ROMY: On the operation and monitoring of a heterolithic large ring laser array

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1 About ROMY

ROMY, **R**otational **MO**tions in seismolog**Y**, consists of four triangular Sagnac interferometers of about 12 m side length (*Igel et al, 2021*). The level of the horizontal ring laser is about 3 m and the tip about 15 m below the surface. This causes a depth dependent exposure to environmental changes, dominantly ambient air temperature and air pressure. The length of a heterolithic cavity, thus the optical frequency, is affected by differential deformation of the corners due to temperature, pressure or differential ground tilt.

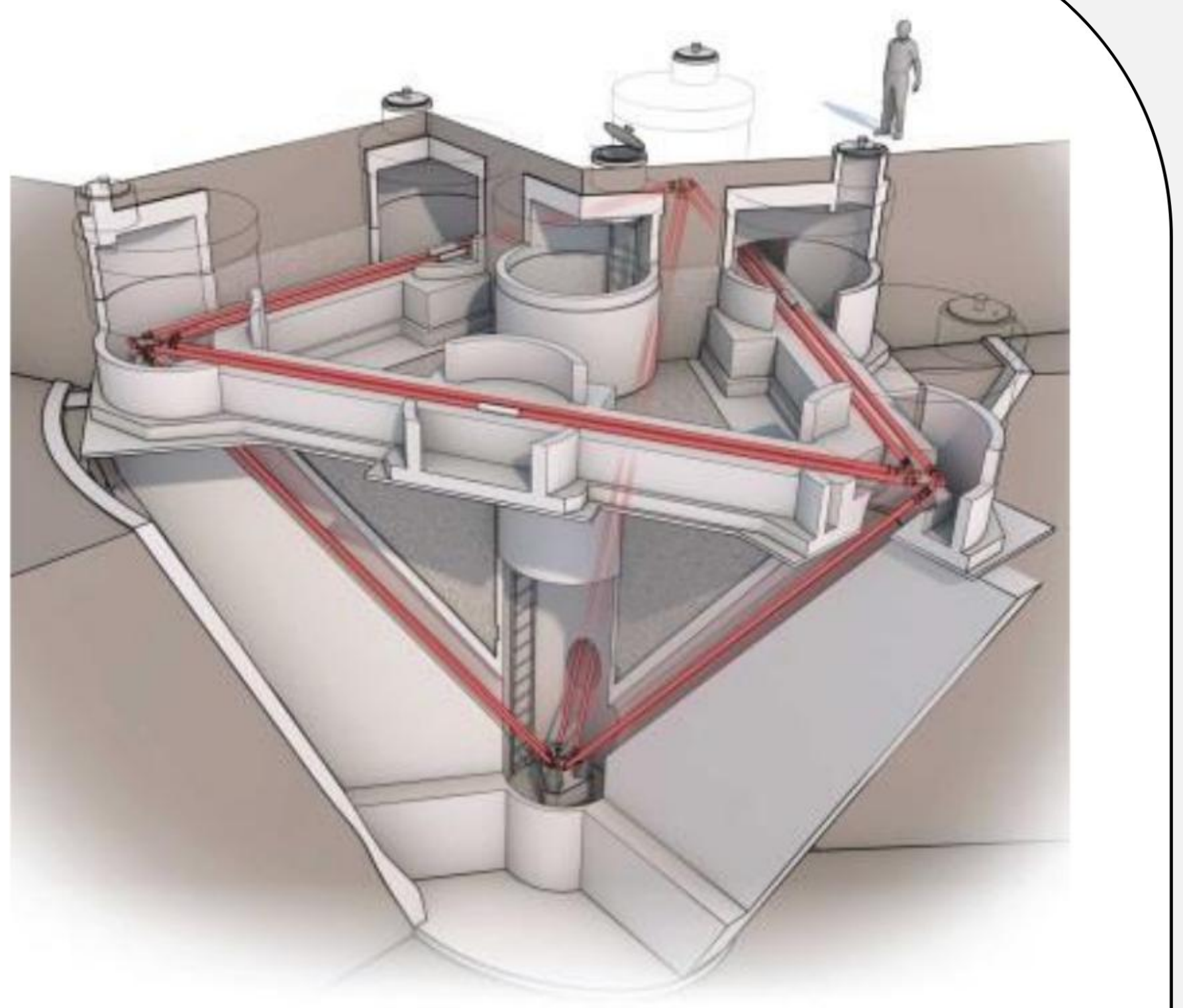


FIG 1: *Tetrahedral, near-subsurface structure assembling for triangular Sagnac interferometers with about 12m side length. Figure modified after (Hand, 2017)*

Monitoring:

- environmental sensors inside ROMY since summer 2021 with a weather station (FURT) outside ROMY for comparison.
- 3 two-component Lippmann tiltmeters (TROMY, ROMYT & BROMY) at the tip and two corners of ROMY.

2 Unstabilized cavity

Variations of the Sagnac beat frequency of 10 mHz are observed at the horizontal ring RZ (Fig. 2 and 3). The contrast mirrors these variations. A triggered mode competition to establish a mono-mode operation is indicated by purple lines.

