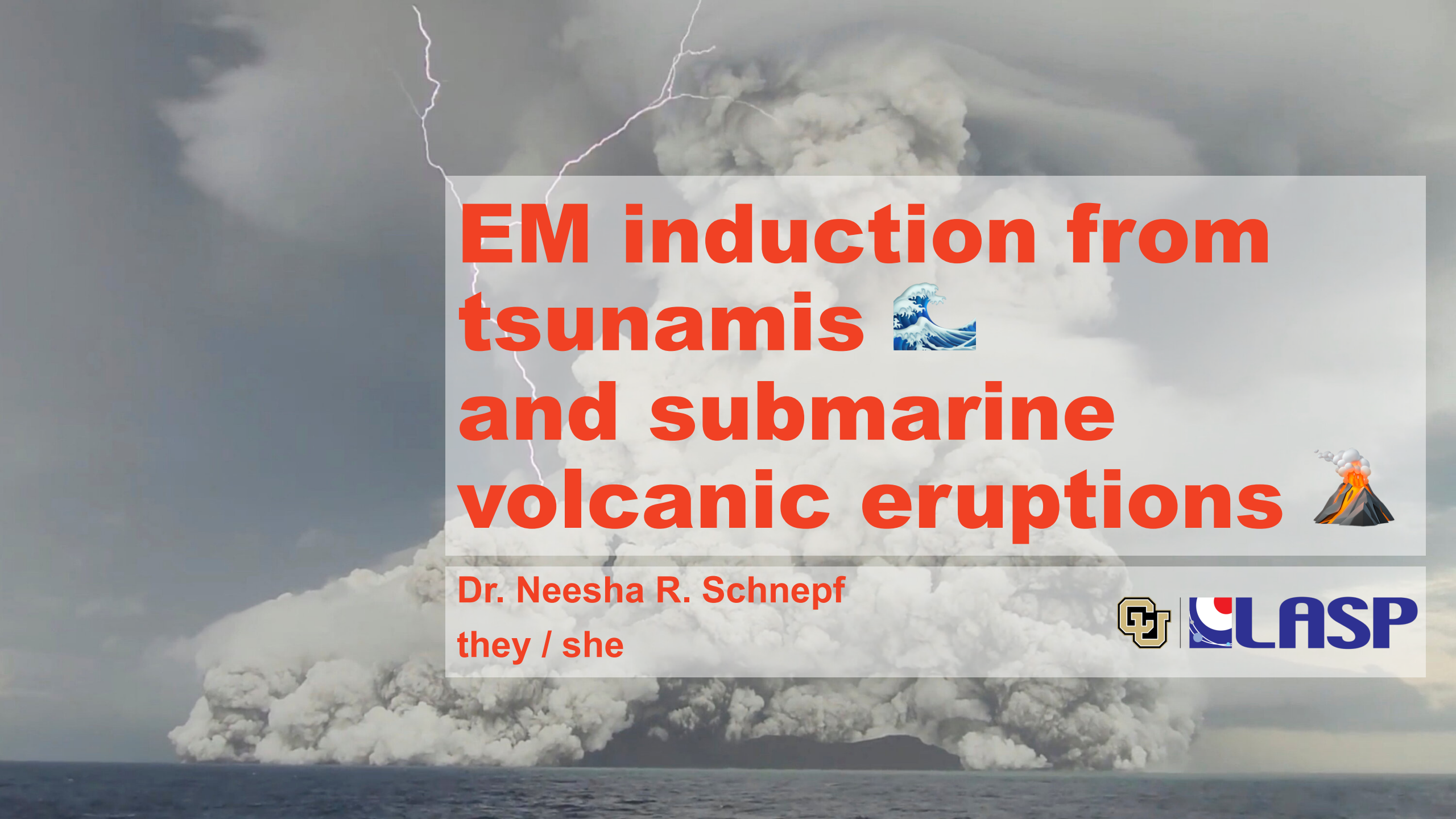


EM induction from tsunamis 🌊 and submarine volcanic eruptions 🌋

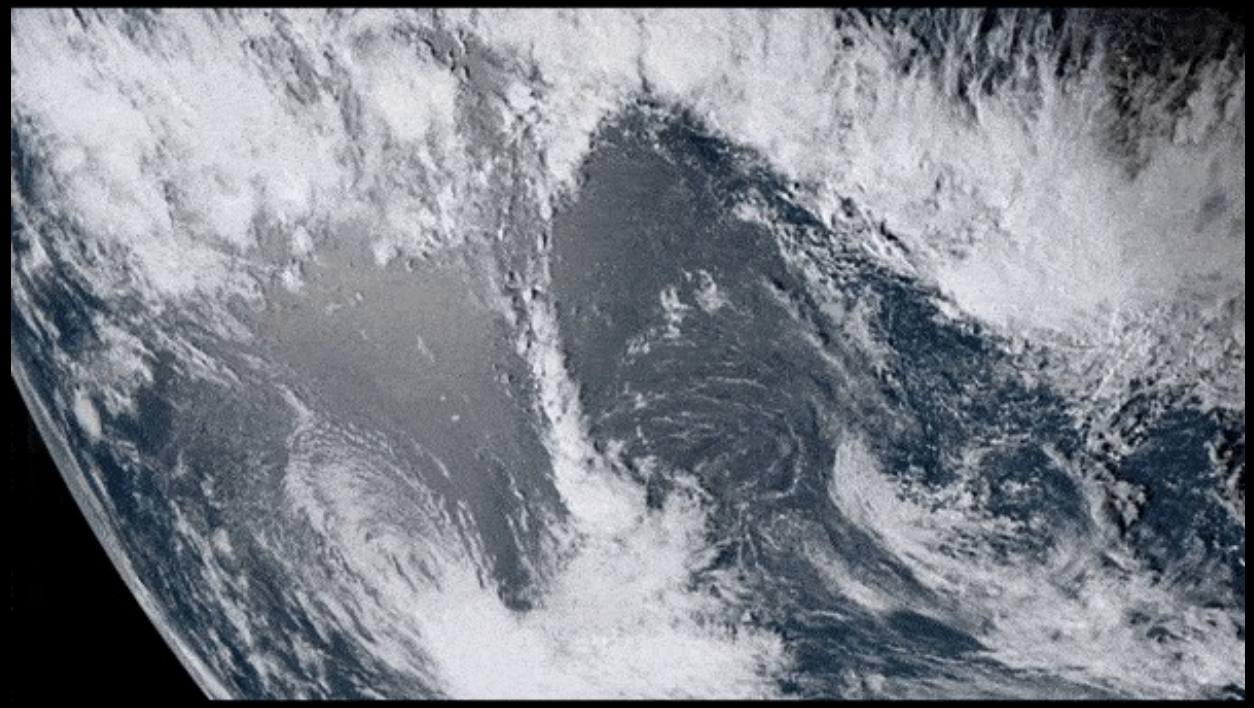
Dr. Neesha R. Schnepf
they / she

LASP

March 11, 2011 : The Tohoku tsunami

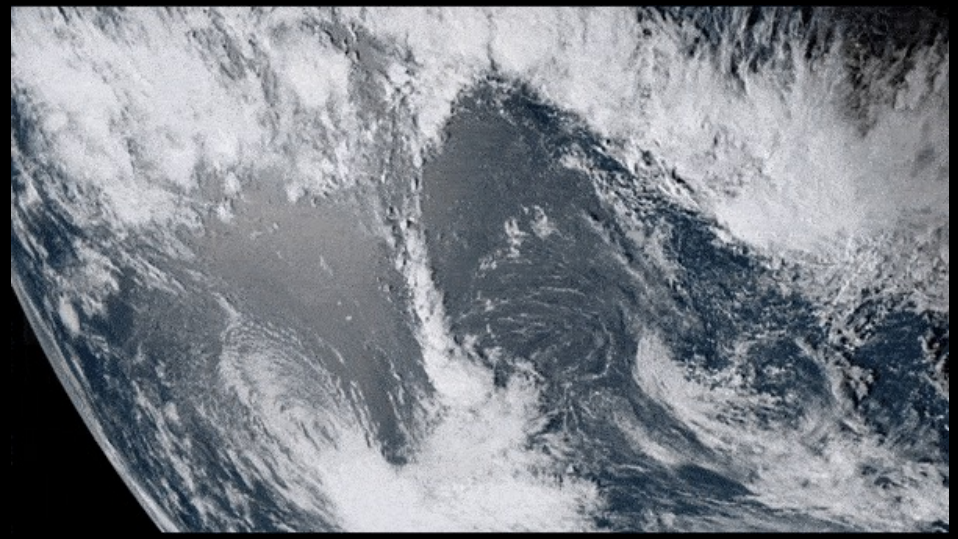
- M9.0 earthquake
- Sendai had 8-10 minutes of warning
- Fukishima nuclear disaster
- Human toll:
  - 19,759 deaths
  - 6,242 injured
  - 2,553 people missing
  - As of 2015, 228,863 people still displaced

January 15, 2022: The Hunga Tonga submarine volcano eruption

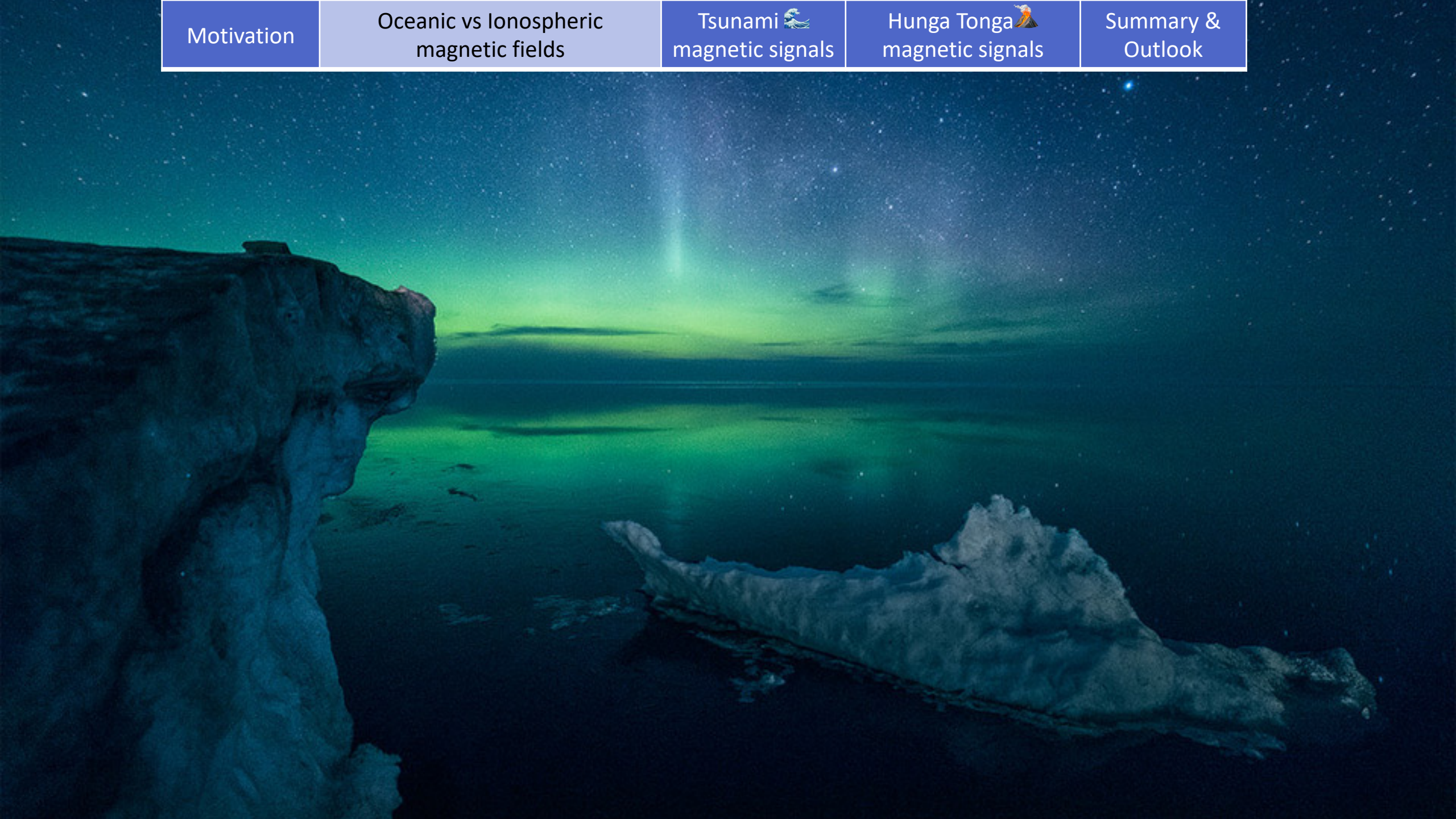


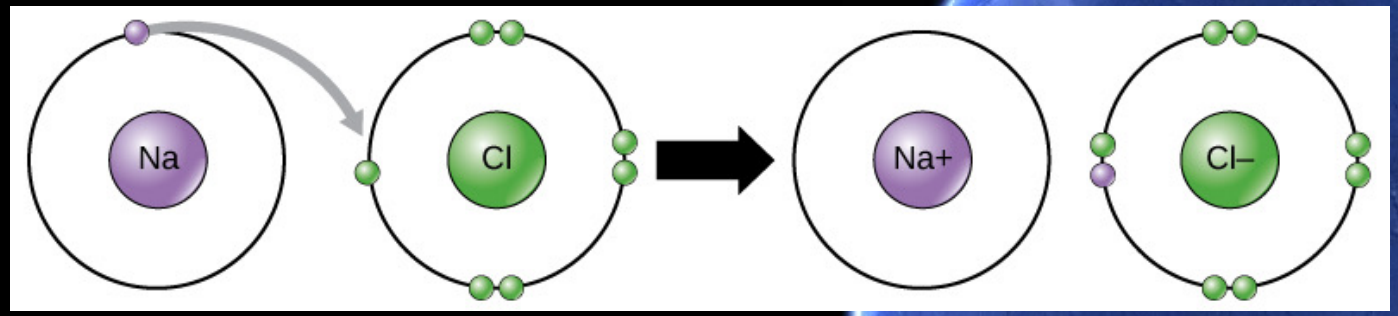
- VEI-5 eruption
- Displaced 10 km^3 of rock, ash and sediment
- Largest atmospheric explosion recorded by modern instrumentation

- Human toll:
  - At least 6 deaths
  - Some injured & missing in Tonga (main island 40mi south of the eruption)

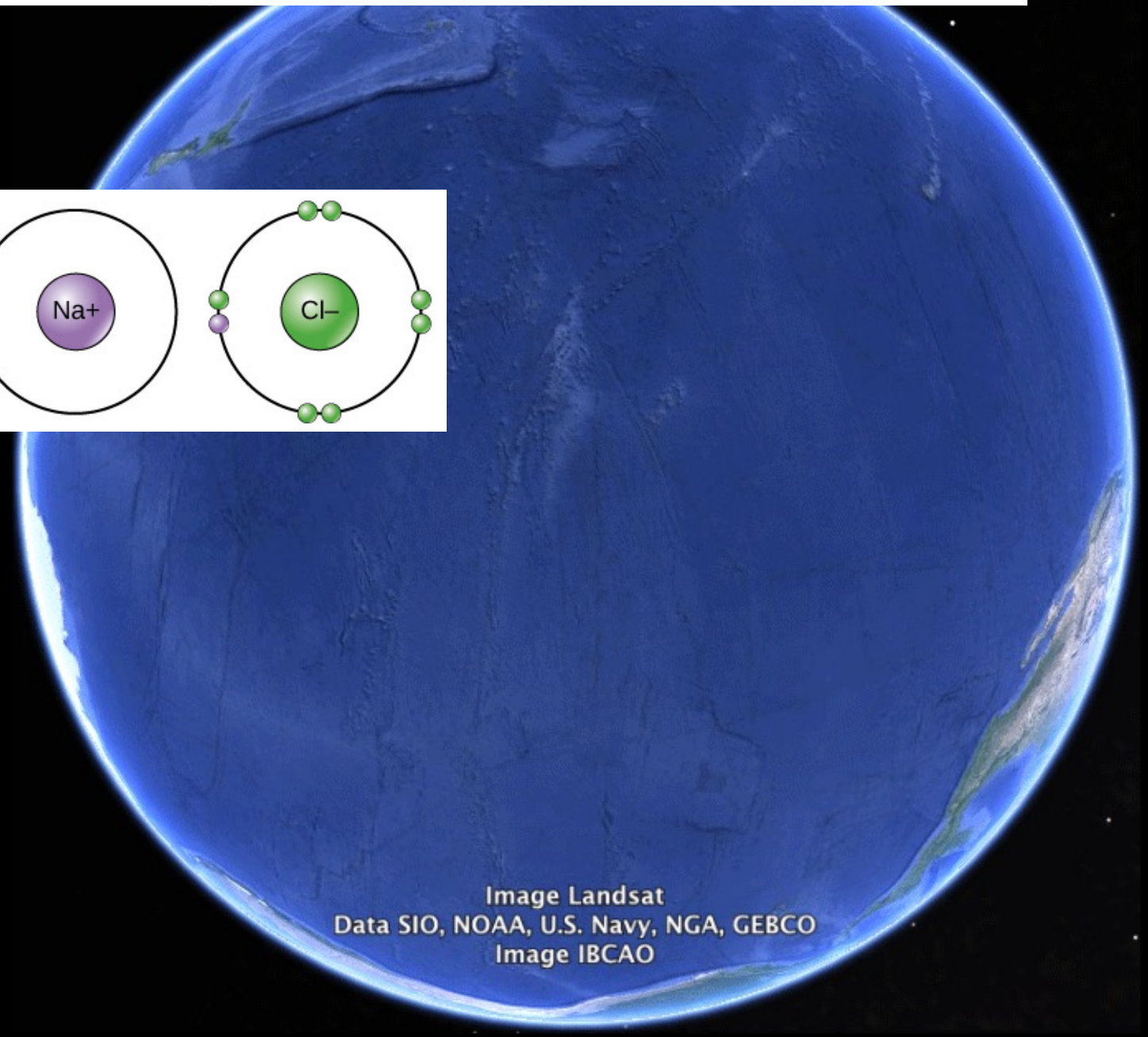


- **What magnetic signals can be identified from these events?**
- Can those magnetic fields be used to better understand the geophysical processes occurring here?
- Can magnetic fields be incorporated into warning systems?





Salt water is an electrically conductive material.



