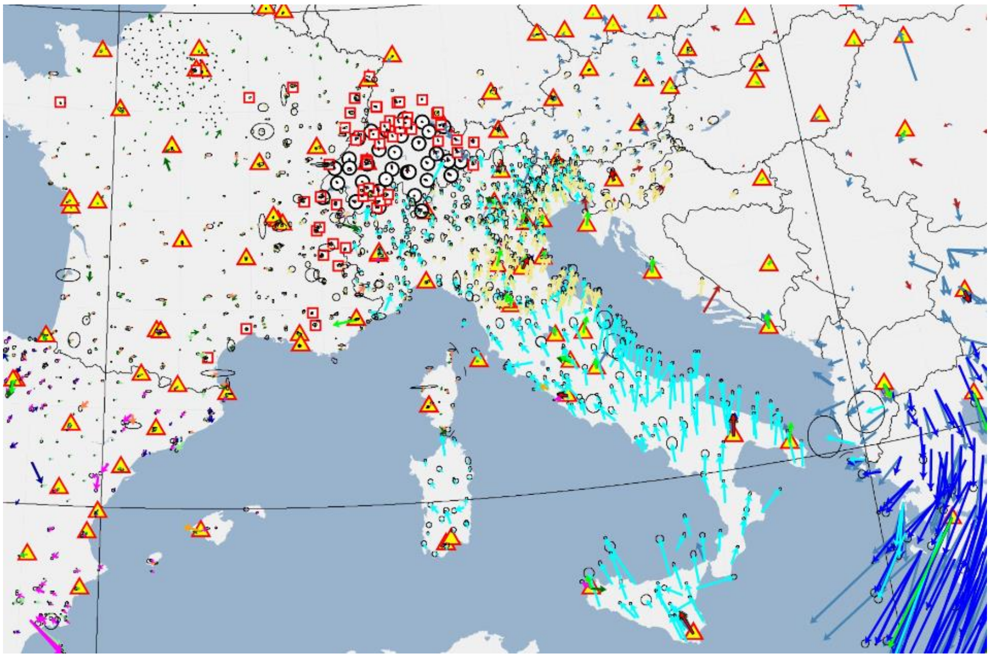
Charter

EUREF Working Group on "European Dense Velocities"



Version 0: March 2017– Draft proposal

Version 1: April 2017 – Draft proposal including partner comments and corrections

Version 2: May 2017 – including inputs from Greece, Catalania, Italy; inputs from TWG members, Kick-off meeting participants, Resolution 2 (Wroclaw, May 2017)

Focus

EUREF is responsible for coordinating all activities related to reference frame maintenance in Europe. With the introduction of ETRS89 a European-wide coordinate reference system is defined which allows to express all geo-basis data in a common reference system.

A basic principle of the coordination work is that networks can be densified from a global level down to a local level. If similar methods and models are applied this can even be done without loss of precision compared to a solution where global and local data are analysed in a common adjustment. In geodesy, this method was applied more than 100 years ago when the national triangulation networks were adjusted. In satellite geodesy this method is used right from the beginning: Global permanent stations are used for estimating global parameters. These estimates are then used for further densifying the networks on the continental or local scale. In statistics this approach is also called "Sequential Least Squares Adjustment". This method is perfectly suited to estimate densified velocity fields in Europe.

Reference frame maintenance means in general to keep track of the position as well as the possible movement of a station. On a global level, station velocities may reach several centimetres per year and a realization of a reference frame means to assign coordinates at a certain epoch and velocities to a station. For Europe the intra-plate velocities of the Eurasian plate are in general small. Therefore, ETRS89 was defined to be identical with the ITRS89 reference system at Epoch 1989.0 and to move with the Eurasian plate about 2.5 cm per year towards North-East.

The ETRF2000 reference frame is the current conventional realization of ETRS89. Most countries define their national reference frames based on ETRF2000 or its predecessors. In such a "static" system the official national ETRF coordinates agree on a 1-3 cm level at a given epoch with "scientific" coordinates, which are derived in a kinematic approach taking into account also the velocity estimates for each station (Brockmann, 2016b).

