FIG WORKING WEEK 2017

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Future of Reference Frames

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Surveying the world of tomorrow –
From digitalisation to augmented reality

Contents

- Reference Frames
- Consequences of increased accuracy requirements
- Static– Semi dynamic– Dynamic
- Future visions

Technical development allows new ways of coordinate measurements

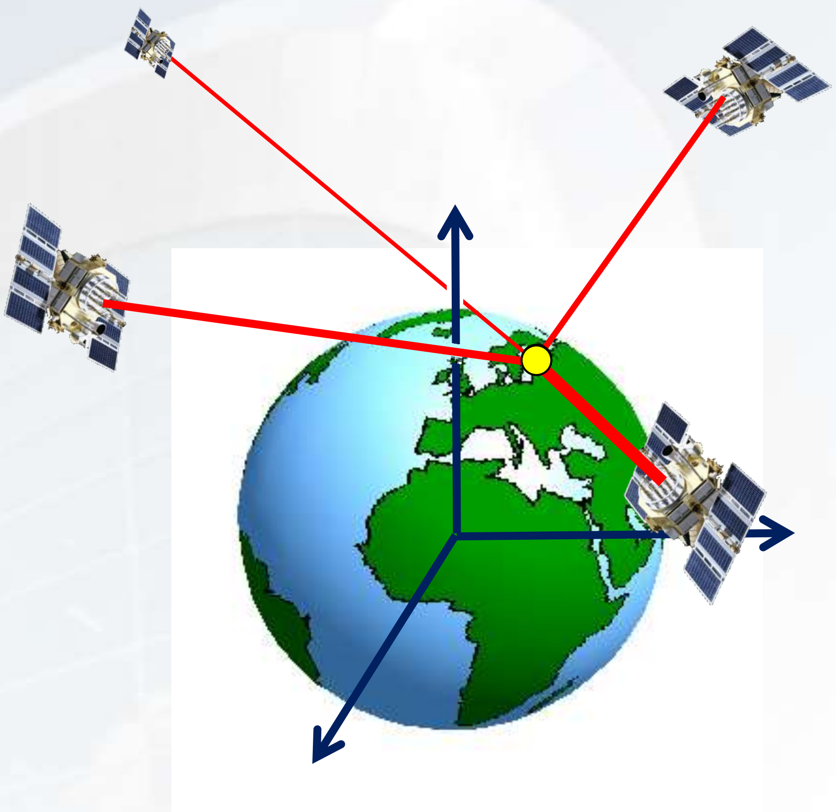
- *faster*
- *more cost effective*
- *more accurately*
- *in global system*

BUT: *What are the consequences? Are we ready? Do we have instructions and regulations? What legislation-related issues may arise?*

Reference Frames

- With GNSS we are measuring in a global reference system; realization called a reference frame (ITRF2014 newest one)
- We get absolute positions on the globe
- Reference frame is three-dimensional,

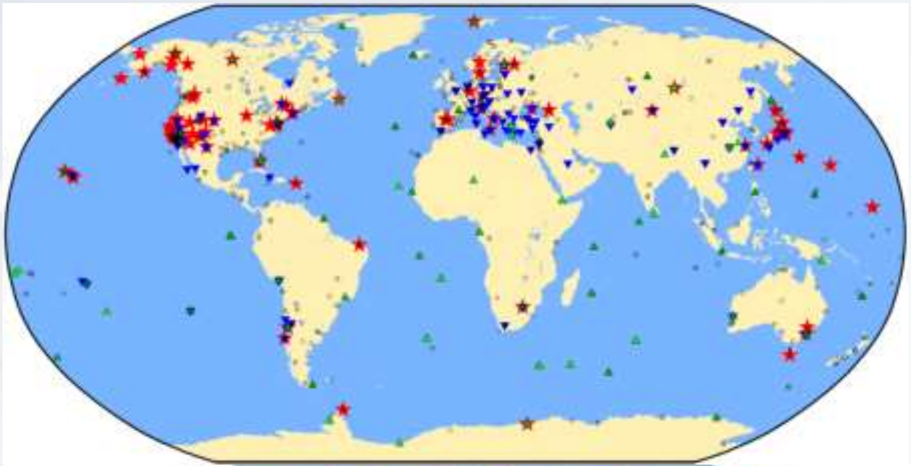
- Heights are gravity-related
- A geoid model is needed for heights (unless measured traditionally with levelling)



Global Reference Frame

- A reference frame is realized with a global network of permanent geodetic observing stations
- Stations defining the realization are on different continents
- Coordinates of stations are changing a few cm/year
- For practical purposes time-dependent coordinates have not been preferable

BUT: how it will be in the future?

