EGU23-10288: The 2022 Hunga Tonga-Hunga Ha'apai Volcanic Earthquake's Source Mechanism Revealed Through a Hierarchical Bayesian Treatment of Moment Tensor and Single-Force

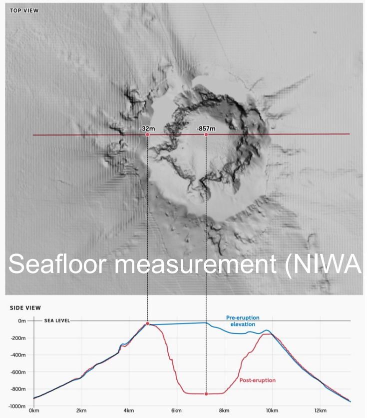
Presenter: Jinyin Hu

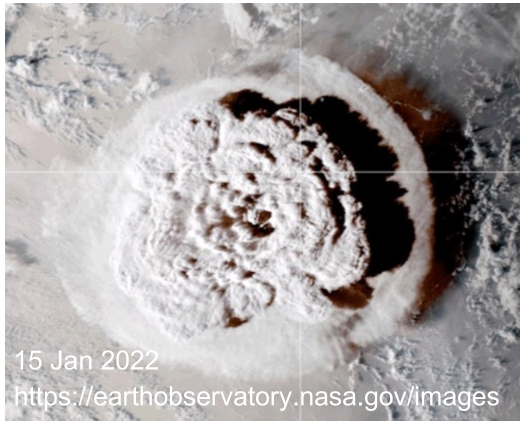
Background

Challenges in determination of shallow explosive sources:

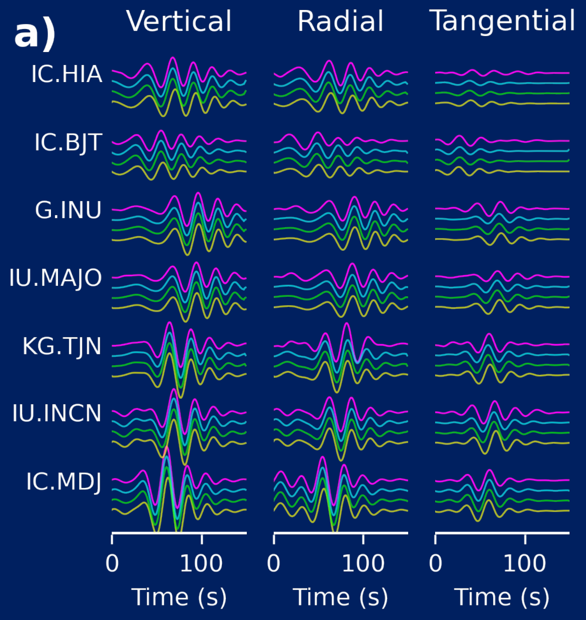
(1) Source-type tradeoff

(2) Uncertainty estimate: data noise & theory error

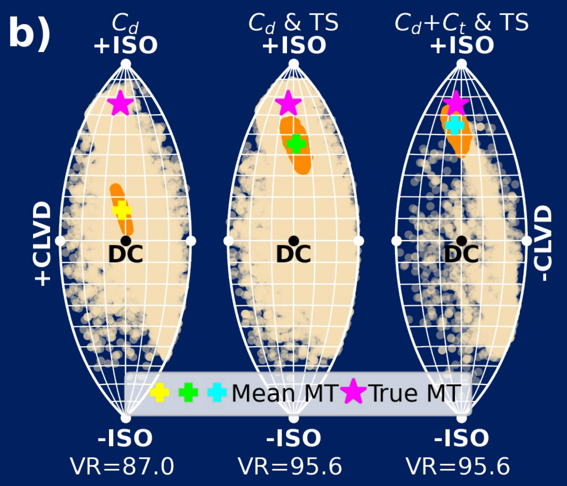




Explore the source model of the 2022 HTHH eruption from the seismological observations



Observations (magenta) and three sets of predictions in yellow, green and cyan corresponding to three MT solutions denoted by pluses in (b);



Synthetic results demonstrate the importance of source and data uncertainty quantification from Poster#EGU23-10667.

Source representation:
- Single Force (SF) — 1st order-approximation
- Moment Tensor (MT) — Explain data well
- MT+SF — Explain data well

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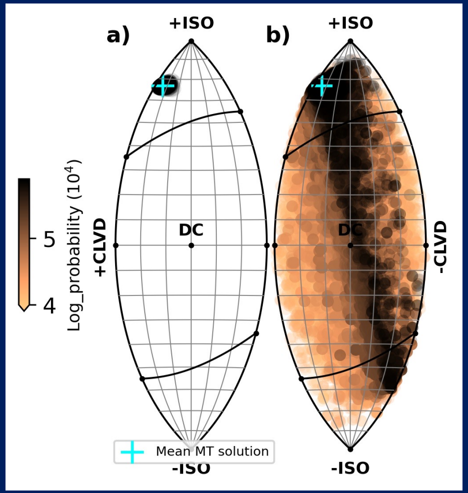
Sharing is encouraged

The possible model for a composite source solution of **explosive moment tensor and an upward single force** in this study

- **Explosive MT**



Lune-diagram of source type in converging stage (left) and the whole inversion (right).

