

Meter-scale deformation on the Reykjanes Peninsula 2020-2024: a volcano-tectonic rifting episode

Halldór Geirsson,

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Nordvulk, Institute of Earth Sciences, University of Iceland; Icelandic Meteorological Office; GNS Science, New Zealand

NKG, Mar. 12, 2024



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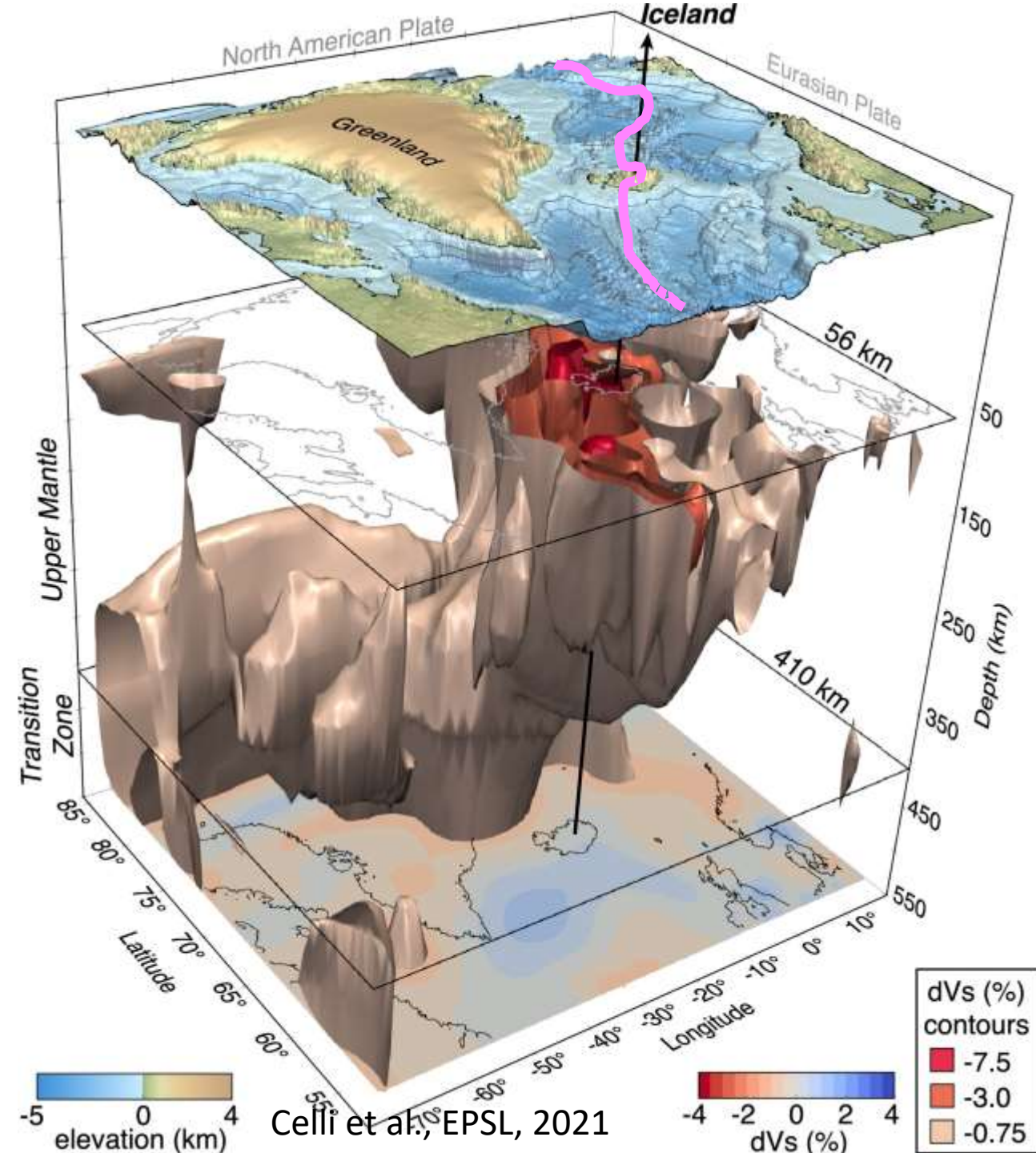
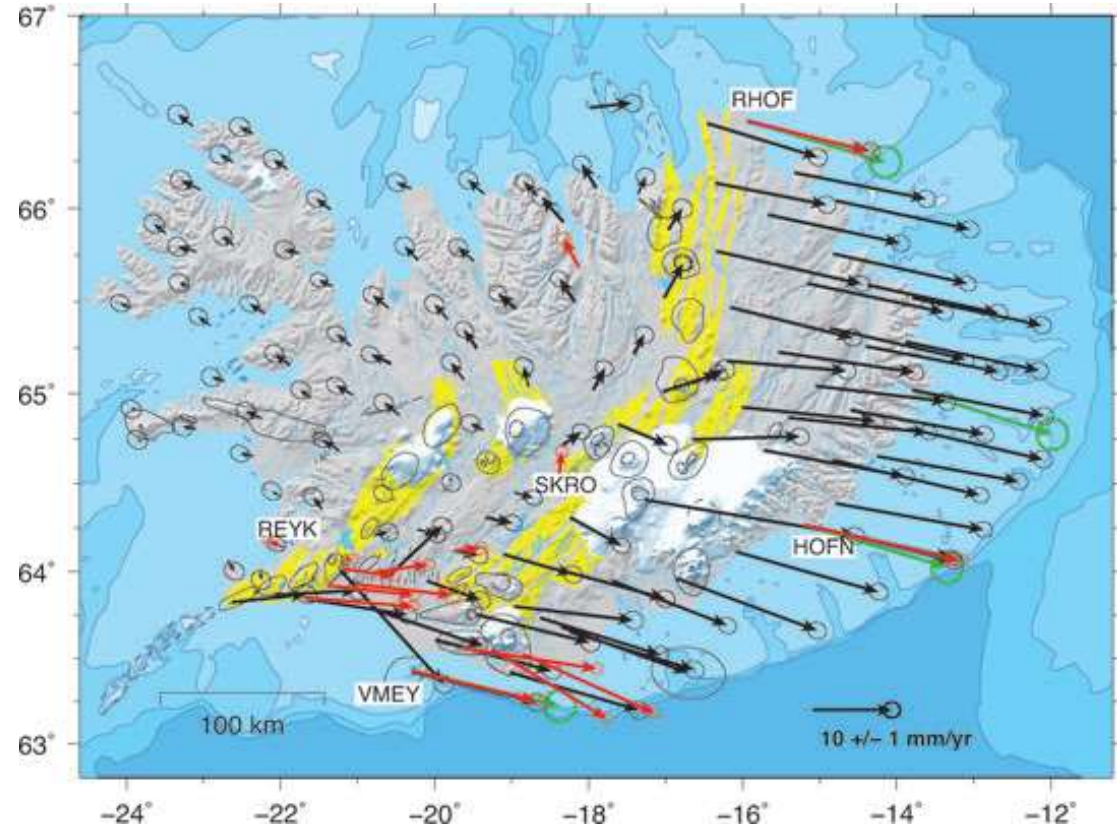
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AI?
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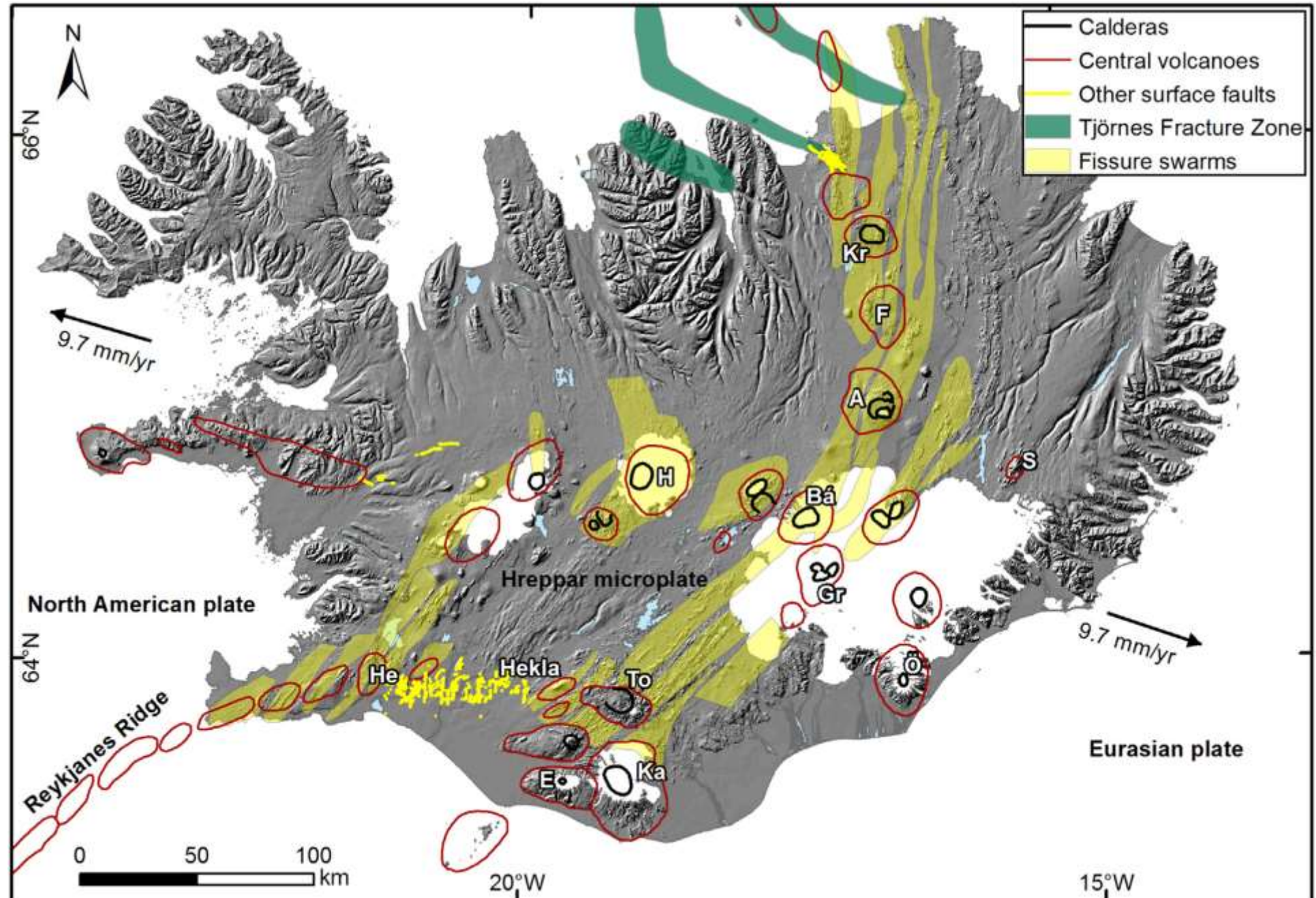


Photo: Almannavarnir

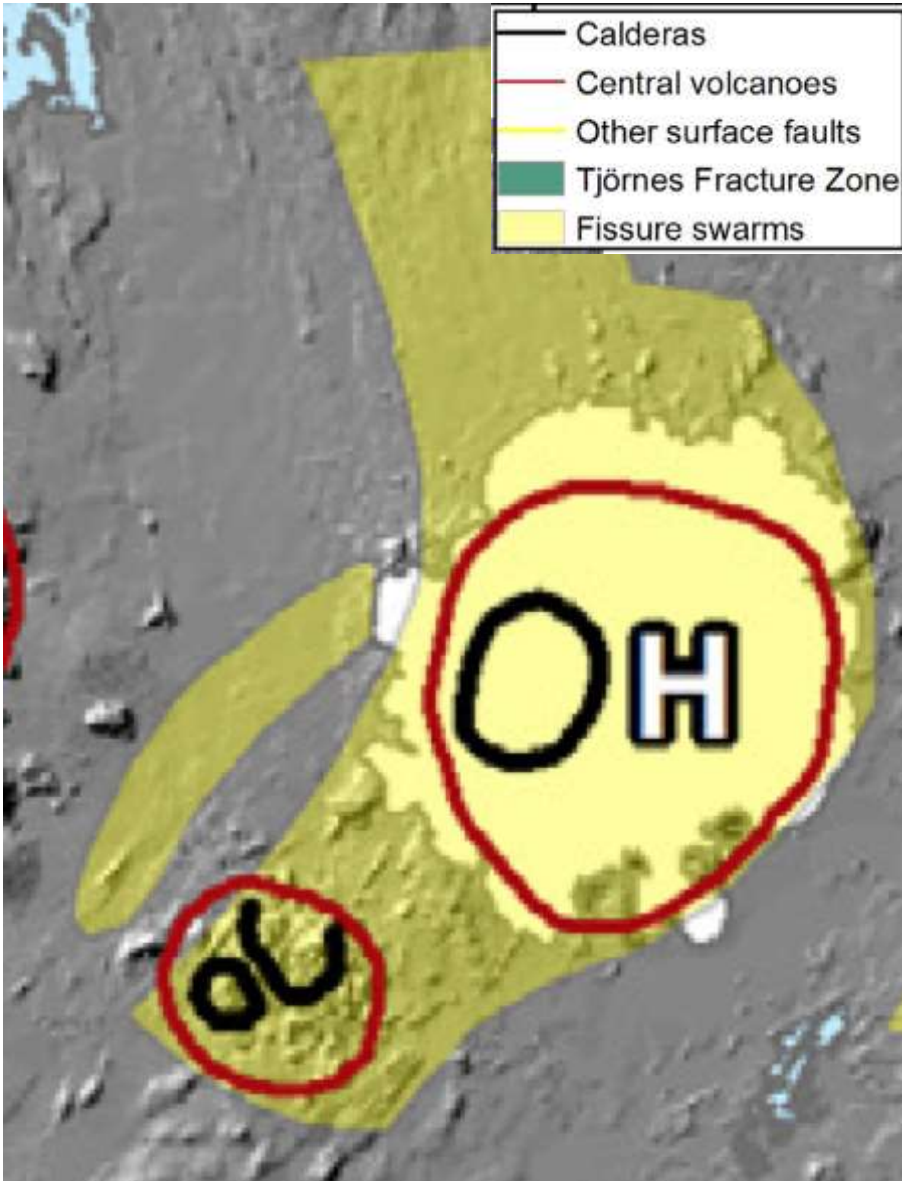
The two main geodynamic drivers in Iceland are the Iceland hotspot and EU-NA plate motion (1.8-1.9 cm/yr). GIA is also important (up to 3.5 cm/yr)



Terminology: Volcanic systems, central volcanoes, calderas, fissure swarms



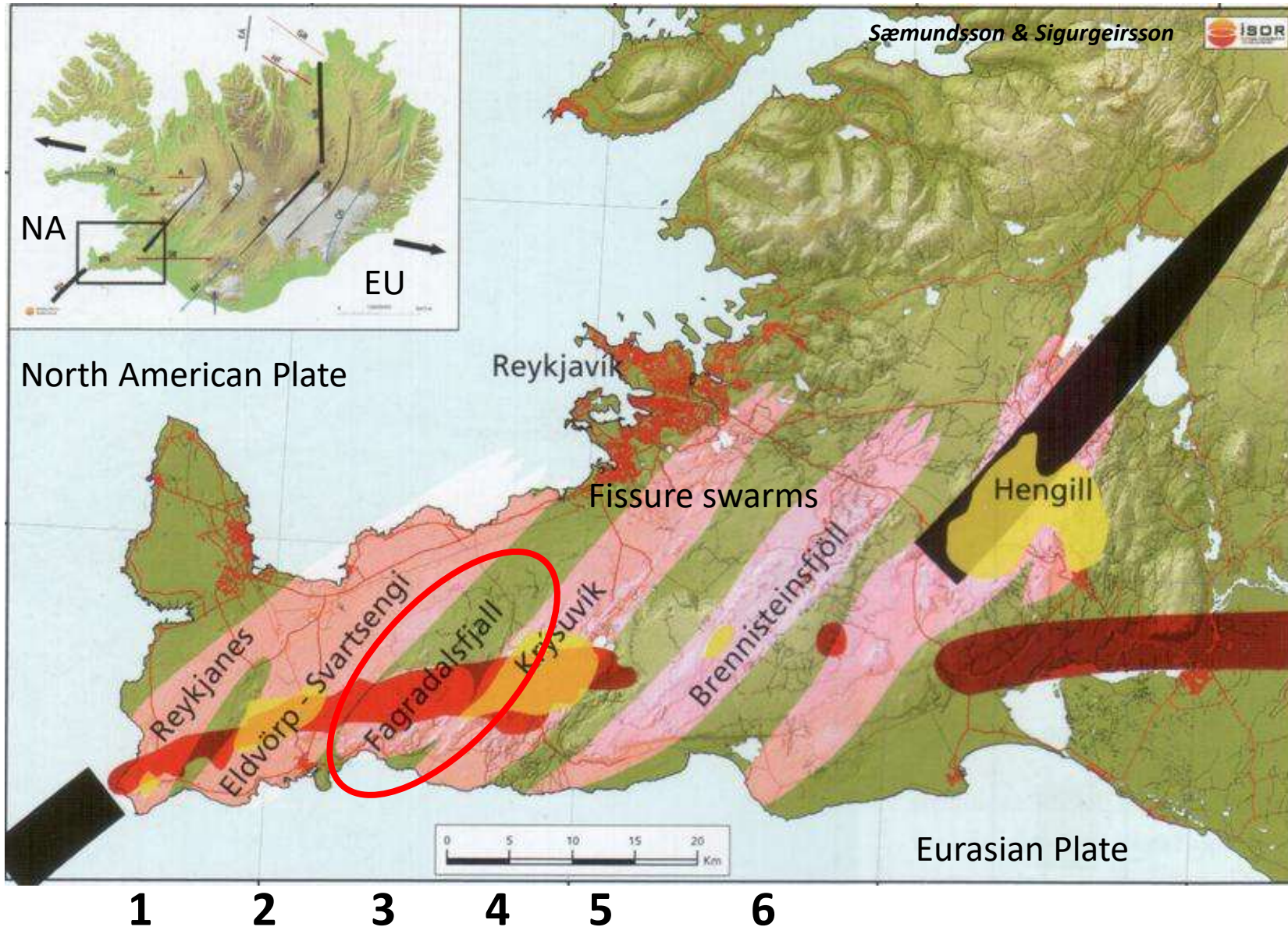
Volcanic systems



A volcanic system has some or all of the following characteristics:

1. A central volcano or a center of production
2. A distinct petrological signature (“geochemical fingerprint”)
3. A transecting *fissure swarm*
4. Caldera
5. Geothermal system

Tectonics and volcanic systems of the Reykjanes Peninsula



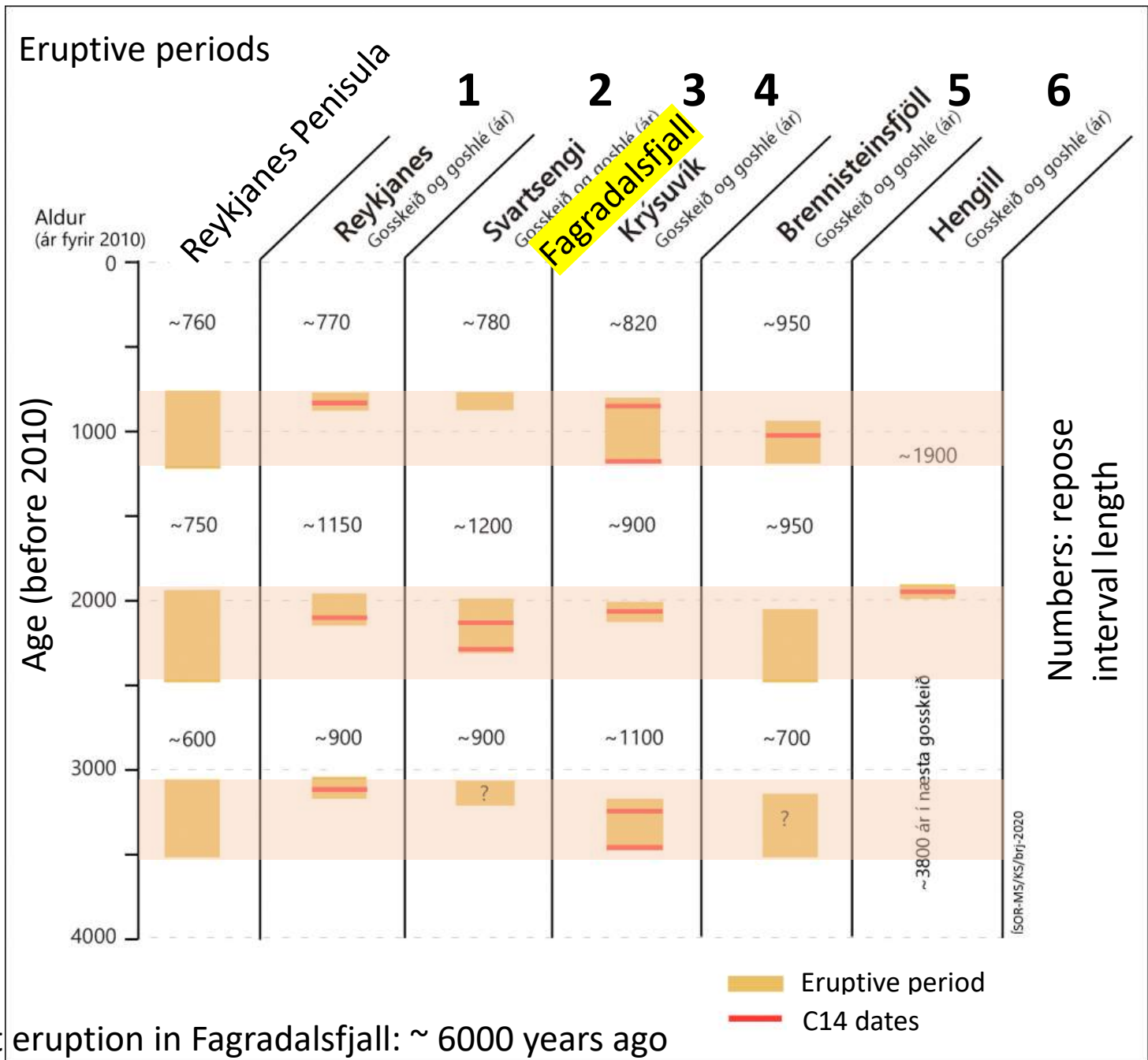
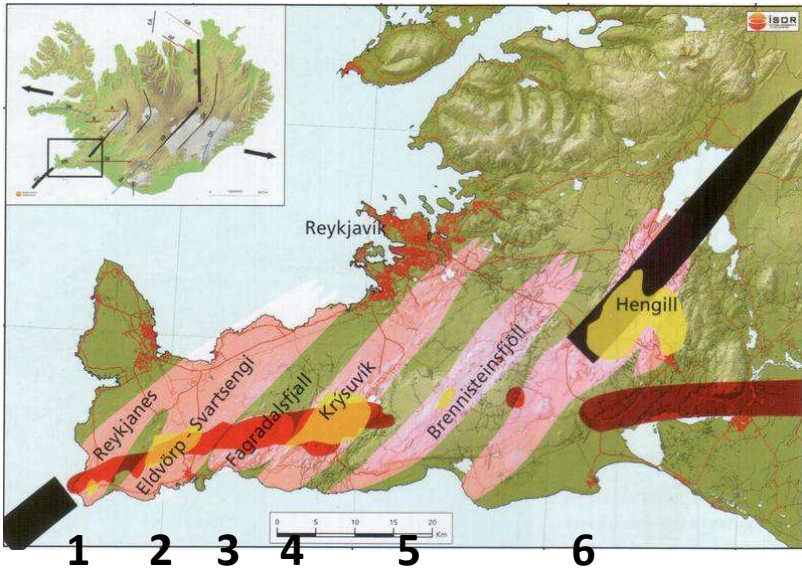
- Oblique, or trans-tensional, plate boundary (19 mm/yr) → builds stresses
- “Backyard” of Iceland’s capital, Reykjavík
- Approximately 6 “volcanic systems”
- **All but Brennisteinsfjöll (#5) have shown signs of magma movements in the past 5 years**

