How to fix the geodetic datum for reference frames in geosciences applications?

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IAG Scientific Assembly, Symposium 1, Buenos Aires 2009

Introduction

1. The definition

The Geodetic Datum provides the origin, orientation and unit length of a geodetic coordinate system with respect to a physical body (e.g., the Earth). All geodetic parameters refer to the given Geodetic Datum.

2. The problem

The most challenging task of modern geodesy is the accurate measurement and reliable representation of global phenomena and processes of the System Earth for applications in geosciences (e.g., global change).

3. The requirement

For a unique and unequivocal representation we need a reference frame relating to one and the same datum over *very long time periods* (stability over decades).

Nomenclature

1. **Datum parameters**
   Origin, orientation, unit length

2. **Network (or frame) motions** (w.r.t. to ***one*** given datum)
   Network shift, network rotation, network dilatation

3. **Similarity transformation parameters**
   Translation, orientation change, scale factor of one network w.r.t to another one with a **different** datum.

- A deformed network is ***not*** similar to the original net. E.g., change of flattening requires affine transformation.
- A similarity transformation ***changes*** the datum.
- Transforming two geocentric networks at different times provides parameters of the average **network motions** (and **not** a datum change, which remains geocentric)

Current Status

- The Geodetic Datum of the International Terrestrial Reference Frame (ITRF) is ***defined*** by

  - the origin of the coordinate system in the Earth's centre of mass (geocentre),

  - the orientation of the coordinate axes according to Earth Orientation Parameters (EOP) of BIH 1984.0.

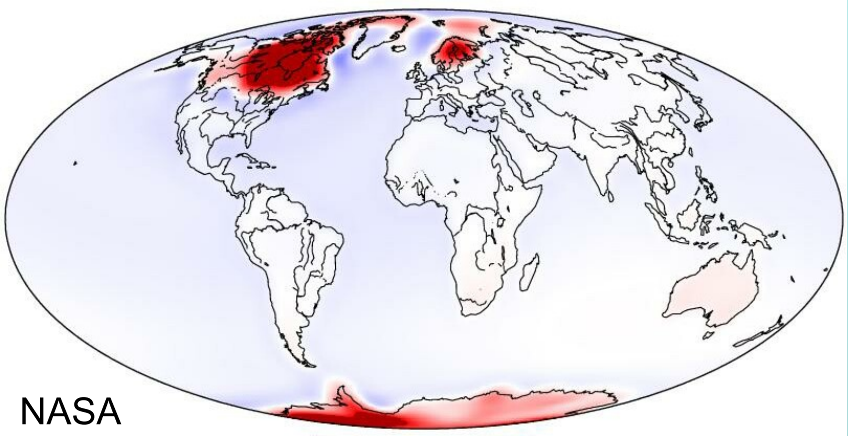
  - the unit length metre according to BIPM convention.

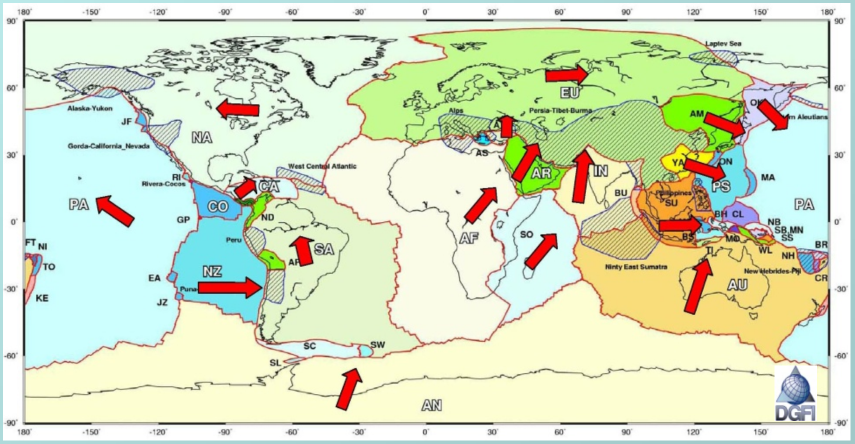
- The Geodetic Datum is often ***realized*** by transformation of an observed station network to an existing reference frame, e.g., by “no net translation”, “no net rotation” and/or “no net scale” conditions (NNT, NNR, NNS).