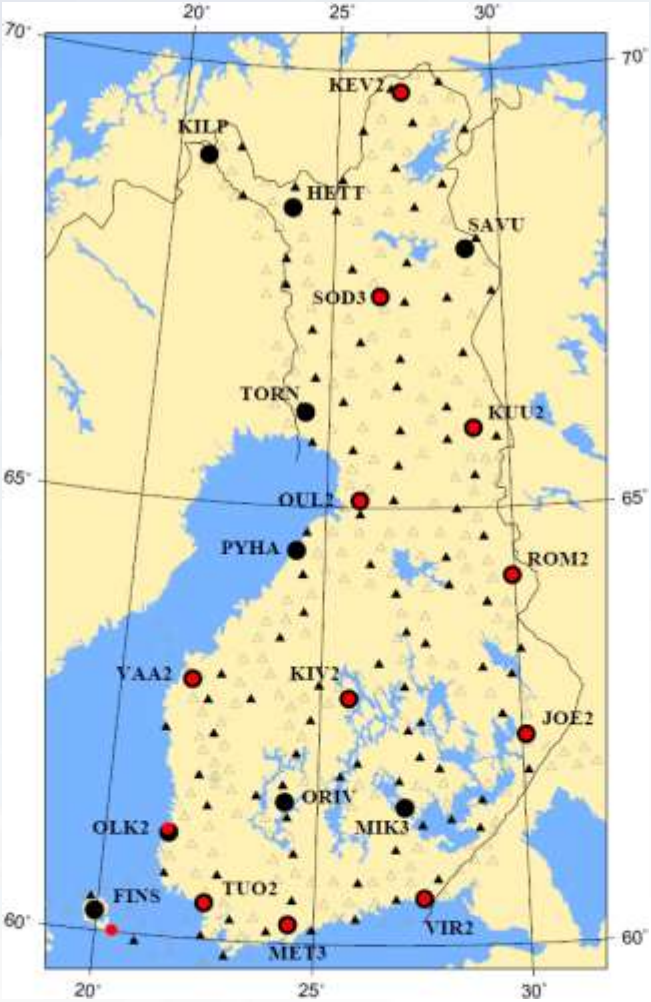


Regional Reference Frames

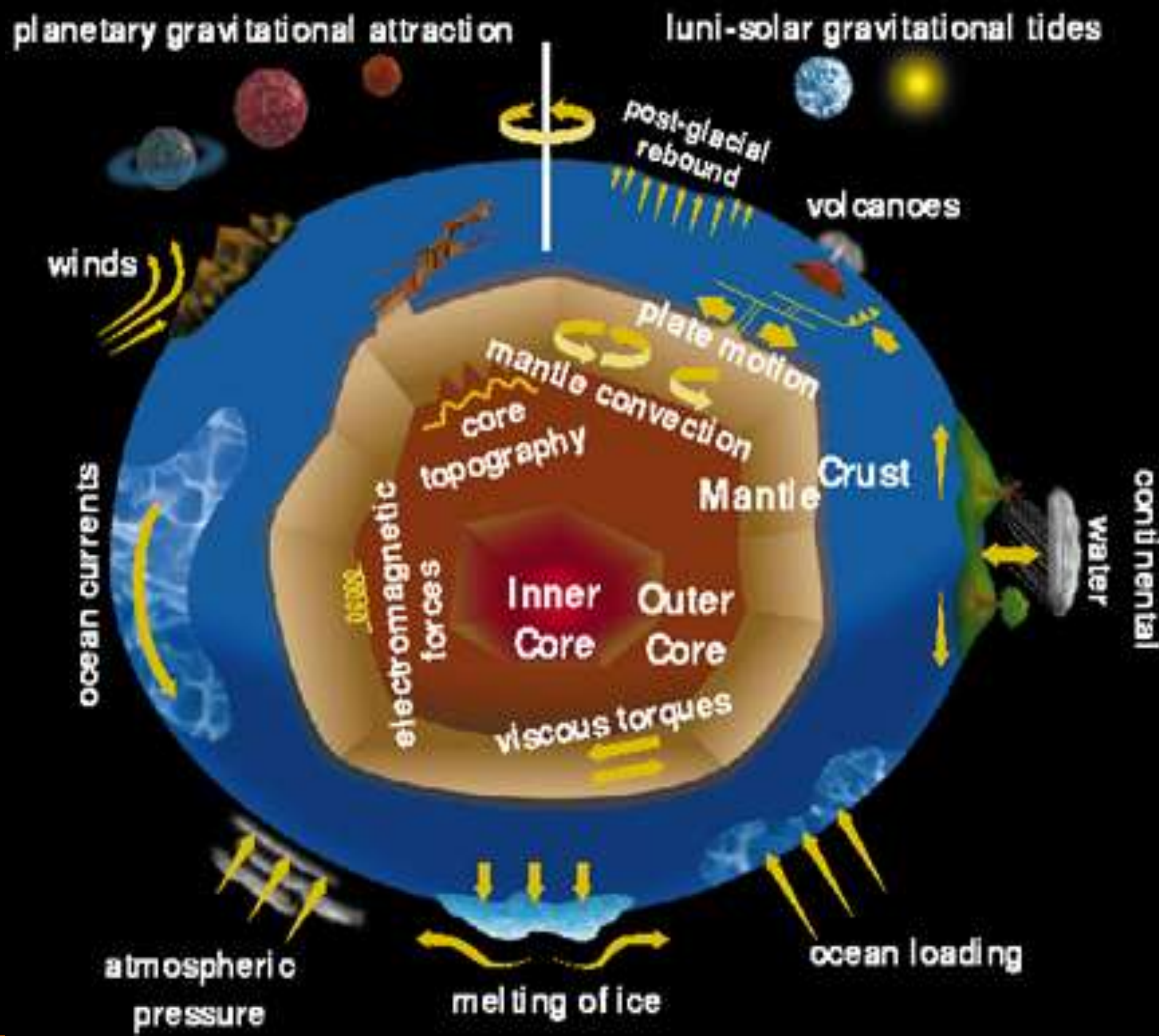
- To overcome issues in global reference frame, regional systems / frames have been established
- In Europe, **ETRS89 → ETRF2000 / ETRF2014**
- Fixed on and moving with the Eurasian continent
- As the first approximation, station coordinates in ETRFxx will not change with time
- ETRS89 based reference frames are in use in European countries;
- **Regulated by EU Directive INSPIRE**

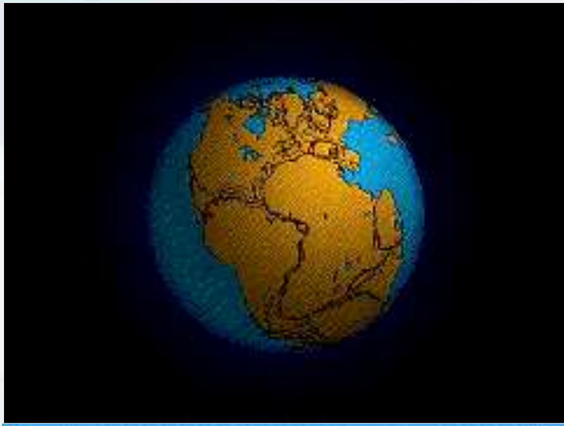
Local reference frames

- National and local reference frames are either based on ETRS89 (e.g. in Finland EUREF-FIN), or something else
- Traditionally, e.g. land information is based on coordinates in a local 2-D system



