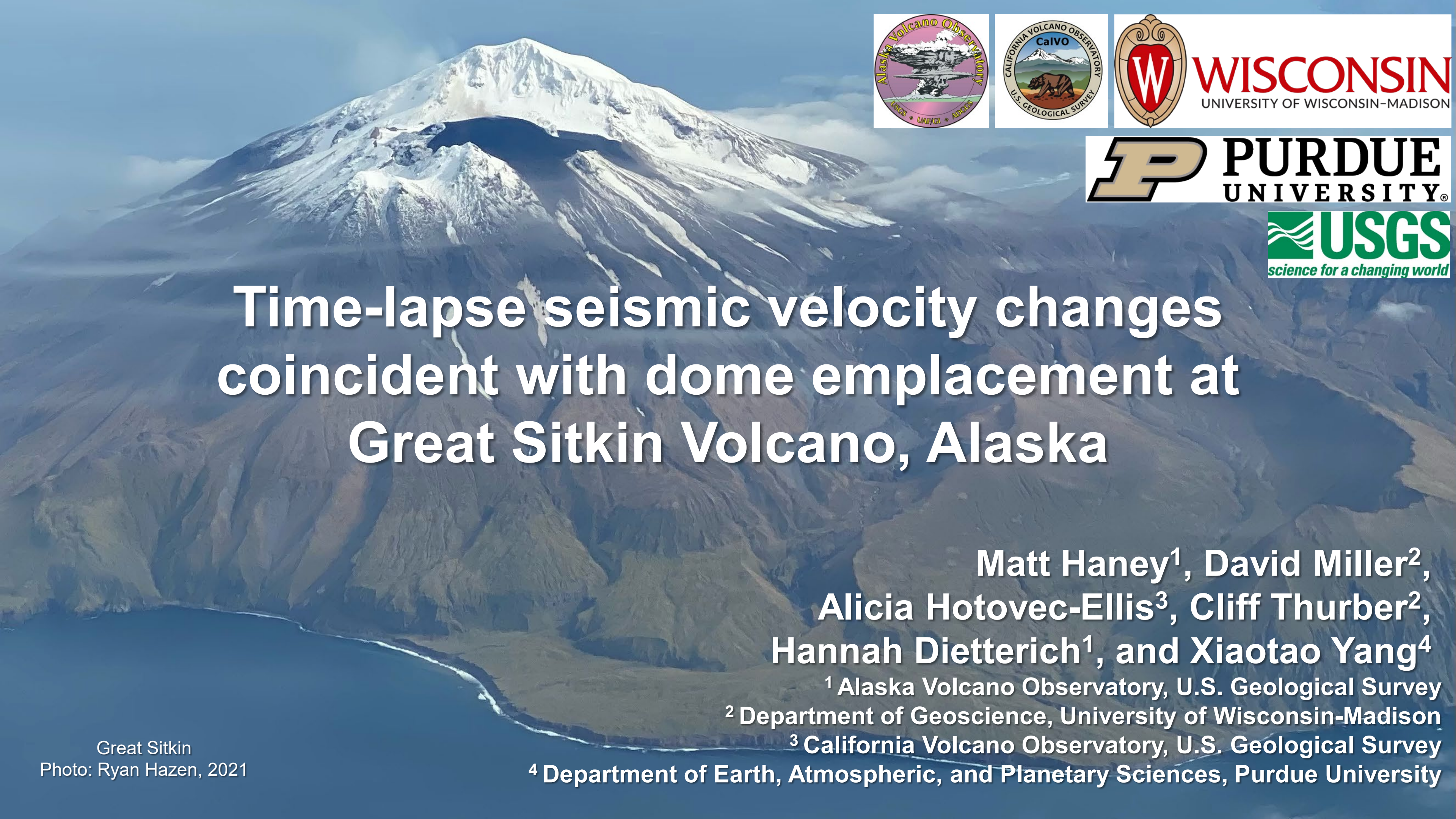


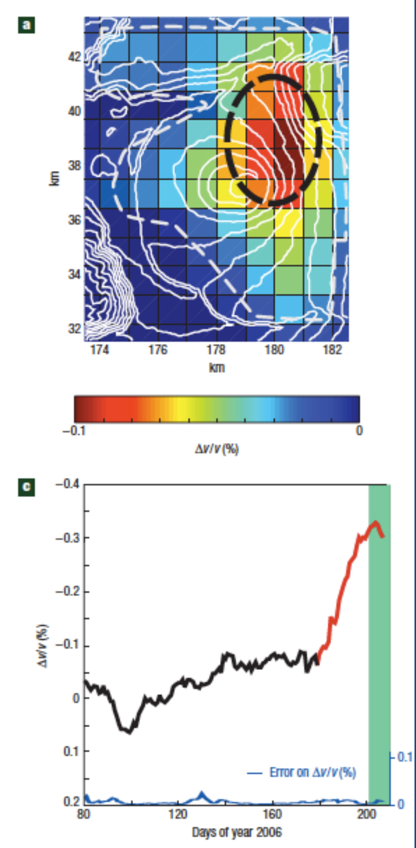
Time-lapse seismic velocity changes coincident with dome emplacement at Great Sitkin Volcano, Alaska

Matt Haney[1], David Miller[2], Alicia Hotovec-Ellis[3], Cliff Thurber[2], Hannah Dietterich[1], and Xiaotao Yang[4]

[1] Alaska Volcano Observatory, U.S. Geological Survey
[2] Department of Geoscience, University of Wisconsin-Madison
[3] California Volcano Observatory, U.S. Geological Survey
[4] Department of Earth, Atmospheric, and Planetary Sciences, Purdue University

