Coordinate Reference Systems for GEOSS
The IAG perspective

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(with inputs from Zuheir Altamimi, Claude Boucher, Rui Fernandes, Hans-Peter Plag)

SUMMARY

Architecture Task AR-07-03

This Task has the purpose to ensure the availability of accurate, homogeneous, long-term, stable, global geodetic reference frames as a mandatory framework and the metrological basis for Earth observation.

Identification of steps towards ensuring consistent, high-accuracy, homogeneous, and long-term stable global geodetic reference frames for Earth observation and the observing systems contributing to GEOSS.

Description of the Work to be Performed

- *User requirement coordination:*

  Establish a comprehensive GEOSS database of user requirements concerning georeferencing and geodetic reference frames by identifying, describing and establishing links to relevant user communities in the nine societal benefit areas and conducting appropriate surveys

- *Georeferencing:*

  Ensure the availability of appropriate global geodetic reference frames for GEOSS

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- ***Introduction: Architecture Task AR-07-03***
- ***About the International Association of Geodesy (IAG)***
- ***Space geodetic observing system***
- ***Geodetic reference systems and frames: ITRS, ITRF***
- ***Relationship with other systems (WGS84, …)***
- ***GRS for geo-spatial referencing; regional initiatives***
- ***Conclusions***

CREATION OF THE IAG

- *1861: General Baeyer presented a report aiming at the cooperation of the central Europe states for the measurement of the Earth's shape and dimensions (Mitteleuropäische Gradmessung)*
- *1864: 1st International Geodetic Conference at Berlin*
- *1867: 2nd International Geodetic Conference (Europäische Gradmessung); Portugal and Spain join the organization*
- *1885: end of General J.J. Baeyer's presidency*
- *1887: creation of the International Association of Geodesy (Internationale Erdmessung) integrated by 20 states*

THE IUGG

International Union of Geodesy and Geophysics
Union Géodésique et Géophysique Internationale

- *Non-governmental scientific organization founded in 1919*
- *Member of the ICSU (International Council for Science)*
- *Integrates 8 Associations*

IAG	*Geodesy*
IASPEI	*Seismology and Physics of the Earth's Interior*
IAVCEI	*Volcanology and Chemistry of the Earth's Interior*
IAGA	*Geomagnetism and Aeronomy*
IAMAS	*Meteorology and Atmospheric Sciences*
IAHS	*Hydrological Sciences*
IAPSO	*Physival Sciences of the Oceans*
IACS	*Cryospheric Sciences*

IAG STRUCTURE

Approved in Budapeste, 2001 (IAG Scientific Assembly)

Ratified in Sapporo, 2003 (IUGG General Assembly)

- Services
- Commissions
- Inter commission committees
- IAG Projects
- Communication and Outreach

COMMISSIONS

- *Commission 1 Reference Frames*
- *Commission 2 Gravity Field*
- *Commission 3 Earth Rotation and Geodynamics*
- *Commission 4 Positioning and Applications*

INTER COMMISSION COMMITTEES

- *Inter commission committee on Theory (ICCT)*
- *Inter commission committee on Geodetic Standards (ICCGS)*
- *Inter commission committee on Planetary Geodesy (ICCPG)*

International Association of Geodesy

SERVICES

- **IERS** *(International Earth Rotation and Reference Systems Service)*
- **IGS** *(International GNSS Service)*
- **ILRS** *(International Laser Ranging Service)*
- **IVS** *(International VLBI Service for Geodesy and Astrometry)*
- **IGFS** *(International Gravity Field Service)*
- **IDS** *(International DORIS Service)*
- **BGI** *(International Gravimetric Bureau)*
- **IGES** *(International Geoid Service)*
- **ICET** *(International Centre for Earth Tides)*
- **PSMSL** *(Permanent Service for Mean Sea Level)*
- **BIPM** *(Bureau International des Poids et Measures - time section)*
- **IBS** *(IAG Bibliographic Service)*

GGOS

GLOBAL GEODETIC OBSERVING SYSTEM

- *System that integrates*
  - *Different geodetic techniques*
  - *Different models*
  - *Different approaches*
- *for a better understanding of the geodynamic processes and the global changes*
- *and serve as a basis for the research in geo-sciences*

THE MEANING OF INTEGRATION

- *Co-location of different instruments and techniques*
- *Estimation of parameters from different types of observations and common processing*
- *Delivery of a set of homogeneous and consistent parameters*

SOME MOTIVATIONS

- *Need for a long-term continuity of the space missions and the global observation networks*
- *Promote the free delivery of data*
- *The use of official products as a guarantee of quality and reliability*

Friedrich Georg Wilhelm Struve (1793-1864)

Struve Geodetic Arc

- *265 main stations*
- *2820 km*
- *10 countries*
- *1816 - 1855*

United Nations
Educational, Scientific and
Cultural Organization

World
Heritage

The Struve Geodetic Arc represents a scientific project with a breadth of importance to mankind, and with a level of human achievement, which is absolutely unique.

