Axial Seamount Differential Uplift Analysis

Development Conventions

Package Management

- **Use `uv`** for Python dependency management
- Add packages with: `uv add <package>`
- Run scripts with: `uv run python <script.py>`
- Dependencies are tracked in `pyproject.toml`

Code Organization

- **Prefer scripts over notebooks** for reproducible analysis
- Notebooks are for documentation and exploration only
- Scripts go in the project root (e.g., `analysis.py`)
- All scripts should be runnable via `uv run python <script.py>`

Research Context

This project calculates differential uplift between two Bottom Pressure Recorders (NANO-BPRs) at Axial Seamount.

Sign Convention (IMPORTANT)

Uplift_F - Uplift_E (Central Caldera uplift minus Eastern Caldera uplift)

Since BPR measures water depth (which DECREASES when seafloor rises), we compute:

```
differential = -(depth_F - depth_E) = depth_E - depth_F
```

This is equivalent to `uplift_F - uplift_E` and matches the Axial research team's geophysical convention (see https://axial.ceoas.oregonstate.edu/axial_blog.html): - **Increasing values** = inflation (uplift at caldera center) - **Decreasing values** = deflation (subsidence at caldera center)

Data Sources

Station	Location	Path
MJ03E	Eastern Caldera (reference)	`/home/jovyan/ooi/kdata/RS03ECAL-MJ03E-06-BOTPTA302-streamed-botpt_nano_sample_15s/`
MJ03F	Central Caldera (max uplift)	`/home/jovyan/ooi/kdata/RS03CCAL-MJ03F-05-BOTPTA301-streamed-botpt_nano_sample_15s/`

- **Format**: netCDF files
- **Time period**: 2015-01-01 to 2026-01-16

Technical Environment

- **Language**: Python 3.12
- **Package manager**: uv
- **Key packages**: xarray, pandas, matplotlib, netcdf4, pyarrow
- **Working directory**: `/home/jovyan/repos/specKitScience/my-analysis_botpt/`

Pressure-to-Depth Conversion

```
depth_m = (pressure_psia - 14.7) * 0.670
```

This linear approximation ignores seawater compressibility, temperature, and salinity effects. For differential measurements these factors largely cancel between stations.

Instrument Drift Considerations

BPRs exhibit long-term drift (typically 1-10 cm/year). The differential measurement (uplift_F - uplift_E) cancels common-mode drift affecting both sensors equally.

Limitations: - Any **differential drift** between MJ03E and MJ03F would appear as a spurious trend - This analysis does **not** apply drift corrections - Long-term trends should be validated against campaign pressure measurements (ROV-based calibrations) when available - The OOI team performs periodic calibrations; check data quality notes for specific time periods

Quality Control: Spike Removal

Spikes are removed using Median Absolute Deviation (MAD), which is more robust to outliers than standard deviation.

Algorithm

1. Calculate rolling median over 24-hour centered window
2. Compute absolute deviation from rolling median for each point
3. Calculate rolling MAD (median of absolute deviations)
4. Scale MAD by 1.4826 to approximate standard deviation (for normal distributions, std ≈ 1.4826 × MAD)
5. Flag points where deviation > threshold × scaled_MAD
6. Replace flagged points with NaN

Thresholds

Data	Threshold	Rationale
Individual station depth	5.0	Conservative; catches obvious sensor glitches
Differential signal	3.5	More aggressive; catches glitches that appear when one sensor spikes but not the other

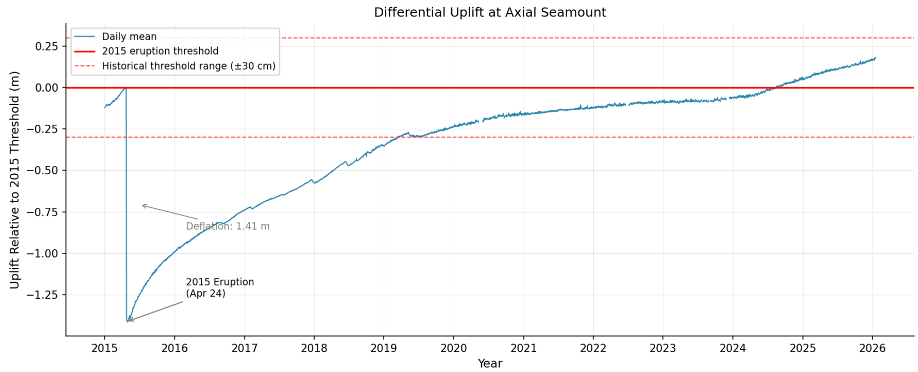
Why MAD over Standard Deviation?

