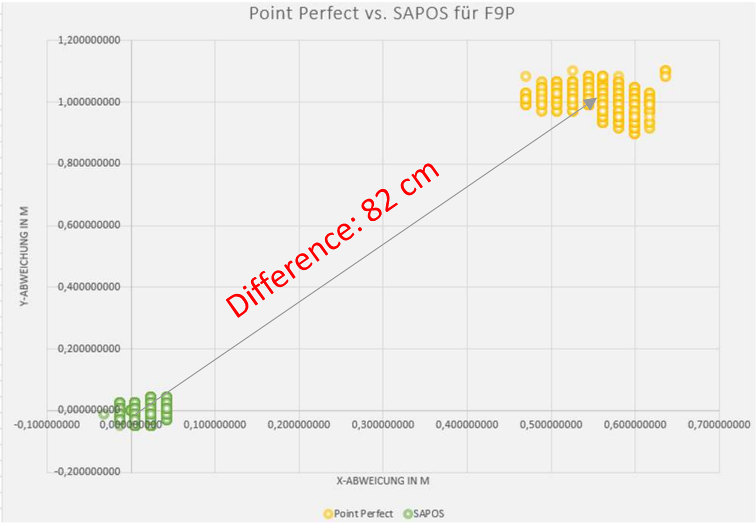
Correction service reference frames

07.12.2022

u-blox SER

What is the problem?

Comparing different correction service providers might lead to different results



Europe

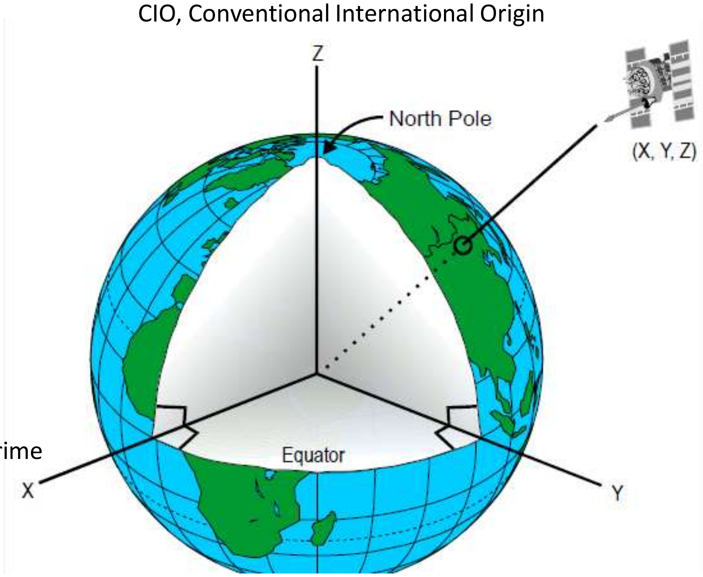
Customer Case Germany

Which solution is the right one?

Coordinate System

Worldwide Coordinate **System** for GNSS

CIO, Conventional International Origin



Going through prime meridian / Greenwich

Coordinate System

System Definition

Center: XYZ=0, Center of Earth's mass

Axis: Orientation of axis

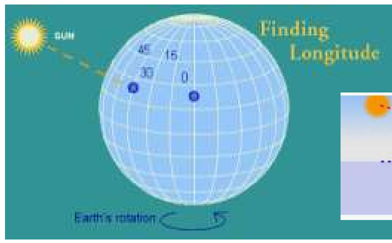
Sum of all movement on Earth's surface is zero

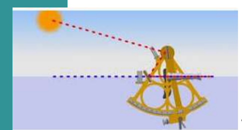
There is no practical use in having a defined (theoretical) system. You do not see the center or any axis, you need **reference points** to be able to connect or tie in to the coordinate system