Reykjanes Peninsula: Eruptive episodes every ~800-1000 years

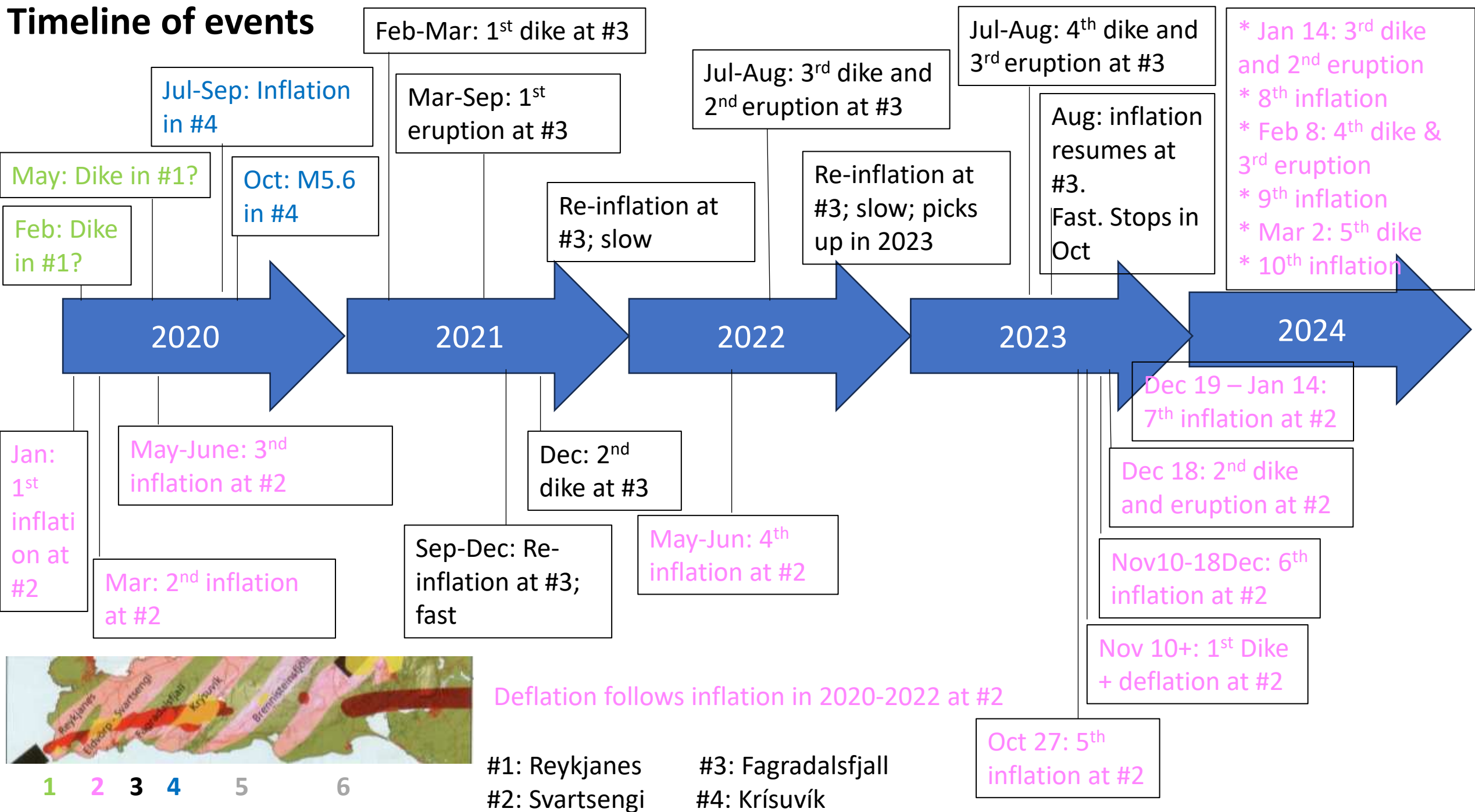
Each episode lasts for about 200-400 years, then quiescence for 600-1000

Last eruption: 1241 CE

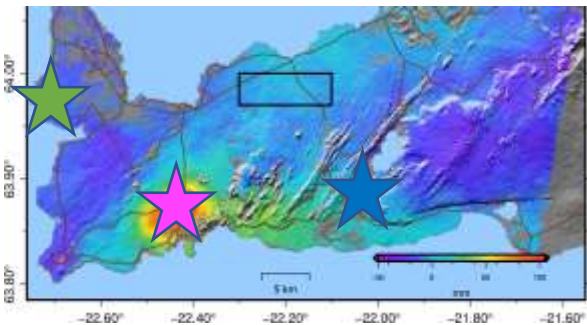
Is one event triggering the next, or are they all triggered from below?



Timeline of events

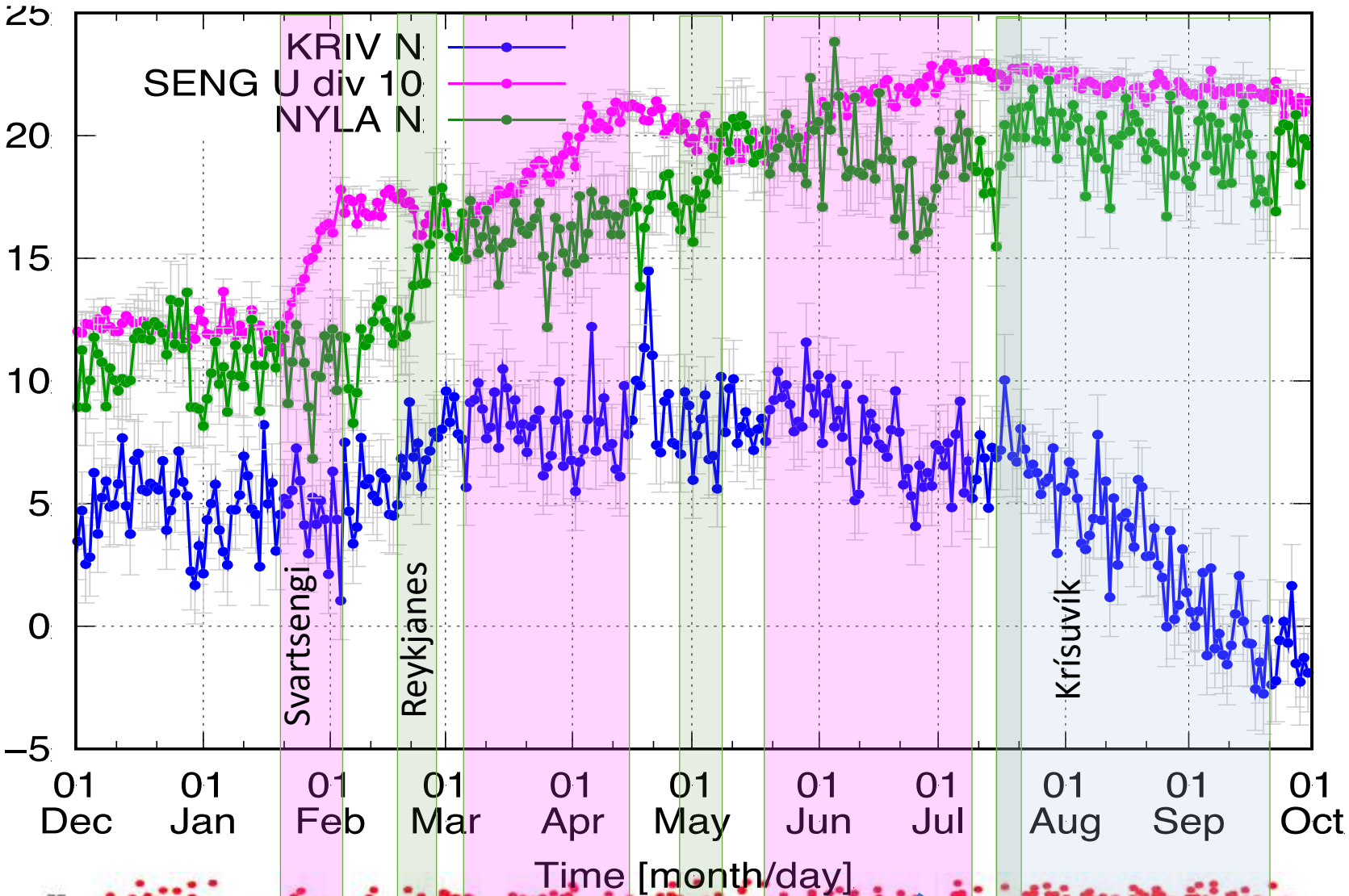


2020: Unrest alternated between different parts of the Reykjanes Peninsula

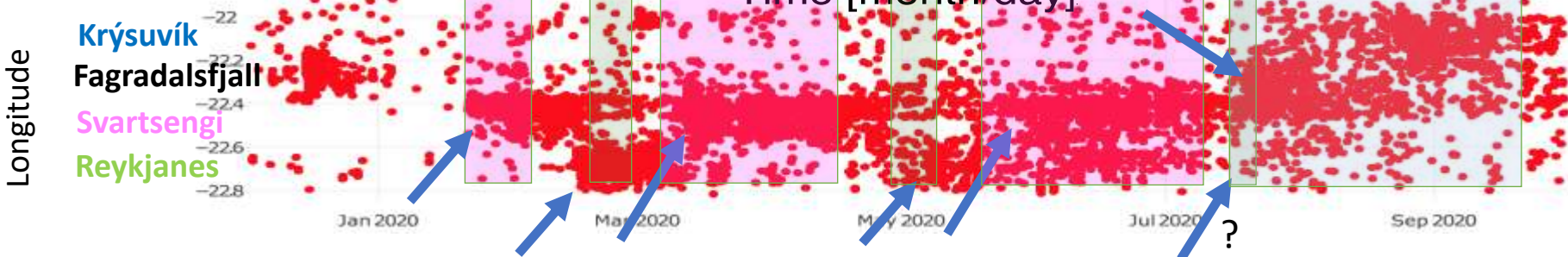


GPS time series from three different systems: Reykjanes (#1), Svartsengi (#2), Krýsuvík (#4)

Displacement [mm]



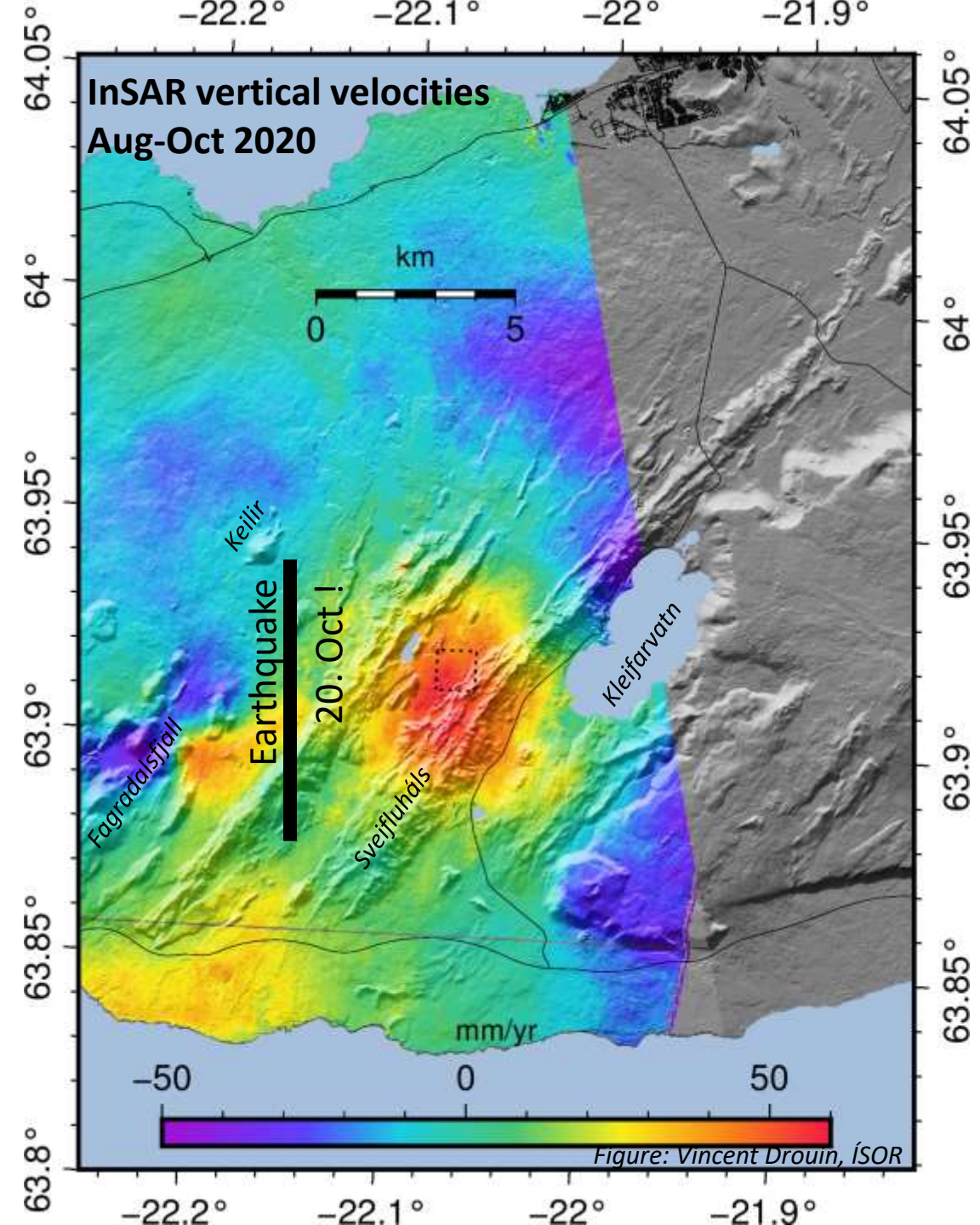
Seismicity at the Reykjanes Peninsula by longitude



Krýsuvík (#4) inflation: late July to Sep/Oct. 2020

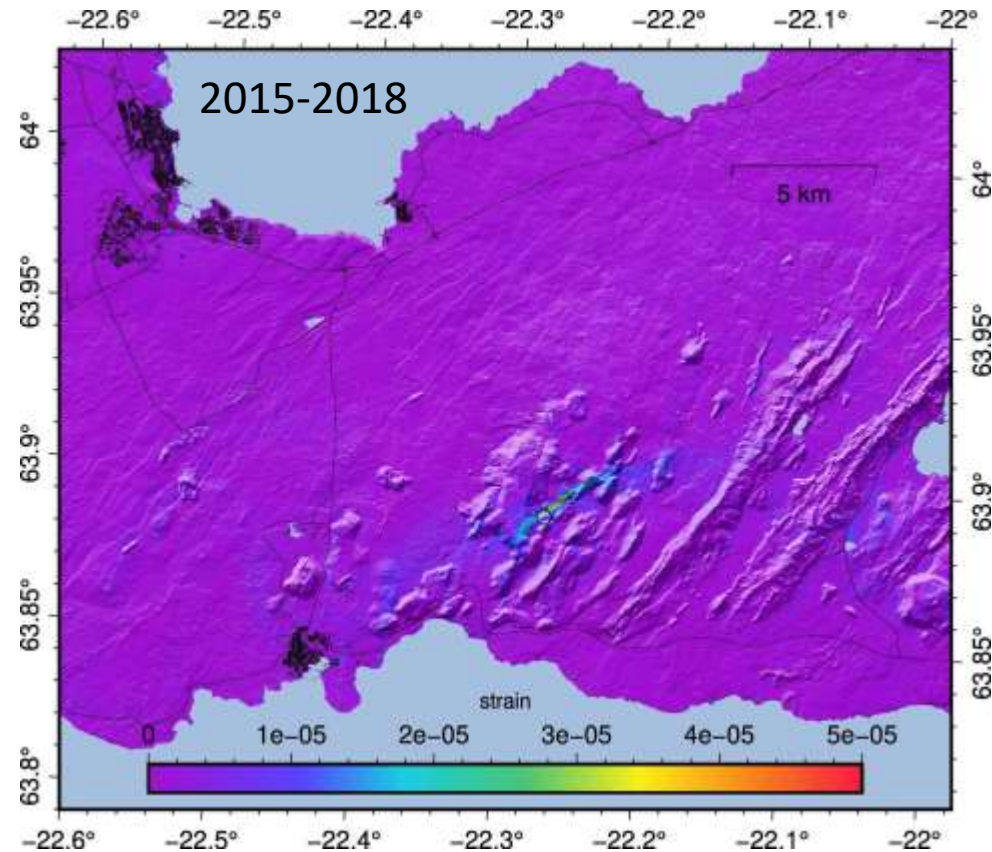
Krýsuvík inflation occurs in a similar location as two previous inflations and deflations in 2007-2019. Uplift ~ 2 cm, Depth ~ 5 km; vol. ca 5 Mm^3

Then M5.6 earthquake

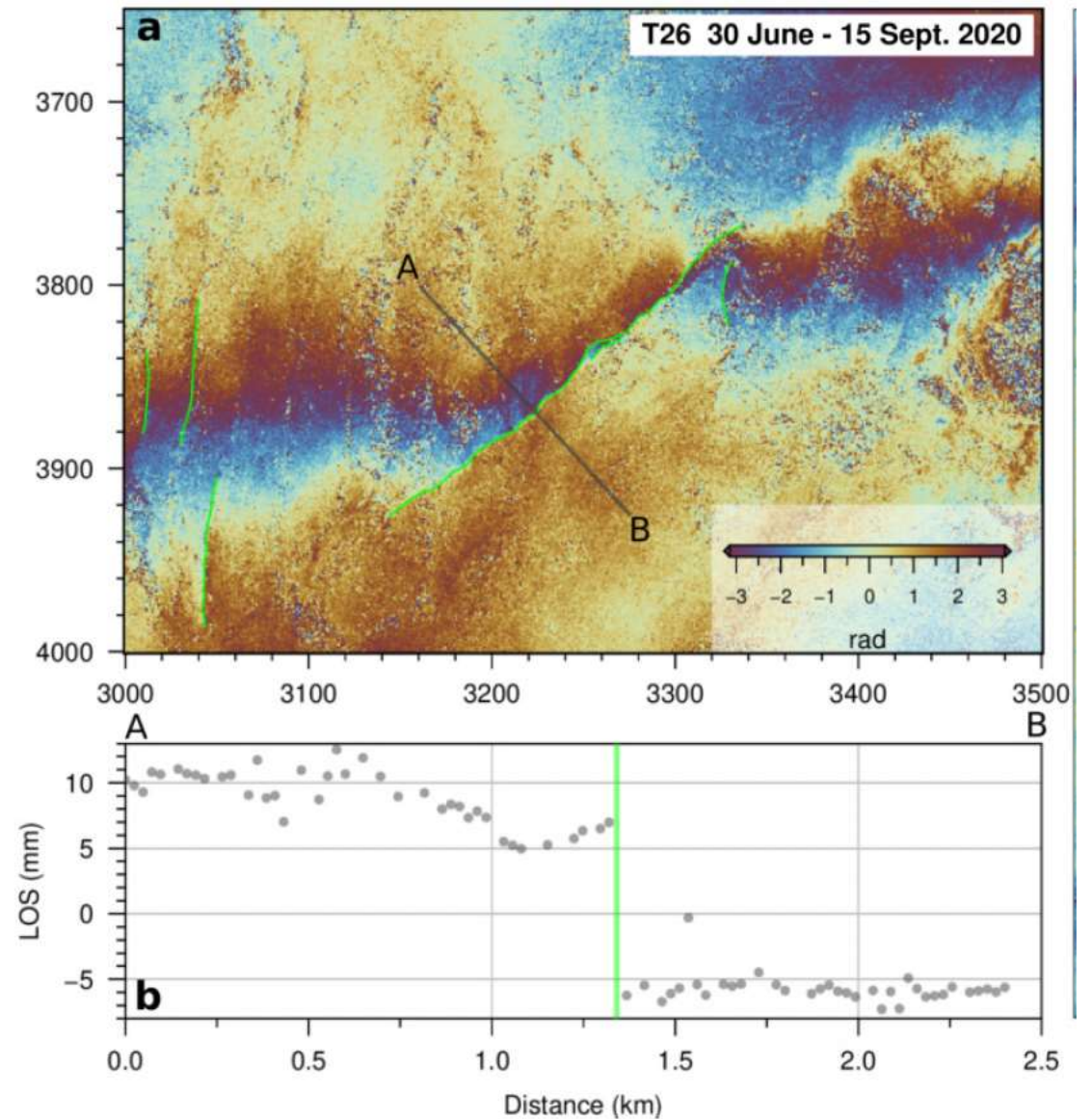


Fagradalsfjall (#3) shallow fault creep preceded the main unrest

No signs of previous magma accumulation.
But some creep (& seismicity) on a 45° striking fault which eventually coincided with the eruptive vent(s)

