

Tsunami monitoring with space altimetry

New perspectives from SWOT

Lucie Rolland, Antoine Delepouille, Yannice Faugère, Mauricio Fuentes, Hélène Hébert, Philippe Heinrich, Jean Roger



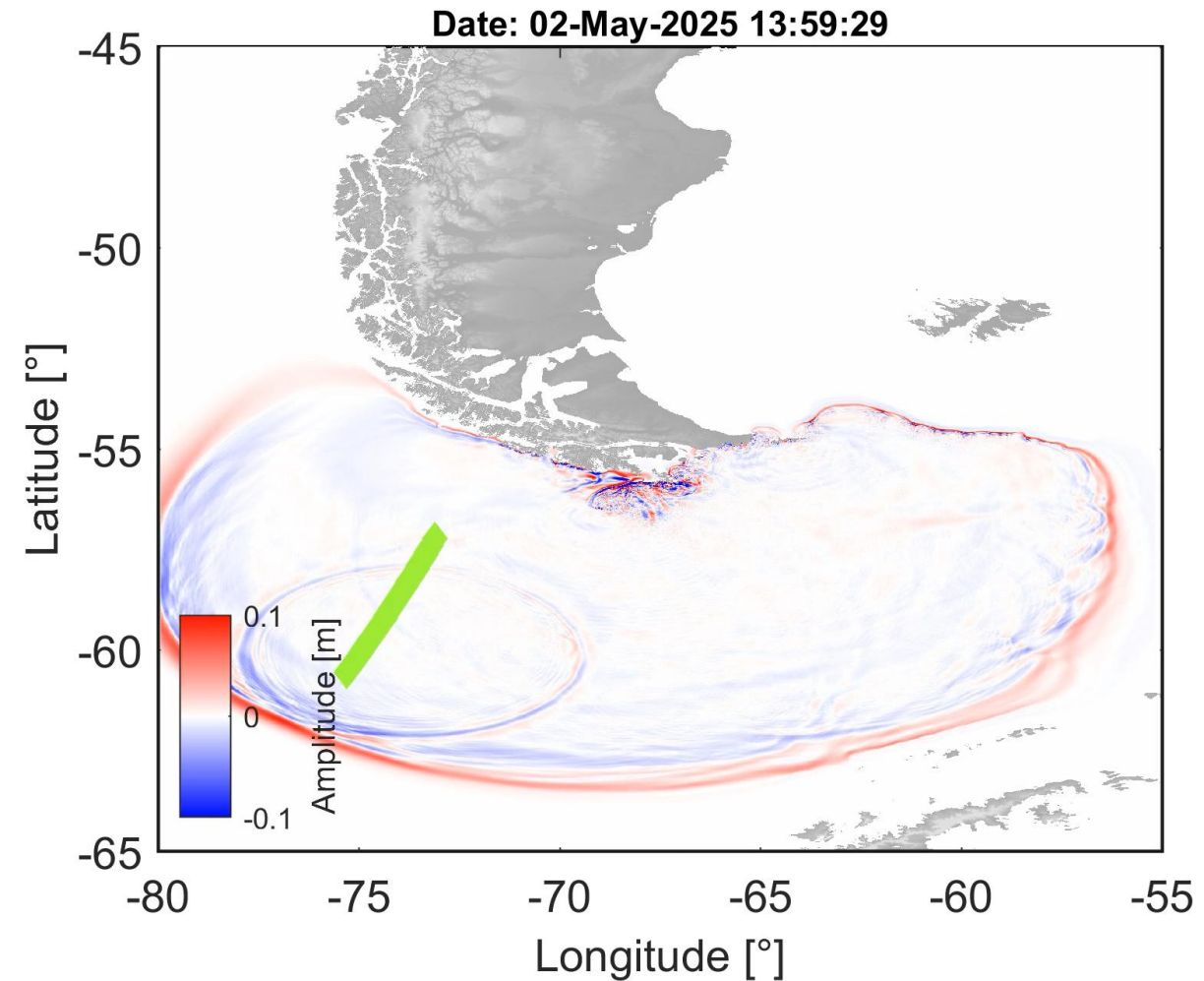
XI Hotine-Marussi Symposium, Genova, 7-11 September 2026

The open-ocean observation gap - why altimetry matters

A tsunami crossing the deep ocean is a long wave (wavelength $\sim 100\text{-}200\text{ km}$) with small amplitude (centimeter to meter).

- Seismic data constrain rupture, but not the complete sea-surface response.
- DART buoys remain sparse.
- Coastal tide gauges detect the wave late.

Conventional tsunami data used for mapping the tsunami wave field (sea-surface height estimations) are sparse

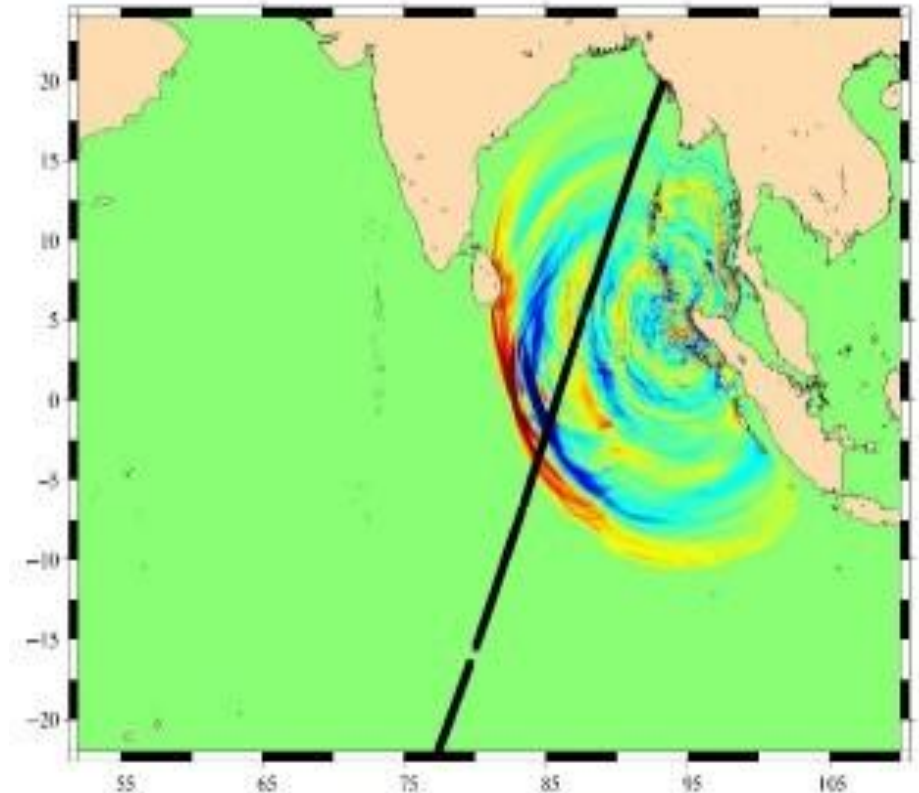


Tsunami wave: 50-200m/s
Space altimeters: 6-7 km/s

Three decades of tsunami detections with conventional Nadir Altimetry

Many events already demonstrated the physical observability of tsunami sea-level anomalies from space with Nadir Altimetry :

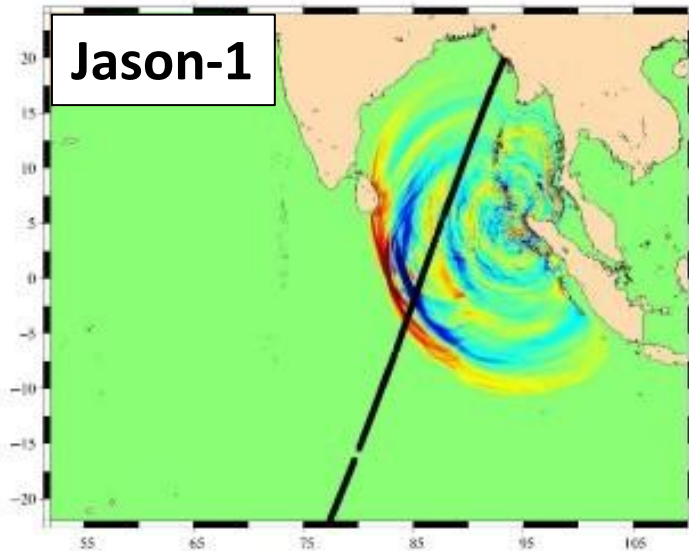
- **1992 Nicaraguan (ERS-1) and 1995 Chilean (TOPEX/Poseidon) tsunami:** Okal et al. (1999)
- **2004 Sumatra-Andaman tsunami :** Wang and Liu, (2006), Ablain et al. (2006), Gower et al. (2007), Godin et al. (2009) – 3 Nadir altimeters
- **2010 Chilean tsunami,** Hamlington et al. (2011)
- **2011 Tohoku tsunami,** Hamlington et al. (2012)
- **2022 Hunga Tonga-Hunga tsunami :** Faugere et al. (2022) – 6 Nadir altimeters (DUACS)



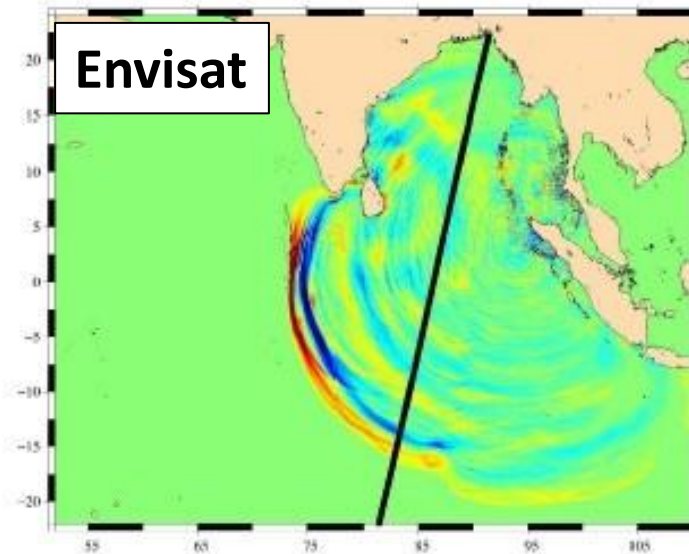
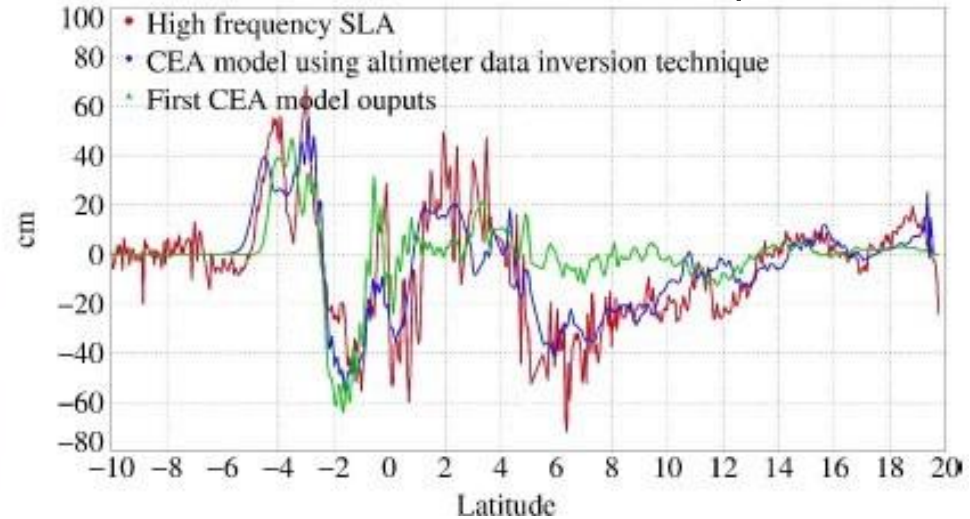
Ablain et al. (2006)

