On the border between geothermal and volcanology (2)

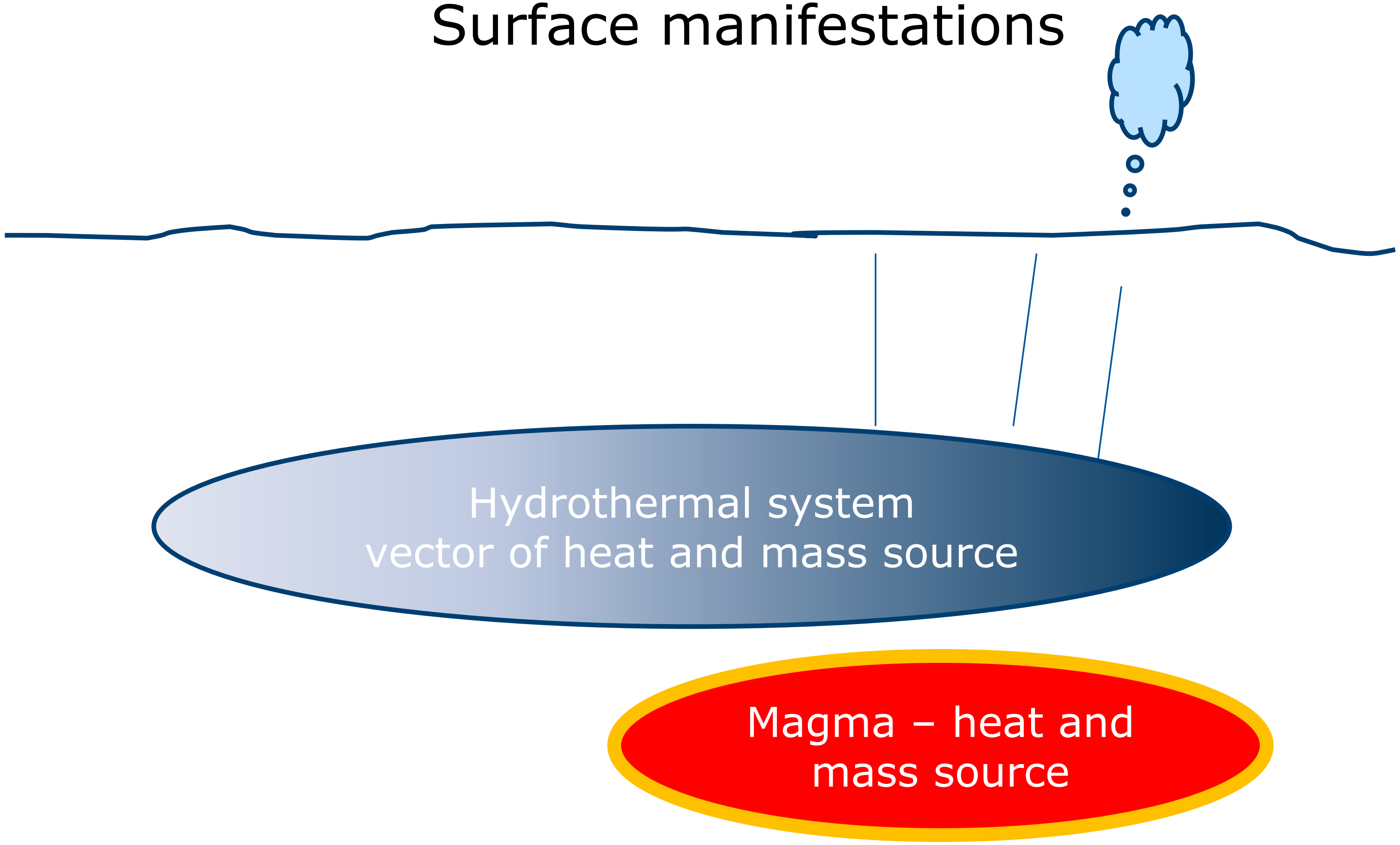
Workshop
GFZ Potsdam
27-29 April 2022

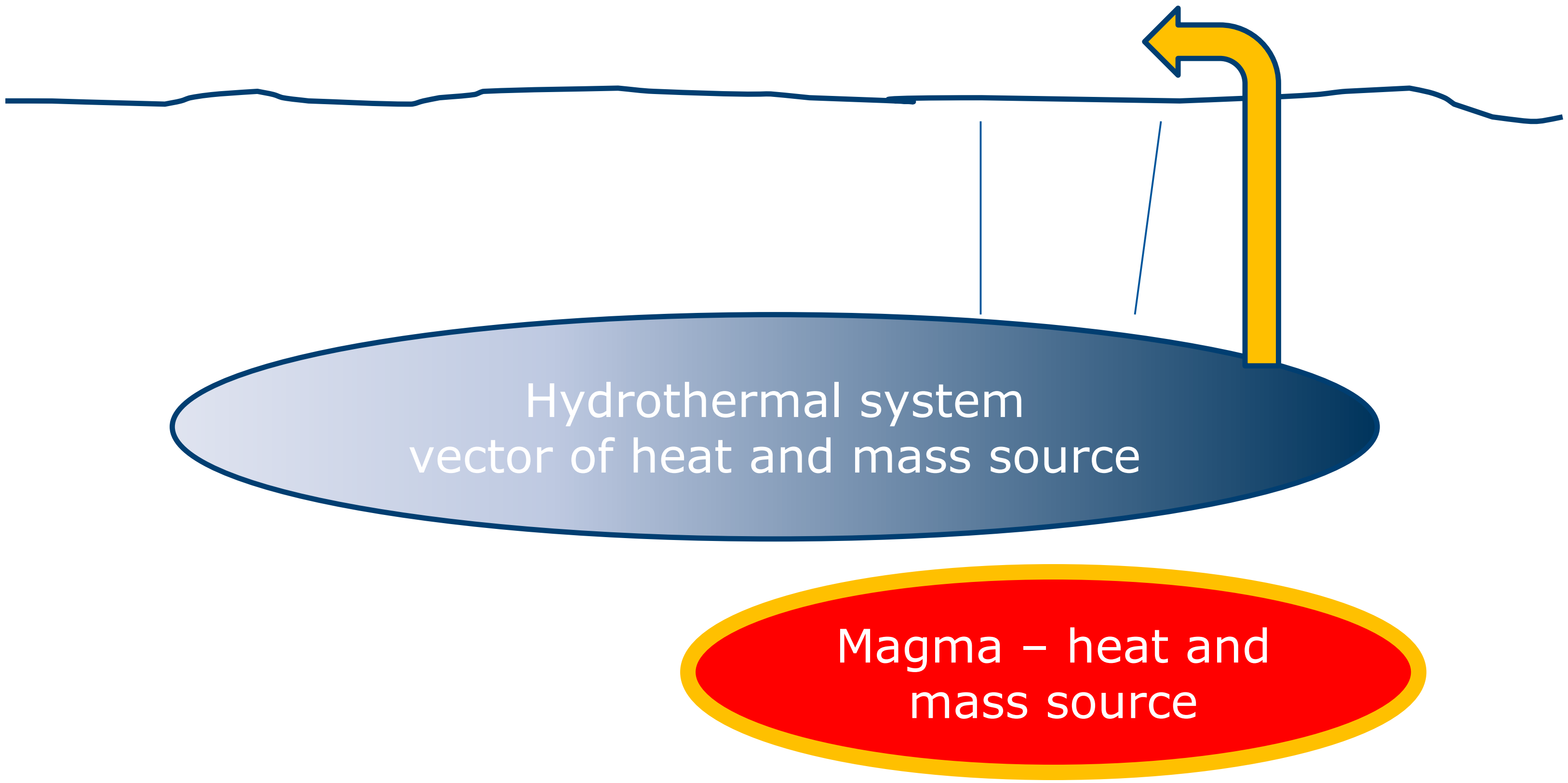
Philippe Jousset

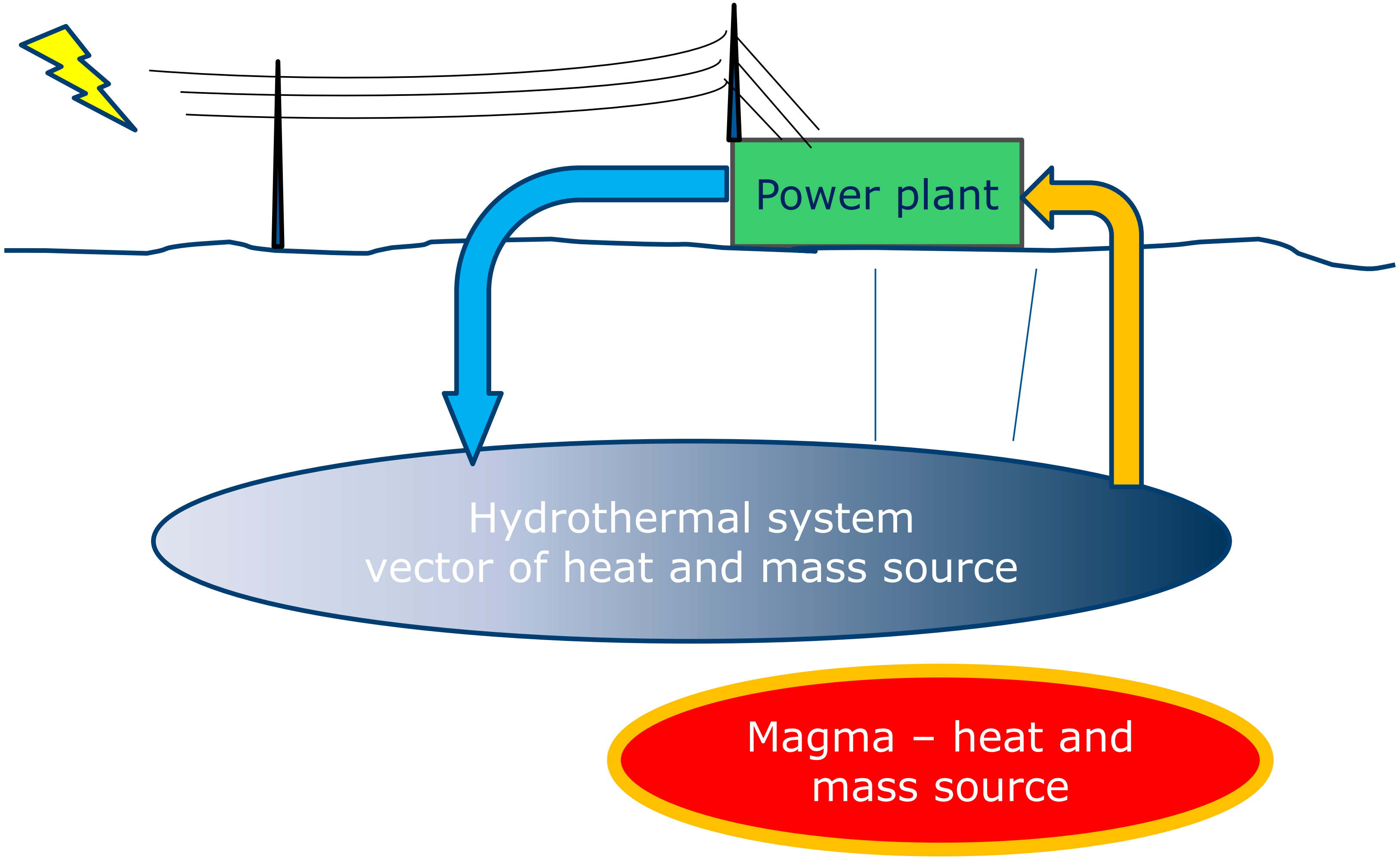
SMARTIES - Objectives

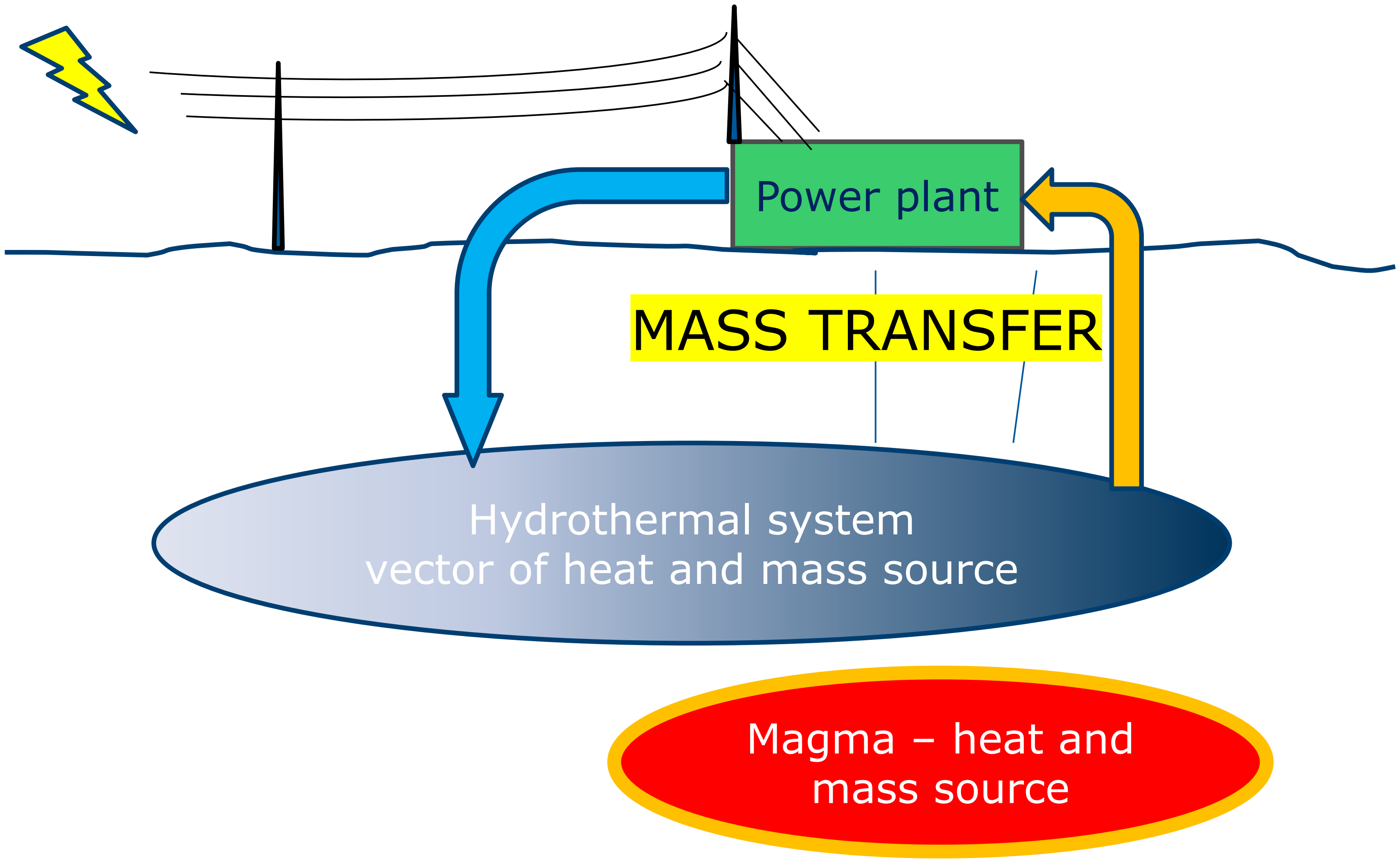
- Observe and model the structure and dynamics of magmatic/hydrothermal systems and their transition zone to assess potential volcanic hazards and quantify the geothermal energy potential
- Characterize and model processes of mass and energy transfer within supercritical and "superhot" hydrothermal reservoirs under natural and anthropogenic forcing

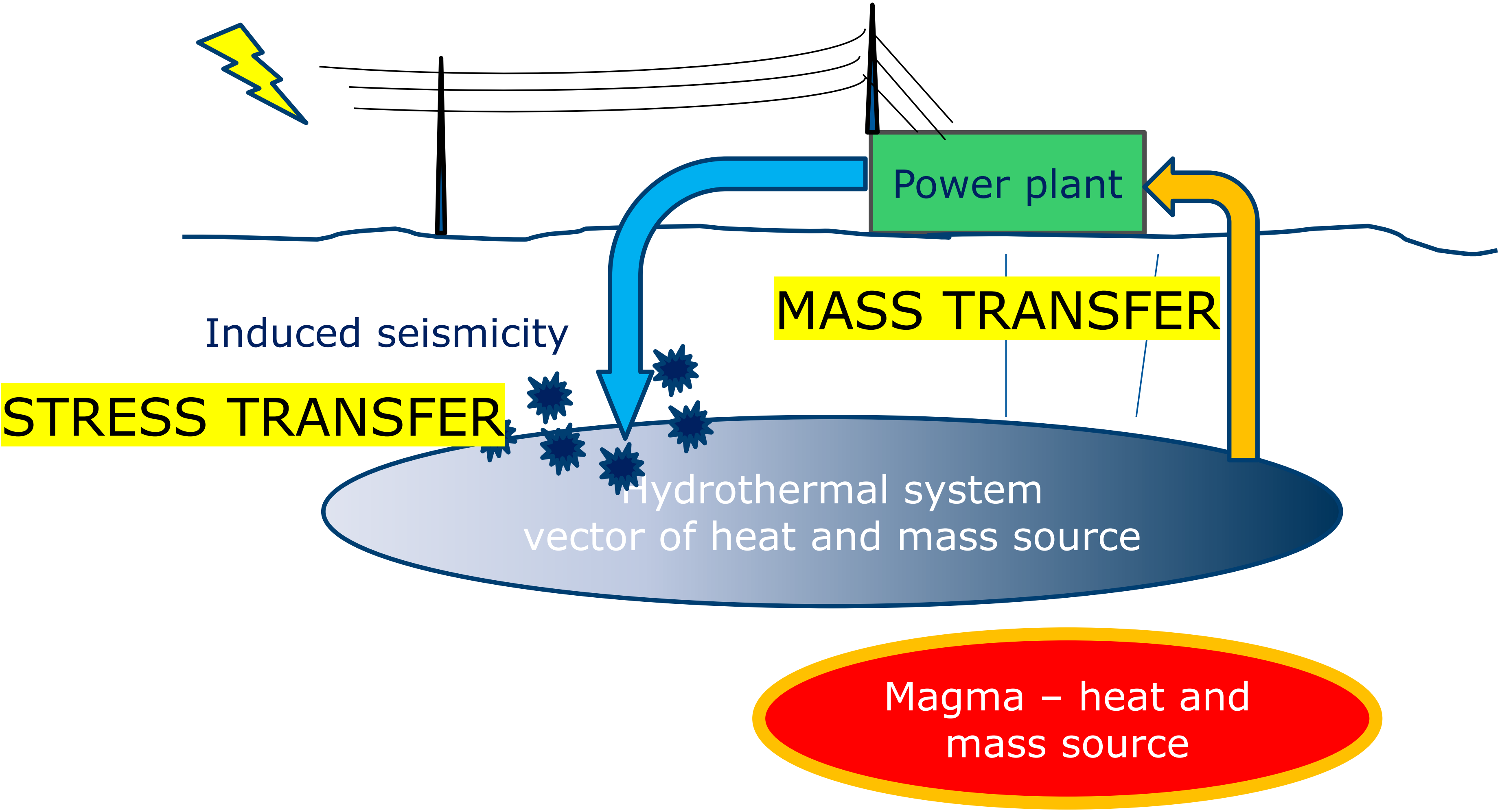
Surface manifestations




Hydrothermal system
vector of heat and mass source
Magma – heat and
mass source


Power plant
Hydrothermal system
vector of heat and mass source
Magma – heat and
mass source


Power plant
MASS TRANSFER