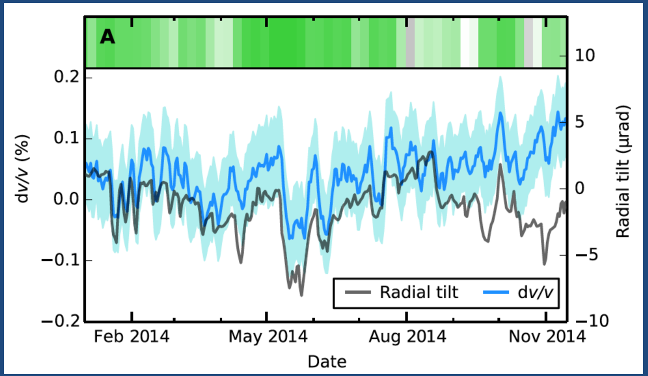
Great Sitkin
Photo: Ryan Hazen, 2021

AMBIENT NOISE MONITORING



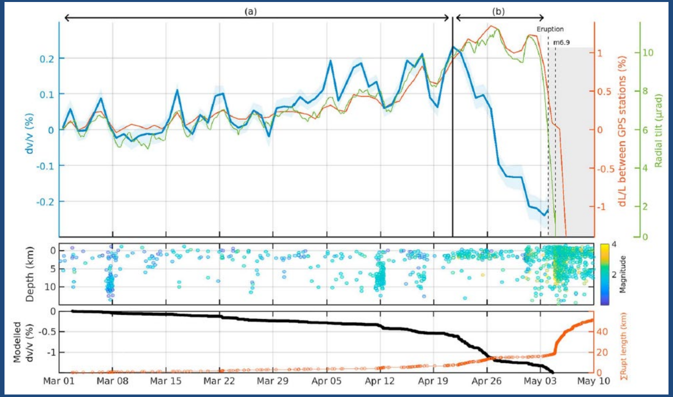
[Brenguier *et al*., 2008; Nat. Geosci.]

- Magma intrusions need not trigger significant seismicity
- In such cases, subtle changes in subsurface elastic properties may be the only indication an intrusion took place
- Of interest given eruptions of Okmok (2008) and Pavlof (2016) in Alaska lacked extensive precursors

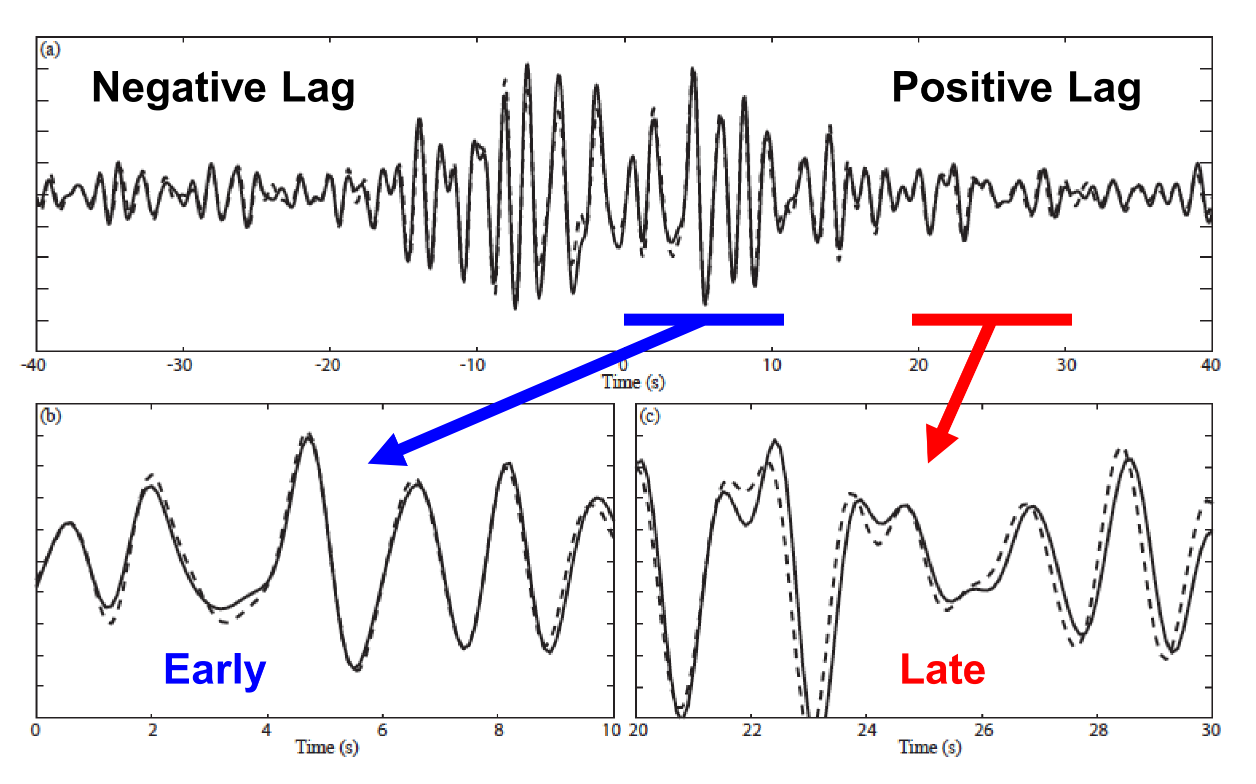


[Donaldson *et al*., 2017; Sci. Adv.]

[Olivier *et al*., 2019; GRL]