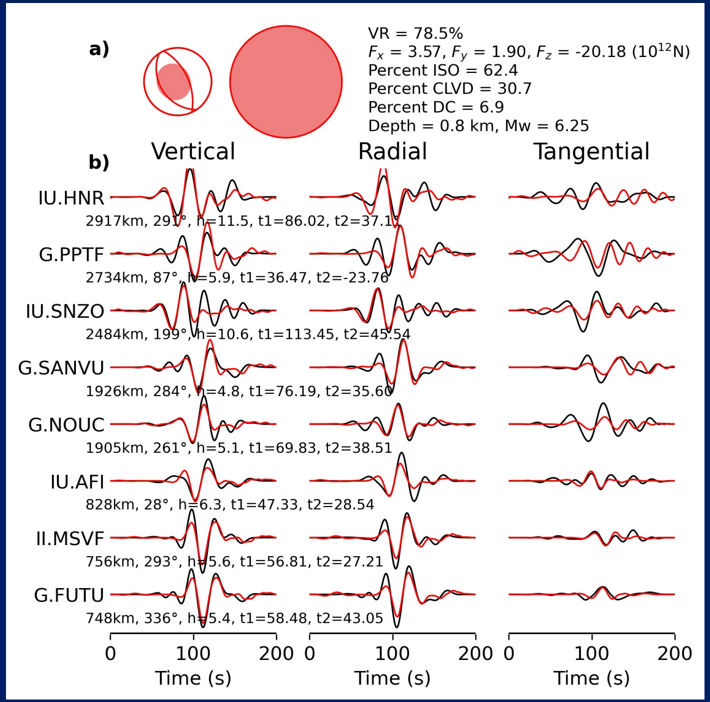
- **Upward SF**

$$F_x = 0.357\text{e}13\ \text{N}$$

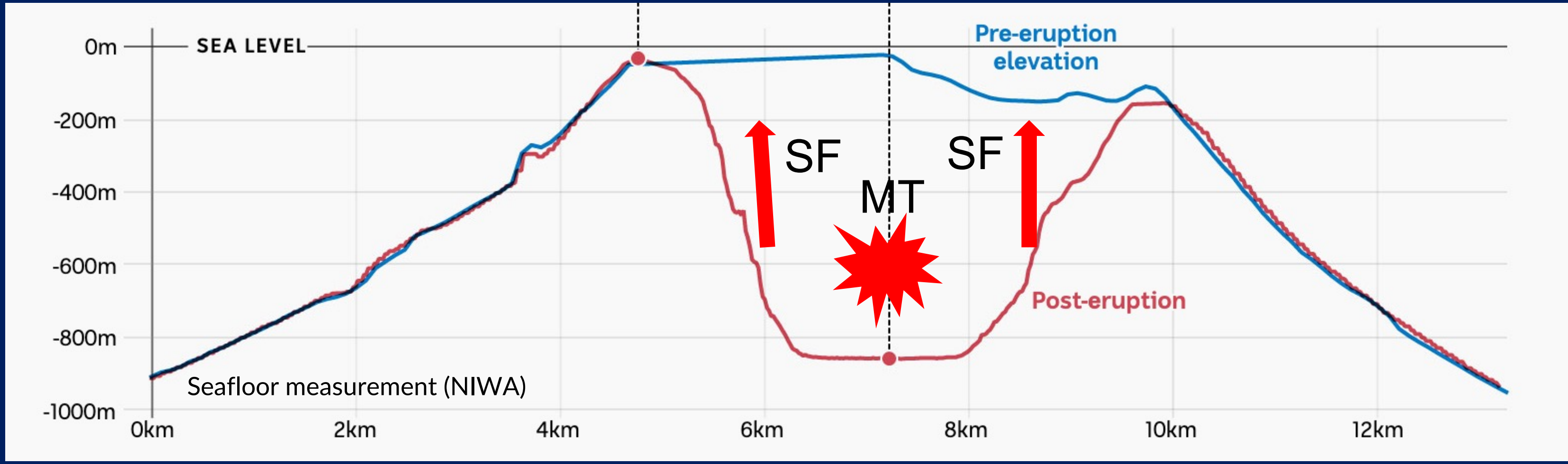
$$F_y = 0.19\text{e}13\ \text{N}$$

$$F_z = -2.02\text{e}13\ \text{N}$$

Upward force could be explained as a drag force due to viscous materials moving upward in the conduit (e.g., Ohminato et al., 2006)



Waveform fit



A possible model: Shallow explosion and a drag force acting on the remaining walls.

Seismic source inversion for the 2022 HTHH eruption

Methodology in a nutshell

- Bayesian seismic source inversion

$$p(\mathbf{d}|\mathbf{m},\mathbf{h},\boldsymbol{\tau}) = \prod_{i=1}^{M} \frac{1}{\sqrt{(2\pi)^N |C_i|}} exp\left(-\frac{1}{2}(g_i'(\mathbf{m}) - d_i)^T C_i^{-1} (g_i'(\mathbf{m}) - d_i)\right)$$

where

$$g_i'(\mathbf{m}) = F^{-1}\left[F[g_i(\mathbf{m})] \cdot e^{-i\omega\tau}\right]$$

$$g_i(\mathbf{m}) = \mathbf{G}_i\mathbf{m}$$

SF Noise Time shift

$$[\mathbf{m},\mathbf{h},\boldsymbol{\tau}] = \left[M_{xx}, M_{yy}, M_{zz}, M_{xy}, M_{xz}, M_{yz}; F_x, F_y, F_z; h_1, \cdots h_n;\ \tau_1, \cdots \tau_n\right]$$

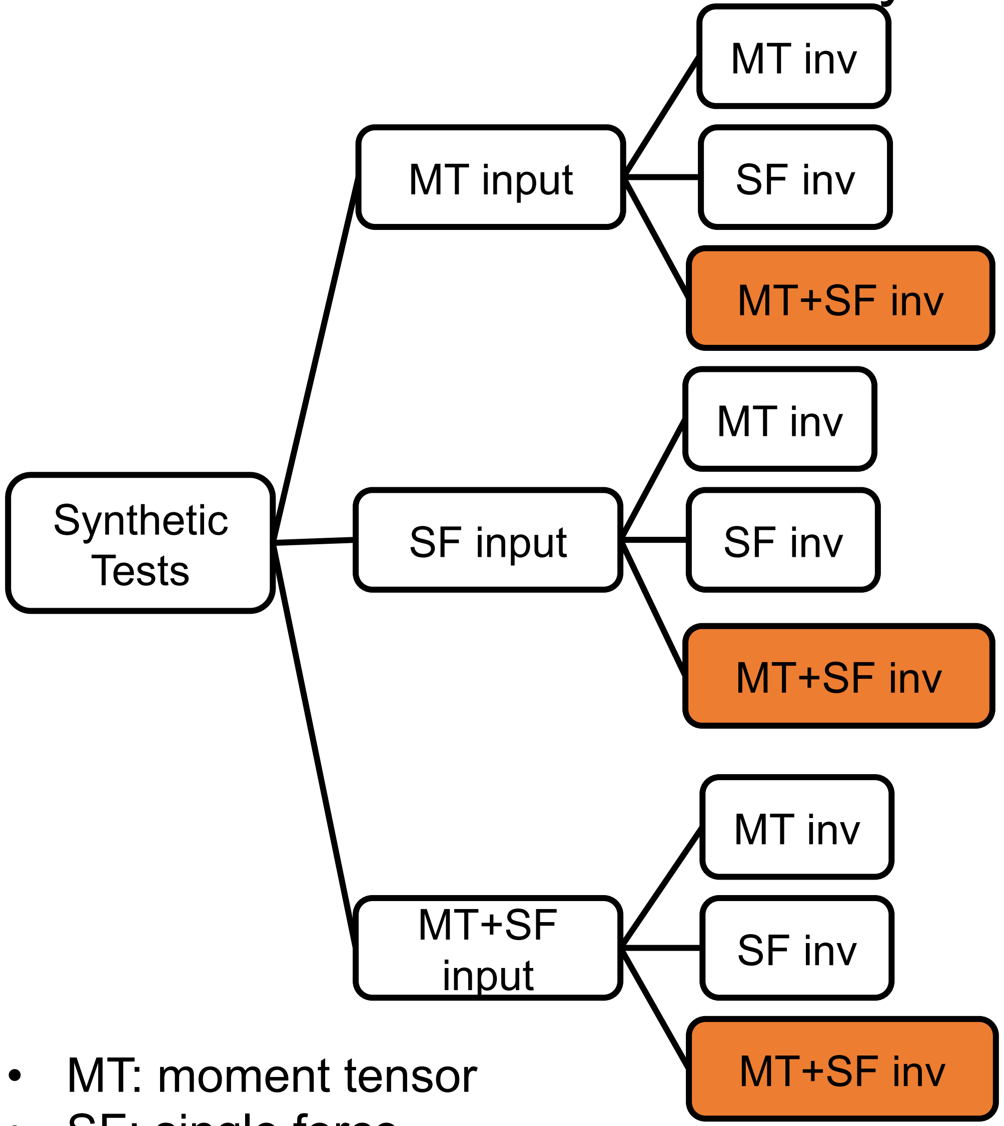
MT source (n: number of stations)

