

**United Nations Ocean Decade 2021-30  
Safe Ocean Laboratory Satellite Activity  
“Further Challenges for Warnings of Tsunamis”**

**SESSION B**

**What do we know and need to know to warn for  
Tsunamis generated by non-seismic and complex sources ?**

**Keynote**

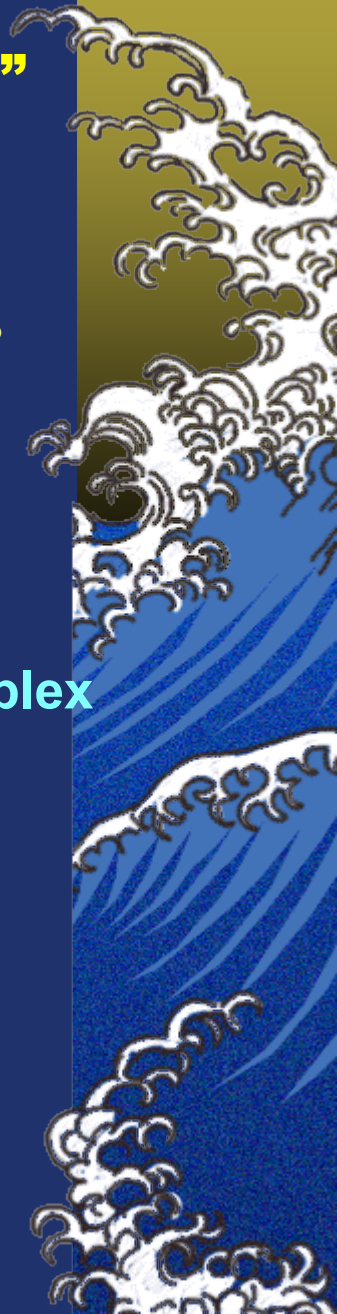
**What are the Tsunamis generated by non-seismic and complex  
sources and how do we warn for them ?**

**François Schindelé**

*(International Tsunami expert – CEA – France*

*Past Chair ICG/PTWS, ICG/NEAMTWS*

*UN Decade Tsunami Programme Scientific Committee)*



# “Further Challenges for Warnings of Tsunamis”

What are the Tsunamis generated by non-seismic and complex sources ?

- **Three types of non-seismic sources :**

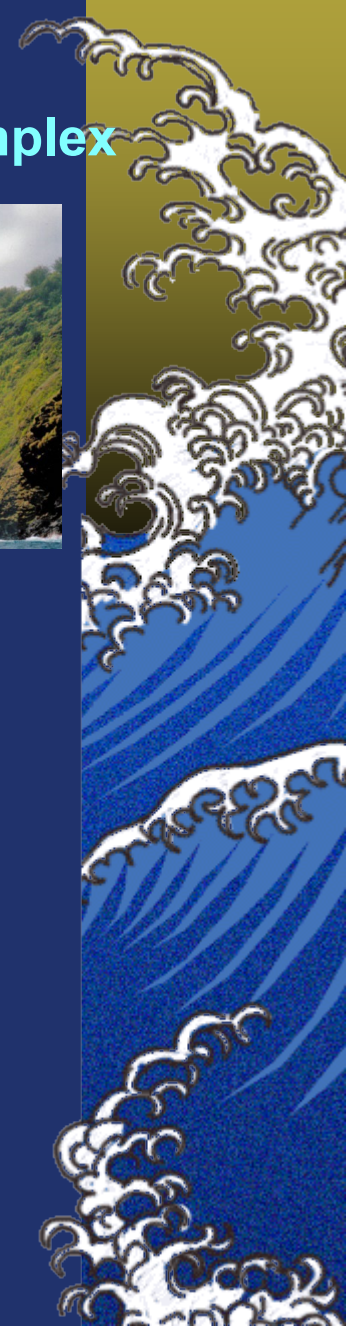
- *Landslides (Aerial , submarine, combined)*



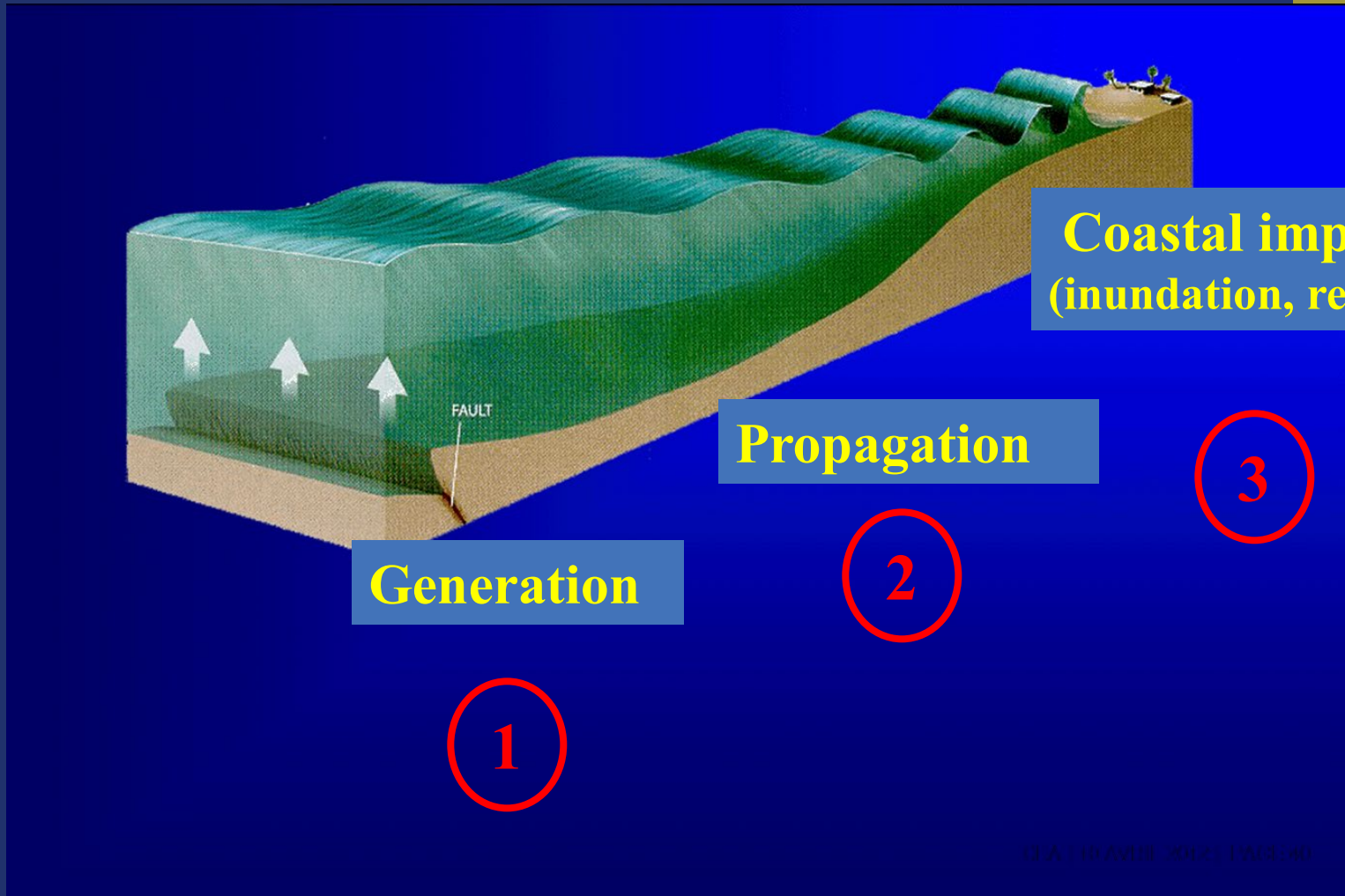
- *Volcano ( seven types of sources – Item 4 by Raphaël Paris)*



