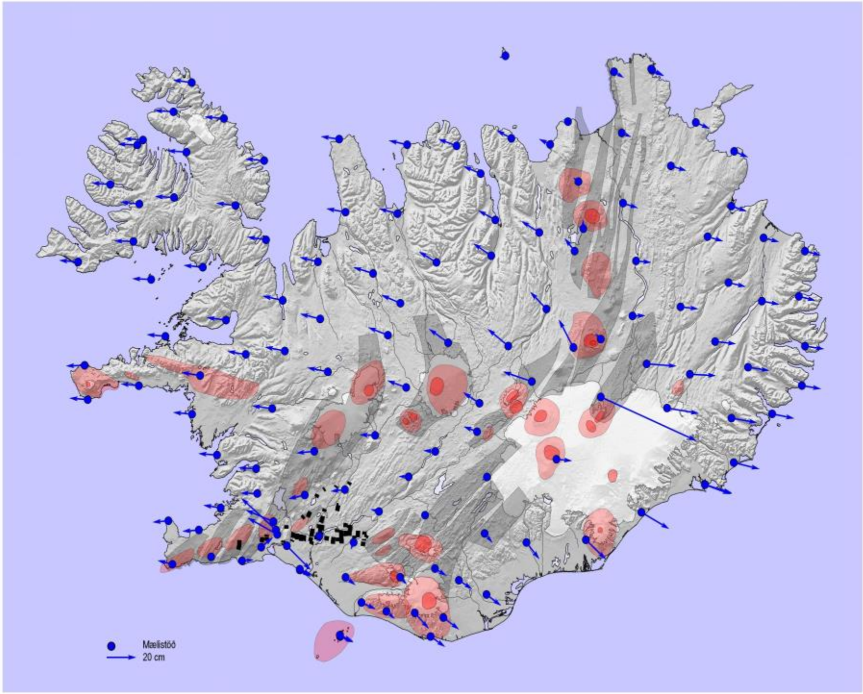
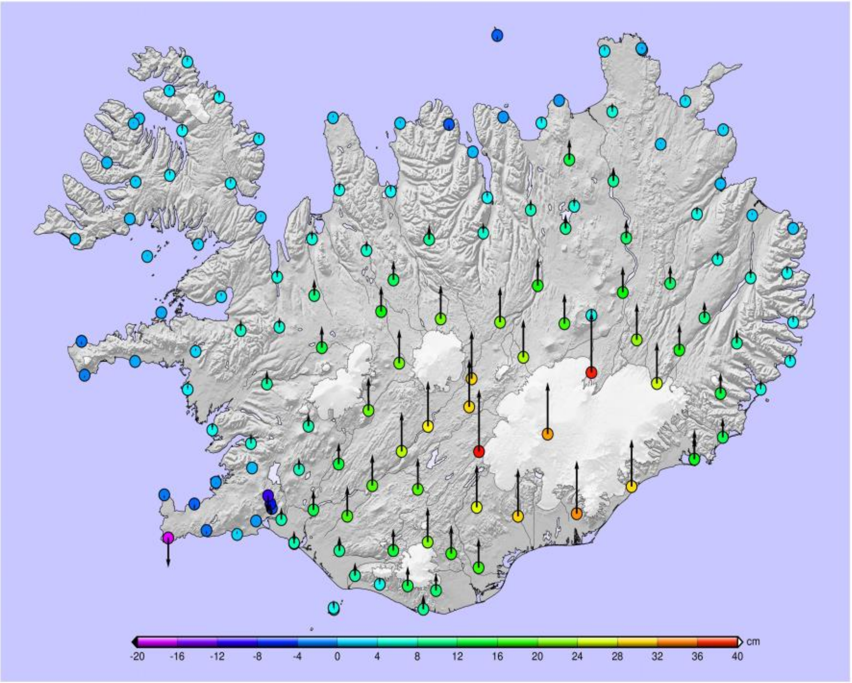
Dynamic Reference Frames (DRF) – concepts and NKG activities

Science week in Reykjavik, 9 / 3 - 2020

Kartverket





Halfdan Pascal Kierulf, Gudmundur Valsson, Dalia Prizginiene, Kristian Evers, Pasi Häkli, Martin Lidberg,

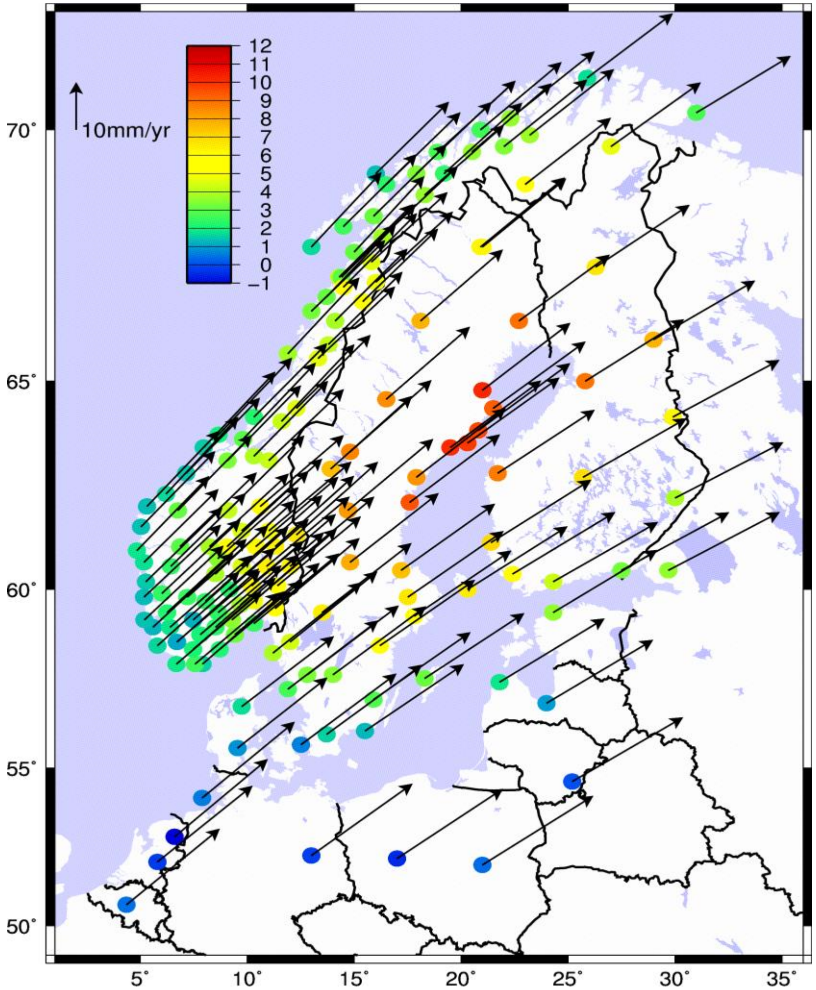
Background

- Scenario: Smartphones give positions within dm or cm accuracy
  - in real time
  - in a global and dynamic reference frame
- Autonomous driving sets new demands on the seamless reference frames over boarders
- Australia has decided to implement a fully dynamic reference frame in 2020
- Is a static “plate fixed” reference frame the best solution for the users in the future?

