):
BPBD together with the military, police, the national search and rescue agency (Basarnas), local government office, Ministry of Social Welfare Volunteers (Tagana), Indonesian Red Cross (PMI), volunteers and the community are providing emergency response support to the affected people.
Government has not yet declared emergency status or released response structure yet, currently it's being locally coordinated along with the establishment of command post, field kitchen and displacement site. Heavy equipment is being dispatched to clear debris to ease evacuation and response.
The causes of the tsunami event are being investigated by BMKG (Agency for Meteorology, Climatology, and Geophysics), BNPB (Indonesian Disaster Management Authority) and PVMBG (Centre of Volcanology and Geological Disaster Mitigation). This Government has issued a warning of no activity along the coastal area.

Response by PMI and IFRC:
PMI and the IFRC Country Cluster Support Team (CCST) in Jakarta are coordinating with each other and also coordinating with BNPB to obtain more information on the humanitarian impact. Based on initial information from secondary sources as well as from PMI teams on the ground, immediate needs include evacuation and management of injuries, medical and health services including referral services, food and non-food items and evacuation sites.

PMI has been on the ground from the onset of this event, with a total of 71 volunteers from provincial chapter and four branches on the ground to support search and rescue efforts, delivery of immediate assistance and undertake rapid assessment and coordination with BNPB and other stakeholders. PMI has mobilised 2 units of ambulance for referral service and dispatched the following relief materials from its regional warehouse in Banten: 150 blankets, 20 boxes of mineral water, tarpaulins, 20 sets of equipment to clean the area of Carita and Anyer (shovel, mattock, etc.), family kits and 40 hygiene kits. The IFRC Country Cluster Support Team (CCST) in Jakarta is providing technical support and working in coordination with PMI on needs assessment and to support communications and media relations needs. The CCST is also set to provide financial support to enable the mobilization of personnel and supplies by PMI. In this regard, initial discussions are currently being held with the Australian Embassy in Jakarta to access emergency response funds – from the Department of Foreign Affairs and Trade (DFAT) – based on an existing in-country agreement. If required, additional financial resources will be sought via the relevant IFRC international disaster response mechanism.

As local and government aid agencies rushed to the area to help with the search and rescue operation, bringing supplies of food and shelter, international organisations were also preparing to assist. At the moment, however, the Indonesian Government indicated that the disaster can be faced with National resources.

Emergency handling continues in areas affected by the tsunami in the Sunda Strait. Current emergency handling priorities are coordination, evacuation, search and rescue of victims, health services, handling refugees, repairing emergency damaged infrastructure. Evacuation, search and rescue of victims continues. Allegedly there are still victims who are under the rubble of buildings and material washed

away by the tsunami. Health posts, public kitchens, and refugees were established in several places. Logistics assistance continues to be channeled (source: BNPB website, post of the 24 December 2018, 7:16 UTC). PLN continues to make improvements to the electricity network that was extinguished due to the tsunami in the affected areas. PLN officials are still repairing electricity in the Batu Hideung Beach area of Tanjung Jaya Village, the route to the Kec. Pandeglang well *(source: BNPB's spokesperson's twitter account)*.

***Figure 15** - Tsunami impact (source: IFRC)*

A quite impressive video in Twitter, showing the moment of the wave arrival that destroys the band podium and crashes on the people. An arbitrary estimate of the height in this video can suggest a wave height between 2 and 3 m.

***Figure 16** - the initial image of the concert; few minutes after it will be destroyed*
https://twitter.com/davidlipson/status/1076662318862225408

2.3 Meteorological Situation

Current Condition - coastal areas of Sunda Strait:

Cloudy, with the possibility of light to moderate rain. Details on the current weather are shown in the bottom figure on the right, containing the surface weather map - isobars and winds - valid for 24 Dec 00 UTC; the areas of wind speeds higher than 35 km/h are shaded by yellow colour (data source: NOAA-GFS /GDACS), while the last 24 h accumulation rainfall (data source: NOAA-GFS / GDACS) is shown on the bottom-right.

More information on the current weather at http://www.bmkg.go.id

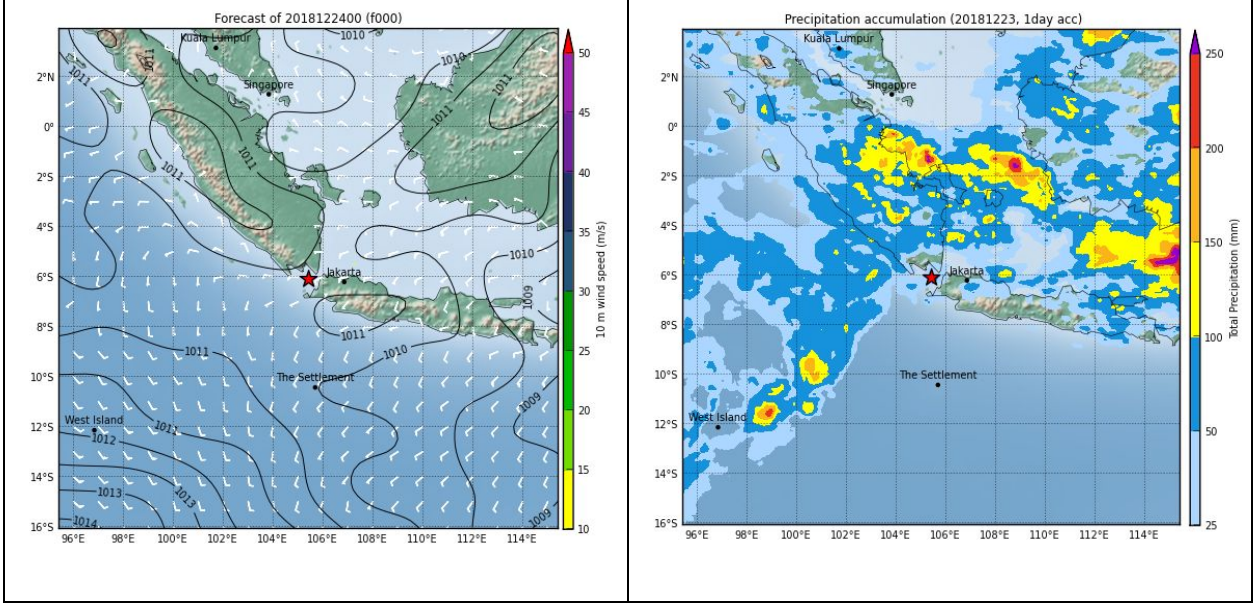
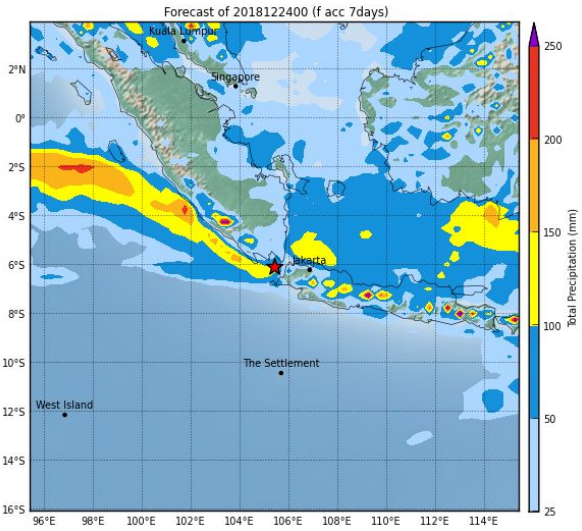