1992 to 2022: repeated proof of concept

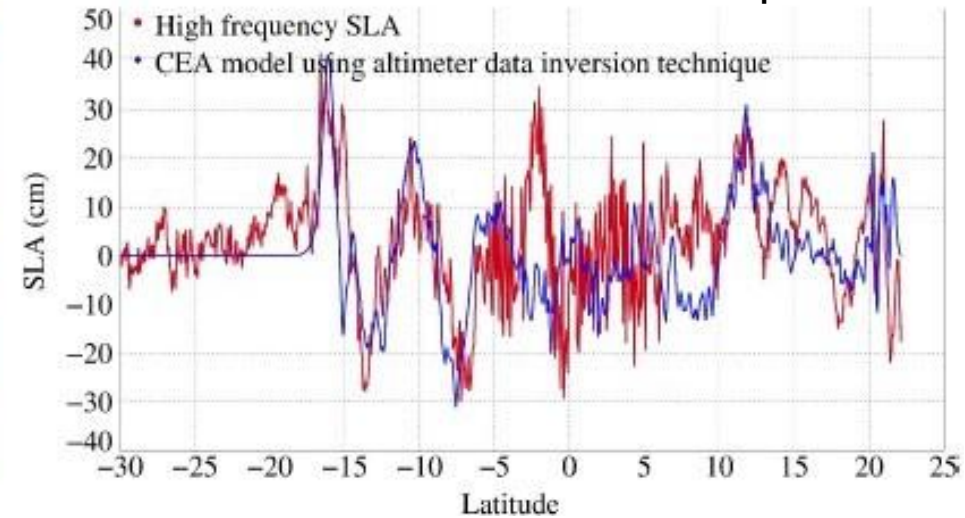
Sumatra-Andaman 2004 (Ablain et al., 2026)



1:53 hour after the earthquake

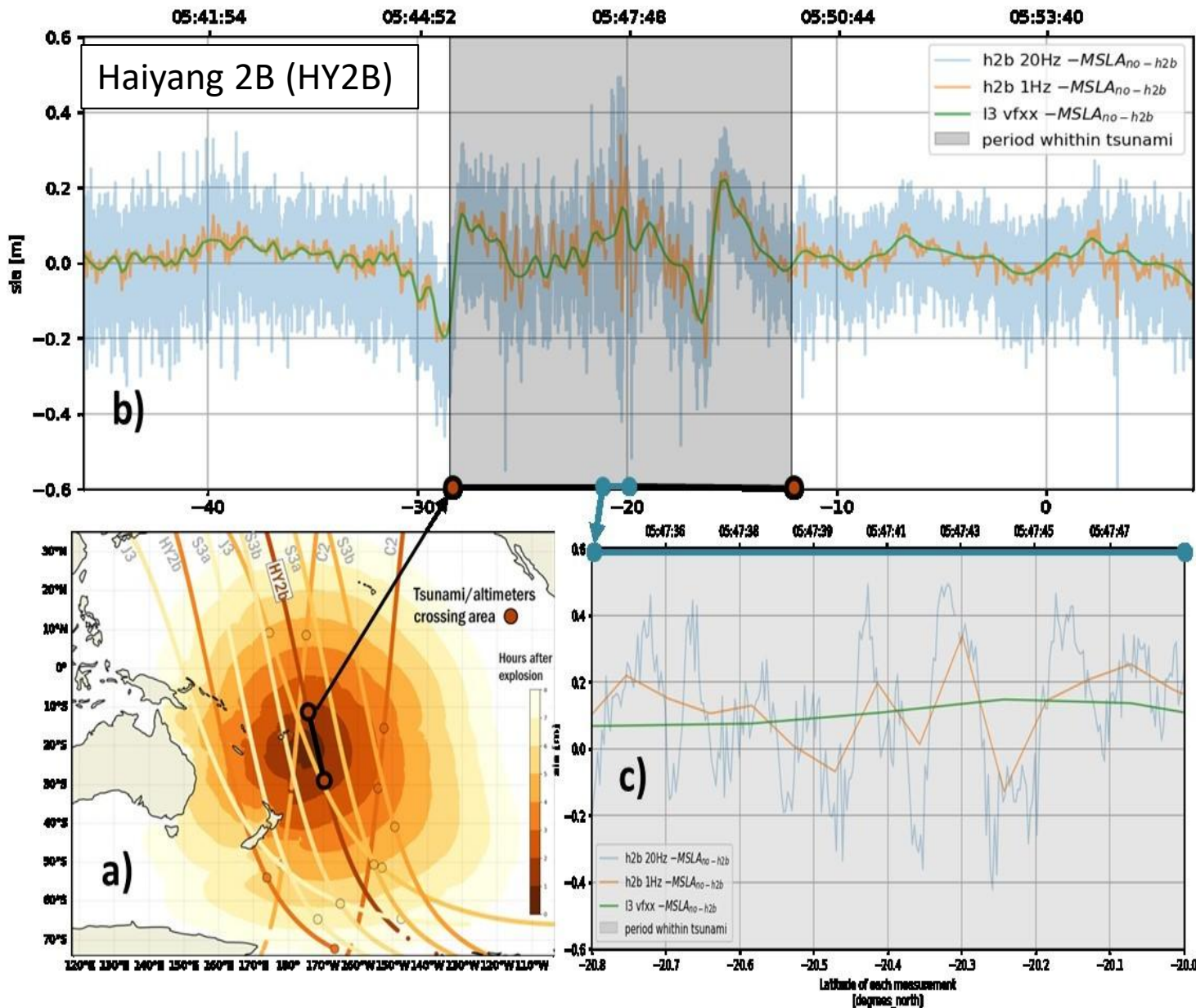


3:15 hours after the earthquake.



Jason-1 and Envisat sampled the modelled wave field at different times. The measurement remained **one-dimensional** along each narrow ground track.

Hunga Tonga-Hunga Ha'apai 2022 (Faugère et al. 2022)

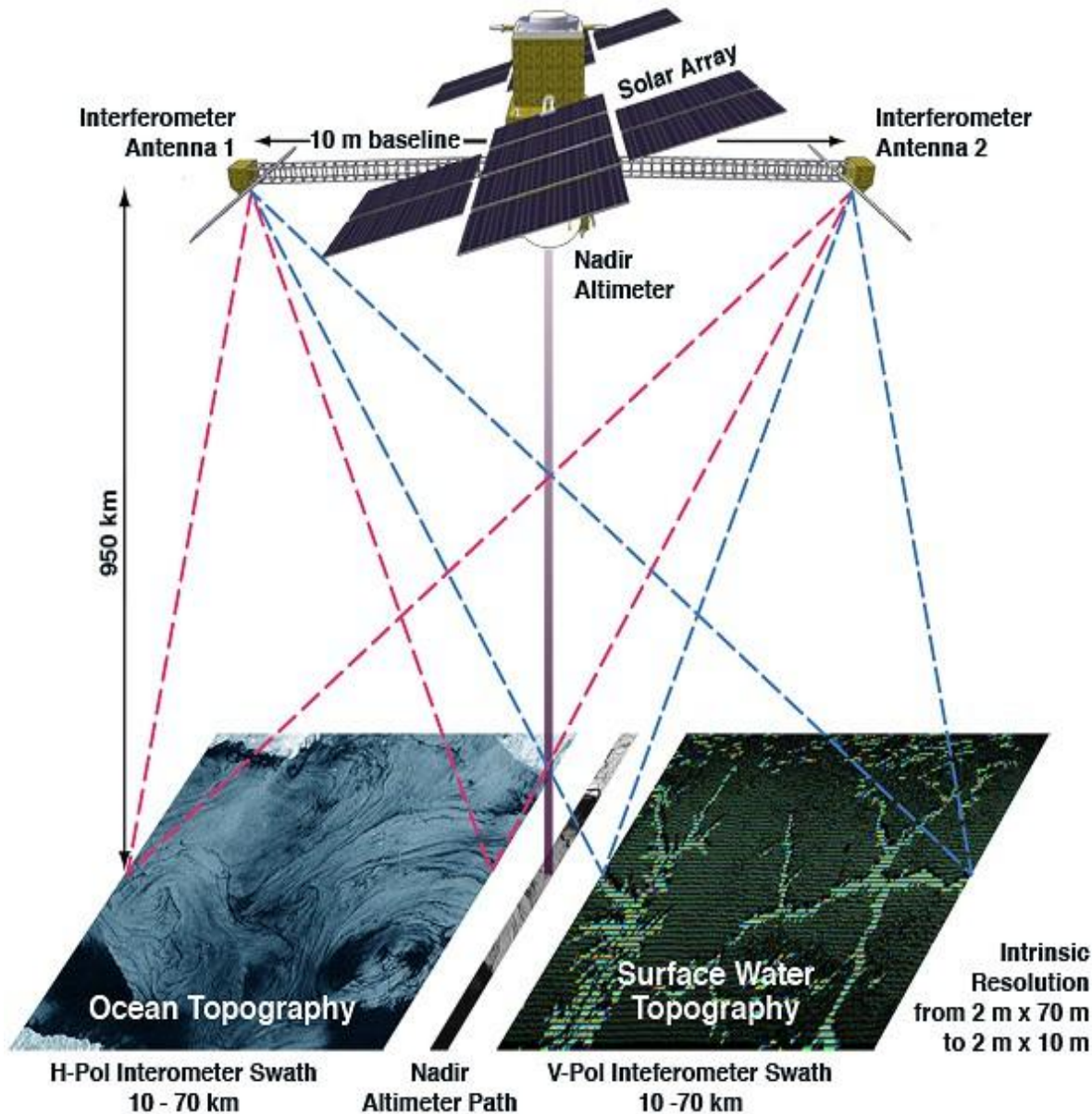


First detection with Haiyang 2B (HY2B): HY-2B crossed the region about 1h30 after the explosive eruption and resolved oscillations near 40 cm height at wavelengths near 100 km.