The NKG-presidie initiated a pilot project on Dynamical Reference ***DRF-Iceland***

NKG focus area: Dynamic Reference Frames

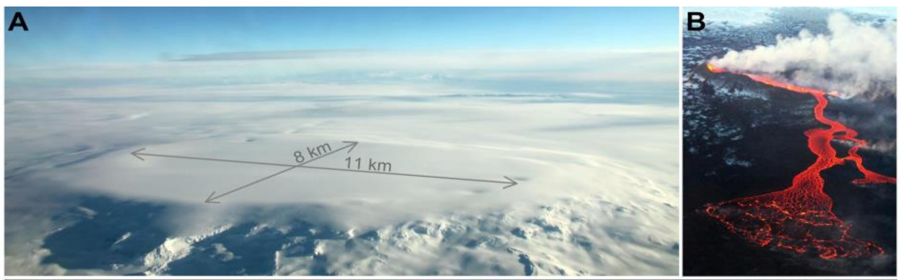
The earth and the Nordic countries are subject to crustal deformations that influence the reference frames



- Scandinavia has moved since ETRS89 was realized in our countries
  - ~75 cm to North-East
  - 0-25 cm Up
- ITRF and realizations of ETRS89 differ
- Should the reference frame follow the “stable”- plate or the global system?

In Iceland the deformations are much more complex

-Two plates are drifting apart ~2-3 cm/year
-Deformations within the plates
-Earthquakes ~50 cm
-Volcanoes
-Melting graciers ~40 mm land uplift annually
~more than 10 mm/yr horizontally
-Geothermal power plants - subsidence



If we could handle the situation in Iceland, we could handle the situation in Scandinavia.

The following competent group was put together to solve the problems

- Halfdan Pascal Kierulf, Prosject leader
- Gudmundur Valsson, Iceland
- Ásta Kristín Óladóttir, Iceland
- Hafliði Magnússon, Iceland
- Dalia Prizginiene, Iceland
- Martin Lidberg, Sweden
- Per Knudsen, Denmark
- Kristian Evers, Denmark
- Markku Poutanen, Finland
- Teemu Saloriutta, Finland
- Pasi Häkli, Finland
- Olav Vestøl, Norway
- Geir Arne Hjelle, Norway
- Martin Haakanson, Sweden

- Per Erik Opseth, Norway, Project owner
- NKG Presidium, Steering committee

From the first meeting in Akranes Feb. 22-23, 2017

It is important to have a common understanding of definitions and vocabulary

-Static RF (Plate fixed, Epoch fixed):

The RF moves with the tectonic plate.
The coordinates (of physical objects) do not change with time.

-Dynamic RF (Earth fixed, kinematic):

The RF does not move with the tectonic plates.
The coordinates (of physical objects) change with time.

-Semi-dynamic RF:

Any possible combination of static and dynamic thinking.
E.g. A “time-series” of static reference frames
A static reference frame with a deformation model
(e.g. realizations of ETRS89 in our Nordic countries)

The project used a more precise definitions of a 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
  (but the coordinate of a physical object is different at different epochs)

In addition, we need:

- a *deformation model* to compile or compare coordinates with different epoch

NOTE:

Because of the time tagging you can:

- store coordinates in your database even though your deformation model is not updated (e.g. after a large earthquake)
- always use the latest and most precise deformation model

Positions in a DRF can be accessed with all techniques

Examples:

-PPP: direct determination in the DRF

-DD: determination through the ITRF coordinates of your reference stations

-RTK: direct determination if the RTK-GNSS stations are continuously updated in ITRF

-Positioning relative a local marker also works, but the time stamp will be the same as for the local markers.

i.e. all techniques determine positions in the same reference frame without transformations.

Kartverket

The project identified ten pre-conditions for a successful DRF:

1) A sufficiently dense active geodetic infrastructure (CORS) with known coordinates (and uncertainties) in a global reference frame (ITRF).

2) A way to distribute the reference frame to the users, e.g. positioning services.

3) Transformations to other reference frames.

4) Deformation models with sufficient accuracy to meet the future demands for comparison and compiling coordinates from different epochs.

5) Geodetic data archive able to store and handle dynamic coordinates.

6) 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.

7) Legal foundation of dynamic reference frames (e.g. for cadastre).

8) Training and education of surveyors.

9) Training and education of GIS users.

10) Willingness of the users to take such a system into use.

Deliverables of the DRF-Iceland projects included: 11 documents, three sets of results and two test services

	Document	Results	Test service

DRF-Iceland pre-project	
	How to define a dynamic reference frame
	Geodesy in Iceland
	Spatial data infrastructure in Iceland
	GIS and dynamic reference frames
DRF-Iceland-S1	DRF Iceland project proposal
WP1: Realization of DRF-Iceland	D1.1: Specification of the GNSS analysis strategy and reference frame realization for the DRF-Iceland
	D1.2: Set up an operational GNSS analysis of Icelandic CORS
	D1.3: Determine a preliminary secular velocity field for the Icelandic GNSS stations
	D1.4: Time-series analysis for determination of velocities and deformations of Icelandic GNSS stations
WP2: Access to DRF (user perspective)	D2.1: Review of the RTK software options with respect to the requirements of dynamic coordinates in a DRF
	D2.2: Implementing a test-RTK service delivering DRF coordinates
	D2.3: Review of the quality of global PPP for positioning
WP3: Deformation model	D3.1: Description of concept for deformation model D3.2: Description of concepts for handling secular motions and deformation events
	D3.3: Determination of a preliminary deformation model
	D3.4: Description of how to implement deformation model in GIS systems
WP4: Plan for a long term NKG-activity	D4: Document describing the plan for the NKG-activity 2018-2022

The documents are available on the NKG web-pages

From the *“NKG_structure_2018_2022_181126.pptx”* DRF Mile stones (MS)

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. 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 and semi-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 deformation model 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.
13. Study: User analysis: What is the need for dynamic reference frames and when do they need to be implemented?
14. Study: How to organize the geospatial data to make an efficient upgrade of the reference frame when needed
15. Study: How to deal with dynamic cadaster data? What about legislation?

Project view on the DRF Focus Area mile stones 2018-2022

DRF- Iceland
DRF- User perspective
WG - Geodynamic
WG - Ref. Frame
WG - Positioning

2019 2020 2021 2022

M 3 Nordic-Baltic ITRF
M 12 (Outreach activity)
M 1,2
M 13
M 14
M 15
M 6,9
transf
M 7,8
InSAR
M 4 (
Activi
Positi
M 5 (
M 5b
TAPA
M 11

The DRF-group has also drafted plans for five possible activities for NKG in 2019-2022

DRF-P1: **Deformation models,** (6-8)
DRF-P2: **Outreach/user perspective,** (1,2,12-15)
DRF-P3: **RTK-Service,** (5)
DRF-P4: **Full-scale test,** (11)
DRF-P5: **Reference frame realization,** (3,4)

(The number in the parentheses refers to the milestones proposed by the presidium for the NKG-focus area on DRF)

