Monitoring strain on the seafloor offshore Northern Chile using acoustic direct-path ranging techniques

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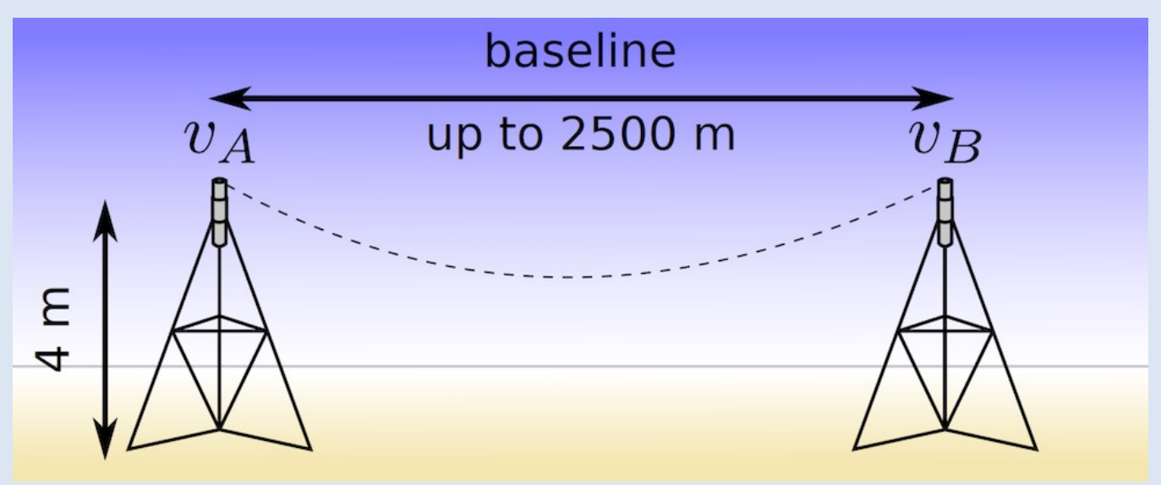
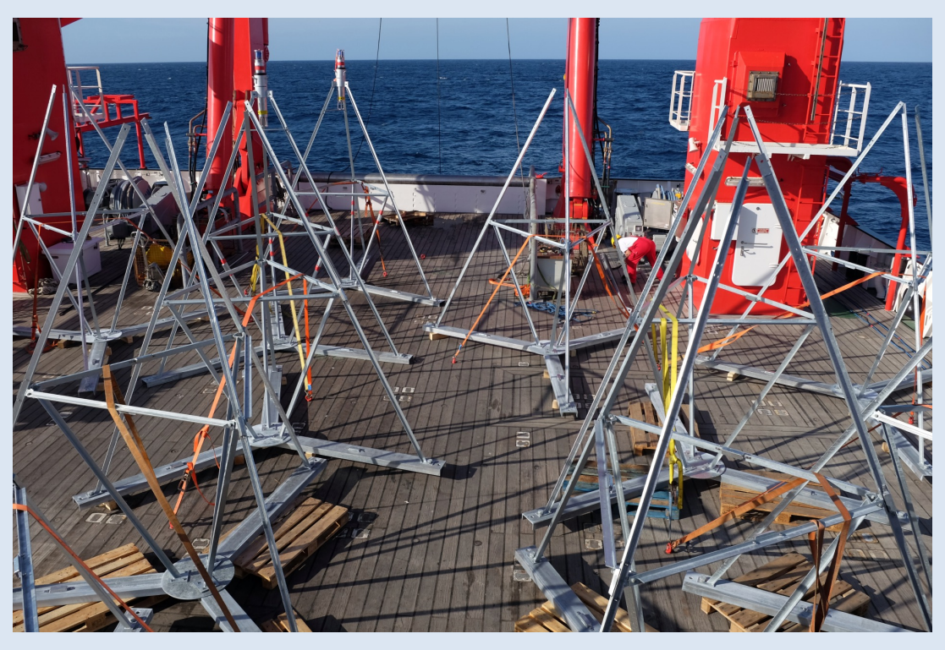
Abstract

We use acoustic ranging techniques between stations on the seafloor to measure crustal strain of the marine forearc and the incoming plate. Three geodetic networks on the seafloor off northern Chile were installed in 2015 during SO244 and recovered during SO288. All stations worked for ~2.5 years as expected, and only a smaller number of temperature sensors stopped logging. Overall, we observe absence of crustal strain within a strain rate precision of up to 2E6/yr on the marine forearc. The pressure data for all three networks indicate no sudden vertical movement of the marine forearc.

Measuring strategy: **distance = velocity · time**

Logged by transponders:
- travel time t
- absolute pressure
- temperature
- inclination
- water sound velocity v (low resolution). Therefore, sound speed is estimated from temperature and pressure measurements, assuming a constant salinity.