In most cases, relative velocities between stations of a country are negligible. There are exceptions in several regions (Scandinavia, Italy, Greece, and Turkey). It is worth to mention that the increased precision and the availability of long-term solutions allow to determine velocities on a level of below 0.5 mm / year.

Velocities are becoming an important enhancement to the classical coordinates for all mapping agencies.

The generation of a European velocity field, which is optimally (e.g. in the least squares sense) aligned to existing international reference frames and also to the national frames, is the next logic step to improve the accuracy of the reference frame realisations in Europe. The distributed concept proposed in this project optimally combines the needs of national partners with the harmonisation aspects of the European coordination work.

Structurally, this WG is in between the EUREF Working Groups "EPN Densification" (Kenyeres, 2015) and "Deformation Models" (Lidberg, 2012). This working group is designed as a complementary activity, rather than competing, to other initiative in this area like the mentioned EUREF working groups and other activities in the area of geophysics. It is best suited for all countries which prefer to deliver their sophisticated velocitiy fields. The project accepts the products of WG "EPN Densification" as an additional input for validation. The most important user of the velocity field generated in this collaboration is the WG "Deformation Models". Therefore, the close collaboration with that group is essential during the entire project.
With the existence of a dense, with the countries harmonized kinematic model for station movements, the goal can be reached to extend the reference frame realization accuracy from a given value at a specific epoch (target of 1 cm) to the same amount at any time for entire Europe. The success of maintaining the EU reference frame can be extended from sharing coordinates by adding dense velocity information.

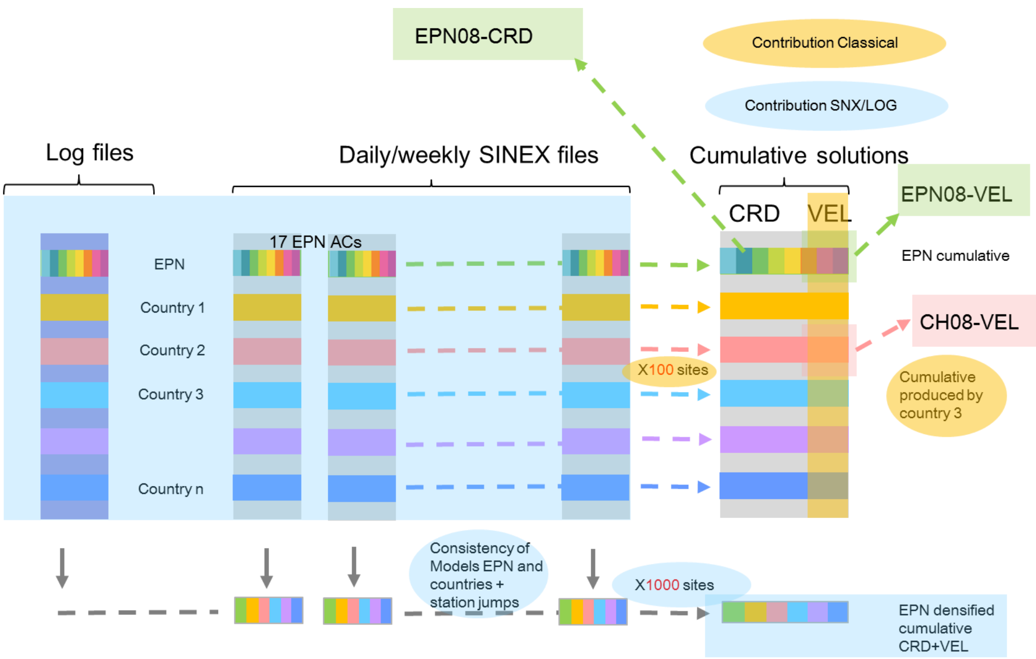


Figure 1: Combination methods: Classical approach (VEL column with yellow background) and alternative approach based on daily/weekly SINEX files and LOG files for each station (light blue background).