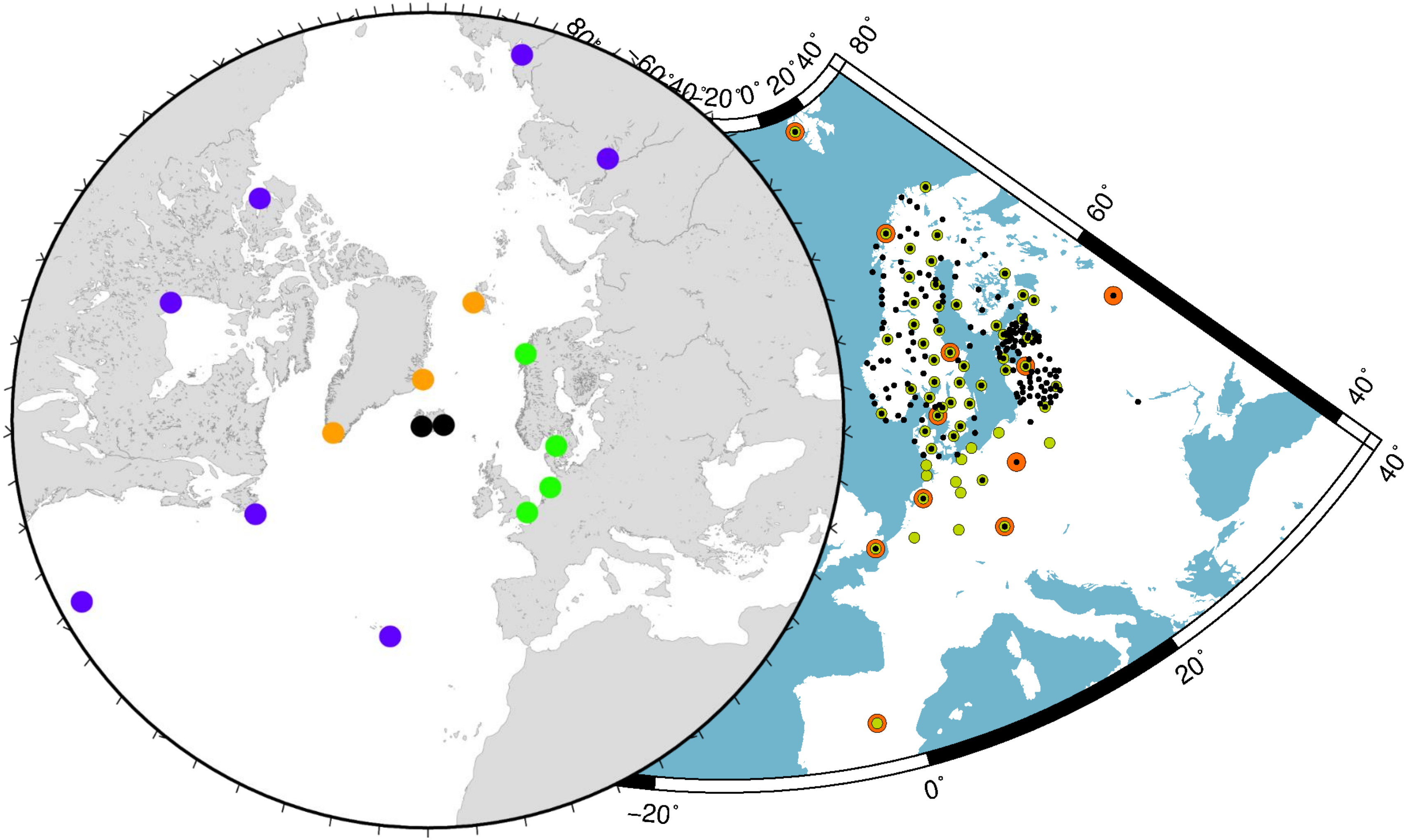
After the NKG-GA the DRF work has continued

	Document	Results	Test service
DRF-NKG			
DRF-NKG-2019	M1 Deformation model Fennoscandia: (NKG2016LU, NKGRV17vel, NKG transformation)		
	M2 Deformation model Iceland (Continue 2020)		
	M3 Evaluate DRF-concepts (Presentation for presidium in 2019)		
	M4 Evaluate the test of RTK-DRF on Iceland (Presentation)		
DRF-NKG-2020	D1. Deformation model Iceland (Velocities compiled)		
	D2. InSAR and geodesy in Iceland.		
	D3. InSAR and geodesy in Norway.		
	D4. Presentation of RTK in DRF. (Presentation at Science week)		

And:

DRF-group more an expert group that supports the DRF-user-perspective(/outreach) group in geodetic questions

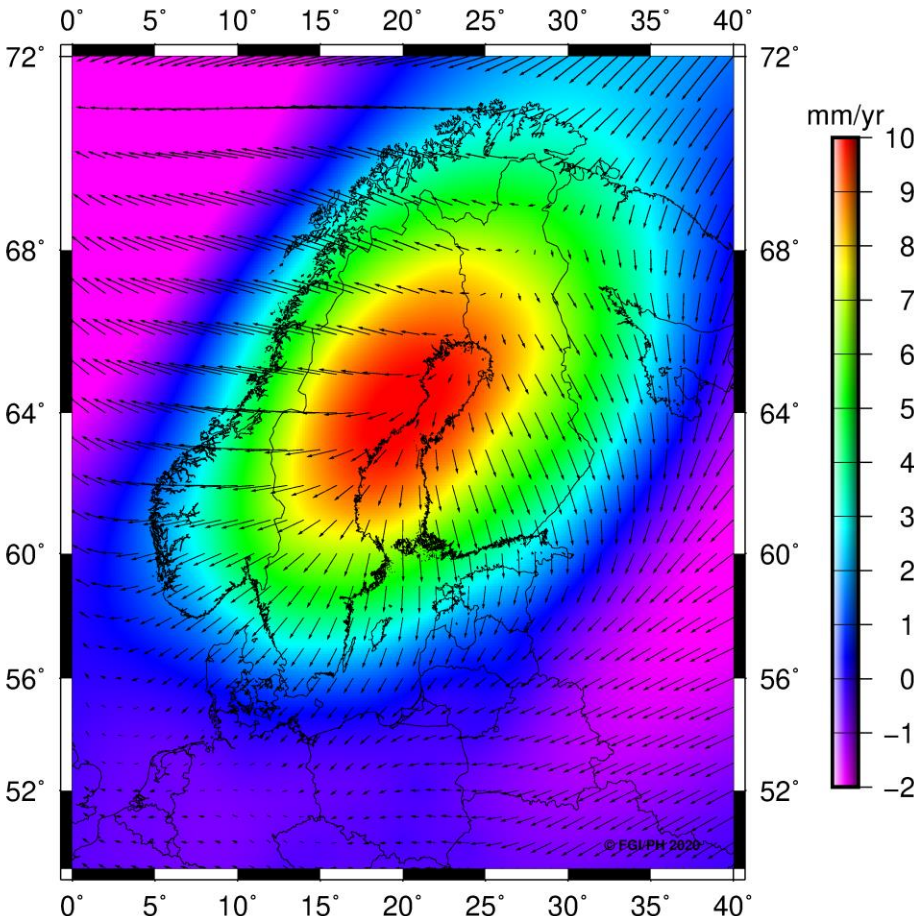
The reference frame realization will be based on the NKG-GNSS analysis center



- Include stable stations surrounding Iceland
- Might be necessary with lower latency

NKG_RF17vel model

- Crustal motion model (2D+1D) for estimating intraplate deformations (mainly GIA effect)
  - Data: GNSS and levelling data and GIA models
  - Method: Least-squares collocation
- Developed within the NKG working groups
  - Up component: NKG2016LU_abs completed in 2016 (uncertainties in 2019)
  - Horizontal component of the NKG_RF17vel completed in the end of 2019
- Utilized for example in the NKG transformations (from global reference frames to national ETRS89 realizations)



model minus observations

- NKG_RF17vel model minus GNSS velocity (NKG Repro1+BIFROST)
- Good agreement between the model and the GNSS station velocities (considering the uncertainties of the GNSS station velocities)

