Agency for
Data Supply and
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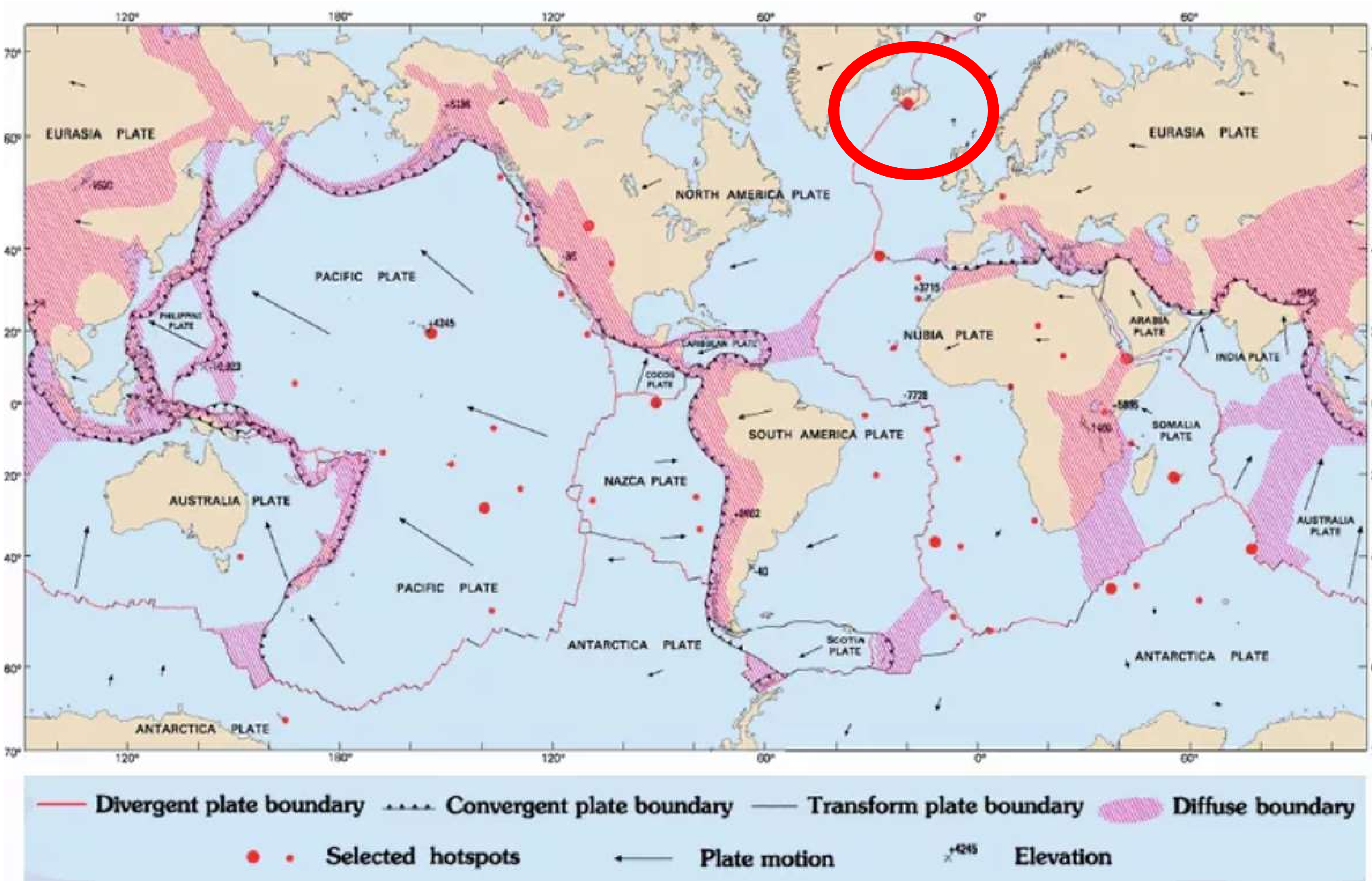
Dynamic reference frames
A case study in Iceland

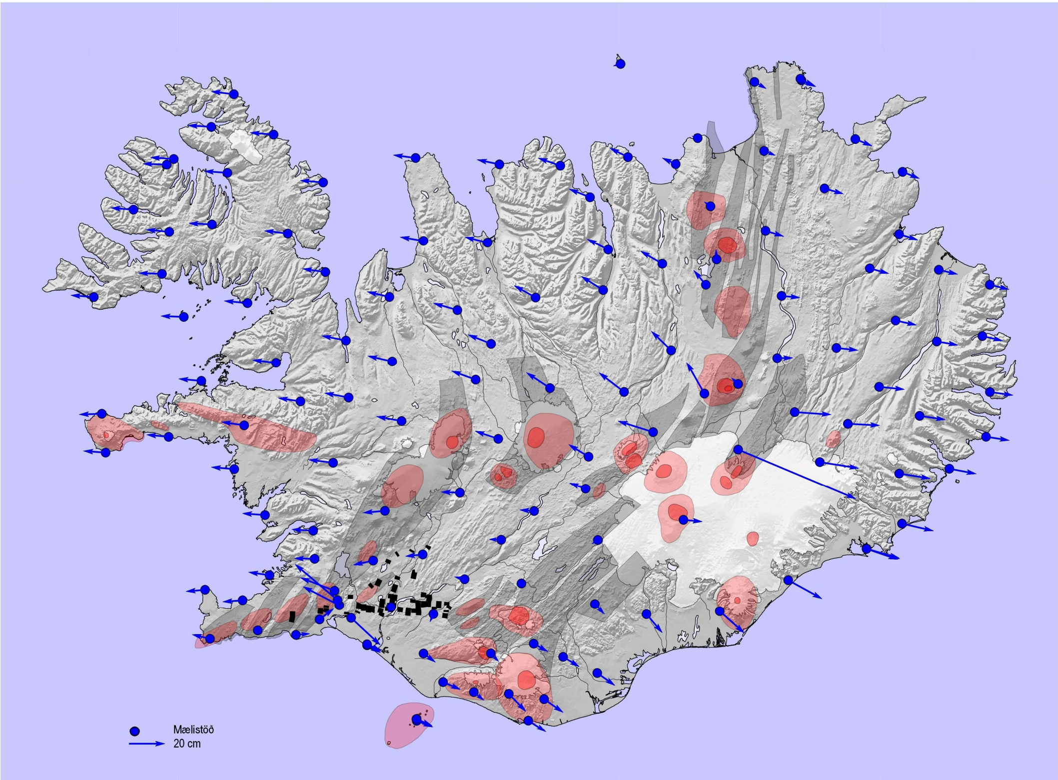
Kristian Evers, Denmark
Martin Lidberg, Sweden
Pasi Häkli, Finland
Halfdan Pascal Kierulf, Norway
Guðmundur Valsson, Iceland

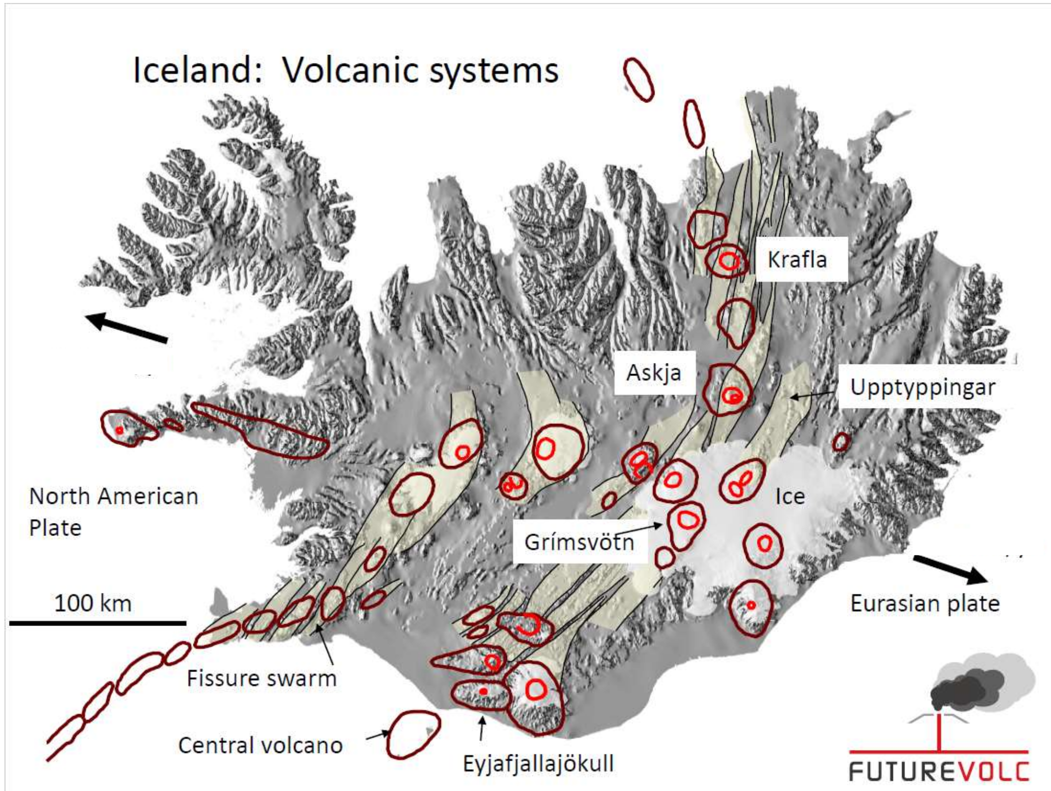
Outline

- Icelandic geology/geophysics
- Project background
- Our definition of the dynamic reference frame
- Deformation models
- Coordinate transformations


