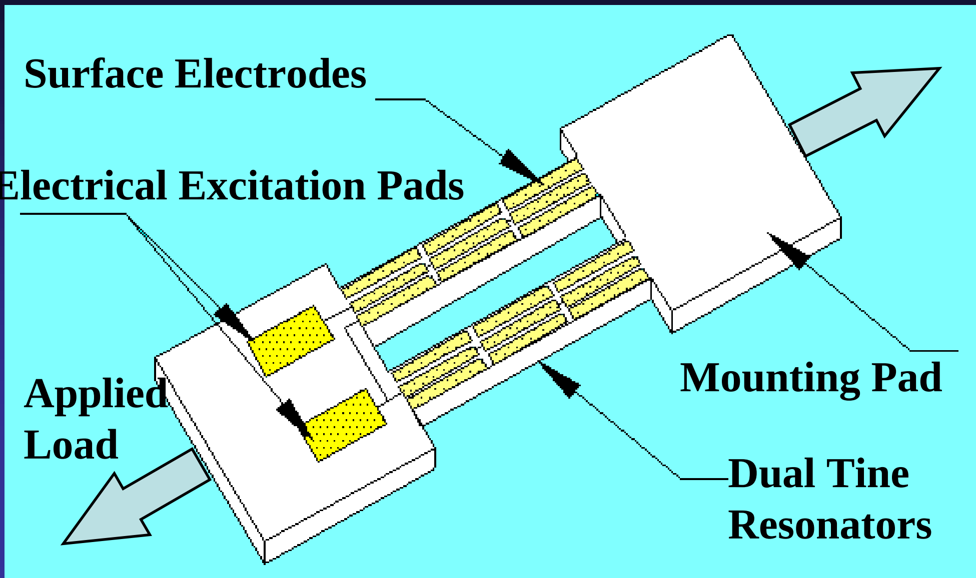
Quartz Sensors for Improved Disaster Warning Systems and Geodetic Measurements

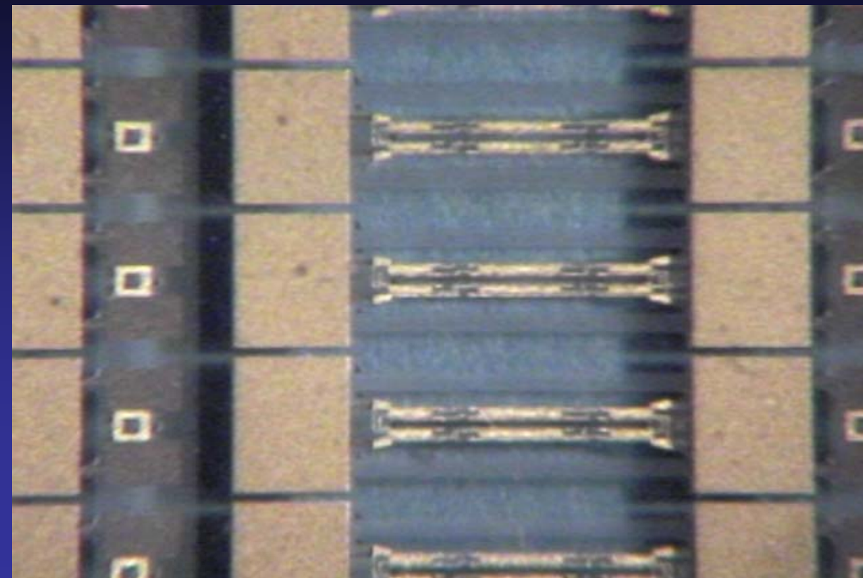
Paroscientific and Quartz Seismic Sensors

Quartz Crystal Resonators Convert Analog Forces to Digital Outputs with Parts per Billion Resolution

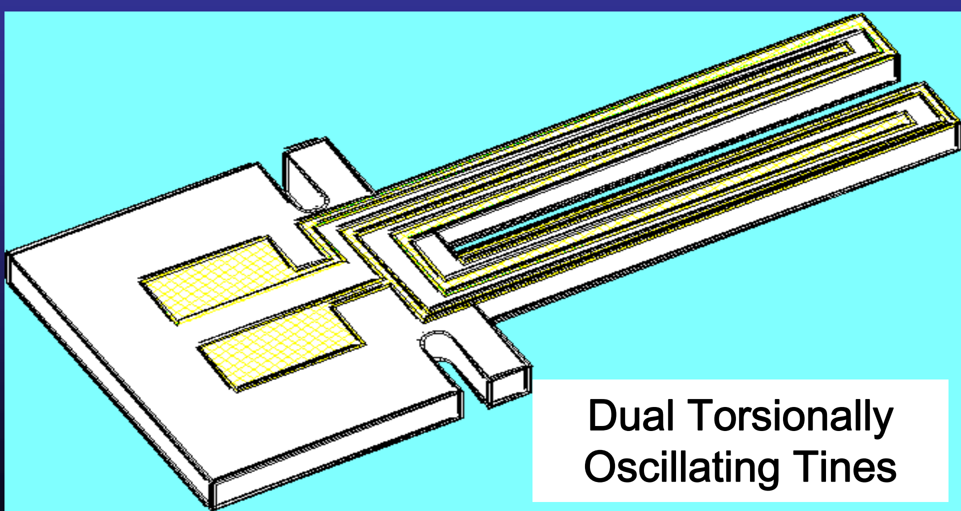
Digiquartz® Technology

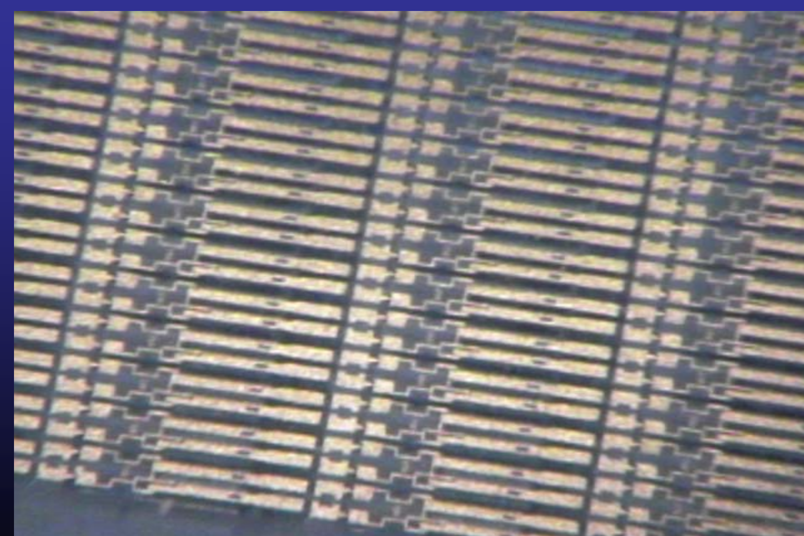
Double-Ended Tuning Fork Force Sensors



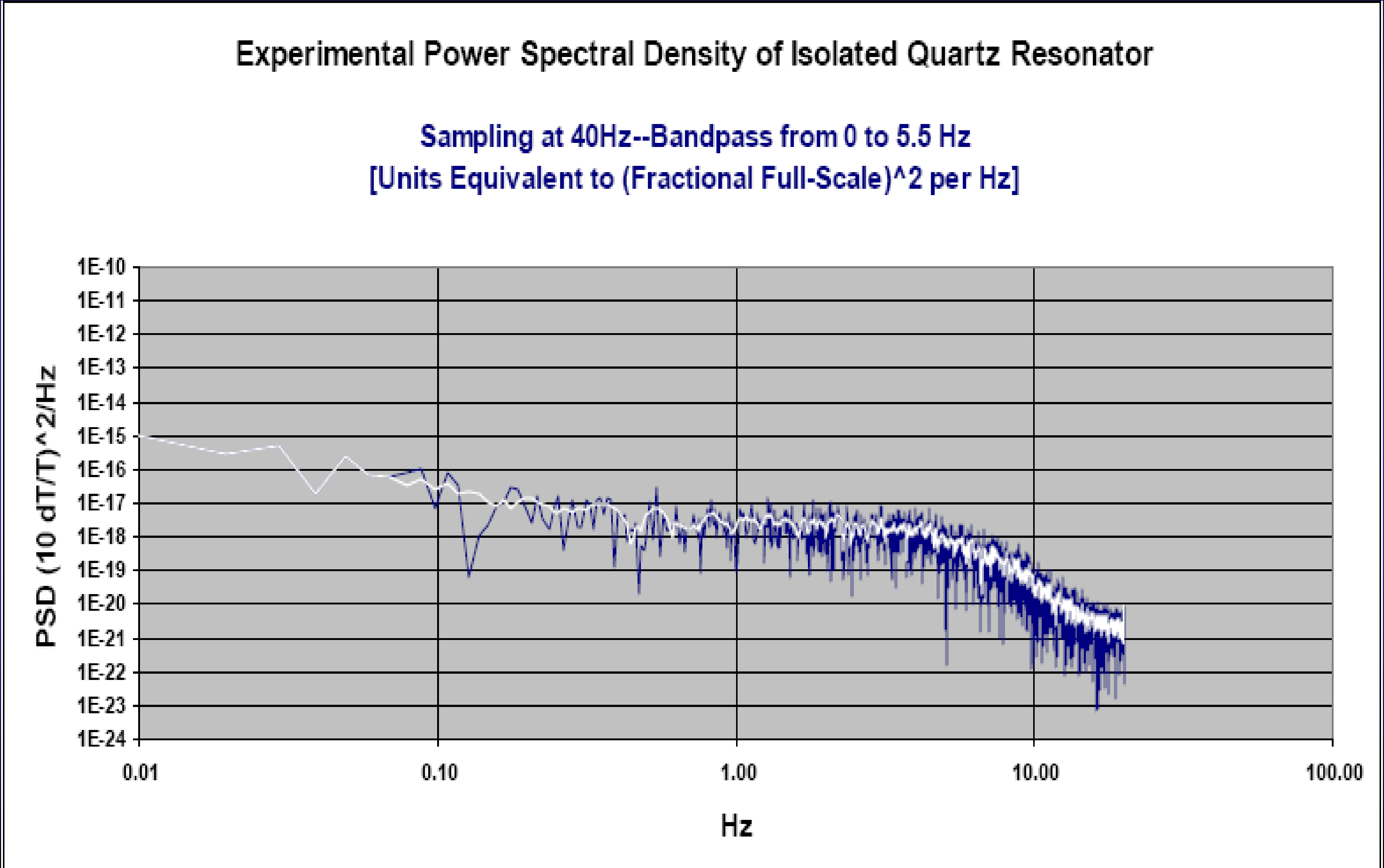


Torsional Resonator Temperature Sensors





Nano-Resolution Full-scale PSD Spectrum for Pressure Sensors, Accelerometers, & Tiltmeters



Goals

- **Improved disaster warning times for earthquakes, tsunamis, volcanic eruptions and extreme weather events**

- **Improved geodetic measurements for scientific research and predictions of natural disasters**

Solutions

“Geophysical measurements can now be made with unprecedented clarity from beneath the seafloor, to the ocean bottom, through the water column, and through the atmosphere in a single coherent array”

