SnT 2025 8 SEPTEMBER ONLINE DAY 9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
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Seasonal variations of the magnitude residuals at IMS three-component and array seismic stations

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Technical specifications for IMS stations require accuracy of calibration parameters to be known within 5% and 5-degrees for amplitude and phase of the nominal response, respectively. Taking into consideration that the operating temperature for equipment components is specified between -20°C to +45°C, the sensors and dataloggers must assure operational quality within the specified nominal response and traced over the operational lifetime. It was discovered that ambient temperature variations may influence CALIB values acting as conversion factors to ground motion (ECS/PRES/WGB-62/WEG). Seasonal temperature variations at equipment vaults could reach up to tens of degrees and such variations may affect station performance impacting station magnitude estimates.

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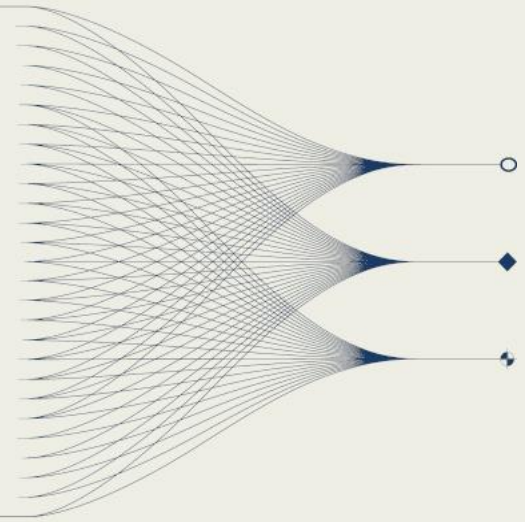
INTRODUCTION AND MAIN RESULTS

Observation of magnitude residuals (MR) at some IMS stations at high latitudes revealed seasonal variations, which could relate to temperature changes also depending on sensor type, emplacement depth and vault insulation quality. The observed seasonal MRs are found to be up to **0.25** magnitude units for **mb** and less prominent for **Ms** which is exceeding expected values caused by the seasonal temperature variation. It may require a better vault insulation to fully exclude the temperature related component and better understand the primary source of MR variations. Additional factor possibly affecting MRs is the background noise variations that often have a seasonal component. The combination of seasonal noise and temperature are presented as key parameters affecting the magnitude estimation at IMS stations, but it requires further investigation of other factors. Once the source is identified, introduction of station specific corrections to mitigate MR seasonal variations could be the way to enhance station magnitude computation.



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Highlights

Besides the strength characterization, in context of verification works, different types of magnitudes (for ex. **mb, Ms**) are used for natural and man-made event screening.

1. Station magnitudes are computed by conversion of the digitally recorded waveforms to the kinematic units of the ground motion by utilizing calibration parameters of the seismic system "in-use" (**CALIB&CALPER** and full frequency response).

2. Minimum requirements for **IMS** station specifications in seismic Operational Manual define **5%** and **5-degree** as accuracy thresholds for amplitude and phase responses respectively across the channel passband.

3. Magnitude computation is based on the signal displacement amplitude (**A**) to its period (**T**) ratio, for ex:

$$\mathbf{m_b} = \mathbf{log}\left(\frac{\mathbf{A}}{\mathbf{T}}\right) + \mathbf{Q}(\Delta) \qquad (\mathbf{1})$$

where $\mathbf{m_b}$ is the body wave magnitude and $\mathbf{Q}(\Delta)$ is the epicentral correction factor.
Taking the derivative of **(1)** one gets:
$\boldsymbol{dm_b} = \frac{\mathbf{1}}{\boldsymbol{ln10}}\frac{\boldsymbol{dA}}{\boldsymbol{A}}$ where $\frac{\boldsymbol{dA}}{\boldsymbol{A}}$ is a relative error in amplitude estimate. Accounting the above accuracy requirement, we get $\boldsymbol{dm_b}$ ~ **0.02** units of magnitude relevant for such uncertainty. This value is **well below** significand in rounding of the **REB** event magnitudes.

Data: Magnitude residuals

Magnitude residual is a known quality control metric often used in seismic network monitoring practice. It reflects deviation of the station magnitude relative to the network average. It is applicable for different magnitude types. In PTS practice it is presented for each seismic station in the IDC **MUTIP** environment.