Dynamic Earth

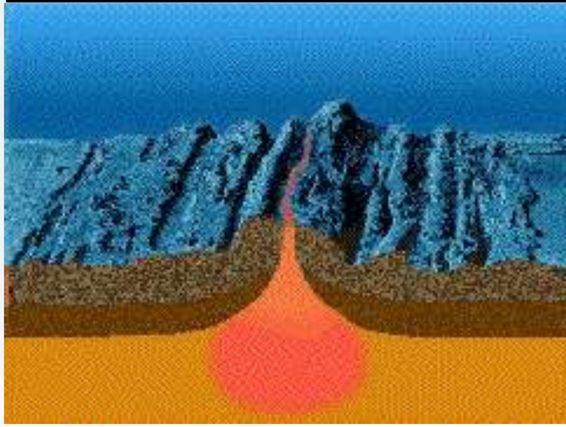




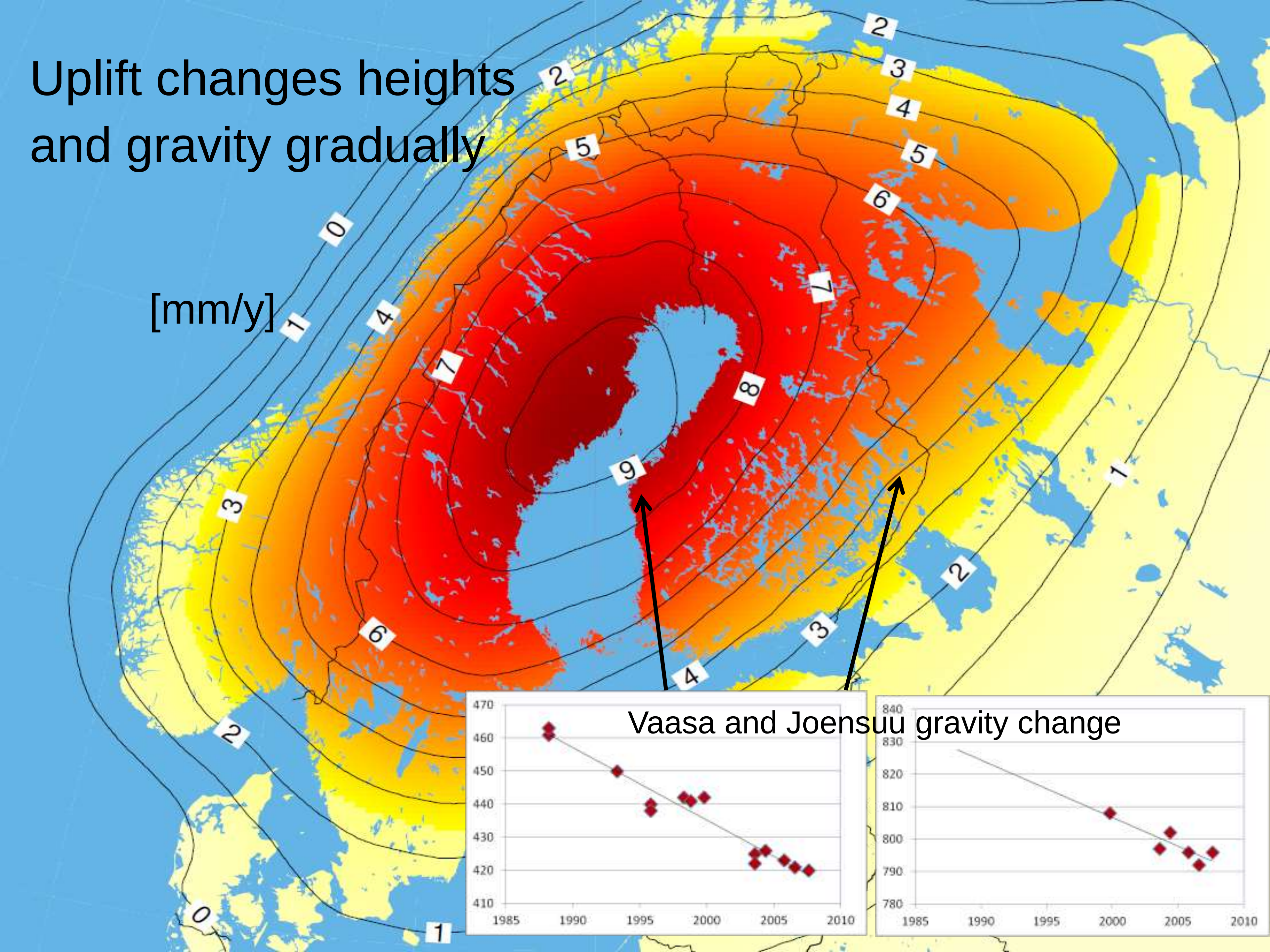
Crustal deformation

There are movements of reference points on several scales

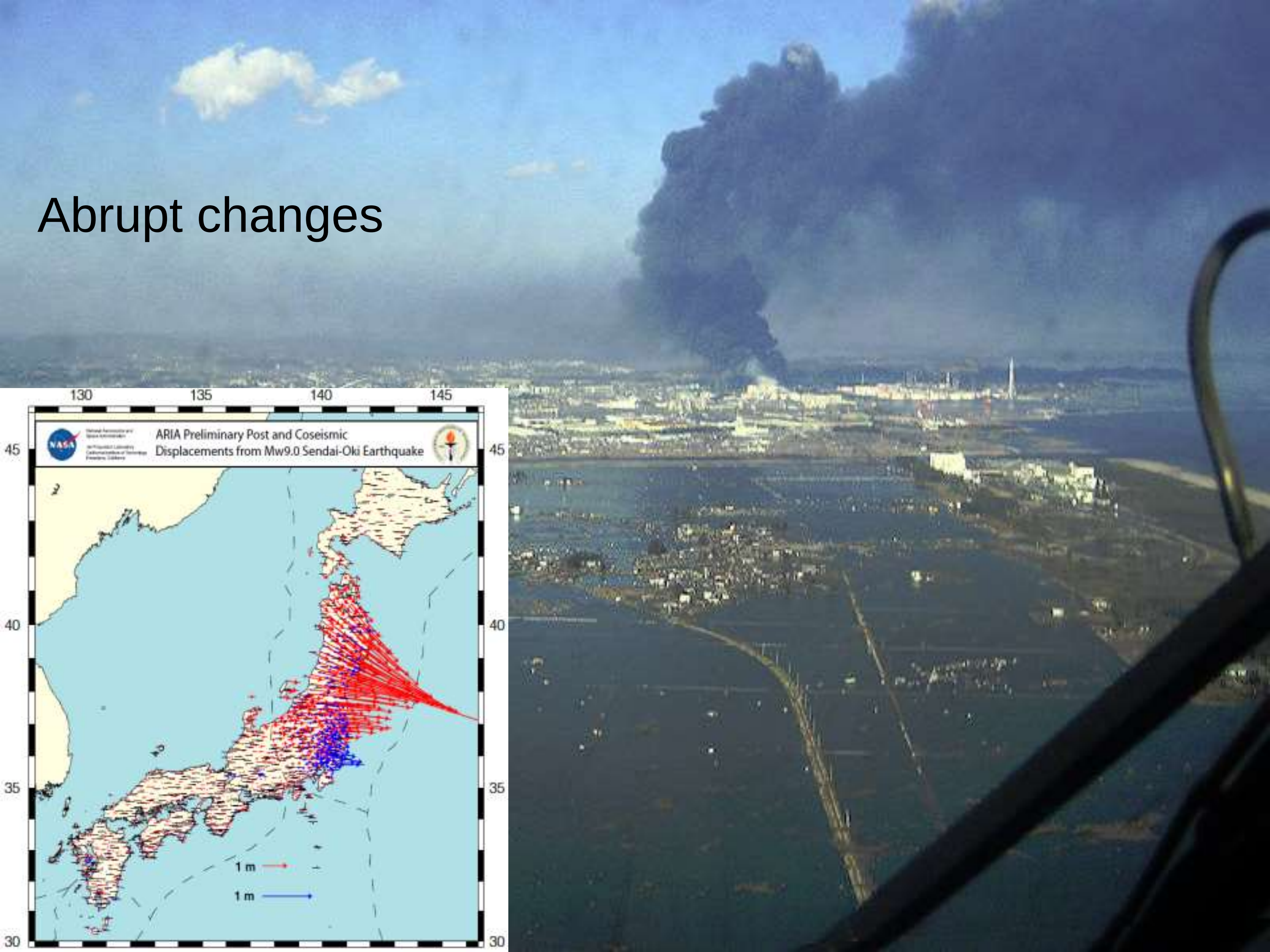
1. **Continents are moving** a few cm/year ⟶ absolute position on the Earth is changed
2. **Wide area movements within a continent**; as an example the post-glacial rebound in Fennoscandia and Canada or deformations at plate-margin areas
3. **Local abrupt movements**, like earthquakes or landslides
4. **Local slow movements**, like subsidence, local tectonics, volcanos