Hydrothermal system
vector of heat and mass source
Magma – heat and
mass source



Expected mass change signals larger for non-stationary systems

In stationary system, earthquakes may be very small

Geophysical methods for tracking mass and stress in geothermal or magmatic reservoirs

- Gravity methods (density, mass distribution)
  Reservoir location
  Sustainability of the reservoir (fluid extraction and recharge)
- Seismic methods (seismic velocities, attenuation, stress)
  Fractures and reservoir location
  Fluid content
  Fluid dynamics
- Electromagnetic methods (resistivity)
  Rock permeability, porosity, fractures and fissures
  Temperature, Fluids
- Additional methods that may influence gravity:
  Elevation, deformation (GNSS, tiltmeters, InSAR ...)
  Hydrological parameters

Which target?

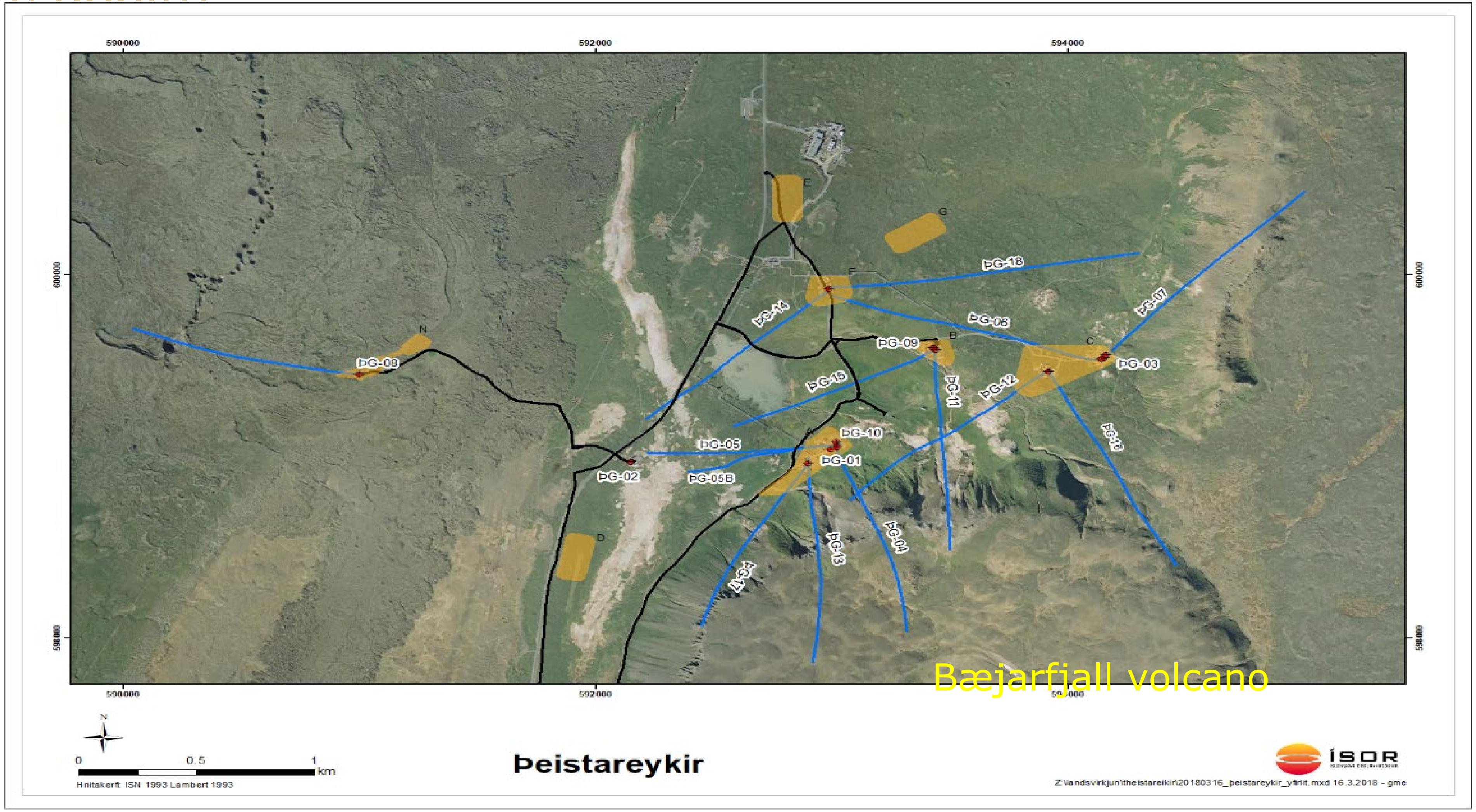
Microgravimotis started in 2017 for Iceland part (before Indonesia)