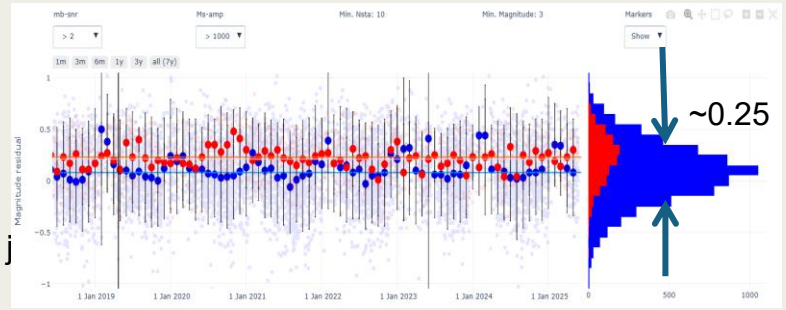
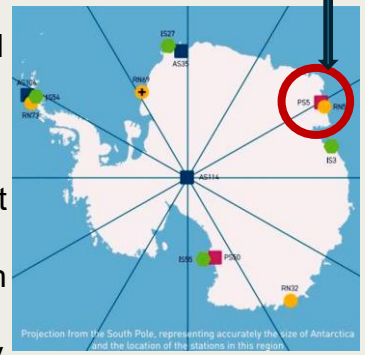


Fig1. Example plot of magnitude residuals over a 7-year time window observed at IMS Antarctic station MAW, AU.

Ms residuals (red dots) and **mb** (blue dots) are shown for events recorded at the station. Residual values were averaged over one month interval. Distribution histogram illustrates the ***rms*** value for residuals spread about **0.25** of the magnitude units. It translates in **~75%** of calibration uncertainty if assigned to equipment parameters instability.



Data: Seasonal temperature noise variations

It was pointed out [2] that temperature variations may impact calibration parameter of SP and BB sensors [3]. Therefore, possible correlation between magnitude residuals and temperature effects is exciting hypothesis for investigation. Variation of seismic background noise level may cause constructive/destructive interference and also impact signal amplitude measurements.
https://meteostat.net/en/
Daily temperature variations are available at the nearest weather stations from the IMS station locations. It was shown [2] (Fig2.) that for surface vaults the external air temperature, vault and sensor probe measurements are well correlated.

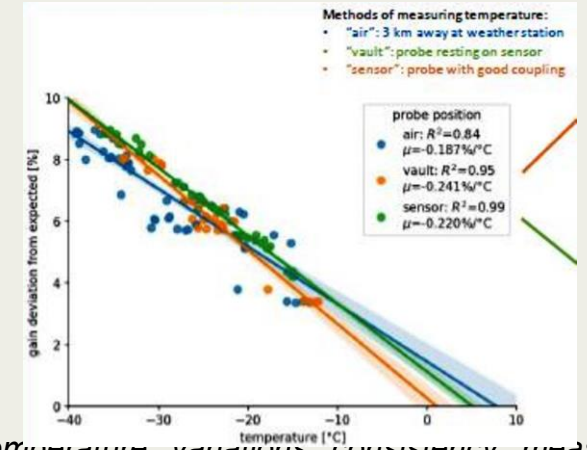


Fig 2. Temperature variations consistency measured at nearest weather station, in the vault and on sensor probe made in YKA array [2]

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SP sensor sensitivity to temperature effects