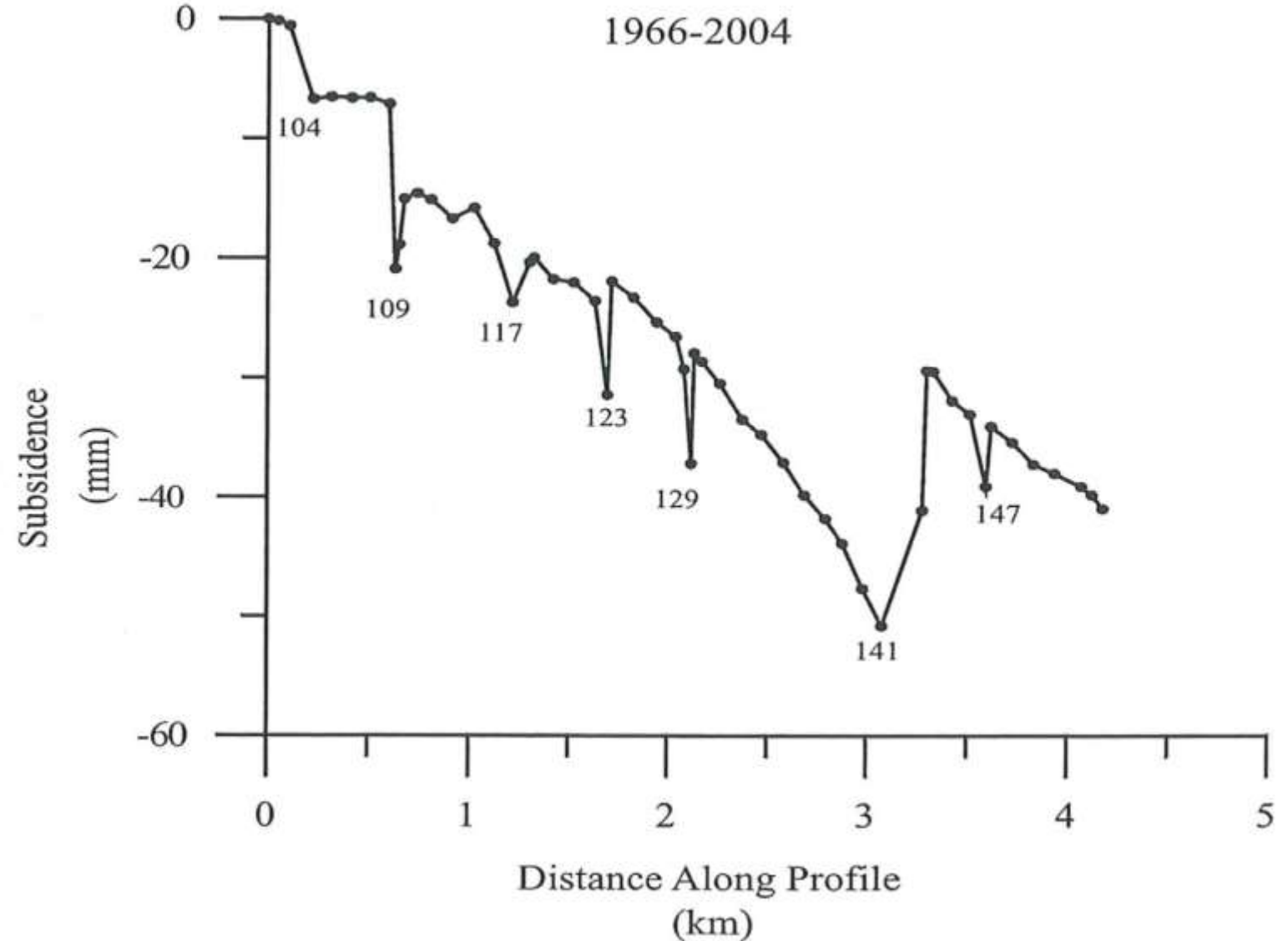


Sigmundsson et al. 2022

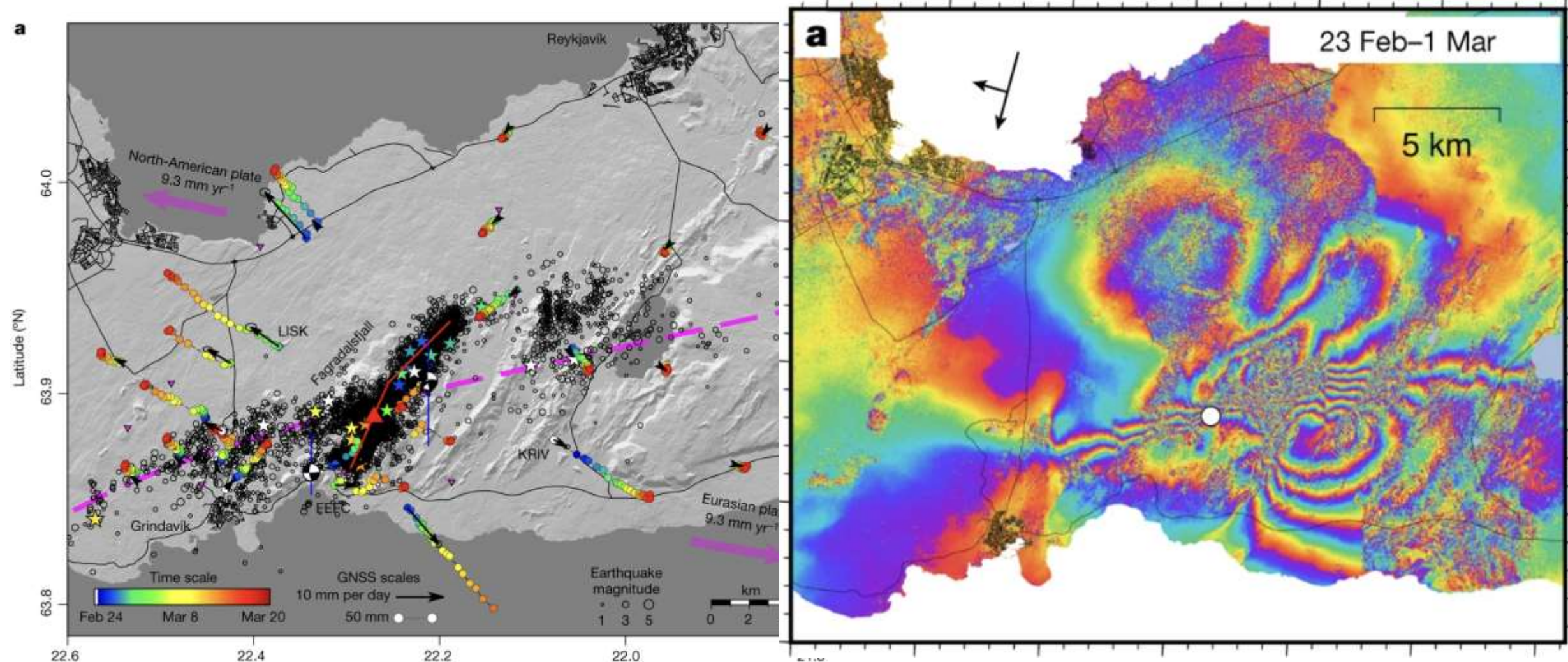


Ducrocq et al., 2023

Levelling and InSAR + GPS show no signs of long-term magma accumulation at Fagradalsfjall preceding the unrest

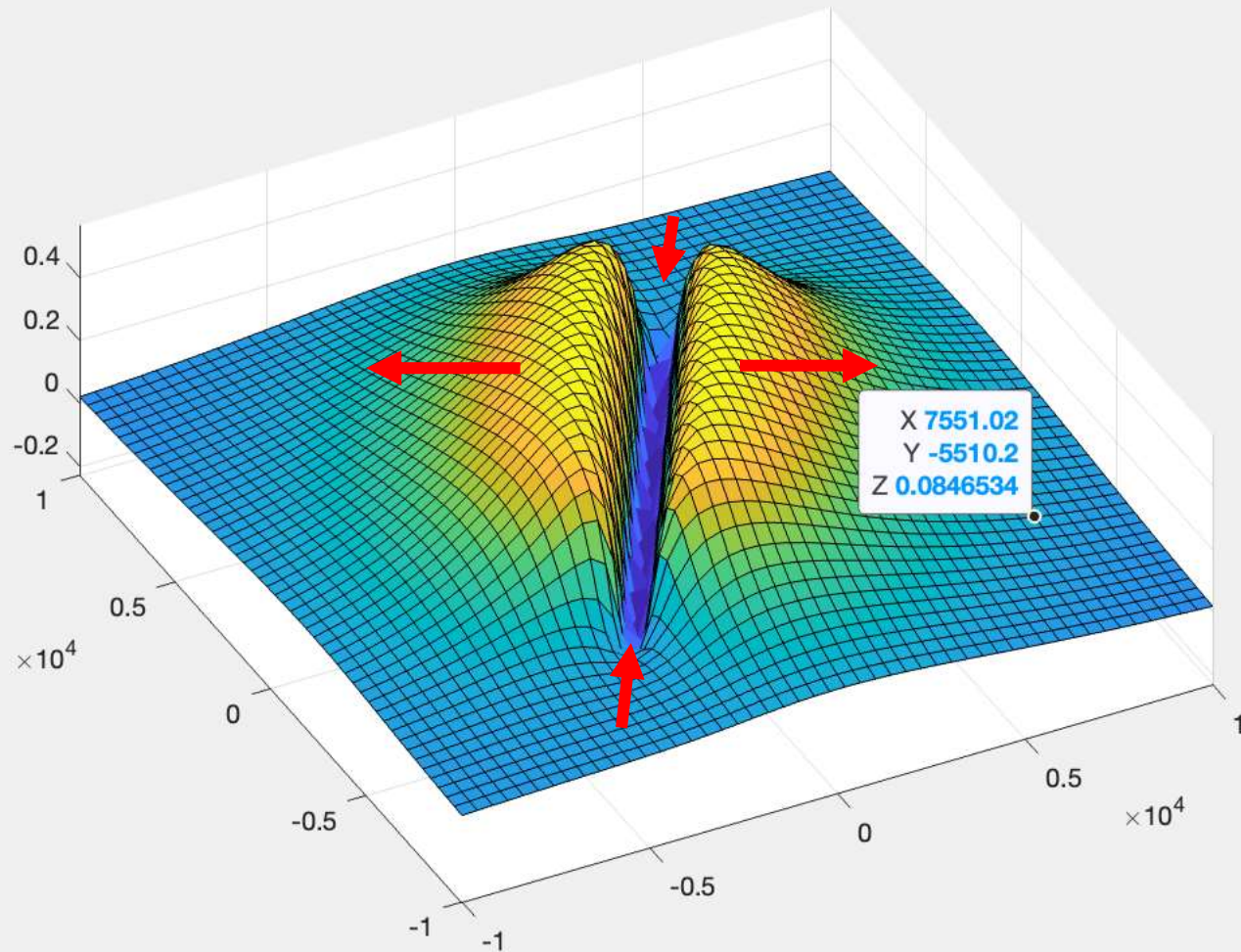


Fagradalsfjall (#3) dike and plate boundary offset Feb-Mar 2021



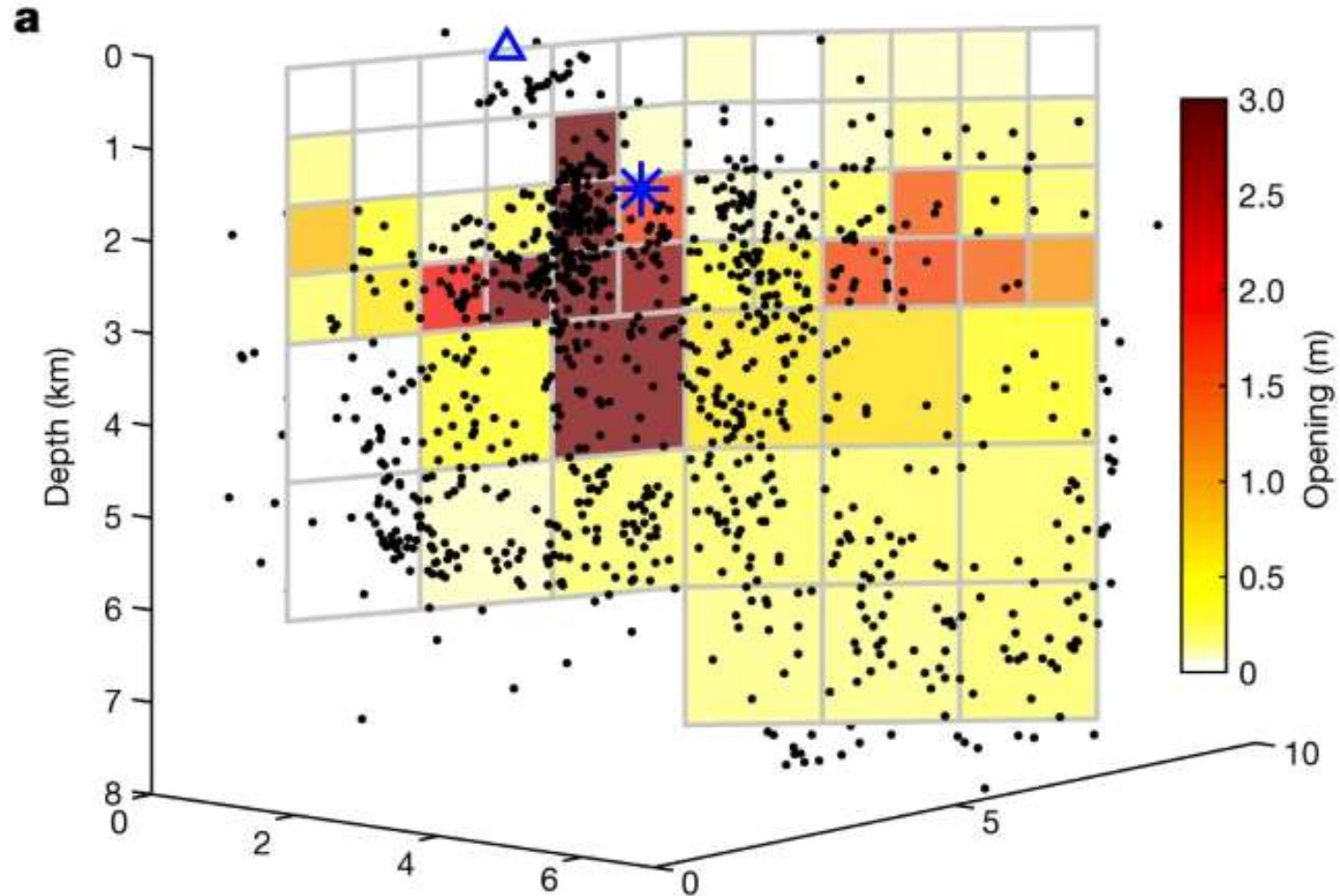
Sigmundsson et al., 2022

Dike deformation: upward and outward displacements at flanks; subsidence and inward movement in center → „graben“



Dike deformation at Fagradalsfjall: up to several meters of opening

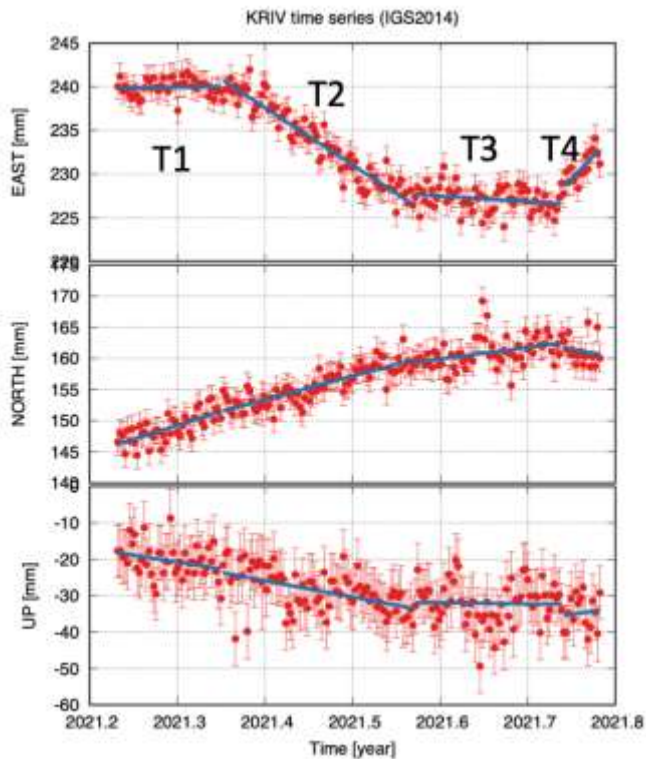
Fig. 3: Geodetic modelling results.



Mar-Sep 2021 eruption: 150 Mm³



Co-eruptive, 2021 eruption.
Small signals, deep
deflation (~10 km)



Following the end of the eruption, inflation resumed

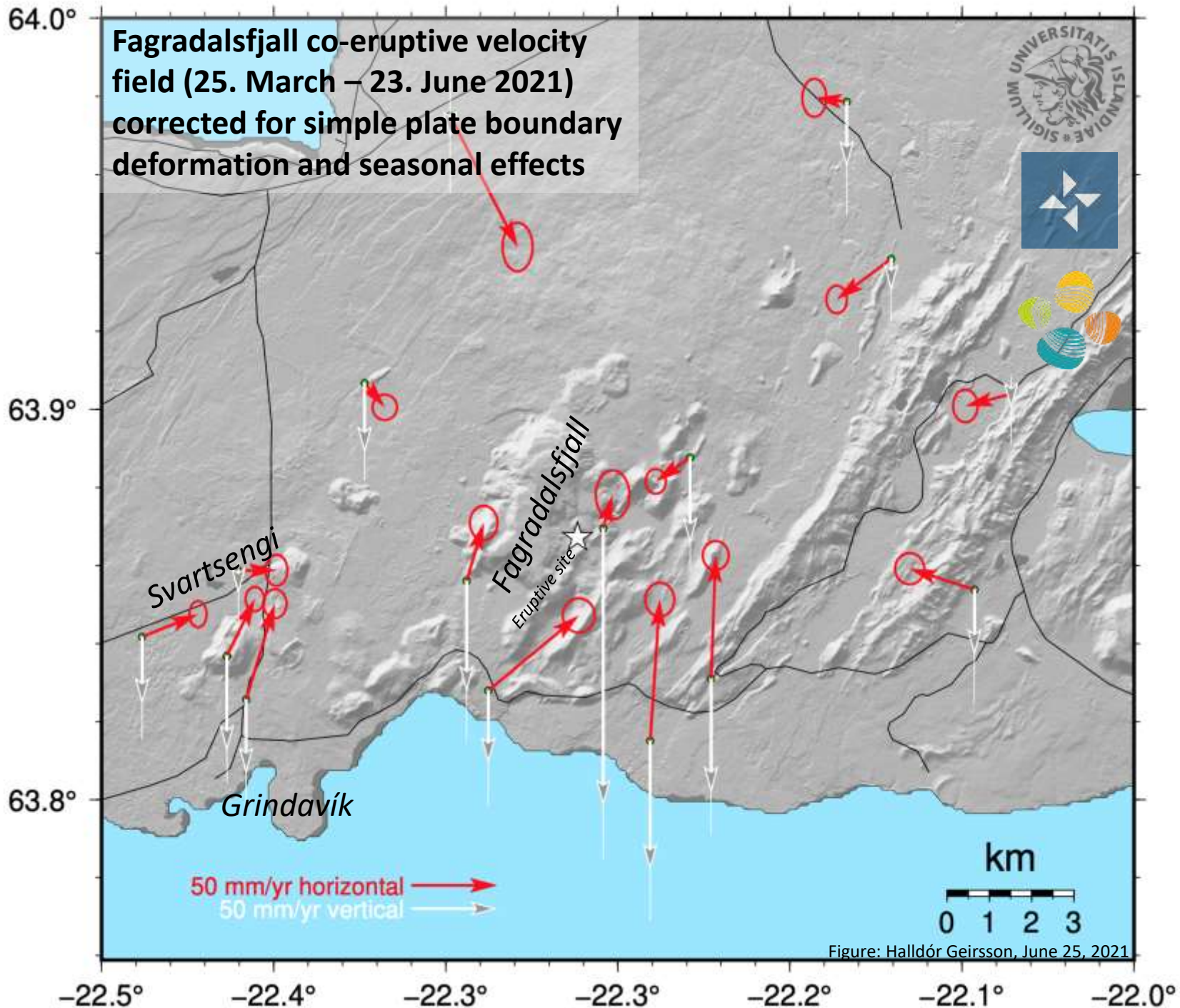
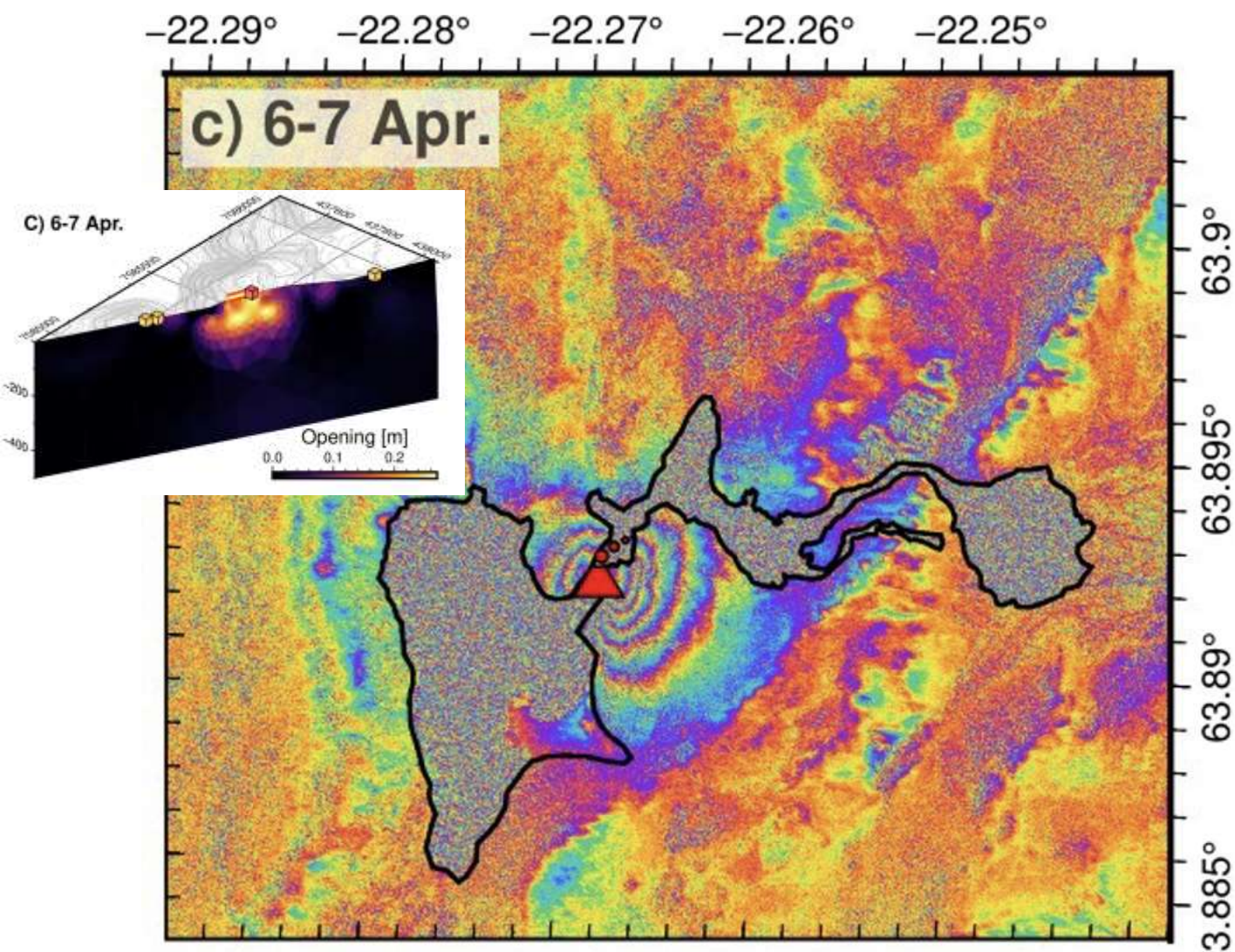