Followed by Sentinel3B (S3B), Cryosat-2 (C2), Jason-3 (J3), Sentinel6a (S6a), each with successful detection.

Spatio-temporal overlap is the primary requirement for successful detection.

SWOT revolutionizes the measurement geometry (from profile to swath)



Nadir altimeter
a 1D sampling of amplitude

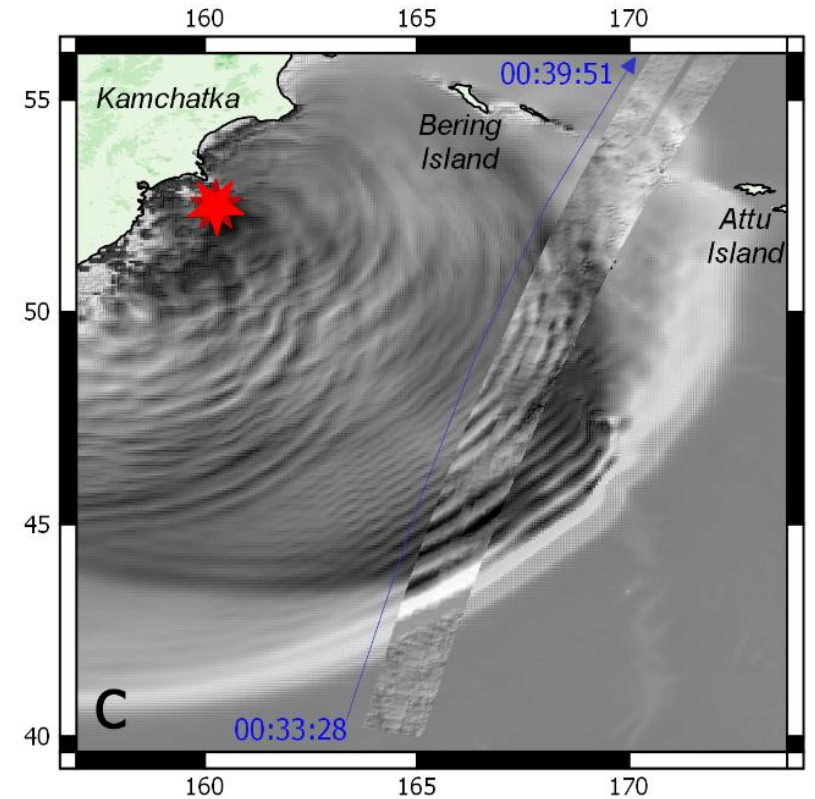
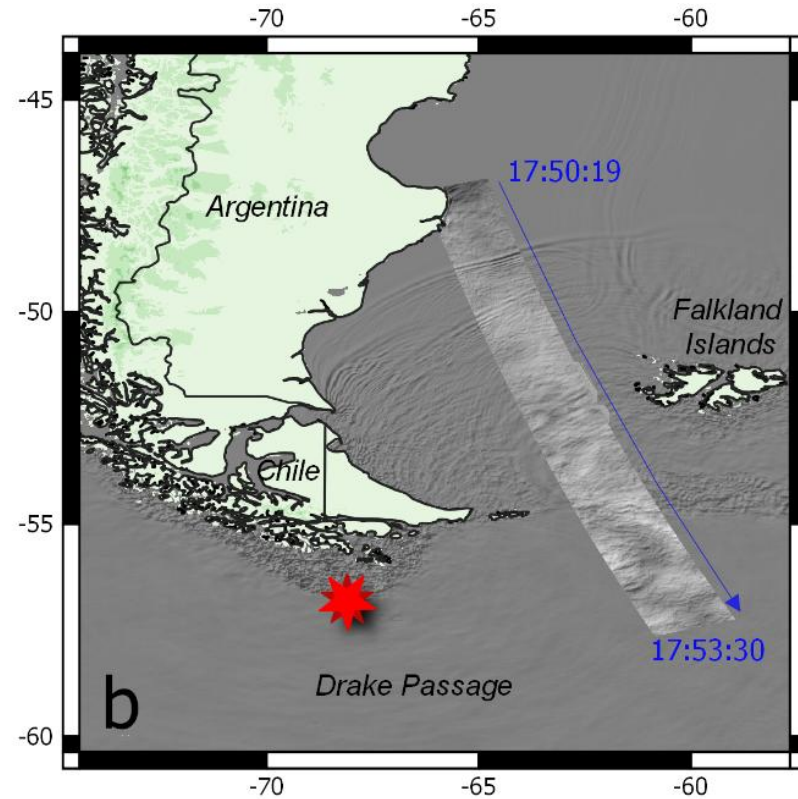
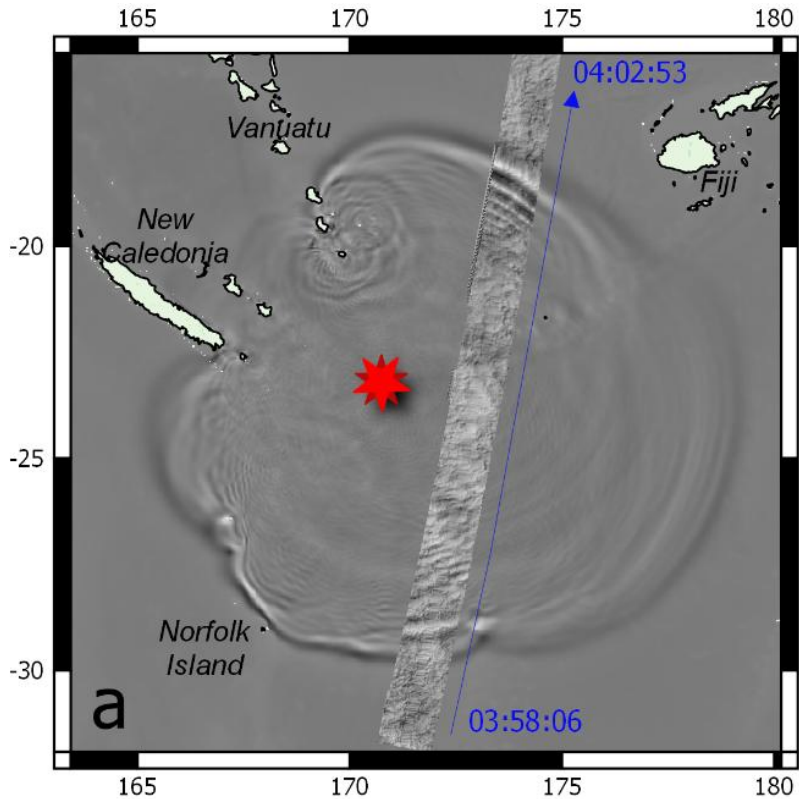
KaRIn wide swath
2D sampling resolves wavefront curvature

Three tsunami images in two years : a rapidly growing record



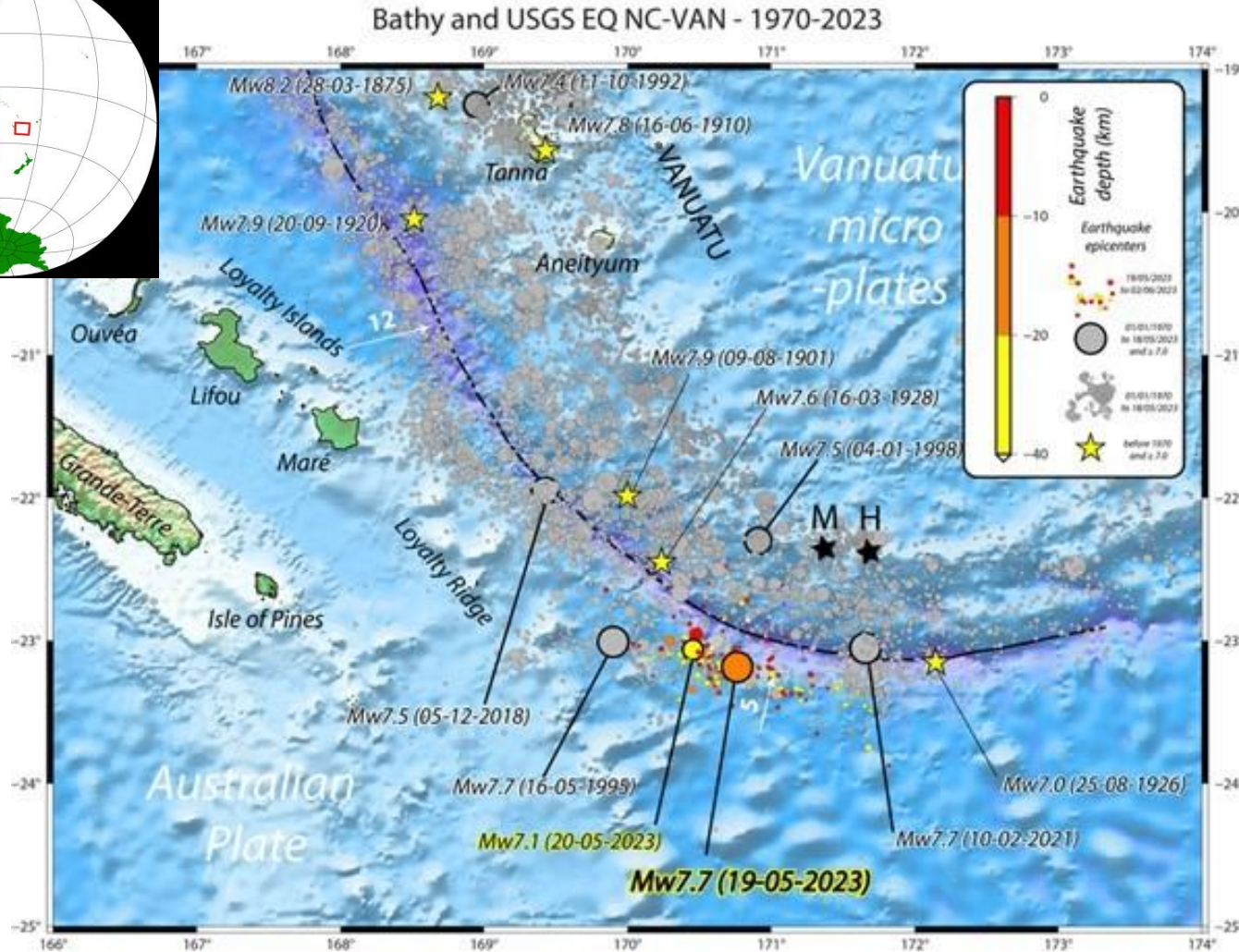
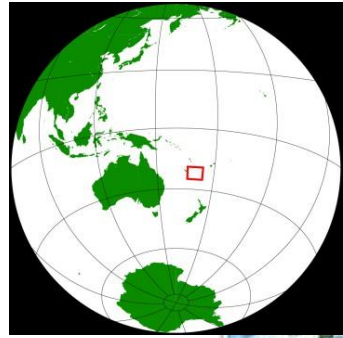
Each overpass captured a different source, propagation distance and oceanographic setting.