Baseline change (cm)	Parameter		unit
4.185	Temperature	0.01	°C
1.317	Salinity	0.01	PSU
1.751	Pressure	10	kPa*

*10 kPa = 0.1 bar =m 1 dbar ~ 1 m Water column

Figure 1: (Top) Schematic sketch of ranging between acoustic transponders mounted on 4 m high tripods. The two-way traveltime and the measured water sound velocity are converted to acoustic distance (baseline).

Figure 2: The 4 m high tripods on deck of R/V Sonne in 2015.

Table 1: Dependency of baseline lengths on water parameters for a 750 m long baseline (e.g., 1.500 m acoustic two-way distance).

Networks

Three geodetic networks were installed during cruise SO244-2 in December 2015, on the marine forearc and outer rise of the South American subduction system around 21°S (Figure 3). The array in AREA1 (Fig. 4, left panel) on the continental slope in ~2700 m water depth measures baselines across four topographic ridges. AREA2 (~4000 m water depth, Fig. 4, central panel) is located on the outer rise seaward of the trench, to monitor extension across plate-bending related normal faults identified in the AUV bathymetry. AREA3 is located at water depths ~5200 m on the lower continental slope (Fig. 4, right panel) to measure potential diffuse strain build-up. Data from all networks and all stations were successfully uploaded with an acoustic modem during cruise MGL1610 of RV Marcus Langseth and with a vessel from the Chilean Navi. All transponders were deinstalled during SO288 with the ROV.

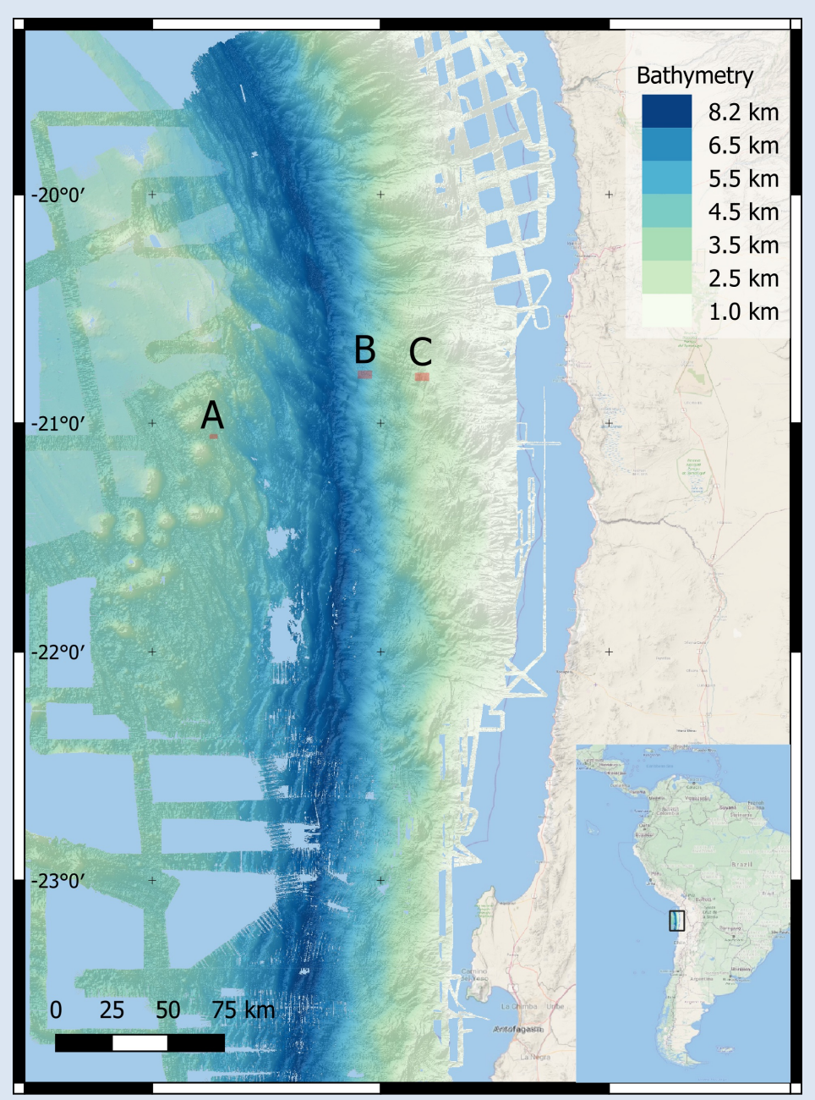


Figure 3: Location map of geodetic networks. A: Outer rise network (AREA2), B: Lower slope network (AREA3), C: Middle slope network (AREA1).