The electric current from ocean flow

$$\mathbf{j} = \sigma(\mathbf{u} \times \mathbf{B})$$

seawater electrical conductivity

Global mean = 3.31 S/m

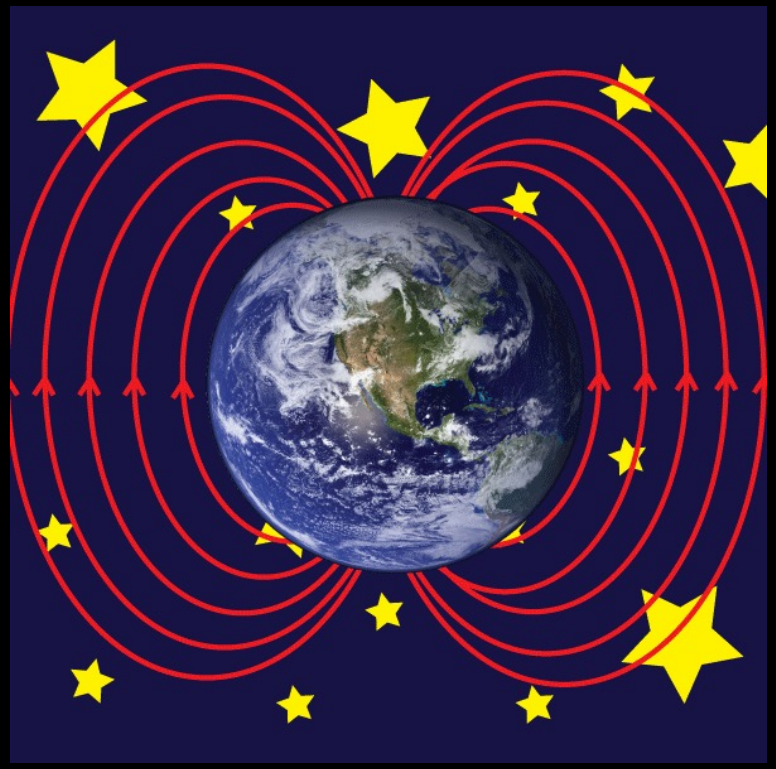
velocity of the ocean flow

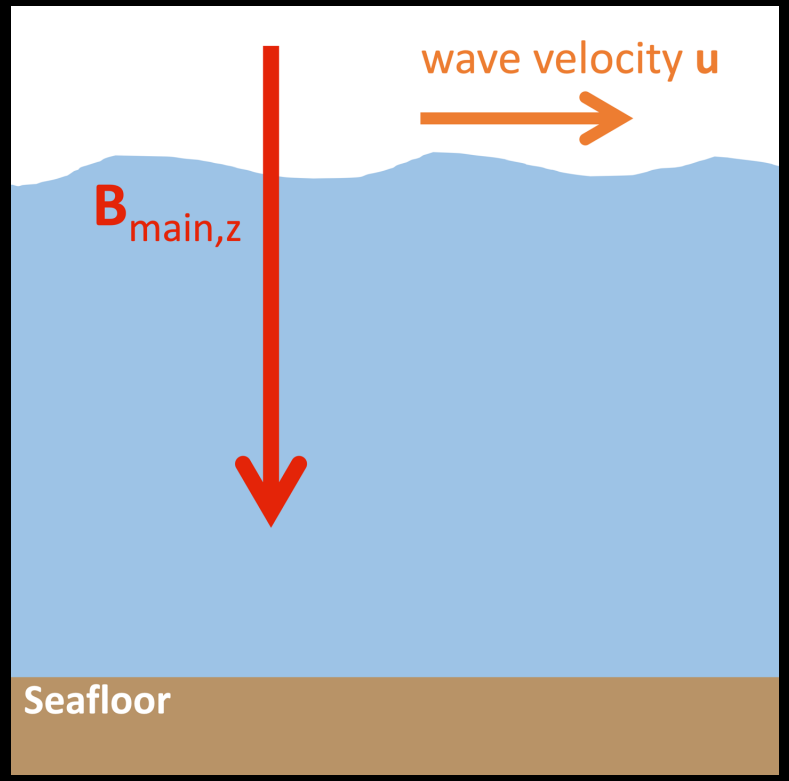
Tides, circulation, tsunamis

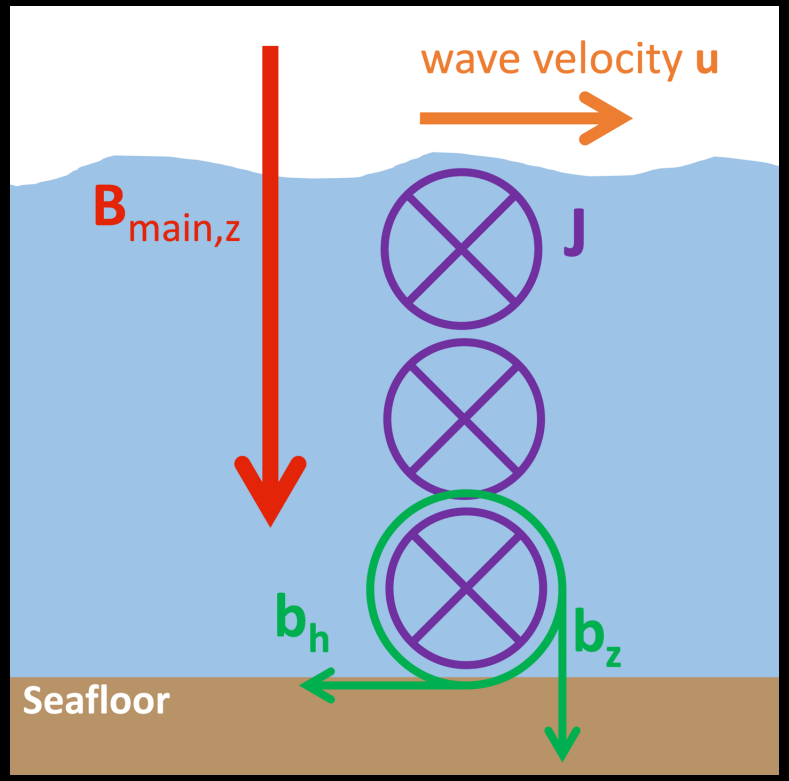
Earth's core magnetic field

Very well known-- IGRF or WMM model

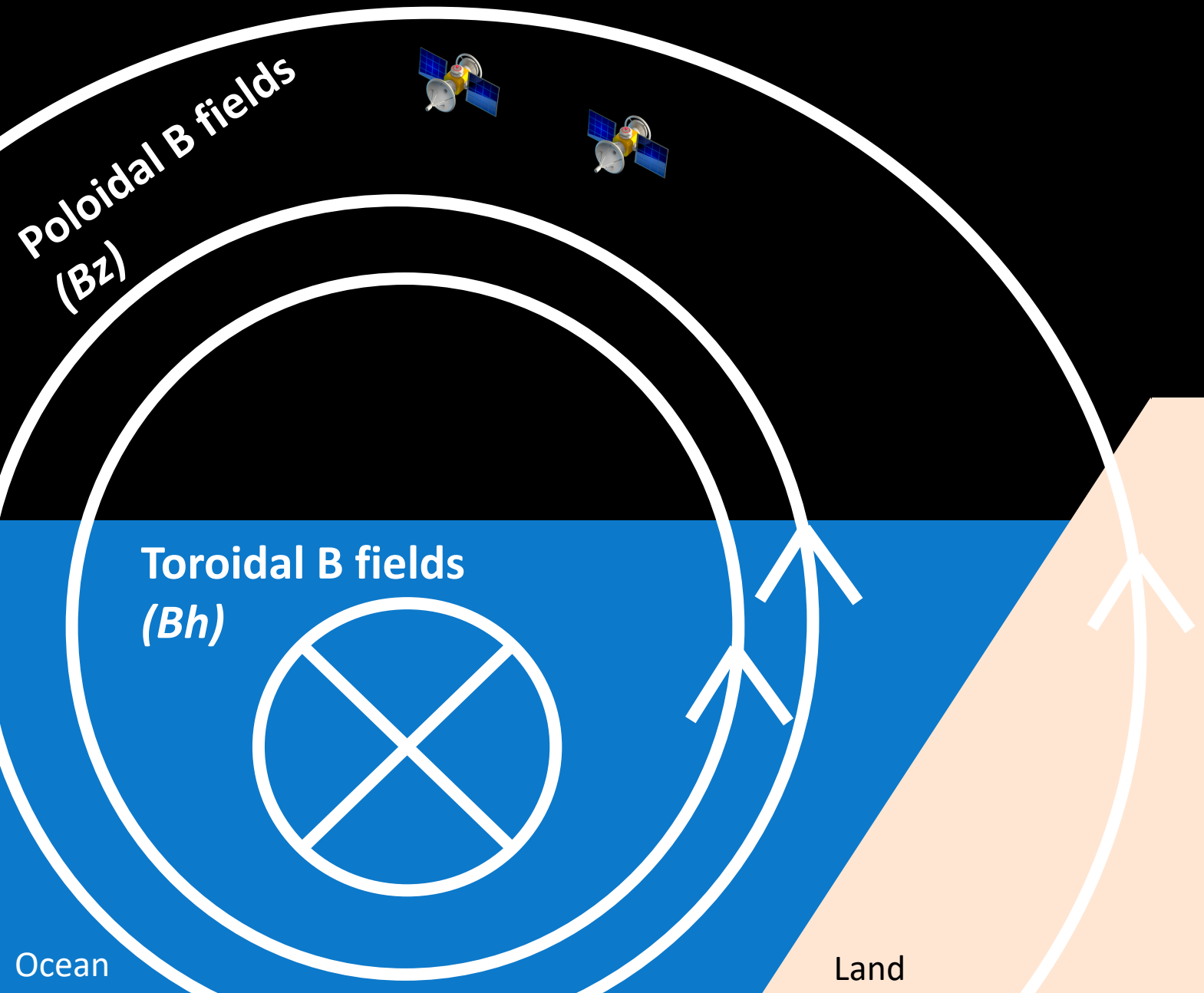
Marine electromagnetic induction







Oceanic magnetic fields

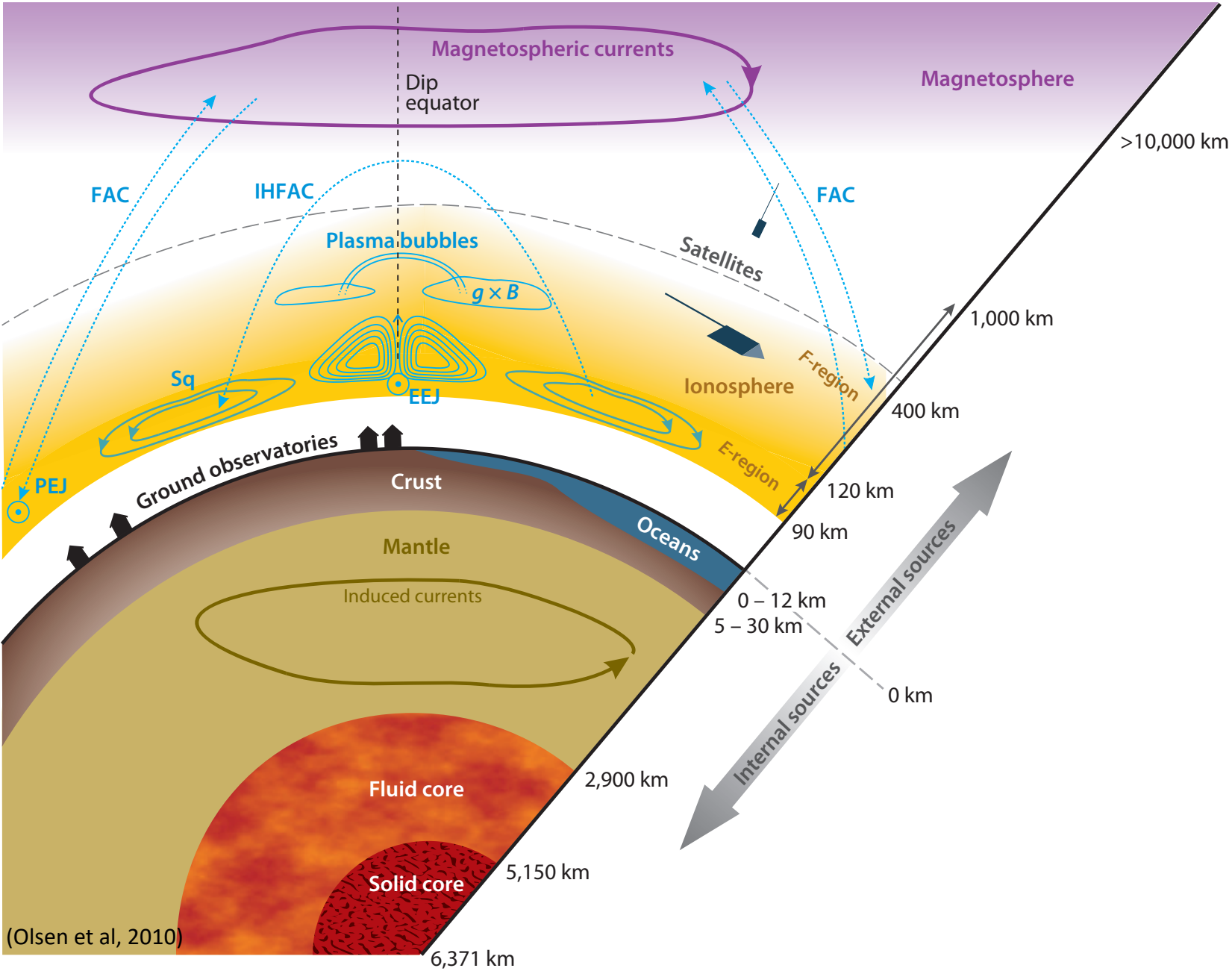


The ocean's toroidal magnetic fields, and electric fields, are measurable at observatories within the ocean or on the seafloor.
→ Bh

The ocean's poloidal magnetic fields are measurable at observatories external to the ocean.
→ Bz

Oceanic vs. Ionospheric magnetic fields

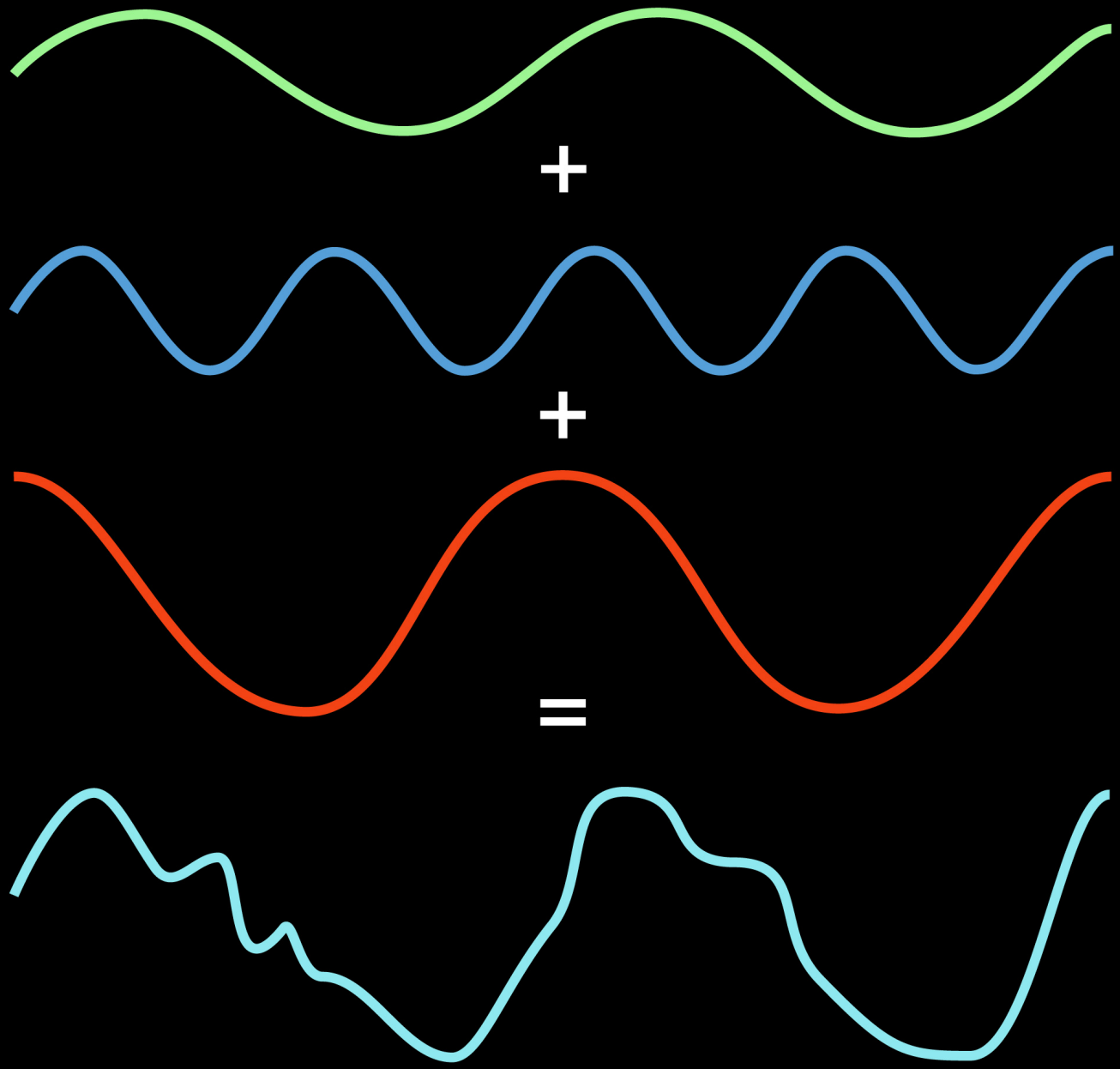
- Ionosphere's electrical conductivity depends on solar ionization, is time-of-day dependent
  - ➢ Oceanic electrical conductivity depends on salinity & temperature
- Ionospheric magnetic fields can be driven by neutral waves
  - ➢ Oceanic magnetic fields are driven by all types of ocean flow
- At a ground observatory, oceanic magnetic fields are *internal* and ionospheric magnetic fields are *external*
  - ➢ Enables separating the two field sources

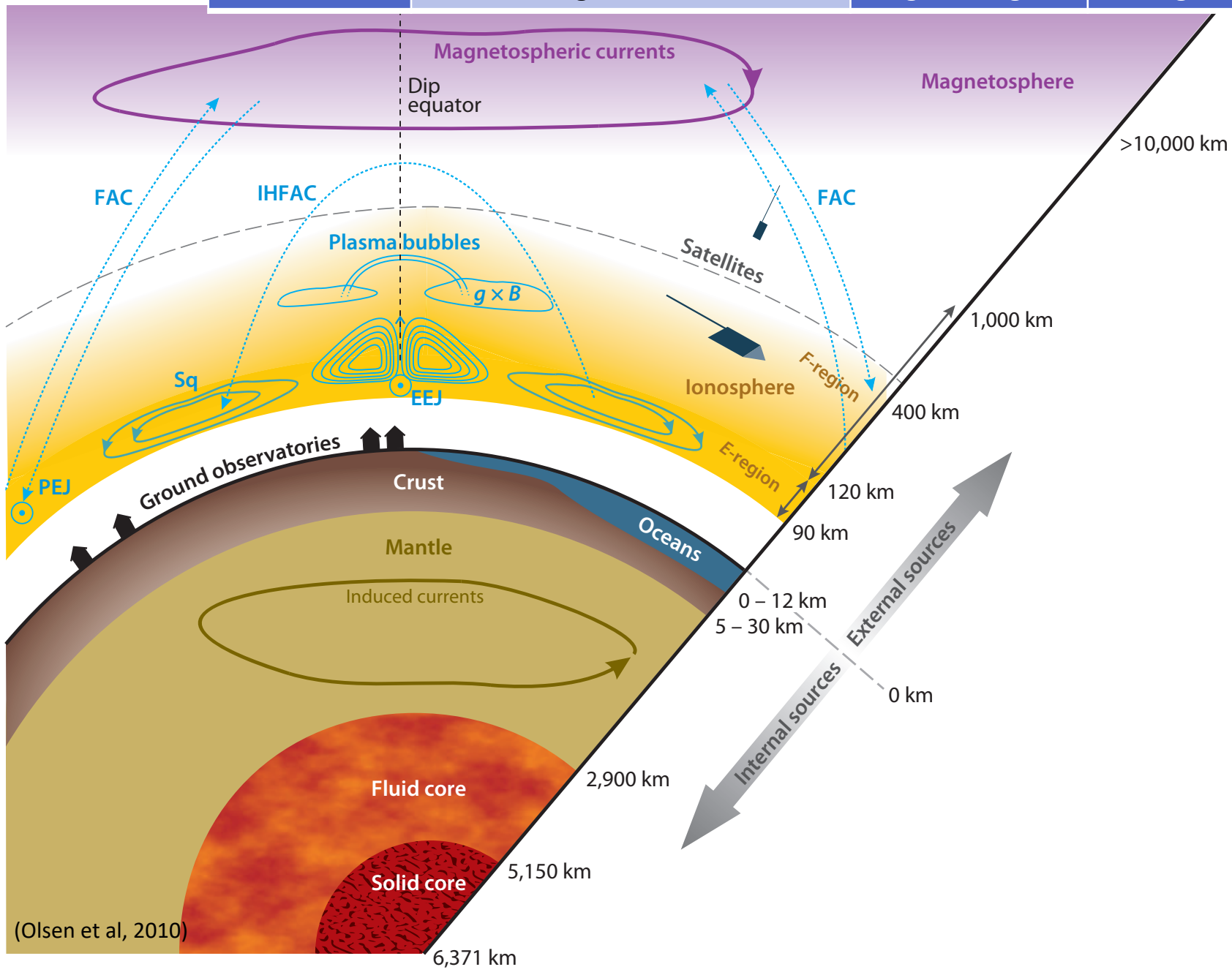


(Olsen et al, 2010)

