The 2022 Honga Tonga Tsunami monitored by satellite altimetry and SAR

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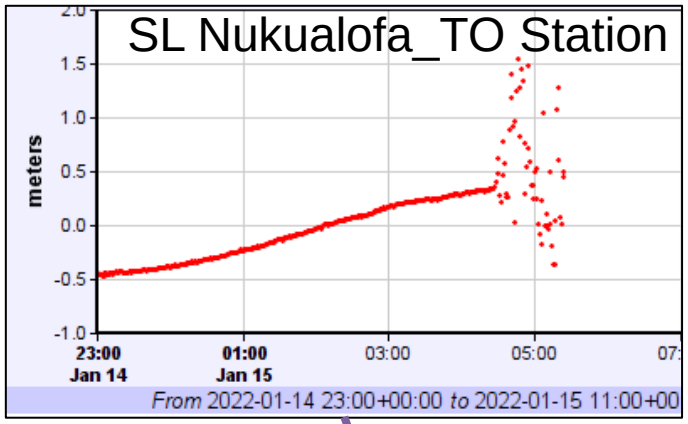
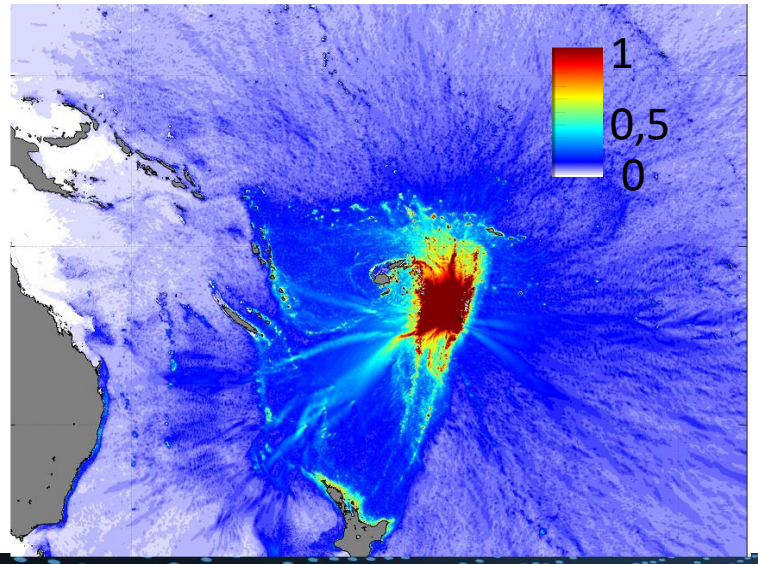
2022 Ocean Surface Topography Science Team (OSTST) meeting | October 31 > November 4

Chronology of the event

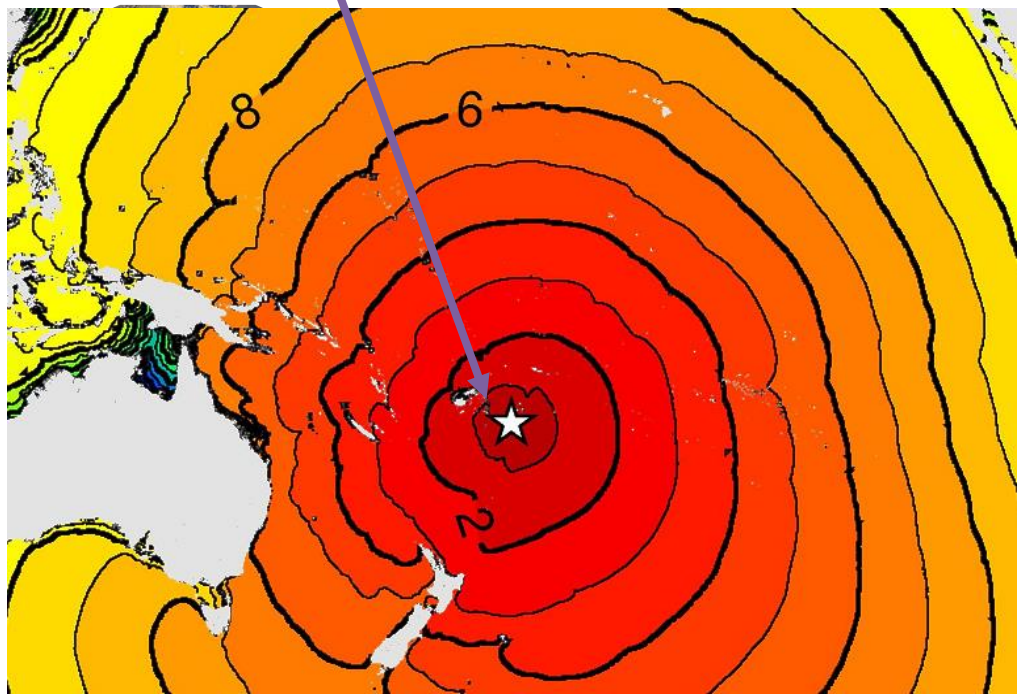
- The underwater volcano Hunga-Tonga in the Tonga Islands, about 65 km north of the country's capital, produced a very violent explosion on Saturday 15/01/2022 at about 04:15 UT (17:15 local time)
- The energy emitted by the explosion was mainly diffused into the atmosphere and the sea inducing **trans-oceanic tsunami**
- The tsunami was strongest on the Tonga Islands and in particular on the main island where the capital with **waves of up to 1.4m**
- Around the Pacific, ocean level disturbances continued for more than 24 hours after the tsunami hit



