Multidisciplinary Stations: A Next Generation Tool Kit for Geoscience

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Abstract

As cross-disciplinary science becomes increasingly critical to understanding geophysical phenomena, a multidisciplinary approach is essential for integrating instrumentation and ensuring reliable and efficient data acquisition for successful scientific outcomes.

The scientific community requires adaptable solutions for the co-location of diverse sensor types. Deploying such instruments in remote, volatile environments while ensuring reliable, continuous data acquisition presents additional challenges. The complexity and cost associated with deploying, operating and maintaining remote stations are significantly increased if using multiple independent sensors, each with dedicated acquisition infrastructure. Recent efforts, such as the European Plate Observing System, aim to address this by integrating multidisciplinary geophysical applications into unified and efficient deployments.

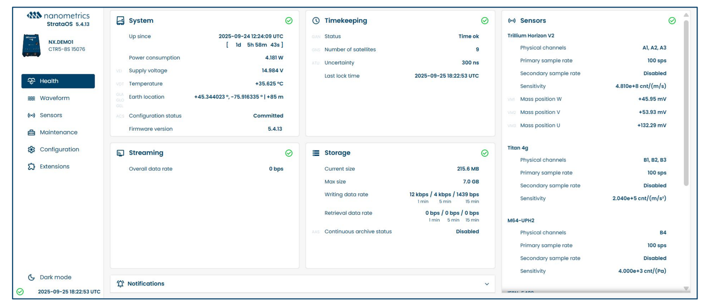
Modern seismic data loggers, such as the Nanometrics Centaur Gen5, support integration of a wide range of sensing elements, while maintaining ultra-low power consumption, precise timing, local data storage and reliable real-time data transmission. Enhanced capabilities regarding customization and edge computing allow the implementation of functionality tailored to meet specific monitoring objectives for unique station configurations.

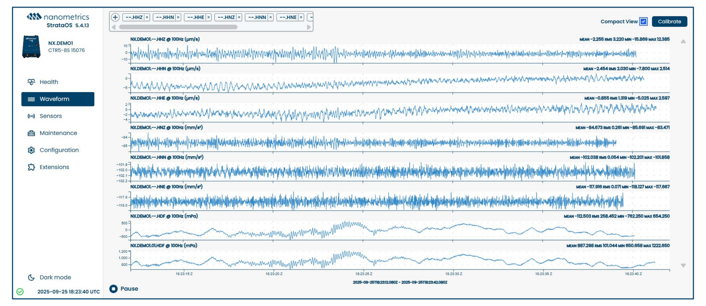
A case study is presented for a multidisciplinary geophysical monitoring station that leverages these capabilities to enable comprehensive, reliable and efficient data collection. The multidisciplinary station configuration and end-to-end data pipeline, from remote sensing to science doorstep in the data center, are discussed.

Enabling Data Logger Capabilities

Multidisciplinary science requires, by definition, the collection of scientific data from a diverse, often evolving set of monitoring instruments. Data logger adaptability, flexibility, capacity and performance are critical to ensure changing monitoring requirements can continue to be met.

The ***Centaur Gen5 8-Channel data logger*** has been designed to meet the challenges of multidisciplinary remote sensing networks. The Gen5 series incorporates both hardware updates and a major operating system update with the release of ***StrataOS***. This release incorporates a new user interface to streamline support for multidisciplinary use cases, enhance network security and significantly improve the Centaur's processing performance, enabling increases to existing capacity limits and the addition of new functionality, now and into the future.





Expanded and Enhanced Sensor Interfaces

8 High Resolution Channels
- Differential analog inputs with support for 32-bit resolution and maximum sample rate 10 ksps.

9 SOH Inputs
- Single-ended ±10V analog inputs on the External SOH and Sensor ports.

2 Dedicated Serial Ports
- RS-232 serial ports, on the Auxiliary connector, dedicated for direct integration of "Serial Sensors".

"Ethernet Sensors"
- Acquire data via TCP/IP streams from co-located Ethernet-enabled devices, such as GNSS receivers, for local storage and streaming.

Core Data Logger Features

There are key data logger features that are fundamental to all remote sensing applications, and remain critical for multidisciplinary applications.

Low Power Consumption
- Minimizing power consumption reduces station complexity, as well as the cost and risk of operation. The Gen5 8-Channel model maintains low power consumption at 1.7W for 8-channel streaming operations.