Main challenge: separating magnetic fields

Magnetic field amplitude at satellite altitude	
Core B field	60,000 nT
Magnetospheric B field	60 nT
Ionospheric B field	**30 nT**
Crustal B field	20 nT
Oceanic B field	**2 nT**





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Main challenge: separating magnetic fields

Magnetic field amplitude at satellite altitude	
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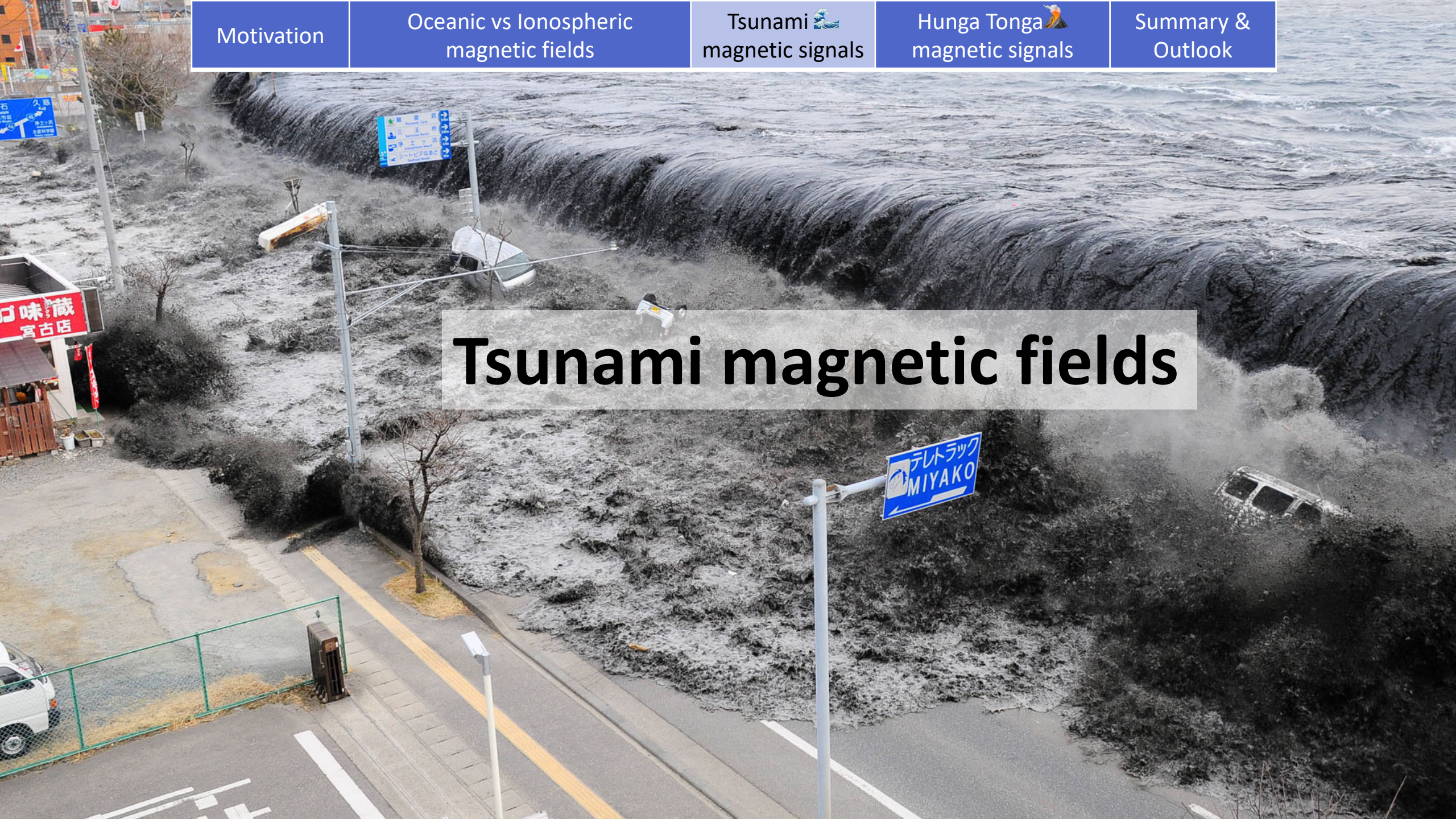
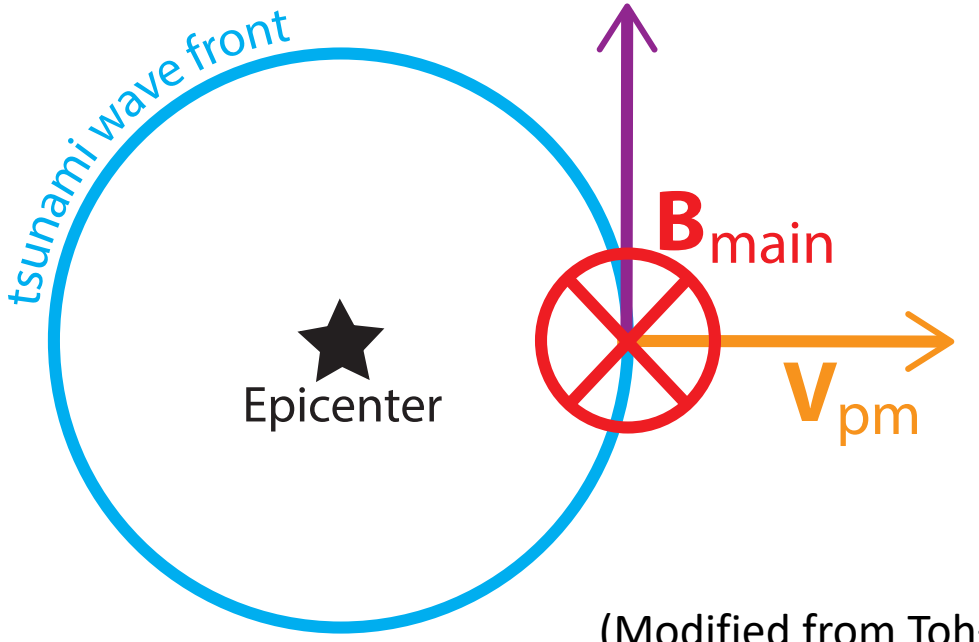


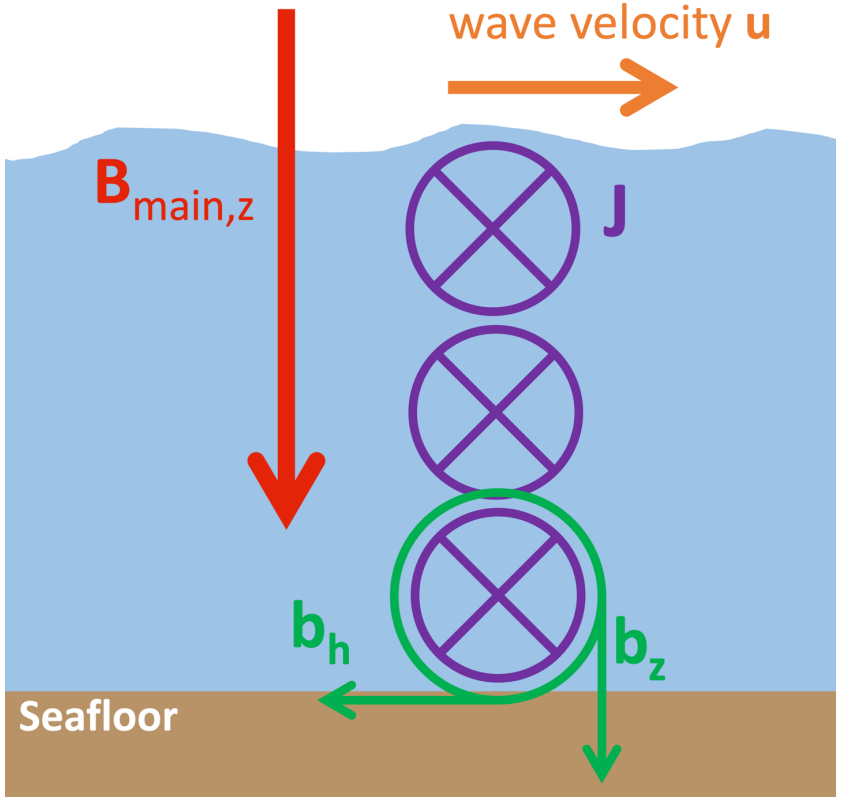
Tsunami magnetic fields

- Water wave propagates from epicenter
- Produces a “frozen-in” magnetic field
- Field dominated by Lorentz force contribution
  - But there is also a self-induction contribution from db/dt

$$\mathbf{J} = \sigma_{SW}(\mathbf{V}_{pm} \times \mathbf{B}_{main})$$



(Modified from Toh+2011)



Tyler (2005):

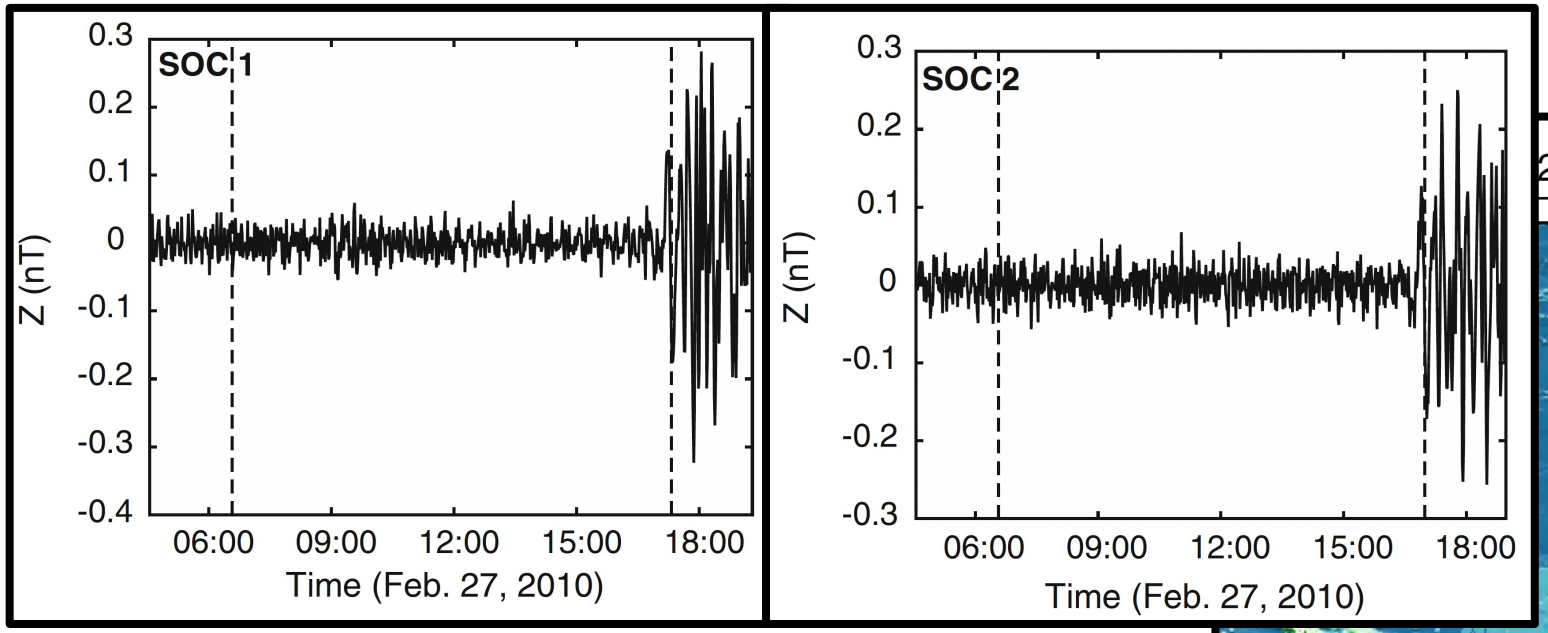
- $\frac{b_z}{B_{main,z}}$ varies directly with $\frac{\eta}{h}$

b_z - vertical component of tsunami magnetic field
η - tsunami sea surface height
h - ocean depth

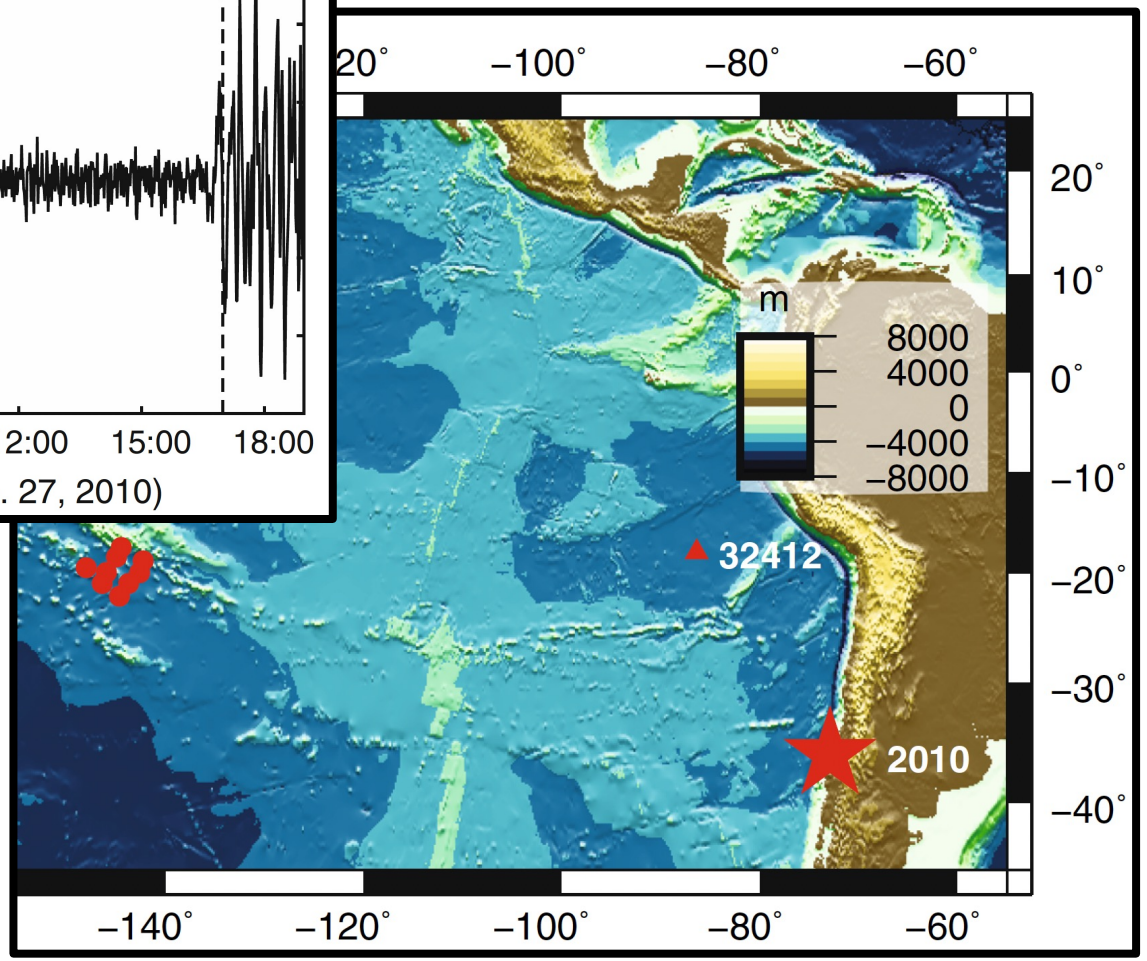
- Can determine tsunami velocity vector from 1 observatory's vector magnetic field observations

Kicked off excitement for using magnetic field data to improve tsunami warning systems

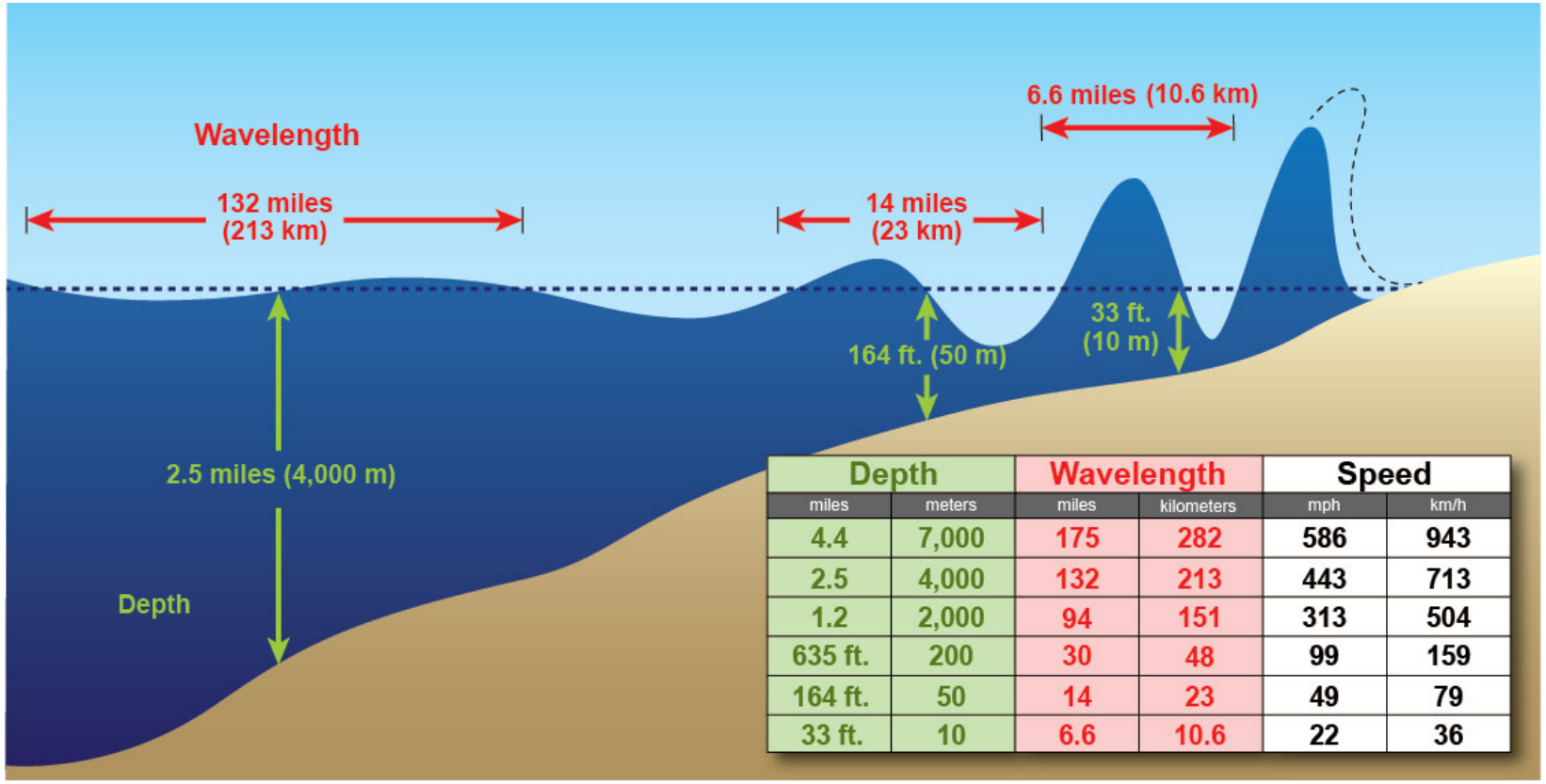
Manoj et al (2011): observed tsunami magnetic field from the Feb. 27 2010 Chilean earthquake (M8.8).



