2024.May.15(Wed)
UNESCO/IOC's
Scientific Experts Meeting

A New Tsunami SOP of VMGD based on the Tsunami Catalog of Vanuatu

Van-REDI Project(2019-2024)

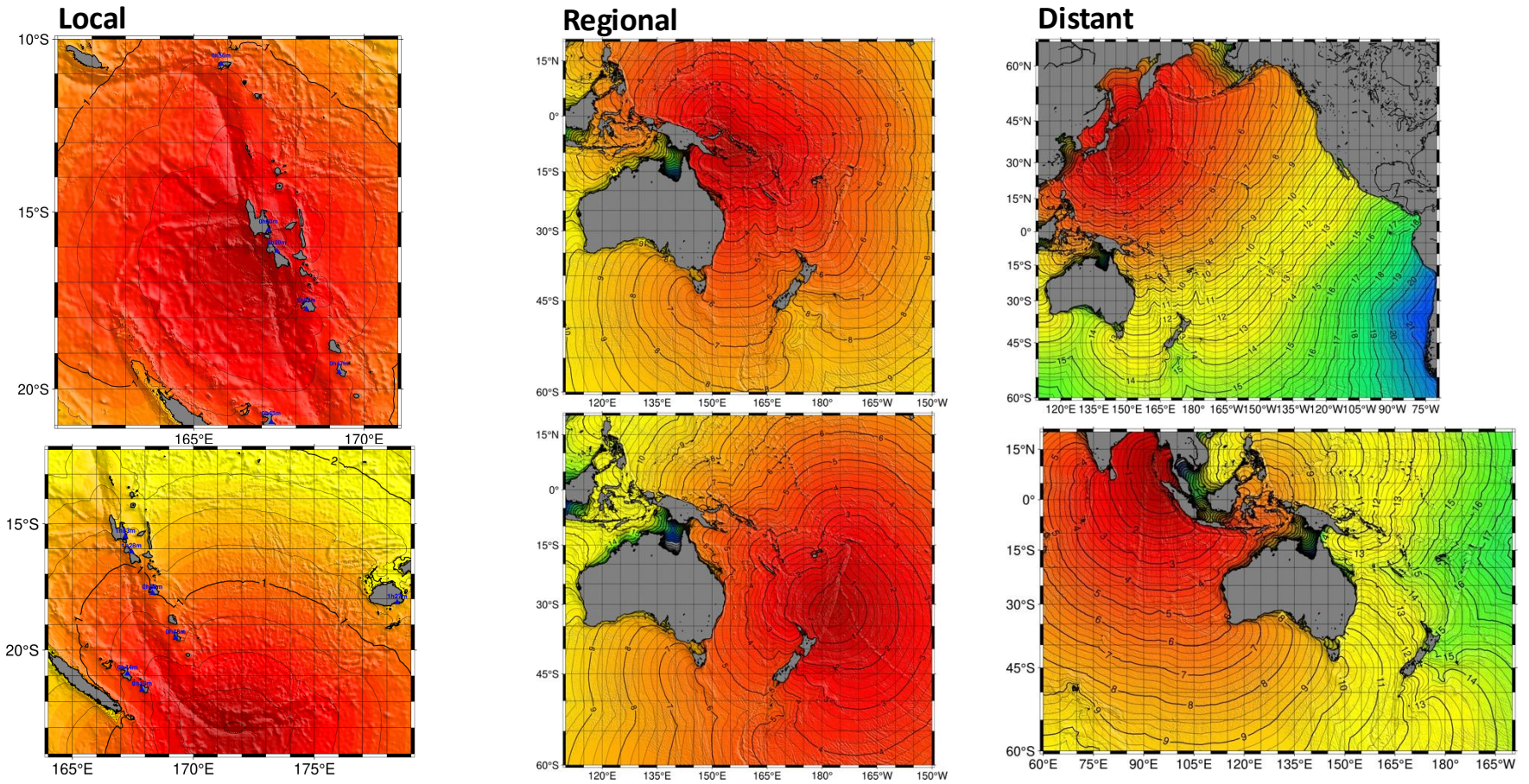
Osamu KAMIGAICHI
JICA VAN-REDI Project team
(JMBSC, ex.JMA)

How prompt should you be after the earthquake occurrence?

In Local area (left), wherever earthquake occurs,
Tsunami will arrive at the nearest coast within 1 hour (sometimes, within a few minutes!).
In Regional area (center), the earliest arrival of tsunami in the Vanuatu territory is
North Vanuatu : ～1.5 hours from Outer Solomon
South Vanuatu : ～2.5 hours from Tonga to Kermadec
In Distant area (right), more than 8 hours.

→ You need to be as quick as possible!

→ You can wait for a quantitative tsunami amplitude estimation provided from PTWC



Background condition in VMGD

Formally, GeoHazard Division is responsible for tsunami warning in VMGD.
But, GeoHazard Division doesn't have 24/7 system.
Forecast Division has, and is undertaking tsunami warning dissemination duty for over 10 years in an ad-hoc manner.

→ New SOP should be simple so that Forecast Division personnel without seismological knowledge can carry out.

Assuring promptness and reliability at the same time.

Considering the reliability and receiving time, usage of hypocentral parameters in **PTWC's message(in about 10 minutes)** is recommended.

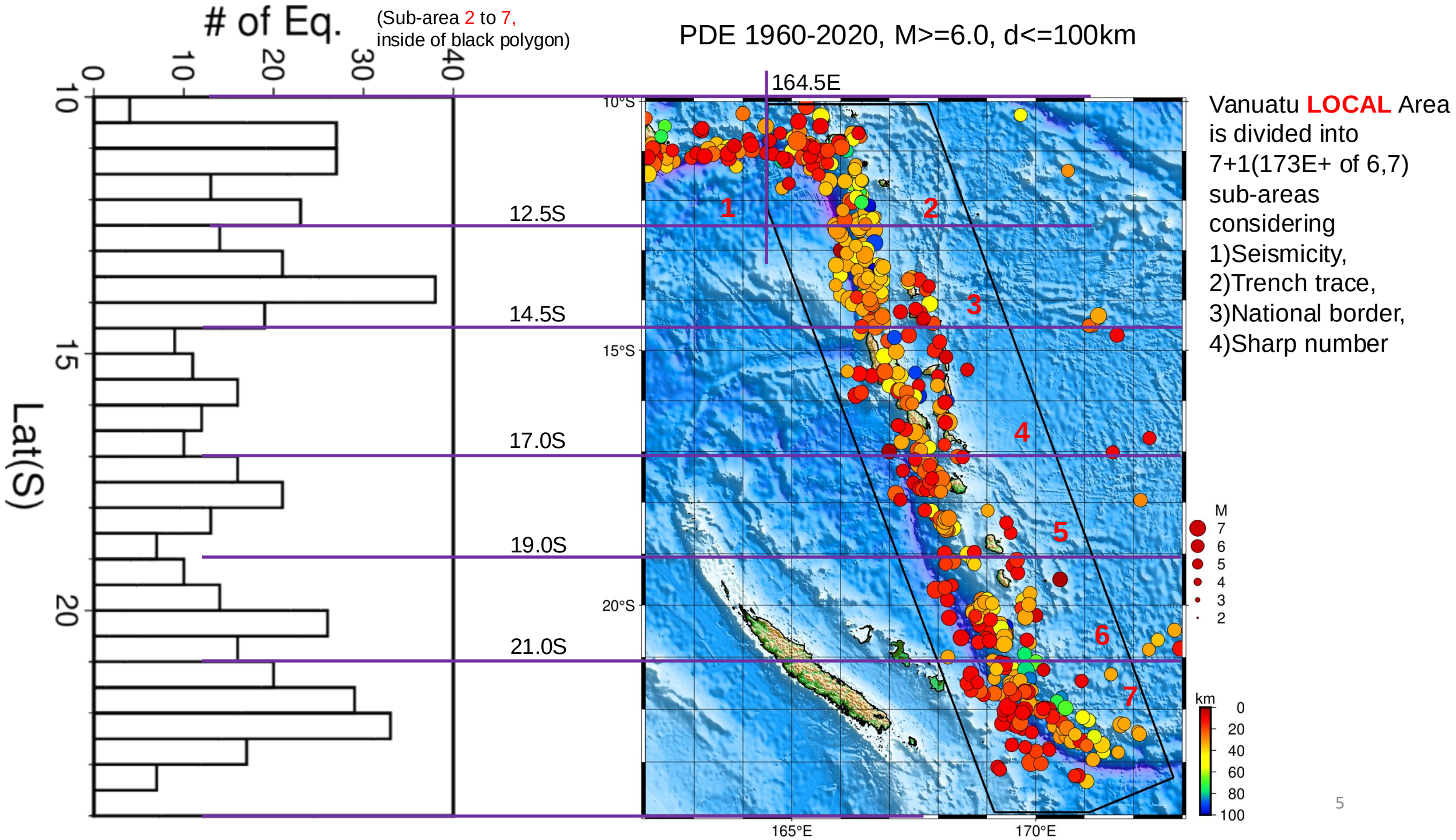
Magnitude >=6.5 is covered by PTWC's messages.
But, for Back Arc earthquakes with 6.2<=M<=6.4, **SeiscomP** hypocenter must be used.