Accurate Timing
- The highly accurate timing applied by Centaur to all data acquired from the various sensor inputs ensures consistent timing throughout, which is critical for temporal correlation across datasets.

Environmental Robustness, Reliable Operation and Ease of Use
- Centaur Gen5 has a rugged IP68 enclosure and extended operating temperature range (-45°C to +70°C). Centaur has a long history of reliable operation and Gen5 offers a rich, intuitive user interface with streamlined support for multidisciplinary applications.

Network Security
- Modern data loggers must have modern protections. Centaur Gen5 delivers robust cyber security measures, including "memory-safe" firmware, user authentication, HTTPS, OpenVPN and more.

StrataOS Extensions

StrataOS, the new Gen5 operating system, has allowed the introduction of an Extensions Framework on Centaur. **Extensions** are modules, executed by *StrataOS*, to implement custom capabilities on the Centaur. Extensions are developed independently of the core firmware, providing greater flexibility to implement and exercise new functionality with minimal overhead.

The framework has been designed to initially support Extensions that integrate digital sensors, via serial RS-232 or Ethernet. As it evolves, additional useful capabilities envisioned for Extensions include the following:
- generation of derived time series channels / data products (ex. sensor tilt from mass positions),
- custom trigger / event processing, workflow automation (ex. station commissioning, built in self-test),
- industrial control system integration,
- implementation of custom streaming protocols over serial / Ethernet modems,
- integration of multiple digital sensors on one serial port via an RS-232 to RS-485/SDI-12 adapter

Extensions provide the flexibility and agility needed to support the unique use cases and requirements associated with multidisciplinary monitoring.