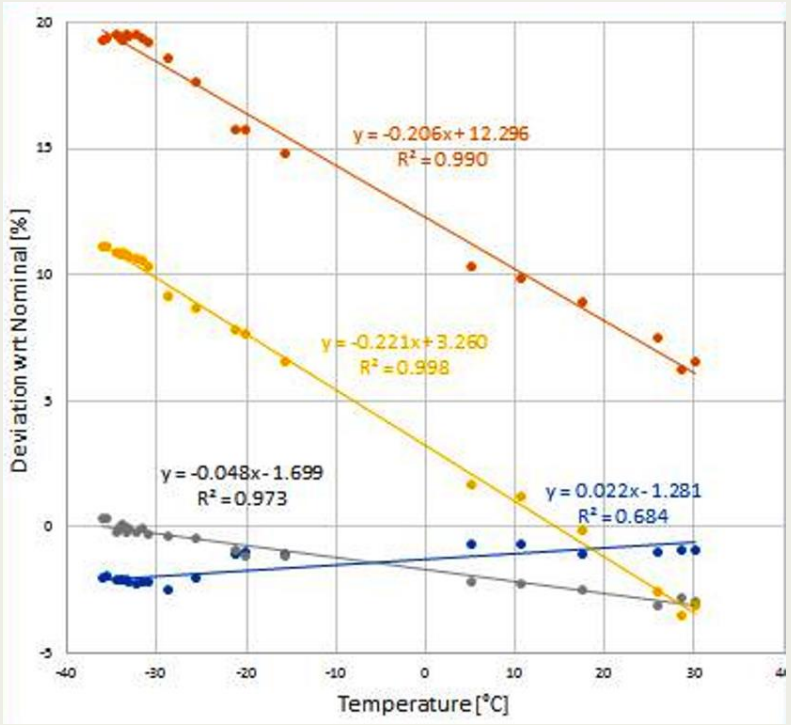

*Fig.3 Temperature effect on passive sensor sensitivity, damping resistor (**brown**), calibration gain (**yellow**) and resonance frequency of passive sensor (**grey**, **dark blue**) [the plot is taken from [2]).*

The overall temperature coefficient of SP sensor sensitivity [2] is **~ - 0. 206% / ºC.** Seasonal ΔT variations of **~60C** translate into **~10 - 12%** of sensitivity change or **0.05** magnitude units (1).