EURASIA PLATE
NORTH AMERICA PLATE
PACIFIC PLATE
PHILIPPINE PLATE
COCOS PLATE
CARIBBEAN PLATE
NUBIA PLATE
ARABIA PLATE
INDIA PLATE
SOUTH AMERICA PLATE
SOMALIA PLATE
NAZCA PLATE
AUSTRALIA PLATE
SCOTIA PLATE
ANTARCTICA PLATE
Divergent plate boundary
Convergent plate boundary
Transform plate boundary
Diffuse boundary
Selected hotspots
Plate motion
Elevation

Geology and geophysics in Iceland





Background

Background

The Director Generals of the Nordic NMCA's requested NKG to come up with a ***project proposal for a an implementation of a dynamic reference frame on Iceland***.

The goal is to assure that Iceland has a ***plan for implementation of a reference frame that allow precise positioning and direct access with global techniques***. And in the longer term ***"the plan is a pilot for similar implementations in Scandinavia"***

The outcome of this pre-study should be a project proposal for implementation of a dynamic reference frame (DRF) on Iceland. ***The proposal must highlight how to implement the DRF, the costs involved, resources needed, scope, quality level and time needed***.

Phase 1: Pre-study (Jan.—Sep. 2017)

Milestone	Descrition	Deadline
MP1	Project group in place and mandate accepted by both the steering committee and the project group	2017/01
MP2	First draft finalized and presented to Director Generals at "small bi-annual meeting"	2017/05
MP3	Second draft finalized and prepared for review	2017/06
MP4	Final delivery finalized and presented to Director Generals at "big bi-annual meeting"	2017/08
MP5	NKG presidium closes the pre study and discusses the way forward	2017/09

Phase 2: Pilot project (Sep. 2017 – Sep.2018)

Work package	**Date**	**Deliverable** **Document (D), Service (S), Results (R)**
WP1: Realization of DRF-Iceland	2017-11	D1.1: Specification of the GNSS analysis strategy and reference frame realization for the DRF-Iceland (D)
	2018-05	D1.2: Set up an operational GNSS analysis of Icelandic CORS (S)
	2017-11	D1.3: Determine a preliminary secular velocity field for the Icelandic GNSS stations (R)
	2018-06	D1.4: Time-series analysis for determination of velocities and deformations of Icelandic GNSS stations (D/R)
WP2: Access to DRF (user perspective)	2017-10	D2.1: Review of the RTK software options with respect to the requirements of dynamic coordinates in a DRF(D)
	2018-06	D2.2: Implementing a test-RTK service delivering DRF coordinates (D/S)
	2018-05	D2.3: Review of the quality of global PPP for positioning (D)
WP3: Deformation model	2018-02	D3.1: Description of concept for deformation model (D)
	2018-02	D3.2: Description of concepts for handling secular motions and deformation events (D)
	2018-06	D3.3: Determination of a preliminary deformation model (R)
	2018-03	D3.4: Description of how to implement deformation model in GIS systems (D)
WP4: Plan for a long term NKG-activity	NKG-GA-2018	D4: Document describing the plan for the NKG-activity 2018-2022 (D)

Phase 3: Long term initiative (Sep. 2018 – Sep. 2022)

Vision:

Establish a common Nordic DRF (DRF-NKG). That includes: Regular/continuous update of the reference frame, sufficient accurate deformation model and the necessary routines for handling time evolution in GIS systems

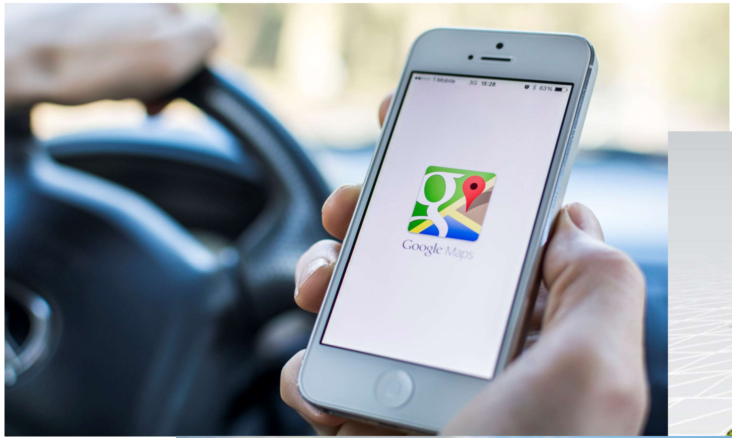
Milestones:

1. Clarify the concepts and describe the merits of static, semi-dynamic and dynamic reference frames, including the “two frame concept” where ITRF and national realizations of ETRS89 are used in parallel for various applications.
2. Evaluate the different concepts as basis for our geospatial data sets and for various positioning and surveying techniques.
3. Further develop the NKG analysis center for DRF needs, e.g. continuous coordinate updates of the Nordic and Baltic CORS (automated process?).
4. Establish routines to update rest of geodetic networks (by interpolation from CORS or prediction based on deformation models).
5. Setting up an RTK-service delivering DRF-coordinates in a test area.
6. Improve existing deformation models for the NKG-area and customize them for DRF use
7. Test of InSAR as a source for local deformations, and evaluate if local deformations are relevant in the velocity model.
8. Testing algorithms that combines GNSS time-series, geophysical models (especially GIA) and InSAR (if found useful in M7) to carry out a high-resolution in Iceland and in another test area.
9. Develop the necessary routines (e.g. in PROJ) to handle dynamic coordinates in GIS systems.
10. Finalizing the Icelandic case study and draw conclusions.
11. Define a new test area (outside Iceland) and set up a full-scale test of a dynamic GIS.
12. Outreach work – setting up a common campaign to convince the owners of the geospatial data.

The gist of it all…

Create a reference frame that gives everyone[1] access to high-precision coordinates in regular day-to-day use

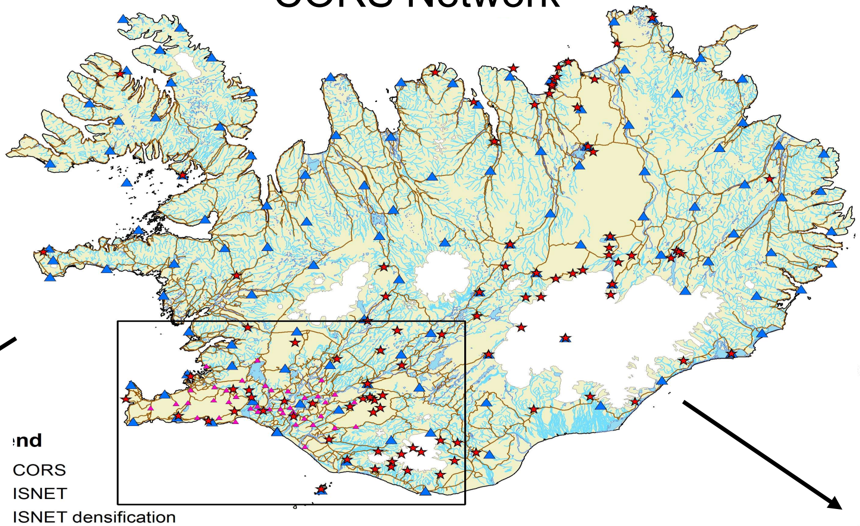
1. For some approximate value of everyone