- *Meteo tsunami*



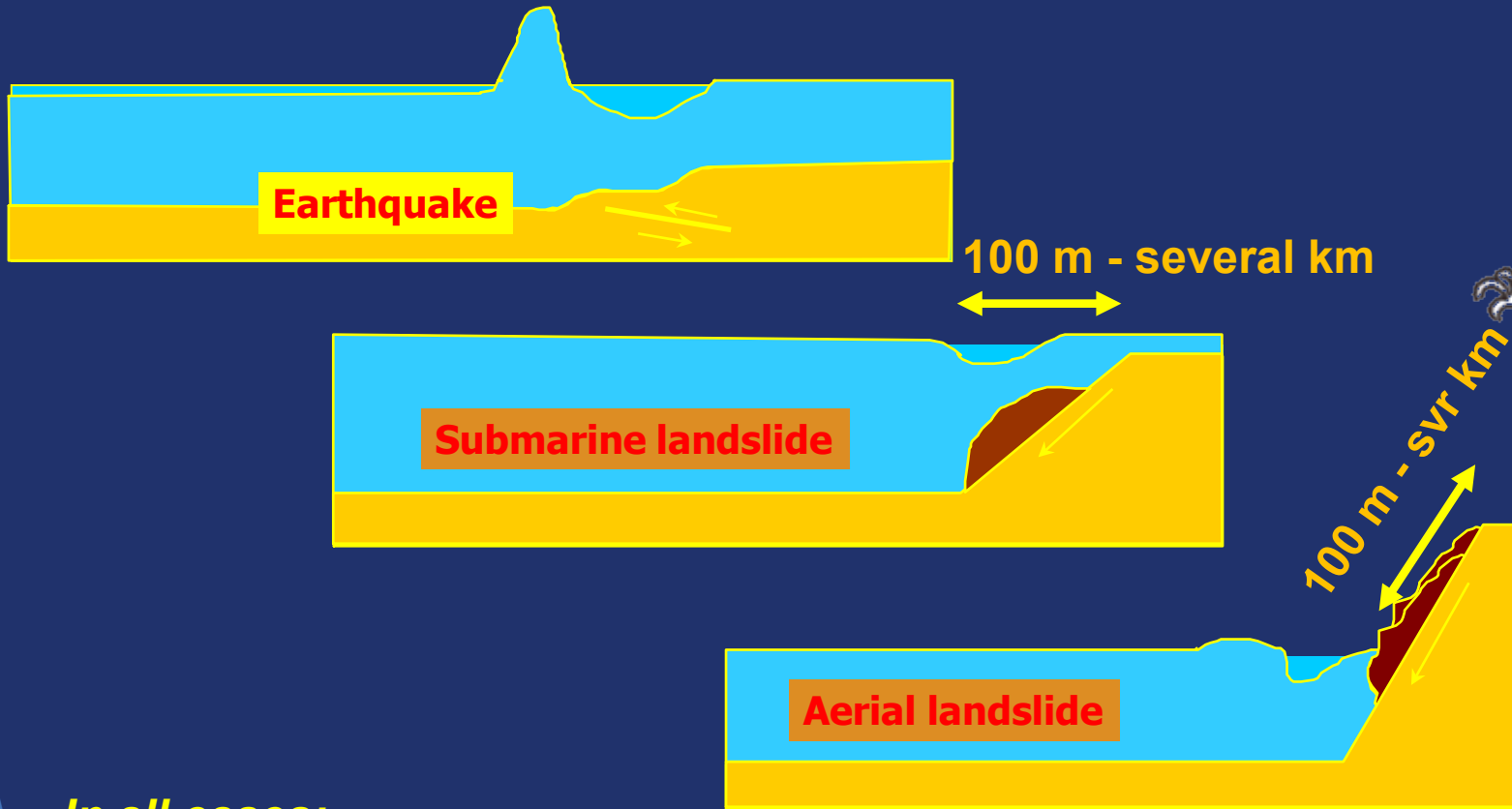
# 3 steps of tsunami phenomena



© IAN HARRIS 2002/1993/90

# The sources of tsunamis

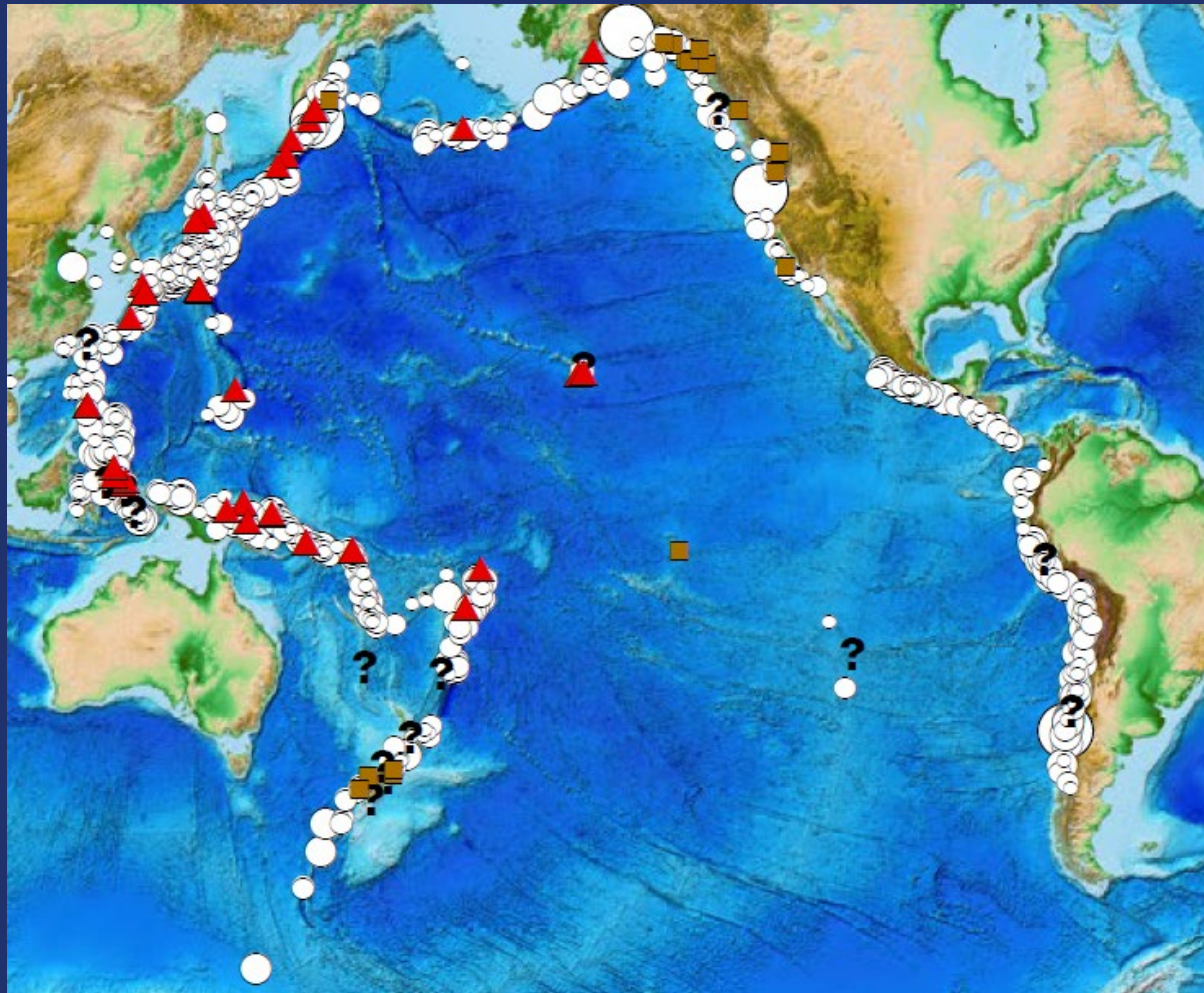
SIZE 10 km – >200 km



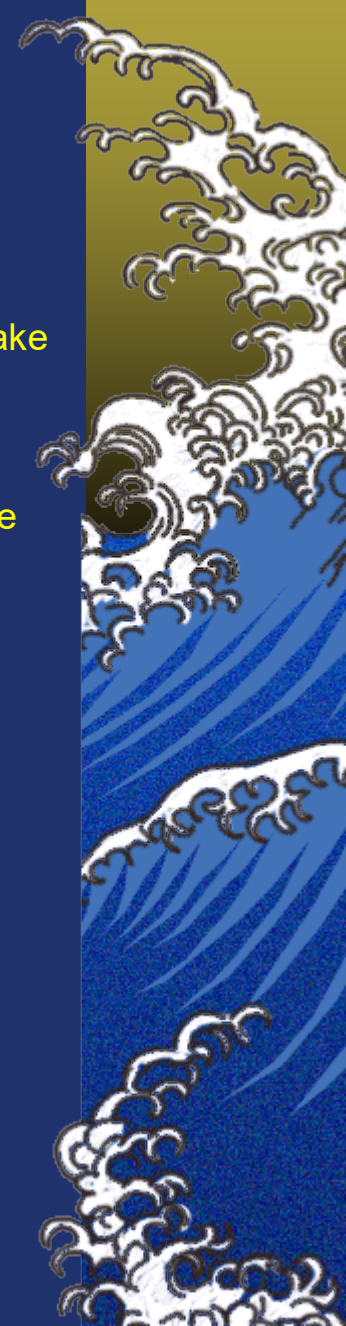
- ✦ **In all cases:**
  - ✦ water column deformation (up-lift or/and down-lift)
- ✦ **Gravity wave propagation**

# “Further Challenges for Warnings of Tsunamis”

## Pacific Tsunami Sources



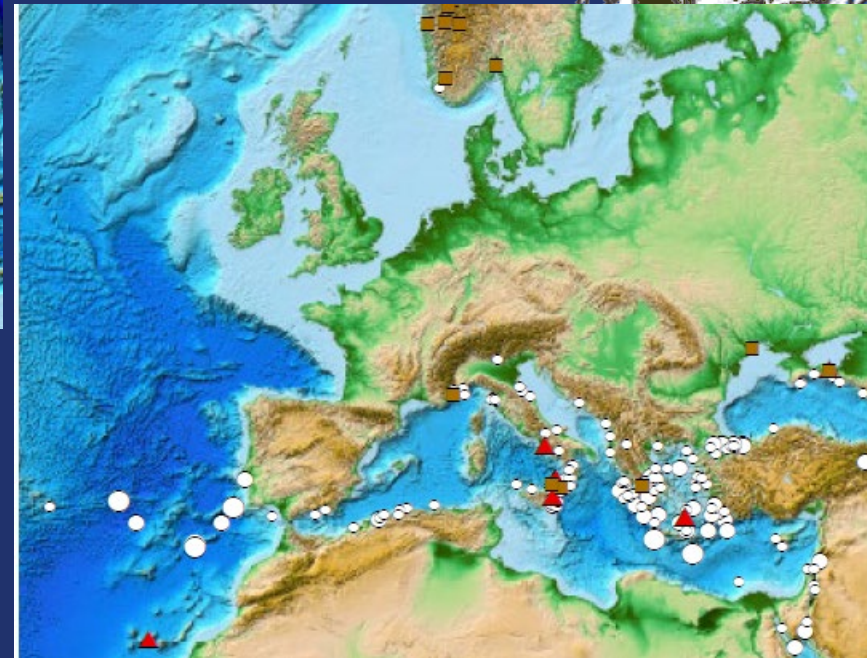
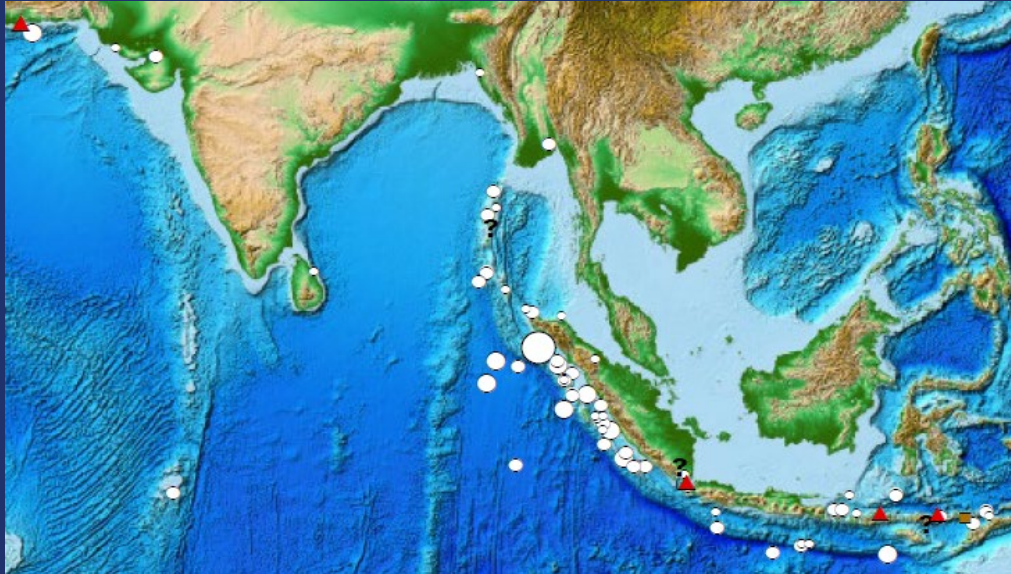
- Earthquake
- ▲ Volcano
- Landslide



