GNSS Networks for Solid Earth Science in Europe in the Perspective of EUREF and EPOS

EPOS-N Final Workshop January 27 2021

Martin Lidberg, Chairman of EUREF, member of EPOS GNSS TCS CB, Secretary of NKG

Material from the EPOS GNSS group, especially Carine Bruyninx, Rui Fernandes, Anne Socquet

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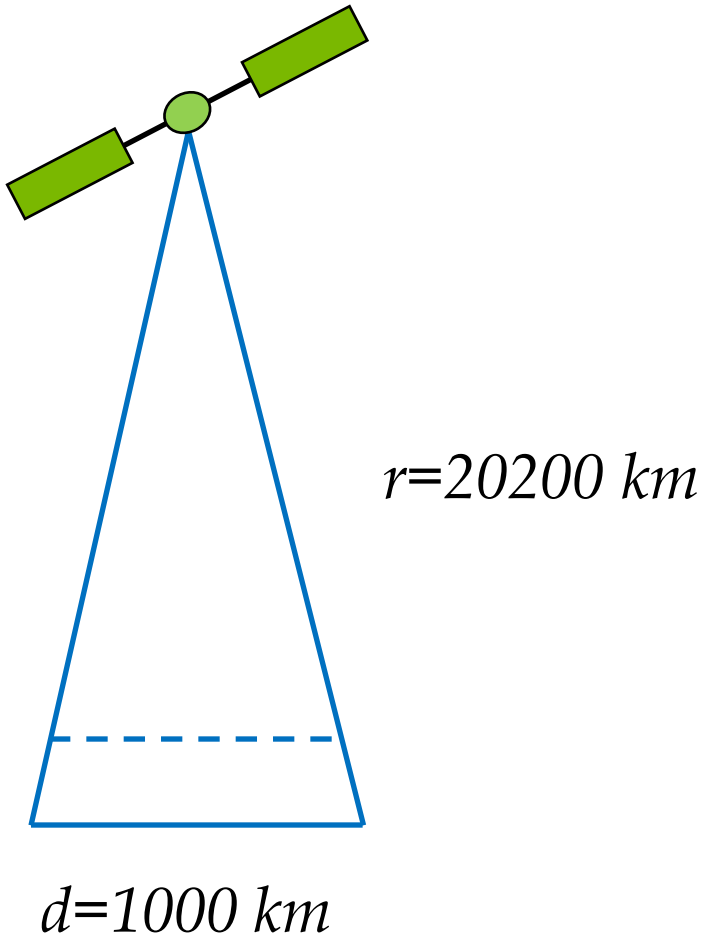
OUTLINE

- What is needed to use GNSS for Solid Earth Science - Back to basics!
- The need for a global infrastructure and the "Global Geodetic Reference Frame
- Presentation of EUREF
- The EPOS GNSS TCS GNSS data & products
- Handling of metadata in EPOS TCS GNSS – common handling also for EUREF
- The EPOS data & product line
- Some brief examples of use cases

BACK TO BASICS – SATELLITE ORBITS



Example:
An **orbit error of 2 m** cause an error in baseline of 10^{-7}.
This cause **10 cm error** for a 1000 km baseline.

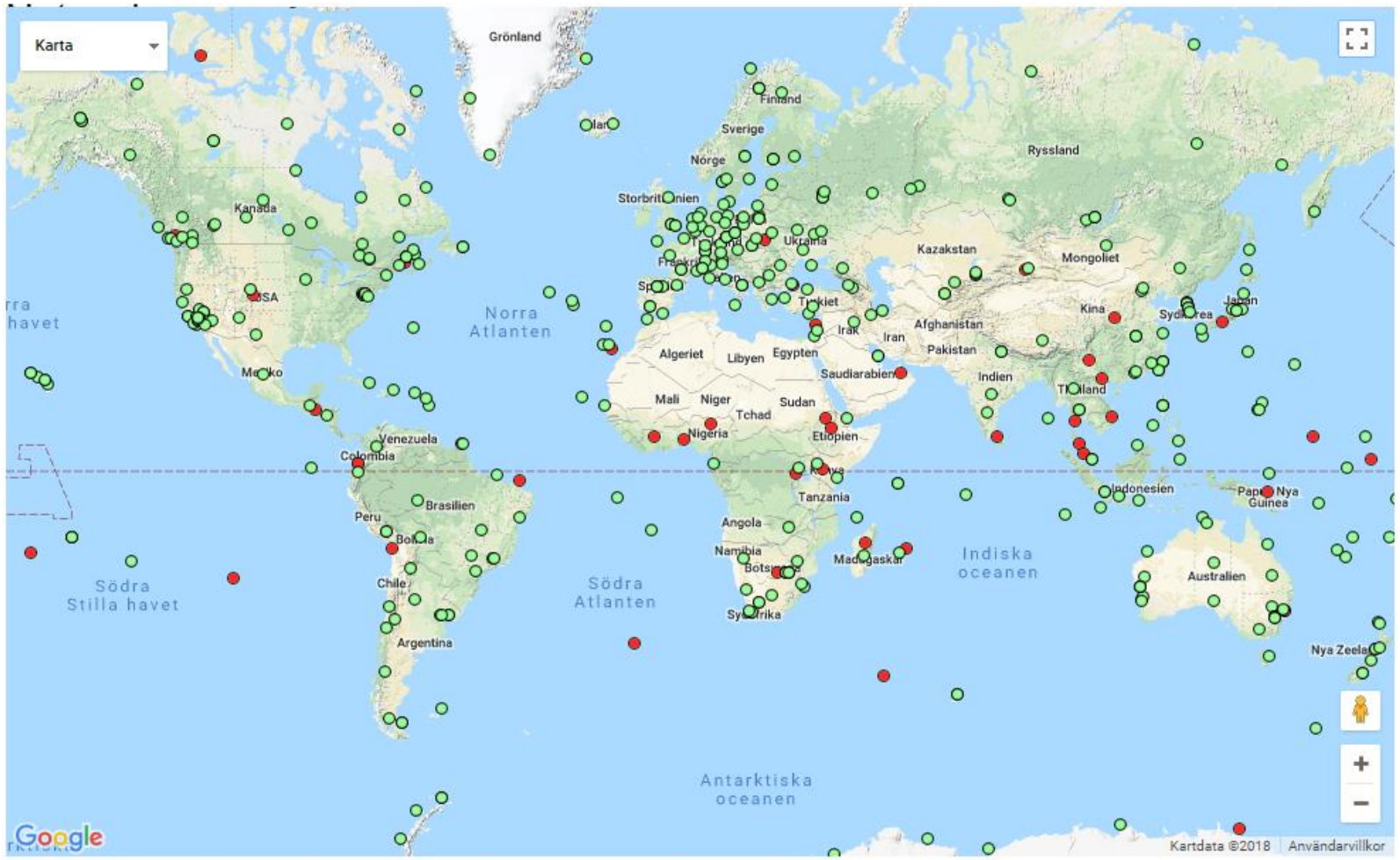
IGS – THE INTERNATIONAL GNSS SERVICE

Precise orbits and clock information are provided from the IGS:

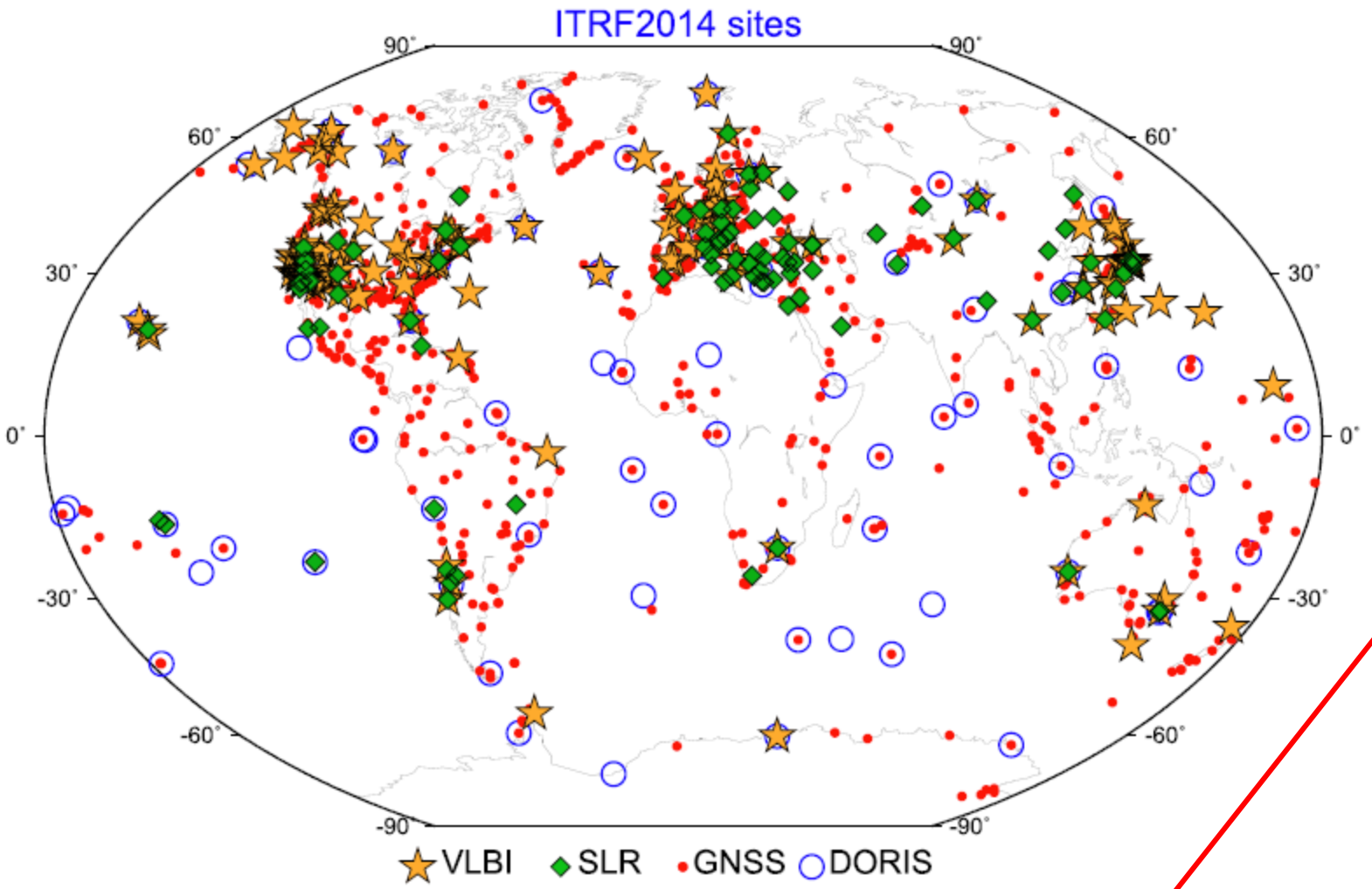
Predicted GPS orbits:
~5 cm
~3 ns (RMS)
Final GPS orbits:
~2.5 cm
~75 ps (RMS)
Final GLONASS orbits:
~3 cm

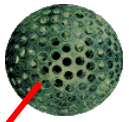
Also Galileo available

http://www.igs.org/



ITRS and ITRF2014



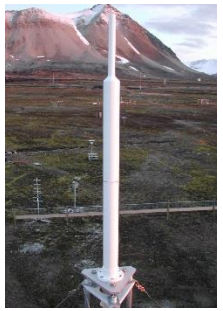


ITRF2014 map from: Altamimi, Z., P. Rebischung, L. Métivier, and C. Xavier (2016), ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, *J. Geophys. Res. Solid Earth*, *121*, doi:10.1002/2016JB013098

⇒ VLBI sites ⇐

SLR/LLR laser ⇒

GPS station



DORIS ⇐

WHAT IS EUREF?