John Delaney

Quartz Sensors Solutions for Improved Disaster Warning Systems and Geodesy

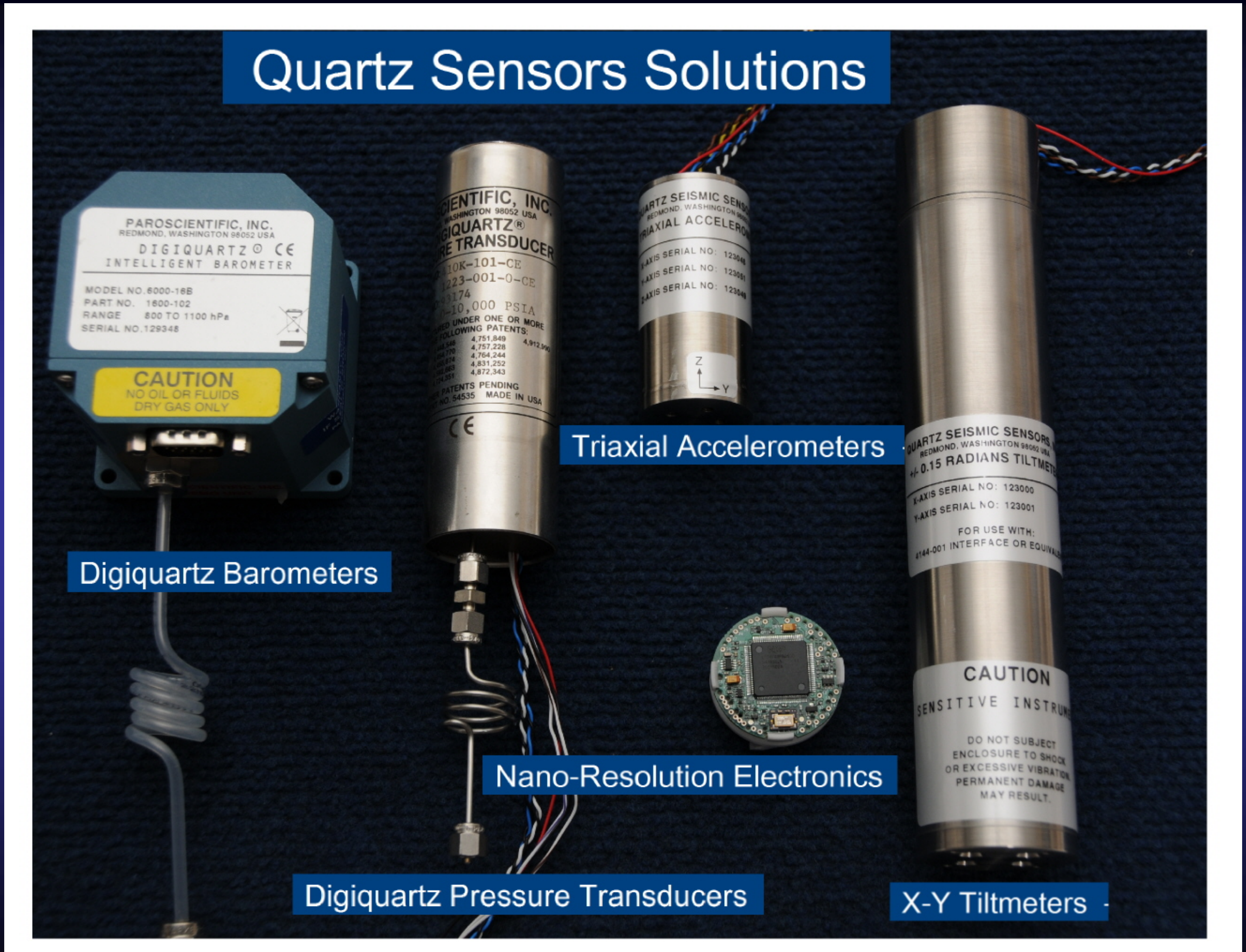
- Pressure Sensors
- Triaxial Accelerometers
- Tiltmeters
- Nano-Resolution Electronics
- In-situ Calibration Methods

→ Measurements on the Surface of Land and Through the Atmosphere

→ Measurements in Boreholes on Land

→ Measurements on the Sea-floor

→ Measurements in Boreholes Underneath the Sea-floor


Quartz Sensors Solutions
Digiquartz Barometers
Digiquartz Pressure Transducers
Triaxial Accelerometers
Nano-Resolution Electronics
X-Y Tiltmeters
PAROSCIENTIFIC, INC.
REDMOND, WASHINGTON 98052 USA
DIGIQUARTZ®
INTELLIGENT BAROMETER
MODEL NO.6000-16B
PART NO. 1600-102
RANGE 800 TO 1100 hPa
SERIAL NO.129348
CAUTION
NO OIL OR FLUIDS
DRY GAS ONLY
CAUTION
SENSITIVE INSTRU
DO NOT SUBJECT
ENCLOSURE TO SHOCK
OR EXCESSIVE VIBRATION
PERMANENT DAMAGE
MAY RESULT.

Examples of Nano-Resolution Measurements

- **Atmospheric**

  Measure absolute barometric pressure fluctuations to nano-bars for infrasound detection of tsunamis, extreme weather, & eruptions.

- **Oceanic**

  Measure water level fluctuations to microns with absolute deep-sea depth sensors for detection of tsunamis and seafloor movement.

- **Seismic**

  Measure acceleration to nano-g's with 3 g full-scale strong motion sensors and tilt to less than 1 nano-radian with +/- 9 degrees Quartz Tiltmeters.

Atmospheric Measurements

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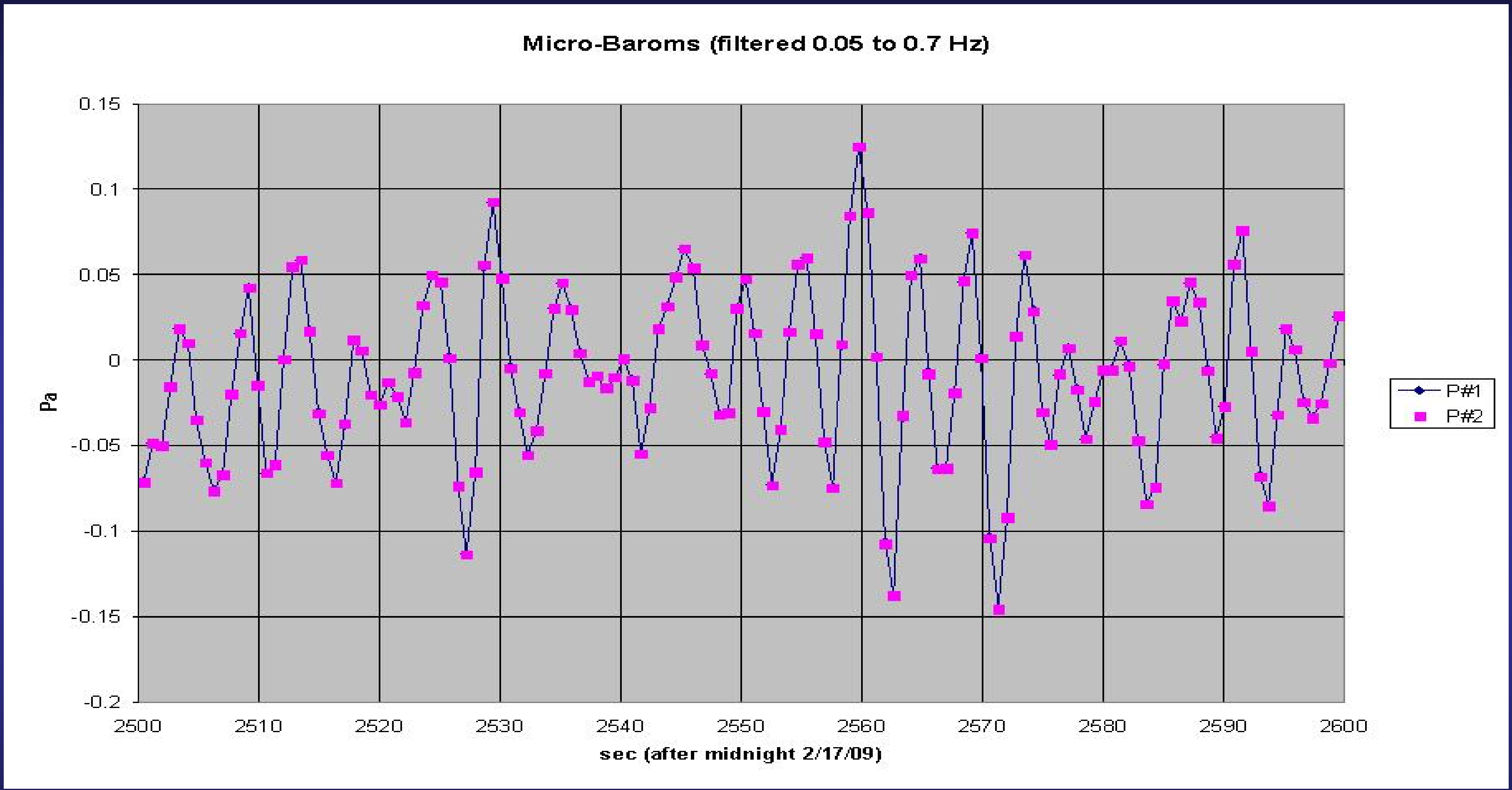
Technology