Coordinate Frame

Way to tie in / Reference **Frame**

Long long time ago





Sextant

Sun & Moon used as reference

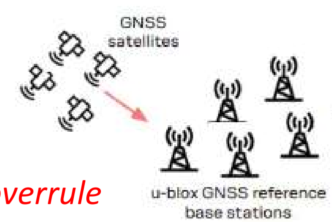
Not too long ago and still in use

Tachymeter

Physical Surveying Control Points

Today

XYZ



XYZ

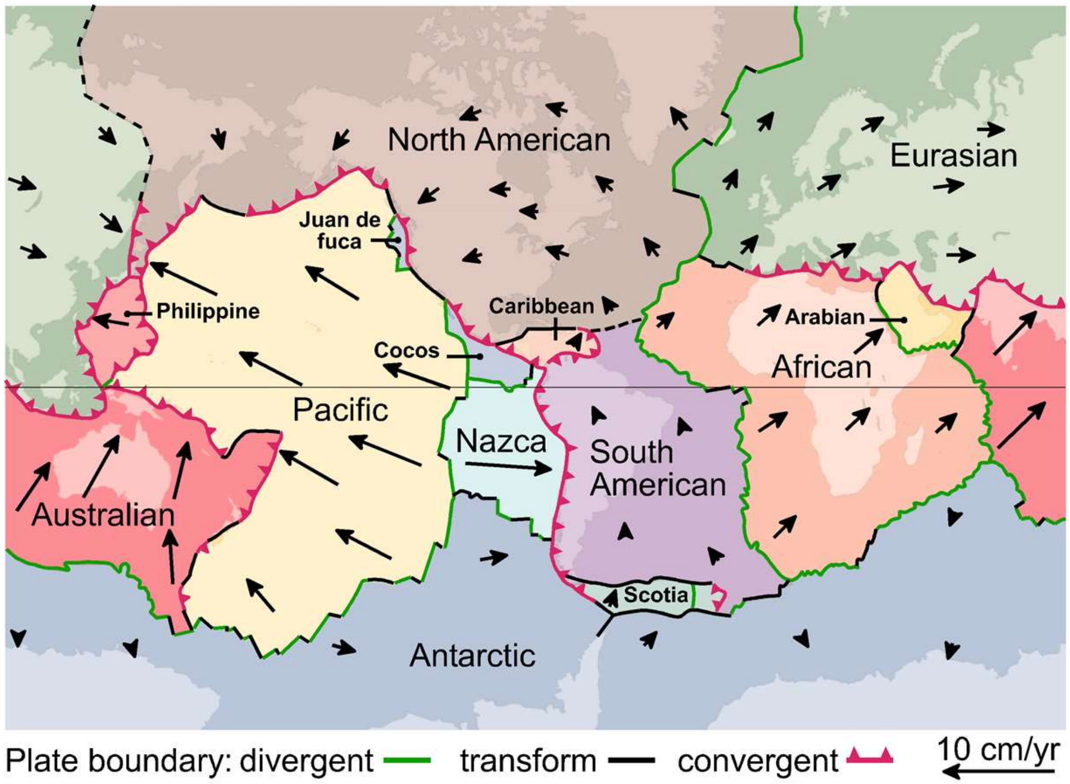
GNSS device

Virtual Reference Points, satellites and reference stations

Note: Reference Station coordinates overrule satellite coordinates

Problem – The Earth's surface is not static

NAMED TECTONIC PLATES and their motion

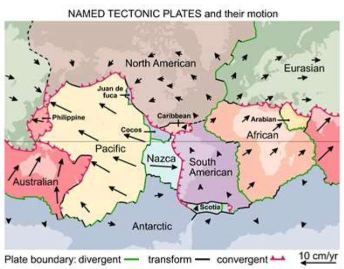


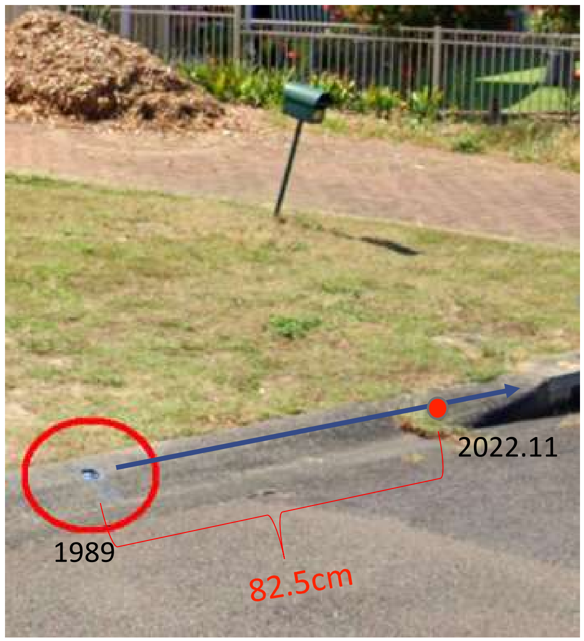
While the coordinate system itself is fixed and does not change the point on the surface move and change over time (Europe and North America ~ 2.5 cm a year).

Not only where you are but also "when"

Problem – The Earth's surface is not static

Visualization





33years*~2.5cm = ~82.5 cm

Let's assume the blue arrow is the direction of plate movement of this specific place on earth.

~80cm movement in 30 years

Solution by IERS

International Earth Rotation and Reference Systems Service (IERS)

International Earth Rotation and Reference Systems Service

https://www.iers.org/IERS/EN/DataProducts/ITRS/itrs.html

https://www.iers.org/IERS/EN/DataProducts/ITRF/itrf.html

- Established 1987
- Definition of International Terrestrial Reference System (ITRS - the ideal reference system)
- Providing worldwide set of reference points realizing the ideal system, called International Terrestrial Reference Frame

The International Terrestrial Reference Frame (ITRF)

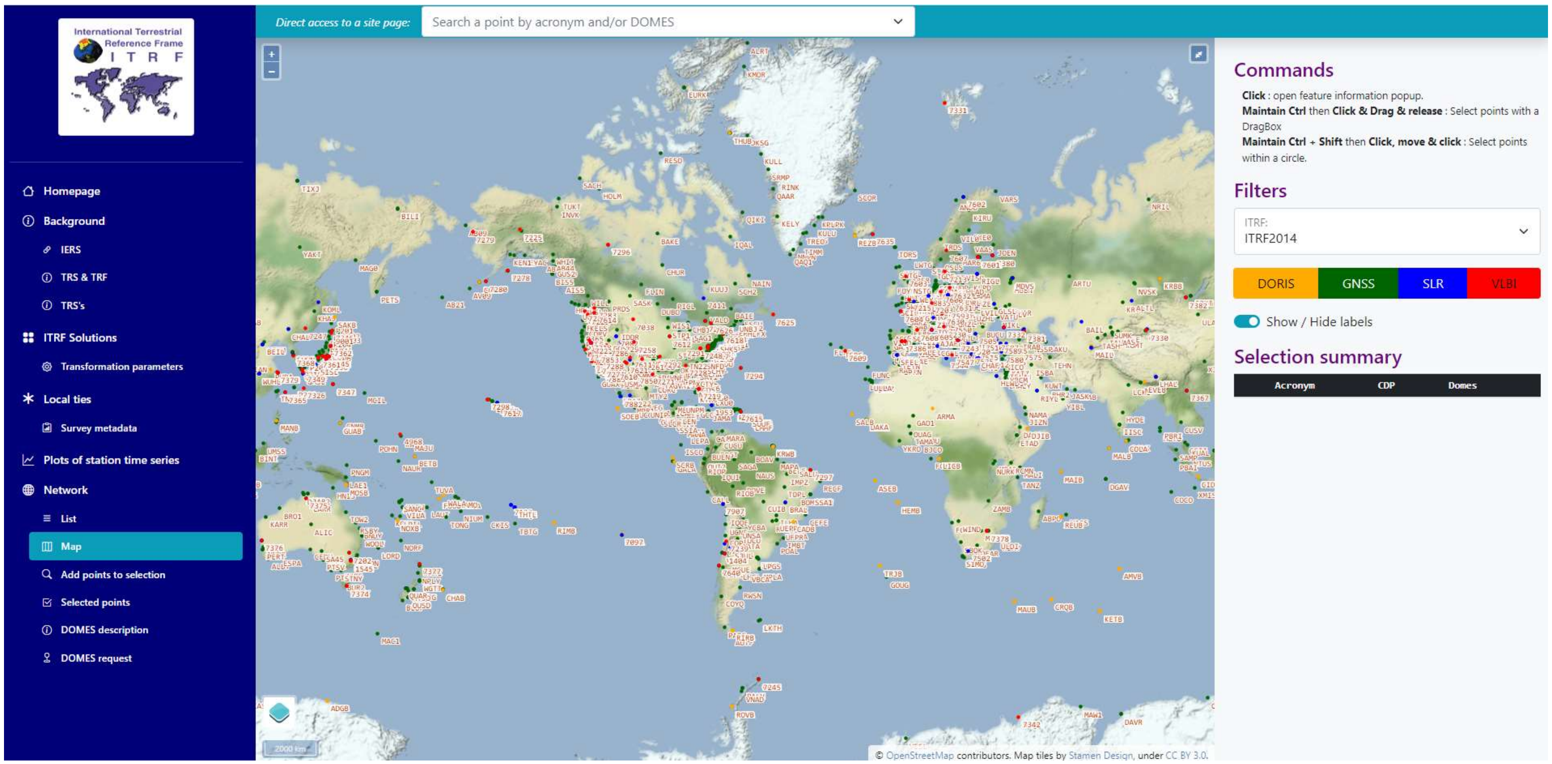
The International Terrestrial Reference Frame (ITRF) is a set of points with their 3-dimensional cartesian coordinates which realize an ideal reference system, the International Terrestrial Reference System (ITRS), as defined by the IUGG resolution No. 2 adopted in Vienna, 1991.