EUREF is the IAG **Reference Frame** Sub Commission for Europe

Founded in 1987

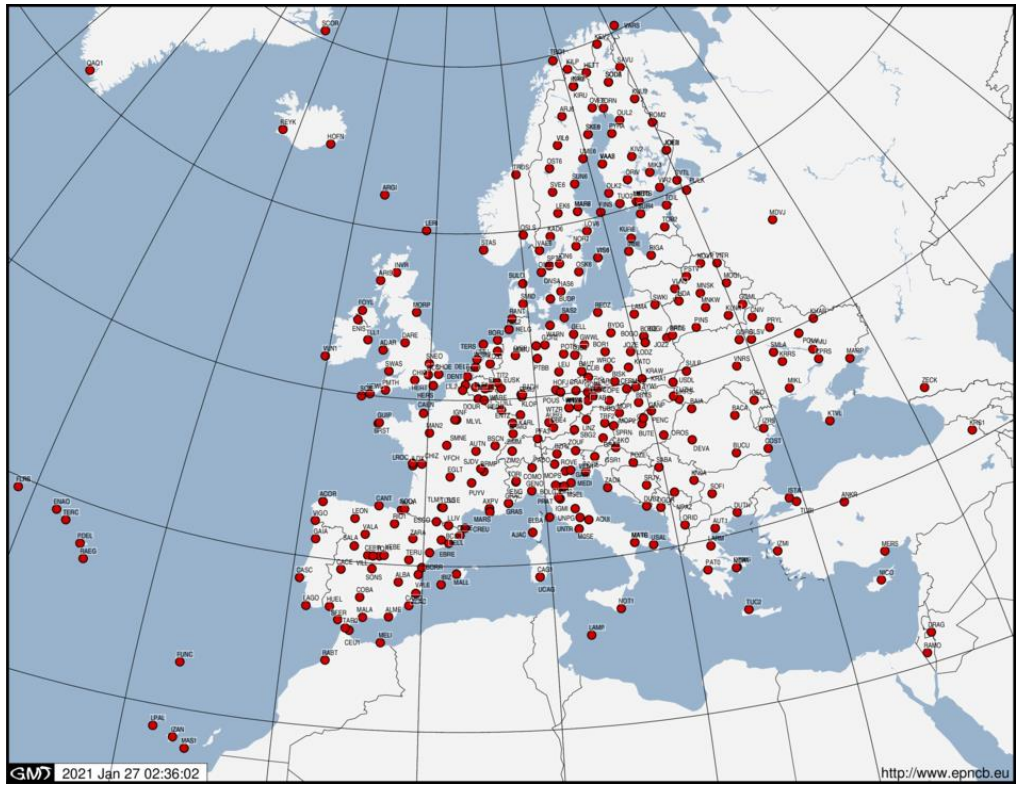
Members of EUREF are the European countries (following the IUGG membership rules)

Contributors to EUREF are **hundreds of agencies and institutions** providing data, resources, and manpower on a voluntary basis

EUREF provides all its products on the **„best effort“ basis and free of charge to the public**

IAG: International Association of Geodesy
IUGG: International Union of Geodesy and Geophysics

WHAT IS EUREF?



EUREF Permanent Network (EPN),
Currenlty some 350 permanent GNSS stations

Main objectives of EUREF are the maintenance of the

- European Terrestrial Reference System (ETRS89)
- European Vertical Reference System (EVRS)

Basis and infrastructure for them are the

- EUREF (GNSS) Permanent Network (EPN)
- Unified European Levelling Network (UELN)

→ www.euref.eu http://epncb.oma.be/

EUREF AND ETRS89

At the global level we have the International Terrestrial Reference System and Frames (ITRS/ITRF)

For Europe we have the European Terrestrial Reference System, ETRS89, and its realizations:

- ETRS89 is by its definition **coincident with ITRS at epoch 1989.0**, and **fixed to the stable part of the Eurasian Plate**
- i.e. **velocities** in ETRS89 are related to the "stable part" of the Eurasian Tectonic Plate

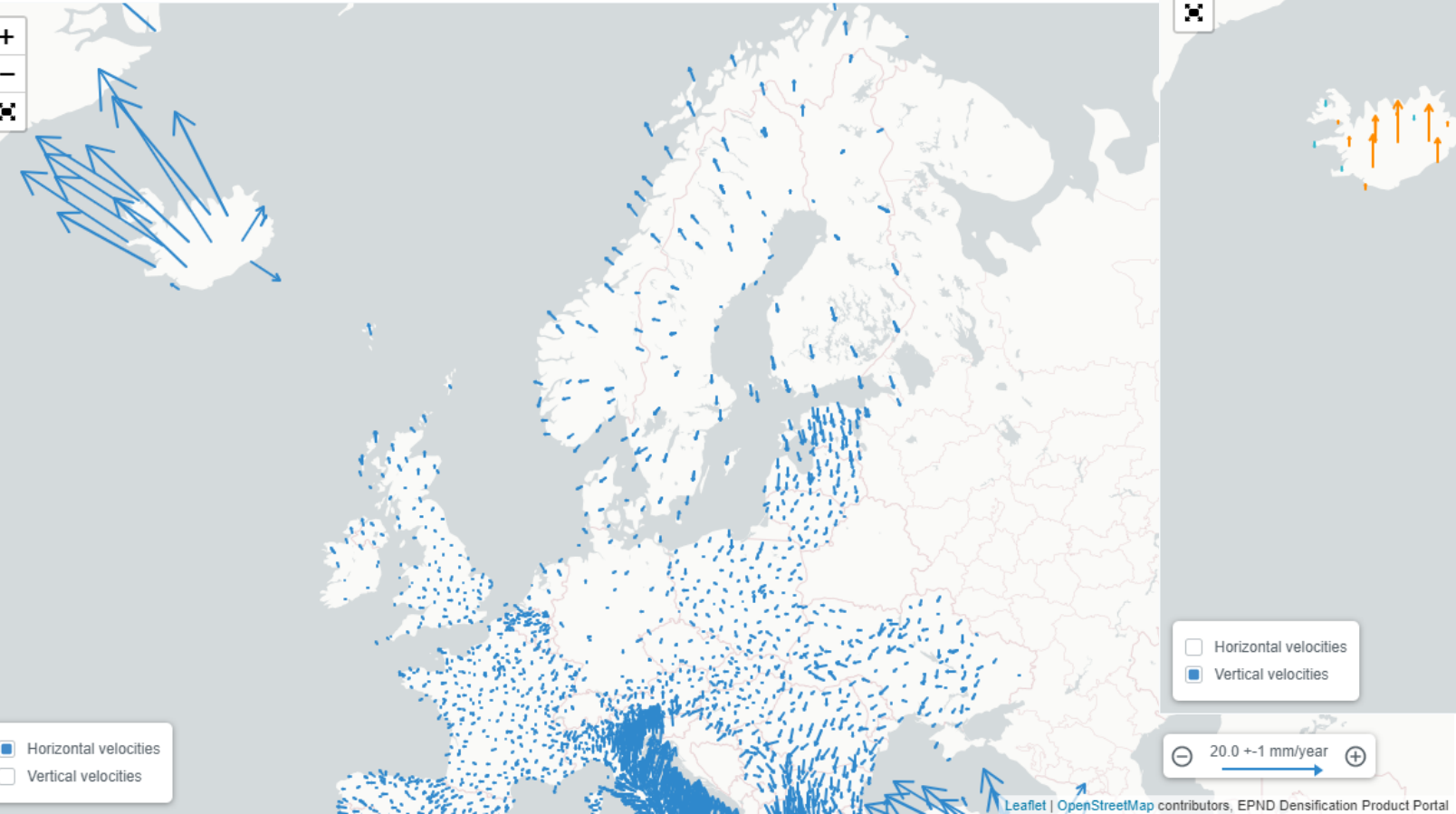
ETRS89 is mandatory for data exchange under the INSPIRE Directive 2007/2/EC, within EU member countries.

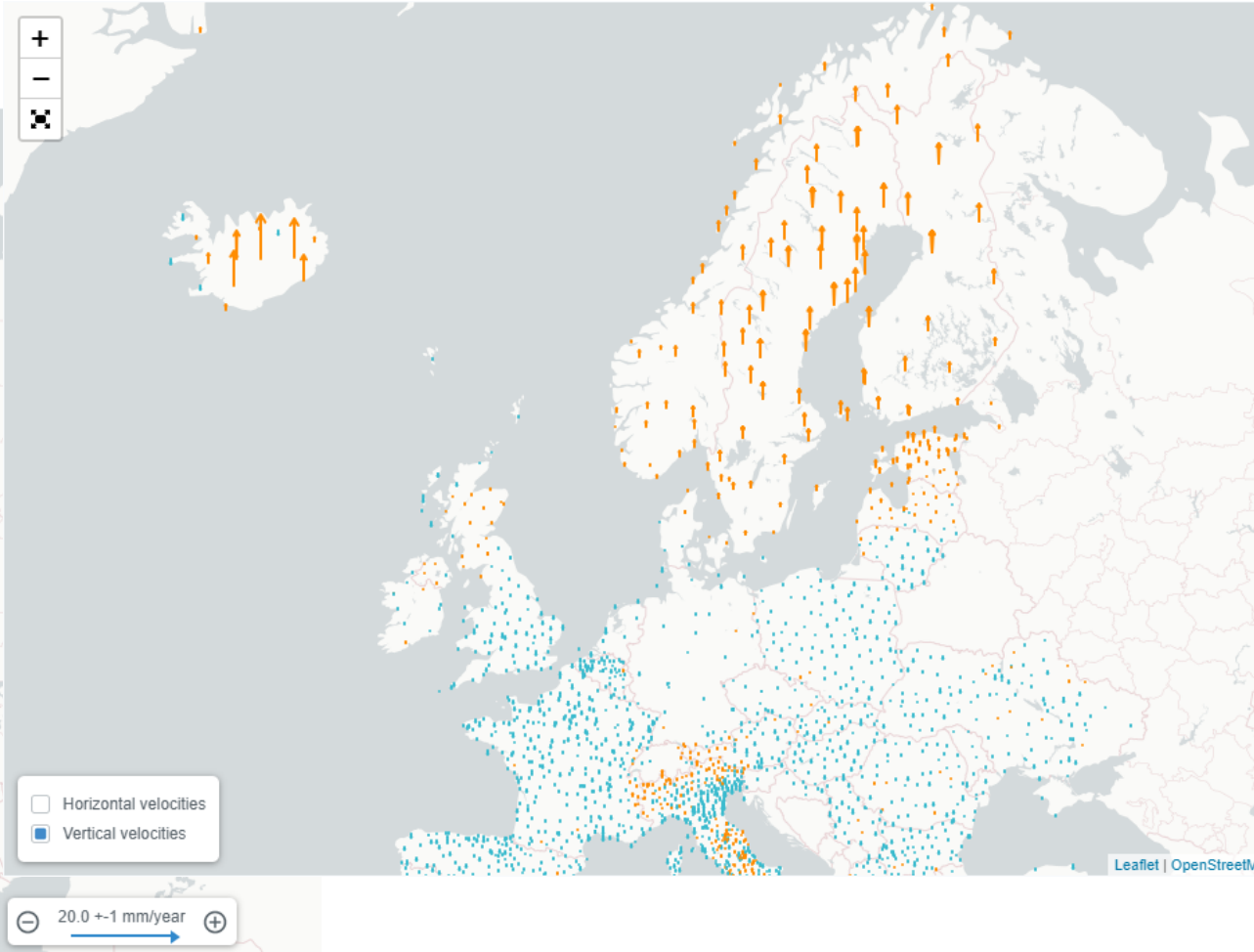
Practically all countries in Europe have a realization of ETRS89

EPN Densification https://epnd.sgo-penc.hu/

Based on EPN, but complemented by computed weekly position solutions from some 20 networks. Today "some 3000" stations.

Evolves towards common EUREF – EPOS products!!