Recorded by all tide gauges in the pacific in the following hours



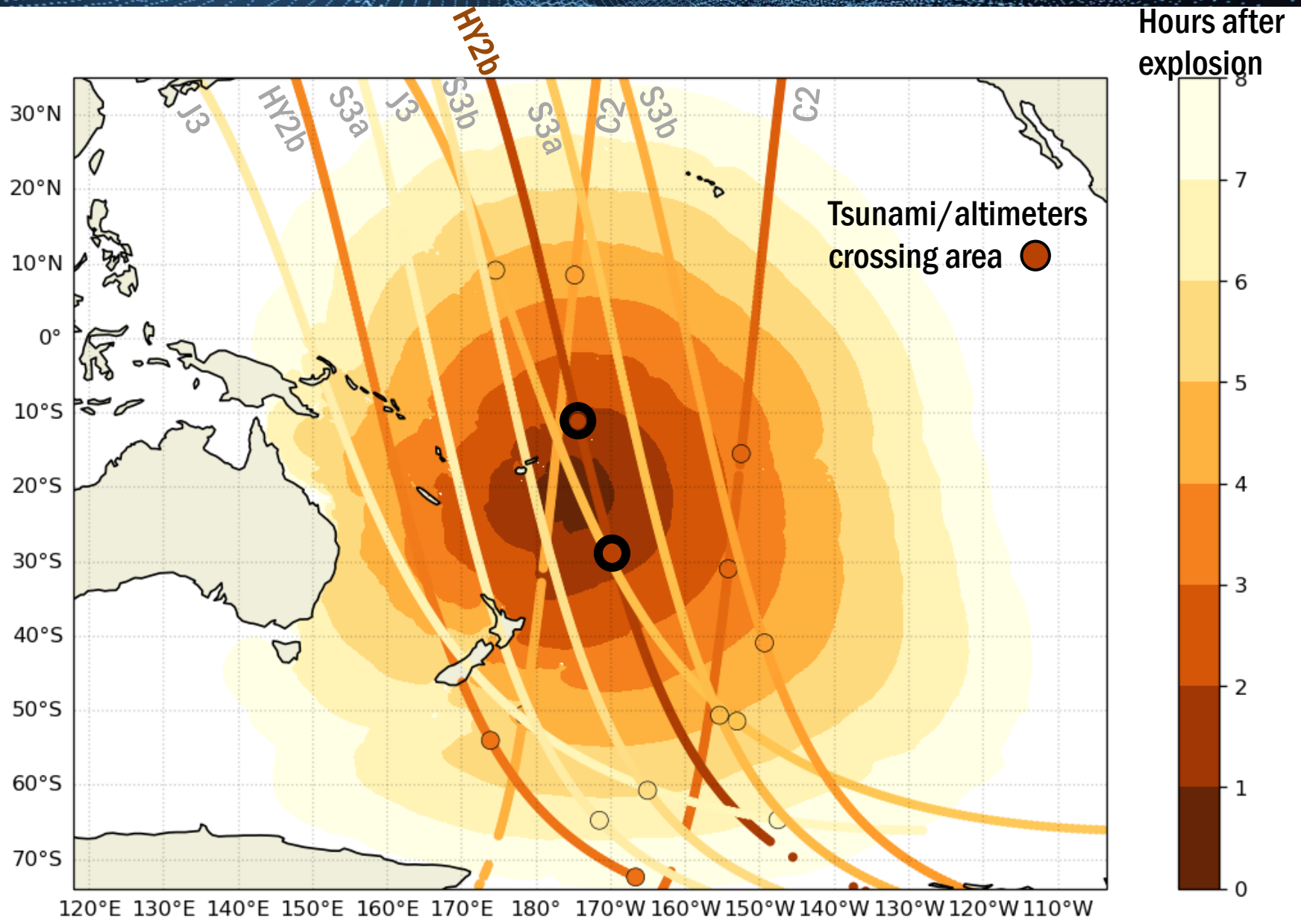
Maximum simulated tsunami in Meter (Heidarzadeh , 2022)



Tsunami Travel Time in Hour (ITIC tool)

Event seen from altimetry constellation

- 10 altimeter tracks (from 5 different satellites) over the area between 04h15 TU and 12h00 TU
- The Chinese satellite HY2B satellite is the first to fly over the area 1h30 after the eruption (track 315, Cycle 84)
- Other satellites, Cryosat-2, Jason-3, Sentinel3-a & b, also crossed the area but more than 4 hours after the event



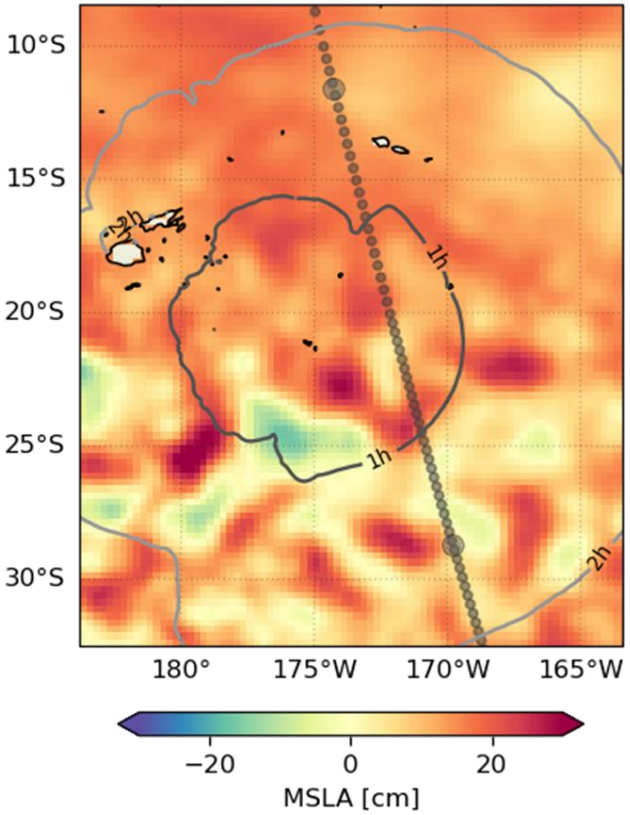
Separating tsunami from ocean variability