- Standard deviation is sensitive to extreme values—a single large spike inflates the std, making other spikes harder to detect
- MAD uses medians, so outliers have minimal influence on the threshold calculation

Eruption Threshold Reference

The 2015 pre-eruption differential is used as a reference threshold for forecasting. Key observations: - **2015 eruption threshold**: ~30 cm higher than the 2011 threshold - **Threshold uncertainty**: ±30 cm bands reflect this variability - **Forecasting caveat**: “the pattern could change” (per Axial research team)

Differential Uplift Figure



Differential Uplift at Axial Seamount

The figure shows differential uplift at Axial Seamount from 2015-2026, referenced to the 2015 pre-eruption threshold:

- **Y-axis**: Uplift relative to 2015 threshold (0 = threshold level)
- **Red solid line**: 2015 eruption threshold
- **Red dashed lines**: Historical threshold range (±30 cm based on 2011 vs 2015 difference)
- **Blue line**: Daily mean differential uplift

Key Features Visible

1. **April 2015 Eruption**: Sharp deflation of ~1.4 m (differential) following the eruption
2. **Post-eruption recovery**: Steady re-inflation from 2015-2026
3. **Current state** (early 2026): ~0.2 m above the 2015 threshold

Interpretation

The volcano has re-inflated past the 2015 pre-eruption level, entering the historical threshold range where previous eruptions have occurred. However, eruption thresholds vary between cycles, and "the pattern could change."

Validation Against Published Data

Comparison with Axial Research Team Results

Our uncorrected analysis was compared against the Axial team's drift-corrected results for the period 2022-Oct 2025:

Metric	Axial Team (corrected)	Our Analysis (uncorrected)	Difference
	~2.2 m	1.29 m	0.9 m

Metric	Axial Team (corrected)	Our Analysis (uncorrected)	Difference
2022 value			
Oct 2025 value	~2.6 m	1.55 m	1.05 m
Change 2022→Oct 2025	~0.4 m	0.26 m	0.14 m

Reference: https://axial.ceoas.oregonstate.edu/Blog_images/Axial-corrected-NANO-DIFF-uplift-2022-Oct2025.png

Discrepancy Analysis

The ~1 m offset and ~35% rate difference are likely due to:

1. **Drift corrections**: The Axial team applies corrections using campaign pressure measurements (ROV-based calibrations). Our analysis uses raw, uncorrected data.

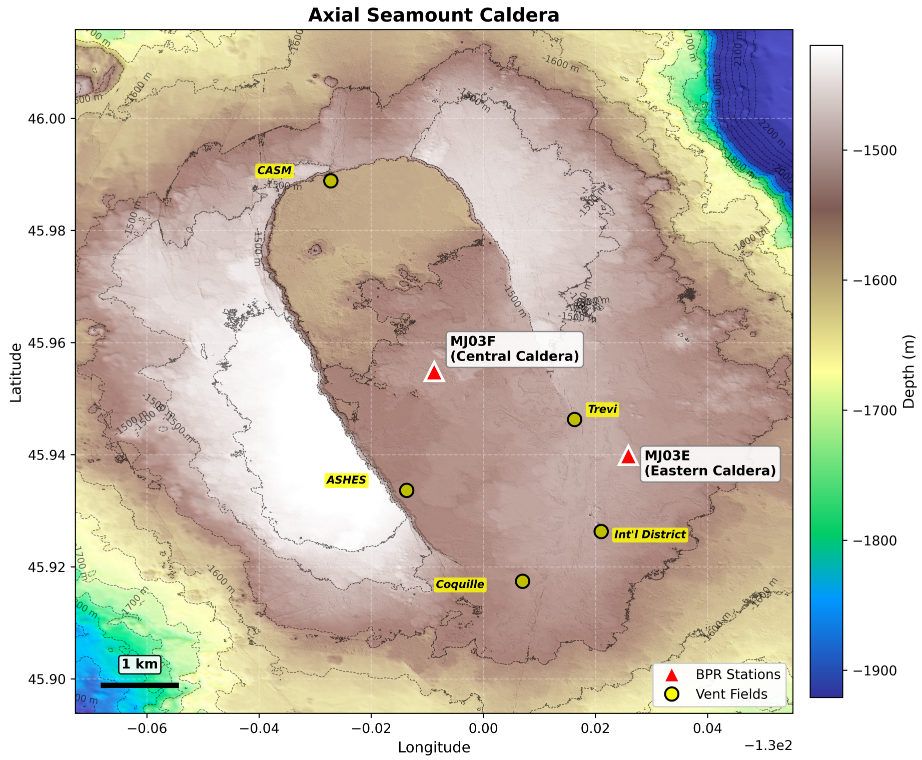
2. **Pressure-to-depth conversion**: We use a simple linear factor (0.670 m/psi). The Axial team may use a more sophisticated equation of state.