CODA WAVE INTERFEROMETRY

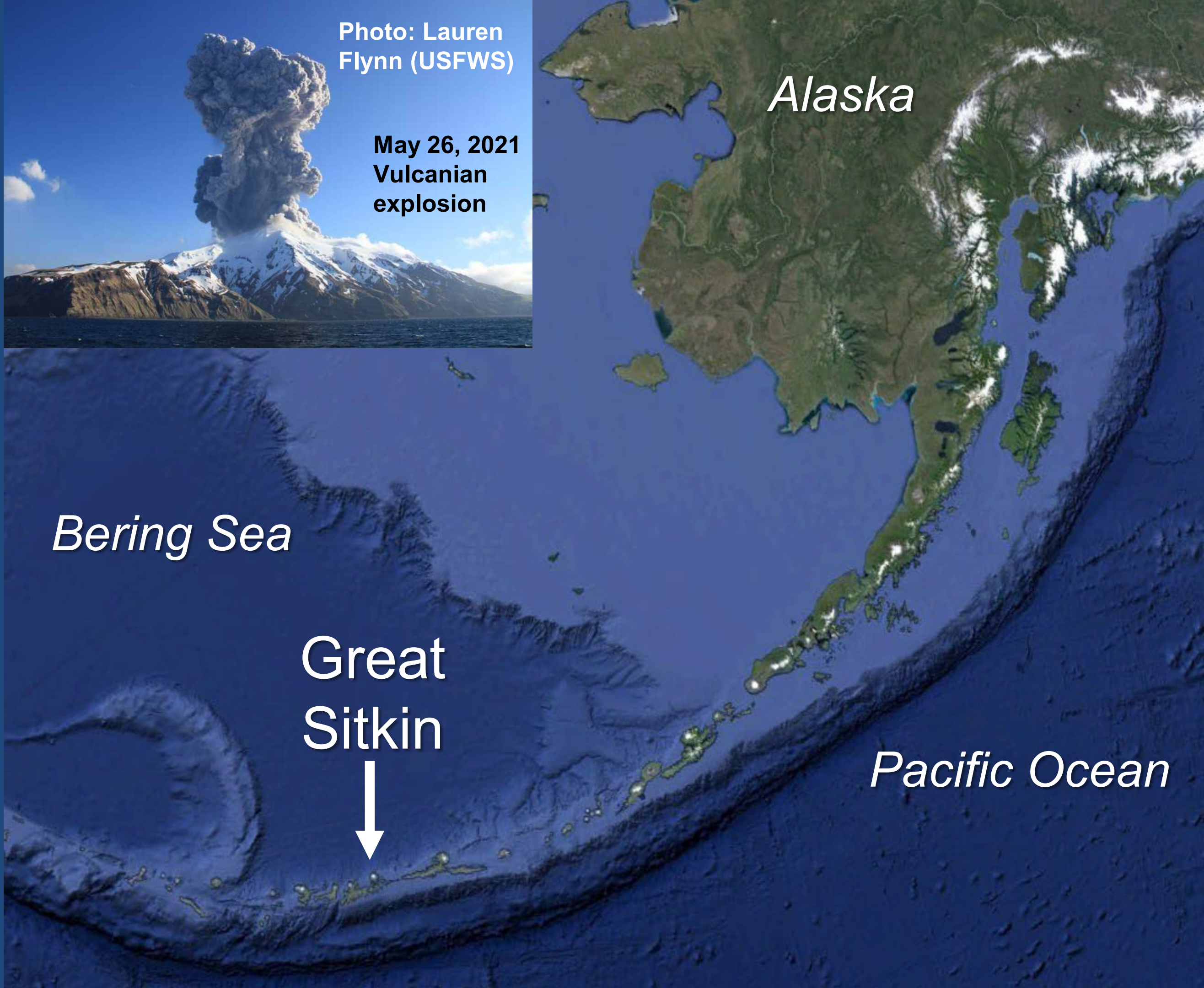


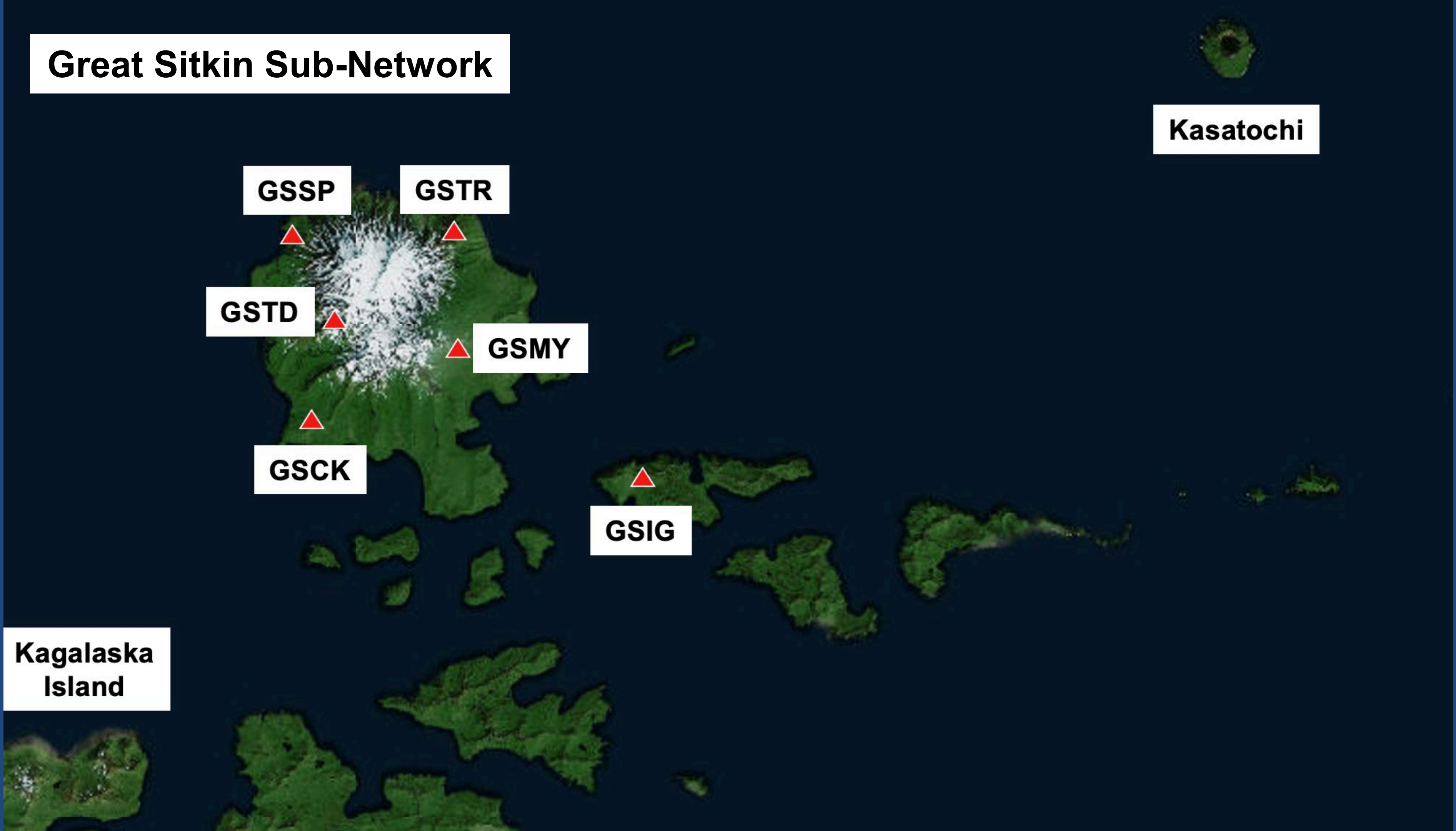
[Bennington *et al*., 2015; JGR]

- Standard technique for coda wave interferometry (CWI) applied to ambient noise correlations
- Bandpass 0.5-2 Hz, with whitening and automatic gain control
- Correlations averaged over 12 day moving window and compared to reference
- Running time-shifts measured over 10 s windows up to 50 s lag if good similarity
- Linear fit to obtain dv/v
- Quality control applied