-> when IMPROVE (ITN network) submitted ~ first time

Initial target: Krafla (KMT as background)

–> shift to Theistareykir (25 km) as exploitation starting: larger Δg expected

Geothermal wells in Þeistareykir
(~2000 m depth)



Geothermal wells in Þeistareykir
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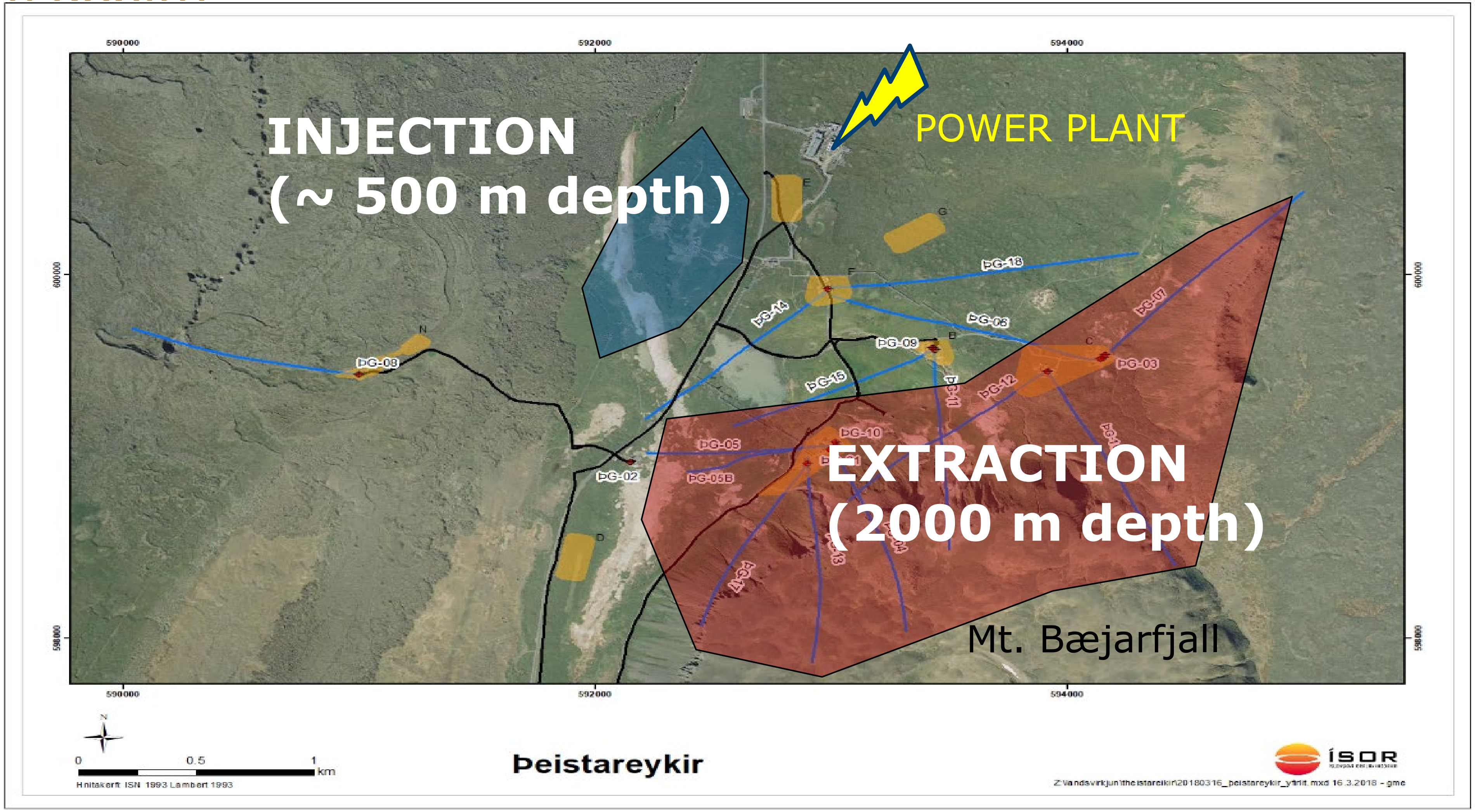

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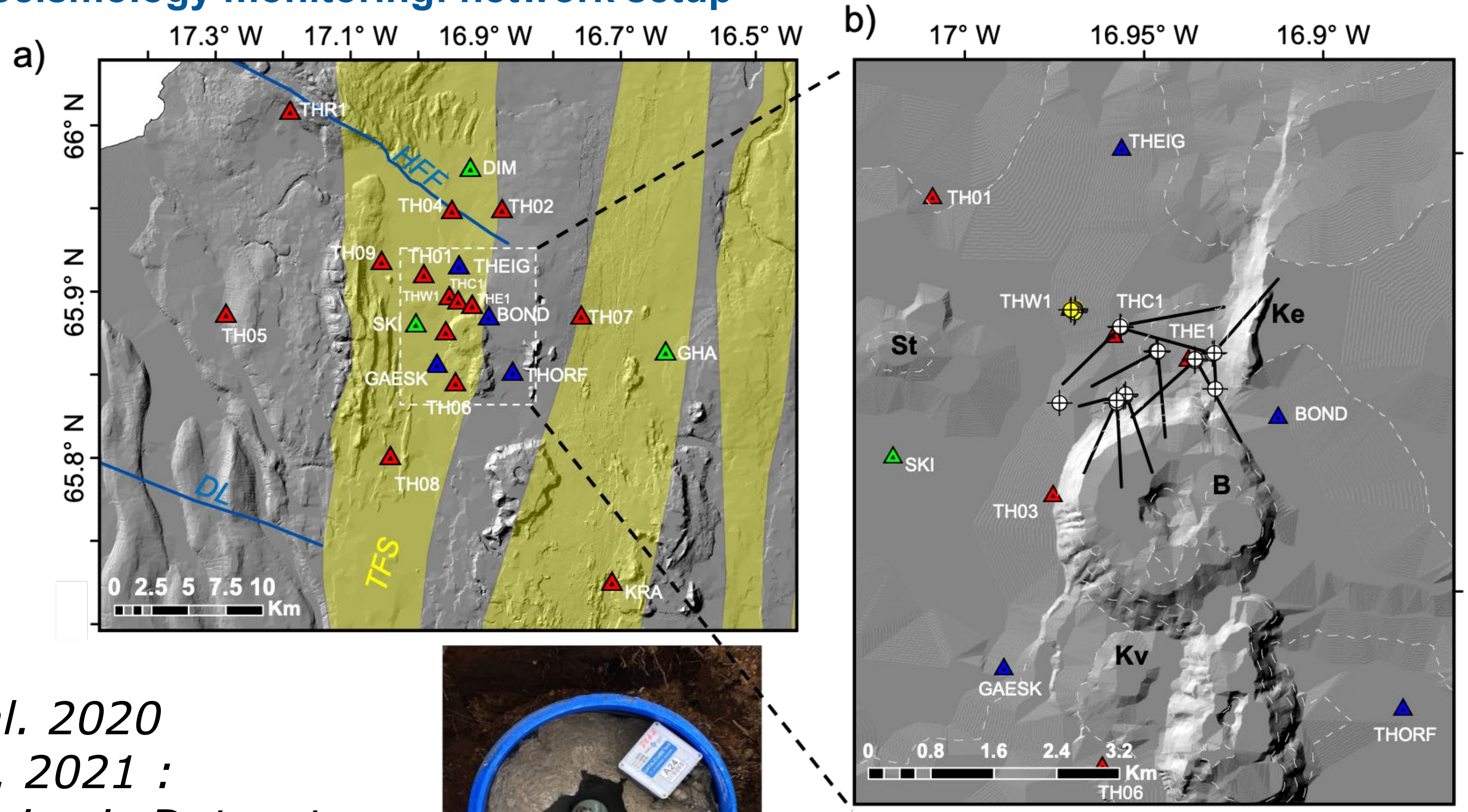
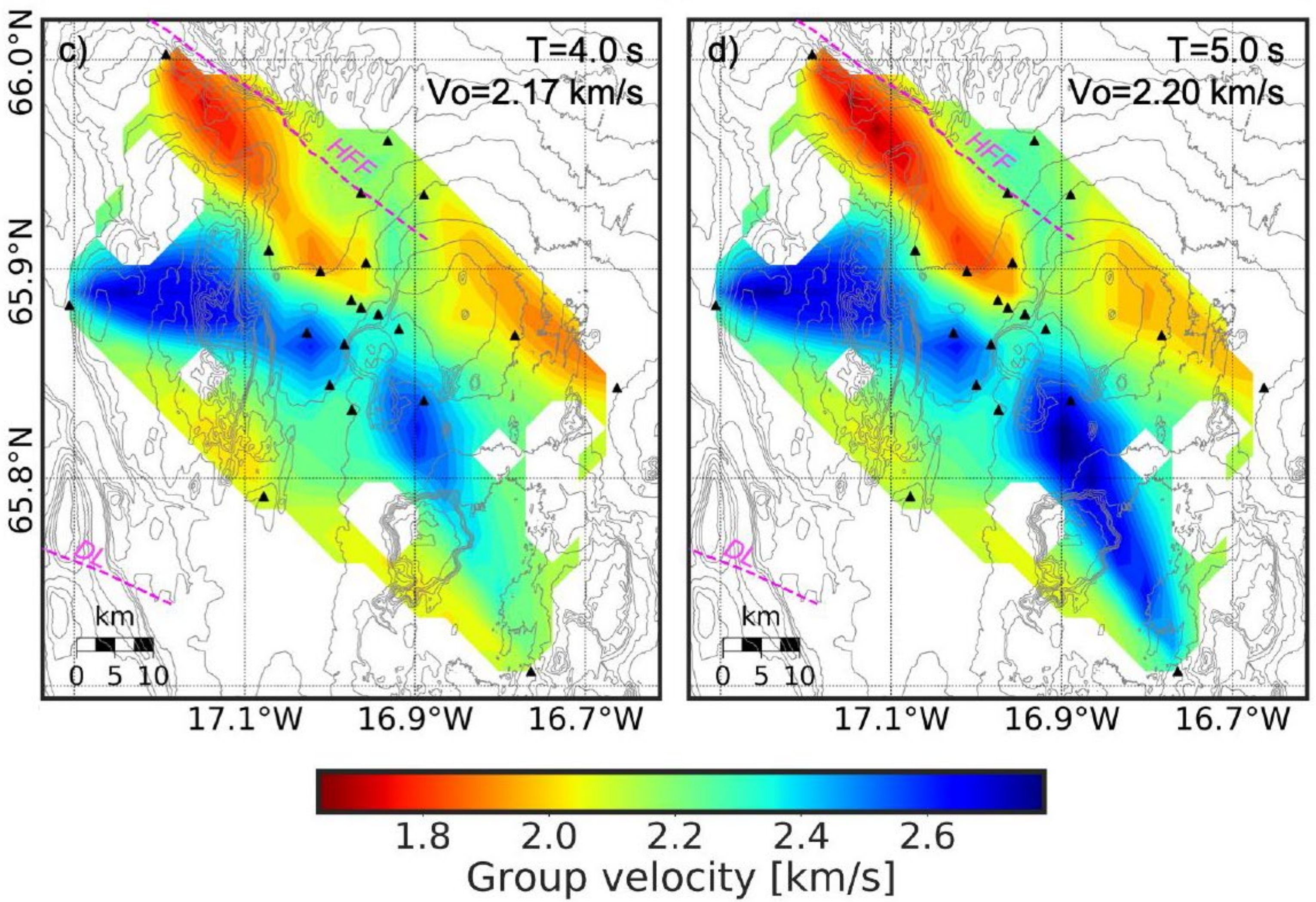
Seismology monitoring: network setup