Coordinate Frame is a set of points described by 3D cartesian coordinates and their velocities – a realization of the "ideal" Coordinate System

ITRF 2014

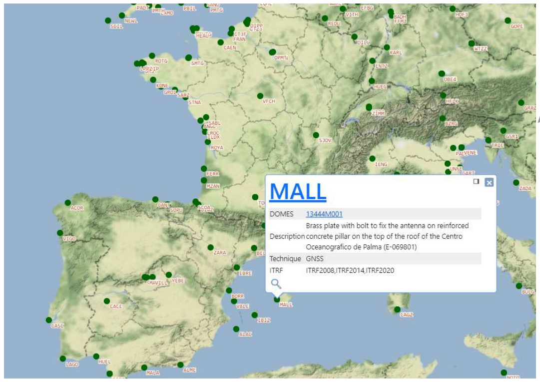
How does it look like?

https://itrf.ign.fr/en/solutions/itrf2014



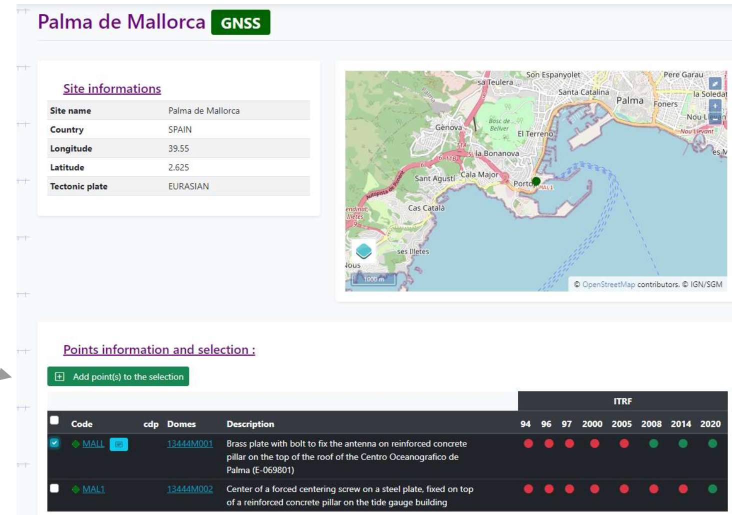
ITRF 2014

How does it look like?



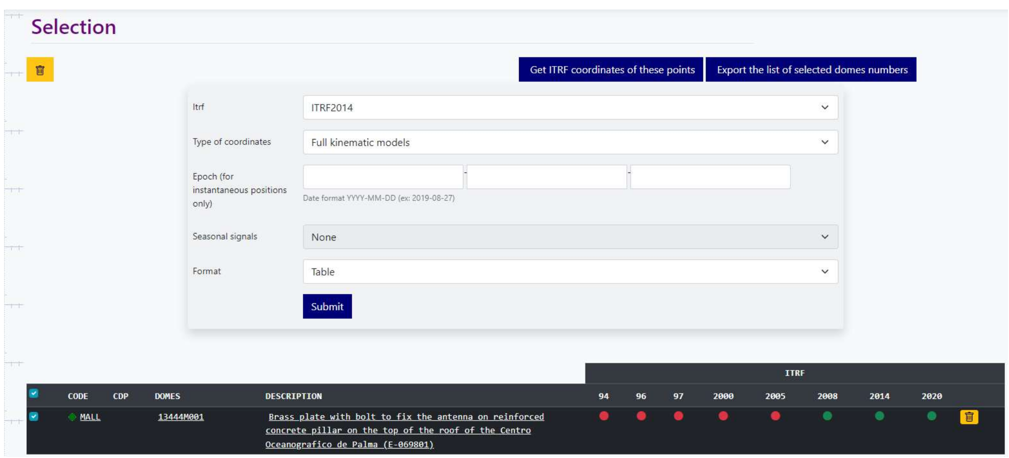
- Zoom in, filter for GNSS only and pick a site
- Click on site

1



Mark site and choose +Add ….

2



3

- Choose Get ITRF coordinates….
- Choose Full kinematic models
- Submit

Also available as excel sheet or txt with same station naming convention

ITRF 2014 Mallorca

How does it look like?