(Schnepf+2016)



Tsunami magnetic field may arrive *before* the tsunami water wave by 4-20 minutes [Minami et al, 2015; Tatehata et al, 2015; Schnepf et al, 2016]

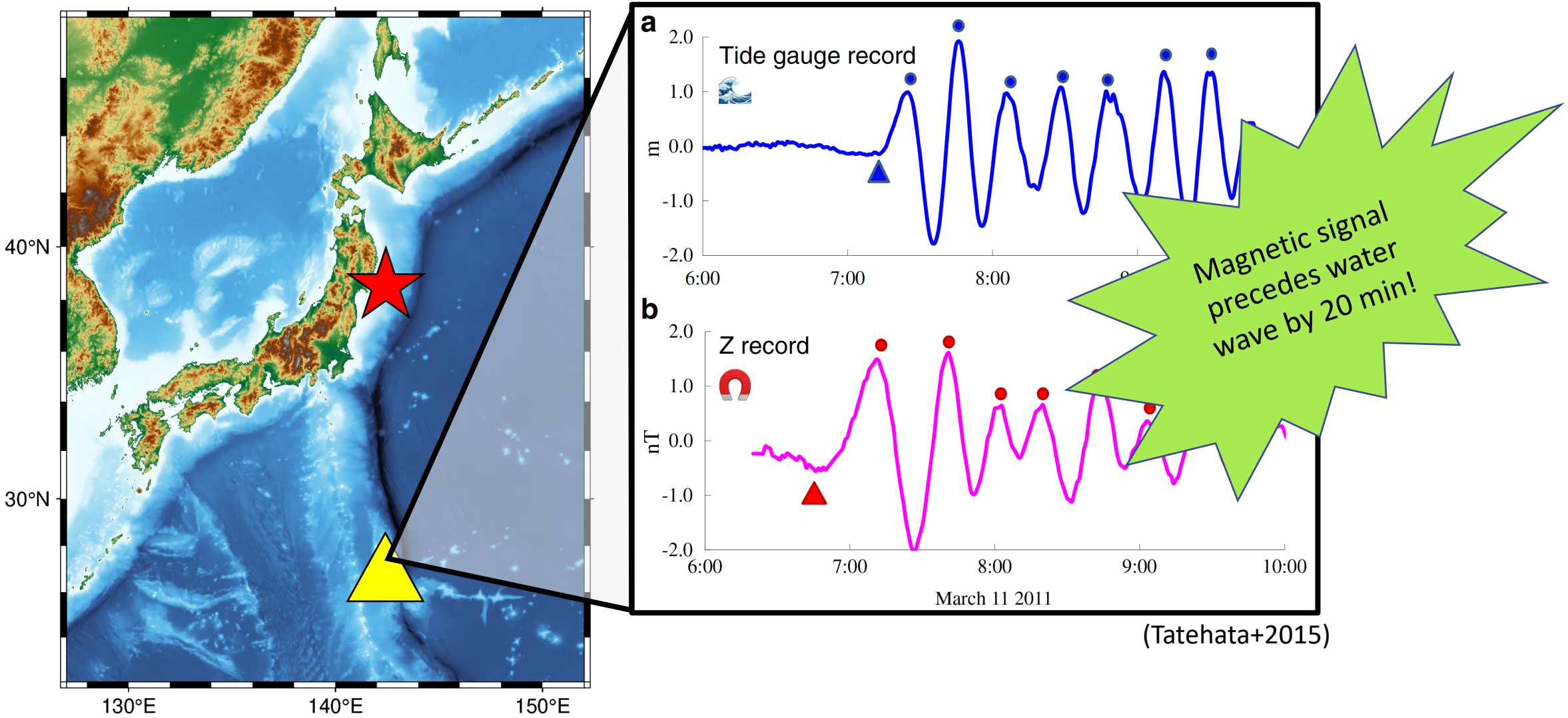


Depth		Wavelength		Speed	
miles	meters	miles	kilometers	mph	km/h
4.4	7,000	175	282	586	943
2.5	4,000	132	213	443	713
1.2	2,000	94	151	313	504
635 ft.	200	30	48	99	159
164 ft.	50	14	23	49	79
33 ft.	10	6.6	10.6	22	36

Self-induction dominant regime ⟷ Diffusion dominant regime

Minami+2015: tsunami magnetic field depends on ocean depth.

Tsunami magnetic field may arrive *before* the tsunami water wave by 4-20 minutes [Tatehata et al, 2015; Minami et al, 2015; Schnepf et al, 2016]



(Tatehata+2015)

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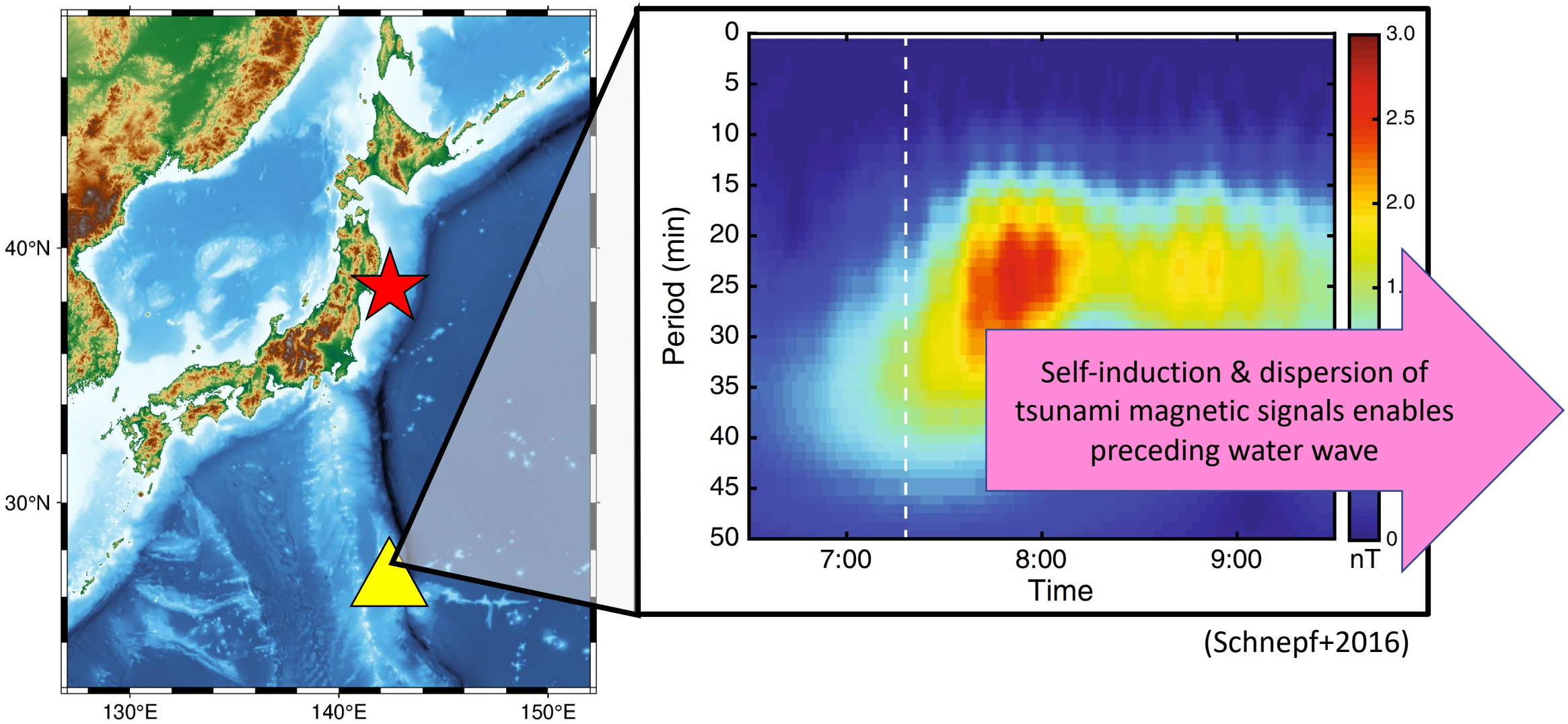


(Schnepf+2016)

… but can these magnetic signals actually be used for tsunami warning systems?

Challenge #1: Earth's main field term

tsunami electric current

$$\mathbf{j} = \sigma(\mathbf{u} \times \mathbf{B})$$

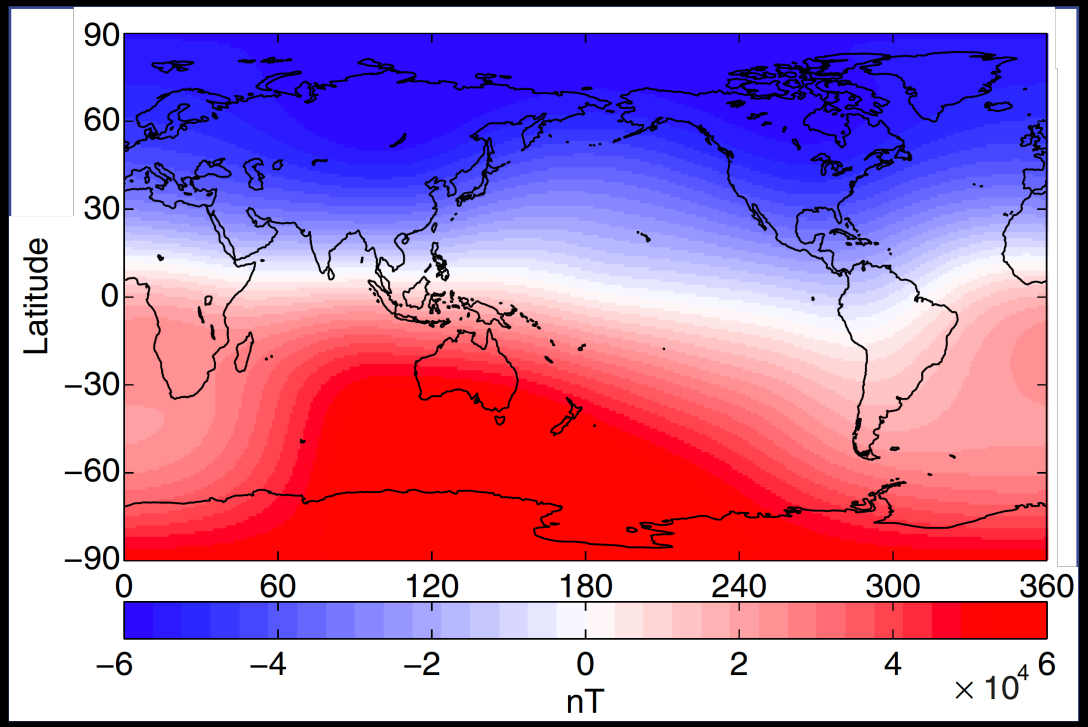
seawater electrical conductivity

tsunami velocity

Dominated by horizontal flow

Earth's core magnetic field

Dominated by vertical field



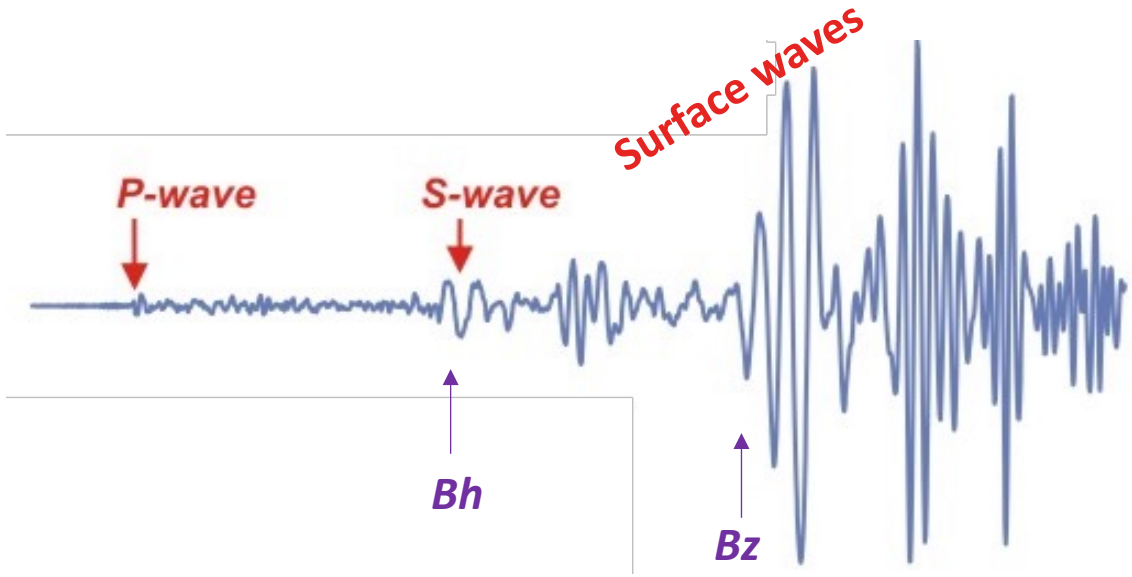
B_z from World Magnetic Model

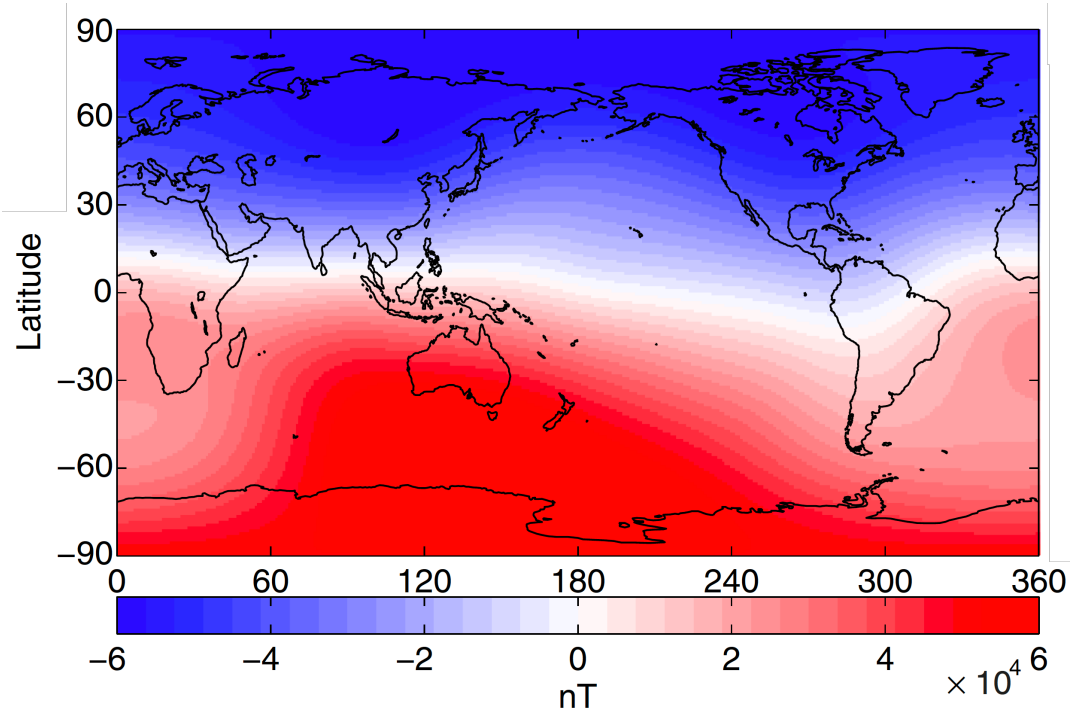
Detection challenges near magnetic equator!?