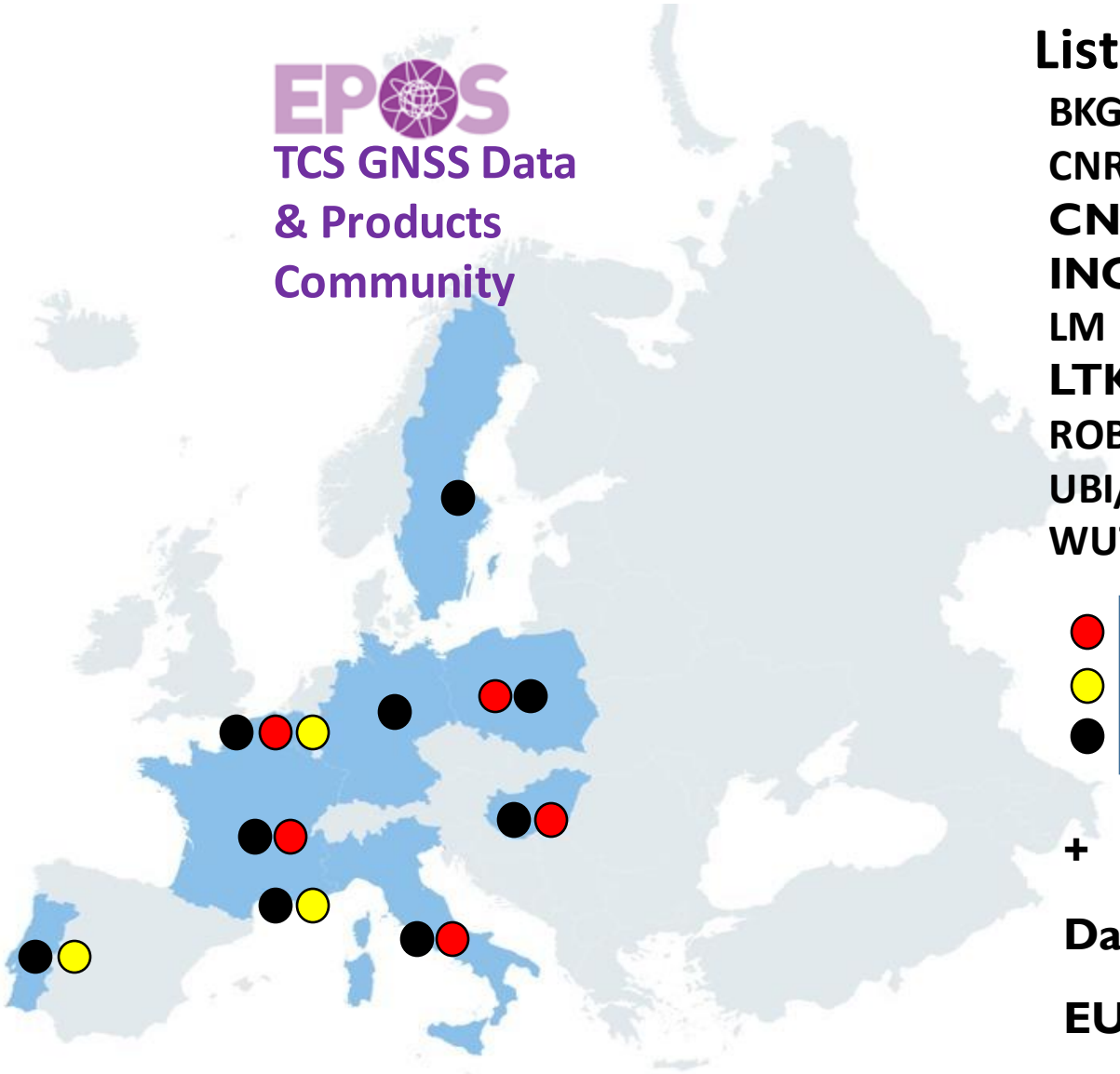


OBJECTIVES EPOS TCS GNSS DATA & PRODUCTS

- Maintain the governance of TCS GNSS Data & Products in EPOS;
- Interact with the geodetic community in Europe, at national and Pan-European (EUREF) levels;
- Ensure interoperability between EPOS GNSS services (data and products) and EPOS ICS;
- Promote multidisciplinary interoperability with other disciplines within EPOS;
- Implement distributed dissemination of file-based GNSS data (currently for ~1150 stations), and derived Products: CRD, VEL, STR (currently ~2700 stations).

EPOS-GNSS

GNSS TCS (EPOS-ERIC) Partners



List of Pan-European Service Providers:

BKG Bundesamt für Kartographie und Geodäsie, DE
CNRS-OCA Observatoire Cote d'Azur, FR
CNRS-UGA Université Grenoble Alpes, FR
INGV Istituto Nazionale di Geofisica e Vulcanologia IT
LM Lantmäteriet, SW
LTK Lechner Knowledge Center, HU
ROB Royal Observatory of Belgium, BE
UBI/C4G U. Beira Interior/Colaboratory for Geosciences, PT
WUT Warsaw University of Technology, PL

- 5 Product Centers
- 3 Portals (M3G, Data, Products)
- 11 Service Providers

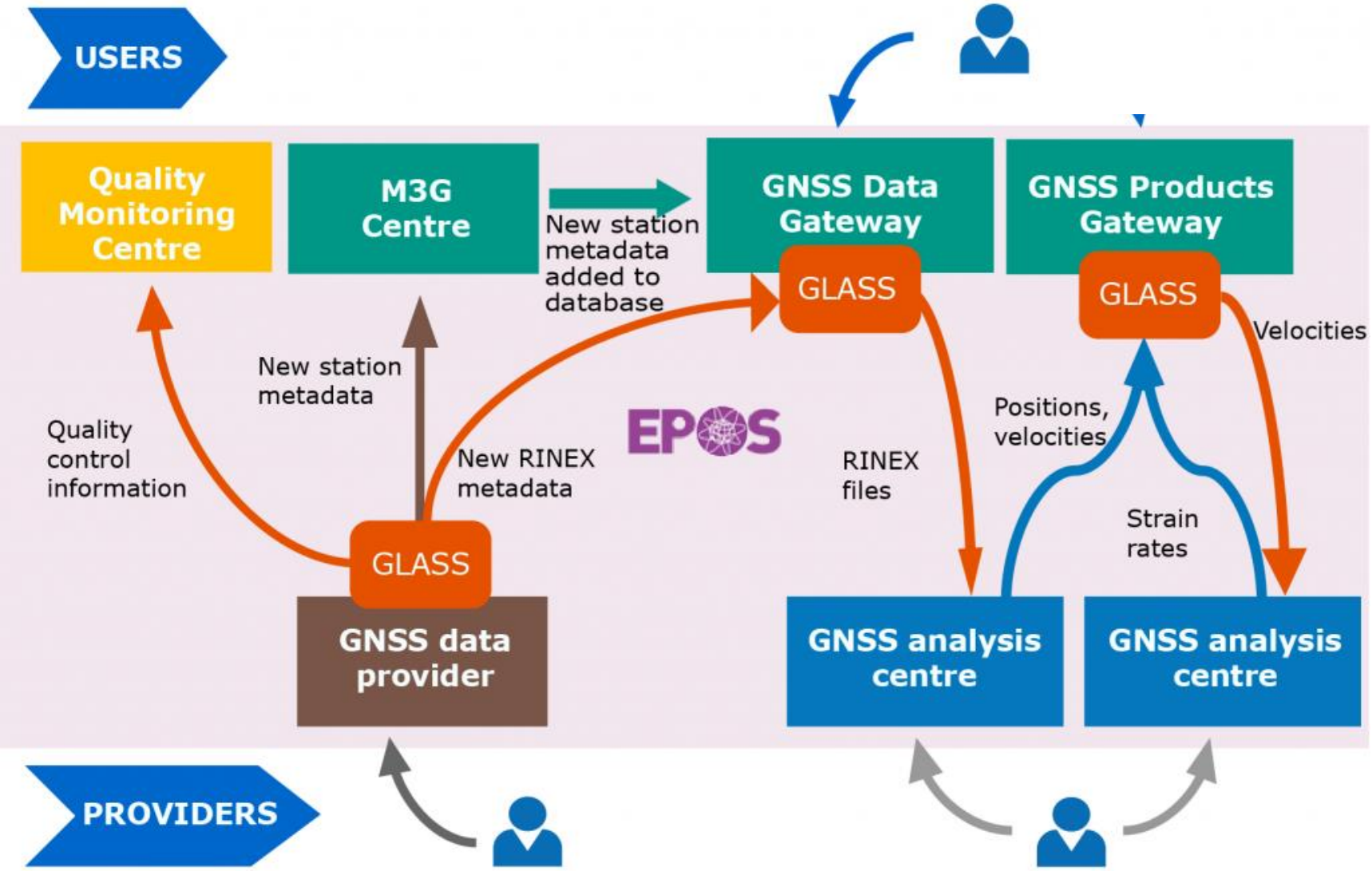
+

Data Providers (National Research Infrastructures)

EUREF (Data, Data Products & Services)

GNSS DATA AND PRODUCTS

EPOS GNSS work flow



EPOS PILOT-OPERATIONAL PHASE

Not all EPOS-GNSS services are fully operational:

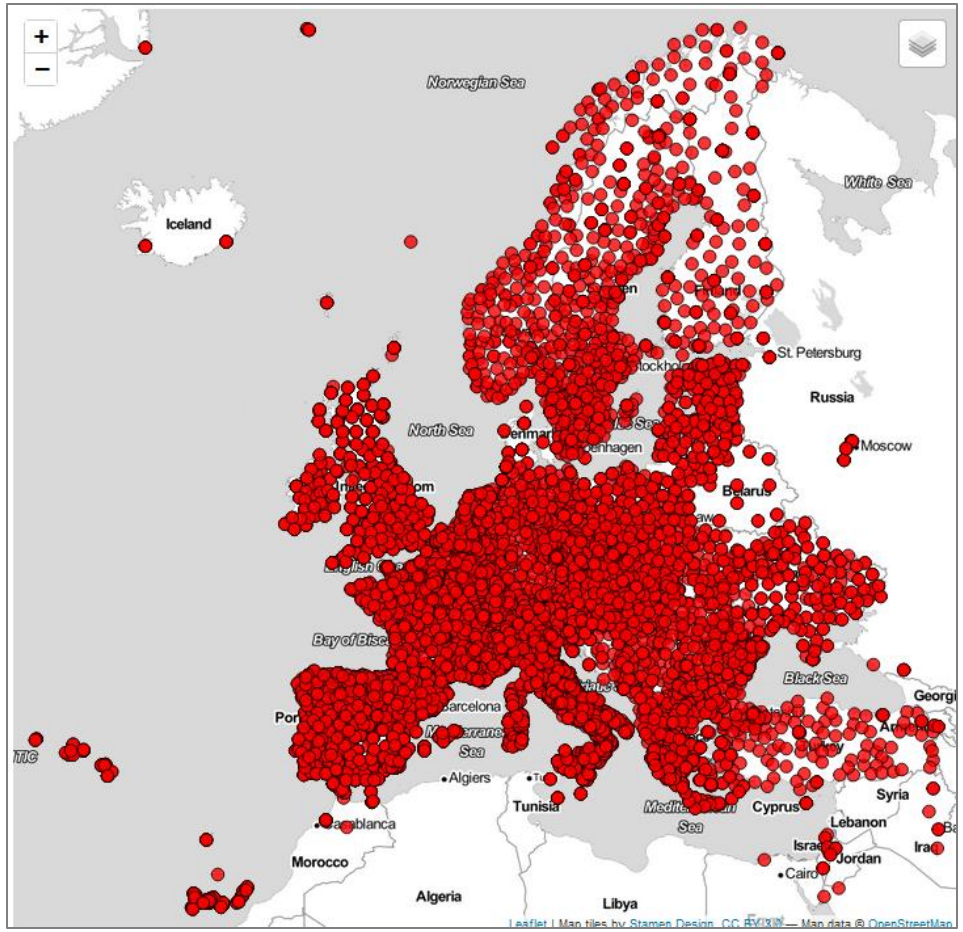
- GNSS network is being build
- GNSS data flow is set up
- GNSS products are being refined