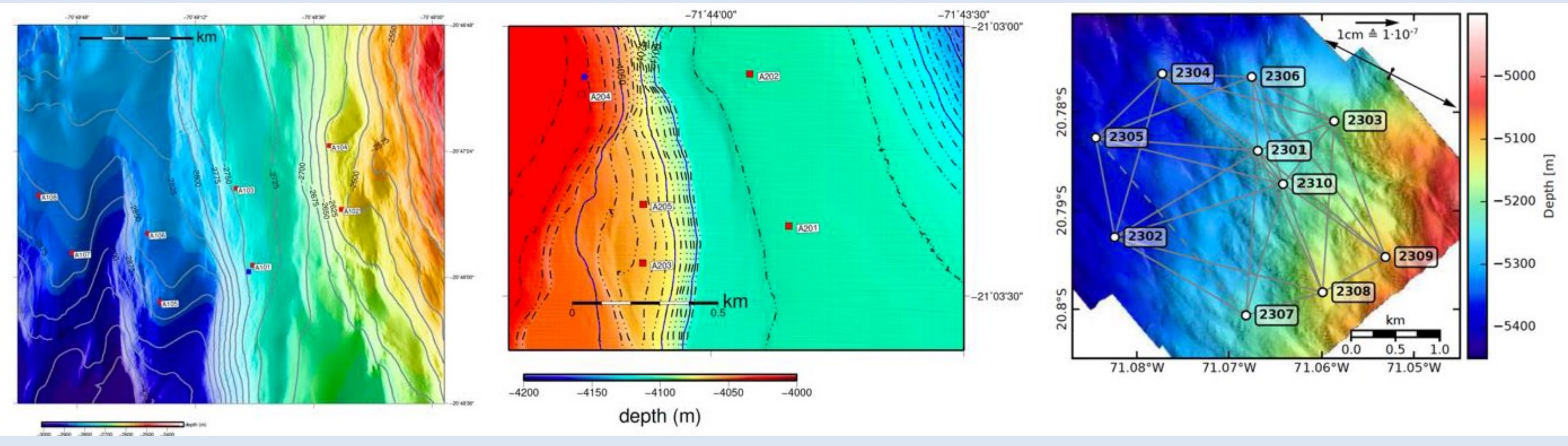
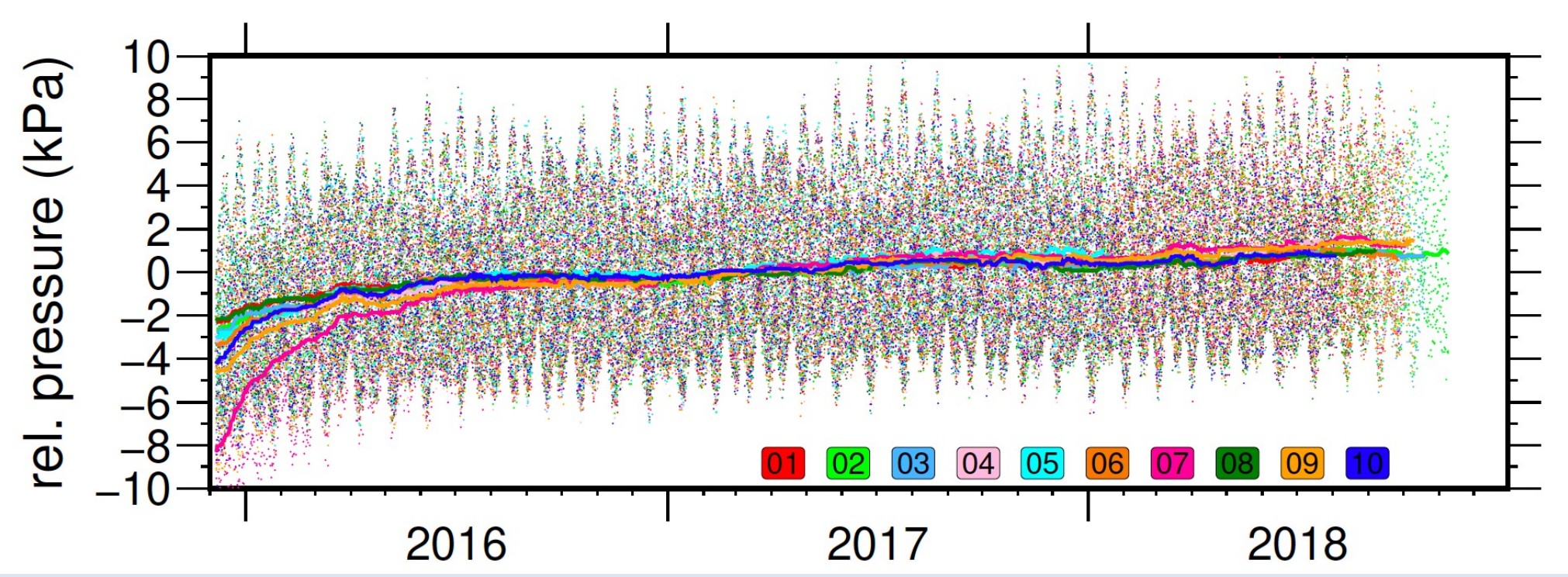


