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Annual and long-term relative seismic velocity variations at Axial Seamount observed with seismic ambient noise

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1. Introduction

Correlation of seismic ambient noise between two seismometers can give information about temporal changes in seismic velocity which can then provide information about Earth's subsurface properties in the region (i.e. Shapiro and Campillo, 2004). At volcanic systems, seismic ambient noise has also been used to monitor volcanic activity (i.e. Bennington et al., 2015; Brenguier et al., 2008; Donaldson et al., 2017; Donaldson et al., 2019). Seismic studies on land have found evidence for possible annual periodicity in the seismic velocity changes which have been mostly attributed to seasonal changes in temperature, ground-water, and/or precipitation (i.e. Donaldson et al., 2019; Hillers et al., 2015). The deep seafloor is an ideal ambient noise study location to monitor temporal seismic velocity changes associated with active volcanic processes and to examine seismic velocity variations less likely to be influenced by weather variations. In our study, we utilize ambient noise of a long-term dataset at a seamount to determine whether annual variations can be detected that isn't influenced by weather variations and to also understand how seismic velocity changes over time beneath an active seamount.

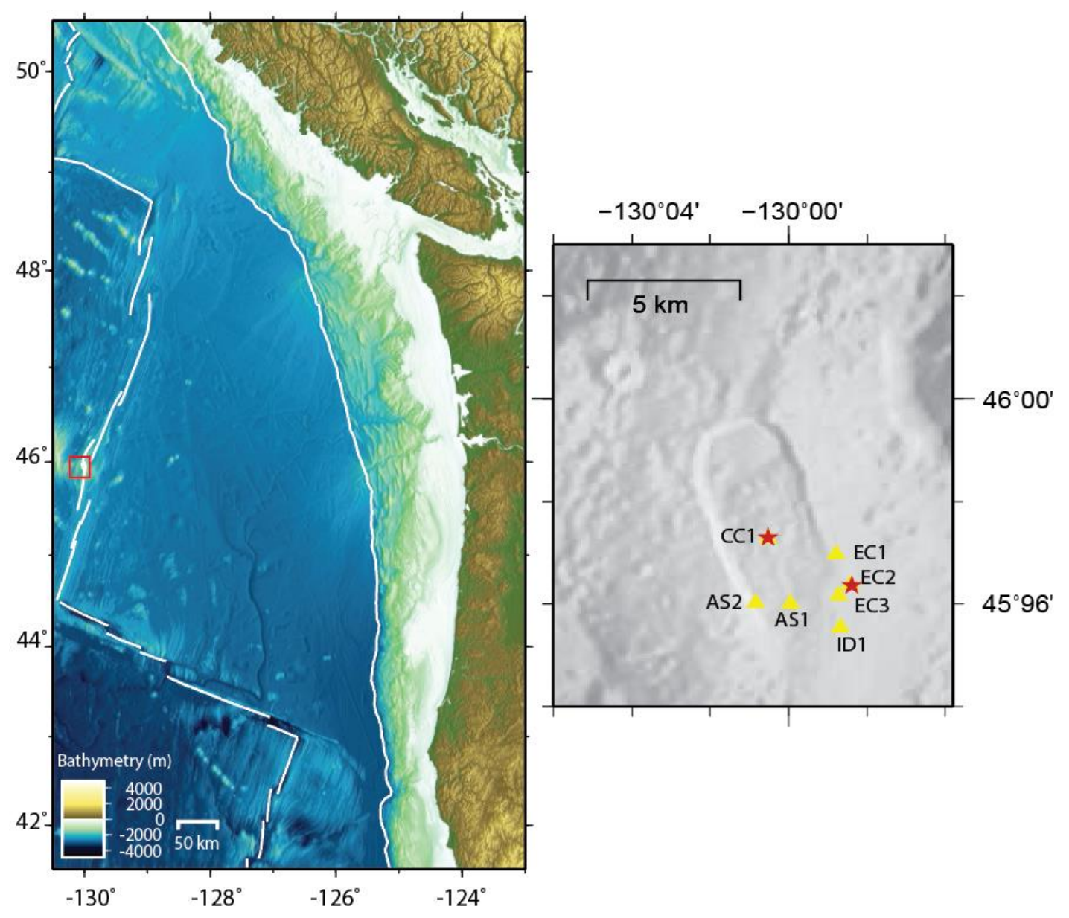


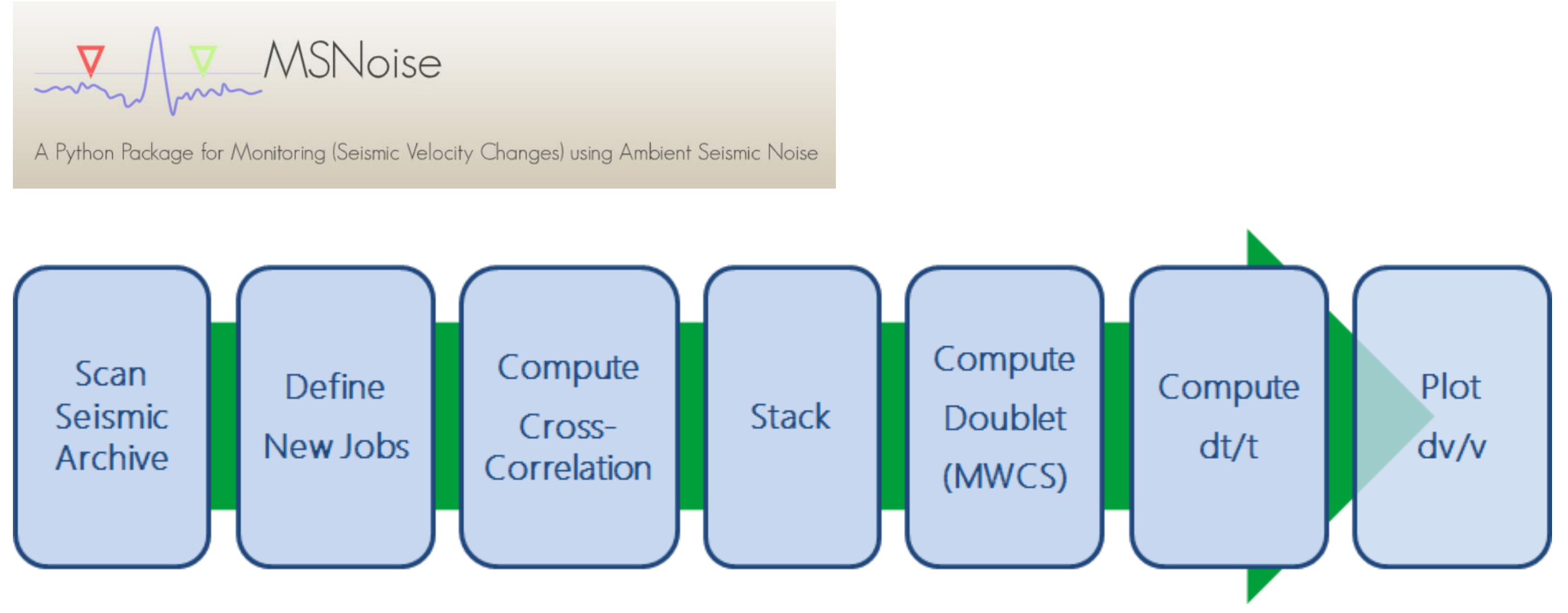
Figure 1: *Bathymetric map of Juan de Fuca (left) with red box indicating geographic extent of bathymetric map of Axial Seamount (right). The yellow triangles indicate location of the OOI ocean bottom seismometer stations with labels and the two red stars indicate location of the BPR stations.*