Figure: Halldór Geirsson, June 25, 2021

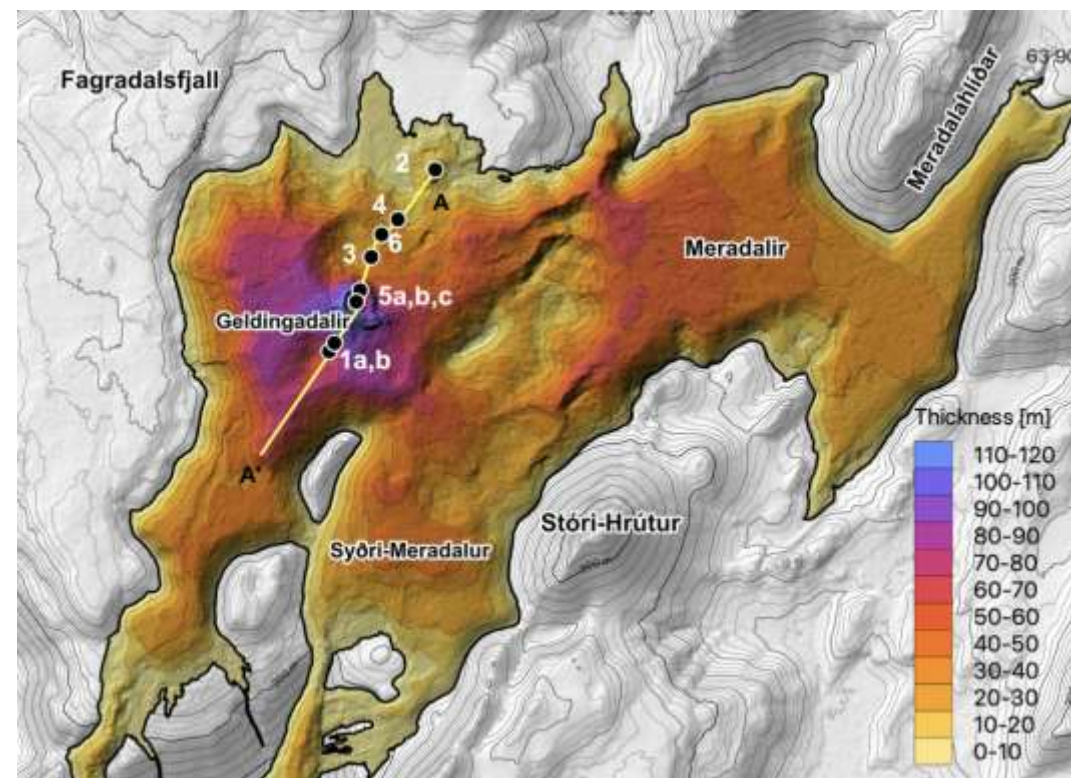
Mar-Sep 2021 eruption: 150 Mm³



Vent migration: Fagradalsfjall (#3) dikelets imaged by 1-day interferograms (ICEYE)

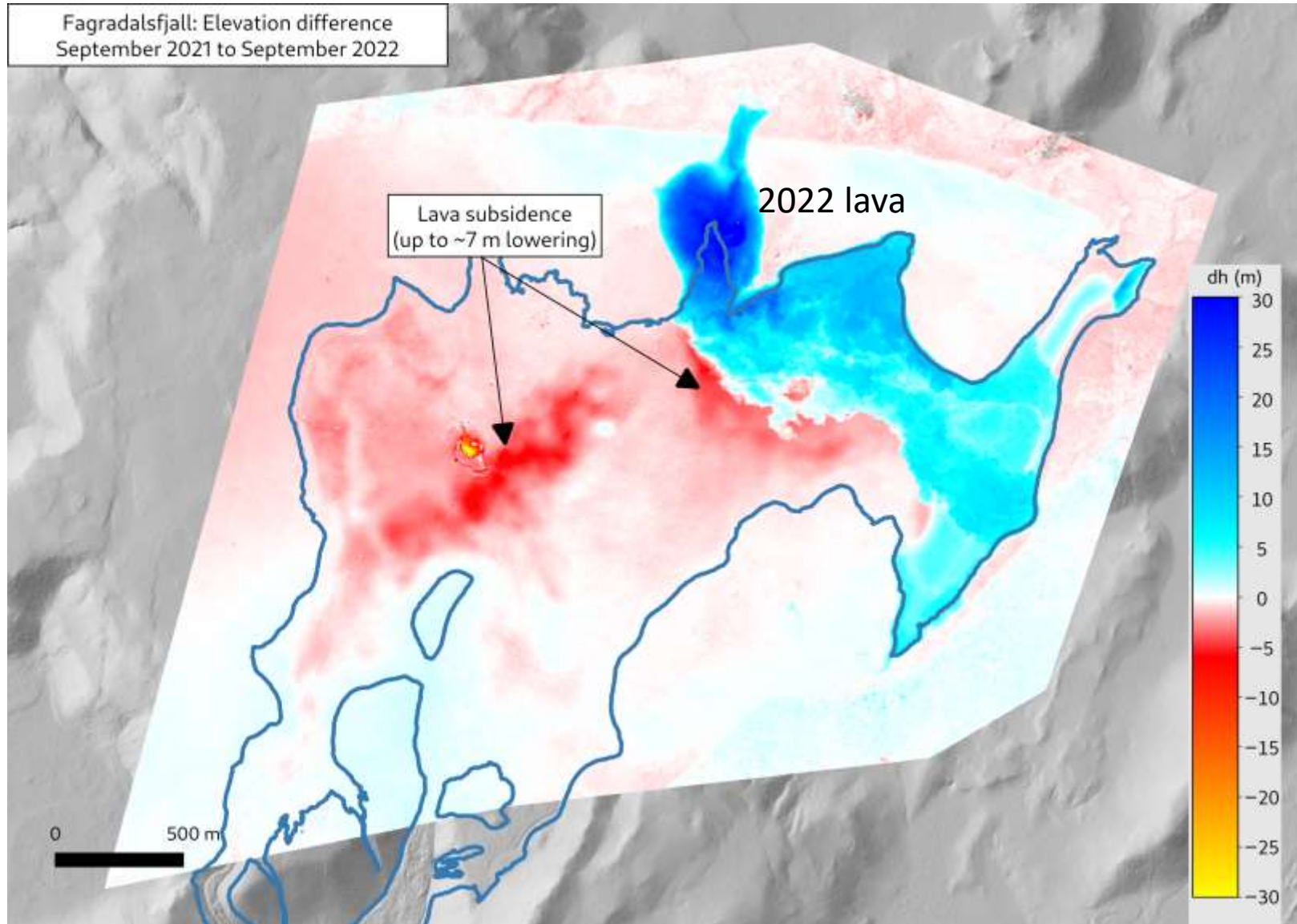


Vincent Drouin, IMO



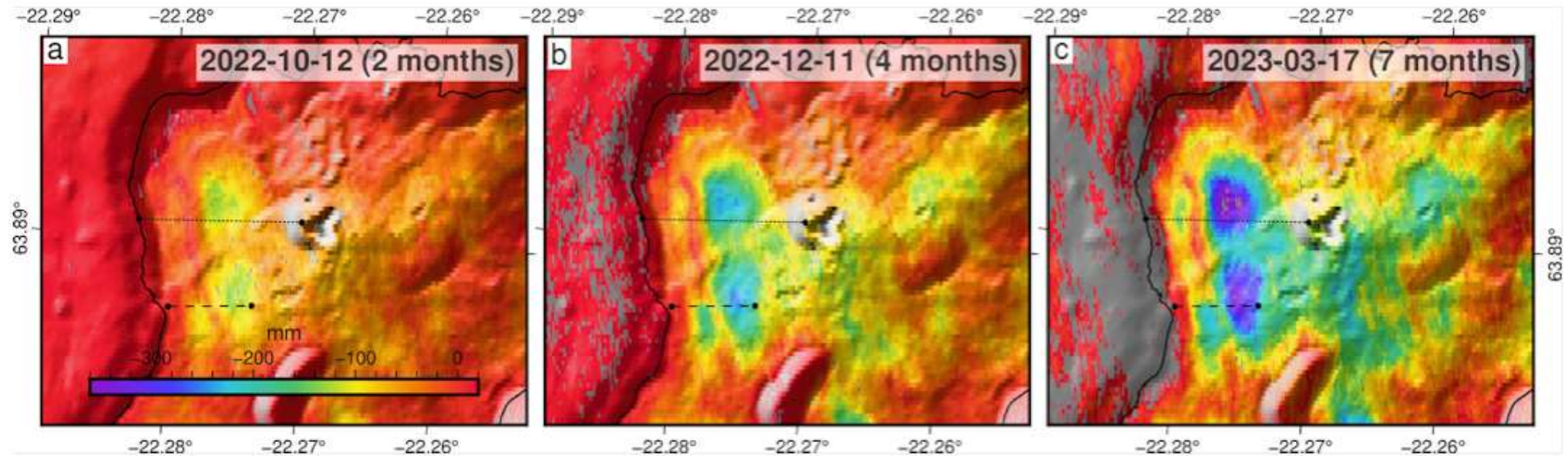
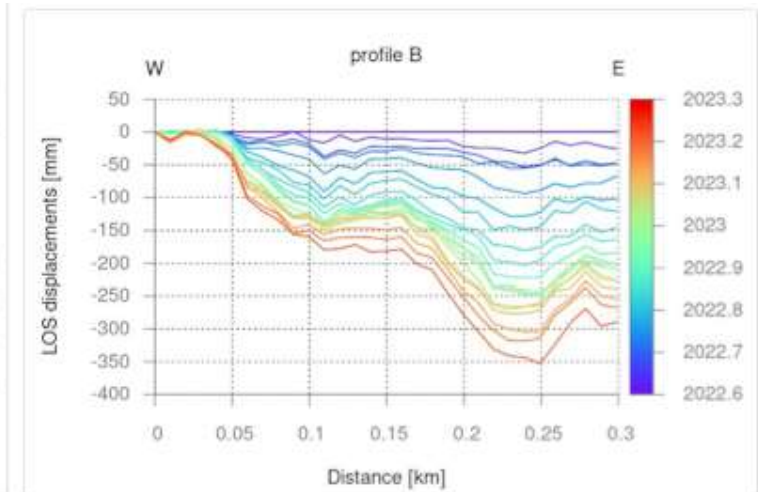
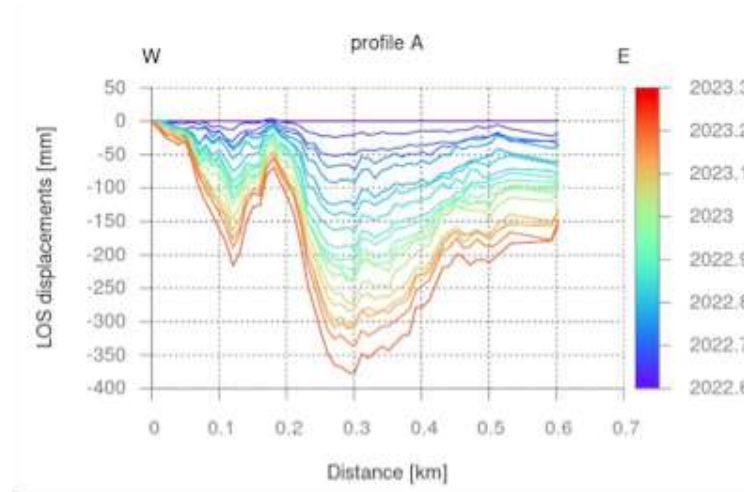
Pedersen et al., 2022. Vent numbers and lava flow thickness from differential DEM based on repeat areal photogrammetry

Post-eruptive subsidence of 2021 Fagradalsfjall lava from DEM differences

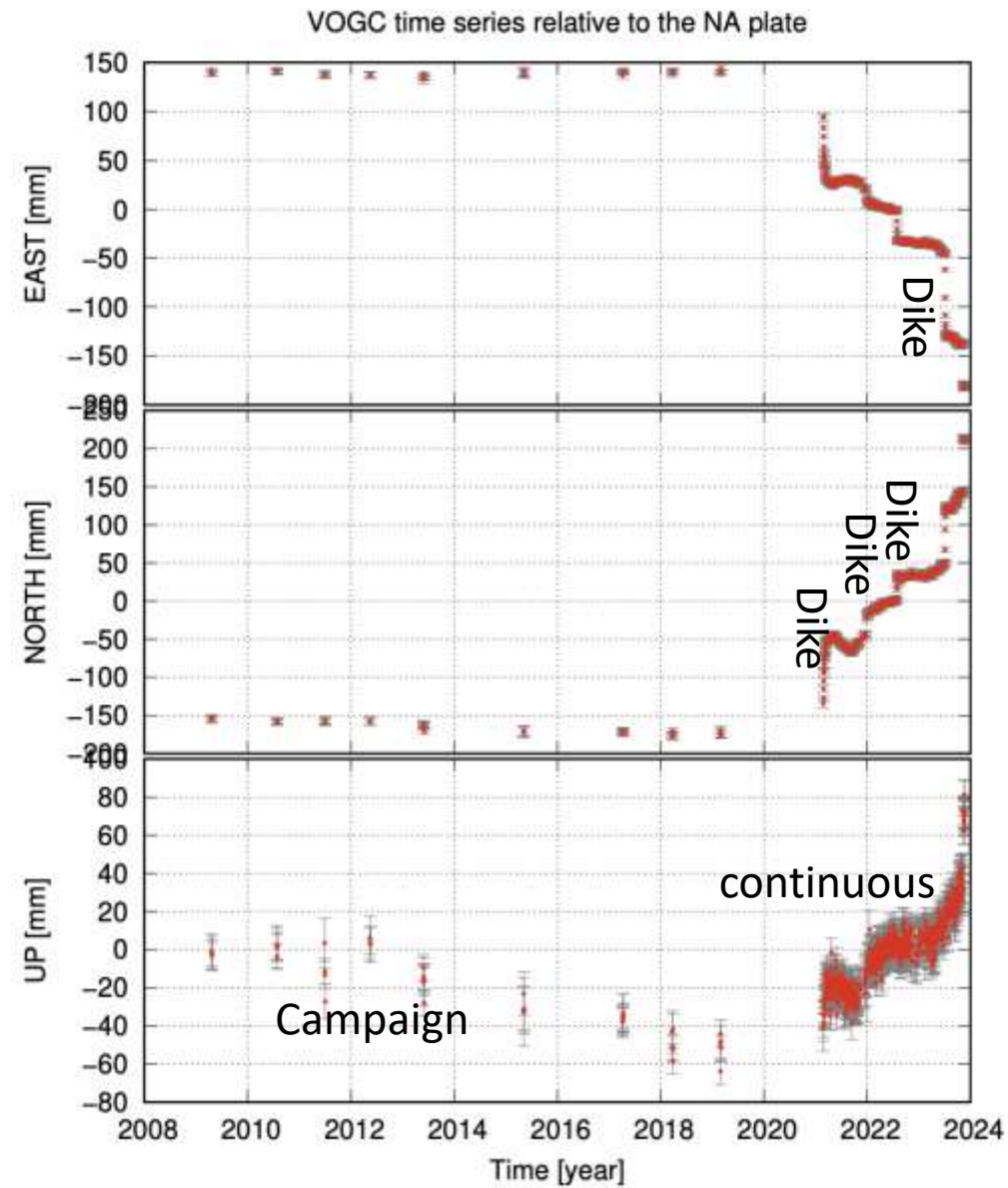
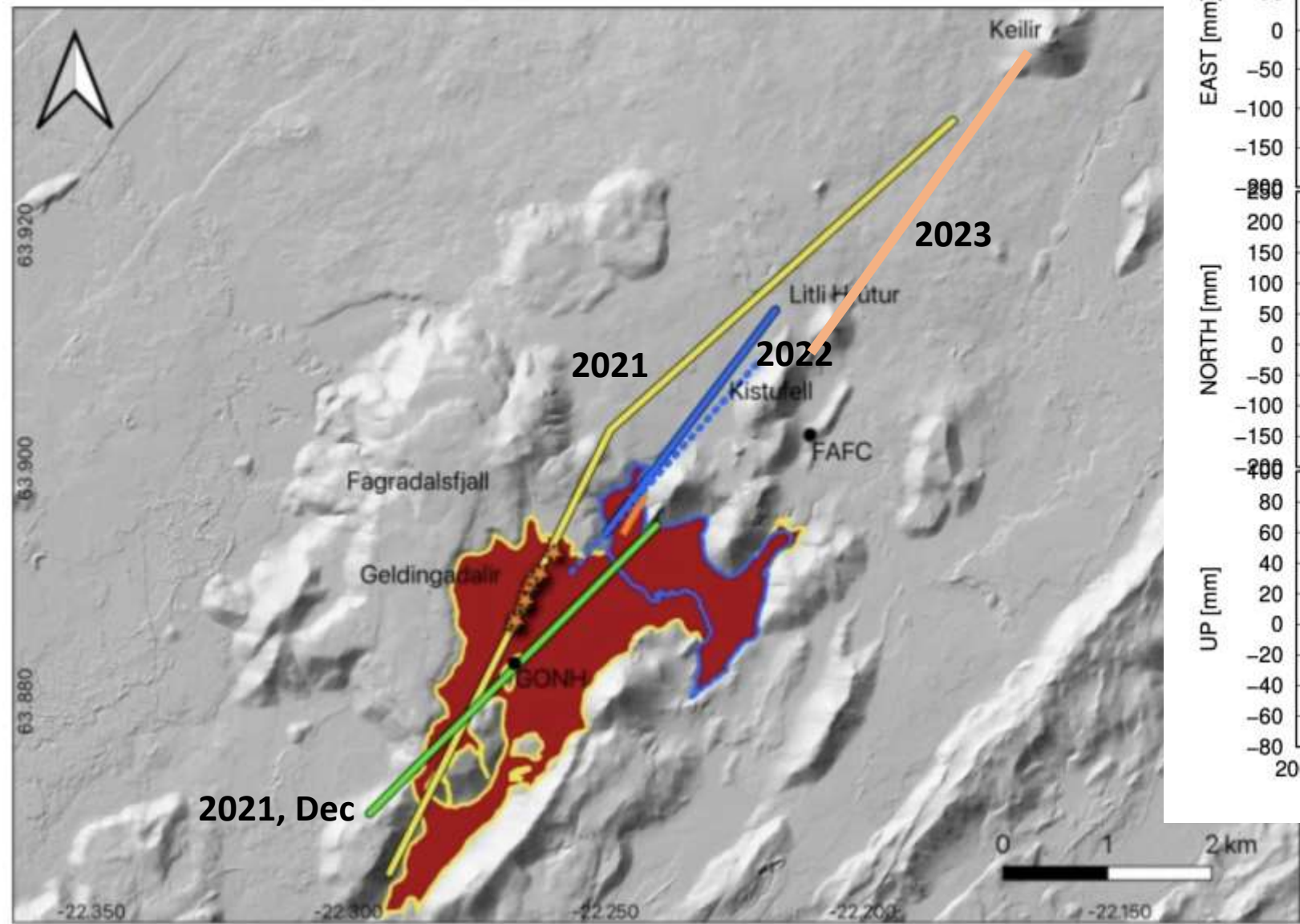


Analysis & figure: Joaquin Munoz Belart, LMI

Post-eruptive subsidence of 2021-2022 Fagradalsfjall lava from InSAR

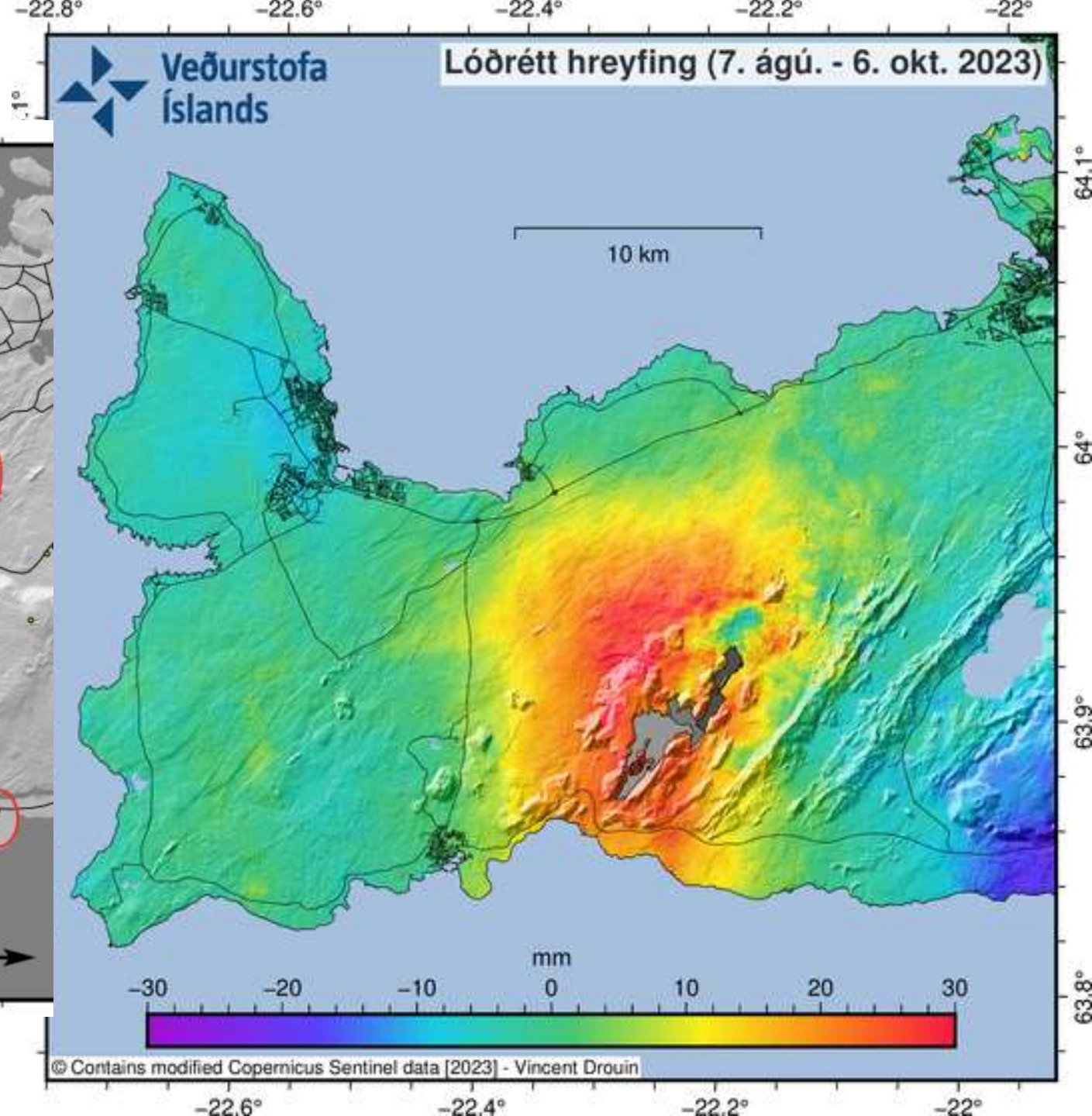
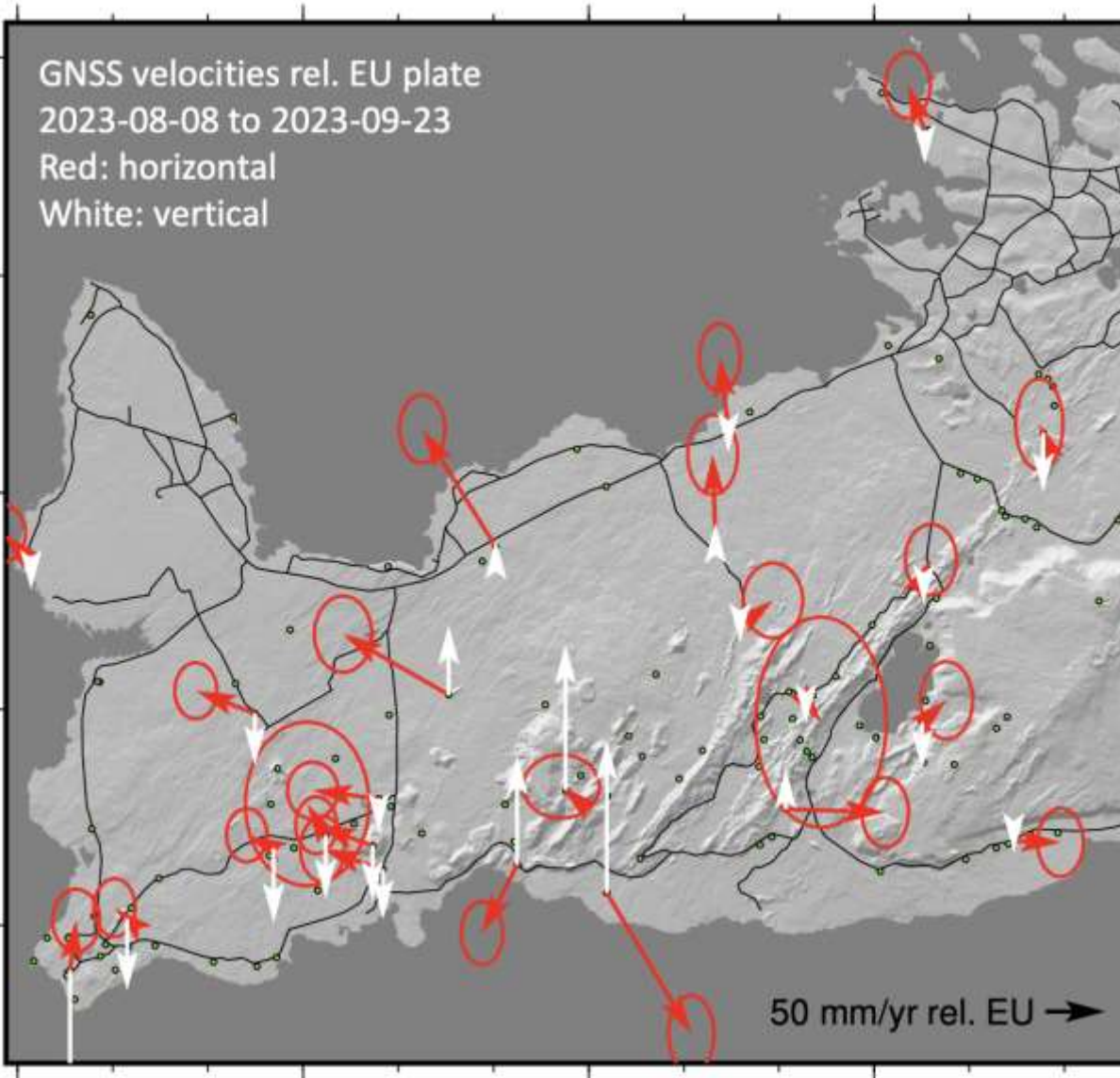