Figure 4: Maps showing the geodetic networks. Left: AREA1, Mid slope, Middle: AREA2, outer rise, right: AREA3, lower slope. The bathymetry is from the AUV mapping conducted during SO244, Leg1.

Data Measured on the Lower Slope (AREA 3), 5200 m Water Depth

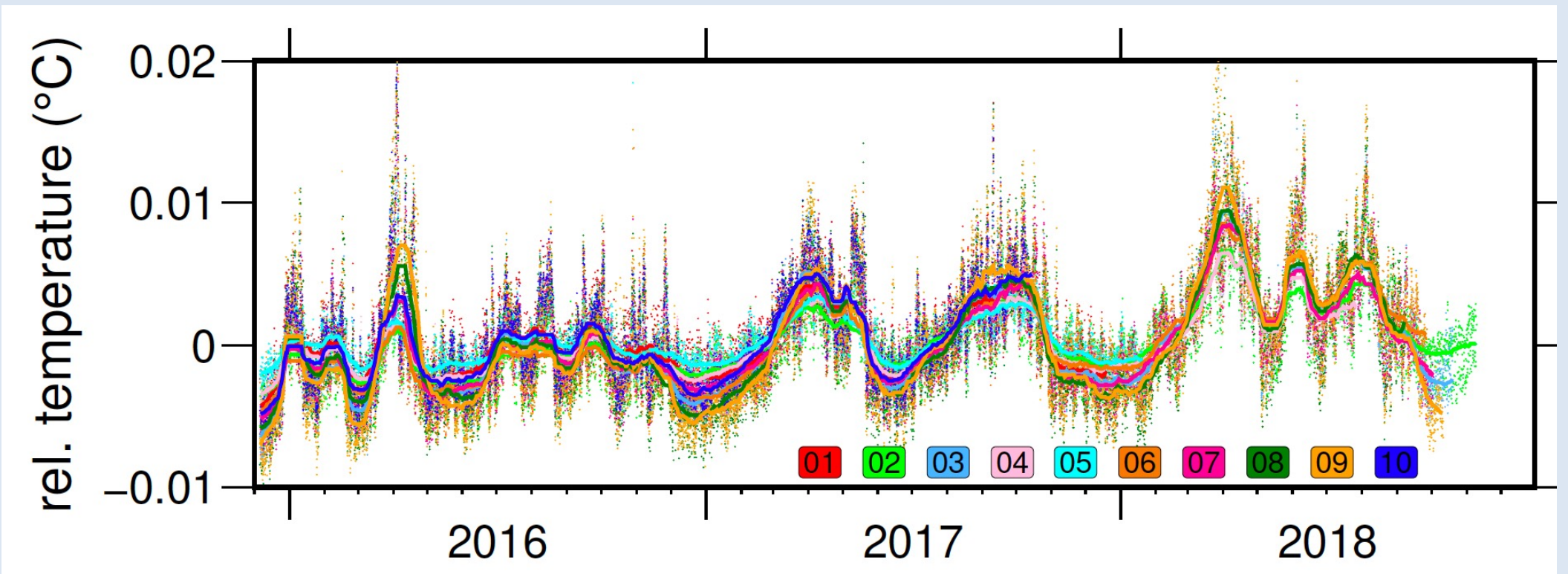
Pressure

Figure 5: Pressure recordings of the lower slope network. The strong drift for the first three months of the time series is an artifact, related to sensor drift. For visualization, all values were set to zero set for June 2017.



Temperatures

Figure 6:, Measured temperatures. For visualization, the temperatures were set to zero at the beginning of 2016.