Challenge #1: Earth's main field term ✅

Minami, Schnepf, Toh (2021):
Tsunami-generated magnetic fields have primary and secondary arrivals like seismic waves

- ➢ *can always use at least Bh or Bz to identify tsunami magnetic signals!*

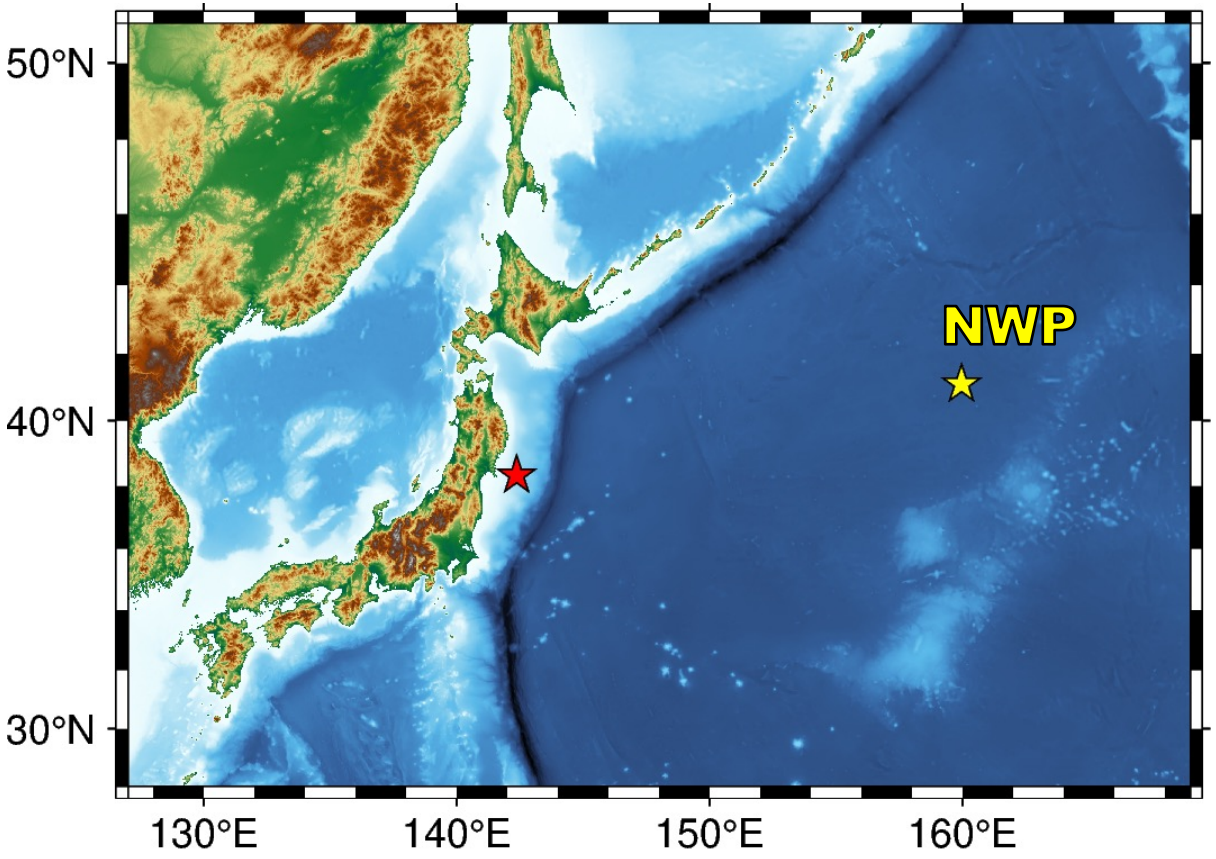




B_z from World Magnetic Model

Detection still possible near magnetic equator!

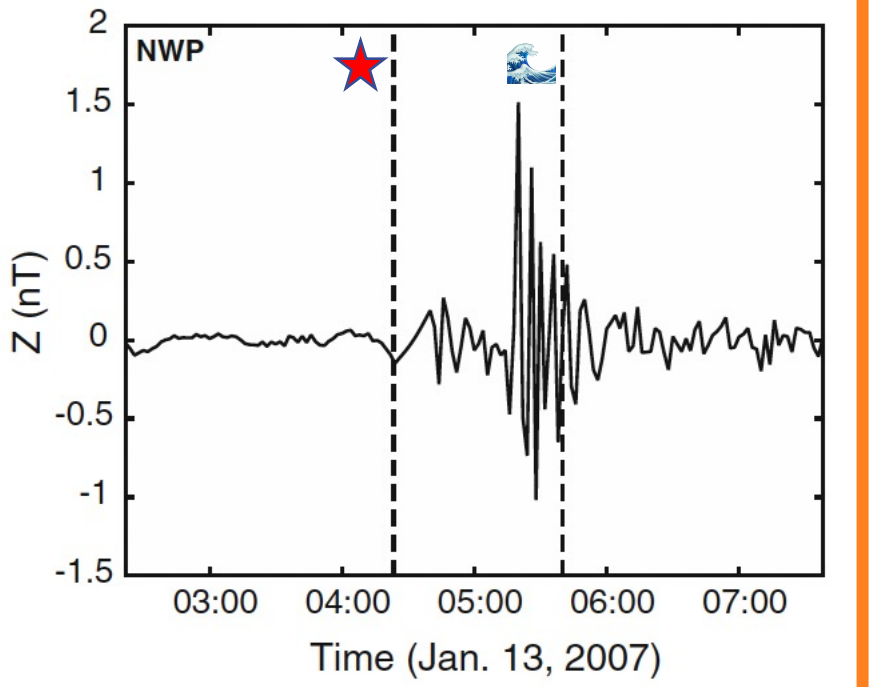
Challenge #2: real-time tsunami detection



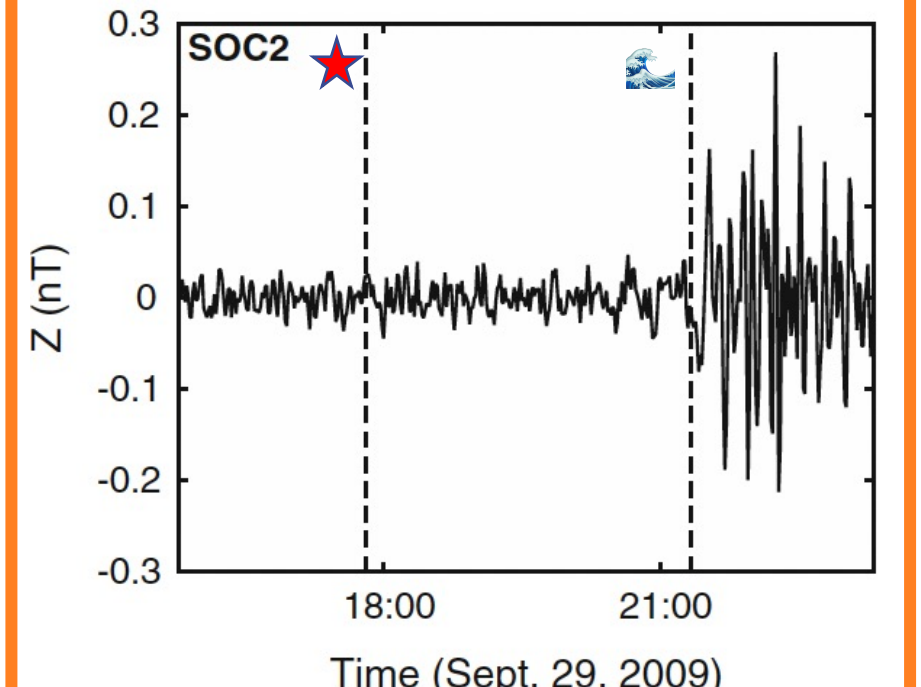
- NWP was the only near-continuous, near-real-time seafloor geomagnetic observatory (Toh+2004, Toh+2006)
  - ➢ Trying to deploy a long-term seafloor magnetometer
- Work needed to develop time-frequency methods suited to real-time (rather than historic) tsunami identification

Challenge #3: events must be large

Kuril Islands M8.1 on 1/13/2007



Samoa M8.0 on 9/29/2009



(Schnepf+2016)

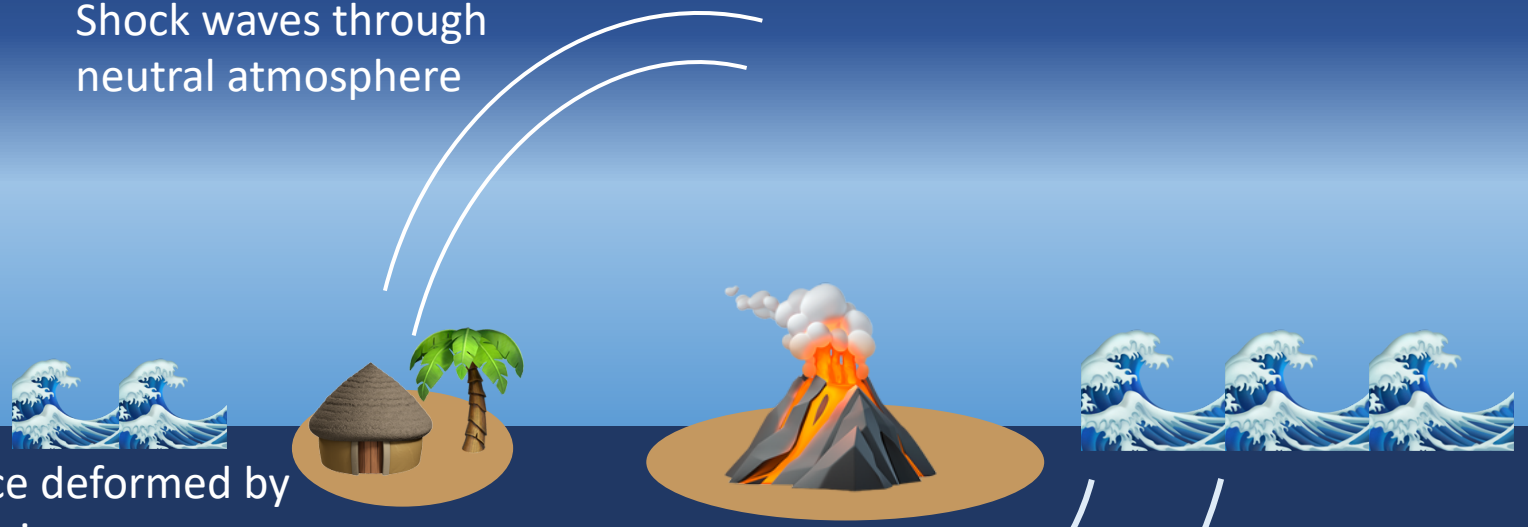
These are the *smallest* earthquakes causing tsunamis with detectable magnetic fields… and they are still M8+!

Magnetic Signatures of the January 15 2022 Hunga Tonga-Hunga Ha`apai Eruption

Waves through electrically conductive ionosphere

External magnetic field 🧲

Shock waves through neutral atmosphere



Sea surface deformed by atmospheric waves—meteotsunami

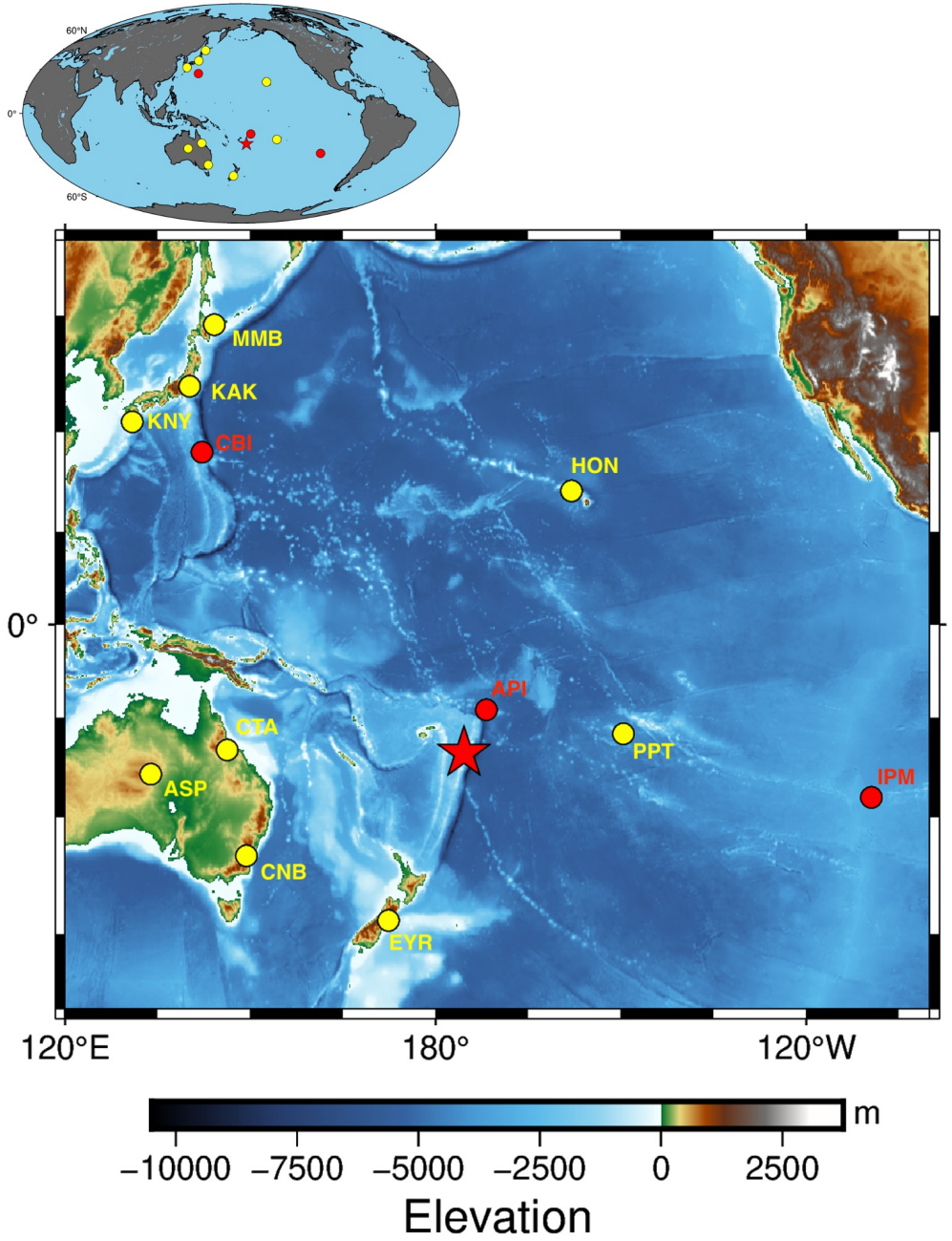
Internal magnetic field 🧲

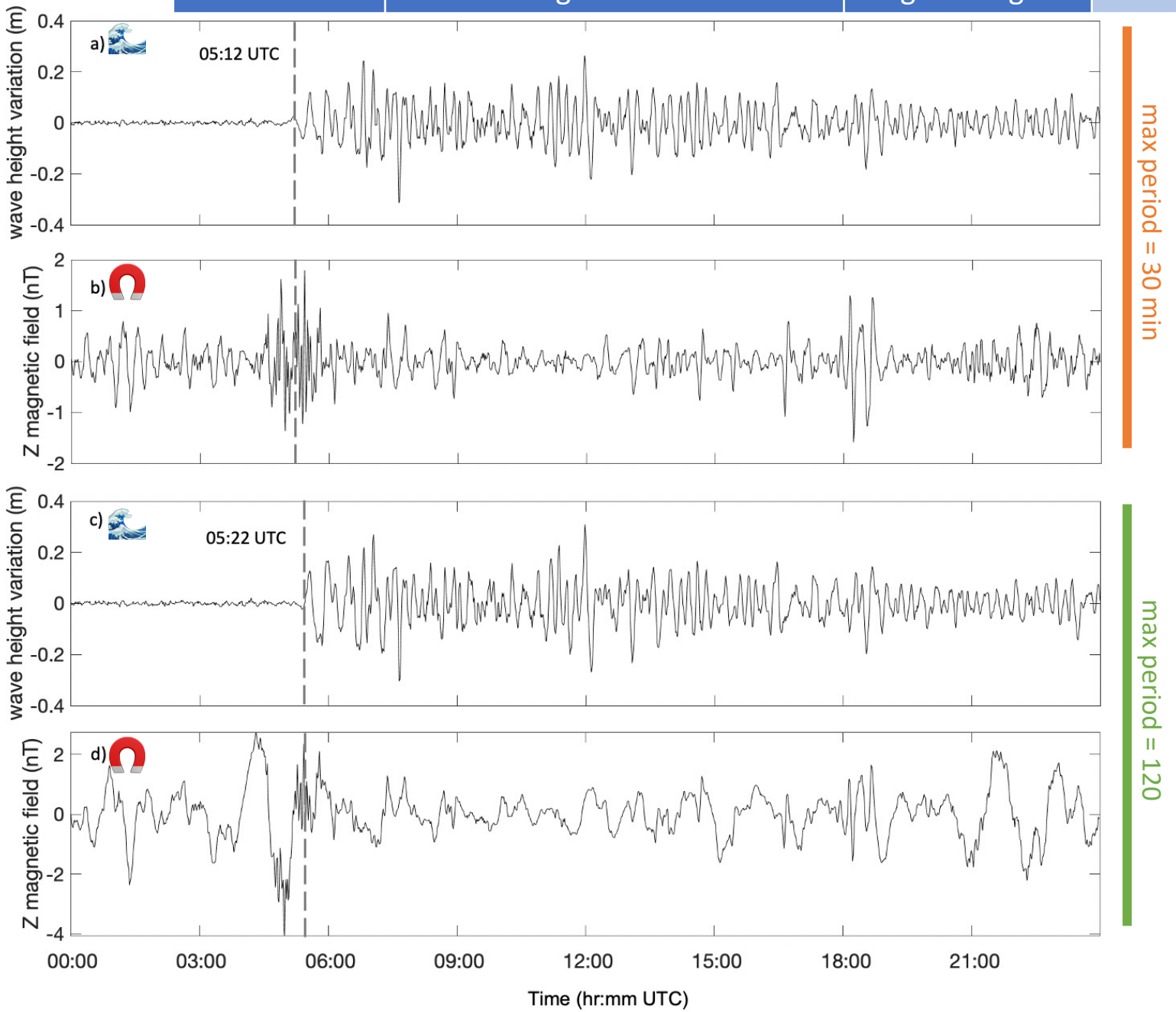
Tsunami from oceanic shock wave

Internal magnetic field 🧲

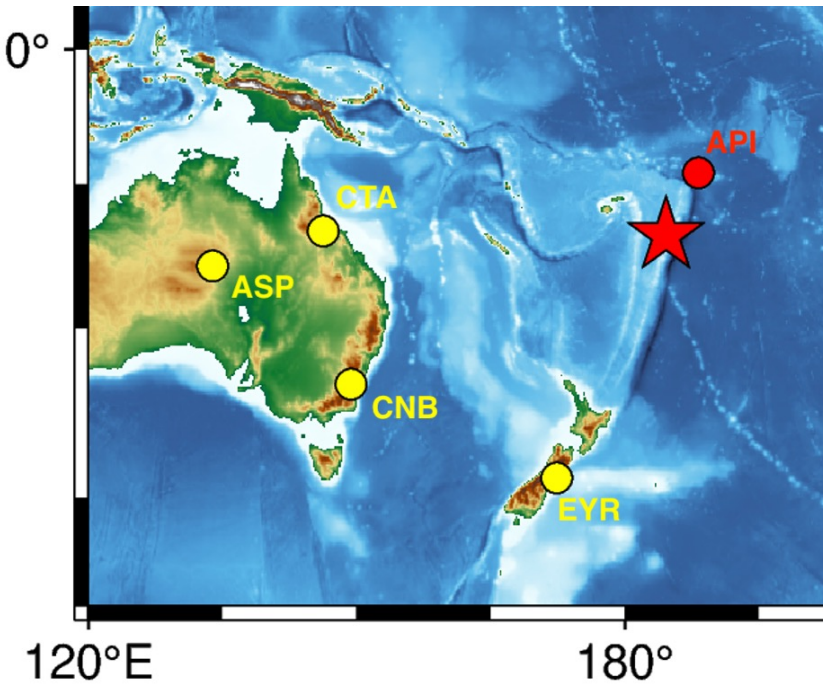
- INTERMAGNET observatories
- 1 minute sampling rate
- Vertical component, *Z*
- Horizontal component, $H = [X^2 + Y^2]^{0.5}$
- Red: magnetic signals likely from eruption
- Challenge: most of the day was geomagnetically disturbed

(Schnepf+2022, *GRL*)