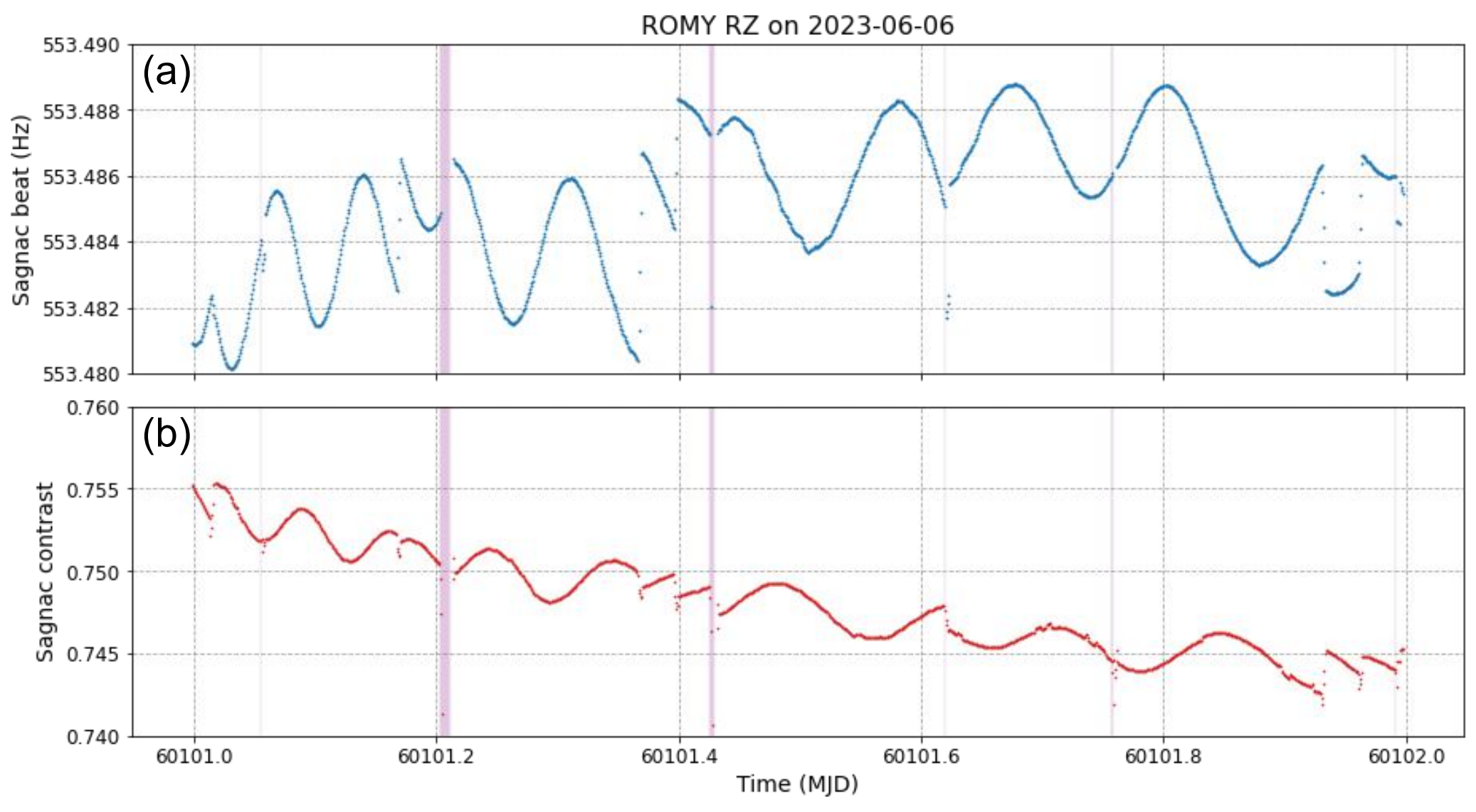