The services that are working are under test

EPOS ambition

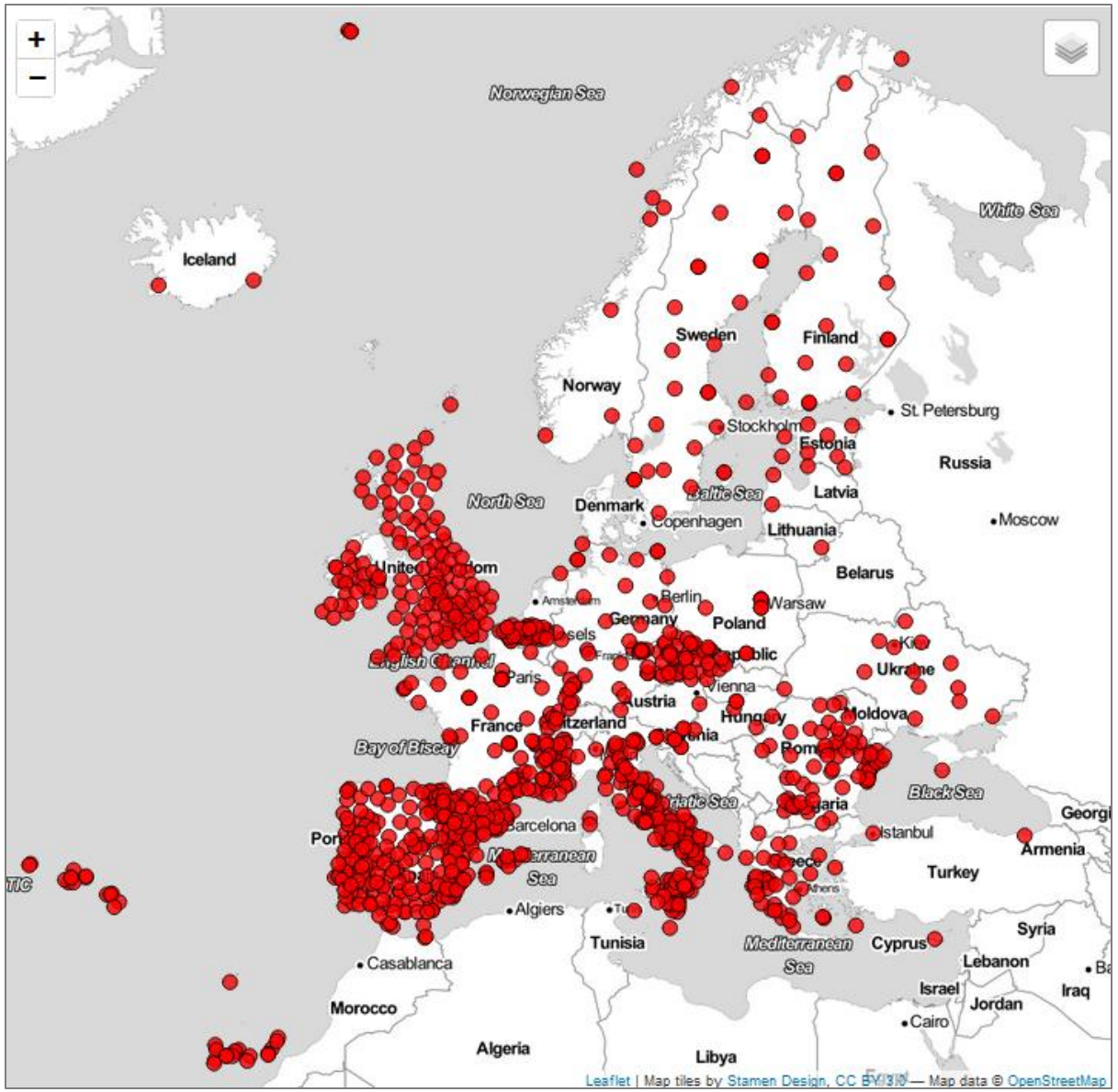
Provide access to data from ~3000 GNSS stations

~ 5000 permanent GNSS stations



Cite as: Bruyninx C., Fabian A., Miglio A., Legrand J. (2021). How to integrate a GNSS station in EPOS? EPOS-GNSS webinar, 18-19 Jan. 2021, https://doi.org/10.24414/ROB-EPOS-GNSS.PR.01.2021

1145 EPOS-GNSS stations – January 2021



GENERAL GNSS STATION REQUIREMENTS

1. Permanently tracking GNSS stations
   a) Presently active
   or
   b) Decommissioned stations that worked for minimally 3 years

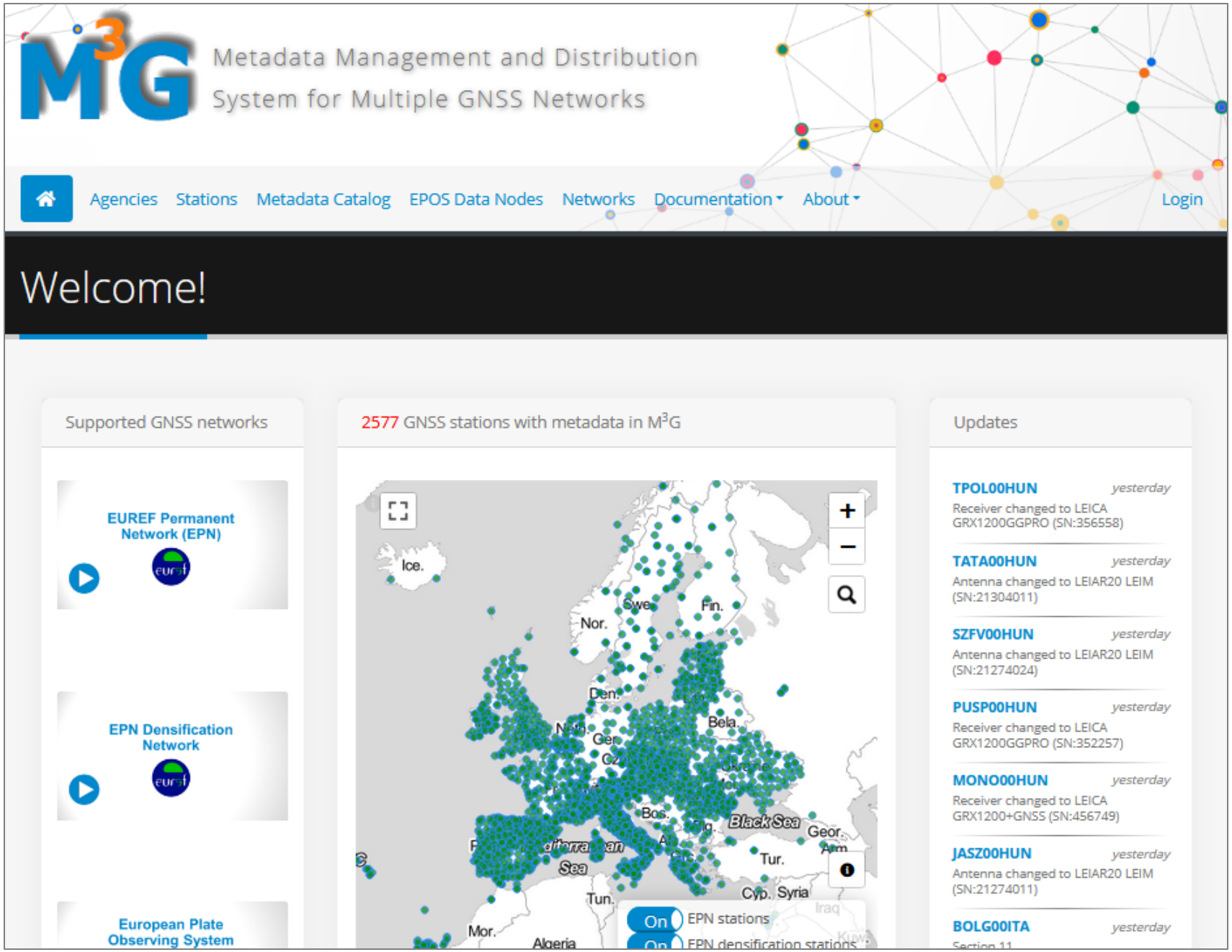
2. Provide free access to daily RINEX data (v2 or v3)

3. Maintain station metadata (site log + other metadata)

GNSS DATA AND PRODUCTS

Cite as: Bruyninx C., Fabian A., Miglio A., Legrand J. (2021). How to integrate a GNSS station in EPOS? EPOS-GNSS webinar, 18-19 Jan. 2021, https://doi.org/10.24414/ROB-EPOS-GNSS.PR.01.2021

https://gnss-metadata.eu



GNSS DATA AND PRODUCTS

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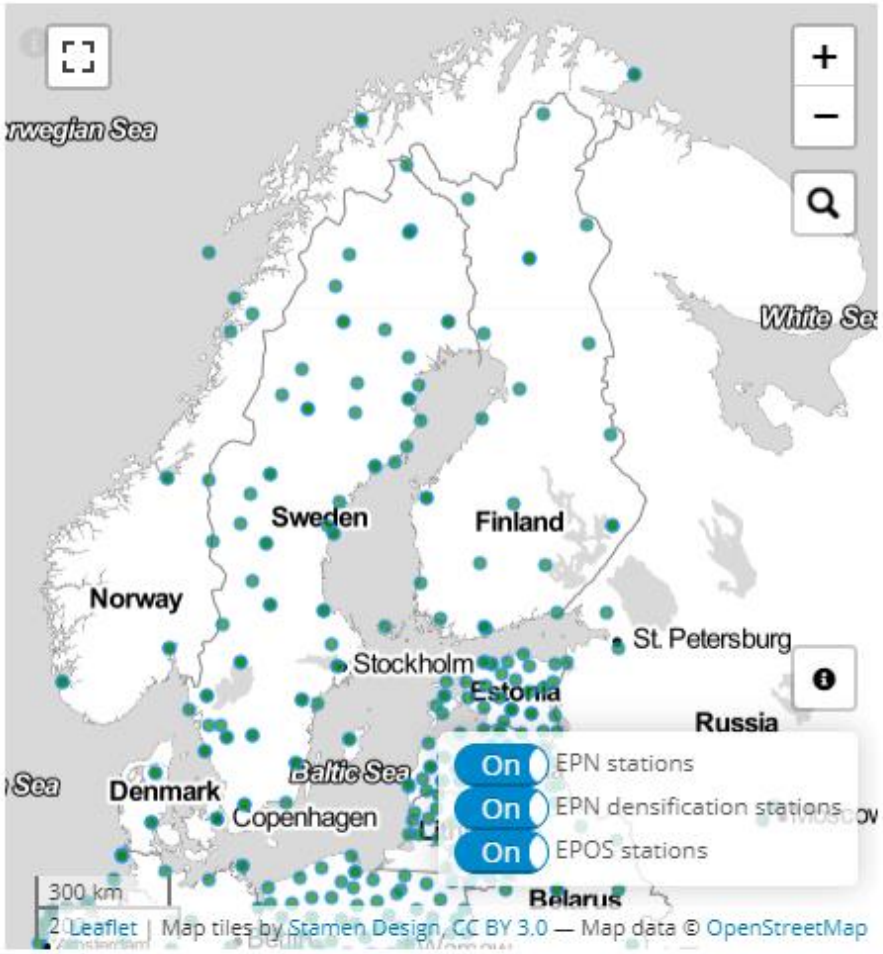
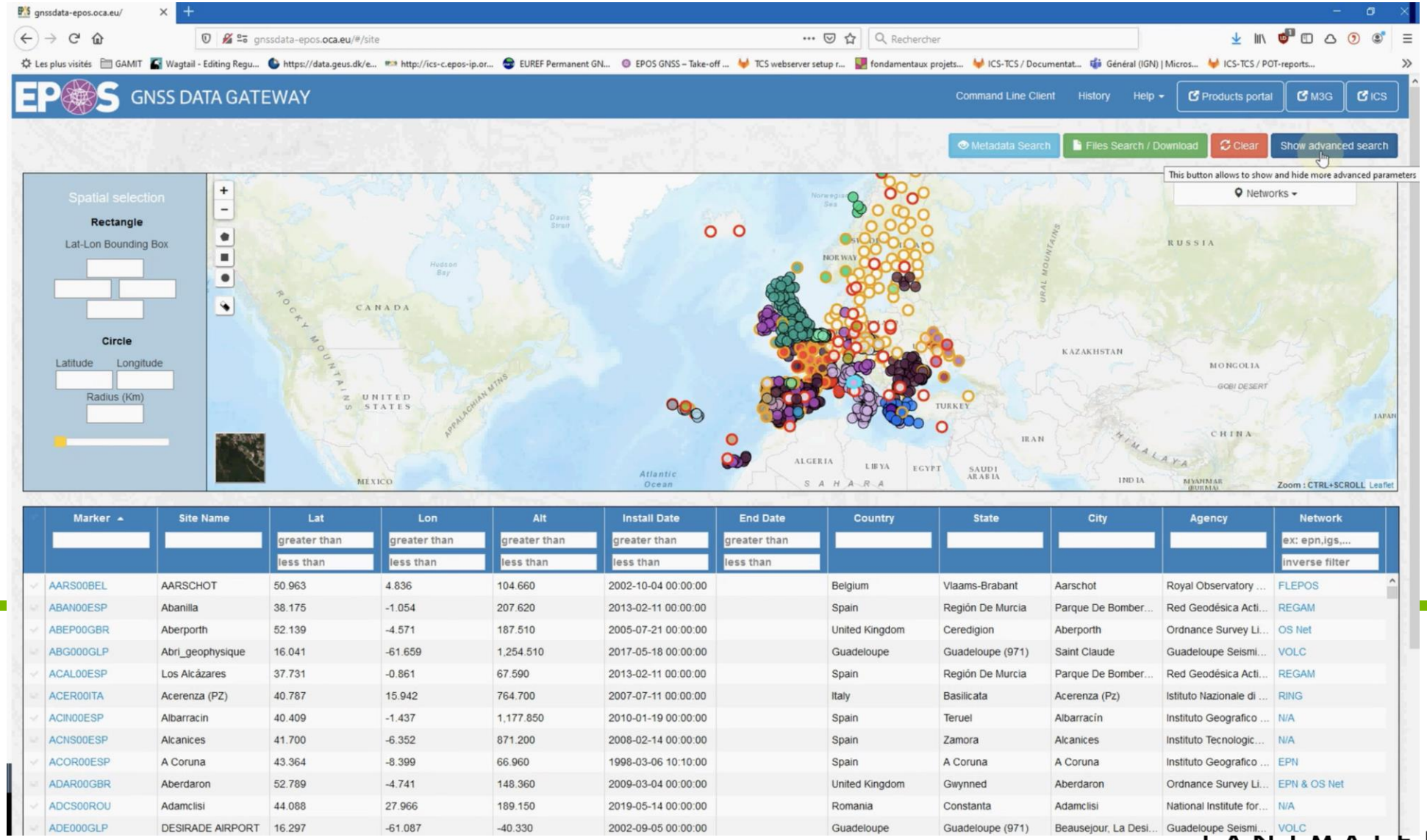
M3G Metadata Management and Distribution System for Multiple GNSS Networks