- To highlight the Tsunami signal, the variability of the ocean has to be removed => Specific DUACS multimission Sea Level Anomaly grids are used for that purpose

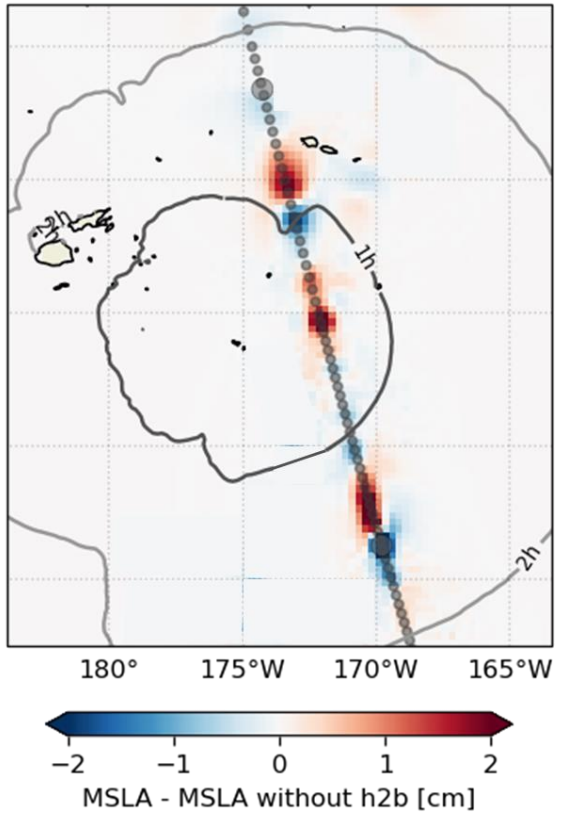
- HY2B pass 315 was NOT ingested in these maps
  To avoid the transformation of the tsunami signature into ocean mesoscale structure

- In the operational maps the tsunami signature created several mesoscale structure (positive and negative

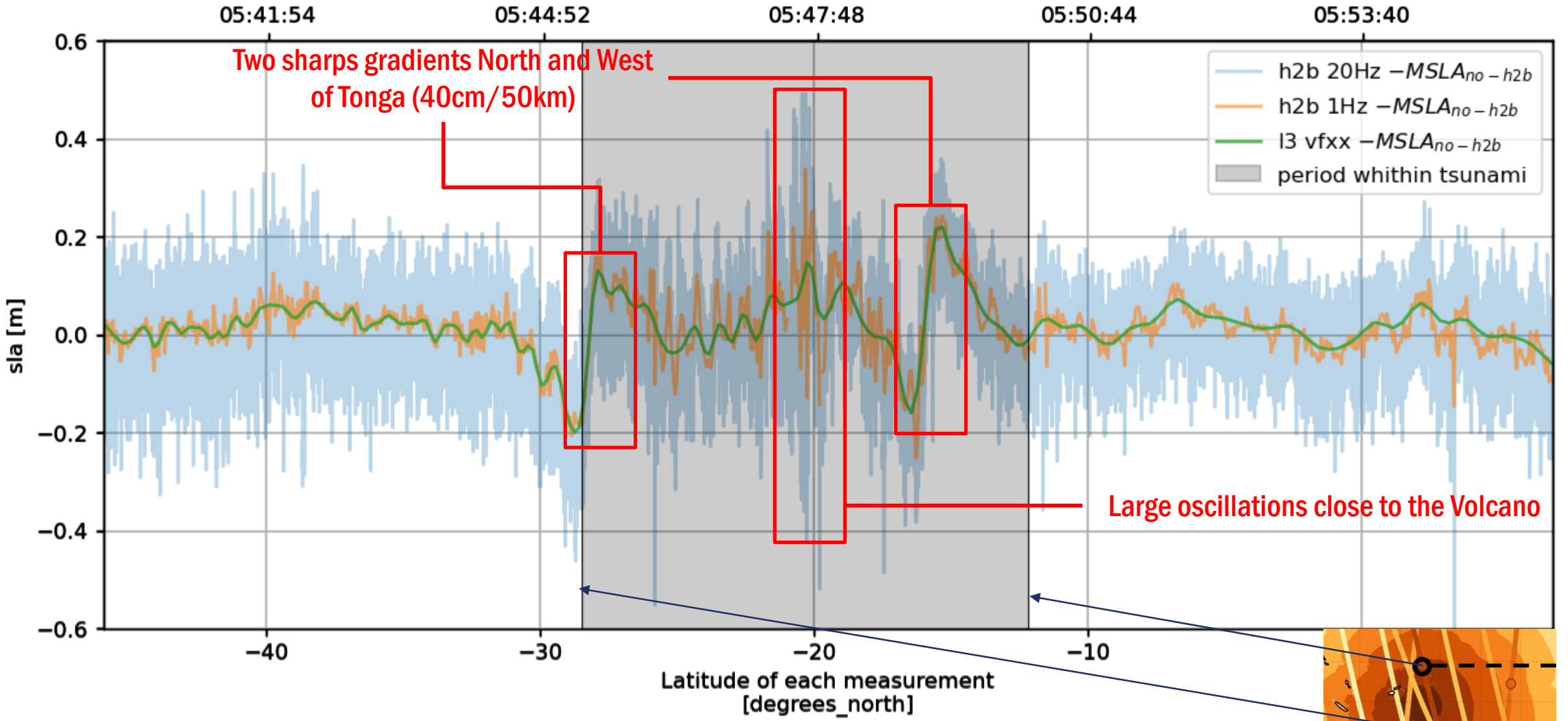
Specific DUACS multimission Sea Level Anomaly grids