Google Maps

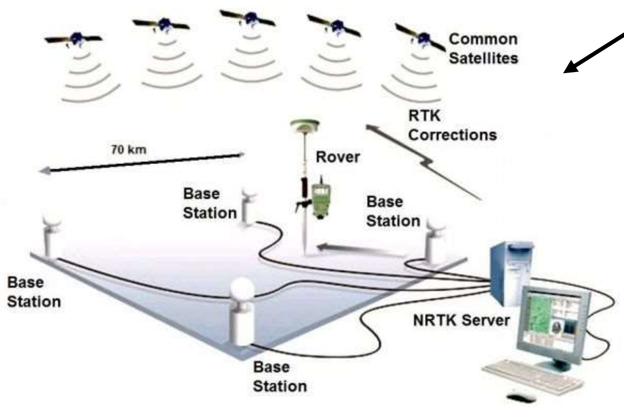
Preconditions for success

1. A sufficiently dense active geodetic infrastructure (CORS) with known coordinates in a global reference frame (ITRF)
2. A way to distribute the reference frame to the users, e.g. positioning services
3. Transformations and/or deformation models with sufficient accuracy to meet the future demands for comparison and compiling coordinates from different epochs
4. Geodetic data archive able to store and handle dynamic coordinates
5. GIS systems that are able to handle dynamic coordinates in general and in particular the time dimension of a dynamic reference frame and the various transformations needed
6. Training and education of surveyors
7. Training and education of GIS users
8. Willingness of the users to take such a system into use

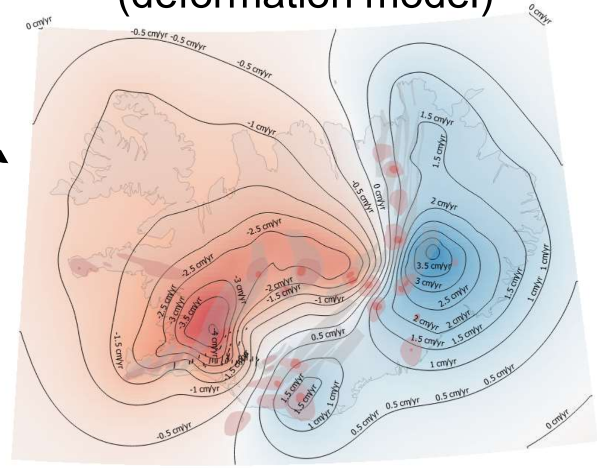
CORS Network



Positioning service



Transformations (deformation model)



GIS

Defining the dynamic reference frame

A point in a DRF is given by 4-parametres (x,y,z,t), where (x,y,z) is the spatial location in a global reference frame (e.g. ITRF) at epoch t.

A point (x,y,z,t) is:

- -uniquely defined and
- - is given directly in the global reference frame
- - have the accuracy of the measurements technique
- - do not change over time

An epoch-realization is a realization of the reference frame at a certain epoch

Semi-dynamic RF is:

- -An epoch-realization of the DRF including a velocity model
- or
- -A series of epoch-realizations of the DRF

We need deformation models
to compile or compare coordinates with different epoch

Transformations could be on the fly or regular updates

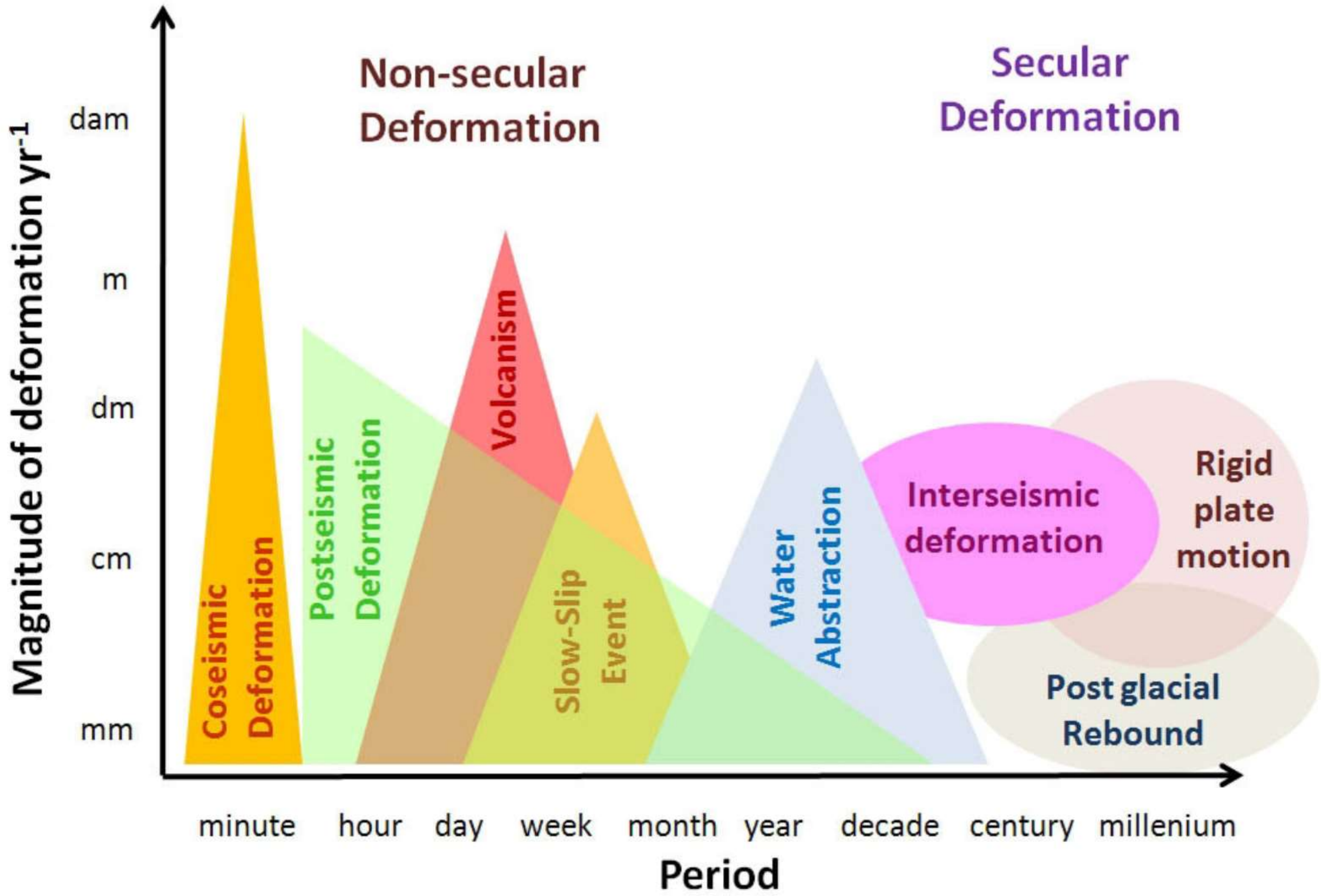
ISN_DRF implementation details

- The underlying Terrestrial Reference System is ITRS
- ISN_DRF is aligned to the most recent ITRF, consequently it
- is a crust-based TRF and realized through a network and data of continuously operating reference stations (CORS)
- will be updated accordingly when a new ITRF solution by the ITRS-PC and associated products are available

Following the previous definitions, the ISN_DRF presupposes a dense enough network of continuously operating reference stations (CORS) for realizing and materializing the ISN_DRF. GNSS CORS network is a pre-requisite for:

1. aligning the ISN_DRF to the ITRF,
2. estimating time-dependent (kinematic) coordinates in the ISN_DRF,
3. providing accurate access to the ISN_DRF (real-time coordinates) to users through a positioning service based on the CORS network,

Deformation models


Non-secular
Deformation
Secular
Deformation
Magnitude of deformation yr-1
dam
m
dm
cm
mm
Coseismic
Deformation
Postseismic
Deformation
Volcanism
Slow-Slip
Event
Water
Abstraction
Interseismic
deformation
Rigid
plate
motion
Post glacial
Rebound
minute
hour
day
week
month
year
decade
century
millenium
Period

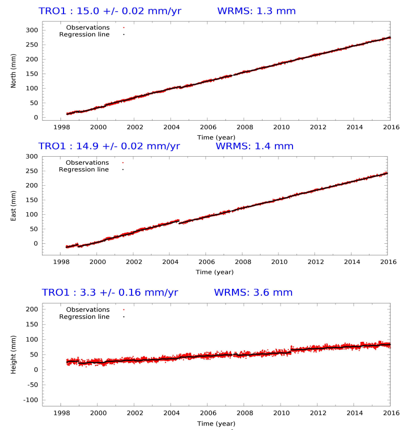
The main focus will be on the development of the necessary deformation models for a DRF in Iceland based on integration and compilation of GNSS velocities and time-series, InSAR, Geophysical models and interpolation routines

