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The Five M's of Seismic Station Quality: Machines, Methods, Metadata, Monitoring, Maintenance

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ABSTRACT

For data generated by seismic monitoring networks to serve the intended purposes of the network, they must be sufficiently accurate and precise in order for signal processing and analysis to generate trustworthy results. While it is obviously necessary that the individual seismic instruments comprising the network be appropriately accurate and precise, that on its own is not sufficient due to many additional factors that affect seismic station accuracy.

To make it easier to keep in mind a more complete set of necessary and sufficient conditions for seismic station quality, we provide a useful mnemonic device: the "Five M's of Seismic Station Quality":
Machines, Methods, Metadata, Monitoring, and Maintenance.

We propose that there are five critical elements necessary for seismic stations to have sufficient, known, consistent accuracy and precision: the "five M's": "Machines" refers to the instruments themselves, "Methods" to how the instruments are deployed and installed, "Metadata" to the critical importance of documenting the nature of the data so it can be properly interpreted, "Monitoring" to the need to regularly inspect the goodness of the station, and "Maintenance" to the need to keep the station in proper running order.

In this presentation we introduce and define all five of the "M's", and elaborate the first three in more depth. We discuss in detail what "Machine" quality entails - the key measures of instrument accuracy, precision, and consistency/interoperability, and how quality is achieved, calibrated, certified and documented. We elaborate the nature of proper "Methods" (installation and operation) and the various types of station quality impairments that can be introduced by installation deficiencies. Finally, we touch on the importance of, and methods for, creating and managing station metadata, including how specific metadata creation functions within some seismic instruments can help facilitate the assembly of correct and complete metadata.

The Five M's Definitions

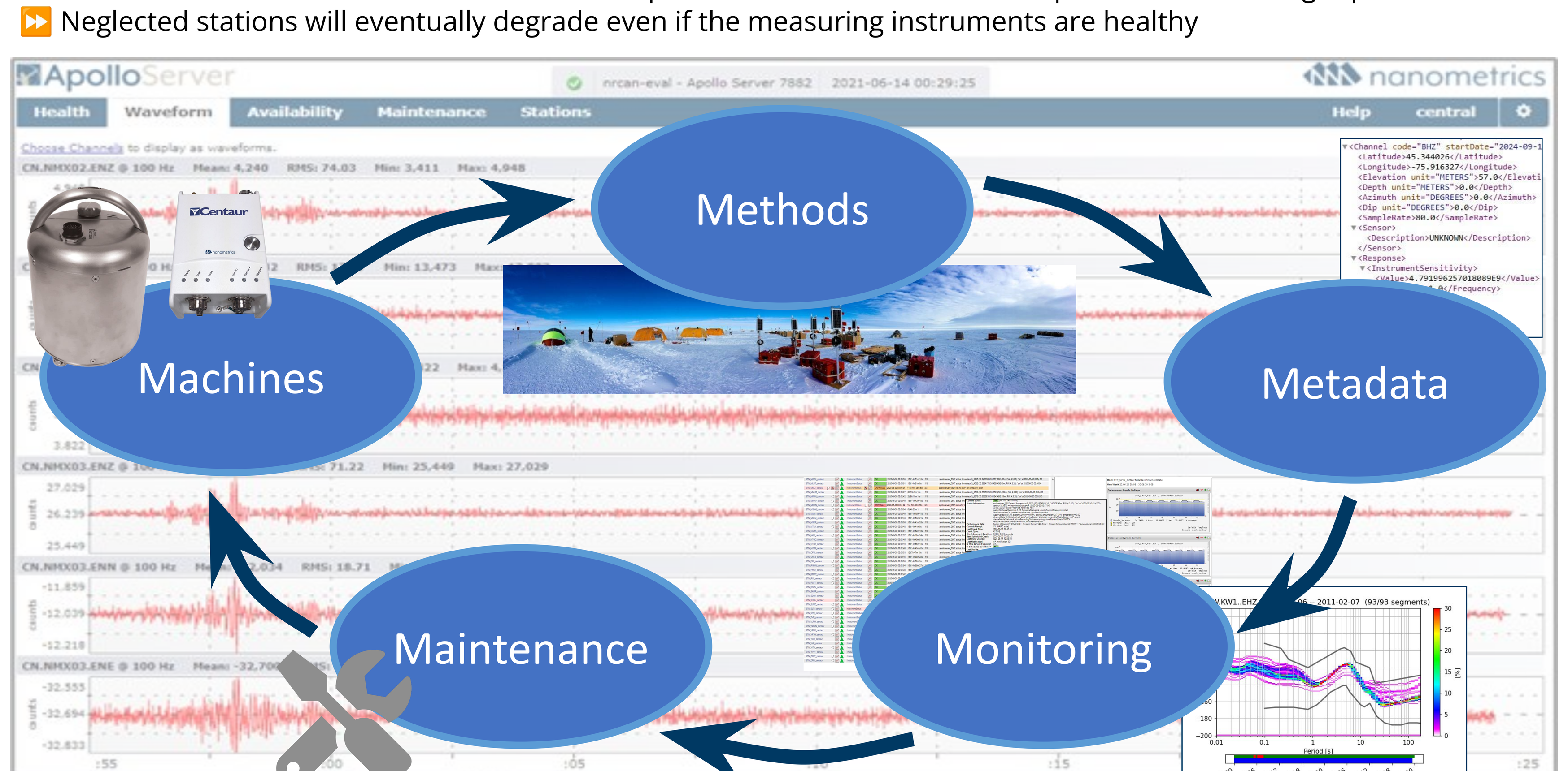
Machines - Sensing instruments (seismometers, digitizers, etc) and associated infrastructure (power, telemetry, etc)
⏩ The measuring and support equipment must meet the needs of the use case