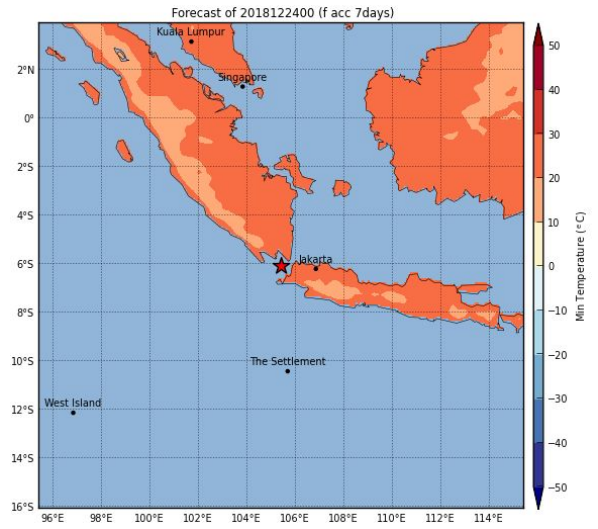
Figure 17 - 18 *- LEFT: Surface weather analysis map (isobars and winds) valid for 24 Dec 00 UTC Data Source: GFS (Global Forecast System of NCEP / NOAA, as of 24 Dec, 00 UTC), see GDACS. RIGHT: Last 24h acc. Rainfall, NASA/GPM (source: GDACS)*

Forecast: Over the next 7 days, locally heavy rains and thunderstorms could affect parts of Indonesia, including south-eastern Sumatra and Java islands (see next 7 days rainfall accumulation in the image on the right, red star=volcano, and the **high wave warning** on the next page).

In **Serang, Java** (25-26 Dec), cloudy, with the possibility of light rainfall. Max temperatures forecast: 33°C on 25 Dec and 34° on 26 Dec. Min temperatures: 23°C during the early hours of 25 and 26 Dec (see BMKG and WMO).

In **Bandar Lampung, Sumatra** (25-26 Dec), mostly cloudy, with the possibility of light rainfall. Max temperatures forecast: 32°C on 25 Dec and 26°C on 26 Dec. Min temperatures: 23°C during the early hours of 25 and 26 Dec (see BMKG and WMO).





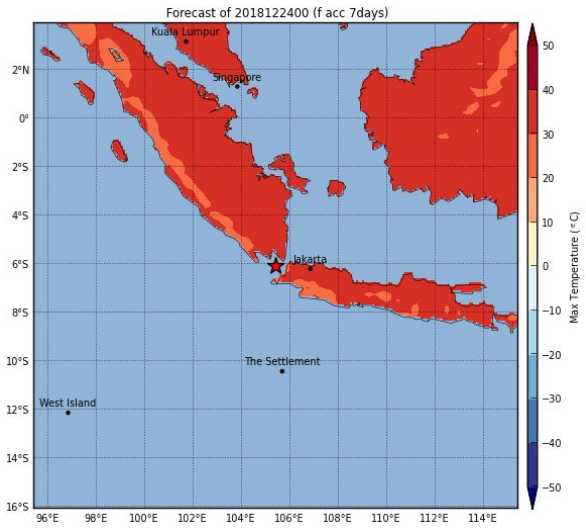


Figure 19-21 *- 7-days precipitation accumulation forecast, Minimum temperature (Bottom-LEFT) and maximum temperatures (Bottom-RIGHT) over the next 7 days*
Data Source: GFS (Global Forecast System of NCEP / NOAA, as of 24 Dec, 00 UTC), see GDACS

High Waves Warning

As reported in AHA Flash report 1: “Public have been advised to increase the alertness of the maximum tide threat for 24-25 Dec for the South Coast of Sumatra, **Lampung**, Coastal, West Kalimantan, North Java (**Banten**, Jakarta, West Java, Central Java, East Java) and North Bali”