Our method considers both data noise (h_i) and 2D Earth's structural error (τ_i).

(Hu, Phạm & Tkalčić, in review)

Seismic source inversion for the 2022 HTHH eruption

Nine inversions for the recovery test



- No fake SF is obtained if the input source only includes MT
- No fake MT is obtained if the input source only includes SF
- If the source include SF and MT components, both can be recovered

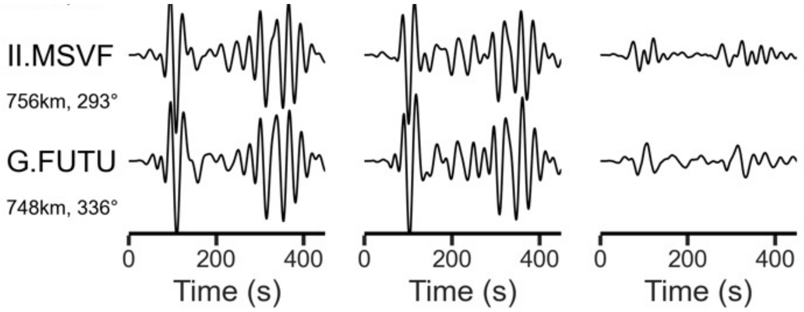
- MT: moment tensor
- SF: single force

Seismic source inversion for the 2022 HTHH eruption

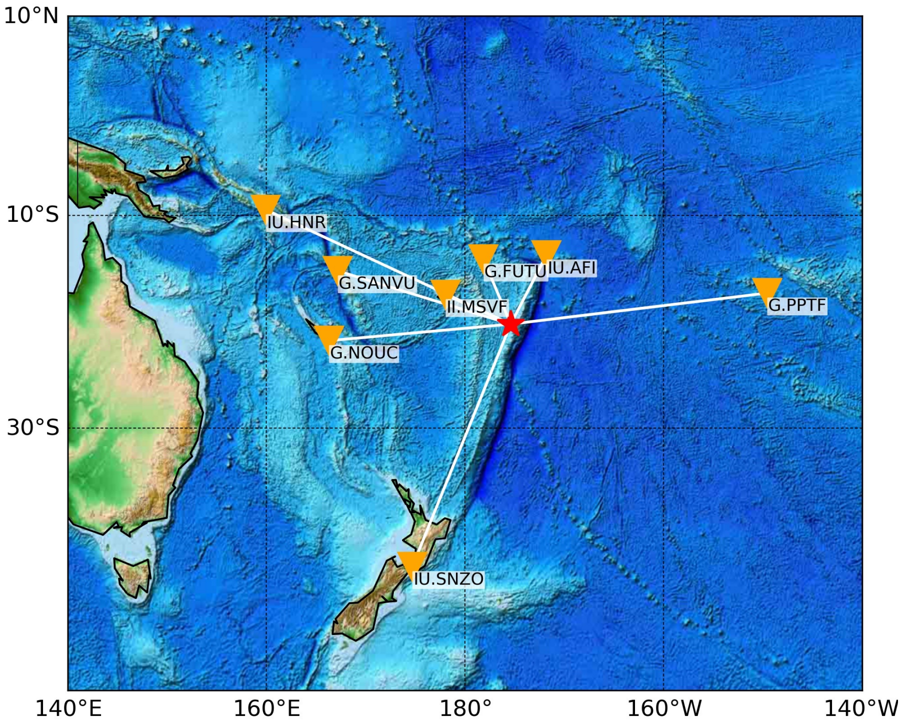
Real data application

Focus on the first sub-event HTHT volcanic explosion

(Hu et al., in prep)



- Allow 2 time shifts as free parameters per station: one for Z/R component, one for T component
- Treat uncorrelated data noise
- AK135F model (Montagner & Kennett, 1996)
- Greens functions are obtained from online database: syngine https://doi.org/10.17611/DP/SYNGINE.1.