Pacific Ocean Microbaroms Using IIR Filter



Residual Noise Between Two Independent Barometers = 0.4 mPa

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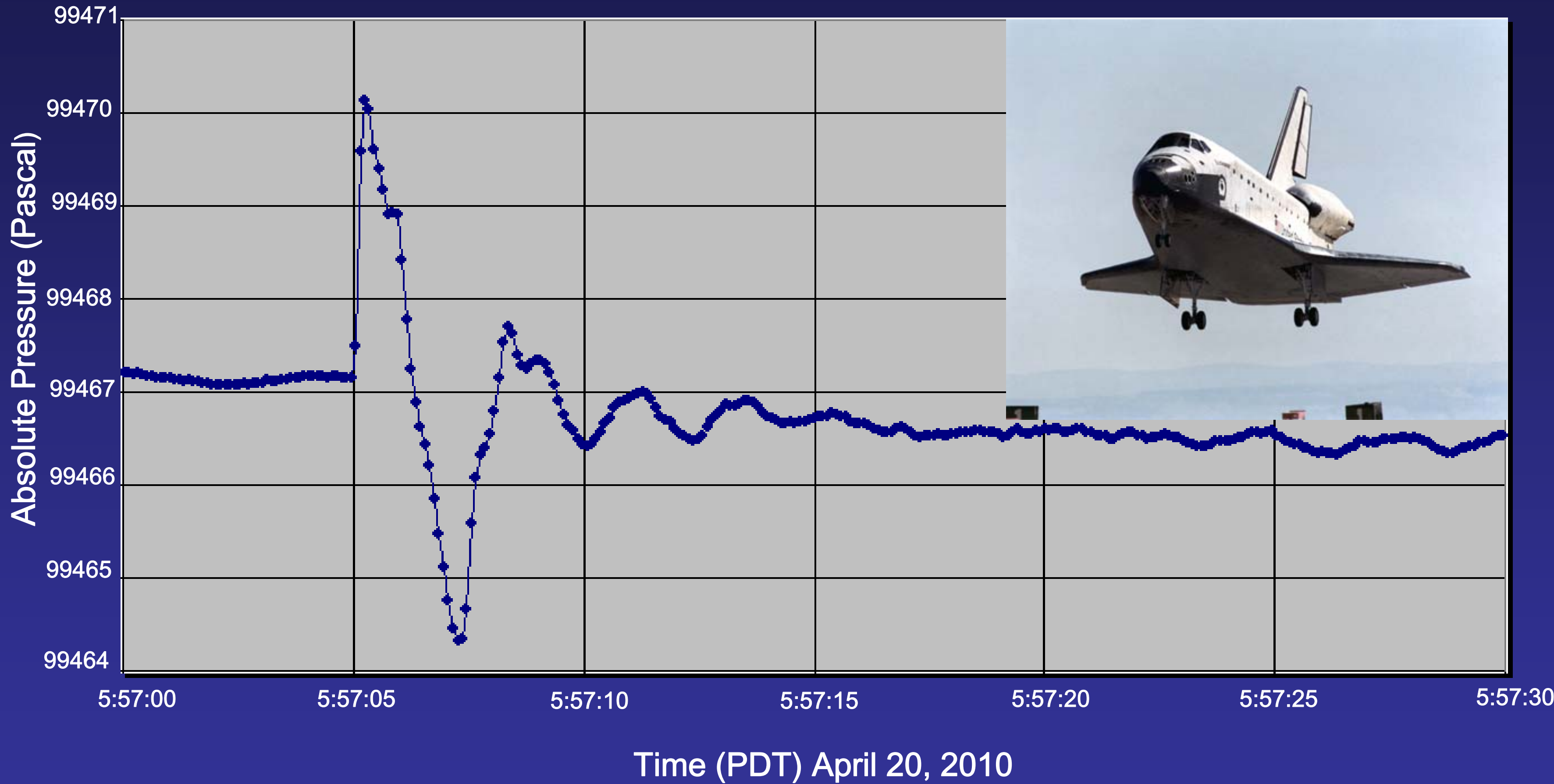
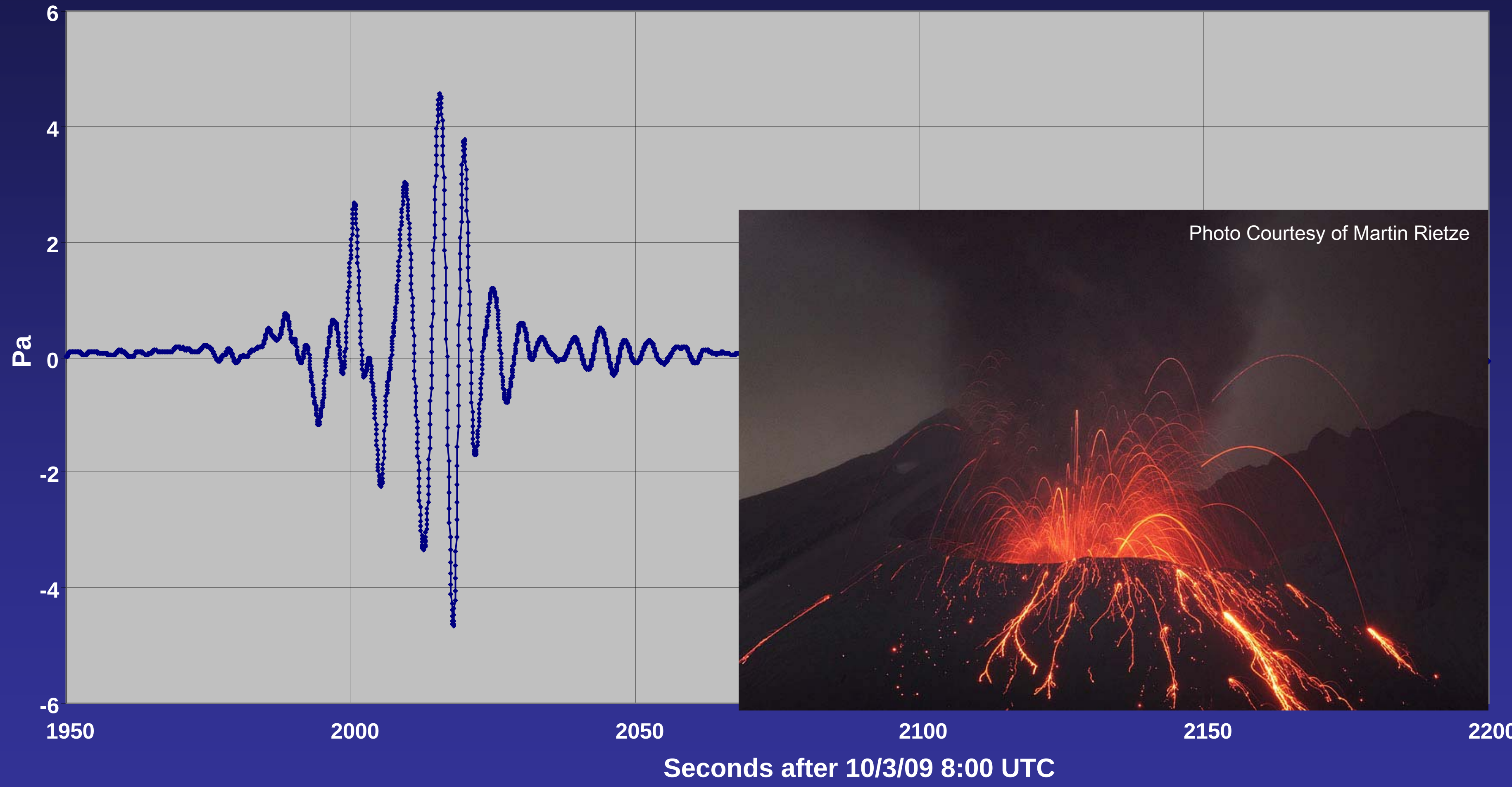
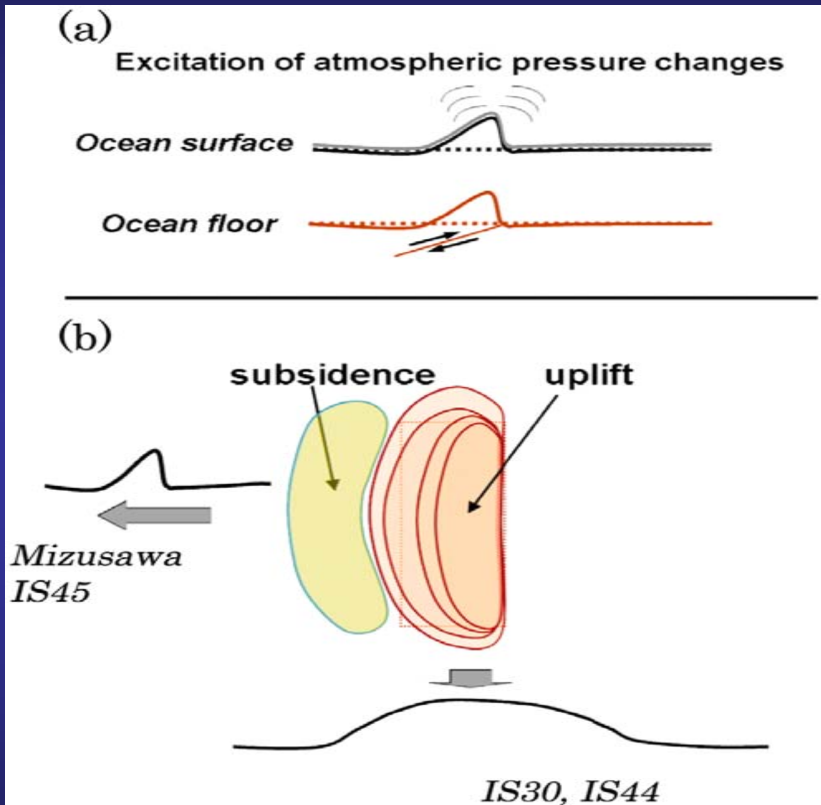
Space Shuttle Pressure Signature