# “Further Challenges for Warnings of Tsunamis”

Indian Ocean –

North east Atlantic-Mediterranean

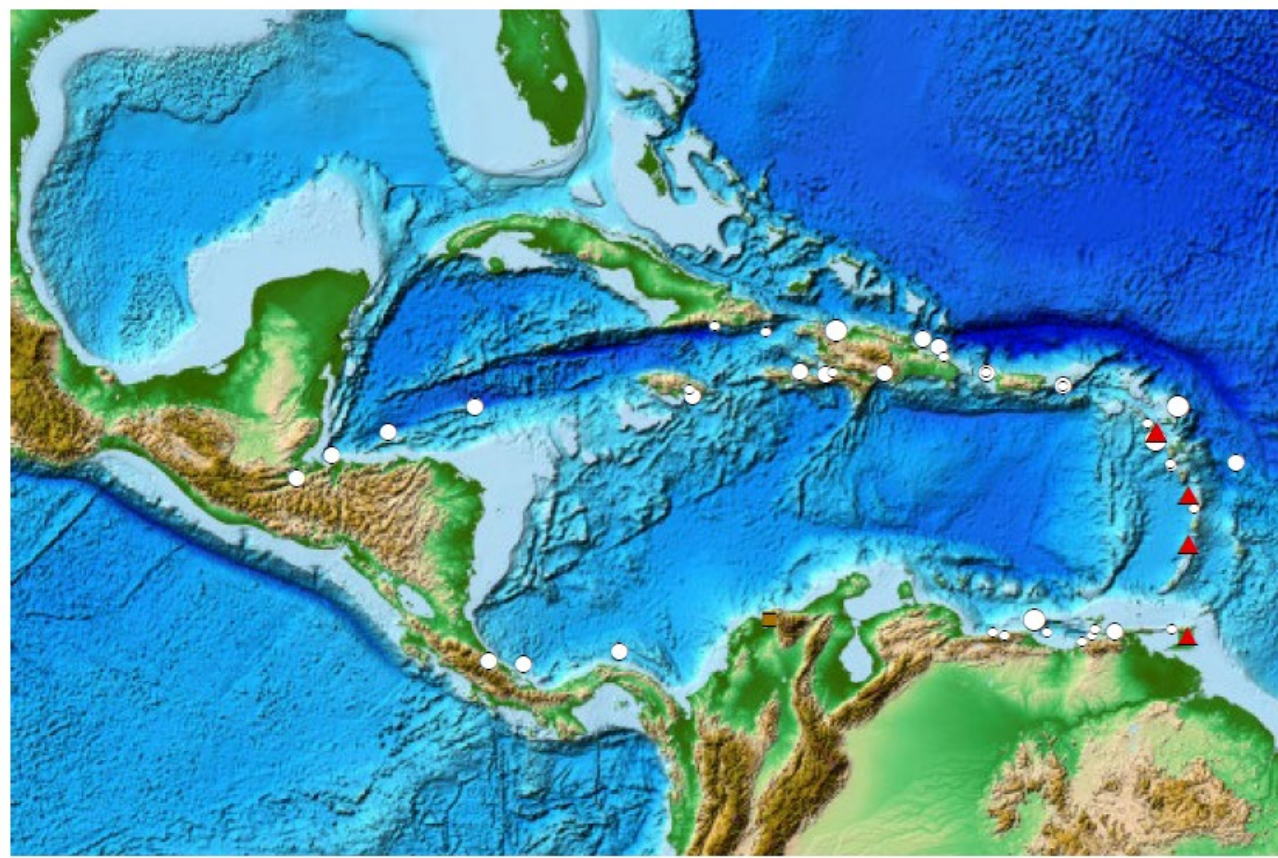


- Earthquake
- ▲ Volcano
- Landslide

IOC Tsunami Glossary

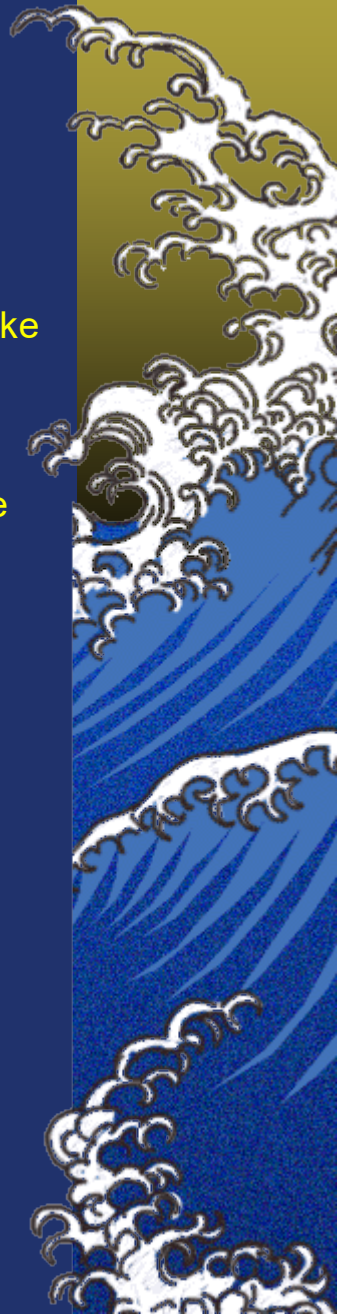
# “Further Challenges for Warnings of Tsunamis”

## Caribbean Tsunami Sources

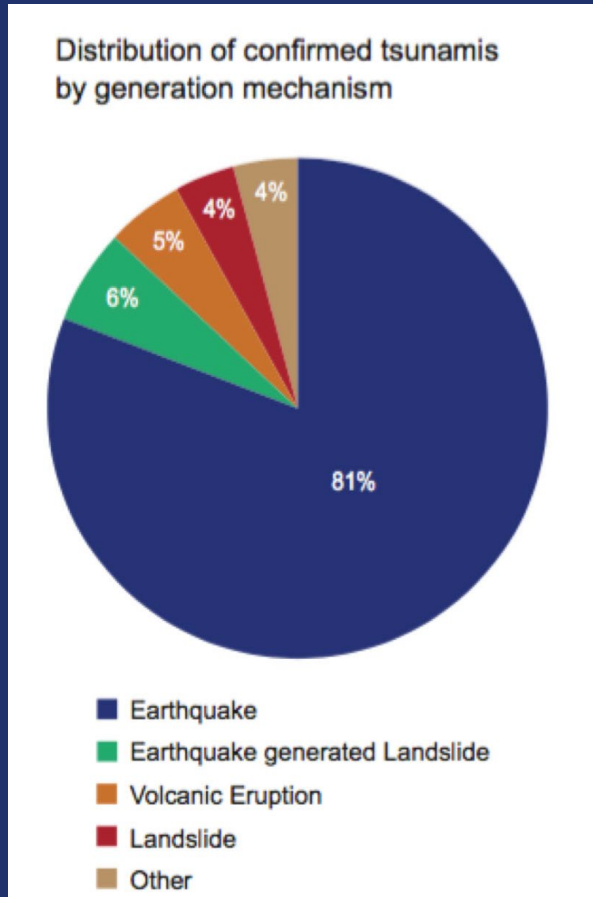


- Earthquake
- ▲ Volcano
- Landslide

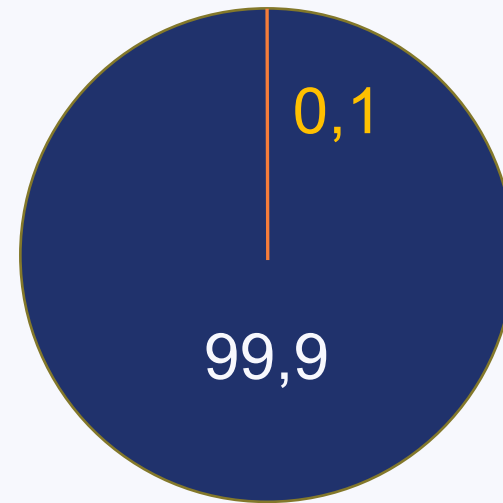
IOC Tsunami Glossary



# Distribution of confirmed tsunami by generation mechanism



## Distribution of transoceanic tsunamis (impact > 1000 km) by generation mechanism



- 3 **Volcanic** eruptions :
- Santorini -1650 BC
  - Krakatau August 1883
  - HungaTonga 15/01/2022

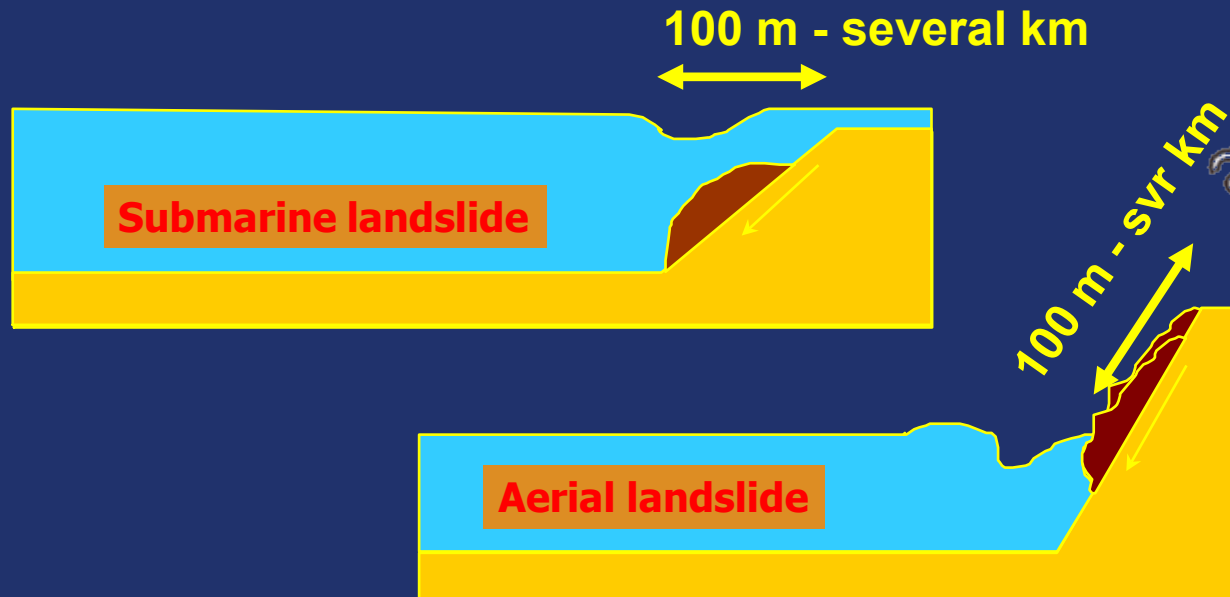
**19 % tsunamis are generated by non-seismic or complex sources**



