FUTURE CIRCULAR COLLIDER

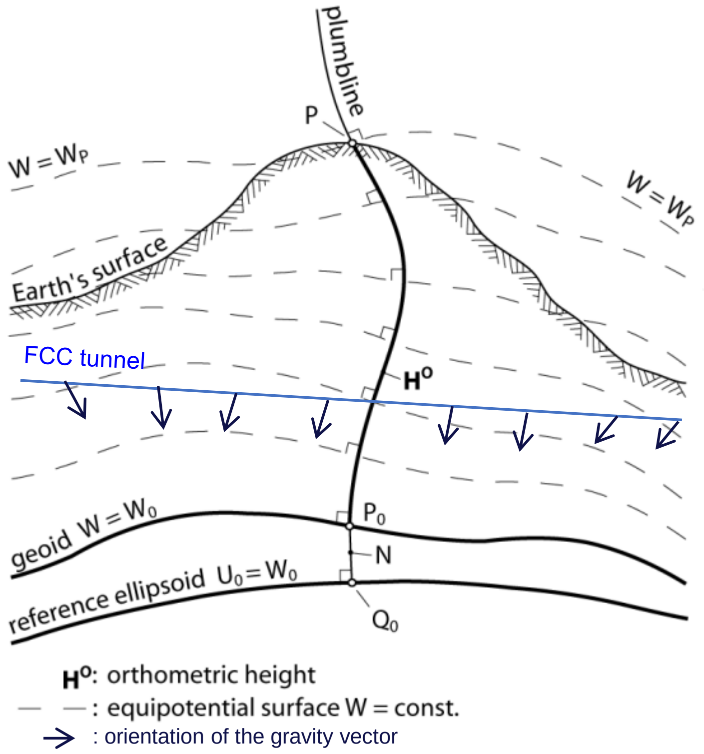
GEODESY UPDATE

Objectives of the geodetic studies

Establish the geodetic infrastructure for the Futur Circular Collider

- Define coordinate reference systems
- Establish the necessary geodetic reference frames
- Study the determination of a high-precision gravity field model for the FCC area

Developpe and provide necessary documentation and transformation tools and software



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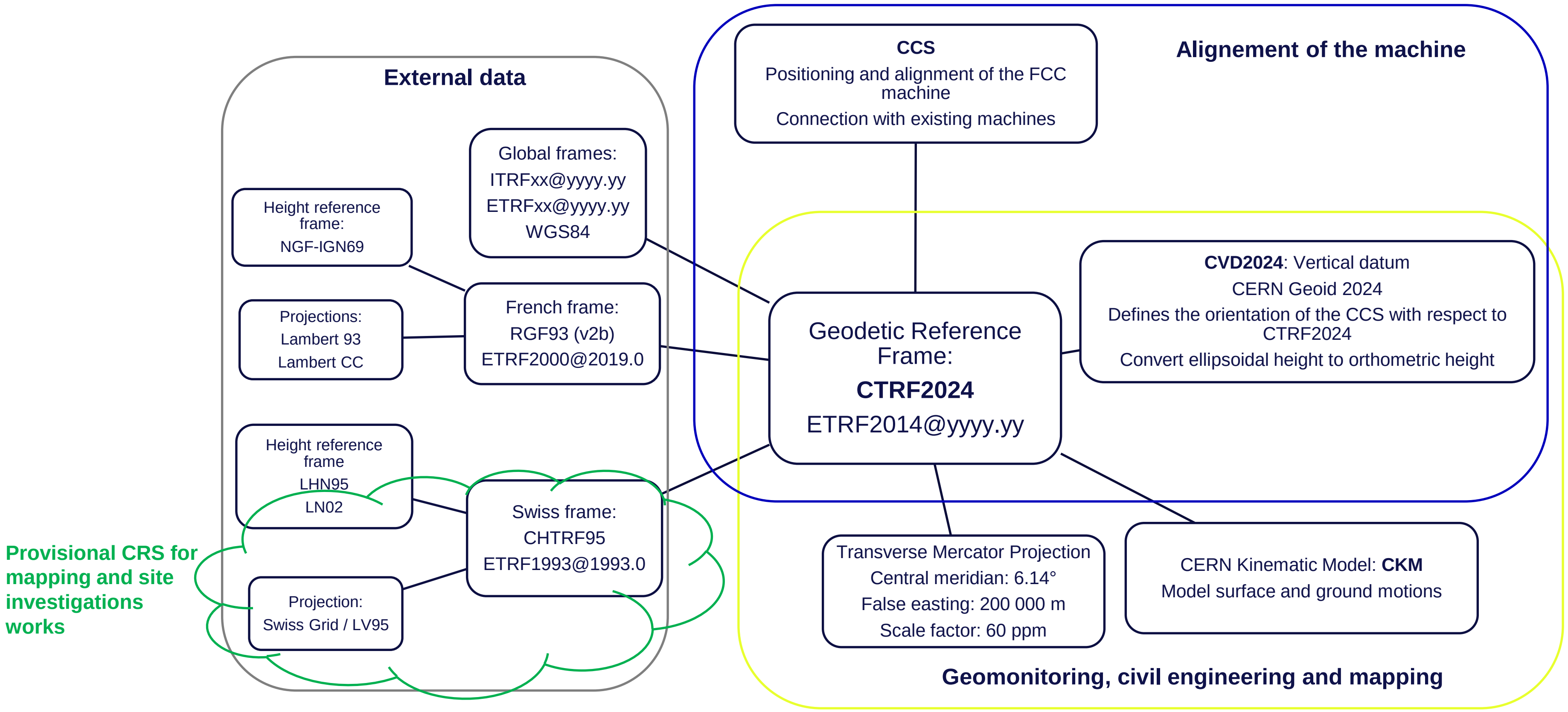
Coordinate Reference Systems for FCC