Difference with operational maps

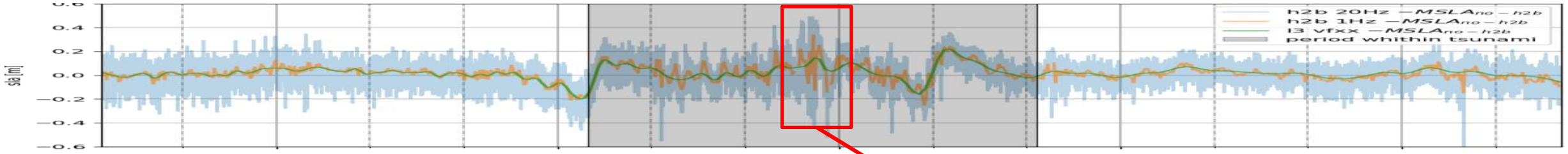


Tsunami signature in HY2B pass 315 (1Hz)

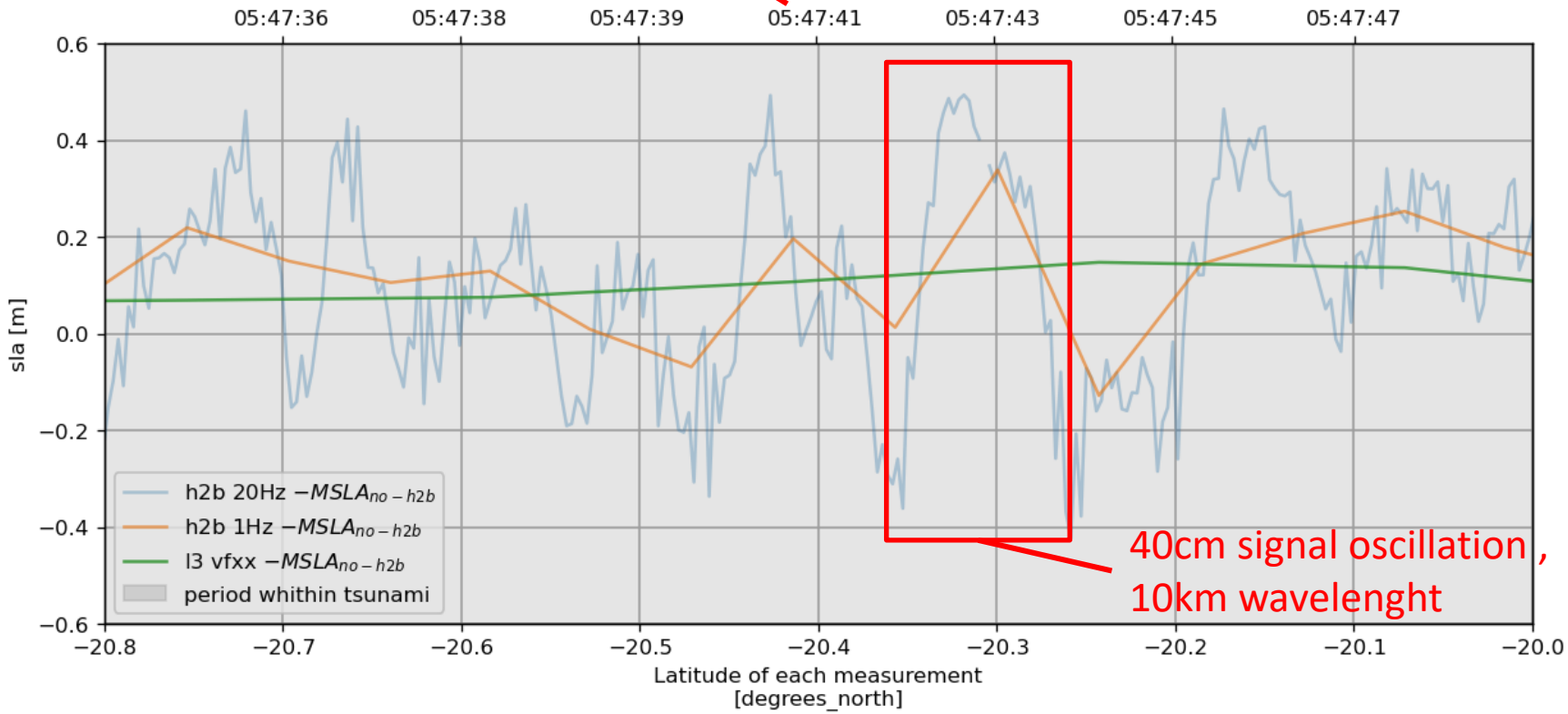


- At 28°S and 16°S, HY2B measures sharp gradients close to the expected positions in the model
- Sharper signal detected at 20°S =>20Hz data needed