Data:
GPS
Seismic
Geophysical models
InSAR

- Compilation
- Analysis
- Combination
- Interpolation (with geophysical constraints)

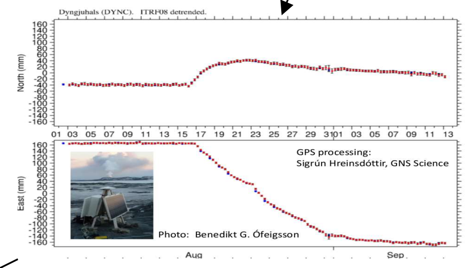
Grid:
-Linear (back ground velocities)
-Deformations
Secular
Non-secular

-operationalization and automation

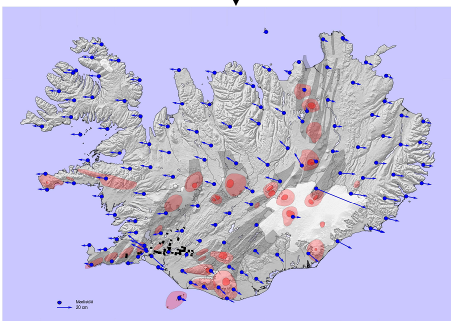


Simple time-series

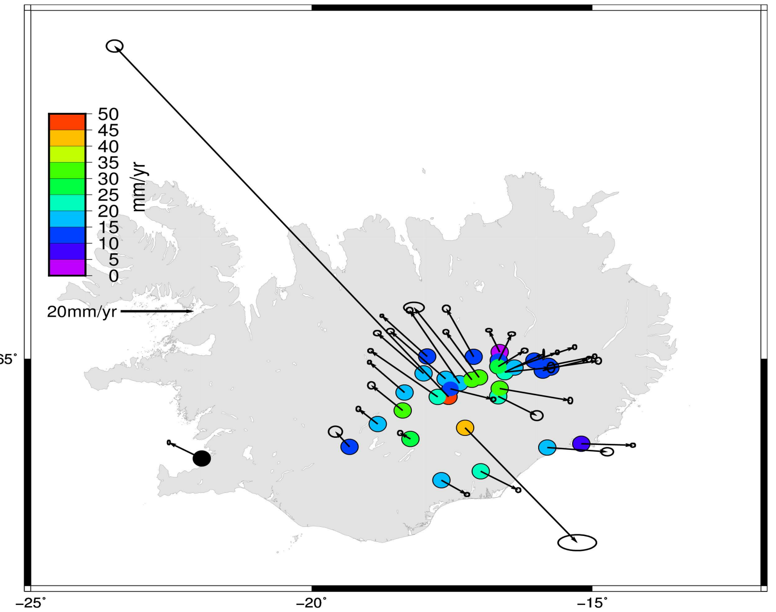
Challenging time-series

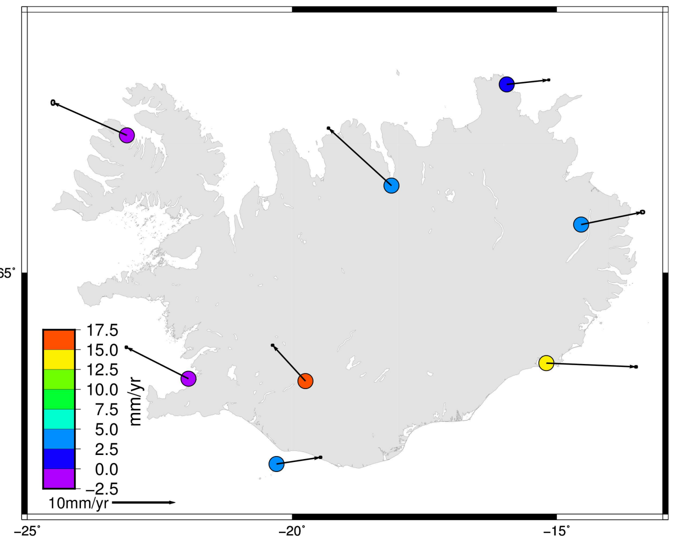


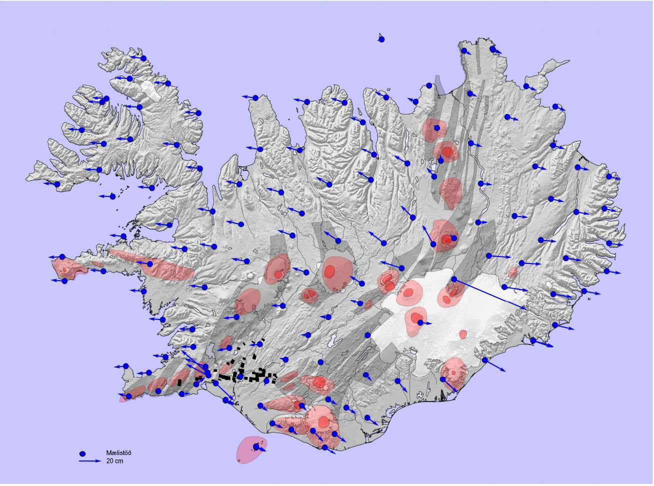
How?