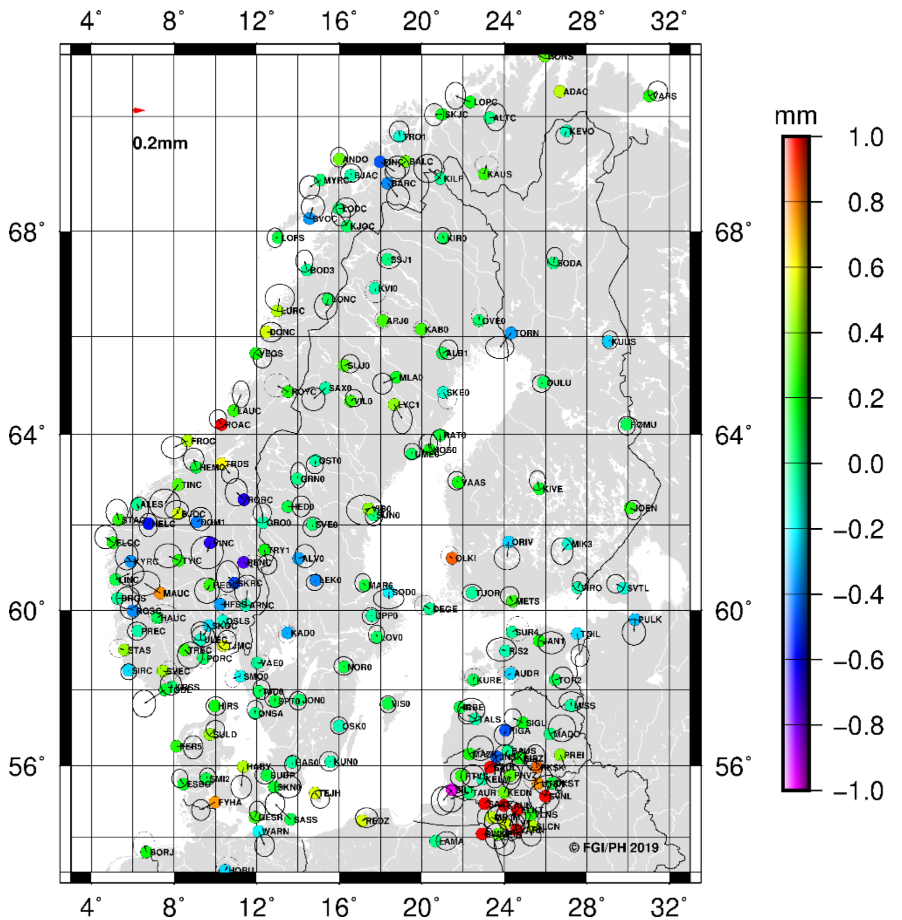
Model area:

NKG2016LU_abs

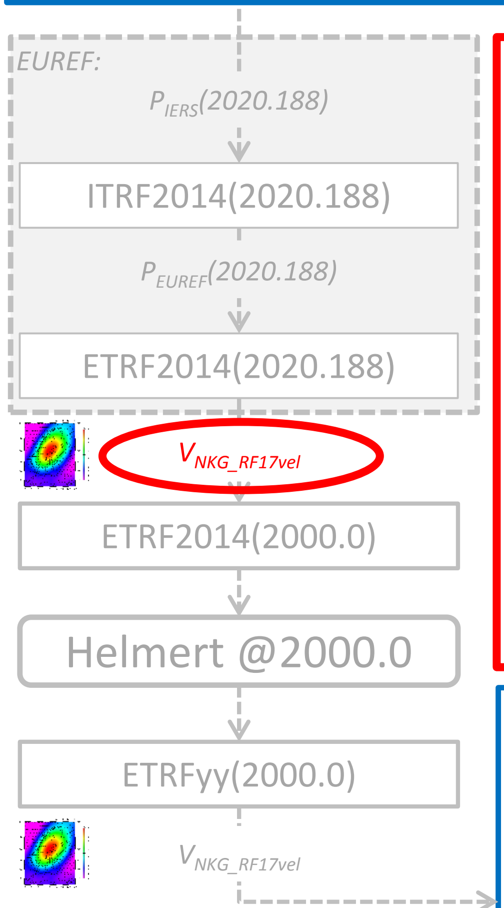
n=196	dVN	dVE	dVU
Min	-0.57	-0.48	-2.46
Max	0.26	0.27	2.44
Mean	-0.01	-0.00	0.07
Stdev	0.13	0.12	0.50
rms	0.12	0.12	0.50
95%	0.24	0.23	1.07

LU area (VU>=0):

n=163	dVN	dVE	dVU
Min	-0.57	-0.48	-2.46
Max	0.26	0.27	1.16
Mean	-0.01	-0.01	-0.01
Stdev	0.12	0.11	0.42
rms	0.12	0.11	0.42
95%	0.25	0.22	0.72



ITRFyy(t_c), e.g. ITRF2014(2020.188)

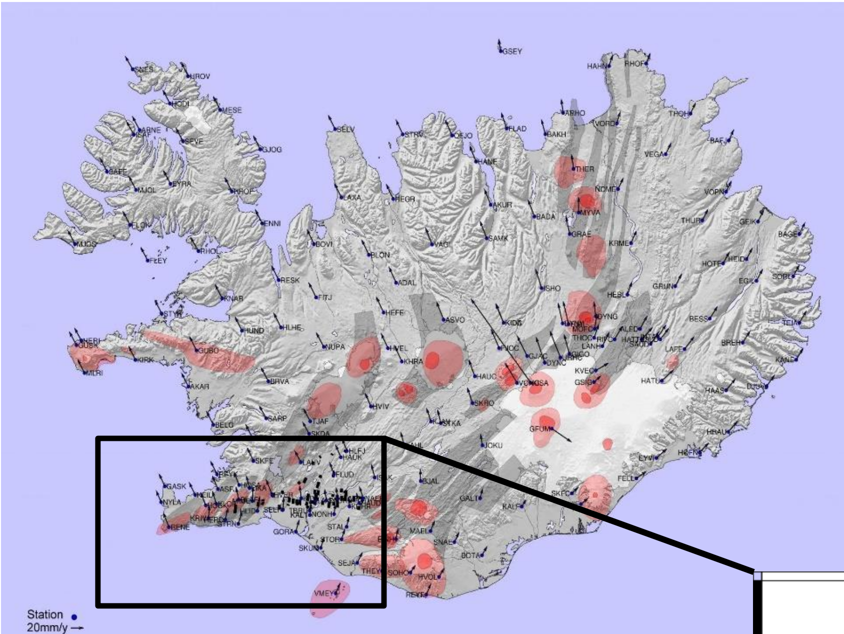


NKG transformation (updated 3/2020):

- Method to transform 3D (4D) coordinates from global dynamic reference frames to static Nordic/Baltic ETRS89 realizations – can be considered as an implementation of a semi-dynamic reference frame.
  - Extension to the EUREF transformation that corrects for intra-plate deformations – can be used to transform from/to any ITRFyy and epoch
  - A combination of similarity (14-parameter Helmert) transformation and deformation corrections
- National transformation residuals from a few mm to about 1 cm
- Making available to users → implementation to PROJ