Great Sitkin

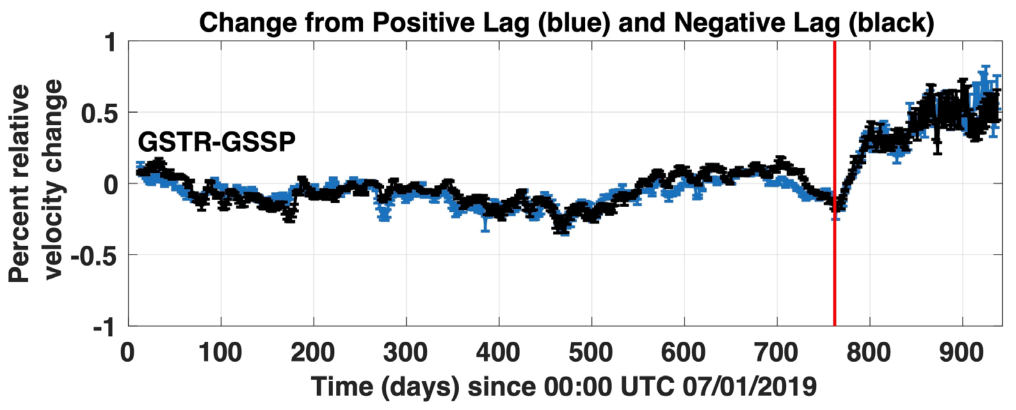
- Primarily andesitic stratovolcano with eruption beginning in 2021
- Previous magmatic eruption in 1974
- Local seismic network installed in 1999 and upgraded to digital in 2019
- Multi-year volcanic unrest starting in 2017 with an increase in earthquakes and phreatic explosive events
- Prior to 2017, most significant recent activity a swarm in 2002

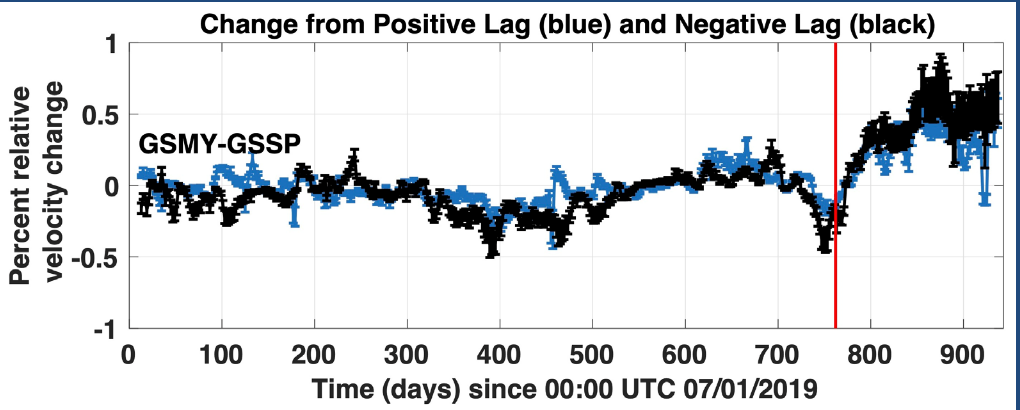



Great Sitkin Sub-Network
Kasatochi
GSSP
GSTR
GSTD
GSMY
GSCK
GSIG
Kagalaska Island