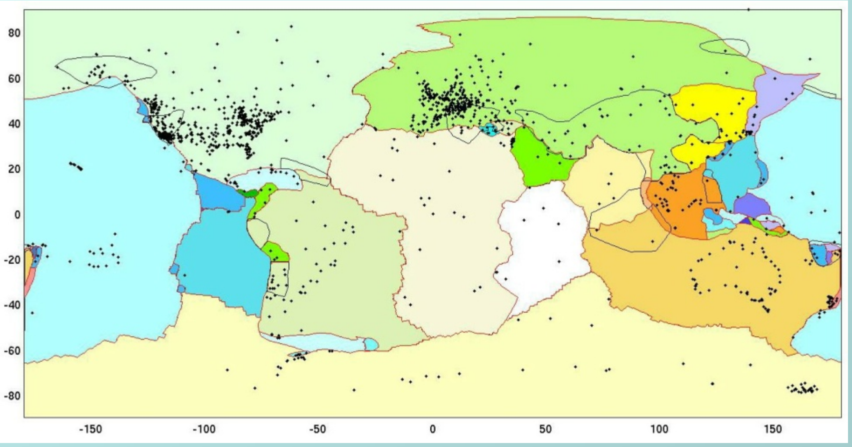
- These transformations cause the trouble of using the reference frame for applications in geosciences: They change the datum by *similarity transformations*.

Geophysical Prerequisites

- The Earth's surface undergoes *global* deformations, e.g., ***vertical*** deformations by glacial isostatic adjustment, ***horizontal*** deformations by tectonic processes (plate tectonics, intra- and inter-plate deformations)

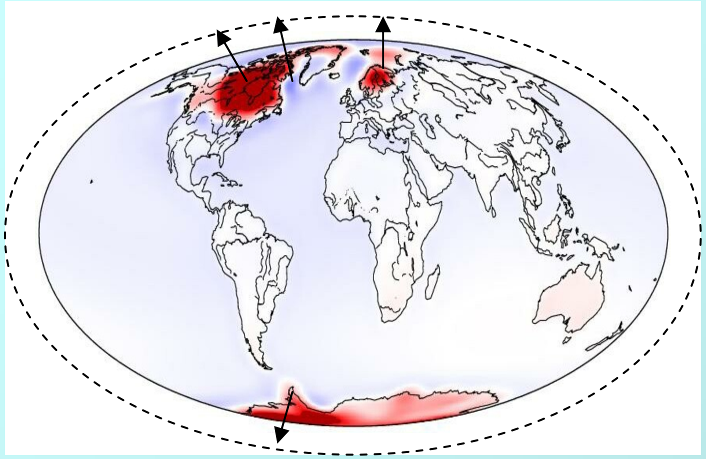


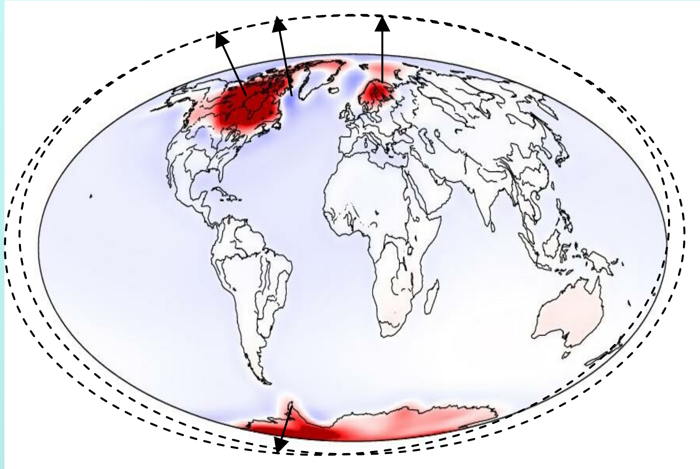




- The station distribution for monitoring the deformations is very inhomogeneous (bulk in North America and Europe)

Effects of Similarity Transformations
1. Vertical Deformations





We transform a network observed at time t + Δt to the same net at time t.

a) If the vertical motion is the same in all points, it appears as a scale factor, *not* as a displacement.

b) If the vertical motion is different in the northern and the southern hemi-spheres, it appears as a translation **and** as a scale factor.