For the determination of Advisory/Warning grade, tsunami amplitude estimation is necessary.

How to estimate tsunami amplitude?

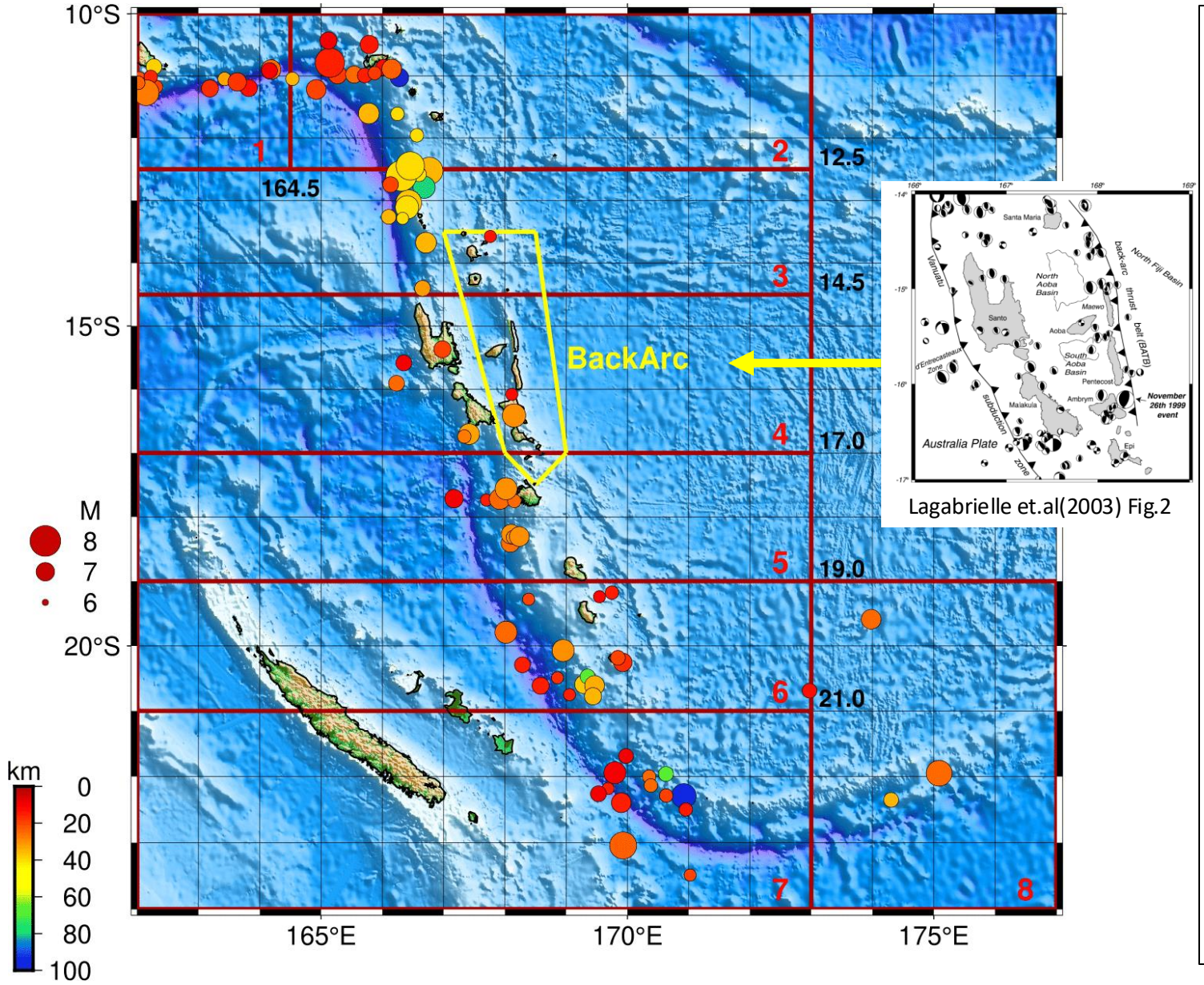
1) Using empirical relation between magnitude and tsunami amplitude record of the past events.
→"Tsunami Catalog" for LOCAL events

2) Using tsunami propagation numerical simulation (as in JMA)
→Quantitative tsunami amplitude estimation provided from PTWC for Outside of LOCAL events.



Vanuatu **LOCAL** Area is divided into 7+1(173E+ of 6,7) sub-areas considering
1)Seismicity,
2)Trench trace,
3)National border,
4)Sharp number

ISCGEM, 1904-2015, M>=6.5, d<=100km



Lagabrielle et.al(2003) Fig.2

2

Transition zone from South Solomon Trench to New Hebrides Trench.
In 2013, four Mw>=7 earthquakes including Mw7.9 occurred in 14 hours.

3

In 1980, 1997, Mw7.7, 7.7 occurred.
In 2009 Mw 7.6,7.8,7.4 earthquakes occurred in 1 hour. Very deep(d>600km) seismic activity can be seen in this sub-area.
Many of Mw>=7.7 earthquakes occur in sub-area 2 and 3

4

D'Entrecasteaux Ridge is colliding, and trench trace is unclear. Seismicity is low, and relatively high in the Back Arc area.

5

In the west and south of Efate Isl., clusters exist.

6

In the west of Tanna Isl., cluster exists.

7

Trench trace bends to the east.
In 1995 Mw7.8 occurred. Outer rise normal fault seismic activity is clear.