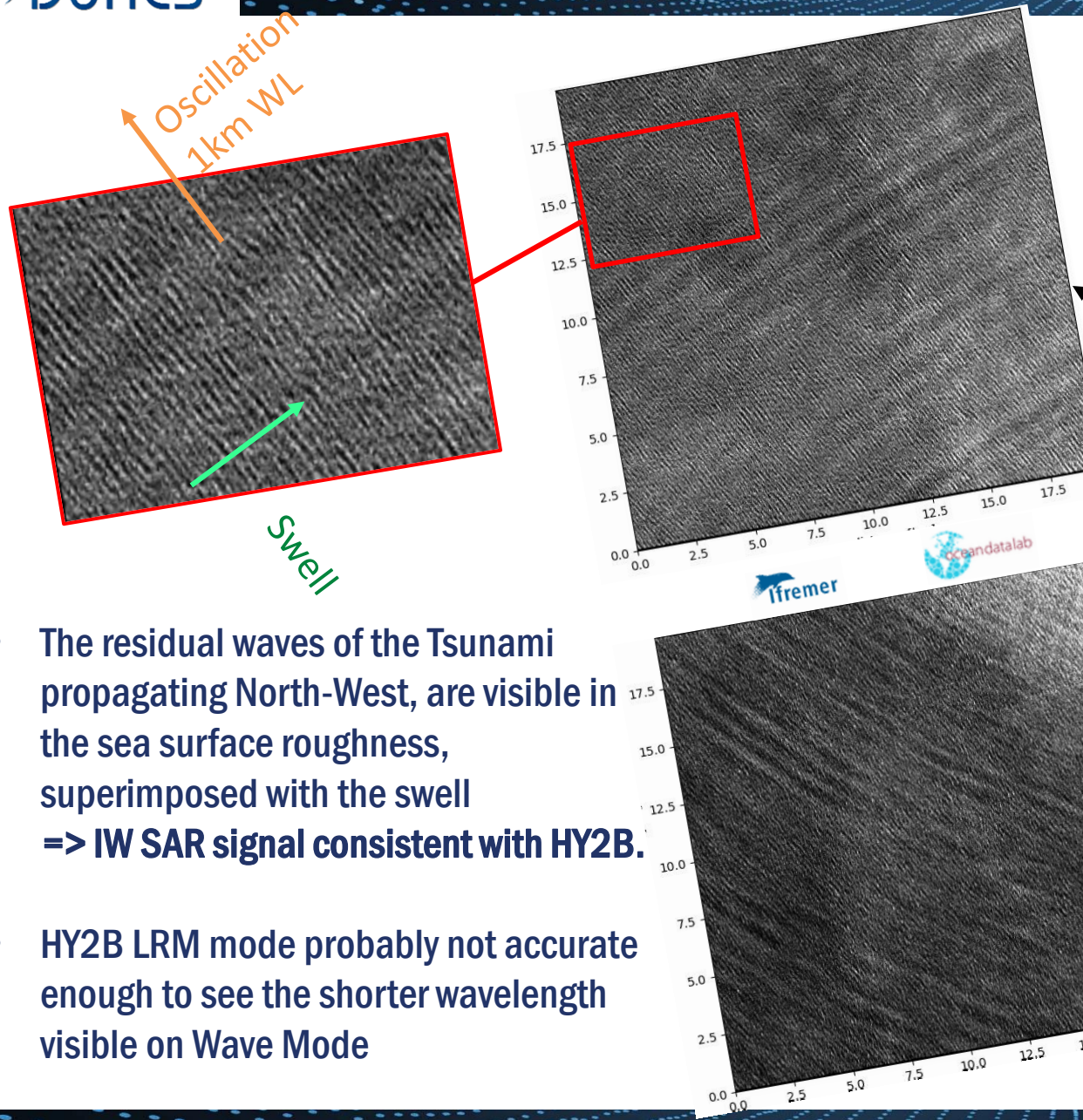
Tsunami signature in HY2B pass 315 (20Hz)



- The large Oscillation near the Volcano Area is not noise=> perfectely periodic oscillation (observed on Jason-1 in during the 2004 Indian Ocean tsunami (Ablain et al, 2006)
- Smaller (km) wavelength would also be superimposed, but mixed with noise data (below the observability)