Note that the M3G GNSS metadata service is common for EUREF and EPOS and possibly other network stations

https://gnss-metadata.eu



DATA PORTAL



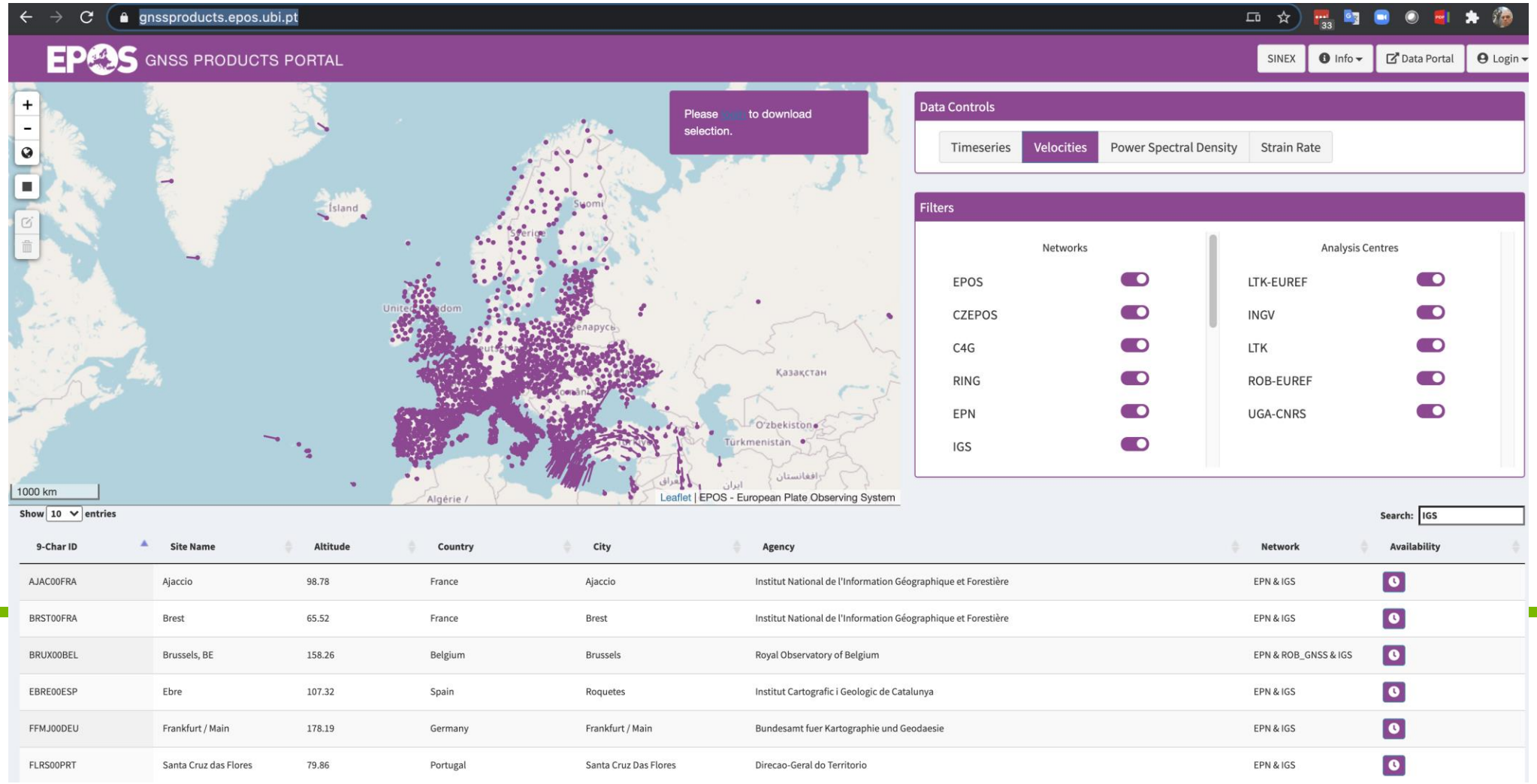
Marker	Site Name	Lat	Lon	Alt	Install Date	End Date	Country	State	City	Agency	Network
		greater than / less than	greater than / less than	greater than / less than	greater than / less than	greater than / less than					ex: epn,igs,... / inverse filter
AARS00BEL	AARSCHOT	50.963	4.836	104.660	2002-10-04 00:00:00		Belgium	Vlaams-Brabant	Aarschot	Royal Observatory ...	FLEPOS
ABAN00ESP	Abanilla	38.175	-1.054	207.620	2013-02-11 00:00:00		Spain	Región De Murcia	Parque De Bomber...	Red Geodésica Acti...	REGAM
ABEP00GBR	Aberporth	52.139	-4.571	187.510	2005-07-21 00:00:00		United Kingdom	Ceredigion	Aberporth	Ordnance Survey Li...	OS Net
ABG000GLP	Abri_geophysique	16.041	-61.659	1,254.510	2017-05-18 00:00:00		Guadeloupe	Guadeloupe (971)	Saint Claude	Guadeloupe Seismi...	VOLC
ACAL00ESP	Los Alcázares	37.731	-0.861	67.590	2013-02-11 00:00:00		Spain	Región De Murcia	Parque De Bomber...	Red Geodésica Acti...	REGAM
ACER00ITA	Acerenza (PZ)	40.787	15.942	764.700	2007-07-11 00:00:00		Italy	Basilicata	Acerenza (Pz)	Istituto Nazionale di ...	RING
ACIN00ESP	Albarracin	40.409	-1.437	1,177.850	2010-01-19 00:00:00		Spain	Teruel	Albarracín	Instituto Geografico ...	N/A
ACNS00ESP	Alcanices	41.700	-6.352	871.200	2008-02-14 00:00:00		Spain	Zamora	Alcanices	Instituto Tecnologic...	N/A
ACOR00ESP	A Coruna	43.364	-8.399	66.960	1998-03-06 10:10:00		Spain	A Coruna	A Coruna	Instituto Geografico ...	EPN
ADAR00GBR	Aberdaron	52.789	-4.741	148.360	2009-03-04 00:00:00		United Kingdom	Gwynned	Aberdaron	Ordnance Survey Li...	EPN & OS Net
ADCS00ROU	Adamclisi	44.088	27.966	189.150	2019-05-14 00:00:00		Romania	Constanta	Adamclisi	National Institute for...	N/A
ADE000GLP	DESIRADE AIRPORT	16.297	-61.087	-40.330	2002-09-05 00:00:00		Guadeloupe	Guadeloupe (971)	Beausejour, La Desi...	Guadeloupe Seismi...	VOLC

LANIMAIERIET

http://gnssdata-epos.oca.eu/

More Details: DATA PORTAL - HOW TO DOWNLOAD DATA & METADATA, M. Vergnolle & J-L Menut