Methods - How the instruments and the entire station is installed and deployed
⏩ The best equipment poorly installed can produce inaccurate, misleading or incomplete data

Metadata - Information that gives data meaning (sensitivity, transfer function, sample rates, location, etc)
⏩ The best raw data are just numbers without knowing what they represent

Monitoring - Supervision of station state-of-health, supervision of the station data
⏩ Watching for problems, or conditions that lead to problems: minimize downtime, maximize data quality

Maintenance - Scheduled remote and onsite preventative maintenance, and plans for conducting repairs
⏩ Neglected stations will eventually degrade even if the measuring instruments are healthy

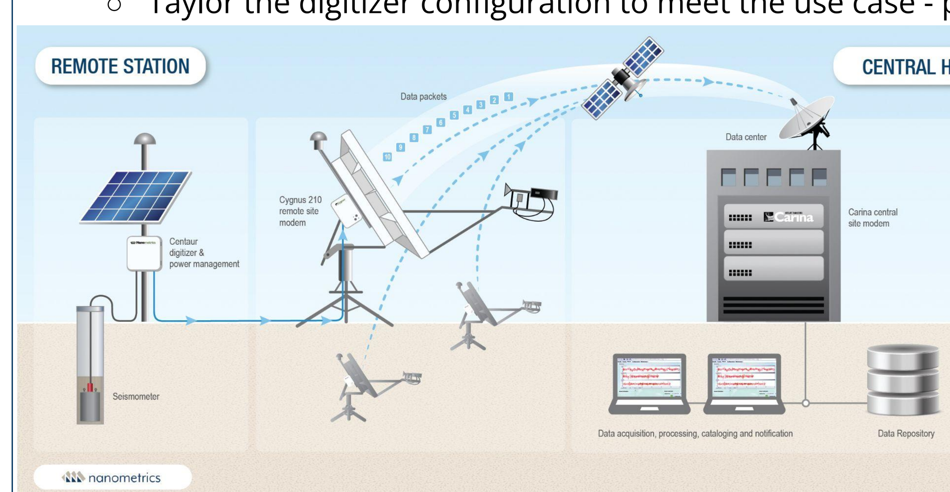


MACHINES - the instrumentation

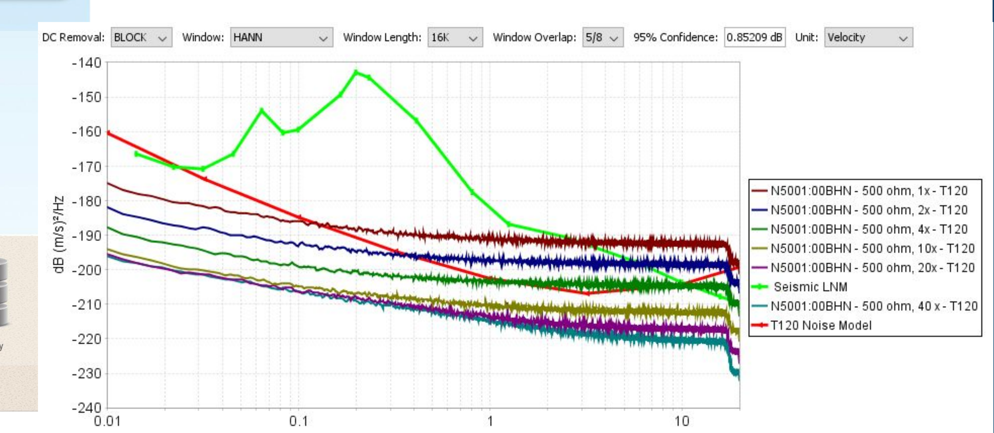
Seismometer performance - necessary but NOT sufficient