Method

Basically, two methods exist to generate / combine velocity estimates of densified networks (beside the method that all original data are processed by a single AC and therefore do not require a combination).

This project makes use of the classical approach, shown in yellow background colouring in Figure 1. The velocity estimates provided by the contributing agencies can directly be used to generate a harmonised European velocity field.

Millimeter-precise coordinates are not required. Also meta data (LOG files) of stations are not required. This method is extremely efficient and guarantees the conservation of the inner geometry of the provided velocity field. Alignment of the local velocity field can be realized by comparing the velocities of commonly processed stations.

The approach which is based on an accumulation of SINEX files (blue in Figure 1) is used by the EPN Densification Working Group. Providers need to send daily/weekly solutions following a common processing procedure together with meta data information (LOG files). The velocity estimation is done centrally based on an accumulation of the provided SINEX files.

As can be seen from Figure 1, a pre-combination of all solutions of a day/week needs to be performed assuming identical modelling and analysis methods. Afterwards, thousands of stations need to be treated to ensure that equipment changes are taken properly into account.

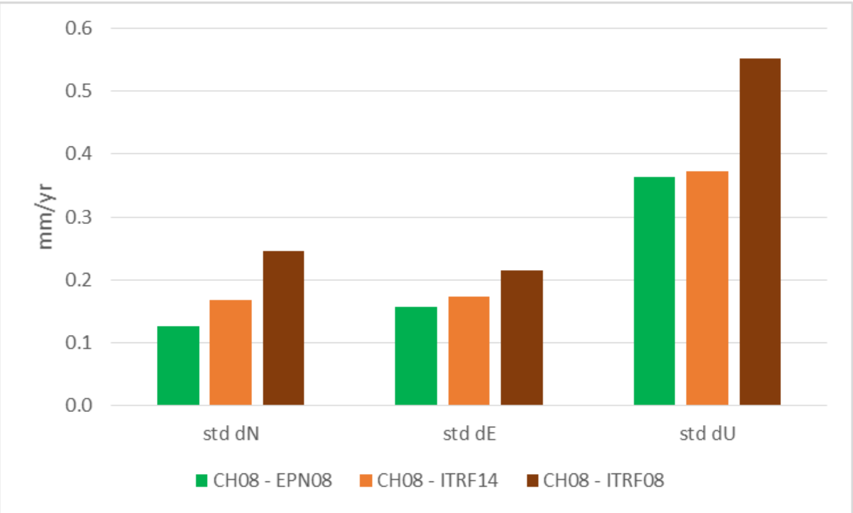


Figure 2: Agreement (standard deviation; std) of the Swiss velocity field CH08 with EPN velocity estimation EPN08 (1875; spring 2016; 81 sites in common), ITRF08 (52 sites in common) and ITRF14 velocities (59 sites in common).

Results generated by analysing the data of a single provider (classical approach) may therefore be different from a solution generated with such a central organized combination scheme.

According to Brockmann (2016a), regional velocity fields generated with the classical approach are highly consistent to continental or global velocity fields (Figure 2).

Nationally generated velocity fields (example of the Switzerland) agree on a high level of accuracy with international velocity fields:

- horizontally: ± 0.2 mm/yr
- vertically : ± 0.4 mm/yr

Errors detected in international / continental frames demonstrate that no reference velocity field is error-free (other comparisons: see chapter "pilot project").

A big advantage of the classical concept is the independence of the modelling used by the velocity field provider. There is no necessity that a common processing procedure is strictly followed. Velocities are almost independent of the used GNSS analysis (tropo models, antenna PCVs). It is much more important that the long-term solutions of the individual providers are based on a consistent modelling over the entire time interval.

Also velocity estimates stemming from PPP solutions, which do not have normal equations containing correlations to neighboring stations as we have when processing network solutions, can be accepted without any difficulties. The velocity fields can be exchanged based on simple ASCII files.

The classical approach involves the partners optimally. It is worth to mention that the contributing partners are often responsible to maintain the national reference frame in their countries. This means that coordinate and velocity estimation is a major task of them. With the existence of permanent networks over time periods of years until decades many countries are already experienced in generating velocity fields.