PRODUCTS PORTAL

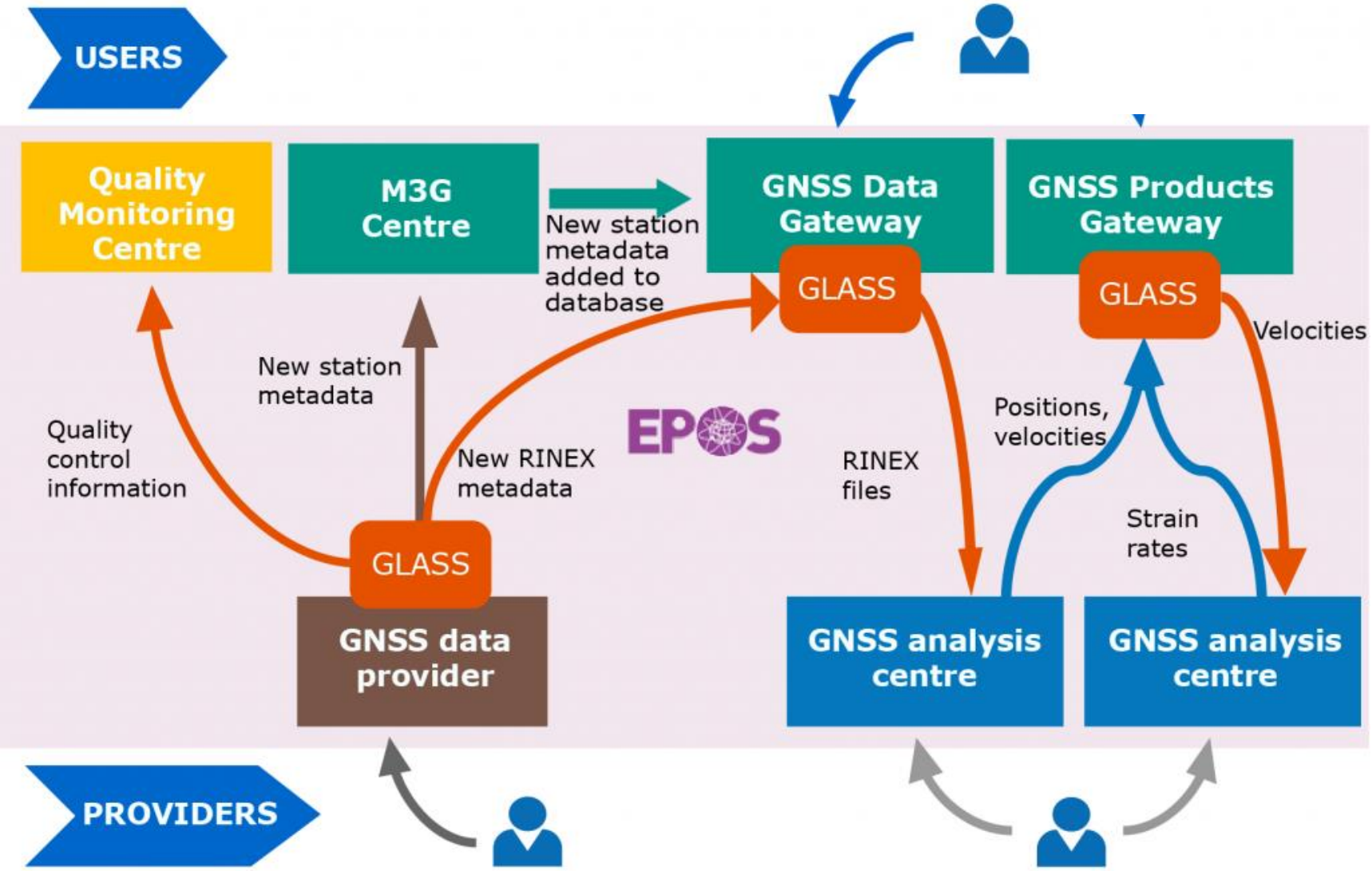


http://gnssproducts.epos.ubi.pt/

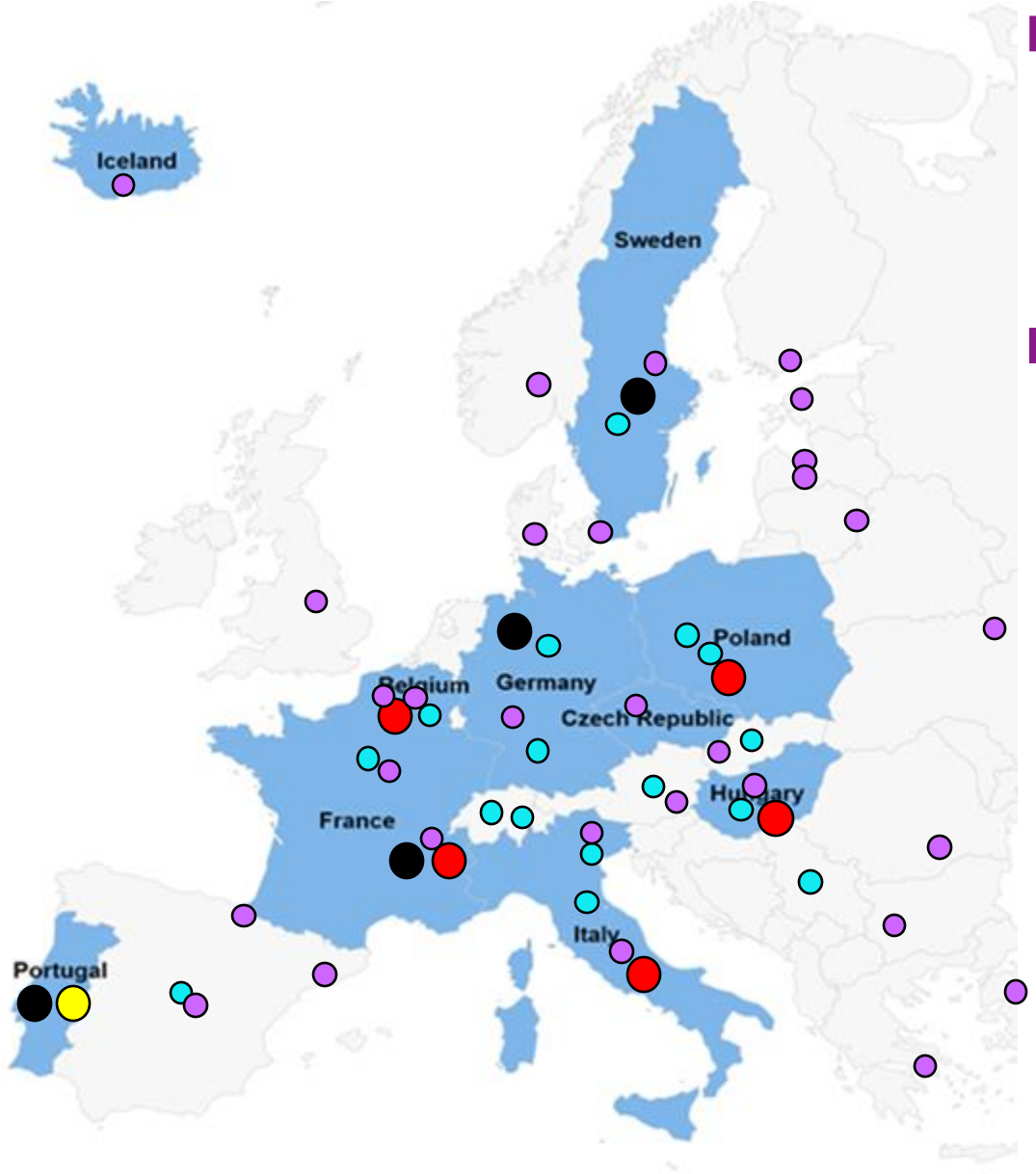
LANTMÄTERIET

More Details: *PRODUCTS - WHAT PRODUCT FOR WHAT USAGE?, Anne Socquet*
PRODUCTS PORTAL - HOW TO DOWNLOAD PRODUCTS, M. Bos & J. Manteigueiro

EPOS GNSS work flow



Who contributes to EPOS GNSS Products ?



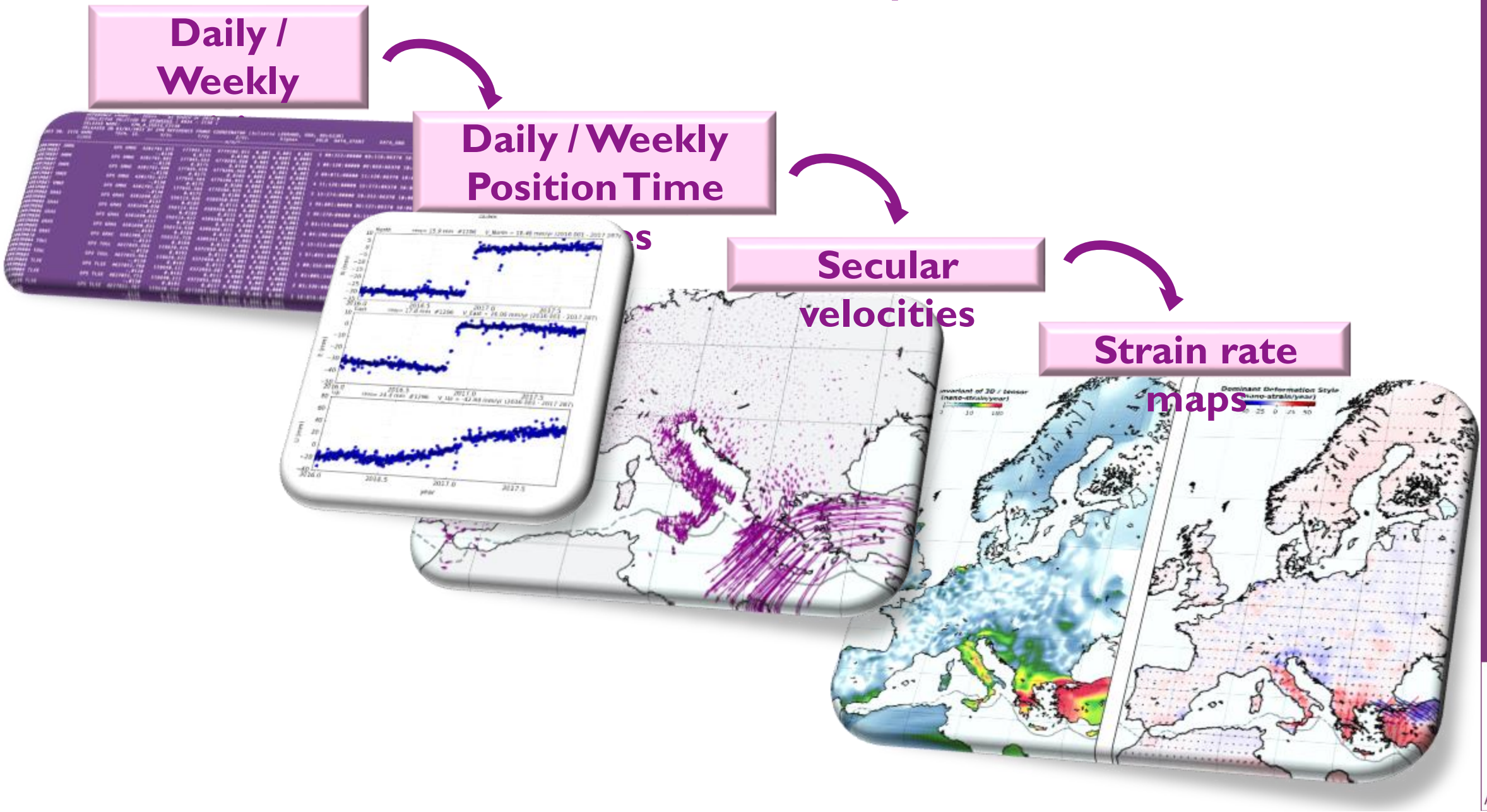
Pan-European Service providers for EPOS-GNSS Products

- 5 Analysis Centers
- 1 Product Gateway
- 4 Other Product-Related Services

National contributions to EPOS-GNSS Products

- 16 EUREF Analysis Centers
- 30 Analysis Centers for EPOS-EUREF-Densified

What are the GNSS products?



What are the different products labels? What are their specificities?

EPOS, EUREF, EPOS-EUREF

Two product solutions developed specifically for EPOS

Principles:

- **Open science, reproducible**
  - **All data available:** RInEx from EPOS-GNSS Data Gateway, metadata available & verified
  - **Fully documented** processing strategies using **open-source softwares**
- **Specifically designed for geophysical studies** (including for slow movements)
  - Each solution is internally-consistent, generated @ a single Pan-European processing center with one strategy

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Daily positions & Multi-year solutions @ 2 Pan-European EPOS Analysis Center

Positions
Time Series
Velocities

Quality Check

Independent cross-comparison and validation @ Pan-European Analysis Combination Center

- Two independent daily solutions :
  - generated @ 2 independent processing centers
  - with 2 independent processing Strategies & Softwares :

Double difference GAMIT/GLOBK/PYACS Automatic updates @ D-2 & D-25	PPP GIPSY-OASIS-II Regular Updates

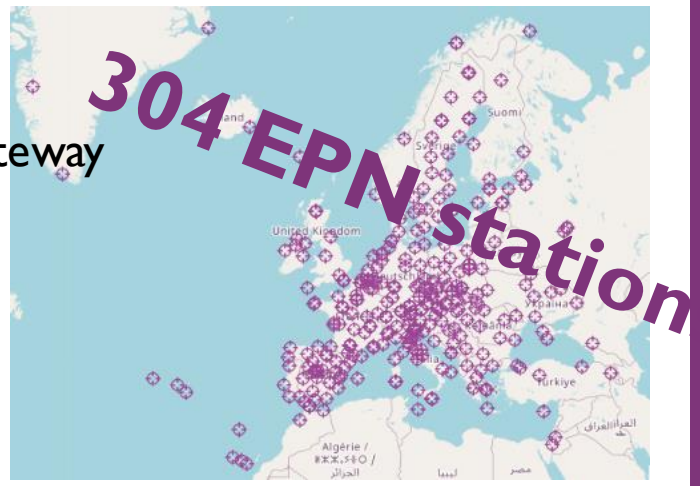
- Automated outlier rejection, introduction of discontinuities in time series
- Velocities Computed with MIDAS, station classification based on uncertainty

- Comparison of Positions Time Series using CATREF
- Identification of outlier and inconsistencies
- Validation or feedback to the EPOS Analysis Centers

What are the different products labels? What are their specificities?