More dikes at Fagradalsfjall in 2021-2023



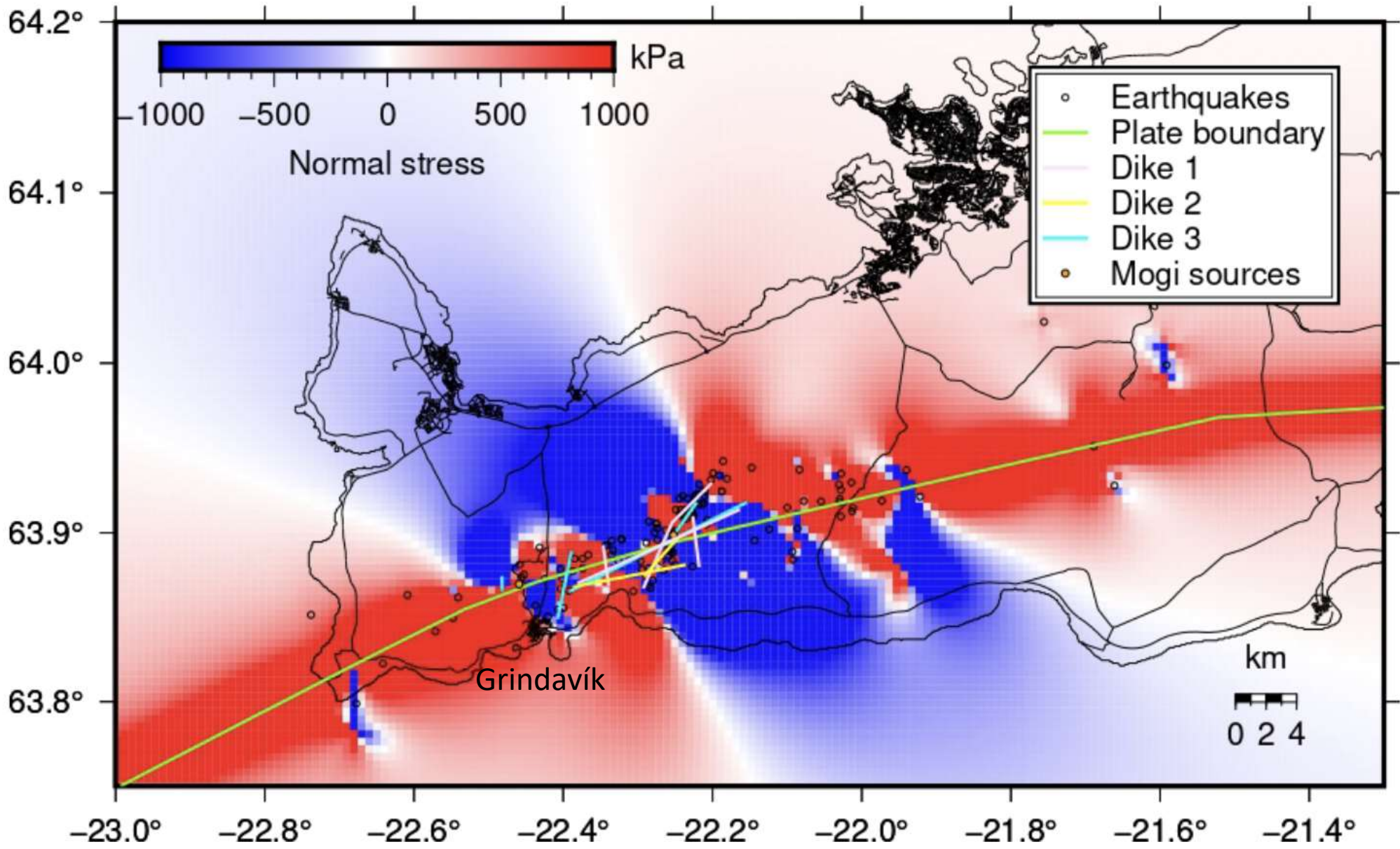
Modified from Parks et al., 2023

Fagradalsfjall last inflation period

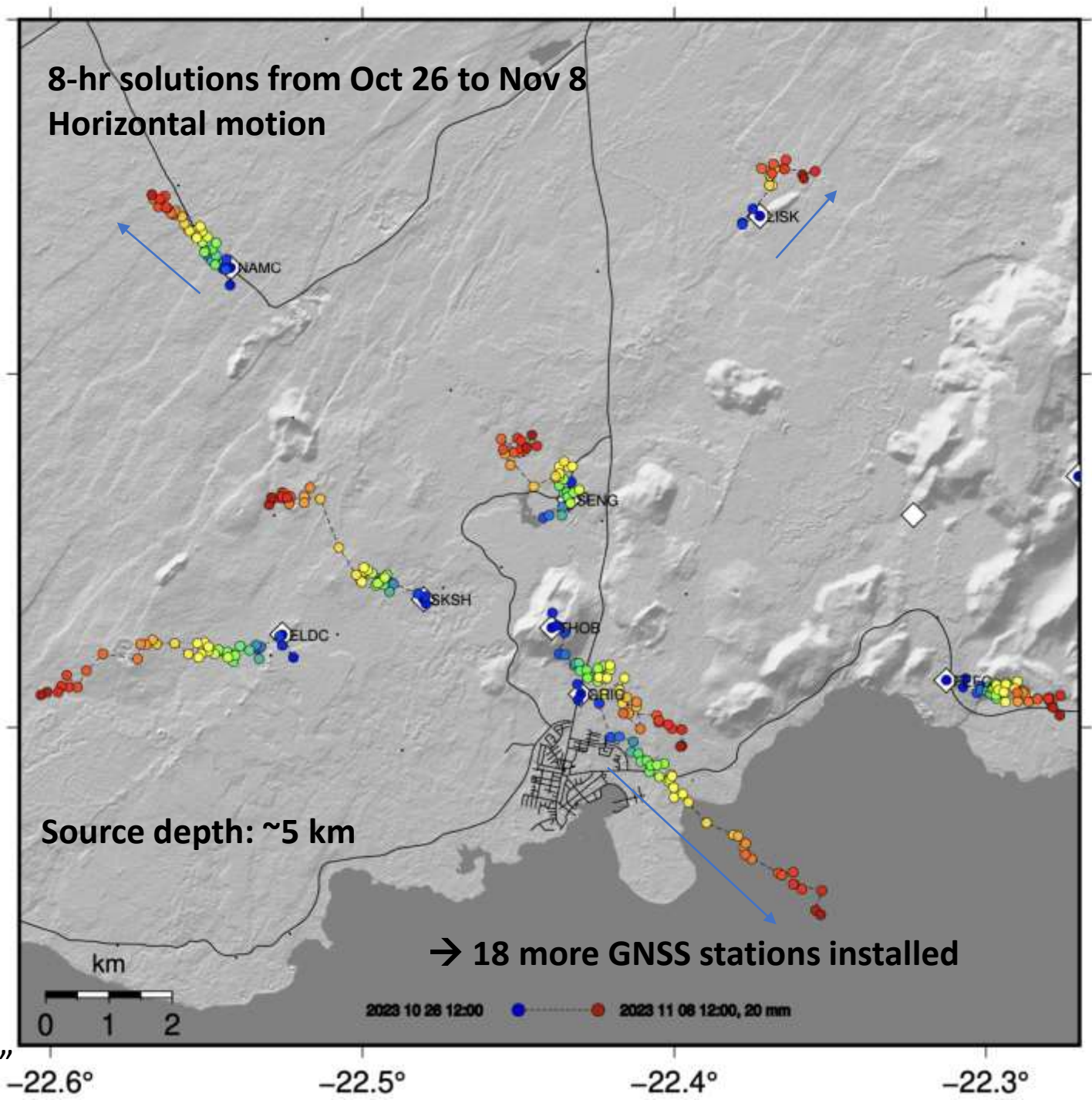
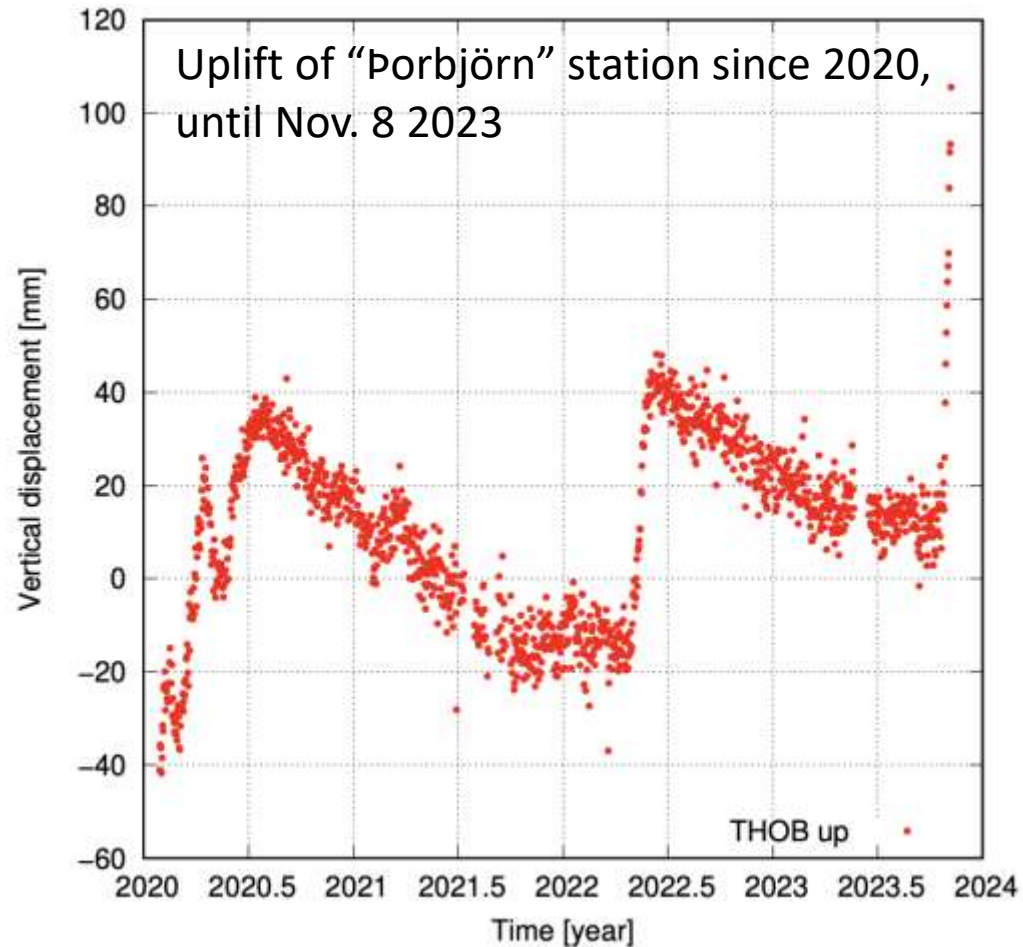


Stress changes on the Reykjanes Peninsula 1998-2022

Normal stress
changes on vertical
structures striking
30°

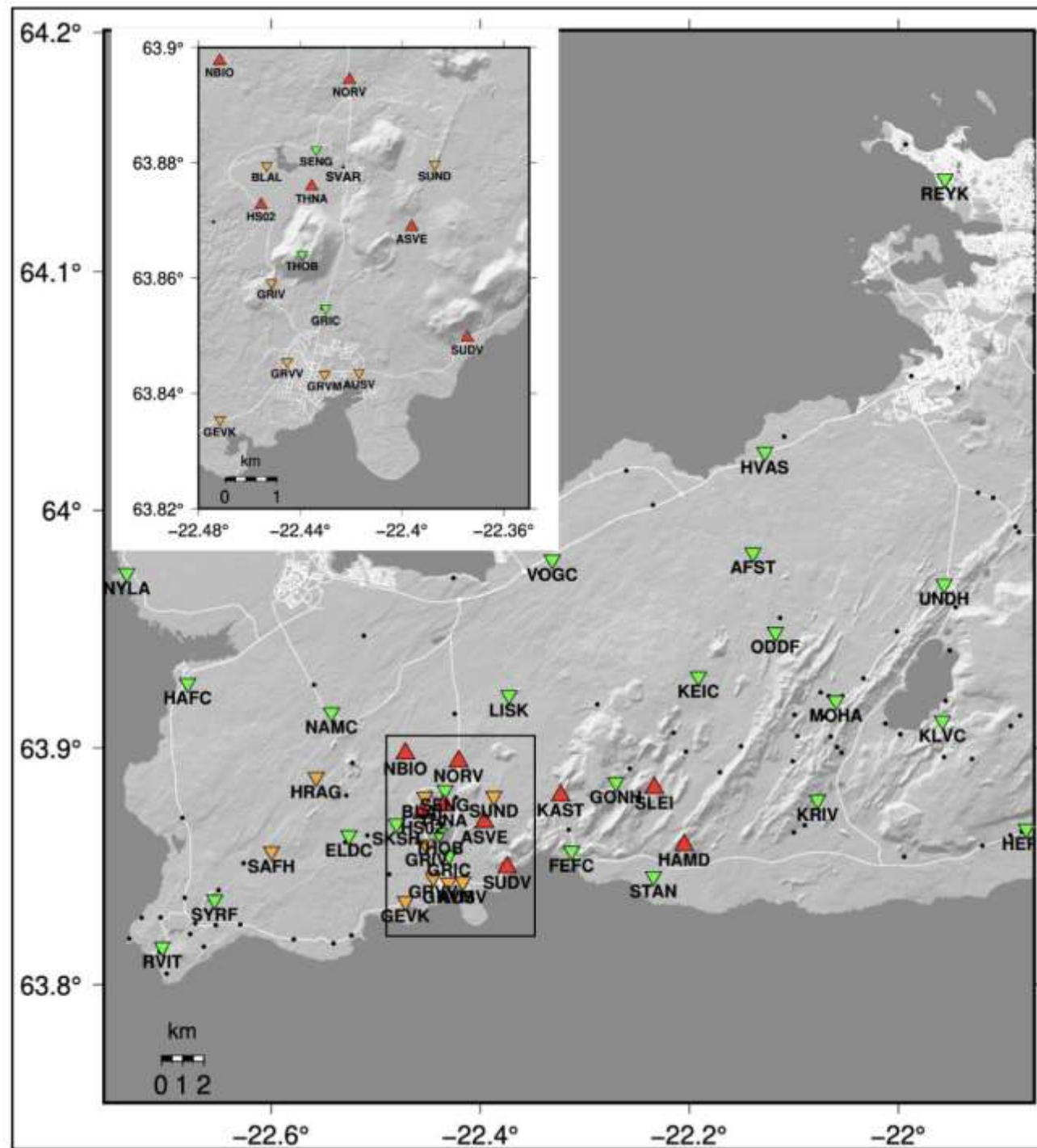


The 5th inflation episode at Svartsengi (#2)



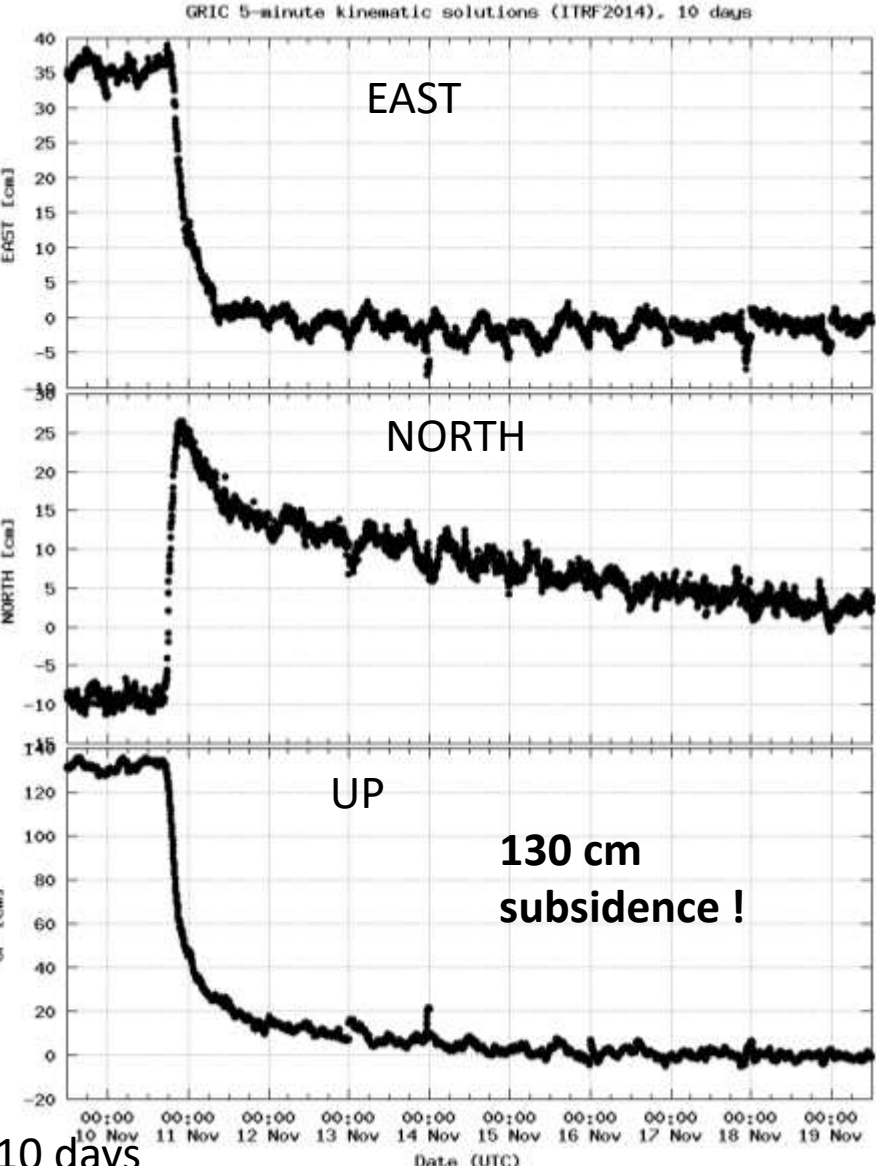
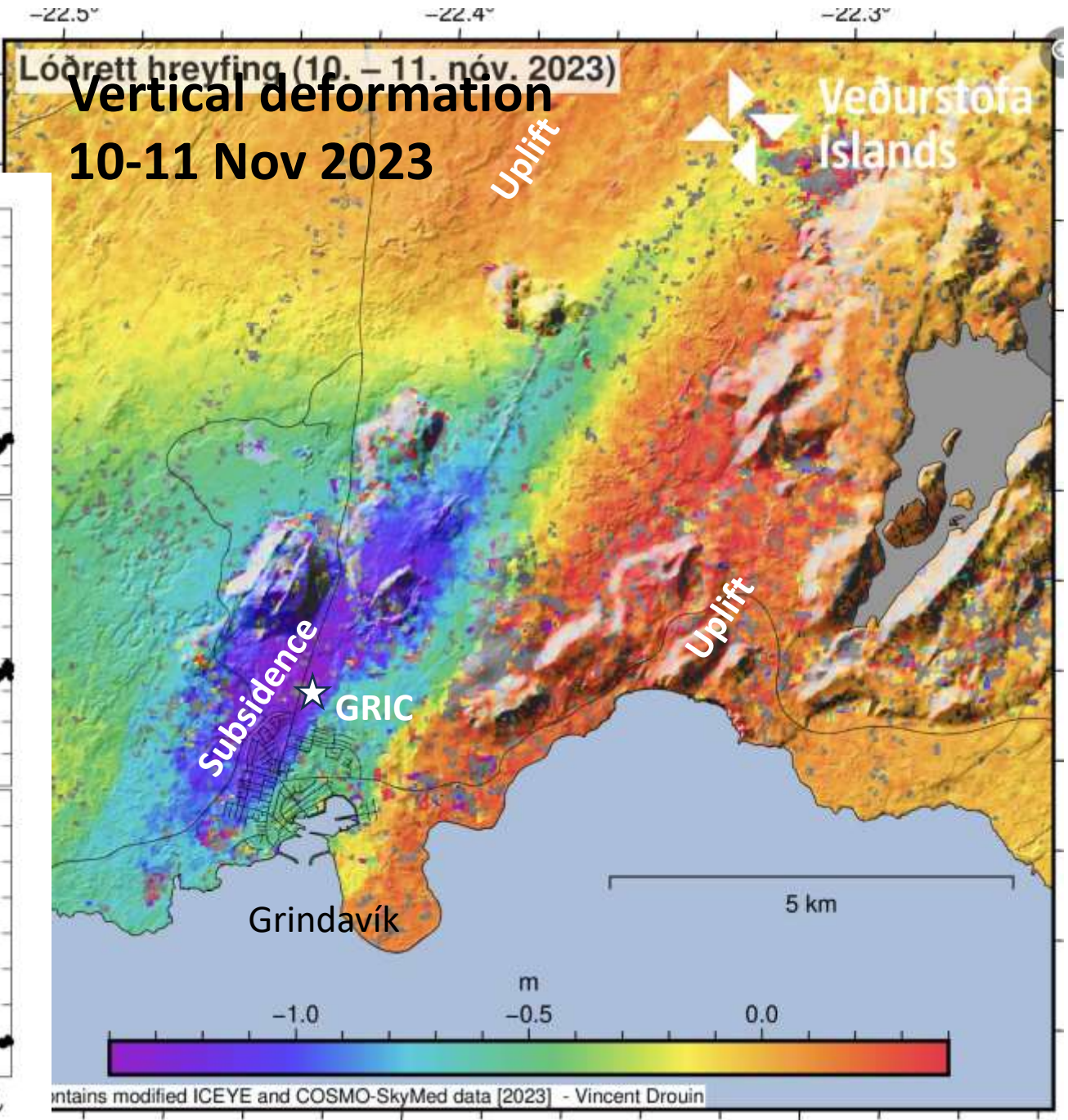
Most rapid uplift rate of the five episodes
New GNSS stations installed: goal: look for “dike signal”

→ Even more cGNSS stations !