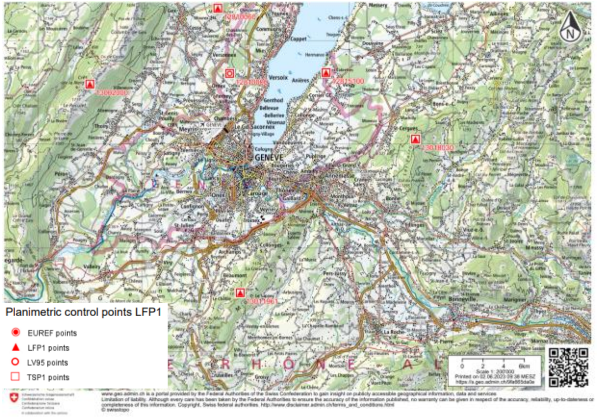


Implementation of P-SGN

Primary Surface Geodetic Network (P-SGN)

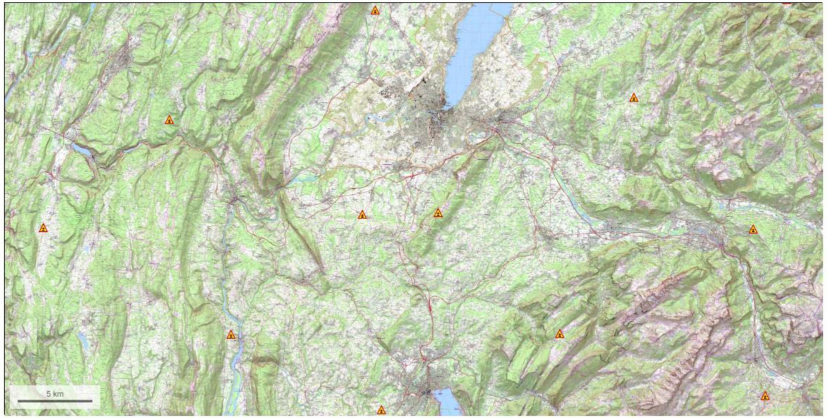
- P-SGN will serve different purposes
  - Materialization of the CERN Terrestrial Reference Frame (CTRF)
  - Civil-engineering and surveying works required for the construction of the FCC tunnel
  - Providing the long-wavelength basis for the later alignment work
  - Providing the reference for the geokinematic monitoring of the FCC area

- Collaboration between CERN, IGN and Swisstopo for a densification of the French and Swiss national geodetic networks around FCC area
  - P-SGN markers will be available for the entire survey community



géoportail

Réseau de Base Français

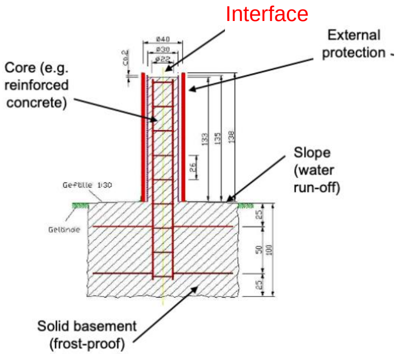


Implementation of P-SGN

Geodetic pillar design and interface

- **Requirements**
  - Force centering system
  - Highly repeatable setup
  - Limit the source of errors
  - Flexible (allowing different kind of survey instruments)
  - Easy to use (following common standard as much as possible)