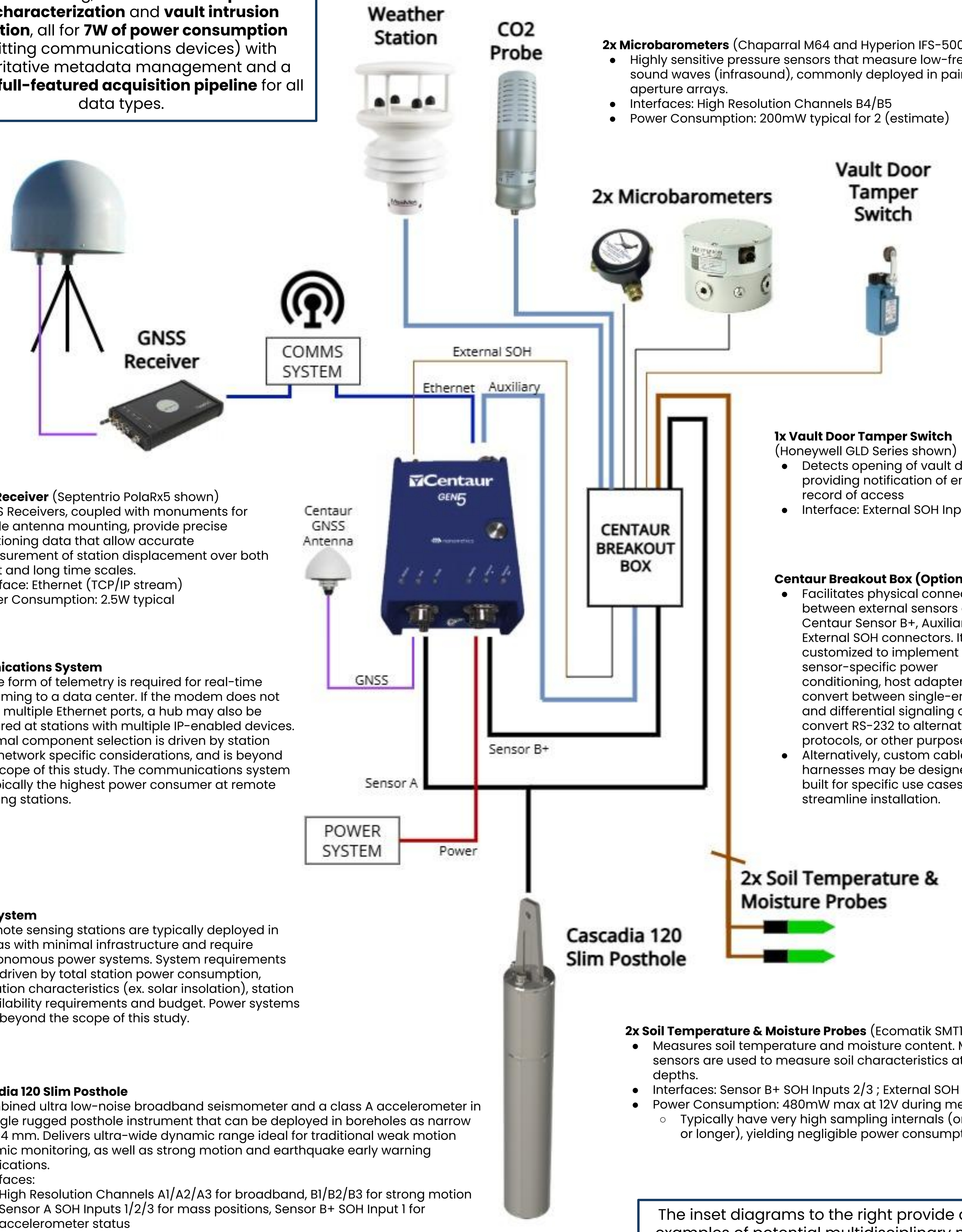
Next Gen Multidisciplinary Monitoring

This station provides an example of the range of multidisciplinary science that can be supported by the **8-Channel Centaur Gen5** with the new **Extensions Framework**. Nine different sensors provide comprehensive **broadband**, **strong motion**, **infrasound**, **meteorological** and **geodetic** monitoring, as well as **atmosphere and soil characterization** and **vault intrusion detection**, all for **7W of power consumption** (omitting communications devices) with authoritative metadata management and a **unified full-featured acquisition pipeline** for all data types.

1x Weather Station (Gill GMX500 shown)
- Measures wind speed, wind direction, ambient temperature, humidity, rain and other weather parameters.
- Interface: Auxiliary Serial Port 1
- Power Consumption: 312mW average

1x CO2 Probe (Vaisala GMP343 shown)
- Measures CO2 concentration and other parameters
- Interface: Auxiliary Serial Port 2
- Power Consumption: "<1W"

2x Microbarometers (Chaparral M64 and Hyperion IFS-5000 shown)
- Highly sensitive pressure sensors that measure low-frequency sound waves (infrasound), commonly deployed in pairs or small aperture arrays.
- Interfaces: High Resolution Channels B4/B5
- Power Consumption: 200mW typical for 2 (estimate)



1x GNSS Receiver (Septentrio PolaRx5 shown)
- GNSS Receivers, coupled with monuments for stable antenna mounting, provide precise positioning data that allow accurate measurement of station displacement over both short and long time scales.
- Interface: Ethernet (TCP/IP stream)
- Power Consumption: 2.5W typical

Communications System
- Some form of telemetry is required for real-time streaming to a data center. If the modem does not have multiple Ethernet ports, a hub may also be required at stations with multiple IP-enabled devices. Optimal component selection is driven by station and network specific considerations, and is beyond the scope of this study. The communications system is typically the highest power consumer at remote sensing stations.

Power System
- Remote sensing stations are typically deployed in areas with minimal infrastructure and require autonomous power systems. System requirements are driven by total station power consumption, location characteristics (ex. solar insolation), station availability requirements and budget. Power systems are beyond the scope of this study.