Year Day

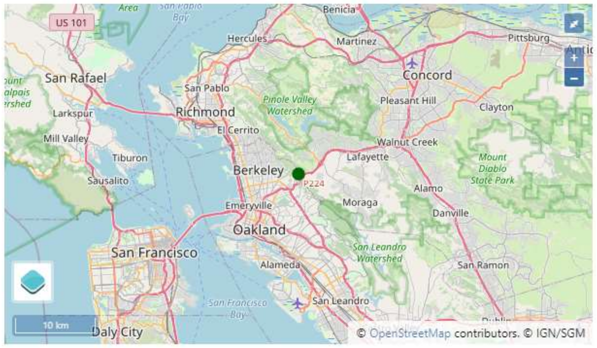
Coordinates

DOMES	ID	PT	PARAMETER TYPE	VALID_FROM	VALID_UNTIL	UNIT	VALUE	SIGMA
13444M001	MALL	A	X position at t0 = 15:001:00000	00:000:00000	03:229:00000	m	4.91936934642661e+06	3.59107e-02
13444M001	MALL	A	Y position at t0 = 15:001:00000	00:000:00000	03:229:00000	m	2.25500064369740e+05	1.34814e-02
13444M001	MALL	A	Z position at t0 = 15:001:00000	00:000:00000	03:229:00000	m	4.03984996274968e+06	2.81715e-02
13444M001	MALL	A	X velocity	00:000:00000	03:229:00000	m/y	-1.14316987698867e-02	2.85035e-03
13444M001	MALL	A	Y velocity	00:000:00000	03:229:00000	m/y	2.00873055726511e-02	1.08198e-03
13444M001	MALL	A	Z velocity	00:000:00000	03:229:00000	m/y	1.23370647664247e-02	2.23462e-03
13444M001	MALL	A	X position at t0 = 15:001:00000	03:229:00000	08:304:00000	m	4.91936935617296e+06	9.53512e-03
13444M001	MALL	A	Y position at t0 = 15:001:00000	03:229:00000	08:304:00000	m	2.25500024830929e+05	3.22225e-03
13444M001	MALL	A	Z position at t0 = 15:001:00000	03:229:00000	08:304:00000	m	4.03984996865617e+06	7.97187e-03
13444M001	MALL	A	X velocity	03:229:00000	08:304:00000	m/y	-1.13552921105753e-02	1.06069e-03
13444M001	MALL	A	Y velocity	03:229:00000	08:304:00000	m/y	1.73045368233061e-02	3.58272e-04
13444M001	MALL	A	Z velocity	03:229:00000	08:304:00000	m/y	1.37241020258569e-02	8.82619e-04
13444M001	MALL	A	X position at t0 = 15:001:00000	08:304:00000	00:000:00000	m	4.91936934955635e+06	1.08741e-03
13444M001	MALL	A	Y position at t0 = 15:001:00000	08:304:00000	00:000:00000	m	2.25500064150793e+05	7.30220e-04
13444M001	MALL	A	Z position at t0 = 15:001:00000	08:304:00000	00:000:00000	m	4.03984996592737e+06	9.42075e-04
13444M001	MALL	A	X velocity	08:304:00000	00:000:00000	m/y	-1.18589498780141e-02	2.06277e-04
13444M001	MALL	A	Y velocity	08:304:00000	00:000:00000	m/y	1.99279065911488e-02	8.06658e-05
13444M001	MALL	A	Z velocity	08:304:00000	00:000:00000	m/y	1.21609540528245e-02	1.67085e-04

Velocities per year

Latest entry: 2008, day 304
Moving per year:
X direction: -1.2cm
Y direction: 2.0 cm
Z direction: 1.2 cm

ITRF 2014 – Berkeley near San Francisco



DOMES	ID	PT	PARAMETER TYPE	VALID_FROM	VALID_UNTIL	UNIT	VALUE	SIGMA
49405M001	P224	A	X position at t0 = 15:001:00000	00:000:00000	14:236:37244	m	-2.68820146249141e+06	1.13830e-03
49405M001	P224	A	Y position at t0 = 15:001:00000	00:000:00000	14:236:37244	m	-4.26564351513211e+06	1.48585e-03
49405M001	P224	A	Z position at t0 = 15:001:00000	00:000:00000	14:236:37244	m	3.89377862306368e+06	1.31193e-03
49405M001	P224	A	X velocity	00:000:00000	14:236:37244	m/y	-2.04629809351052e-02	1.54775e-04
49405M001	P224	A	Y velocity	00:000:00000	14:236:37244	m/y	1.84938407459053e-02	2.19311e-04
49405M001	P224	A	Z velocity	00:000:00000	14:236:37244	m/y	5.34468108405318e-03	1.88517e-04
49405M001	P224	A	X position at t0 = 15:001:00000	14:236:37244	14:357:37080	m	-2.68820146010886e+06	2.64473e-03
49405M001	P224	A	Y position at t0 = 15:001:00000	14:236:37244	14:357:37080	m	-4.26564351334747e+06	3.76648e-03
49405M001	P224	A	Z position at t0 = 15:001:00000	14:236:37244	14:357:37080	m	3.89377862512030e+06	3.21772e-03
49405M001	P224	A	X velocity	14:236:37244	14:357:37080	m/y	-2.04629766203208e-02	1.54778e-04
49405M001	P224	A	Y velocity	14:236:37244	14:357:37080	m/y	1.84938413315177e-02	2.19313e-04
49405M001	P224	A	Z velocity	14:236:37244	14:357:37080	m/y	5.34468322076354e-03	1.88520e-04
49405M001	P224	A	X position at t0 = 15:001:00000	14:357:37080	18:326:00000	m	-2.68820145717346e+06	1.10594e-03
49405M001	P224	A	Y position at t0 = 15:001:00000	14:357:37080	18:326:00000	m	-4.26564350909551e+06	1.44515e-03
49405M001	P224	A	Z position at t0 = 15:001:00000	14:357:37080	18:326:00000	m	3.89377862412439e+06	1.27157e-03
49405M001	P224	A	X velocity	14:357:37080	18:326:00000	m/y	-2.04629722963826e-02	1.54781e-04
49405M001	P224	A	Y velocity	14:357:37080	18:326:00000	m/y	1.84938419050361e-02	2.19315e-04
49405M001	P224	A	Z velocity	14:357:37080	18:326:00000	m/y	5.34468534760665e-03	1.88522e-04
49405M001	P224	A	X position at t0 = 15:001:00000	18:326:00000	00:000:00000	m	-2.68820143993677e+06	1.13126e-02
49405M001	P224	A	Y position at t0 = 15:001:00000	18:326:00000	00:000:00000	m	-4.26564350781970e+06	1.66380e-02
49405M001	P224	A	Z position at t0 = 15:001:00000	18:326:00000	00:000:00000	m	3.89377861892892e+06	1.35623e-02
49405M001	P224	A	X velocity	18:326:00000	00:000:00000	m/y	-2.44274945135942e-02	2.31320e-03
49405M001	P224	A	Y velocity	18:326:00000	00:000:00000	m/y	1.79896655231172e-02	3.40220e-03
49405M001	P224	A	Z velocity	18:326:00000	00:000:00000	m/y	6.81931396135365e-03	2.76619e-03

Latest entry: 2018, day 326

Moving per year:

X direction: -2.4cm

Y direction: 1.8 cm

Z direction: 0.7 cm

Two Types of frames used by correction services

HxGN SmartNet | Datenblatt

Produktdatenblatt Deutschland

Korrekturdaten[1)2)]

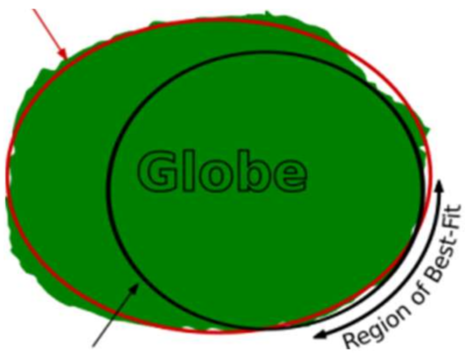
Koordinaten Bezugssystem	Netzwerk Korrekturdaten für das überregionale Koordinatensystem ETRS89/DREF91, Realisierung 2016	Korrekturdatenformate: (1) RTCM 3.1 (2) CMR+ (3) RTCM 3.2 (MSM4/5)

```
13444M001 MALL  A | X position at t0 = 15:001:00000  | 08:304:00000 00:000:00000    m  4.91936934955635e+06 1.08741e-03
13444M001 MALL  A | Y position at t0 = 15:001:00000  | 08:304:00000 00:000:00000    m  2.25500064150793e+05 7.30220e-04
13444M001 MALL  A | Z position at t0 = 15:001:00000  | 08:304:00000 00:000:00000    m  4.03984996592737e+06 9.42075e-04
13444M001 MALL  A | X velocity                       | 08:304:00000 00:000:00000  m/y -1.18589498780141e-02 2.06277e-04
13444M001 MALL  A | Y velocity                       | 08:304:00000 00:000:00000  m/y  1.99279065911488e-02 8.06658e-05
13444M001 MALL  A | Z velocity                       | 08:304:00000 00:000:00000  m/y  1.21609540528245e-02 1.67085e-04
```