$$D(\%) = -0.206 * T^{o}C + 12.296$$

Long term magnitude residuals for IMS stations 1/3

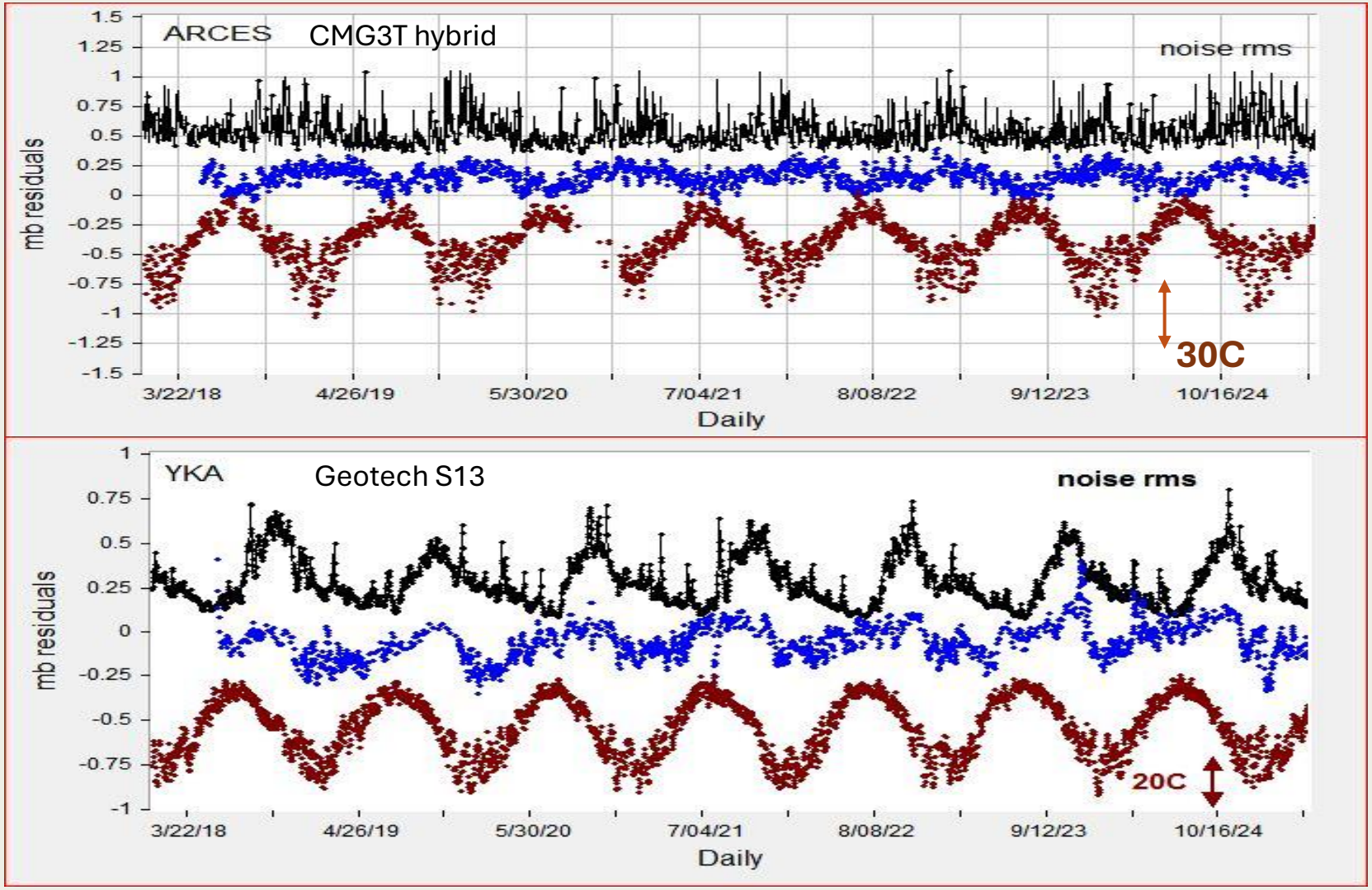

*Fig. 4. 7-year seasonal variations of magnitude (mb) residuals (**blue**), noise rms cnts (**black**) and air temperature (**brown**) for **ARCES** (opposite polarity) and **YKA***

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Long term magnitude residuals for IMS stations 2/3

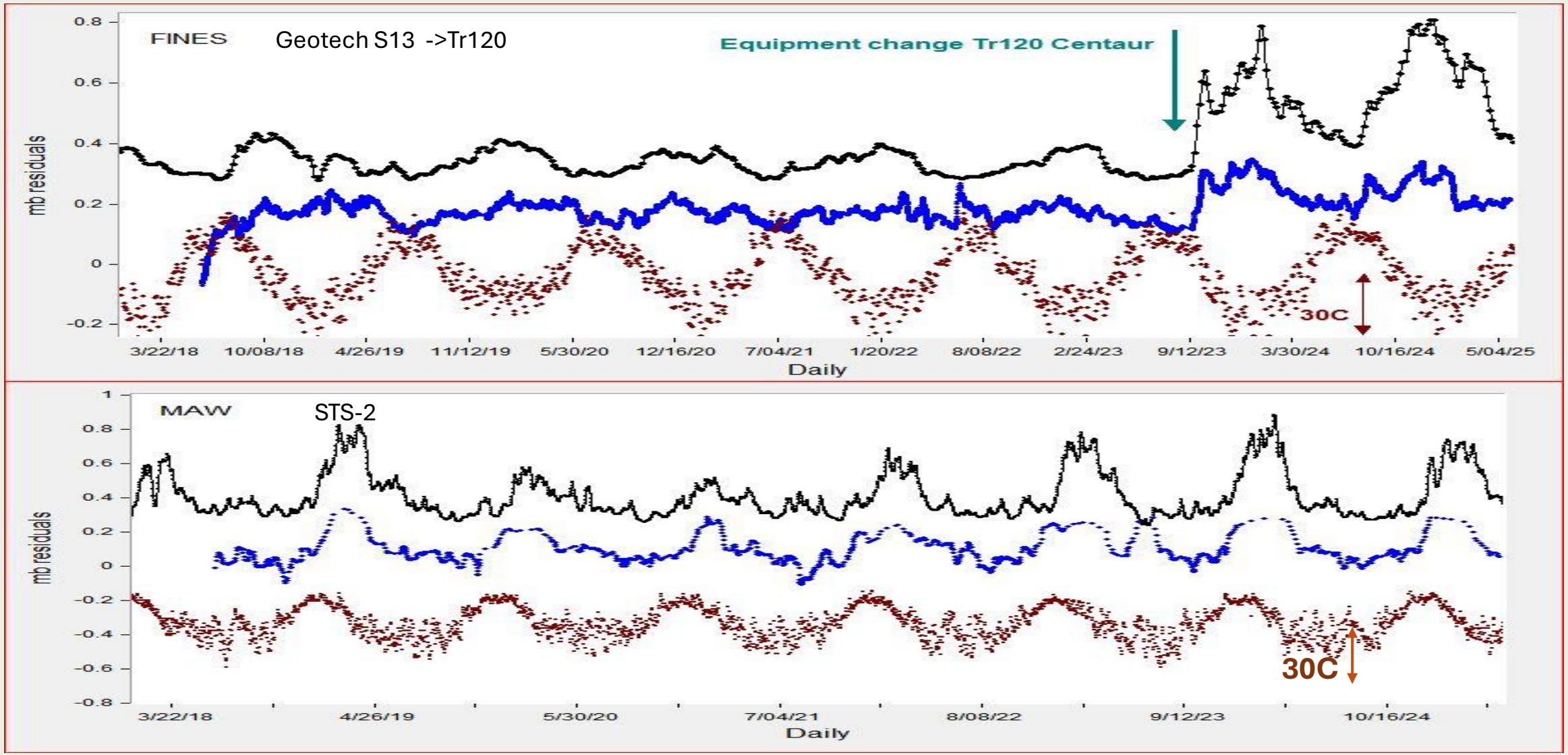

*Fig. 4. 7-year variations of magnitude (mb) residuals (**blue**), noise rms in cnts (**black**) and temperature (**brown**) for **FINES** (opposite phase) and **MAW**. The noise level in cnts may create spurious impression about bigger effect on Tr120.*