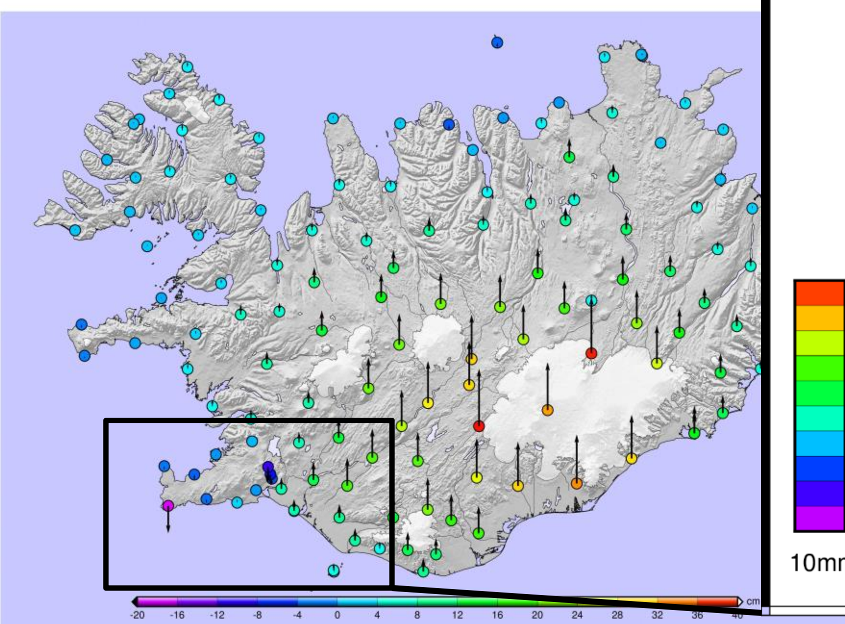
National ETRS89 realizations (epoch: t_r)

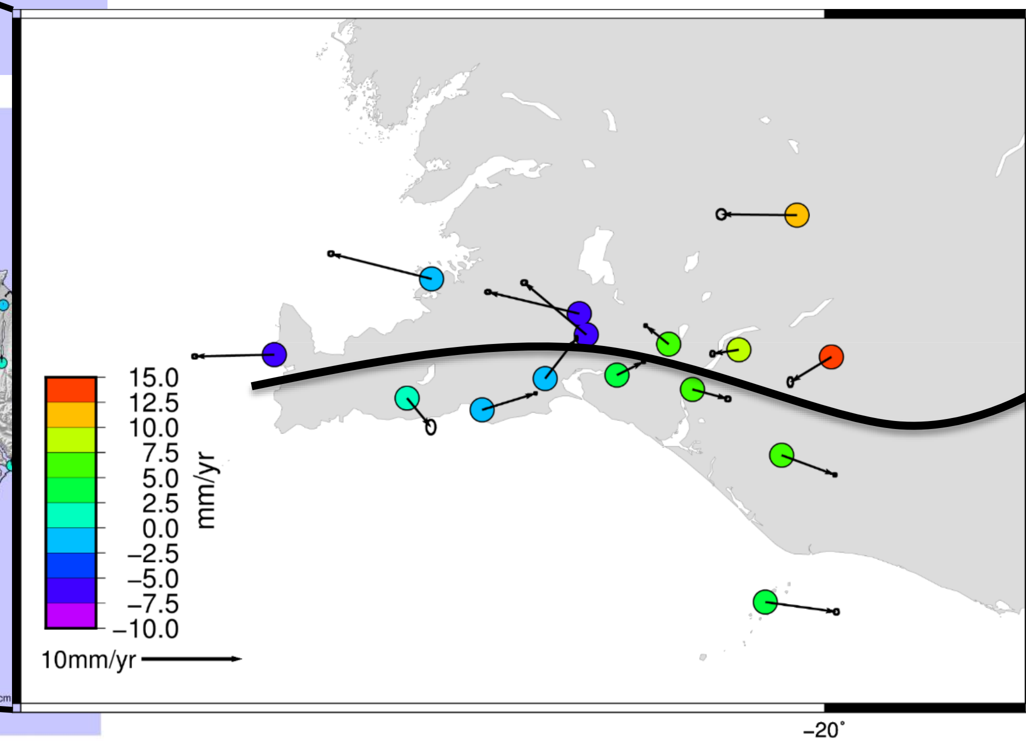
- DK: ETRF92(1994.704)
- FI: ETRF96(1997.0)
- LV: ETRF89(1992.75)
- SE: ETRF97(1999.5)
- EE: ETRF96(1997.56)
- LT: ETRF2000(2003.75)
- NO: ETRF93(1995.0)



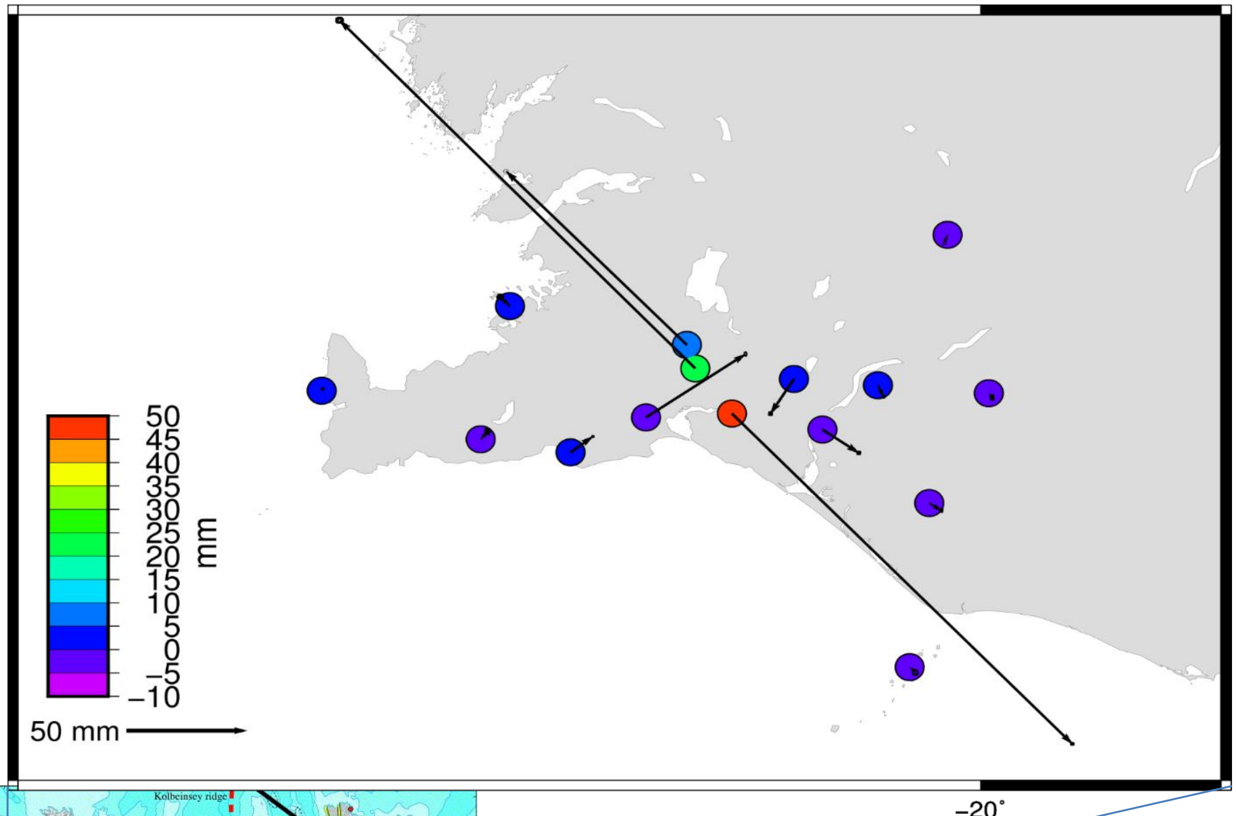
- In Fennoscandia colocation works well
- In Iceland the situation is more complex