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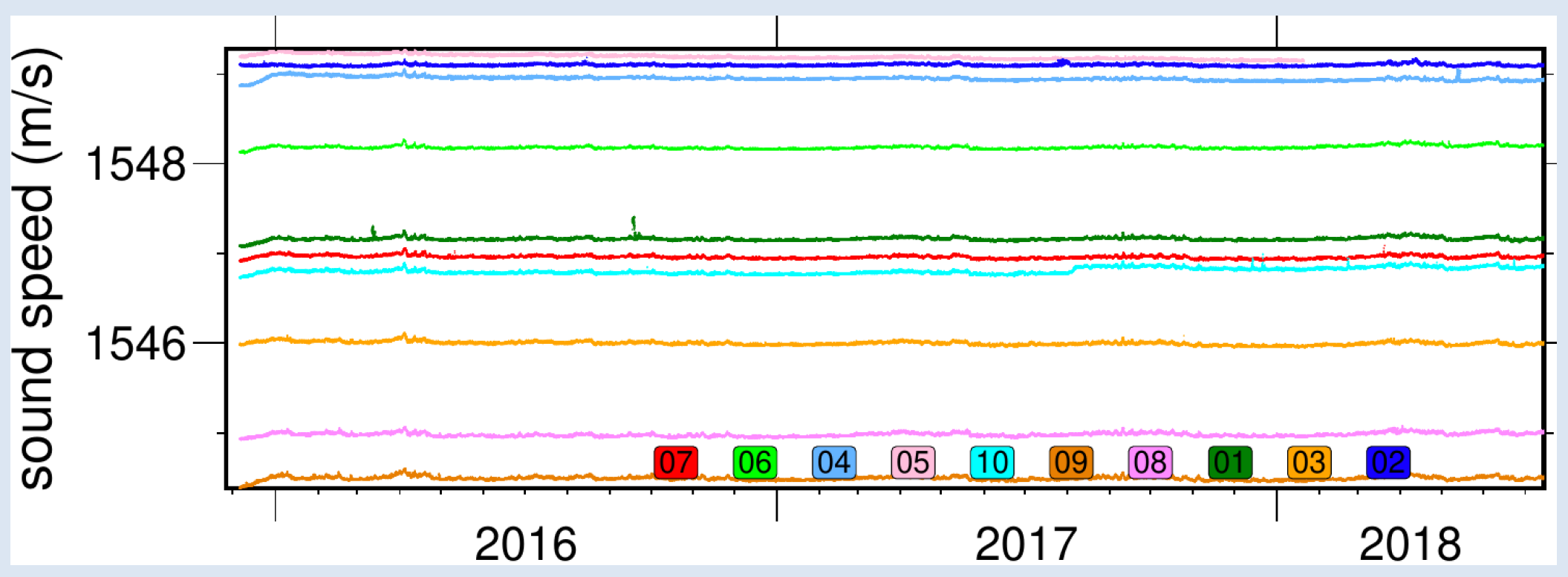
Estimated Sound Speed

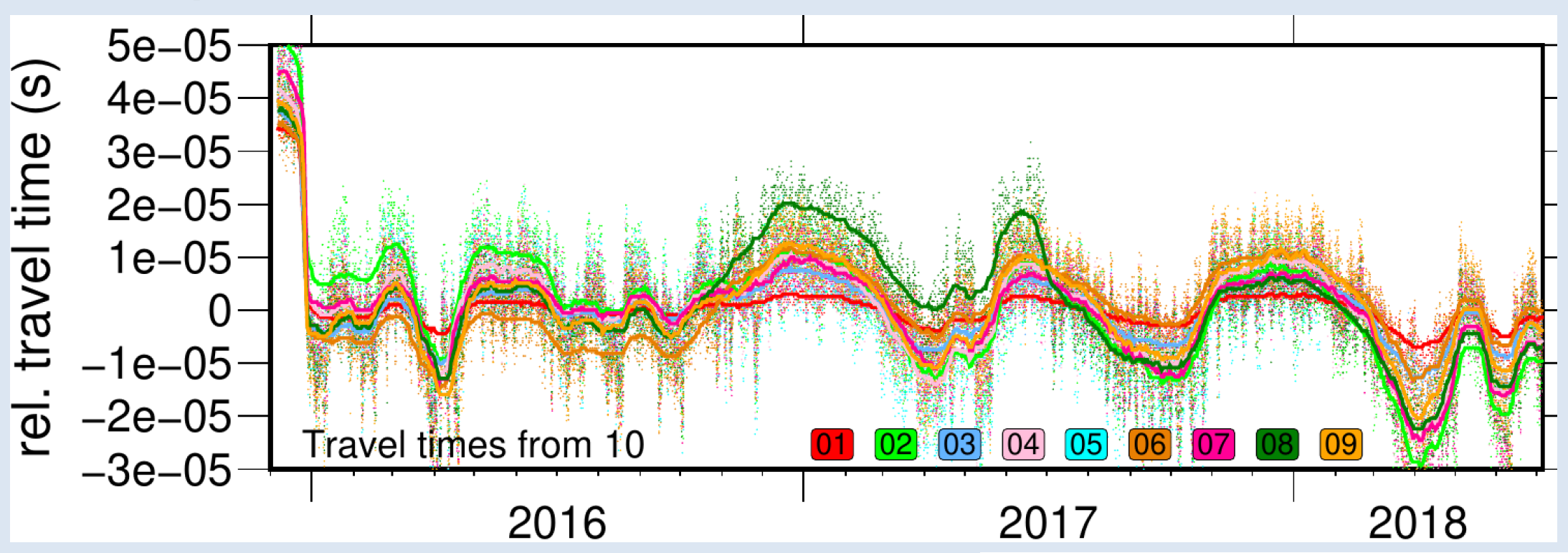
Figure 7: Sound speed in water is estimated from the measured temperatures and pressure, using constant salinity.