Furthermore, the countries keep a much better eye on the station and have much better knowledge of possible station environment changes which are not mentioned in any log file. *This project may further encourage the collaboration in this field – extending the knowledge of optimally generating reference frame parameters from the domain of coordinates to the domain of velocities.*

Due to the fact that the provided velocity fields generally keep the internal geometry it is ensured that a final European velocity field is best possible harmonized with the nationally used one.

A huge benefit is that the work can be distributed among the contributing partners. There is no central organisation which needs to take all specialities into account.

The collaboration follows a classical distributed "processing" concept. The bigger responsibility of the partner might also be beneficial for the visibility of the organisations in their countries. The partner is not only a provider of daily analysis results and provider of up-to-date log files: *The velocity product, probably one of the most important product geodetic departments and geophysical institutes are responsible for, is directly used. It is also a perfect opportunity to share results and to profit from the evaluations performed within the project.*

National velocity fields may also include additional observations (levelling, GNSS campaigns) to further stabilize or densify the networks. This is only possible in the classical approach. The inclusion of other sources such as levelling is an important contribution to generate reliable vertical velocity models. The current existing vertical velocities are due to the weaker geometry and the bigger effect of equipment changes probably about 5 times worse compared to the horizontal velocity fields. To provide all information (campaigns, levelling, modelling information from earth models as in the Nordic countries) also to the EPN densification in order to allow a combination is in view of the complexity level not realistic. Here, the project benefits from the activities of the partners. Furthermore, it would be a waste of resources if same activities are doubled.

Velocity fields, which are generated in the country and further developed to a grid (example Nordic countries) can also be used as input for the generation of a European velocity field. The European dense velocity field integrates this national grid without introducing any distortions. Such a procedure guarantees also for a country that EU- and national solutions using such grids for datum transformations are compatible.

Prototype

Many positive reactions followed the presentation in San Sebastian (Brockmann, 2016a). With a delay of only one day a complete velocity field for Greece was provided to the author. Several other velocity fields followed the weeks after, the latest contribution was from OLG end of summer 2016.
It is impressive how many velocity fields are already existing (and are available already in the reference frame ETRF2000). This proves the statement that the countries are taking their responsibility of reference frame maintenance (coordinates and velocities) already very seriously.

Table 1 indicates the contributions, the number of provided velocities and the approximate focus of the area.

Identifier	Agency	Region	# stations
EPN08	EPN, Kenyeres	Europe	259
ITRF2014	IGN, Altamimi	Global	148
ITRF2008	IGN, Altamimi	Global	103
CH08	swisstopo	Switzerland	230
GR08	Aristotle Univ. Thessaloniki	Greece	181
CGN08	CEGRN consortium	East Europe	61
IT08	Univ. Padova	Italy	645
ESP08	IGN Spain	Spain	341
BASC08	ARA	Spain	251
RGP08	IGN France	France	544
WALP08	Univ Montp.	West Alps	182
NOQU08	Univ Montp.	West Alps	76
ALP08	AlpArray	Alps, Italy	498
NKG03	NKG	Nordic EU countries	556*
ARE08	OLG	Austria	117
EGU08	OLG	SE-Europe	181
IUG08	OLG	SE-Europe	47
MON08	OLG	SE-Europe	69
CAT08	IGCG	Catalonia	150

* Velocity grid (1/12° Lat. x 1/6° Lon.) – can be plotted with any resolution.

Table 1: Solutions of the pilot project. Ordering is according to the time of providing the field. First four contributions are used in Brockmann 2016a for evaluation (see Figure 2).

In the pilot project, the provided velocity fields were combined in a simple way. All velocity fields were already aligned to ETRF2000, thus no special reference frame alignment had to be applied.

A quick view on the achieved results is given in Figure 3 for the horizontal velocity field and in Figure 4 for the vertical velocity field.

The main focus of the pilot project was not an evaluation of the quality of each solutions. The general agreement between the solutions is encouraging, as shown in Figure 5 for some selected sites (zoom-ins of Figure 3 and Figure 4).

