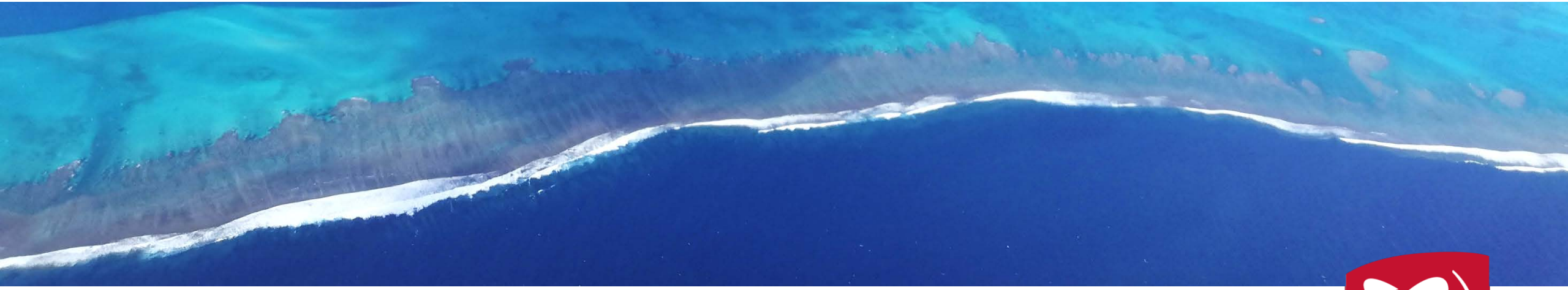
Tsunamigenic potential of the Vanuatu Subduction Zone



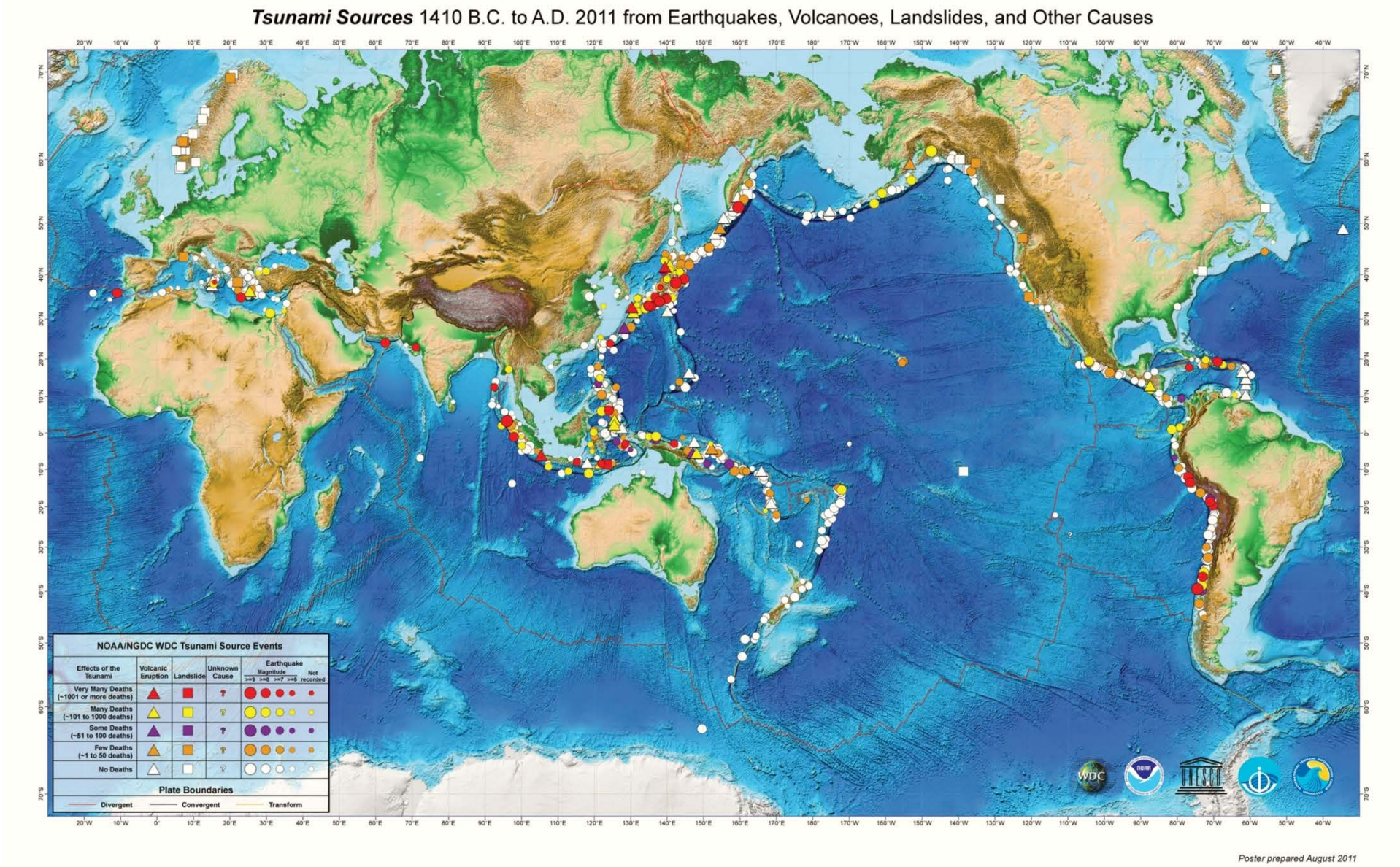
Dr Jean Roger, GNS Science, Lower Hutt, New Zealand

ICG/PTWS Scientific meeting
Port Vila, Vanuatu, 14-17 May 2024

Objectives

- Overview of the seismo-tectonic context of the VSZ
- Present the available knowledge in terms of historical tsunamis
- Discuss the tsunami potential of the VSZ
- Highlight the gaps of knowledge
- Discuss the future research

The Vanuatu Trench in the World



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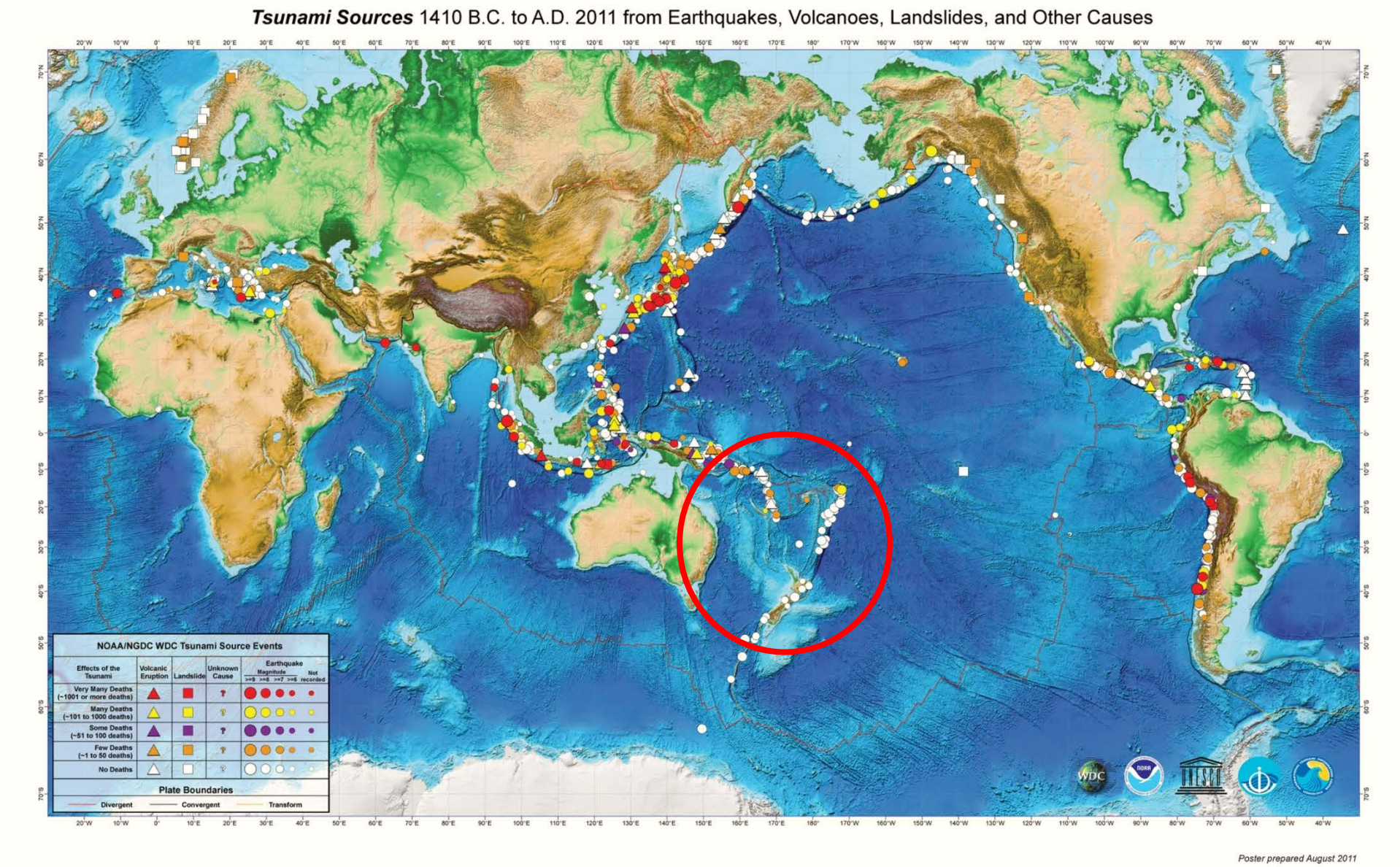
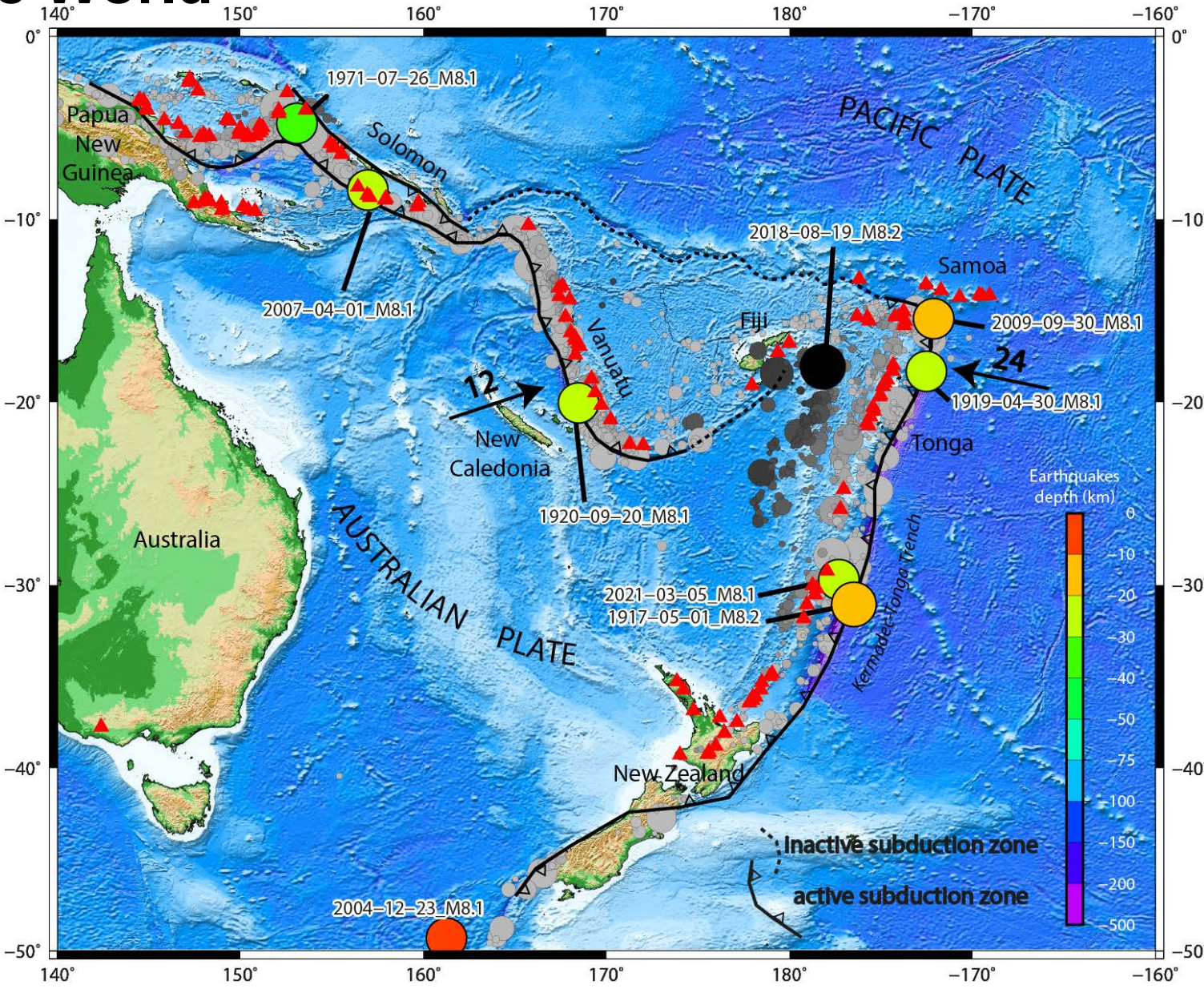


The Vanuatu Trench in the World

Earthquakes

- $M_w \geq 6.0$ since 1976 (grey circles) (Data: USGS)
- $M_w > 8.0$ since 1900 (large circles)



Credit: J. Roger

The Vanuatu Trench in the World

Earthquakes

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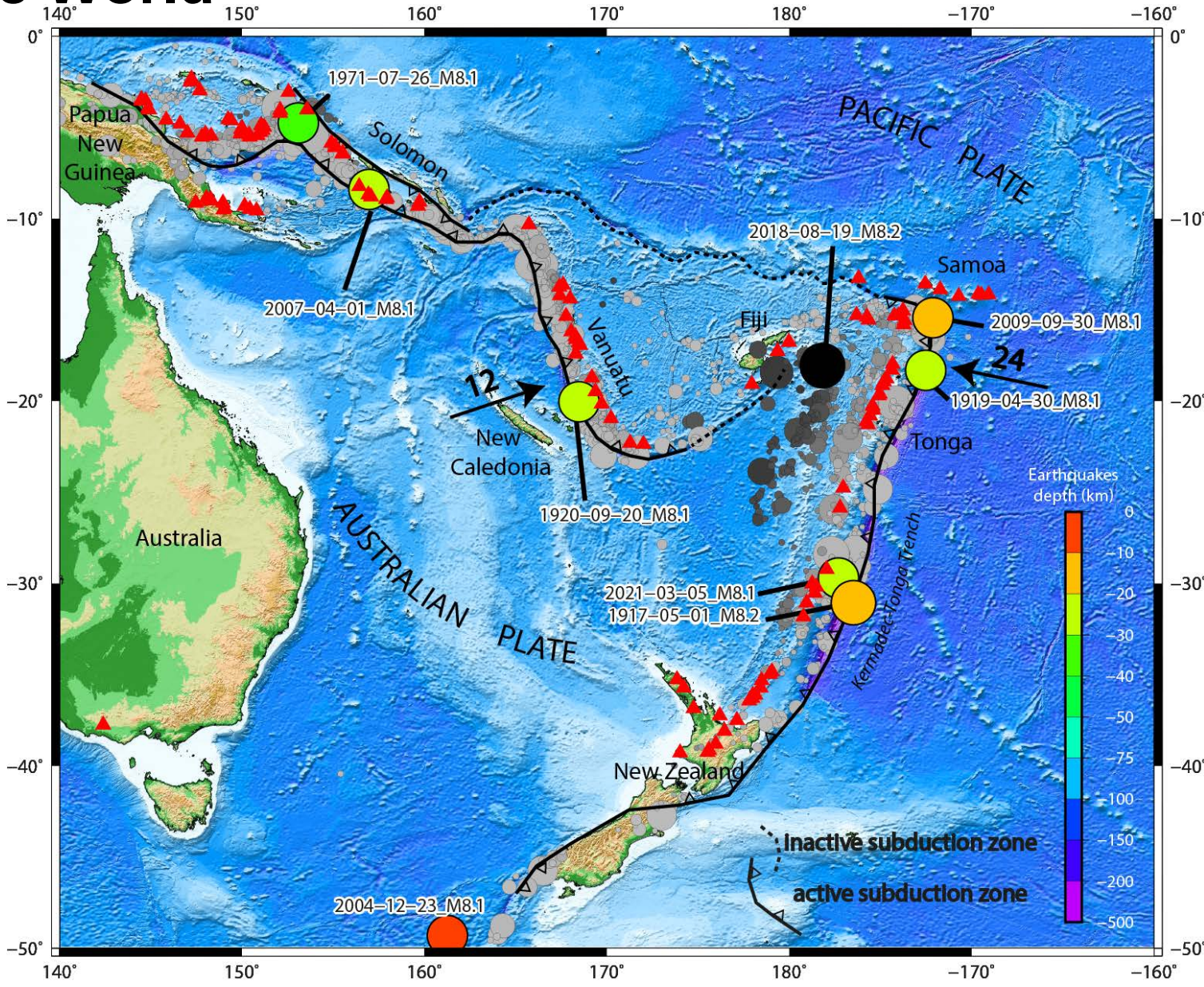
- $M_w > 8.0$ since 1900 (large circles)

Active volcanoes in red (Global Volcanism Program; https://volcano.si.edu)
→ Lots of active volcanoes (15 known in Vanuatu incl. 3 submarine edifices)



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The Vanuatu Trench in the World

Earthquakes

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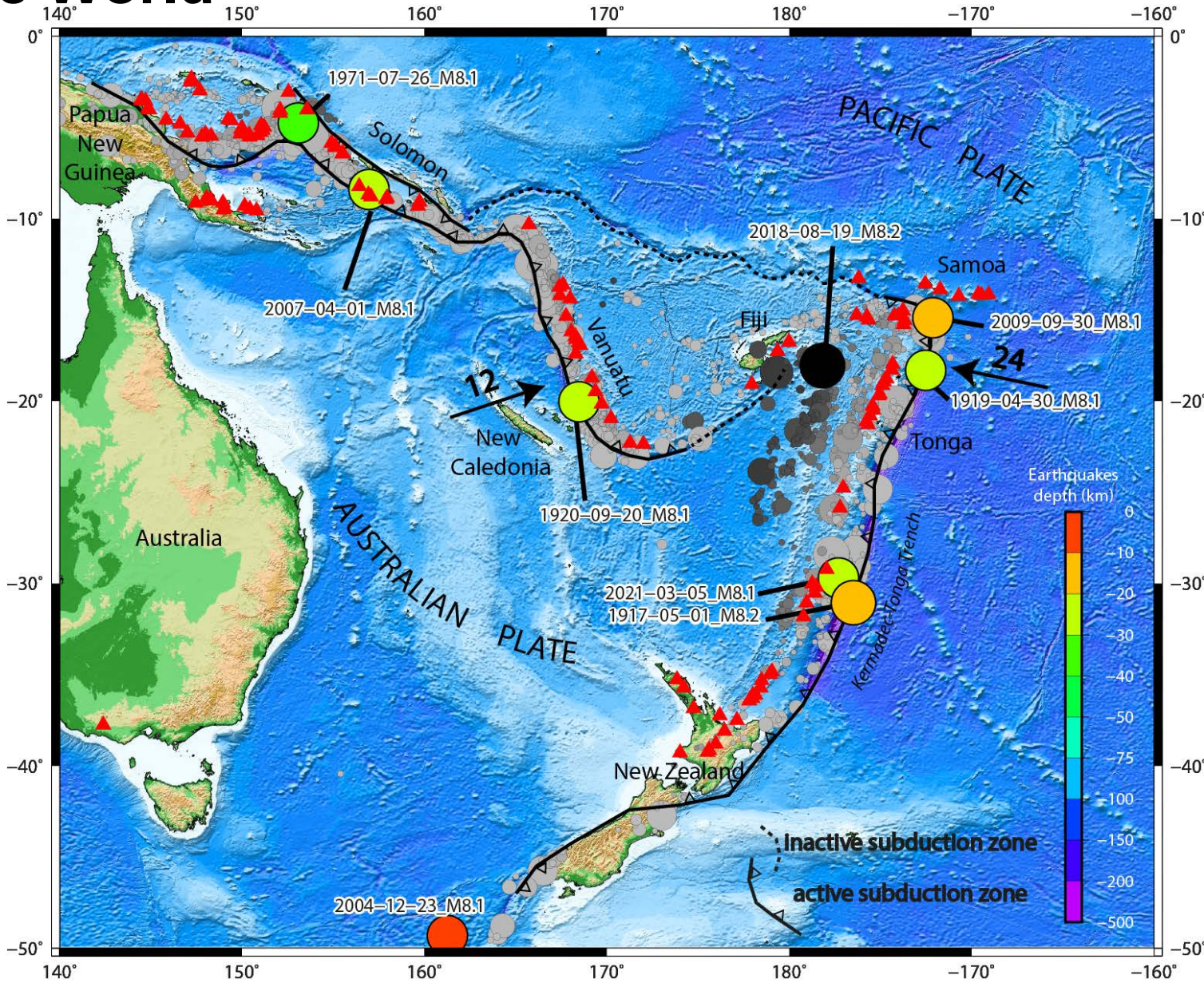
- $M_w > 8.0$ since 1900 (large circles)

