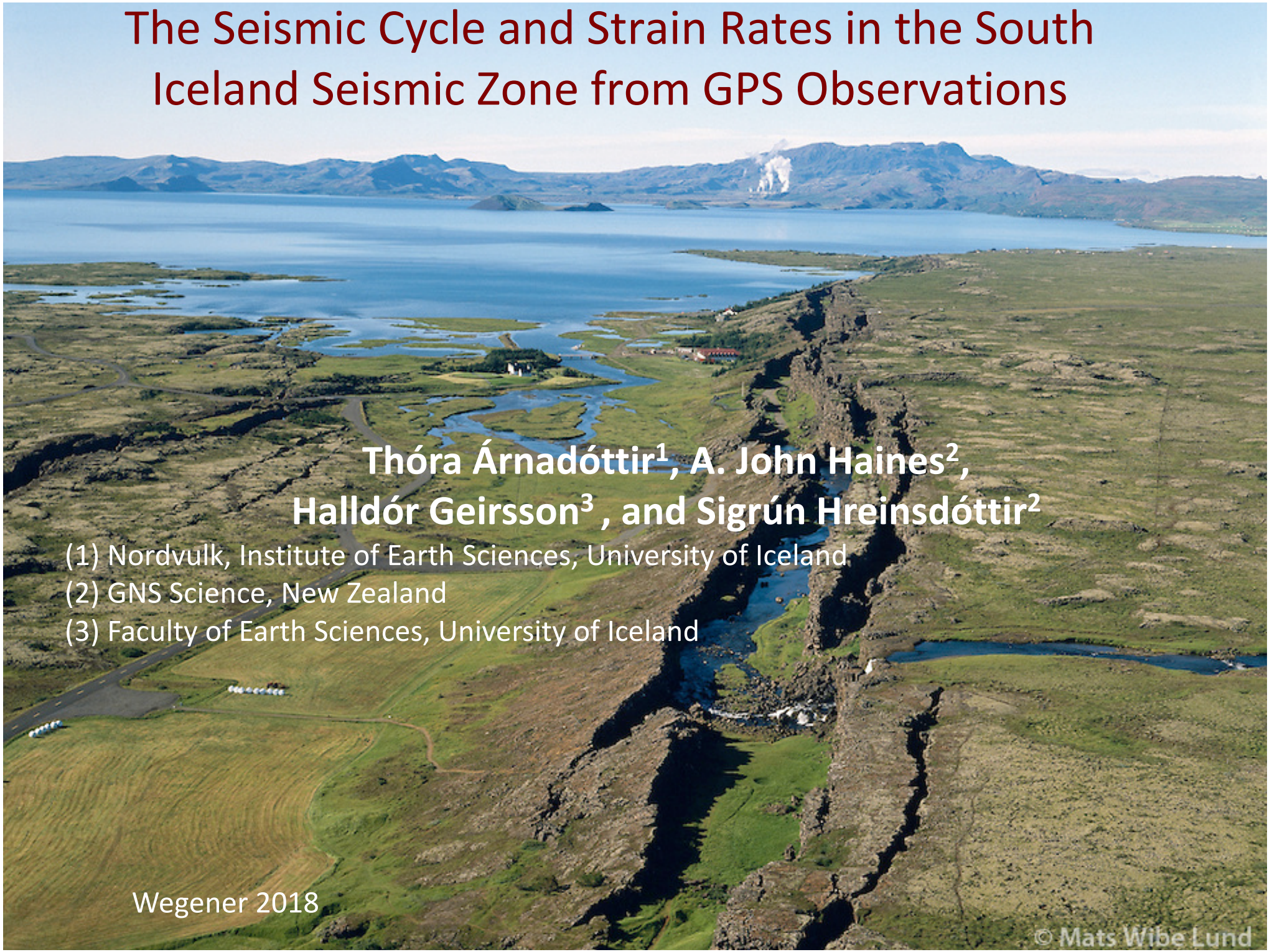
The Seismic Cycle and Strain Rates in the South Iceland Seismic Zone from GPS Observations



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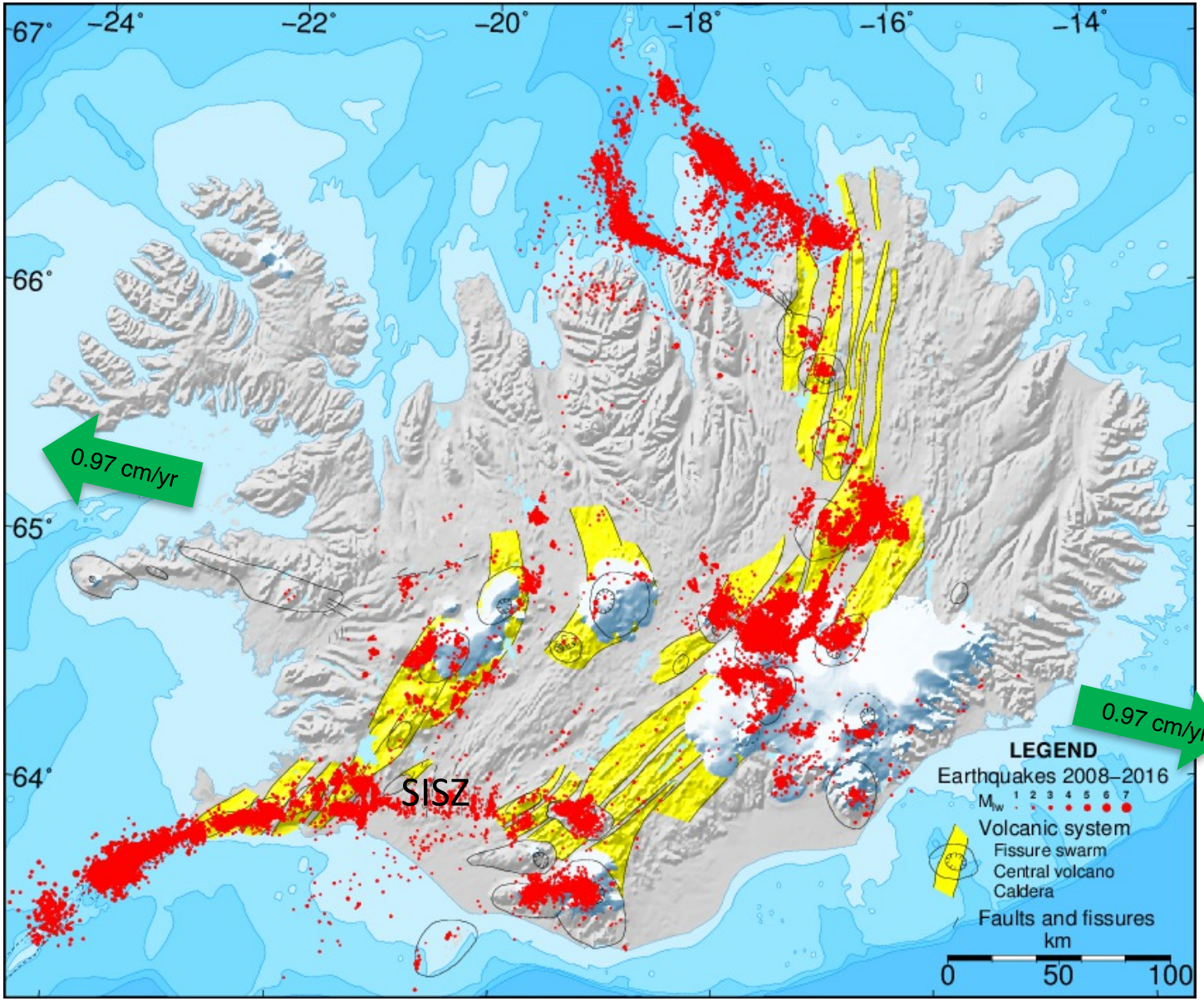
Wegener 2018

NOTE - copyright

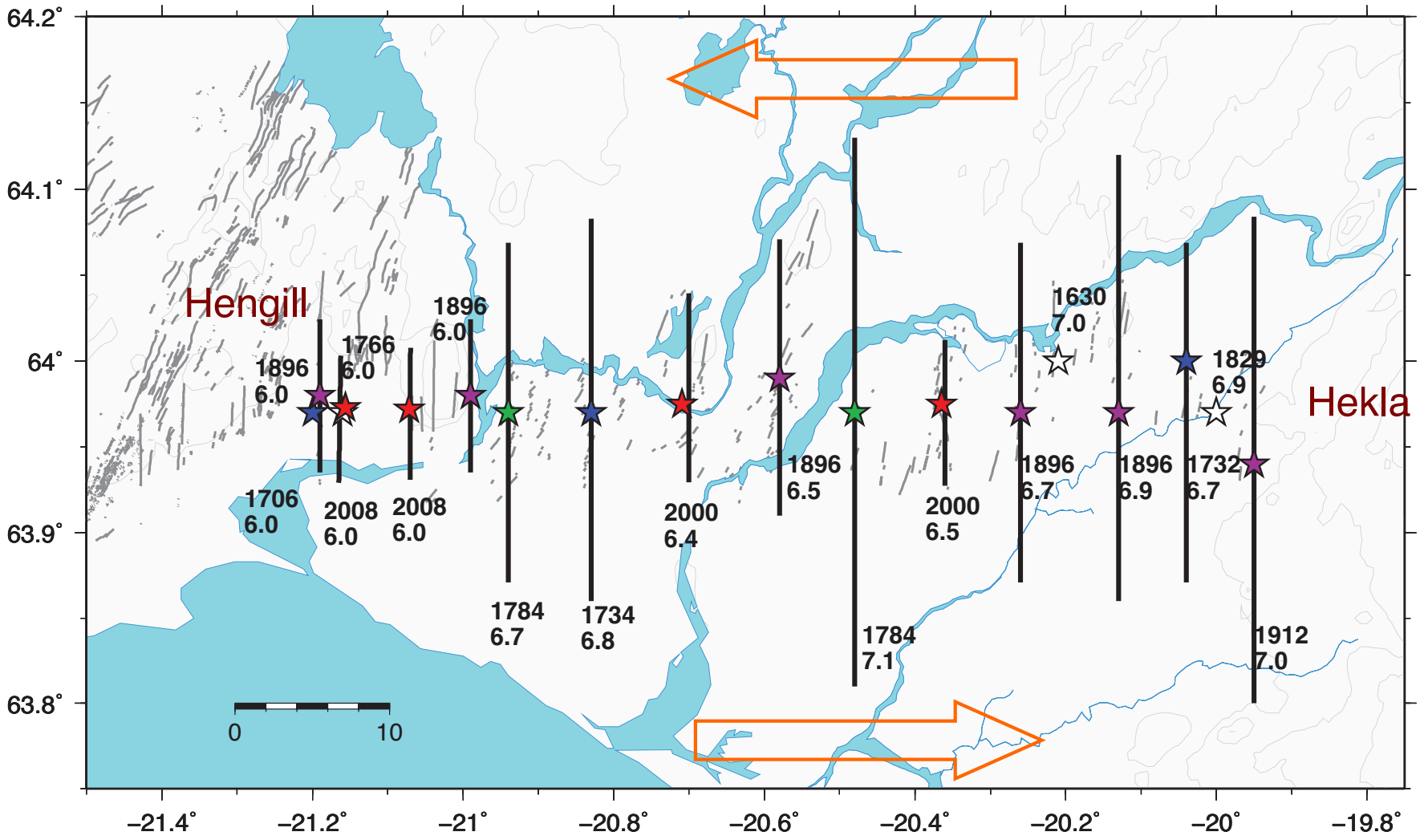
- The results shown in this presentation are unpublished, unless a reference is given.
- Earthquake locations are from the SIL network operated by the Icelandic Meteorlogical Office.
- Any use of the figures (in particular GPS velocities and strain rates) is not permitted without permission from the authors of this presentation.
- A manuscript is currently under revision for publication in JGR:

Árnadóttir, T., A.J. Haines, H. Geirsson, S. Hreinsdóttir, A pre-seismic strain anomaly detected before M6 earthquakes in the South Iceland Seismic Zone from GPS station velocities, under revision, J. Geophys. Res., Sept. 2018.