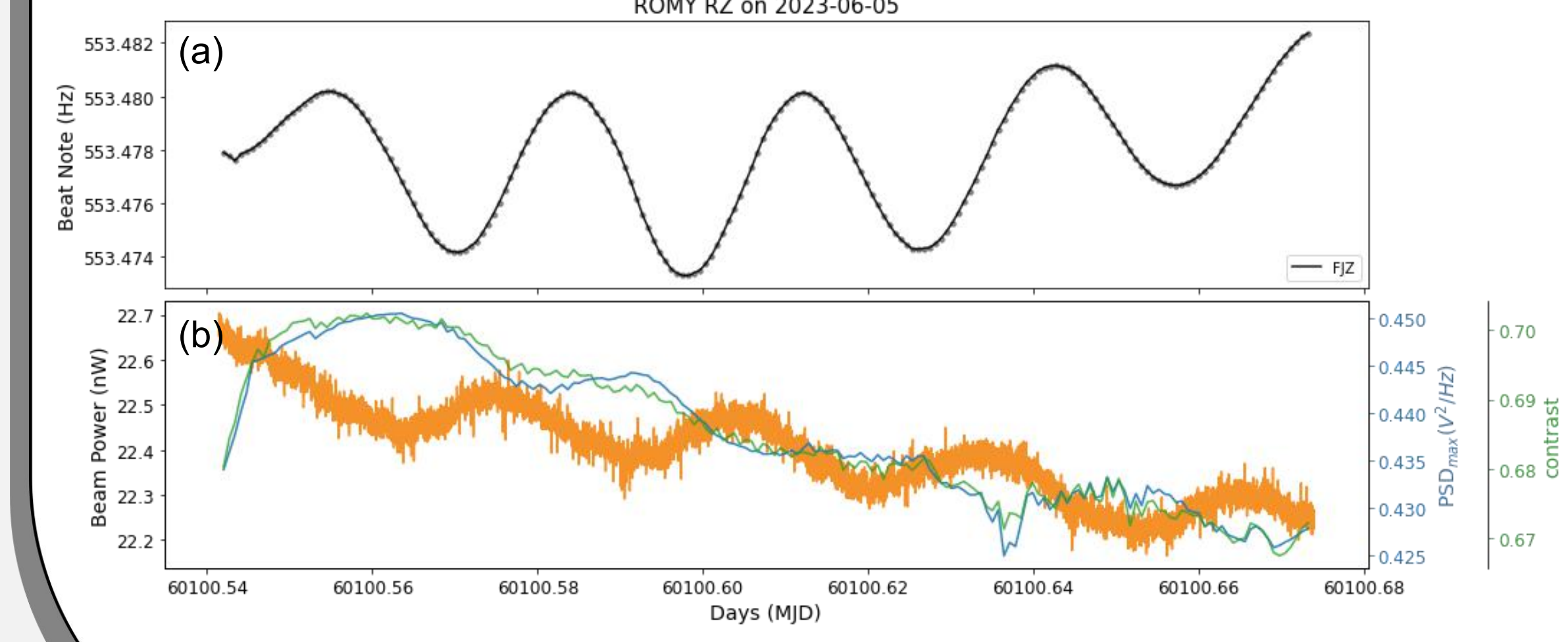