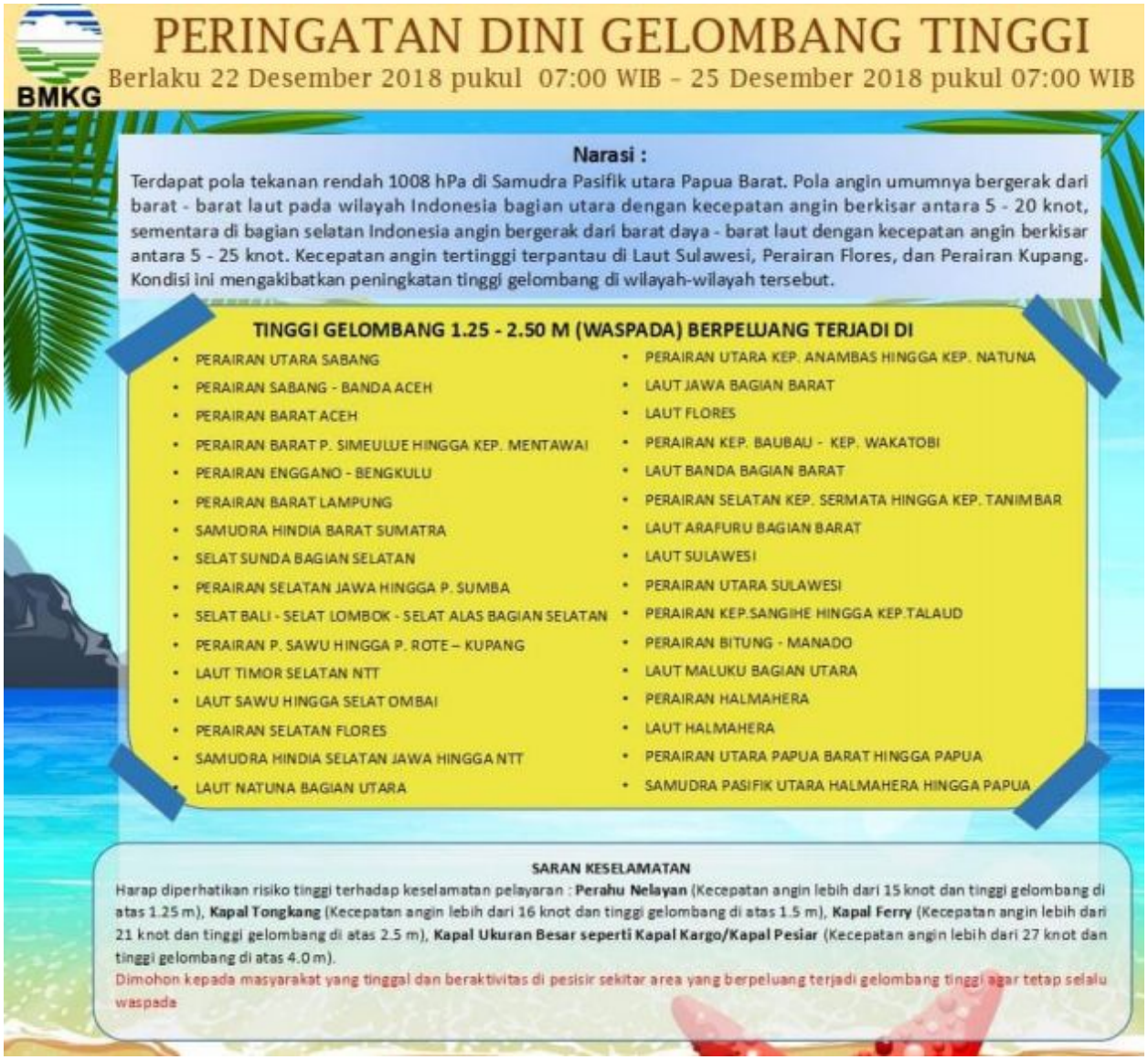


***Figure 22**- High waves warning (BMKG, AHA report)*

2.4. Historical events

2.4.1 The major event at Krakatau volcano (1883)

The 1883 eruption of Krakatau is one of the largest volcanic explosions that has occurred in human history. The sound waves generated by the eruption were heard over 4000 km across the Indian Ocean. The atmosphere was polluted with vast quantities of volcanic ash and aerosols, and a fall in surface temperatures was observed in many areas (Simlin and Fislke, 1983[5]). The explosion re-faced the island of Krakatau; the northern portion of Krakatau Island disappeared and a caldera up to 270 m deep replaced it (Sigurdsson et al., 1991[6]). Pyroclastic flow deposits and other ejecta shallowed the bathymetry around Krakatau considerably. The tsunamis that the eruption generated killed about 34,000 people and destroyed numerous coastal villages [Simlin and Fiske, 1983] - Extracted from: Nomanbhoy and Satake, 1995[7].

Also in that case, several hypothesis were analyzed: (1) large-scale collapse of the northern part of Krakatau island, (2) submarine explosion and (3) emplacement of pyroclastic flows. It was concluded that the most likely mechanism for the eruption is a Mt. St. Helens scenario, in which collapse of part of the original volcanic edifice propagated a major explosion. Extracted from: Francis, P. W., 1985[8].

2.4.2 Other Volcano generated Tsunami historical events

Volcanoes are one source that can produce tsunamis as high as those produced by the largest earthquake. They can be caused by mechanisms such as volcanic earthquakes, undersea eruptions, pyroclastic flows, caldera collapse, landslides, lahars, phreatomagmatic eruptions, lava bench collapse, and airwaves from large explosions. There have been 110 eruptions that caused tsunamis' (NGDC/WDS). Below are a few examples of volcanic eruptions that have caused a tsunami:

- In 1792, the eruption of Mount Unzen in Japan produced a destructive landslide generating a 165-foot tsunami. The death toll from the disaster is estimated at over 15,000 people, making it the most deadly volcanic eruption in Japan's history.
- The 1883 eruption of Krakatoa in Indonesia caused by *pyroclastic flows entering the water (A base surge resulting from collapse of the eruption column) that produced run-up heights of 120 feet and killed over 26,000 people and many coastal villages destroyed.
- The 1980 Eruption of Mount St. Helens in Washington (USA) caused partial collapse of the volcano's flank and an avalanche into Spirit Lake producing a 780-foot tsunami.

[5] Simkin, T., and R. Fiske, Krakatau, 1883 - the volcanic eruption and its effects, 464 pp., Smithsonian Institution Press, Washington D.C., 1983.
[6] Sigurdsson, H., S. Carey, and C. Mandeville, Submarine pyroclastic flows of the 1883 eruption of Krakatau volcano, Nat. Geog. Res. Explor., 7, 310-327, 1991.
[7] Generation mechanism of tsunamis from the 1883 Krakatau eruption Nazli Nomanbhoy and Kenji Satake, GEOPHYSICAL RESEARCH LETTERS, VOL. 22, NO. 4, PAGES 509-512, FEBRUARY 15, 1995]
[8] The origin of the 1883 Krakatau tsunamis. Francis, P. W. Journal of Volcanology and Geothermal Research (ISSN 0377-0273), vol. 25, 1985, p. 349-363.