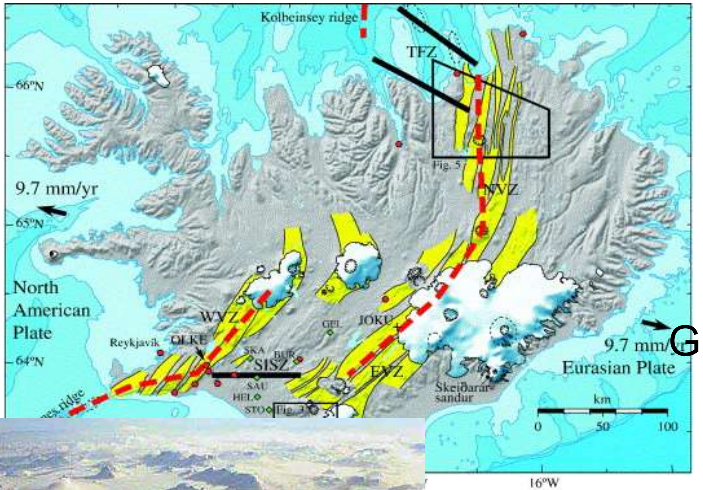


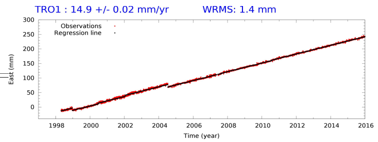
GNSS velocities

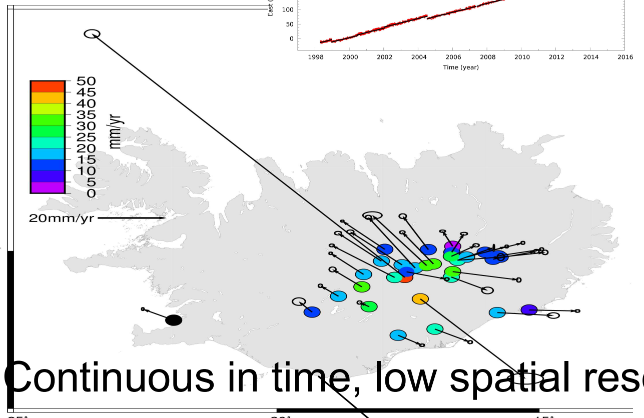


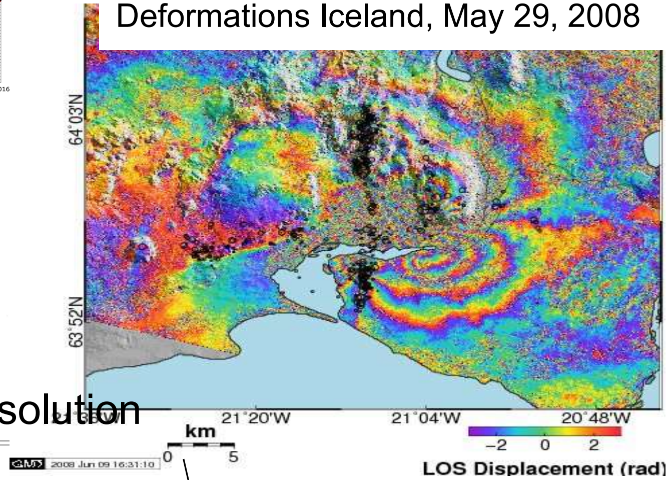




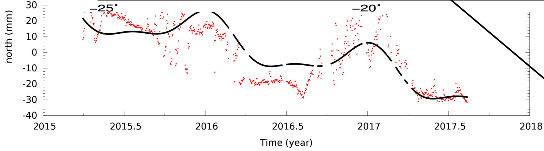








GNSS Continuous in time, low spatial resolution



Geophysical model

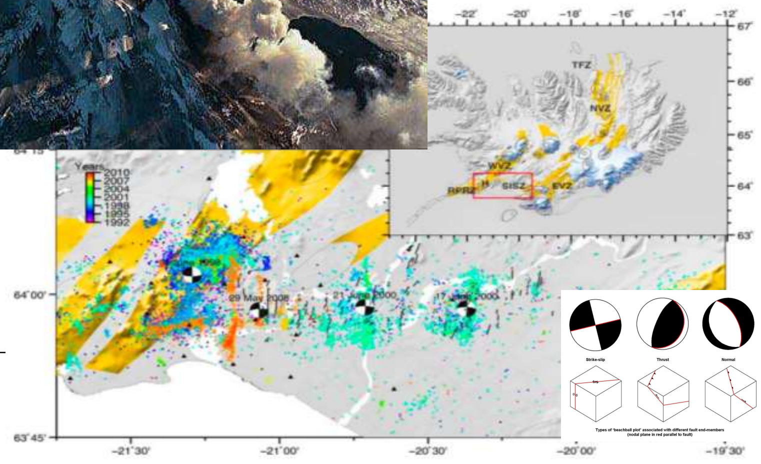
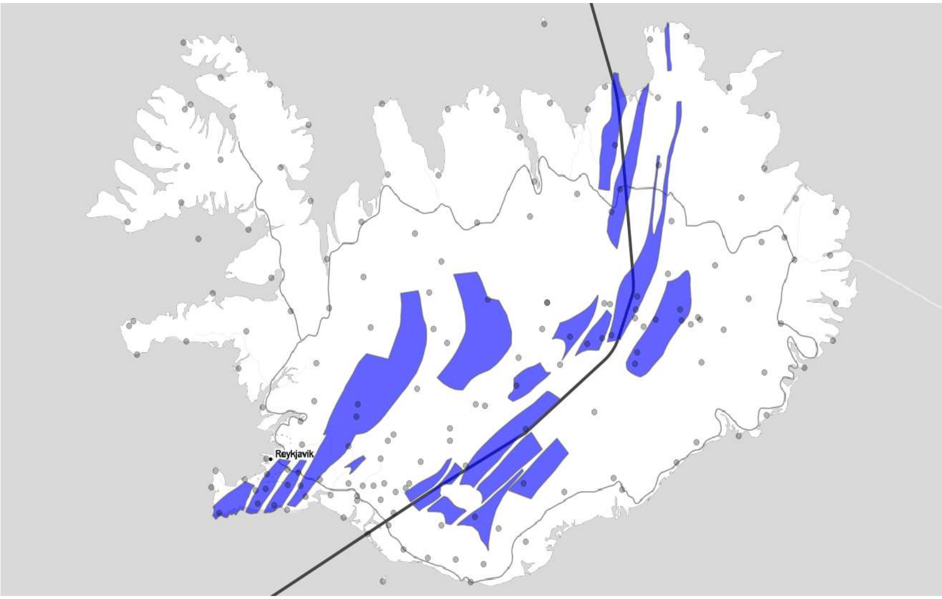


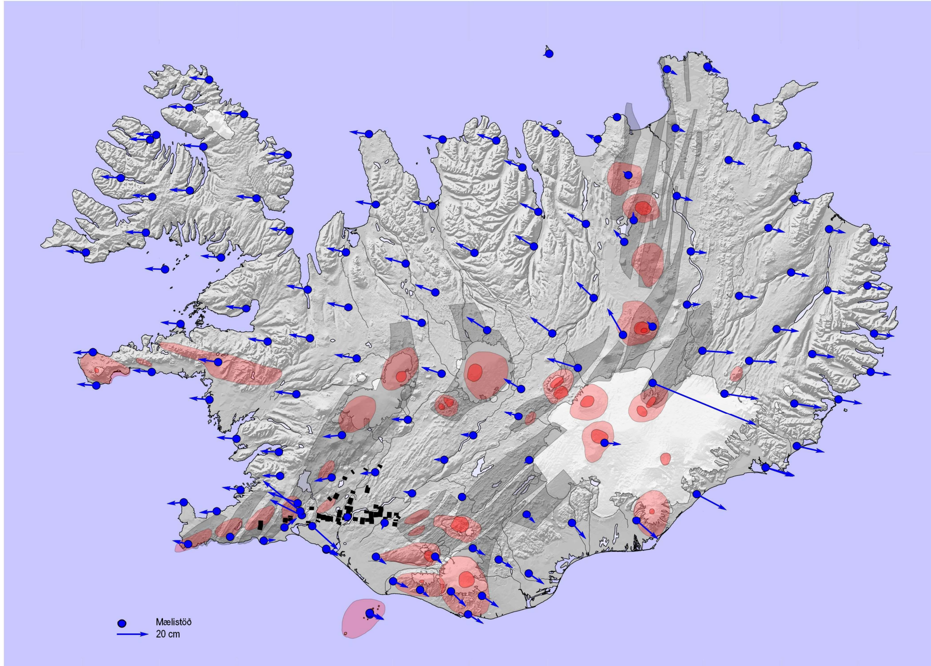
Figure 1. Seismicity within the South Iceland Seismic Zone and Hengill Triple Junction (H), 1992–2009. Event locations

InSAR:
Continuous in space,
but only 2D
Sampling: 7 days (sentinel1A/B)

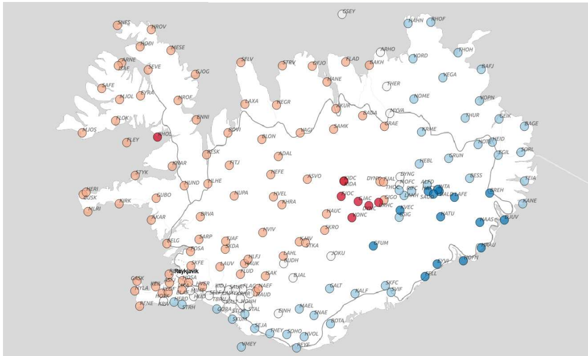
The ultimate goal:
A spatial and temporal continuous deformation model.
Automatically updated in real time