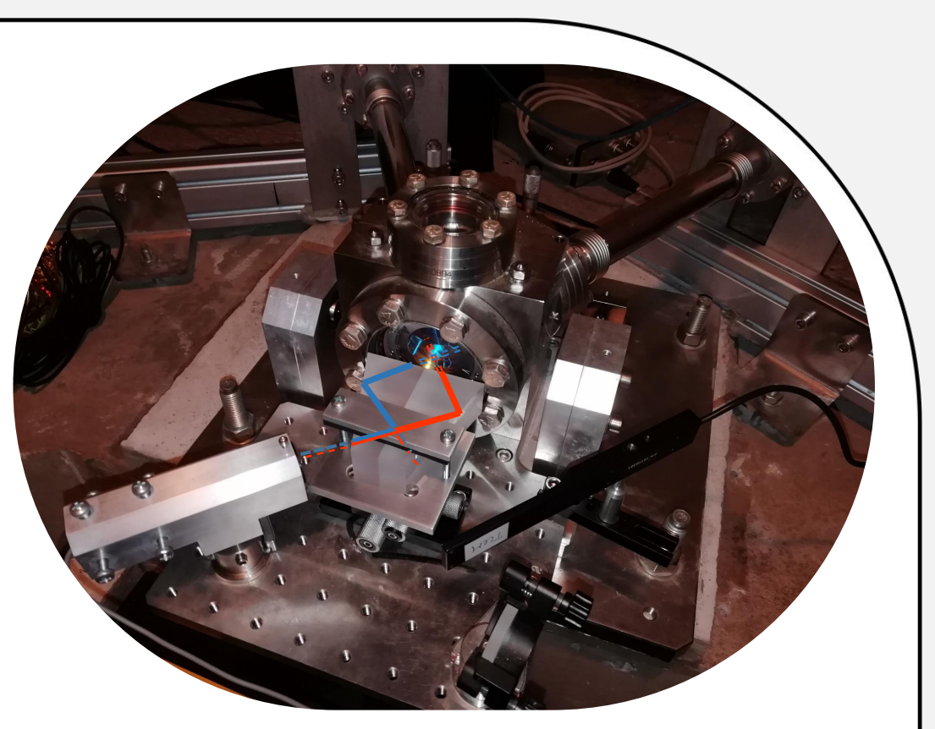
FIG 2: *(a) Sagnac beat variation and (b) signal contrast and triggered lasing mode competition (purple bars).*



Split beam power ranges at 22.5 nW and can be related to the maximal PSD value of the signal and the signal contrast (Fig. 3).

FIG 3: *(a) Sagnac beat variation compared with (b) measured beam power, maximal PSD value and contrast.*

3 Koester prism



Koester prisms have been recently installed instead of discrete beam combining to enhance the interferogram quality by reducing free-air propagation effects.

→ Koester prisms and new electronics promise an enhanced signal quality for detection of Sagnac signal and monobeams. Stronger signal to noise ratio for Sagnac beam (Fig. 4b) and less noise peaks (Fig. 4a).