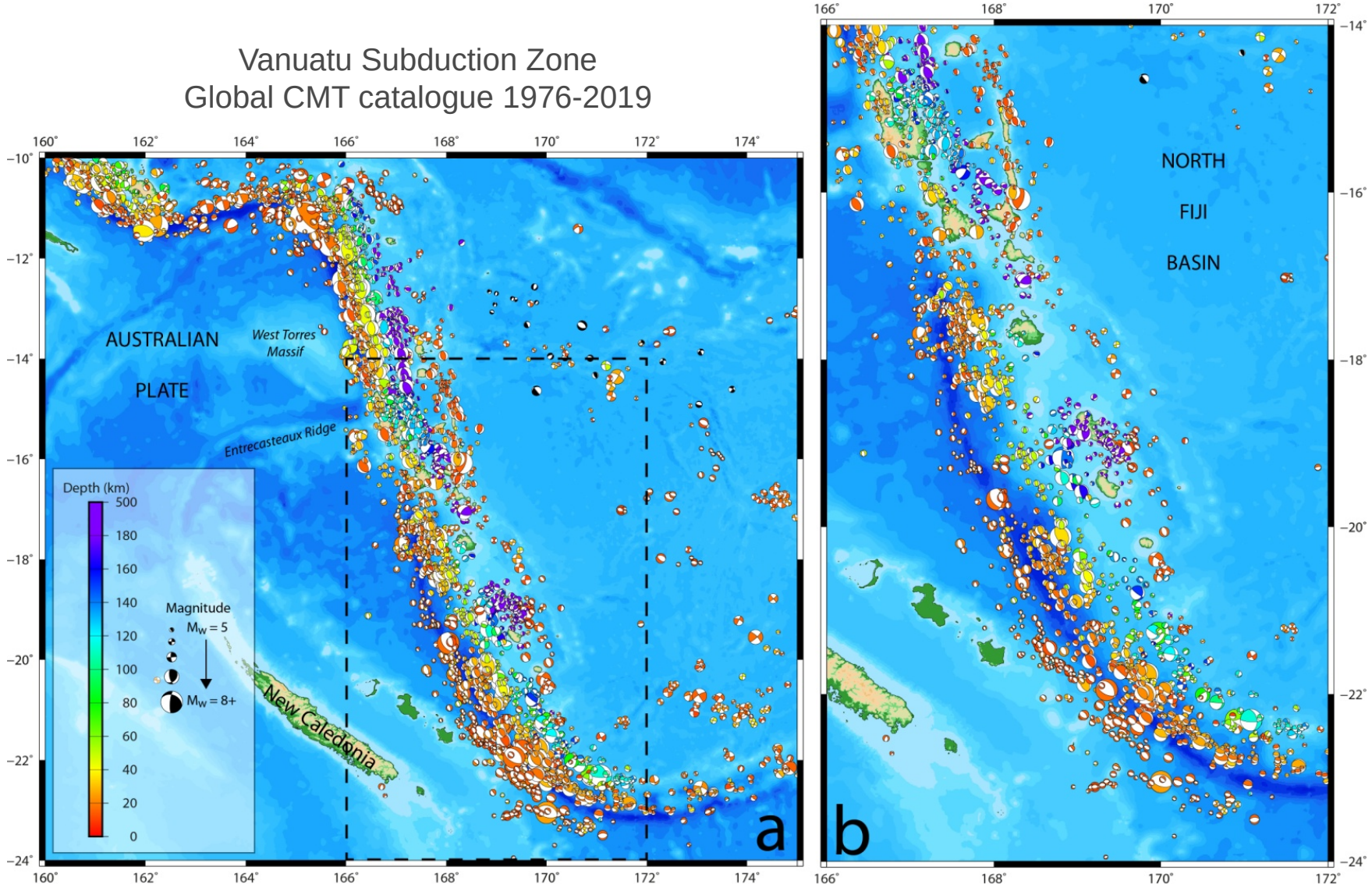
Active volcanoes in red (Global Volcanism Program; https://volcano.si.edu)

→ **Tectonically complex region**
→ **High rate plates convergence (up to 24cm/yr under Tonga block; Bevis et al., 1995)**
→ **¼ of world seismicity**
→ **10 Earthquakes of magnitude Mw ≥ 8.0 in ~100 years**

Credit: J. Roger



The Vanuatu Subduction Zone sismo-tectonic context

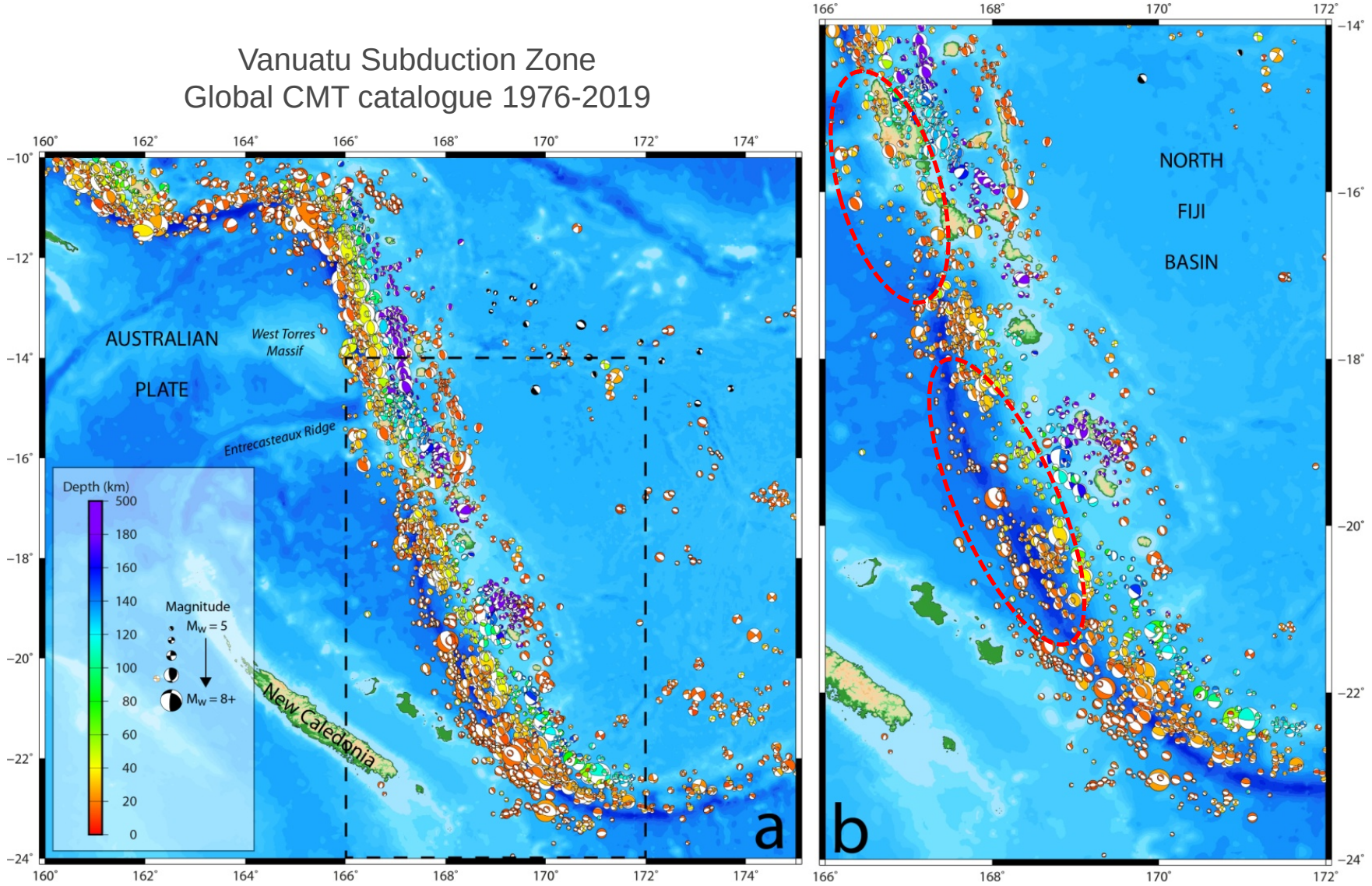


Roger et al., in prep.

The Vanuatu Subduction Zone sismo-tectonic context

2 seismic gaps

→North: from Baillard et al., JGR, 2015
→South: from Ioualalen et al., Tectonophysics, 2017



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The Vanuatu Subduction Zone sismo-tectonic context

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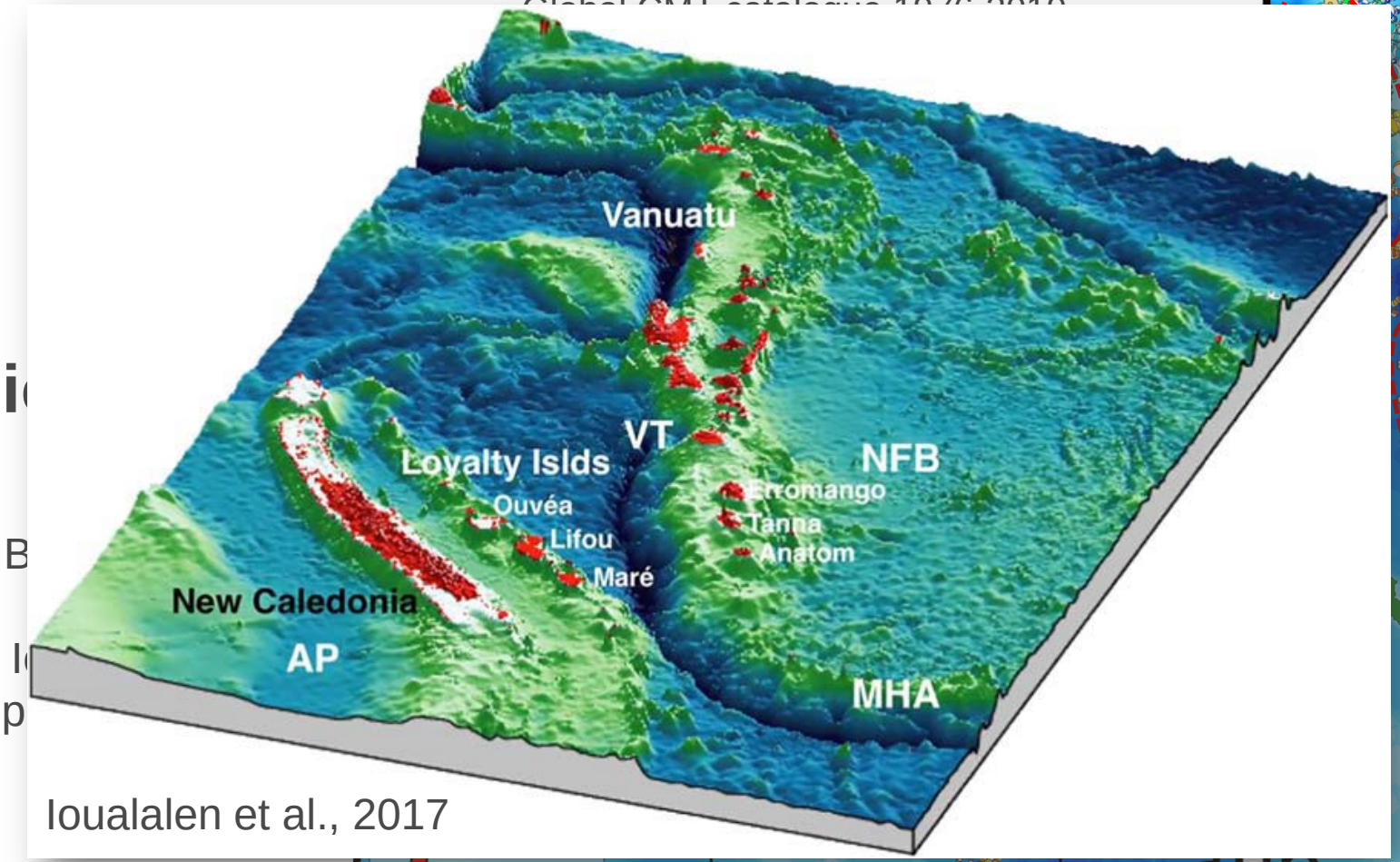
Vanuatu Subduction Zone



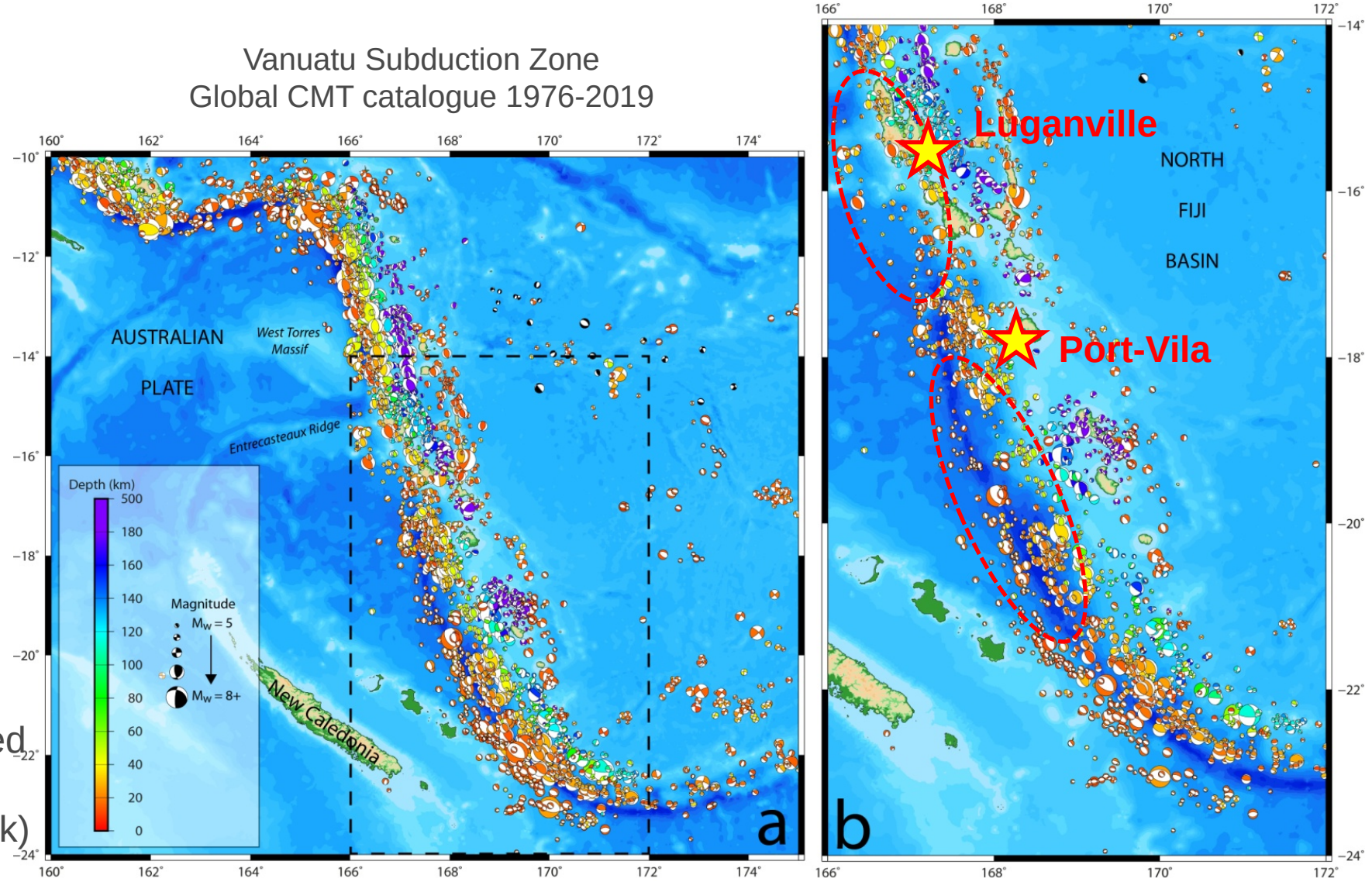
Ioualalen et al., 2017

Roger et al., in prep.

The Vanuatu Subduction Zone sismo-tectonic context

2 seismic gaps

→North: from Baillard et al., JGR, 2015
→South: from Ioualalen et al., Tectonophysics, 2017
→Near the two most populated towns of Vanuatu
(Port-Vila: 51k, Luganville: 16k)

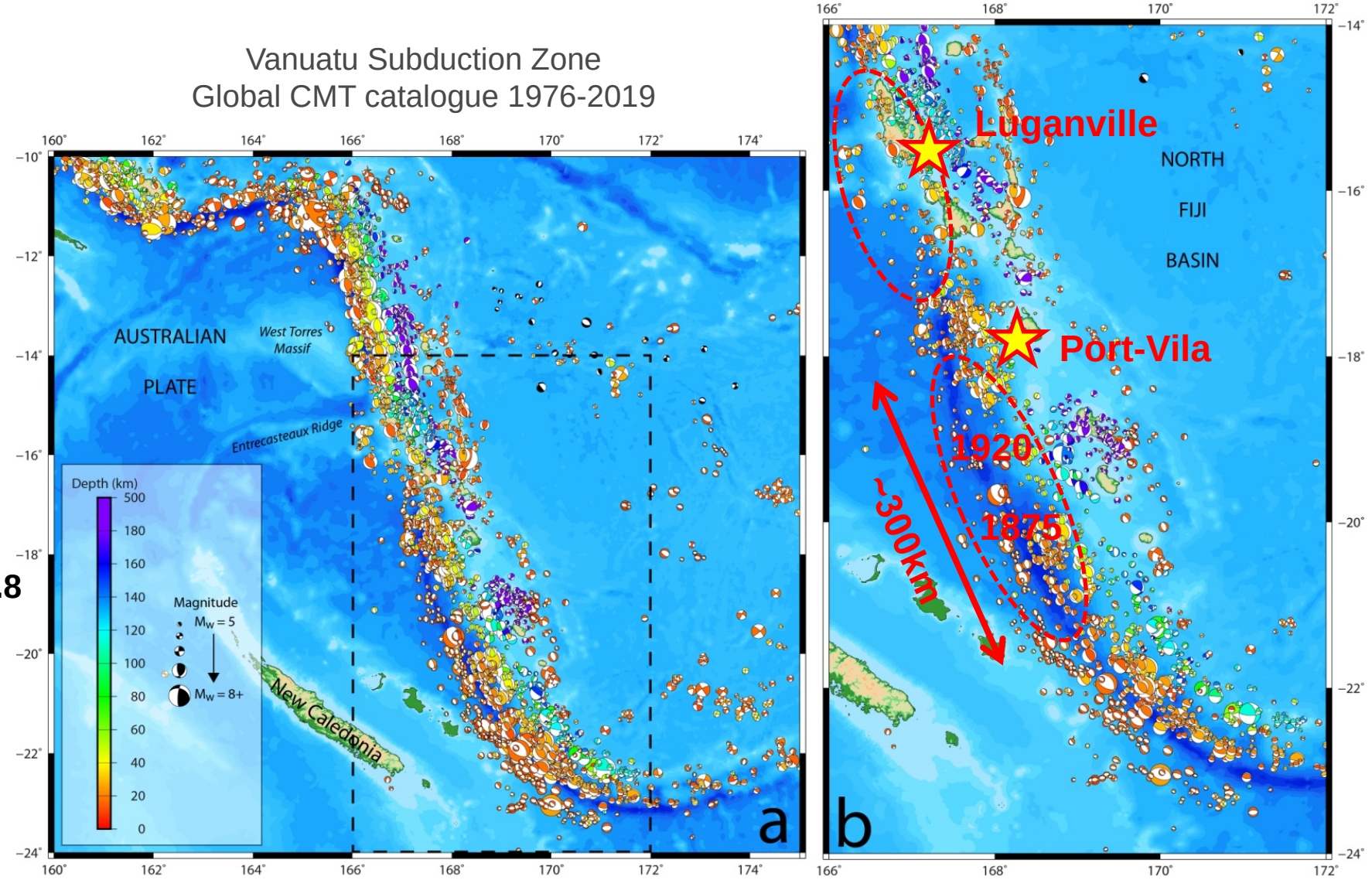


Roger et al., in prep.