3 tsunami events with satellite imagery



Delepouille et al., under revision

Loyalty Islands, 19 May 2023 – a complex tsunamigenic earthquake



Mw 7.7 normal faulting event, followed by a Mw 7.1 tsunamigenic aftershock.

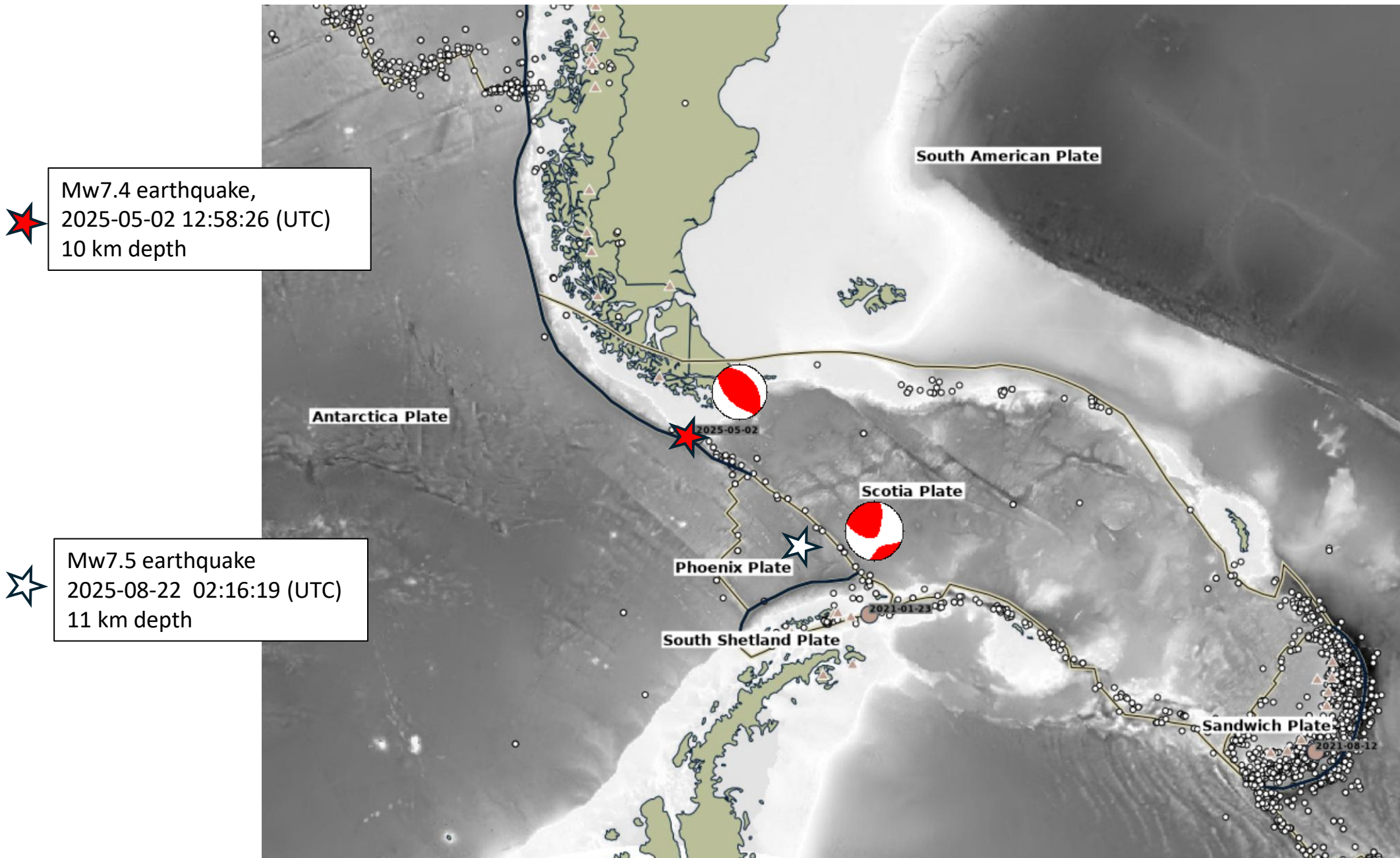
Available source models performing poorly to reproduce tide gauge records simultaneously.

Roger et al. (2026)

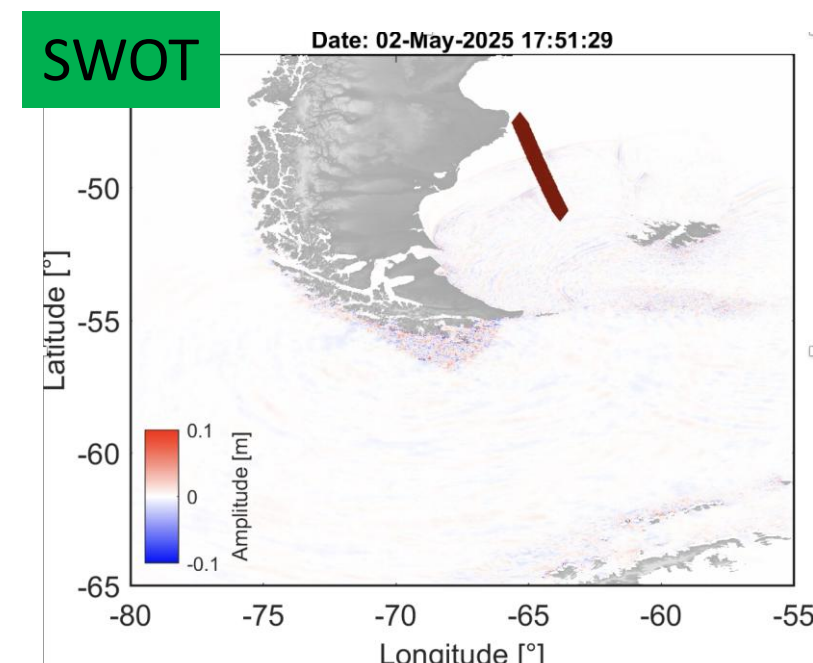
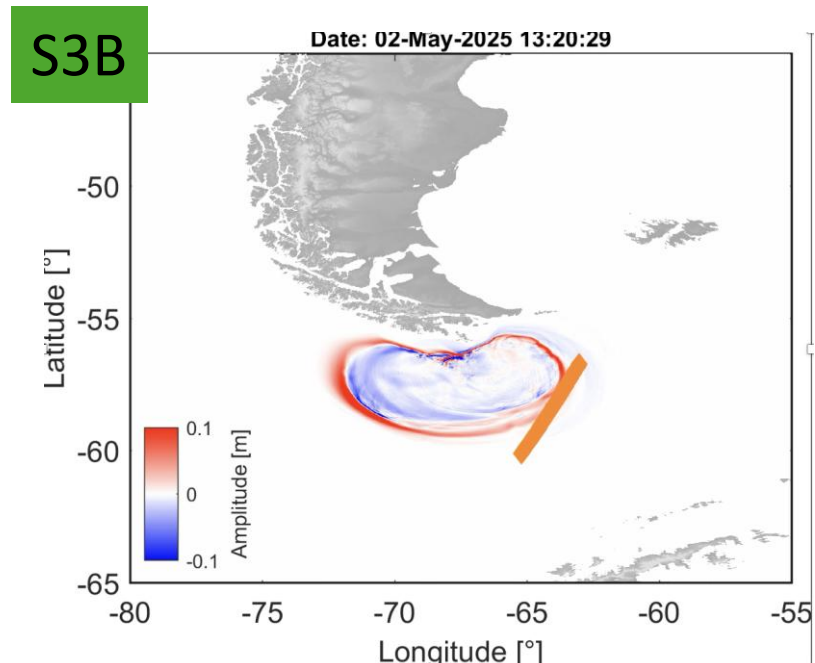
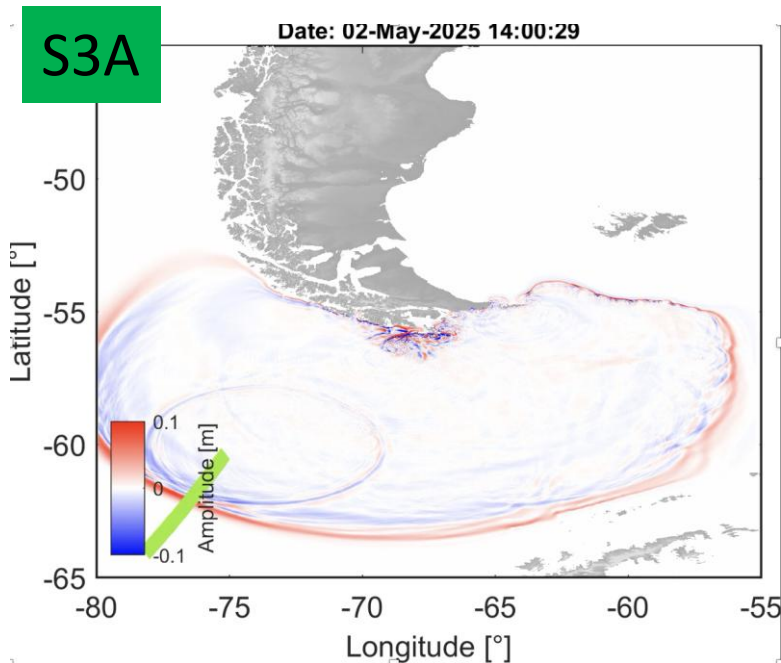
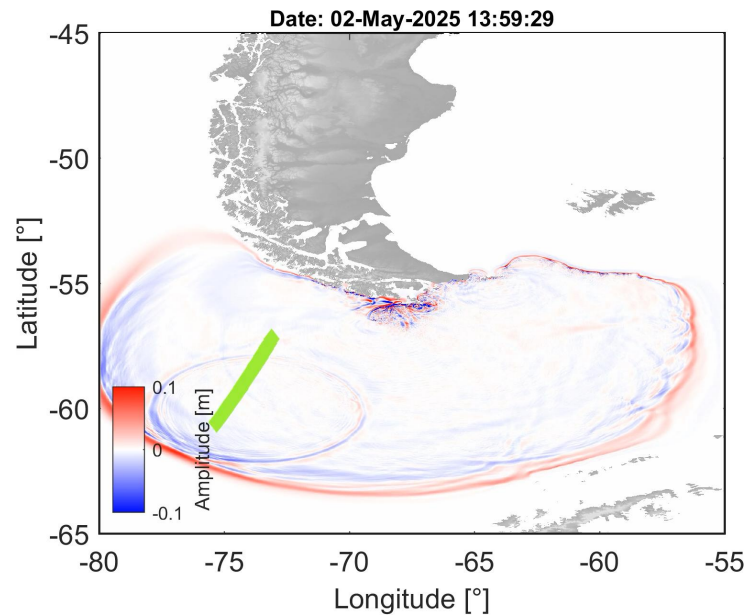
SWOT Sea Level Anomaly