- **4 systems identified**
  - CERN socket and cover (a)
  - **Kern centering and mounting system (b)**
  - Pillar plate (without screw) (c)
  - **Pillar plate (with 5/8” screw) (d)**

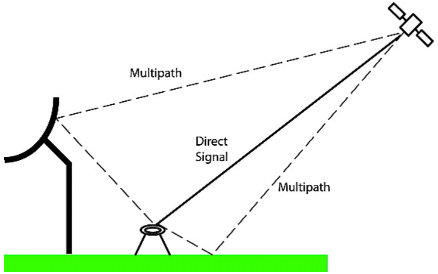


Geodetic pillar sample design (TU Graz)

Implementation of P-SGN

Site selection criteria

- Optimal GNSS (Global Navigation Satellite System) environment
  - Avoid obstructions, multipath, electromagnetic interferences
- Durability
  - Long term stability, low destruction risk
- Operational criteria
  - Close to FCC surface sites, accessibility, safety

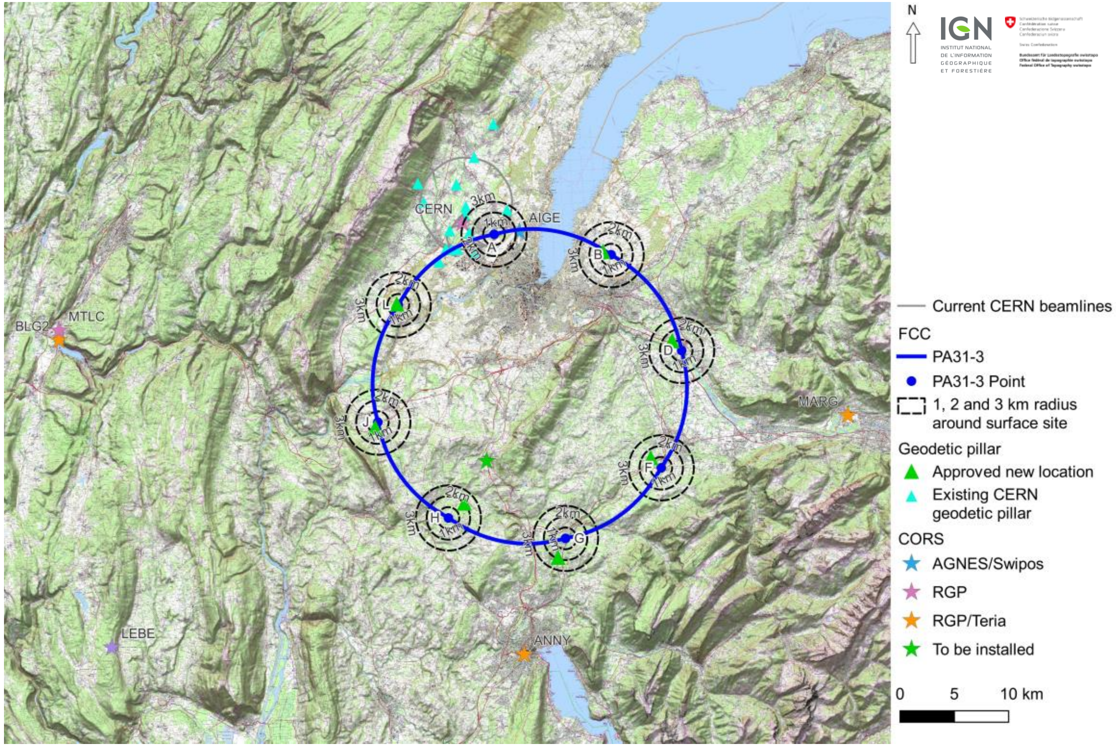


Byun, S. H et al. (2002)