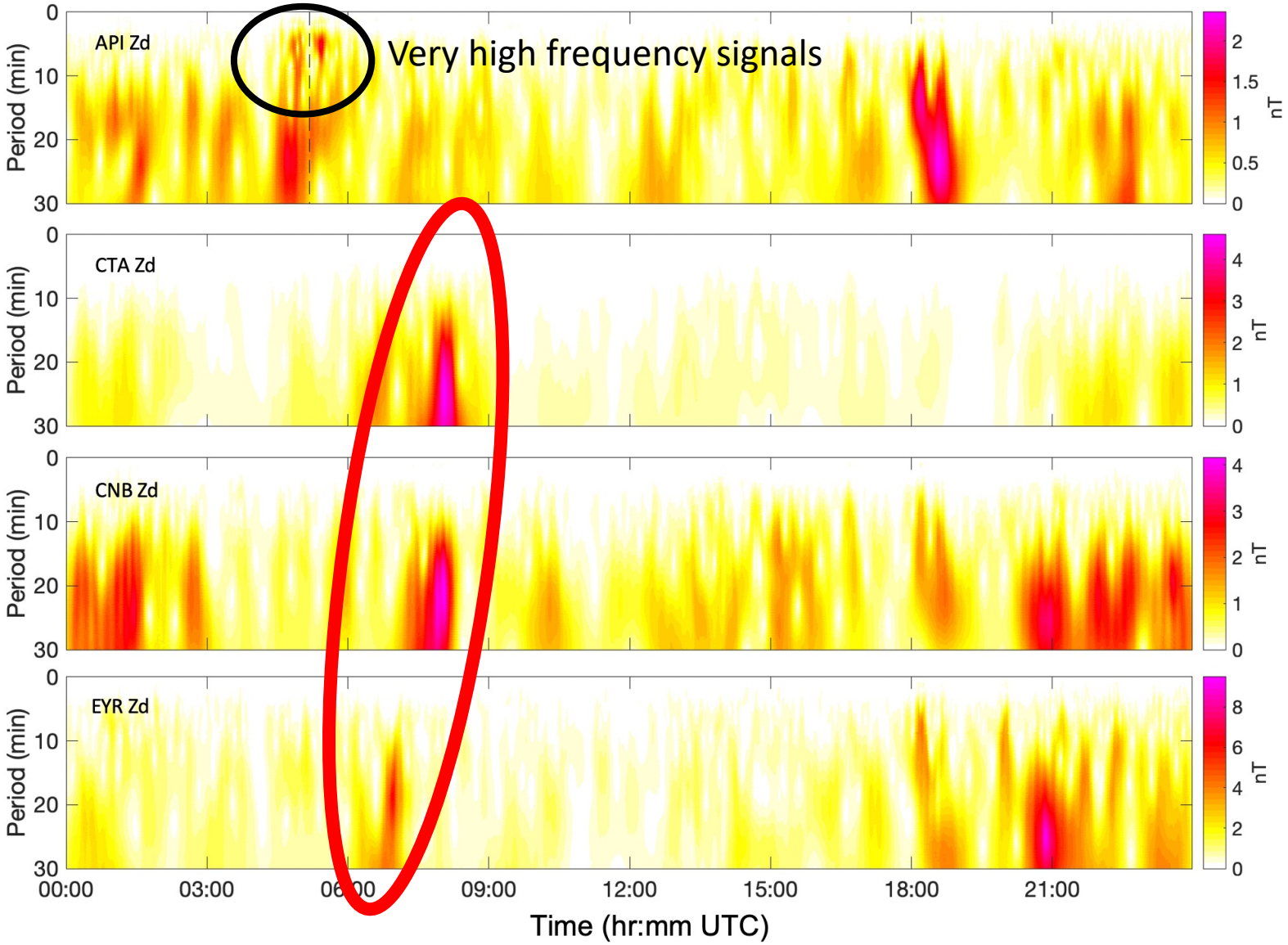




@ API



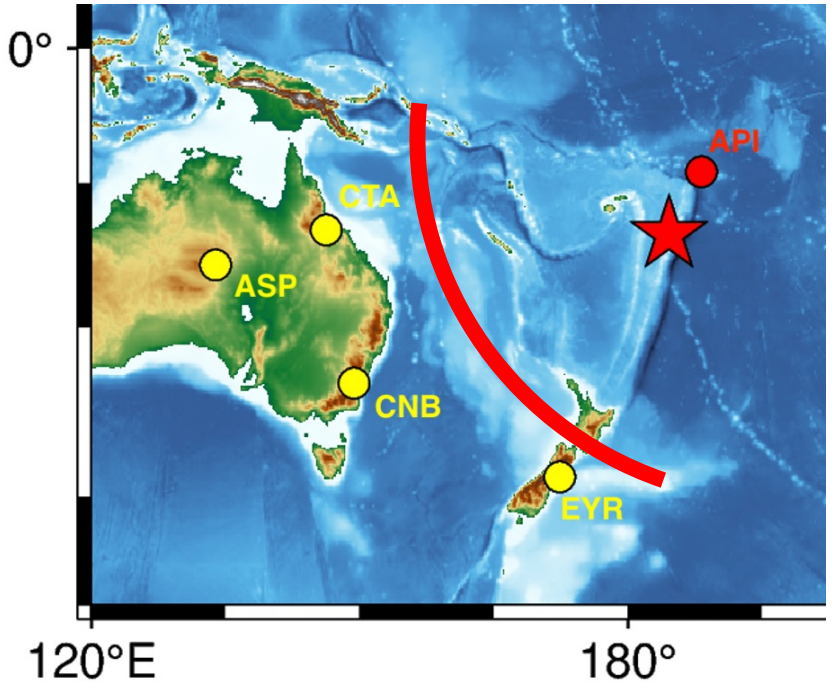
(Schnepf+2022, *GRL*)



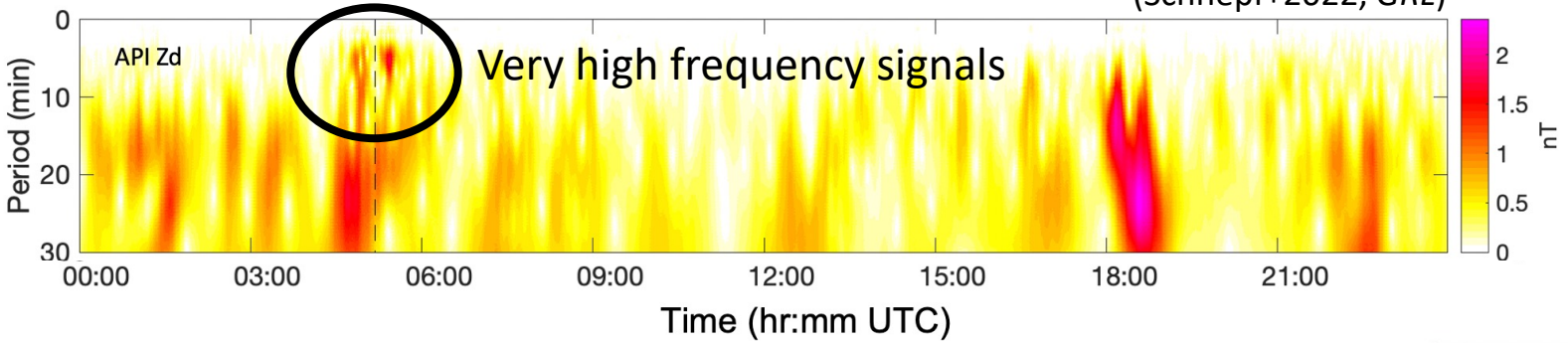
(Schnepf+2022, *GRL*)

External signals common to the ASP station have been removed from these wavelet spectrograms.

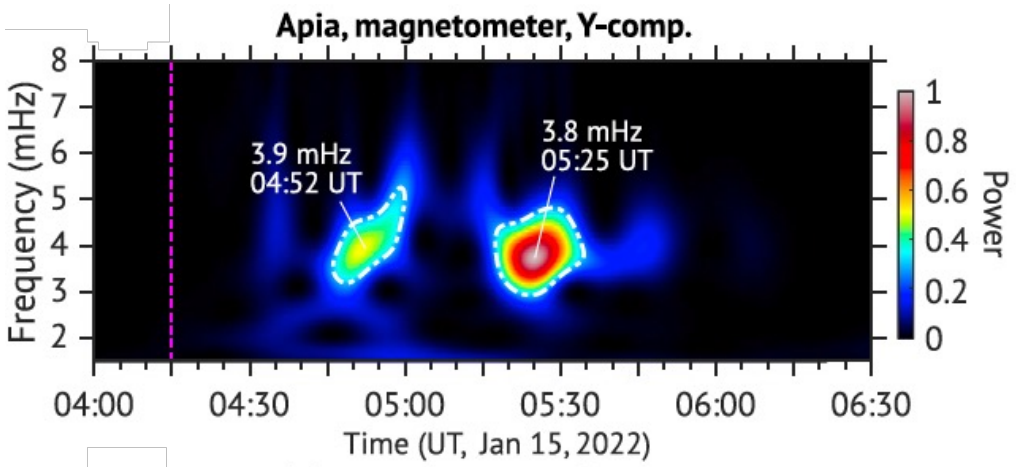
API is the only observatory to have these sort of high frequency signals.

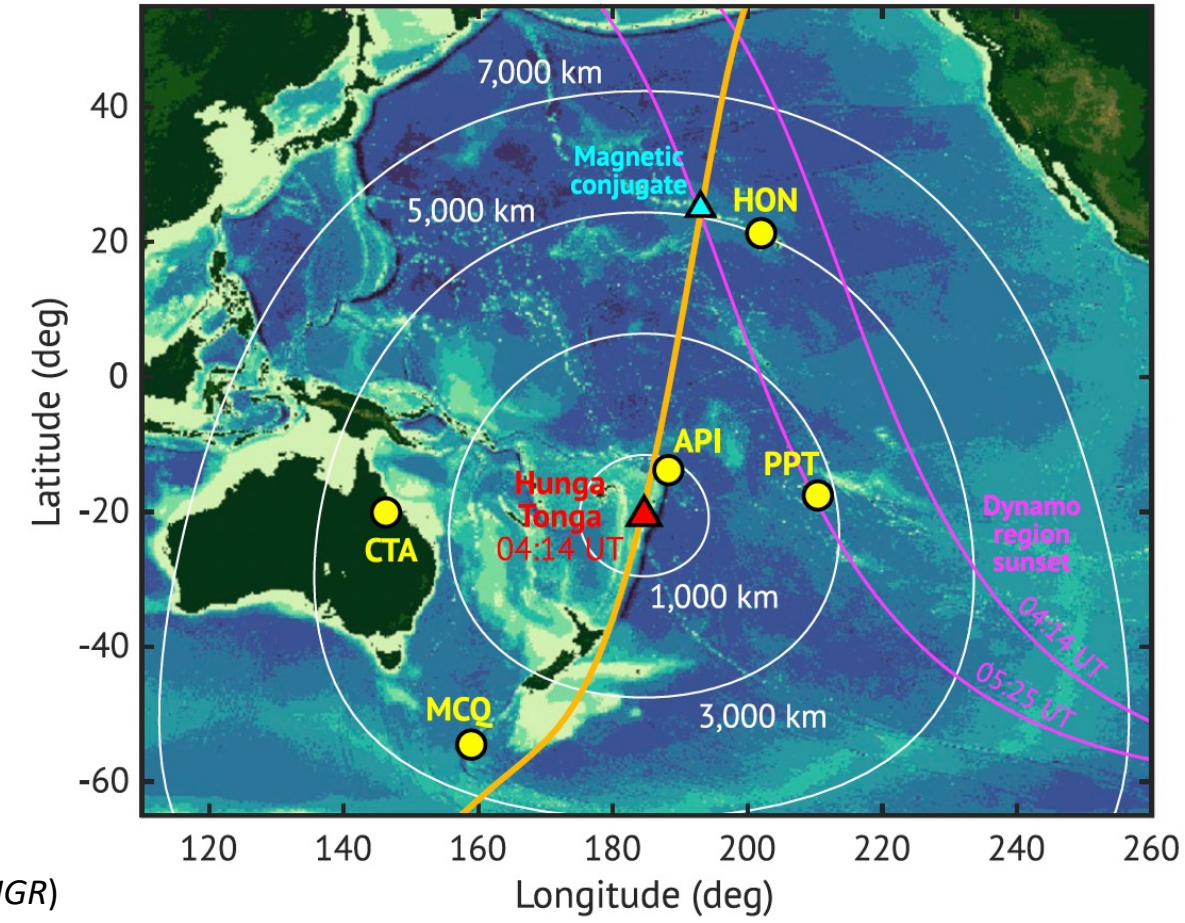


(Schnepf+2022, *GRL*)



Signals "consistent with the atmospheric oscillation due to acoustic waves trapped between the ground and thermosphere, or acoustic resonance at 3.6-4.0 mHz"
-- Yamazaki+2022, *JGR*





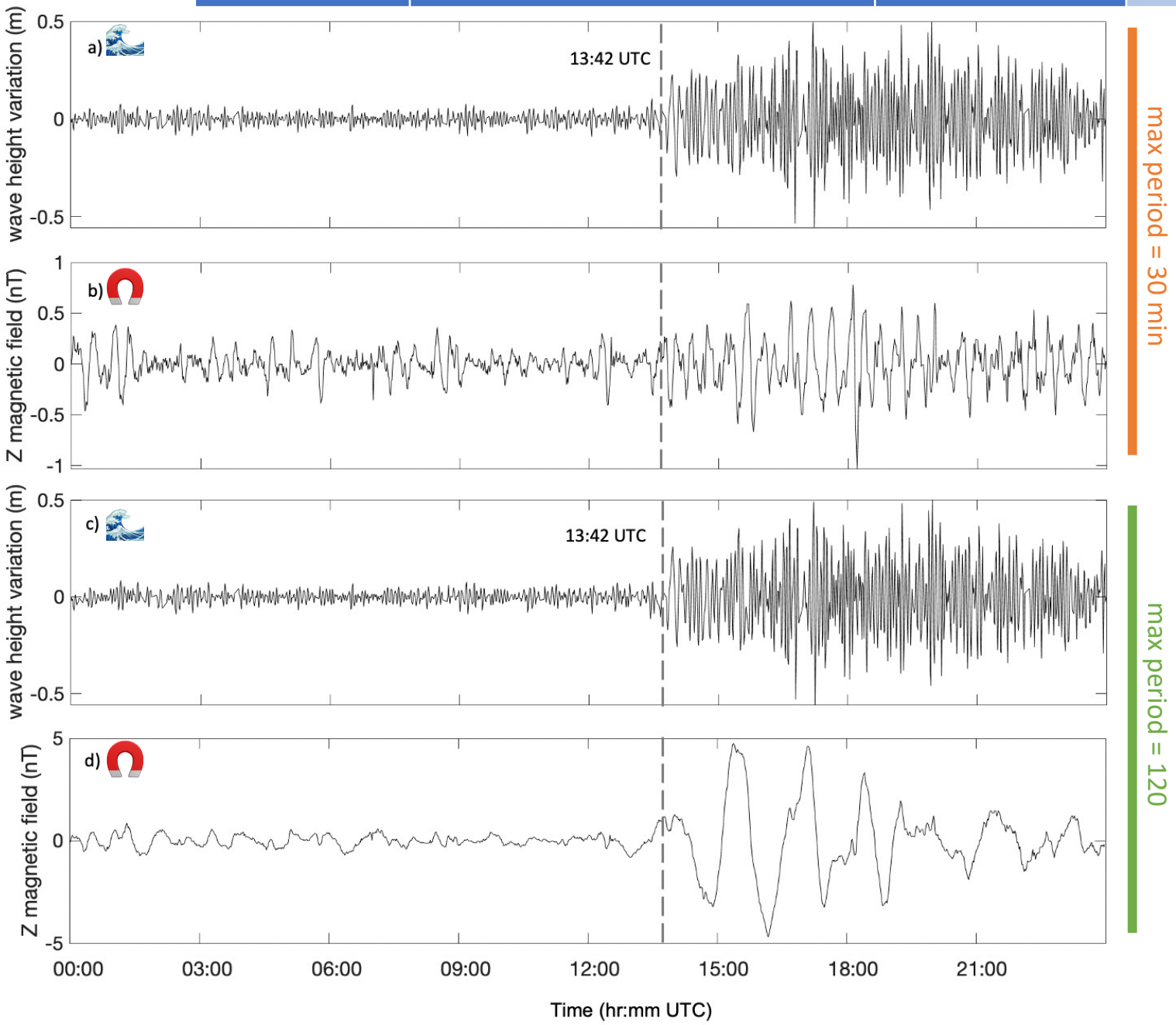
(Yamazaki+2022, *JGR*)


Apolima Strait
Salua
Satapuala
Malua
Safa'atoa
Salamumu
Vaitele
Sataoa
Apia
Upolu
Solosolo
Saleilua
Lotofoga
98%
Imagery date: 12/14/15–newer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
Landsat / Cope…
20 km
Camera: 169 km

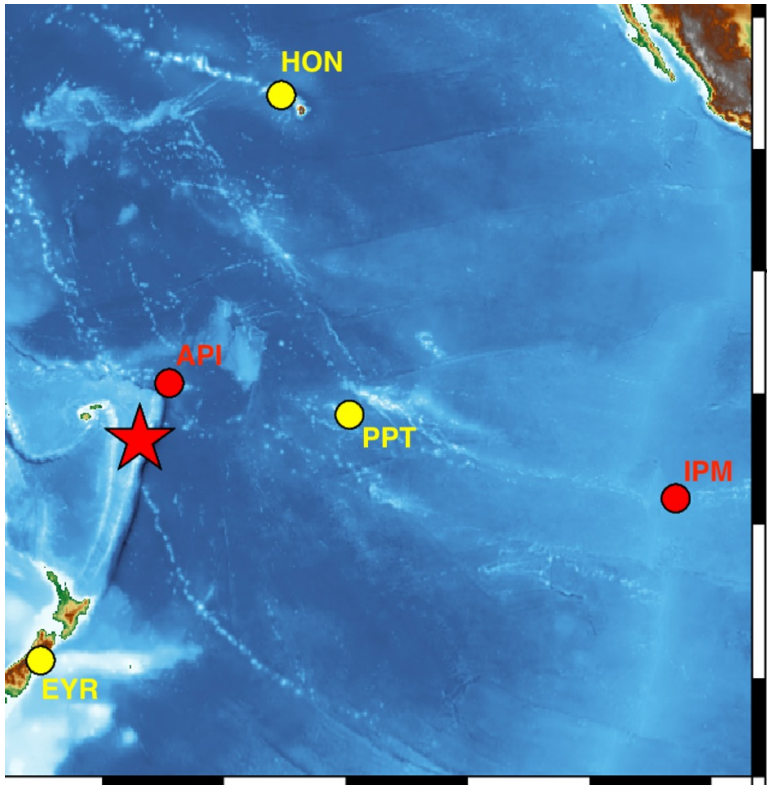
Email your support in the API observatory to:

Mr. Lameko Talia, Principal Scientific Officer
Meteorology Division Ministry of Natural Recourses and Environment (MNRE)
Apia, Samoa
lamekotalia@mnre.gov.ws

Dr. Tanja Petersen I Applied Research Senior Specialist / Project
Leader Geomagnetism Project
GNS Science, New Zealand
T.Petersen@gns.cri.nz