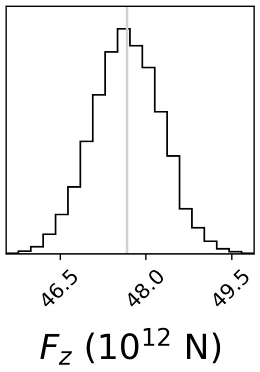


Source depth is assumed at 0.8 km

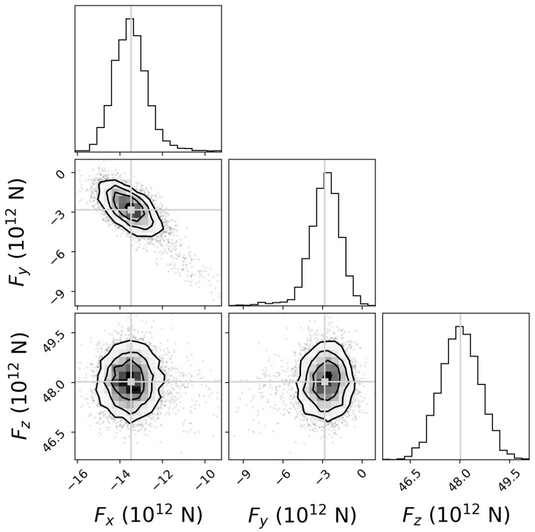
Seismic source inversion for the 2022 HTHH eruption

➢ SF inversion

- **A downward force is obtained**

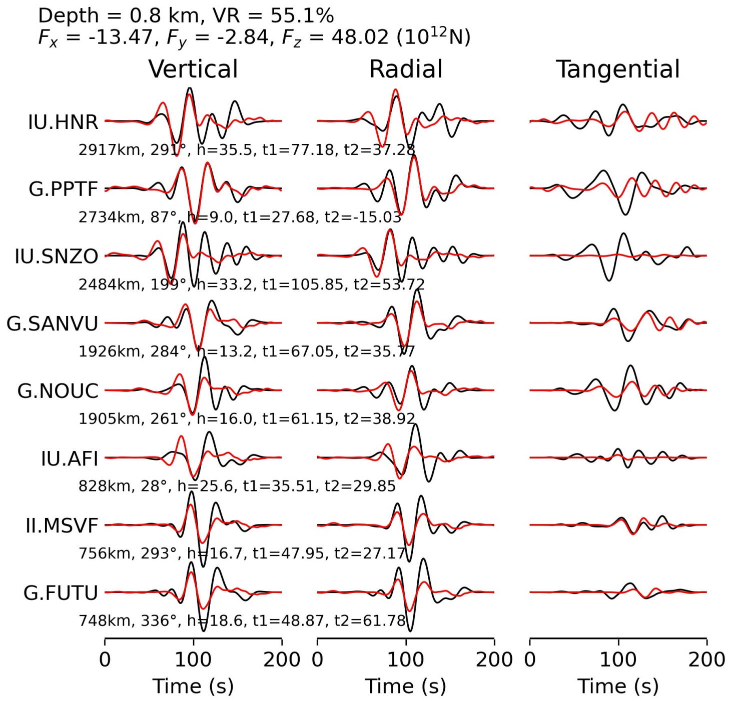


Vertical SF inversion

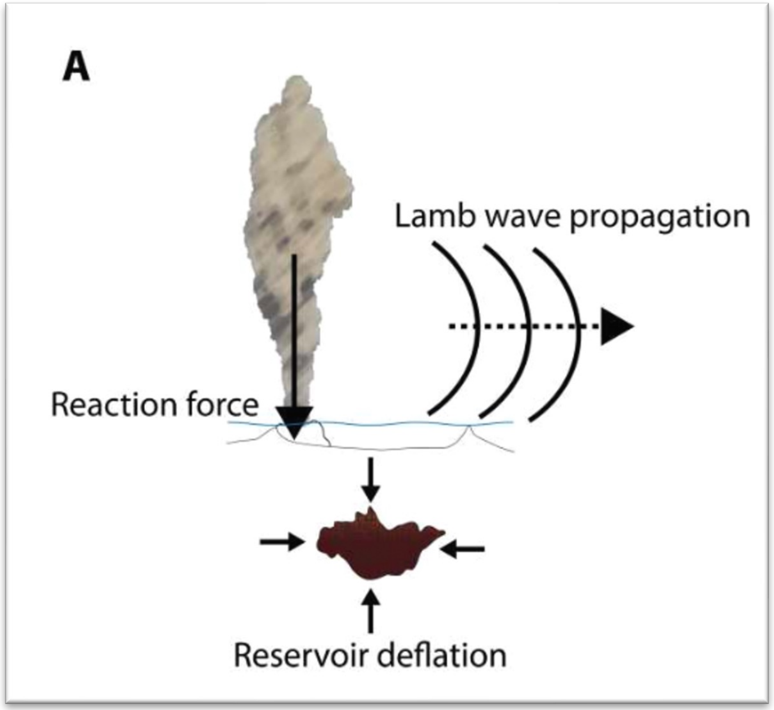


Full SF inversion

Posterior distribution of SF parameters



— Observation — Predictions

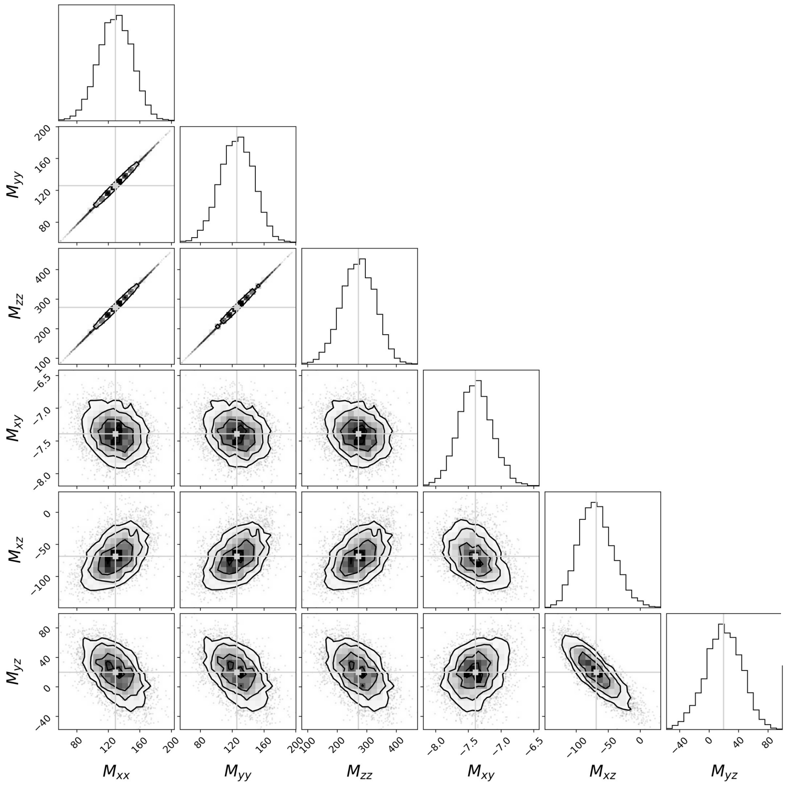


(e.g., Poli and Shapiro, 2022; Garza-Girón et al., 2023)