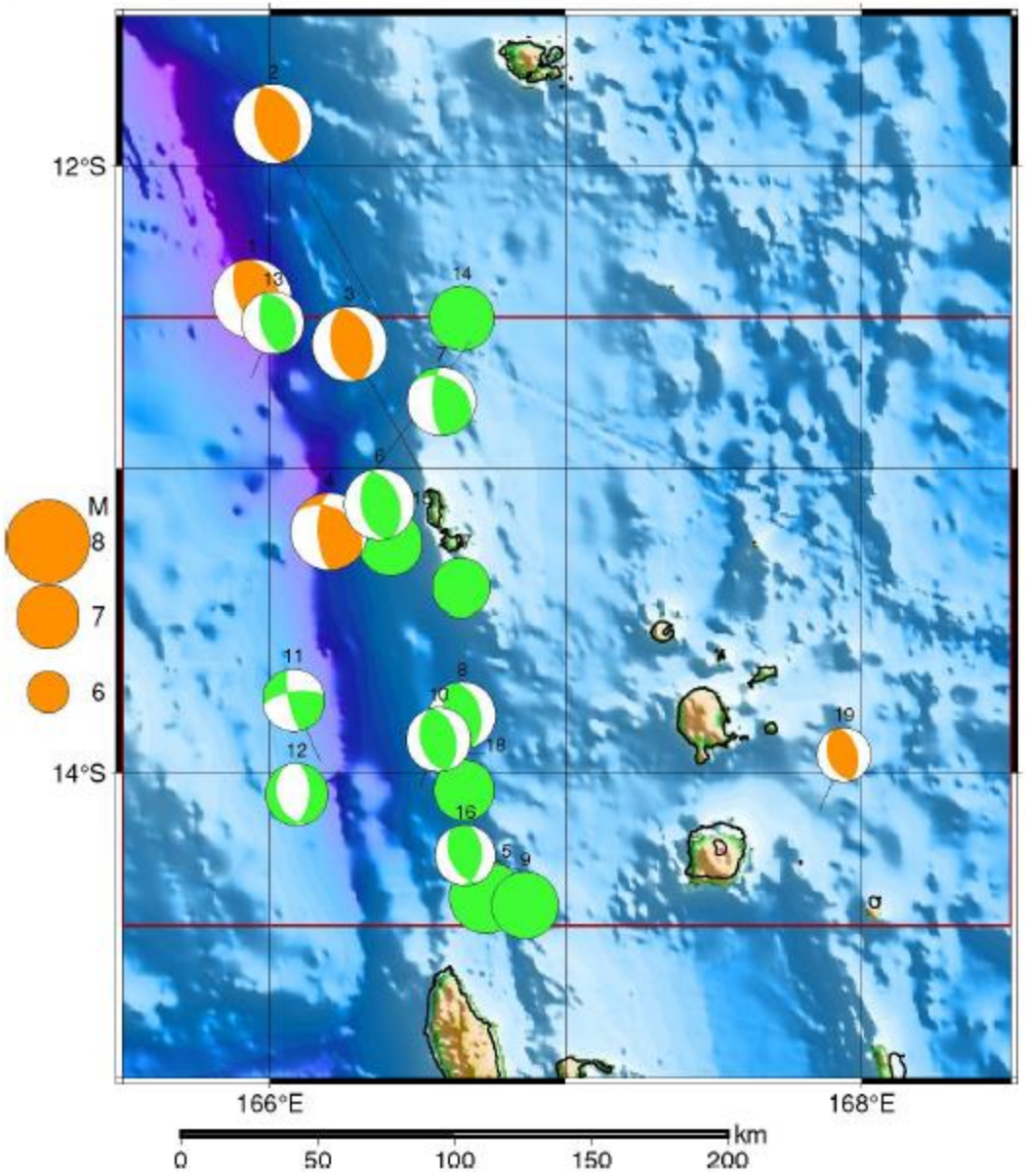
8

Seismicity is low, trench trace and subduction become unclear.

(Mw values are GCMT's)

Region 3: Torres to Banks Islands

[Location Map of Earthquakes in the Region] M≧7.0, Since 1970



Excerpt from Tsunami Catalog of Vanuatu : Region 3(1)

[Information of each Earthquake] M≧ 6.9 and with Tsunami, Since 1970

No.	Magnitude	Origin Time	Tsunami	Latitude	Longitude	Depth (km)
R3-1	7.9	1980-07-17 19:42Z	Yes	-12.53	165.92	33
R3-2	7.8	2009-10-07 22:18Z	Yes	-12.52	166.38	35
R3-3	7.7	2009-10-07 22:03Z	Yes	-13.01	166.51	45

R3-4	7.7	1997-04-21 12:02Z	Yes	-12.58	166.68	33
R3-5	7.5	1973-12-28 13:41Z		-14.46	166.60	26
R3-6	7.4	2009-10-07 23:13Z		-13.09	166.50	31
R3-7	7.3	1999-02-06 21:47Z		-12.85	166.70	90
R3-8	7.2	2010-05-27 17:14Z		-13.70	166.64	31
R3-9	7.2	1974-01-10 08:51Z		-14.43	166.86	34
R3-10	7.1	1985-12-21 01:13Z		-13.97	166.52	43
R3-11	7.0	1985-11-28 03:49Z		-13.99	166.19	33
R3-12	7.0	1985-11-28 02:25Z		-14.04	166.24	33
R3-13	7.0	1982-08-05 20:32Z		-12.60	165.93	31
R3-14	7.0	1975-10-06 22:24Z		-12.52	166.50	54
R3-15	7.0	1972-01-23 21:17Z		-13.25	166.407	35
R3-16	6.9	2016-04-03 08:23Z		-14.32	166.86	26
R3-17	6.9	1981-04-24 21:50Z		-13.43	166.42	33
R3-18	6.9	1970-08-11 10:22Z		-14.06	166.66	45
R3-19	6.6	1987-07-06 02:49Z	Yes	-14.07	167.83	48

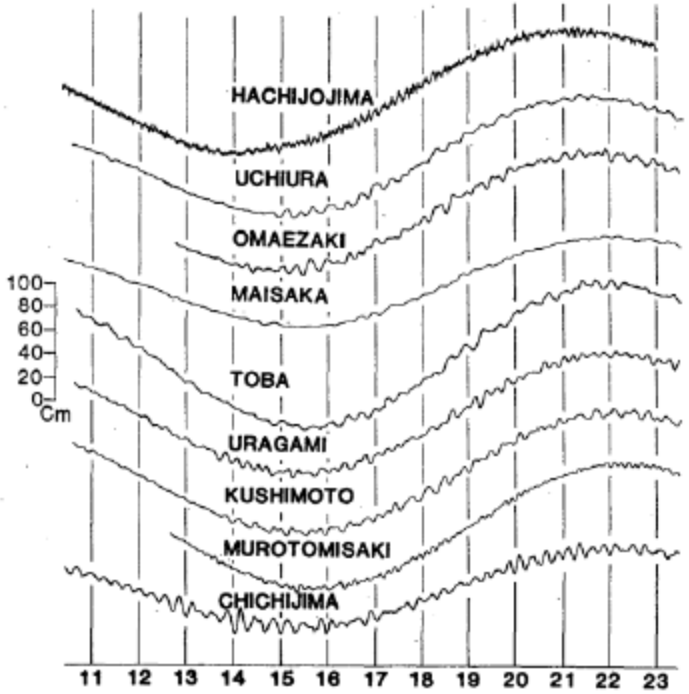
Excerpt from Tsunami Catalog of Vanuatu : Region 3(2)

[Details of Earthquake caused Tsunami]

R3

No.	M	Date & Time	Location	Depth	Situation (Tsunami and Casualties)
R3-1	7.9	1980-07-17 19:42Z	12.5 S 165.9 E	33 km	**Possible Significant Local Tsunami** Very small Tsunami was recorded at Hawaii and Japan.

M: 7.9 earthquake near the Santa Cruz Islands could generated a tsunami; but no local information is available. A weak tsunami was registered on the coast of Hawaii and Japan; around 10 cm.



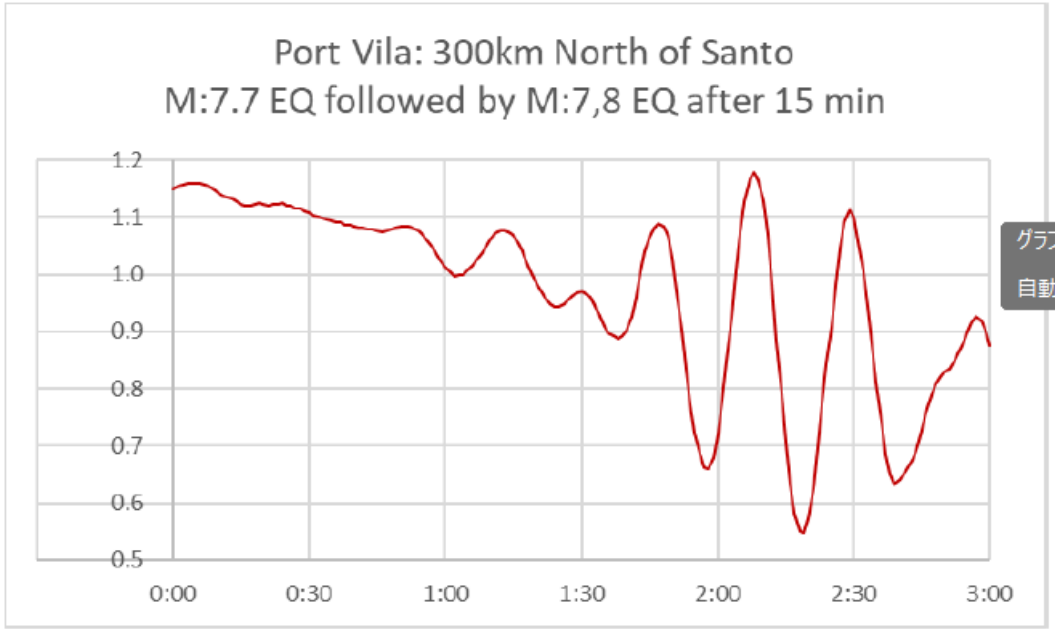
Source: JMA, 1987

No.	M	Date & Time	Location	Depth	Situation (Tsunami and Casualties)
R3-2	7.8	2009-10-07 22:18Z	12.5 S 166.4 E	35 km	196 km NW of Sola, Vanuatu Tsunami is generated by the Uplift of Torres Island
R3-3	7.7	2009-10-07 22:03Z	13.0 S 166.5 E	45 km	148 km NW of Sola, Vanuatu Tsunami is generated by the Uplift of Torres Island

[Twin Tsunami]

M 7.7 Earthquake took place at first, and followed by M: 7.8 earthquake after 15 minutes.