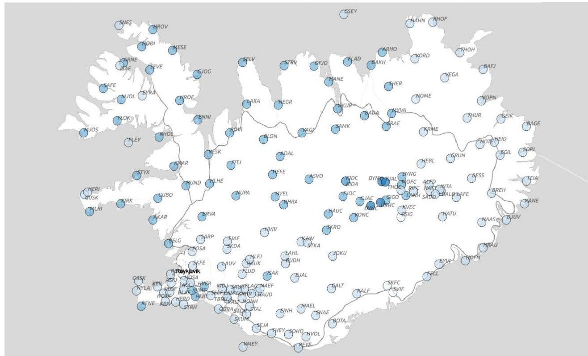
Collocation with constraints

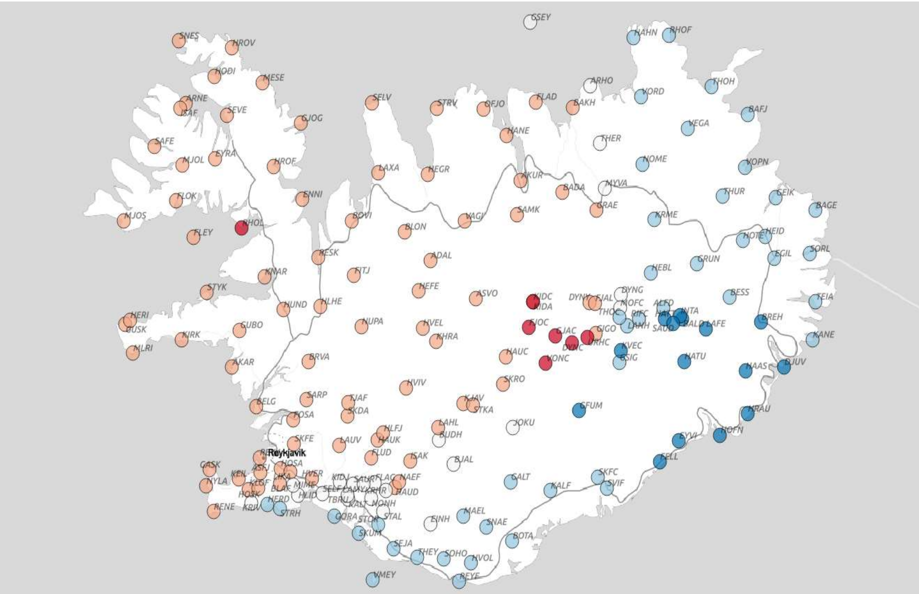




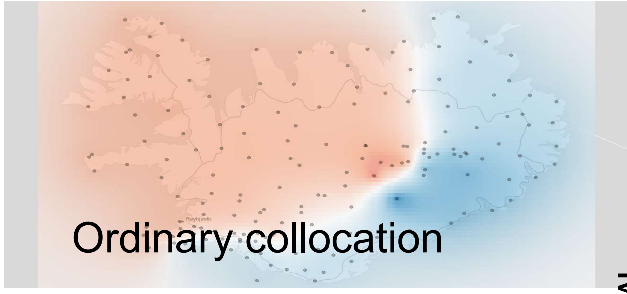
Map with faults and a ridge

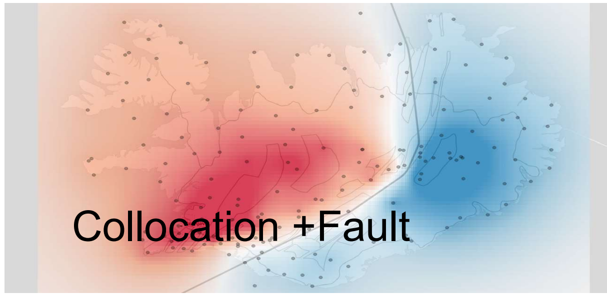


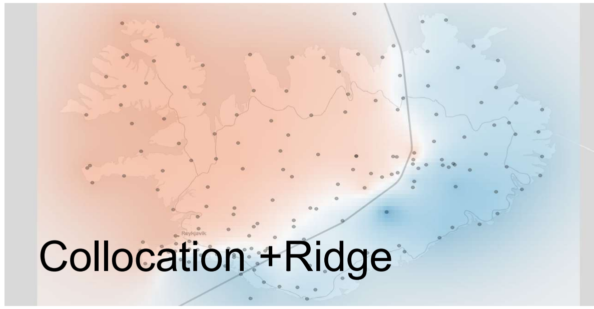


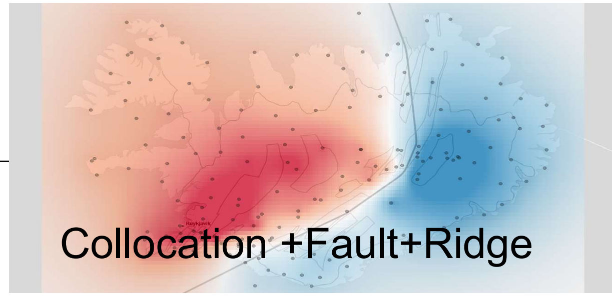


174 stations
KISA removed









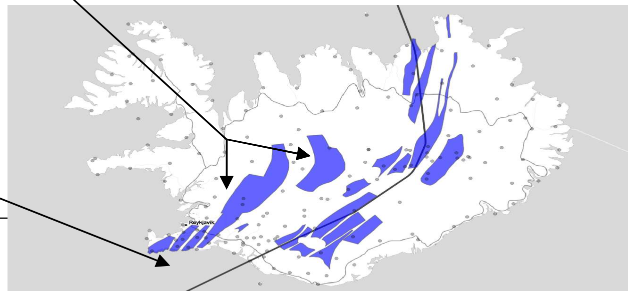
Models: (Red = -0.025, Blue = 0.025)

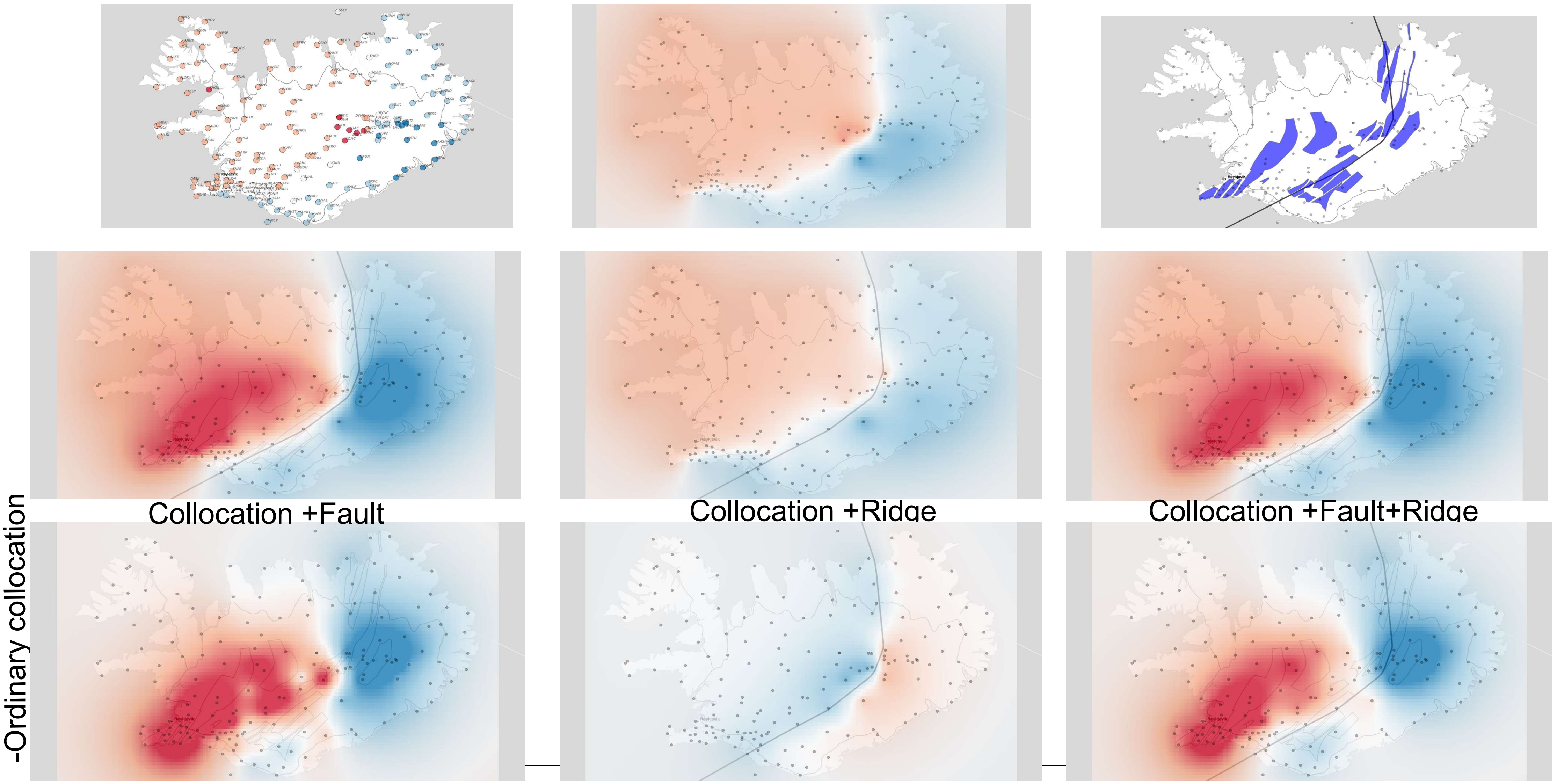
Collocation: Trend + signal1 (35 km) + signal12 (5 km)

Fault: Fault stretch factor 20 (inside fault zone)