Type A: Coordinates used at fixed epoch. Static coordinate, does (almost) not change. Example: ETrF, NAD used by network RTK providers like Smartnet (Hexagon), VRSnow (Trimble), TOPNET (TOPCON)

Type B: In addition to the origin coordinate the station coordinates are updated continuously to follow station velocity. Following the tectonics is called “current epoch”. Examples: u-blox PointPerfect, Trimble RTX, WGS84,

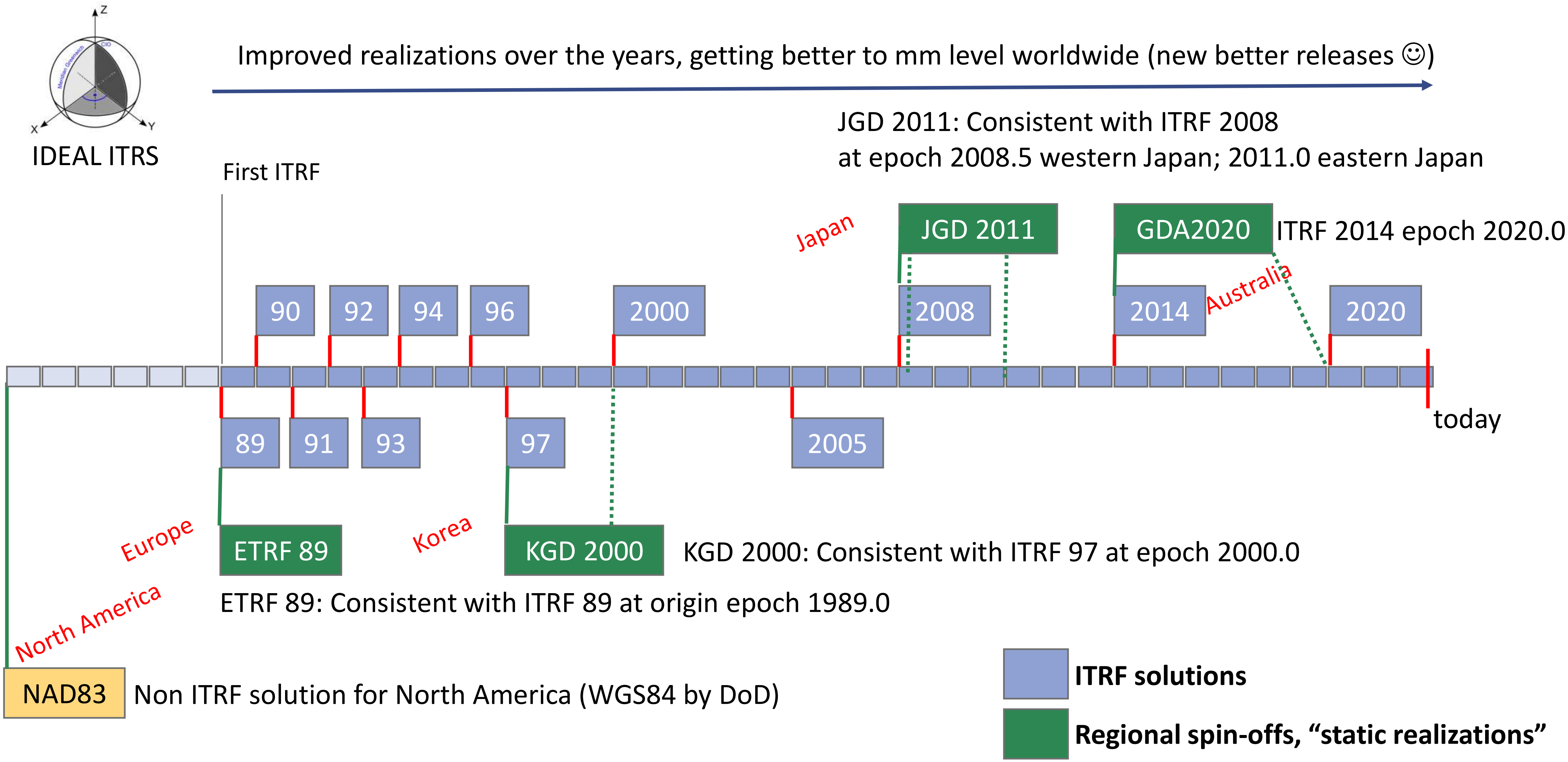
ITRS, system rotates with pole



ETRS, system moves with the European tectonic plate

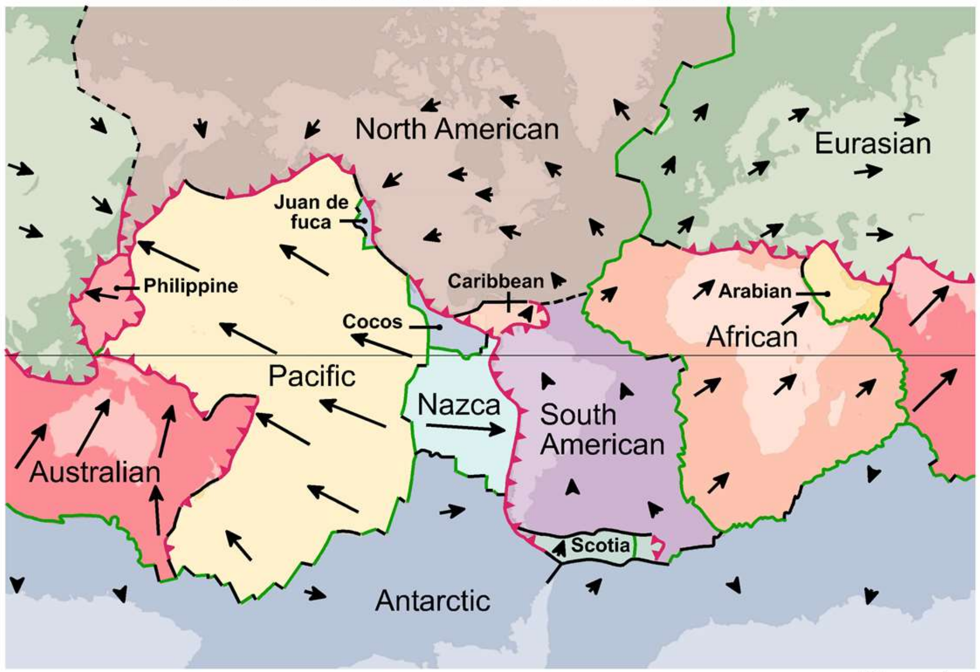
Reference frame	ITRF2014 current epoch

ITRF – different solutions over time and regional spin-offs



Why do spin-offs, why global ITRF?