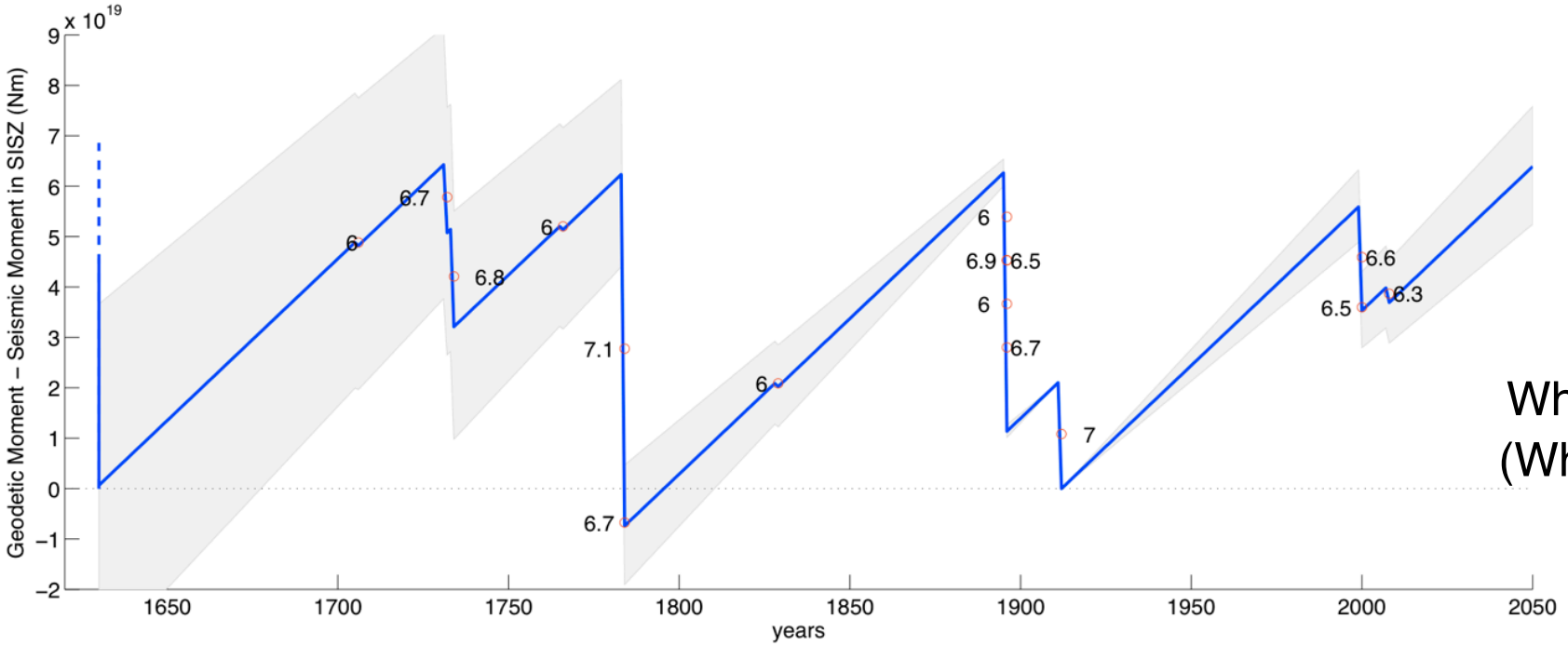


Seismicity recorded by the SIL network 2008-2016
(Gunnar B. Guðmundsson, IMO, 2017)

Historical earthquakes (M>6) since 1630 in the SISZ



The earthquake cycle in the SISZ



Where??
(When?)

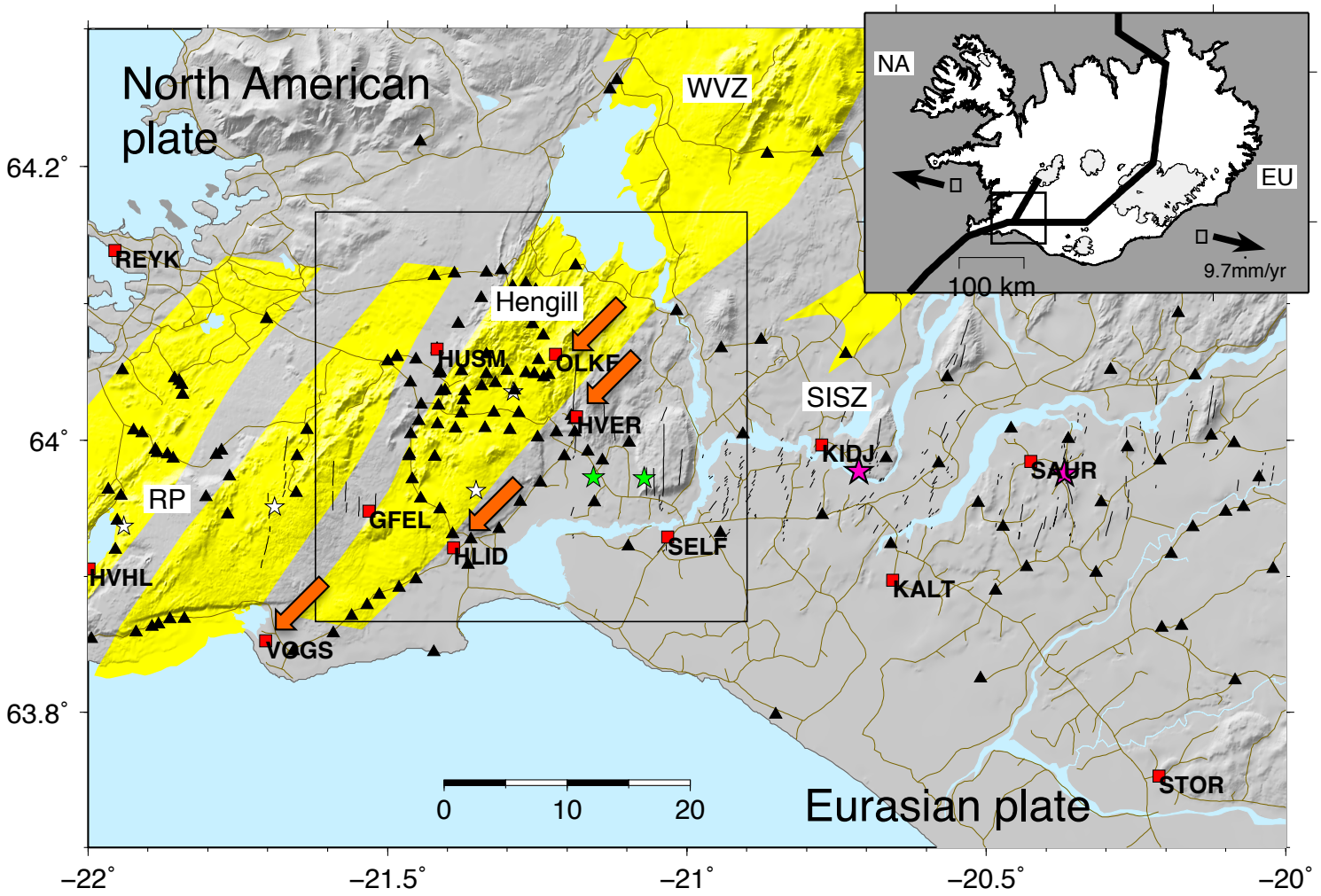
Annual rate of geodetic moment accumulation is equivalent to a Mw5.5-6 earthquake every year!

Decriem, Árnadóttir et al. (GJI, 2010)

Motivation

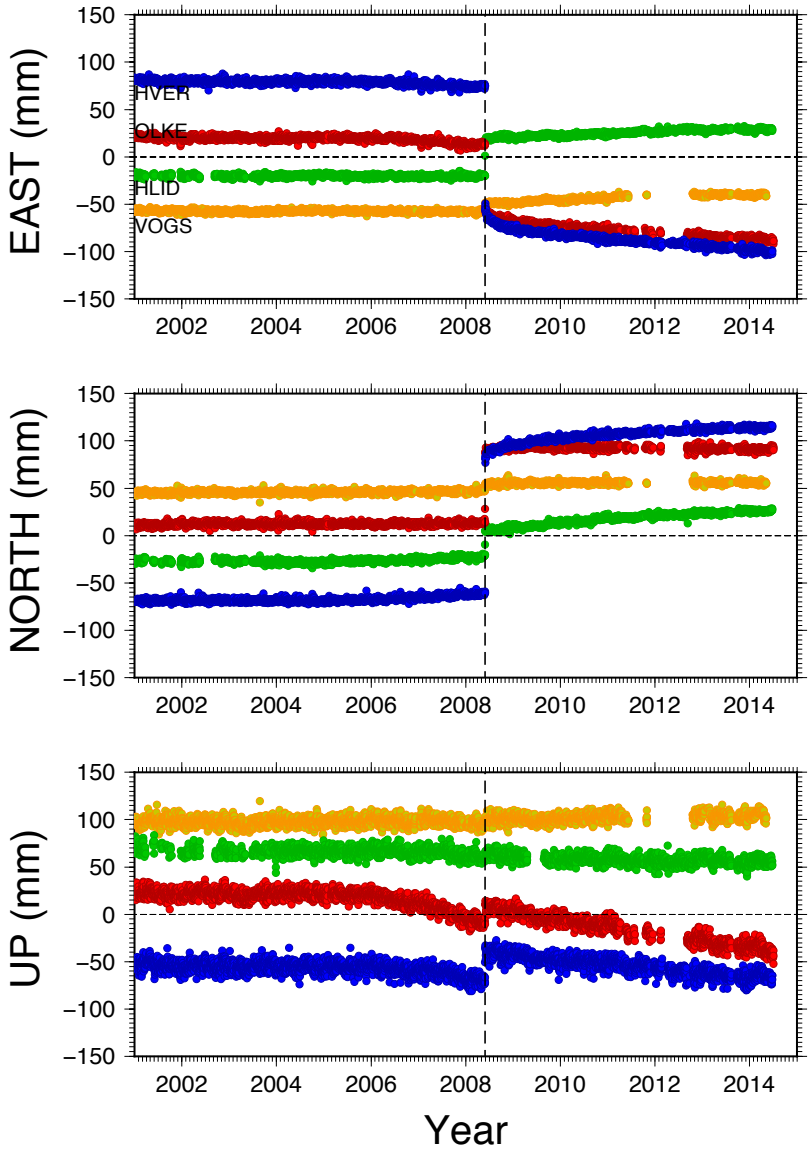
- Unravel the different deformation signals in South Iceland:
  - Plate motion
  - Earthquakes (co- and post- seismic)
  - Local deformation in Hengill
  - Hekla volcano
- We are in the middle of an earthquake cycle in the SISZ – can expect a M7 or several M6+
  - Look for areas of potential future earthquakes (M6+)

GPS network

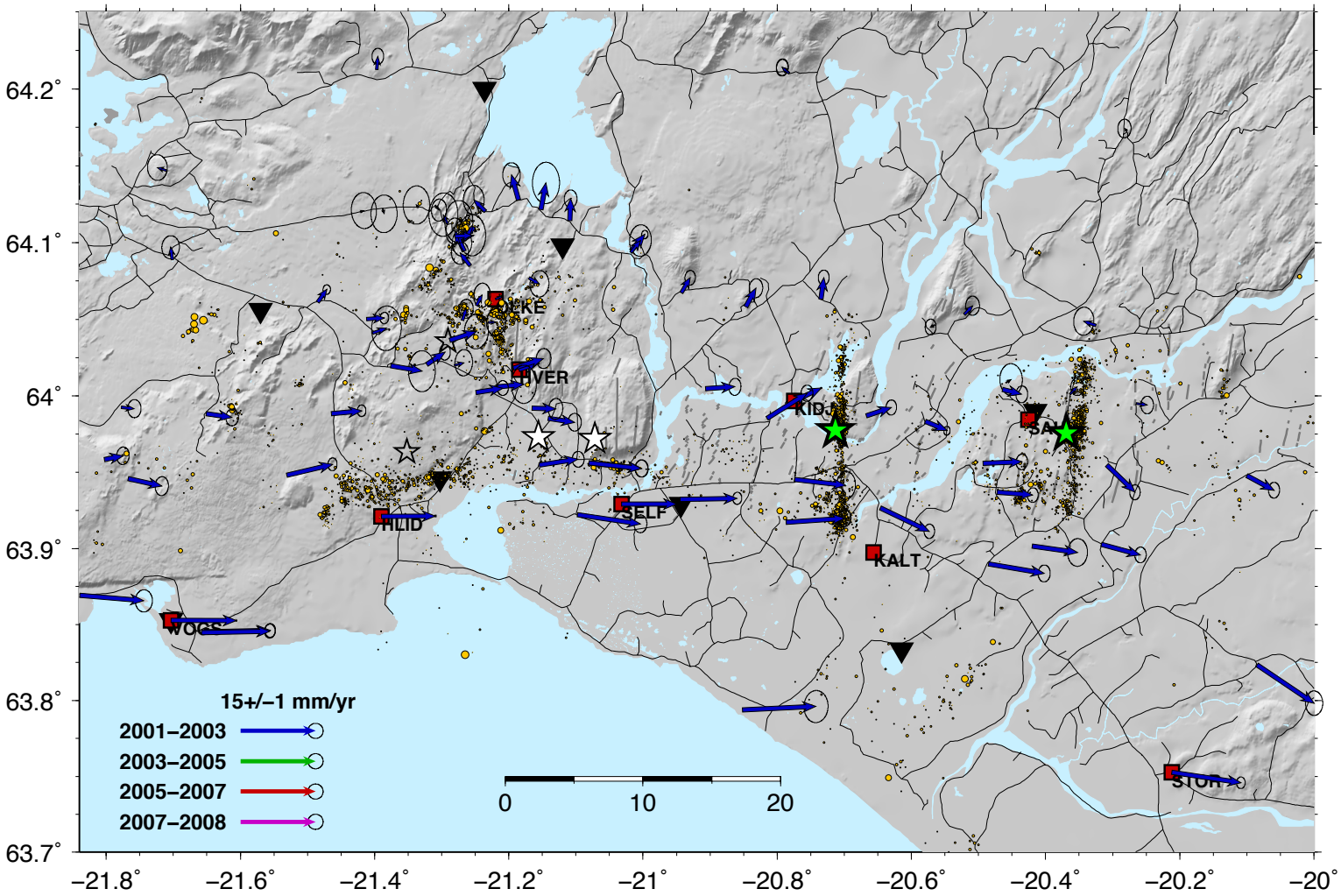

North American plate
Eurasian plate
WVZ
SISZ
RP
Hengill
REYK
HUSM
OLKF
HVER
GFEL
HLID
SELF
KIDJ
SAUR
KALT
STOR
HVHL
VOGS
NA
EU
9.7mm/yr
100 km
0
10
20
64.2˚
64˚
63.8˚
−22˚
−21.5˚
−21˚
−20.5˚
−20˚