To manage the temporal variation in our reference frame, we should know the movements better than 0.5 mm/year. **Only case 1 is manageable, partly case 2.**

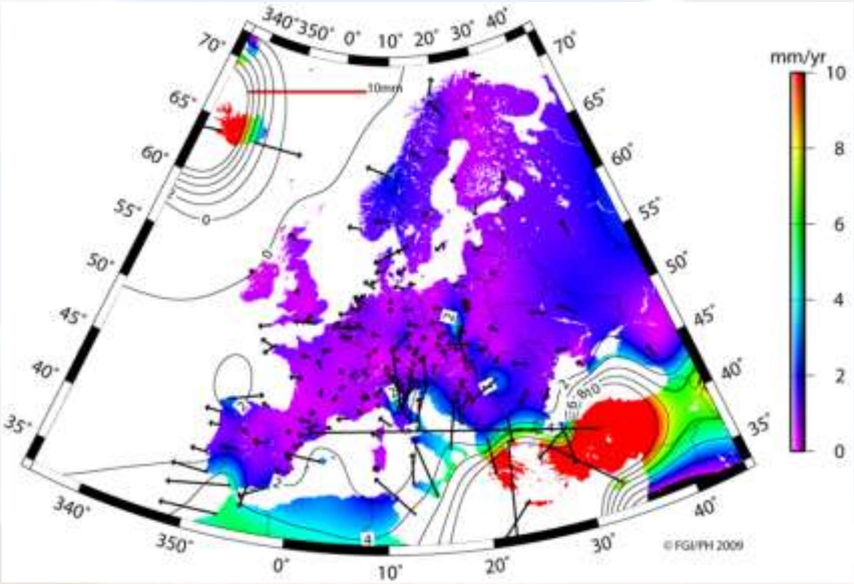

Uplift changes heights
and gravity gradually
[mm/y]
0
1
2
3
4
5
6
7
8
9
Vaasa and Joensuu gravity change
470
460
450
440
430
420
410
840
830
820
810
800
790
780
1985
1990
1995
2000
2005
2010

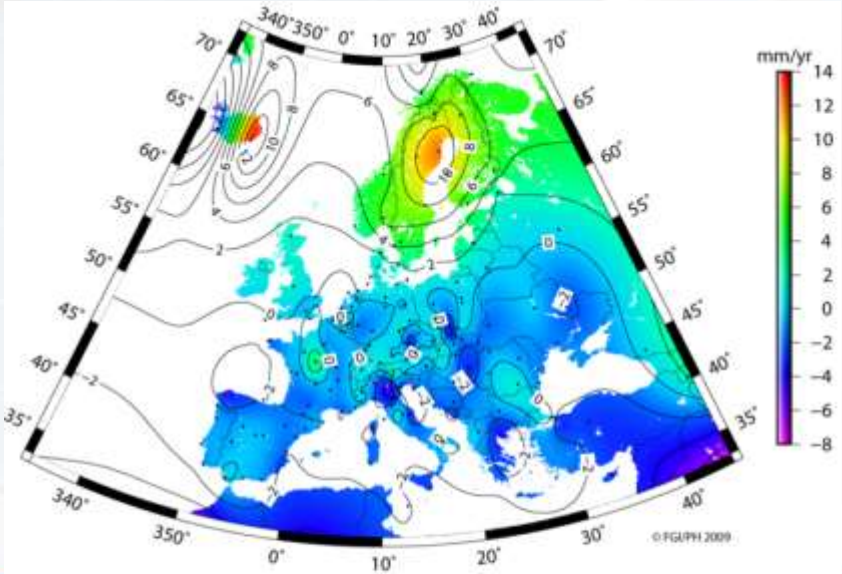
Abrupt changes



Crustal deformation within a continent

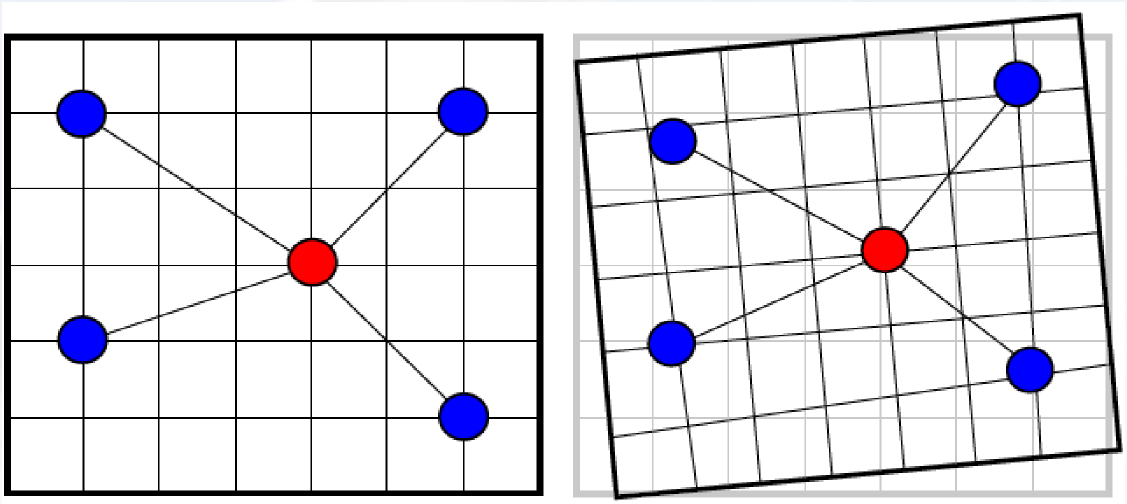
- Horizontal and vertical deformation of Eurasian plate. There are large differences within the continent. No single model can describe the motion.
- Continuous monitoring the motion, improving models, updating reference frames,…