EPOS, EUREF, EPOS-EUREF

Original EUREF product made available through the EPOS GNSS Product Gateway



Principles:

- **Open data :** RInEx available from EPN data centers, metadata available & verified
- **Specifically designed for geodesy and reference frame studies :**
  - Geodetic-class stations from the EUREF Permanent Network (EPN)
  - Densifies ITRF over Europe and provides access to European Terrestrial Reference Frame (ETRF/ETRS89)

Regional daily position solution @ 16 EPN Analysis Centers

- each station processed by at least 3 ACs to insure redundancy and increase reliability
- 3 softwares: Bernese, Gamit, Gipsy

Daily and Weekly Combined Positions @ EPN Analysis Combination Center

Positions

- Pan-European combinations with Bernese
- Each AC solution is compared to the combined solution to identify and reject outliers
- Aligned to IGS14 using no-net-translation

Multi-year Solution @ EPN Reference Frame Analysis Center

Positions

Time Series

Velocities

- Updated each 15 weeks
- Using CATREF
- Outlier rejection by visual inspection of time series, introduction of position and velocity discontinuities, station classification based on velocity uncertainties from Hector and velocity variability

What are the different products labels? What are their specificities?

EPOS, EUREF, EPOS-EUREF

Densification Product from EUREF and EPOS

Principles:

- **Provide a densified velocity field,** including non-EPOS stations that do not release raw data (yet?)

Regional daily position solution @ 30 EPND & EPOS Analysis Centers → **Multi-year Combined Solution @ EPOS-EUREF Combination Center**

Positions
Time Series
Velocities

- 3 softwares: Bernese, Gamit, Gipsy

- Weekly Combined Positions Time Series using CATREF
- Velocities using CATREF, MIDAS, HECTOR
- Station metadata harmonization
- Outlier rejection by automated and visual inspection of time series, introduction of position and velocity discontinuities, velocity filtering, removal of non-representative stations (data quality or monumentation)

LECHNER TUDÁSKÖZPONT

GNSS DATA AND PRODUCTS

WHAT PRODUCTS FOR WHAT USAGE? USE CASES

UC1 : Structural geologist wants to get the secular displacement rates and the strain rate maps in Spain

Recommended products :

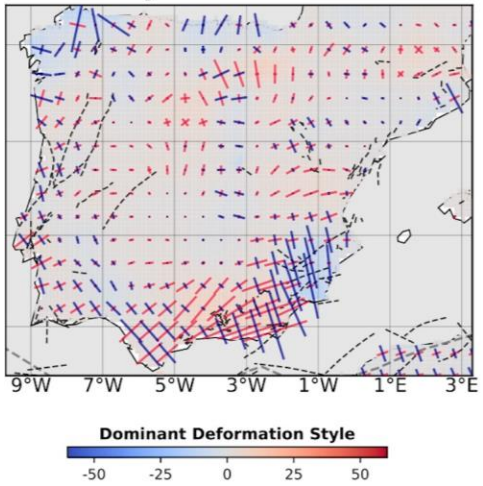
- EPOS–EUREF densified Velocity field from LTK rotated wrt Stable Europe
- Strain Rate products from LM

Additional products :

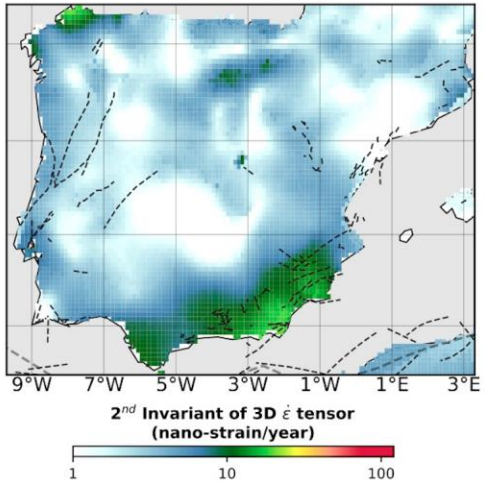
- EPOS velocity fields from INGV and UGA-CNRS rotated wrt stable Europe
- EUREF velocity field from ROB-WUT rotated wrt stable Europe

Secular GNSS Velocities (EPOS-EUREF solution)

Style of Deformation



Strain Rate



Piña Valdes et al., in prep

WHAT PRODUCTS FOR WHAT USAGE? USE CASES

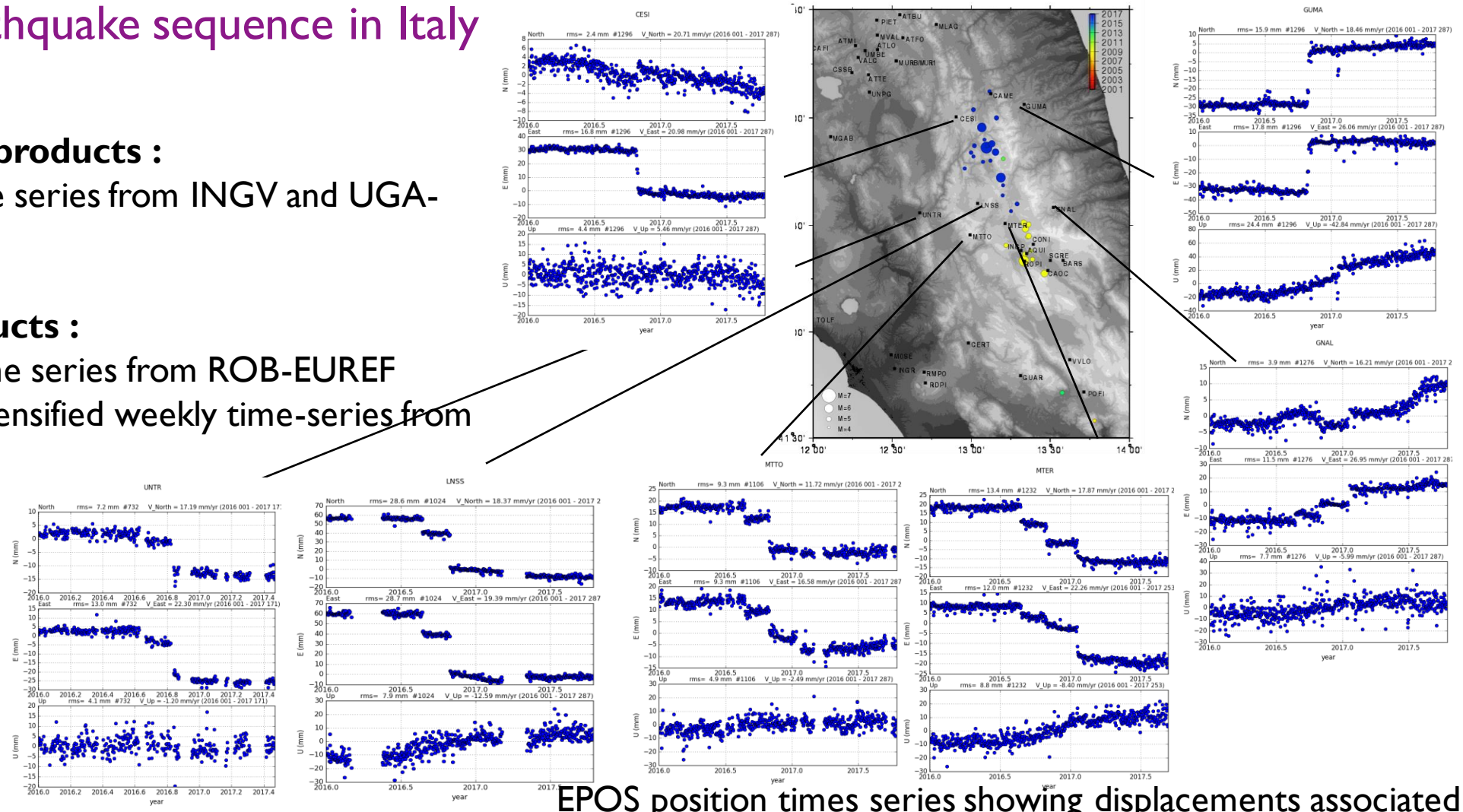
UC2 : Seismologist wants to get the time series associated with the 2016 earthquake sequence in Italy

Recommended products :

- EPOS daily time series from INGV and UGA-CNRS

Additional products :

- EUREF daily time series from ROB-EUREF
- EPOS-EUREF densified weekly time-series from LTK



EPOS position times series showing displacements associated with Amatrice (Mw 6.2) & Norcia (Mw 6.1) earthquakes

WHAT PRODUCTS FOR WHAT USAGE? USE CASES

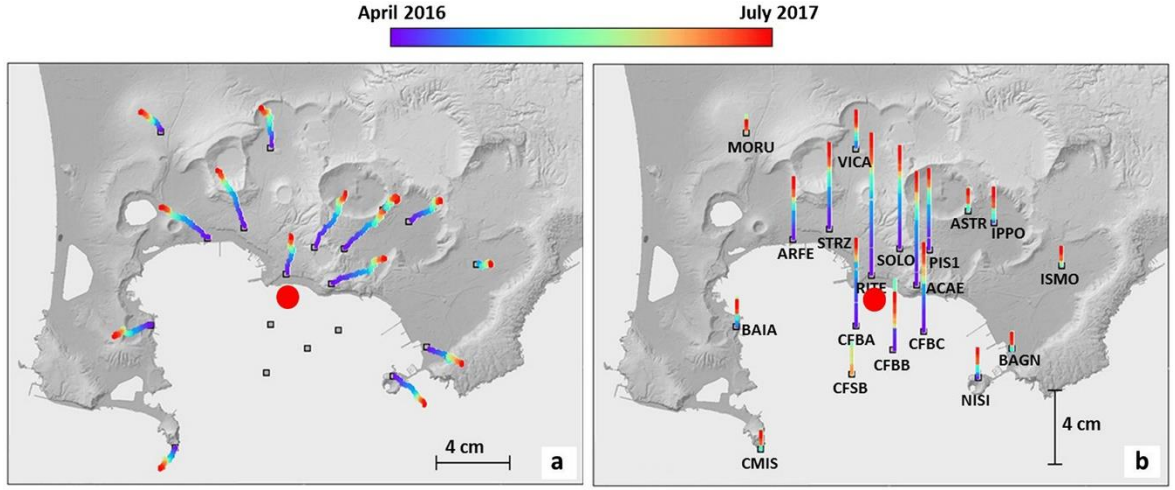
UC3 :Volcanologist wants to get updates on time series in the area affected by recent volcanic unrest

Recommended products :