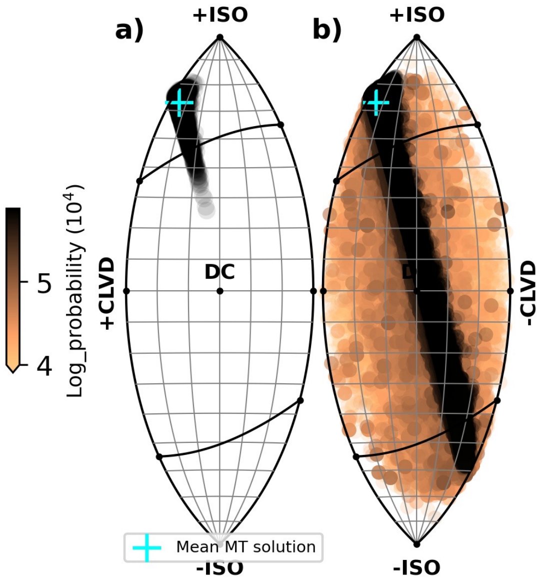
Seismic source inversion for the 2022 HTHH eruption

➢ MT inversion

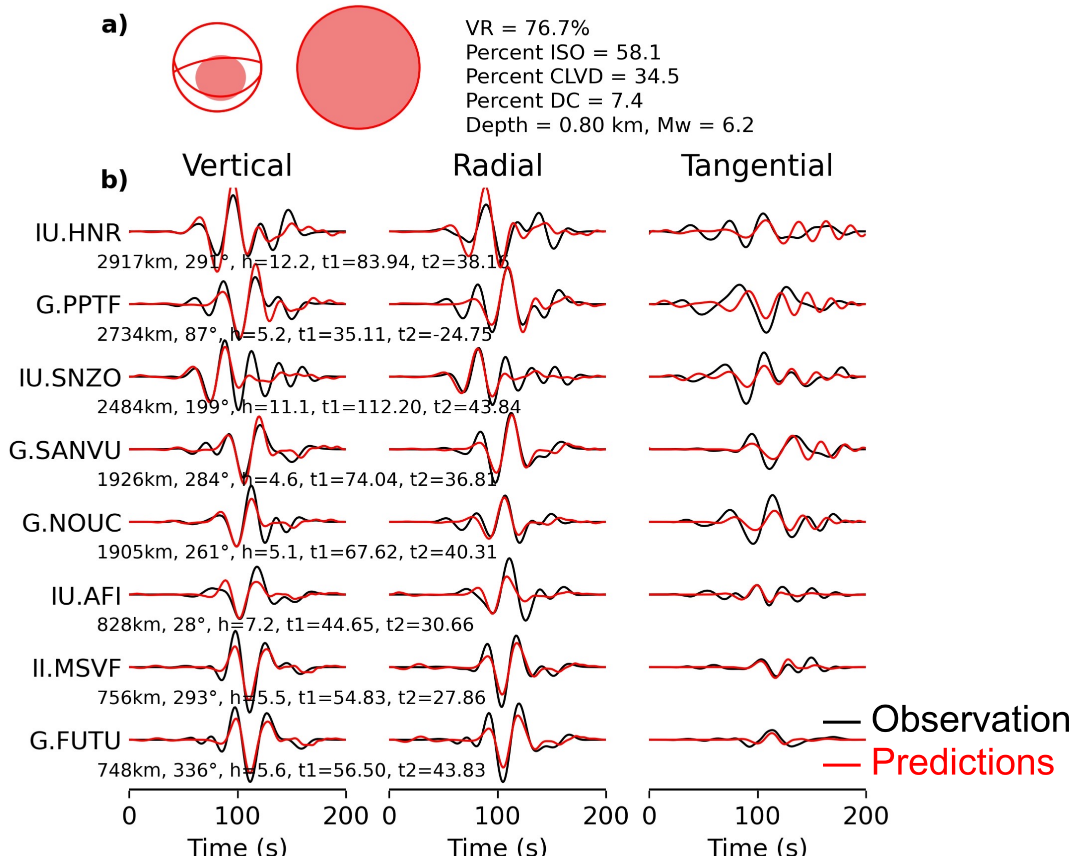
- **An explosive source character is revealed** (58% ISO component in MT)



Posterior distribution of MT parameters



Lune diagram of source types in converging stage (left) and the whole inversion (right).



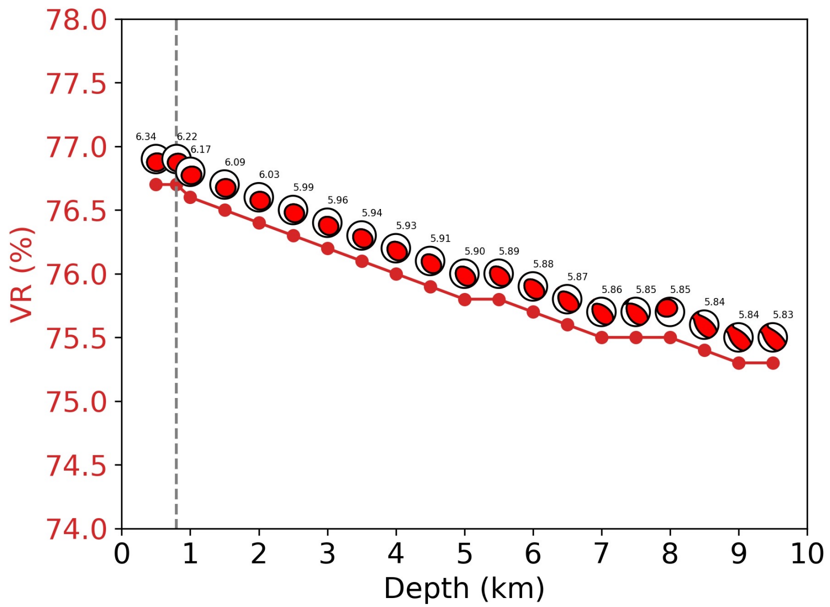
Waveform fit between observations and predictions