Deformations degrade coordinates

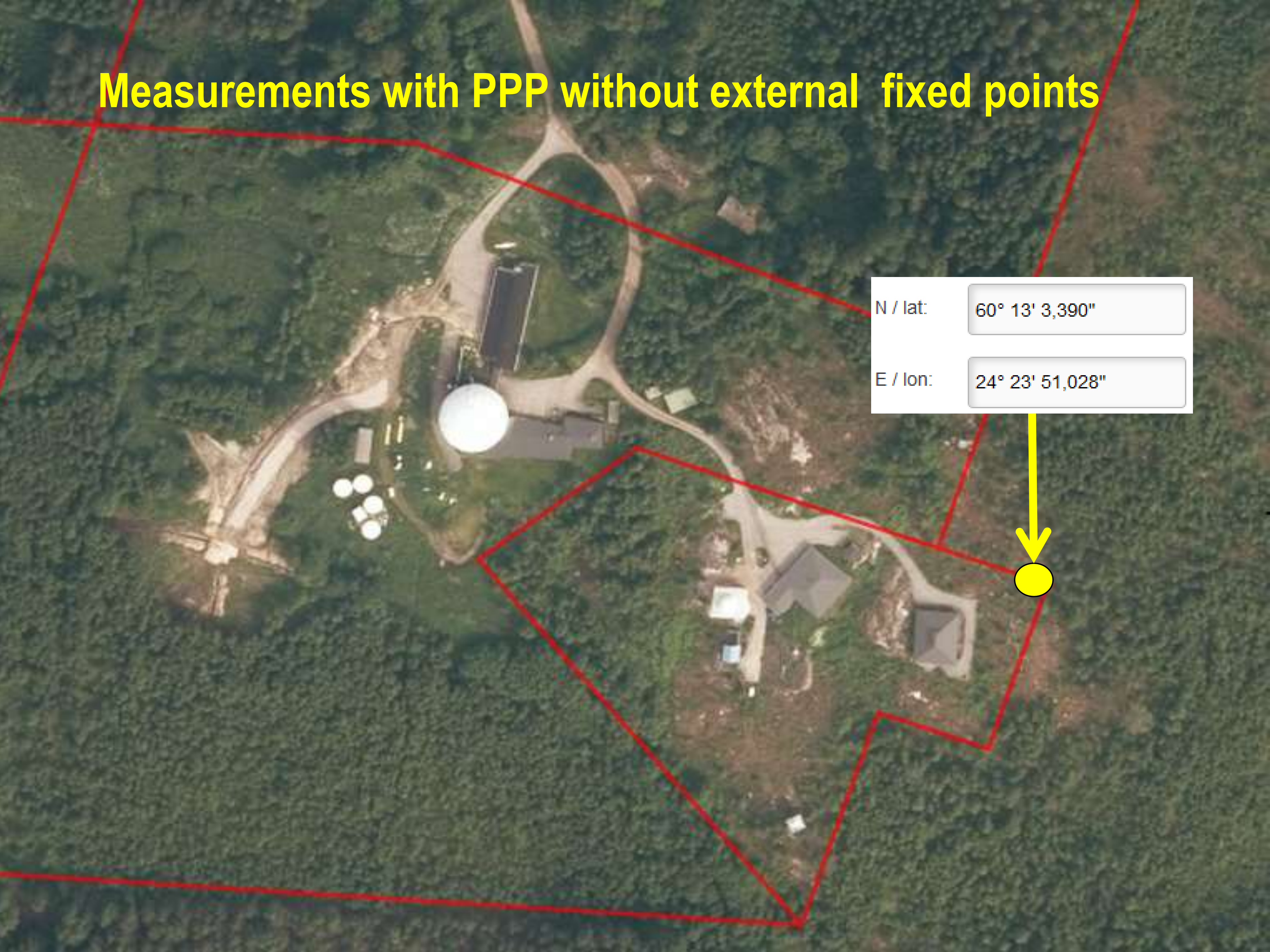
- Coordinates of fixed points are kept unaltered
- Coordinates of new points will be affected by the deformation
- One cannot apply full accuracy of GNSS measurements
- Renewal of the whole system is labourous, expensive and cannot be done very often



Traditional way to measure

- Fixed benchmarks, relative of which measurements are made
- GNSS receivers on every point (or RTK)
- **New points are automatically in the same reference frame**
- Coordinates need update only if the whole reference frame is changed

Measurements with PPP without external fixed points



Fixed coordinates point on a different place every time in a global reference frame!

N / lat: 60° 13' 3,390"

E / lon: 24° 23' 51,028"

…or if we keep the place fixed, every time it has different coordinates

- Coordinates are in the global reference frame at the epoch of the measurement
- Every time we get **different coordinates for the same point** due to crustal movements and deformations
- If we keep **coordinates fixed, they point to a different place**
- To get the measurement show the same point we must change the coordinates
- We should know **crustal movements** within 0.5 mm/yr everywhere
- But we don't and we can't

Passive and active reference frame

- **Passive reference frame**
  - Definition based on coordinates of **passive (fixed) benchmarks on the ground** (traditional situation)
  - Typically no velocities, just (static) coordinates
  - Challenging to maintain in case of deformations, e.g. positioning services
- **Active reference frame**
  - Definition based on coordinates of **active (CORS) stations**
  - Possible to estimate (reliable) station velocities in addition to coordinates – enables handling of deformations
  - Challenges related to instrument changes and aging, changing conventions etc.