Date of Tsunami	Volcano Location	Tsunami Cause and Impact
1638 BC	Santorini, Greece	· Destruction of the population of Crete
79 AD	Vesuvius, Italy	· Caldera collapse · Unknown devastation
1631	Vesuvius, Italy	· Worst Vesuvius tsunami · Result of subplinian eruption · Many boats destroyed
1640	Komagatake, Japan	· Summit collapse from landslide · 700 people killed
1715	Taal, Philippines	· Base surge-induced tsunami
1741	Oshima-Oshima, Japan	· Volcanic earthquake · 1,467 people killed
1749	Taal, Philippines	· Base sure-induced tsunami
1792	Unzen, Japan	· Landslide from nearby Mt Mayuyama · 55m tsunami waves · Around 15,000 people killed
1815	Tambora, Indonesia	· Pyroclastic flows entering sea · Waves over 10m · Over 10,000 people dead
1871	Ruang, Indonesia	· Pyroclastic flow · 26m waves
1878	Yasur, Vanuata	· Volcanic earthquake · 16m waves
1878	Okmok, Alaska, USA	· Volcanic earthquake-induced
1883	Augustine, Alaska, USA	· Volcanic landslide · 9m waves
1883	**Krakatau, Indonesia**	· **40m waves** · **36,000 people dead**
1888	Ritter, Papua new Guinea	· Volcano collapse and avalanche · 15m waves · Hundreds killed on shoreline
1902	Pelee, Carribean	· Pyroclastic flow-induced
1913	Ambrym, Vanuatu	· Underwater eruption
1928	Paluweh, Indonesia	· Volcanic landslide · 10m waves · 150 people killed
1930	Stromboli, Italy	· Volcanic earthquake and landslide · 2m waves
1933	Severgin, Kurile Islands	· Volcanic earthquake · 10m tsunami waves
1956	Bezymianny, Russia	· Shockwave-induced tsunami
1969	Didicas, Philippines	· 3 people killed
1972, 1974	Ritter, Papua New Guinea	· Small tsunamis from subsidence of volcano
1979	Illiwerung, Indonesia	· Volcanic landslide · 9m waves · Over 500 people dead
1980	St Helens, Washington, USA	· Volcanic landslide · 250m waves in Spirit Lake
1983	Illiwerung, Indonesia	· Submarine eruption · Few deaths
1986	Nyos, Cameroon	· Underwater CO_2 eruption · 75m tsunami waves
1988	Vulcano, Italy	· Volcanic landslide · 5.5m waves
1994	Rabaul, Papua New Guinea	· Pyroclastic flow-induced · 1.2m waves
1996	Karymsky, Russia	· Phreatomagmatic eruption · 30m waves
1997	Soufriere Hills, Montserrat	· Volcanic debris slide · 3m waves
2002	Stromboli, Italy	· Landslide-induced tsunami
2007	Ritter, Papua New Guinea	· Eruption-induced landslide · Many homes destroyed

Table 3 - : *Noteworthy Volcanic Tsunamis (J. Keeley, 2010; http://volcano.oregonstate.edu/book/export/html/42)*

2.4.3 Tsunami events with Humanitarian support in the area

The list below indicates the events, the hazard (only earthquake-triggered tsunami), the date and the international humanitarian support in the area close to the event.

Date	Hazard	Magnitude	Humanitarian intervention
28-Sep-18	EQ+TS	7.5	OCHA+ERCC (RfA)
11-Apr-12	EQ+TS	8.6	ERCC activation (Pre-alert)
25-Oct-10	EQ+TS	7.8	OCHA
17-Jul-06	EQ+TS	7.7	OCHA
26-Dec-04	EQ+TS	7.2	OCHA

Table 4 *- Past earthquake and tsunami events, in the affected tectonic area, which required the international humanitarian support (source: https://fts.unocha.org/data-search/ and ECHO/ERCC). The events from 2007 are reported in the map below.*

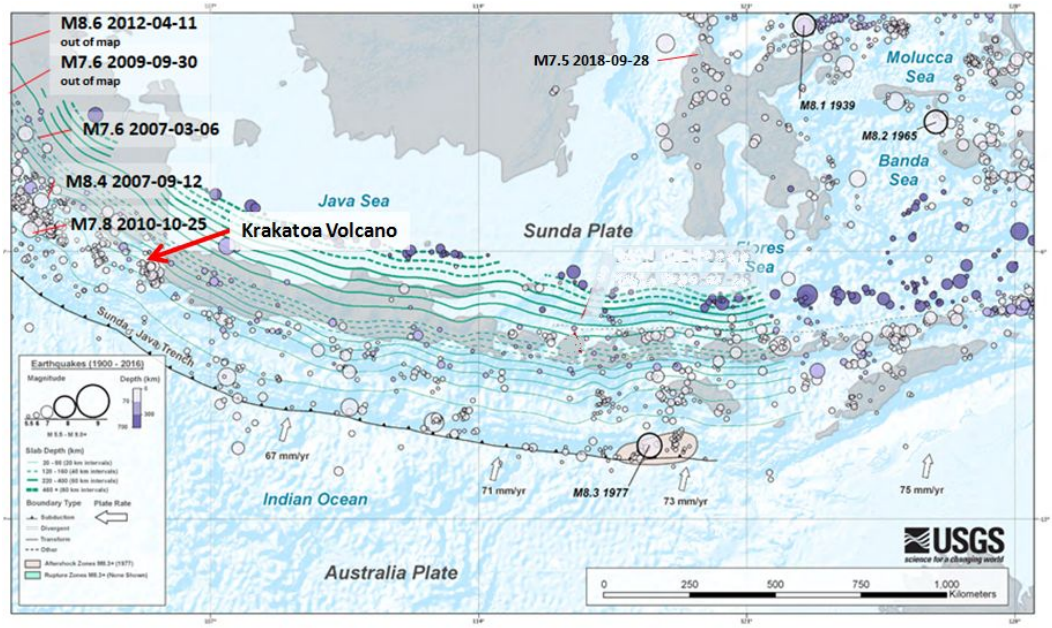


Figure 23 *- Map of tectonic summary regions (USGS, modified with Earthquake-triggered tsunami events which required the OCHA and/or ERCC humanitarian intervention from 2007).*