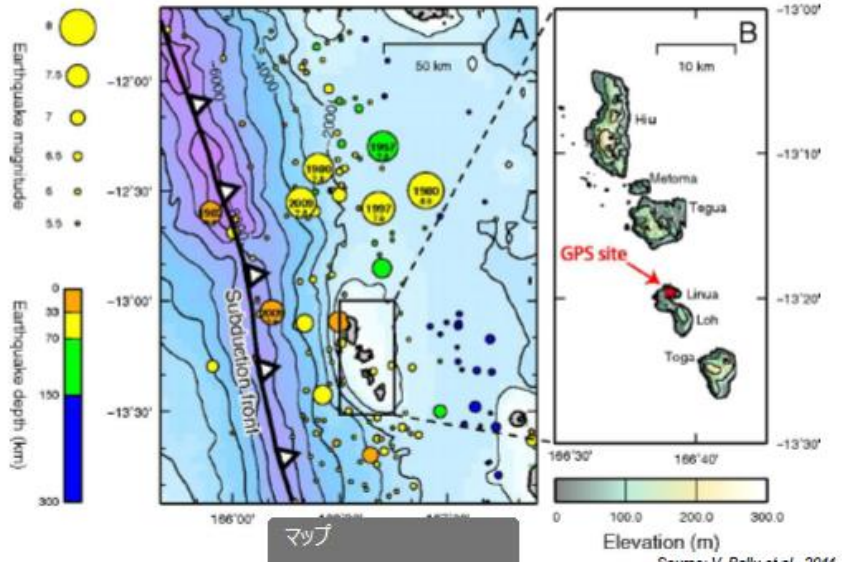
The created tsunami was recorded on tide gauges around the Pacific.
Port Vila: 30.5 cm
Honiala, Solomon; 6.5 cm
Pago Pago, American Samoa; 7.0 cm
Hilo, Hawaii; 7.4 cm
Santa Barbara, California; 15.1 cm
Caldera, Chile; 7.0 cm



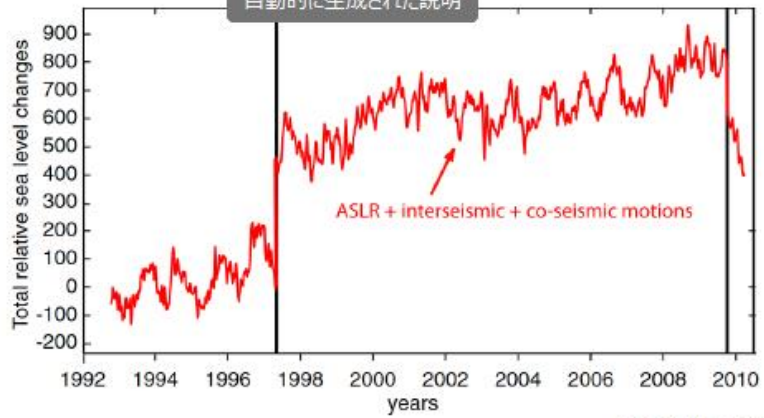
Excerpt from Tsunami Catalog of Vanuatu : Region 3(3)

No.	M	Date & Time	Location	Depth	Situation (Tsunami and Casualties)
R3-4	7.7	1997-04-21 12:02Z	12.6 S 166.7 E	33 km	171 km NNW of Sola, Vanuatu 3 meters Tsunami **Generated by the subsidence of Torres Island**

R3



Source: V. Ballu et al., 2011



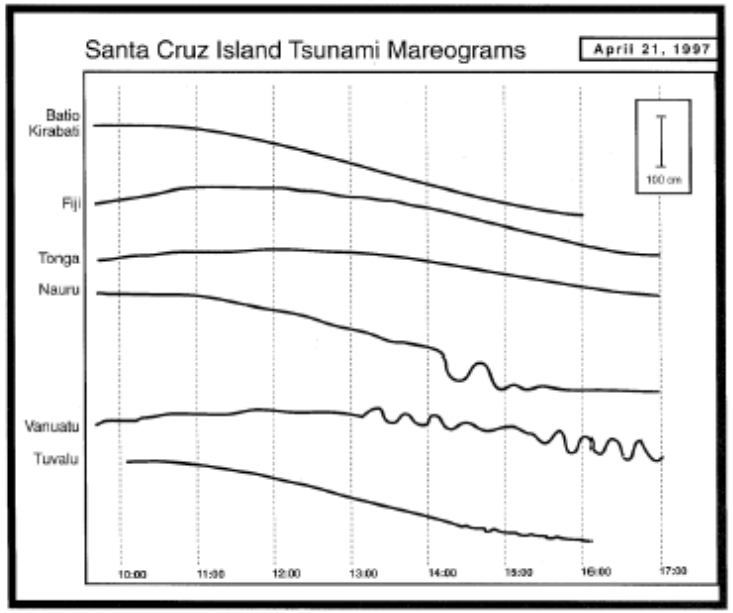
Source: V. Ballu et al., 2011

- Local tsunami generated with wave heights up to 3 meters along the coasts of the Solomon and Vanuatu Islands, causing damage to some houses. (NCEI)
- This earthquake caused significant coastal subsidence of the Torres Islands and was accompanied by a local tsunami.
- The tsunami and further inland inundation due to the subsidence of the islands led to the relocation of a settlement on Tegua Island further inland few years after. (Vanuatu National Report 2015)

Tsunami Catalog 2023

R3

- The earthquake was followed by a tsunami recorded on a few regional gages with heights of one meter or less. It washed away seven houses and destroyed three others. There were no injuries or fatalities reported.
- The tsunami inundated about 7 to 15 meters destroying some concrete buildings. The tower of the automatic weather station at Linua (Vanuatu) was bent by the waves and was left standing at angle. Many fish were washed ashore. (NCEI)
- A magnitude 7.9 Ms (7.7 Mw) caused significant damage to the islands of **Hiu, Tegua, and Lo, Torre Islands and Ureparapara in the Bank islands** of Vanuatu.
- It was recorded with a height of 10 cm at Chichijima, Japan. Funafuti and Suva, Fiji recorded less than 10 cm; Vanuatu Islands recorded less than 20 cm. UNDP/UNDHA, 1997; Lyman,1997.
- On April 21, 1997 a magnitude 7.7 earthquake in northern Vanuatu caused significant coastal subsidence of the Torres Islands and was accompanied by a local tsunami. The tsunami and further inland inundation due to the subsidence of the islands led to the relocation of a settlement on Tegua Island further inland few years after. During that time, the Vanuatu Meteorological Services (at that time) does not have the means to issue tsunami information, advisory or warning.