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Long term magnitude residuals for IMS stations 3/3

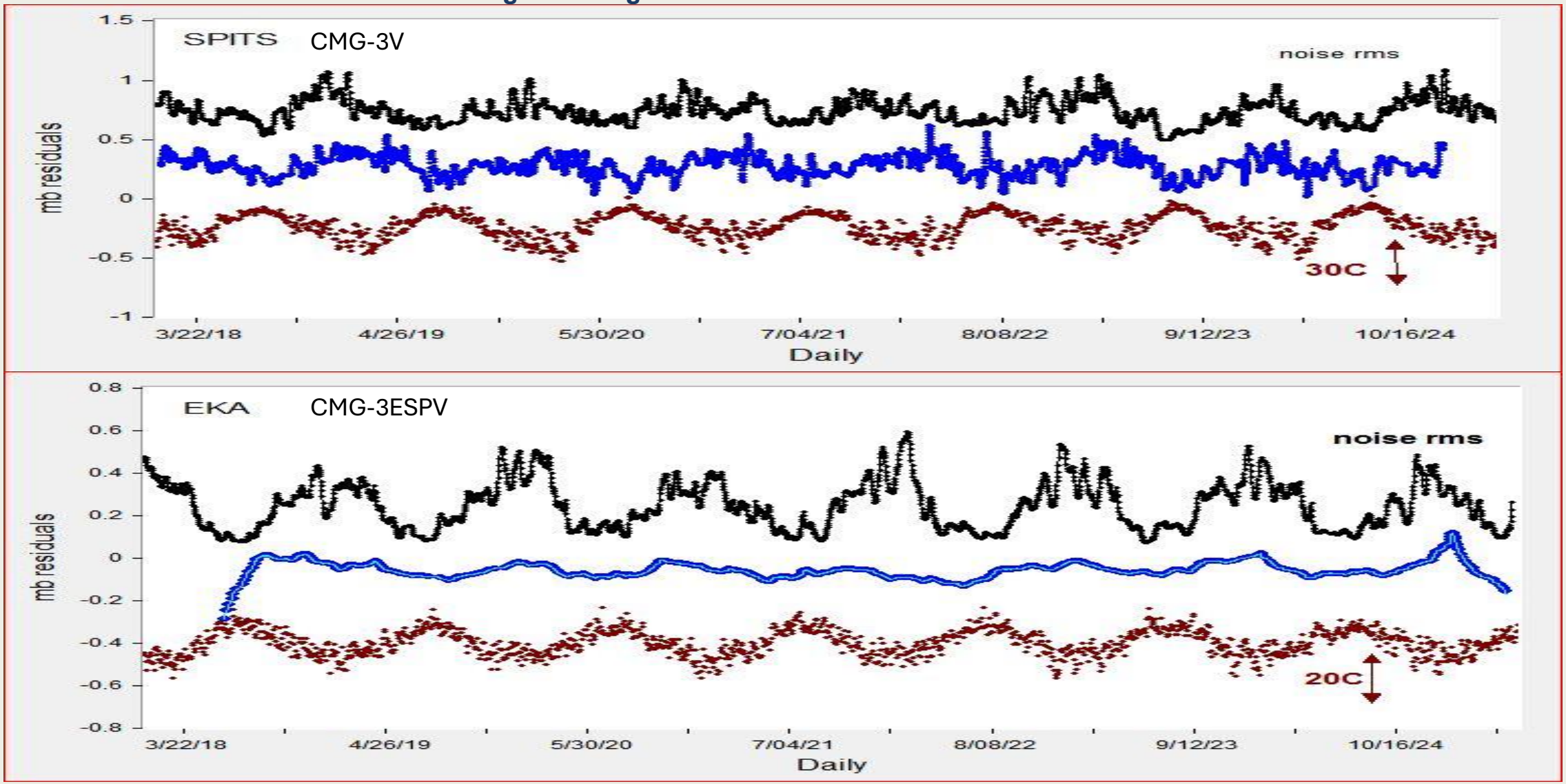

*Fig. 4 7-year seasonal variations of magnitude (mb) residuals (**blue**), noise rms in cnts (**black**) and temperature (**brown**) for IMS **SPITS** and **EKA** (both opposite polarity). Different LP filters applied for Δmb smoothing.*