The area of focus for our study is Axial Seamount, an active seamount located on the Juan de Fuca ridge where it intersects with the Cobb-Eickelberg hot spot. The main magma source beneath Axial Seamount where the eruptions and intrusion events are initiated has been imaged at about ~1.1-2.3km beneath the central caldera, with a slight offset to the east and is referred to as the main magma reservoir (MMR) (Arnulf et al., 2014). Stacked-sills have also been located beneath the MMR and can act as a pathway for magma supply into the reservoir (Carbotte et al., 2020). Axial is also a focus site of the OOI cabled array with seven ocean bottom seismometers (OBS) located near the caldera streaming live data since late-2014 (Figure 1; Kelley et al., 2014)) which provides a long-term ambient seismic noise record to observe variations in seismic velocity. Axial Seamount is an ideal ambient noise study location to monitor temporal seismic velocity changes associated with active volcanic processes and to examine seismic velocity variations less likely to be influenced by weather variations.

2. Methods

For this study we utilize MSNoise, a python package built to monitor seismic velocity changes using ambient noise analysis techniques (Lecocq et al., 2014), to process the continuous seismic noise recorded by the seven OBSs and compute temporal changes in seismic velocity (dv/v) using the moving window cross-spectral method. The workflow (Figure 2) is well-documented and outlined in the MSNoise documentation.

For this study we process data from the OOI seismometers starting on September 1, 2015 until July 1, 2021 (Figure 3). We compute cross-correlation functions (CCFs) for individual pairs of stations using various filters frequency bands. Then the time delays of different arrivals of the coda waves between the CCFs and the reference CCF are measured and estimated using the moving-window cross spectrum (mwcs) analysis method, where the moving stacking window can be defined. In this study we use 1-, 7-, and 14-day moving window stacks. After mwcs, an average of the delays at different correlation lag times are determined as the relative time shift (dt/t) of the data. Seismic velocity variation is then calculated from dt/t where dv/v=-dt/t with the assumption that dv/v is homogenous in space.



Scan Seismic Archive
Define New Jobs
Compute Cross-Correlation
Stack
Compute Doublet (MWCS)
Compute dt/t
Plot dv/v

Figure 1: *General outline of MSNoise processing workflow that was followed for this study. Details for each step of the workflow is well documented and outlined in the MSNoise documentation online (http://msnoise.org/doc/, Lecocq et al., 2014)*

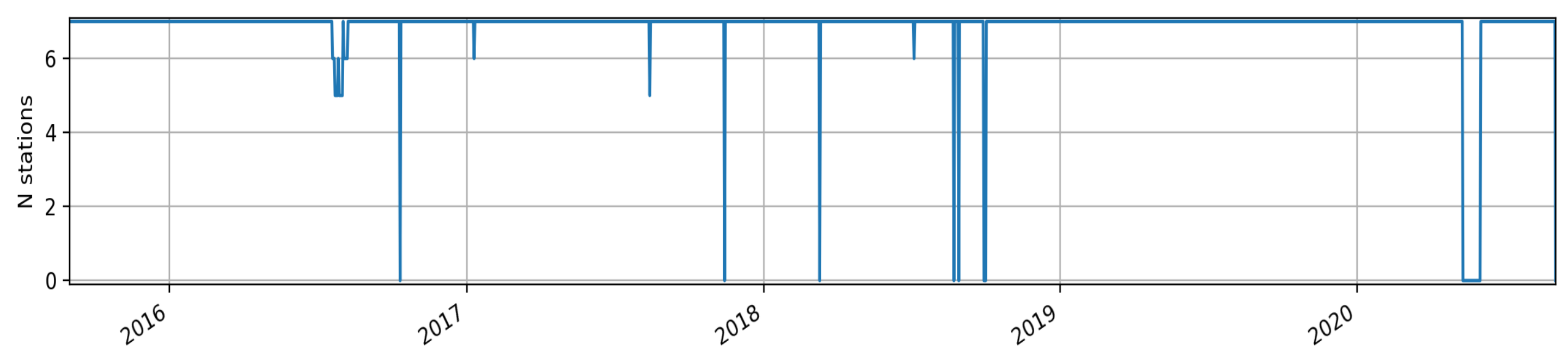


Figure 3: *Data availability from the 7 OBS stations from September 2015 until July 2021. The plot shows the number of stations with data available over time.*

3. Results

0.1-1Hz, 1-2Hz, and 2-4Hz Filters

- ➢ Decreasing long-term trend for all three frequency band filters
- ➢ Annual trend in the 0.1-1Hz filter.