The Vanuatu Subduction Zone sismo-tectonic context

Historical seismicity
→ 2 major events:

- **28 March 1875: Mw 8.1-8.2**
- **20 September 1920: Mw 7.5-7.8**

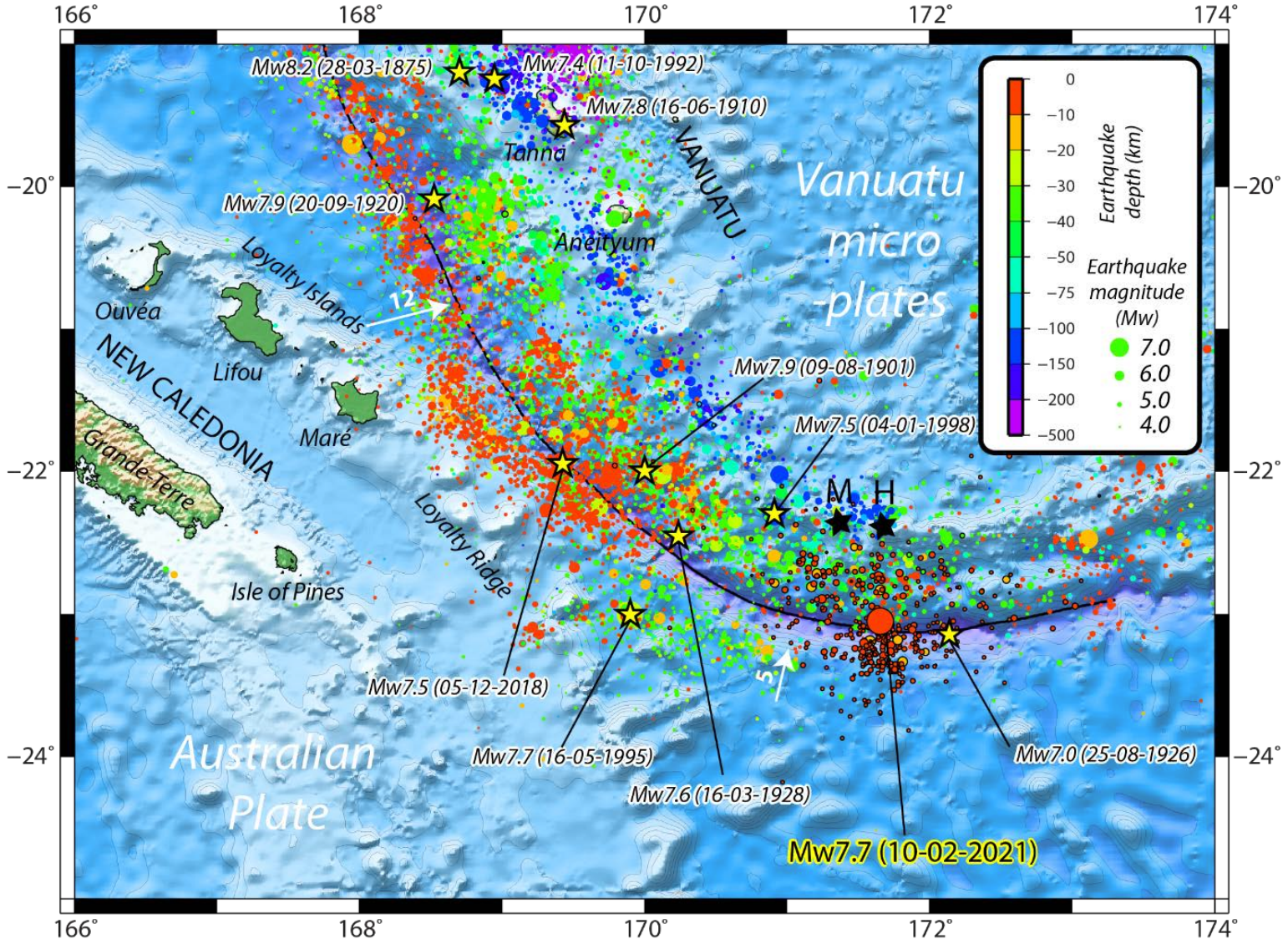


Roger et al., in prep.

The Vanuatu Subduction Zone sismo-tectonic context

The southern part of the Trench

- Subduction of the Loyalty ridge
- Strong seismicity resulting of compressive and extensive processes on the two plates
- 3 recent strong earthquakes
  - 5 December 2018 Mw 7.5
  - 10 February 2021 Mw 7.7
  - 19 May 2023 Mw 7.7



Roger et al., in revision

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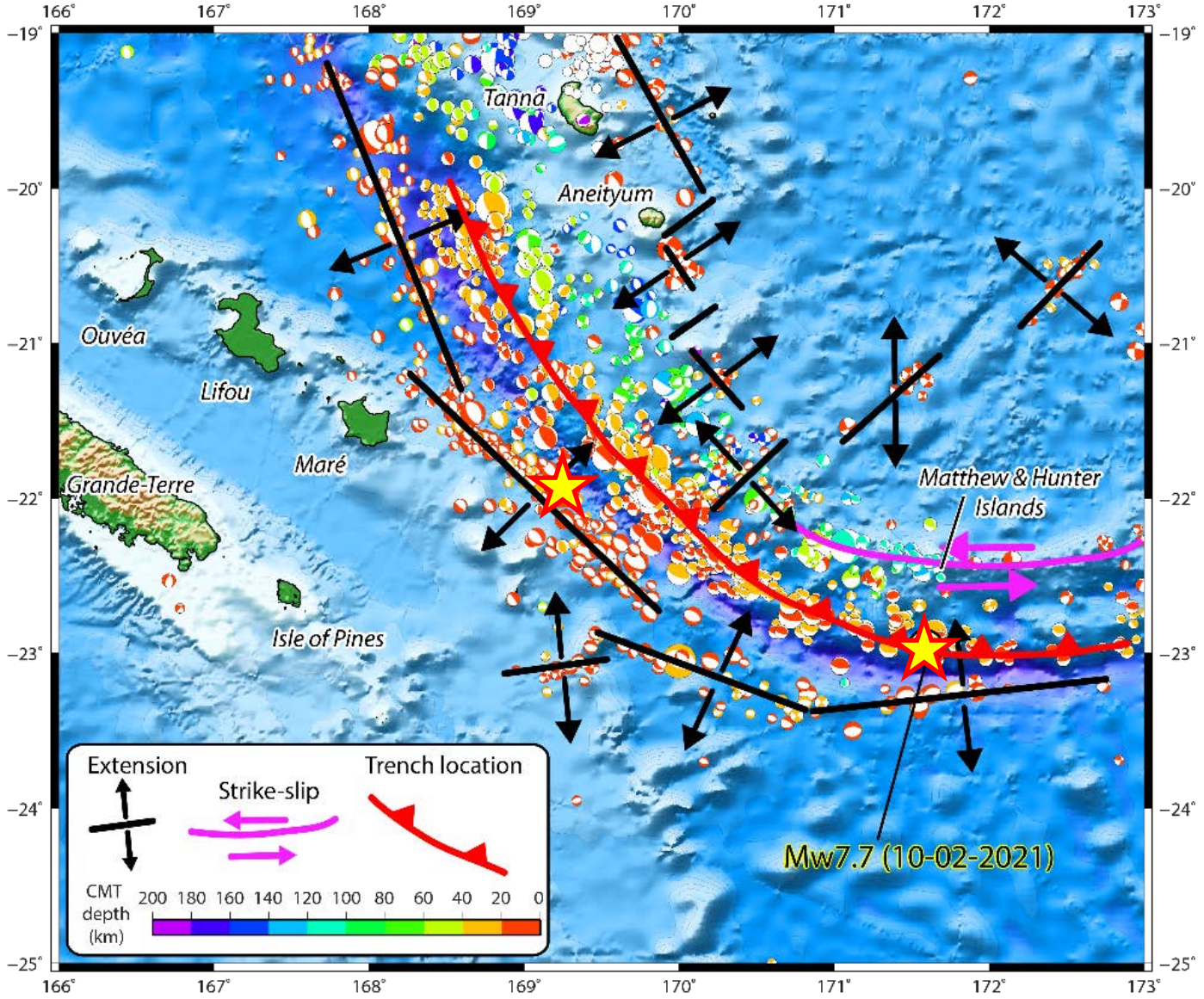

Roger et al., in revision

The Vanuatu Subduction Zone sismo-tectonic context

- An active subduction zone
- 2 seismic gaps
- Recent strong events (2018, 2021, 2023) with lots of recorded data
- 2 major historical events:
  - 28 March 1875: Mw 8.1-8.2
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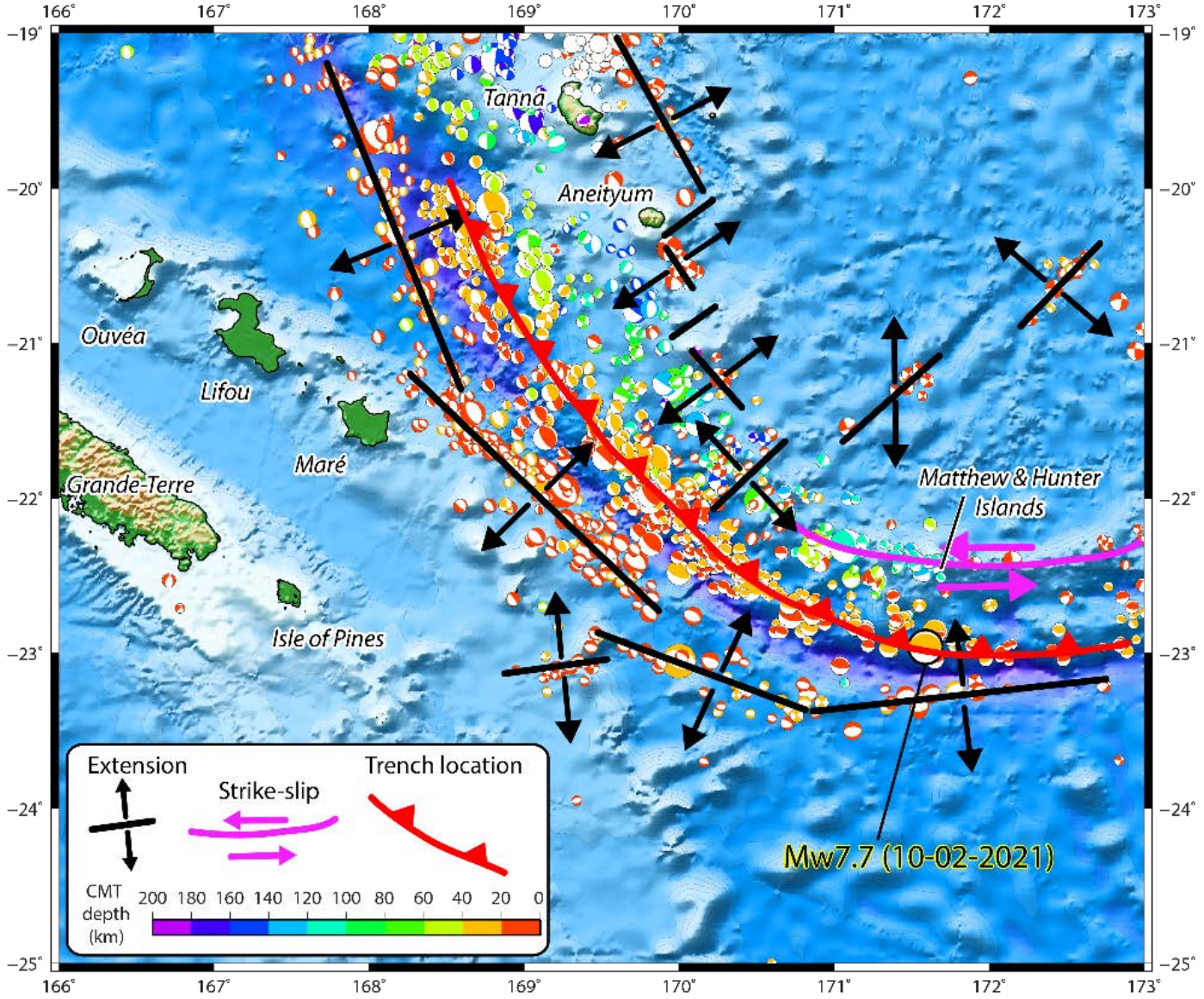
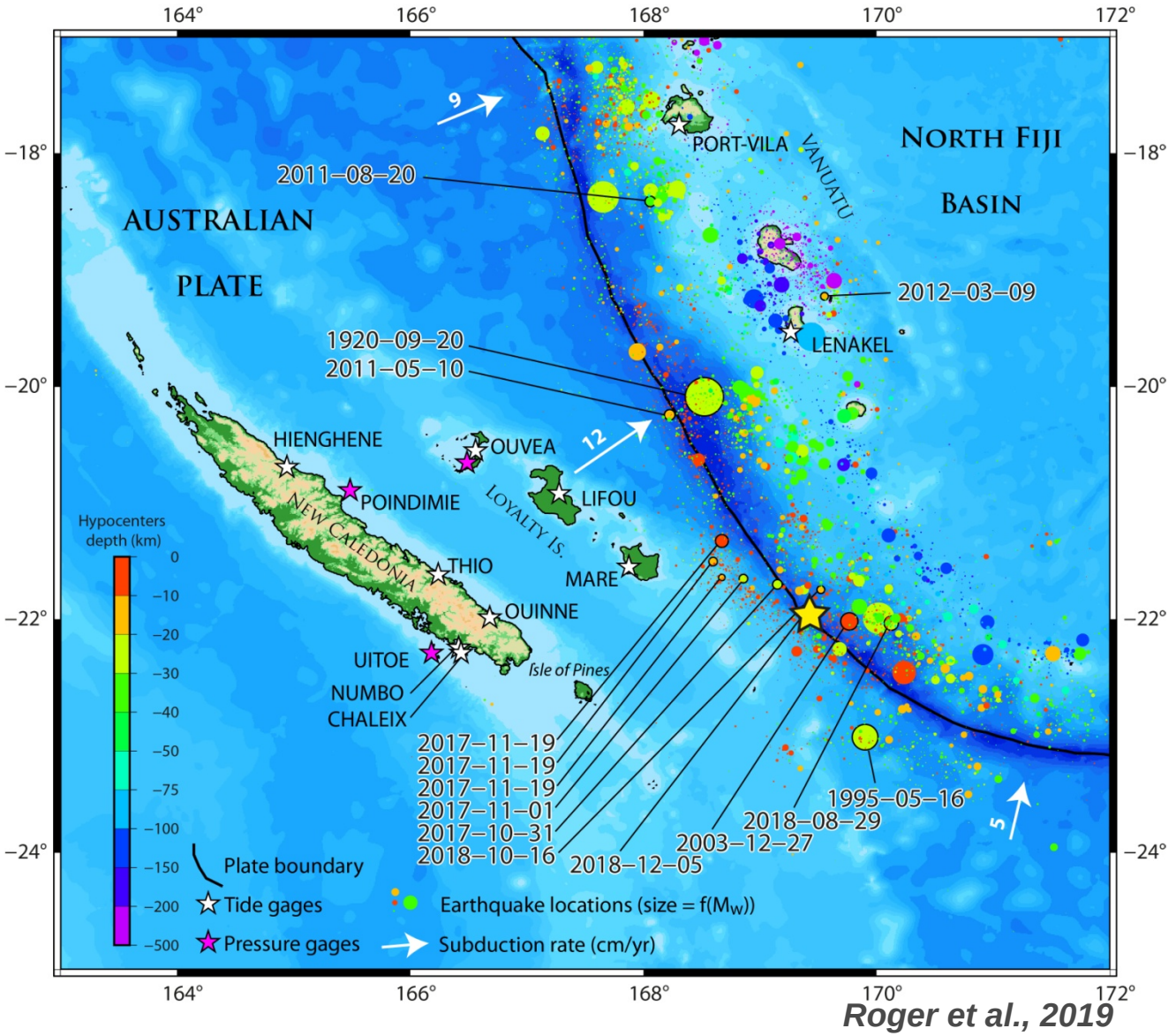


Roger et al., in revision

Tsunamis generated at the Vanuatu Subduction Zone

- 2010: A first catalogue of the **6/12 tsunamis** recorded/reported in New Caledonia from the VSZ → **Sahal et al.**



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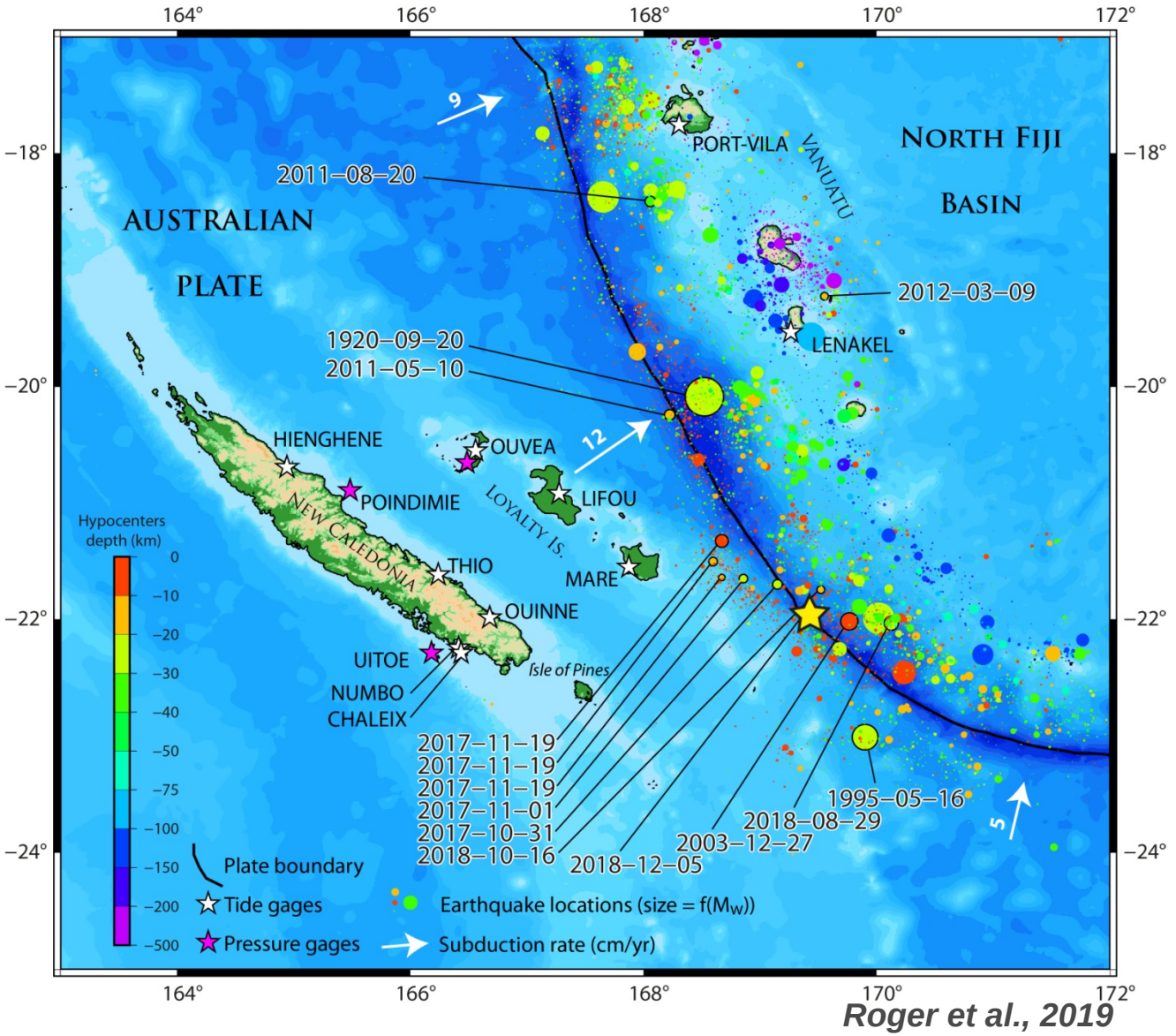