cGPS station time series

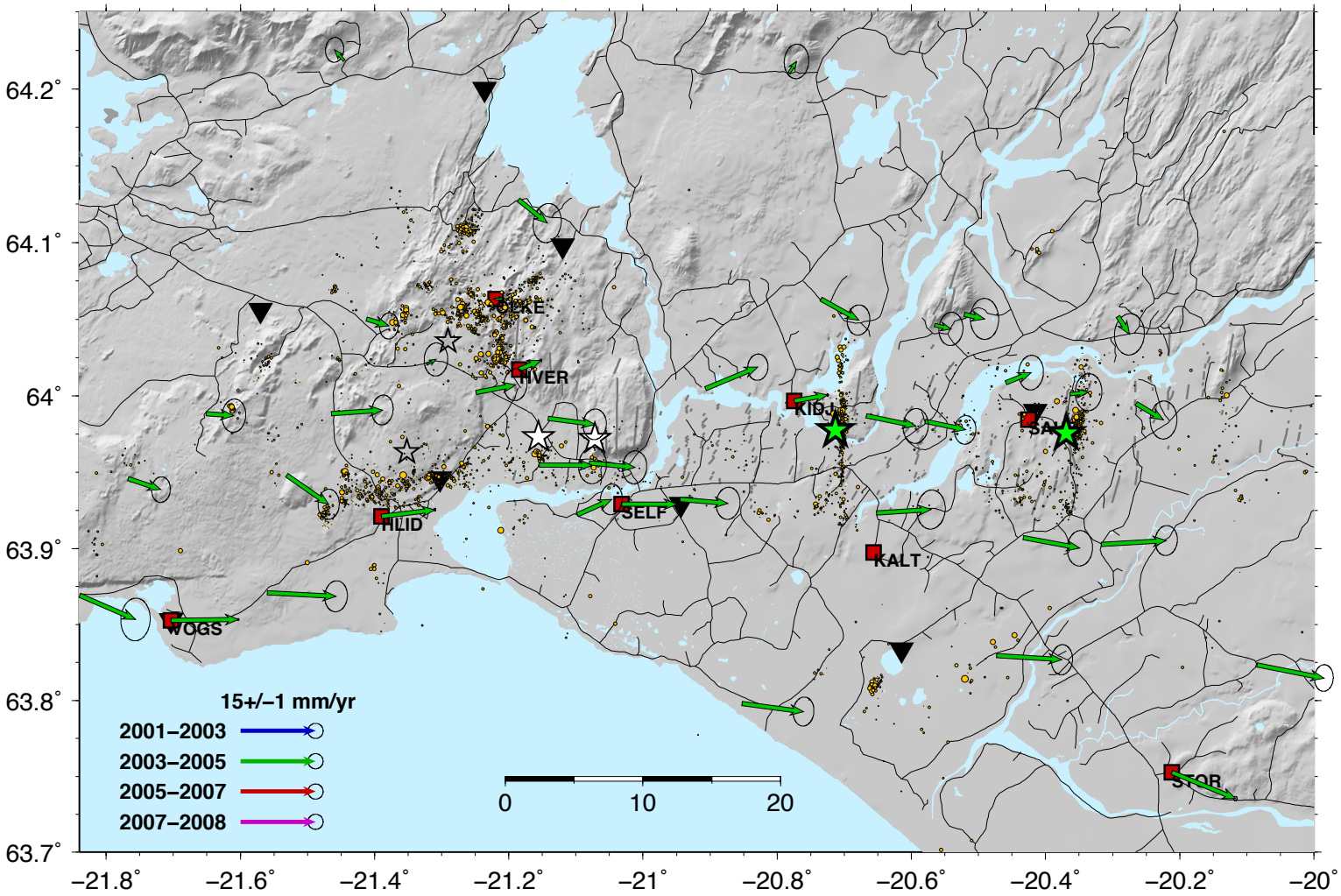
HLID, OLKE, HVER, VOGS (Detrended)