Faugère et al. (2024), Roger et al. (2026)

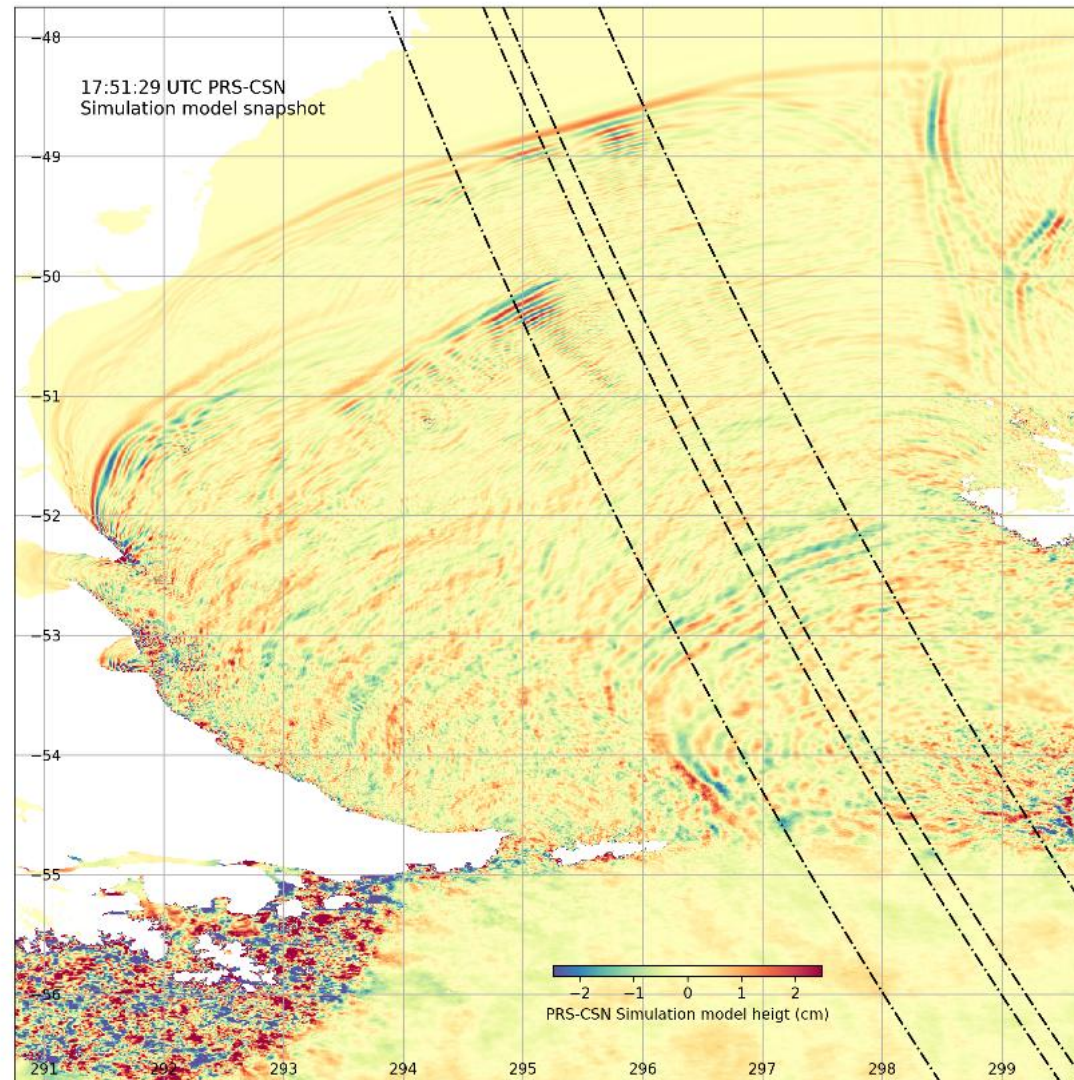
Two rare earthquakes in a sparsely instrumented region



Several altimeters intersected the simulated wave



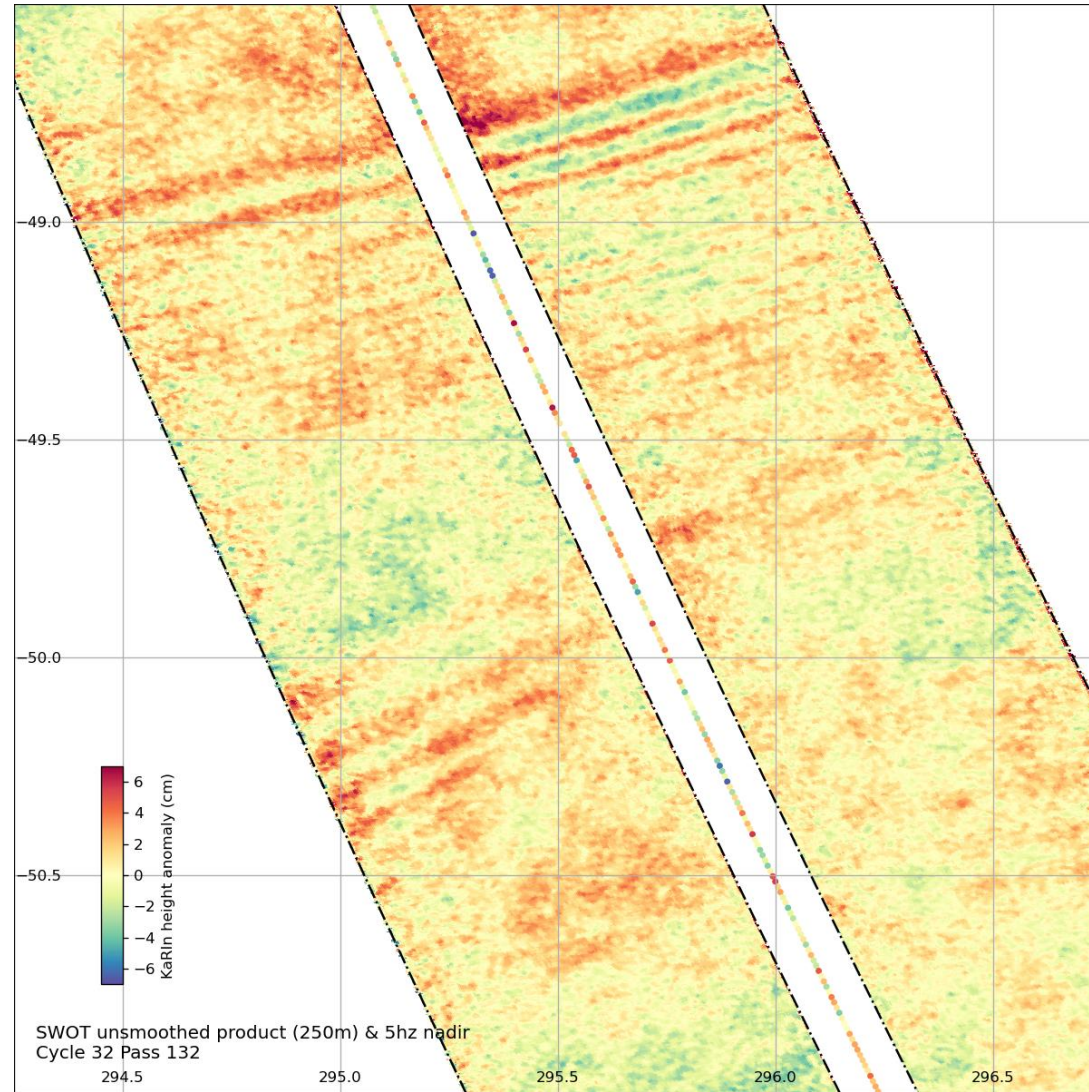
SWOT crossed the tsunami after nearly five hours