Toledo et al. 2020
Erbas et al. 2021 :
GEOFON Seismic Dataset

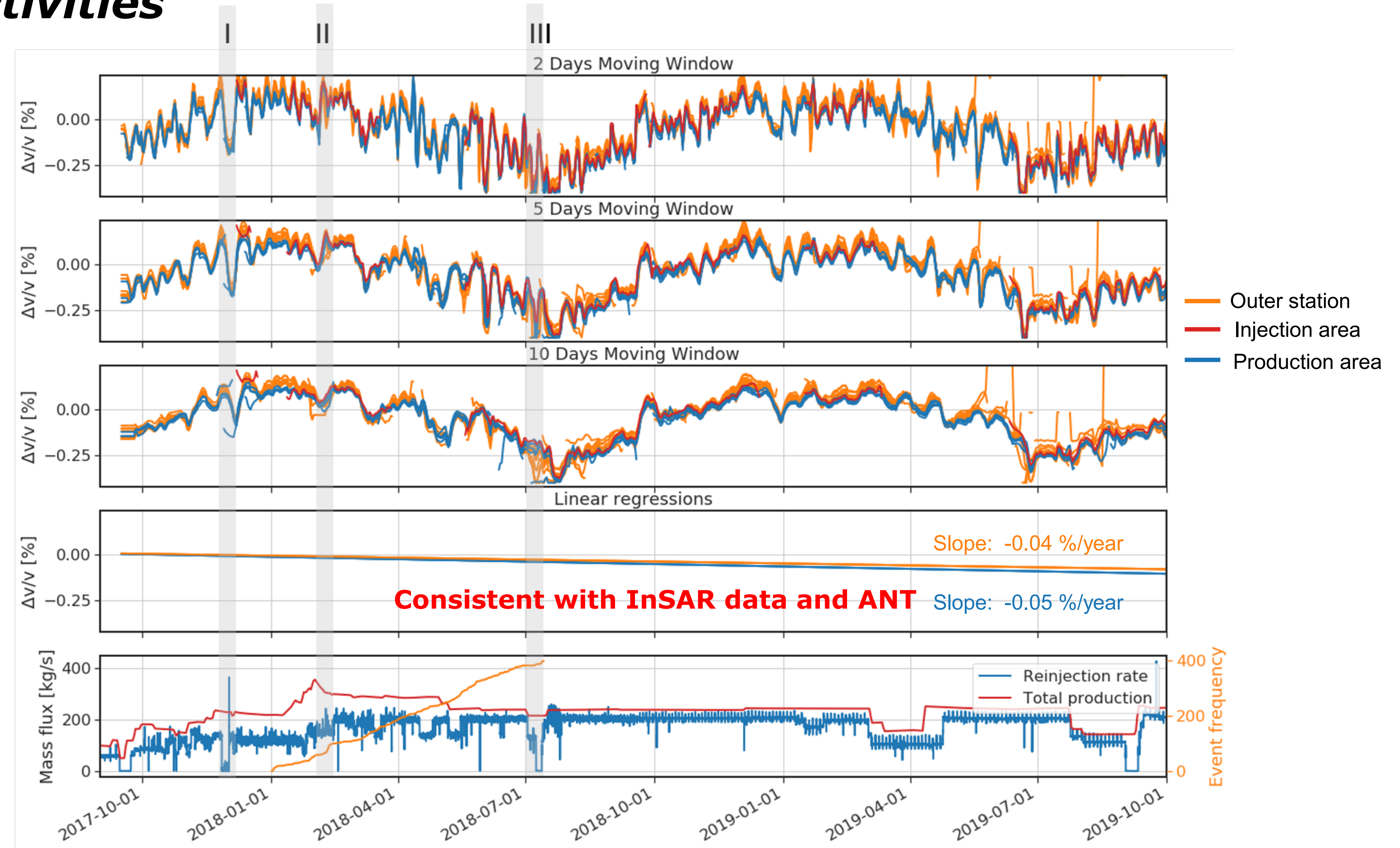
Seismic network
Ambient noise tomography and interferometric methods to monitor velocity changes



Toledo et al., 2020
Toledo et al., in revision

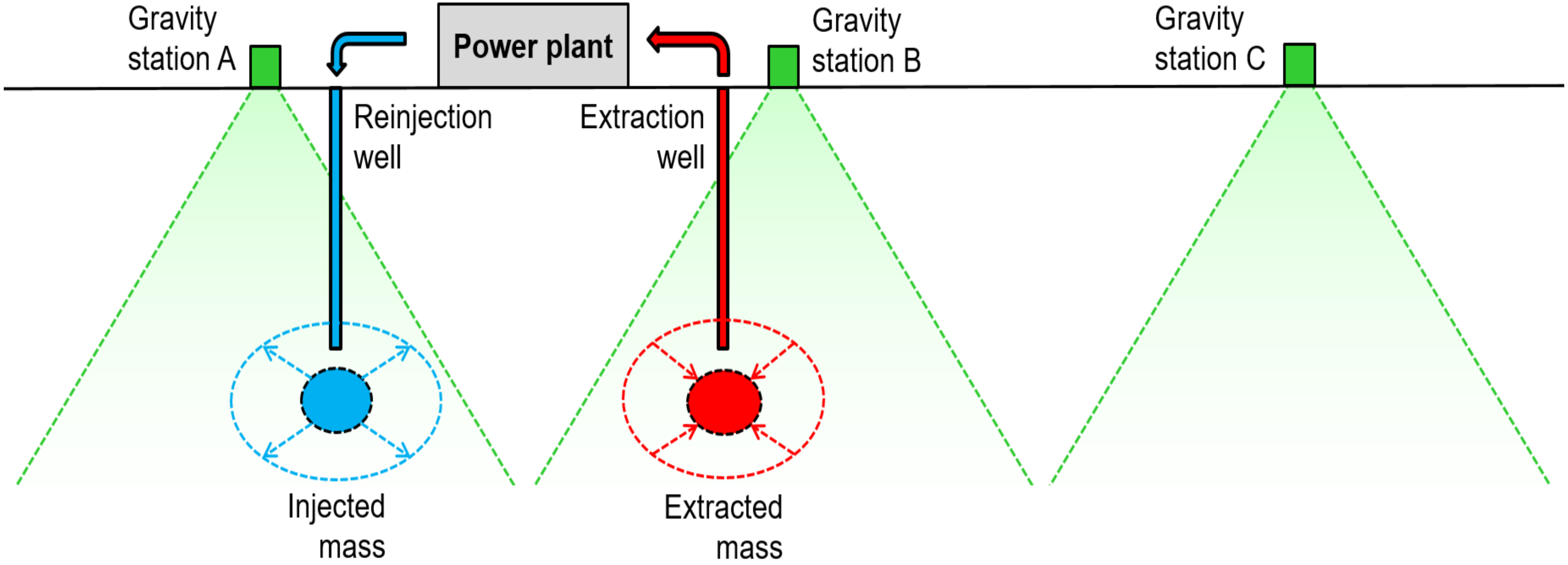
Coda Wave Interferometry:

Identification of structural changes associated to injection/production activities