VELOCITY CHANGE

August 1

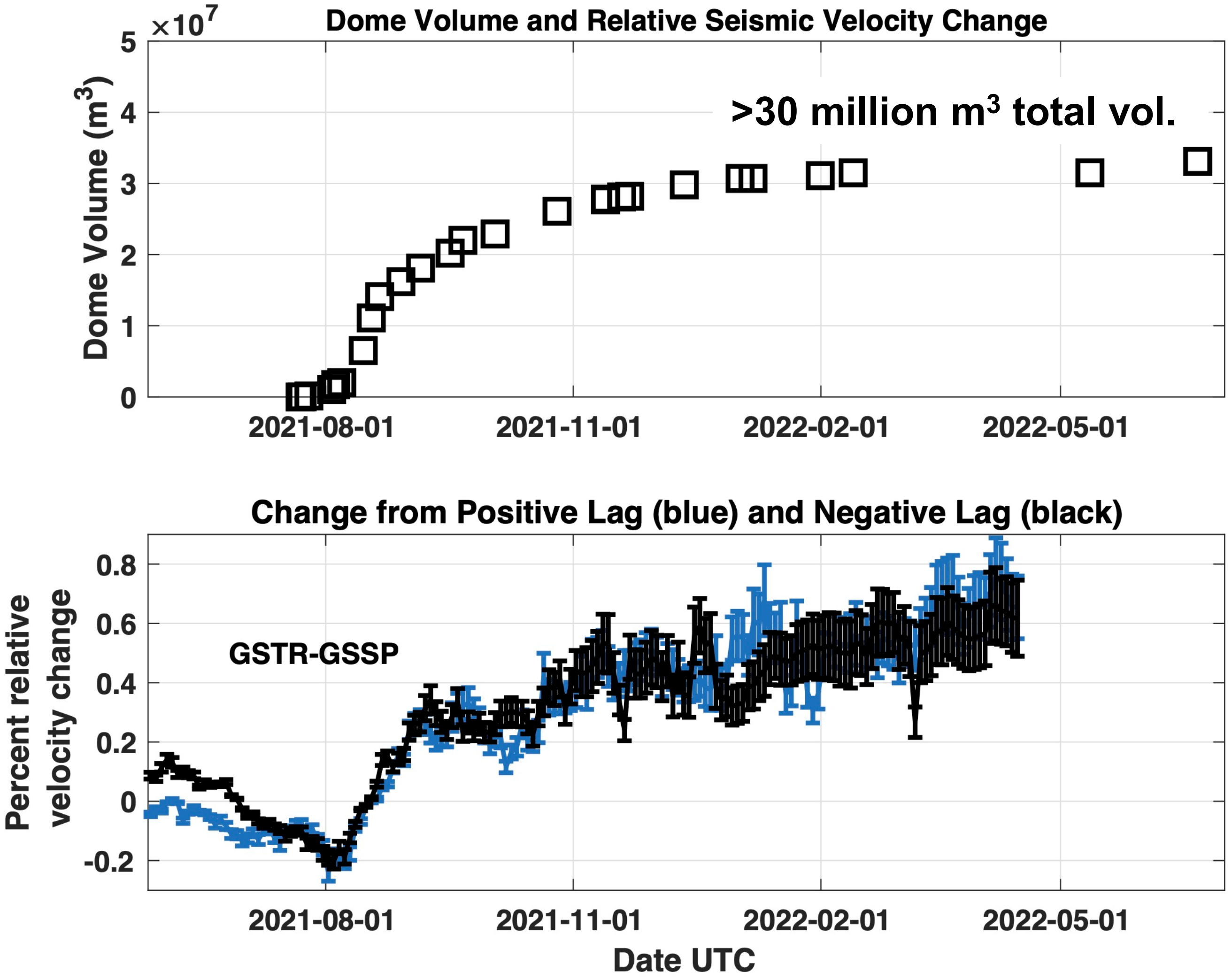




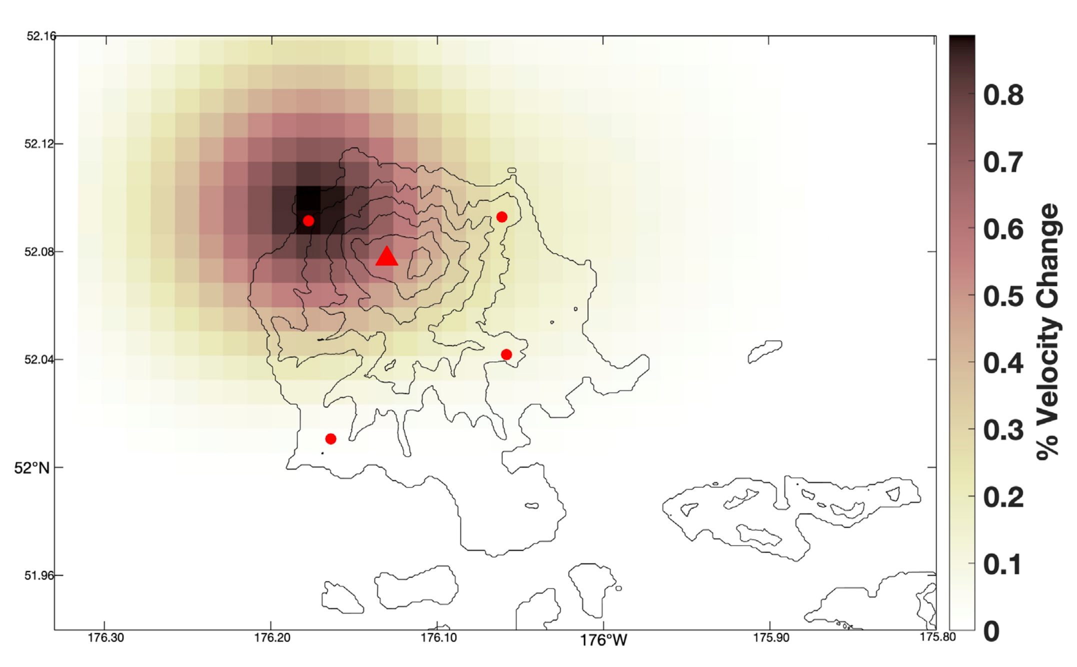
- Velocity increase observed island-wide after August 1, 2021
- No obvious velocity anomalies prior to dome extrusion or the May 26 Vulcanian explosion
- Similar velocity increase reported during dome growth at Merapi [Wegler *et al*., 2006]
- Opposite effect (velocity decrease) observed at Montserrat following explosive destruction of the dome [Baptie, 2010]
- Total of 10 correlations available from 4 local stations: 6 cross-correlations and 4 auto-correlations
- Good azimuthal coverage

VELOCITY CHANGE VS. DOME VOLUME

- Clear correspondence between growth of the dome and velocity increase
- Dome volume measured on very-high-resolution satellite imagery (e.g., Worldview multispectral, SWIR)
- Velocity change time series stops in late April 2022 due to data outage



VELOCITY CHANGE TOMOGRAPHY



Relative changes inverted w/method of Obermann *et al*. [2013; JGR]