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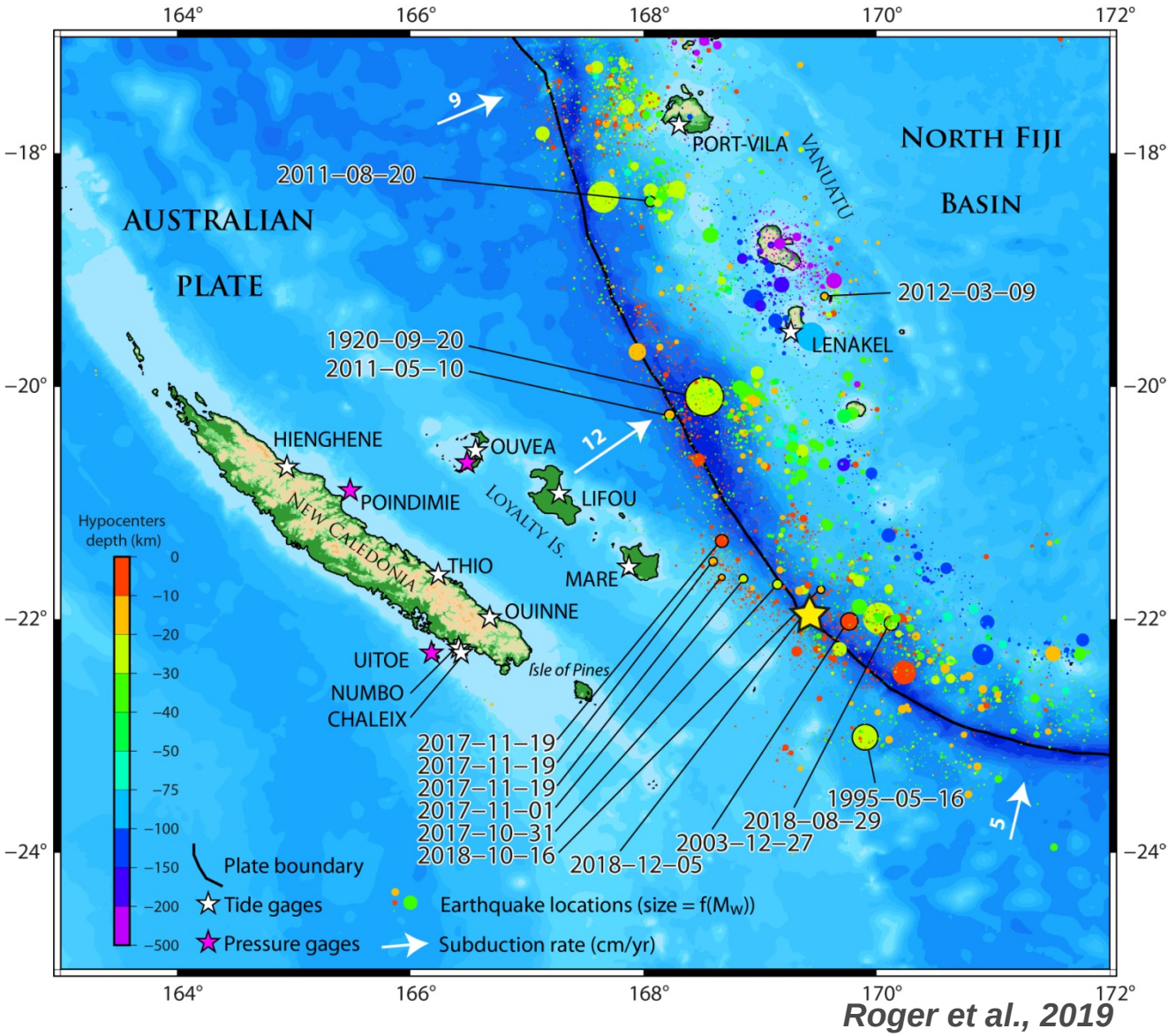
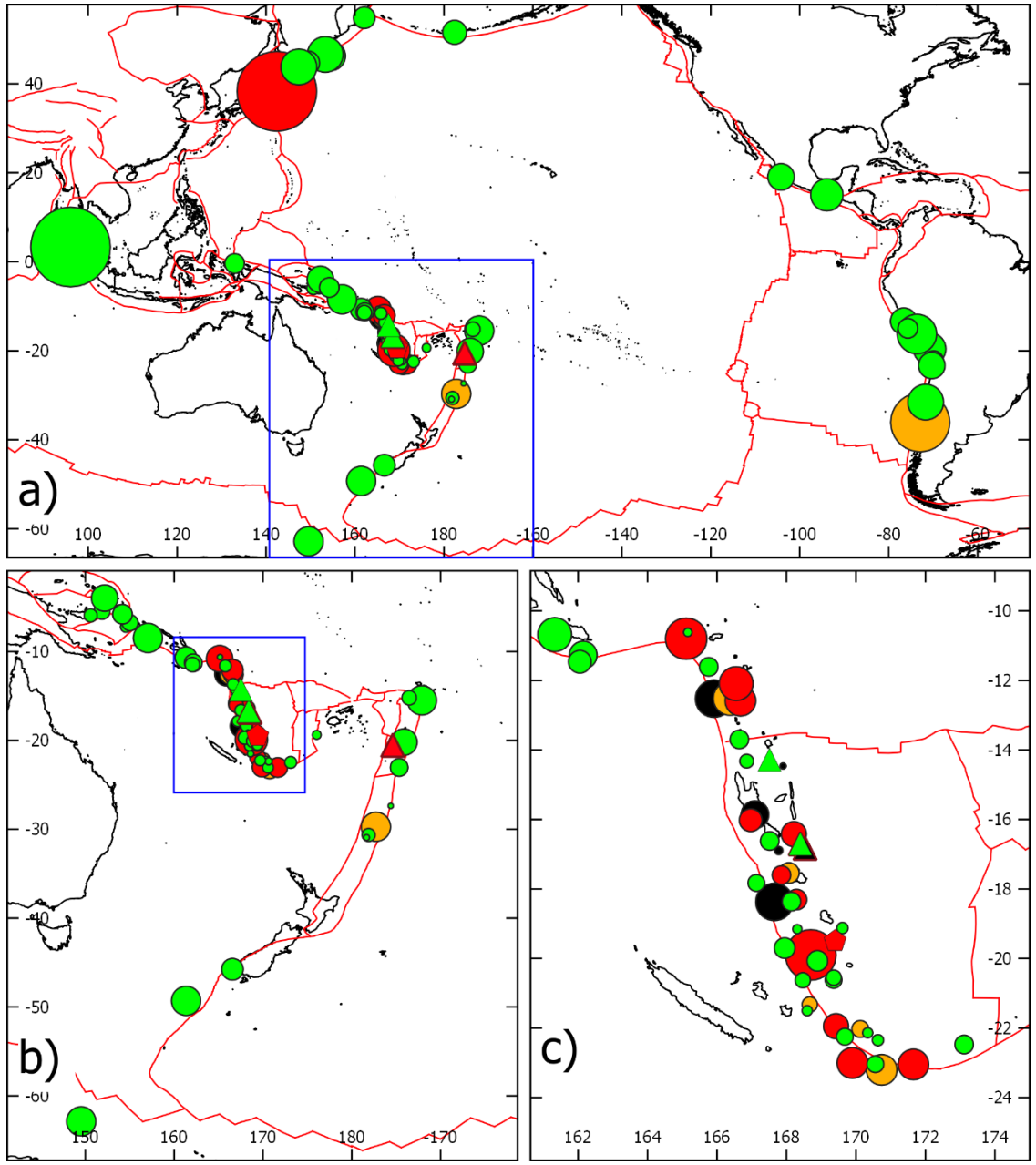


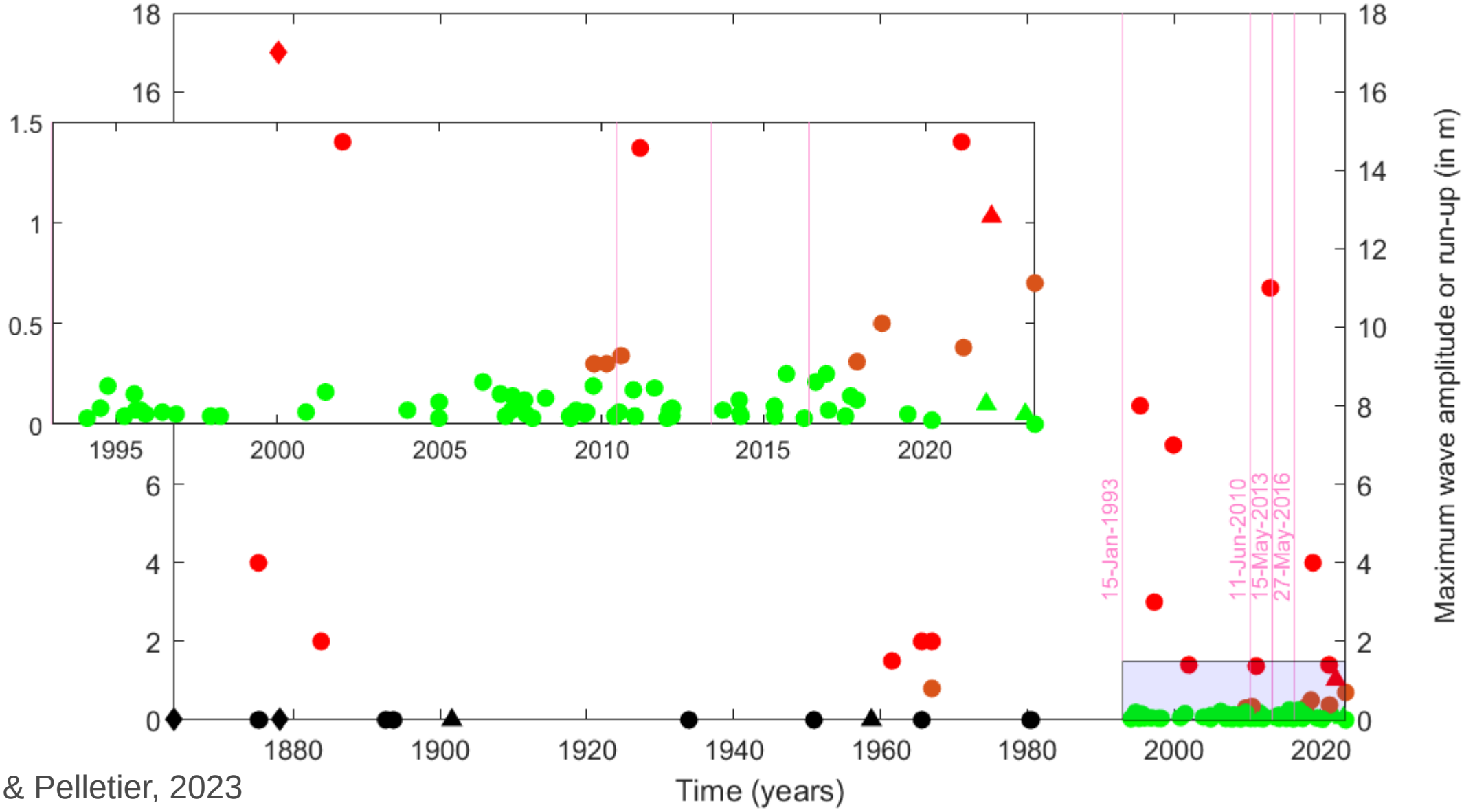
Roger et al., 2019

Sources of tsunamis recorded in the Vanuatu Arc since 1863



Roger & Pelletier, 2023

Green: >0-30cm ; orange: 30cm-1m; red: >1m; black: NaN – Circles: EQ; triangle: volc.



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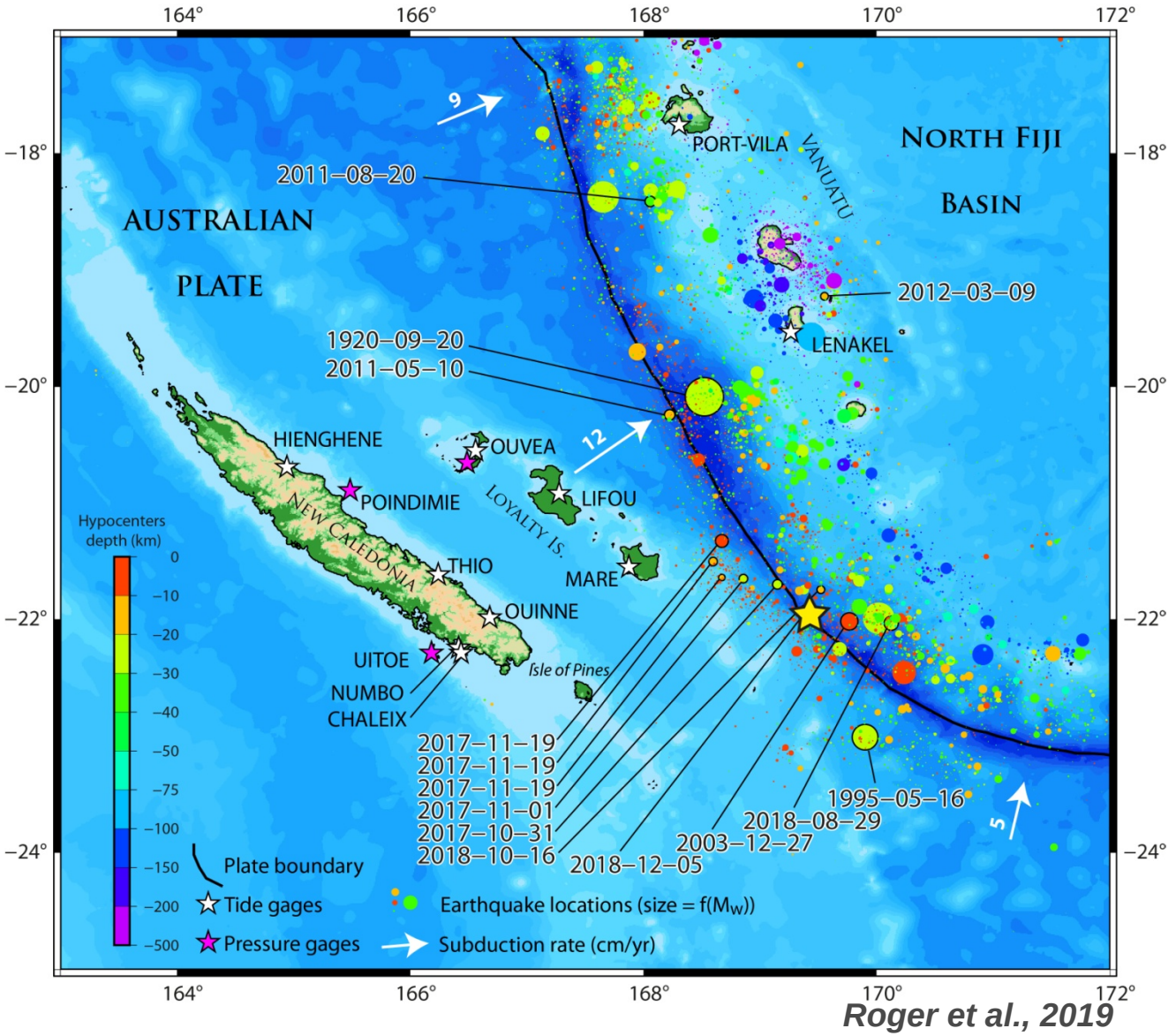
- **NB:** numerous large landslide scars identified in the region (unpublished work, Pelletier et al.)



Roger et al., 2019

Tsunamis generated at the Vanuatu Subduction Zone

6 remarkable events have been studied so far:

1875 → the ONLY deadly tsunami recorded in New Caledonia (25 deaths in Lifou) – no knowledge of the seismic source parameters

1920 → in the tsunamis/earthquakes catalogues, no valuable information about any tsunami waves

1999 → a Mw 7.5 earthquake (on the back-arc faults) triggered a destructive and deadly tsunami in Ambrym and Pentecost islands (Vanuatu) – run-up up to 8 m

2018 → Mw 7.5 earthquake with normal mechanism at the collision between the Loyalty Ridge and the subduction – lots of observations/gauge records

2021 → Mw 7.7 earthquake with reverse mechanism at the southeasternmost part of the subduction zone (toward Fiji) – observations/gauges and DART records

2023 → Mw 7.7/7.1 doublet earthquake with complex normal mechanism (loc. of 1995 Mw 7.7) – observations/gauges and DART records

NB: 9 August 1901 → a Mw7.8 earthquake and tsunami are mentioned in catalogues; there is a strong doubt on the date and location of this event (recent update from USGS)

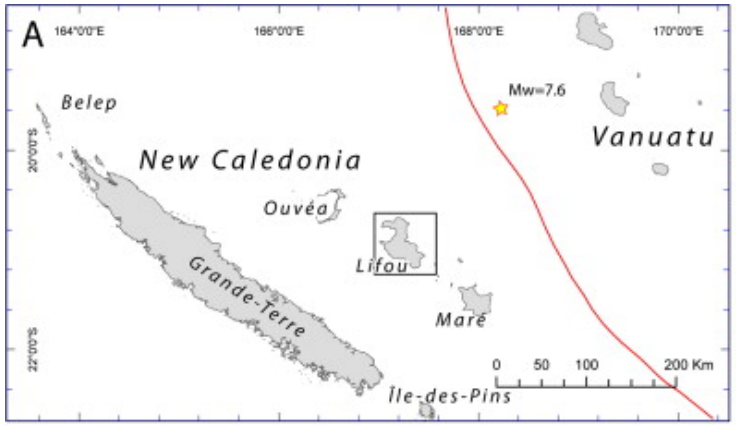
Tsunamis generated at the Vanuatu Subduction Zone

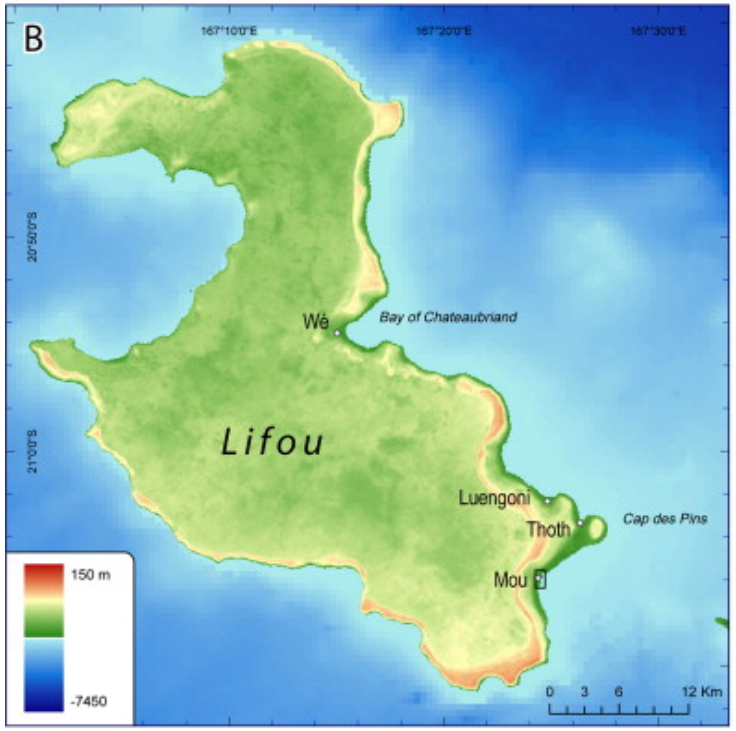
28 March 1875

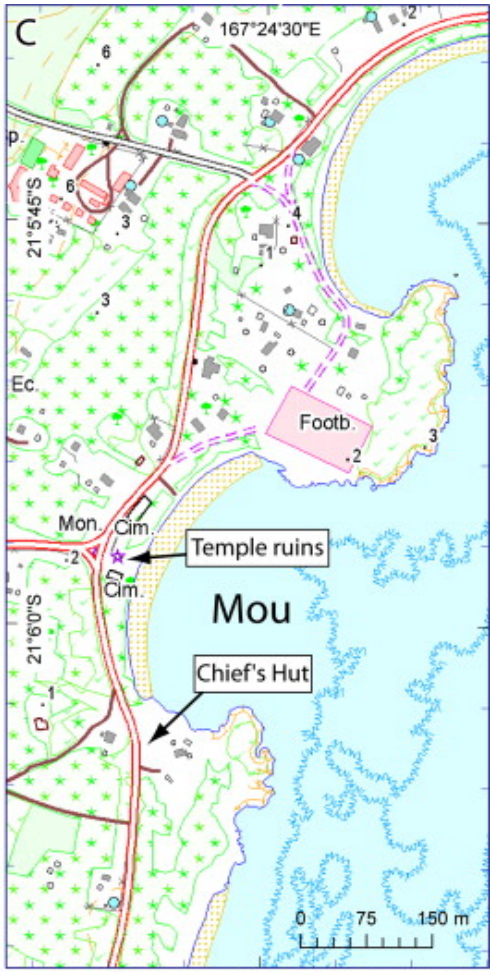
Historical investigations provided

→25 deaths, numerous casualties
→Several places destroyed
→No data about the earthquake

→Scientific study: Ioualalen et al., 2017
- Allows to attribute a magnitude range of the event







Archive Territoriale de Nouvelle-Calédonie, Nouméa, MF Presse Calédonienne, 1MI14(R6), Le Moniteur de la Nouvelle-Calédonie du 28 avril 1875, Communications, Lettre du Père Lubin Gaide datée du 04 avril 1875 à *Gatcha* (Lifou) adressée à un confrère, relative au tremblement de terre au Loyalty, 170 p.