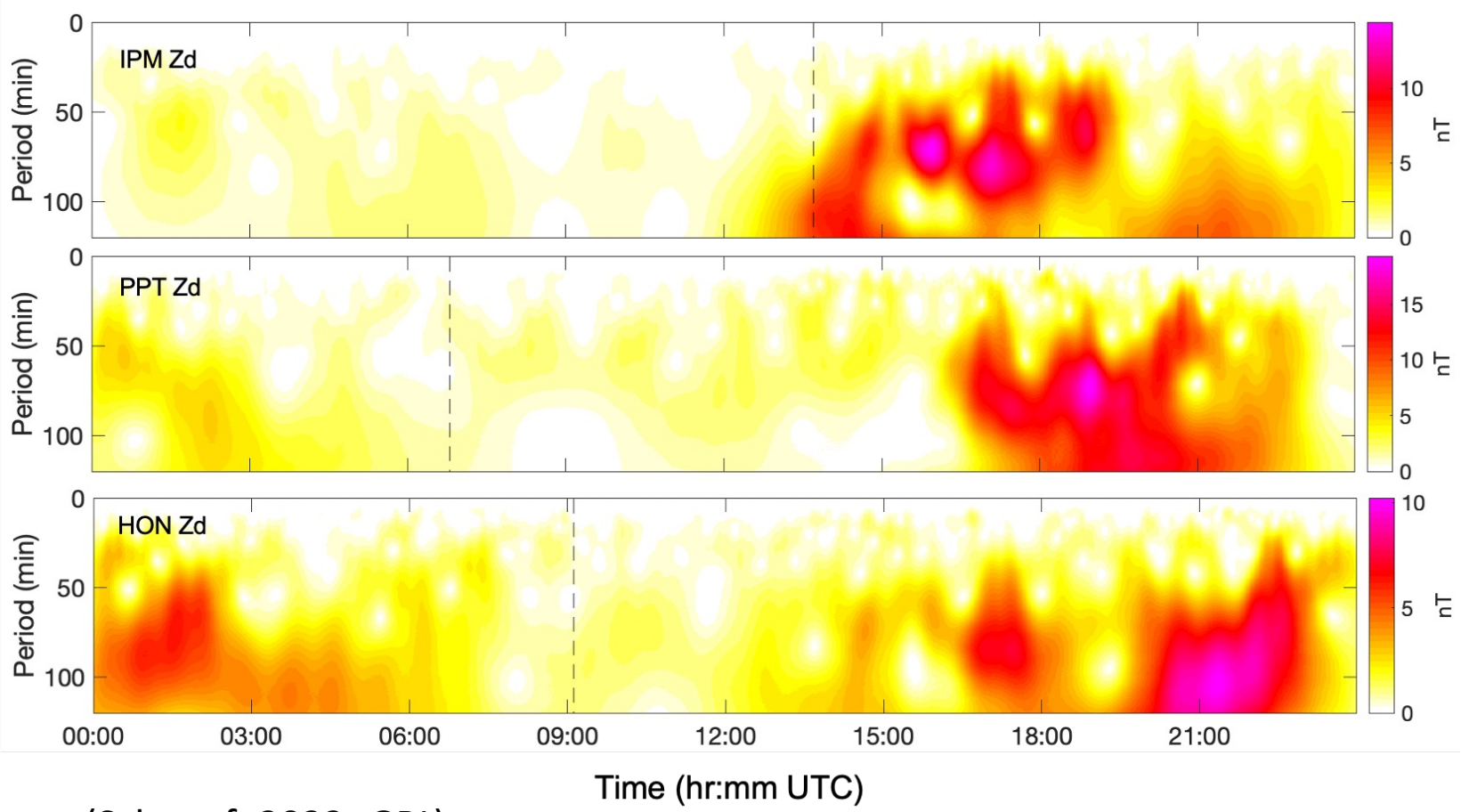


@ IPM



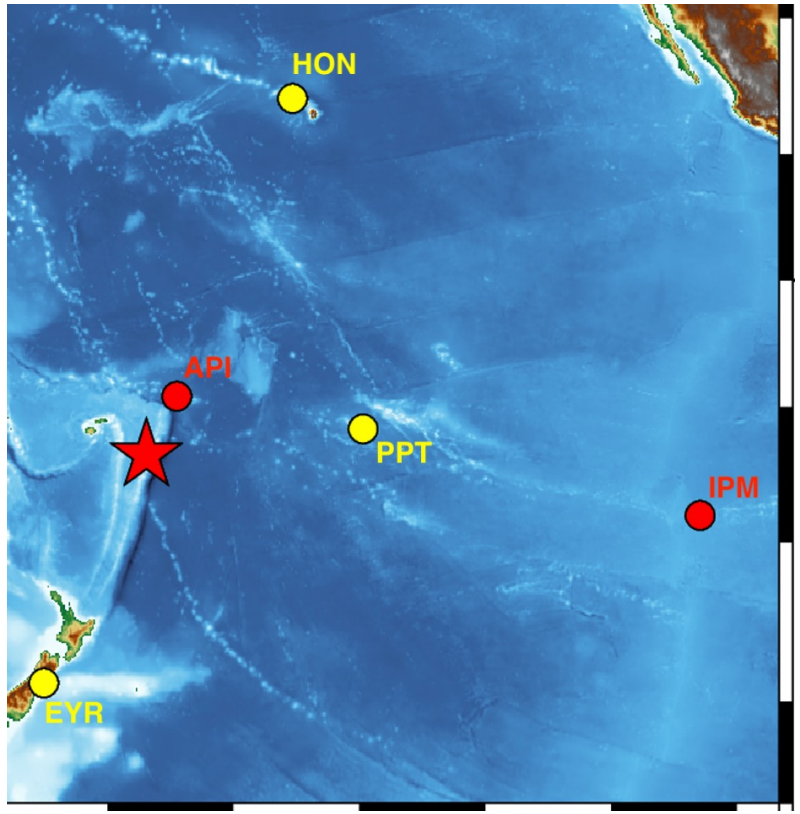
(Schnepf+2022, *GRL*)

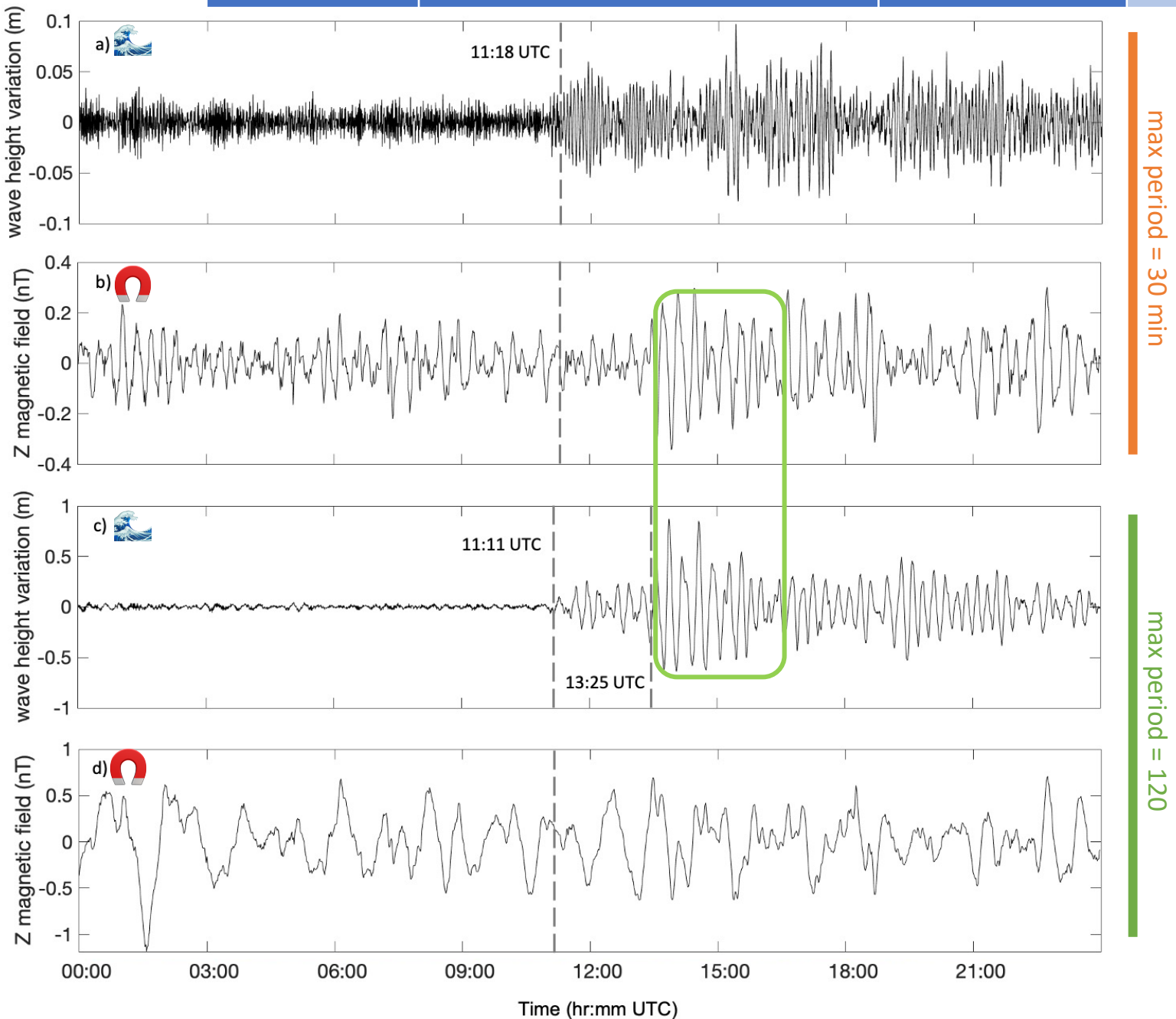
Magnetic signals of 60-90 min period.



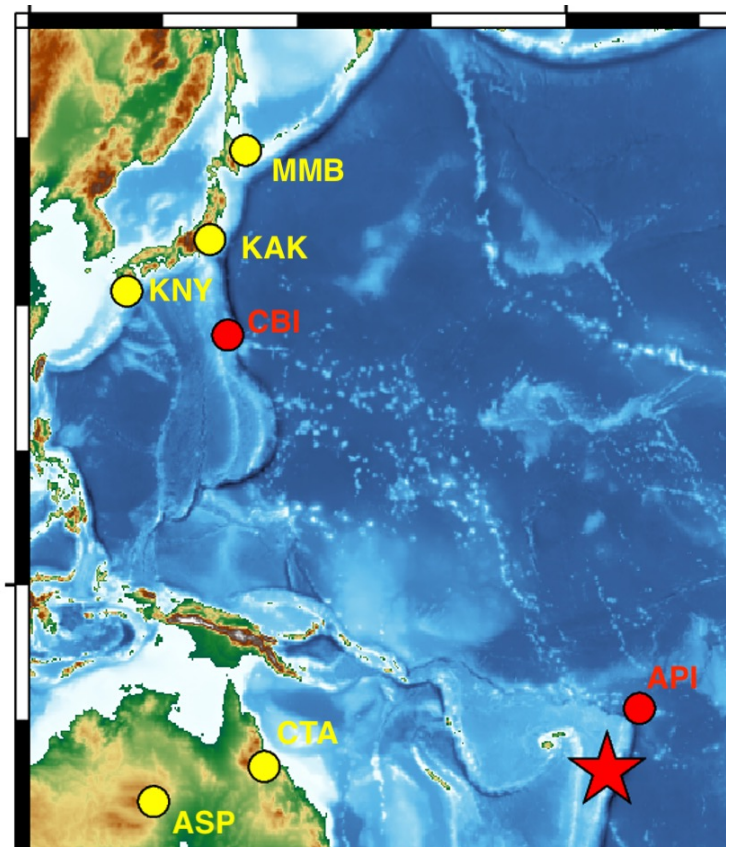
(Schnepf+2022, *GRL*)

External signals common to the ASP station have been removed from these wavelet spectrograms.

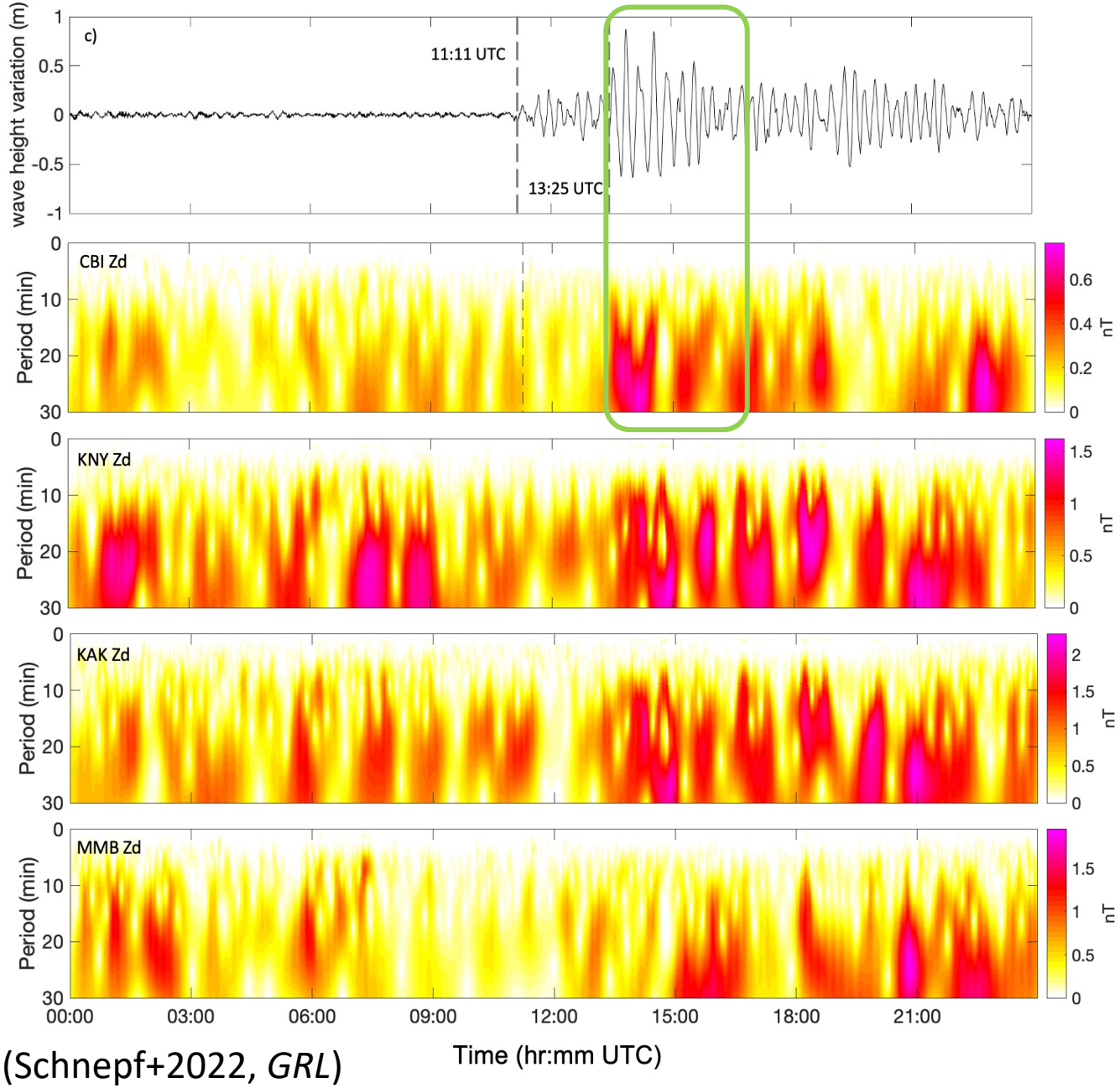




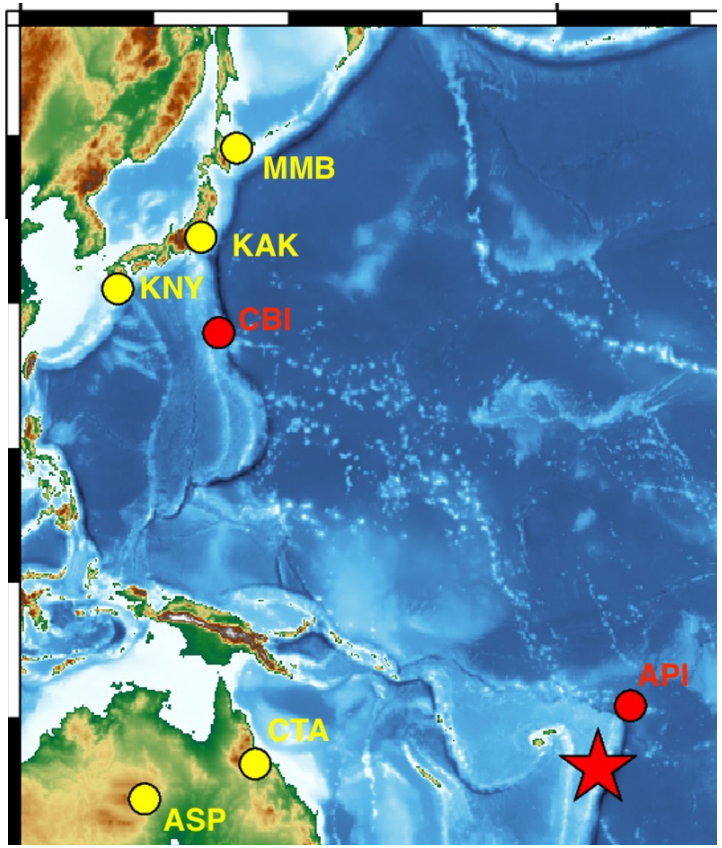
@ CBI



(Schnepf+2022, *GRL*)



(Schnepf+2022, *GRL*)

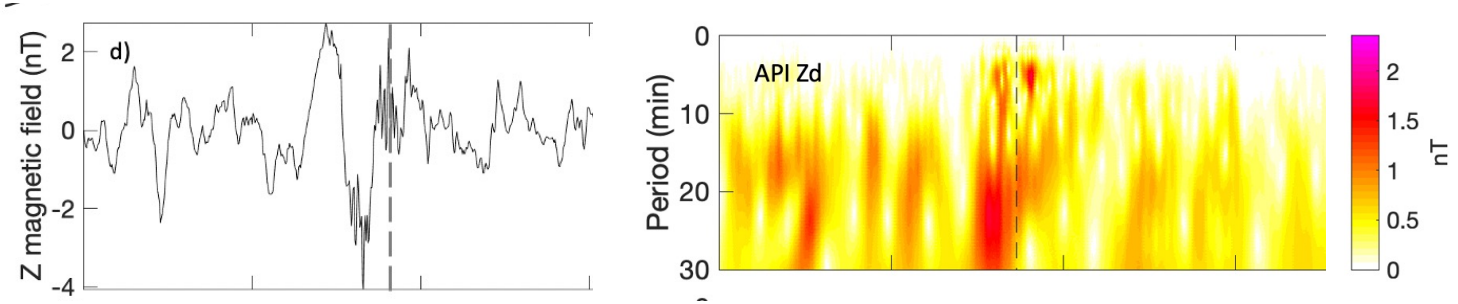


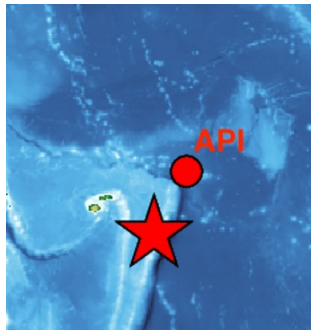
External signals common to the ASP station have been removed from these wavelet spectrograms.