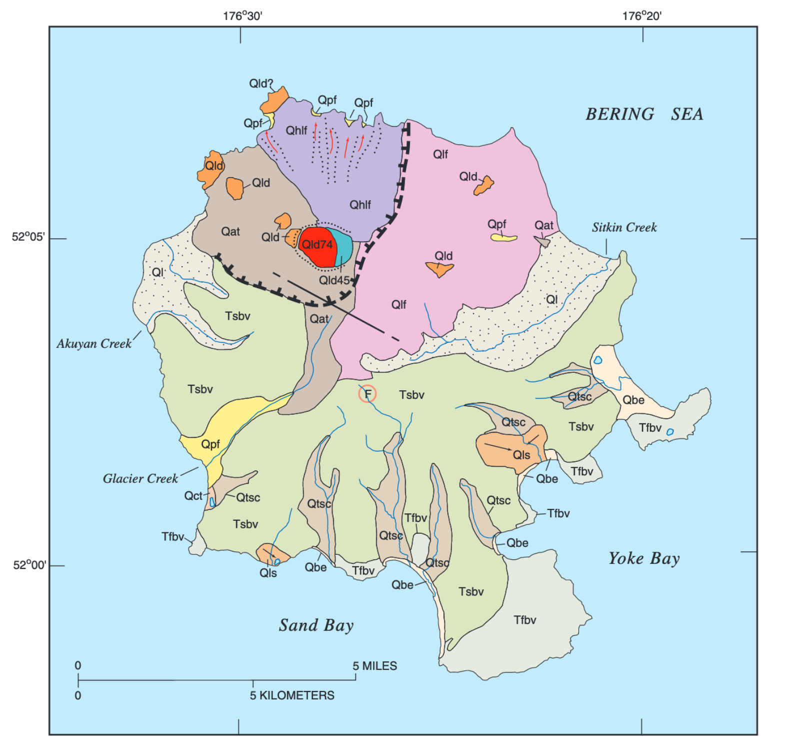


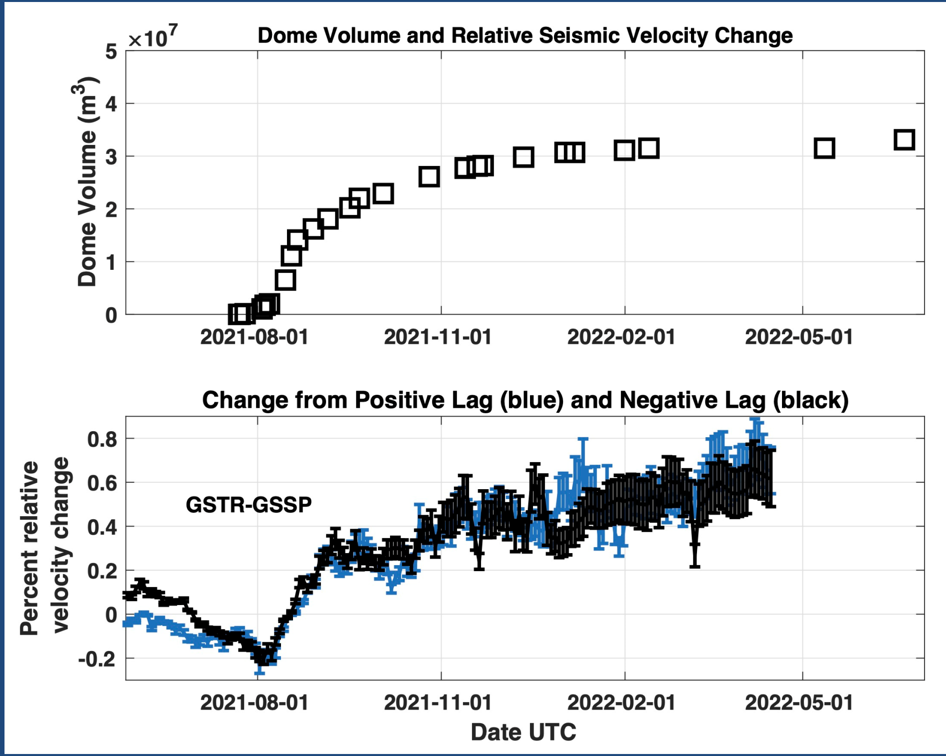
Figure 4. Generalized geology of Great Sitkin Volcano.

- Largest change not centered on the volcano's summit, but on NW flank where edifice failure has occurred
- NW side weaker and has higher susceptibility to applied stress from the weight of the dome and subsidence of the volcano

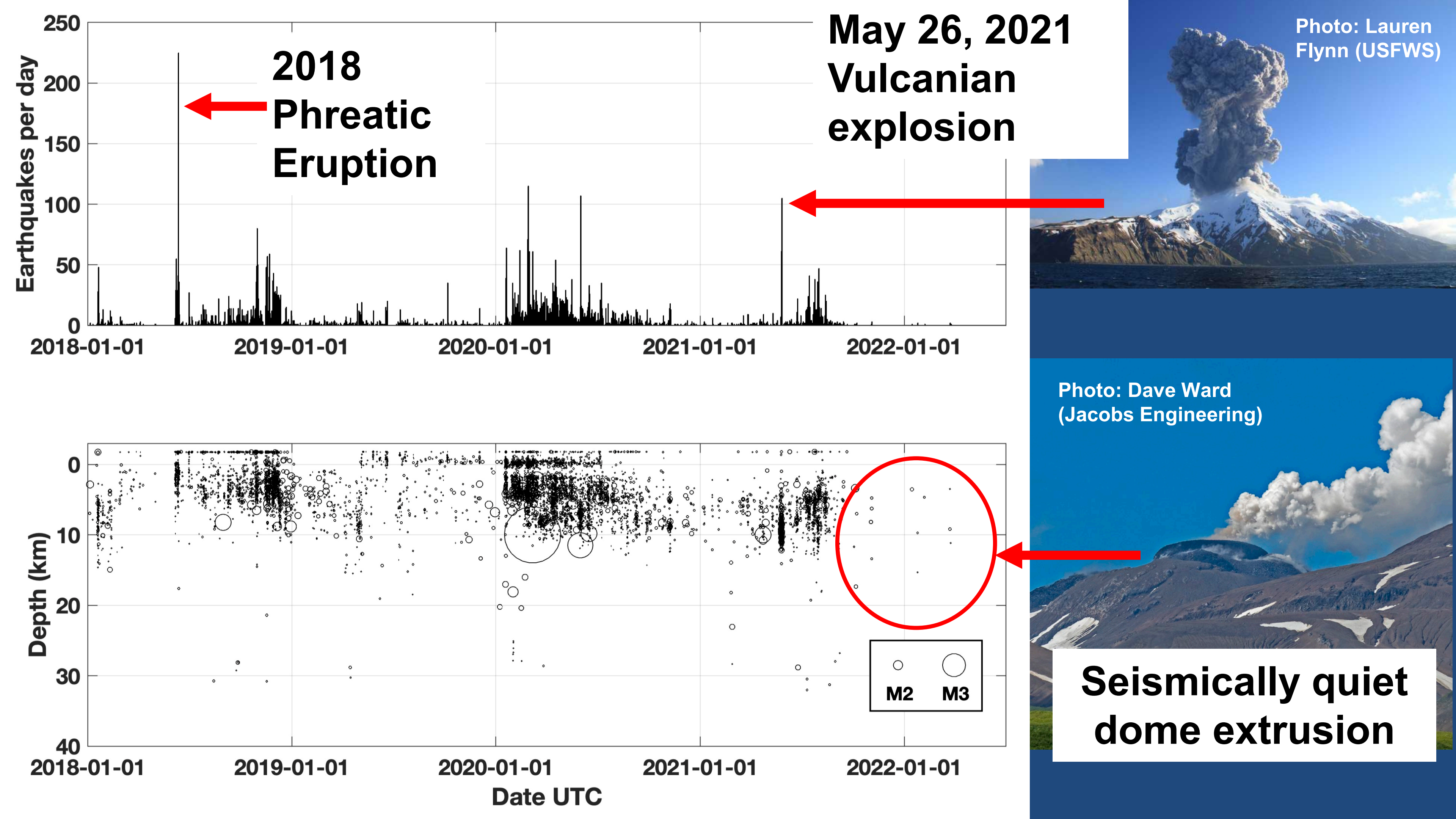
[Waythomas *et al*., 2003]

CONCLUSIONS

- Clear seismic velocity increase during dome emplacement at Great Sitkin
- Any pre-eruptive velocity changes much smaller than co-eruptive change
- Location of velocity increase centered on NW side of island at location of previous edifice failure
- Lateral variation in velocity susceptibility to applied stress of the dome causes anomaly to not be centered about the summit
- Future work will analyze three-component correlations



Extra slides if needed for Q&A



2018 Phreatic Eruption
May 26, 2021 Vulcanian explosion
Photo: Lauren Flynn (USFWS)
Earthquakes per day
250
200
150
100
50
0
2018-01-01
2019-01-01
2020-01-01
2021-01-01
2022-01-01
Photo: Dave Ward (Jacobs Engineering)
Depth (km)
0
10
20
30
40
M2
M3
Date UTC
Seismically quiet dome extrusion

Merapi

- Used active source airgun in pool of water for repeatable signal instead of noise
- Similar observation of velocity increase during dome growth and also variability on different flanks of the volcano

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L09303, doi:10.1029/2006GL025928, 2006

Increase of shear wave velocity before the 1998 eruption of Merapi volcano (Indonesia)

U. Wegler,[1] B.-G. Lühr,[2] R. Snieder,[3] and A. Ratdomopurbo[4]

Received 1 February 2006; revised 9 March 2006; accepted 14 March 2006; published 10 May 2006.