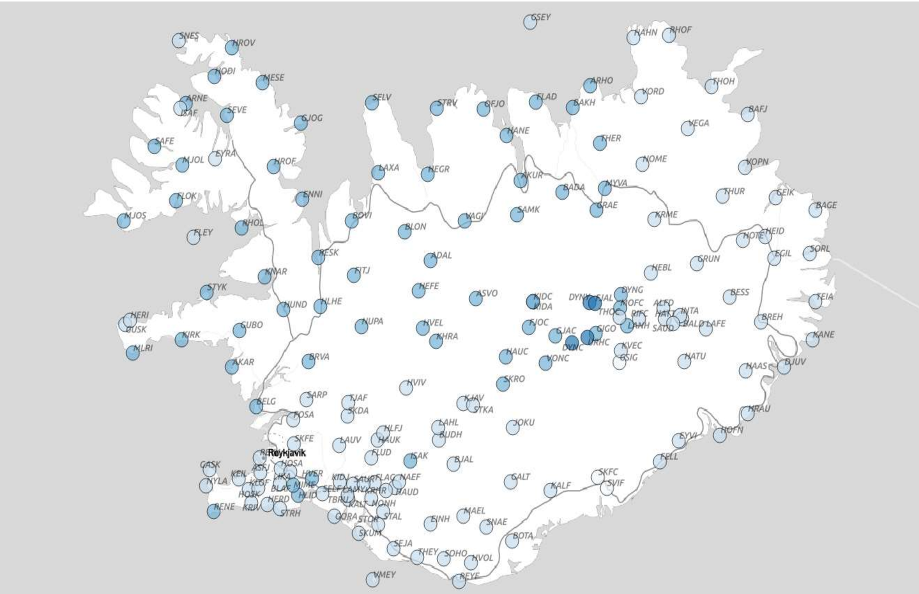
Ridge: Add 1000 km passing the ridge

Kind off Least Cost Path (LCP) analysis

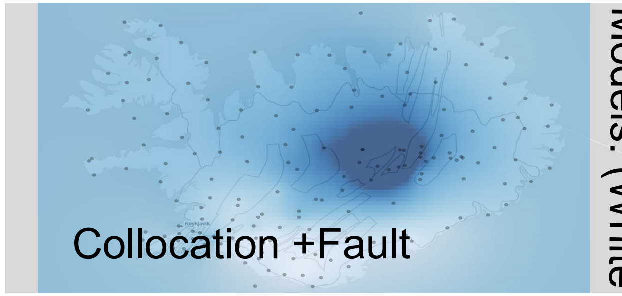


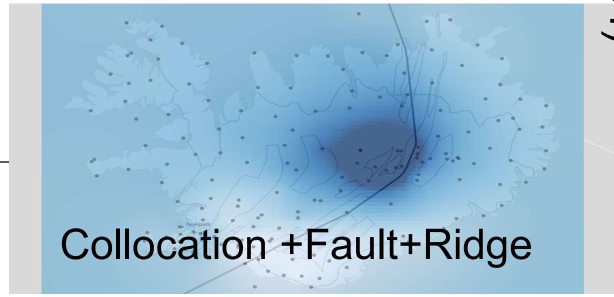


Models: (Red = -0.025, Blue = 0.025) Difference: (Red = -0.015, Blue = 0.015)



173 stations
GFUM and KISA removed



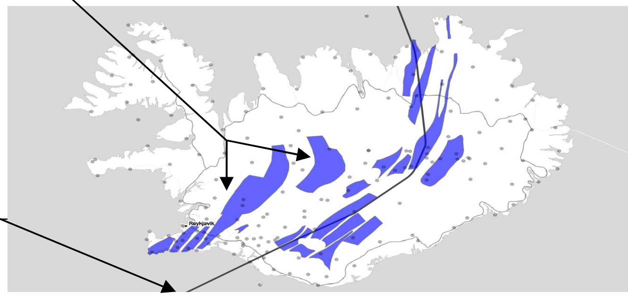


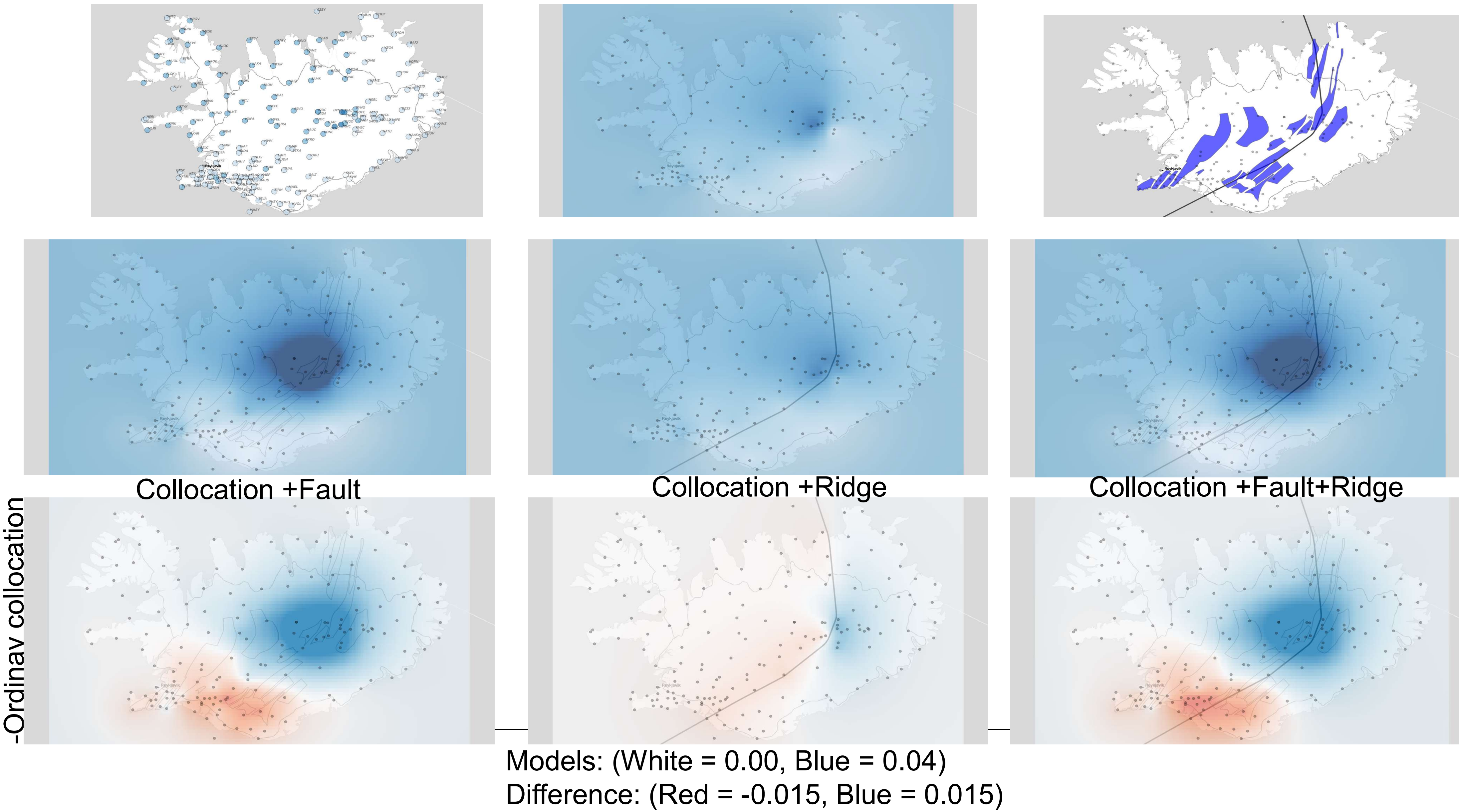
Models: (White = 0.00, Blue = 0.04)

Collocation: Trend + signal1 (35 km) + signal12 (5 km)

Fault: Fault stretch factor 20 (inside fault zone)

Ridge: Add 1000 km passing the ridge




Collocation +Fault
Collocation +Ridge
Collocation +Fault+Ridge
-Ordinav collocation
Models: (White = 0.00, Blue = 0.04)
Difference: (Red = -0.015, Blue = 0.015)

Transformations

PROJ

Transformation Pipelines in PROJ

- A flexible framework that allows for complex transformations
- Transformations are constructed as a set of daisy-chained basic building blocks
- Not limited to spatial transformations – pipelines are fully time-aware
- Many geodetic techniques available
  - **14-parameter shift**
  - **Velocity/deformation models**
  - **Grid shifts**
  - **Molodensky transform**
  - **Polynomial mappings**
  - **…**