3. JRC contributions

For more than 10 years, the Joint Research Centre (JRC) provided scientific support to the Directorate General for European Civil Protection and Humanitarian Aid Operations (DG ECHO), preparing the emergency reports in case of major disasters. During the timeframe of the ARISTOTLE project (All Risk Integrated System TOwards Trans-boundary hoListic Early-warning, 24/7 operational period: Feb 2017-Jan 2018, funded by DG ECHO), JRC operationally supported the ERCC only for the events not covered by ARISTOTLE project (i.e. dam breaks). After the end of this project, until the beginning of a new edition of the project on 30 Oct 2018, ARISTOTLE-2, JRC provided again the ERCC with Emergency reports for all major disasters, consisting in a total of more than 50 reports. After the beginning of the new service, JRC started preparing the emergency reports for ERCC only for the natural hazards not included in ARISTOTLE 2 and ad hoc analyses (e.g. dam break calculations or tropical cyclones preparedness reports).

For this event, ARISTOTLE-2 has been activated by ERCC on 22 Dec at 23:58 UTC. The activation was cancelled as the tsunami was likely due to the volcanic activity in the region, outside the ARISTOTLE-2 monitoring region, and the project does not cover tsunamis due to non-earthquake events.

JRC therefore decided to provide a scientific assessment of the event with this report, that was issued on 24/12/2018 at 12:00 UTC.

3.1 Activities performed (timeline)

JRC started working on the event after the activation of the ARISTOTLE-2 service by ERCC (10 h after the event) and news started to arrive on regular news channels and social media of the new Tsunami event. For about 4 h, until 23 Dec 02:00 UTC there was a continuous discussion with other colleagues in the dedicate chat that was created for the Palu survey, exchanging information, impressions, ideas. The Indonesian colleagues had already started to perform Tsunami calculations.

Tsunami Travel Time calculations have been performed in order to verify and confirm that the source of the Tsunami was indeed the Krakatoa volcano.

We also were in contact with ERCC colleagues from the morning of 23 suggesting the activation of the Copernicus Service (See below) and providing some information on the preparation .

The GDACS system was updated with the introduction of the Volcano event, classified as RED alert (see below) and consequently the OCHA colleagues were informed who then activated the VOSOCC page for first responders (see below).

Starting from 23 December, with the difficulties of working from home and during holiday period the writing team started to arrange this report to inform about the current situation and the activities performed.

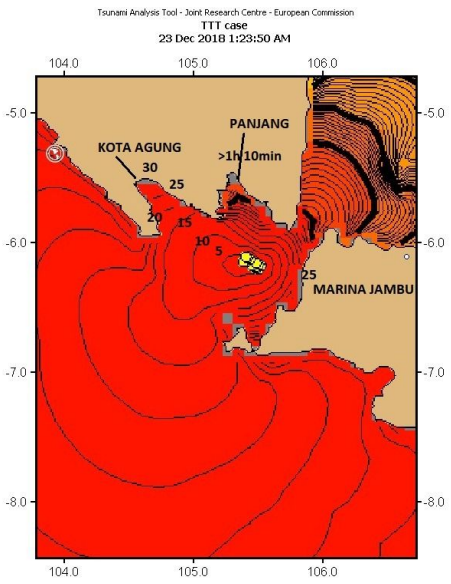


Figure 24 *- Tsunami Travel time from Krakatoa (JRC contribution to the International chat)*

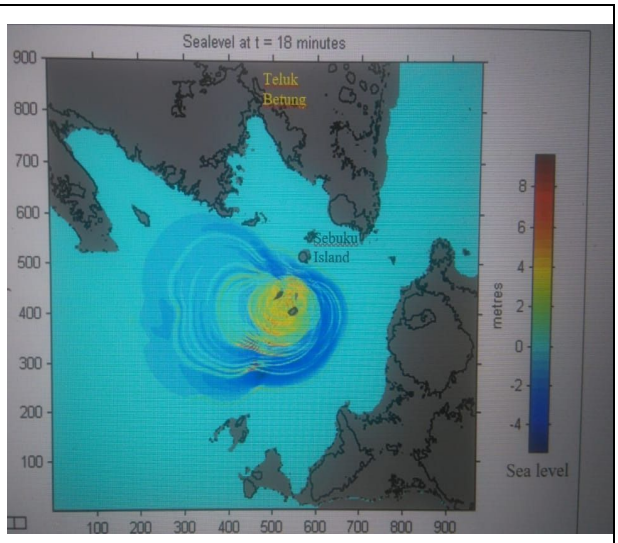
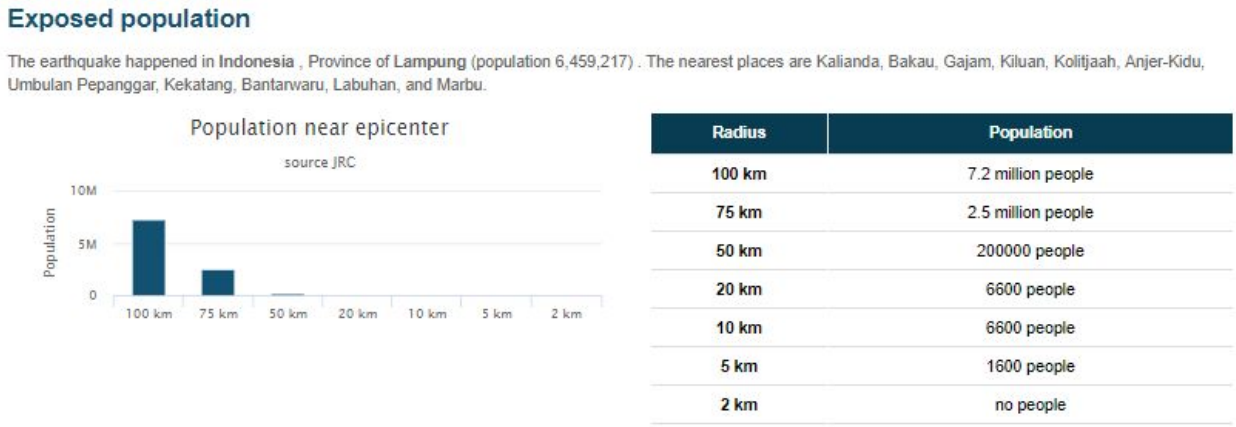