Static, semidynamic, dynamic reference frame

Static: Traditional with **passive benchmarks – all geospatial data in a (static) regional/national system** (e.g. ETRS89/EVRS-based coordinates), no time evolution, no need to fix an epoch; degraded accuracy with time, renewal process slow and expensive

Semi-dynamic: **Positioning in a global** (dynamic/kinematic) ITRS-based coordinates, **registries in national (static) ETRS89-/EVRS-based coordinates**. **Transformation** from epoch/frame of observations to the fixed frame takes care of deformations and saves accuracy between the global and national coordinates

Dynamic: **Everything in global** (dynamic/kinematic) ITRS-based **coordinates** – typically an active reference frame and access based on a positioning service (or PPP). **Time dependent**; every time new coordinates are given to the same point. **Precise deformation model** needed to transfer coordinates between epochs.

Static, semidynamic, dynamic reference frame

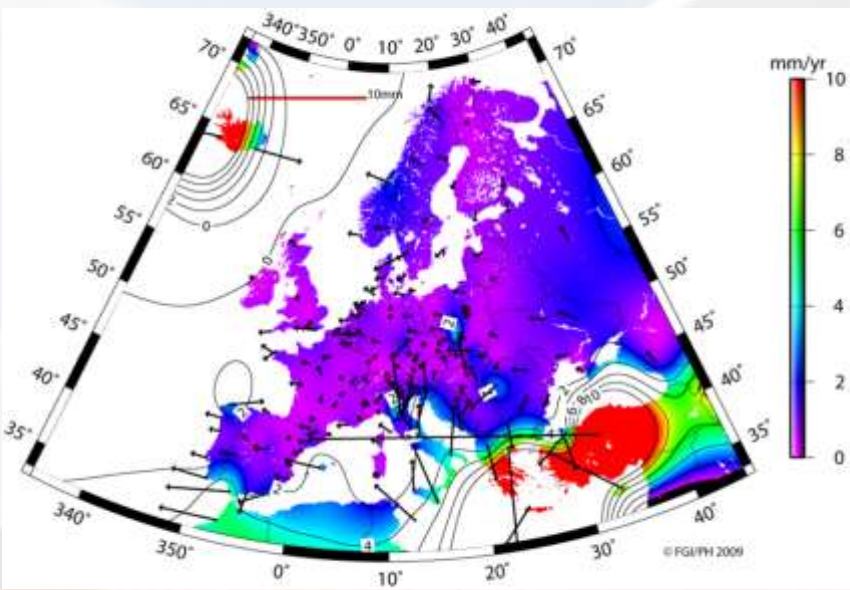
Static: No transformation, computation directly in a national frame; fixed coordinates at fixed place. Deformations degrade accuracy. Business as usual!

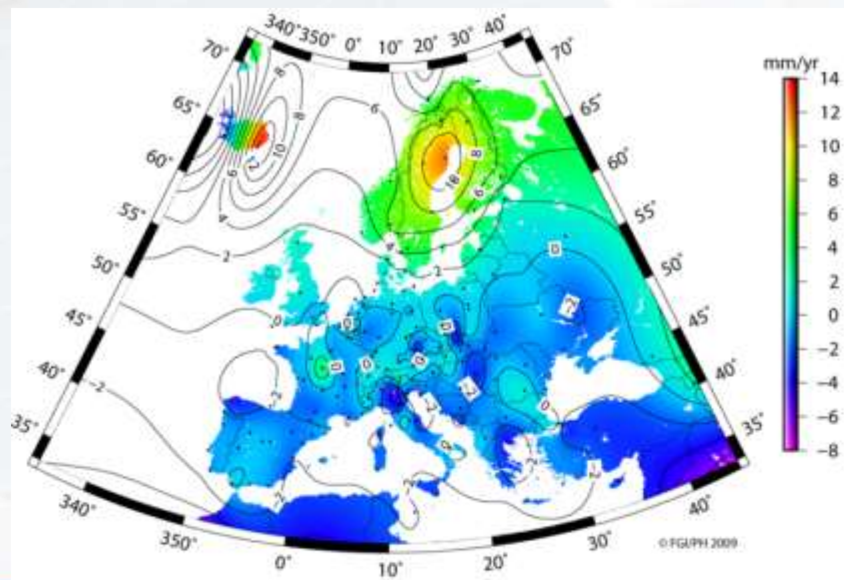
Semi-dynamic: Coordinates transformed to regional/local frame during the measurements, **precese 3D velocities needed**. Users will see fixed coordinates in a regional/local frame. From users point of view, only a slight difference to the current situation. Active reference points (permanent GNSS stations) needed for maintenance of the frame. Current practices already close to the semi-dynamic system.

Dynamic: Global coordinates, old data (in registers) transformed to current epoch if one needs to compare coordinates, **precise velocities needed**. Users will see **changing coordinates**. No passive reference points, no regional/local reference frames; **all in the global system**.

Deformation models / dense velocity fields are needed

- Different needs in different part of Europe
- Do we have good enough information today?
- EUREF Working Groups to study this topic