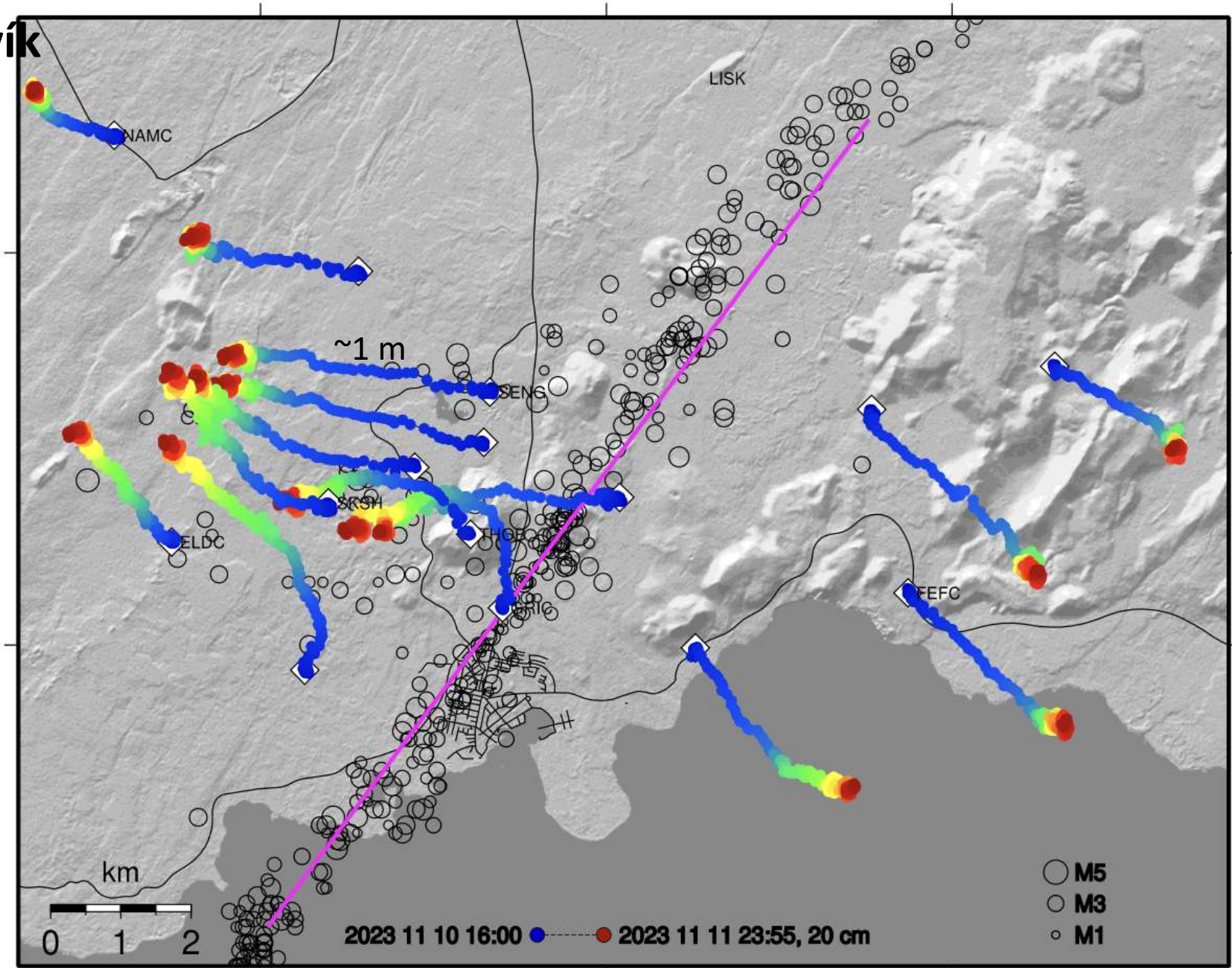
The November 10 „Grindavík dike“ at Svartsengi (#2)

Vertical deformation
10-11 Nov 2023



The November 10 „Grindavík
dike“ at Svartsengi (#2)

Horizontal deformation
5-min solutions



Ultra-rapid magma flow into the Grindavík dike at Svartsengi (#2) on November 10: 7500 m³/sek!

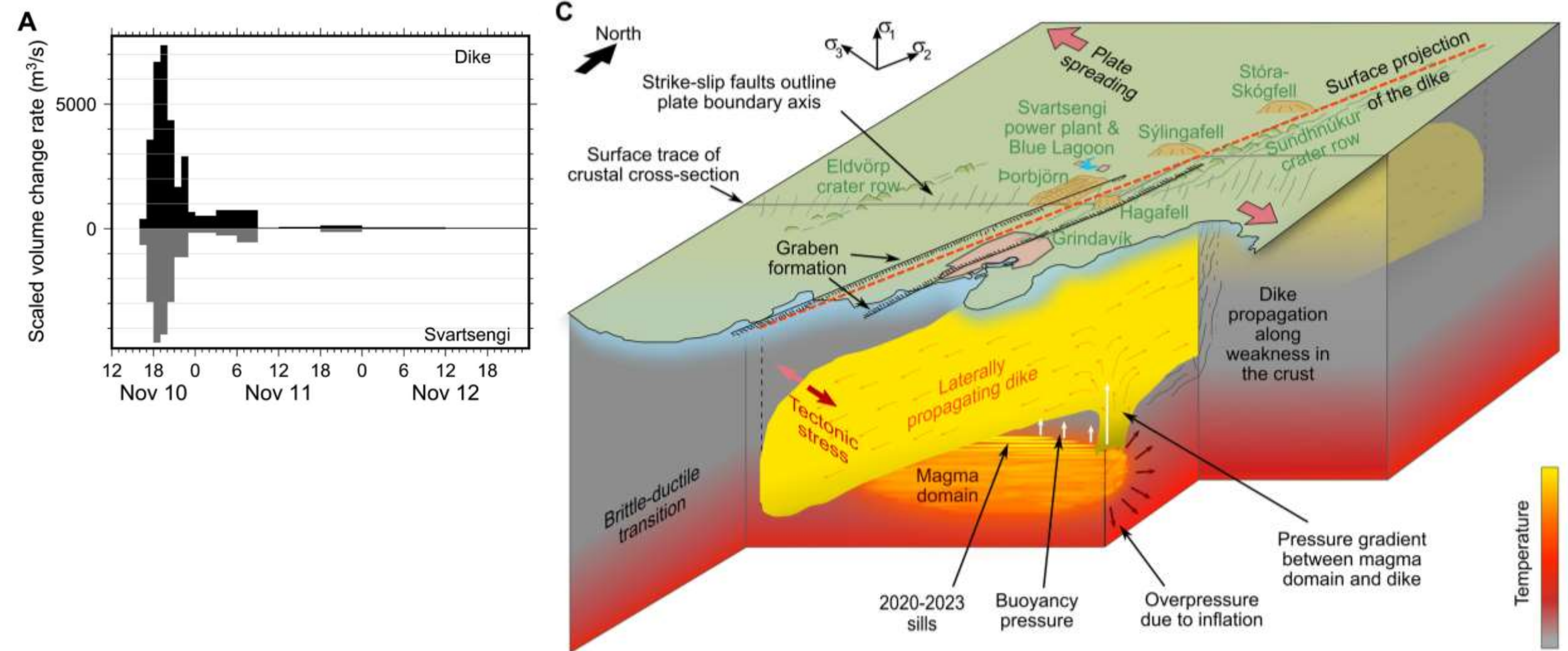




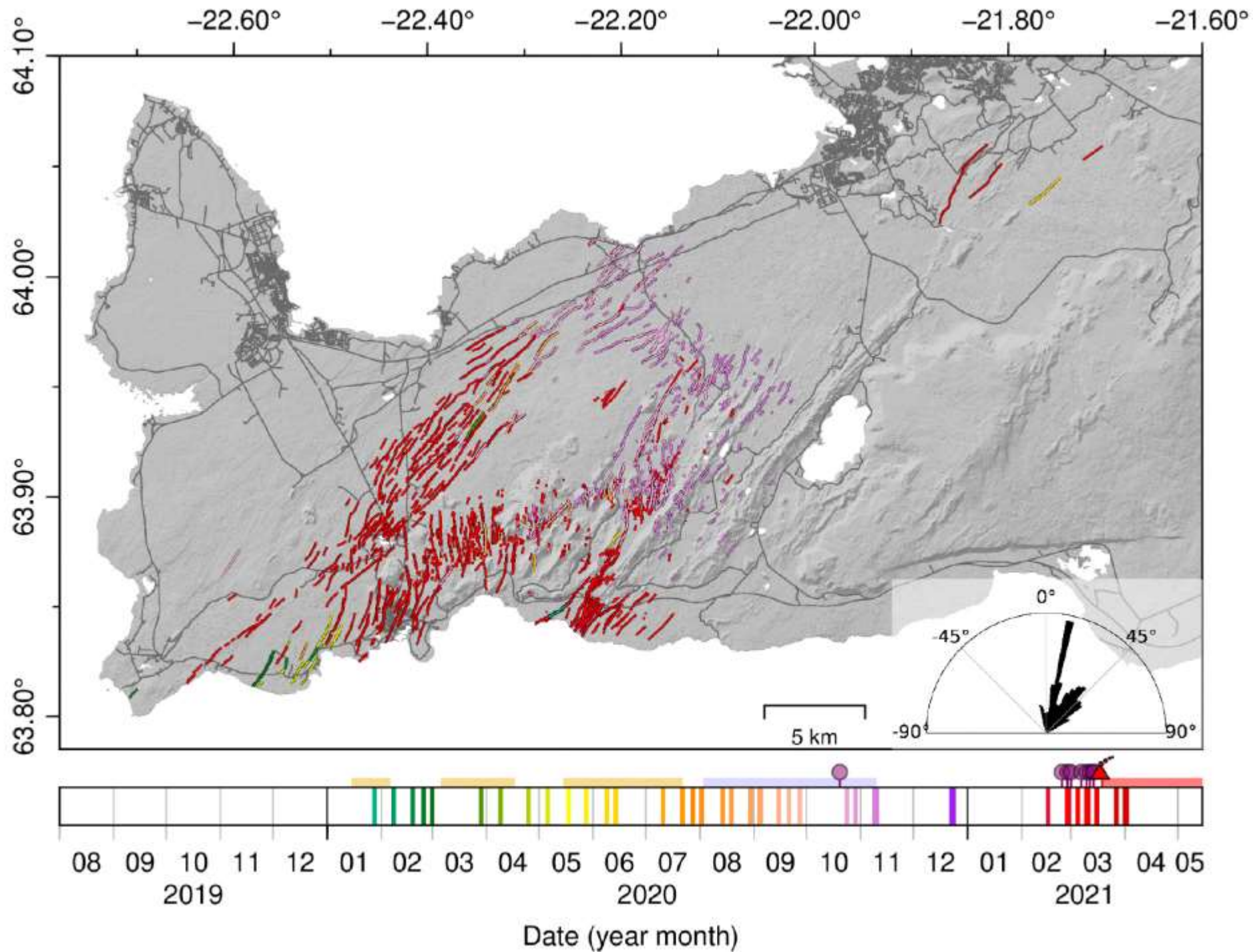
Photo: "the internet"



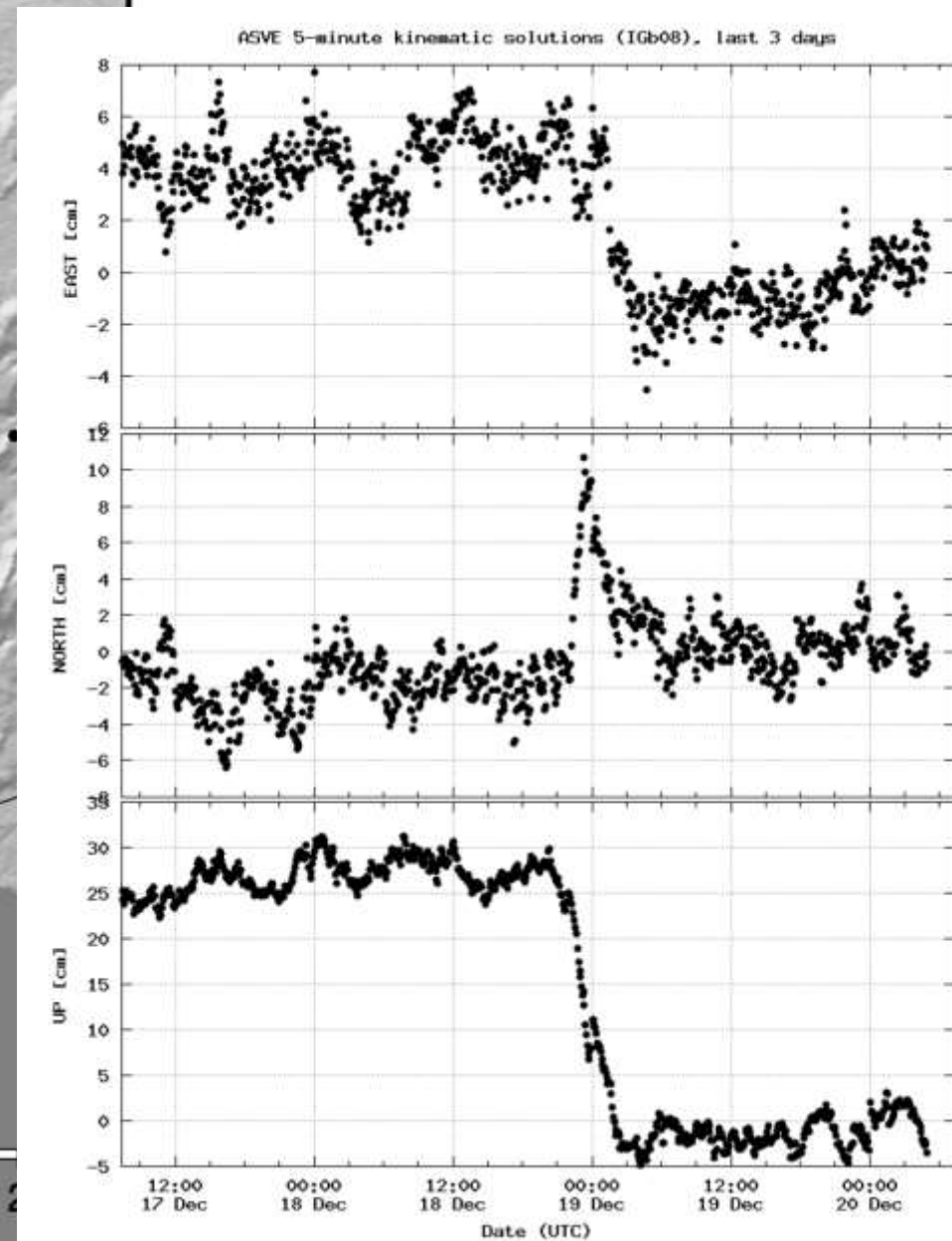
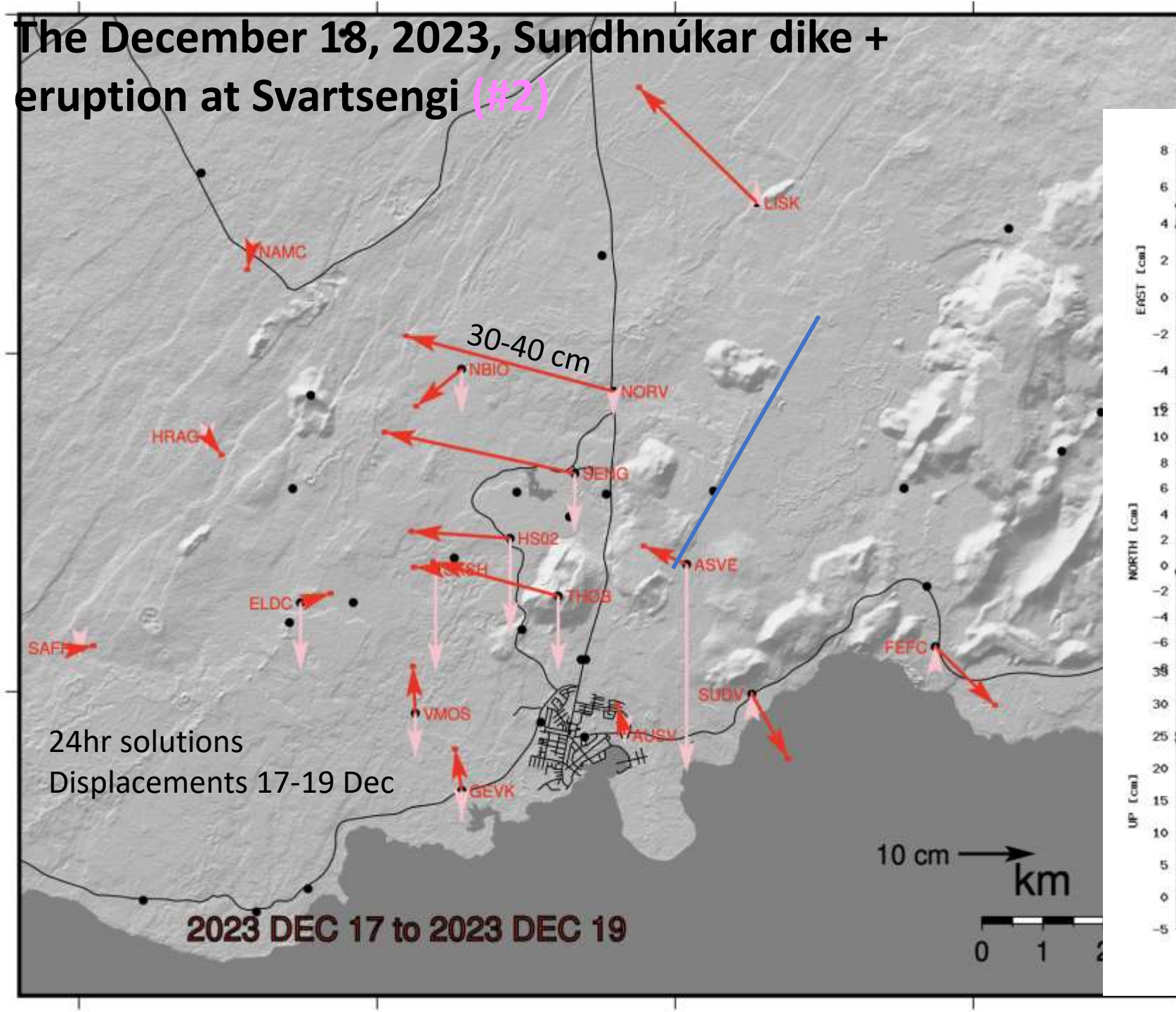
Photo: "the internet"



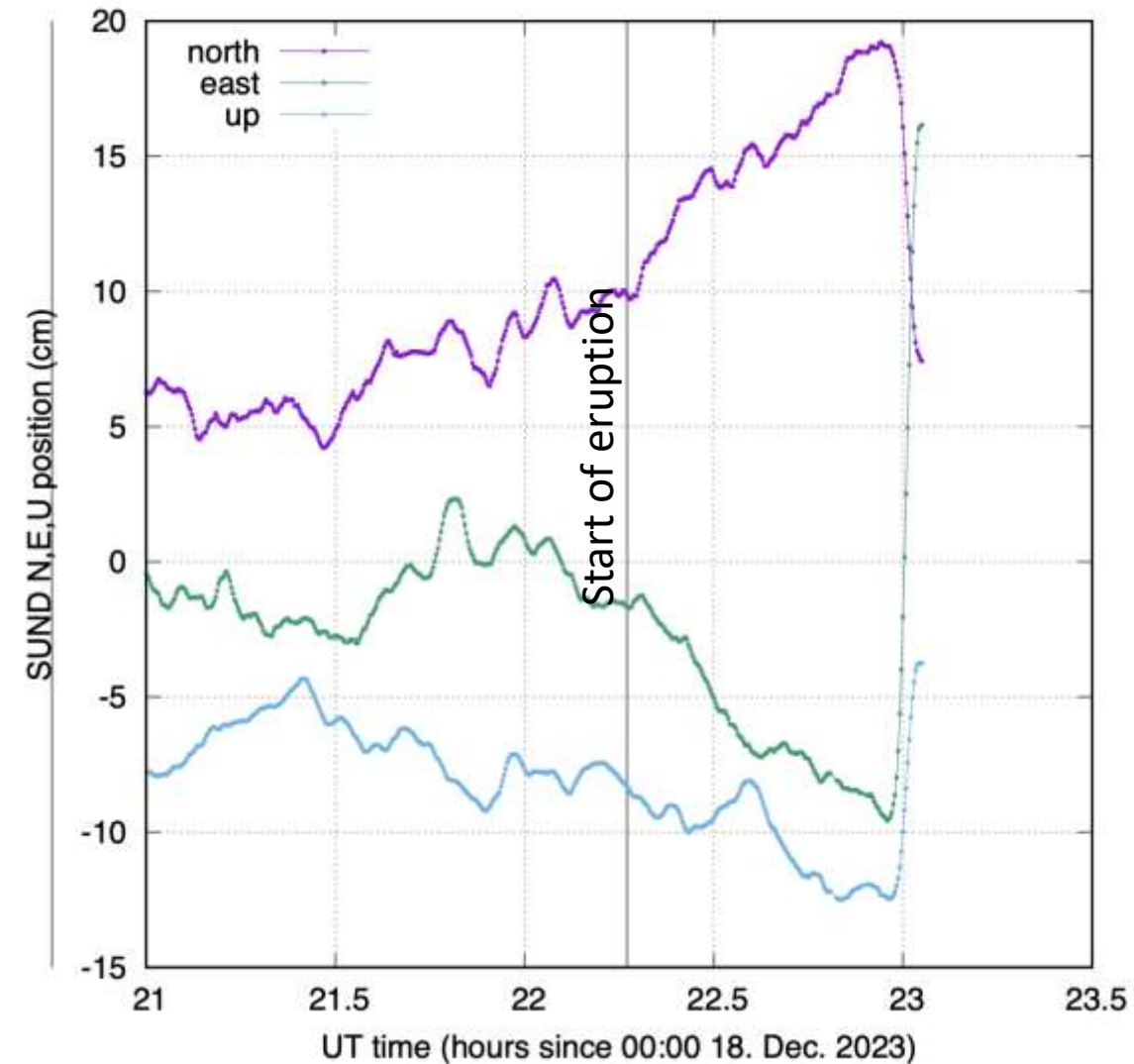
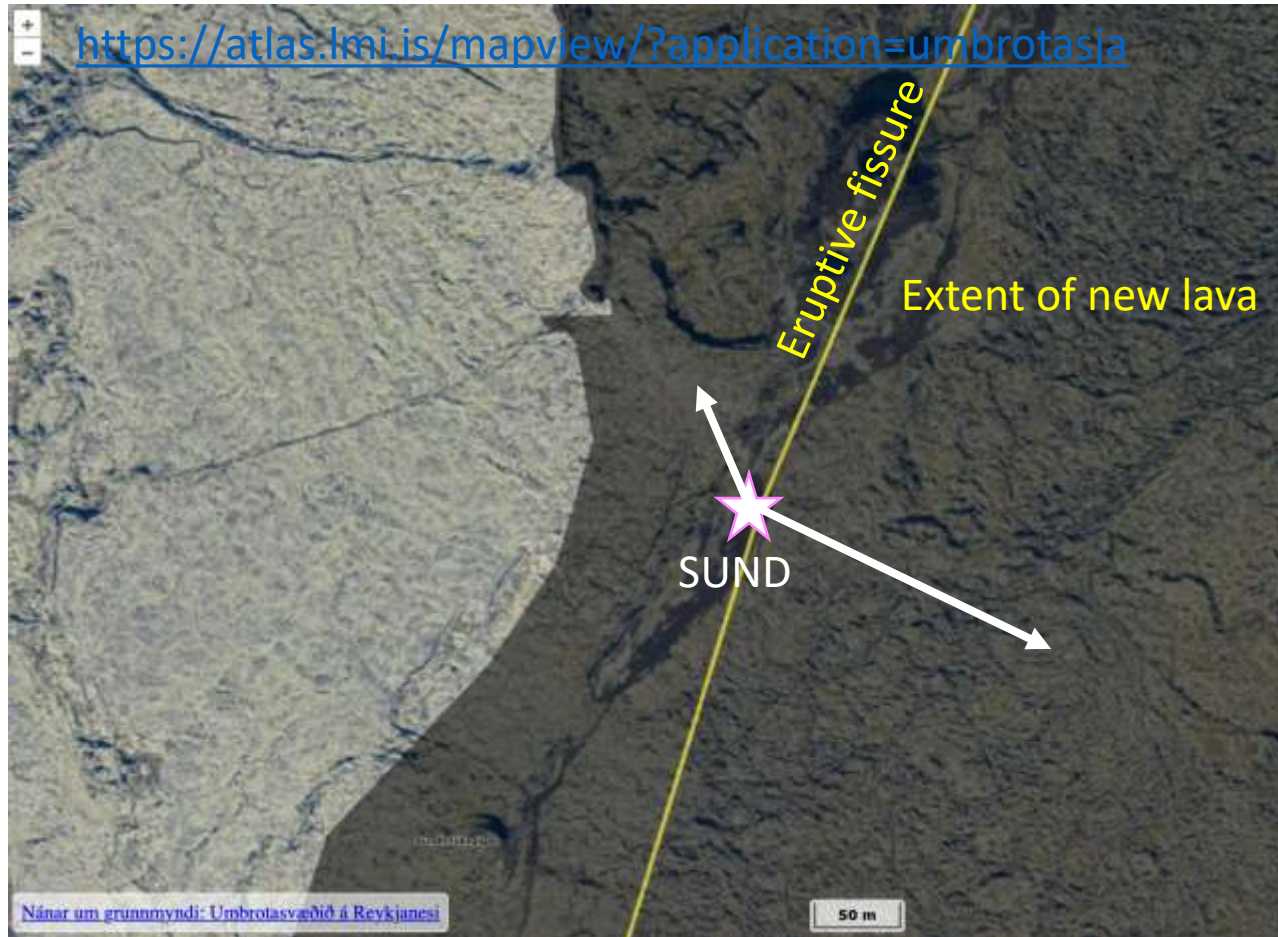
Many of the faults from Nov. 2023 in Grindavík had moved during the 2021 unrest → fault mapping using InSAR