Figure 25 *First calculations of Tsunami impact, shared from the Indonesian scientist fully dedicated in the aftermath of the event*

3.2. Volcano - *GDACS automatic impact estimation*

According to GDACS, there are 7.2 million people within a radius of 100 km and 6600 within 10 km.



Radius	Population
100 km	7.2 million people
75 km	2.5 million people
50 km	200000 people
20 km	6600 people
10 km	6600 people
5 km	1600 people
2 km	no people

Figure 27 *- GDACS - Impact Estimation: population near the volcano.*

Affected Provinces

Region Province	Country	Population
Lampung	Indonesia	6.4 million people
Jawa Barat	Indonesia	38 million people
Jakarta Raya	Indonesia	8.8 million people
Sumatera Selatan	Indonesia	6.6 million people
Bengkulu	Indonesia	1.2 million people
Jawa Tengah	Indonesia	30.6 million people
Christmas I.	Christmas Island	-
Jambi	Indonesia	2.1 million people

Figure 28 *- GDACS - Impact Estimation: affected provinces.*

Critical infrastructure

Airports, ports, nuclear plants and hydrodams at risk, if affected, are listed below.

Airports

Name	IATA Code	Elevation (m)	Usage	Runway type	IFR	Runway Length (ft)	Distance
Branti	TKG	86	Civ.	Paved	No	6000	99 km

Ports

Name	LOCODE	Country	Distance
Kalianda		Indonesia	44 km
Anyer Lor		Indonesia	55 km
Cigading	IDCIG	Indonesia	60 km
Tanjung Gerem		Indonesia	65 km
Merak	IDMRK	Indonesia	67 km
Panjang	IDSPA	Indonesia	72 km

Figure 29 *- GDACS - Critical Infrastructure: Airports, Ports.*

Affected populated places

Name	Region Province	Country	City class	Population	Distance
Kalianda	Lampung	Indonesia	Village5	-	45 km
Bakau	Lampung	Indonesia	Village6	-	46 km
Gajam	Lampung	Indonesia	Village5	-	47 km
Kiluan	Lampung	Indonesia	Village5	-	51 km
Kolitjaah	Banten	Indonesia	Village5	-	51 km
Anjer-Kidu	Banten	Indonesia	Village5	-	52 km
Umbulan Pepanggar	Lampung	Indonesia	Village5	-	53 km
Kekatang	Lampung	Indonesia	Village5	-	54 km
Bantarwaru	Banten	Indonesia	Village6	-	54 km
Labuhan	Banten	Indonesia	Village4	33000 people	54 km
Kaduperasi	Banten	Indonesia	Village5	-	56 km
Ketapang	Lampung	Indonesia	Village5	-	57 km
Tjiteureup	Banten	Indonesia	Village5	-	57 km
Babakancibeber	Banten	Indonesia	Village5	-	59 km
Tarahan	Lampung	Indonesia	Village5	-	61 km
Bodjongdjuruh	Banten	Indonesia	Village6	-	62 km
Menango	Lampung	Indonesia	Village5	-	64 km
Sumur	Banten	Indonesia	Village5	-	64 km
Tambangan	Lampung	Indonesia	Village5	-	65 km
Pasirgadung	Banten	Indonesia	Village6	-	66 km

Figure 30 *- GDACS - Affected Populated places, only the first 20 places, full list at: GDACS*

4. Other Information

4.1. EU Copernicus Management Service activation

The EC Copernicus Emergency Management Service was activated by DG ECHO-ERCC on 23 December 2018 at 09:10 UTC (EMSR335). 10 AoIs were defined by ERCC in cooperation with JRC following the information coming from the field.

The Activation Extent Map (Figure below) shows the mapping plan over the islands of Java and Sumatra, the first images (GeoEye provided by the International Disaster Charter) acquired at 3.39 a.m. UTC were unfortunately cloudy. A new attempt will be done on the 25 December (Copernicus EMS © 2018 EU, [EMSR335] AEM)