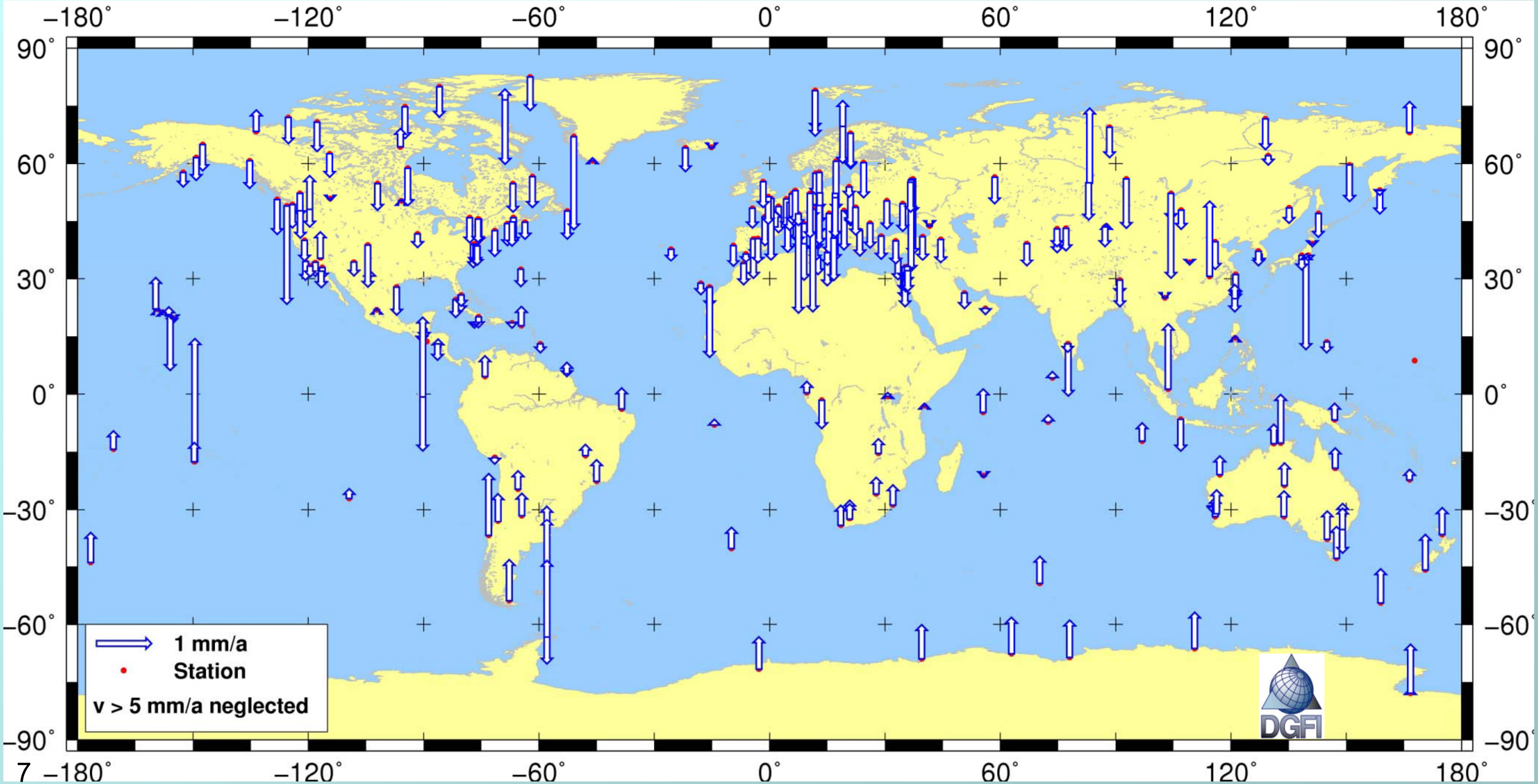
c) Due to the inhomogeneous station distribution (network centre ≠ origin) there may also appear rotations.

What is shown for displacements holds also for velocities!