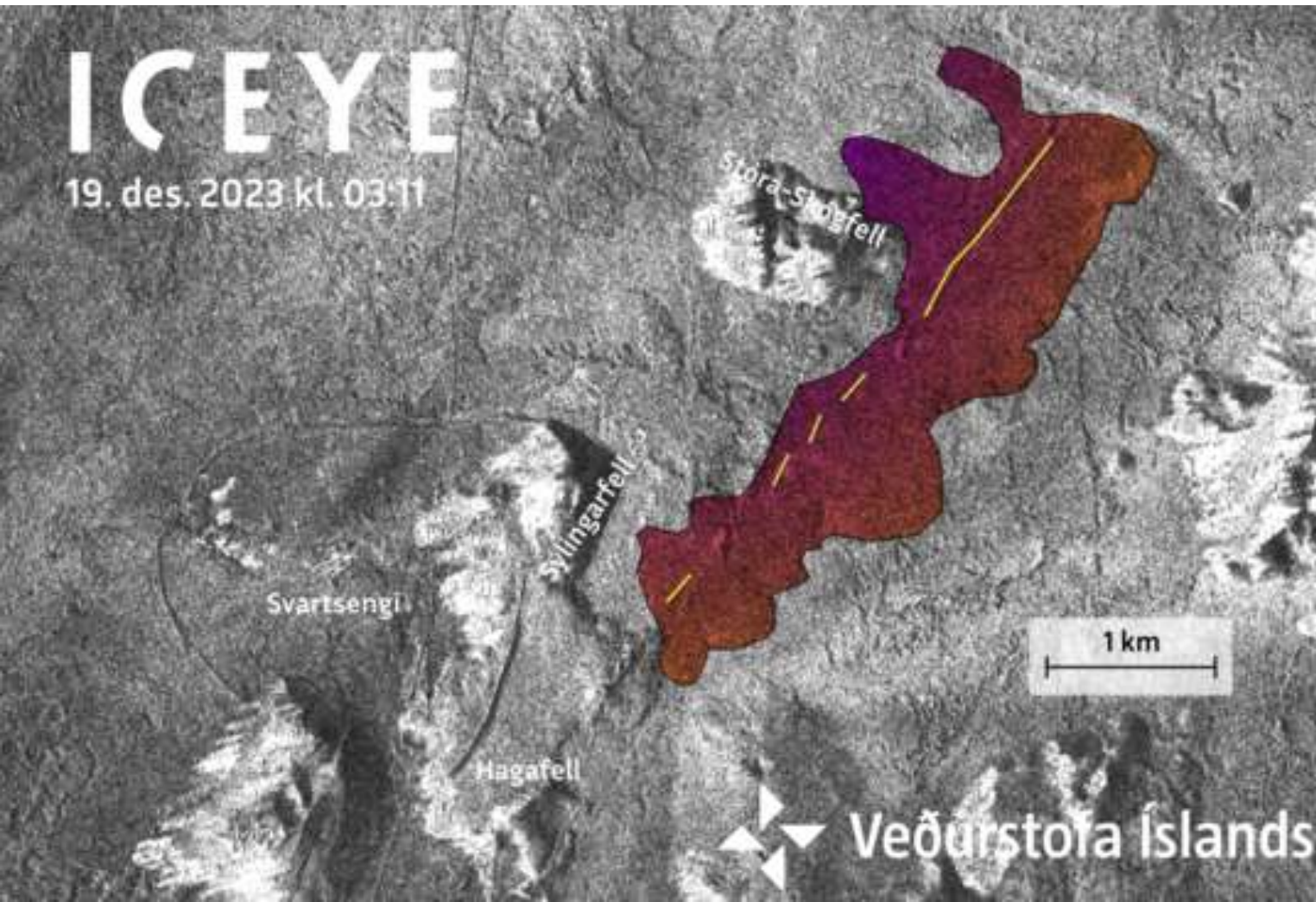
Ducrocq et al., 2023



The December 18, 2023, Sundhnúkar dike + eruption at Svartsengi (#2)



The December 18, 2023, Sundhnúkar dike + eruption „Grindavík dike“ at Svartsengi (#2)



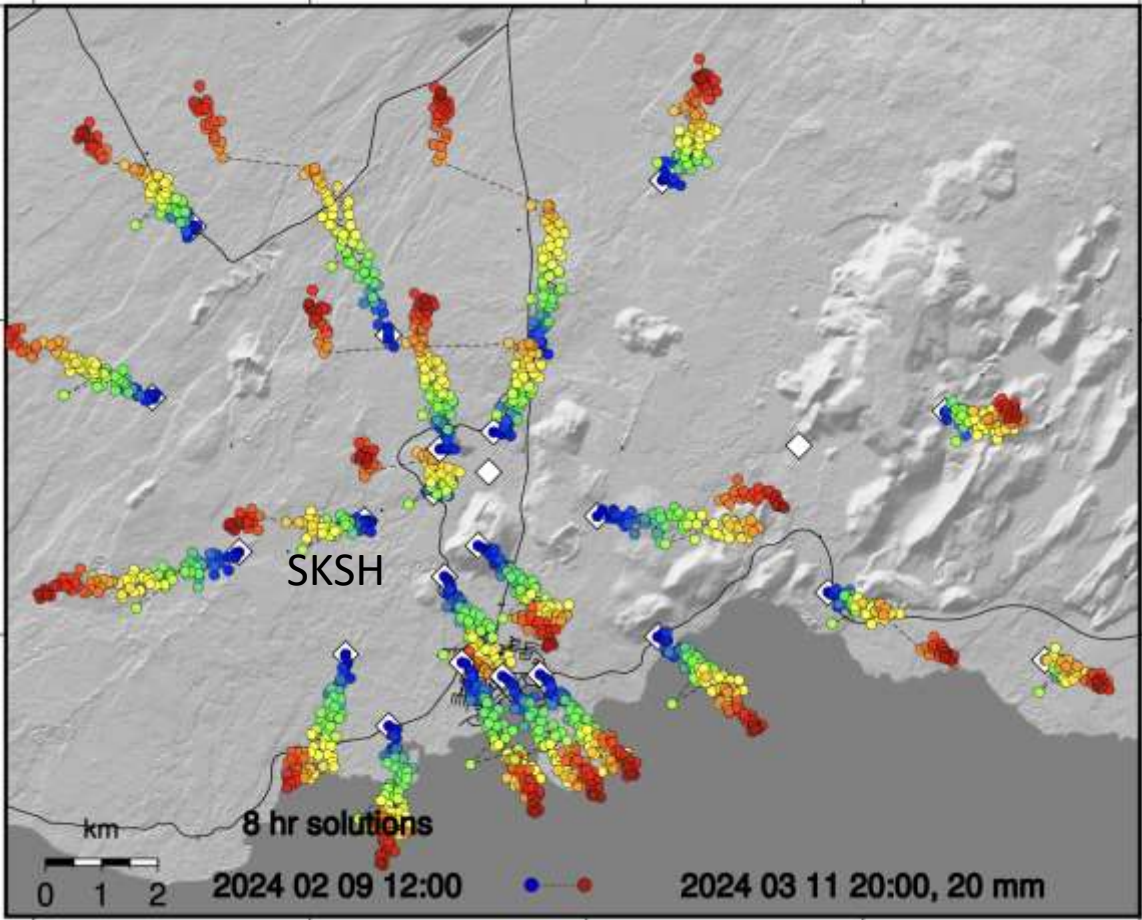
Photos: Civil defense

January 14, 2024: dike+eruption

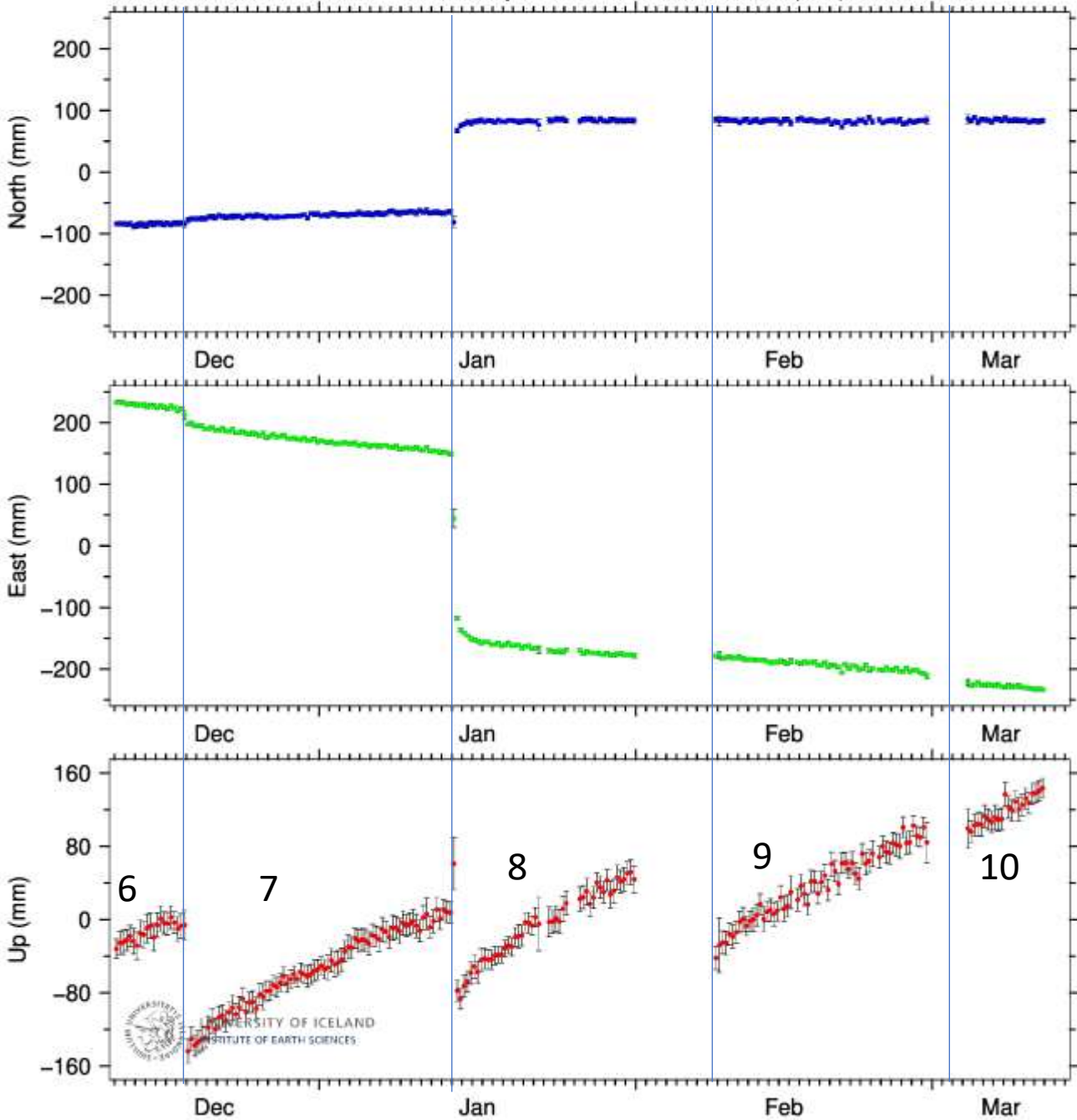


Fissure further south; dike went under Grindavík

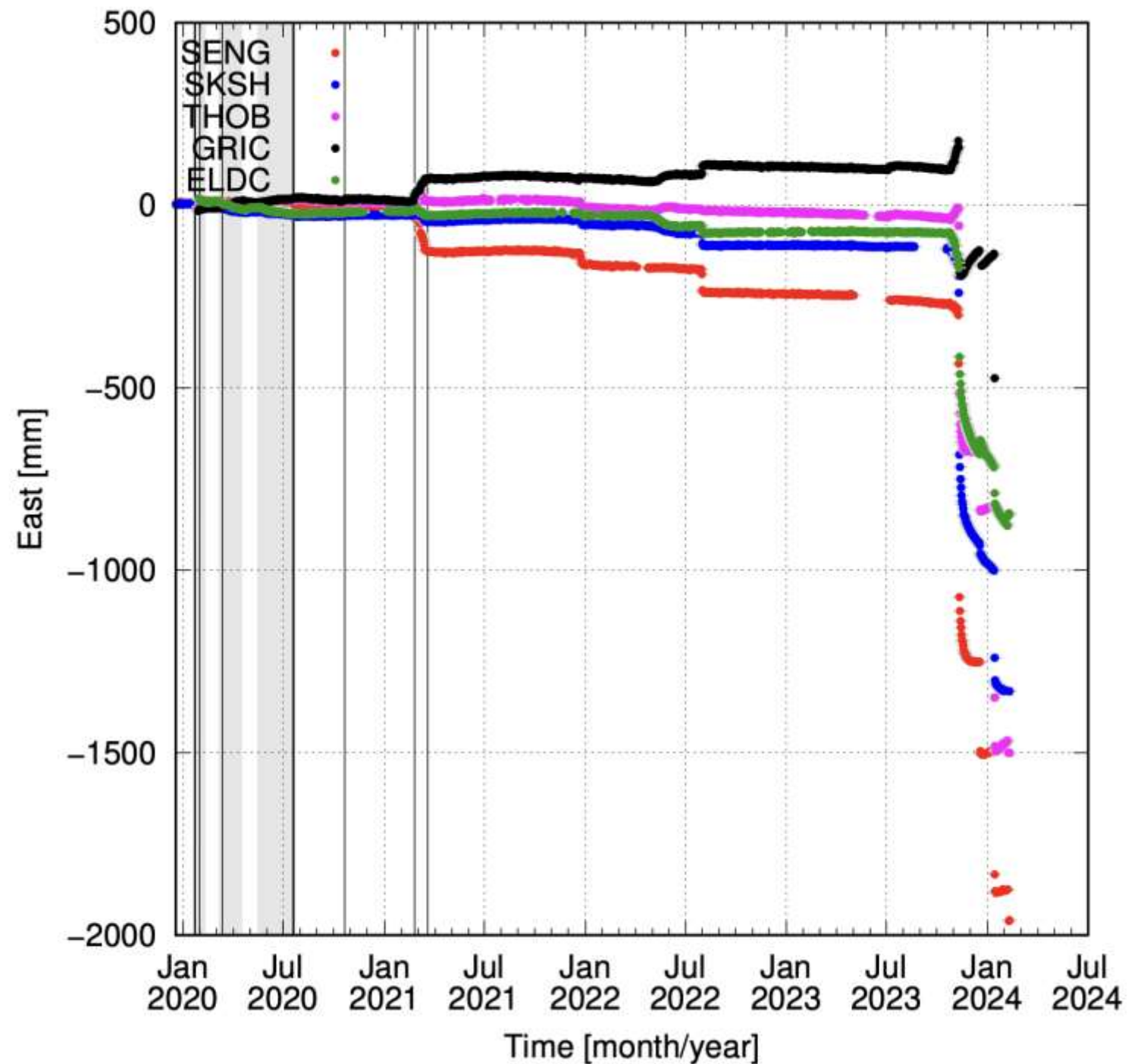
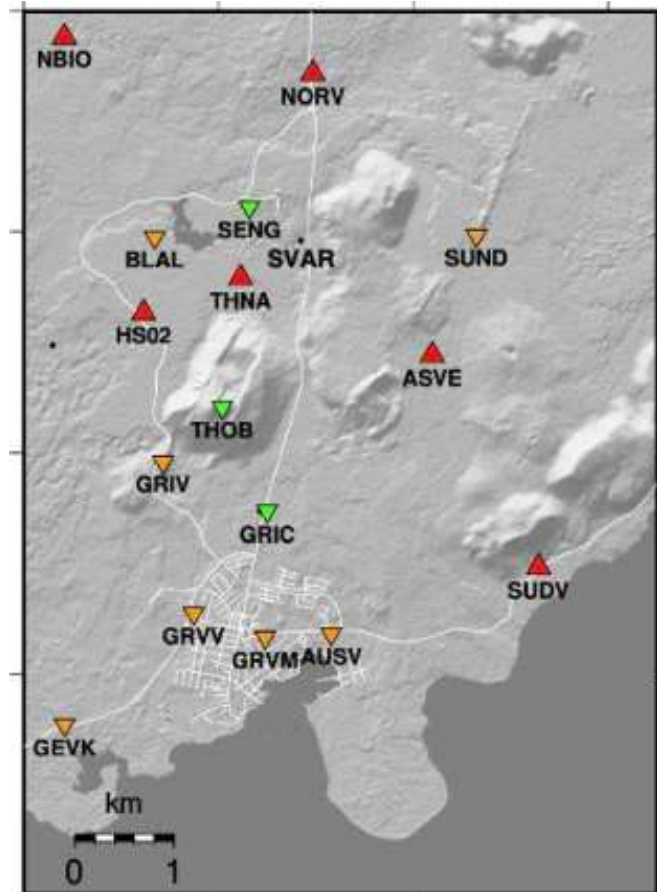
Current (10th) inflation at Svartsengi (#2)



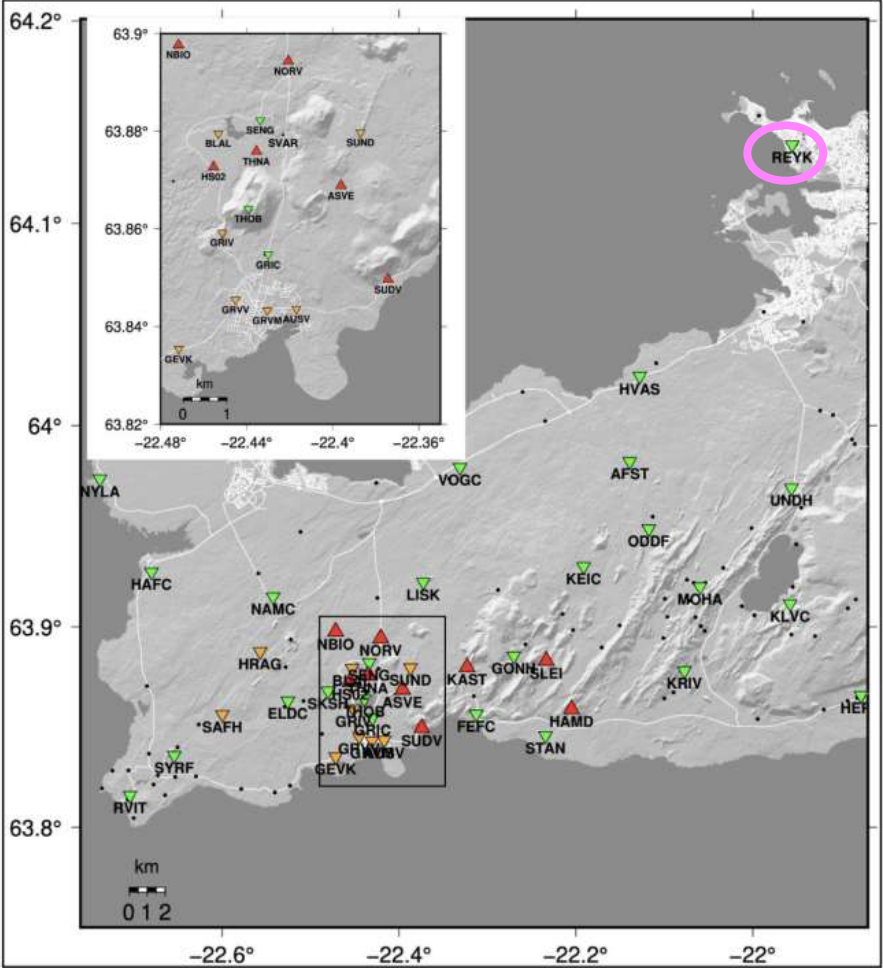
Skipastigshraun SKSH (8 hour), ITRF14-detrended. Last datapoint 11/3/2024 16:00-24:00 UTC
Run 12 Mar 2024 02:11 UTC © University of Iceland/Vedurstofa Islands (IMO)/GNS Science