# Landslides tsunamis

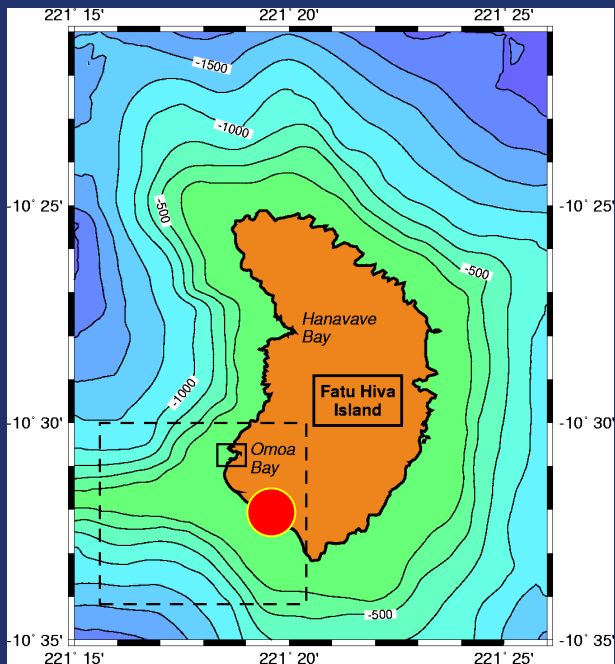
## Problem of detection

- *Landslides generate earth surface deformation and seismic waves*



- *Small size of source => Seismic waves of small amplitude, in comparison to earthquake.*
- *Equivalent magnitude < 5,0 (most < 4,0)*
  - *No robust Automatic Discriminate method of earthquake and landslide*
  - *Implementation of local monitoring systems to detect landslide*

# Fatu Hiva local tsunami (13 sept. 1999) French Polynesia



UNE I  
S'EST ABATTU

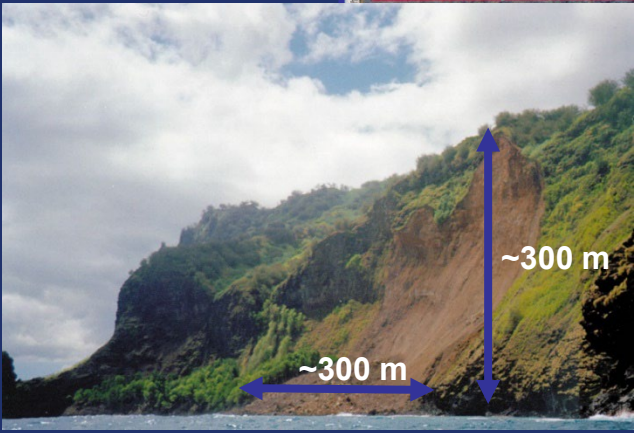
HIVA

## LE RAZ DE MARÉE DÉFERLE SUR L'ÉCOLE

Le témoignage de la directrice de l'école de l'omoa, à la page 5 de l'évaluation des dégâts.

P. 2

1996



E. Okal, 1999

# Groendland 2017



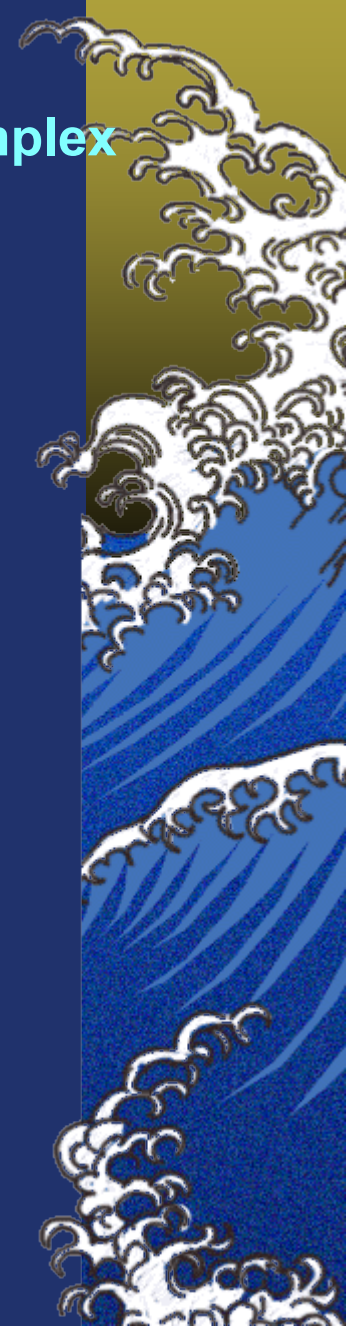
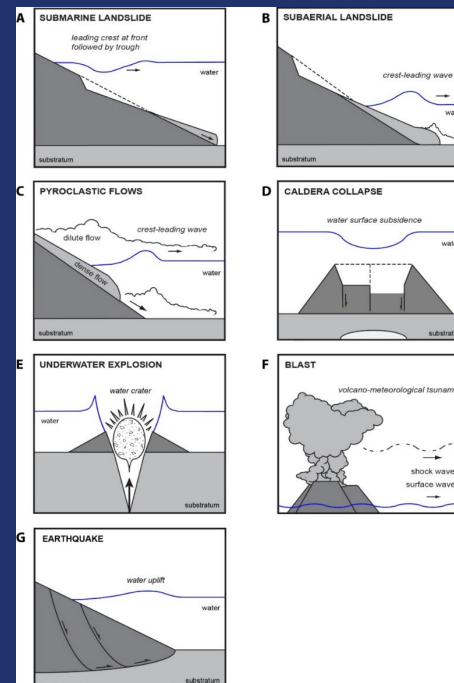
# “Further Challenges for Warnings of Tsunamis”

What are the Tsunamis generated by non-seismic and complex sources ?

- **Complex sources :**

- *Earthquake and Landslide (Aerial , submarine, combined)*

- *Volcano ( 7 types of sources )  
Item 4 by Raphael Paris*



# Complex Source : EQ and submarine Landslide Aitape PNG July 17 1998

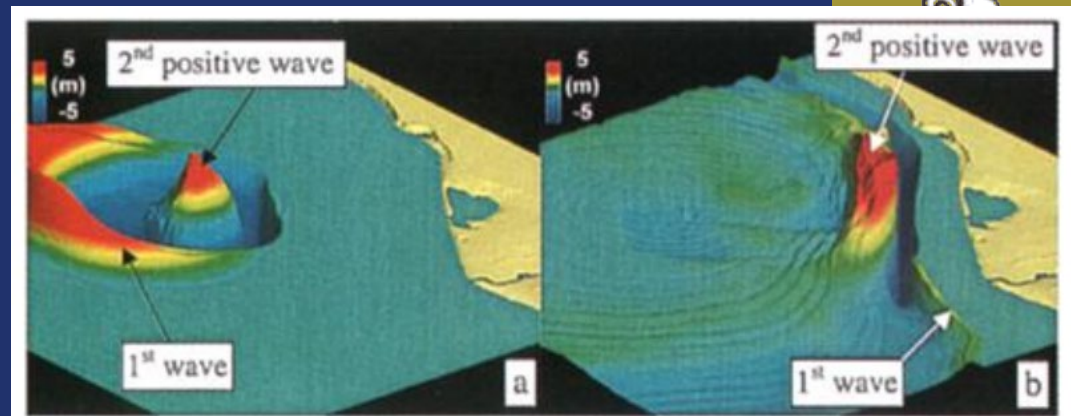
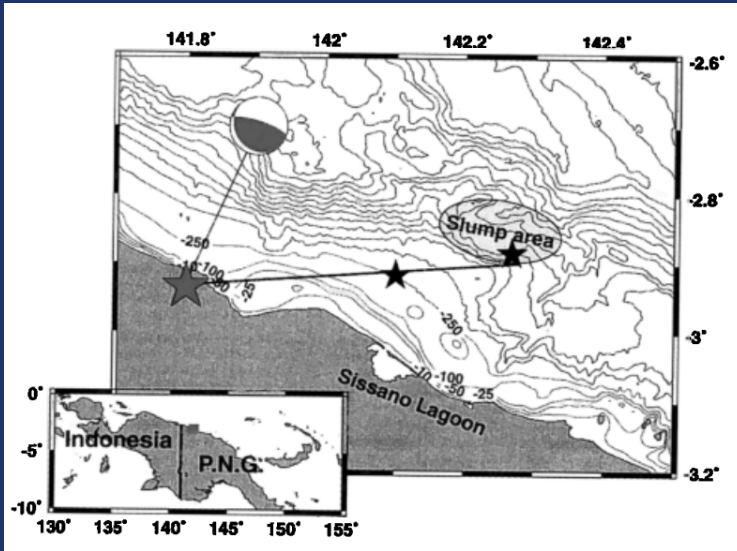
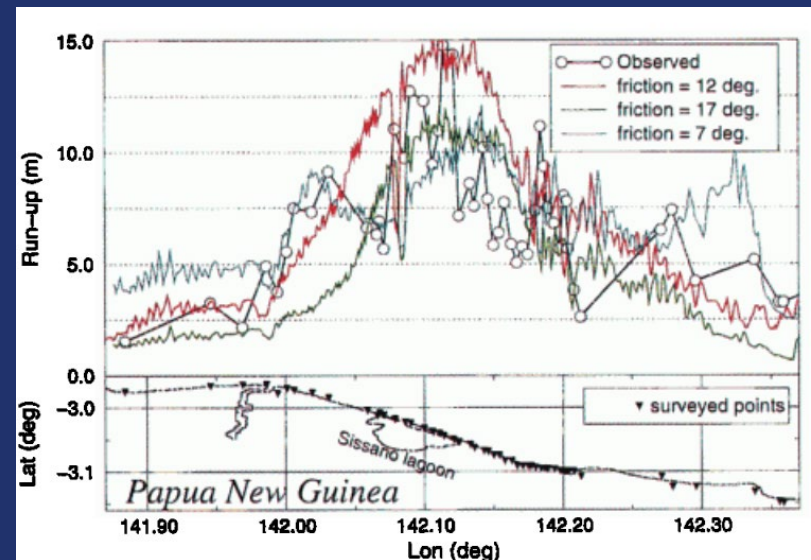