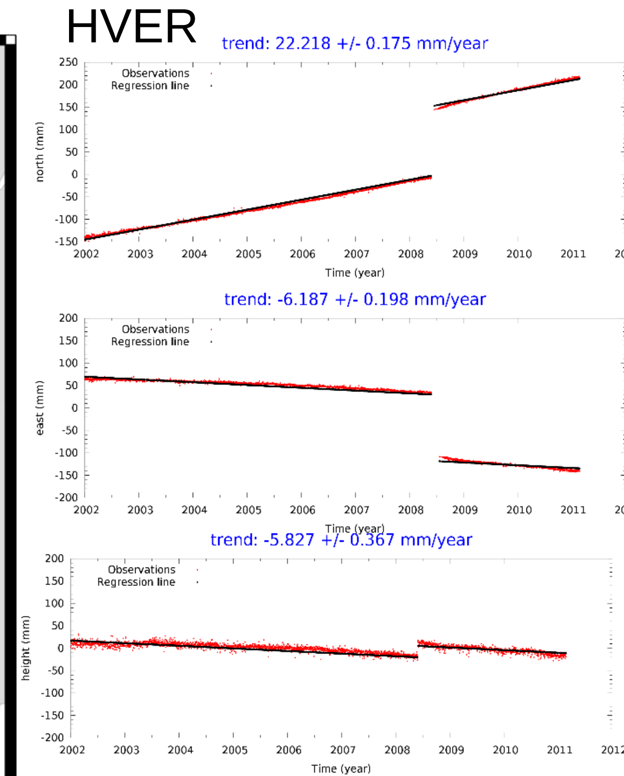
- Colocation with geophysical constraints is a possible solution

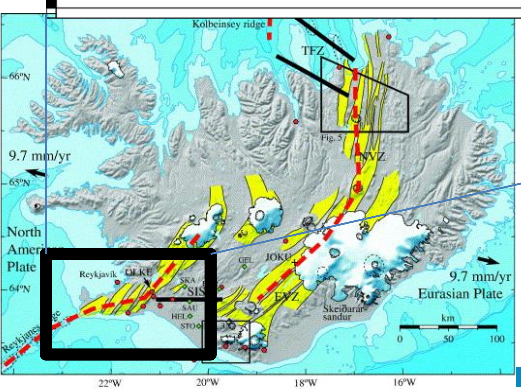




The earthquake in Reykjavik (Mw 6.3) in 2008 caused large crustal deformations







We need more advanced modelling

Lots of planned and on going activities in NKG related to DRF, but outside the project:

- White paper (WGFP)
- Positioning, RTK-services in ITRF (WGFP, Iceland)
- Reference frame – (WGRF)
- Velocity field and deformation models (WGRF/WGGEO)
- InSAR (WGGEO)
- GIS, proj …

National initiatives:

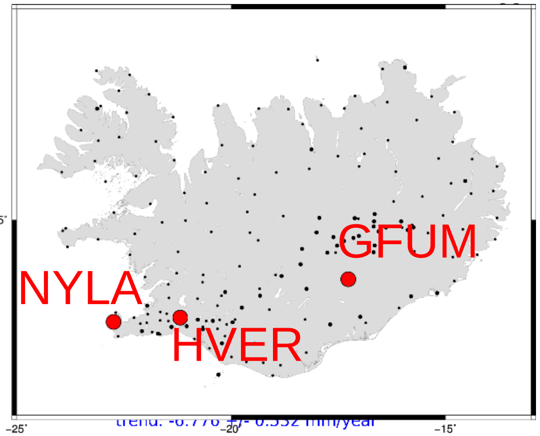
- Norway: Investigation and efficiency improvement of reference frame updates
- Norwegian project proposal to NKG: Scan main road in the Nordic countries and Common seamless positioning service (in ITRF)
-
-

Conclusions and recommendations from the DRF-project:

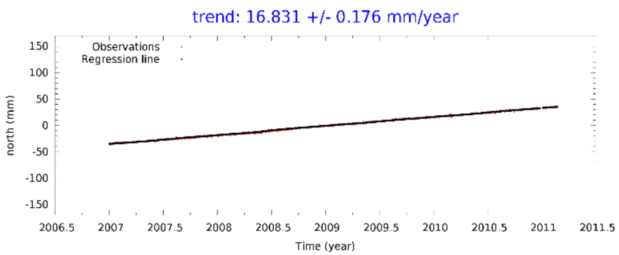
- User groups will request a reference frame homogeneous across boarders and consistent with global positioning systems
- For legal issues e.g. cadastre and inspire directive, a static reference frame is mandatory in foreseeable future.
- A two frame approach might be an alterative (like Australia and New Zeeland)
- Deformation model and velocity field is mandatory regardless of type of reference frame
- The level of implementation might vary between countries
- Traditional geodetic issues necessary for a DRF, like reference frame and transformation, is well cared for in NKG
- The main question: How can we approach the users of reference frames?
- DRF-group recommend that NKG establish a project focusing on user perspective and implementation of DRF.

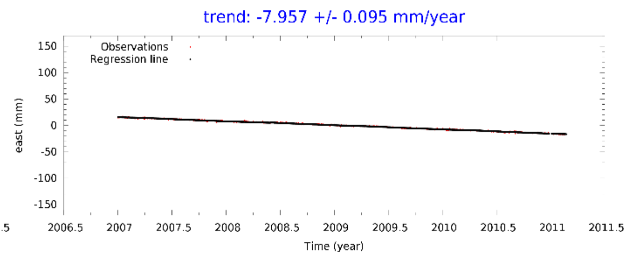
And (discussed in NKG coordinating board):
DRF-group will act as an expert group that supports the DRF-user-perspective group in geodetic questions

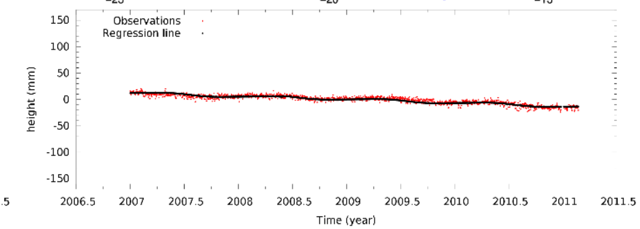
GNSS time-series are our main tool to estimate velocities and deformations



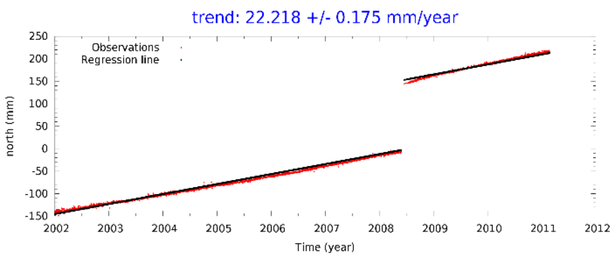
NYLA: Plate tectonics, GIA .. (linear)