Europe
EU horizontally: **bit.ly/EU_VEL_HOR** http://pnac.swisstopo.admin.ch/divers/dens_vel/vel_eu_all_cmb_dh.jpg
EU vertically: **bit.ly/EU_VEL_UP** http://pnac.swisstopo.admin.ch/divers/dens_vel/vel_eu_all_cmb_dv.jpg

South-East Europe (Greece, Italy, Spain)
EU SE: horizontally: http://pnac.swisstopo.admin.ch/divers/dens_vel/vel_eu_se_all_cmb_dh.jpg
EU-SE: vertically: http://pnac.swisstopo.admin.ch/divers/dens_vel/vel_eu_se_all_cmb_dv.jpg

South-West Europe (Spain, Italy)
EU-SW: horizontally: http://pnac.swisstopo.admin.ch/divers/dens_vel/vel_eu_sw_all_cmb_dh.jpg
EU-SW: vertically: http://pnac.swisstopo.admin.ch/divers/dens_vel/vel_eu_sw_all_cmb_dv.jpg

Table 2: Static plots generated in the pilot project.

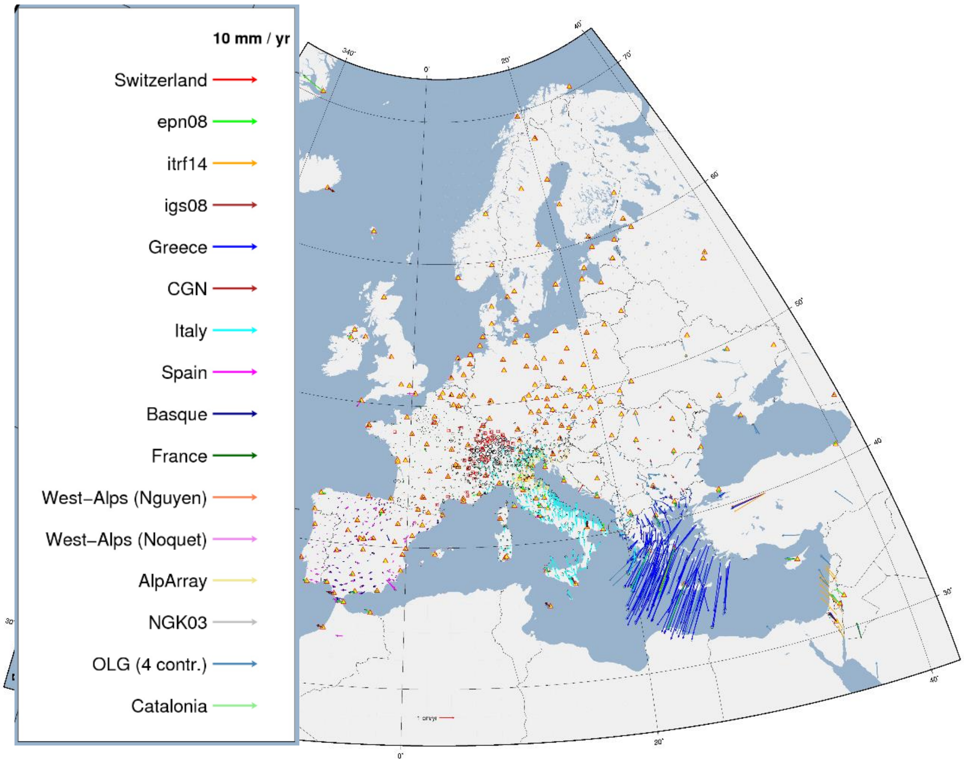


Figure 3: Combined horizontal velocity field of the pilot project. EPN stations are signed as triangles.