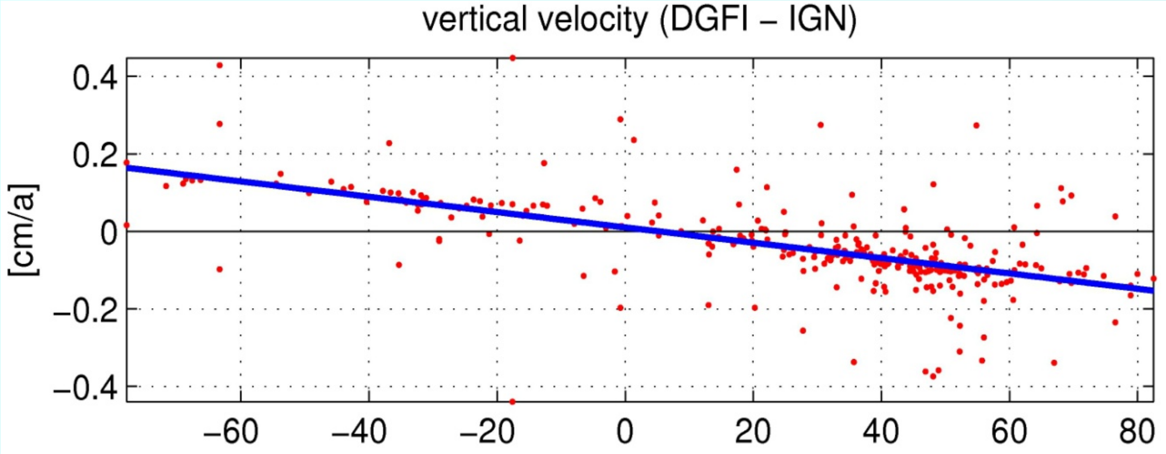
DGFI

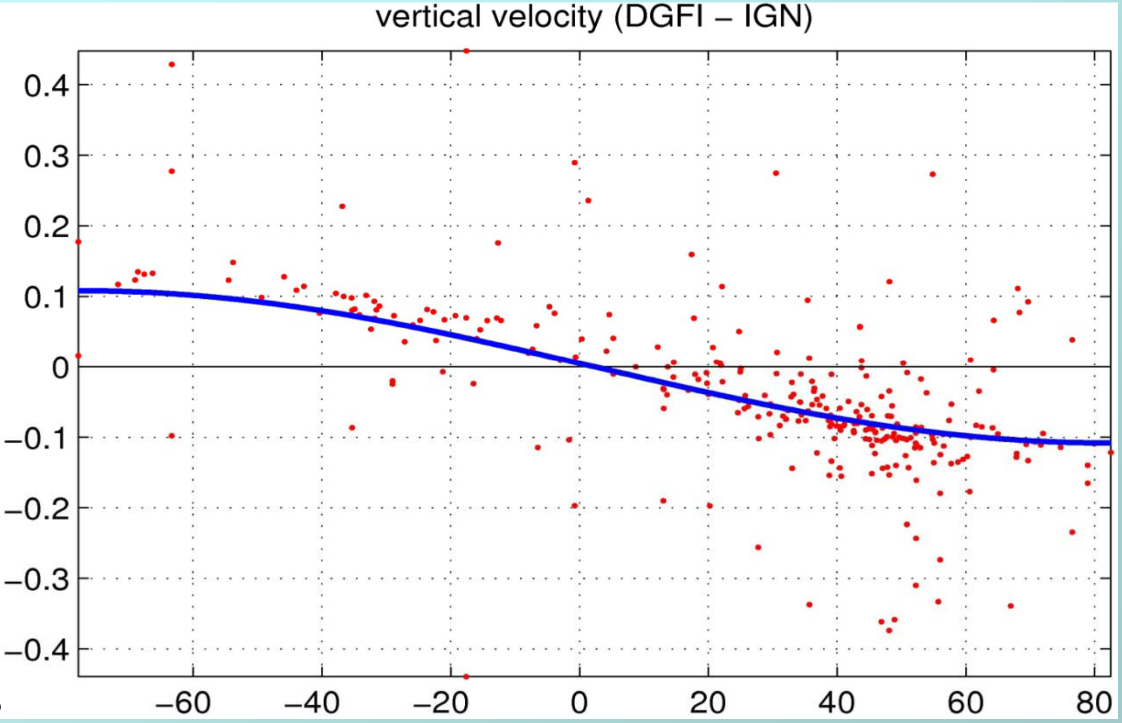
Example 1

The ITRF2005 was computed by IGN Paris using similarity transformations, and by DGFI Munich accumulating normal equations. There are systematic vertical velocity differences.



Example 1 (continued)