Sahal et al., 2019

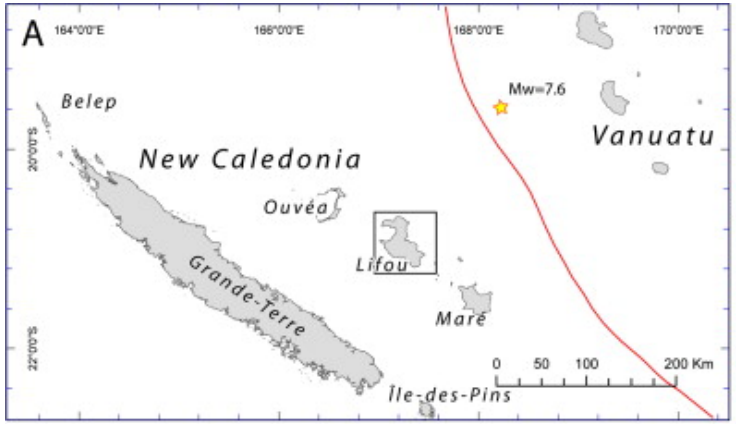
Tsunamis generated at the Vanuatu Subduction Zone

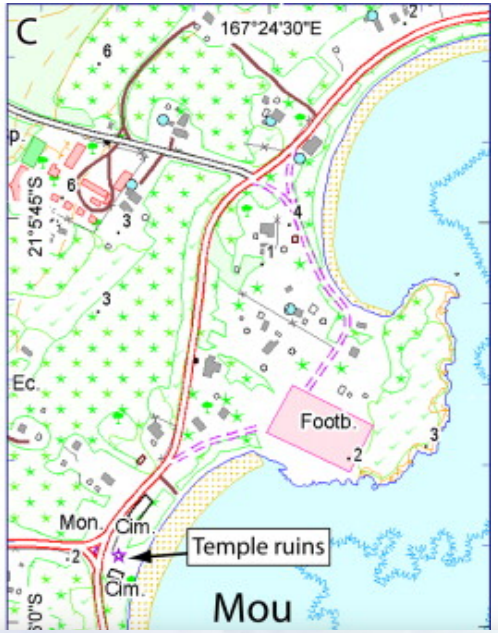
28 March 1875

Historical investigations provided

→25 deaths, numerous casualties
→Several places destroyed
→No data about the earthquake

→Scientific study: Lavigne et al., 2017





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Tsunamis gene…one

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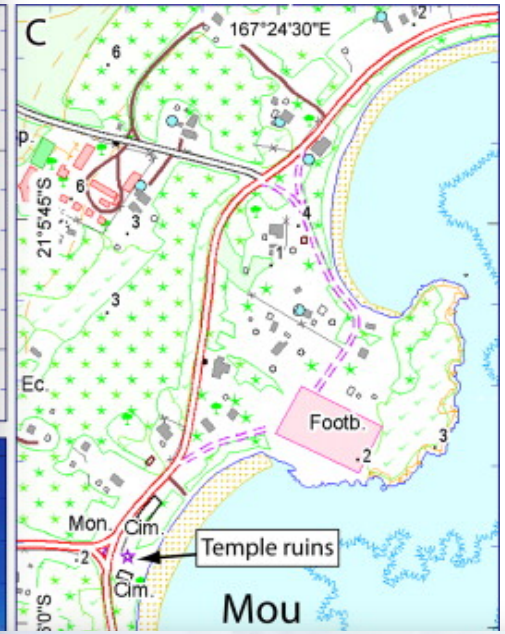

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Tsunamis generated at the Vanuatu Subduction Zone

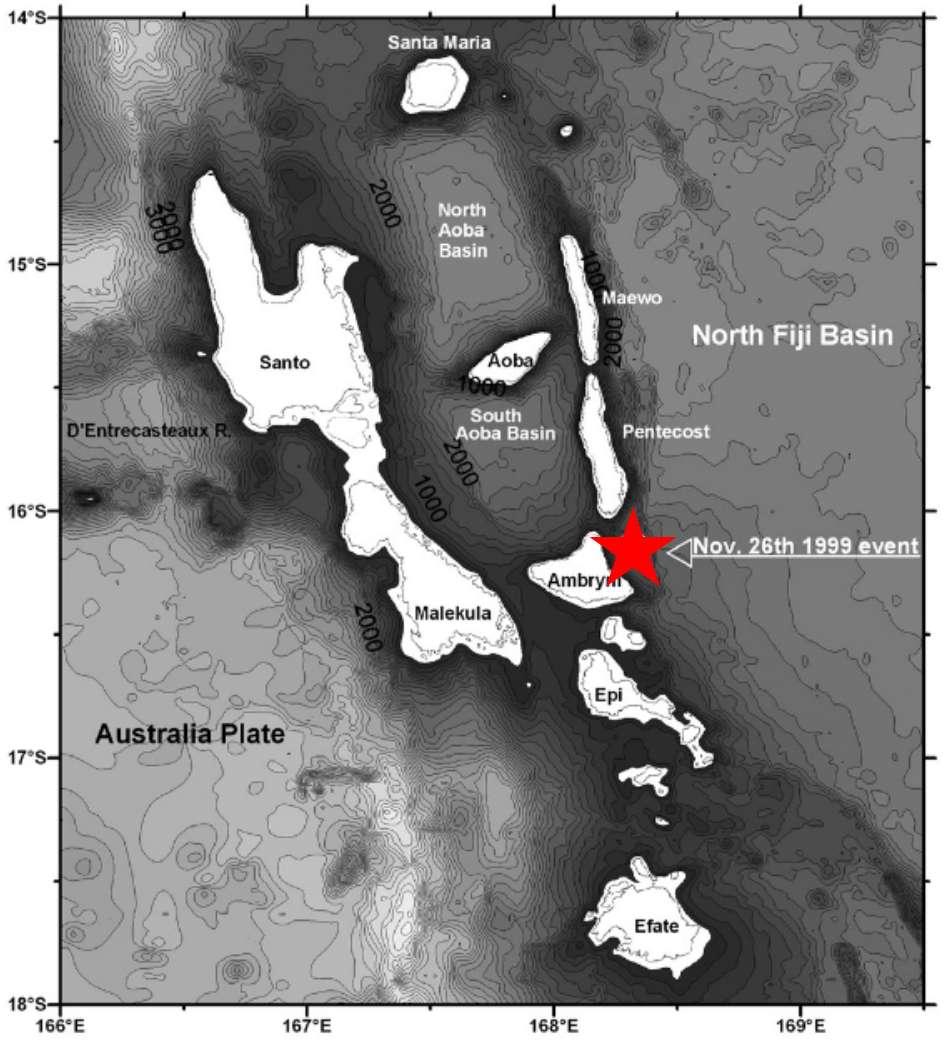
26 November 1999

→ Mw 7.5 earthquake shook central Vanuatu

→ Reverse faulting mechanism on back-arc fault

→ Largest known earthquake in the back-arc of this region

→ Followed by a destructive tsunami



Ioualalen et al., 2006

Tsunamis generated at the Vanuatu Subduction Zone

26 November 1999

Post event field survey provided

→Numerous destructions and victims on Ambrym and Pentecost Islands
→Maximum run-up of 8 m
→Measurement of vertical motion (uplift up to 1.5 m; subsidence) in Ambrym eastern shore and surrounding islands

Credits: Bernard Pelletier

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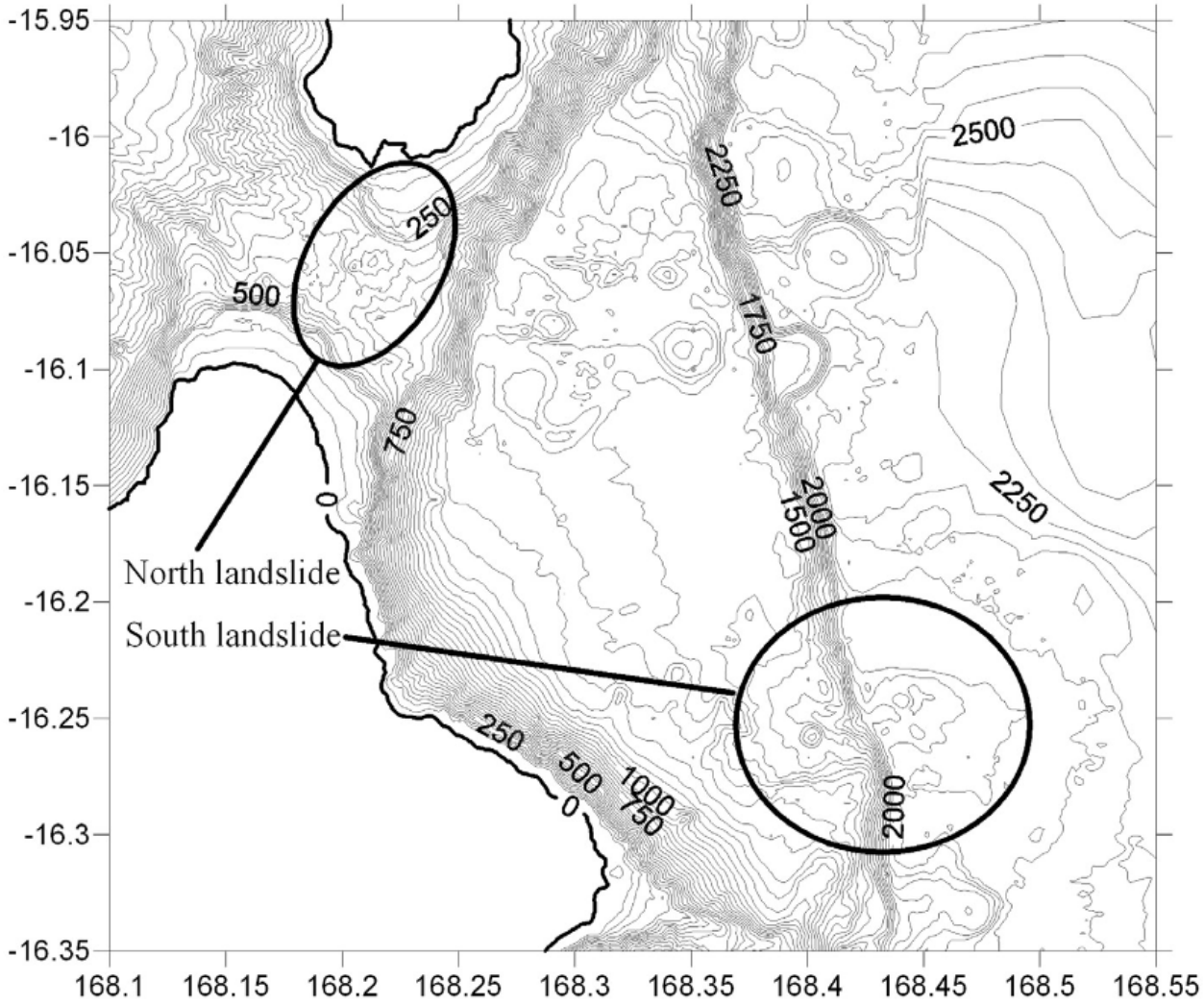
Bathymetric campaign

→Identification of several submarine landslide deposits/scars



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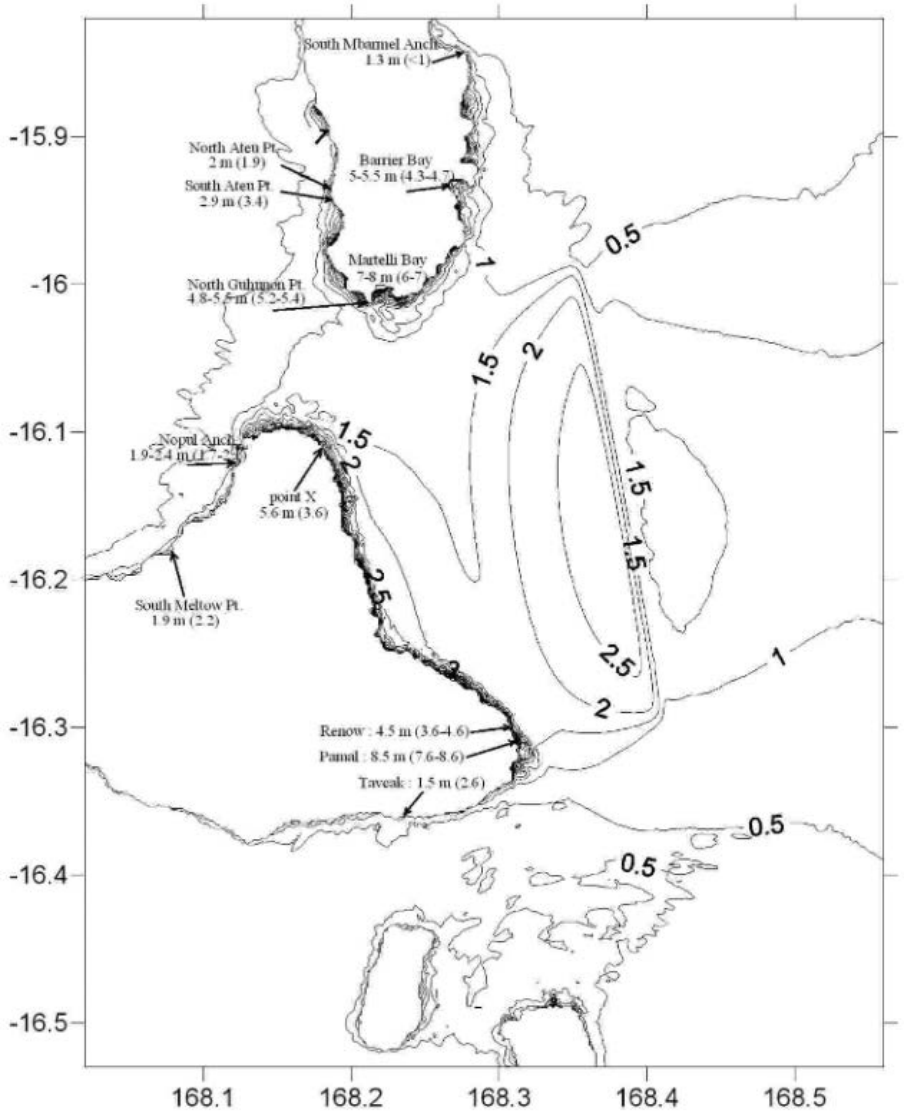
Bathymetric campaign

→Identification of several submarine landslide deposits/scars

→ Three hypothesis of tsunami generation: coseismic deformation, east Ambrym underwater landslide, south Pentecost underwater landslide (Pelletier et al., 2000; Ioualalen et al., 2006)



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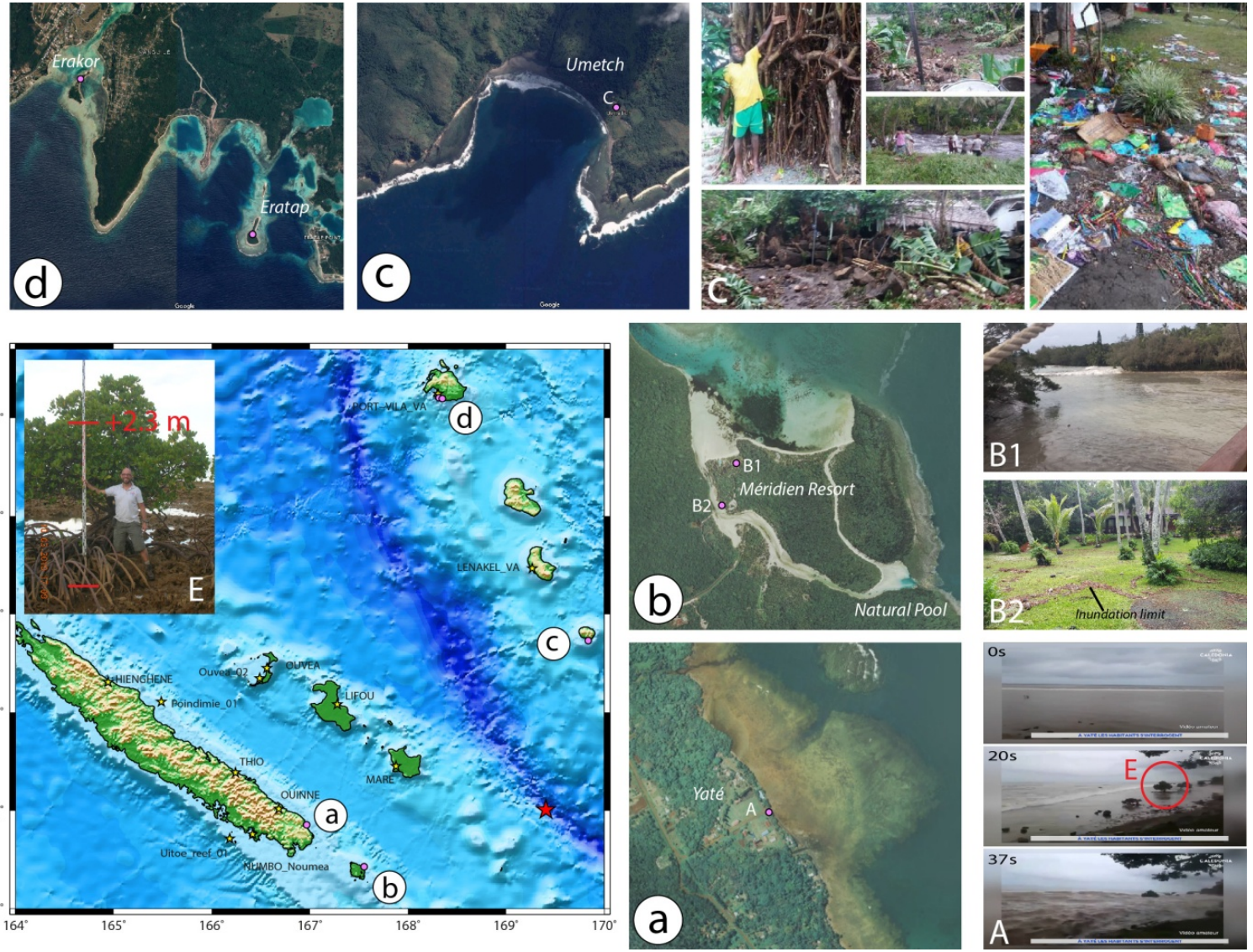
Tsunamis generated at the Vanuatu Subduction Zone

5 December 2018

→1st event recorded on numerous coastal gauges in NC/VAN
→ observations/testimonies (incl. videos/photos)
→ Scientific study: Roger et al., NHESS, 2021
- Able to reproduce most of coastal records and observations in NC/VAN
- Allows calibration of local tsunami model for hazard mapping purpose (New Caledonia gvt. TSUCAL project)



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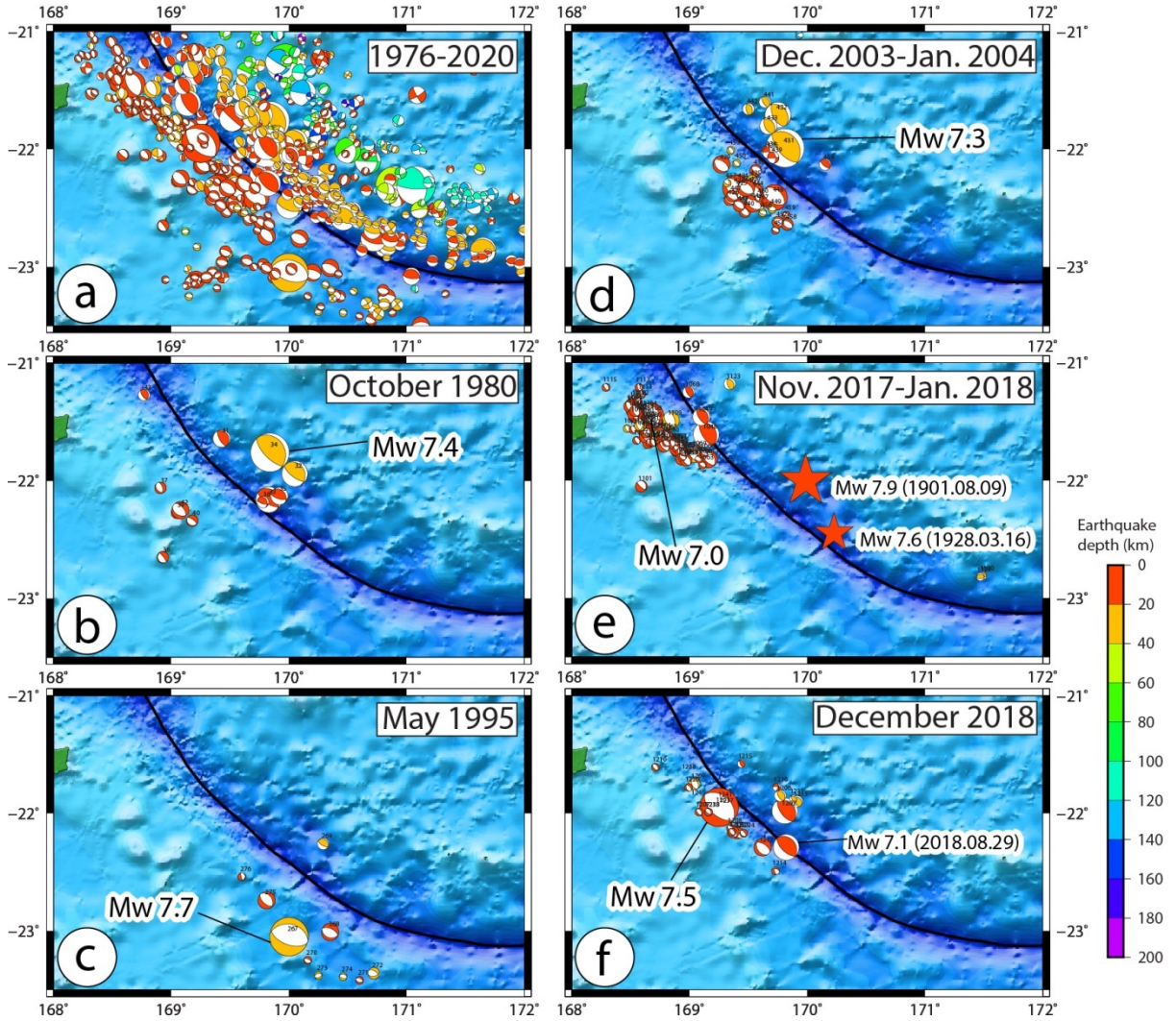
- Able to reproduce most of coastal records and observations in NC/VAN
- Allows calibration of local tsunami model for hazard mapping purpose (New Caledonia gvt. TSUCAL project)
- Interesting tectonic/seismic process alterning reverse and normal mechanisms