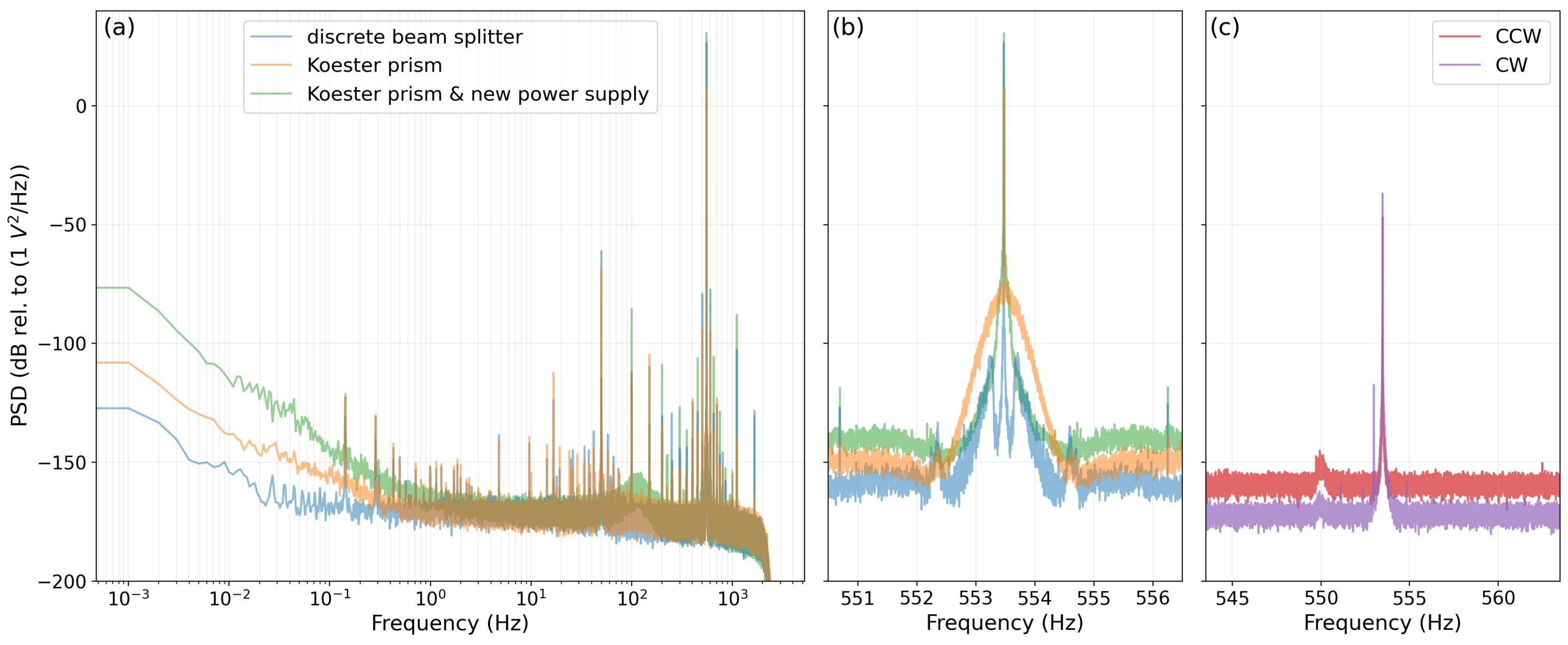


FIG 4: *(a) compares PSDs of Sagnac signals for RZ using a discrete beam splitter, a Koester prism w/o new power supply, while (b) is a zoom-in on the Sagnac peak. (c) shows the monobeam PSDs with Koester prisms and new power supply.*

4 Environmental Monitoring and Tilt

Monitoring from 01-09-2021 onwards (Fig. 5) reveals:

- a damped and delayed exposure to outside temperature and pressure.
  - → enhanced thermal insulation measures for stable conditions are implemented
- tiltmeters are highly sensitive to temperature variations
  - → special insulation and linear correction
  - → borehole tiltmeter BROMY is least affected due to relative stable temperatures at 15m depth.