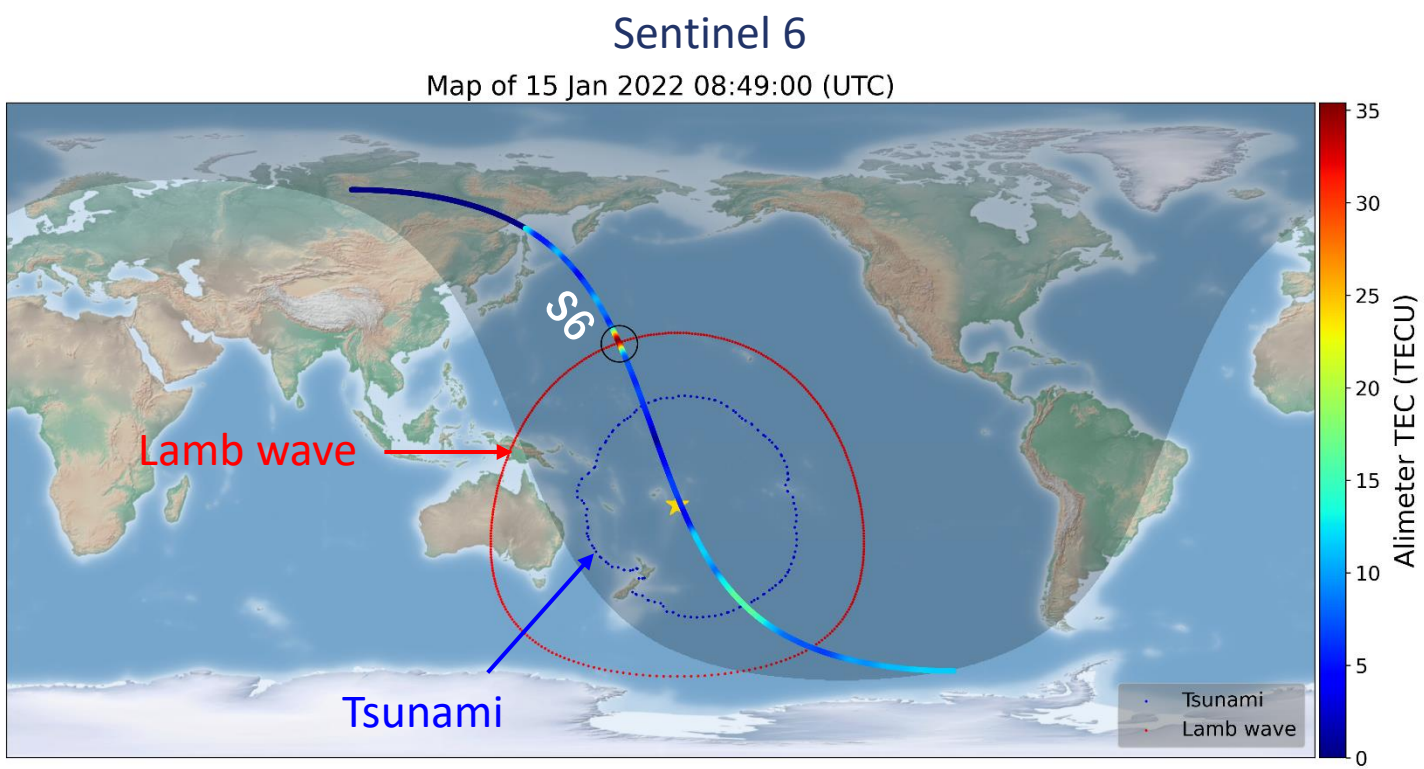
Concentric waves detected in SAR Sentinel1A Images

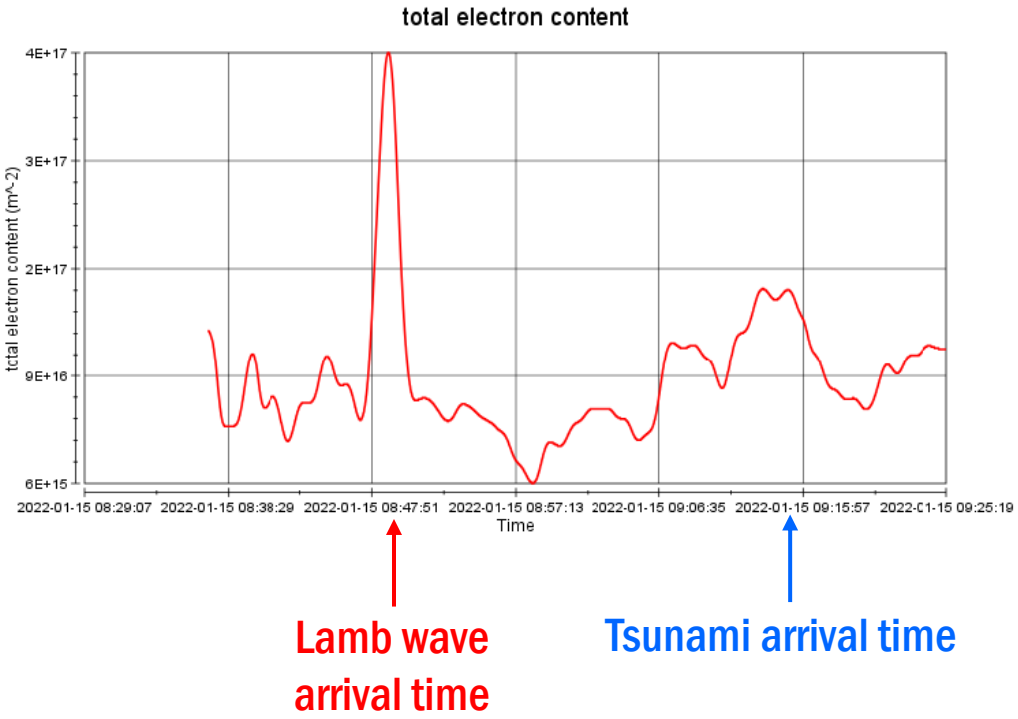


- The residual waves of the Tsunami propagating North-West, are visible in the sea surface roughness, superimposed with the swell
  => IW SAR signal consistent with HY2B.