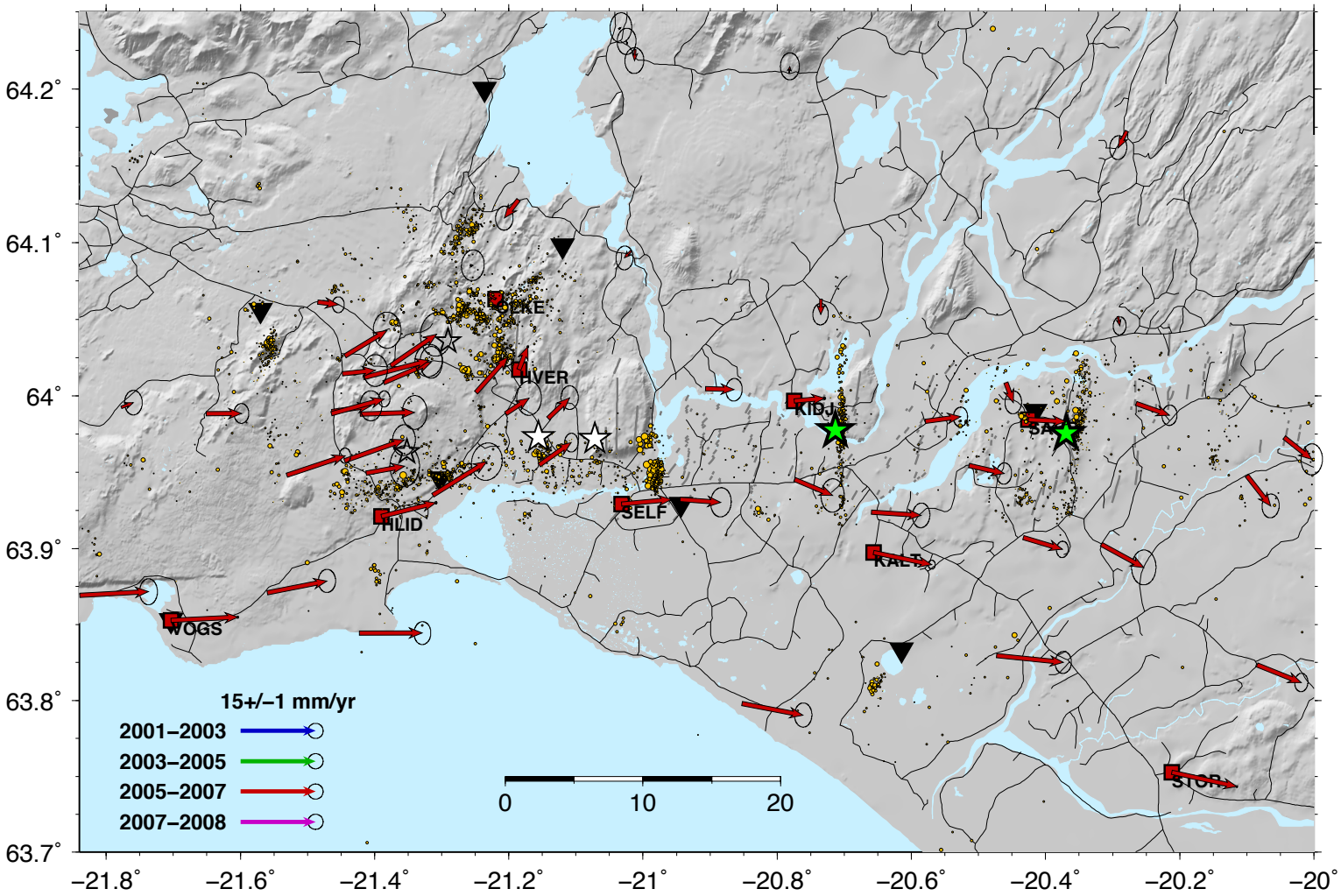
GPS station velocities



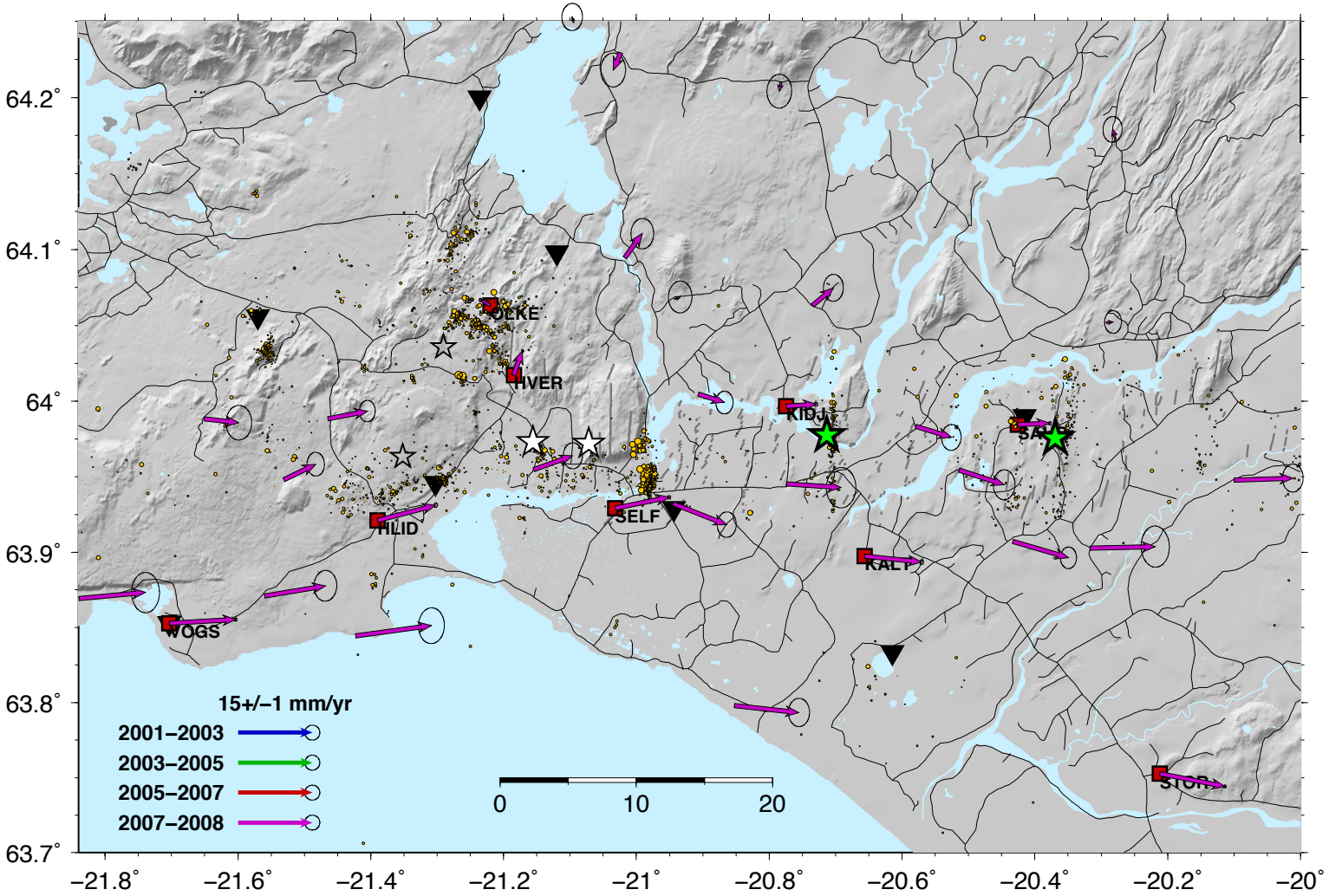
GPS station velocities



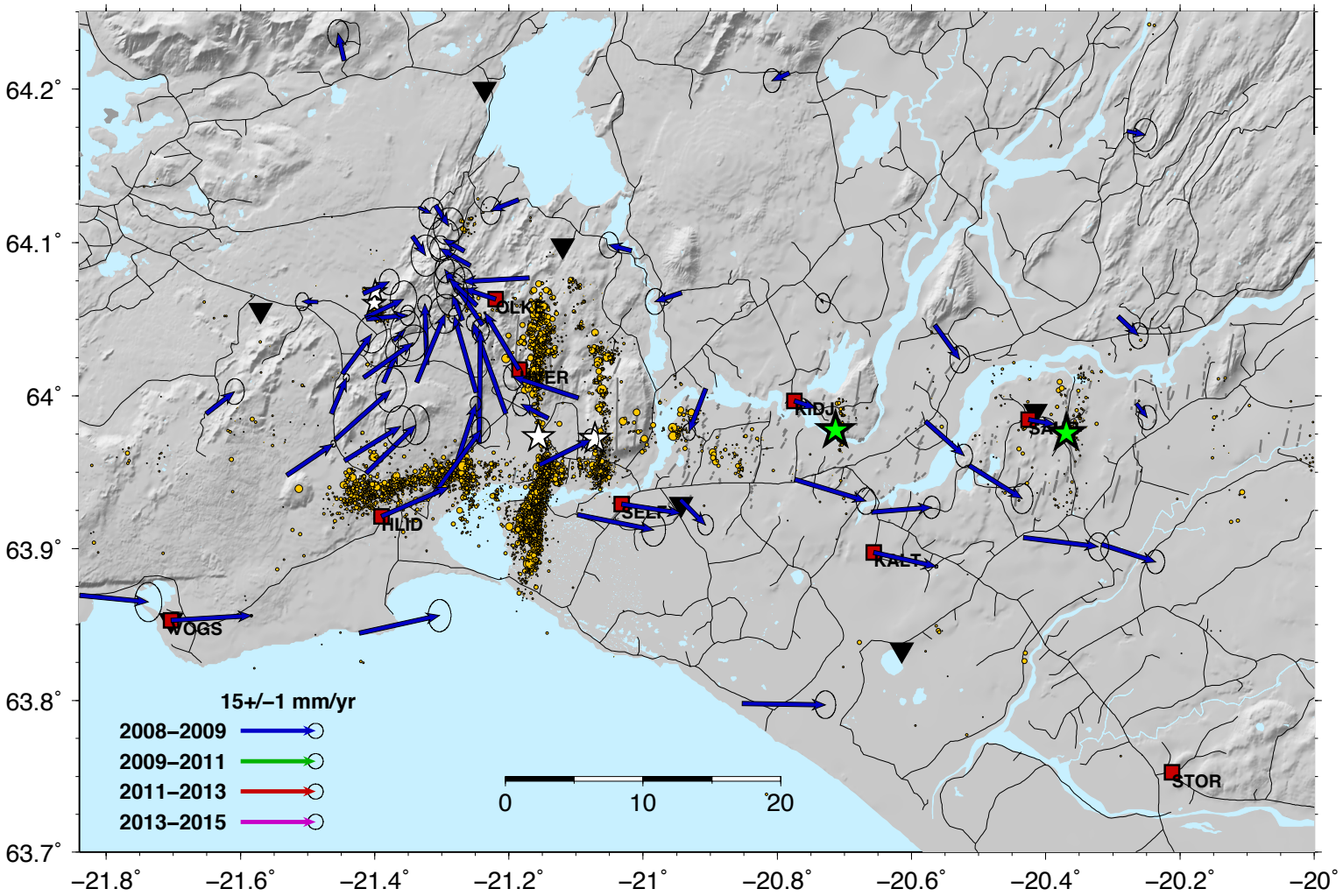
GPS station velocities



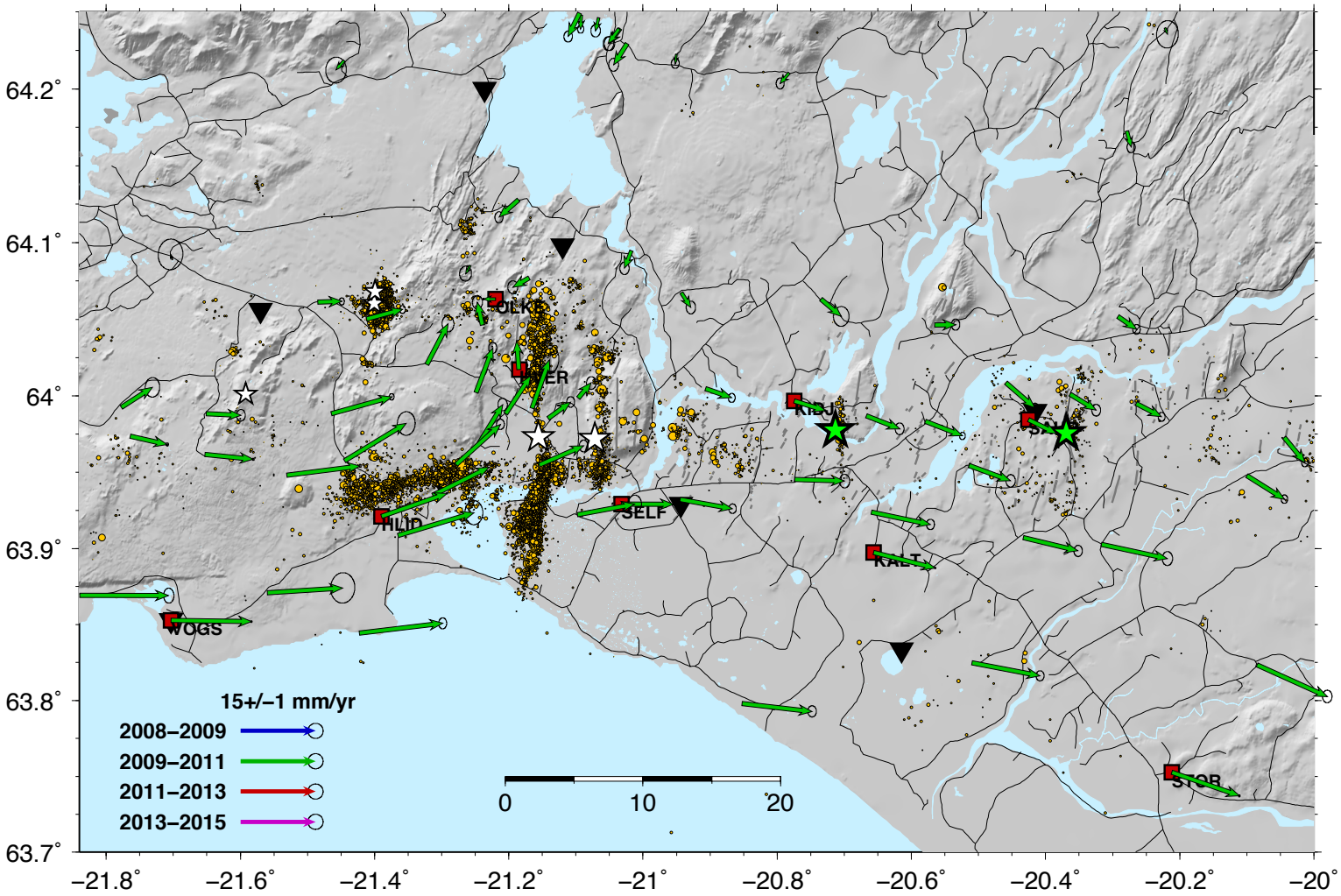
GPS station velocities



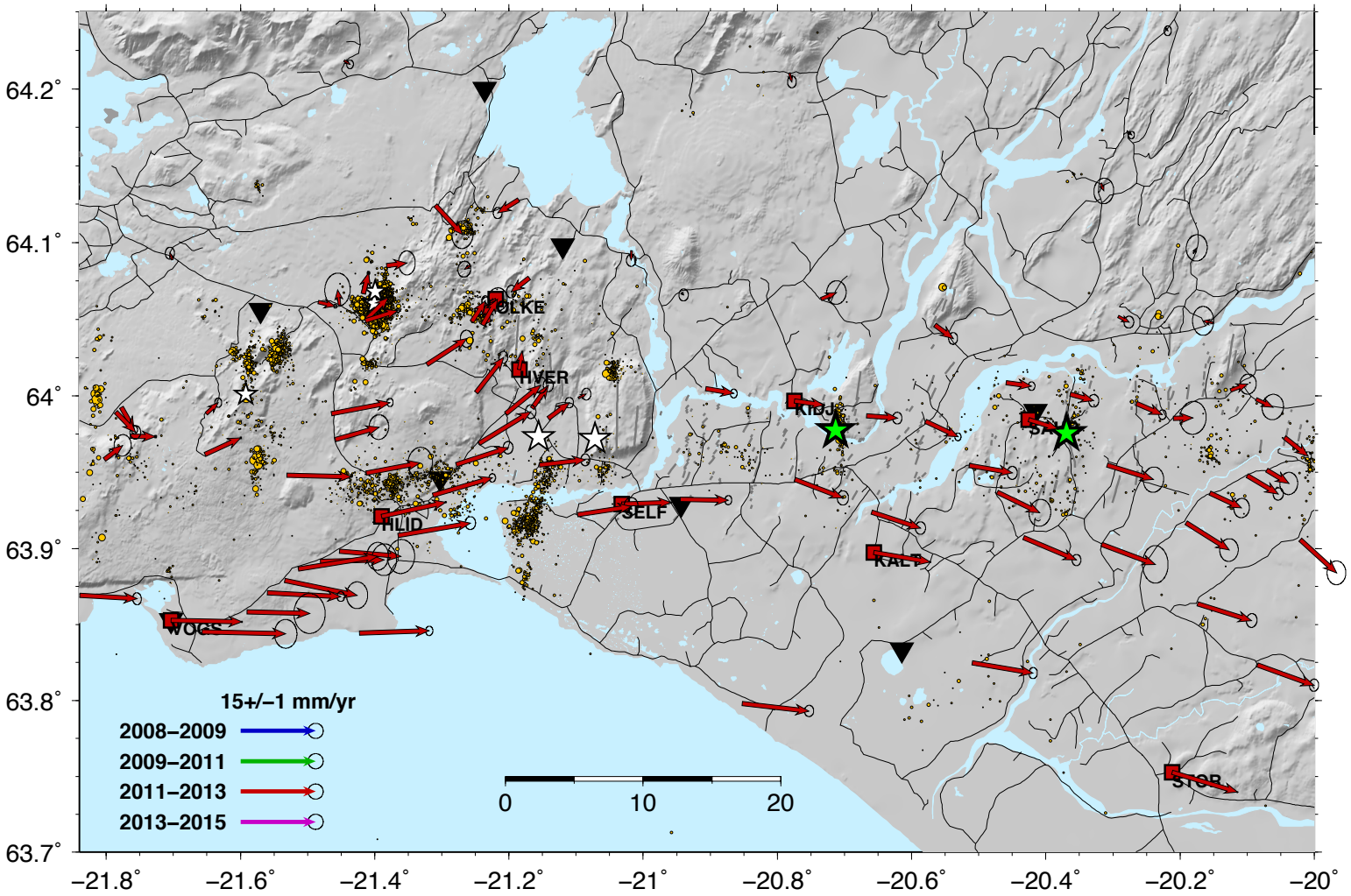
GPS station velocities



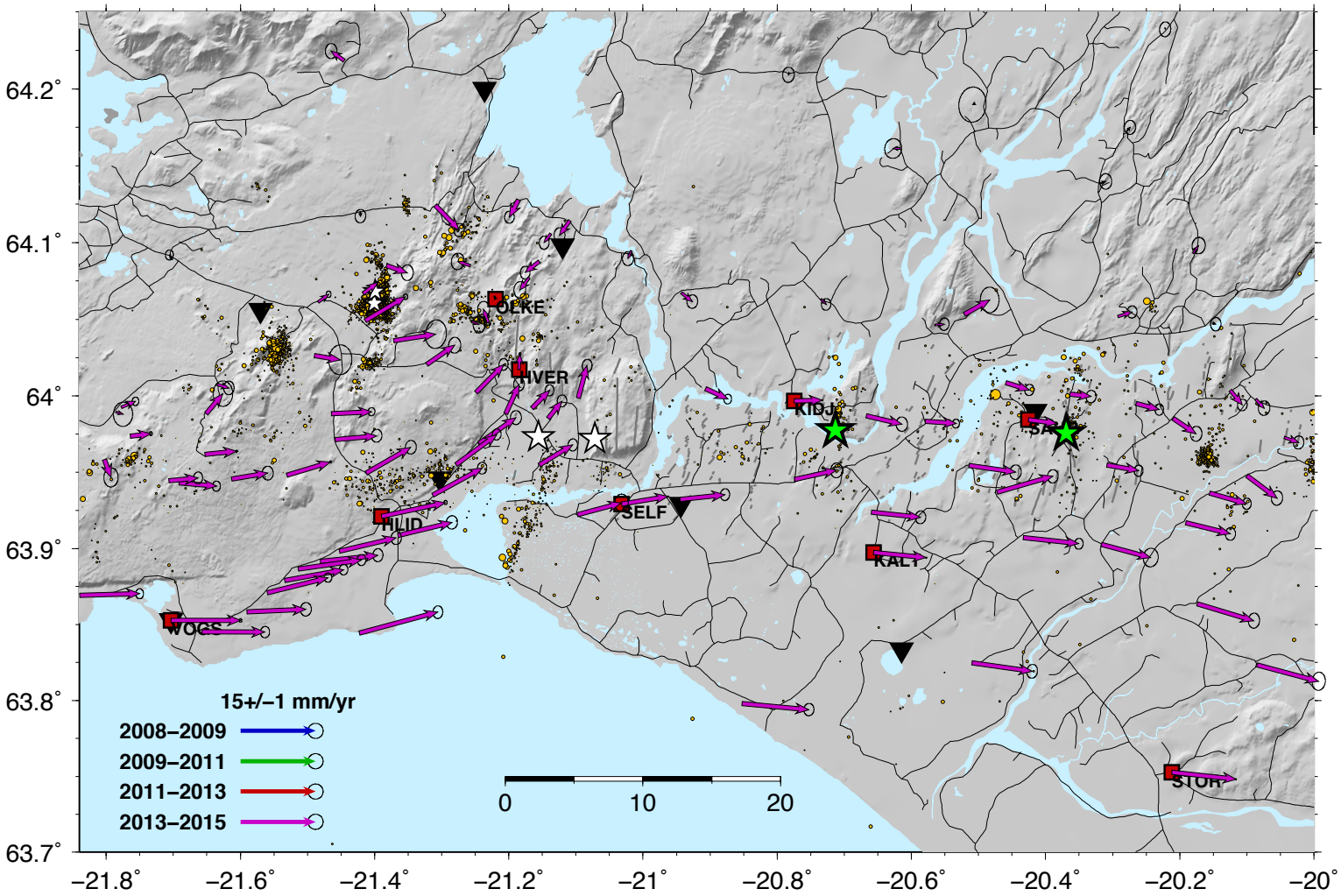
GPS station velocities



GPS station velocities



GPS station velocities



Deformation vs. strain

- Strain can be calculated from surface deformation
- Strain is independent of reference frames
- Strain is a higher-order quantity - the derivative of the deformation - and strain maps thus provide higher resolution of where deformation is occurring
- The deformation field needs to be uniform to avoid singularities in the strain field