Implementation of P-SGN

Implementation of P-SGN

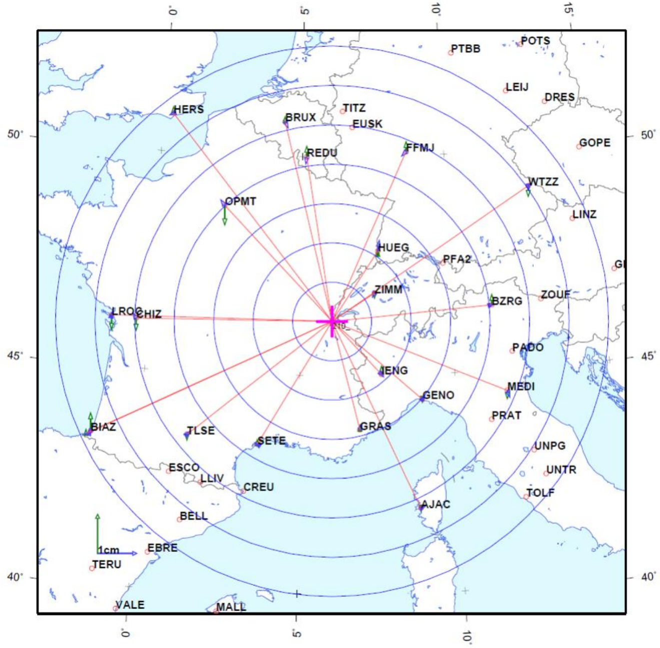
- IGN and Swisstopo got an agreement to build the pillars
  - Point B: Choulex
  - Point D: Nangy
  - Point F: Etaux
  - Point G: Charvonnex
  - Point H: Cercier
  - Point J: Dingy en Vuache
  - Point L: Dardagny
  - New CORS: Jussy



Implementation of P-SGN

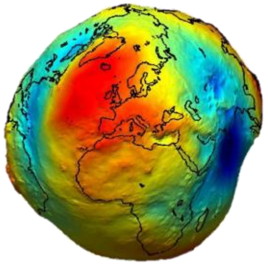
GNSS observations and determination of the coordinates

- 2 static GNSS campaigns separated by one 1 year. 2 sessions of 48 hours per campaign
- Include existing CERN geodetic pillars in the network
- 2 independent processing (one by IGN and one by Swisstopo)
- Tying in International and European terrestrial reference frame (ITRF and ETRF)
- Expected accuracy +/- 2 mm in planimetry and +/- 5 mm in altimetry (at 1-sigma)



Distribution of reference stations from permanent networks known in ITRF2014 (IGS14) around the CERN

Geoid modelling

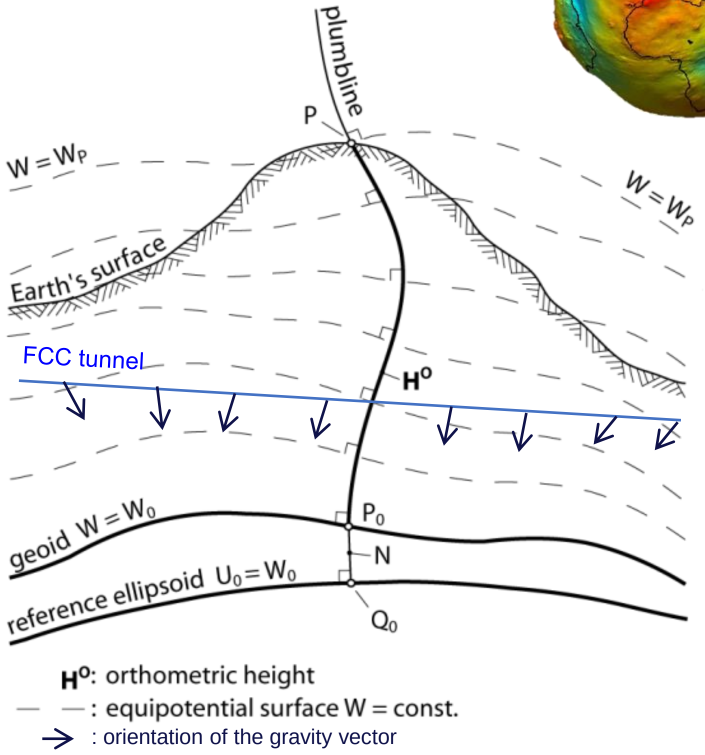


- The geoid is a selected equipotential surface of the earth's gravity field and serves as the reference surface for height determination. It can be considered as an idealised continuation of the mean surface of the oceans beneath the continents.

- Equipotential surfaces are not parallel within the Earth

- Survey observations need to be corrected to take into account variations of the direction of the plumbline (deviation of the vertical) to align accelerator components in an Euclidean plane

- Four different levels of precision will be considered: 1 cm/km for the civil engineering and 30 µm, 50 µm and 100 µm over 225 m for the high-precision gravity field models.