- HY2B LRM mode probably not accurate enough to see the shorter wavelength visible on Wave Mode

Tsunami detection in the TEC from dual frequency

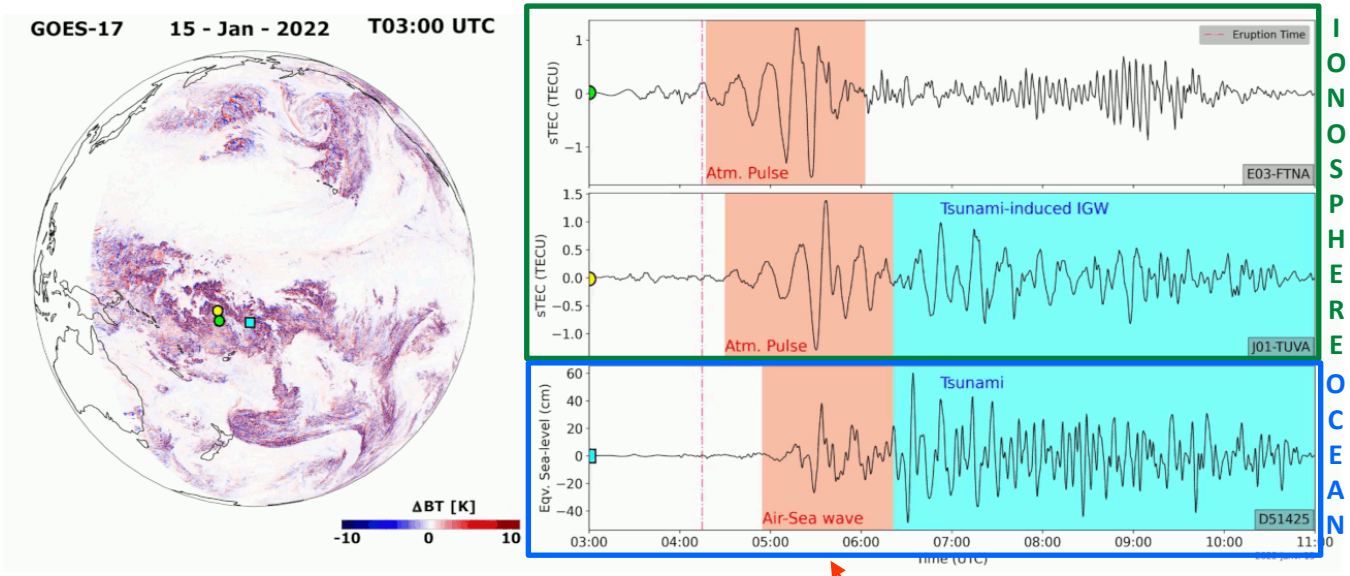




- Sentinel 6 crossing the nighttime ionosphere (more quiet, lower ionospheric noise)
- 318 m/s propagating Lamb wave strongly affects the TEC (~25 TECU pulse)
- The tsunami TEC signature is buried in the noise

Ocean-atmosphere-ionosphere coupling

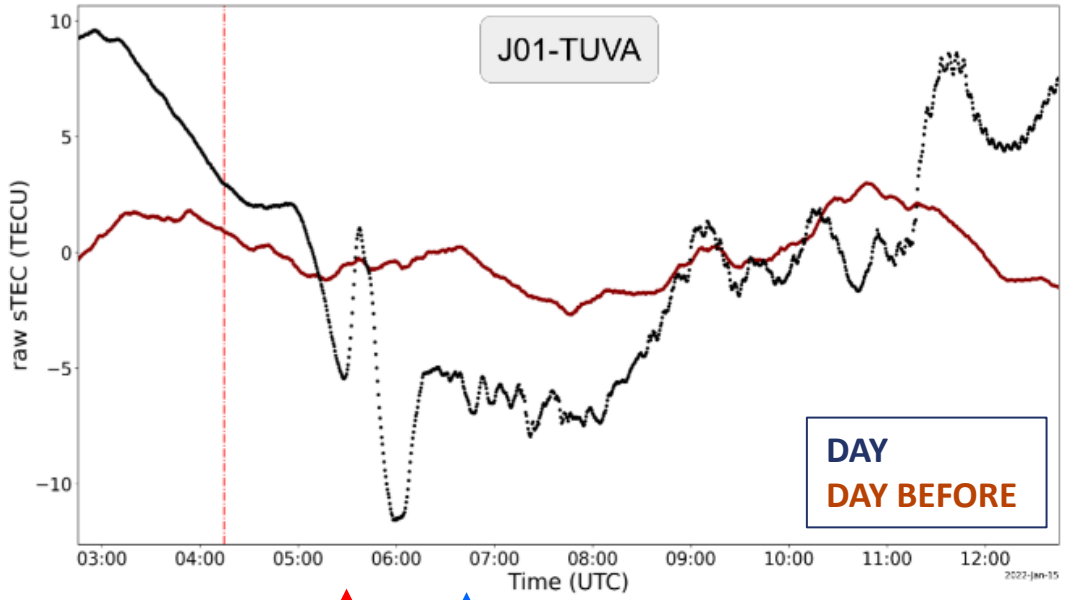
Filtered TEC and sea-level data



After Matoza et al. (2022)

Ocean wave coupled with the atmospheric pulse

Unfiltered TEC data



Lamb wave arrival time

Tsunami arrival time

- Strong ocean-atmosphere-ionosphere coupling
- Rare case of a Lamb wave excited in the atmosphere (very slightly attenuated pulse propagating at ~312m/s)
- Oceanic wave coupled with the atmospheric pulse faster than the tsunami
- The TEC signature of the Lamb wave is more than one order of magnitude larger than the tsunami TEC signature

Forcibly displaced wave by Lamb Wave detected on altimeters?