NAMED TECTONIC PLATES and their motion



Regional Spin-Off

Provide “Static” Reference

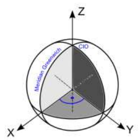
- Assuming similar movement everywhere on the tectonic plate
- Much less movement on plate level relatively to each other (mm instead of cm)
- Do not need to care about when, static coordinates

ITRF current epoch

Provide “Current” Reference

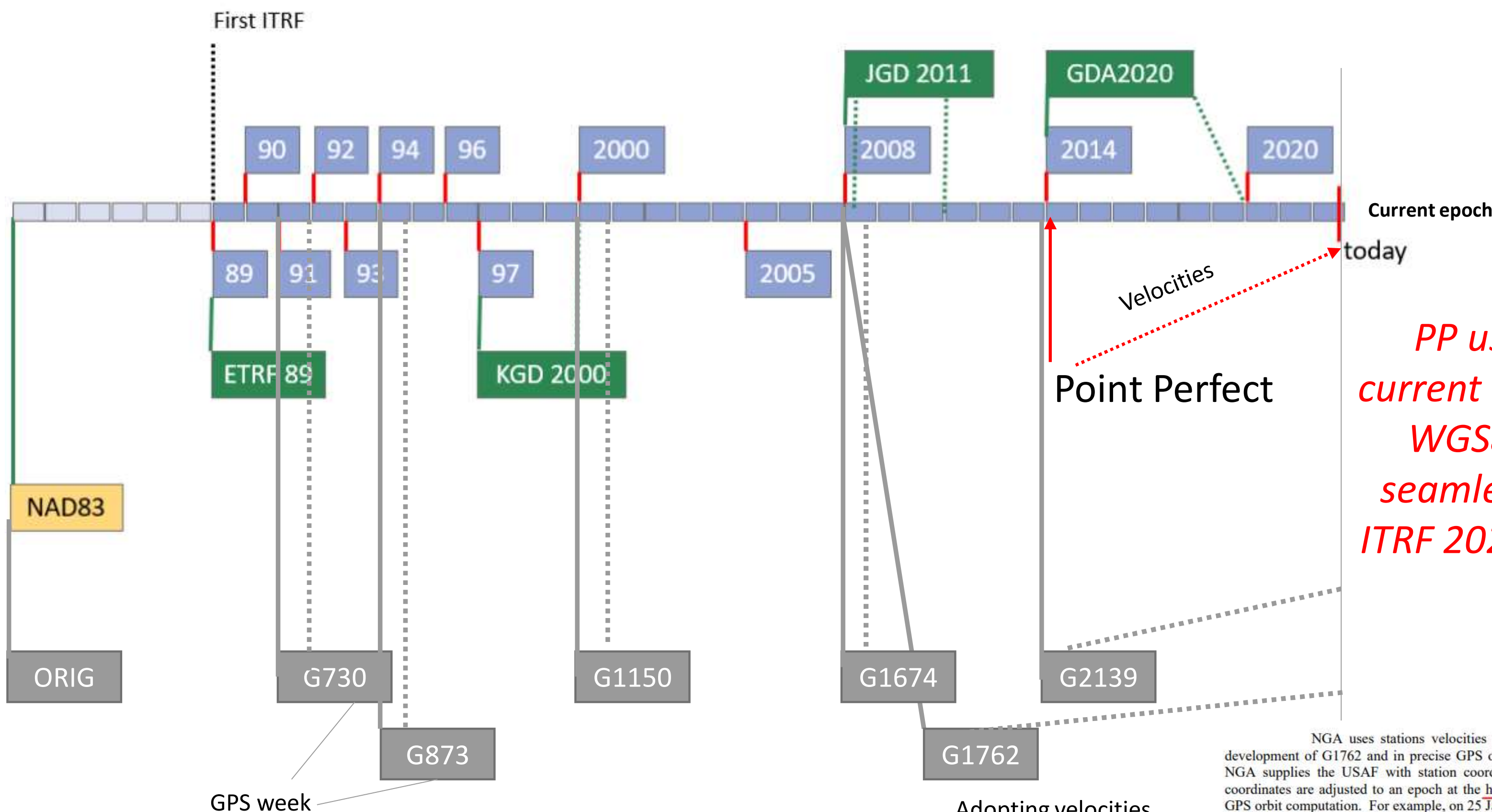
- Most accurate
- Applicable worldwide
- Seamless transition to newer ITRFs
- Near to WGS84 (best synced)

Point Perfect – what do we use, what is GPS (WGS84) using



IDEAL

Improved realizations over the years, getting better to mm level worldwide (new better releases ☺)