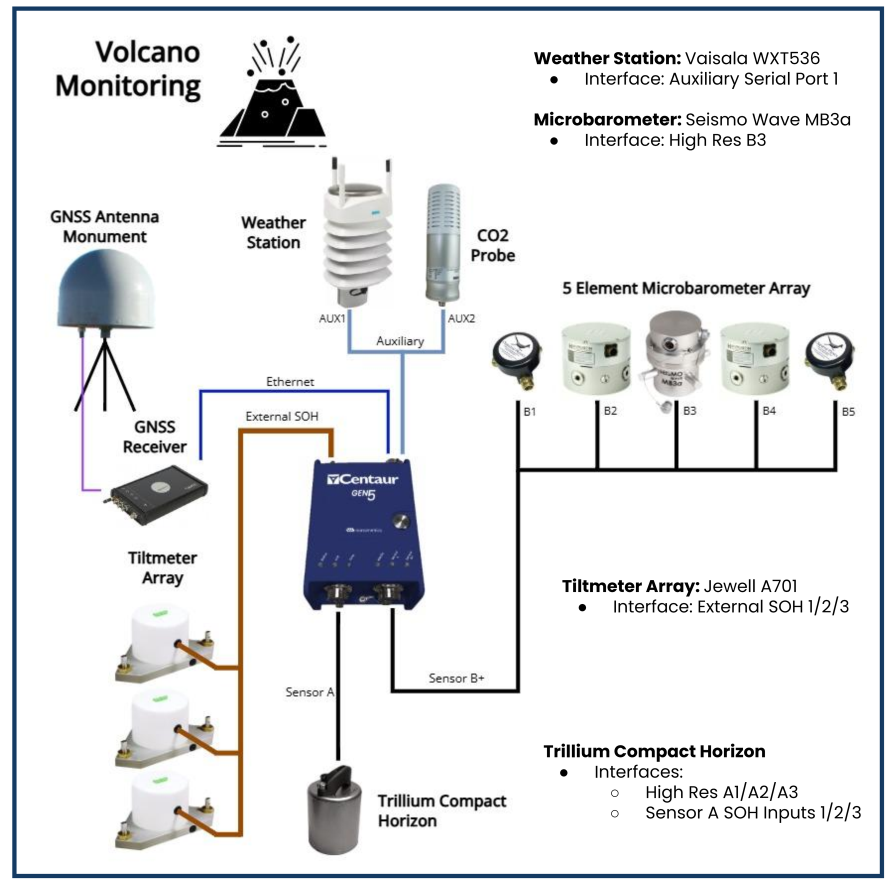
1x Cascadia 120 Slim Posthole
- Combined ultra low-noise broadband seismometer and a class A accelerometer in a single rugged posthole instrument that can be deployed in boreholes as narrow as 104 mm. Delivers ultra-wide dynamic range ideal for traditional weak motion seismic monitoring, as well as strong motion and earthquake early warning applications.
- Interfaces:
  - High Resolution Channels A1/A2/A3 for broadband, B1/B2/B3 for strong motion
  - Sensor A SOH Inputs 1/2/3 for mass positions, Sensor B+ SOH Input 1 for accelerometer status
- Power Consumption: 1.33W typical

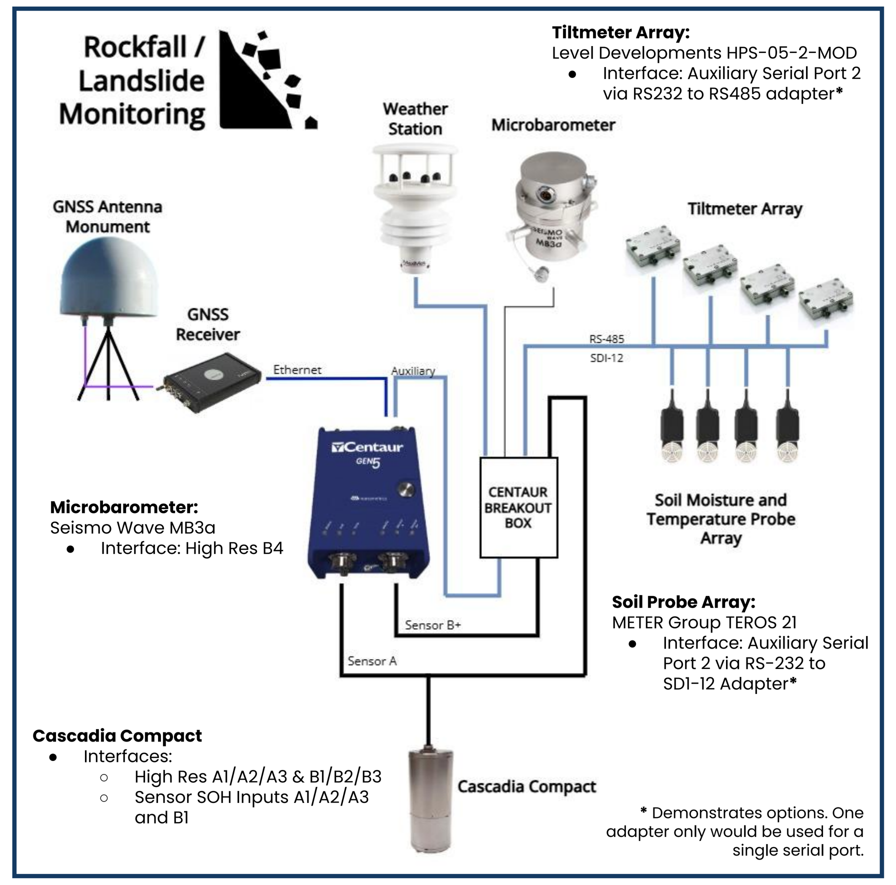
1x Vault Door Tamper Switch (Honeywell GLD Series shown)
- Detects opening of vault doors, providing notification of entry and a record of access
- Interface: External SOH Input 3