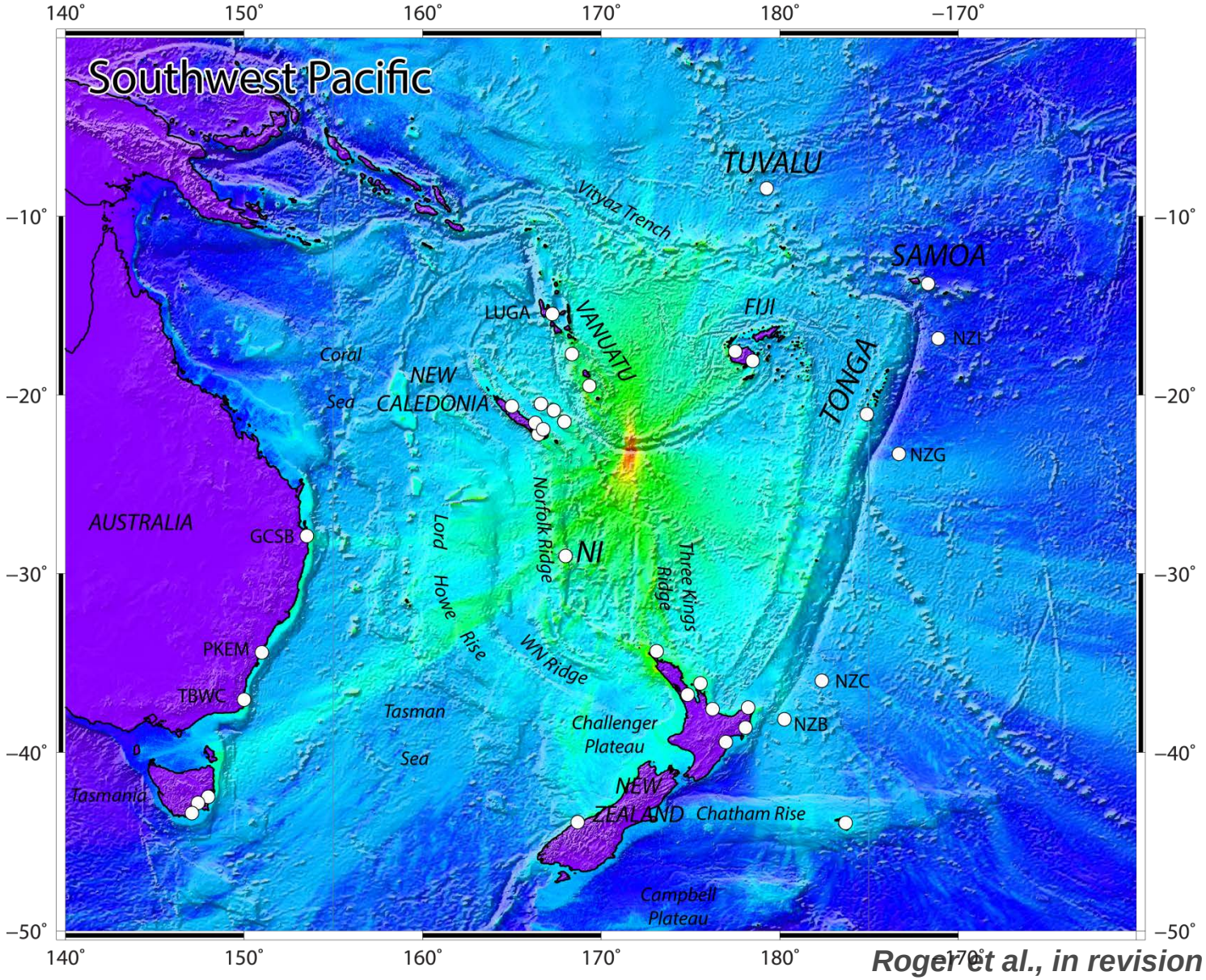


Roger et al., 2021

Tsunamis generated at the Vanuatu Subduction Zone

10 February 2021

→ Regional impact
→ Recorded by most of the SW Pacific coastal gauges (31) and by 4 NZ DARTs (the 3 DARTs off NC were not operational)
→ Scientific studies: Roger et al., NHESS, 2023; Gusman et al., ESS, 2022
- Help to improve the tsunami hazard knowledge for SW Pacific
- Help to improve NZ early warning system using DART data (first waveforms)



Roger et al., in revision

Tsunamis generated at the Vanuatu Subduction Zone

19 May 2023

→ Doublet earthquakes (Mw 7.7 & 7.1)
→ 53% NDC (USGS)
→ Source region of 1995 Mw 7.7 EQ
→ Recorded by many of the SW Pacific coastal gauges and by 11/12 NZ DARTs
→ Scientific studies: Roger & Gusman, in prep., O'Kane et al., in prep.

- Help to improve the tsunami hazard knowledge for SW Pacific
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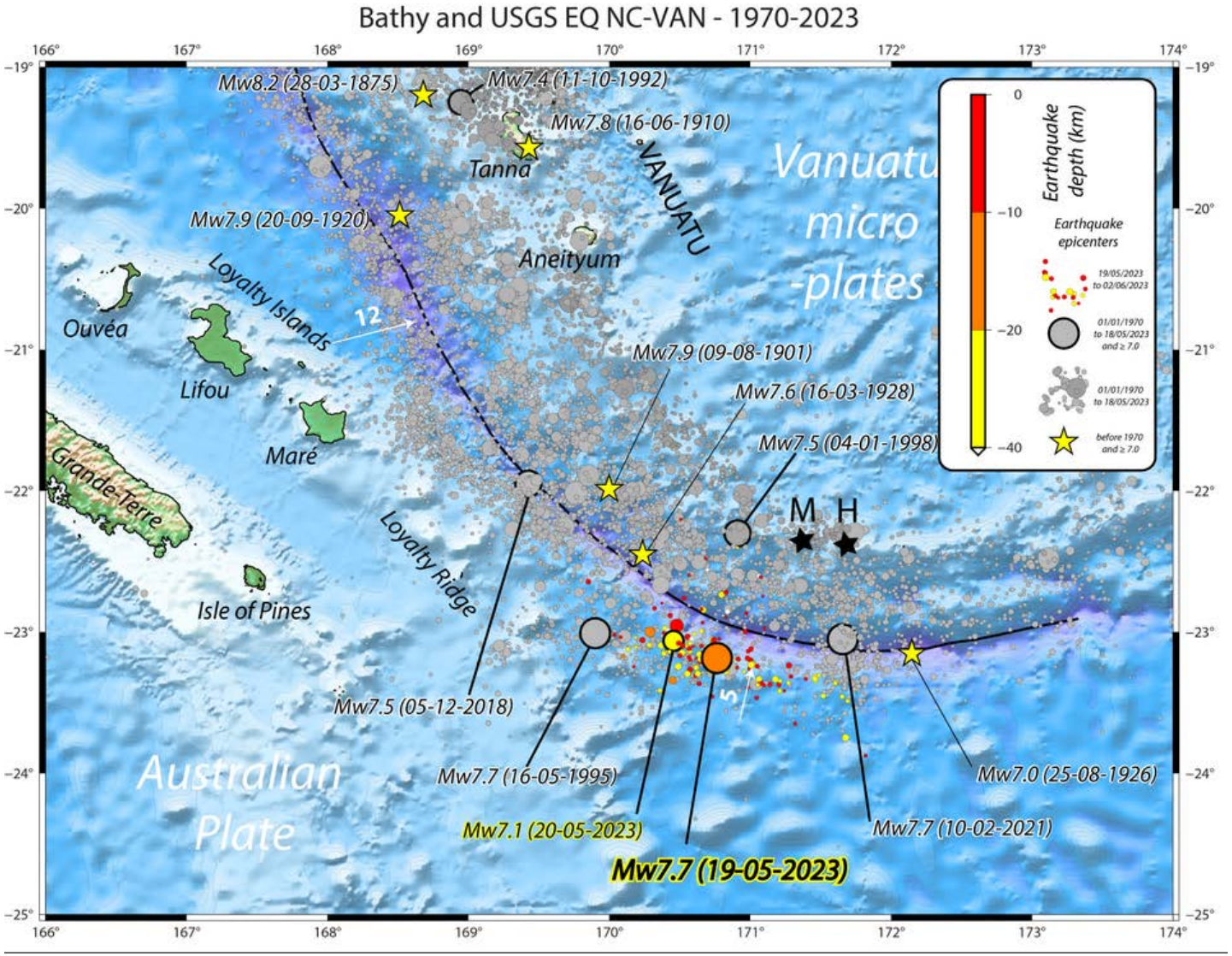

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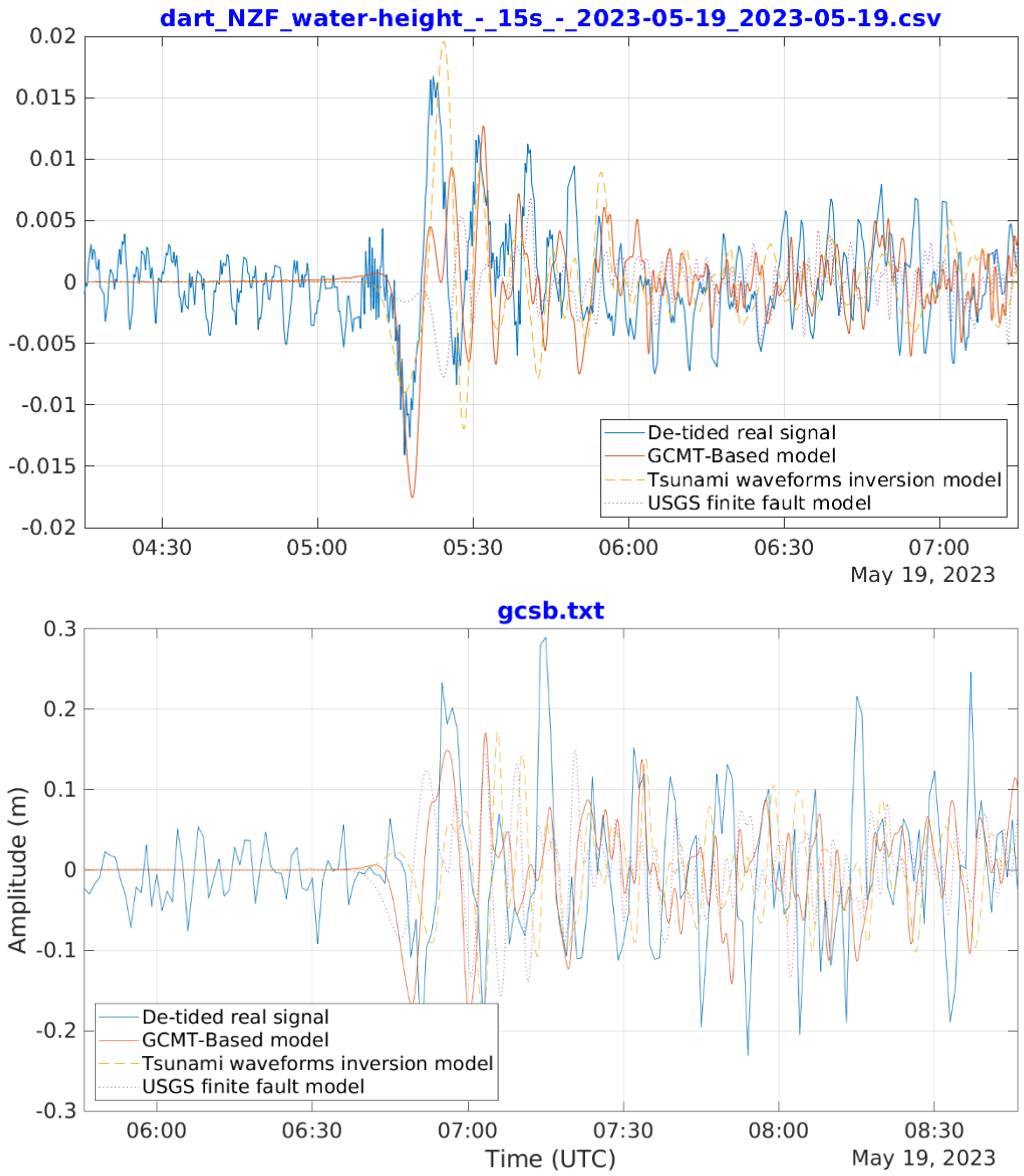

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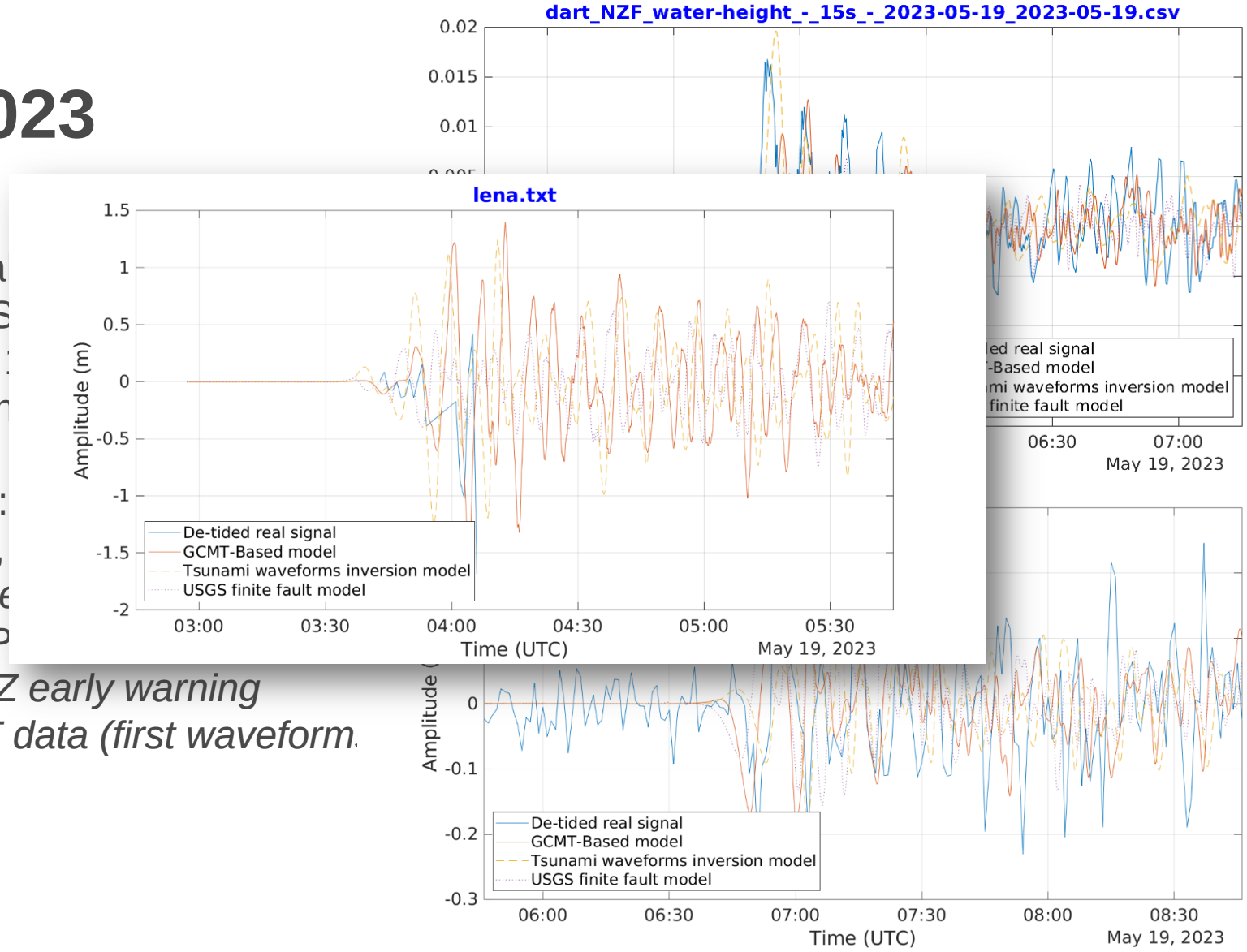

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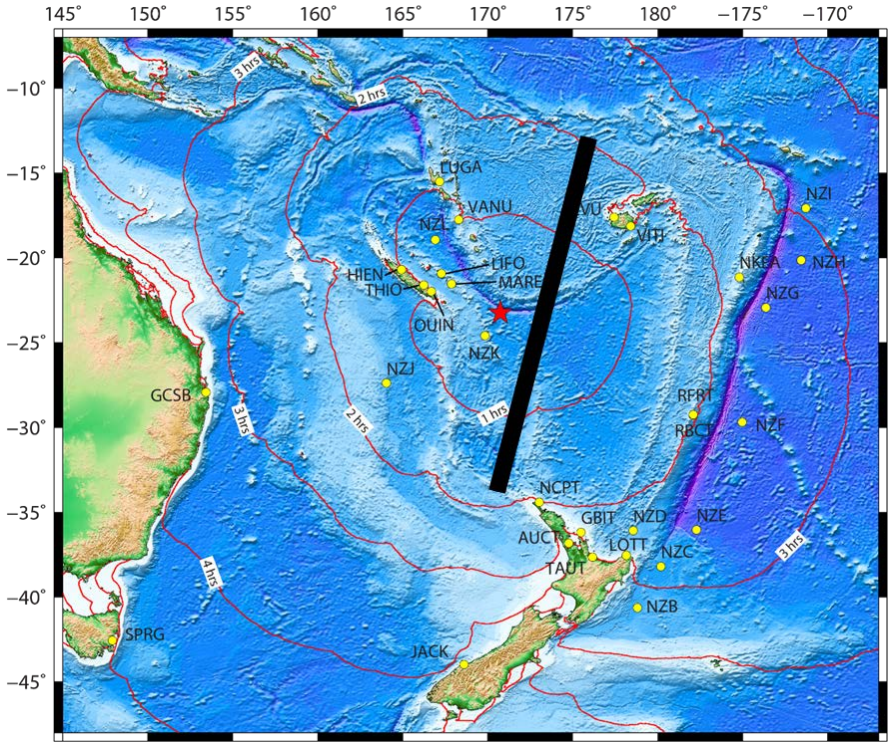
Tsunamis generated at the Vanuatu Subduction Zone

19 May 2023



The 19 May 2023 tsunami near the Loyalty Islands captured by the new SWOT satellite

Faugere.Y.[1], Roger.J.[2], Delepoulle.A.[3], Dibarboure.G.[1], Hébert.H.[4]

cnes

cea

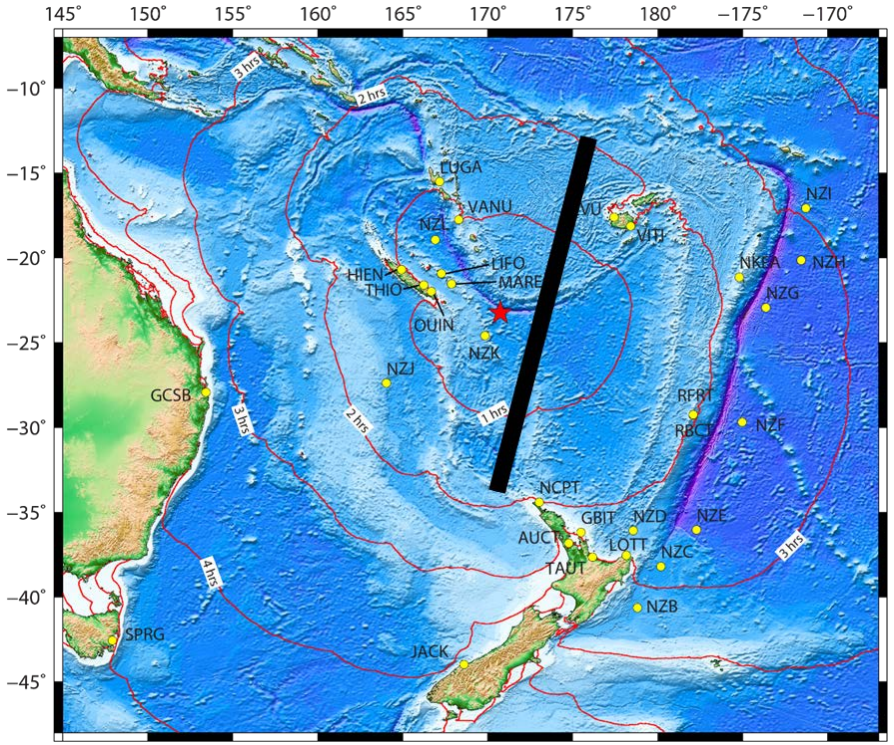
CLS
COLLECTE LOCALISATION SATELLITES

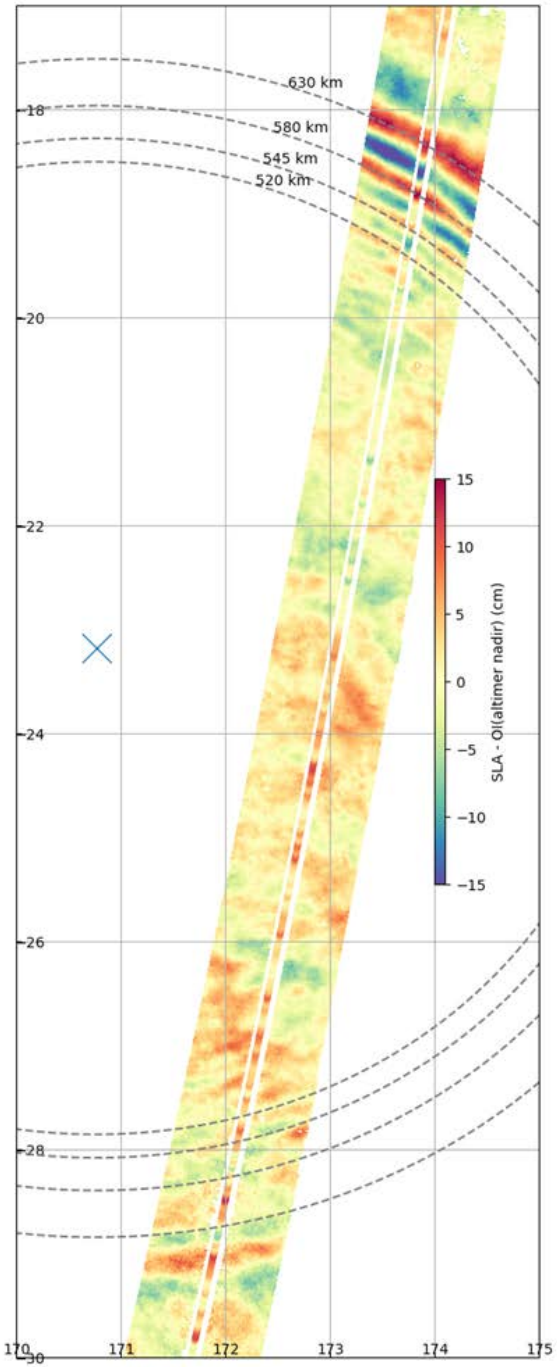
GNS SCIENCE
TE PŪ AO

Faugere et al., in prep.