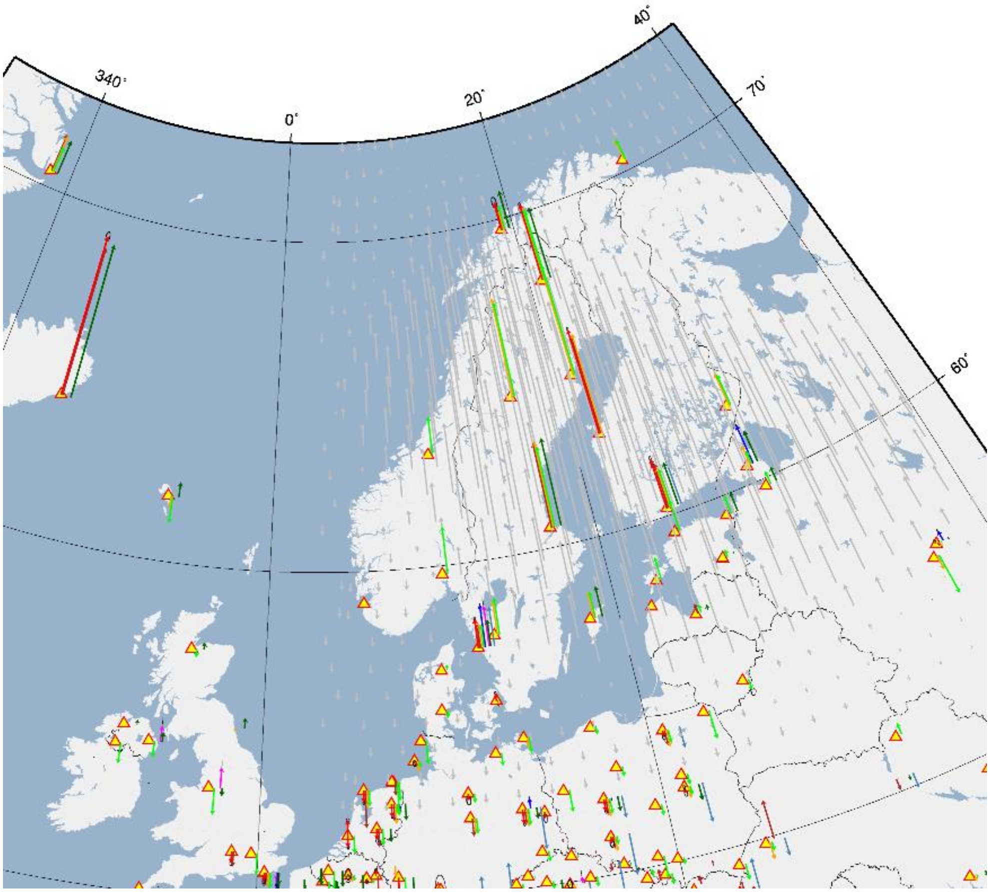


Figure 4: Combined vertical velocity field of the pilot project with the focus on Northern Europe. EPN stations are signed as triangles. The NKG velocity grid is plotted in gray.

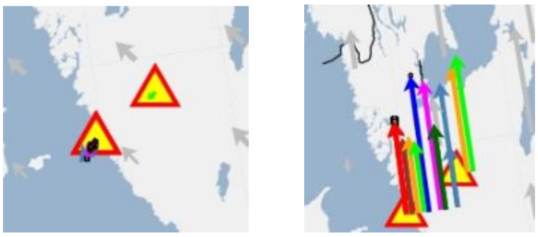
Totally, 2272 different sites with velocity estimates are provided (the 556 NKG grid points are not counted). Many stations are observed by several contributors (13 times: MATE, ZIMM; 12 times: GRAZ; 11 times: NICO, SOFI NICO; 10 times: GRAS, NOT1).

The AlpArray velocity field was generated using the PPP technique. The provider validated also an exchange in the IGb08 frame instead of an exchange in ETRF2000. The Swiss velocity field was compared with their velocity field by estimating translations and rotations using common sites. They reported an RMS fit of 0.19 mm/yr for 114 common sites.