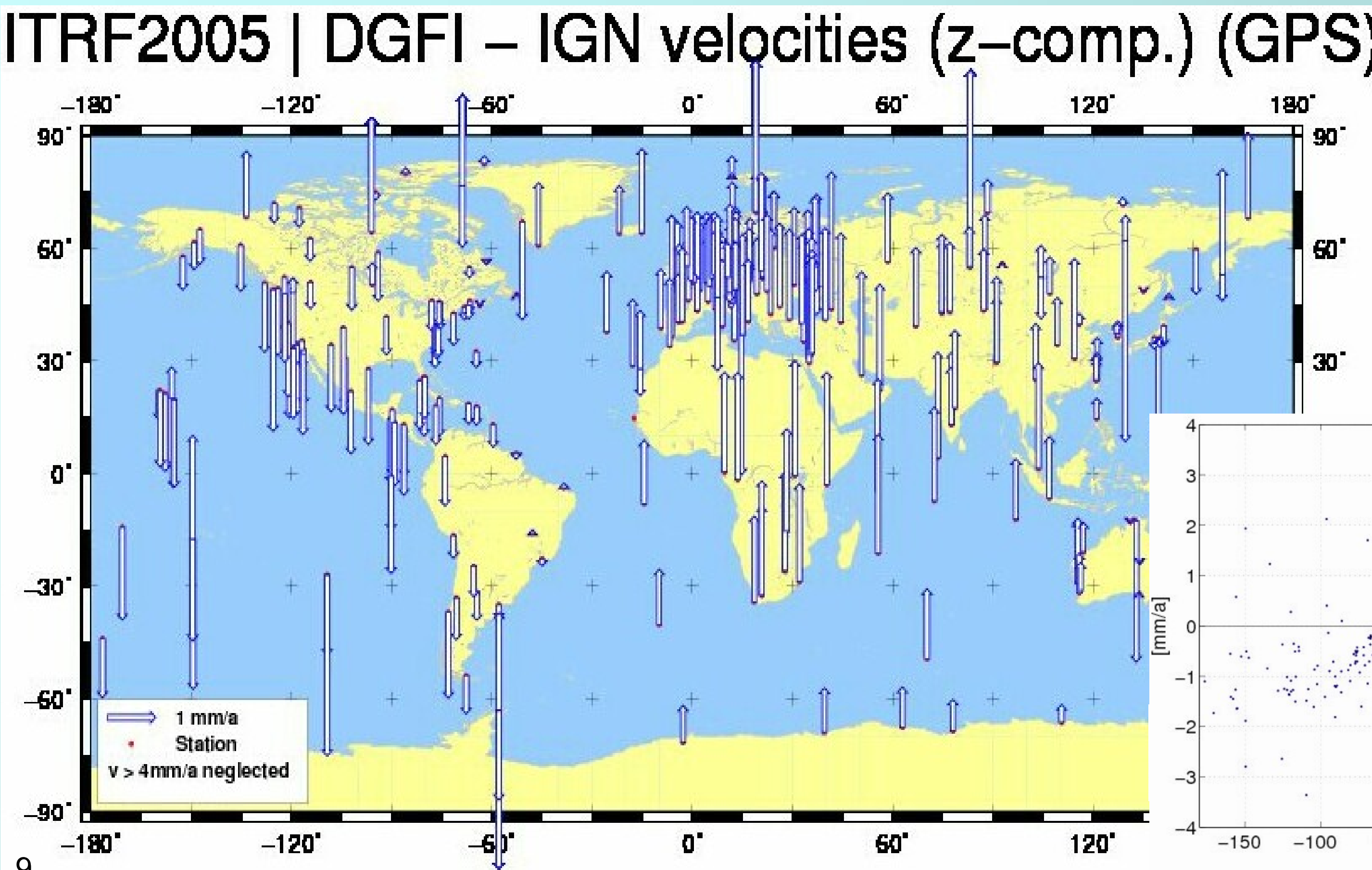


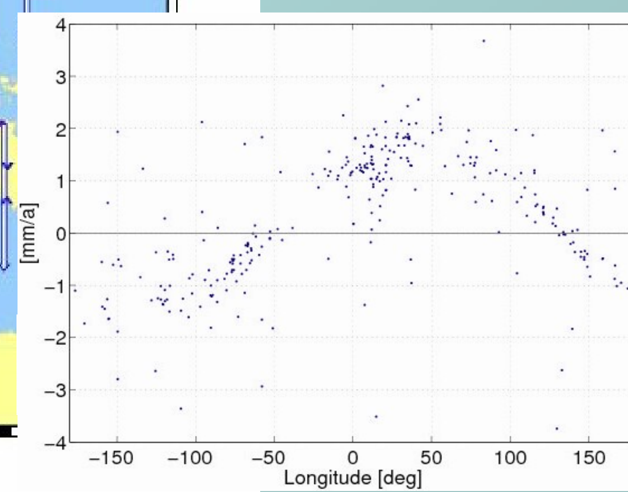
There is a clear systematic effect of differences in vertical velocities depending on the latitude.