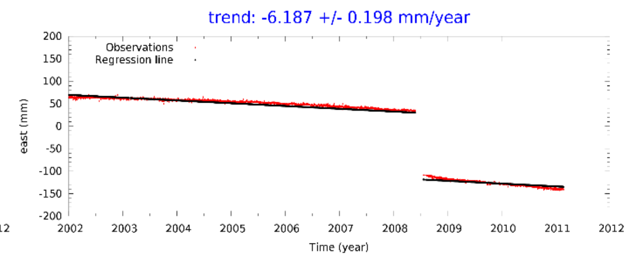


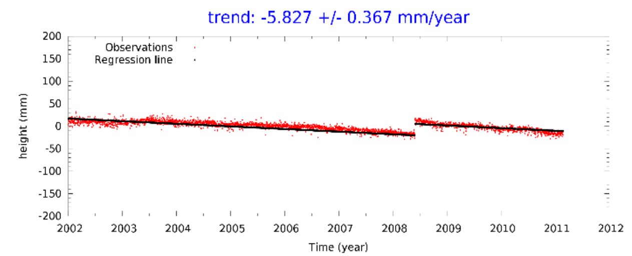




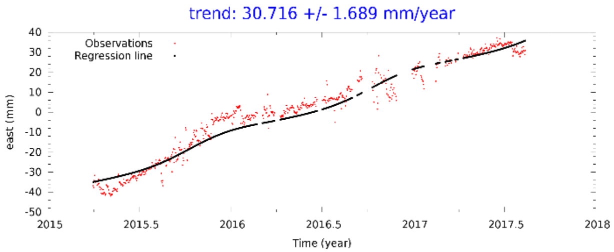
HVER: Earth quakes (breaks and post-seismic deformations)