Tsunamis generated at the Vanuat one

19 May 2023





Faugere et al., in prep.

Tsunamis generated at the Vanuatu Subduction Zone

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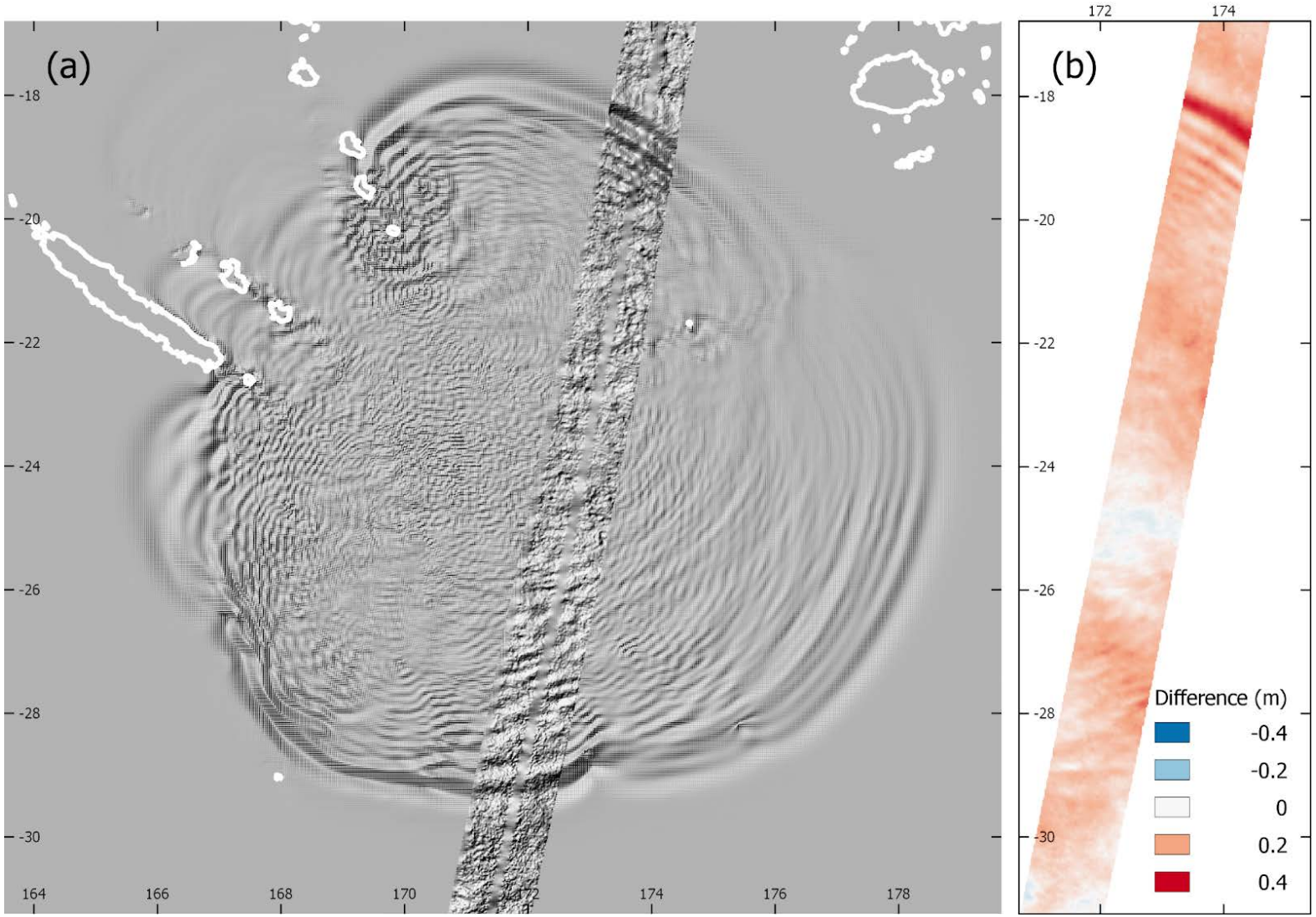


Faugere et al., in prep.

Tsunamis generated at the Vanuatu Subduction Zone

31 January 2023

→ Powerful eruption (recorded as far as Mongolia)
→ Scientific studies: Roger et al., 2023; Roger et al., in prep.
- *Help to improve the tsunami hazard knowledge for SW Pacific (non-seismic sources)*

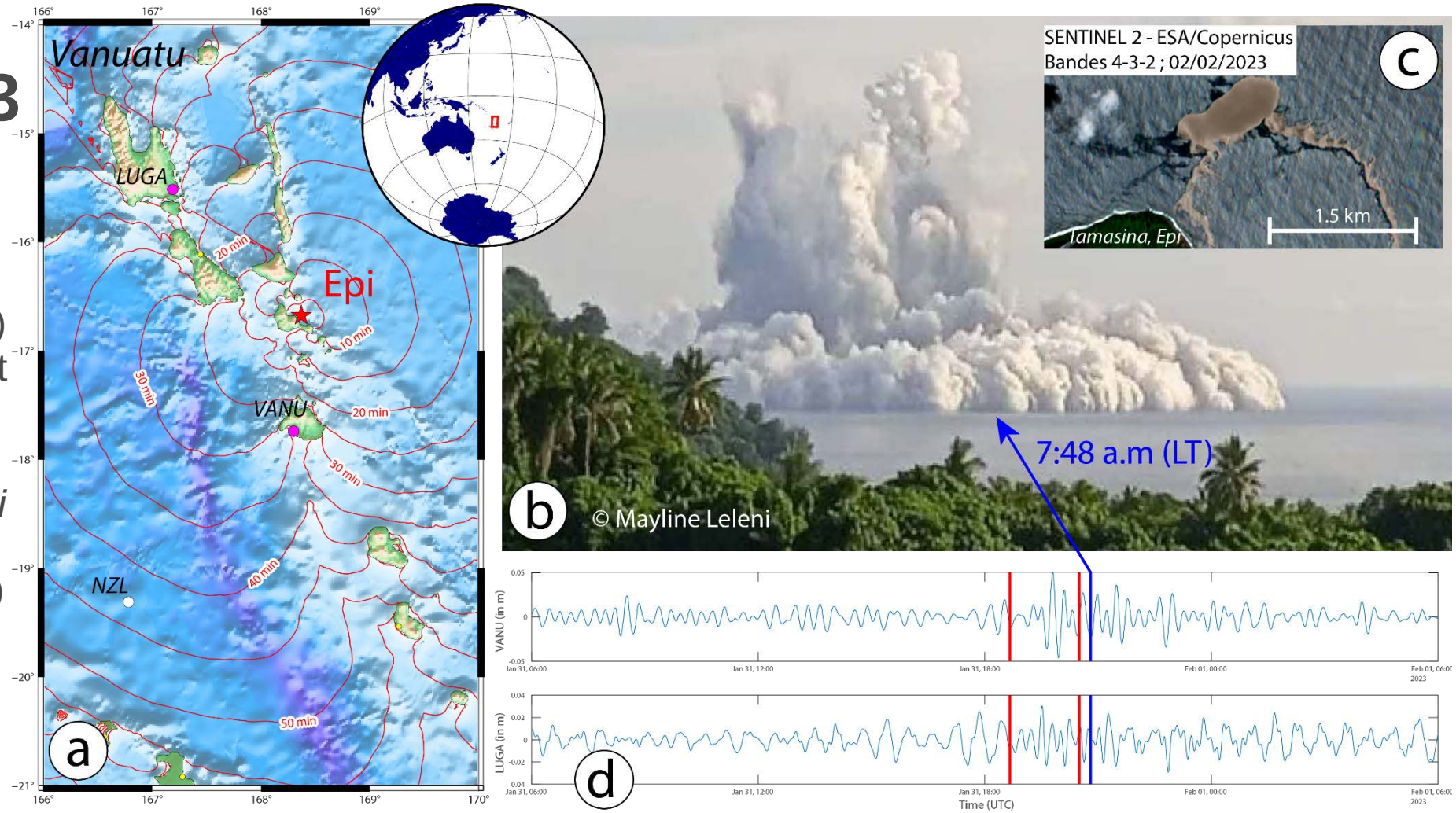


Figure 1 The East Epi Volcano eruption of 31 January 2023 (UTC): (a) Location of the volcano within the Vanuatu Archipelago and tsunami travel times (red lines). Earth inset shows the location of the study zone with a red rectangle. The purple dots locate the coastal gages in Efate and Santo Islands; (b) Picture of the 7:48 am (local time) eruption; (c) Satellite image showing pumice rafts off the east coast of Epi Island; (d) De-tided sea-level records at Port-Vila (VANU) and Luganville (LUGA). The vertical blue line symbolizes the 7:48 am eruption photographed by locals, and the red lines symbolize the atmospheric pressure increases of 0.2 Pa and 0.5 Pa beginning at ~6:40 pm and ~8:30 pm (UTC), respectively, recorded by the CTBTO infrasound array IS22 in New Caledonia (information shared by Jelle Assink, KNMI).

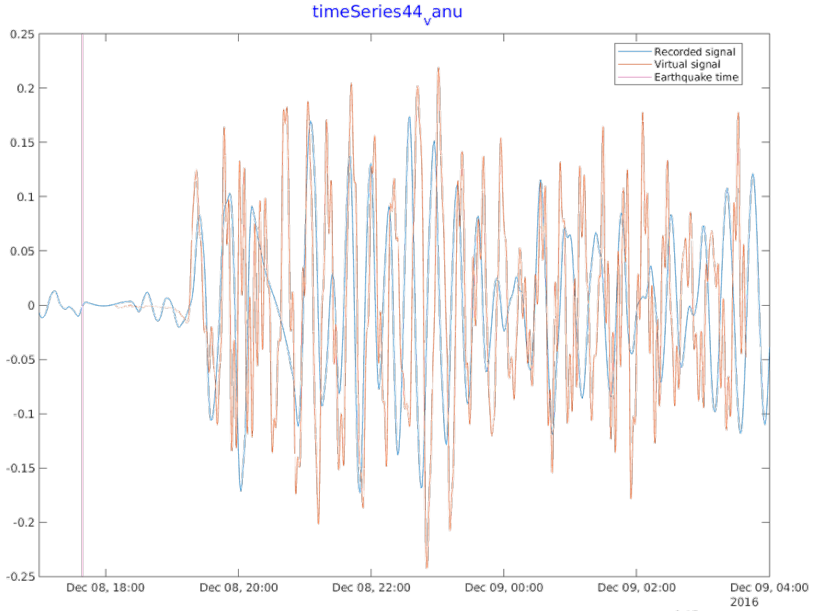
Roger et al., 2023

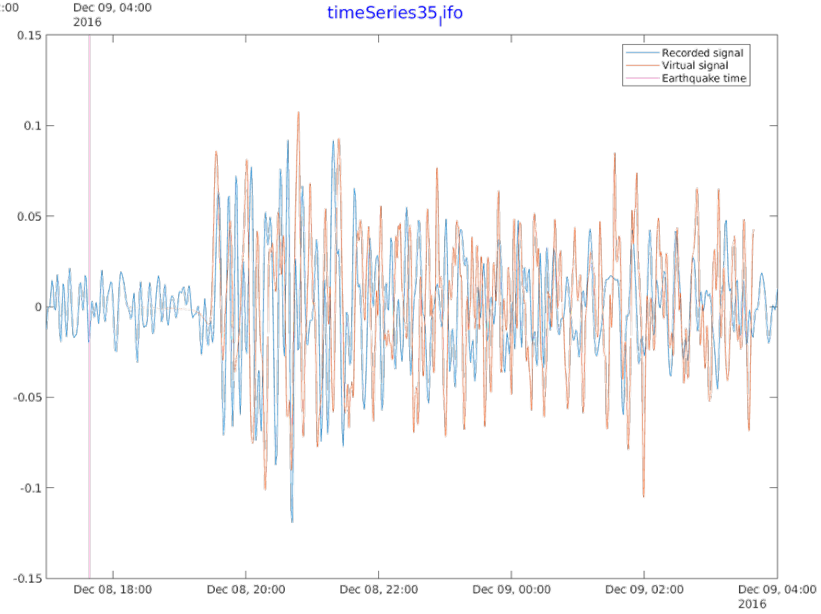
Tsunamis generated at the Solomon Is. Subduction Zone

8 December 2016

→ Mw 7.8 earthquake
→ Interface event
→ Destruction and casualties
→ Recorded by available stations of the SW Pacific and a few DARTs
→ Scientific studies: Thomas et al., in prep.

- Help to improve the tsunami hazard knowledge for SW Pacific
- Help to improve NZ early warning system using ship-based GNSS measurements





Thomas et al., in prep.

Tsunami potential of the Vanuatu Subduction Zone

2 important points we can discuss further:

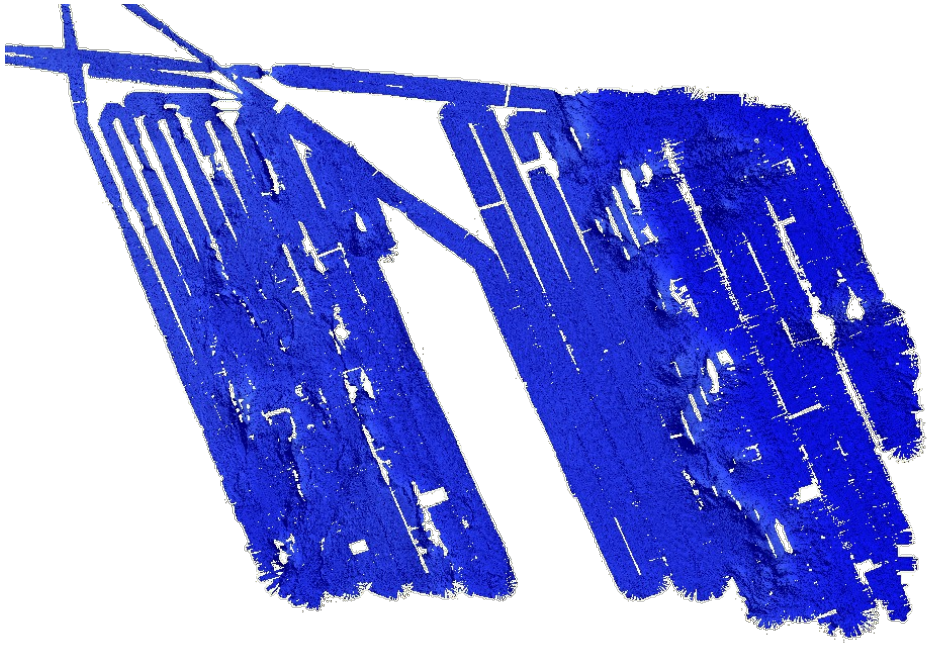
What is the maximum plausible magnitude the VSZ can produce ?

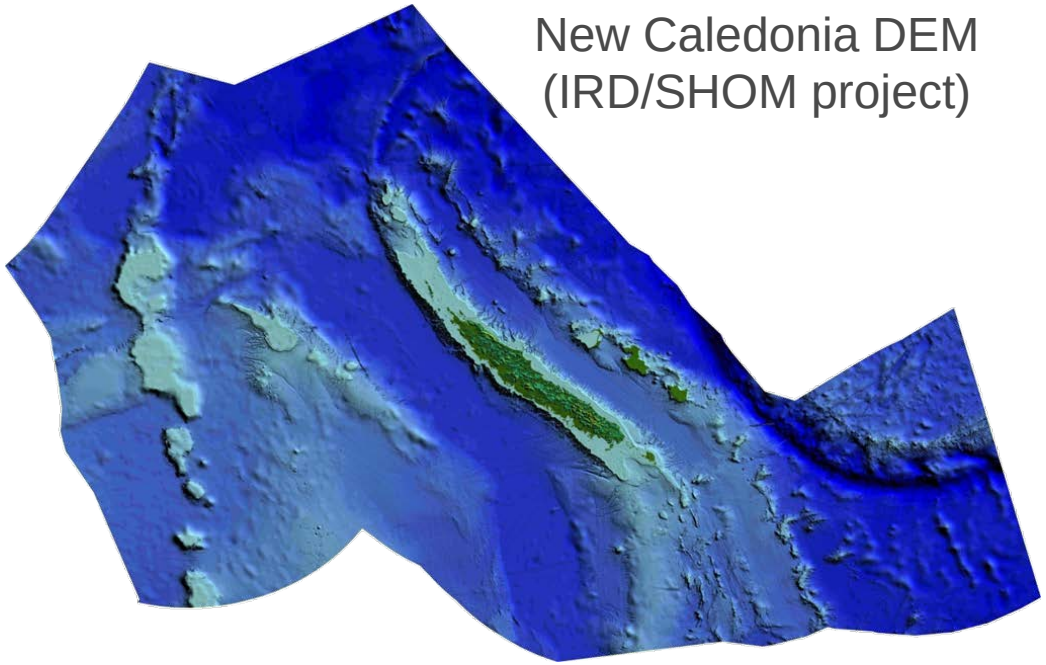
What about the scenarios using other tsunami sources (including volcanic eruptions and landslides) in such a complex region?

Gaps of knowledge

Bathymetric data in New Caledonia

Multiple datasets (nautical charts, ZONECO program, etc.)