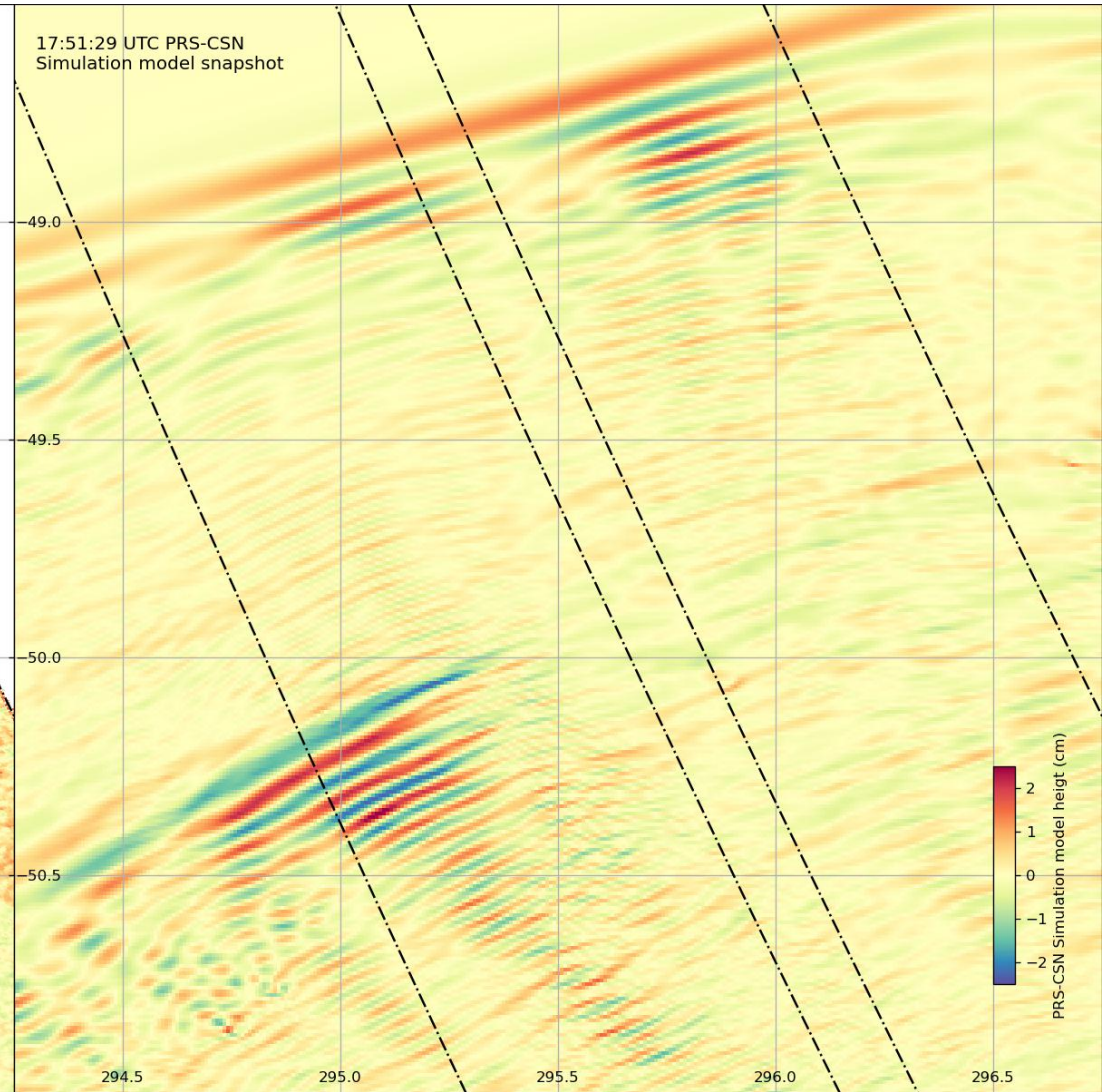
Source: AVISO news

SWOT image of the 2025 Drake passage tsunami

Observation



Simulation

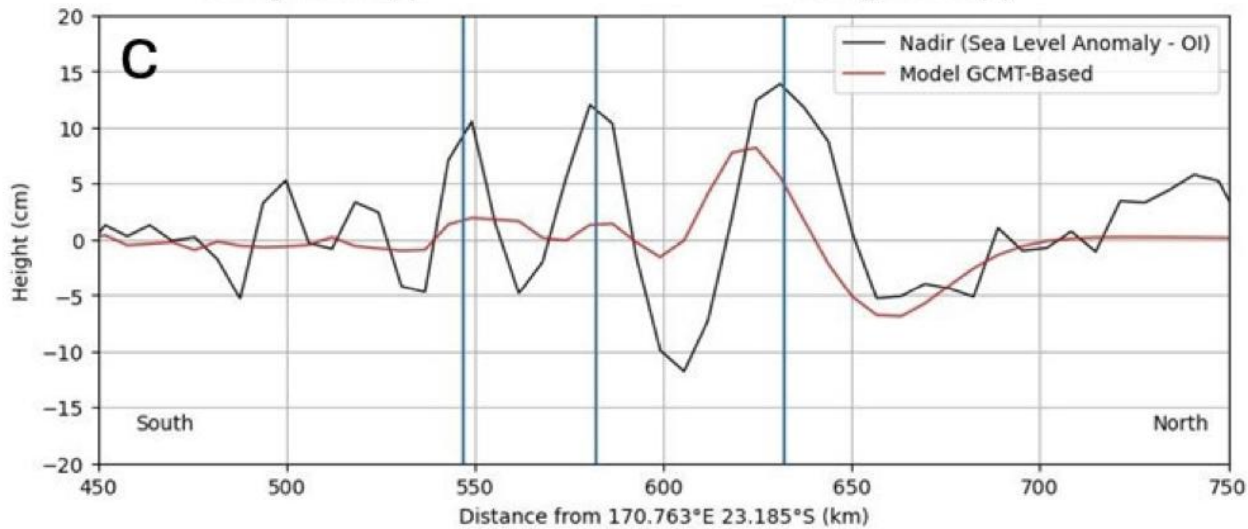
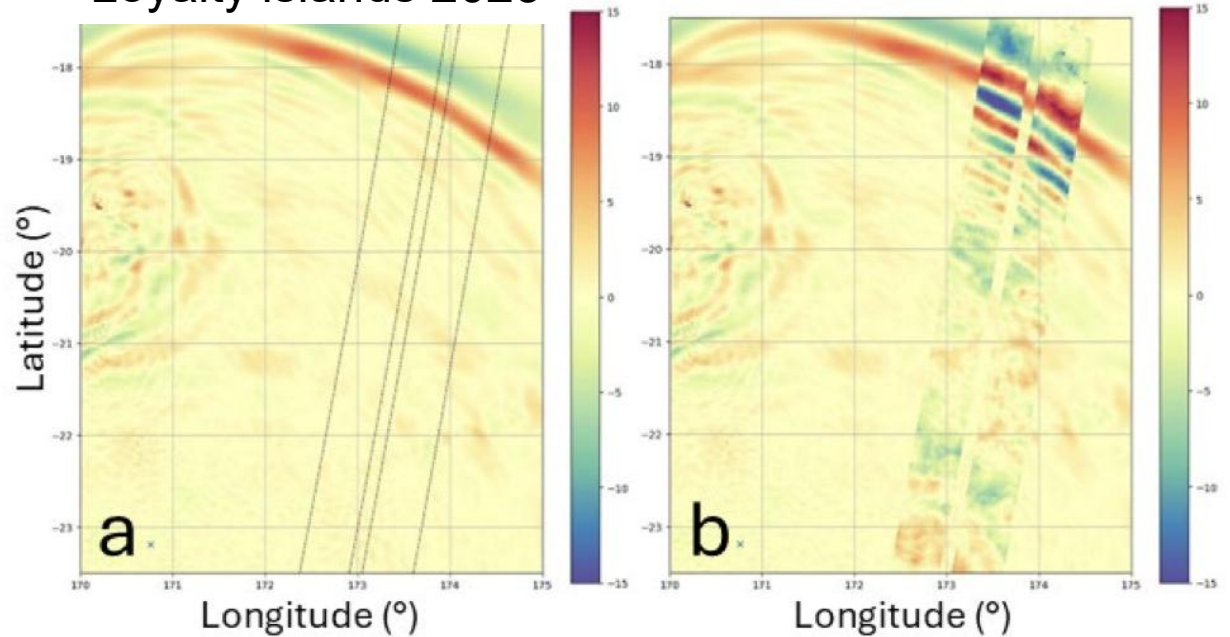


- Excellent waveform similarities – 3-5cm structures
- Model delay: 40 seconds over nearly 5h of propagation < 1%

Source: AVISO news

Two events reveal repeatable dispersive structure

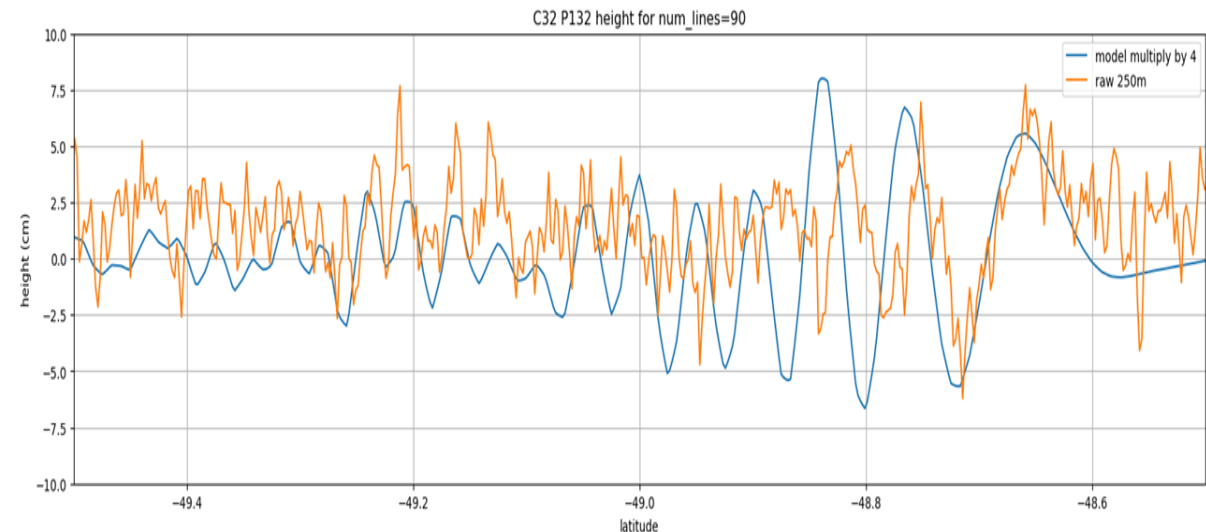
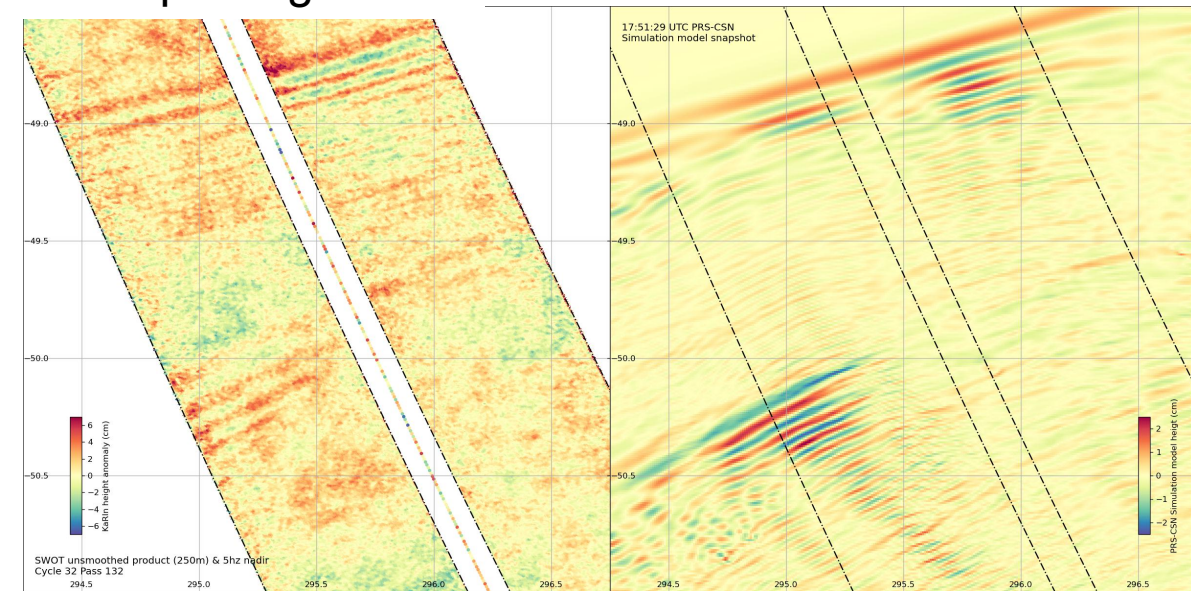
Loyalty islands 2023



Roger et al. (2026)