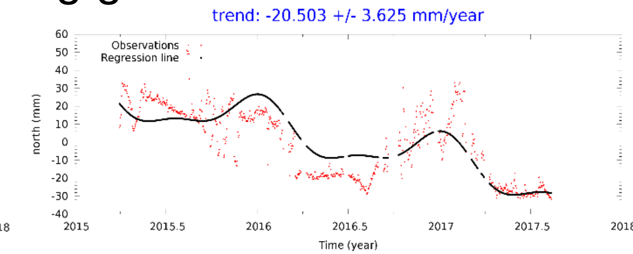


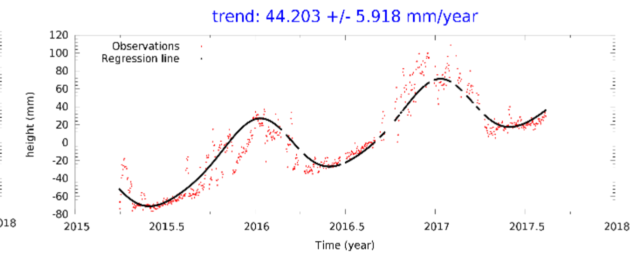




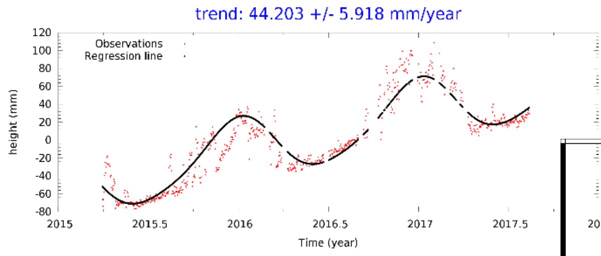
GFUM: Volcanoes and melting glaciers

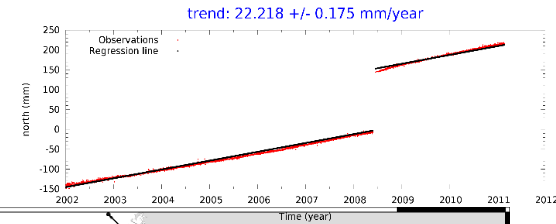


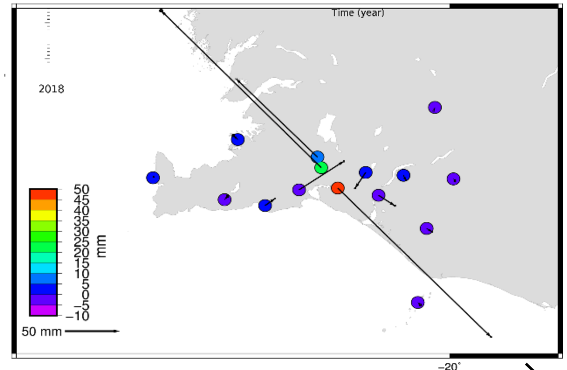


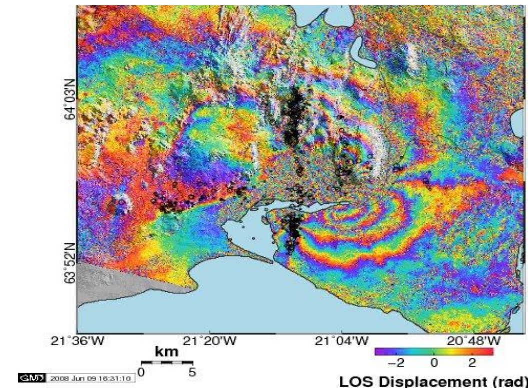


Various models and measurements are necessary to make a good deformation model



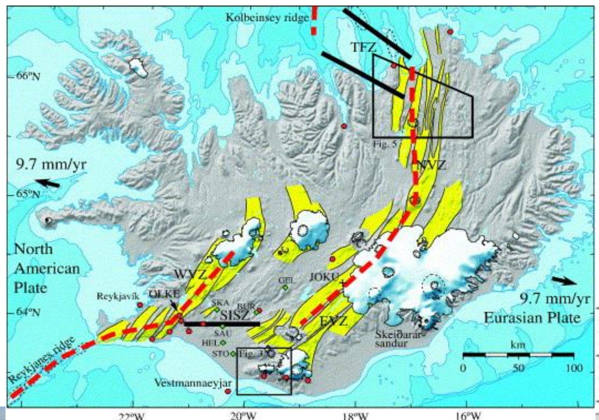


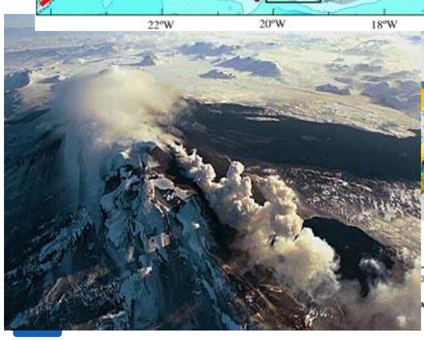


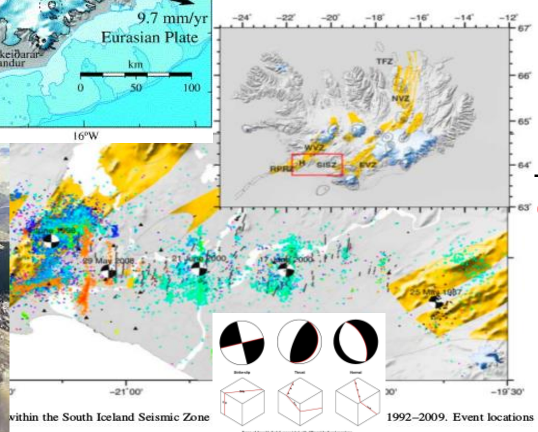


InSAR

GNSS



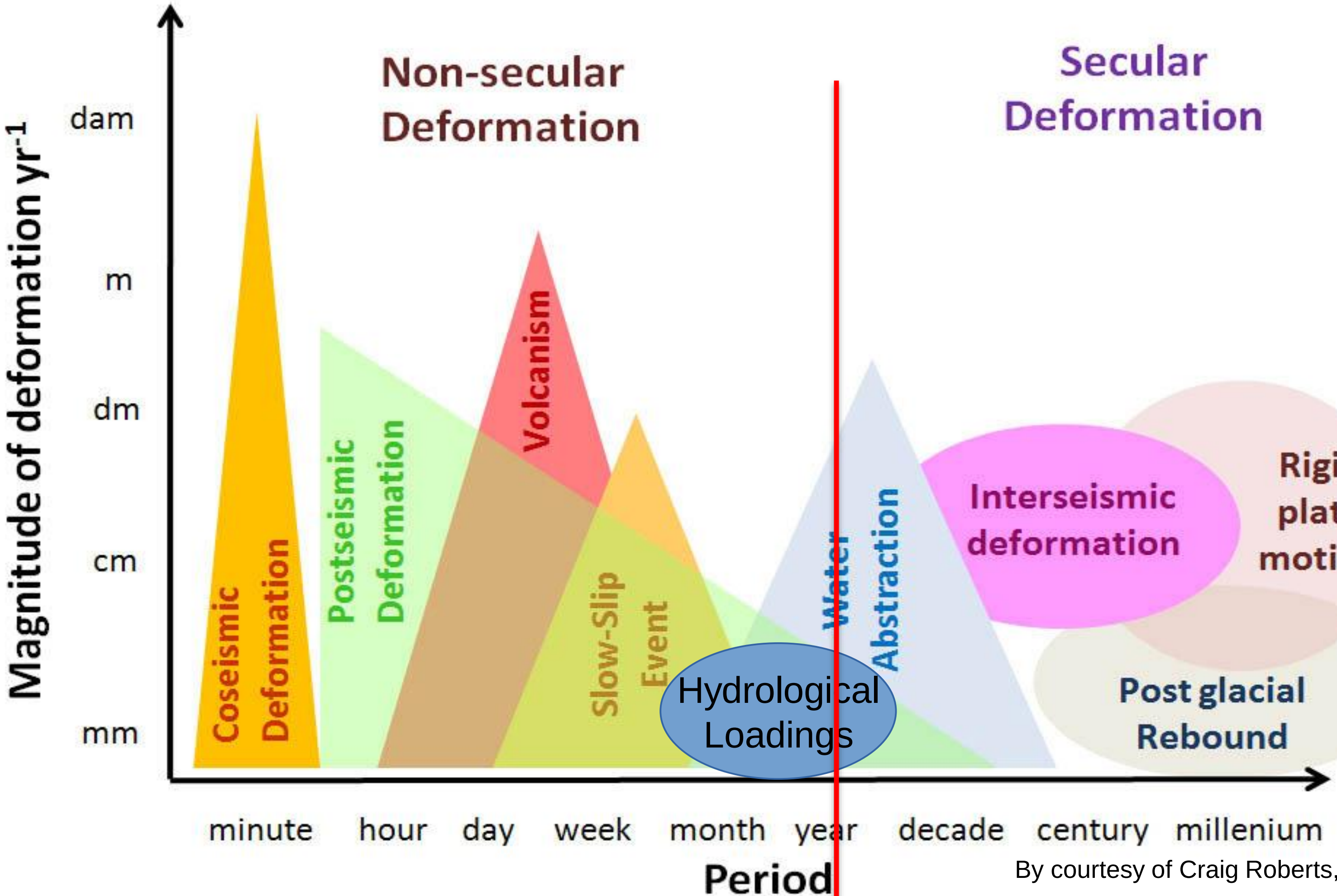




Geophysical models

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

Deformation processes have different spatial and temporal scale and must be handled accordingly



By courtesy of Craig Roberts, Richard Stanaway et at.

Deformation model
Patches or ...

Velocity field

DRF-P1: **Deformation models**

Phase 1

M1 Compiling existing deformation models for the NKG-area and customize them for DRF and semi-DRF use (2019, resources needed: ½? man month)

M2 Improve the preliminary DRF-velocity field for Iceland and develop a patch for the 2008 Reykjavik earthquake (2019/20, resources needed: 3? man month)

Phase 2:

M3 Test of InSAR as a source for local deformations on Iceland and evaluate if local deformations are relevant in the Icelandic deformation model (2019/20, resources needed: 3? man month)

M4 Test of InSAR as a source for local deformations in Århus (TAPAS) and evaluate if local deformations are relevant in a local velocity model (2019/20, resources needed: 3? man month)

M5 Test of InSAR as a source for deformations on Nordic scale and evaluate if local deformations are relevant in large scale velocity models (2021, resources needed: 6? man month)

M6 Testing algorithms that combine GNSS time-series, geophysical models (GIA, Volcanic eruption, earthquakes, etc.) and InSAR (if found useful in M3) to carry out a high-resolution deformation model on Iceland (2022, resources needed: 6? man month)

M7 Testing algorithms that combine GNSS time-series, geophysical models (especially GIA) and InSAR (if found useful in M5) to carry out a high-resolution deformation model in the Nordic/Baltic area (2022, resources needed: 3? man months)

DRF-P2: **Outreach**

Phase1:

M1: DRF concepts
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. (2019-Q2)

M2: DRF for geospatial data:
Evaluate the different concepts described in M1 as basis for geospatial datasets and various positioning and surveying techniques. (2019-Q4)

M3: User analysis
Perform a user analysis that investigates the need for dynamic reference frames. The analysis should determine which groups of users would benefit from a DRF as well as the urgency with which the DRF should be implemented.(2019-Q4)

Phase2:

M4: Information campaign
Create an information campaign with the purpose of introducing the DRF concept to surveyors and GIS specialists in order to convince them to use the DRF. This deliverable can result in either a common Nordic/Baltic campaign or material that can be used individually by the NKG member countries if they decide to introduce a DRF as a national reference frame. (2021-Q3)

M5: Data management
Management of geospatial data in a dynamic reference frame is likely to be more complicated than when using a static frame since it may be necessary to update the coordinates of the data when updates to the reference frame are issued. A study on how to best handle this problem is to be carried out in this deliverable.(2022-Q1)

M6: Cadaster
Perform a study of the ramifications of introducing a dynamic reference frame as the basis for the cadaster. Both technically and legally.(2022-Q2)

DRF-P4: **Full-scale test in the TAPAS area**

(using TAPAS as test area is a proposal from the DRF group)

M1: Test plan

A comprehensive plan for the test of the DRF. The plan should include as many technical topics from the preceding projects as possible. (2021-Q3)

M2. Surveying campaign

A boots-on-the-ground surveying campaign in Aarhus should be carried out for subsequent analysis of the results. The surveying campaign should test the different position services as defined in the DRF-P3 project. This can include simple tests concerning static objects as well as advanced tests involving moving objects. (2021-Q4)

M3: Analysis

Analysis of the data acquired in and test of the use of dynamic coordinates in a GIS. (2022-Q2)

M4: Report on final results

The results of the project is presented at the NKG General Assembly and published in the proceedings after the assembly. (2022-Q3)

Comments: The city of Aarhus in Denmark will be used as the test area for the majority of the activities within the DRF Focus Area. The TAPAS platform in Aarhus offers a state-of-the-art geodetic infrastructure in a challenging urban environment. With the TAPAS platform, it will be possible to test technical aspects of the infrastructure that is needed for a dynamic reference, e.g. different types of positioning services.