[1] We infer temporal changes in the elastic properties of the edifice of Merapi volcano (Java, Indonesia) before its eruption in 1998 by analyzing multiply scattered elastic waves excited by a repeatable controlled seismic source. A pre-eruptive increase of shear wave velocity, which correlates well with pre-eruptive seismicity and dome-growth is revealed. The method can be used as a "pressure-gauge" for pressure changes inside of volcanoes, because increasing pressures in rocks are known to cause proportionally increasing elastic wave velocities. **Citation:** Wegler, U., B.-G. Lühr, R. Snieder, and A. Ratdomopurbo (2006), Increase of shear wave velocity before the 1998 eruption of Merapi volcano (Indonesia), *Geophys. Res. Lett.*, *33*, L09303, doi:10.1029/2006GL025928.

uses multiply scattered waves, which traveled through the volcanic edifice along numerous paths, to infer tiny temporal changes in the mean shear wave velocity. Using this method we are able to monitor temporal changes in relative velocity with an accuracy as small as $\delta v/v = 2 \times 10^{-4}$. Previously, such temporal changes were observed e. g. in fault zones comparing data before and after large earthquakes [*Poupinet et al.*, 1984; *Nishimura et al.*, 2000]. At Merapi volcano earthquake multiplets were studied to infer an increase of shear wave velocity of 1.2% 8 months before the 1992 eruption [*Ratdomopurbo and Poupinet*, 1995]. Unfortunately, in that study the observation of an increasing velocity ended 4 months before the eruption. Because no more similar earthquakes occurred, further analysis was

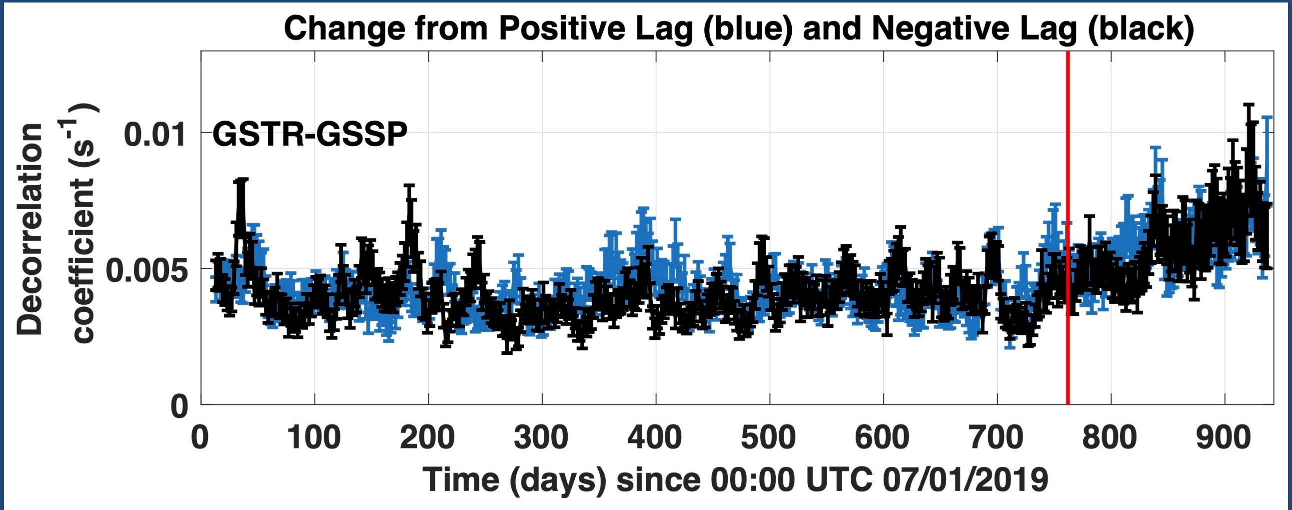
4. Discussion

[9] Within our simple model we cannot explain the decrease of velocity, which was observed for source BAT during the quite period (23–30 June). Clearly, there is no simple model for this observation, because the volcano shows different behavior on its north-eastern slope compared to its southern slope. However, the two different shot-

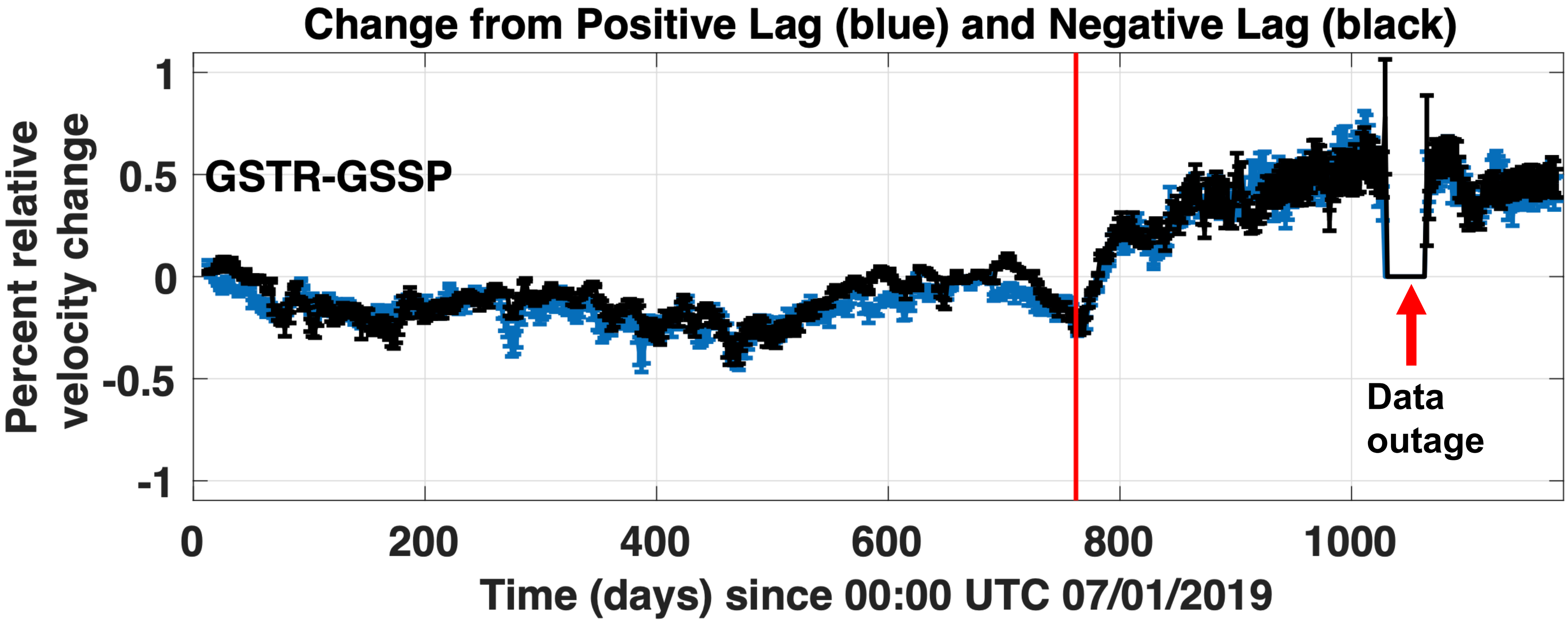
[Wegler *et al.*, 2006]