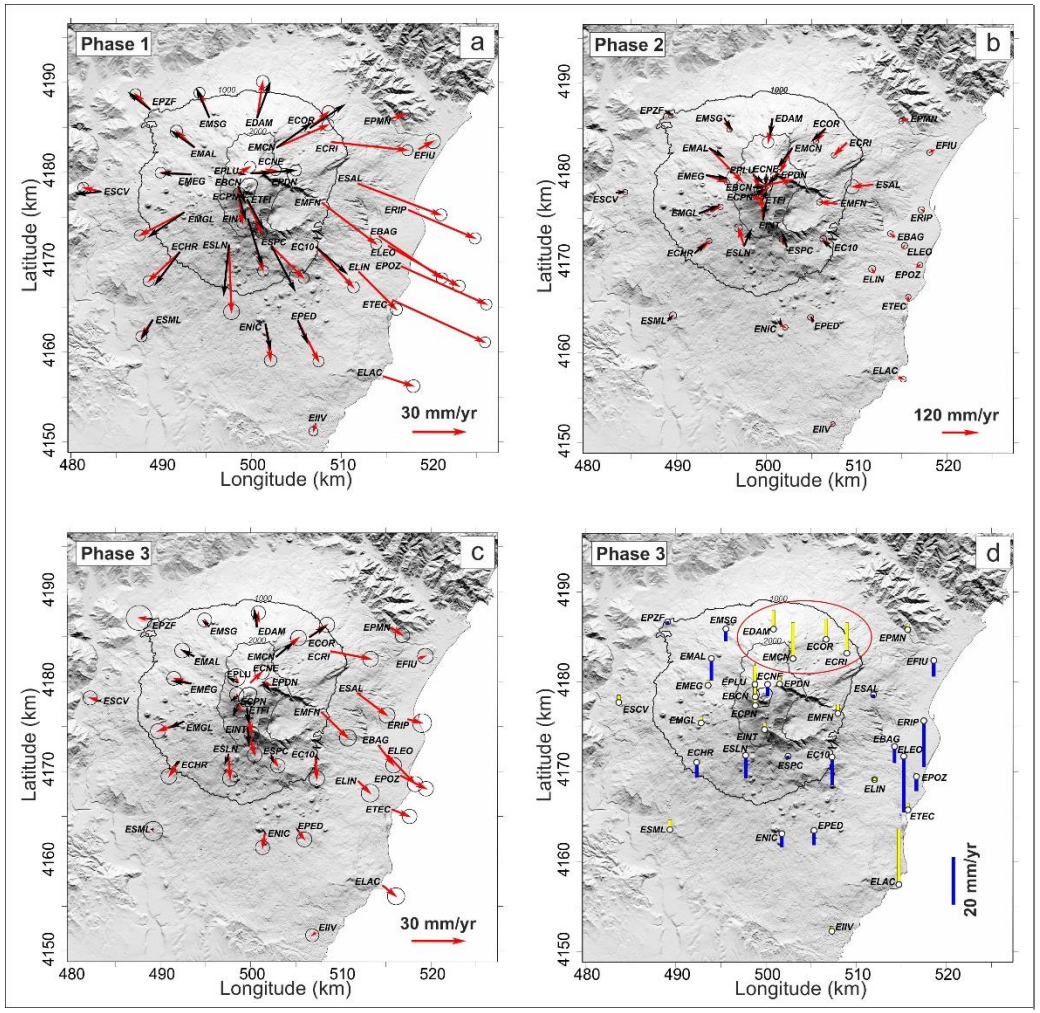
- EPOS daily time series from UGA-CNRS (rapid solution)

Additional products:

- EPOS daily time series from INGV
- EUREF daily time series from ROB-WUT



Campi Flegrei caldera GPS deformation between April 2016 and July 2017 (Iannaccone et al., 2017)



Inflation/deflation processes before/after an eruption onset at Mt Etna (modified from Bruno et al., 2012)

WHAT PRODUCTS FOR WHAT USAGE? USE CASES

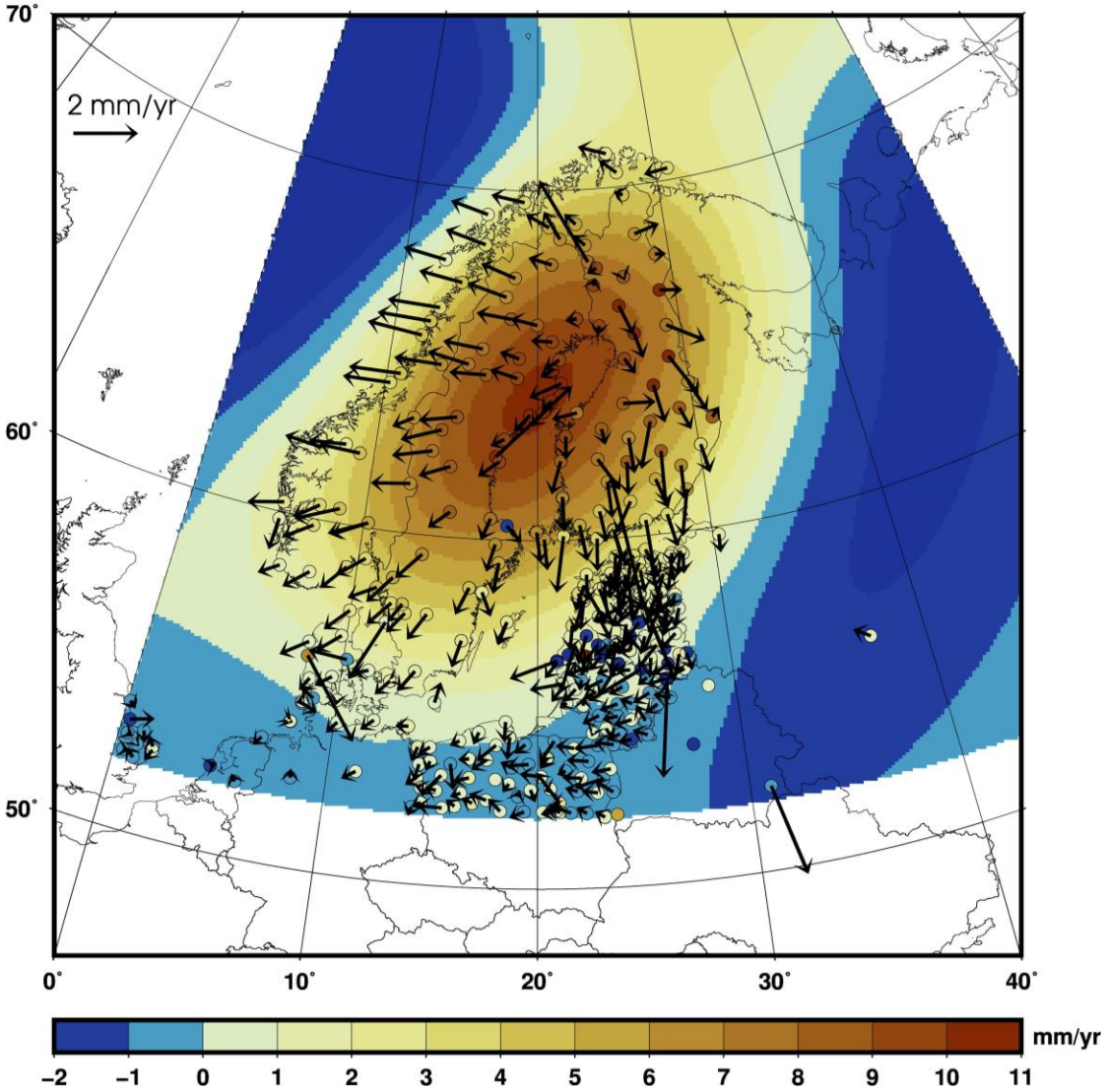
UC4 : Geodynamicist wants 3D velocities to constrain models of isostatic rebound

Recommended products :

- EPOS–EUREF densified Velocity field from LTK rotated wrt Stable Europe

Additional products :

- EPOS velocity fields from INGV and UGA-CNRS rotated wrt stable Europe
- EUREF velocity field from ROB-EUREF rotated wrt stable Europe



Horizontal & Vertical velocities of EPOS-EUREF solution compared to model of Glacial Isostatic Adjustment NGK2016LU (Vestol et al. 2019)

WHAT PRODUCTS FOR WHAT USAGE? USE CASES

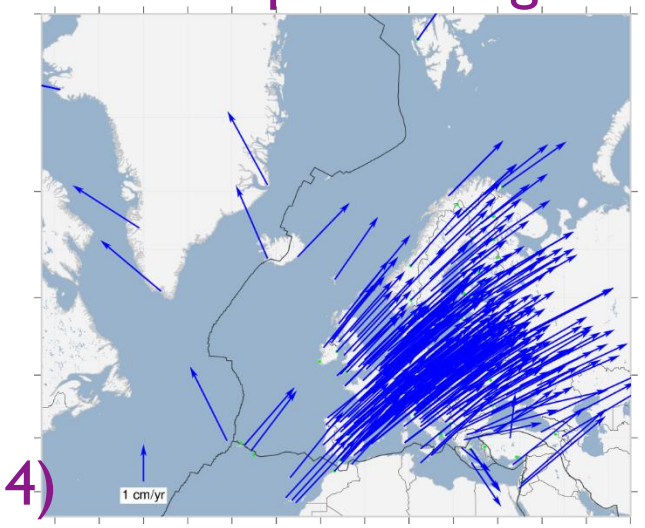
UC5 : Geodesist wants to get reference positions and velocities for his processing

Recommended products :

- EUREF Positions and Velocities (SINEX format) from ROB-EUREF wrt ITRF2014 or ETRF2000/2014

Additional products :

- EPOS–EUREF Positions and Velocities (SINEX format) from LTK wrt ITRF2014



ITRF2014 (IGb14)

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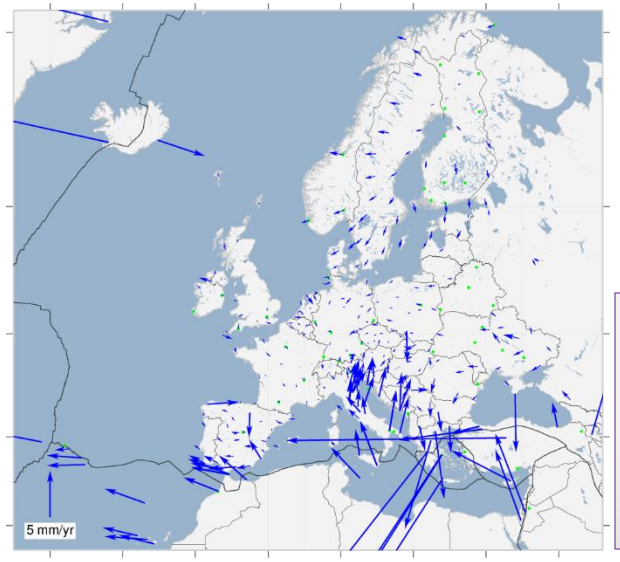
+SOLUTION/ESTIMATE
*INDEX TYPE__ CODE PT SOLN _REF_EPOCH__ UNIT S __ESTIMATED VALUE____ _STD_DEV___
     1 STAX   BOR1  A    1 10:001:00000 m    2 0.373835836922076E+07 0.12576E-03
     2 STAY   BOR1  A    1 10:001:00000 m    2 0.114817378419497E+07 0.57041E-04
     3 STAZ   BOR1  A    1 10:001:00000 m    2 0.502181581428678E+07 0.15176E-03
     4 VELX   BOR1  A    1 10:001:00000 m/y  2 -.173659211197266E-01 0.74991E-05
     5 VELY   BOR1  A    1 10:001:00000 m/y  2 0.156528761430914E-01 0.35223E-05
     6 VELZ   BOR1  A    1 10:001:00000 m/y  2 0.865199891742149E-02 0.91018E-05
```



ETRF2014

```
+SOLUTION/ESTIMATE
*INDEX TYPE__ CODE PT SOLN _REF_EPOCH__ UNIT S __ESTIMATED VALUE____ _STD_DEV___
     1 STAX   BOR1  A    1 10:001:00000 m    2 0.373835873071839E+07 0.12576E-03
     2 STAY   BOR1  A    1 10:001:00000 m    2 0.114817344767030E+07 0.57041E-04
     3 STAZ   BOR1  A    1 10:001:00000 m    2 0.502181562212145E+07 0.15176E-03
     4 VELX   BOR1  A    1 10:001:00000 m/y  2 -.151748349201475E-03 0.74991E-05
     5 VELY   BOR1  A    1 10:001:00000 m/y  2 -.372108189692187E-03 0.35223E-05
     6 VELZ   BOR1  A    1 10:001:00000 m/y  2 -.498730946492080E-03 0.91018E-05
```

Thanks a lot for your attention!

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