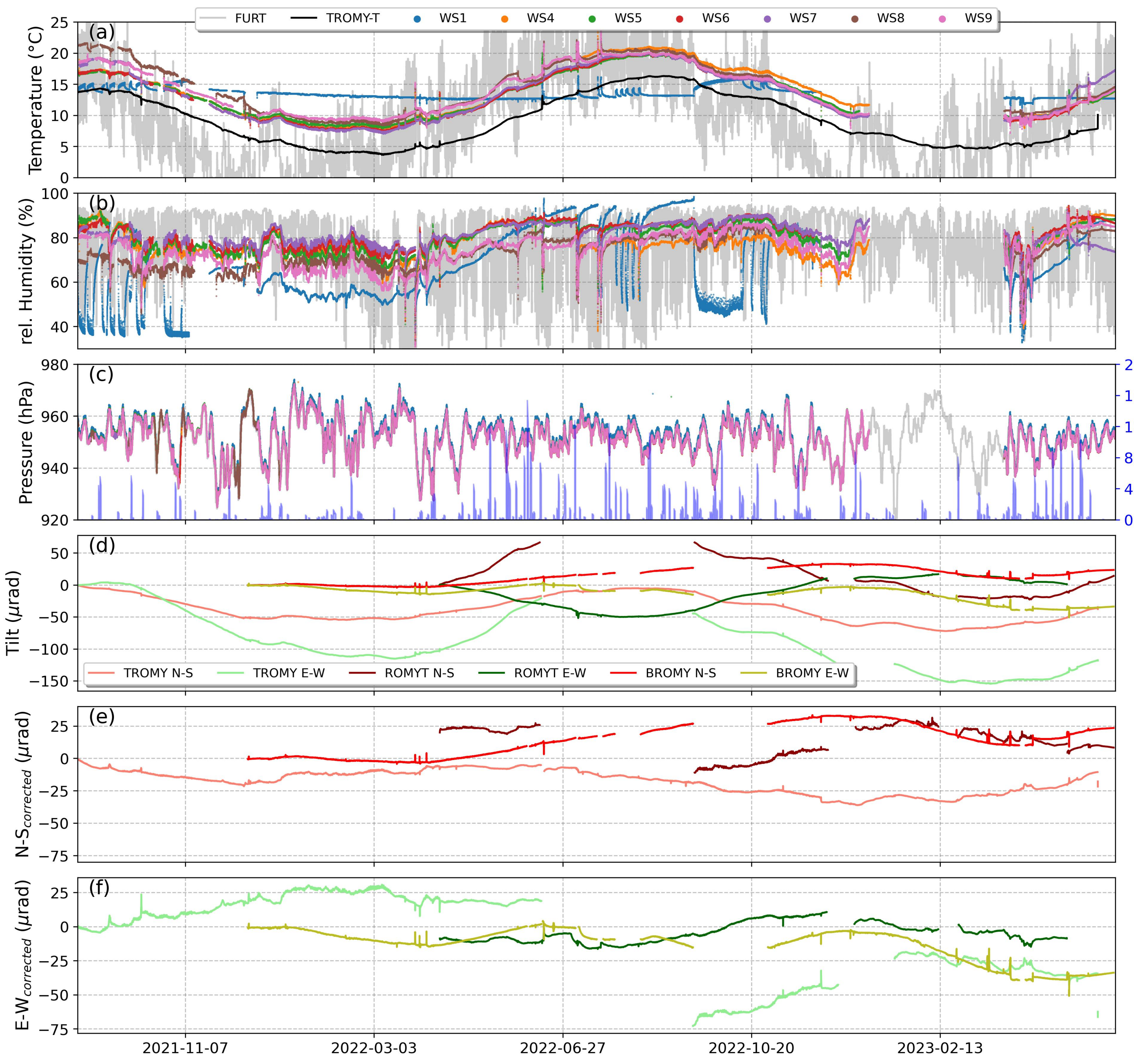


FIG 5: *Environmental changes of (a) temperature, (b) relative humiditiy and (c) air pressure inside (WS1-9) and outside ROMY (FURT) are shown between 2021-09-01 and 2022-05-31. (c) includes the 5-day-cumulative percipitation record. (d) shows all tiltmeter observations with a correction for manual recentering. (e) and (f) show N-S and E-W tilt, respectively, with a linear temperature correction applied.*

5 Sagnac beat frequency drift analysis

The Sagnac beat frequency over 160 days is related to tilt and cavity length changes (Fig. 6):

- beat frequency is converted to N-S tilt (θ) using: $\delta f = \frac{4A}{\lambda P} \Omega_E \sin(\varphi+\theta)$
- triangular height (H) serves as cavity length proxy: $\delta f = \frac{2H}{3\lambda} \Omega_E \sin(\varphi)$

10% of converted tilt matches well with the low-temperature-afftected tilt of BROMY, while the triangular height deformation of submilitmeter seems realistic for thermal expansion considering observed temperatures.