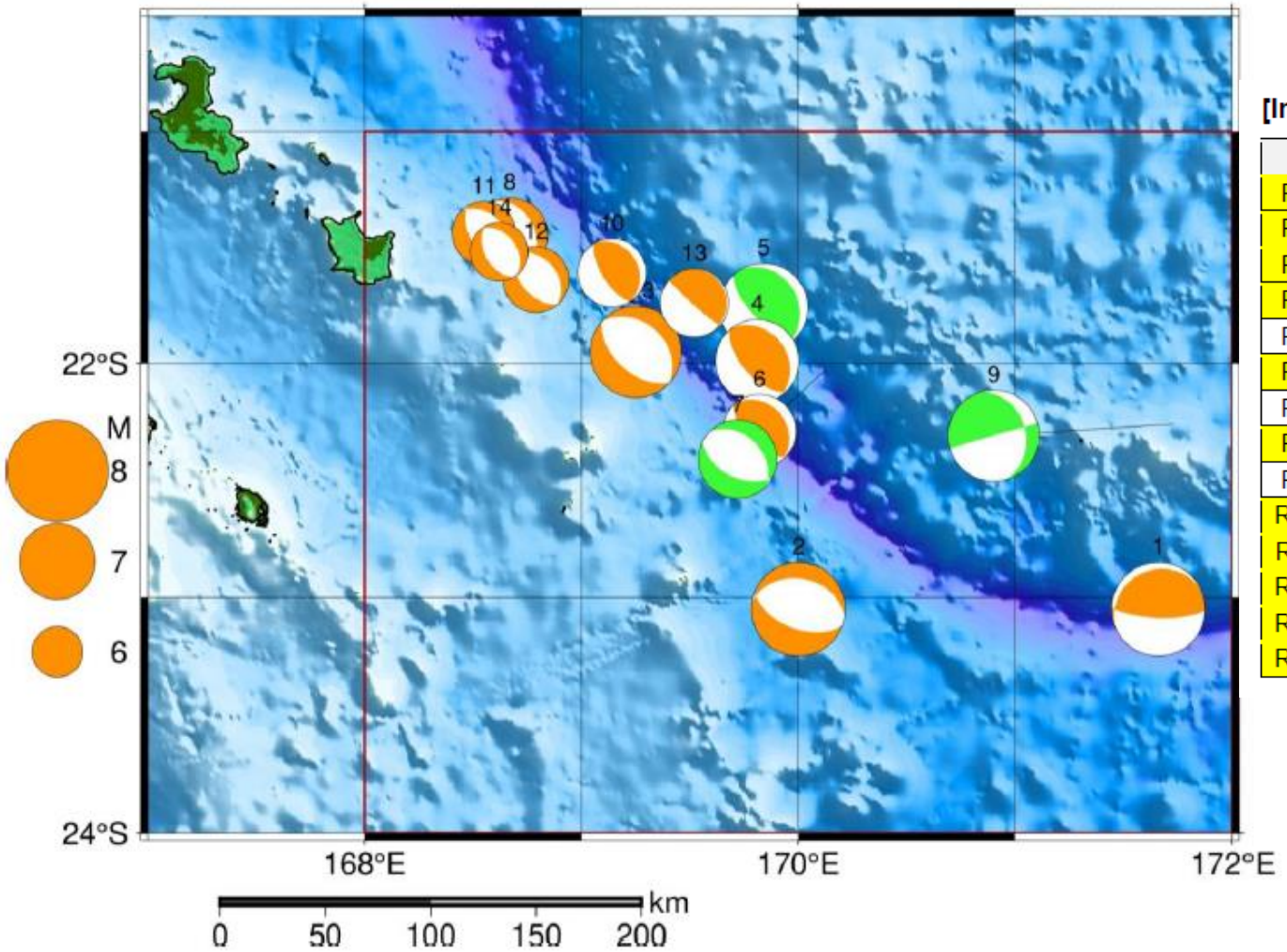
Source: UNESCO/IOC/ITIC, 1997

The Torres Islands frequently experience earthquakes and tsunamis that threaten (mainly) coastal settlement. For example, subsidence following an earthquake in 1997 caused an entire coastal coconut plantation on the nearby island of Loh to become submerged in seawater. Another earthquake in 2003–04 uplifted the area again.

Excerpt from Tsunami Catalog of Vanuatu : Region 7(1)

Region 7: Southeast of Loyalty

[Location Map of Earthquakes in the Region] M≧6.9, Since 1970



[Information of each Earthquake] M≧7.0 and with Tsunami, Since 1970

No.	Magnitude	Origin Time	Tsunami	Latitude	Longitude	Depth (km)
R7-1	7.7	2021-02-10 13:19Z	Yes	-23.05	171.66	10
R7-2	7.7	1995-05-16 20:12Z	Yes	-23.01	169.90	20
R7-3	7.5	2018-12-05 04:18Z	Yes	-21.95	169.43	10
R7-4	7.3	2003-12-27 16:00Z	Yes	-22.02	169.77	10
R7-5	7.2	1980-10-25 11:00Z		-21.89	169.85	33
R7-6	7.1	2018-08-29 03:51Z	Yes	-22.03	170.13	21
R7-7	7.1	2004-01-03 16:23Z		-22.25	169.68	22
R7-8	7.0	2017-11-19 22:43Z	Yes	-21.32	168.67	10
R7-9	7.0	1981-07-06 03:08Z		-22.29	171.74	33
R7-10	6.7	2017-10-31 00:42Z	Yes	-21.70	169.15	24
R7-11	6.6	2017-11-19 15:09Z	Yes	-21.50	168.60	13
R7-12	6.6	2017-11-01 01:23Z	Yes	-21.65	168.86	22
R7-13	6.5	2018-10-16 01:03Z	Yes	-21.74	169.52	17
R7-14	6.3	2017-11-19 09:25Z	Yes	-21.64	168.67	14

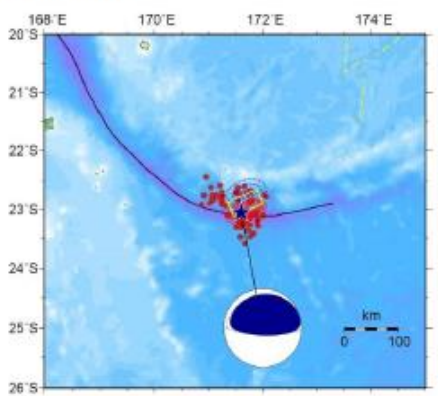
Excerpt from Tsunami Catalog of Vanuatu : Region 7(2)

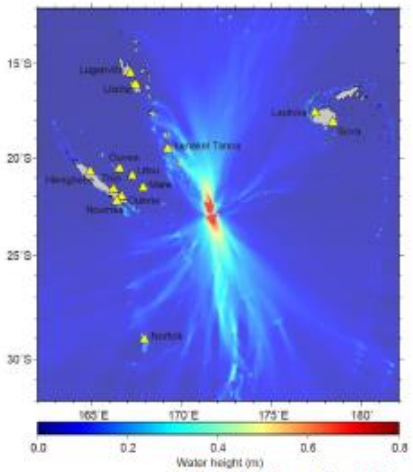
[Details of Earthquake caused Tsunami]

R7

No.	M	Date & Time	Location	Depth	Situation (Tsunami and Casualties)
R7-1	7.7	2021-02-10 13:19Z	23.1 S 171.7 E	10 km	Southeast of the Loyalty Islands 1.5 m Tsunami at Pango, Efate Moderate Tsunami at N.C.

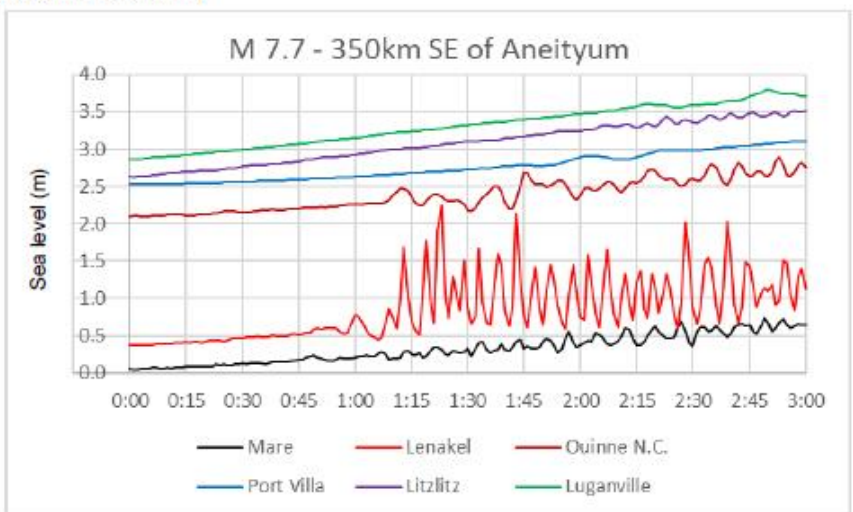
[Earthquake]





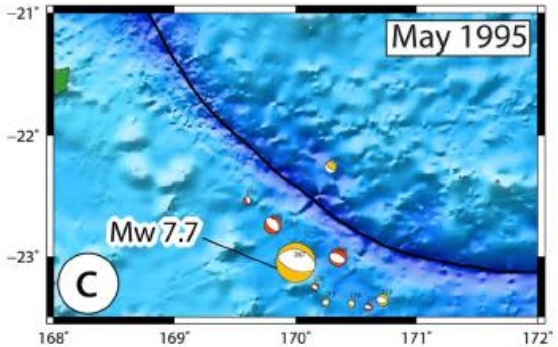
Source: BRI Japan, Recent Tsunamis

[Tsunami Waveform]



R7

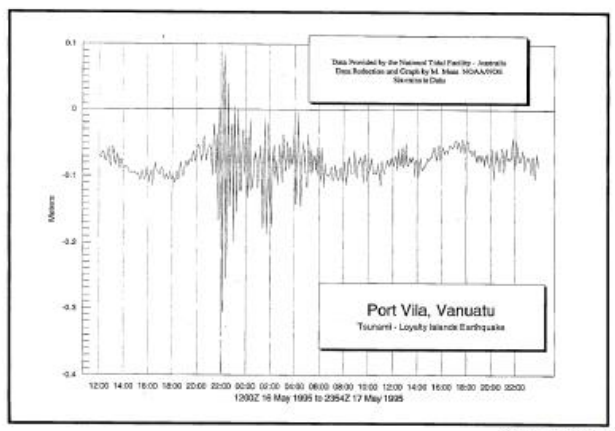
No.	M	Date & Time	Location	Depth	Situation (Tsunami and Casualties)
R7-2	7.7	1995-05-16 20:12Z	23. 0 S 169.9 E	20 km	249 km E of Vao, New Caledonia **Tsunami**



Source: J. Roger et al., 2018

- 50 cm at Mare
- unusually high sea levels are reported in Aneytum Island
- The base of bungalows of Erakor islet and the restaurant at Pango road were reached by the sea. The amplitude is estimated to be 1.5 m. (Lardy, 1995)
- Tsunami with heights of 40 cm at Port-Vila, Vanuatu, 10 cm at Pago-Pago, American Samoa; 6 cm at Lautoka, Viti Levu, Fiji; and 5 cm at Suva, Fiji; 3 cm at Apia, Western Samoa; 3 cm at Nuku'alofa, Tonga; 5 cm at Rarotonga, Cook Islands; and along the coast of New South Wales. PDE.