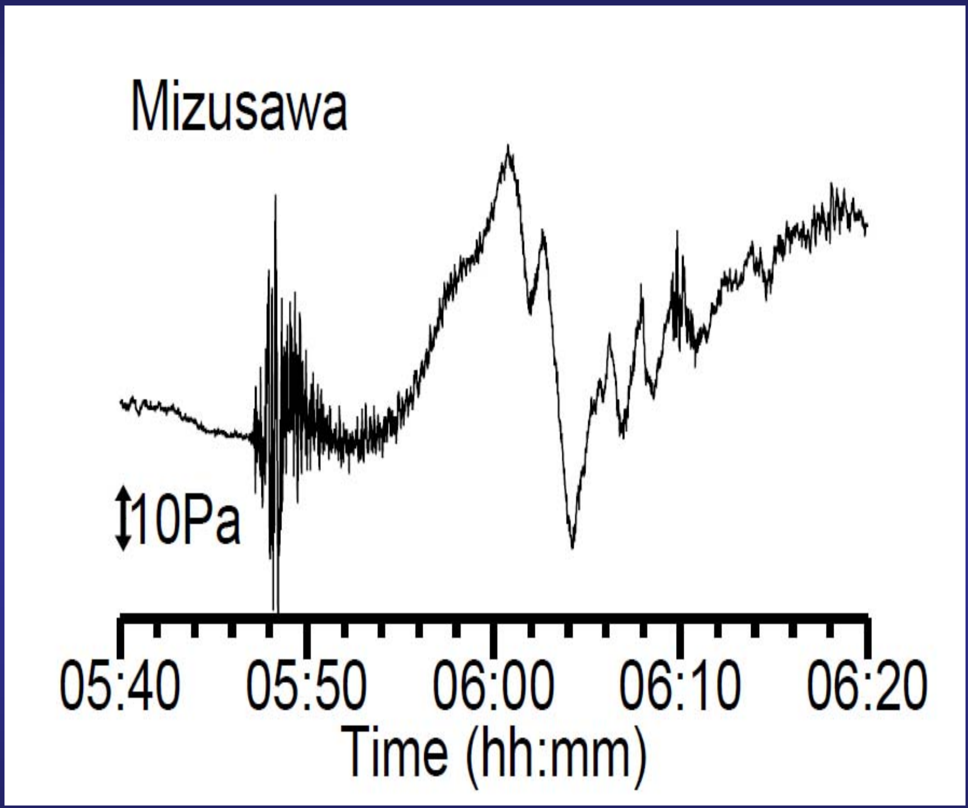


Sakurajima Eruption Measured 1000 km Away at Nuclear Test Monitoring Site



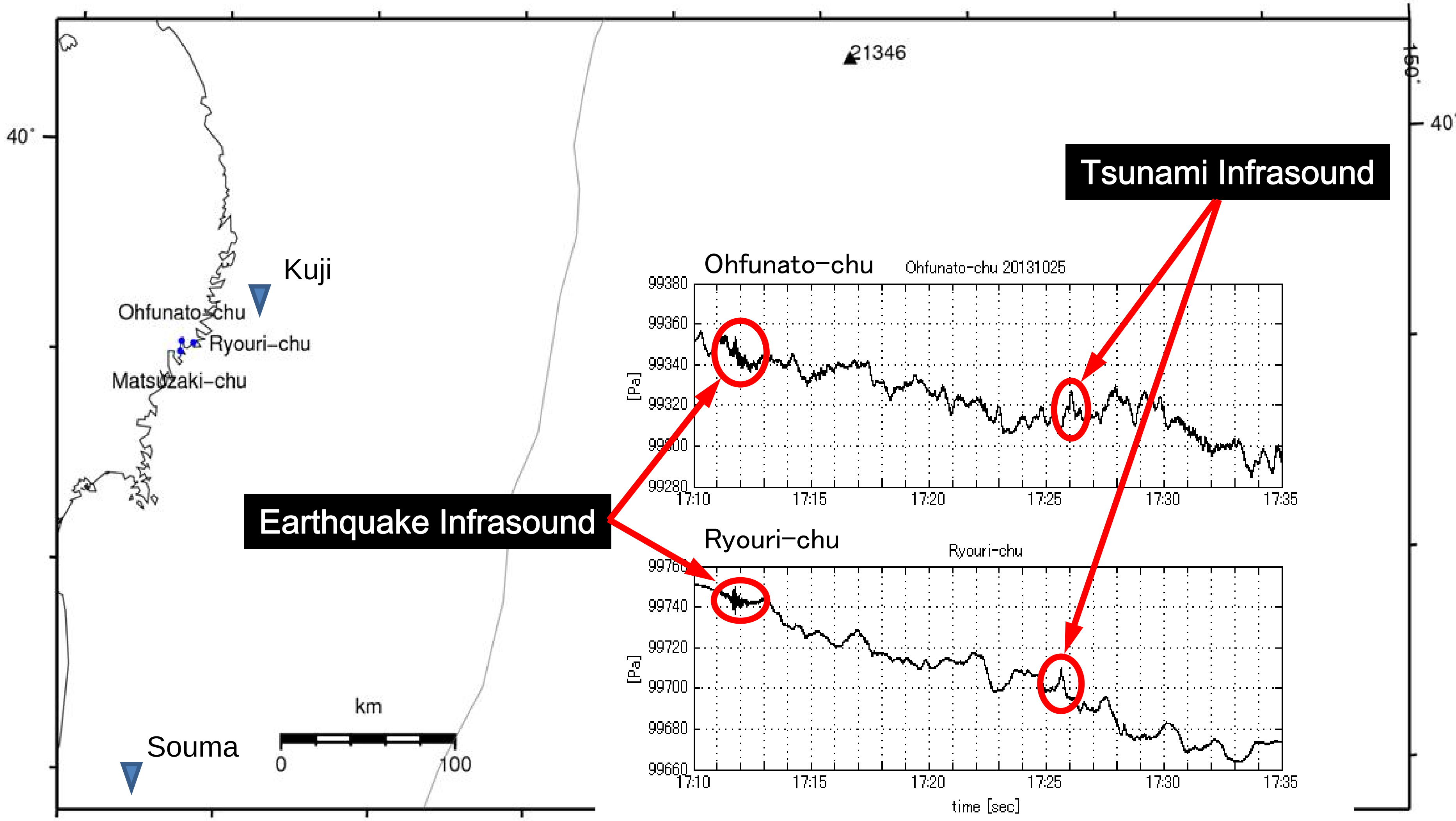
Infrasound Detection of Tsunamis





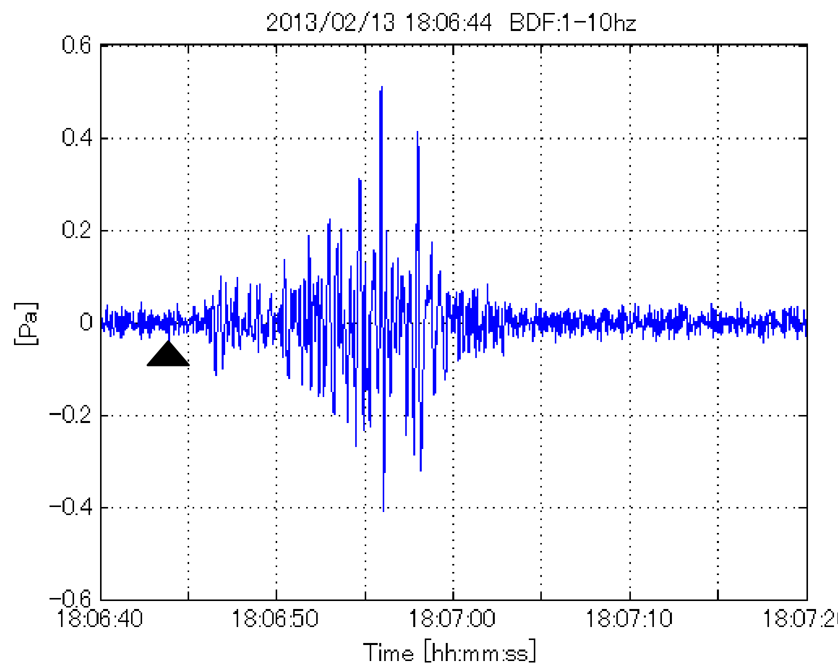
Plot courtesy of Dr. Nobuo Arai

Infrasound signals associated with the outer-rise earthquake of Oct. 25, 2013 were detected.

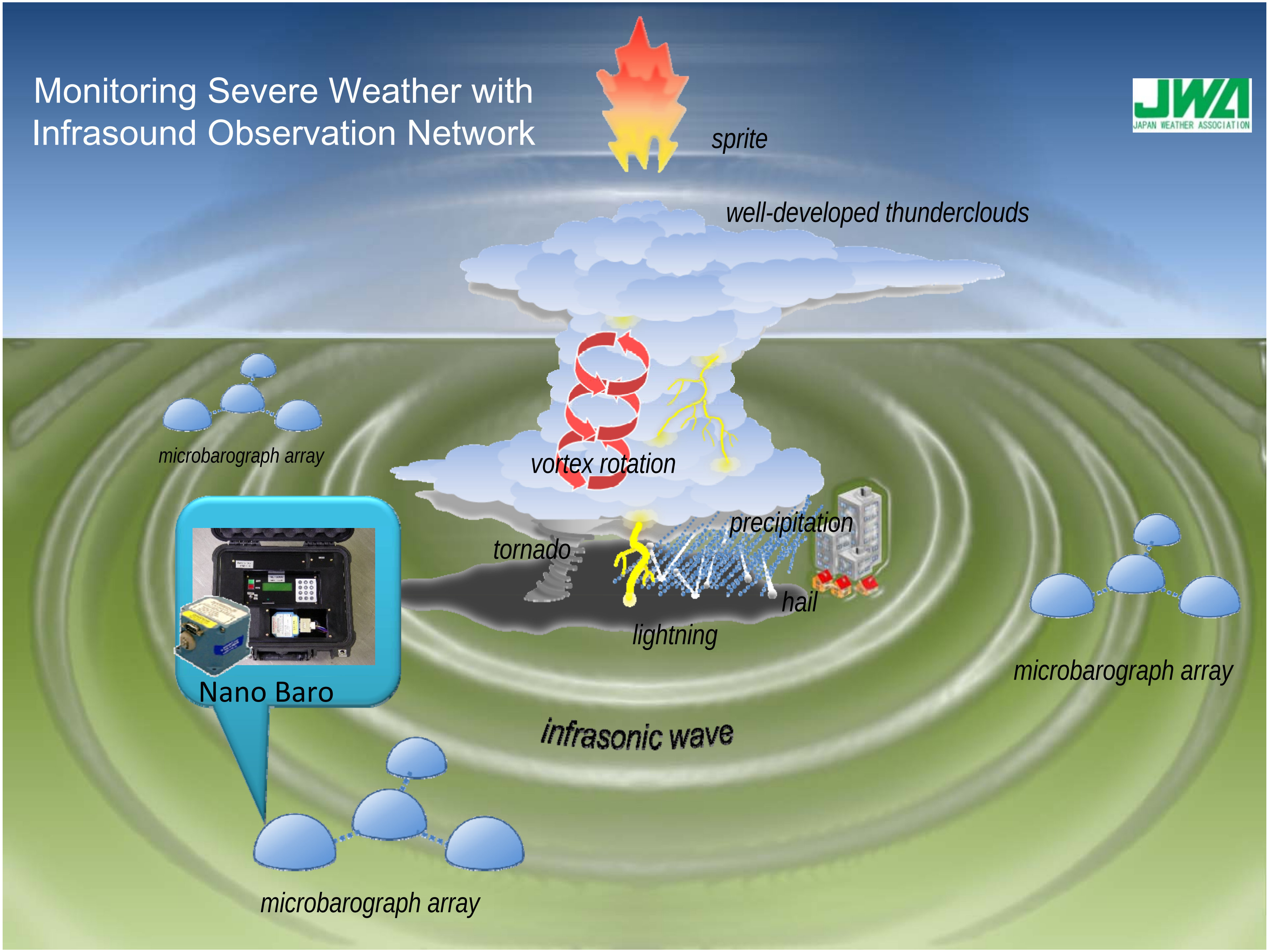


Outer-rise earthquake (*Mw=7.1*) 2013/10/25 17:10 (UTC) , 10/26 02:10 (JST)
Observed tsunamis : Kuji 18:23 (UTC) 40 cm & Souma 18:38 (UTC) 40 cm

System for Monitoring the Acoustic Signals of Snow Avalanches

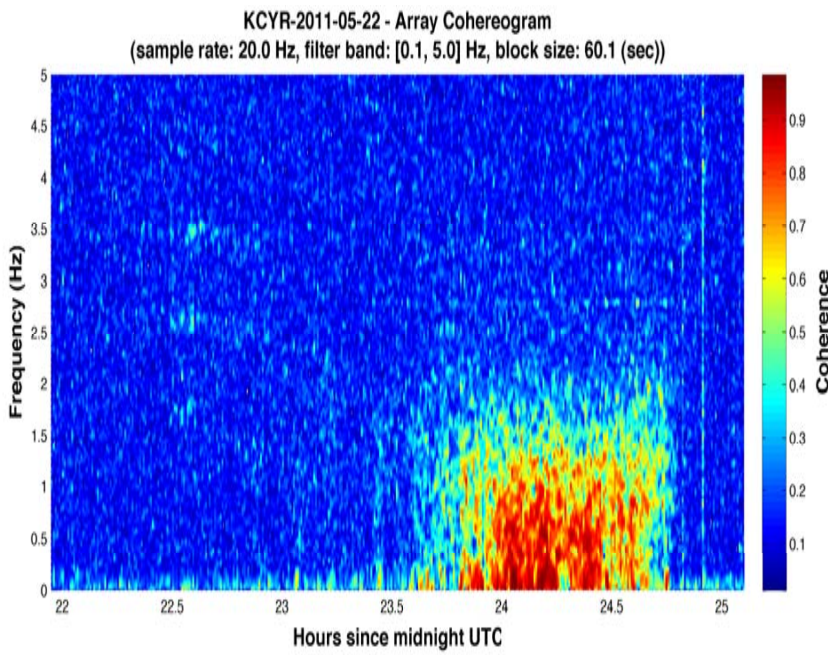


6000-16B (Paroscientific)