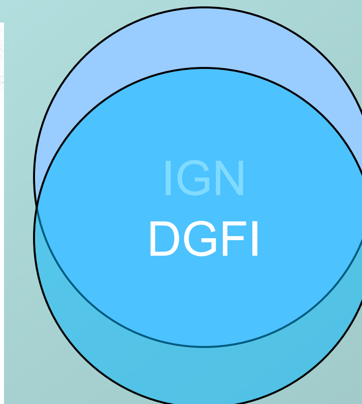
The good fit of the sine of latitude function indicates a translation of the network in z-direction

Example 1 (continued)

There is a clear systematic effect of differences in z-direction appearing as a translation parameter in similarity transform and a longitude dependence indicating a rotation.

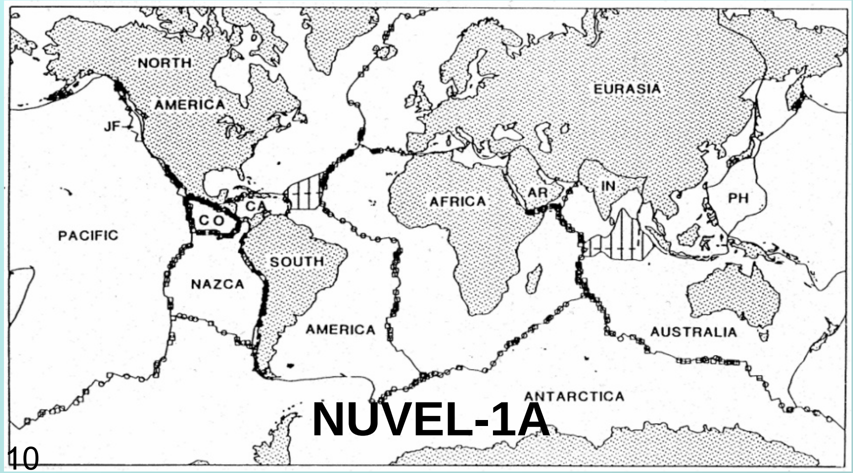




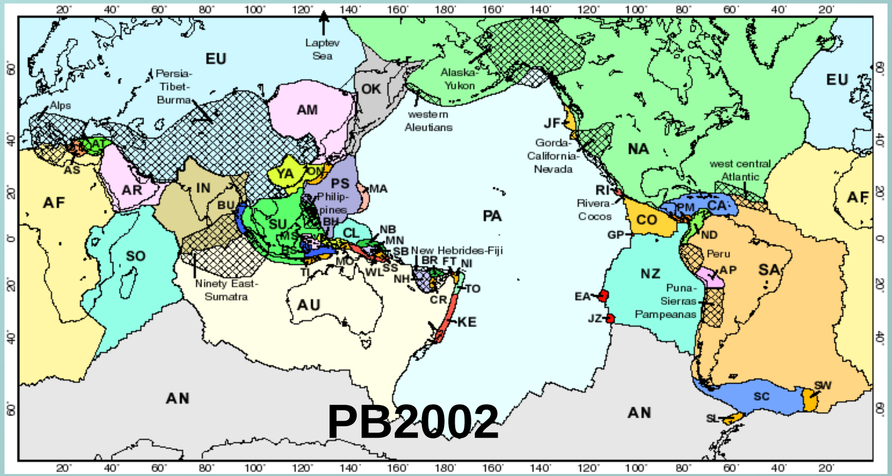


Effects of Similarity Transformations
2. Horizontal Deformations

- Horizontal deformation is mainly caused by plate tectonics.
- The kinematic datum of the ITRF is *defined* by a condition of no net rotation with regards to horizontal tectonic motion.
- The kinematic datum is *realized* by transforming geodetic velocities to NNR NUVEL-1A geologic-geophysical model.
- NNR NUVEL-1A does not fulfil the NNR condition, because the extended deformation zones are not considered.