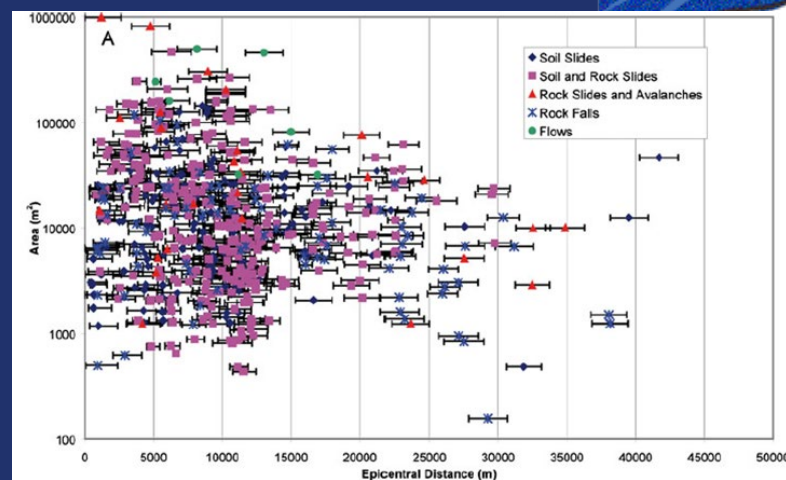
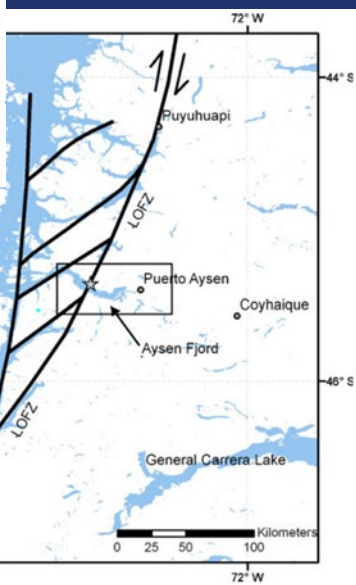
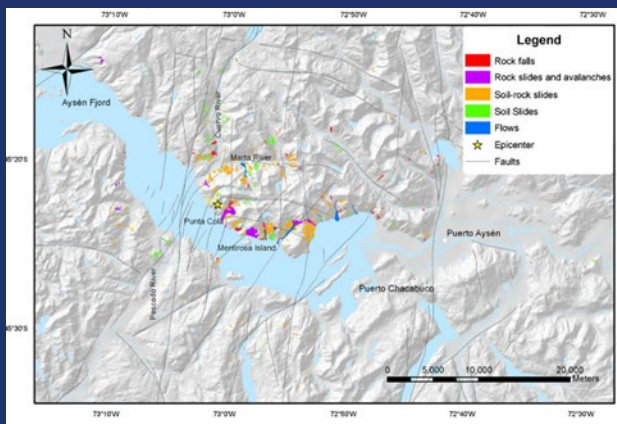
Figure 4. Snapshots of the computed water surface at  $t=90$  s (a) and  $t=360$  s (b) after the slide initiation. Same horizontal



Heinrich et al. GRL, 2000

# Complex Source : Earthquake and 500 aerial landslides

## Chile April 21 2007 Aysen Fjord M 6,2



*Sepulveda et al. Landslides , 2010*

# “Further Challenges for Warnings of Tsunamis”

How to warn tsunamis generated by non-seismic and complex sources ?

- **Three types of non-seismic sources :**

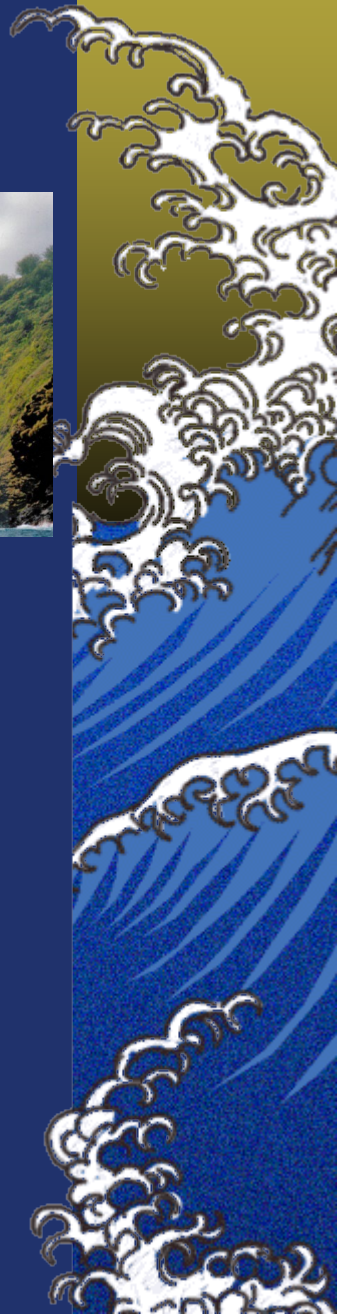
- *Landslides (Aerial , submarine, combined)*



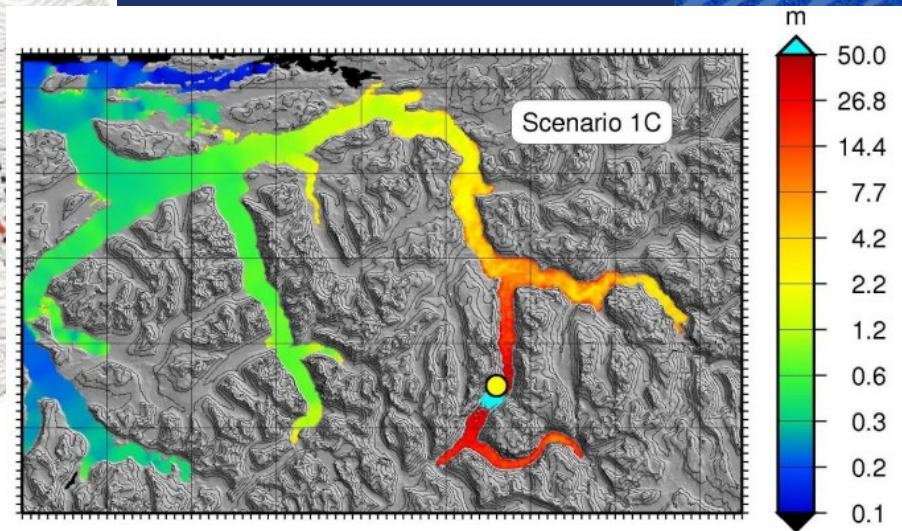
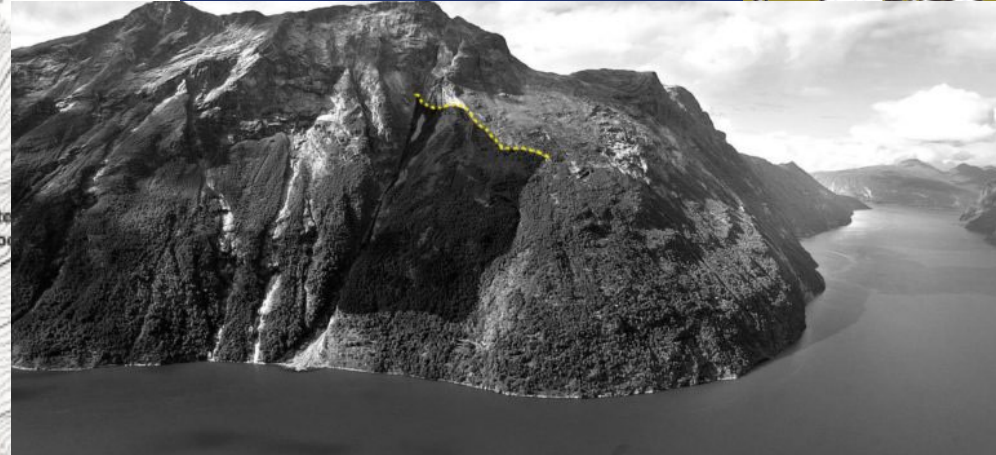
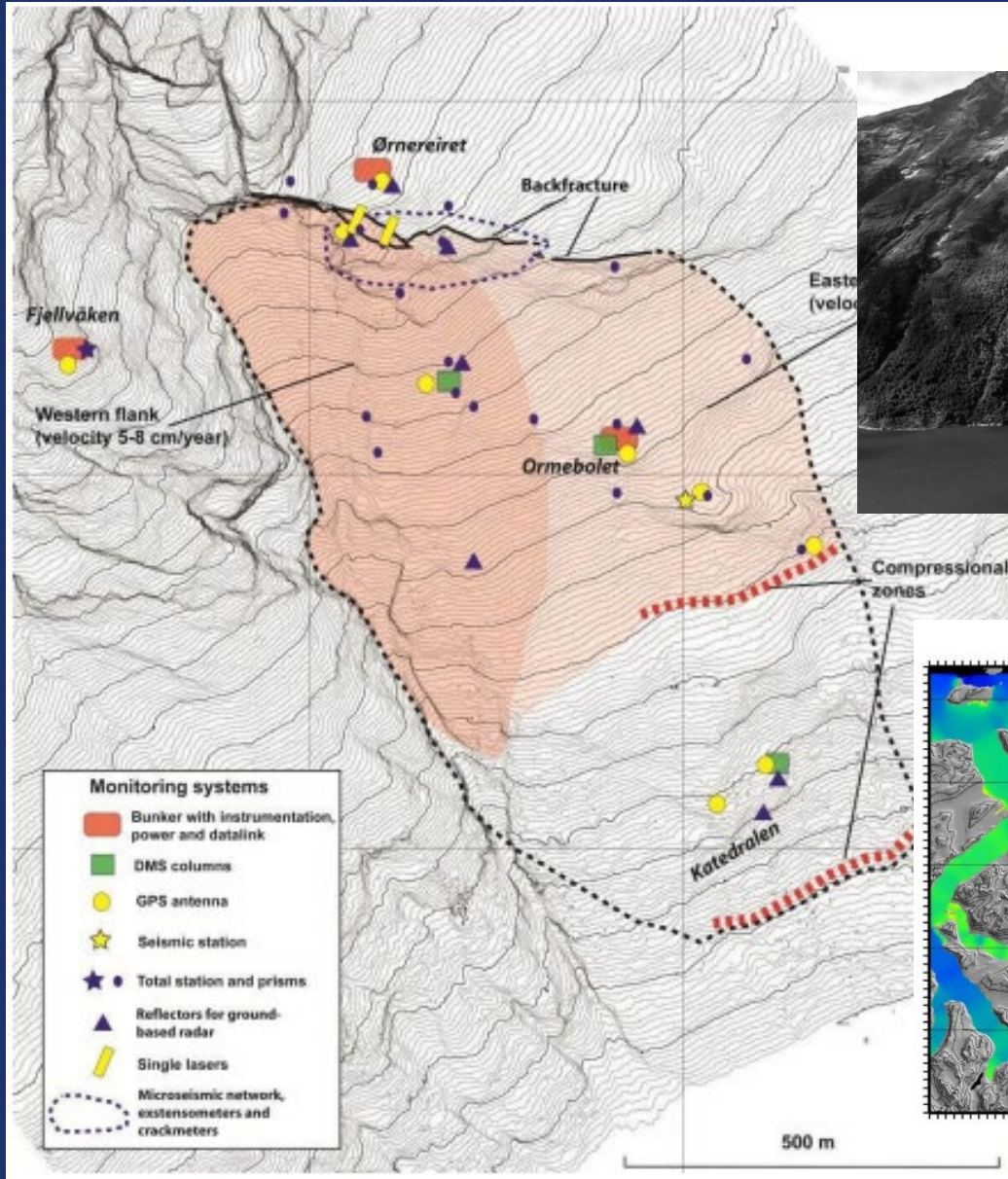
- *Volcano ( seven types of sources – Item 4 by Raphaël Paris)*