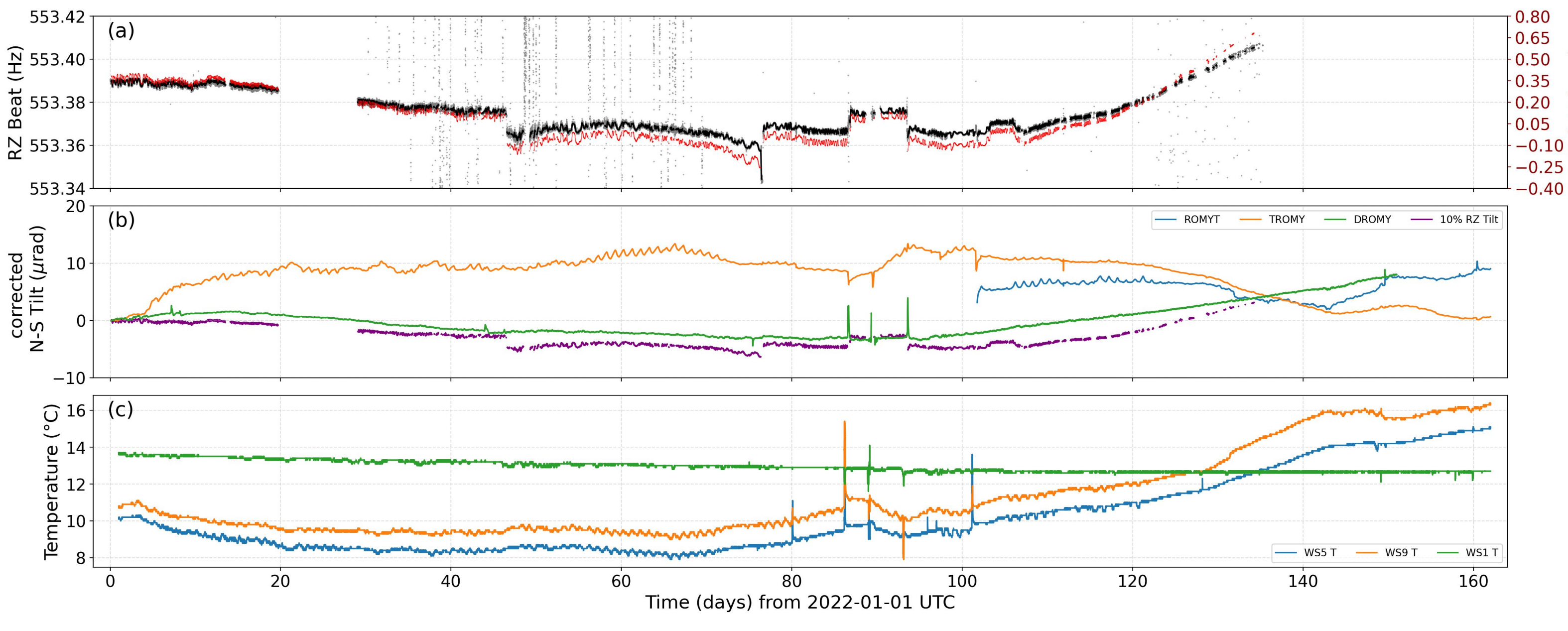


FIG 6: *(a) Sagnac beat frequency of RZ and converted relative triangular length (H). (b) shows the temperature corrected N-S tilt and (c) the temperature record.*

References:

- Igel et al. (2021), ROMY: a multicomponent ring laser for geodesy and geophysics, GJI, https://doi.org/10.1093/gji/ggaa614
- Hand (2017), Lord of the rings, Science, https://doi.org/10.1126/science.356.6335.236

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