Toledo et al., in revision

Gravity principle for measuring mass transfer



Florian Forster, 2022, PhD dissertation

Mass transfer and „hybrid“ gravity concept

1. Repeated measurements: spatial coverage

2. Continuous measurements: temporal coverage

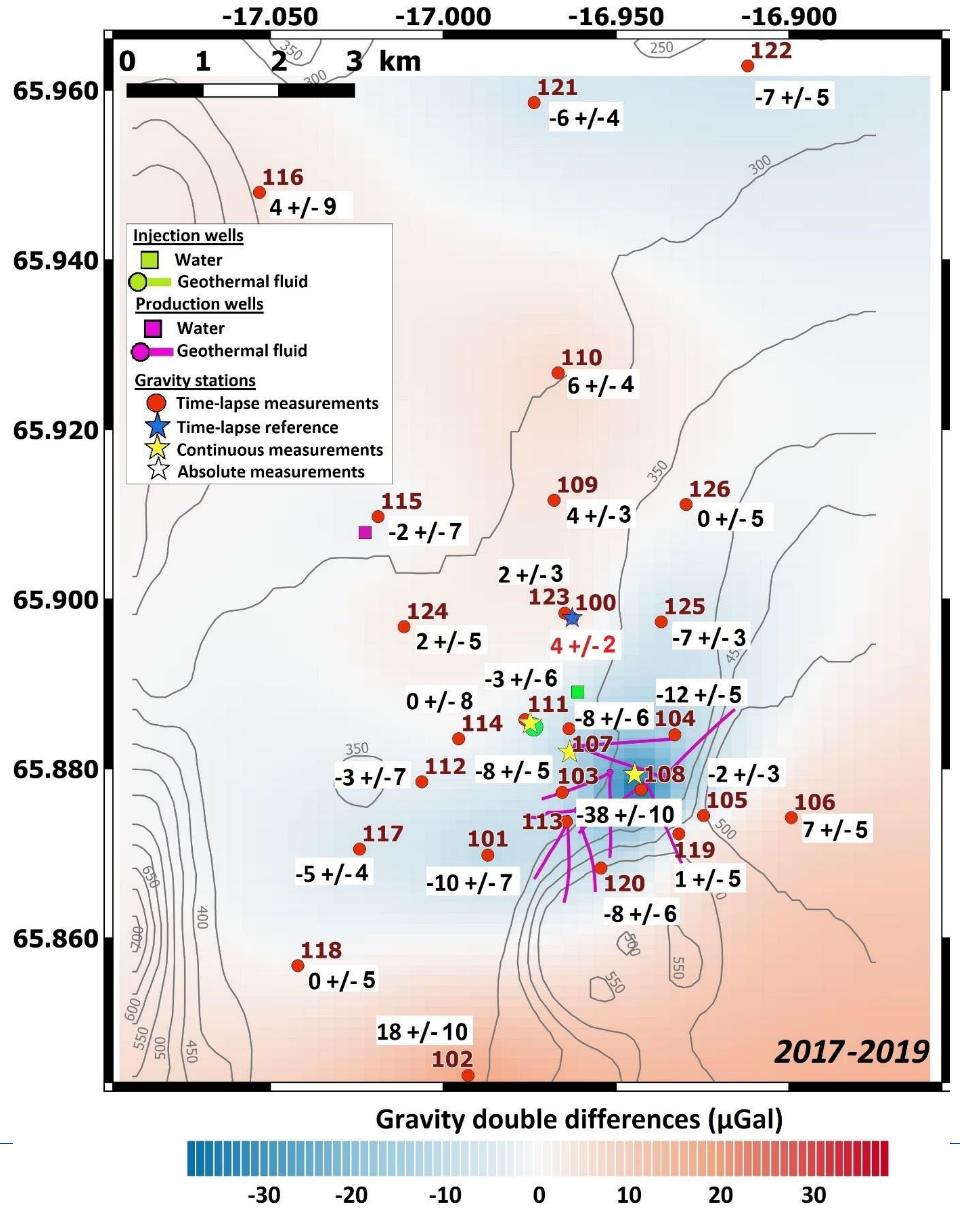
3. Absolute gravity measurements:
   Calibration and validation of instrumental drift

e.g., Hinderer et al., 2022

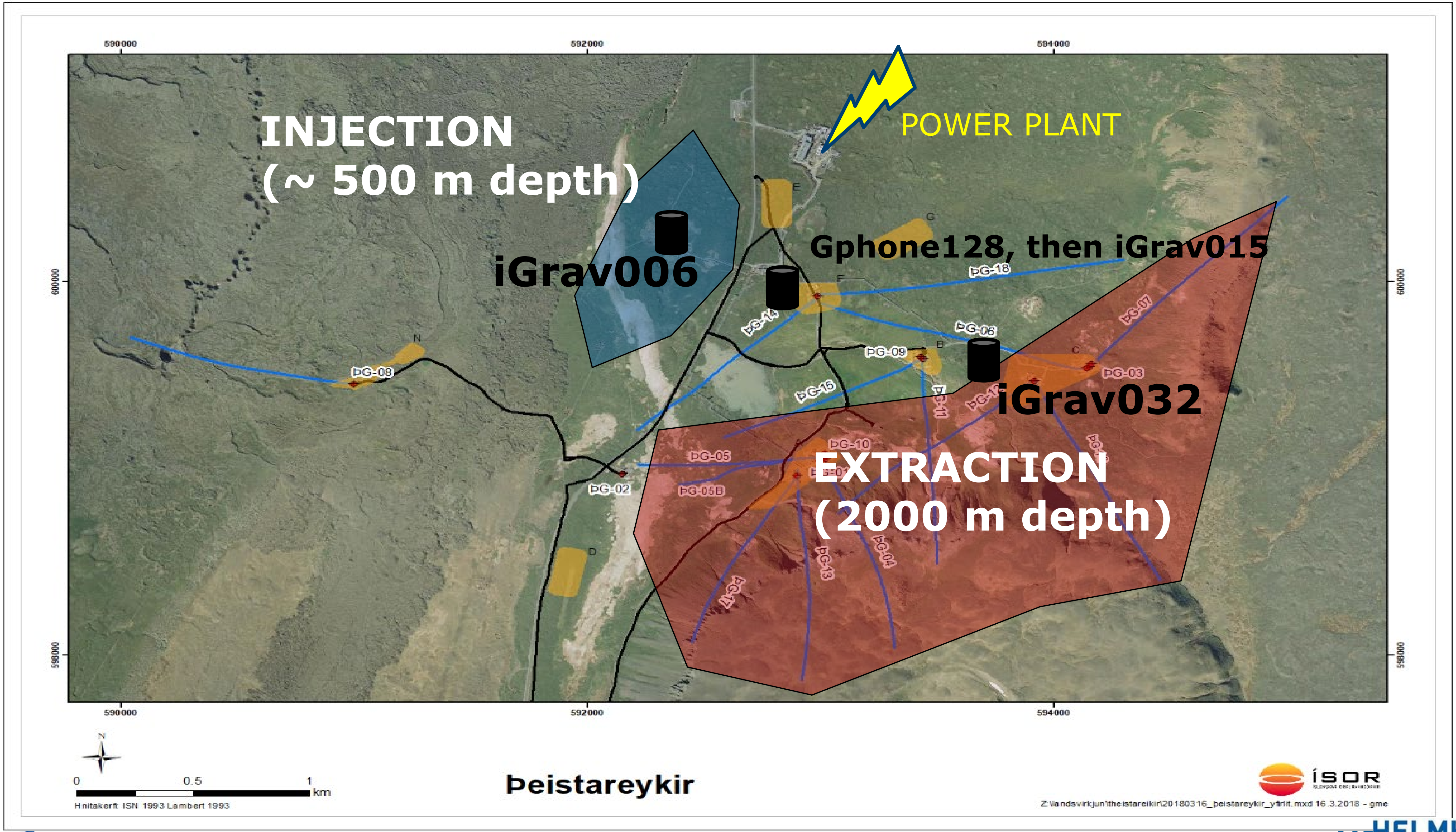
Repeated gravity measurements including a network at Krafla caldera.

Summer 2017
Summer 2018
Summer 2019
Summer 2020,2021 cancelled (COVID)

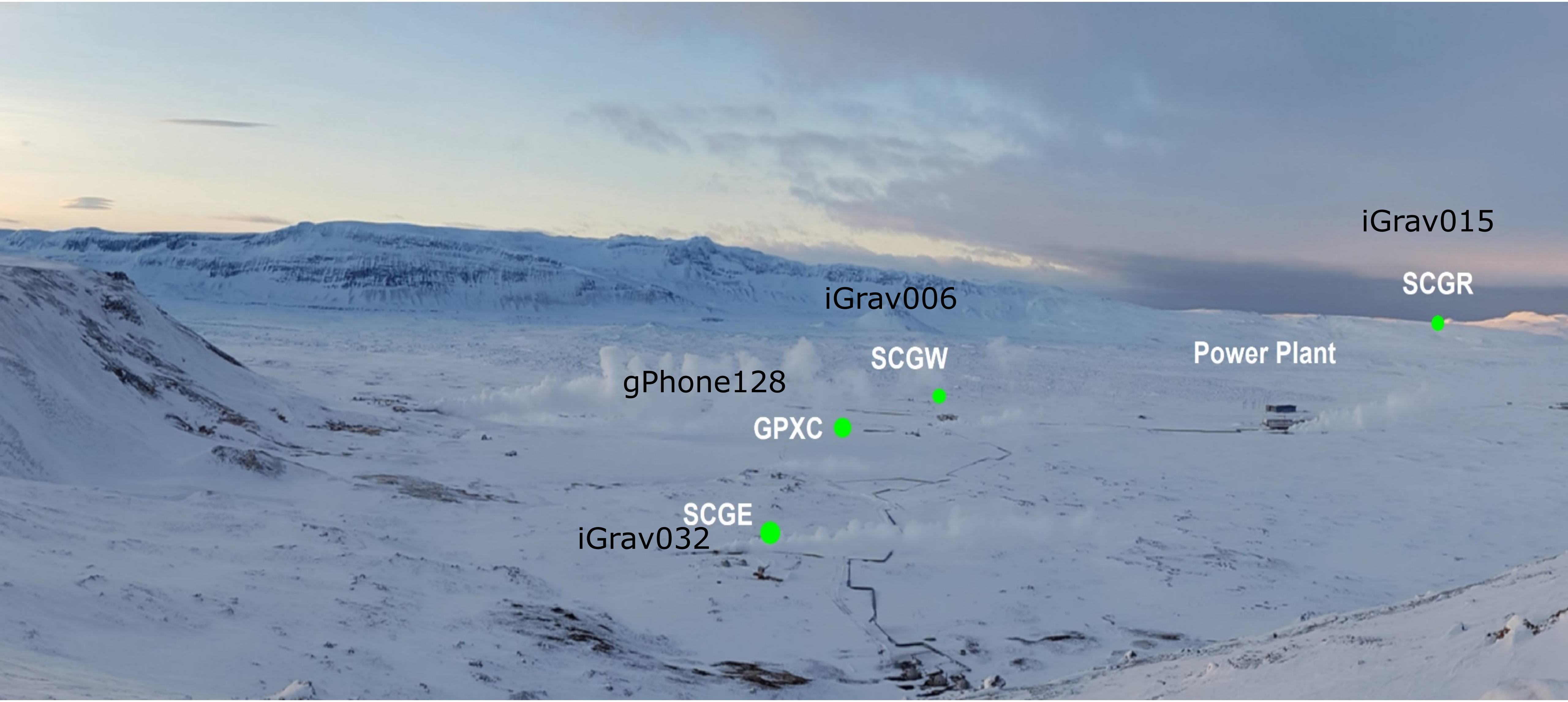
Next: Summer 2022



Portier et al., 2022



INJECTION
(~ 500 m depth)
POWER PLANT
iGrav006
Gphone128, then iGrav015
iGrav032
EXTRACTION
(2000 m depth)
ÞG-18
ÞG-14
ÞG-06
ÞG-09
ÞG-07
ÞG-03
ÞG-08
ÞG-15
ÞG-10
ÞG-05
ÞG-05B
ÞG-02
ÞG-13
ÞG-04
ÞG-11
590000
592000
594000
600000
598000
N
0
0.5
1
km
Hnitakerfi: ISN 1993 Lambert 1993
Þeistareykir
ÍSOR


iGrav015
SCGR
iGrav006
SCGW
Power Plant
gPhone128
GPXC
SCGE
iGrav032

July-August 2017 – pillar construction

5 locations:
- 3 in Theystareykir
- 1 in Krafla
- 1 remote

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December 2017 – Superconducting gravimeters‘ deployment with the great help of Landsvirkjun