Primary objective: Station is Fit-for-Purpose

- **Equipment is able to meet the performance and operational objectives of the station**
  - Consider the use case (clip level, noise floor, bandwidth, etc) and match station specifications accordingly
- **Accuracy and Precision are important, but so are:**
  - power consumption, power system, monitoring capabilities, usability, serviceability, security (physical and electronic), telemetry, reliability, lifespan, environmental conditions, and more
  - Consider all components of the data gathering chain, from site selection to archiving the data and metadata
- **Digitizer and seismometer performance are both important**
  - Accuracy, precision, clip level, noise floor of each combine to constrain the station performance
  - Digitizer self-noise far more important than number of bits. Number of bits can be very misleading.
  - Taylor the digitizer configuration to meet the use case - preamp/gain, sample rate, bit depth, timing, etc



Station quality: the entire end-to-end system is critical, from the site and sensors, to the data archive



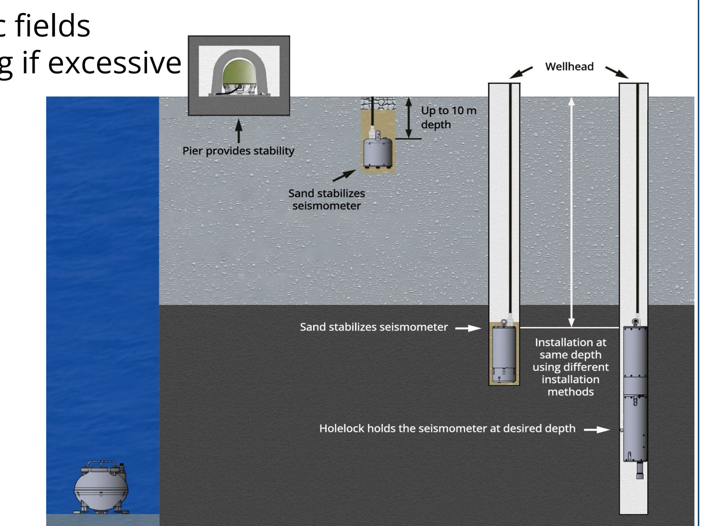
Seismometer and Digitizer self-noise relative to NLNM

METHODS - the installation

Good instrumentation + poor installation = poor performance

Primary objective: Install and deploy to maximize station performance

- **Installation impairments can degrade performance - and getting it right can be tricky.**
- **Good station instruments + poor installation = poor performance**
- **Site selection and commissioning considerations:**
  - Site conditions and geology: assess and select.
  - Prefer rock, avoid soft sediment, away from sources of cultural/natural noise.
  - Access - permitting, seasonal considerations, expected site visit intervals
  - Security (theft, vandalism, animal damage)
  - Solar power and expected weather: e.g. hours of sunlight, rain/snow
- **Seismometer installation - potential impairments to mitigate**
  - Achieve solid stable ground-to-seismometer coupling - the sensor moves exactly as the ground moves
  - Prevent shifting, slumping, tilting - extremely small motions differing from ground motion create noise
  - Extreme environmental interference - acoustic noise, strong electromagnetic fields
  - Long-term tilt - requires repeated mass centering or seismometer re-levelling if excessive
  - Dynamic tilting - shows up as horizontal noise
  - Temperature changes, air drafts (breezes, convection), air pressure changes
- **Seismometer installation method considerations**
  - Installation type: borehole (cased/uncased), posthole, shallow bury, vault
  - Stabilizing technique: pier, clamped borehole, freestanding, sand, grout