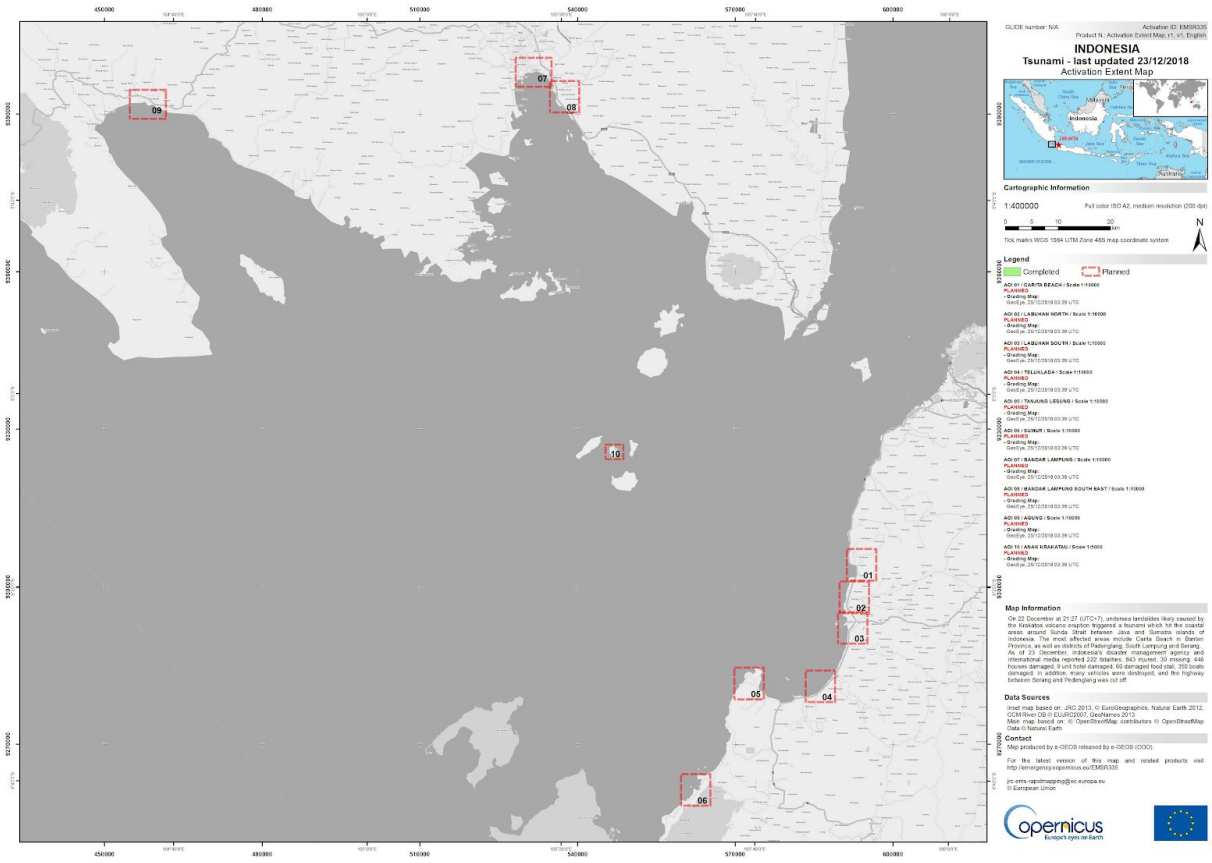


***Figure 31** - Activation Extent Map (AEM) as of 24 Dec at 10 a.m. UTC .*

4.2. Virtual OSOCC Activation

A new breaking emergency discussion has been initiated in VOSOCC web site on 23 December late morning, after the GDACS alert was created.

The last situation update from OCHA is the following:

*OCHA Indonesia has been in contact with BNPB and the AHA Centre and was informed that **the Government considers the emergency response to the impact of disaster to be within national capacity**; there has been no indication of acceptance of offers of international assistance at this point.*

Further updates are present at this public page
https://vosocc.unocha.org/GetFile.aspx?xml=59281g1FAqju1fKc9x8IaUwOkGM0hvKahGaRmKnYAkn3S2wx_I1.html&tid=5928&laid=1

While more detailed analyses and requests/offer of assistance are in the dedicated VOSOCC page restricted to humanitarian organizations.

4.3. International Charter activation

The International Charter has been activated on 23 December 2018 4:55 UTC as activation #594
https://disasterscharter.org/web/guest/activations/-/article/ocean-wave-in-indonesia-activation-594-

5. Expected Updates

Further update will be provided if needed.

6. References and contact points within JRC

Contact points within JRC: Disaster Risk Management Unit
- Alessandro Annunziato, alessandro.annunziato@ec.europa.eu
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Head of Unit and deputy:
- Alessandra Zampieri, alessandra.zampieri@ec.europa.eu
- Tom de Groeve, tom.de-groeve@ec.europa.eu

For updated information on the disaster, please consult the following web sites:

- GDACS: http://www.gdacs.org/report.aspx?eventid=514&episodeid=1&eventtype=VO
- Copernicus EMS: https://emergency.copernicus.eu/mapping/list-of-components/EMSR335
- International Disaster Charter: https://disasterscharter.org/web/guest/activations/-/article/ocean-wave-in-indonesia-activation-594 -
- BNPB: https://www.bnpb.go.id/
- BMKG: http://www.bmkg.go.id

Appendix A - The Krakatau Volcano, Indonesia

***Figure 32** - The Krakatau Volcano and the lava accumulated during the eruption of the last months (Smithsonian Institute Global Volcanism Programme)[9] .*

Anak Krakatau Volcano is located in the Sunda Strait in Indonesia, along the so-called “Ring of Fire”. It is a type A volcano and is a young volcano that appeared in the caldera, after the paroxysmal eruption in **1883** from the Krakatau volcanic complex, which triggered a deadly tsunami. Anak Krakatau means “Son of the Krakatoa”.

Eruption activities after the formation began in 1927, when the volcanic structure was still below the sea surface. The Son of Krakatau's structure has surfaced since 2013. Since then and until now Anak Krakatau is in the construction phase (enlarging its body). Now the Anak Krakatau has the highest elevation of 338 meters from the sea level (measurements in September 2018). The character of the eruption is a magmatic eruption in the form of a weak explosive eruption and an effusive eruption in the form of lava flow. In 2016 the eruption took place on June 20, 2016, whereas in 2017 the eruption occurred on February 19, 2017 in the form of a strombolian eruption. In 2018, it erupted again since 29 June 2018 until now in the form of strombolian eruptions. Eruptions in 2018, precursors of the 2018 eruption began with the emergence of earthquake tremors and increased number of Low Frequency and

[9] https://volcano.si.edu/volcano.cfm?vn=262000

Blowing earthquakes on 18-19 June 2018. increased and finally on June 29, 2018 Anak Krakatau erupted. Most eruptions of material fell around the crater of Mt. Anak Krakatau or less than 1 km from the crater, but since July 23 it was observed throwing incandescent material that fell around the coast, so the hazard radius of Krakatau is extended from 1km to 2km from the crater (Alert level II).

Recent Activities, December 22, as usual in the previous days, the eruption of Mt. Anak Krakatau occurred. Visually, eruptions with high smoke ranged from 300 - 1500 meters above the top of the crater. In seismicity, earthquake tremors are recorded continuously with overscale amplitude (58 mm). At 9:03 a.m., an eruption occurred, and then after several hours the tsunami occurred.