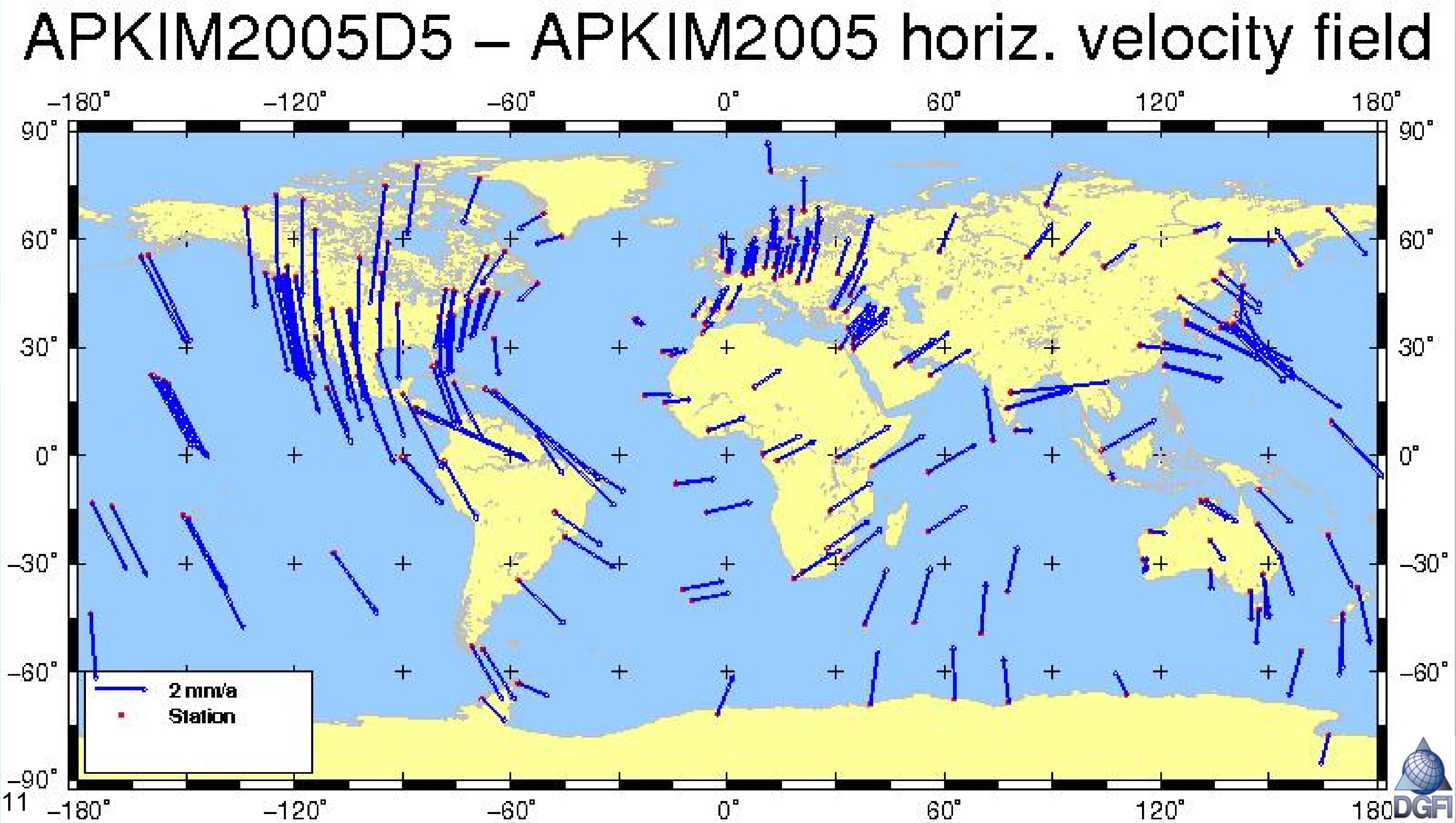
NUVEL-1A



PB2002

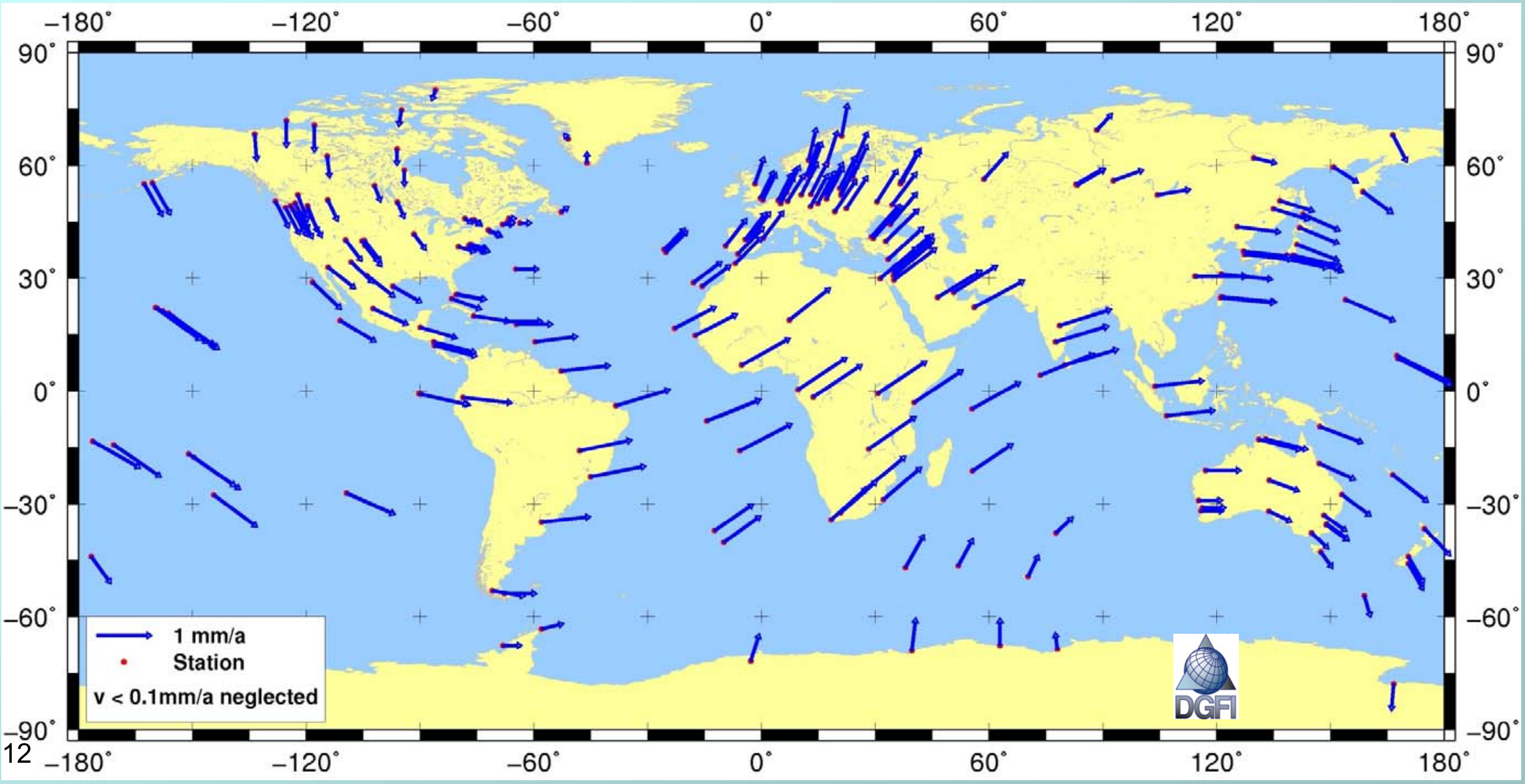
Example 2

In ITRF2005, IGN computed velocities w.r.t. NNR NUVEL-1A, DGFI computed an Actual Plate Kinematic Model. Differences:



Example 2 (continued)

The no net rotation condition for the kinematic datum realized by DGFI (ITRF2005D) is similar to differences between DGFI and IGN velocities. (⇒ Plate motions cause translations, too!)



How to Fix the Geodetic Datum?

- The realization of the geodetic datum by similarity transformation to other reference frames is **not** a suitable approach, because network deformations in arbitrarily selected stations change the datum definition.
- Fixing the **origin** to the geo-centre must by done by a gravimetric approach as a *network independent* method:

Geo-centre = mass centre / Gravity spherical harmonics

$$X_0 = \iiint X \, dm / M \qquad C_{11} = \iiint X \, dm / a M$$
$$Y_0 = \iiint Y \, dm / M \qquad S_{11} = \iiint Y \, dm / a M$$
$$Z_0 = \iiint Z \, dm / M \qquad C_{10} = \iiint Z \, dm / a M$$

- There is no time evolution of the origin. It remains for ever in the geo-centre and has to be realized this way in order to guarantee the long-time stability for geosciences.
- Model errors must go to the parameters not to the datum!

How to Fix the Geodetic Datum?

- The **orientation** could also be realized by gravimetric methods through the principal axes of inertia. As these axes cannot be determined with the required accuracy, the orientation must be fixed conventionally (BIH84).
- The time evolution of the orientation must guarantee consistency between EOP and station velocities. This requires a *present-day* no net rotation constraint and cannot be fulfilled by geological-geophysical models.
- The **scale** has to be fixed to the metre unit by precise calibration of the measuring instruments and correct reduction of physical effects.
- There is no time evolution of scale (it remains metric).
- All problems discussed here for the **global** datum and **long-term** motions are similar for **regional** frames and **periodic** station movements (see SIRGAS presentation).

Thank you very much!