- *Meteo tsunami*



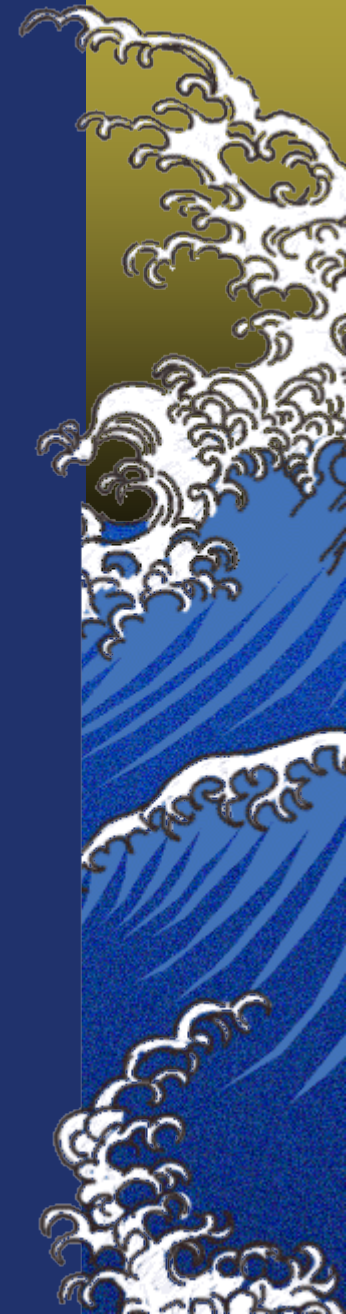
# Aknes (Norway) Rockslide monitoring and warning system



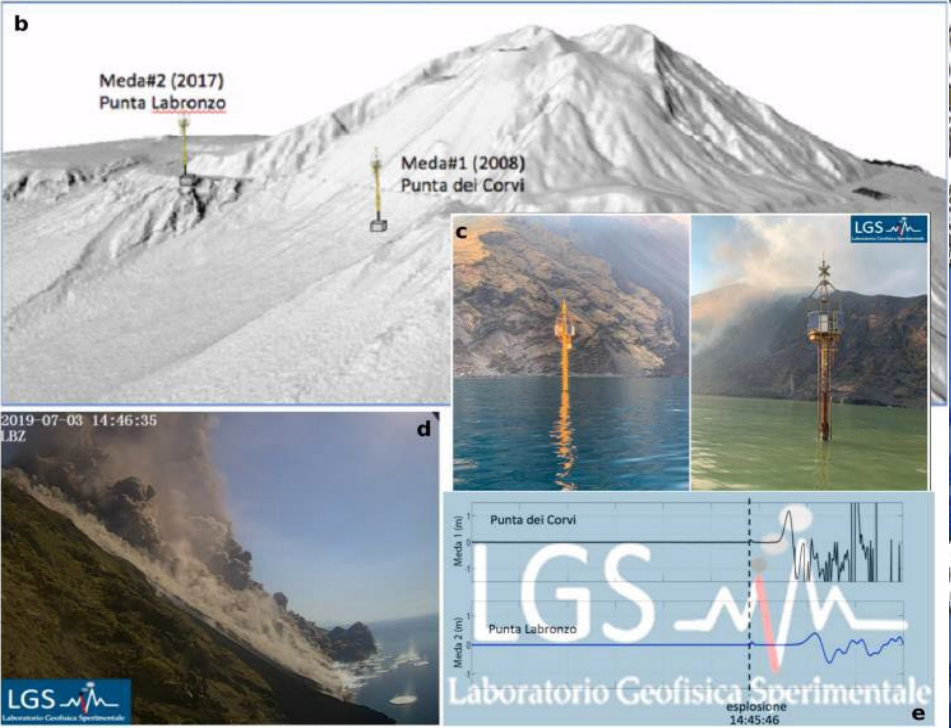
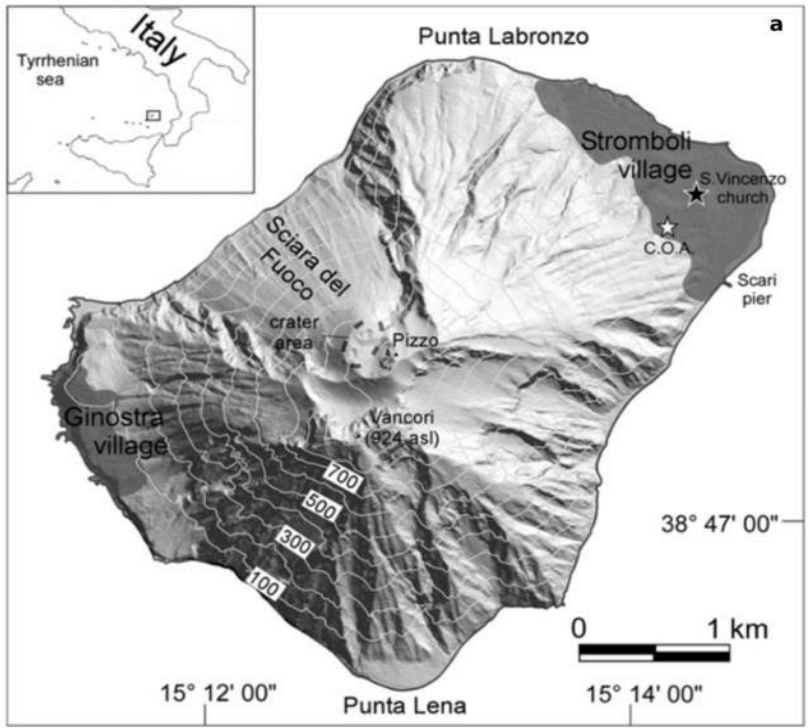


# Aknes (Norway) warning system

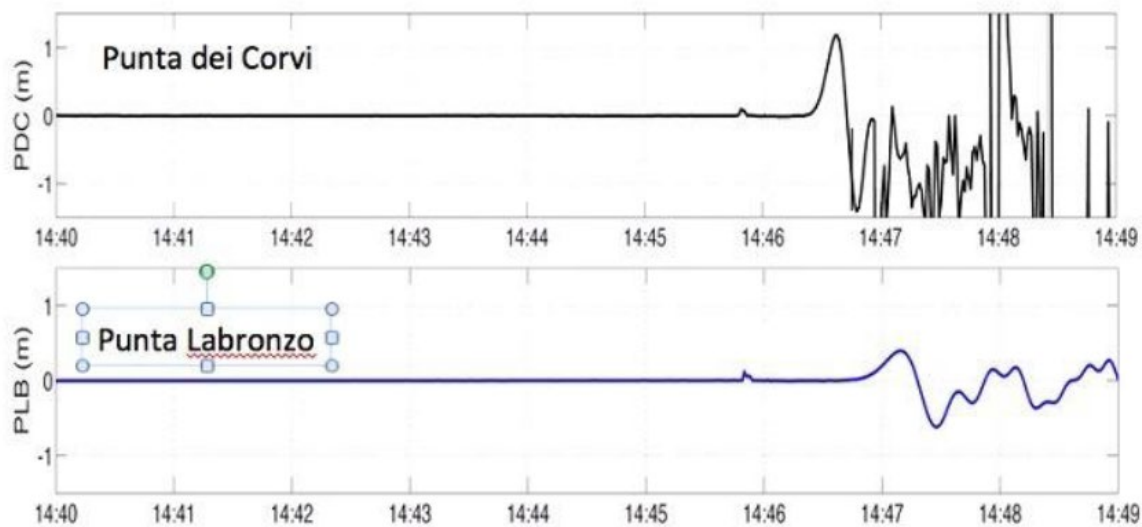
Geologisk situasjon	Farenivå	Beredskapsnivå og -tiltak
Stabil bevegelse med sesongvariasjoner	Lav fare	<b>Grønn beredskap:</b> <ul style="list-style-type: none"><li>• Overvåking</li><li>• Planlegging</li><li>• Øving</li></ul>
Økt bevegelse, utover sesongvariasjon	Moderat fare	<b>Gul beredskap:</b> <ul style="list-style-type: none"><li>• Intensivert overvåking</li><li>• Gjennomgang av planverk</li><li>• Aktivisering av samordningsfora</li><li>• Forberede komplekse tiltak</li><li>• Informasjonstiltak</li></ul>
Akselererende bevegelse	Høy fare	<b>Oransje beredskap:</b> <ul style="list-style-type: none"><li>• Intensivert beredskap</li><li>• Flytting av sårbare objekt</li><li>• Reduksjon av aktivitet og ferdsel</li></ul>
Skred nært forestående	Ekstrem fare	<b>Rød beredskap:</b> <ul style="list-style-type: none"><li>• Evakuering</li><li>• Redning</li></ul>
Skred har gått, kan gå igjen		<b>Rød beredskap:</b> <ul style="list-style-type: none"><li>• Opprettholdelse av evakuering</li><li>• Reetablering av overvåking</li></ul>