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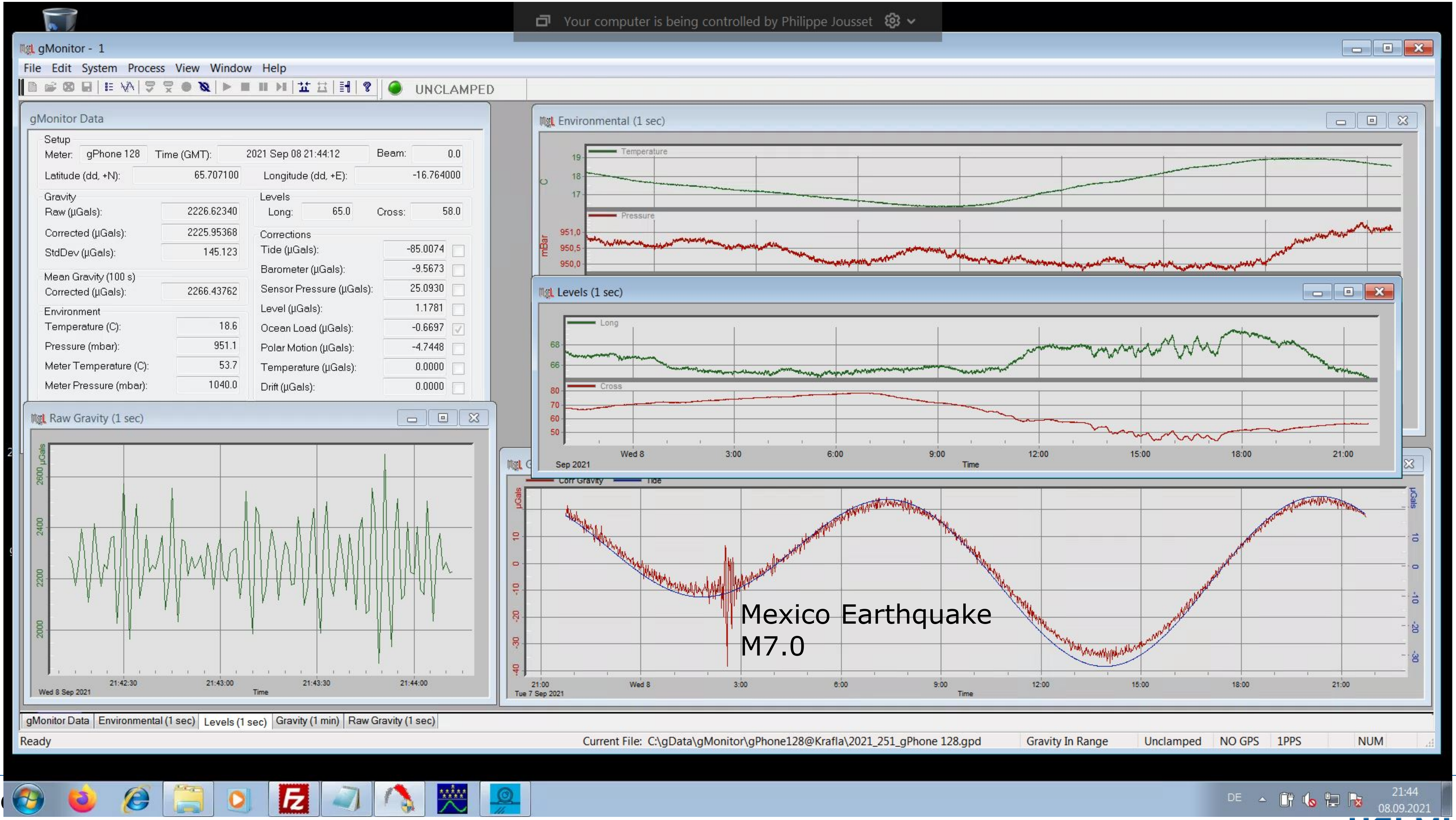
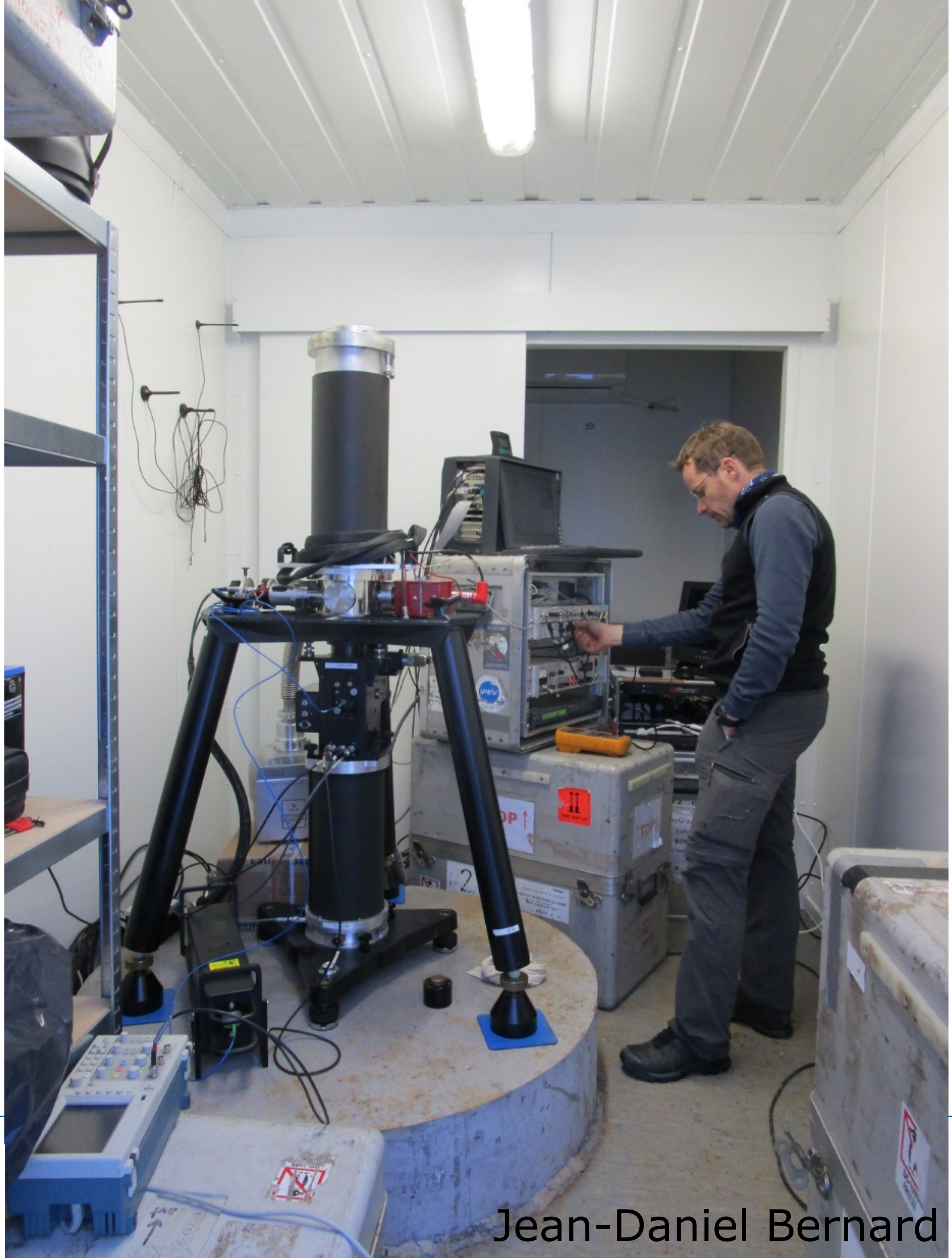
Tanja Ballerstedt
Stephan Schröder

Sensors,
Compressor,
Helium bottle
Cooling system
Communication
(wifi or SIM card),
....

Ready to operate!



gPhone128: Screenshot: 08.09.2021



Jean-Daniel Bernard

Absolute gravity measurements on the second pillar of each container

Gravity monitoring network

January 2018

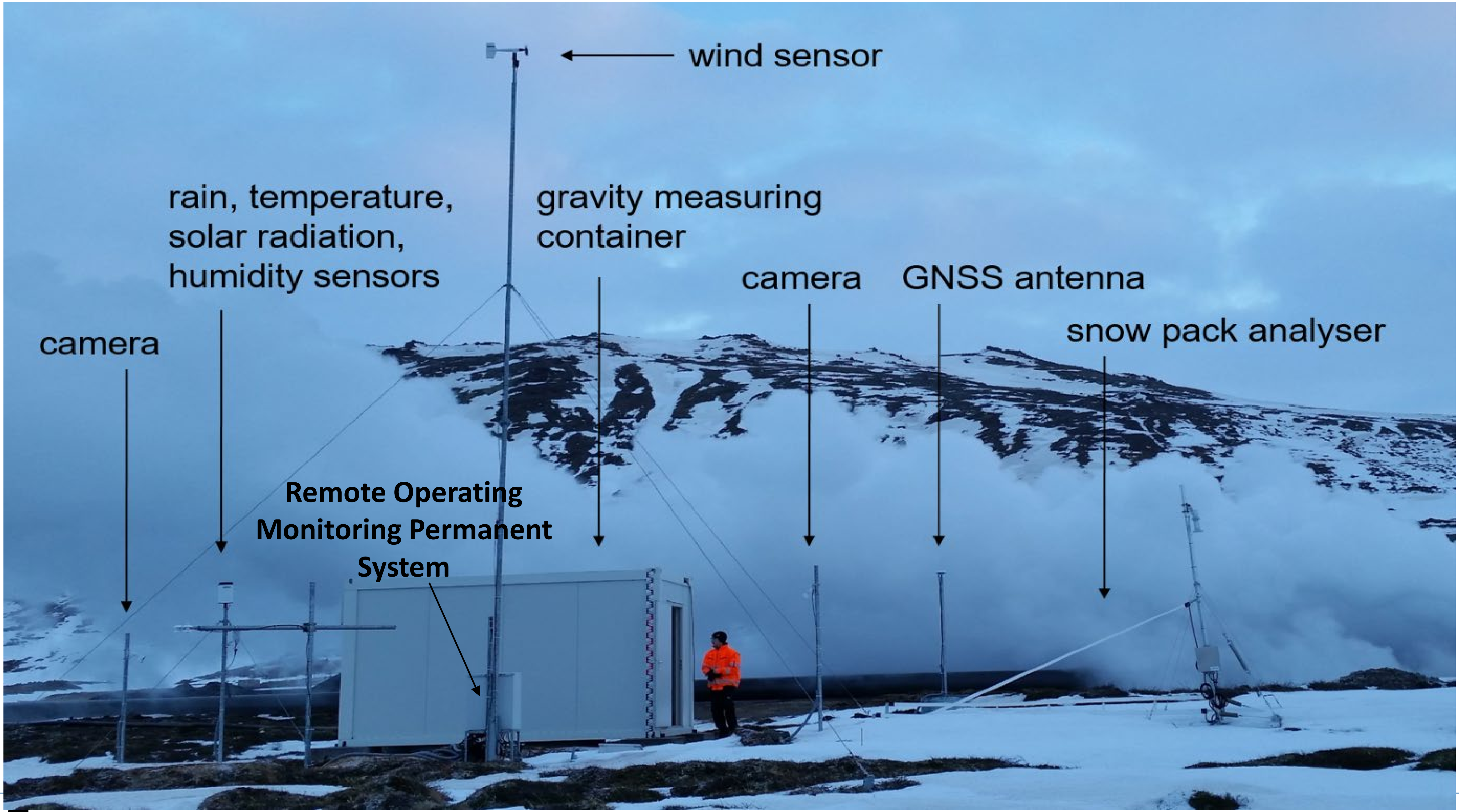
Summer 2018

Summer 2019

Summer 2020,2021 cancelled (COVID)