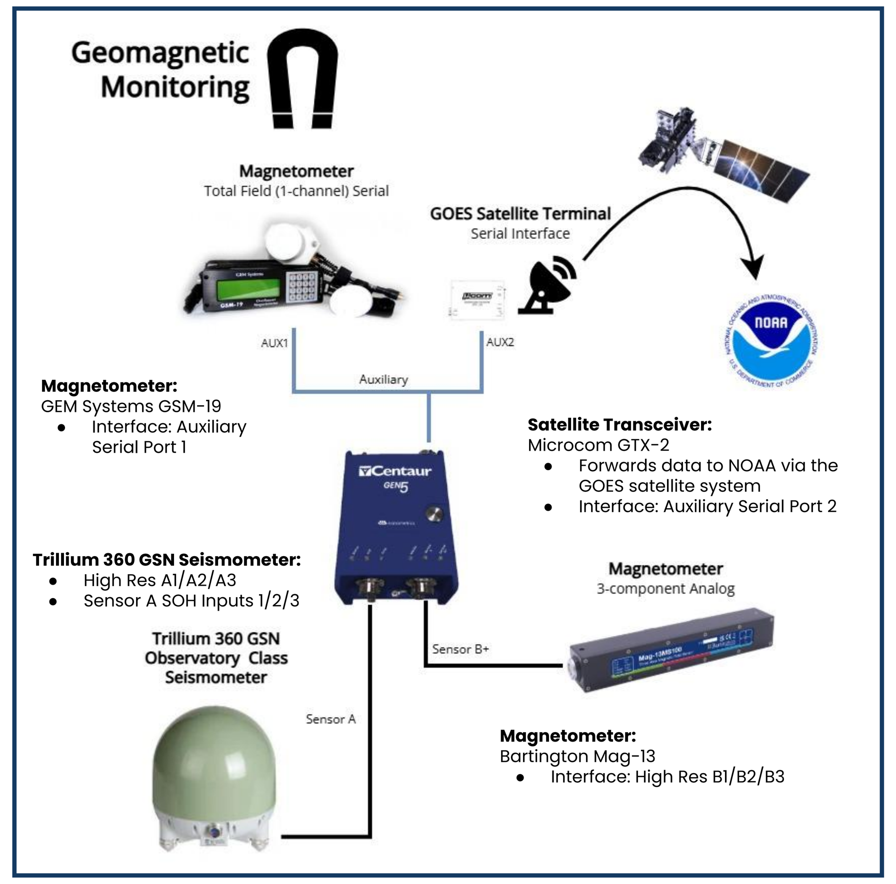
Centaur Breakout Box (Optional)
- Facilitates physical connectivity between external sensors and the Centaur Sensor B+, Auxiliary and External SOH connectors. It may customized to implement sensor-specific power conditioning, host adapters to convert between single-ended and differential signaling or convert RS-232 to alternate protocols, or other purposes.
- Alternatively, custom cable harnesses may be designed and built for specific use cases to streamline installation.

2x Soil Temperature & Moisture Probes (Ecomatik SMT100 shown)
- Measures soil temperature and moisture content. Multiple sensors are used to measure soil characteristics at different depths.
- Interfaces: Sensor B+ SOH Inputs 2/3 ; External SOH Inputs 1/2
- Power Consumption: 480mW max at 12V during measurement
  - Typically have very high sampling internals (once per hour or longer), yielding negligible power consumption

The inset diagrams to the right provide additional examples of potential multidisciplinary monitoring stations, targeted for specific applications.
These are simplified representations to highlight potential integrations. Some details are omitted.







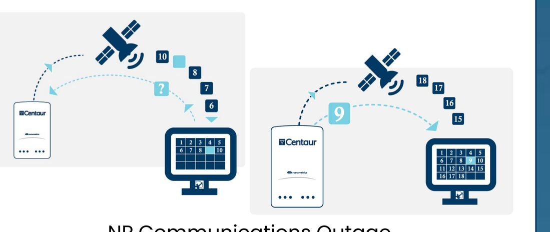
Unified Data Pipeline

For real-time remote sensing networks, the primary mission of a data logger is the acquisition of remotely generated raw data, so it can be used promptly to serve the mandate of the network. Acquisition includes early data path steps such as digitization, signal processing, timestamping and local recording, as well as real-time streaming to central data centers and associated capabilities, such as automated recovery of data missed due to communications outages.