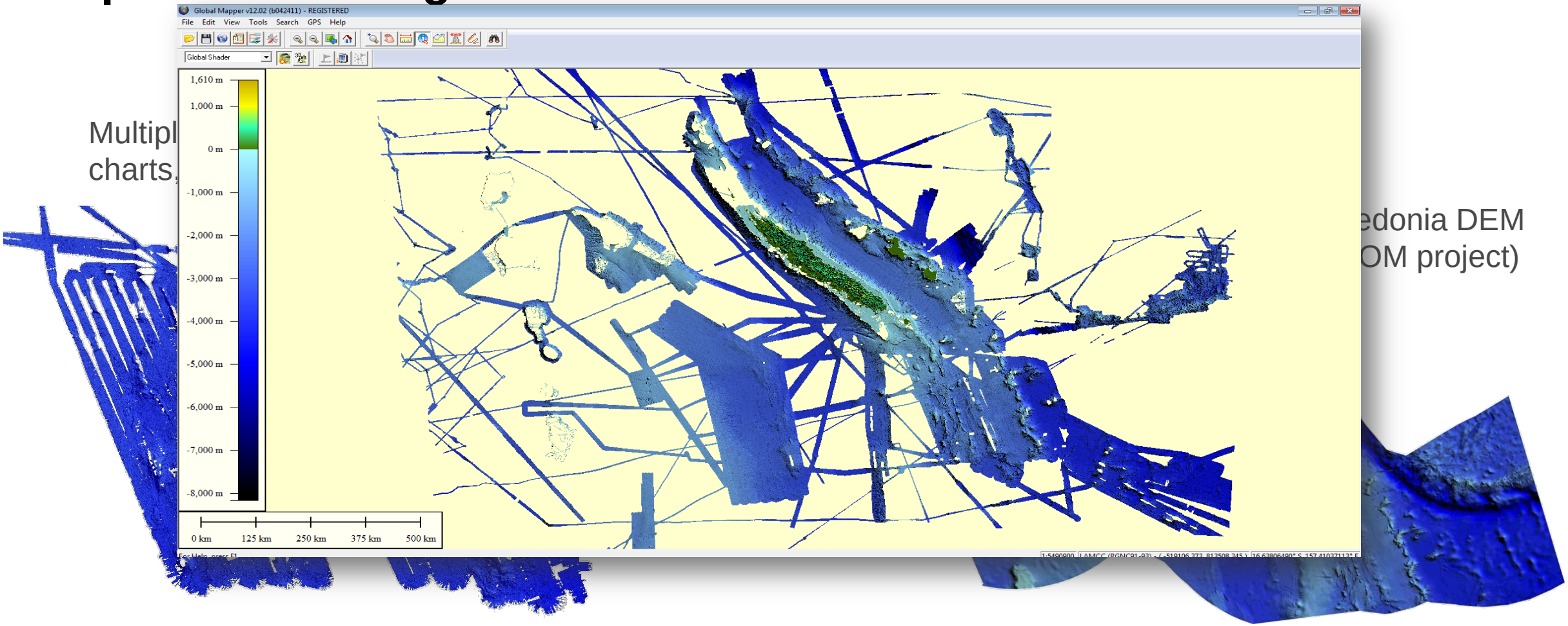


New Caledonia DEM (IRD/SHOM project)

Roger, 2020

Gaps of knowledge

Multipl
charts,



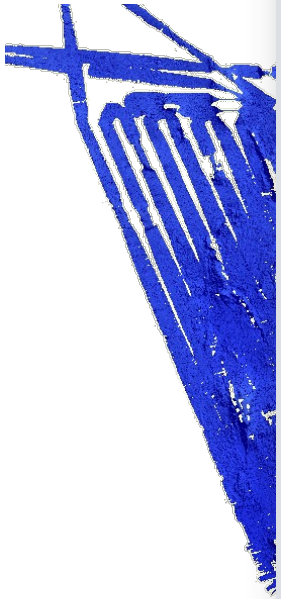
edonia DEM
OM project)

Roger, 2020

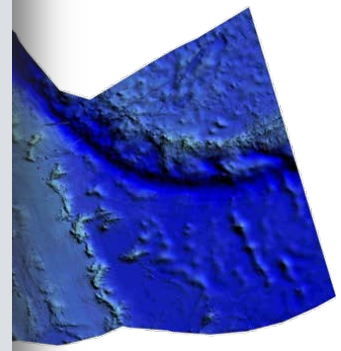
→general lack of data in the lagoons and deep-sea areas not covered yet by multibeam campaigns

Gaps

Multipl
charts,



edonia DEM
OM project)



→general

https://diffusion.shom.fr/pro/risques/bathymetrie/mnt-bathymetrique-de-facade-de-la-nc

67%

Getting Started

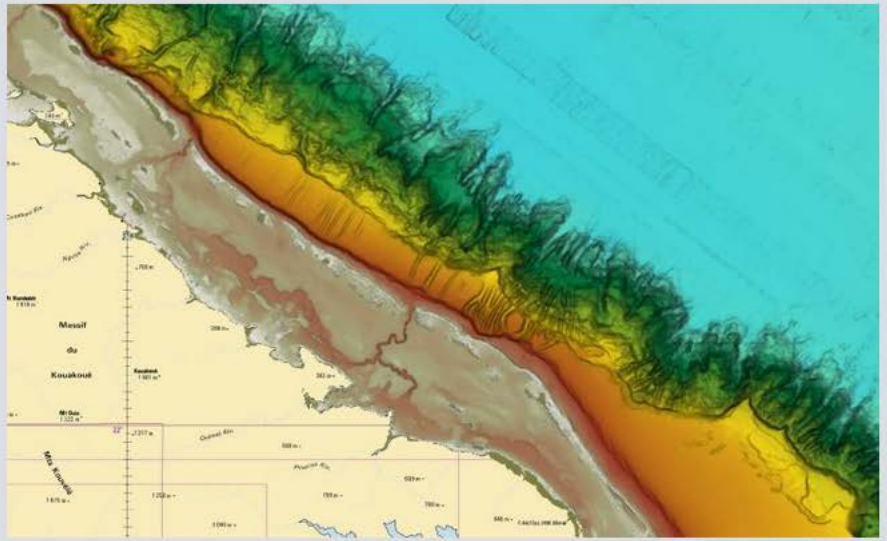
SHOM

Professionnels

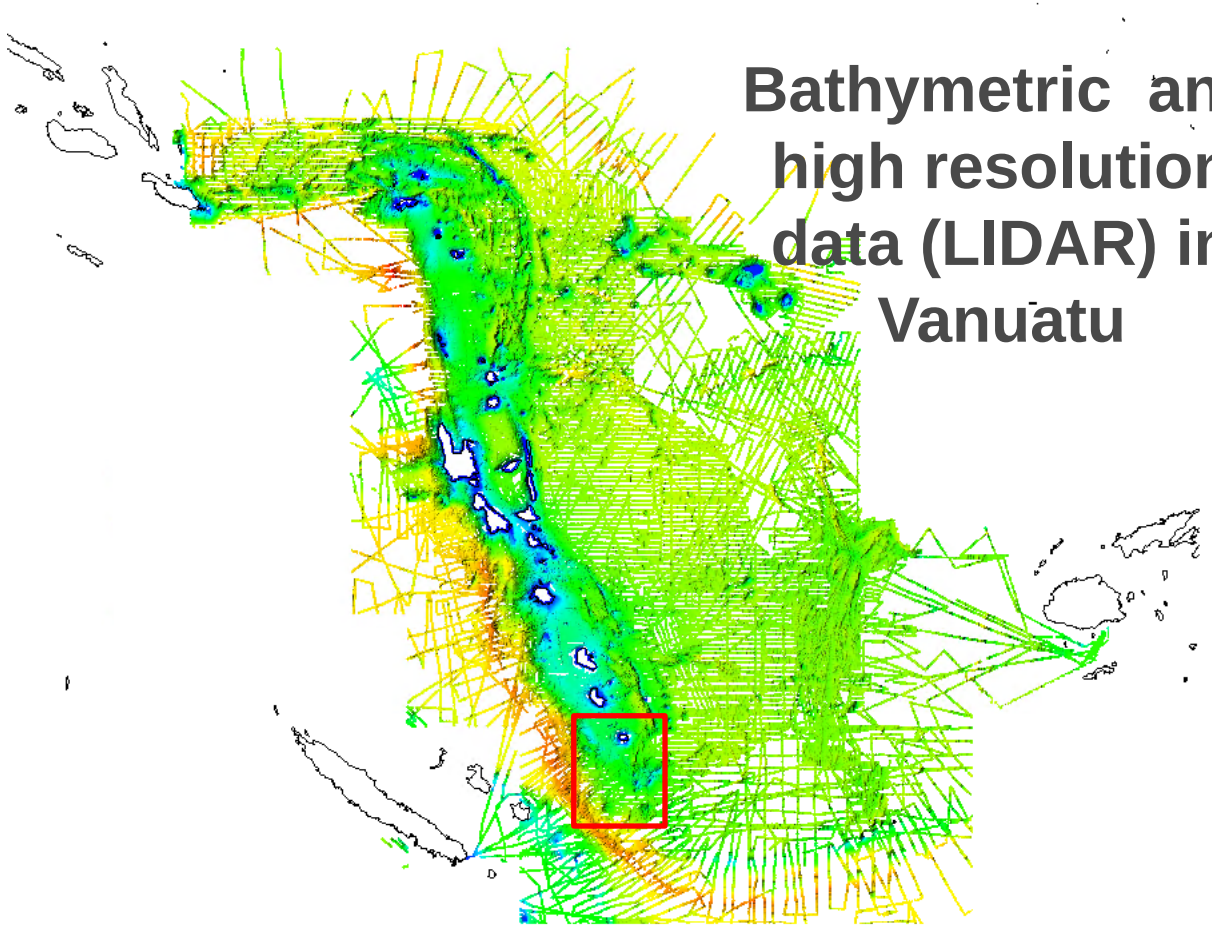
ACCUEIL NAVIGATION RISQUES RESSOURCES AMÉNAGEMENT ENVIRONNEMENT EXPERTISES

Accueil > MNT bathymétrique de façade de la Nouvelle-Calédonie

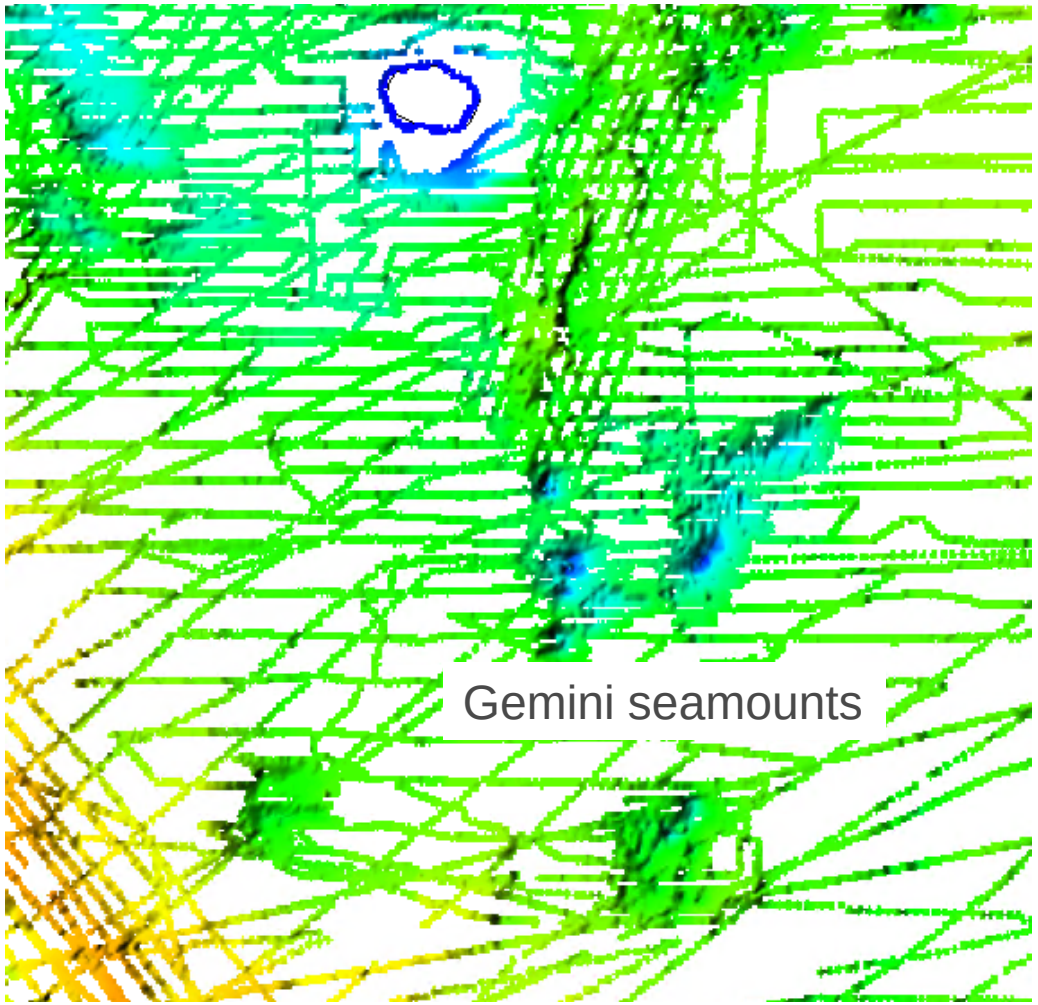
MNT bathymétrique de façade de la Nouvelle-Calédonie



Gaps of knowledge



Bathymetric and high resolution data (LIDAR) in Vanuatu



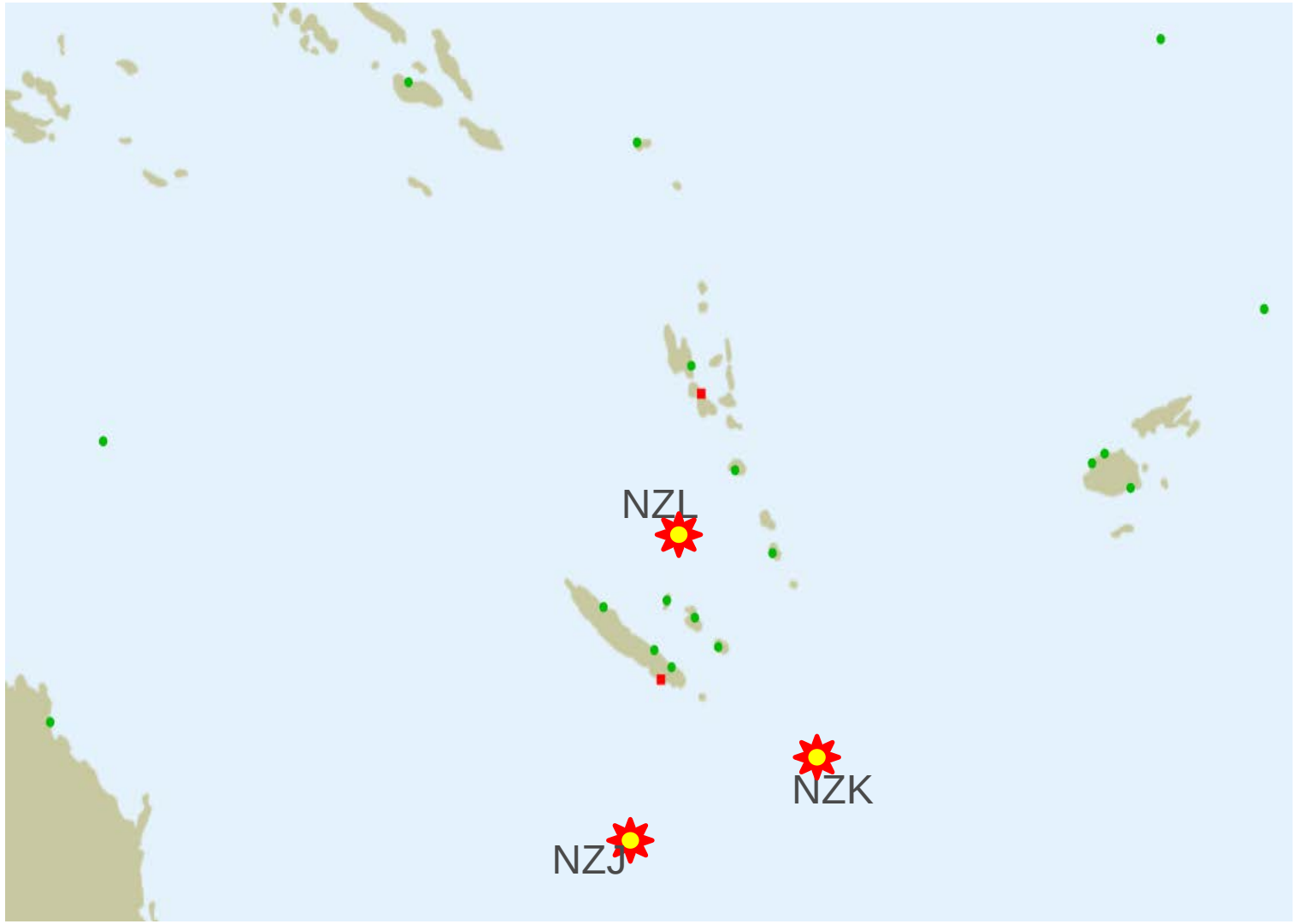
→ Increase knowledge of potential tsunami sources (submarine landslides & volcanoes); better tsunami simulations with high resolution coastal data

Gaps of knowledge

Marigraphic data

Coastal gauges: 7 (NC), 4(VAN)
DART: 3 (NZ) *(off NC),* 2 (AUS)

Attention: LENA is off for more than one year



→ Increase knowledge of tsunami impact in coastal areas; usefull for alert/warning processes and to calibrate tsunami models

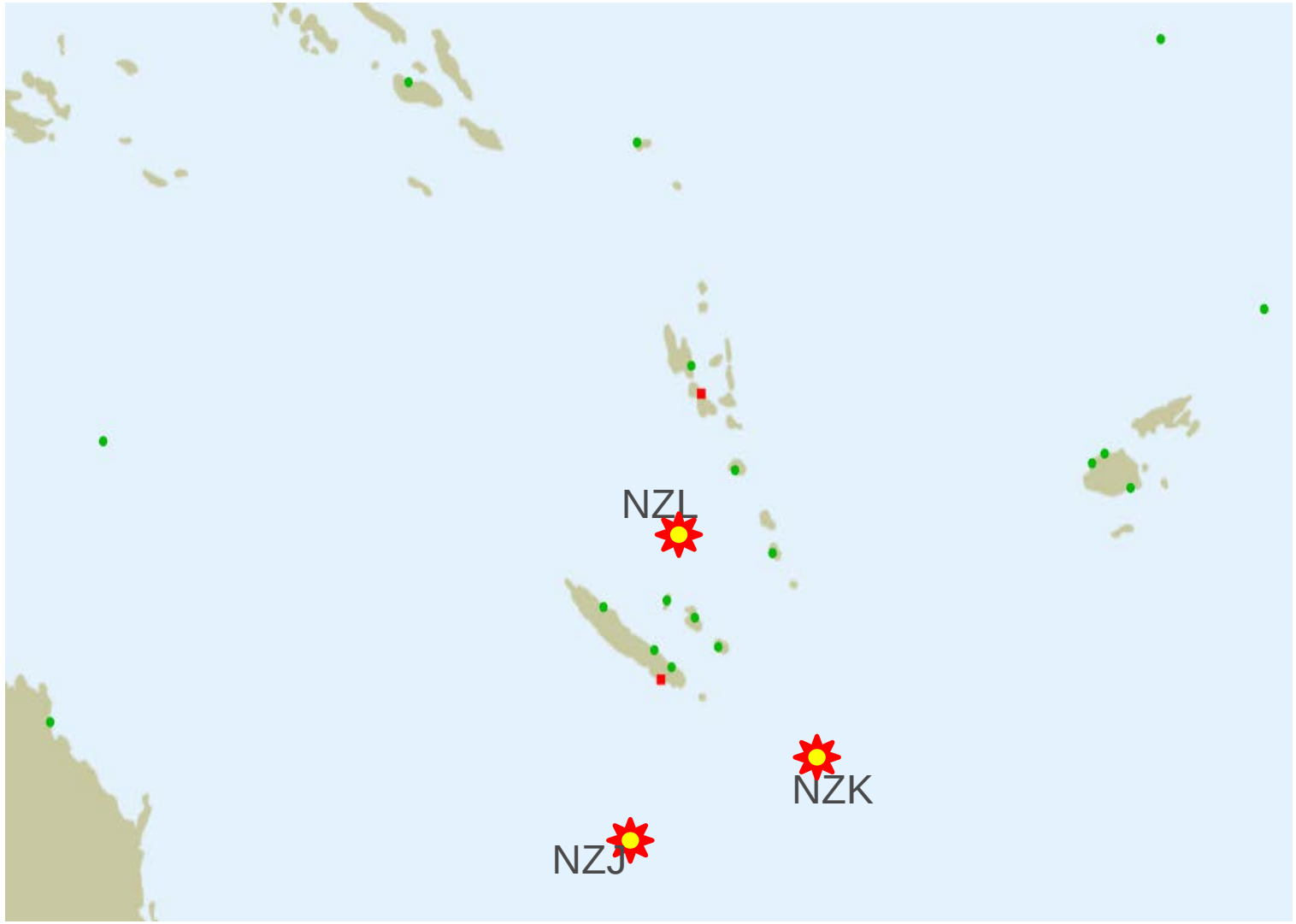
Gaps of knowledge

Marigraphic data

Coastal gauges: 7 (NC), 4(VAN)
DART: 3 (NZ) *(off NC),* 2 (AUS)

Attention: LENA is off for more than one year

→ Insufficient coverage in Vanuatu according to the complexity of the archipelago and large potential of tsunami sources



→ Increase knowledge of tsunami impact in coastal areas; usefull for alert/warning processes and to calibrate tsunami models

Gaps of knowledge

Historical data

→ Written history over ~150 years
→ Not enough information for large events

→Look for tsunami sedimentary records
- NC: PALEOTSU-NC project Oct. 2019 (IRD Nouméa, LMV, Paris 1) (Paris et al., 2023)
- Vanuatu: June 2023 (Analyses: Work in progress)

Hienghène's mangrove

Back beach, Pouébo

Several pumices deposits > 10m altitude
→ Strong eruptions and tsunamis ? Vanuatu, Tonga, elsewhere ?

→ Increase knowledge of tsunami impact in coastal areas

Conclusion

- The VSZ is an active and complexe tectonic zone
- Subduction processes are able to produce at least Mw 8.1-8.2 earthquakes
- It is able to trigger tsunamis regularly, some of them being destructive
- There is an evident lack of knowledge, especially on the Vanuatu side

Conclusion

- The VSZ is an active and complexe tectonic zone
- Subduction processes are able to produce at least Mw 8.1-8.2 earthquakes
- It is able to trigger tsunamis regularly, some of them being destructive
- There is an evident lack of knowledge, especially on the Vanuatu side

→ More researchers should focus on this incredible region !!

What can we expect to be done next ?

- Probabilistic tsunami hazard assessment (PTHA) using the thousands of scenarios from TSUCAL project – collaboration with NC
- Use of real-time DART data in local warning processes (NC/VAN) – collaboration with NZ + SMART cable (!!)
- Focus work on unknown sources (underwater volcanoes, submarine landslides – see method. in Roger et al., 2024, sedimentary studies → more bathy surveys & paleotsunami studies !!
- High-resolution bathymetric data acquisition (LiDAR) for improving coastal simulations
- Perception studies to prepare local populations (see method. in Thomas et al., 2021)


Tankiu tumas !
Yasur, Tanna, Vanuatu

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