# Stromboli (Italy) Tsunami Warning system



# Stromboli 2019

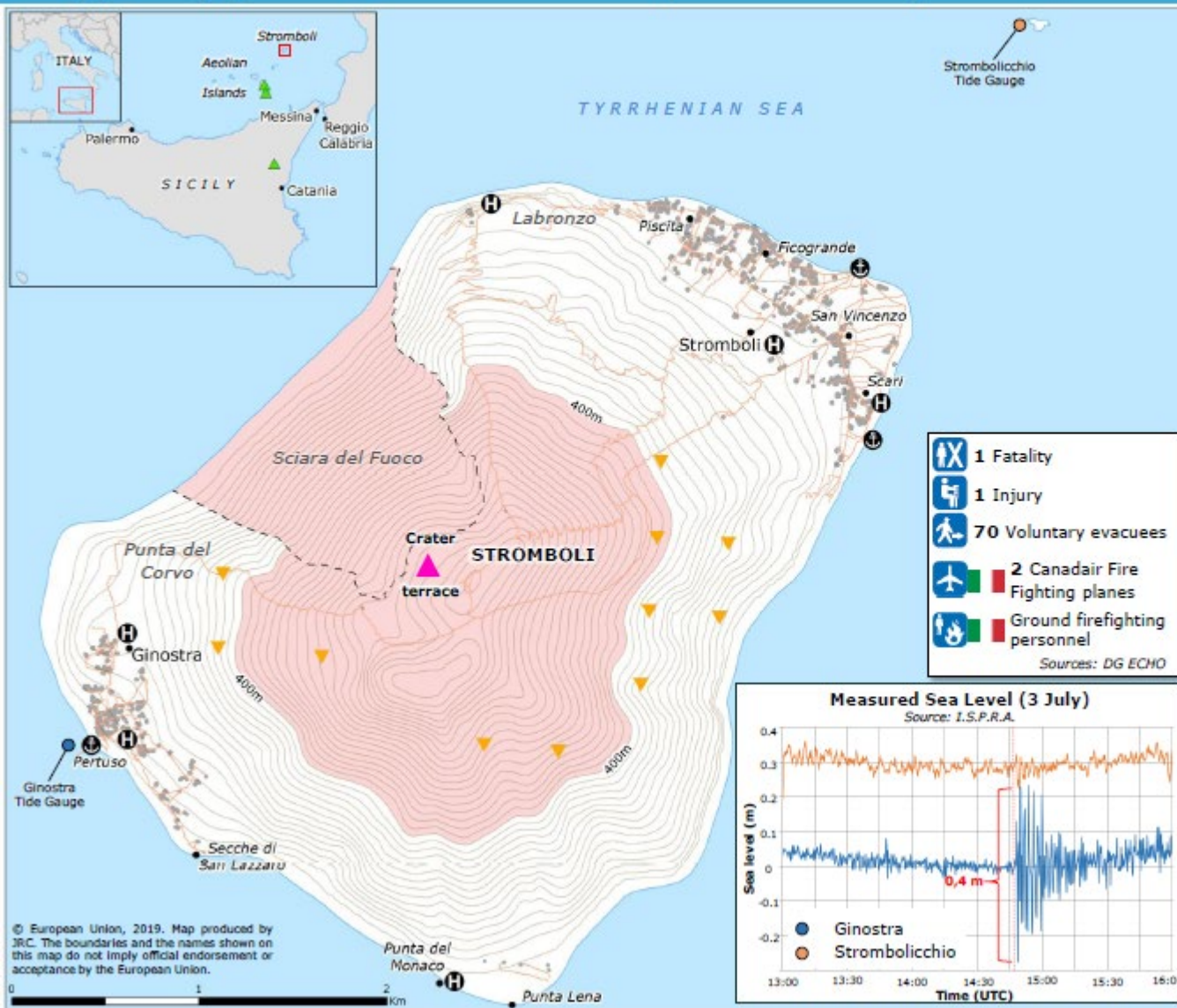


Sea level signals from the University of Florence

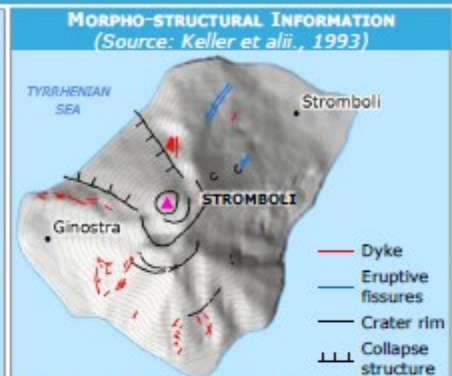
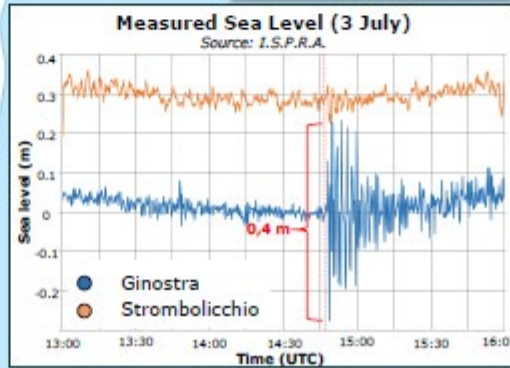
# Stromboli 2019

Emergency Response Coordination Centre (ERCC) – DG ECHO Daily Map | 04/07/2019

## Italy, Sicily | Stromboli Volcano Eruption of 3 July



- 1 Fatality
  - 1 Injury
  - 70 Voluntary evacuees
  - 2 Canadair Fire Fighting planes
  - Ground firefighting personnel
- Sources: DG ECHO



### SIGNIFICANT STROMBOLI VOLCANO ERUPTION SINCE 1900 (Source: NOAA NCEI)

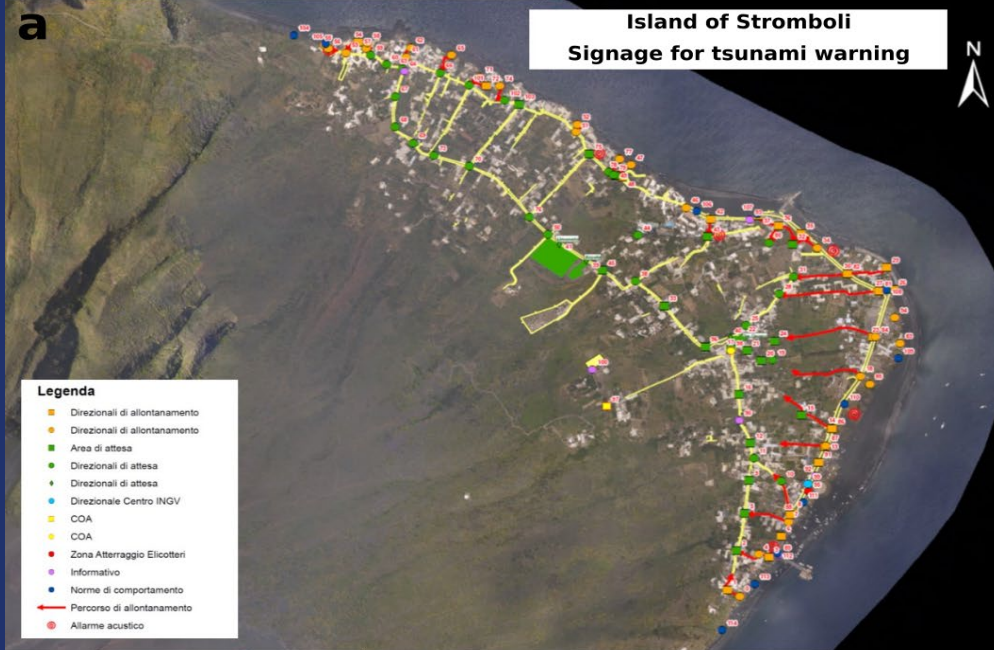
Date	Associated Events
3 Jul 1916	
22 May 1919	
11 Sept 1930	
20 Aug 1944	
Feb-Mar 1954	
24 Jul 1986	
20 Oct 2001	
30 Dec 2002	

- Volcano
- Active volcano
- No-access Zone
- Active Fires detected by JRC-EFFIS as of 4 July (VIIRS)
- Settlement
- Landslide
- Tsunami
- Heliport
- Sea Jetty

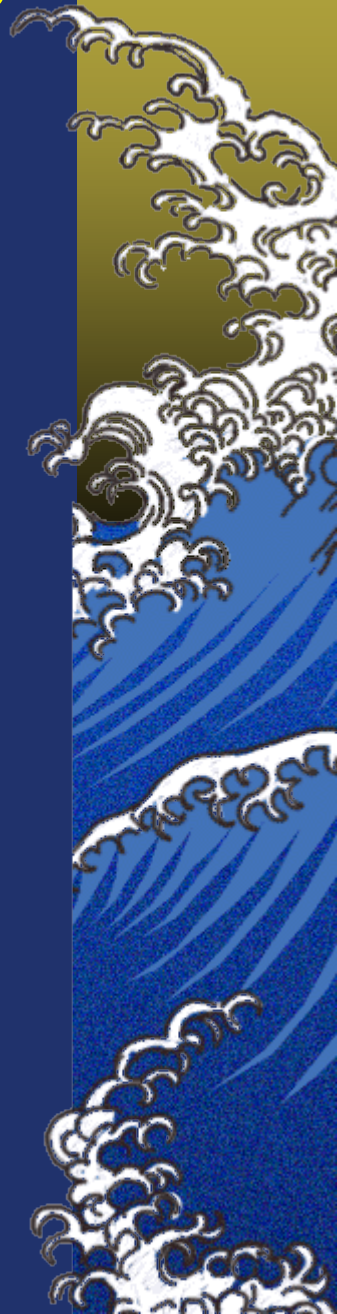
© European Union, 2019. Map produced by JRC. The boundaries and the names shown on this map do not imply official endorsement or acceptance by the European Union.

Sources: GDACS, Smithsonian Institute, Lipari Municipality

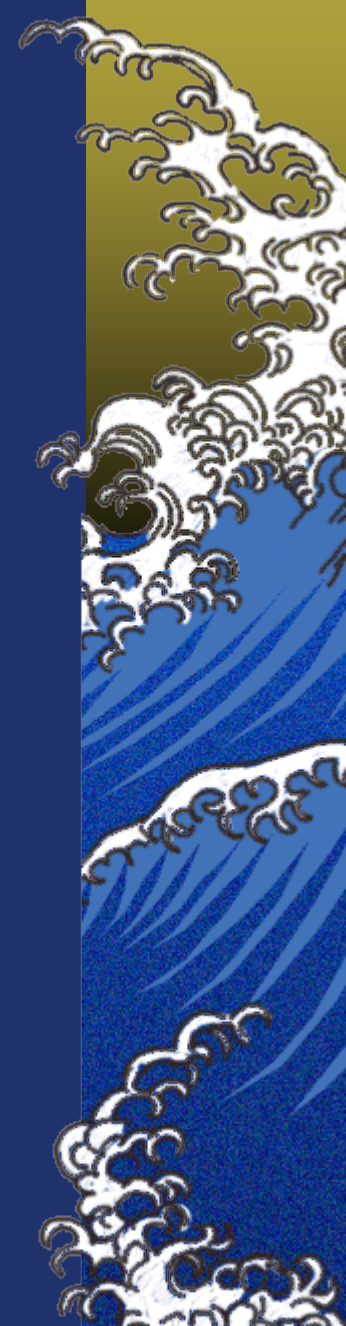
# Stromboli (Italy) Tsunami Warning system



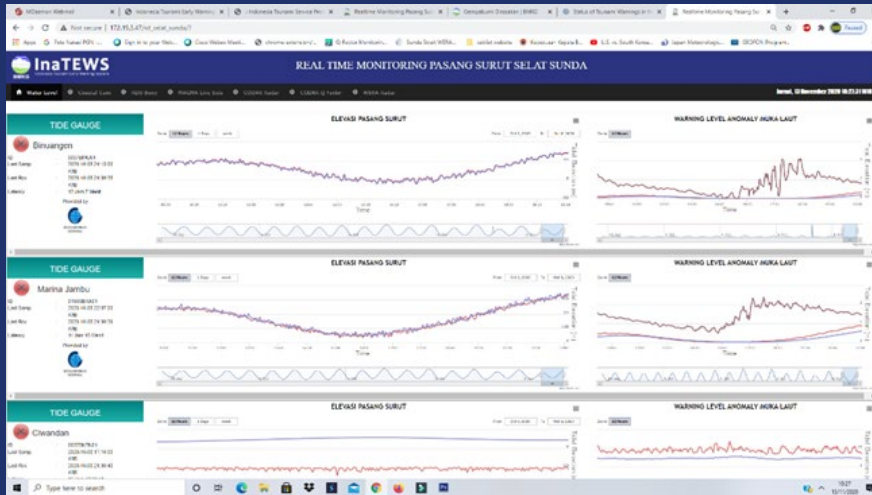
*(photos curtesy of  
Dipartimento della protezione civile)*