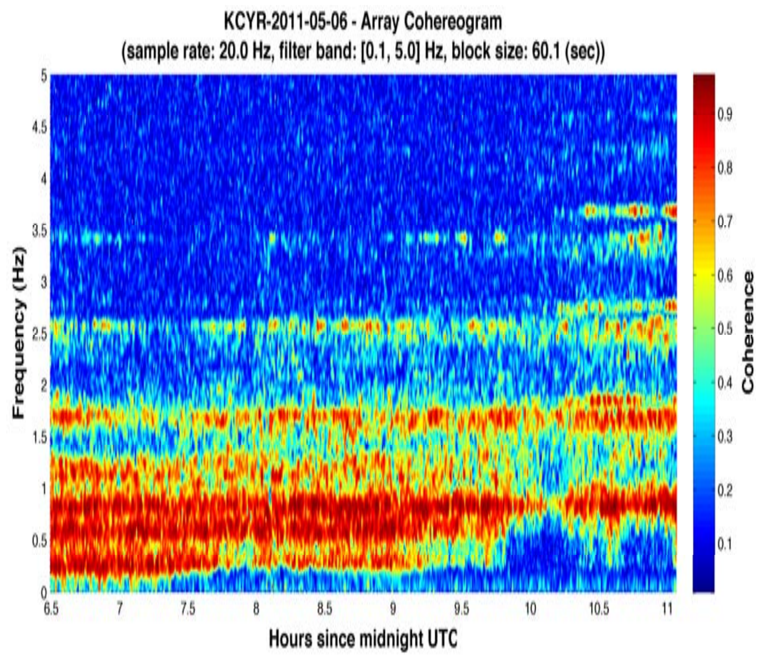

Monitoring Severe Weather with
Infrasound Observation Network
JAPAN WEATHER ASSOCIATION
sprite
well-developed thunderclouds
microbarograph array
vortex rotation
precipitation
tornado
hail
lightning
Nano Baro
microbarograph array
infrasonic wave
microbarograph array

Tornado detection with Nano Baro

- UMass - CASA radar network in Oklahoma
  - The main objectives of CASA's Oklahoma radar network was tornado early detection
  - It had been shown (e.g., Bedard) that tornadoes produce infrasound (~1Hz sound waves)
  - We deployed infrasound arrays at two of the Oklahoma radar sites
- Results (presented at AMS in New Orleans and the EGU in Vienna)
  - Verified the ability of the Paroscientific barometers to detect distant tornadoes
  - Verified the ability of the Paroscientific barometers to detect wind turbine infrasound emissions



Infrasound signature from a tornado



Infrasound signature from a windfarm

Courtesy of David Pepyne

GPS Meteorology

GPS Determination of Precipitable Water Vapor

- Measure Total Delay = Ionospheric + Neutral Delays
- Ionospheric Delay (frequency dependent) determined by comparing L1 & L2 GPS signals
- Neutral Delay=Wet Delay + Hydrostatic Delay (Barometric Pressure, Temperature, Humidity dependent)
- Calculate Precipitable Water Vapor from Wet Delay

GPS-MET and Nano Baro for Flood Forecasting

- Improved flood forecasting benefits from a radar network coupled with a hydrologic model
- A key variable for precipitation forecasting is atmospheric water content
- High spatial-temporal resolution estimates of atmospheric water content can be made with GPS-meteorology

Courtesy of David Pepyne

Drivers become stranded in high waters across North Texas

Street flooding North of DFW, Jan. 2012

Dallas Floodway

Oceanic Measurements

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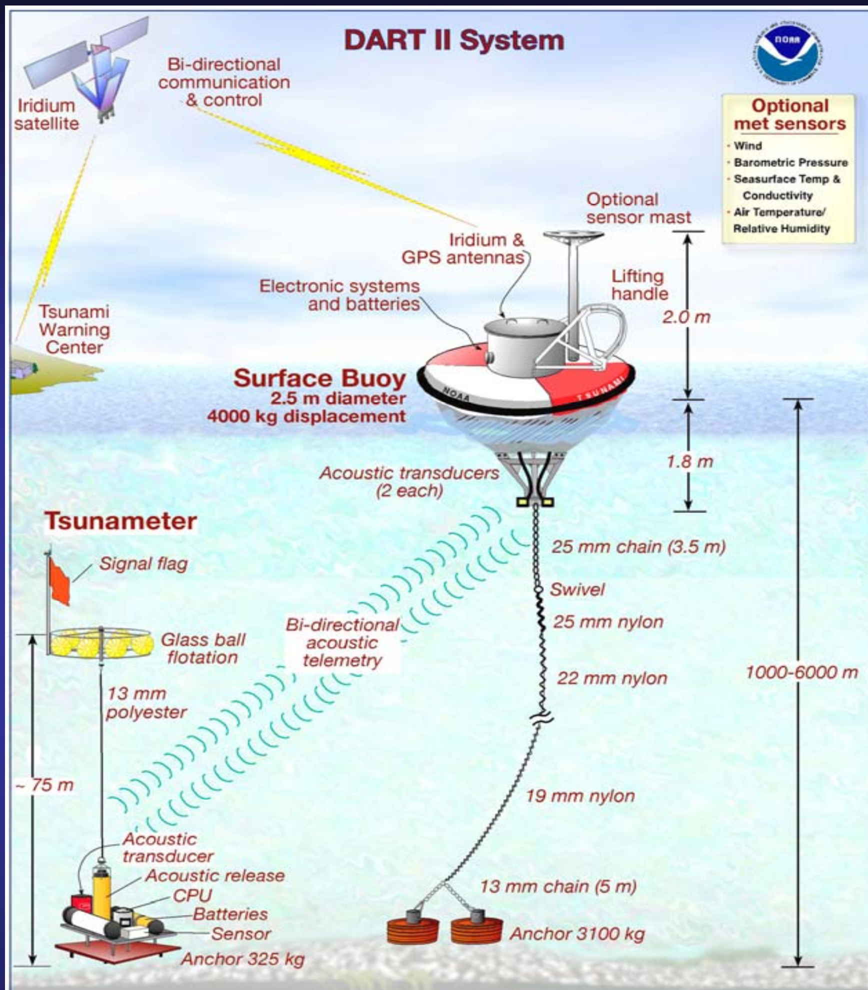
Technology

DART Data Buoy Tsunami Warning System



Photos and Diagrams courtesy of N.O.A.A.

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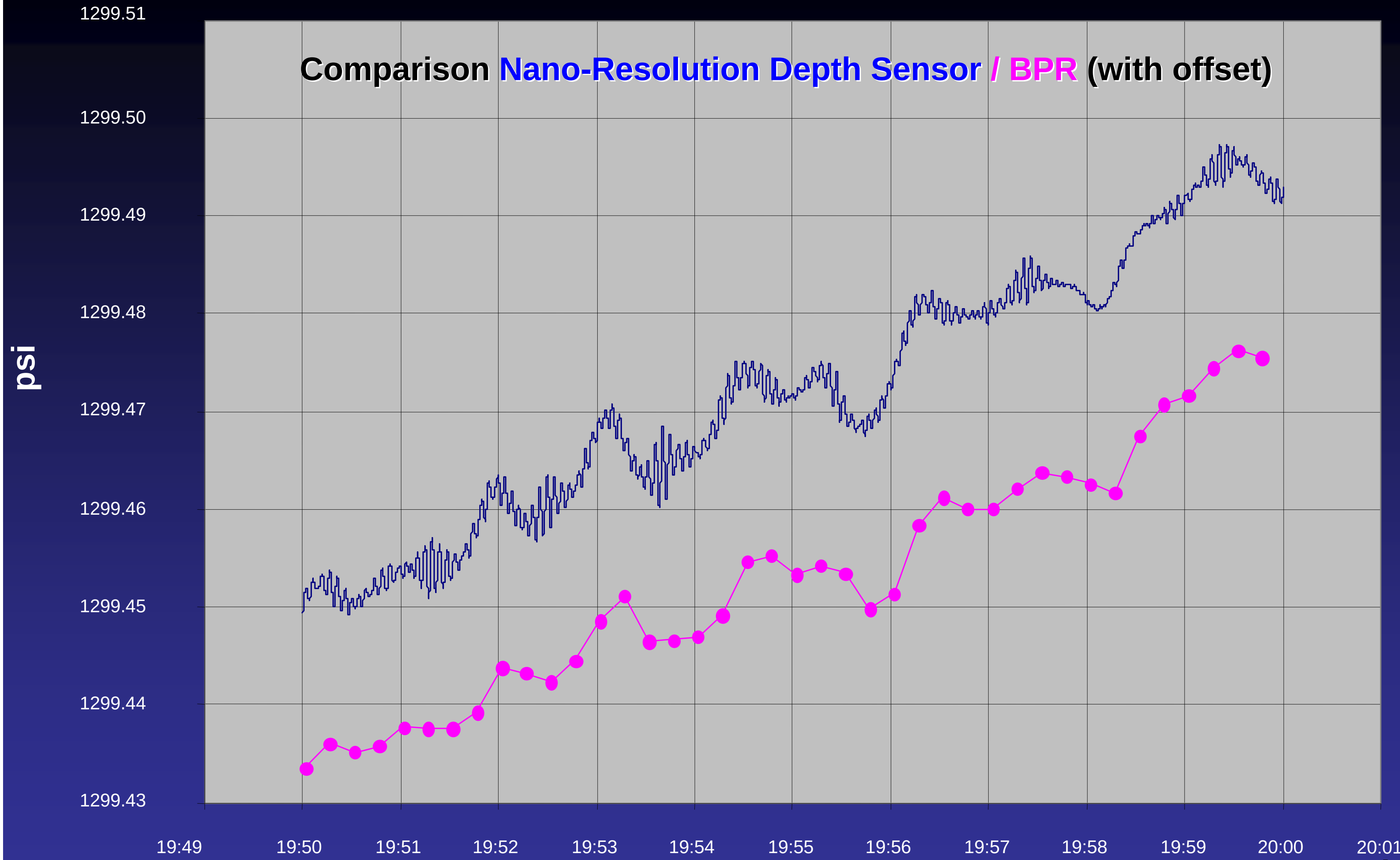

Comparison Nano-Resolution Depth Sensor / Standard BPR

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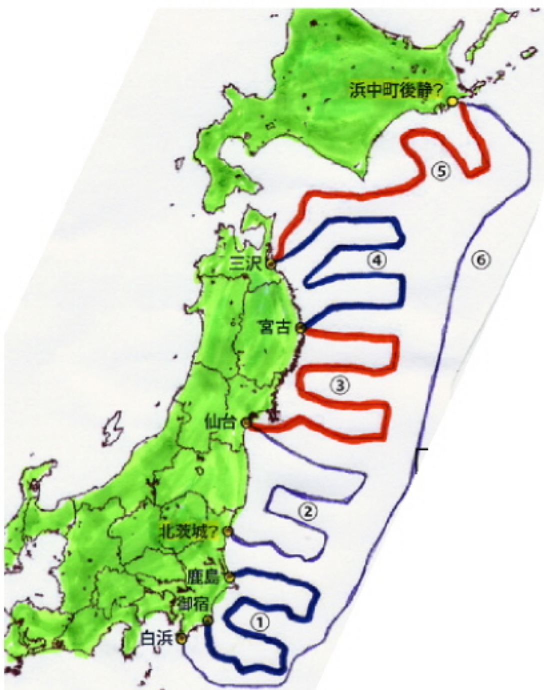
Japan Trench Observation & Tsunami Warning System Over 5200 km of Cable and 154 Instrument Stations.