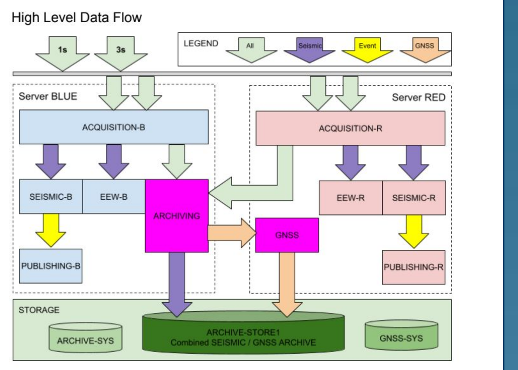
All data captured via any of the available sensor interfaces on Centaur, or produced by an Extension, is packetized, tagged and recorded locally, normalizing the handling of these separate and distinct data types.

Centaur provides multiple options for real time data transfer, including industry standard protocols SeedLink, CD1.1 (authenticating models) and QSCD20. In general, the recommended solution for most applications is the NP protocol, streaming to an Apollo Server acquisition system, due to its superior robustness, efficiency and flexibility. Apollo Server manages data acquisition from the remote network, ensuring maximum data availability, and provides low latency forwarding to downstream consumers via SeedLink. Apollo Server also provides centralized network management capabilities, including batch firmware distribution, to streamline maintenance of a fleet of Nanometrics data loggers. NP is a full featured protocol with several advantages.

Lightweight Communication Protocol: Uses UDP/IP packets, ideal for links that are bandwidth-constrained, have intermittent outages or are TDMA-based.
Automatic Outage Recovery: Robust, persistent capability to automatically recover data missed due to communications outages.
Real-time Prioritization: Real-time data is prioritized ahead of recovering outages.
Multicast Streaming: Supported protocol to route packets to multiple destinations, enabling use of redundant acquisition servers without increasing bandwidth cost.
Bandwidth Throttling: Limit bandwidth utilization to ensure packets are not dropped at telemetry system bottlenecks.
Variable Packet Length: Supports smaller packet sizes to minimize packet latency, as preferred for EEW networks, or use of larger packets to minimize bandwidth overhead.
Short-term Complete: Data distribution feature to temporarily buffer a real-time stream after an outage to allow time for gap recovery, to maximize data completeness while ensuring downstream clients do not receive data out-of-order, if required.
Acquisition Performance Tracking: Comprehensive tracking of packet latency, bandwidth utilization, data completeness and other key acquisition metrics.
Redundant Streaming Path Support: Gracefully support receipt of duplicate packets to allow implementation of sophisticated streaming topologies for mission-critical networks, such as the TRUAA EEW system, providing both redundancy and synchronization.
Multidisciplinary Data Support: Transport, via Extensions, of arbitrary TCP payloads, including GNSS BINEX or RTCM3 data streams.



NP Communications Outage Retransmission Protocol



Sample Data Center Architecture with Redundant Processing Toolchains

Next Gen Benefits

Next Generation Multidisciplinary remote sensing stations based on the 8-Channel Centaur Gen5, powered by *StrataOS*, yield several benefits:
- Using a single data logger to acquire all data types reduces the number of instruments required, **simplifying the station design and reducing the associated footprint**.
- Using a single low power data logger platform reduces overall station power consumption, **simplifying power system requirements and reducing the associated cost, complexity and operational risk**.
- Using a single data logger platform **simplifies station maintenance procedures, inventory management and staff onboarding procedures**.
- Using a single, highly accurate timing source for all multidisciplinary data types **ensures timing consistency throughout datasets for temporal correlation analysis**.
- Using a single data logger platform with support for comprehensive metadata management provides an **authoritative source for accurate metadata**.
- Using a single data logger platform for real-time streaming, particularly with NP to Apollo Server, provides a **unified, high-performing acquisition system for all sensor types and channels**, simplifying network operation.

The 8-Channel Centaur Gen5 is a high-performing, highly adaptable data logger platform that can acquire data from many multidisciplinary sensors concurrently via multiple interfaces. ***StrataOS*** delivers a UI optimized for multidisciplinary use cases, modern network security and, with the new **Extensions** framework, the flexibility to implement new features and edge-computing capabilities for ever-evolving monitoring requirements, future-proofing the network to meet the challenges of today and tomorrow.

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