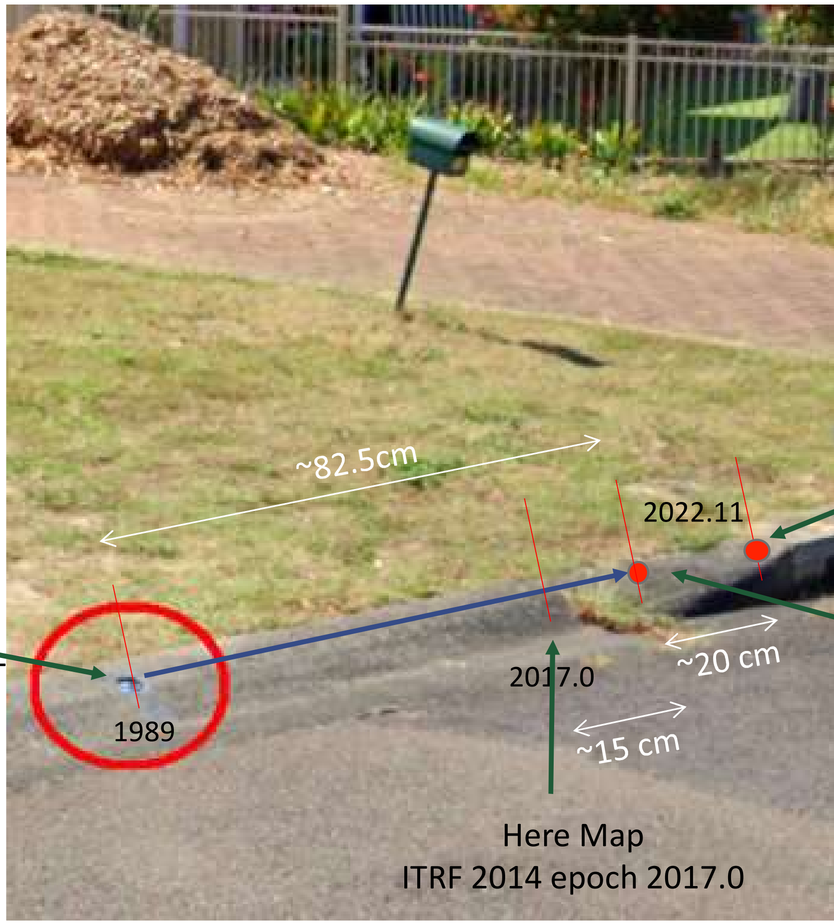
WGS84 – syncing to ITRF

PP uses ITRF 2014 current epoch. Synced to WGS84 and allows seamless transition to ITRF 2020 current epoch (mm)

NGA uses stations velocities to account for plate tectonic motion in both the development of G1762 and in precise GPS orbit calculations. At the beginning of each year, NGA supplies the USAF with station coordinates of both the USAF and NGA sites. The coordinates are adjusted to an epoch at the half year mark for plate tectonic motion for use in GPS orbit computation. For example, on 25 Jan 2013, the USAF began using coordinates for the DoD GPS reference sites with an epoch of 2013.5. This results in an annual step-wise update to the WGS 84 frame used to generate the GPS broadcast message.

Different solutions, different frames and epochs

Invented Example Europe



High Definition Map example HERE

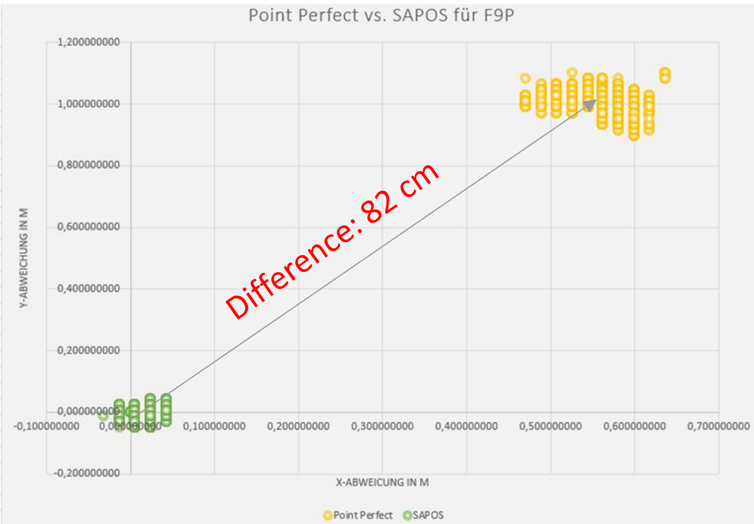
The geoidal ellipsoid of the earth can be approximated by mathematical projection systems modeling earth's irregular shape. A few projection systems are available. When HERE collects map data, we use the ECEF ITRF2014 projection system at epoch 2017.0. (ECEF stands for Earth-Centered, Earth-Fixed and ITRF stands for International Terrestrial Reference Frame.) Third parties that collect map data and submit it to HERE may use a different projection system. Without the use of a projection system, or consideration of Einsteinian changes in the flow of time, the positional error from measuring transmission time alone would be large (multiple kilometers).

Not only where you are but also “when“

Measurement Examples Europe & US

Network RTK vs PP

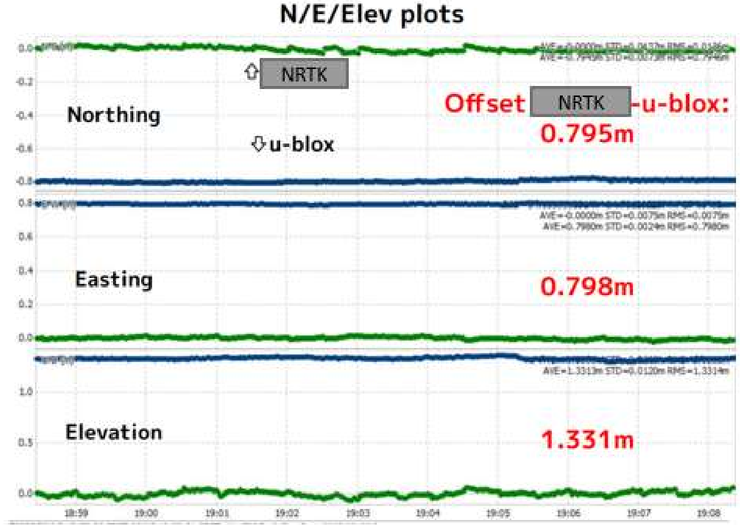
Point Perfect (ITRF 2014 current epoch vs SAPOS (ETRF89))



Europe

Customer Case Germany

Point Perfect (ITRF 2014 current epoch vs N-RTK US (NAD83 (2011))