New method: VDoHS

VDoHS: Vertical derivatives of horizontal stress

Method to calculate strain rates from GPS velocities developed by

John Haines, GNS, NZ

Lada Dimitrova, and Laura Wallace, Institute for Geophysics, University of Texas at Austin

(Haines et al. 2015, Dimitrova et al. 2016)

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Horizontal Force Balance Equations

At the Earth's surface…

$$\frac{\partial \dot{\sigma}_{xx}}{\partial x} + \frac{\partial \dot{\sigma}_{xy}}{\partial y} + \frac{\partial \dot{\sigma}_{xz}}{\partial z} = 0$$

$$\frac{\partial \dot{\sigma}_{xy}}{\partial x} + \frac{\partial \dot{\sigma}_{yy}}{\partial y} + \frac{\partial \dot{\sigma}_{yz}}{\partial z} = 0$$

directly dependent on horizontal velocities and their horizontal derivatives

surface expressions of subsurface sources (VDoHS rates)

inverted using 2D Green's functions for their surface values

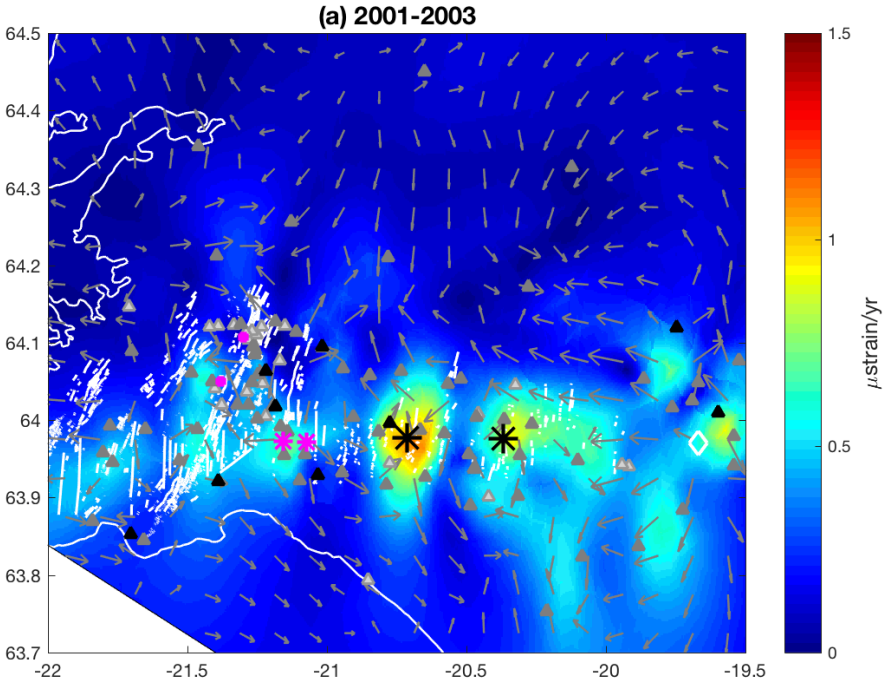
What are Vertical Derivatives of Horizontal Stress (VDoHS) Rates?

- Can be derived from GPS velocities (Haines et al. 2015, Dimitrova et al. 2016) and cGPS time series.
- They are the horizontal-component surface manifestation of all subsurface deformation sources.
- Are the derivatives of stress/strain rates.
- Integrating the VDoHS rates provides the most detailed possible maps of surface strain.

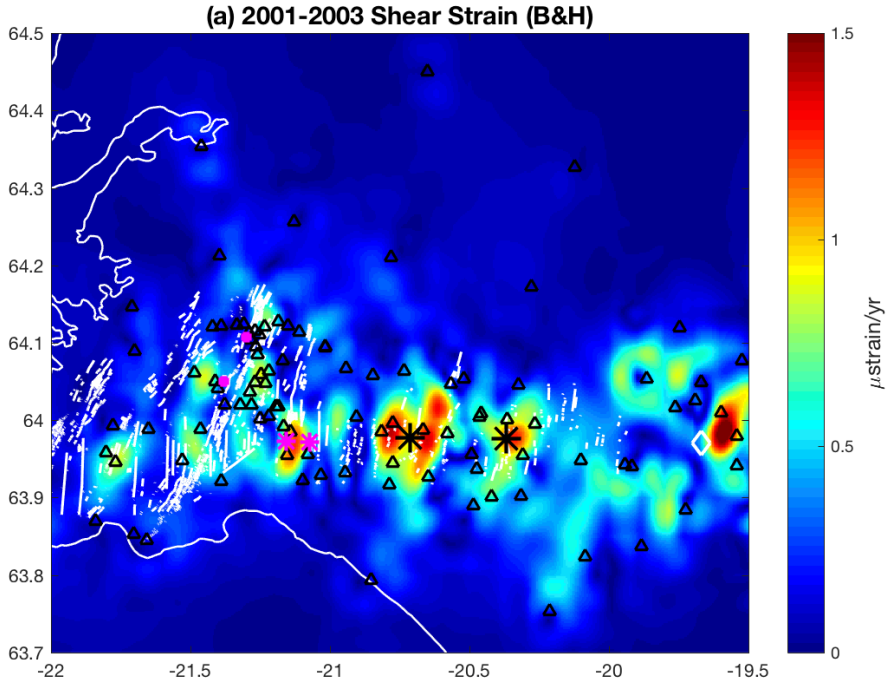
Strain rates

2001-2003

Shear strain rate (VDoHS)



Shear strain rate
(Beavan & Haines method)



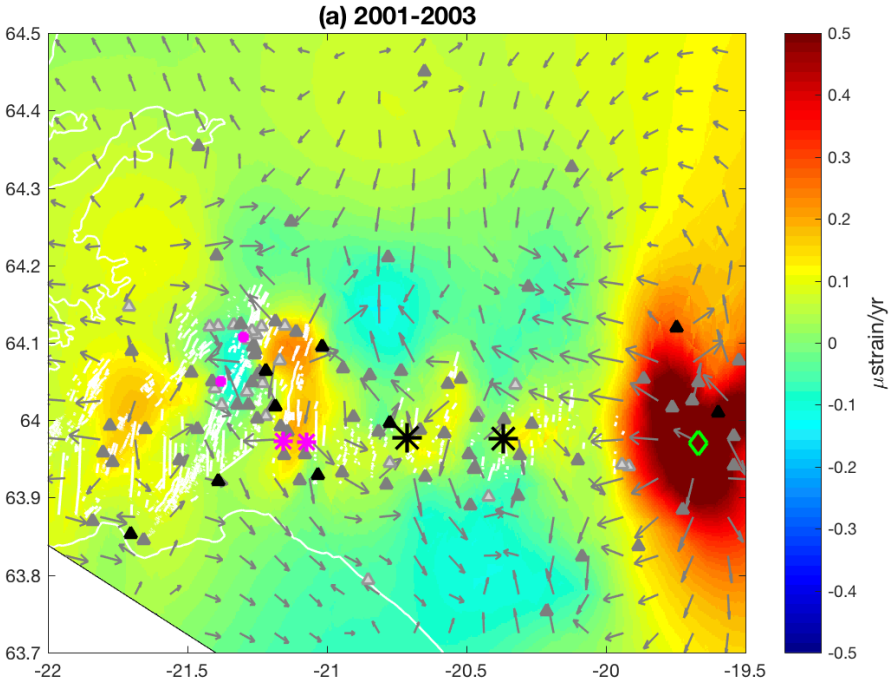
The colour scale indicates strain magnitude in μstrain/yr

The arrows are scaled VDoHS force vectors

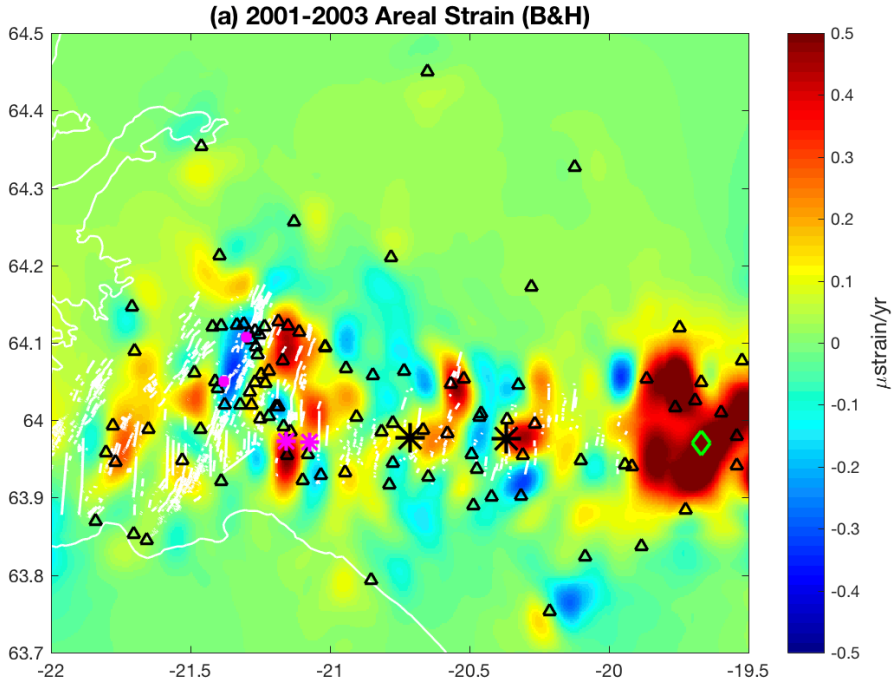
Strain rates

2001-2003

Areal strain rate (VDoHS)



Areal strain rate (Beavan & Haines method)