0.1-0.5Hz, 0.5-0.8Hz, and 0.8-1Hz Filters

- ➢ Broke down 0.1-1Hz filter where an annual trend was observed into smaller range frequency filter
- ➢ decreasing long-term trend is persistent for the 0.5-0.8Hz and the 0.8-1Hz filters
- ➢ annual trend is only observed in the 0.1-0.5Hz filter where the long-term trend is no longer observed.

0.1-0.2Hz, 0.2-0.3Hz, 0.3-0.4Hz, and 0.4-0.5Hz Filters

- ➢ Broke down 0.1-0.5Hz filter into even smaller frequency ranges to constrain where the annual trend is persistent
- ➢ Only in the 0.1-0.2Hz filter can the annual trend be clearly observed.

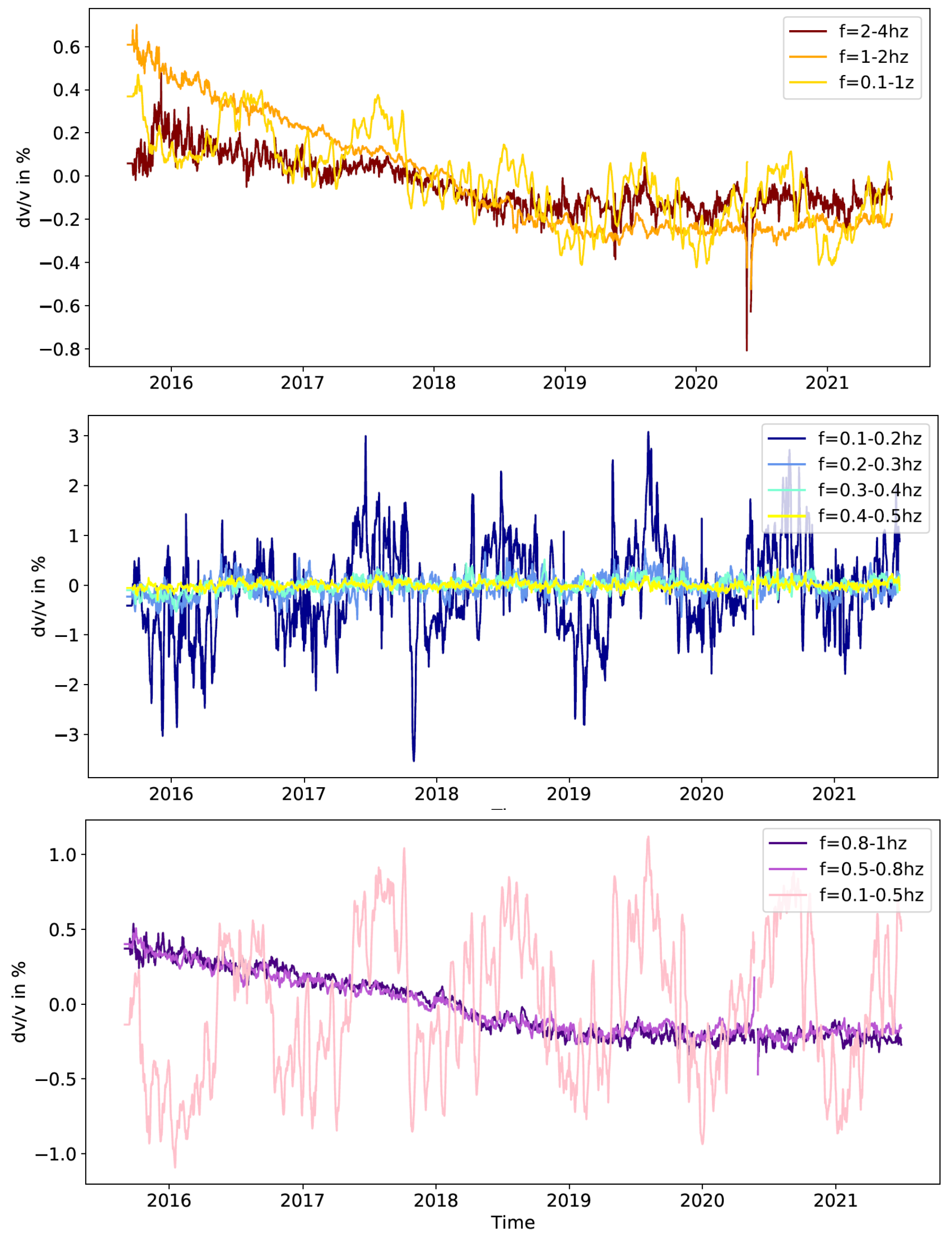


Figure 4: *dv/v results for various filters at 14-day moving window averaged for all station pairs*