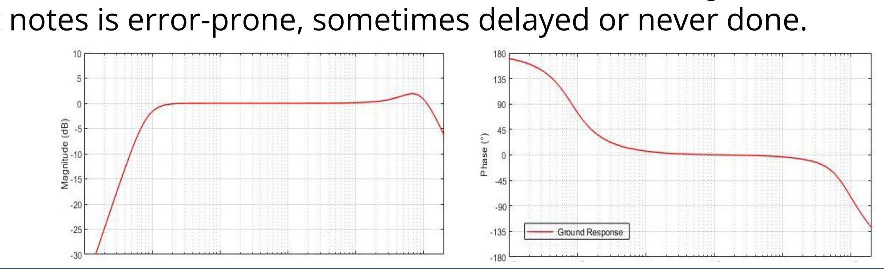


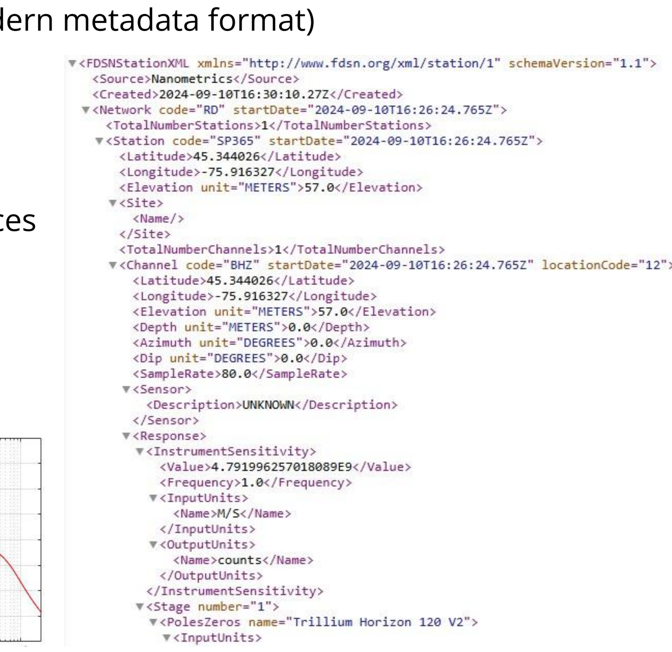
METADATA - the data about the data

Raw data are just numbers - metadata gives it meaning

Primary objective: Ensure the data are meaningful so that they can be interpreted

- **Metadata is necessary to make sense of the raw waveform numbers**
  - Sensitivity and transfer function of the seismometer (e.g. ground velocity input to voltage output)
  - Sensitivity and transfer function of the digitizer (e.g. volts input to sampled numerical output)
  - Sample rate of the digital data, start and stop times of the data
- **Metadata provides important descriptive information about waveform data, such as:**
  - Station location (elev, lat, long), station name, channel codes, sensor type and serial number
  - ...and more
- **Metadata standards:**
  - Metadata can be as simple as documenting the above information in written logbooks.
  - Digital schema have been developed to standardize metadata documentation and facilitate its consumption by seismic data analysis software
    - dataless SEED - binary format of instrument response and station metadata
    - RESP - ASCII format representation of SEED instrument response (omits most station metadata)
    - StationXML - machine readable XML text format (the most modern metadata format)
- **Best practices - ensure metadata is <u>accurate</u> and <u>available concurrently</u> with the data**
  - Accuracy - instruments have known standardized responses represented by the metadata within known tolerances.
  - Accuracy and availability - best if the digitizer automatically produces StationXML metadata, and "knows" the responses of the connected seismic instruments..
    ➔Minimizes errors, is least work, creates timely metadata.
    ➔Manual metadata creation with offline tools transcribing logbook notes is error-prone, sometimes delayed or never done.



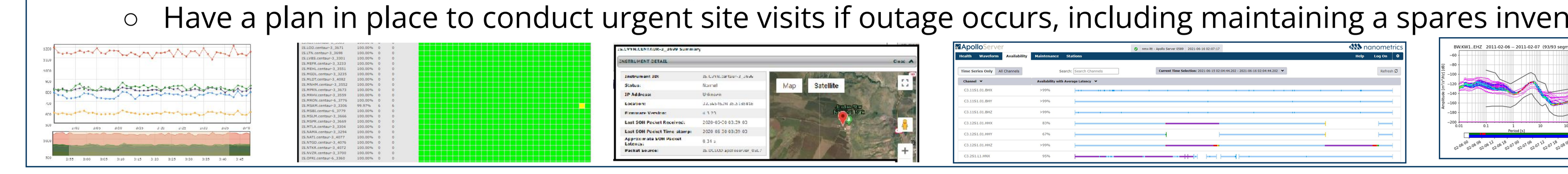


MONITORING and MAINTENANCE

Ounce of Prevention = Pound of Cure

Primary objective: Maintain station quality and availability

- **Monitor station state-of-health (SoH) to anticipate and address issues**
  - e.g. battery voltage cycling on solar power systems, seismometer mass position drift, PSD-PDF for noise floor
  - employ telemetry for SoH monitoring, even for autonomous (non-streaming) stations
- **Monitor environmental records**
  - Watch for extreme weather, fire, flood events that could degrade site
- **Maintain equipment and site to ensure station reliability and performance**
  - Periodic calibration tests to verify functionality and monitor for drift in instrument response
  - Site visits to inspect all infrastructure and equipment, repair/mitigate as needed
  - Replace equipment per expected life cycle (e..g batteries, short lifecycle electronics)
  - Have a plan in place to conduct urgent site visits if outage occurs, including maintaining a spares inventory



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