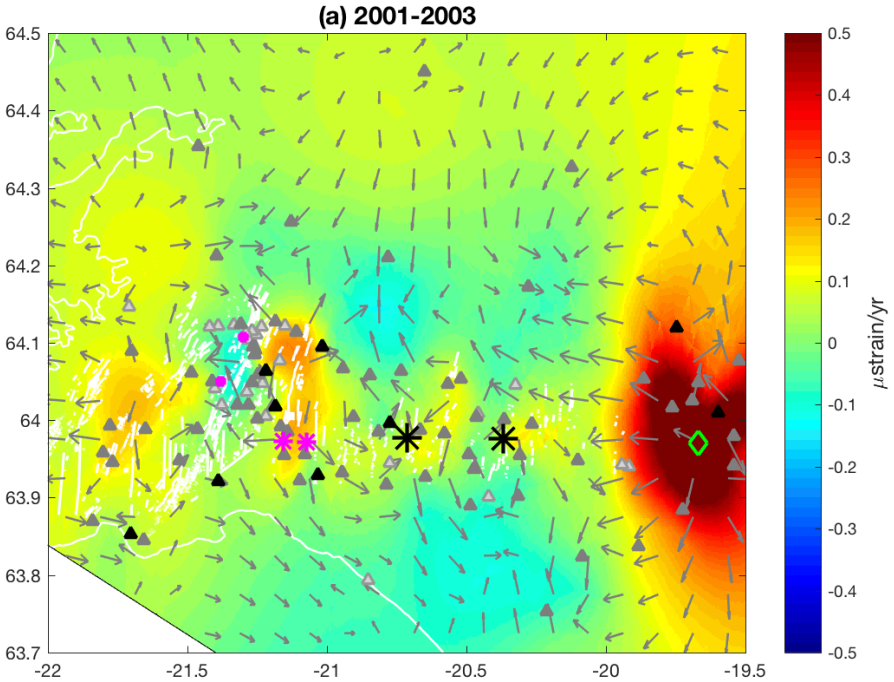


The colour scale indicates strain magnitude in μstrain/yr

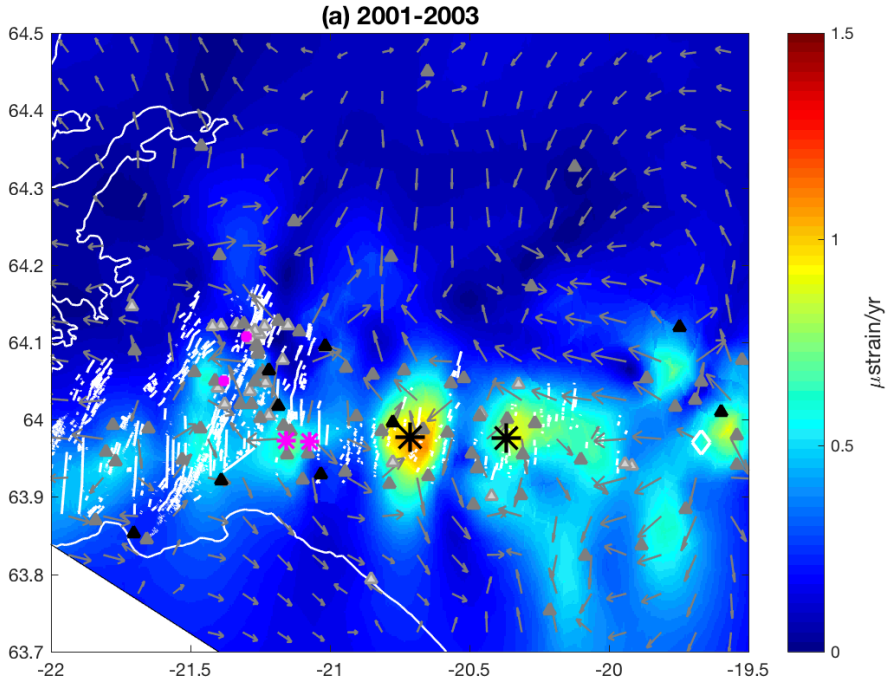
Strain rates (VDoHS)

2001-2003

Areal strain rate



Shear strain rate



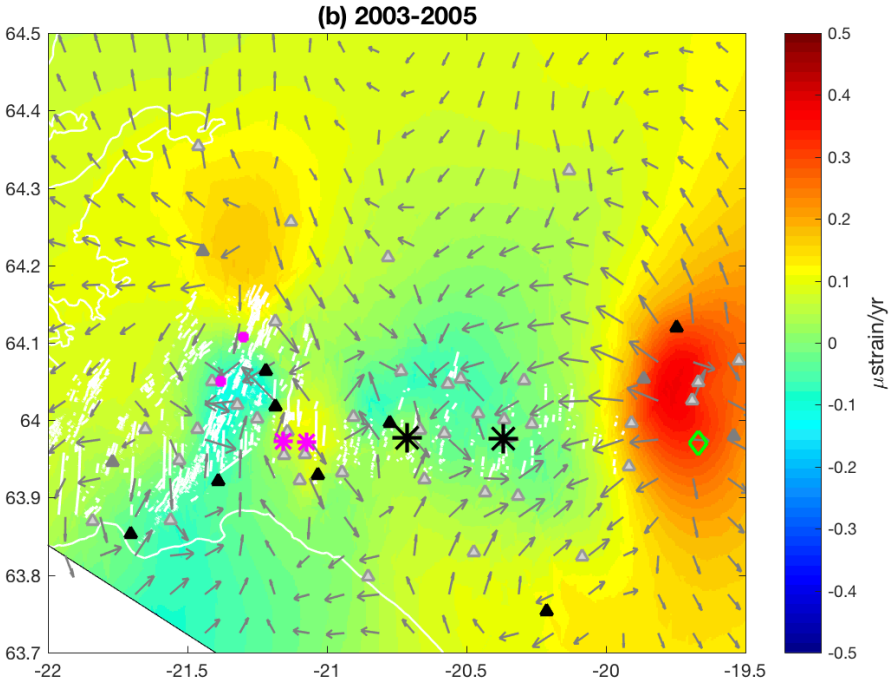
The colour indicates strain magnitude in μstrain/yr

The arrows are scaled VDoHS force vectors

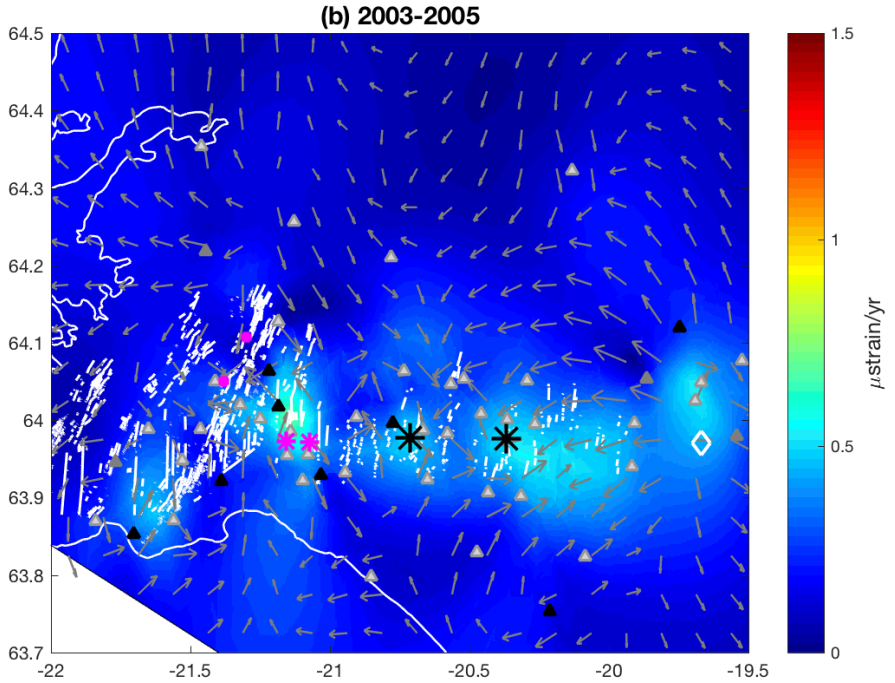
Strain rates (VDoHS)

2003-2005

Areal strain rate



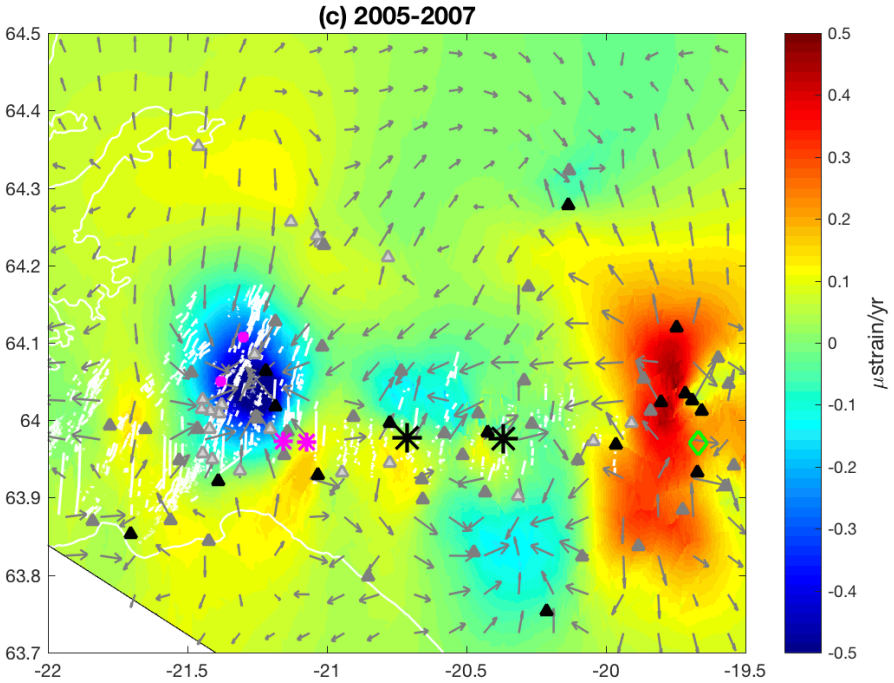
Shear strain rate



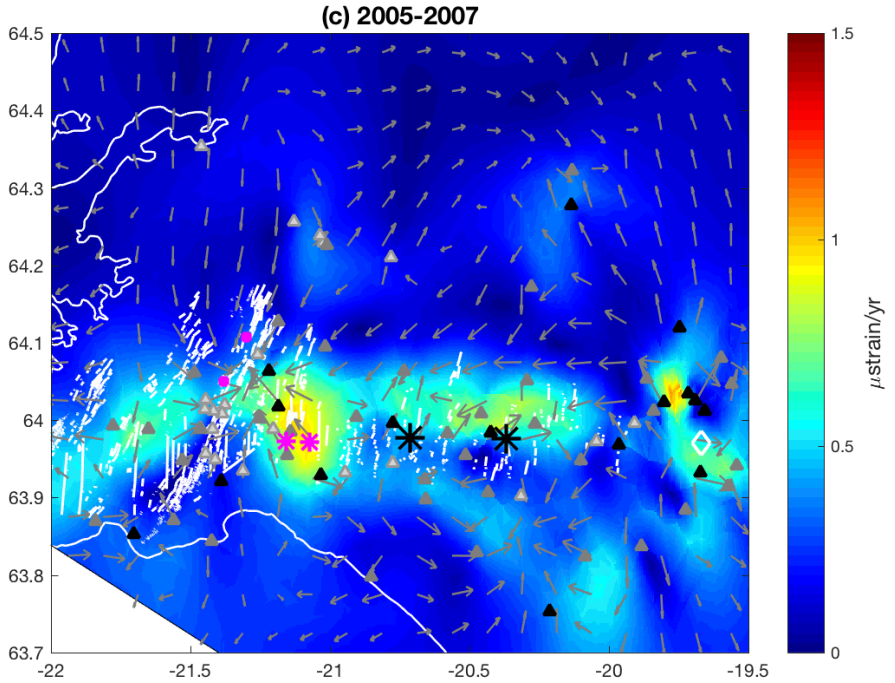
Strain rates (VDoHS)

2005-2007

Areal strain rate



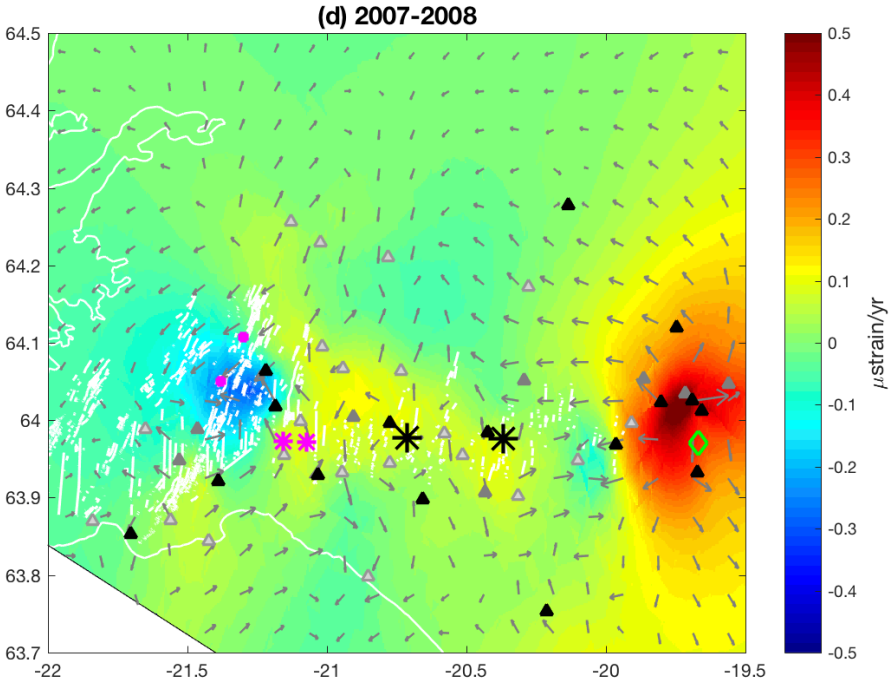
Shear strain rate



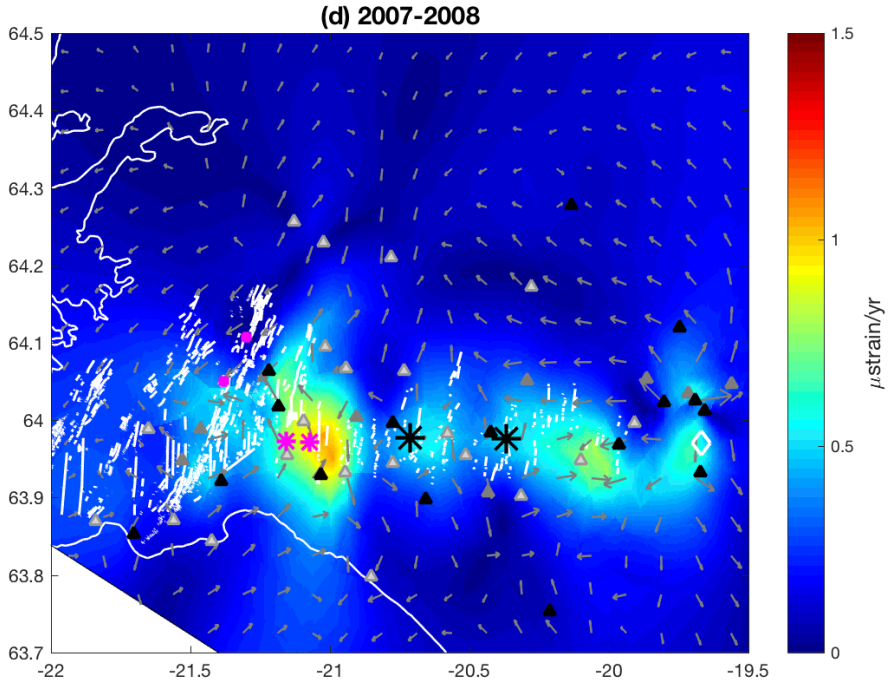
Strain rates (VDoHS)