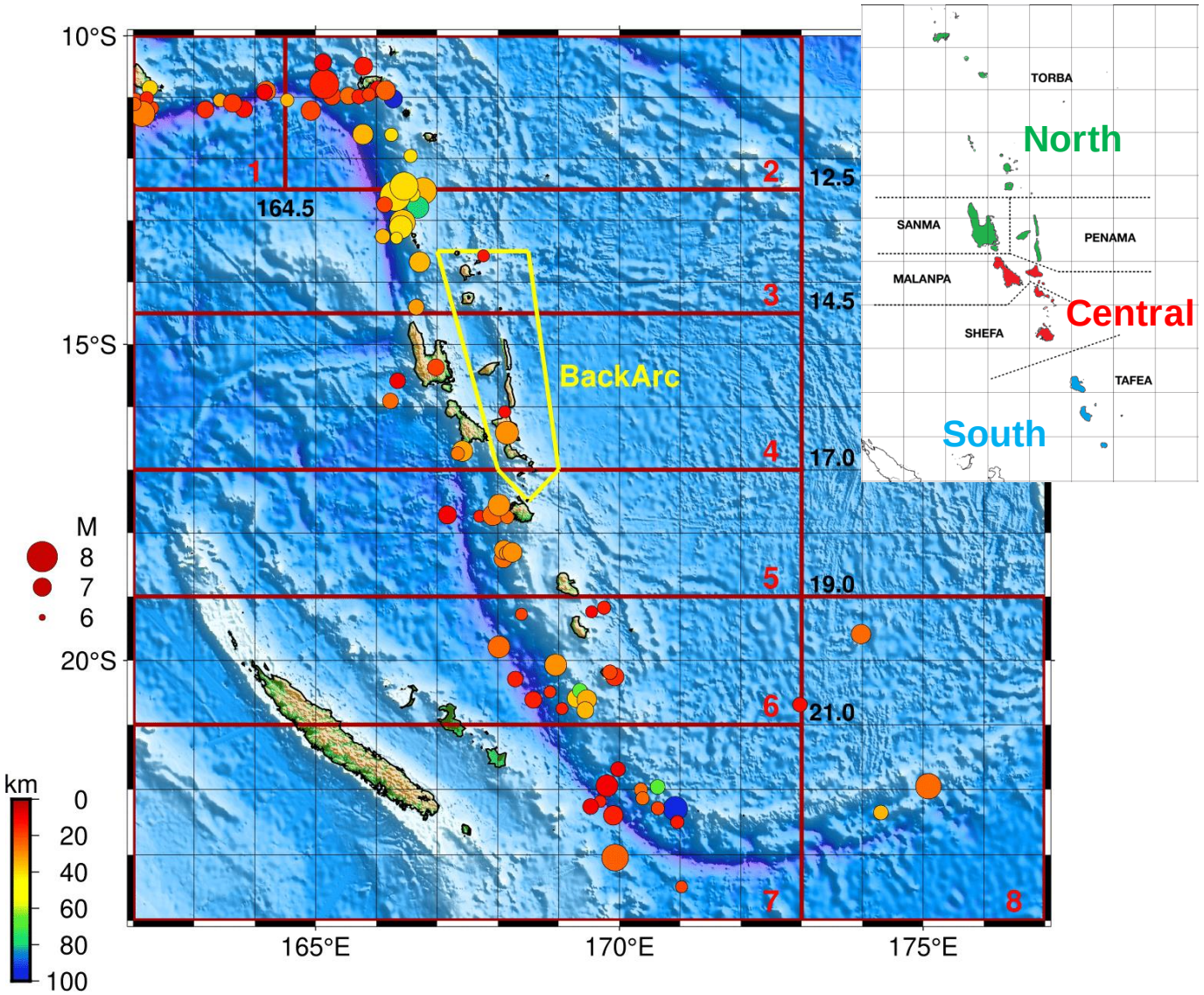
In Vanuatu, 1 hr 30 later, between 8:30 am and 9 am, unusually high sea levels are reported in Aneytum Island and Port Vila in Efate. The base of bungalows of Erakor islet and the restaurant at Pango road were reached by the sea. The amplitude is estimated to be 1.5 m. At the entry of the First Lagoon, witnesses notice that the ocean is agitated and stays at a high level during a 10 to 15 min period.



Source: UNESCO/IOC/ITIC, 1997

Sub-Regions and BackArc in Local Vanuatu

(ISCGEM(1904-2015) M>=6.5, d<100km)



M+0.3 for BackArc earthquakes (6.2 to 6.4 : larger of mB or Mw(mB))

Tsunami Advisory/Warning Criteria for Local Earthquakes in Vanuatu

Even if the epicenter is located on land, the same criteria must be applied because of 1)possible epicenter determination error, and 2) finite fault size of large earthquake (M7 earthquake's fault size is about 30km).

Region 1(West off Lata Island, Solomon)
8.0<=M : Warning for ALL Vanuatu
7.0<=M<=7.9 : Advisory for ALL Vanuatu
6.9>=M : (No threat of tsunami)

Region 2(Near Lata Island, Solomon)
7.5<=M : Warning for ALL Vanuatu
7.0<=M<=7.4 : Warning for North and Central Vanuatu, Advisory for South Vanuatu
6.5<=M<=6.9 : Advisory for North Vanuatu

Region 3(Torres to Banks Islands)
7.0<=M : Warning for ALL Vanuatu
6.5<=M<=6.9 : Advisory for North and central Vanuatu

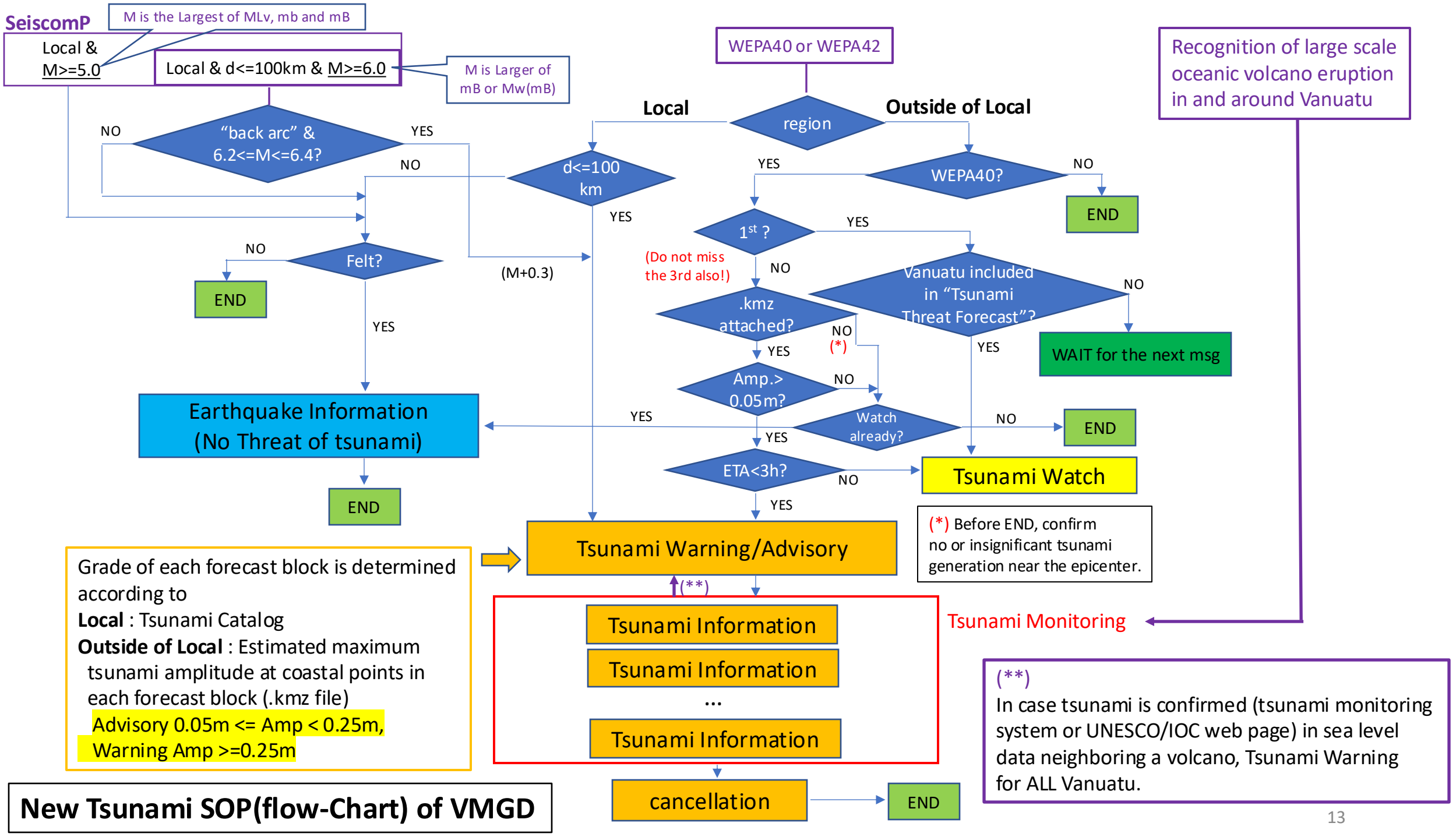
Region 4(Espiritu santo to Shepherd Islands)
7.0<=M : Warning for ALL Vanuatu
6.5<=M<=6.9 : Advisory for ALL Vanuatu