3-D velocity field

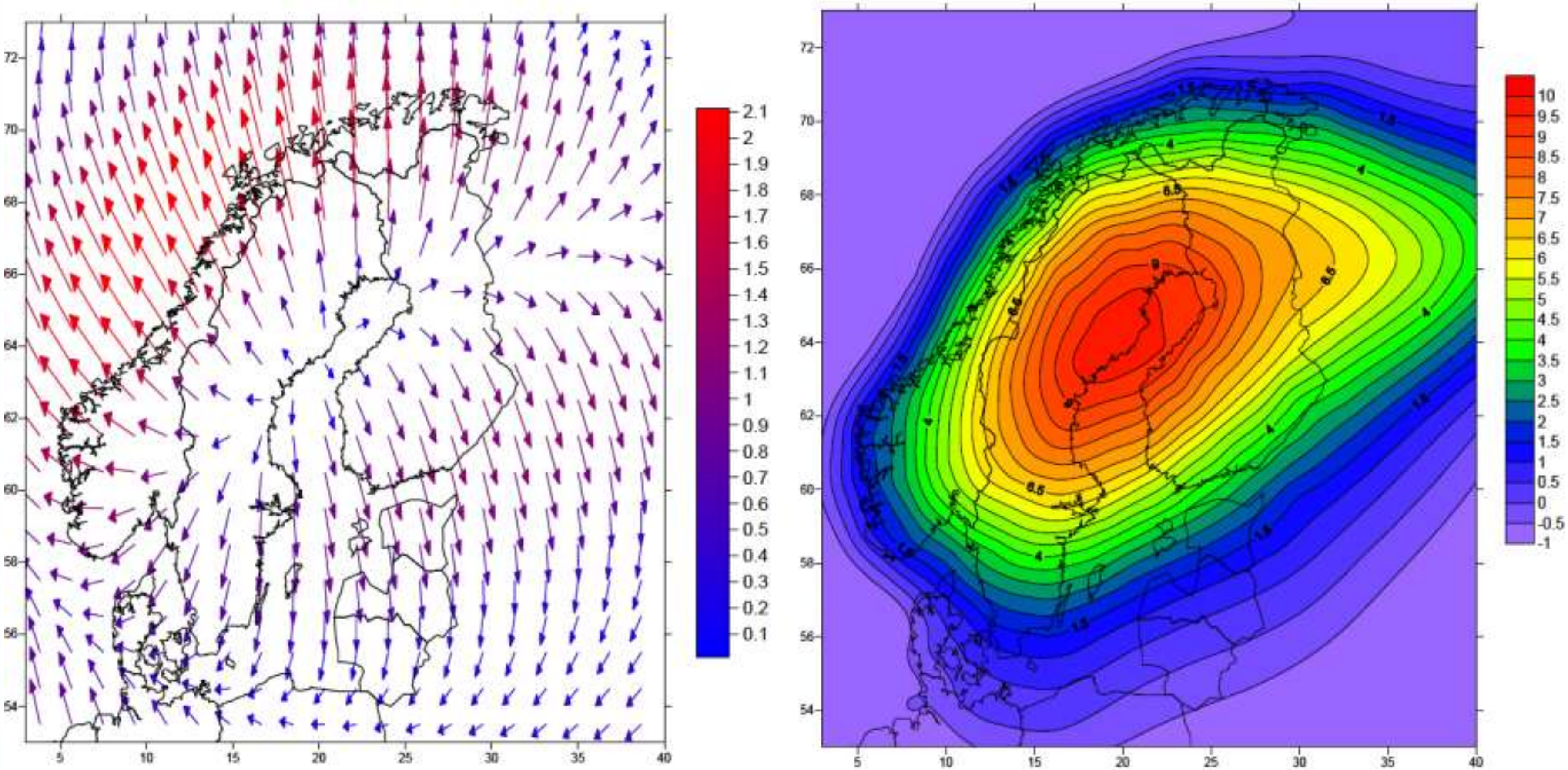
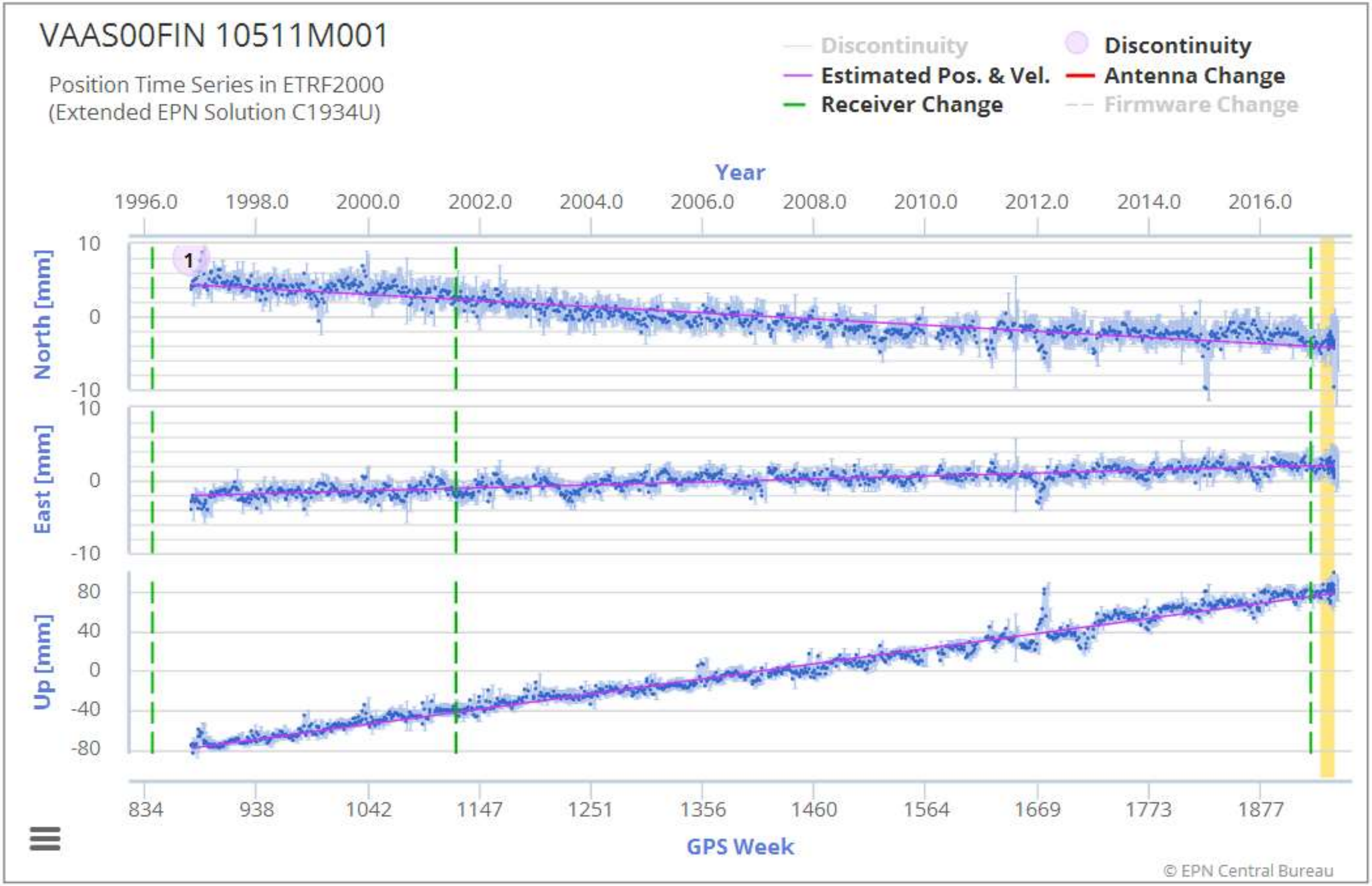


Figure 1. The NKG_RF03vel velocity model. Reference for the horizontal velocity field (left) is "stable Eurasia" as defined by the ITRF2000 Euler pole for Eurasia. The vertical uplift rates are "absolute" values relative the earth centre of mass. Units: mm/year.