3. **Additional corrections**: The Axial team may apply tidal models, oceanographic adjustments, or other corrections not included here.

Implications

- **Relative patterns** (inflation/deflation timing, rate changes) are reliable
- **Absolute values** should be treated with caution and validated against published results
- For publication-quality work, drift corrections using campaign calibration data are recommended

Caldera Bathymetry Map



Axial Seamount Caldera

Data Source

- **File**: `MBARI_AxialSeamount_V2506_AUV_Summit_AUVOverShip_Topo1mSq.grd`
- **Path**: `/home/jovyan/my_data/axial/axial_bathy/`
- **Resolution**: 1m
- **Format**: GMT/NetCDF grid

BPR Station Locations (verified from OOI NetCDF metadata)

Station	Latitude	Longitude	Location
MJ03F	45.95485°N	130.008772°W	Central Caldera
MJ03E	45.939888°N	129.974113°W	Eastern Caldera

Vent Field Locations (user-provided coordinates)

Vent Field	Latitude	Longitude
ASHES	45°56.0186'N	130°00.8203'W
CASM	45°59.332'N	130°01.632'W
Coquille	45°55.0448'N	129°59.5793'W

Vent Field	Latitude	Longitude
Int’l District	45°55.5786’N	129°58.7394’W
Trevi	45°56.777’N	129°59.023’W

Map Generation

```
uv run python make_caldera_map.py
```

Output: `outputs/figures/caldera_map.png` (600 dpi, full 1m resolution)

Outputs

All outputs in the `outputs/` directory:

Data Products (`outputs/data/`)

File	Description
`differential_uplift_hourly.parquet`	Hourly cleaned data with `depth_mj03e_m`, `depth_mj03f_m`, `differential_m`
`differential_uplift_daily.parquet`	Daily averaged data with same columns

Figures (`outputs/figures/`)

File	Description
`caldera_map.png`	High-resolution (600 dpi) shaded relief bathymetry map with BPR stations and vent fields
`depth_mj03e.png`	Time series of Eastern Caldera depth (meters)
`depth_mj03f.png`	Time series of Central Caldera depth (meters)
`differential_uplift.png`	Differential uplift referenced to 2015 threshold with ±30 cm historical range

Usage

```python
import pandas as pd
bpr = pd.read_parquet('outputs/data/
        differential_uplift_daily.parquet')
```

```
other = pd.read_parquet('other_instrument.parquet')
merged = bpr.join(other, how='inner')
```

Project Structure

```
my-analysis_botpt/
├── .gitignore
├── .venv/                          # uv virtual environment
├── pyproject.toml                  # uv dependencies
├── uv.lock                         # Locked dependencies
├── analysis.py                     # Differential uplift analysis
script
├── make_caldera_map.py             # Caldera bathymetry map
script
├── .specify/
│   ├── features/001-differential-uplift/
│   │   ├── plan.md
│   │   ├── spec.md
│   │   └── tasks.md
│   └── memory/
│       └── constitution.md         # This document
└── outputs/
    ├── constitution.pdf
    ├── data/
    │   ├── differential_uplift_daily.parquet
    │   └── differential_uplift_hourly.parquet
    ├── figures/
    │   ├── caldera_map.png
    │   ├── depth_mj03e.png
    │   ├── depth_mj03f.png
    │   └── differential_uplift.png
    └── notebooks/                  # Documentation only
        ├── README.md
        ├── differential_uplift_analysis.ipynb
        └── environment.yml
```

Running the Analysis

```
# Install dependencies (first time)
uv sync

# Run differential uplift analysis
uv run python analysis.py

# Generate caldera bathymetry map
uv run python make_caldera_map.py
```

References

- Nooner, S. L., & Chadwick, W. W. (2016). Inflation-predictable behavior and co-eruption deformation at Axial Seamount. *Science*, 354(6318), 1399-1403.
- Axial Seamount Blog: https://axial.ceoas.oregonstate.edu/axial_blog.html
- OOI Cabled Array: https://oceanobservatories.org/array/cabled-array/

Notes

- Swap xarray dimensions: `ds.swap_dims({'obs': 'time'})`