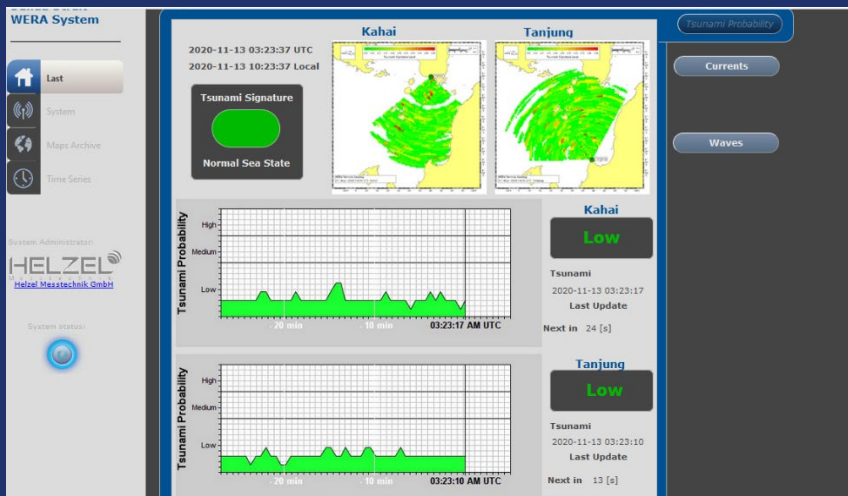
# Krakatau (Indonesia) monitoring system



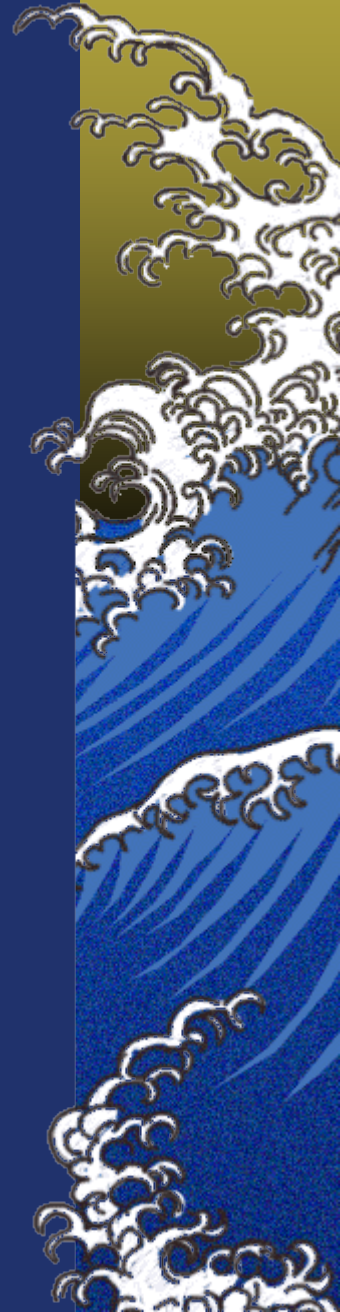
# Krakatau monitoring system



Sea level  
Monitoring



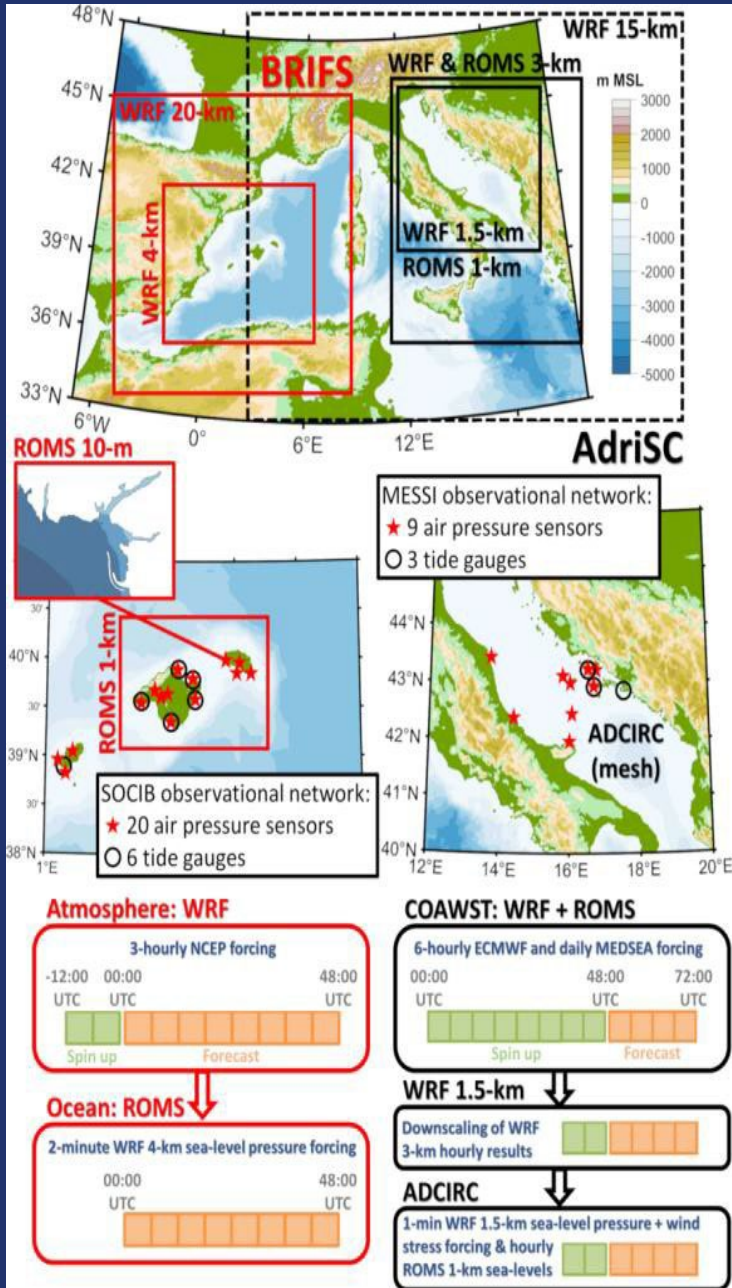
WERA Radar  
Monitoring



# Meteo-tsunami Warning systems

## Balearic Islands BRIFS (Spain)

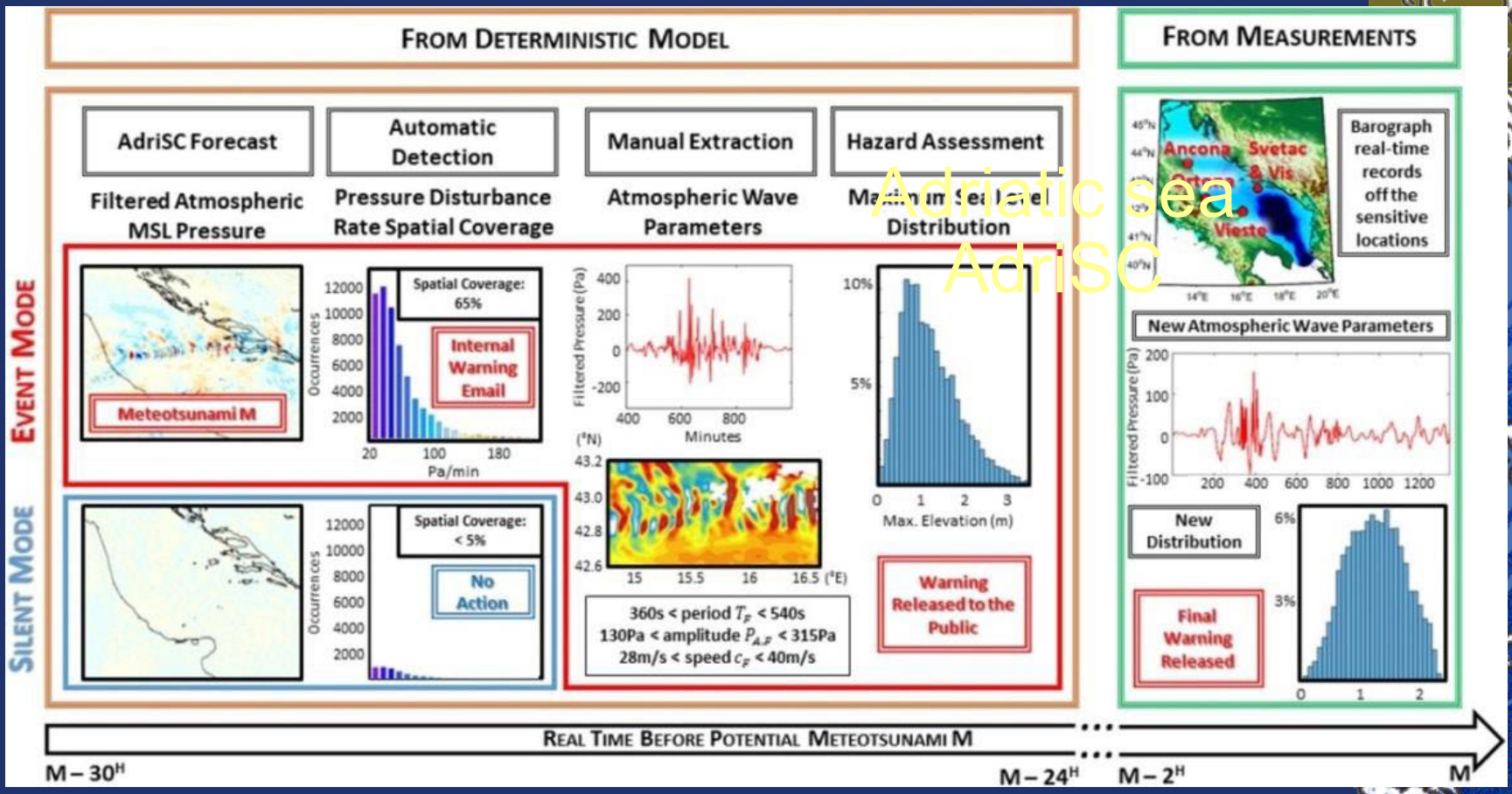
## Adriatic sea AdriSC (Croatia)





# Meteo-tsunami Warning systems

Adriatic sea  
AdriSC



Adriatic sea  
AdriSC

# “Further Challenges for Warnings of Tsunamis”

What are the Tsunamis generated by non-seismic and complex sources and how do we warn for them ?

- **Three types of non-seismic sources :**
  - *Landslides (Aerial , submarine, combined)*
  - *Volcano ( seven types of sources)*
  - *Meteo tsunami*
- **Complex sources :**
  - *Earthquake and Landslide (Aerial , submarine, combined)*
  - *Volcano ( 7 types of sources )*
- **A very few number warning systems are in place :**
  - *Landslides (Norway, Alaska, ?)*
  - *Volcano ( Stromboli (Italy), Krakatau (Indonesia), ?)*
  - *Meteo tsunami (Balearic, Adriatic, ?)*