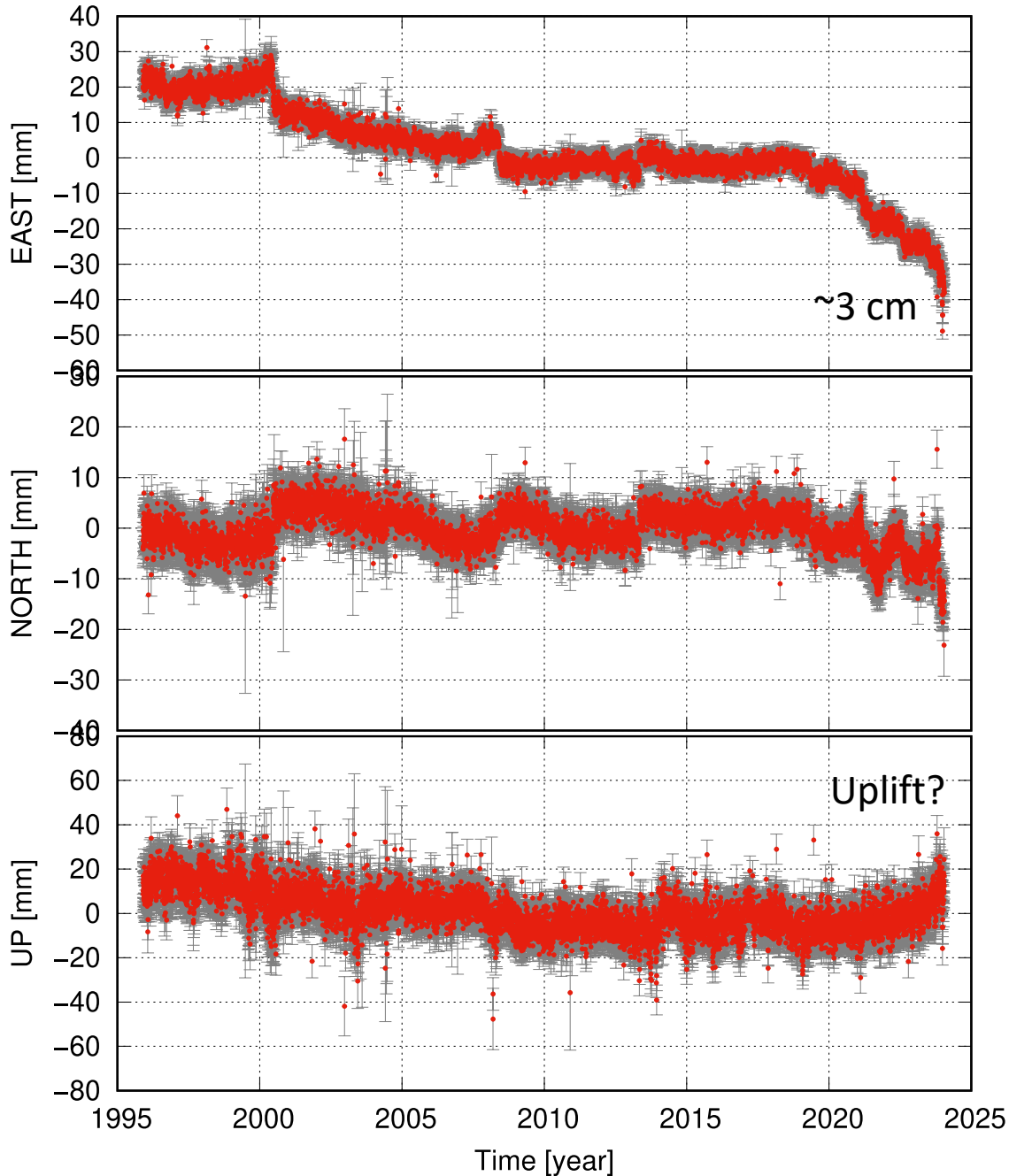
Meter-scale deformation in the near-field of the dikes



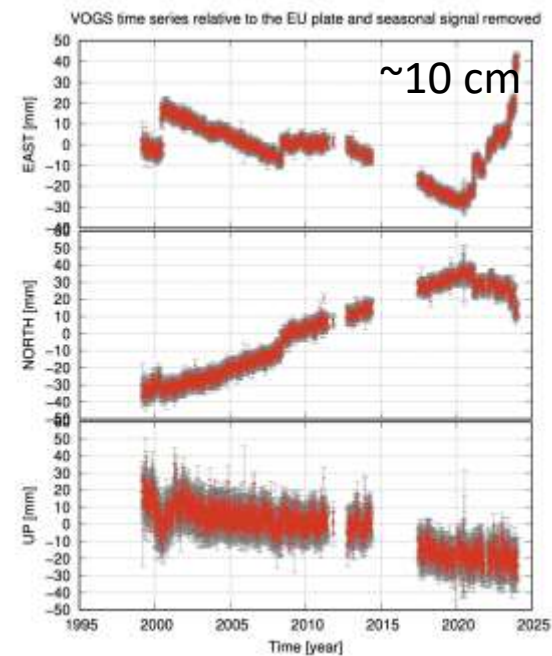
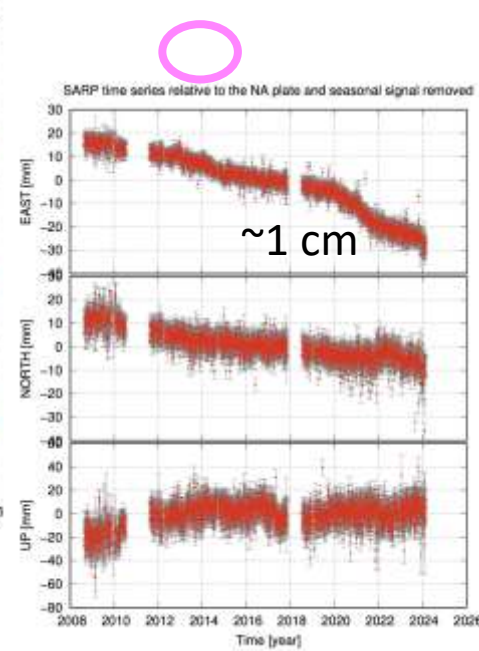
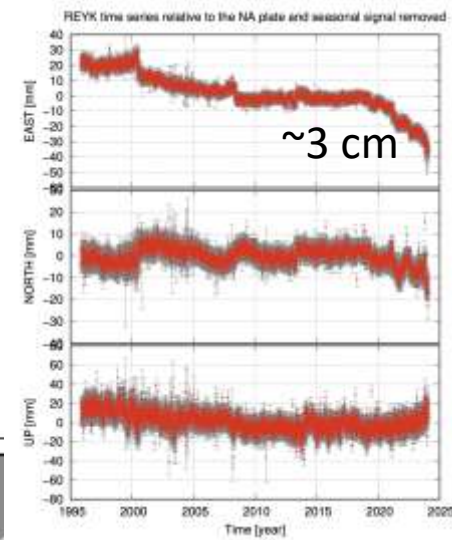
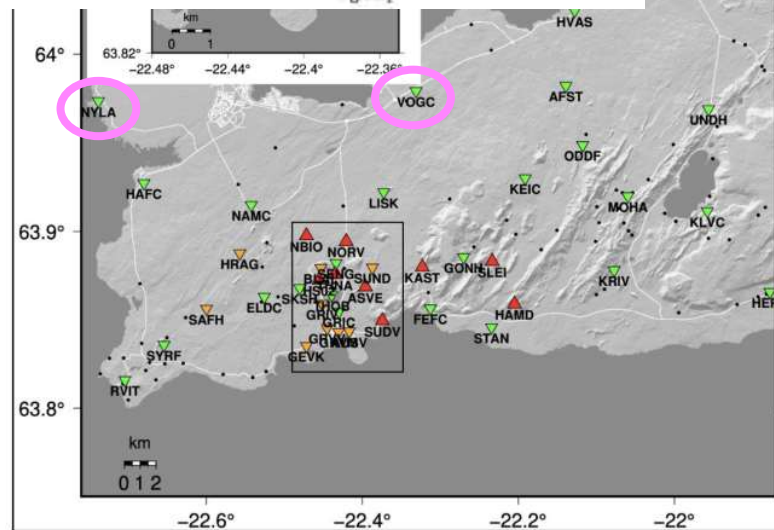
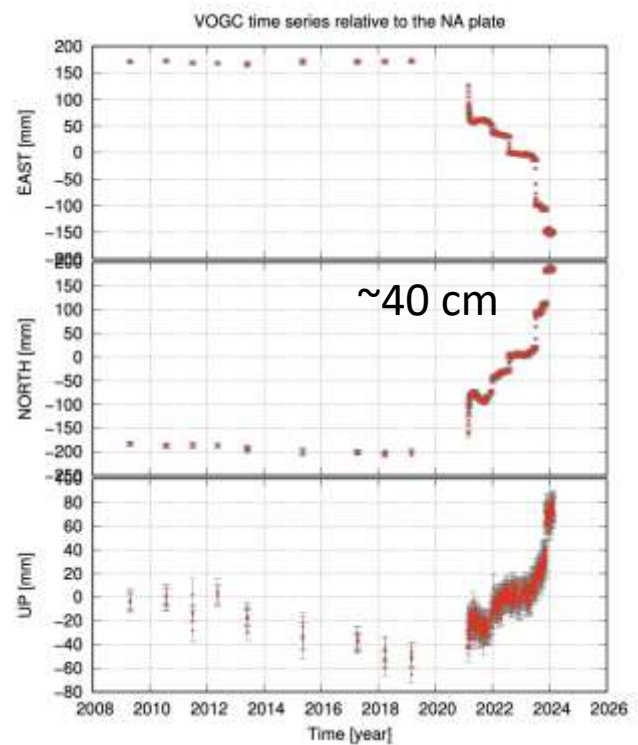
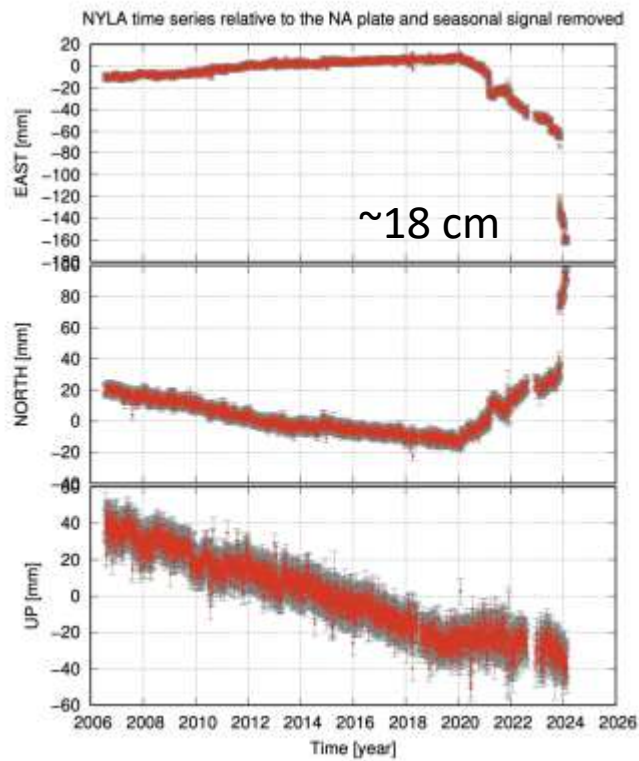
Far-field deformation



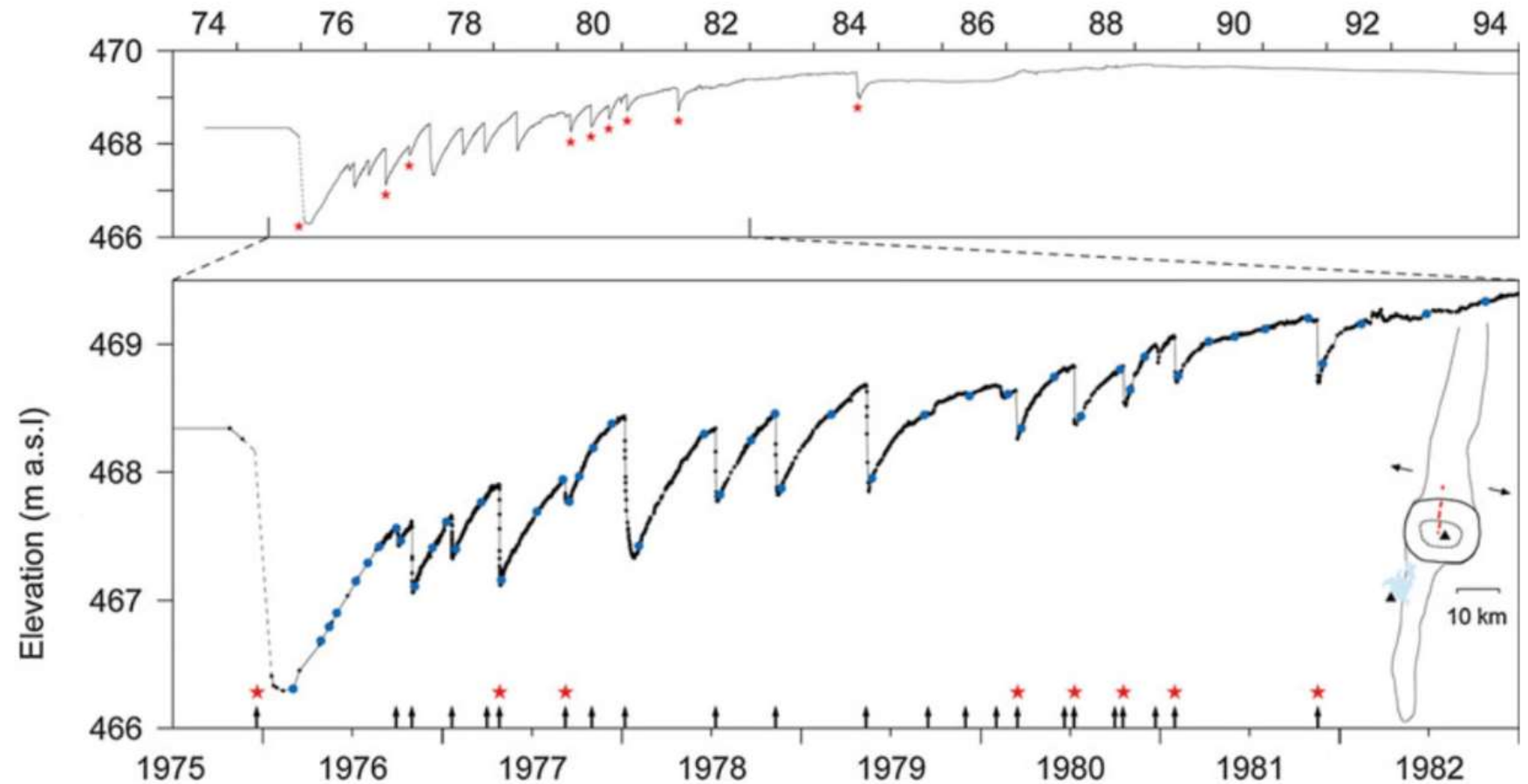
REYK time series relative to the NA plate and seasonal signal removed



Far-field deformation



Krafla: periods of inflation-predictable diking

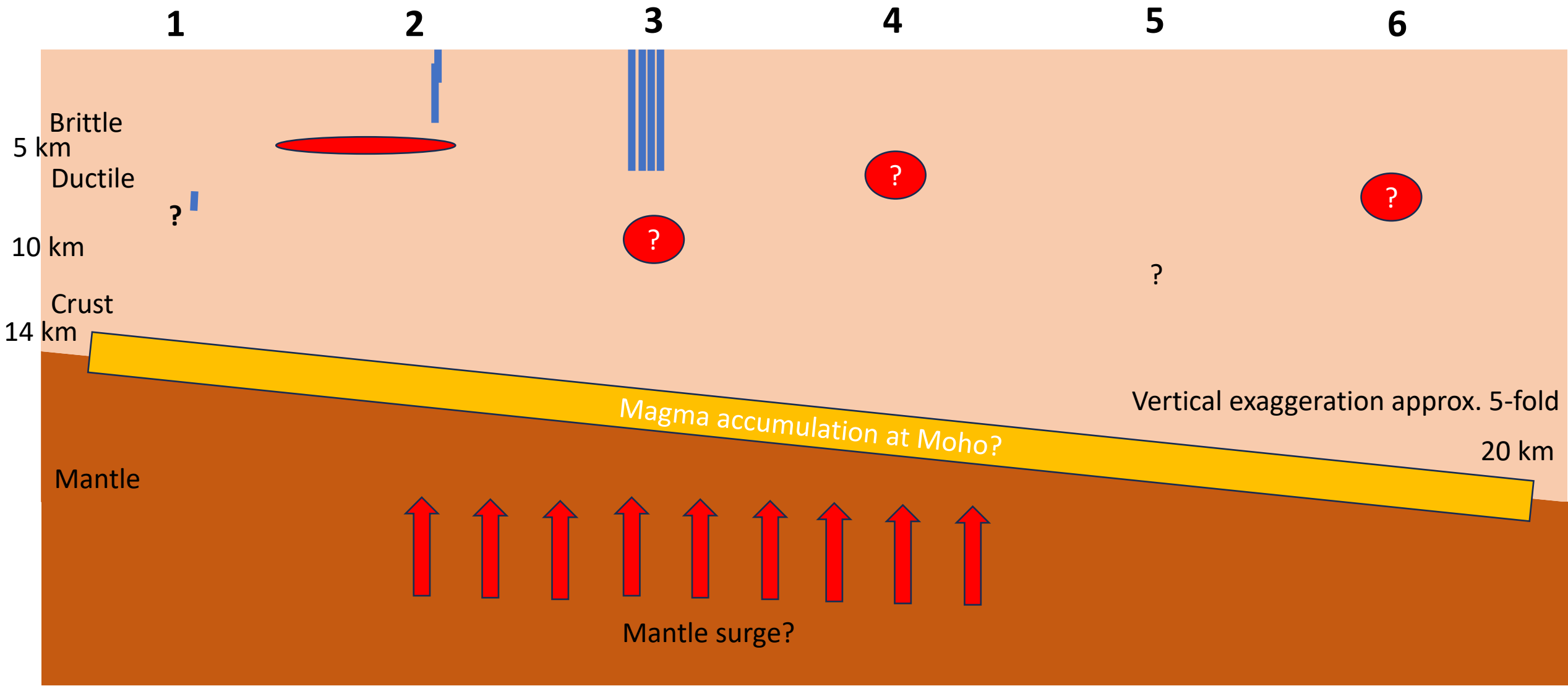


Volcanoes in Iceland and Crustal Deformation Processes, Fig. 8 Elevation changes from 1974 to 1995 at a benchmark FM5596, 1 km SE of the center of the Krafla caldera. The line shows interpolated values based on leveling (blue circles) and tilt measurements (black dots). The leveling was done relative to a benchmark at the southern

shore of Lake Mývatn, 20 km away from the caldera (FM6414). Arrows indicate rifting events, red stars eruptions and triangles show geodetic sites FM5596 and FM6414. (Data from Björnsson and Eysteinsson 1998 and references therein)

Is it all connected? How?

- #1: Reykjanes #3: Fagradalsfjall
- #2: Svartsengi #4: Krísuvík
- #5: Brennisteinsfj. #6: Hengill





Birna Bragadóttir

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— with Elisabet Jonsdottir and 2 others at Ægisíða - Vesturbær.

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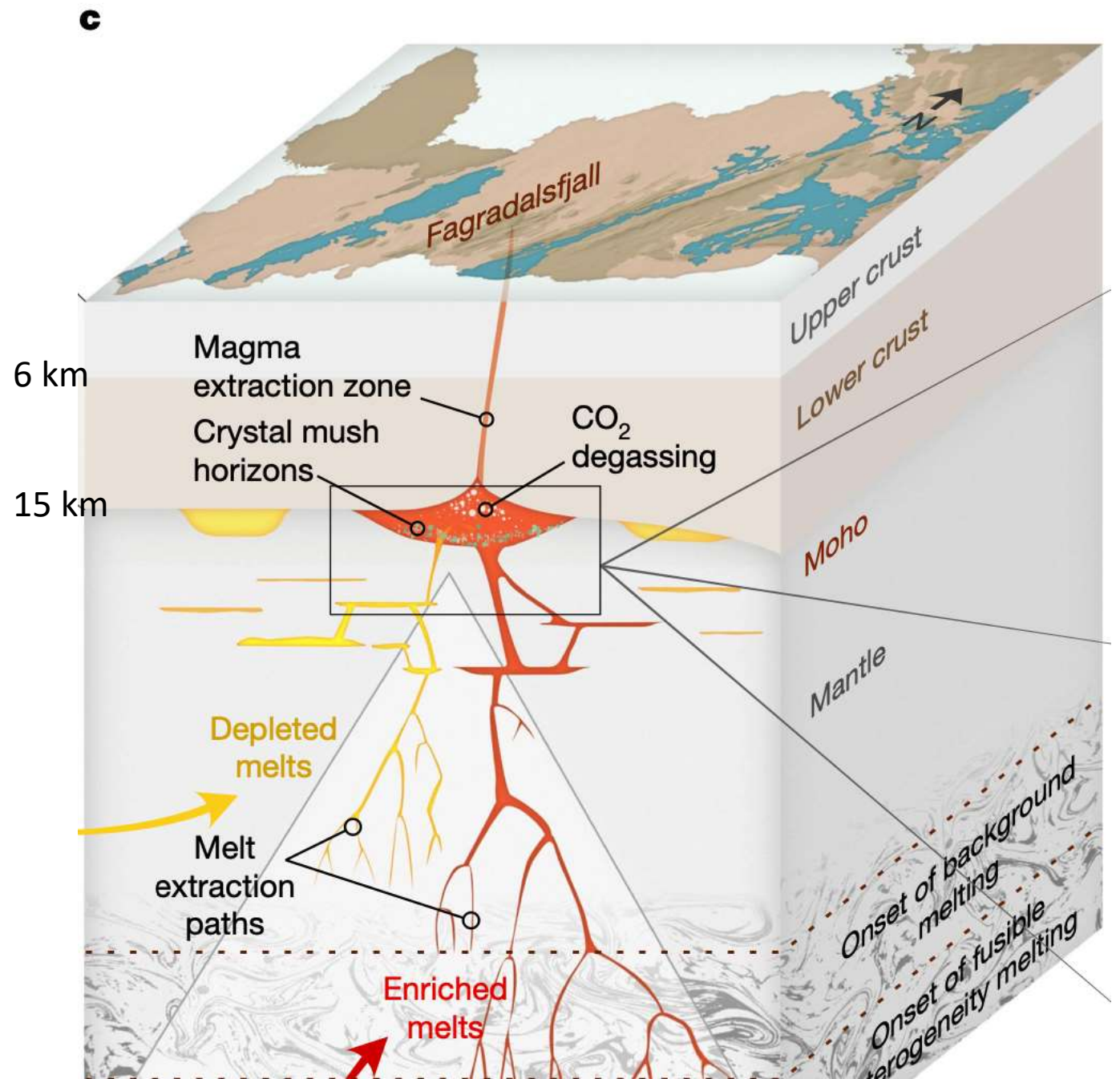
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Conclusions about the Reykjanes Peninsula

- When studying temporally and spatially complex events it is of great importance to have good data!
- Meter-scale deformation
- Far-field deformation: cm-scale well past Reykjavík
- High spatial and temporal resolution deformation imaging
- We have since 2020 had:
 - 6 eruptions
 - 9 dikes
 - 17 inflation episodes
 - Hundreds of faults being displaced
- ... and expect more: We are likely at the beginning of an unrest period lasting 100s of years and involving most systems on the Reykjanes Peninsula
- Evidence of stress interactions and deep pressure connections



The petrology view



Modified from Halldórsson et al., 2022