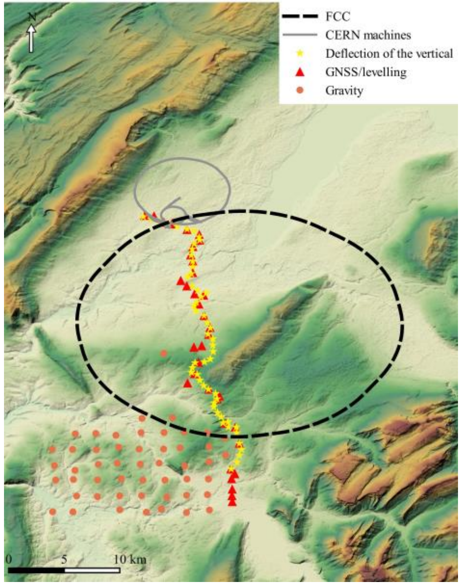
Geoid modelling

Final result of the geodetic control profile

- 83 determination of deflection of the vertical
- 8.8 km cross-border levelling
- 36 GNSS levelling stations
- 55 relative gravity observations along the profile and 51 at the north-east of Annecy

Final results delivered by Swisstopo and ETHZ

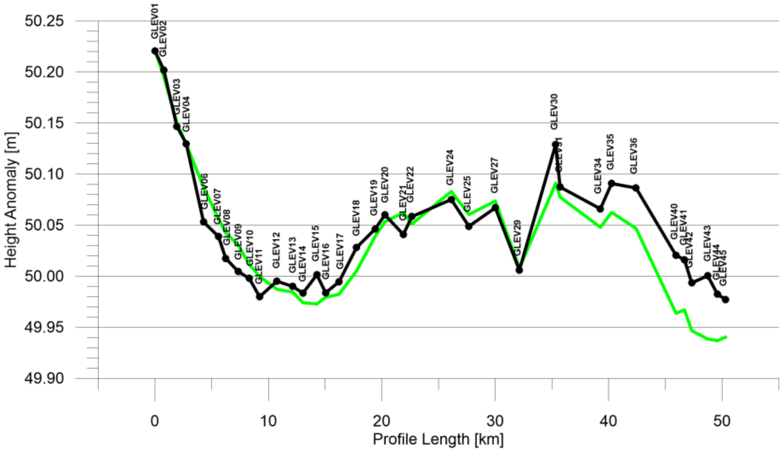
This dataset will serve as ground truth and therefore as validation dataset for all gravity field related studies of the FCC project.



Geoid modelling

Evaluation of CHGeo 2004

- A rather good agreement between the control profile and the quasigeoid model
- There are also some systematic differences of several cm in some regions
- In the South, the model CHGeo04 is not very accurate and drifts away from the GNSS/levelling results



Observed height anomalies along the profile (black) and the Swiss quasigeoid model CHGeo2004 (green)

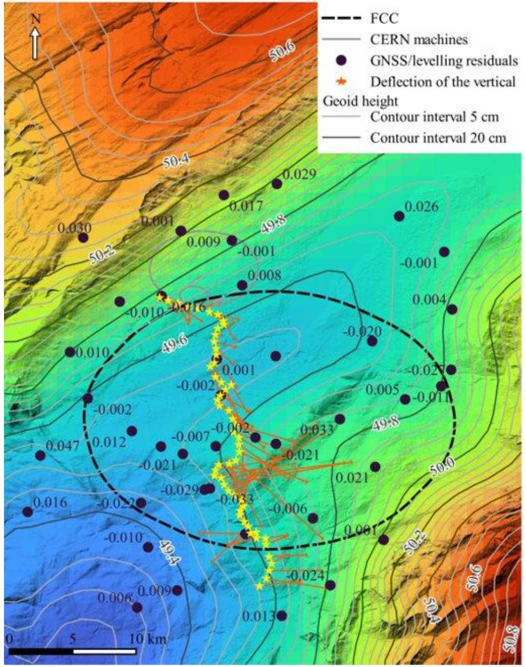
Geoid modelling

Local geoid model computation

- Computation of a first solution of local geoid model using the Stokes Helmert method (master thesis project): precision improved by 30% compared to French and Swiss models
  - Standard deviation on GNSS/levelling point provided by IGN: 1.8 cm
  - Standard deviation on deflection of the vertical along the profile: North-South 1.53'' and East-West 1.18''

- Still room for improvement of the solution

- Alternative geoid modeling approach currently under study: a least square adjustment with a parametrization using radial basis functions (GROOPS toolkit)