Baselines on the Lower Slope (AREA 3), 5200 m Water Depth

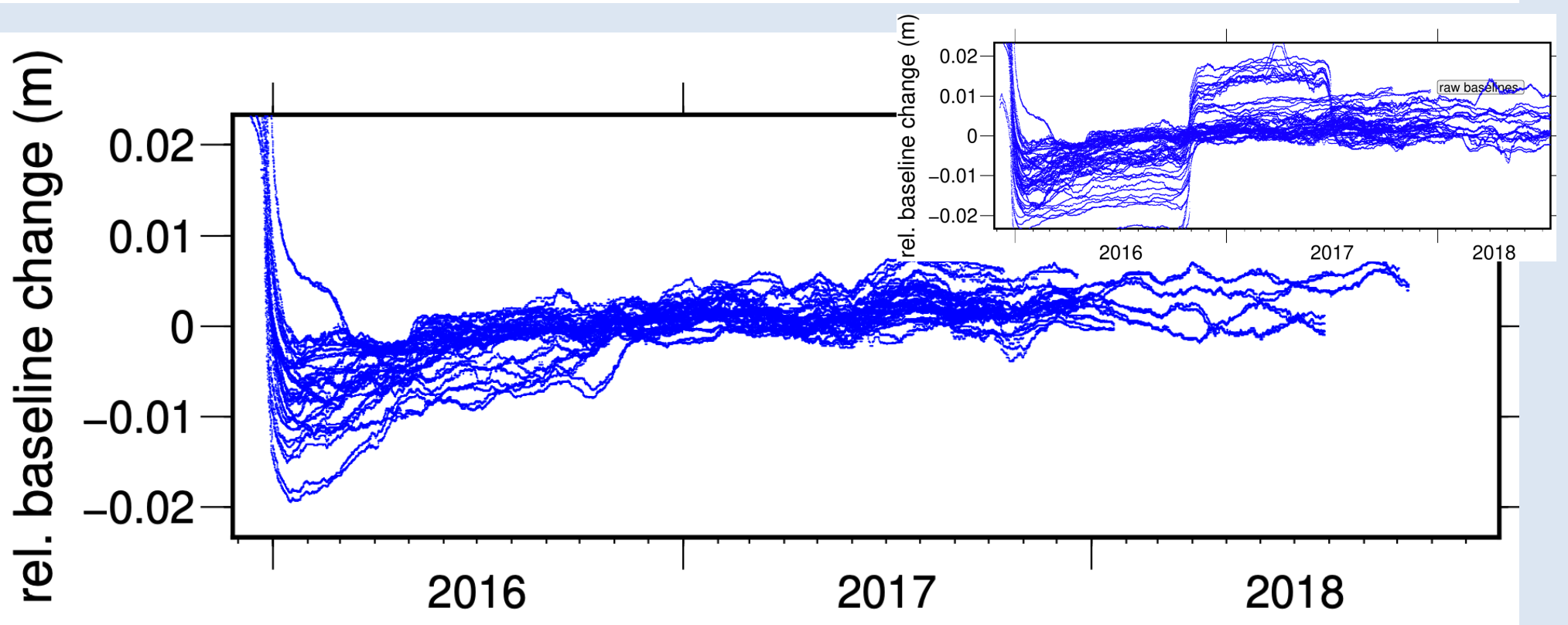
Measured travel times

Figure 8: Travel times measured from station 10, located in the middle of Area3. Please note a drift for the first month months of the time series is an artifact, related to sensor drift.



Baselines

Figure 9: Baselines calculated from travel times and sound speeds measured at the lower slope, excluding stations 6 and 8. Inlay: All baselines including stations 6 and 8 which appear to have been tilted by 0.6°. Since the inclinometers did not show any tilt, these jumps could also be an instrument error since they coincide with the download of data using an acoustic modem.