Region 5(Efate to Erromango)
7.0<=M : Warning for ALL Vanuatu
6.5<=M<=6.9 : Advisory for Central and South Vanuatu

Region 6(Tanna and Aneityum)
7.0<=M : Warning for ALL Vanuatu
6.5<=M<=6.9 : Advisory for Central and South Vanuatu

Region 7(SE of Loyalty Islands)
7.0<=M : Warning for ALL Vanuatu
6.5<=M<=6.9 : Advisory for South Vanuatu

Region 8(Far East of Loyalty Islands)
7.0<=M : Warning for ALL Vanuatu
6.5<=M<=6.9 : Advisory for South Vanuatu



New Tsunami SOP(flow-Chart) of VMGD

In case of large scale eruption of oceanic volcano

How to recognize it?

1) Volcanoes in Vanuatu
- Detection by duty personnel of VMGD
  (Camera, Geostationary Satellite Imagery)
  → Volcanic Bulletin (VAL=4 or 5)
- Reports from Local Authority

2) Volcanos outside of Vanuatu
- VAA(Wellington)
- Detection by duty personnel of VMGD
  (Geostationary Satellite Imagery)

Tsunami Monitoring

Identify the location of the volcano and eruption time.

Run **TTT** to get tsunami travel time chart for an area including the volcano and whole Vanuatu.
Start monitoring of the sea level data around the volcano, with ETA overlaid on the trace.

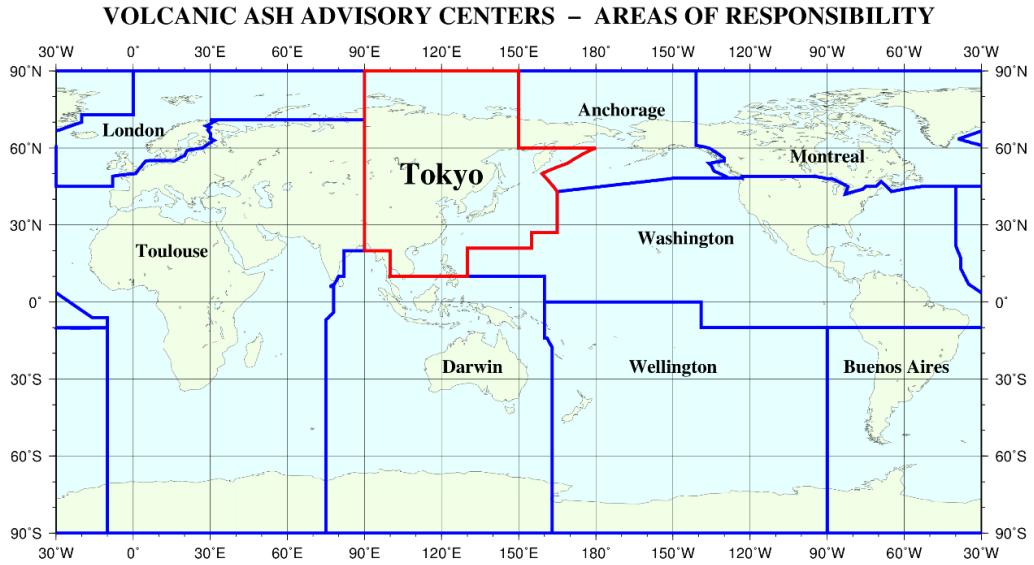
1) Volcanoes in Vanuatu
If tsunami trace is confirmed at either of the sea level stations, or you get reliable tsunami report from local authority,
Warning to all 3 forecast blocks of Vanuatu.

2) Volcanos outside of Vanuatu
Find the sea level station(*) that can detect tsunami more than 3 hours before the earliest arrival time at coasts of Vanuatu.
If tsunami trace is confirmed even at the station(*),
Warning to all 3 forecast blocks of Vanuatu.