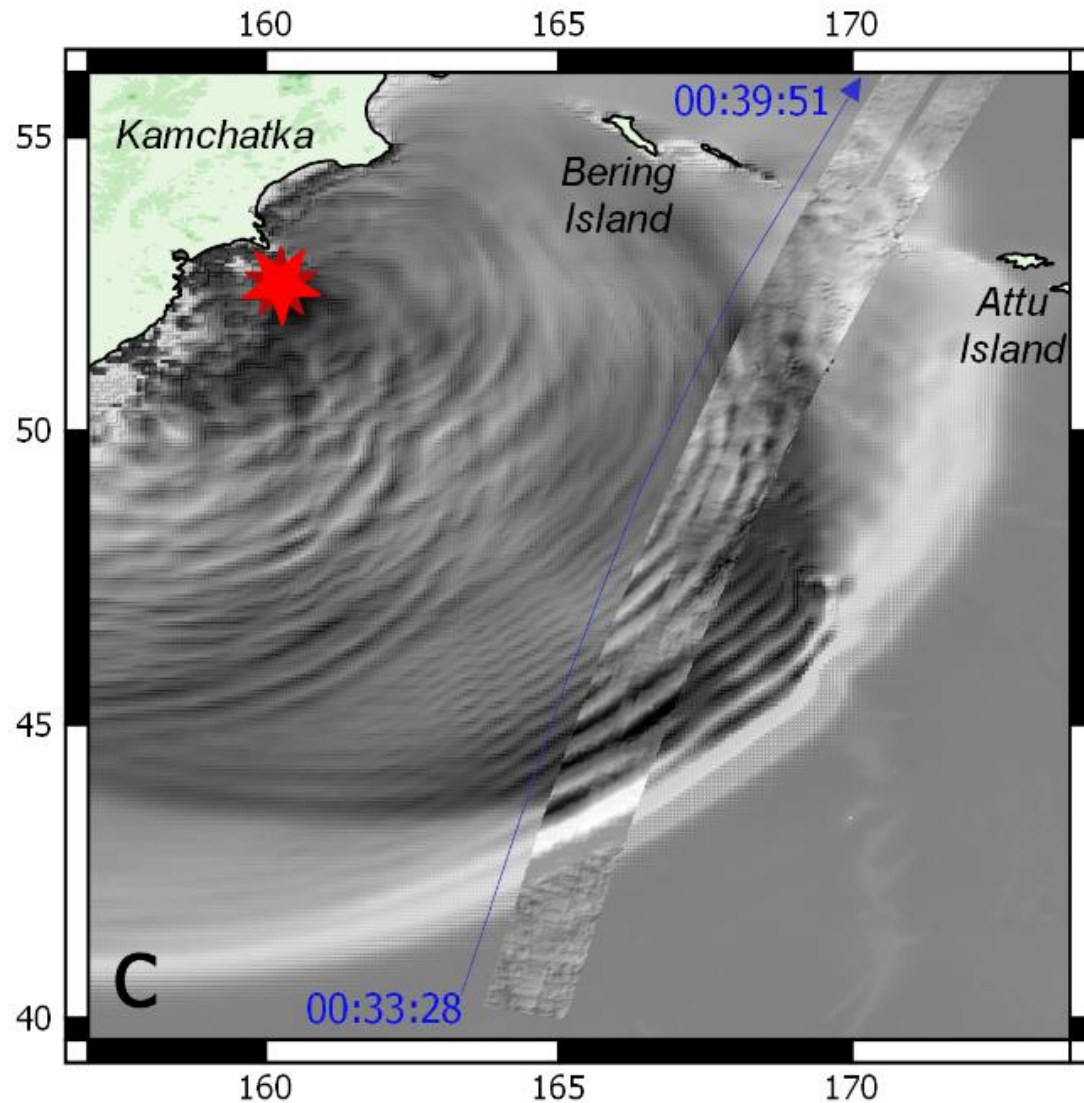
- Mean sea-level (trend) removed

Drake passage 2025



Across both cases, SWOT resolves spatial wave trains that a single profile could easily misinterpret.

Kamchatka, 29 July 2025

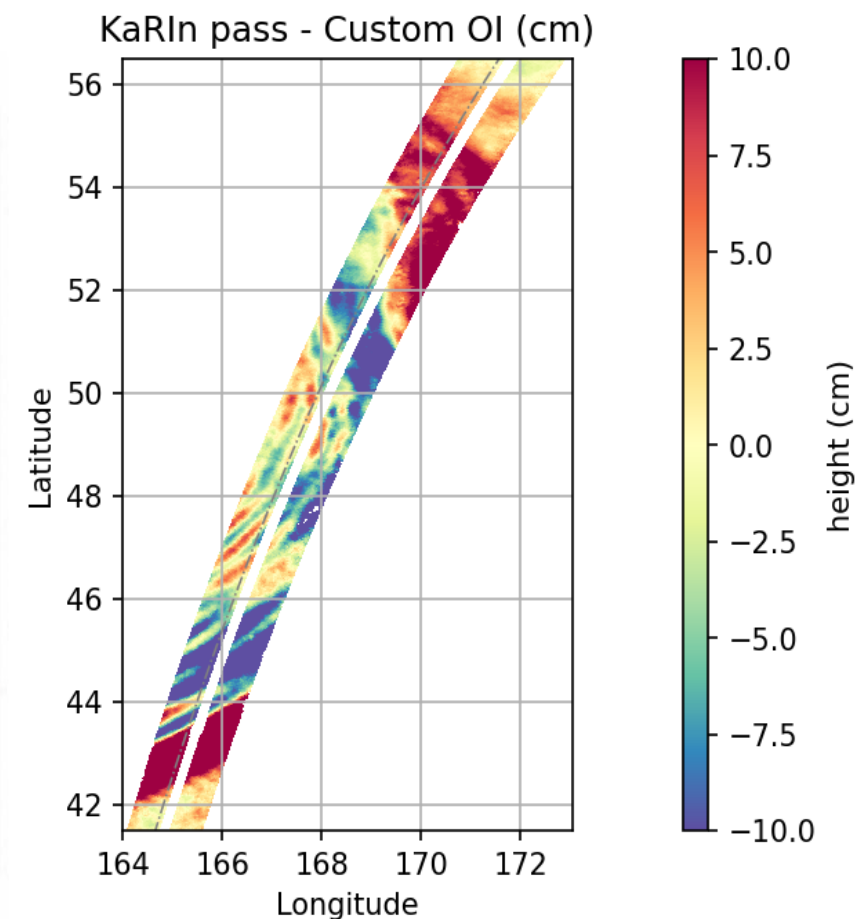
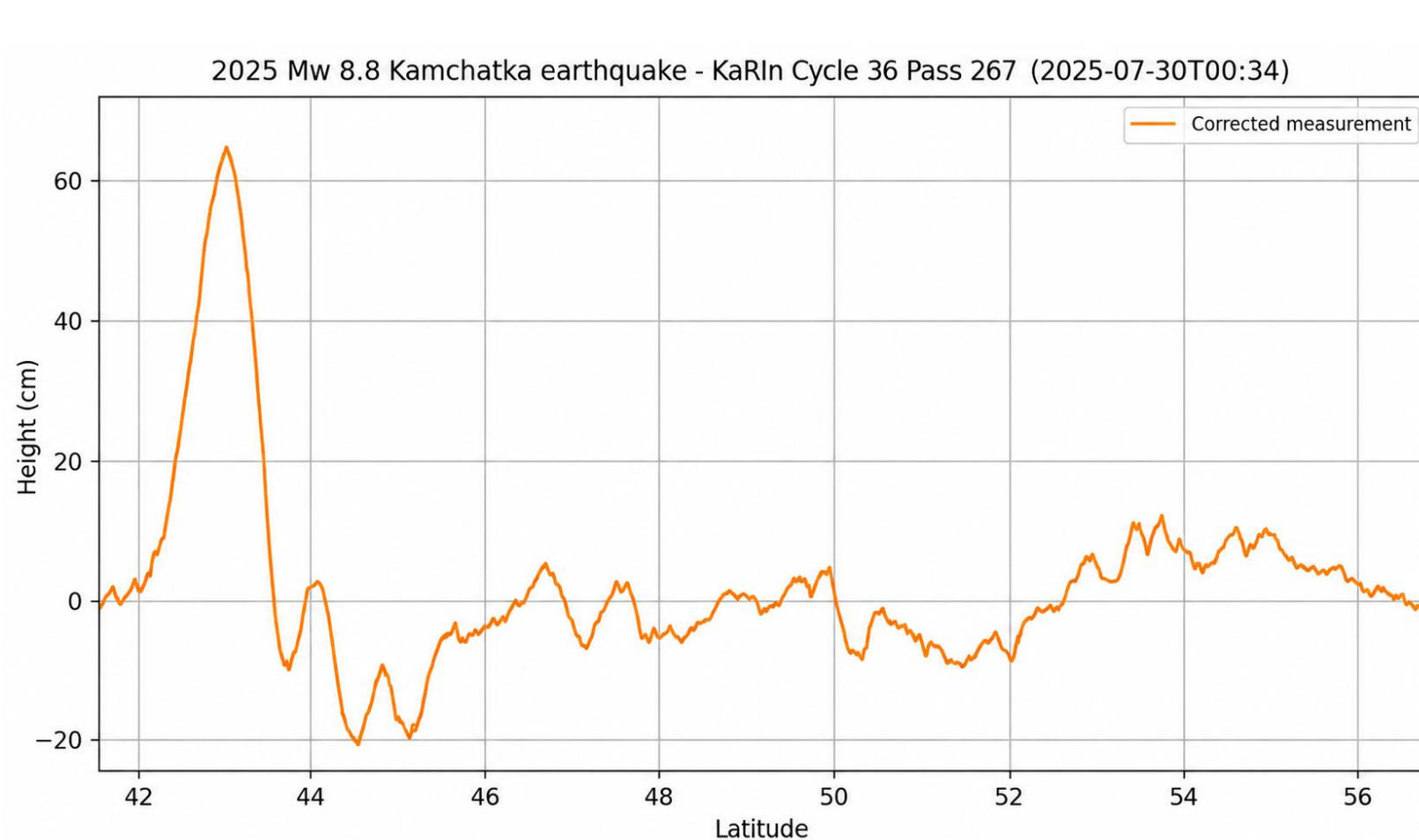


Mw 8.8

SWOT crossed the expanding tsunami about 70 minutes after rupture, roughly 600 km from the source.

KaRIn mapped the leading edge and trailing short-wavelength waves. Sea-level anomalies exceeded 0.45 m in the strongest parts of the image.