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Possible way of mitigating temperature factor

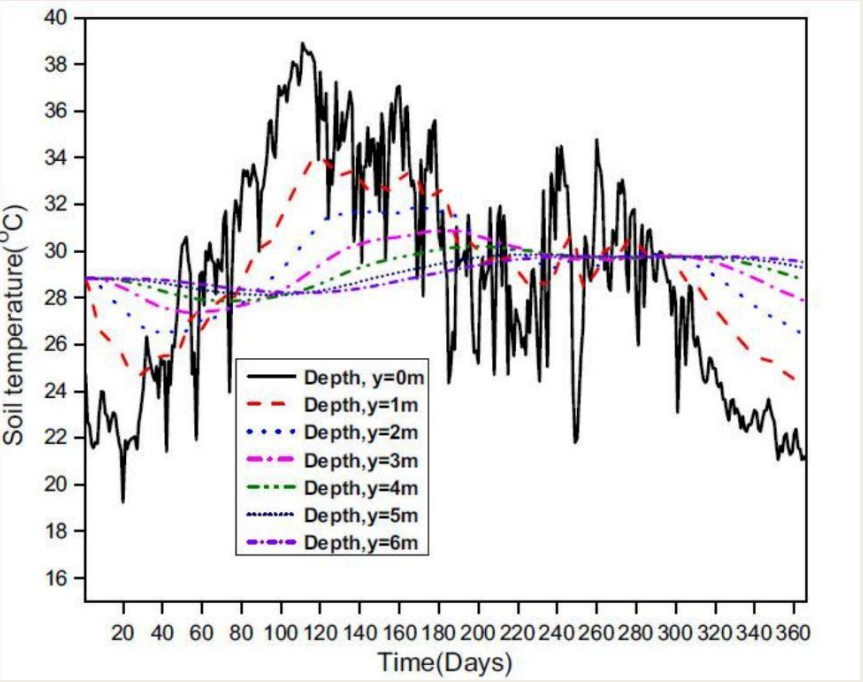

Fig 5. Soil temperature variations for the duration of one year and their attenuation with depth [4]

Emplacement depth of **2m** may decrease amplitude of temperature variations by **5-6** times. This can be achieved by filling with thick insulation dirt layer around the vault.

Future work plan

- Frequency dependent investigation of seasonal noise variations may represent the future efforts to better understand the root cause of magnitude residual variations.
- Magnitude residual variations may reflect combined influence of ambient temperature/pressure and other factors in junction with background noise changes. Investigation of the root cause is crucial.
- IMS is operating different brands and types of weak motion sensors used in borehole and vault installations. Susceptibility to temperature and other factors is different and require investigations.
- Sensors in subsurface vaults may require “first aid” attention by updating and implementing new civil works requirements for IMS vaults.

Conclusion and references

- Seasonal variations of magnitudes residuals have been observed at several high latitude stations.
- ***RMS*** of magnitude residuals are found to be well above 5% accuracy uncertainty for channel calibration parameters.
- Direct temperature effects on channel sensitivity is estimated to have lower effect on magnitude residual than observed.
- Local temperature should be logged as additional State-of-Health value at all seismic stations to track possible sensitivity changes.
- Extra measures for subsurface vaults thermal insulation may supress temperature effects.
- Temperature effects may depend on the type of sensor and vault, and this should continue to be investigated.

References:

1. Operational Manual for seismological monitoring and the international exchange of seismological data**.** CTBT/WGB/TL-11,17/15/Rev.7 2020
2. *Ackerley, N. et al*. Calibration Temperature Effects at the Yellowknife Array GSC. WGB-62-WEG-5 Feb 2024
3. *Bloomquist, D. & J. Merchant*, Calibration Temperature Effects on GS13 Short Period Seismometers. WGB-64, WEG-7, Feb. 2025
4. *Singh, R.K. & R.V. Sharma*. Numerical analysis for ground temperature variation. Geothermal Energy, 5:22, 2017. DOI: 10.1186/s40517-017-0082-z