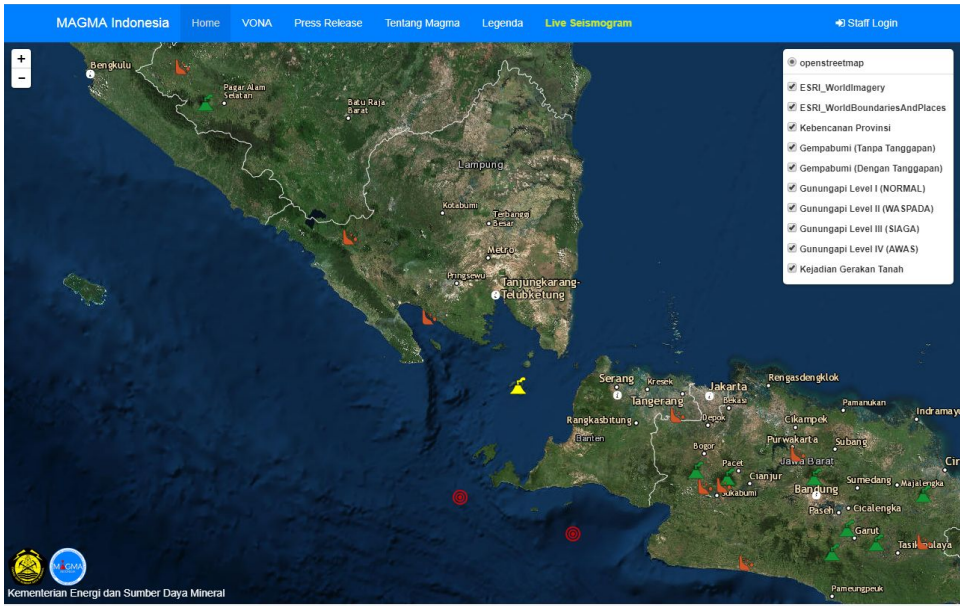

Figure 33 *- The location of the Krakatau Volcano and the Alert Level II (Yellow - https://magma.vsi.esdm.go.id/) .*

Figure 34 *- One of the last significant eruptions (Source:* https://twitter.com/hudasafiro/status/1076805858518982657).

First visual information about the situation on Anak Krakatau island group itself has come in, revealing that a large part of Anak Krakatau's SW flank has collapsed, which most likely is the trigger for the tsunami (https://www.volcanodiscovery.com/krakatoa/2018/dec/eruption-tsunami/updates.html).

Figure 35 *- The image above, taken on 22th Dec shows the lava flow entering into the water (image: Øystein Lund Andersen / facebook).*

Appendix B - Volcano generated Tsunami Hazard Maps in the Sunda Strait

The possibility of a Tsunami originated from the Volcanic Eruption had been considered by the Indonesian Authorities. The maps below, from PVMBG - Indonesia Volcanology Agency report the hazard maps due to possible Tsunami originated from the Krakatau volcano. Those area are the ones that probably have been mostly hit during the event.

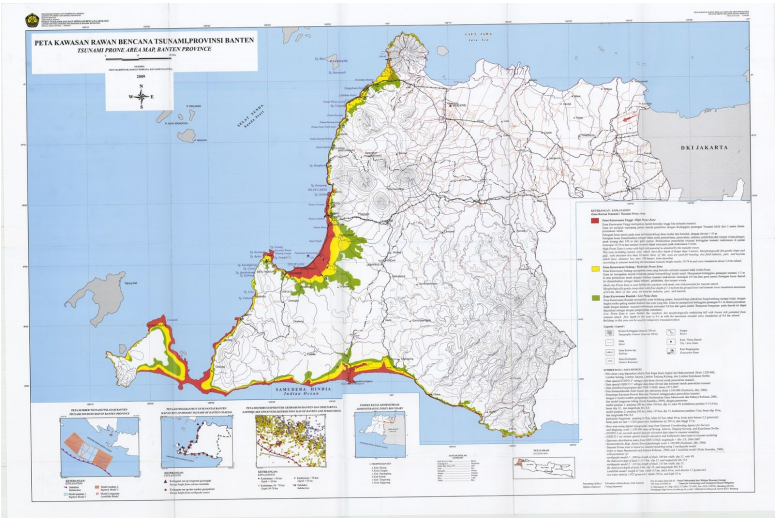

***Figure 36** - Tsunami hazard Map of the Banden Province (https://magma.vsi.esdm.go.id/)*

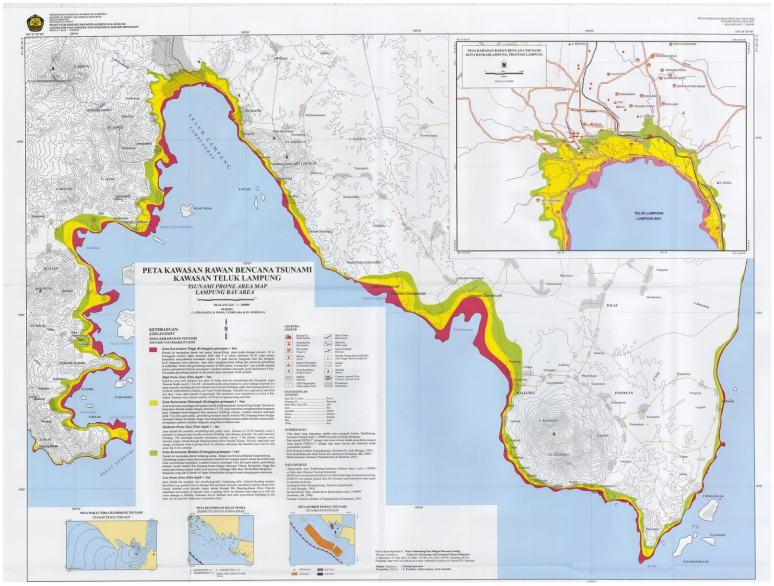

***Figure 37** - Tsunami hazard Map of the Lampung Province (https://magma.vsi.esdm.go.id/)*