Magnetic signals of 13–19 min period at CBI... but lots of noise.

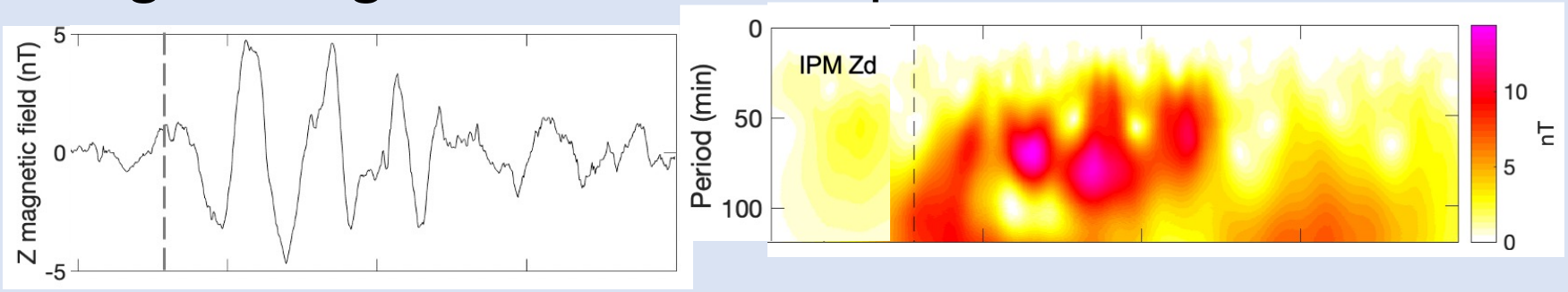
Minami et al presentation at IUGG in July

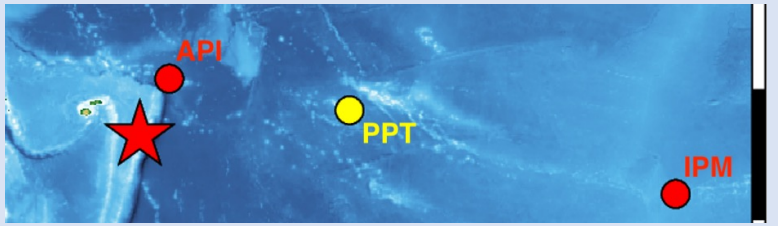
Magnetic signals of 3–8 min period at API.



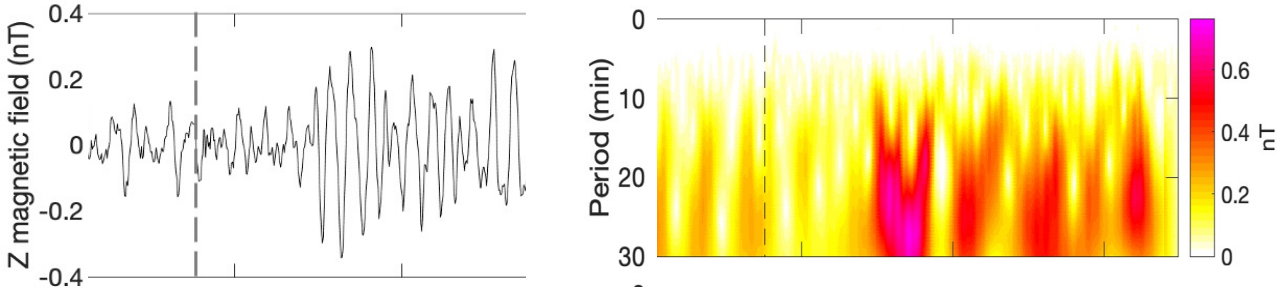


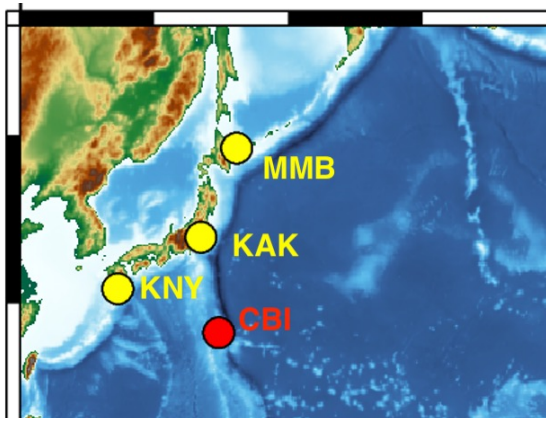
Magnetic signals of 60-90 min period at IPM.



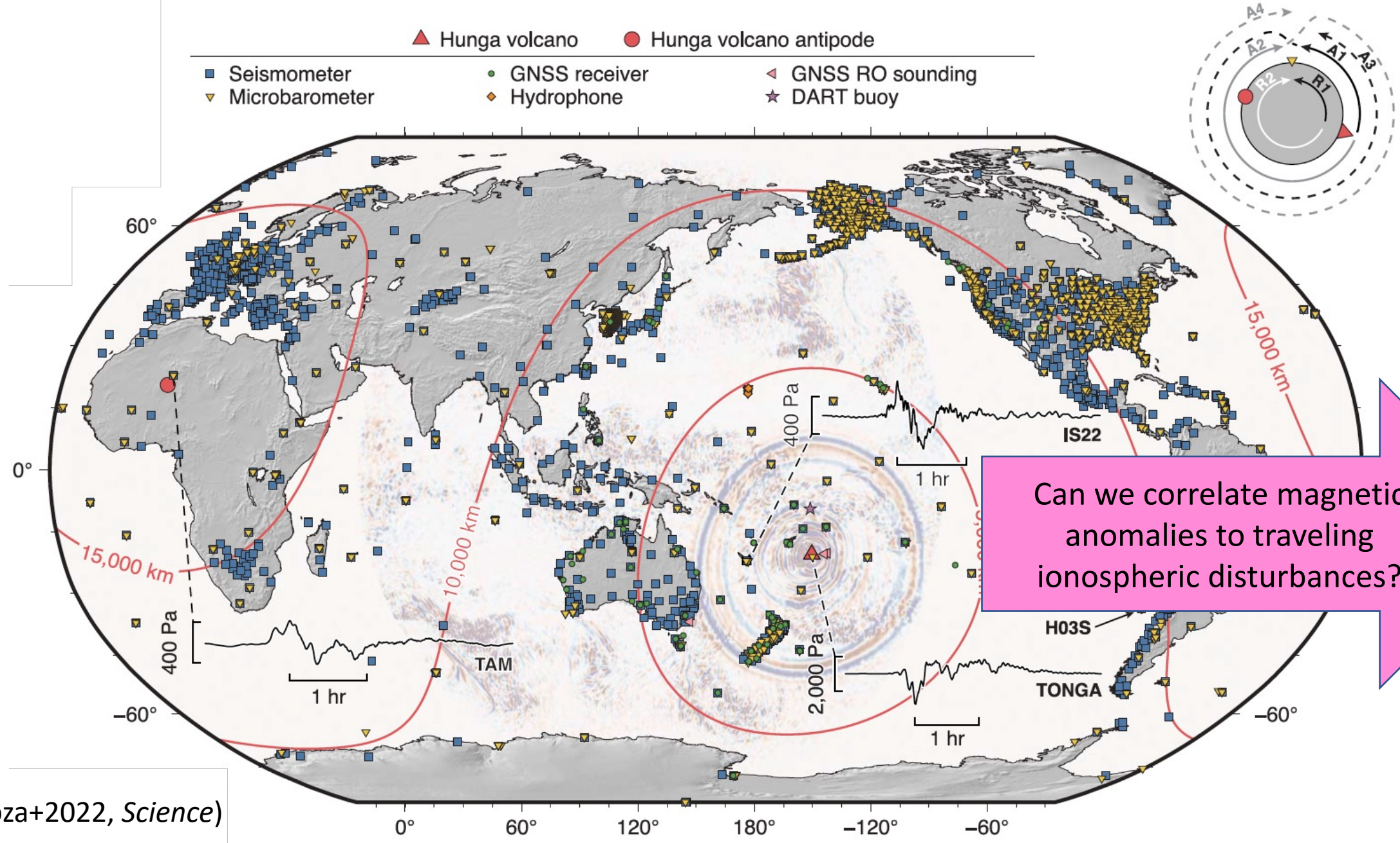


Magnetic signals of 13–19 min period at CBI.



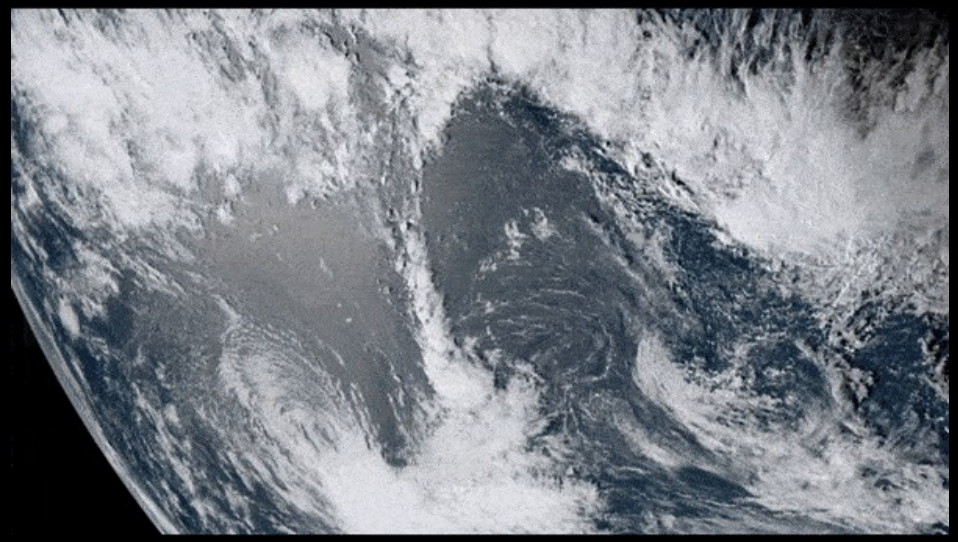


(Schnepf+2022, *GRL*)

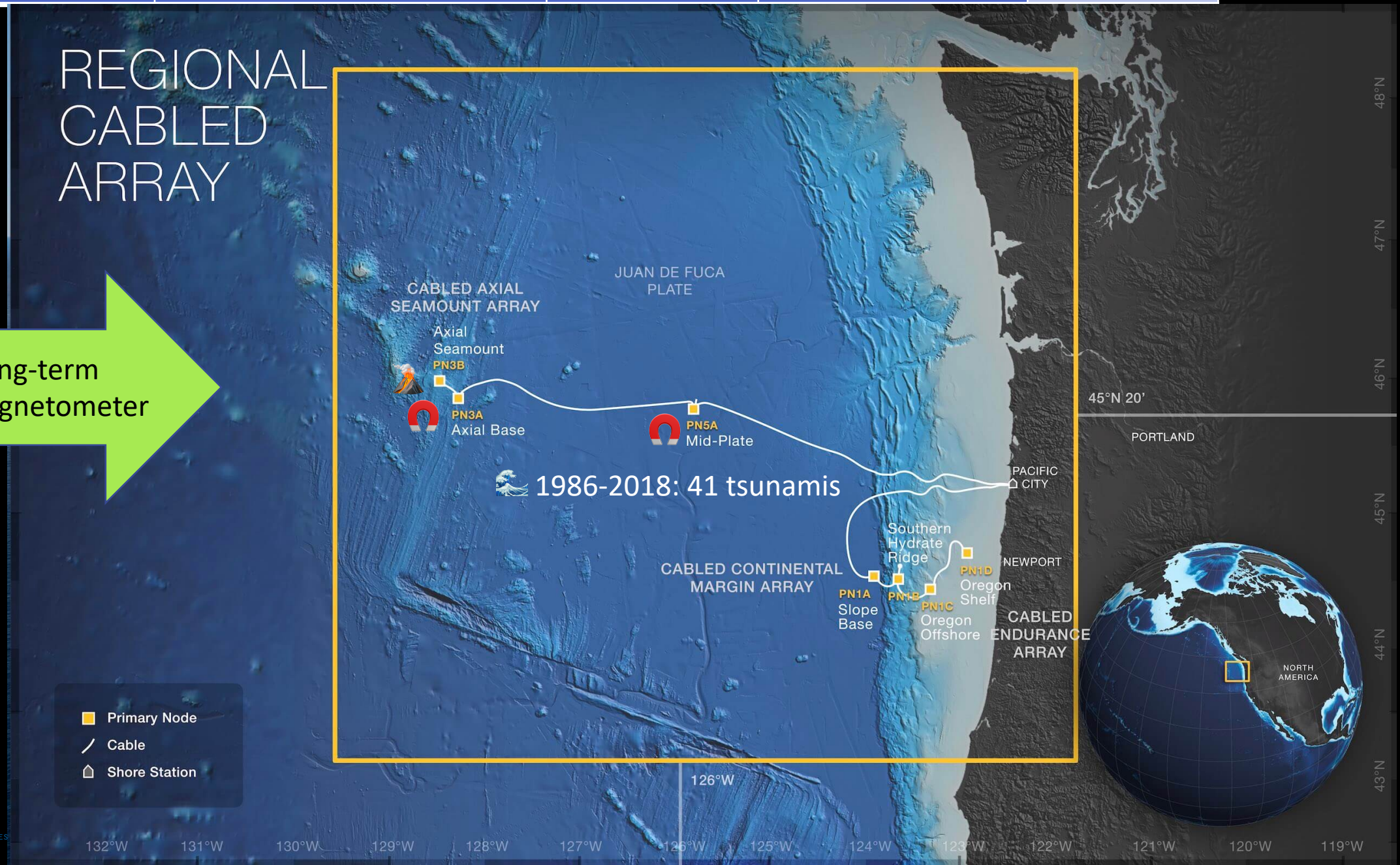


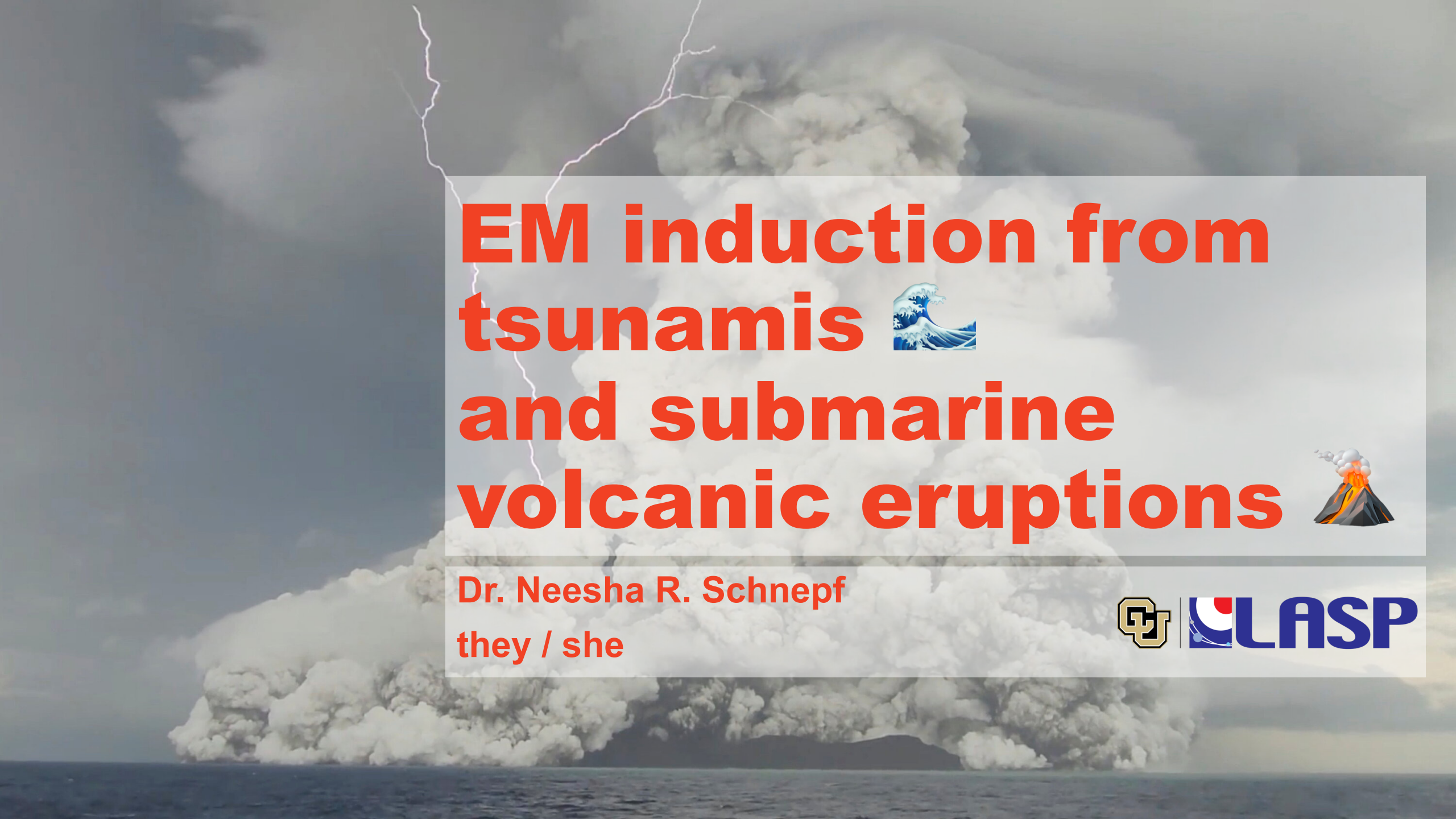
Can we correlate magnetic anomalies to traveling ionospheric disturbances?

(Matoza+2022, *Science*)



- **Magnetic signals identifiable from tsunamis, meteotsunamis, and ionospheric disturbances**
- *Can those magnetic fields be used to better understand the geophysical processes occurring here?*
  - Magnetic fields help clarify tsunami source
  - Need improved understanding of external vs internal sources for post-eruption magnetic fields
- *Can magnetic fields be incorporated into warning systems?*
  - Need long-term seafloor observatory and reliable real-time methods


REGIONAL CABLED ARRAY
Need long-term seafloor magnetometer
CABLED AXIAL SEAMOUNT ARRAY
JUAN DE FUCA PLATE
Axial Seamount
PN3B
PN3A
Axial Base
PN5A
Mid-Plate
1986-2018: 41 tsunamis
PACIFIC CITY
Southern Hydrate Ridge
CABLED CONTINENTAL MARGIN ARRAY
PN1A
Slope Base
PN1B
PN1C
Oregon Offshore
PN1D
Oregon Shelf
NEWPORT
CABLED ENDURANCE ARRAY
PORTLAND
45°N 20'
Primary Node
Cable
Shore Station
126°W
132°W
131°W
130°W
129°W
128°W
127°W
125°W
124°W
123°W
122°W
121°W
120°W
119°W
48°N
47°N
46°N
45°N
44°N
43°N
NORTH AMERICA
OCEAN OBSERVATORIES INITIATIVE



EM induction from tsunamis 🌊 and submarine volcanic eruptions 🌋

Dr. Neesha R. Schnepf
they / she

LASP