Disaster Warning System for Japan

Each cabled node contains:

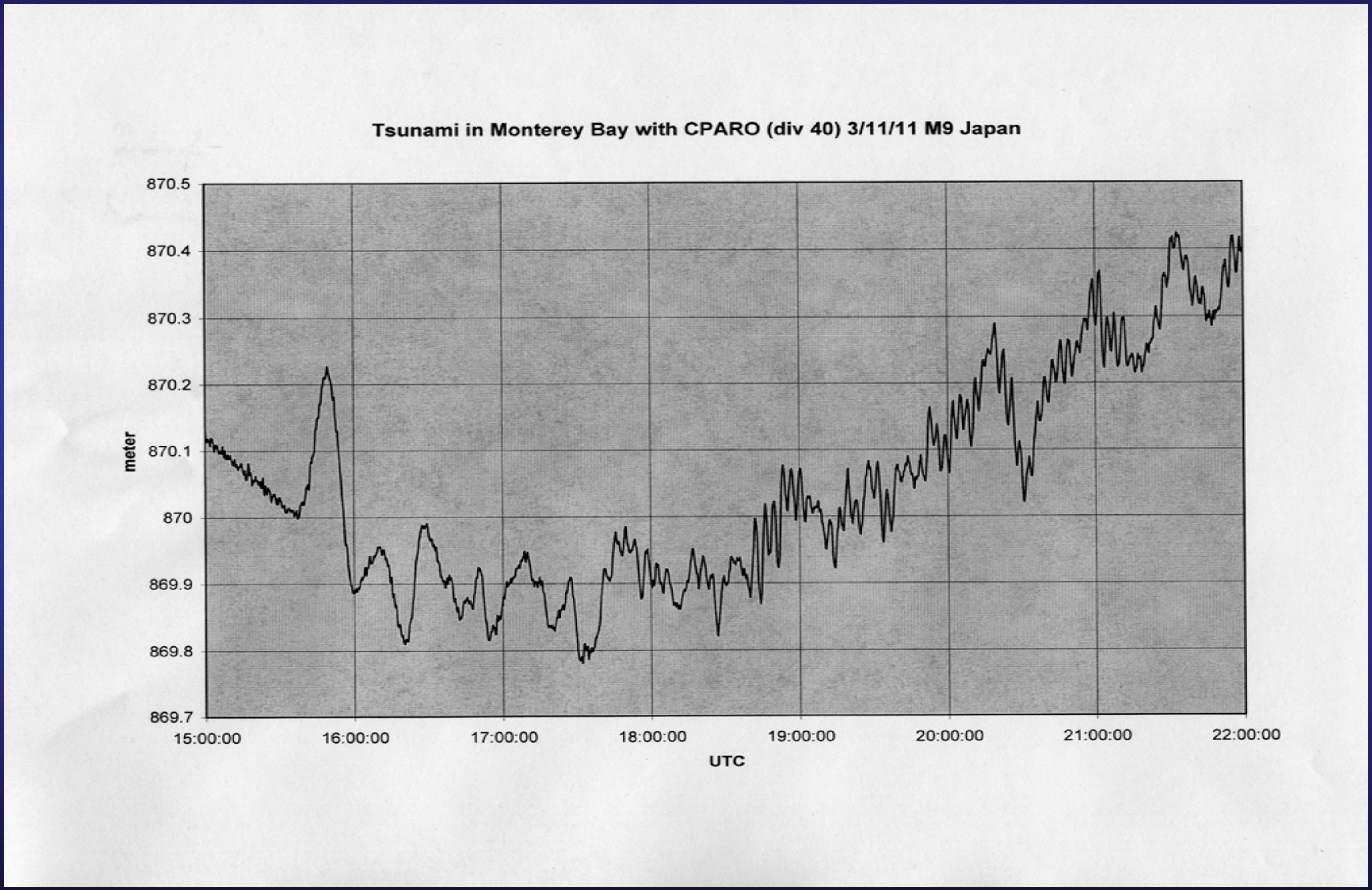
2 Nano-Resolution Depth Sensors for Tsunami Measurements &

3 Nano-Resolution Accelerometers for Seismic & Tilt Measurements



Courtesy of NEC

Tohoku Tsunami Measured in Monterey California with Nano-Resolution Depth Sensor



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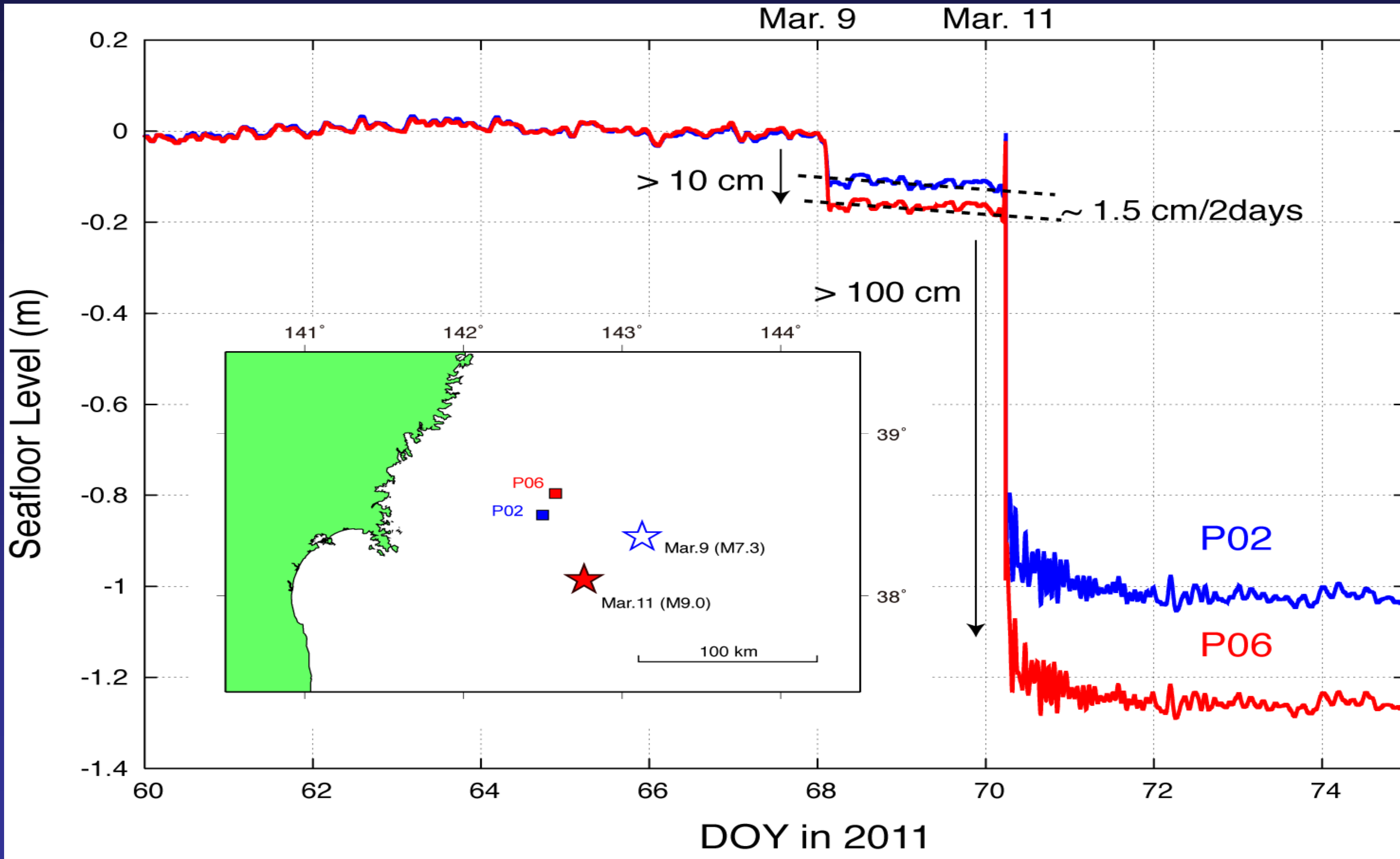
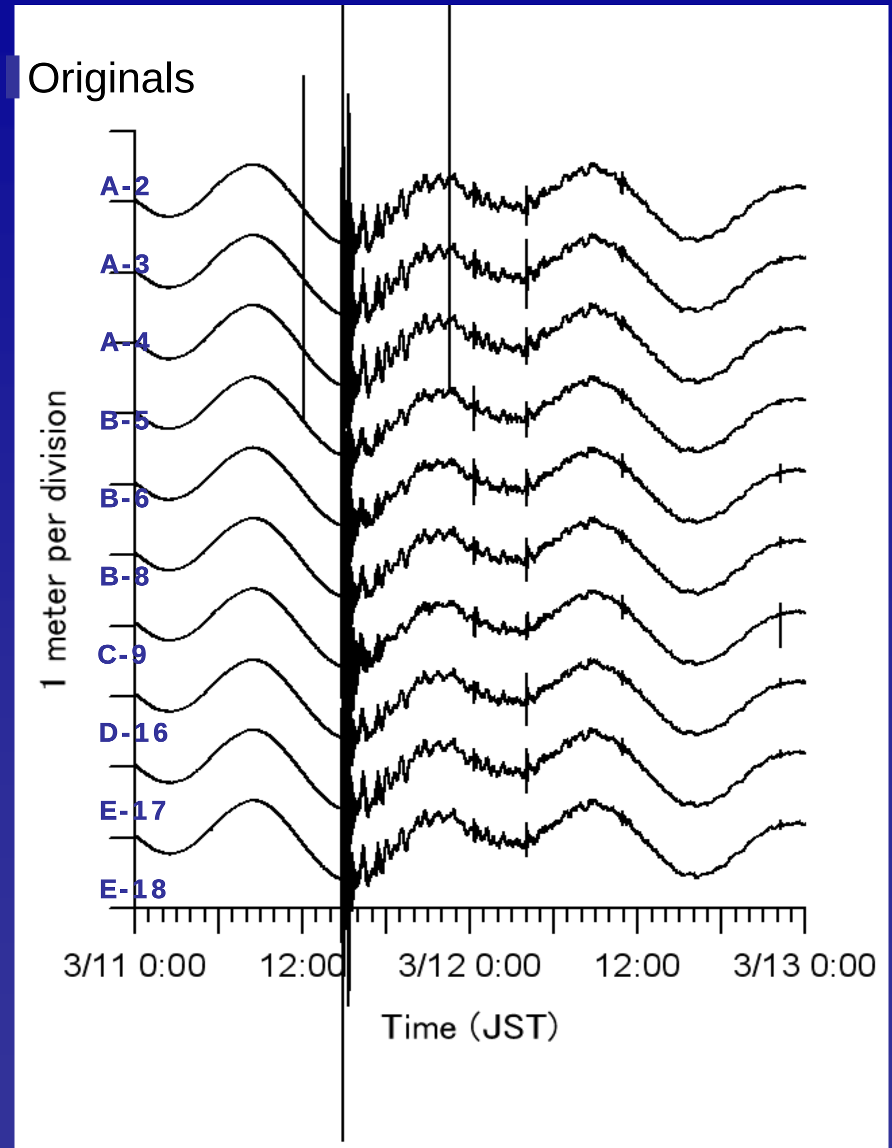
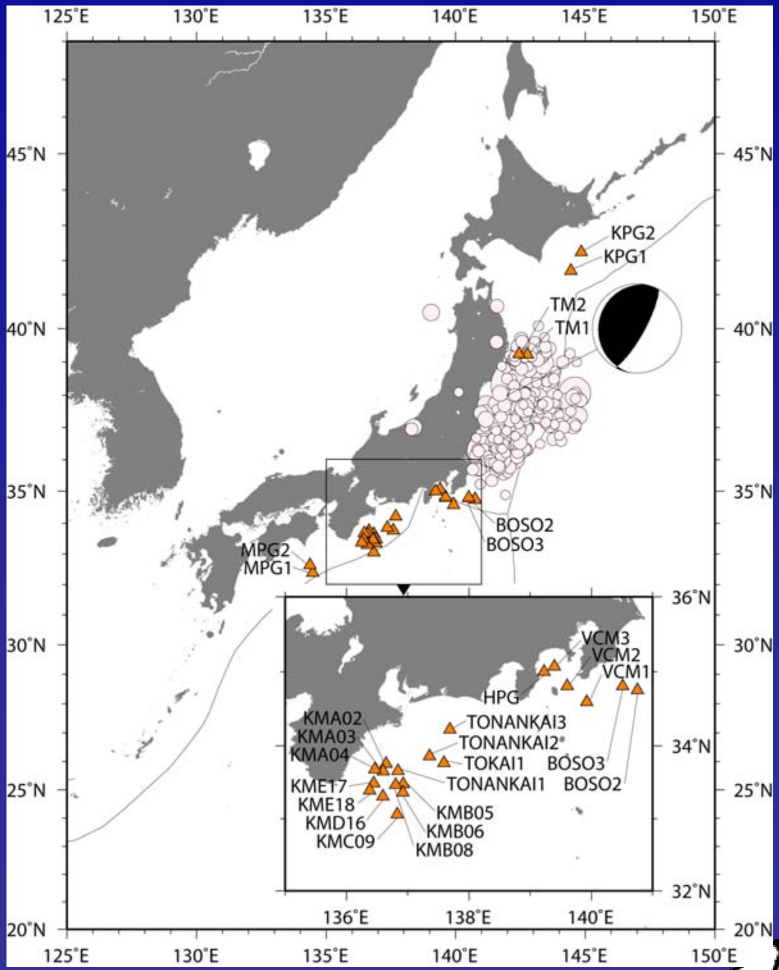
3-9 Precursor to 3-11 Tsunami