2007-2008

Areal strain rate



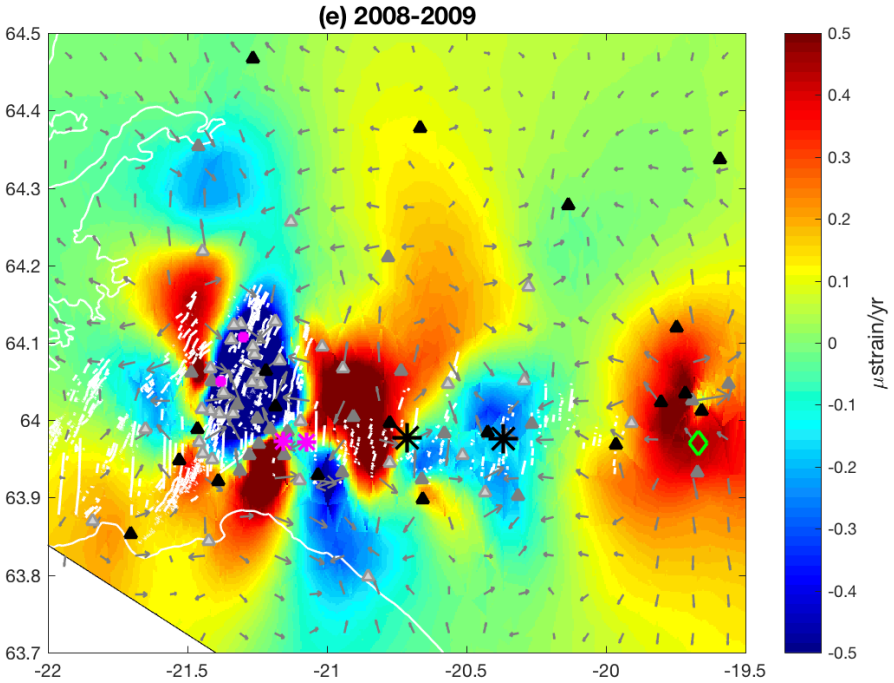
Shear strain rate



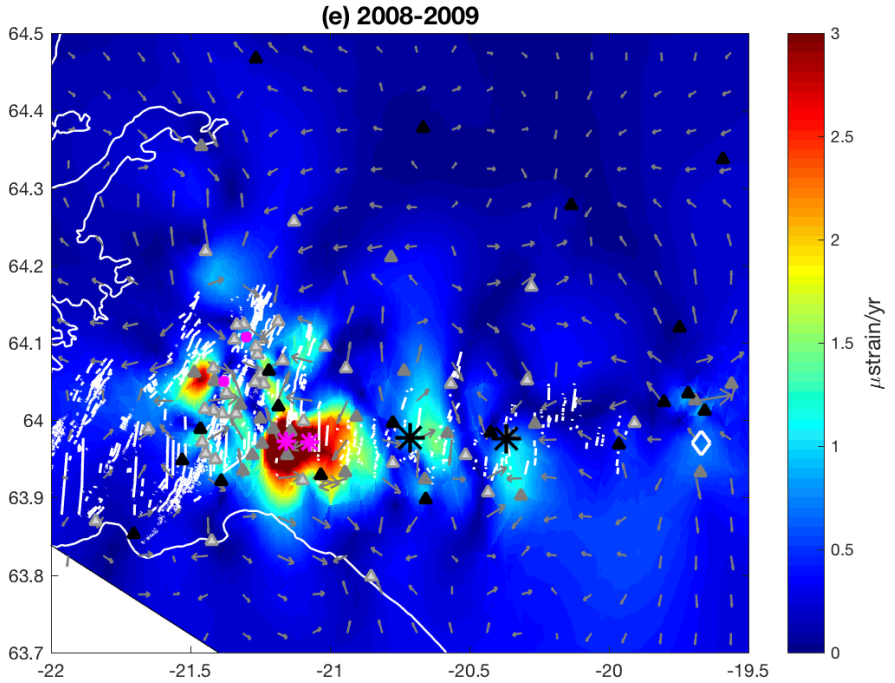
Strain rates (VDoHS)

2008-2009

Areal strain rate



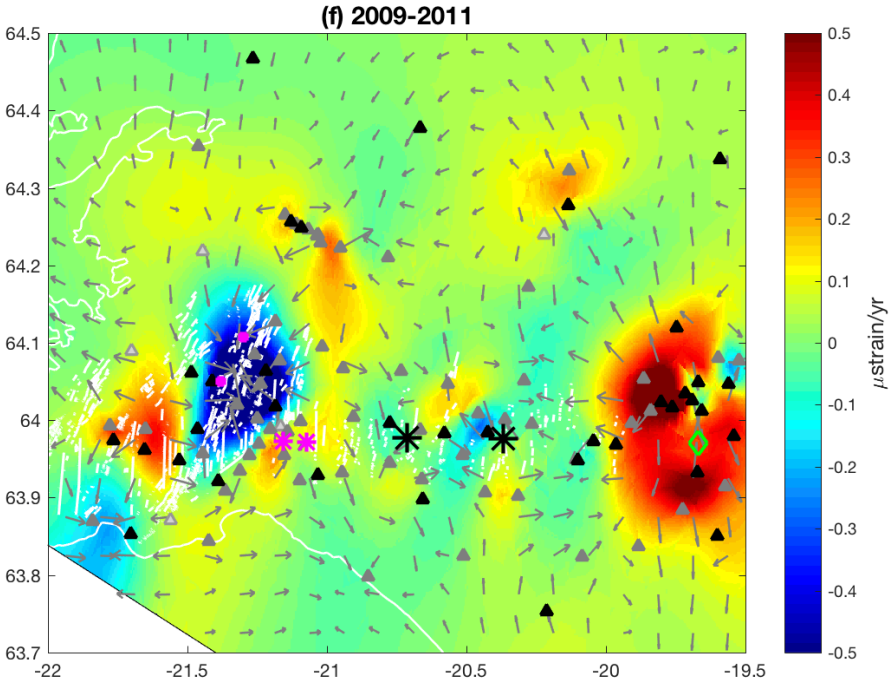
Shear strain rate



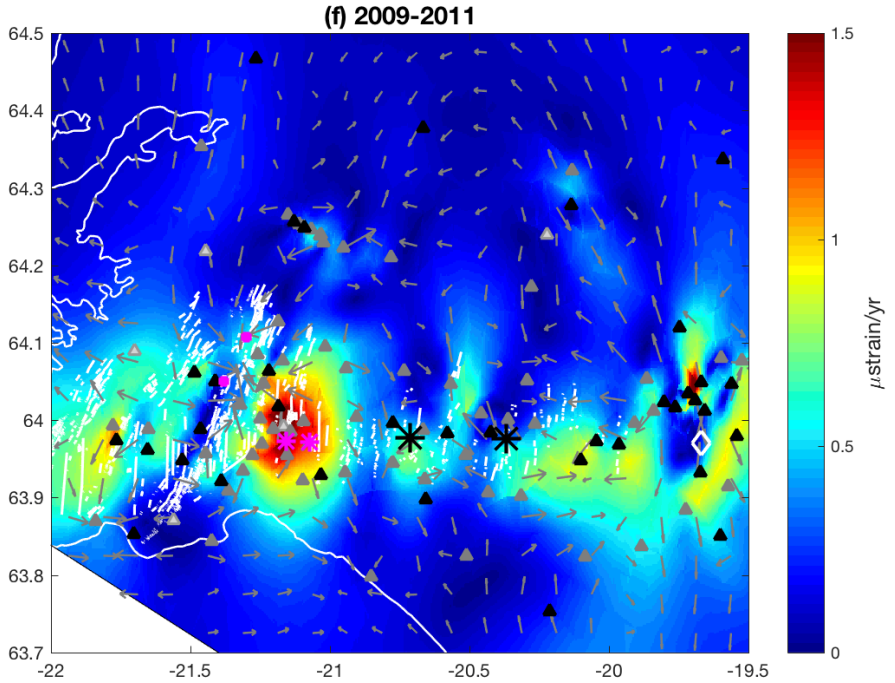
Strain rates (VDoHS)

2009-2011

Areal strain rate



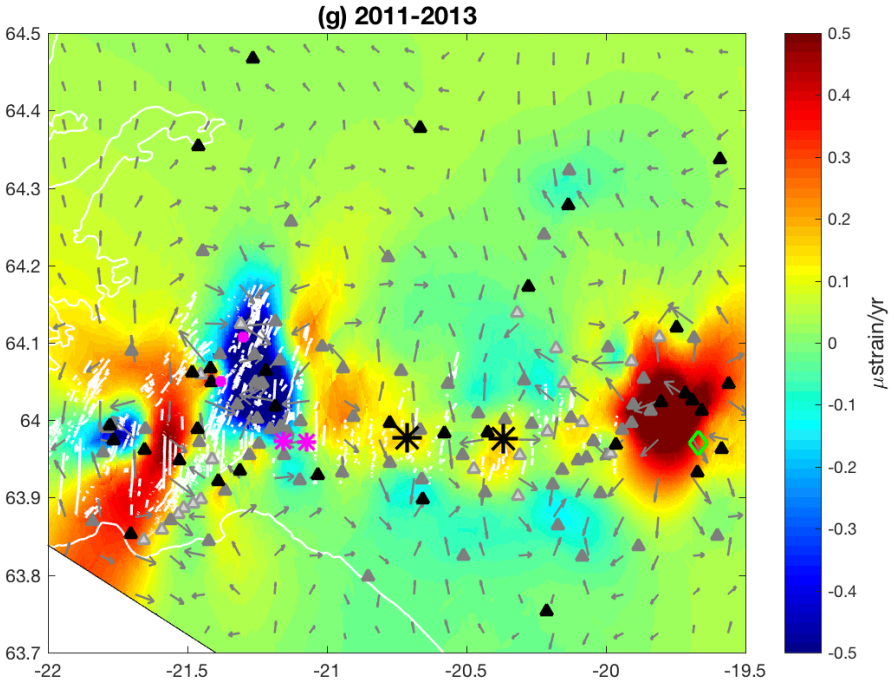
Shear strain rate



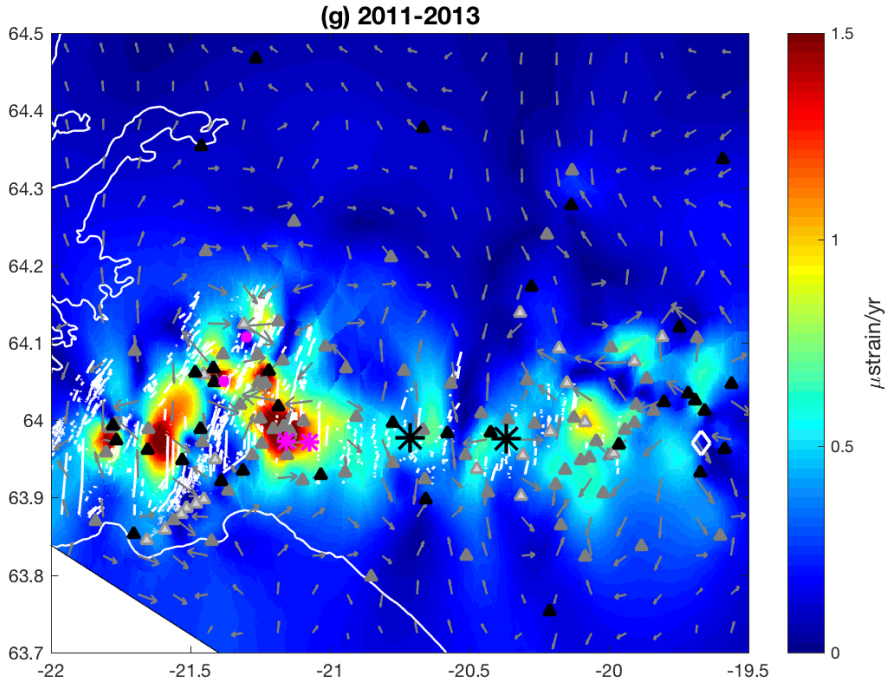
Strain rates (VDoHS)