Secular deformation

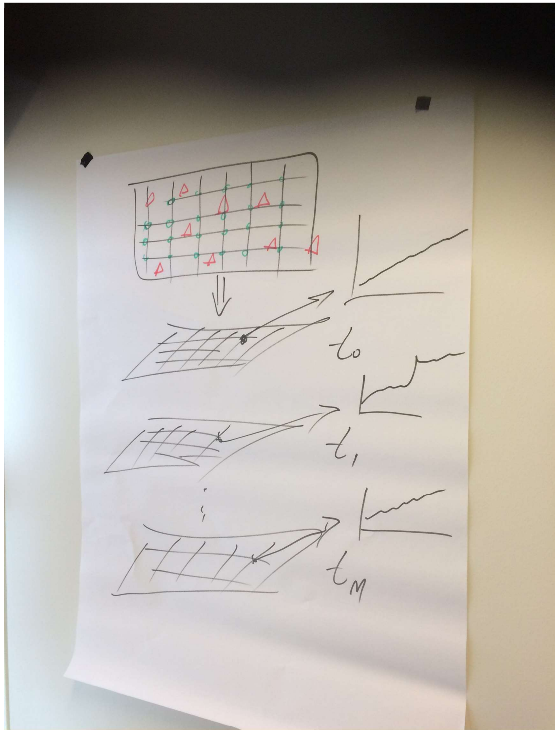
$(x,y,z,t)_{ITRF2014}$

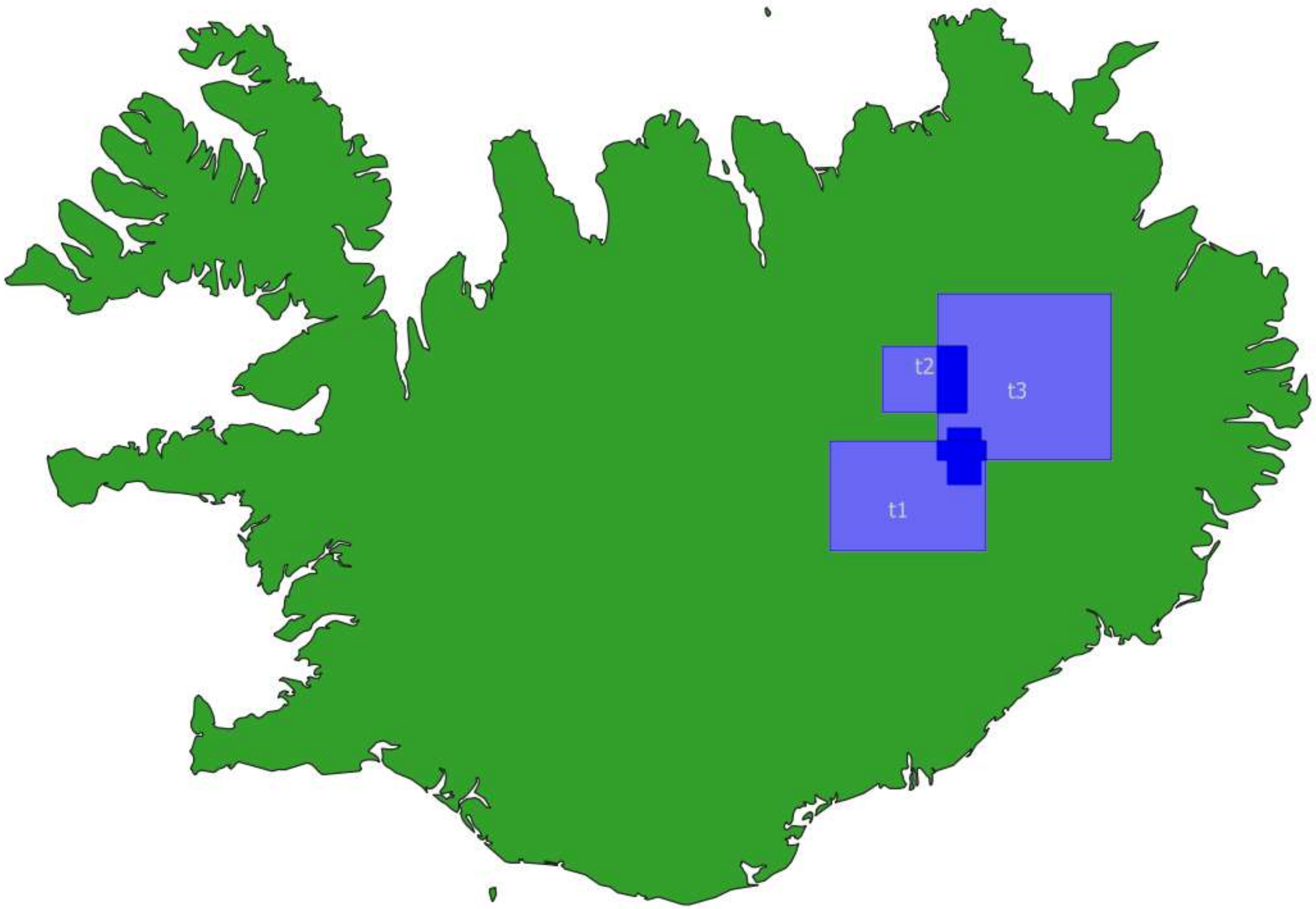
```
+proj = deformation
  +t_epoch=2010.0 # central epoch of ITRF2014
  +xy_grids = @iceland_secular_model_xy.ct2,@null
  +z_grids  = @iceland_secular_model_z.gtx,@null
```

$(x,y,z,t)_{ISN\_DRF}$

Non-secular deformation

- Gridded models of discrete deformations events
- Does not need to cover the entire country – just the deformed area
- Coordinates are grid-shifted if they are inside the grid. Several grid-shifts can occur.
- Each grid is tied to a specific epoch (= that of the deformation event)



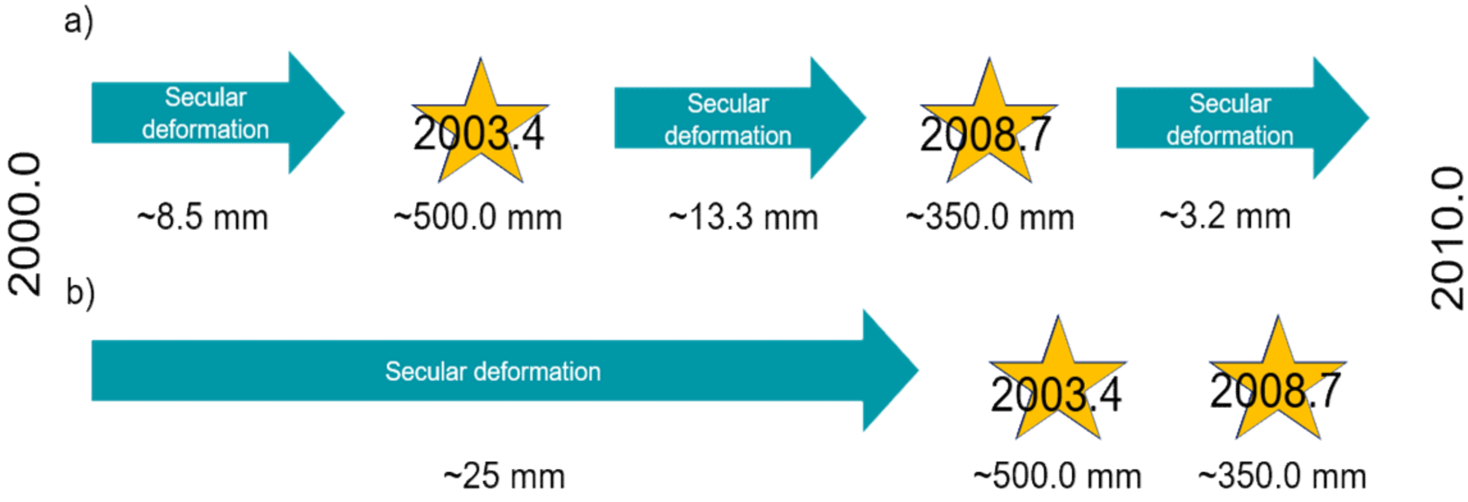

t2
t3
t1

$$(x,y,z,t)_{\text{ITRF2014, t=2018.23}}$$

```
+proj=pipeline +t_final=2025.0
     +step +proj=hgridshift +grids=@event1_xy.ct2 +t_epoch=2019.23
     +step +proj=hgridshift +grids=@event2_xy.ct2 +t_epoch=2020.82
```

$$(x,y,z,t)_{\text{ISN\_DRF, t=2025.0}}$$

Combining secular and non-secular deformation



$(x,y,z,t)_{ITRF2014,\ t=2018.23}$

```
+proj=pipeline +t_final=2025.0
+step +proj=deformation +t_epoch=2010.0
     +xy_grids=@iceland_secular_model_xy.ct2,@null
     +z_grids=@iceland_secular_model_z.gtx,@null
+step +proj=hgridshift +grids=@event1_xy.ct2 +t_epoch=2019.23
+step +proj=hgridshift +grids=@event2_xy.ct2 +t_epoch=2020.82
```

$(x,y,z,t)_{ISN\_DRF,\ t=2025.0}$

In conclusion

- We have defined the dynamic reference ISN_DRF
- Made significant progress on the positioning services
- Made an initial deformation model based on GNSS and geophysical models
- Set up a coordinate transformation prototype which is fully functional within selected GIS applications
- → A prototype for a dynamic reference frame in Iceland!

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Thank you