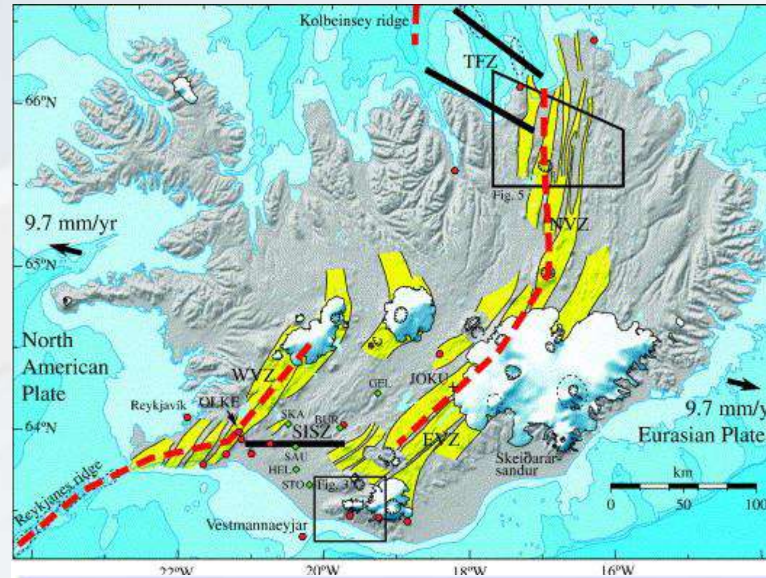
Lidberg, Ågren, Steffen 2017

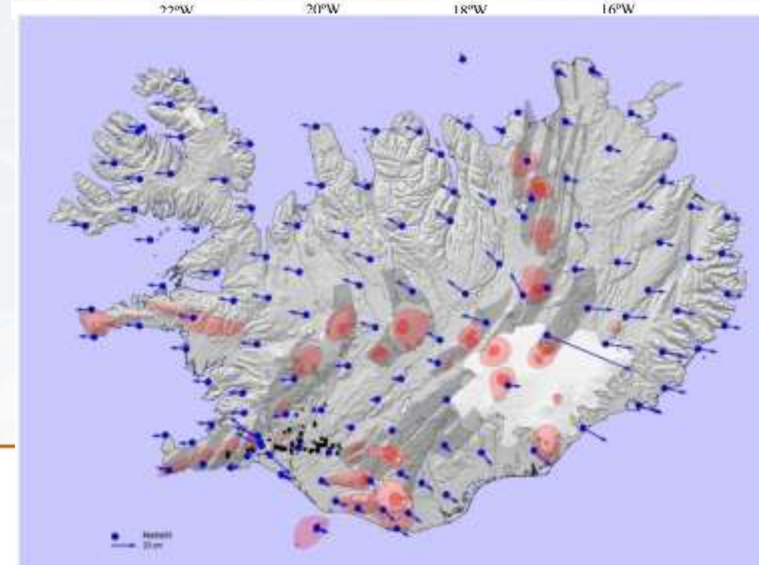
3-D velocity field



Case Iceland

- Directors of Nordic Mapping Authorities gave a task to the Nordic Geodetic Commission (NKG) to study a possibility to create a dynamic reference frame for Iceland
- This is also in accordance to the UN resolution of Global Geodetic Reference Frames for Sustainable Development (2015) to help other countries and collaborate between nations to create and maintain geodetic reference frames
- Outcome will be a plan for a new reference frame in Iceland





Consequences and actions if we move from static reference frames to semi-dynamic or dynamic

Example: cadastre ≈ coordinate reference system + precise positioning + current registry information + legal issues

	Datum type	Precise positioning 3	Reference system in registers	Changes to current register	Legal issues
Now	Static	ETRS89 (regional)	ETRS89, EVRS 2	None	None
Near future	Semi-dynamic	ITRS (global) 1	ETRS89, EVRS 2	None	None(?)
Future?	Dynamic	ITRS (global)	ITRS, IHRS(?) 2	Positions: N,E,H →X,Y,Z,VX,VY,VZ,t 1	Changing coordinates

1 **Improved land uplift model (3D) and practices**

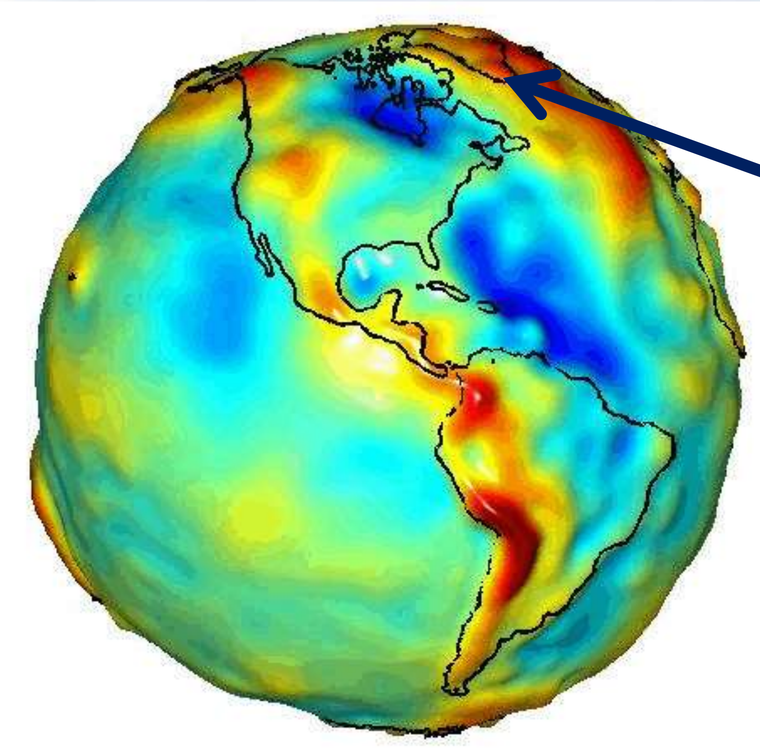
2 **Improved Geoid model (ETRS89→EVRS)**

3 **Improved positioning (techniques)**

Future and conclusion

- Increased demands on accuracy and real-time applications
- Current static reference frames are not sufficient and will degrade accuracy of positioning
- New emerging techniques, like ppp requires new approach also in reference frames
- Australia for dynamic frame, New Zealand semi-dynamic → changes have begun
- Different needs at different parts of the world; depends on the type and magnitude of deformations, applications, existing geodetic infrastructure, …
- Semi-dynamic approach most easily adopted for users;
  - active networks already in use;
  - better 3-D deformation models needed;
  - connection to existing reference frames needed

Thank you for your attention!



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