Measured Strain

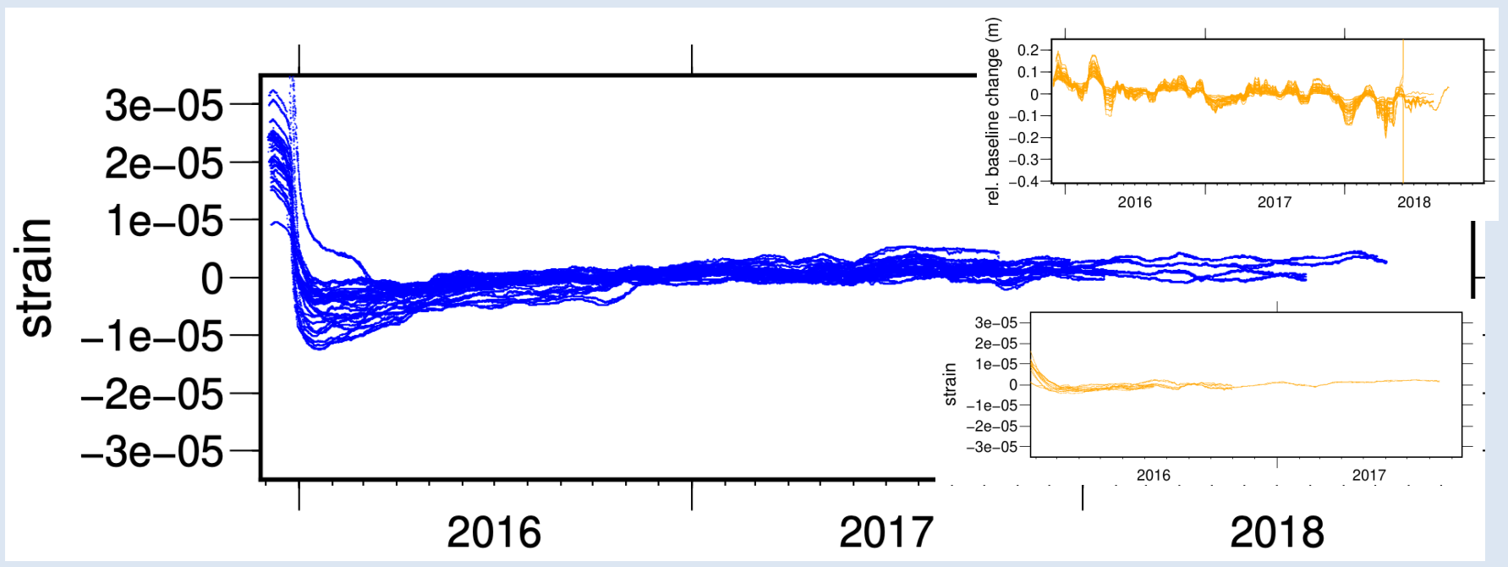


Figure 10: Measured strains:
- **Large panel:** Strain for the lower slope network (~5200 m water depth). Strains of stations 6 and 8 are not shown. The transient signals until March 2023 are from sensors drift.
- **Upper Inlay:** Strain for the mid slope network (~2300 m water depth). This network has less resolution (baseline accuracy ~1cm) due to increased drift of the pressure sensor and temperature fluctuations due to trapped waves, tides and local bottom water currents.
- **Lower inlay:** Strain of the outer rise network (~4100 m water depth). For the outer rise strain could be only estimated until end of 2016. After that, only one single baseline could be determined, which does not cross the normal fault.

Modelling

We modelled surface displacements using the classical Okada analytical method for different locking scenarios. The blue dashed line indicates locking from close to the trench until 70 km away from the trench. The red dashed lines indicate models with varying locking distances starting 3,5,10,20,30 and 40 km away from the trench.