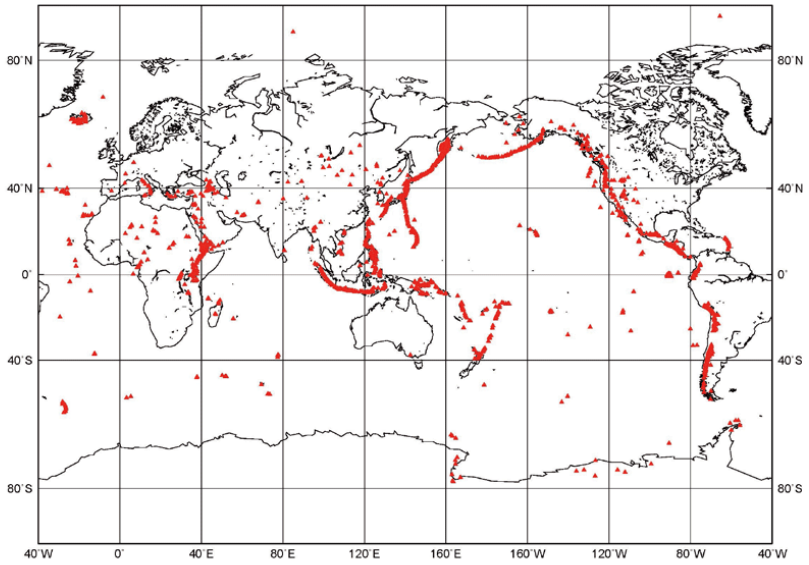
【Reference】

Area of responsibility of VAACs

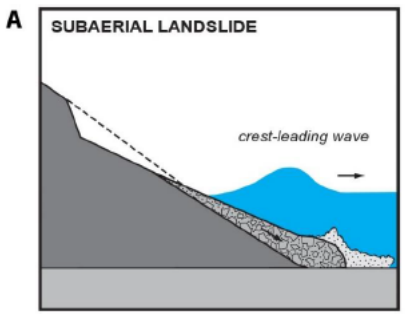
Source : Japan Meteorological Agency

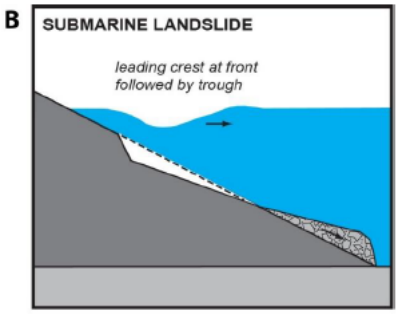


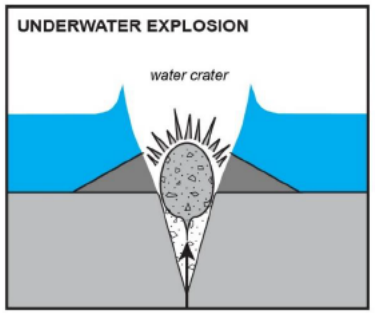
Distribution of Volcanos

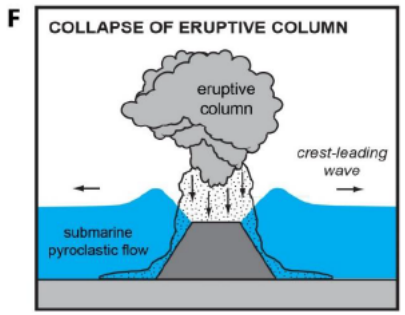


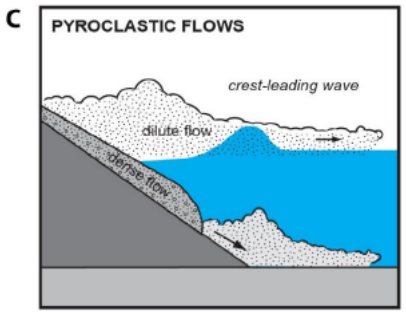
出典：気象庁資料

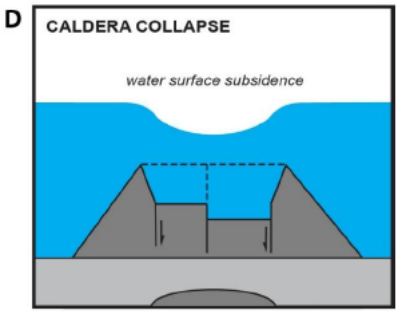


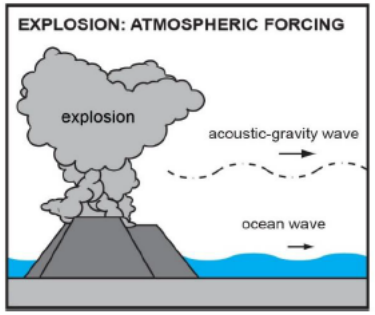


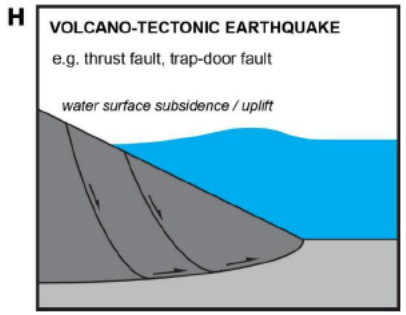












Tsunamis generated by Volcanic Activity and Instability

Source : PTWS

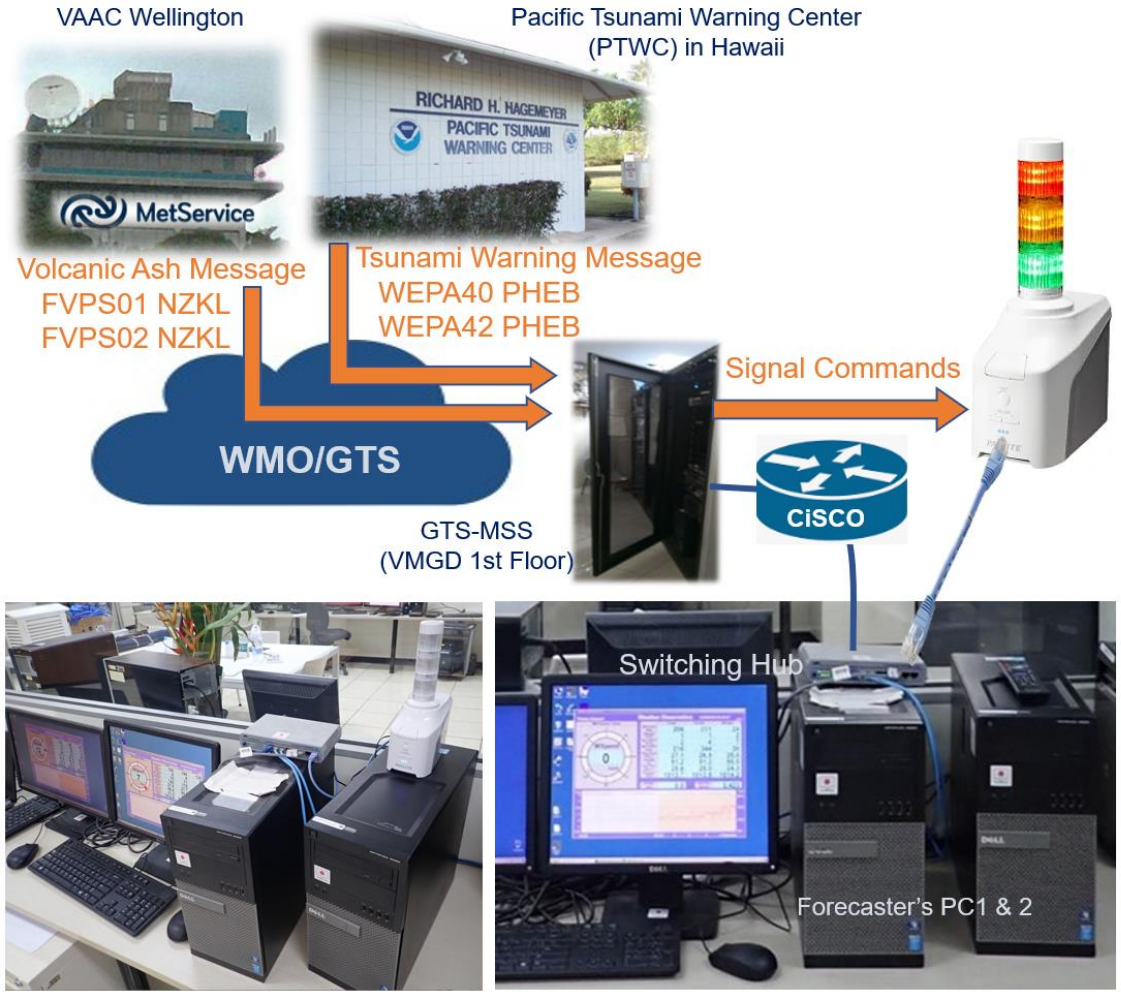
Example of VAA from wellington VAAC for Tongan volcano eruption in 2015.Jan.11

FVPS01 NZKL 112251
VA ADVISORY
DTG: 20150111/2251Z
VAAC: WELLINGTON
VOLCANO: HUNGA TONGA-HUNGA HAAPAI 243040 — Volcano name
PSN: S2034 W17522 — Volcano location
AREA: TONGA
SUMMIT ELEV: 149M
ADVISORY NR: 2015/23
INFO SOURCE: PILOT OBSERVATION.
AVIATION COLOUR CODE: UNKNOWN
ERUPTION DETAILS: OBS VA TO FL160 AT 11/2036Z — Eruption time or time when eruption was confirmed
OBS VA DTG: 11/2300Z
EST VA CLD: SFC/FL160 S2045 W17600 - S2045 W17330 - S2145 W17345 - S2115 W17600 - S2045 W17600 FL160/600
NO VA EXP
FCST VA CLD+6 HR: 12/0500Z SFC/FL160 S2030 W17600 - S2100 W17215 - S2215 W17230 - S2200 W17600 - S2030 W17600 FL160/600 NO VA EXP
(abbreviated)

Notification of incoming of international messages(PTWC, Wellington VAAC), and of large earthquakes occurrence in Vanuatu Local Area(SeiscomP)(right)

Alarm Signal Light to notify Tsunami Bulletin from PTWC and VAA from Wellington VAAC

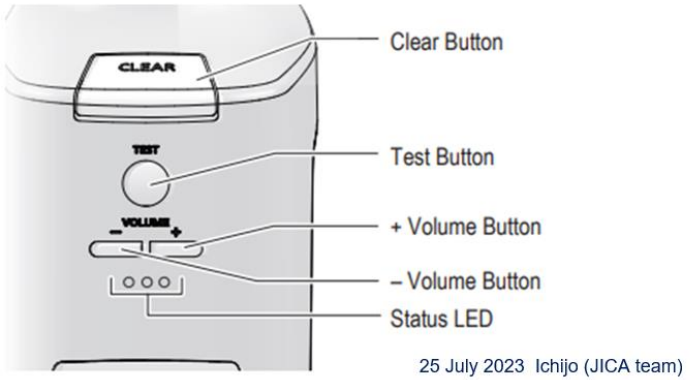
(Forecast Division Room, VMGD 2nd floor)



WEPA40 PHEB	WEPA42 PHEB	FVPS01/02 NZKL
Tsunami Threat Message issued by PTWC	Tsunami Information Statement issued by PTWC	Volcanic Ash Advisory issued by VAAC Wellington
Short tone sound	Long tone sound	Long tone sound
Red and Yellow LED Flashing	Red and Green LED Flashing	Yellow and Green LED Flashing



LED flashing and alarm sound continue until push the clear button



25 July 2023 Ichijo (JICA team)

M6<=

M5<=