4. Discussion (Long-Term Trend)

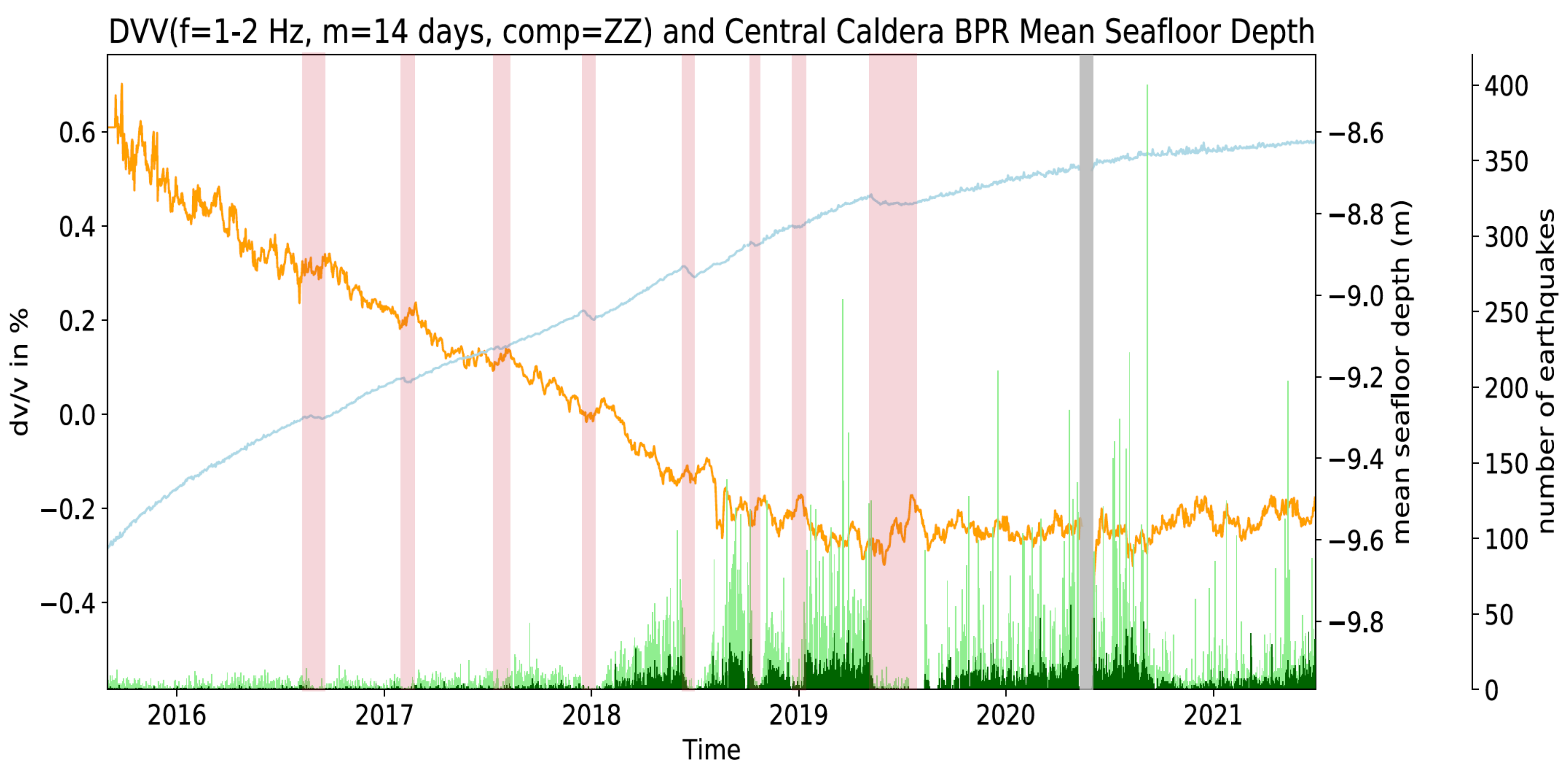


Figure 5: *dv/v results for 1-2Hz filter and 14-day moving window averaged for all station pairs (orange) plotted with differential de-tided seafloor depth from Central Caldera BPR and Eastern Caldera BPR (dark blue; data from Chadwick et al, 2021 and OOI) indicating inflation and deflation patterns at Axial Seamount and seismicity at Axial (green; data from Wilcock et al., 2016). Light green is the seismicity concentrated on the eastern side of the caldera while dark green is the western side. Red bars indicate timing of short-term deflation events identified by Chadwick et al. (2020;2021-in review). Gray bar indicates a month-long data-gap where there was no data due to power shut down (OOI).*

- ➢ Consistent long-term decrease trend in relative seismic velocity at frequency bands between 0.5-4Hz
  - ➢ Strong negative correlation between long-term trend and inflation of caldera
    - ➢ Average correlation coefficient of -0.9 for the 0.5-4Hz frequency bands between dv/v and inflation trend
  - ➢ Decrease in dv/v likely associated to the inflation of the pressure source and crack opening for fluid migration
- ➢ Short-term increase in dv/v associated with times of short-term deflation events and decrease in seismicity
  - ➢ Eight discrete short-term deflation events have been identified between August 2016 and May 2019 (Chadwick et al., 2021)
  - ➢ Increase in dv/v is observed at times of these events
  - ➢ Can be attributed to a reduction of pressure of the shallow magma reservoir and therefore a reduction in stress of the crust