2011-2013

Areal strain rate



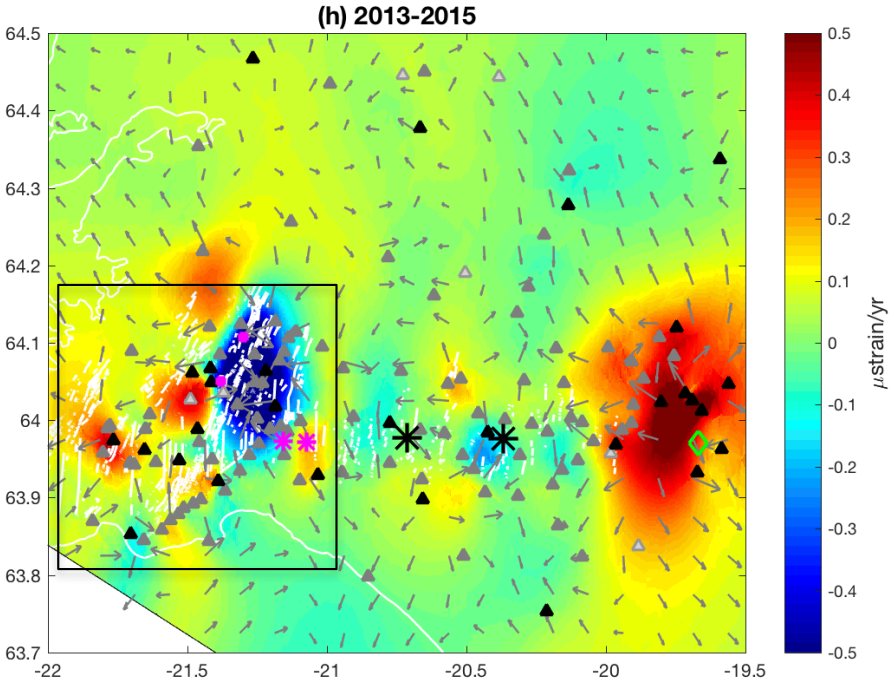
Shear strain rate



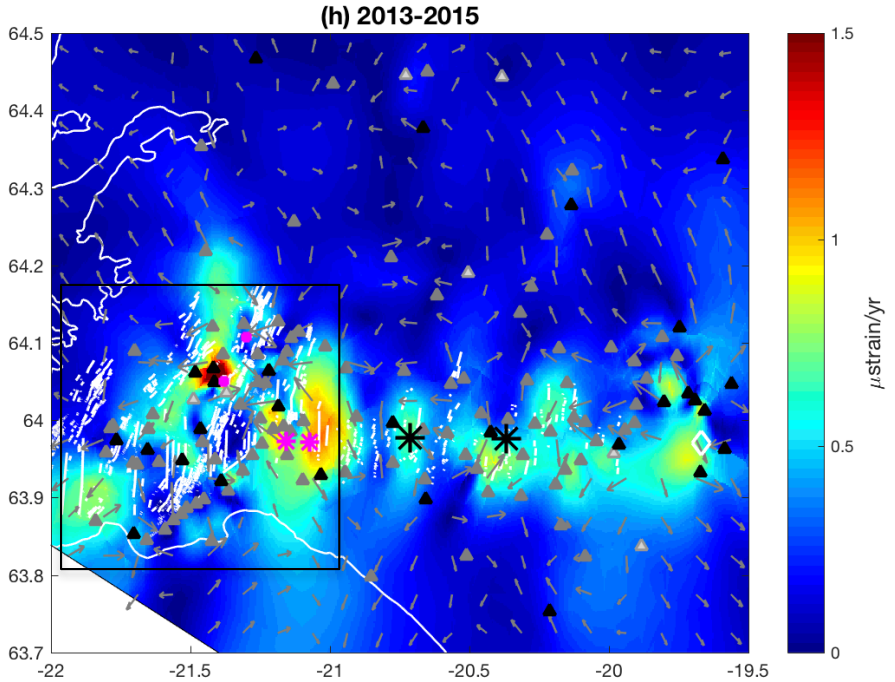
Strain rates (VDoHS)

2013-2015

Areal strain rate



Shear strain rate

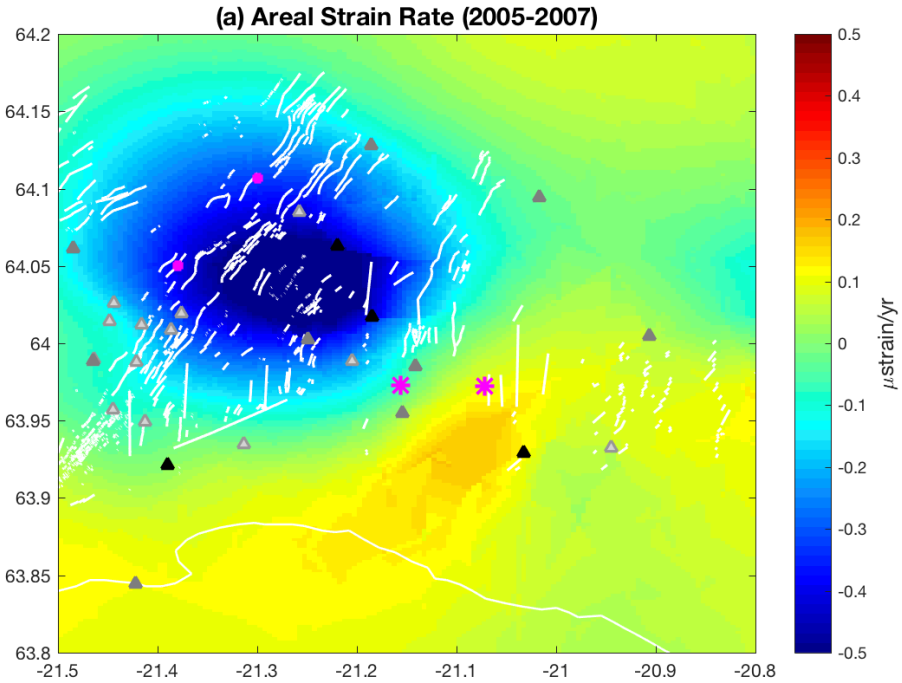


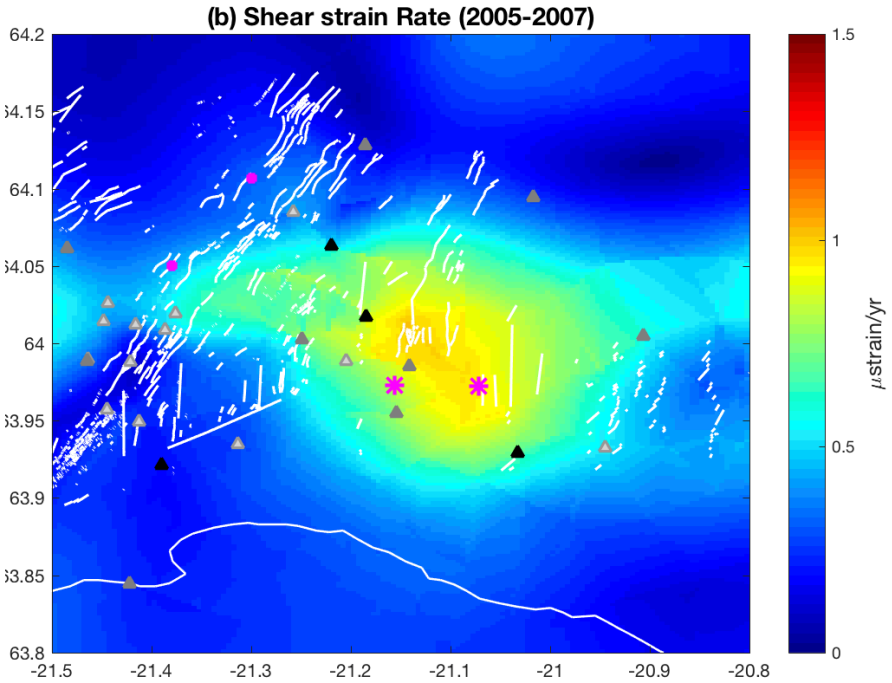
Strain rates before May 2008 eqs

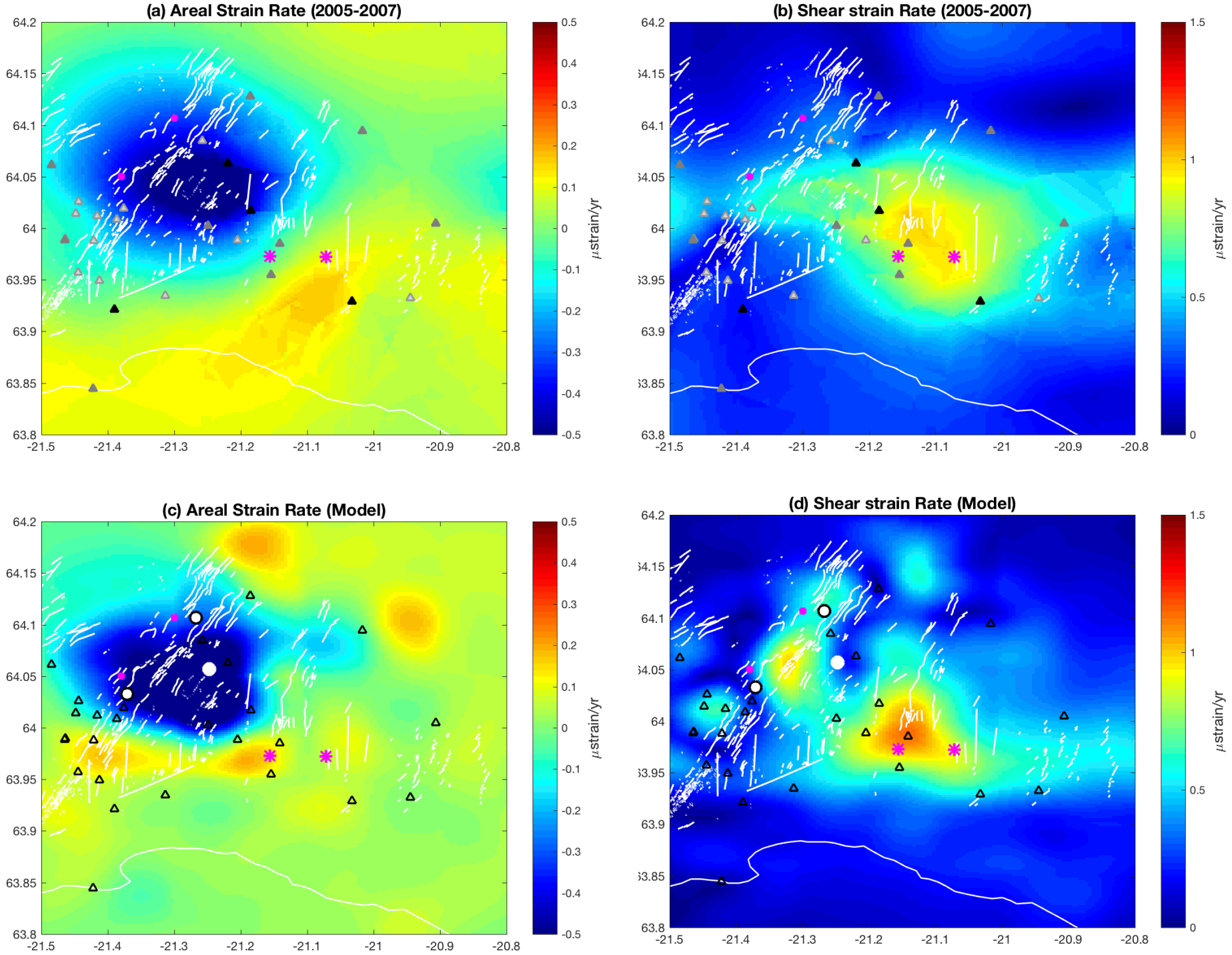
2005-2007

Areal strain rate

Shear strain rate






(a) Areal Strain Rate (2005-2007)
(b) Shear strain Rate (2005-2007)
(c) Areal Strain Rate (Model)
(d) Shear strain Rate (Model)
μstrain/yr
64.2
64.15
64.1
64.05
64
63.95
63.9
63.85
63.8
-21.5
-21.4
-21.3
-21.2
-21.1
-21
-20.9
-20.8
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1.5
1
0.5
0

Summary

- Strain rates from new (VDoHS) methods are less noisy than from conventional methods (B&H)
- Strain rates in SISZ are high (0.5-1 mstrain/yr)
- Temporal and spatial variation in deformation and strain rates in SISZ and Hengill
- Plate motion and increased contraction in Hengill contribute to dilatation and shear signal over a large area around Hengill
  - Higher rate of contraction after increase in rate of extraction of geothermal fluids at power plants
  - Promote failure on N-S faults in May 2008 epicentral area

Questions?