Plot courtesy of Dr. Ryota Hino

DONET Bottom Pressure during the 2011 Tohoku Earthquake





Plot courtesy of Dr. Hiroyuki Matsumoto

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Seismic Measurements

Quartz Seismic Sensors, Inc.

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Technology

Quartz Triaxial Accelerometers & Tiltmeters

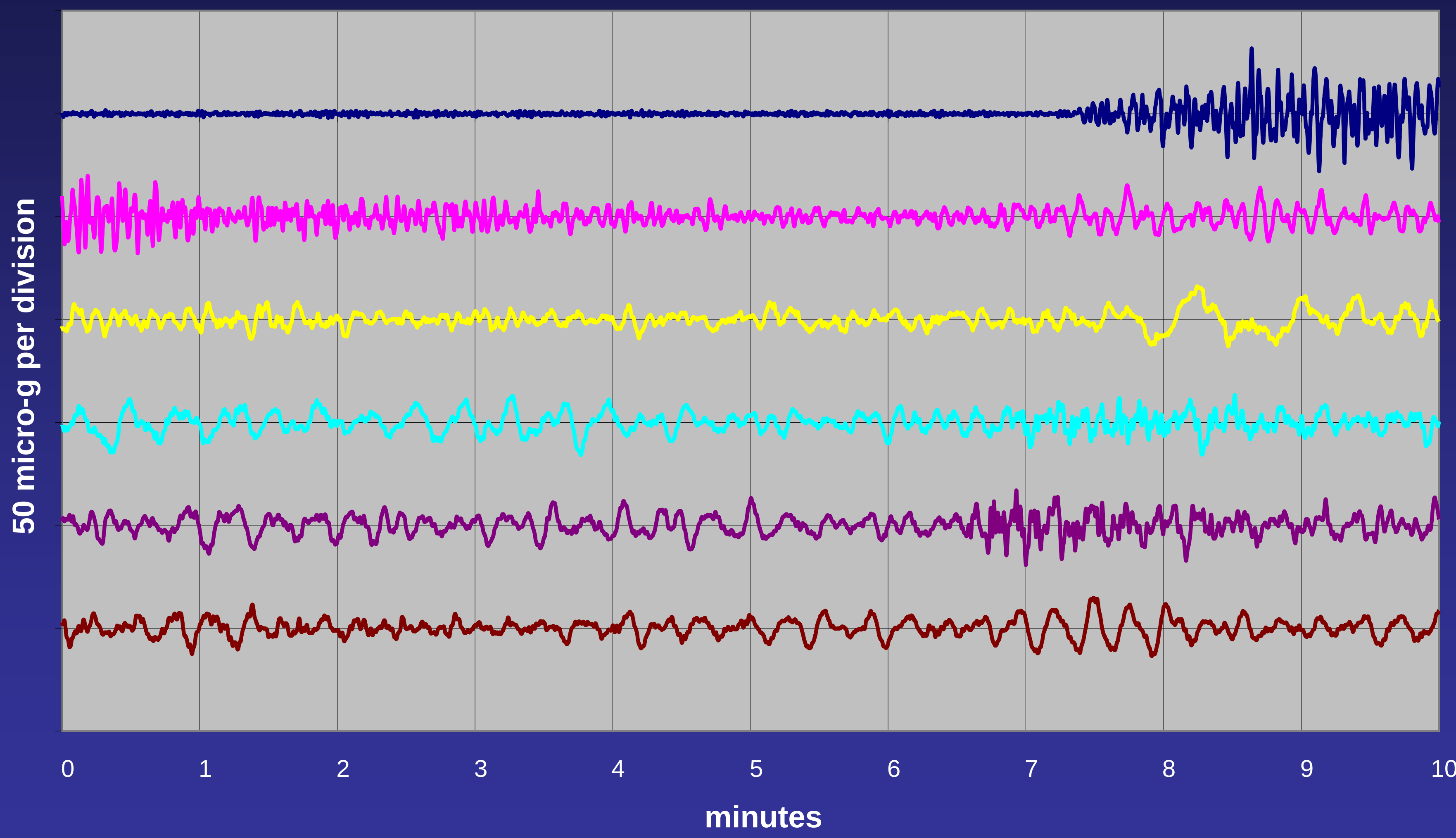
Applications:

- **Land-based earthquake detection and geodetic research**
- **Ocean-based measurements for tsunami warning systems and geodesy**
- **Seismo-acoustic measuring systems with nano-resolution barometers**

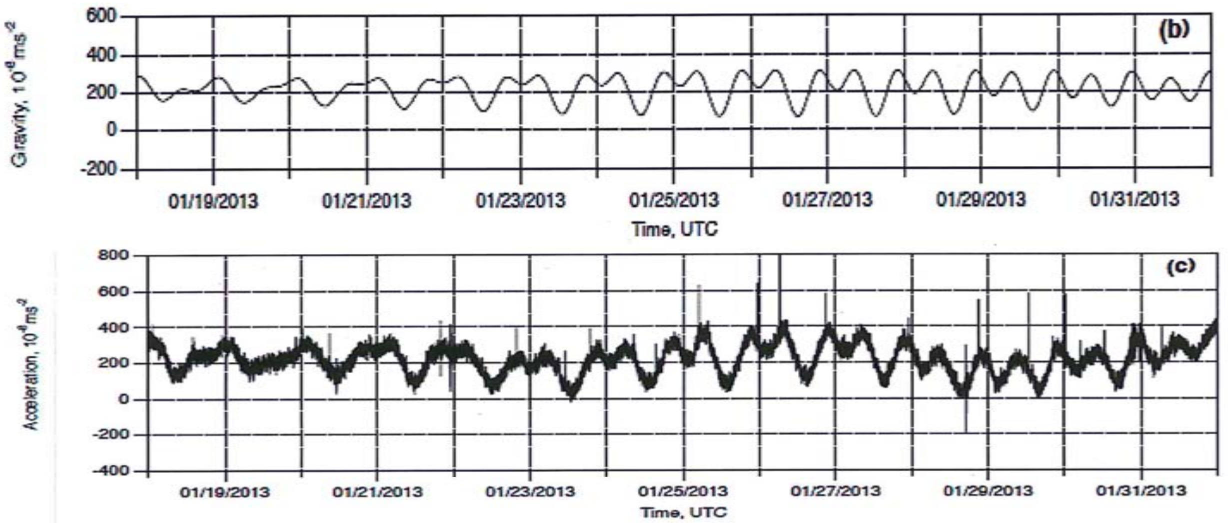
Advantages:

- **Parts-per-billion resolution over a broad spectrum**
- **High ranges to measure strongest events (no clipping)**
- **High accuracy and low power consumption (1 ma at 3.6 V)**
- **In-situ 1 G referenced calibration methods to eliminate drift**
- **Excellent long-term stability and insensitivity to environmental errors**

M9 Honshu Earthquake 11 Mar 2011 05:50-06:50 UTC
Recorded with Nano-Resolution Accelerometer in Seattle, WA USA