Two mechanisms contributed to the 2022 Tonga volcanic tsunami:

1) first the atmospheric pressure waves associated to the Lamb wave
=> It should be visible at -35°S and -3°S on Hy2B Sea Level
=>possible signature at latitude -39°, -13, and 2°N but need to be consolidated

2) then the Gravity waves generated by water mass displacement due to the eruption.
=> model prediction for the Southern wave is well phased with HY2B measurements
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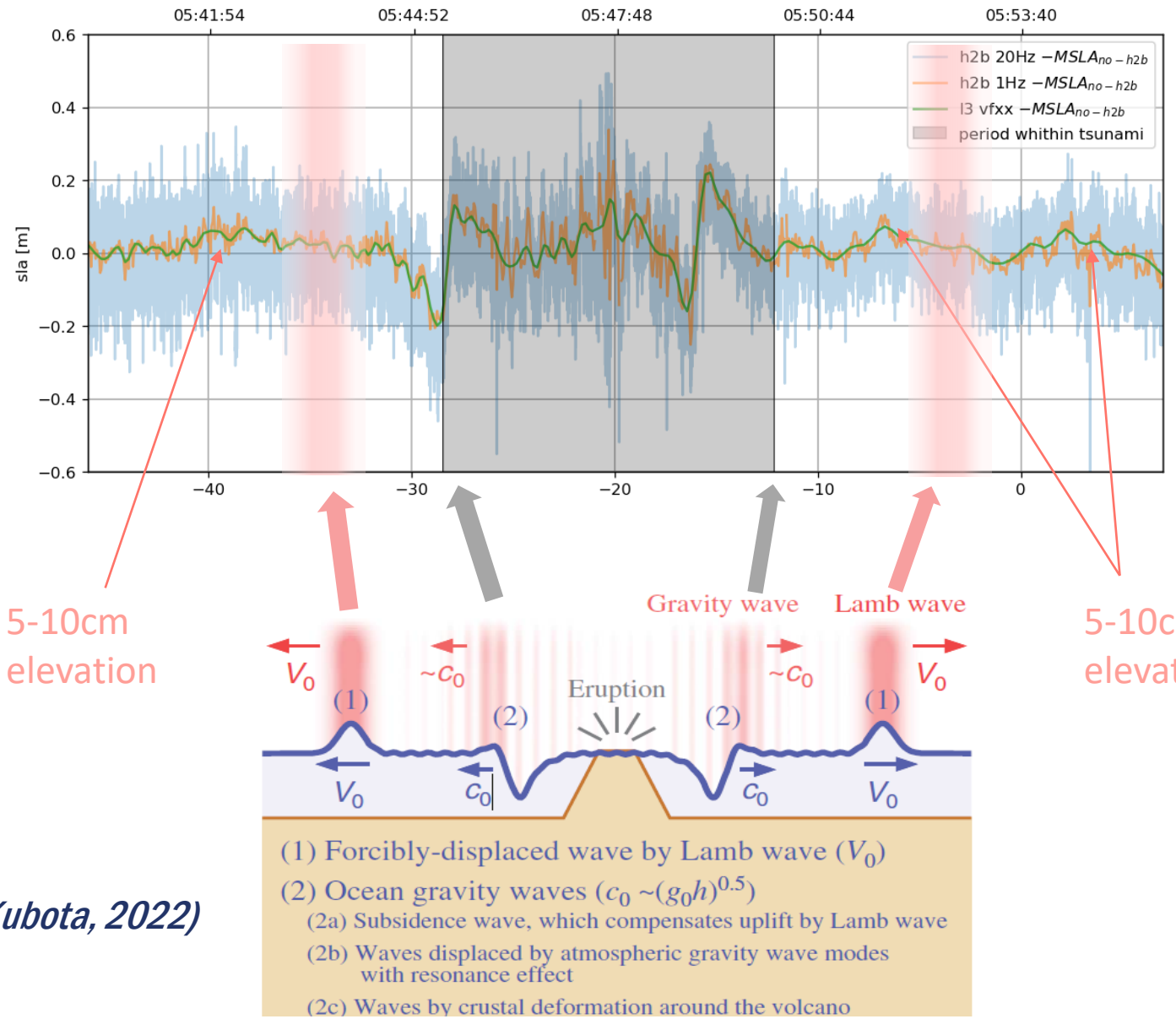

Schematic view of the Tsunami waves (Kubota, 2022)

Conclusion

- HY2B flied over the area of interest 1h30 after the event start and measured several unusual signals which seem to be the signature of the Tsunami
  - Two sharp SLA gradients, of ~40cm measured approximately, not fully consistent with the predicted location
  - 20Hz processing reveals 40cm/10km wavelength oscillations, consistent with SAR images. Limits of HY2B LRM mode to measure a 1km wavelength signal
  - The coupling of the fast propagating atmospheric pulse with the ocean induced a perturbation of the sea-level worldwide before the expected tsunami, possibly visible on HY2B signal

- **Altimetric measurements should be used to assess and improve tsunami modelling**

- Hy2B is a very interesting mission to complement the Copernicus Constellation and help refining the mesoscale.

- Same good performances for HY2C but not ingested yet operationally for budget reasons.

Products & info

CNES/Aviso Catalogue

Marine Service Catalogue

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