5. Discussion (Annual Trend)

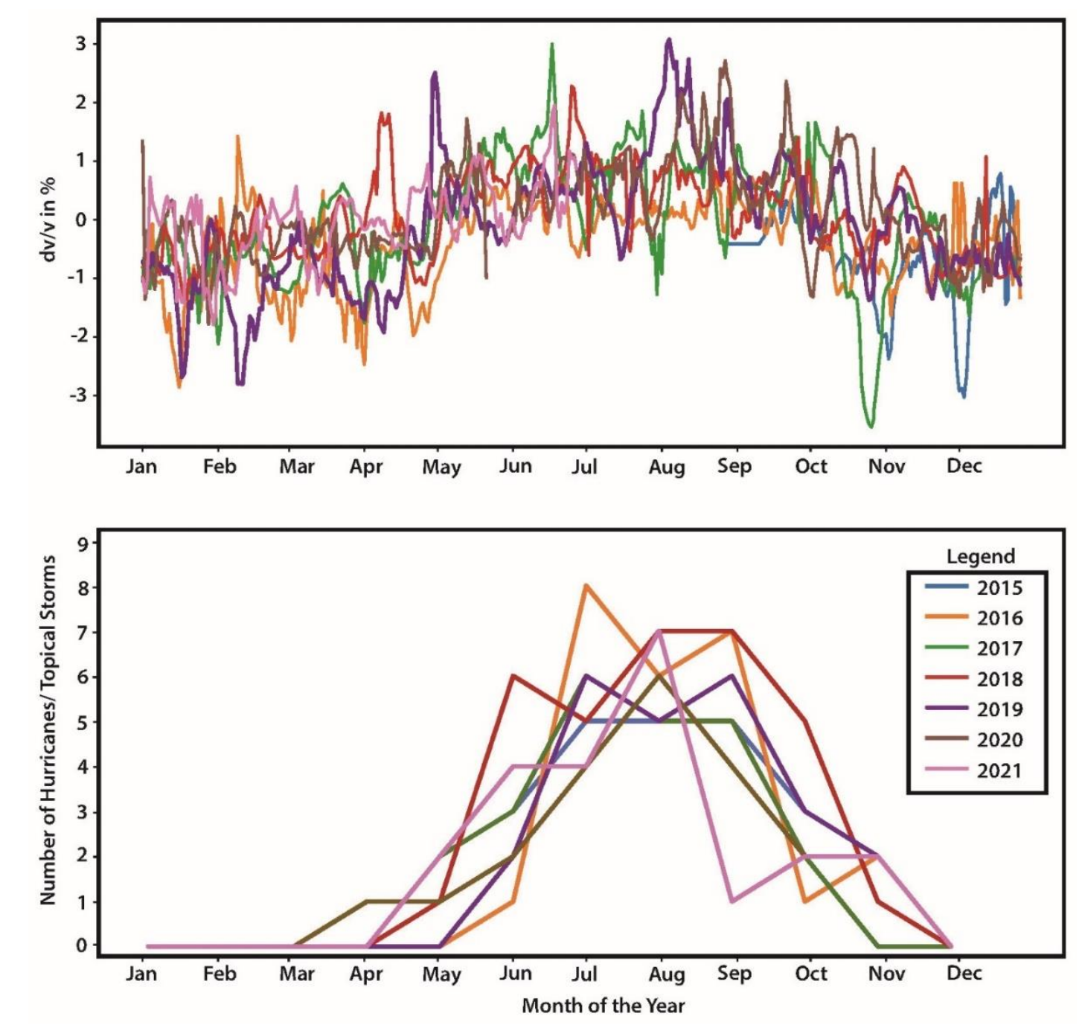


Figure 6: *(Top) Yearly stacks of the dv/v results for 0.1-0.2Hz filter for 14-day moving window. (Bottom) Eastern Pacific Basin hurricane and tropical storm activity in 2015-2021. Data from the NOAA National Hurricane Center yearly reports (https://www.nhc.noaa.gov/data)*

- ➢ Prominent annual trend in dv/v at 0.1-0.2Hz frequency bands
- ➢ Annual trend likely a noise source rather than change in crustal properties
- ➢ dv/v peaks from May to December during the annual cycle
  - ➢ Correlates well with month of hurricane and tropical storms in the Eastern Pacific

6. Conclusions

The seismic velocity change at Axial Seamount derived from the ambient noise study between September 2015 to July 2021, reveals both a long-term and an annual trend. The long-term decrease trend in seismic velocity changes can be associated with the inflation of the caldera. During inflation, pathways for fluid and/or magma likely open which would cause a decrease is seismic velocity. Within the long-term decrease trend, we also observe short-term increases in seismic velocity at the timing of short-term deflation events which would similarly reflect the possible closing of fluid pathways during deflation. Finally, we observe an annual trend in the 0.1-0.2Hz frequency band that is likely a noise source associated with the seasonality of hurricanes and tropical storms in the Eastern Pacific.

In order to better understand the constraints and interpretation of the seismic velocity results, some further work still needs to be done. To understand the constraints on the depth of which the data encompasses, we plan on calculating sensitivity kernels for the caldera region of Axial where the stations are centralized. With the future work, we want to get a better understanding of the temporal changes in crustal properties by calculating the temporal seismic velocity changes using ambient noise.

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