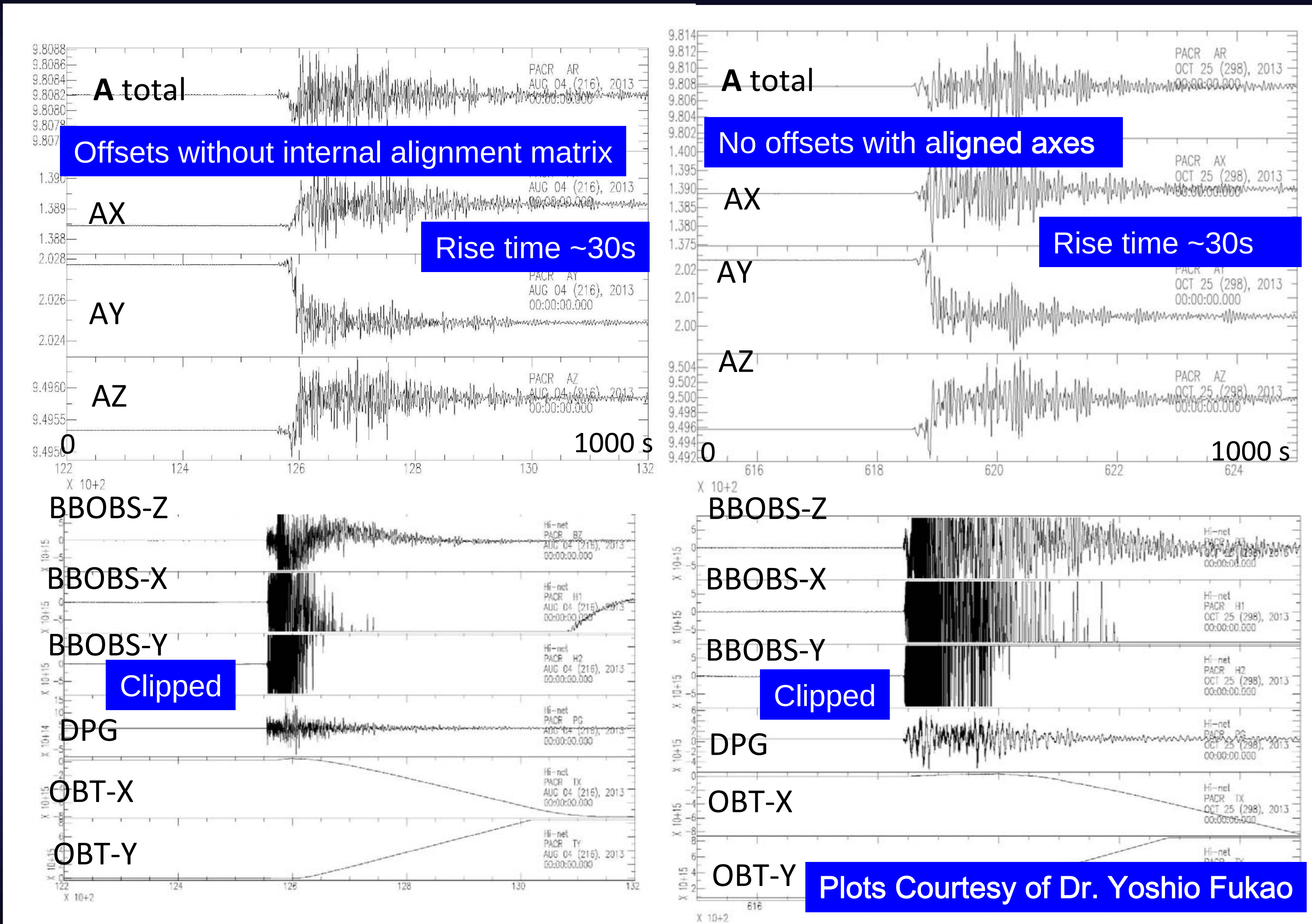


Earth Tides Measured with Nano-Resolution Quartz Accelerometer



Plots courtesy of Dr. Yuichi Imanishi

130804 OFF MIYAGI PREF 6.0/5.8 131025 FAR E OFF NORTH HONSHU 7.1/7.1



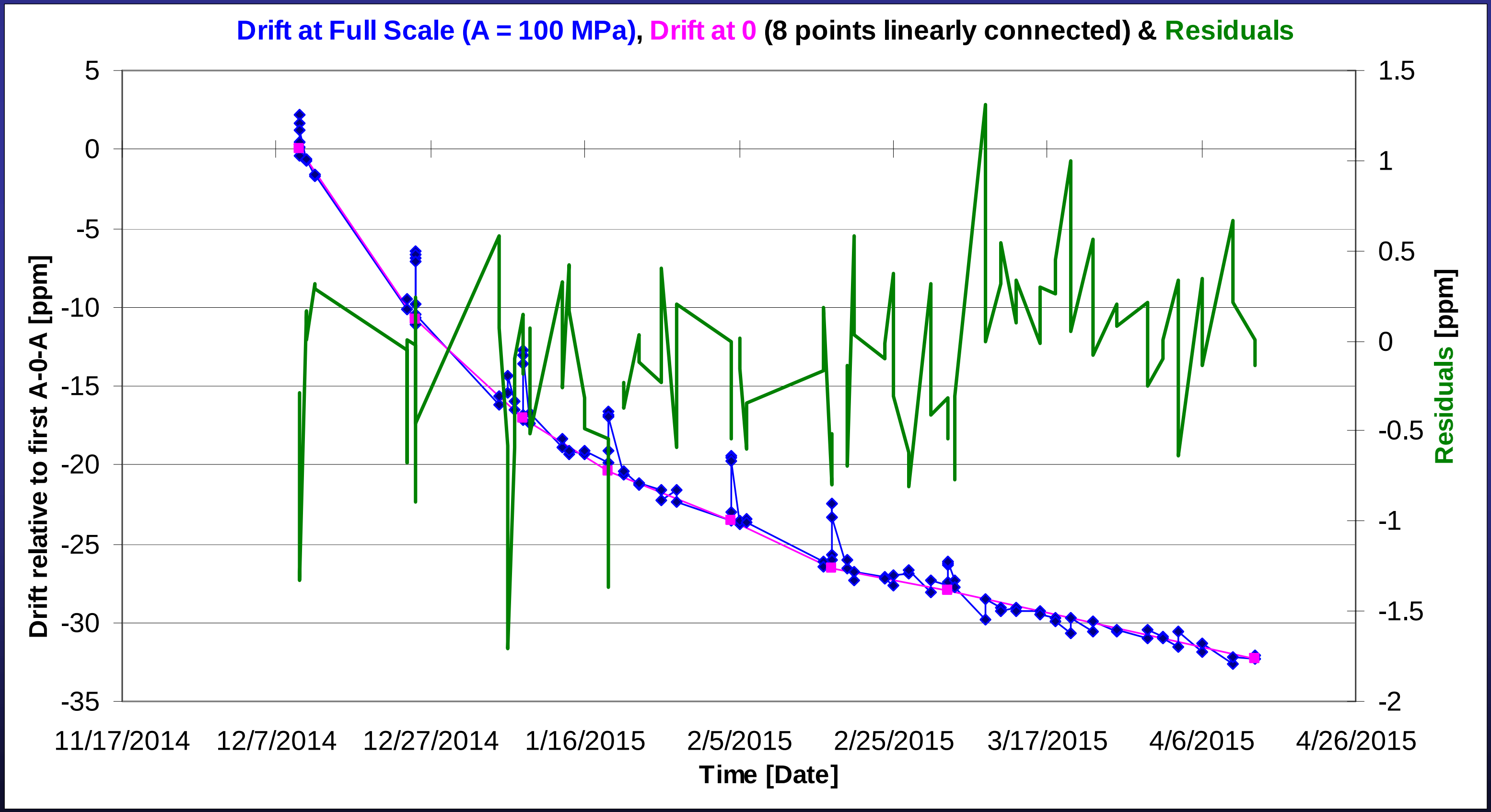
In-situ Calibration Methods for Improved Geodetic Measurements

Stable Long-term Measurements of Earth Movement to 1 cm/year Using Drift Compensation of Absolute Depth Sensors and/or Triaxial Accelerometers for Tilt

- Depth Sensor Stability Referenced to Internal OBS Atmospheric Pressure (A-0-A Calibration Method)
- 1 G Referenced Seismology (Triaxial Accelerometer Axes Compared to the Invariant 1 G Gravity Vector)

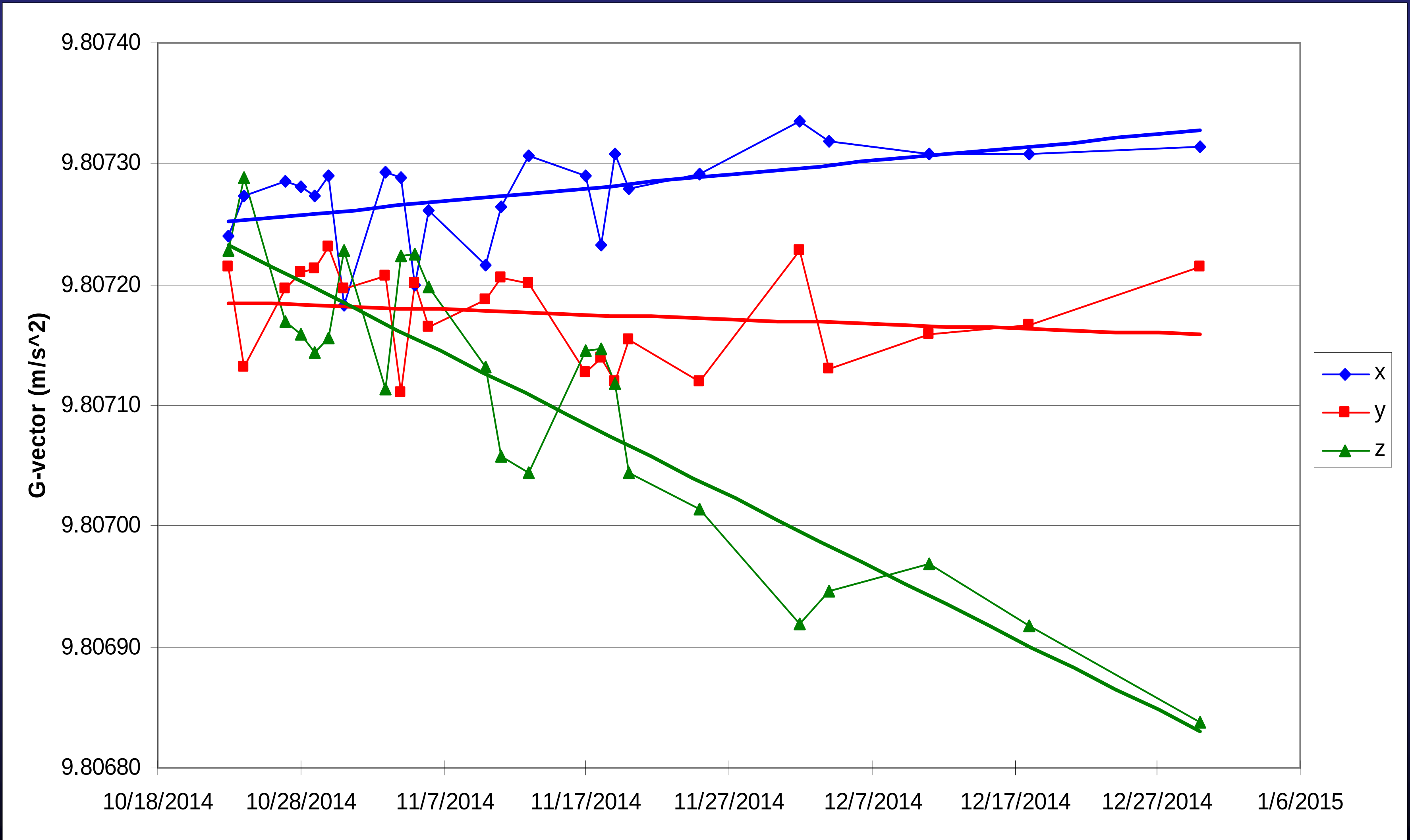
In-situ Calibration Methods for Improved Geodetic Measurements

Depth Sensor Stability Referenced to Internal OBS Atmospheric Pressure Using A-0-A Calibration Method



In-situ Calibration Methods for Improved Geodetic Measurements

Triaxial Acceleration Vector Referenced to 1 G of Earth



Quartz Crystal Pressure Sensors, Triaxial Accelerometers, and Tiltmeters provide:

- Improved disaster warning times for earthquakes, tsunamis, volcanic eruptions and extreme weather events
- Improved geodetic measurements for scientific research and predictions of natural disasters
- Low-cost measurement solutions for new and existing cabled, remote, and mobile platforms

Paroscientific, Inc.
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