Removing oceanic trends with optimal interpolation

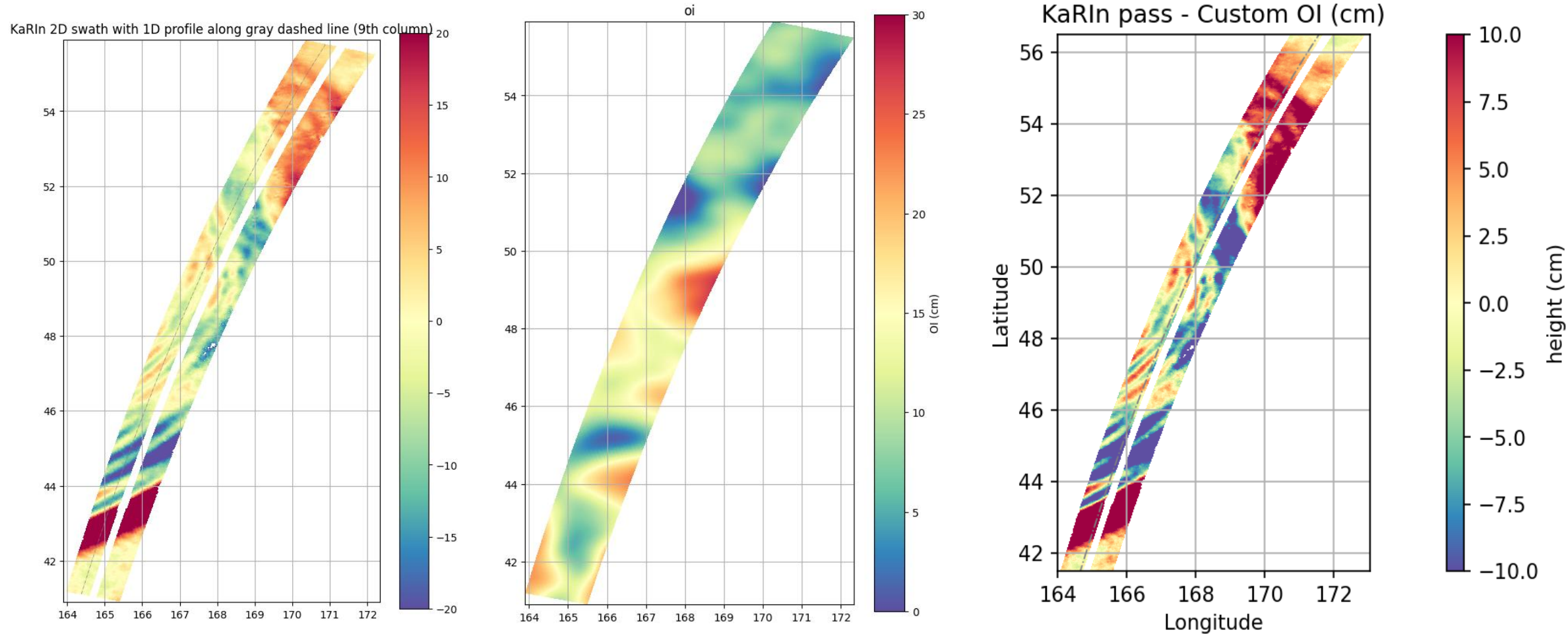


Delepoulle et al., in revision

Raw SWOT SSH → background ocean estimated by OI → subtraction → tsunami residual

Raw SWOT SSH: SWOT L3_LR_SSH product, derived from the L2 SWOT KaRIn low rate ocean data products

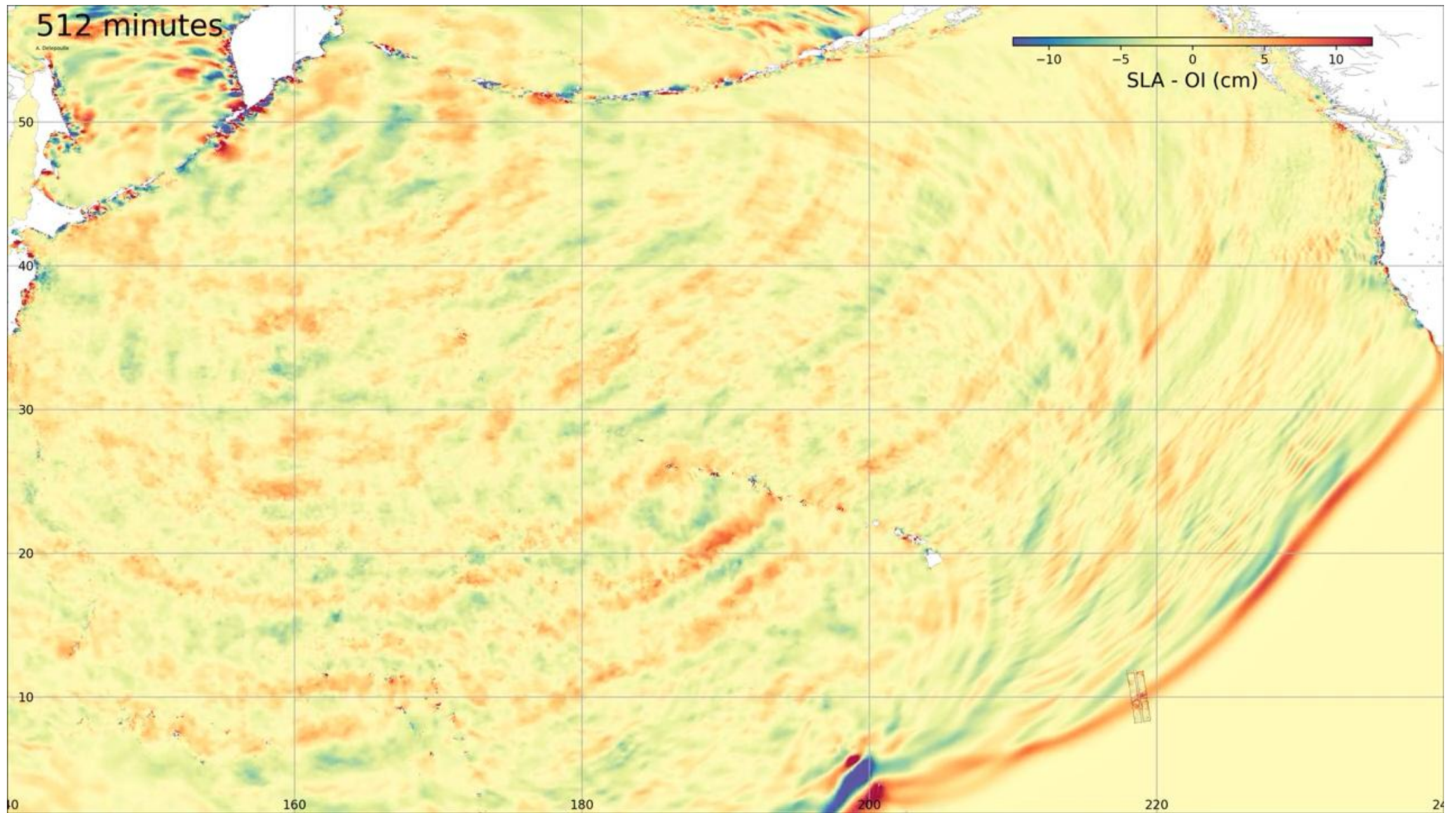
Removing oceanic trends with optimal interpolation



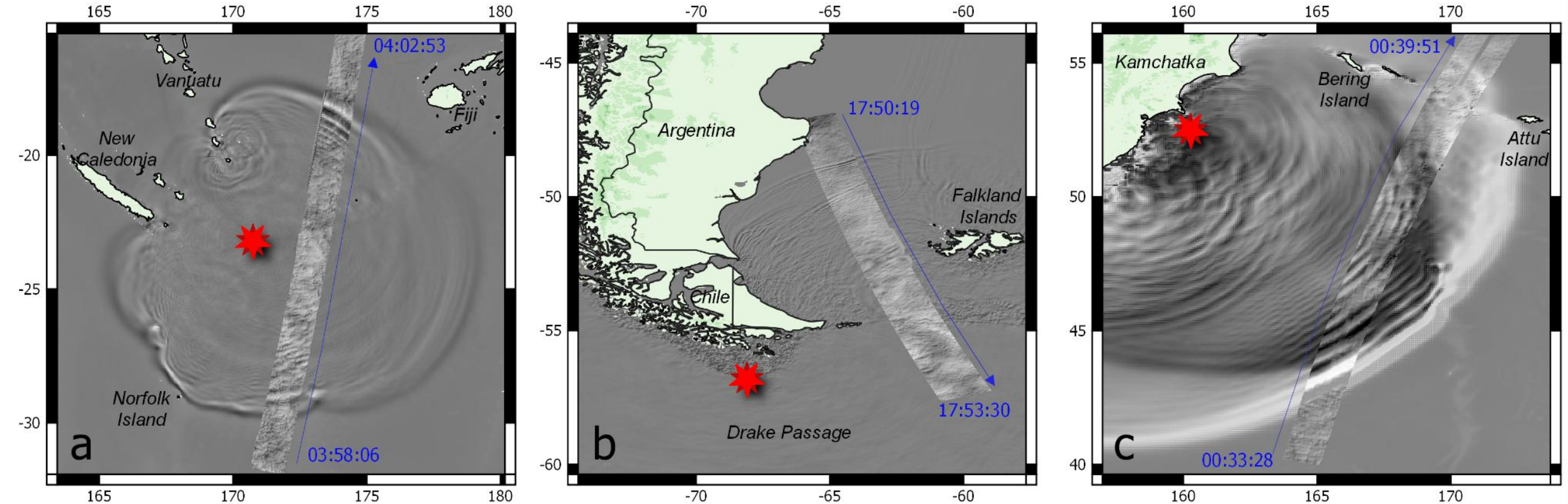
Delepouille et al., in revision

Raw SWOT SSH → background ocean estimated by OI → subtraction → tsunami residual

Raw SWOT SSH: SWOT L3_LR_SSH product, derived from the L2 SWOT KaRIn low rate ocean data products



3 tsunami events with satellite imagery



Delepoulle et al., under revision

A complementary observing system



Seismic networks

Origin time, mechanism and rupture



GNSS-TEC

Rapid vertical-motion and acoustic response



DART and tide gauges

Time series at fixed ocean and coastal points



Nadir altimetry

Precise profiles along satellite tracks



SWOT KaRIn

Two-dimensional sea-surface geometry

What SWOT can change in tsunami monitoring

Today

Model validation
Source inversion after the event
Bathymetry and dispersion diagnostics

Toward warning

Rapid data availability
Event-aware processing
Assimilation into forecast models

The central limitation is sampling: SWOT offers exceptional spatial information only when its orbit intersects the event at the right time.

Three observations, one new capability

01

Two-dimensional evidence

KaRIn resolves wavefront geometry, amplitude variation and dispersion.

02

Learning outcomes from models

Phase and waveform generally agree

03

A broader observing system

SWOT complements seismic, GNSS-TEC, altimetry and in-situ records.

SWOT turns occasional satellite crossings into spatially rich constraints on tsunami generation and propagation.



Grazie mille per la vostra attenzione !