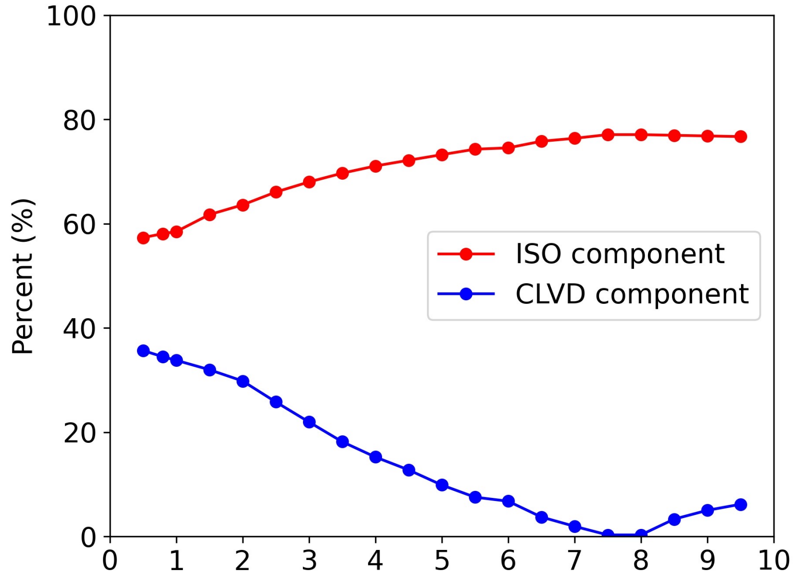
(Lune-plot is basd on Tape & Tape 2012)

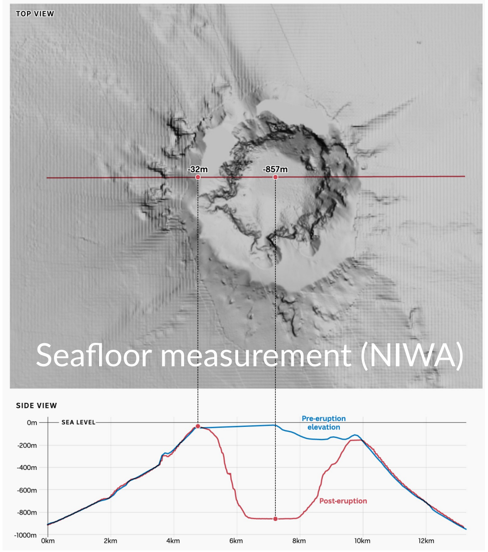
Seismic source inversion for the 2022 HTHH eruption

➢ MT inversion

MT solutions at varying source depths (0.5 – 10 km)







Assume the source depth = 0.8km

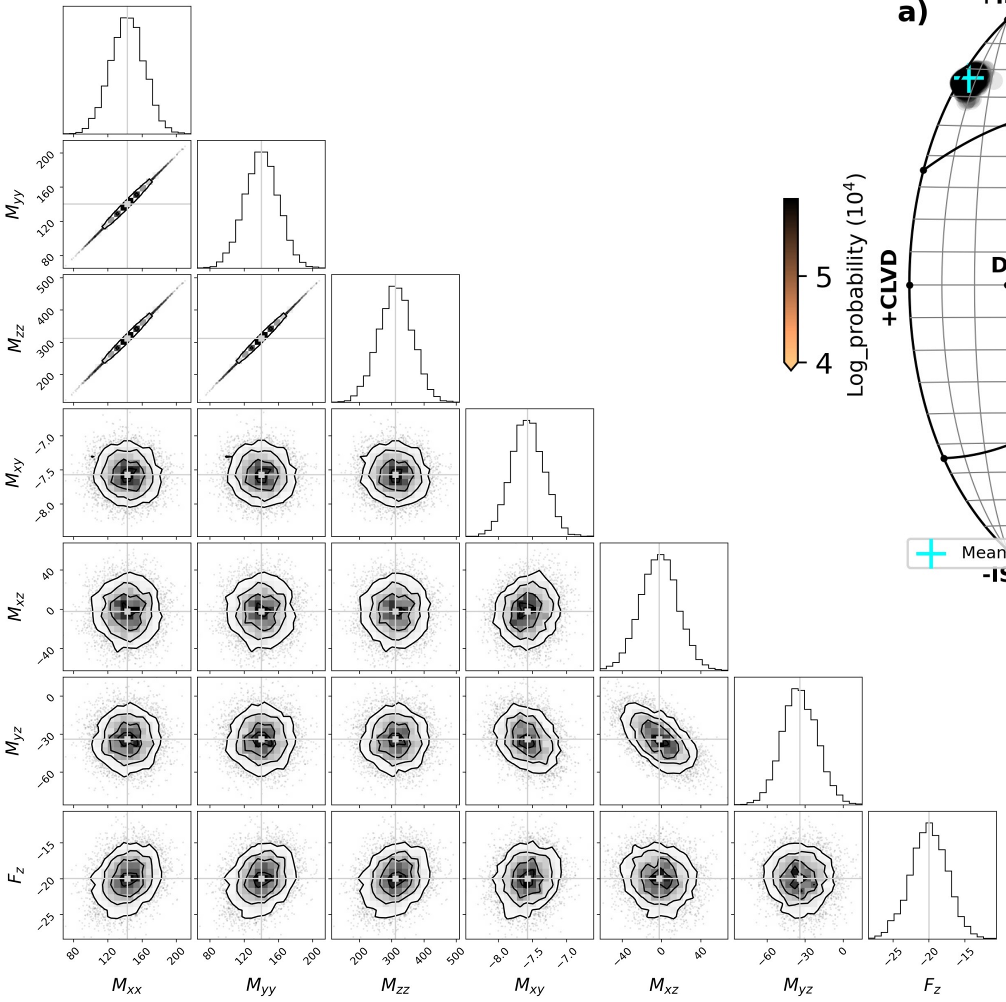
As the source becomes deeper:

- VR decreases
- ISO component increases
- Moment magnitude becomes smaller

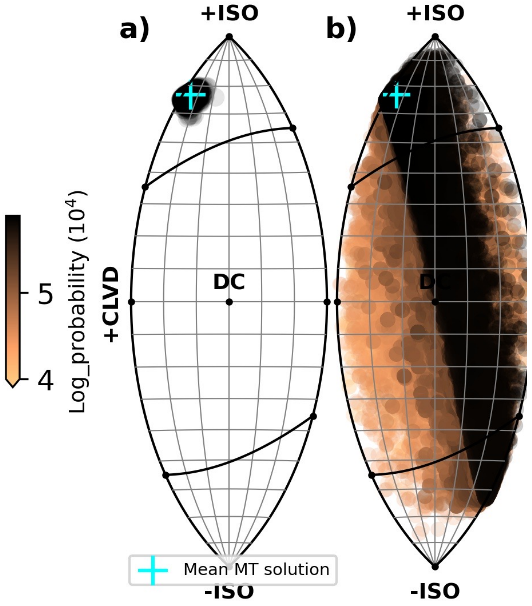
Seismic source inversion for the 2022 HTHH eruption

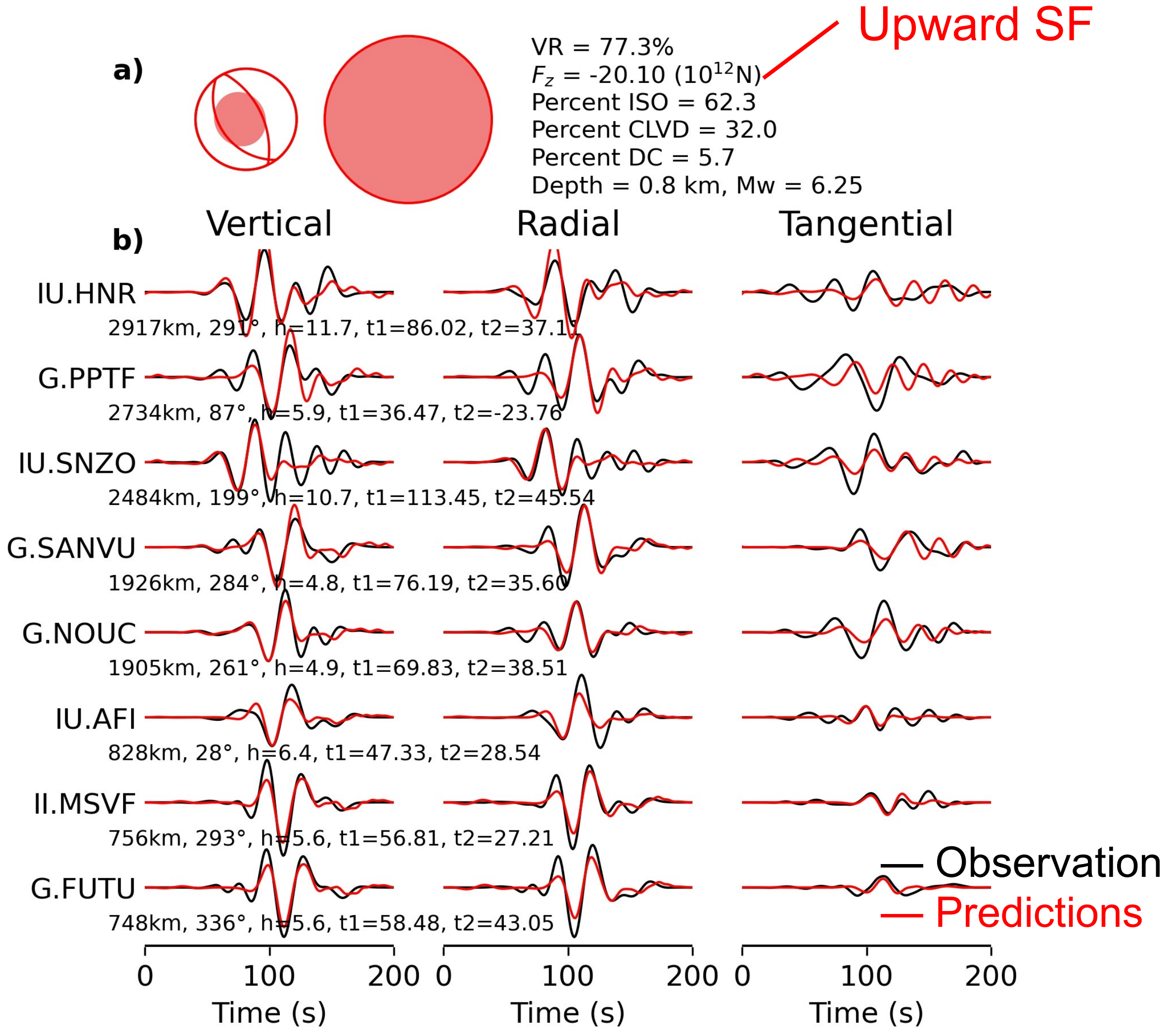
➢ MT+Fz inversion

- **An explosive source + upward force**



Posterior distribution of source parameters



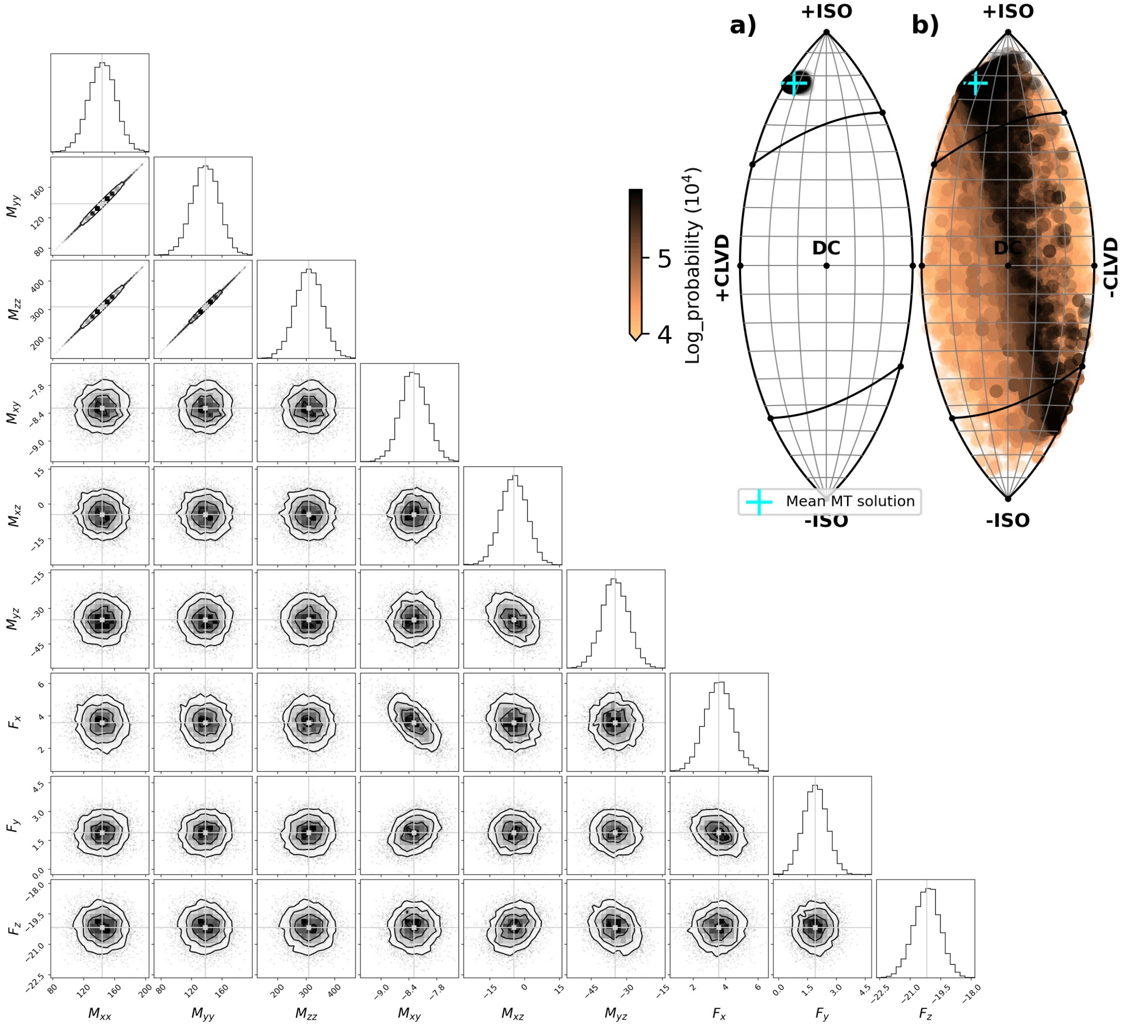


The contribution of SF is 29%

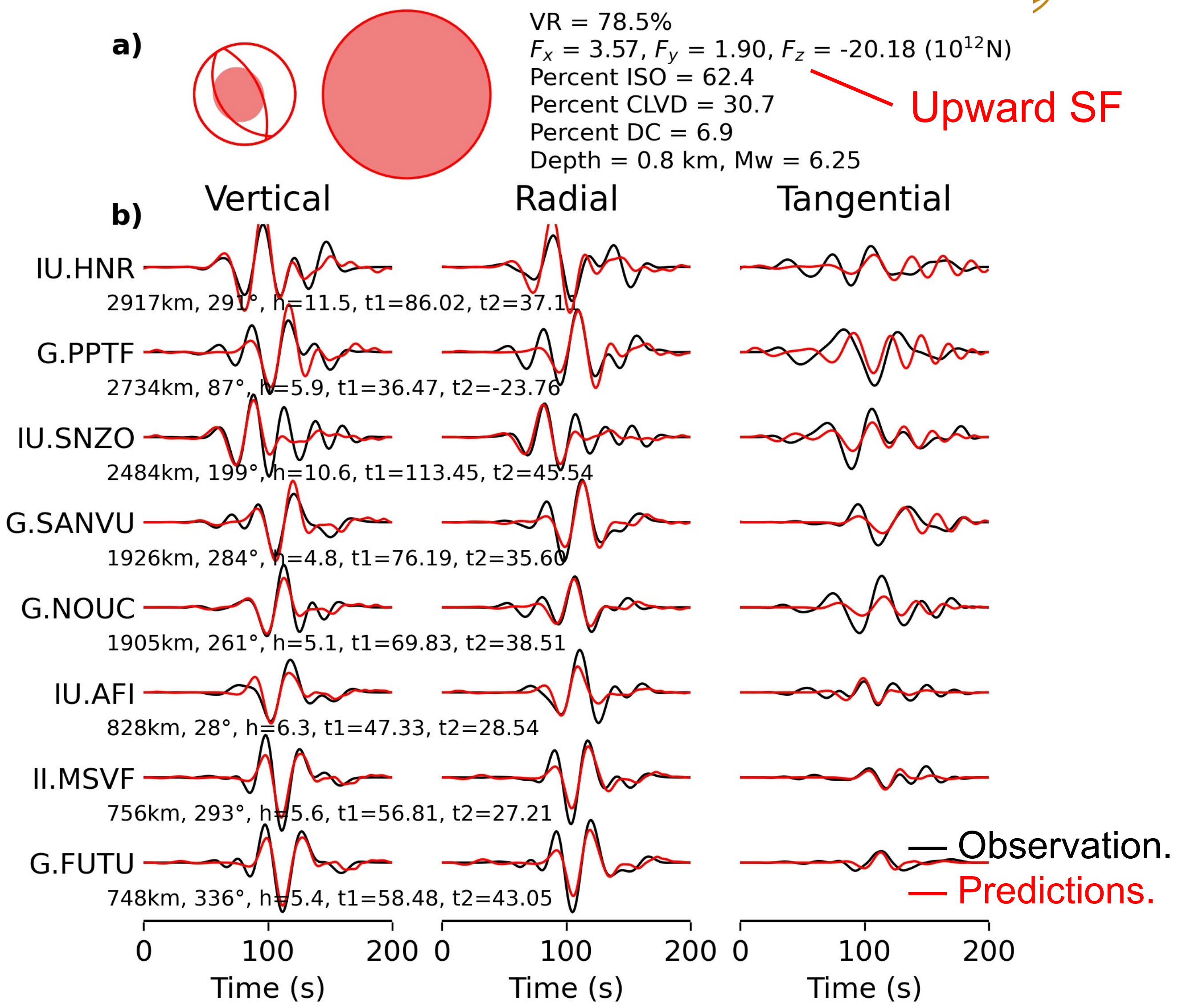
Seismic source inversion for the 2022 HTHH eruption

➢ MT+SF inversion

- **An explosive source + upward force**



Posterior distribution of source parameters



The contribution of SF is 27%

Take-home messages

Different source models (SF, MT, MT+SF) for the 2022 HTHH eruption are investigated.

- Downward SF source, as the first-order approxiamate, provides a preliminary fit to the observations
- Explosive MT source explains the observations well.
- Explosive MT+ upward SF model also explain the observations well.

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