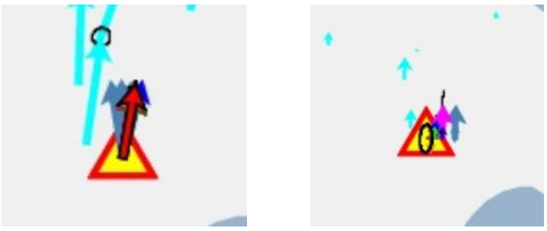
Several other countries expressed their willingness to send a velocity field as soon as they have generated one or expressed their wish to participate in the project in order to extend their knowledge of how to generate a velocity field.

Proposed activities

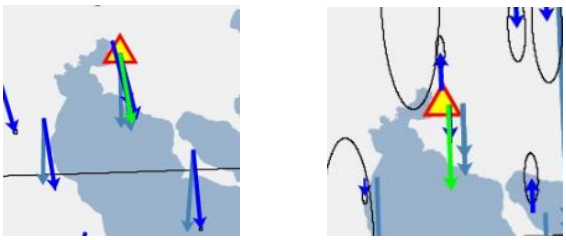
There is a longer list of activities which waits for realization. It is evident that this project is realized by its contributors. During the project run-time tasks may be worked on by several persons.



ONSA (Sweden)



MATE (Italy)



AUT1 (Greece)

SFER (Spain)

Figure 5: Comparison of velocity estimates at some stations (horizontal velocities left, vertical velocities right): Schematic view.

Here, a list of activities, foreseen at project start:

- **Common exchange format**
For the pilot project all ASCII formats were accepted. A generalized format might be beneficial, especially when exchanging the format between the partners. The question may also be answered if in addition to the velocities further information should be provided (formal accuracies, correlation coefficients, time interval used to determine the velocities).
- **Data Policy**
The data of the providers can freely be distributed among the partners of the project. Details on data distribution will be developed within the project.
- **Publications**
Scientific publications using the data or methods developed in this project are welcome. If data from this project are used or individual data stemming from the partners are used within a scientific publication, proper acknowledgement to the contributors is requested.
- **Visualization tool**
Instead of static plots it would be helpful to develop a graphical tool (e.g. based on Google earth) helping to evaluate outliers in velocity estimates. Eventually, a dedicated web page is created for that purpose.
- **Exchange of experiences**
Exchange of tools/software helping to best possible generate a velocity model
- **Evaluation of the accuracy of each contributing velocity field**
Outliers and possible reference frame misalignments need to be identified. From the pilot project we learned that also the ITRF and EPN velocity fields contain outliers. Therefore, the procedure needs to be developed in a way that no pre-defined reference velocity field is used. Also the velocity field of the EPN Densification WG may be evaluated. Iterations and update procedures (after detecting outliers or replacing solutions based on reprocessing effort or because more reliable estimates due to a longer time interval) accomplish the evaluation phase.
- **Interfaces**
Interfaces to the Working Groups "EPN Densification" and "Deformation Models" need to be established.
- **Harmonizing Efforts**
This step is probably the most important step of the project. The velocity estimates for each station need to be adjusted based on the quality detection procedure. The various levels

of products need to be taken into account. If a velocity grid is provided, which is already a product of a complex adjusted velocity field estimation, this grid will be kept fix. Only in case of misalignments of overlaps to neighboring areas a general Helmert shift/rotation/scale might be applied. The harmonization methods need to be developed during the project run time, especially in close collaboration with the "Deformation Model" WG. A final product of this collaboration could be the velocity field for selected sites or a grid (after defining grid type, format and access routines).

- **Invite partners joining the Working Group**
  Several groups expressed their interest. Germany (BKG, KEK), agreed already to contribute densified velocity fields. Everyone, even if not yet capable to contribute a velocity field is invited. Especially groups which like to develop their knowledge or are specialized in helping to work on the task list (visualization, combination, grid generation) are welcome.

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Resolution 2 (Wroclaw, May 2017)

The IAG Reference Frame Sub-commission for Europe (EUREF)

recognising that national, dense velocity fields are now available in several areas of Europe

and considering the demand to derive a dense European velocity field which is compatible with nationally implemented velocity fields

encourages the continued submission of SINEX files to the EPN Densification Working Group and, from institutions computing velocity fields, to deliver these to the Dense Velocities Working Group.

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