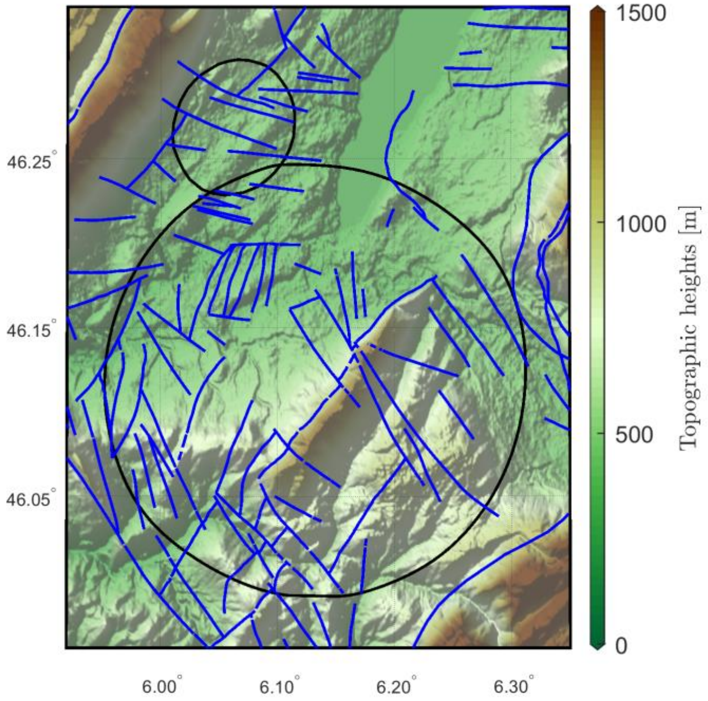
First solution of a local gravimetric geoid model

Upcoming work and futur studies

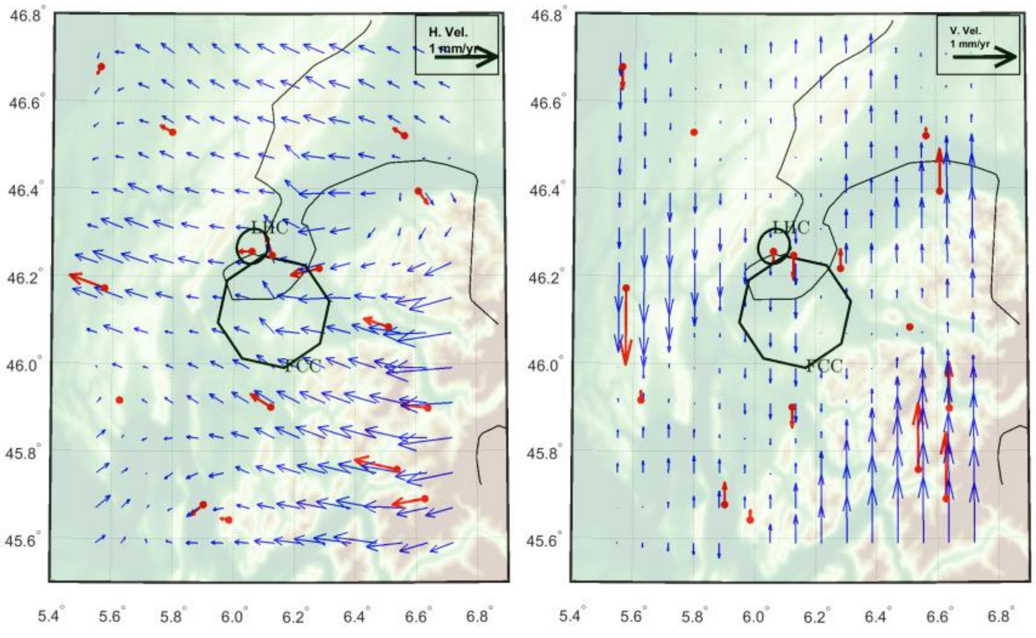
- Coordinate transfer trough LHC shafts
- Determination of transformation parameters between CCS (CERN Coordinate System) and CTRF (CERN Terrestrial Reference Frame)
- Update the geodetic transformation software and its associated DLL
- Geomonitoring study
- Study the underground geodetic network (achievable accuracy)

Thank you
for your attention.

Backup slide: Geomonitoring



(f) Faults (input data source: Clerc and Moscariello 2020).



(a) Horizontal velocities

(b) Vertical velocities

ETRF velocities