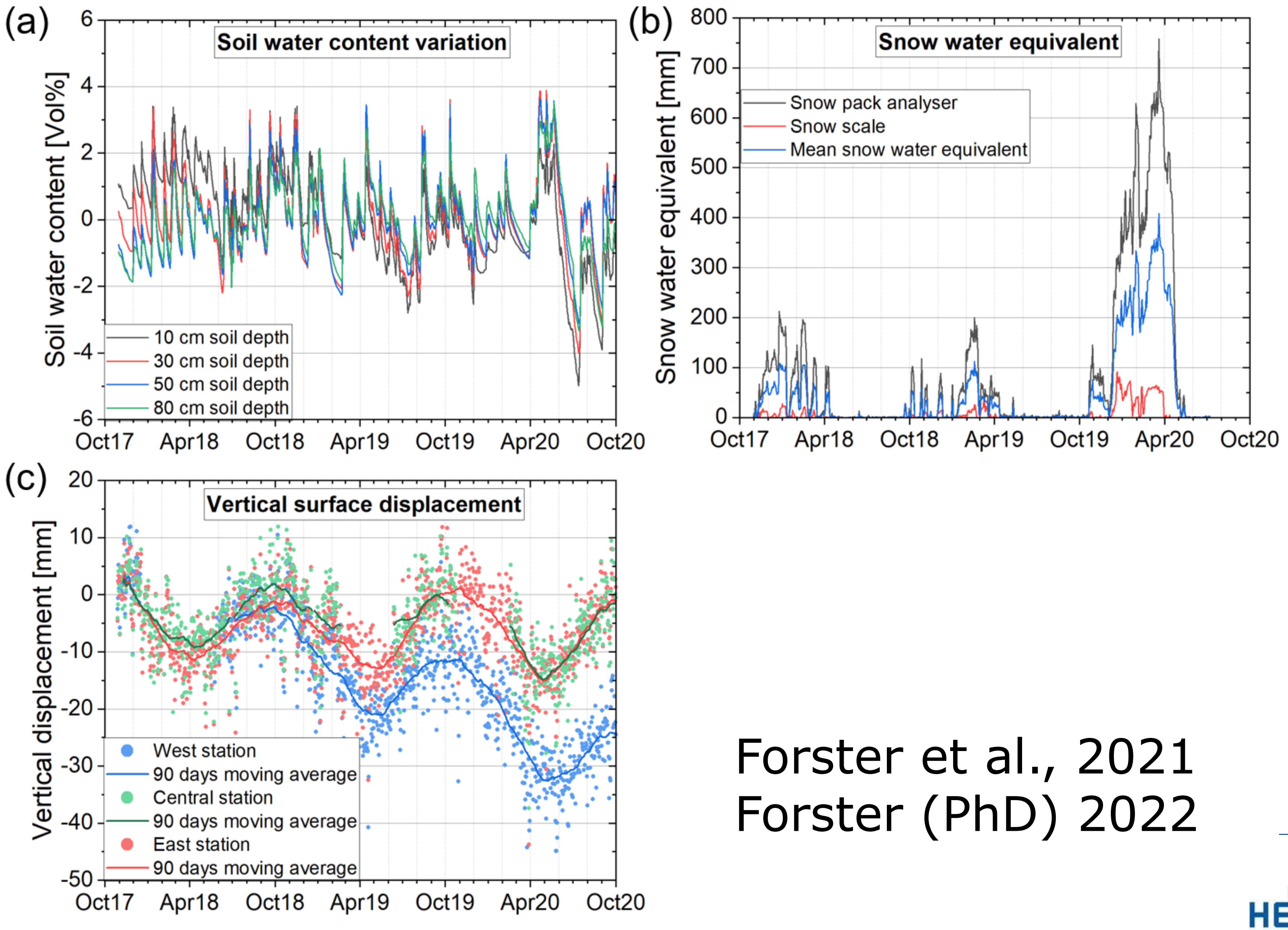
Next: Summer 2022

Jacques Hinderer

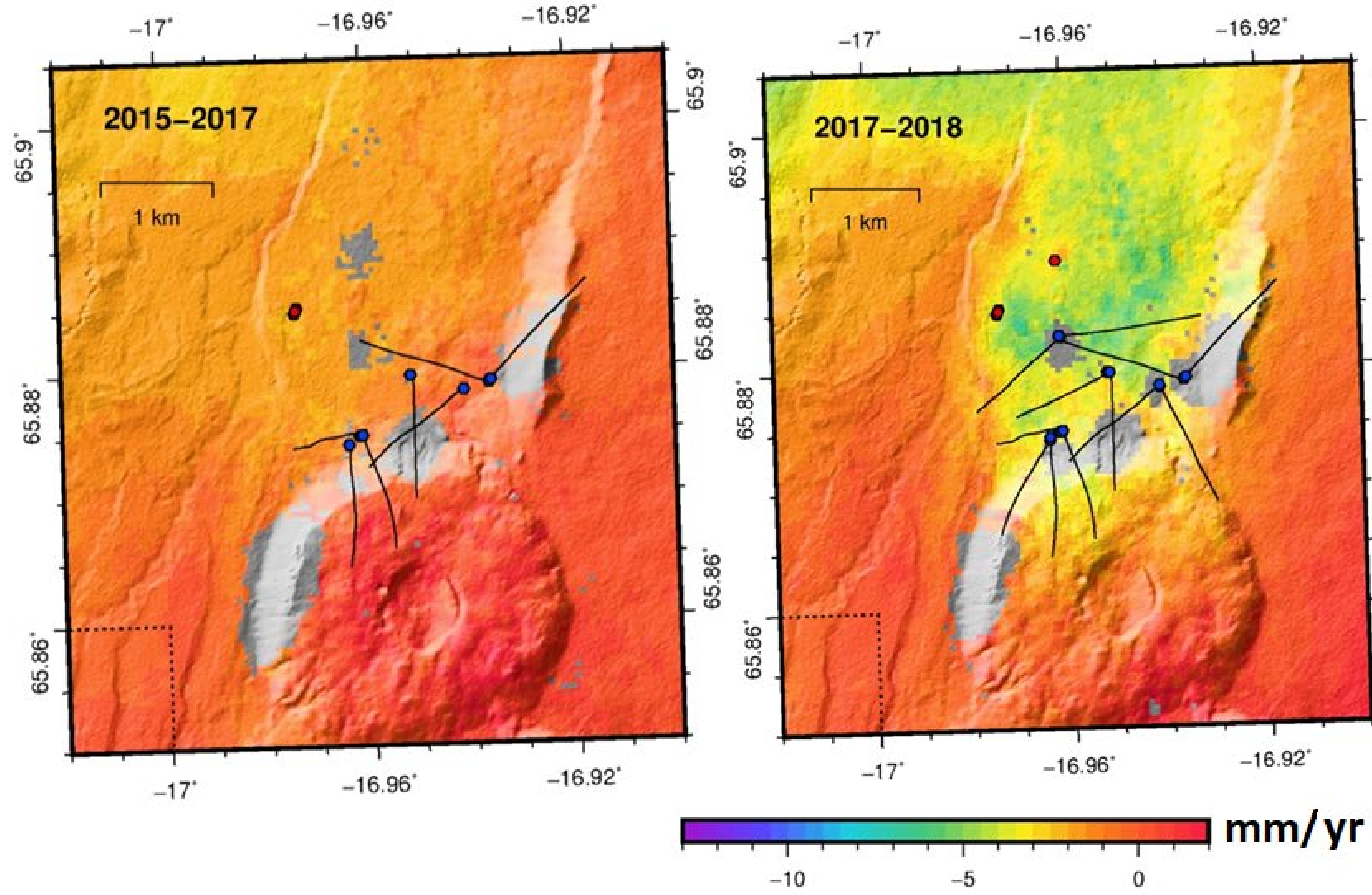


Forster et al., submitted

Environmental observations

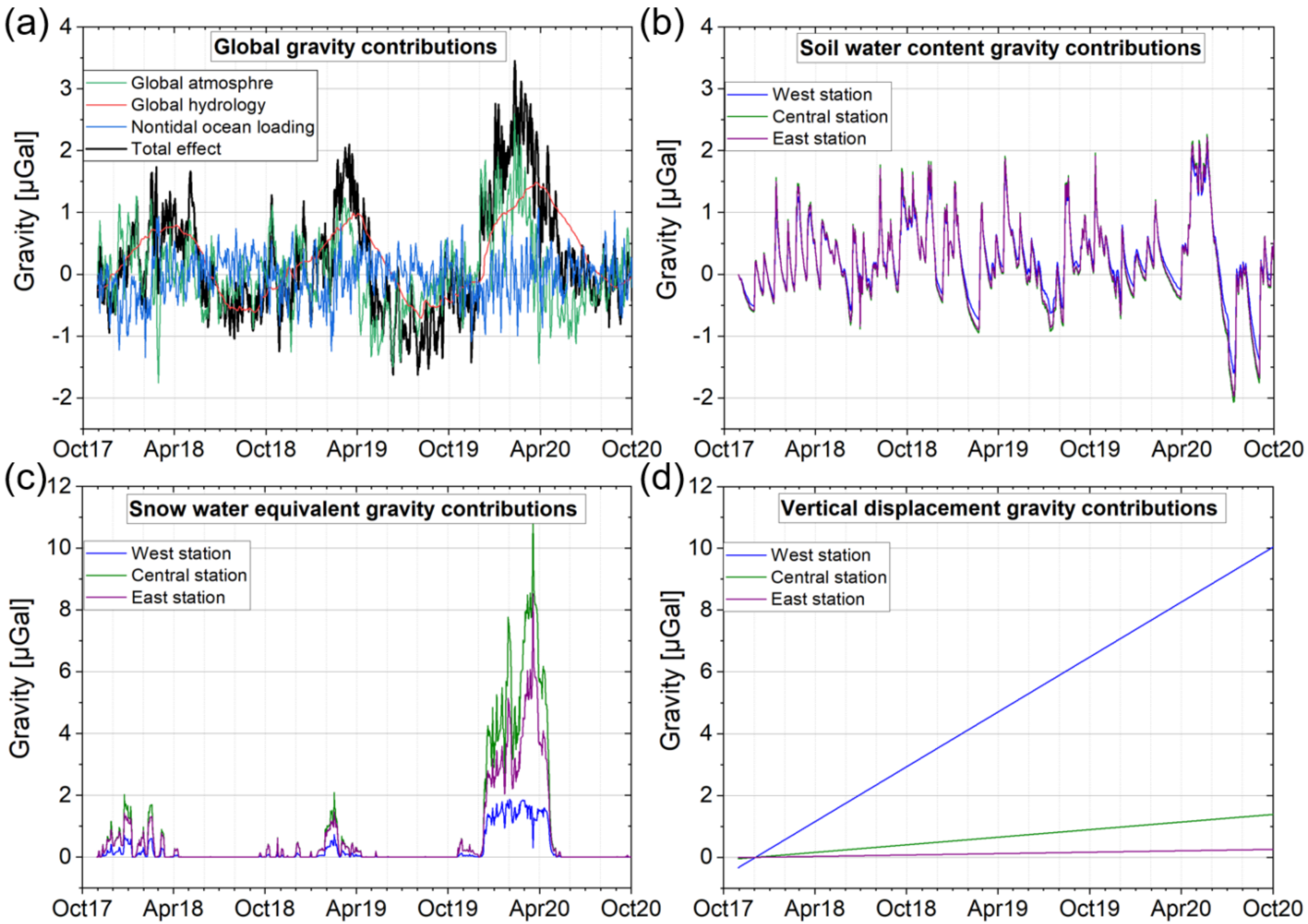


Forster et al., 2021
Forster (PhD) 2022



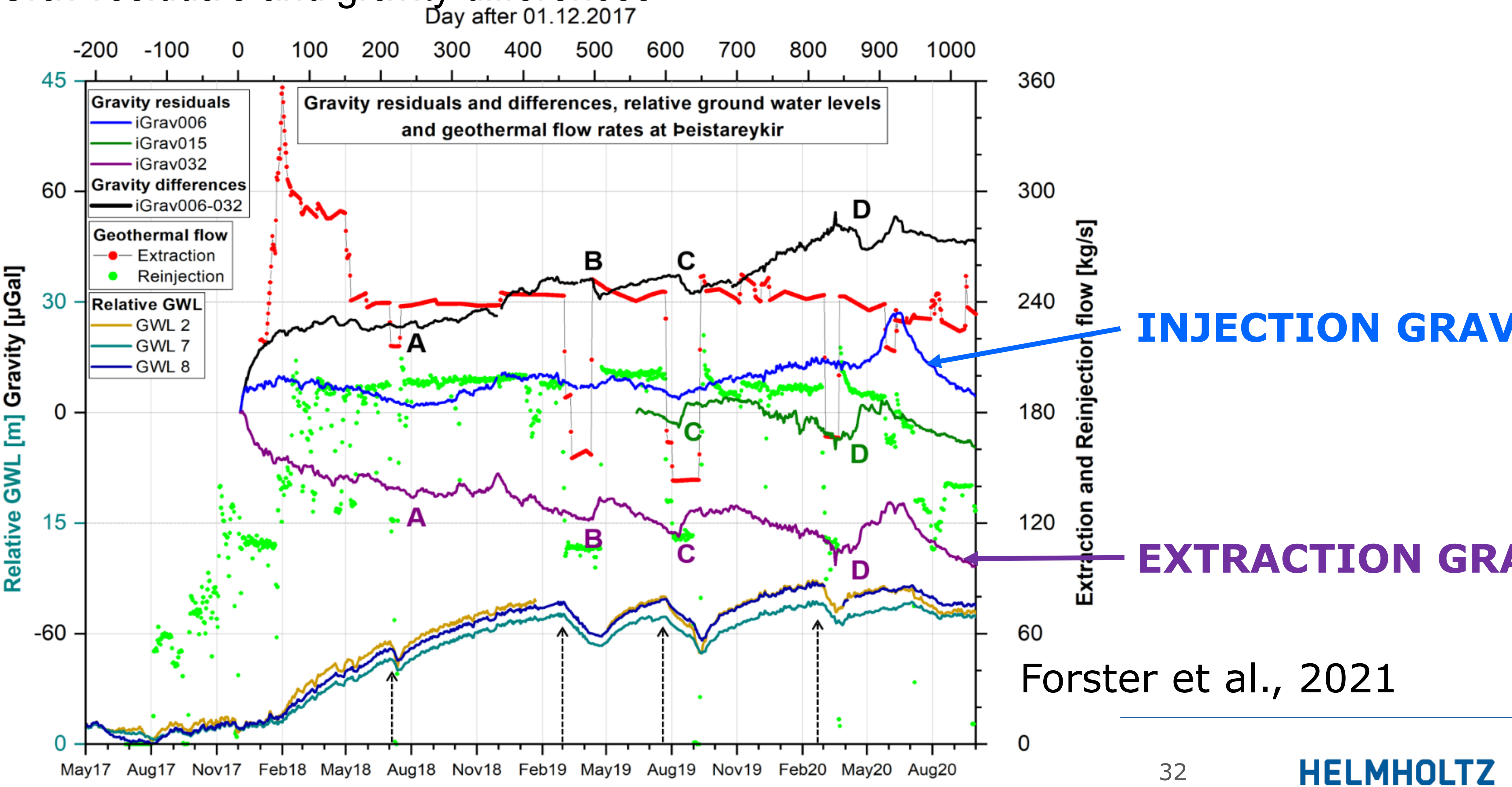
Drouin et al., 2020

Environmental gravity contributions

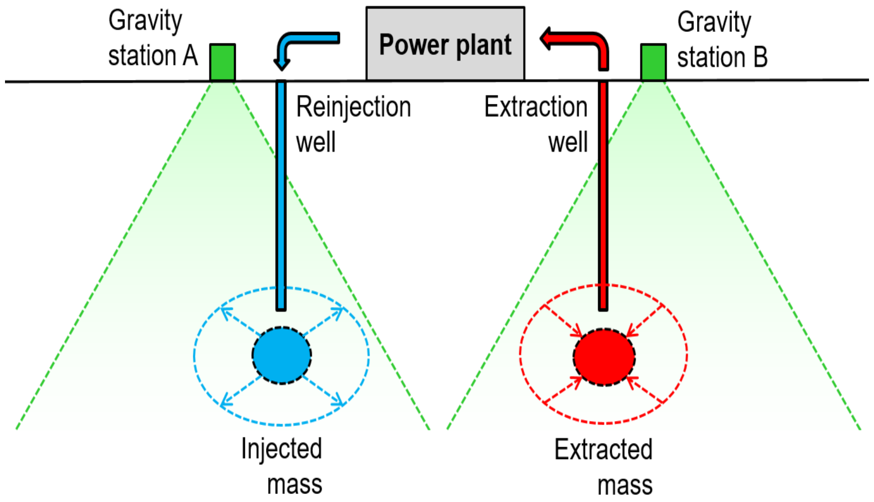


Forster et al., 2021

iGrav residuals and gravity differences



Forster et al., 2021



Forster et al., 2021

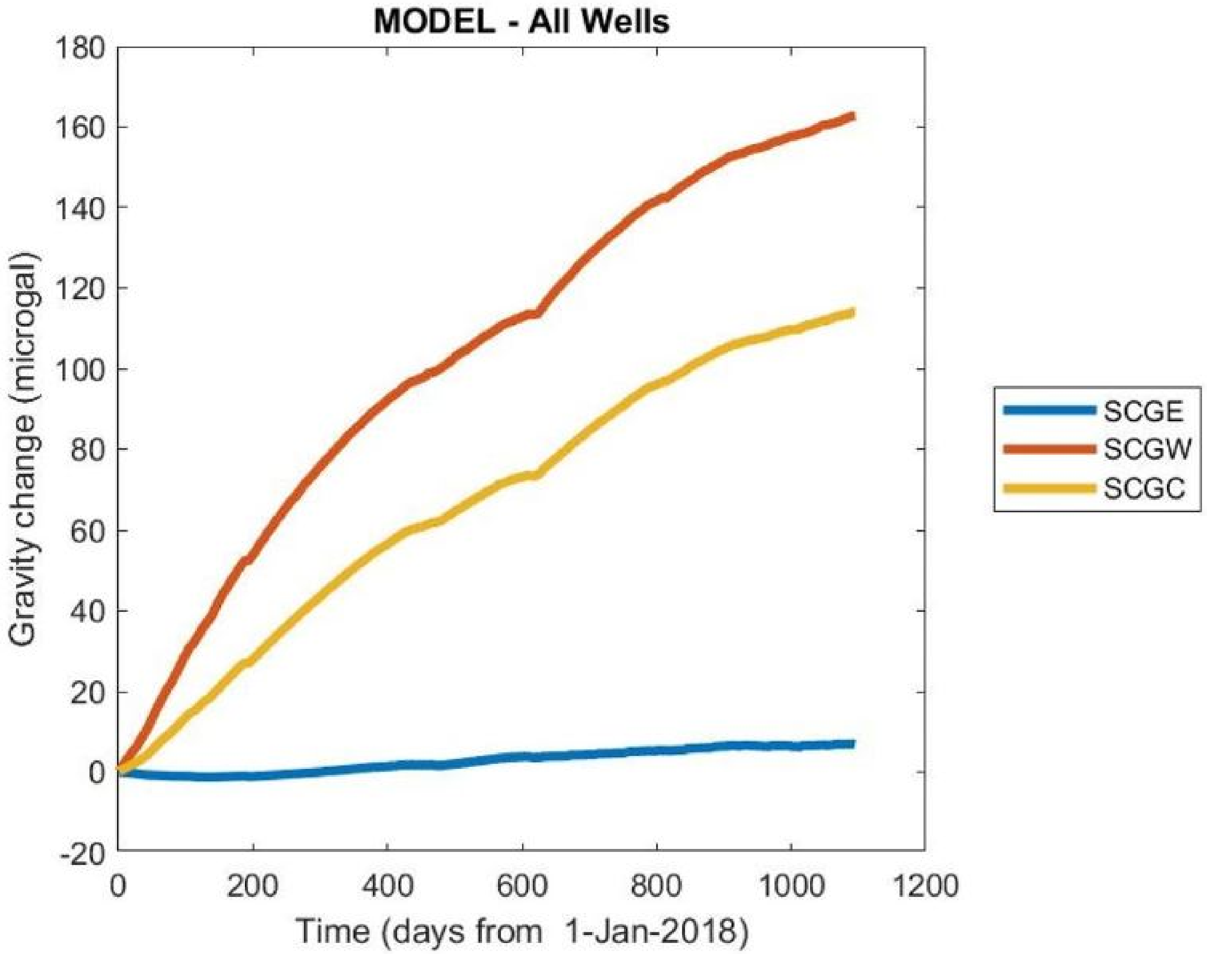


Fig. 10 Gravity modelled for the three gravity stations considering masses extracted/injected from all wells. Although the mass balance is close to zero in the modelling, gravity increases as the injected mass is located closer to the surface, explaining that the modelled total contribution is positive at all three locations

Summary (1)

- **Sub-complete set of measurements gravity, seismicity, deformation, EM, useful for geothermal research and monitoring**

- **Complementary method of gravity measurements:**
  - **Continuous (3 iGravs, 2 gPhones) / Repeated (Scintrex)**
  - **Relative/absolute (FG5)**
  - **4 continuous gravity records (1Hz) are complete for more than three years: first time such large networks such a long time for one single target.**

- **Continuous monitoring of a geothermal reservoir - several supercond. gravimeters**
- **Remotely controlled and locally serviced in ~4 month intervals**

Summary (2)

- **Instrumental drift of iGravs understood (Schäfer et al., 2020)**
- **Additional absolute gravity (FG5) campaigns planned for summer 2022, 2023**
    - Reservoir location and sustainability
    - Gravity variations are smaller than expected
    - Permeability in the area seems to be high and that the production/injection seem not to affect the reservoir a lot – next measurement -> stationarity
    - Provides constraints on reservoir properties and processes of fluid transfer

Organise progressively the transfer of the equipment to Krafla in accordance with
- the objectives of IMPROVE for Krafla
- the completion of scientific objectives in Theistareykir
- Landsvirkjun objectives and help

Thank you !

"My special thanks goes to all the coworkers, staff and institutions involved to make this work possible.

I deeply appreciate all the contributions, efforts, support, and discussions!"

Kemal Erbas