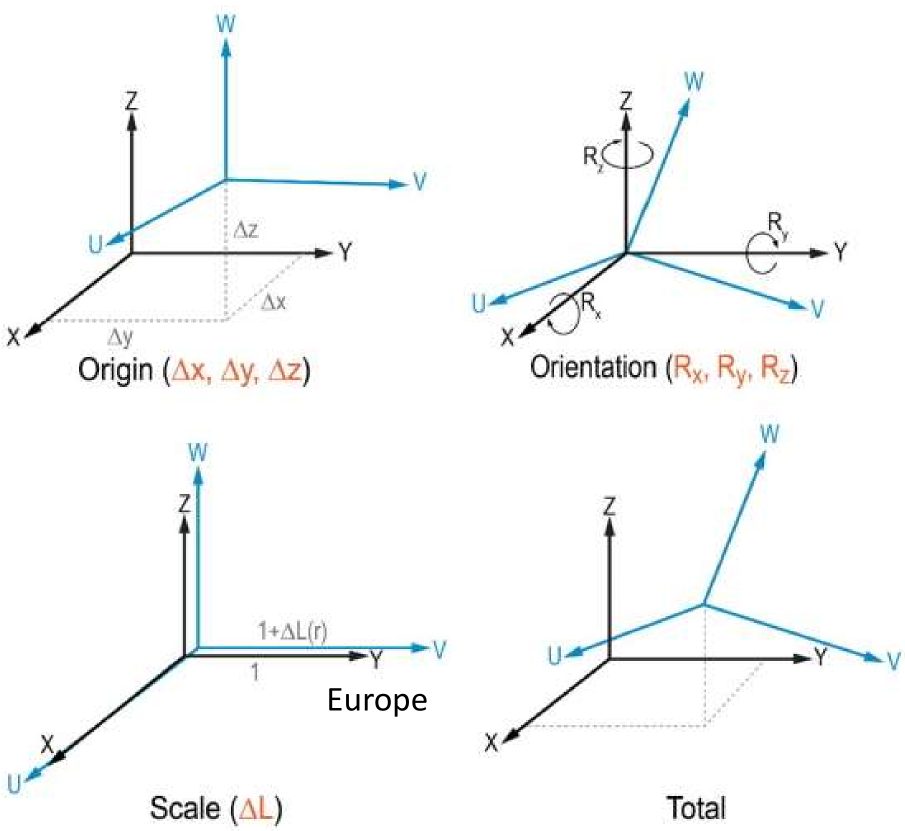


USA

Static Measurements u-center, NRTK provider & Point Perfect

How to compare different frames and epochs

From ITRF xx origin to other Frames



1. Shift origin (3 parameters)
2. Rotation each axis (3 parameters)
3. Apply scale factor (1 parameter)

-> 7 parameter transformation (Helmert transformation)

Excel sheet available

How to

1. Measure statically on one point with Point Perfect
2. The longer the better (averaging out random noise)
3. Enter in excel and compare with reference

What can you expect: coordinate match 1-2cm best case

If you want better: do local transformation (model per state or measured on your own)

What happens if …?

Customers have questions
- Please open a ticket with key word transformation

You have questions around that topic / need more
- Please contact Franco and me

Awareness on potential issues

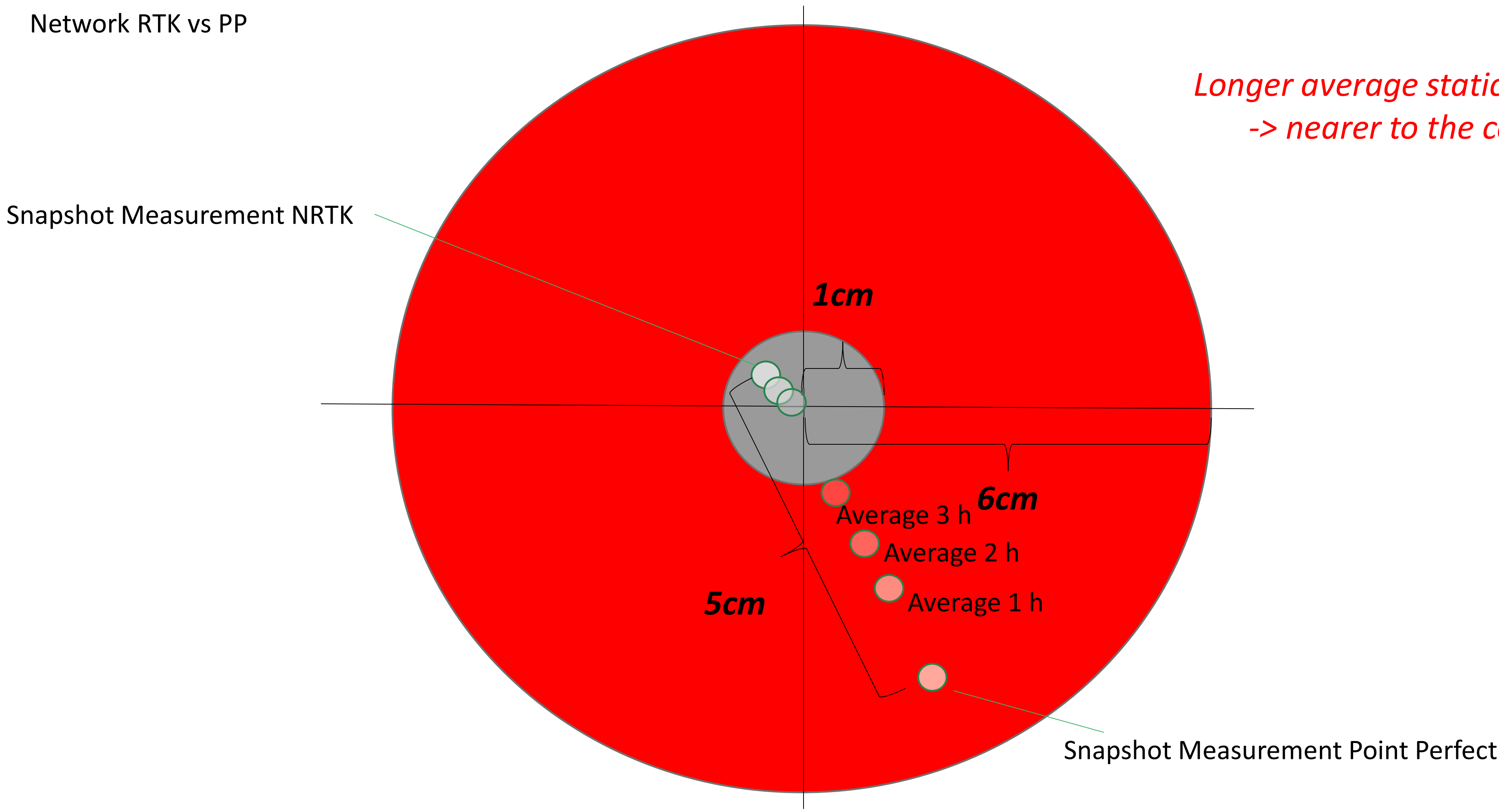
Country	Reference Frame
Australia	GDA2020
Brazil	SIRGAS200
Canada	NAD83(CSRS)v7
Denmark	EUREF-DK94
Estonia	EST97
Finland	EUREF-FIN
France	RGF93v2
Germany	ETRS89-DR91(R16)
Iceland	ISN2016
New Zealand	NZGD2000
Norway	EUREF89
Russia	PZ-90.11
Sweden	SWEREF99
UK	OSNetv2009
USA	NAD83(2011)

Local reference frames may differ (mm,cm), although being based on same original frame

-> ETRS89-DR91 (R16) is based upon ERTF89, but slightly different

Awareness – when comparing NRTK and PP

Network RTK vs PP



Longer average static solution -> nearer to the center