ADDITIONAL MEASUREMENT: DECORRELATION

- Uses correlation coefficient value instead of time-lag
- Measure of changing wave scattering properties in subsurface
- Future work will apply tomography to it



Linear anomaly after August 1



Differences with earthquake variations:

- Velocity increase instead of decrease
- No weeks-to-months-long healing of velocity

Great_Sitkin

10 June, 2018 18:10 - 21:10 UTC

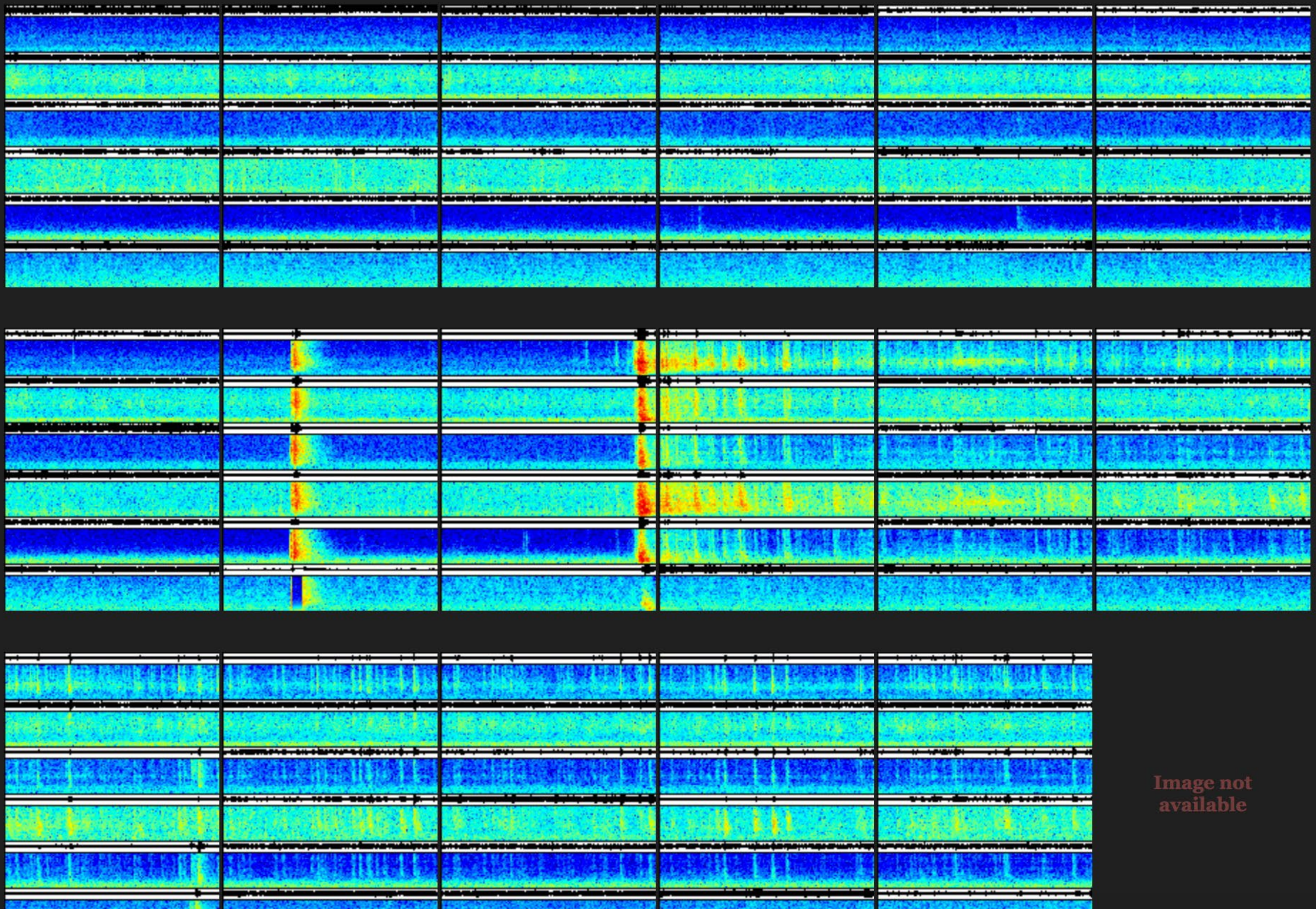
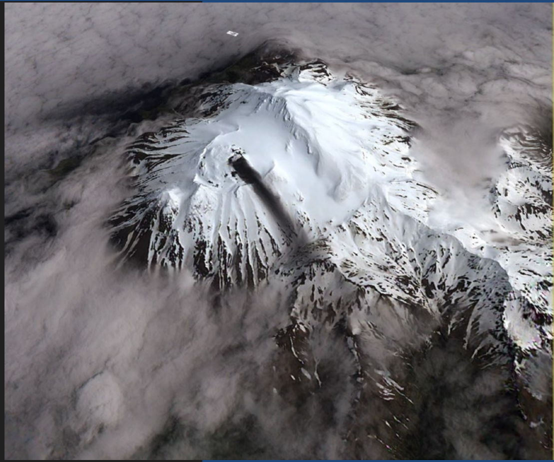


Image not available

20:10 UTC

21:10 UTC



Great Sitkin Phreatic Explosion June 10, 2018

Great Sitkin Magmatic Explosion: May 26, 2021