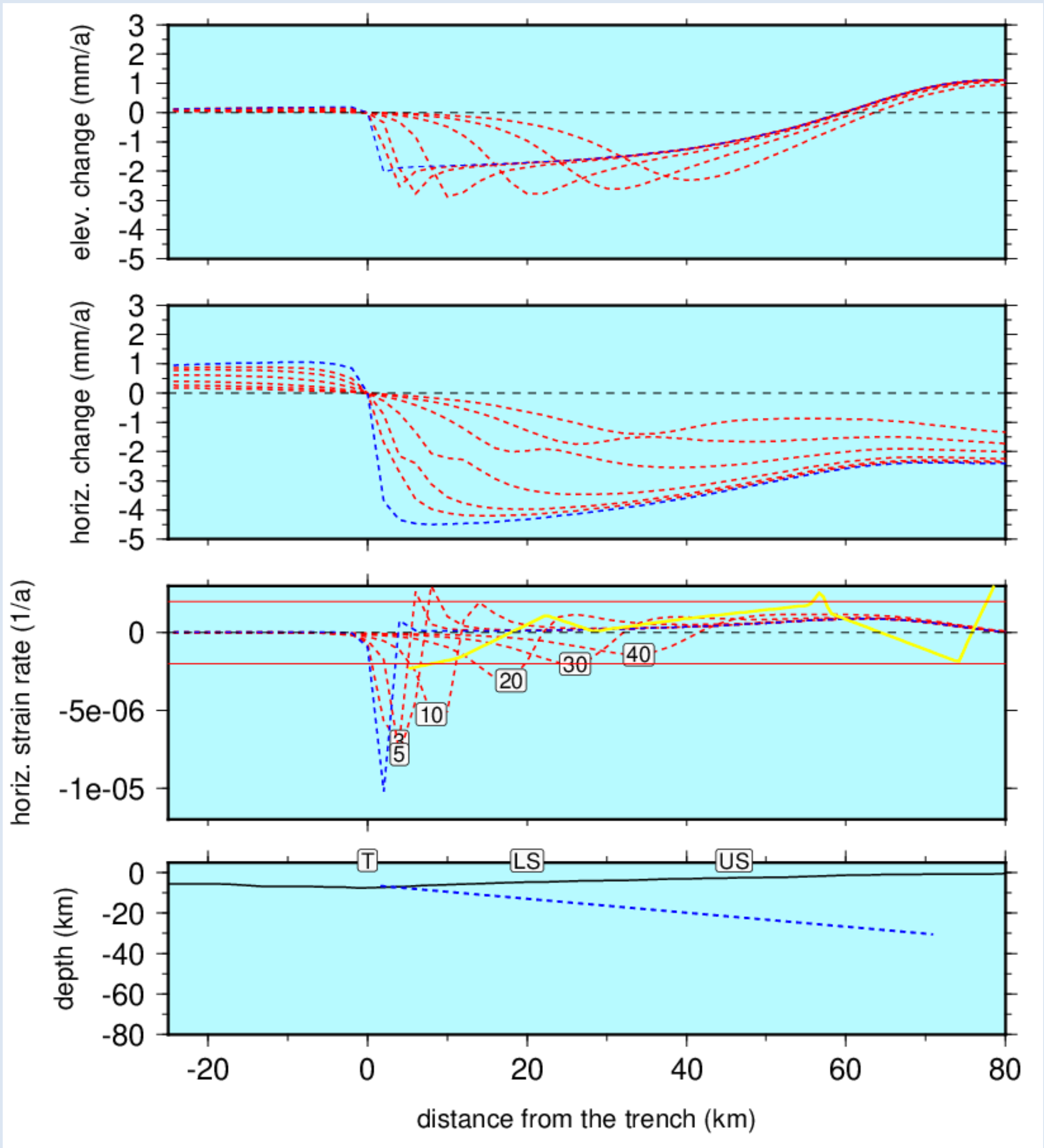


Figure 11:
Panels from top to bottom:
a.) Elevation changes for different locking models with increasing distance from the trench.
b.) Horizontal displacements for the different locking models.
c.) Horizontal strain rates for the different locking models. Horizontal red lines show the resolution capability of the geodetic network. The yellow line represents the post-seismic locking extrapolated from GPS land-stations (J. Bedford, pers. comm.).
d.) Model geometry with the location of the trench (T) and the continental slope networks (LS=AREA3, US=AREA 1)

Conclusions

- We installed three networks with intercommunicating stations on the seafloor offshore northern Chile to measure crustal strain.
- Within our observation time we find no deformation, although the networks are installed in regions of local faulting, as seen in the bathymetry.
- Lower slope: We determined a crustal strain rate of 0+/-2E-6. Two stations might have tilted by 0.6° during the deployment.
- Mid continental slope: Heterogeneities from coastal trapped waves, tides , and local bottom water currents impose noise on the baselines (see Poster from Jegen et al.).
- Outer rise: Studied normal fault shows no significant deformation, which might indicate that active extension only occurs during the co-seismic or early post-seismic phase.

The experiment is the first time that distance changes on the seafloor are measured across a subduction zone using networks of autonomously intercommunicating stations, which acquired data for ~2.5 years. The stations had uptimes of 100%. While the lower slope network, located at a water depth of 5200 had the best resolution for strain rate (2.5E-6) the resolution for crustal strain rate at the mid-slope network was reduced (~1E-5) due to strong heterogeneities in the water column, most likely related to upwelling, and to pressure sensor drift. The network on the outer rise had 5 stations. For three of those stations, the temperature sensors stopped working at the end of 2016, meaning that after 2016 only one baseline, which did not cross the fault, could be evaluated. The strain rate resolution for this network is ~3E-6 corresponding to a 3 mm baseline change over a distance of 1 km.

Acknowledgments

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