It was the first scientific and technical object inscribed on the World Heritage List of UNESCO

It was also the first time that more than 2 nations joined to include heritage in the List

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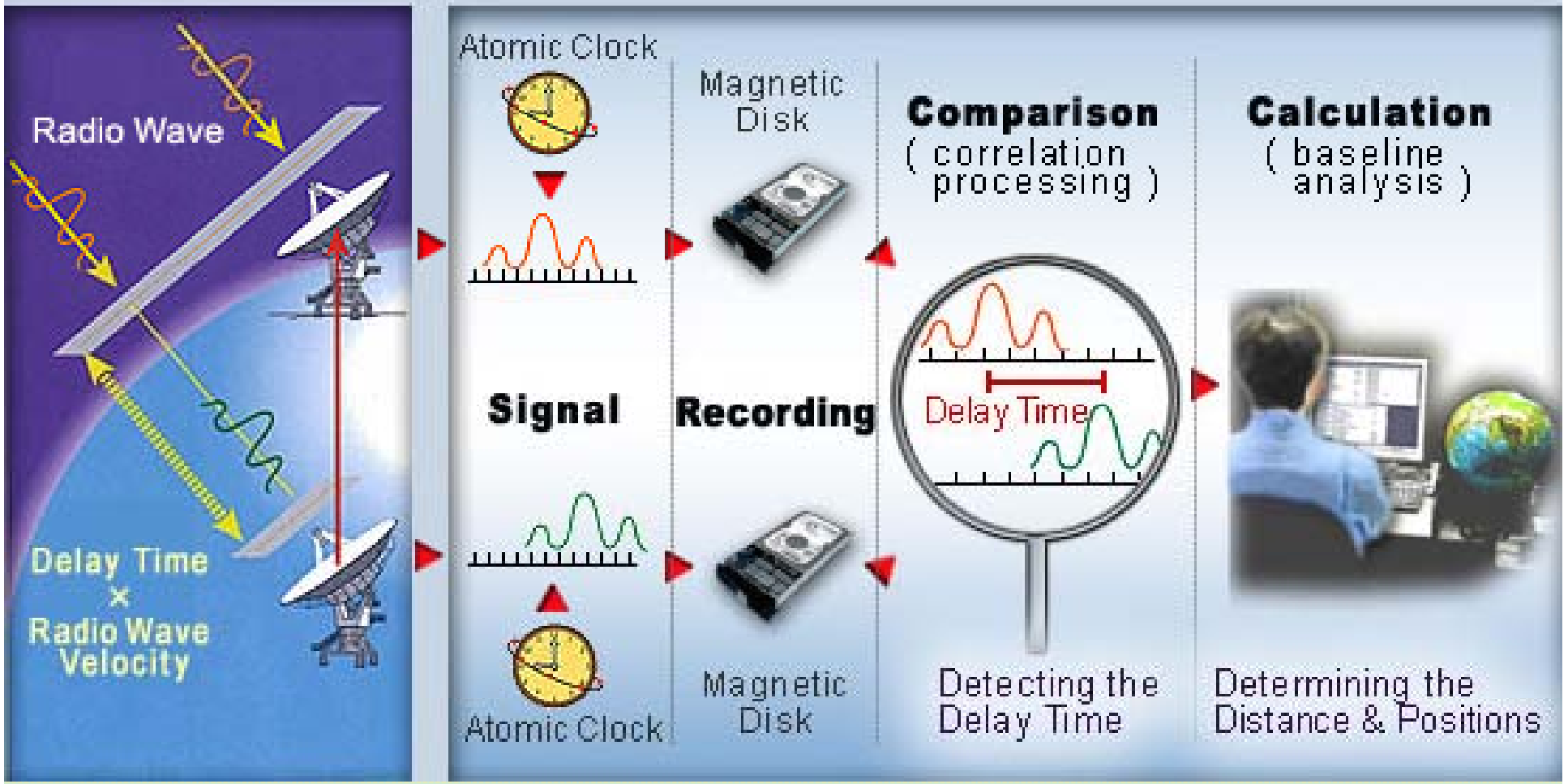
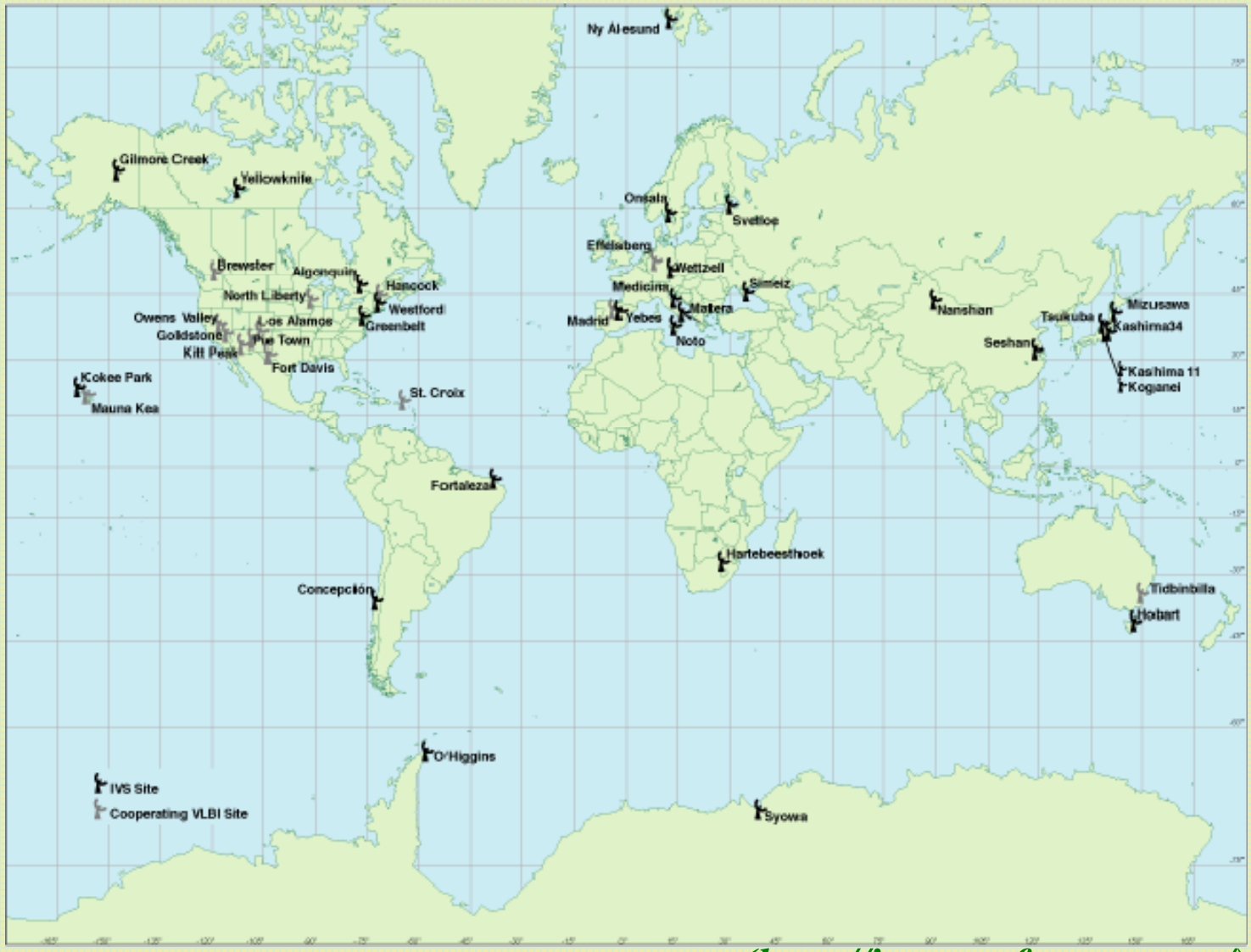
3- Space geodetic observing system

VLBI (Very Long Baseline Interferometry)
(accuracy better than 1 cm/5000 km or 0,002 ppm)



VLBI Global Network

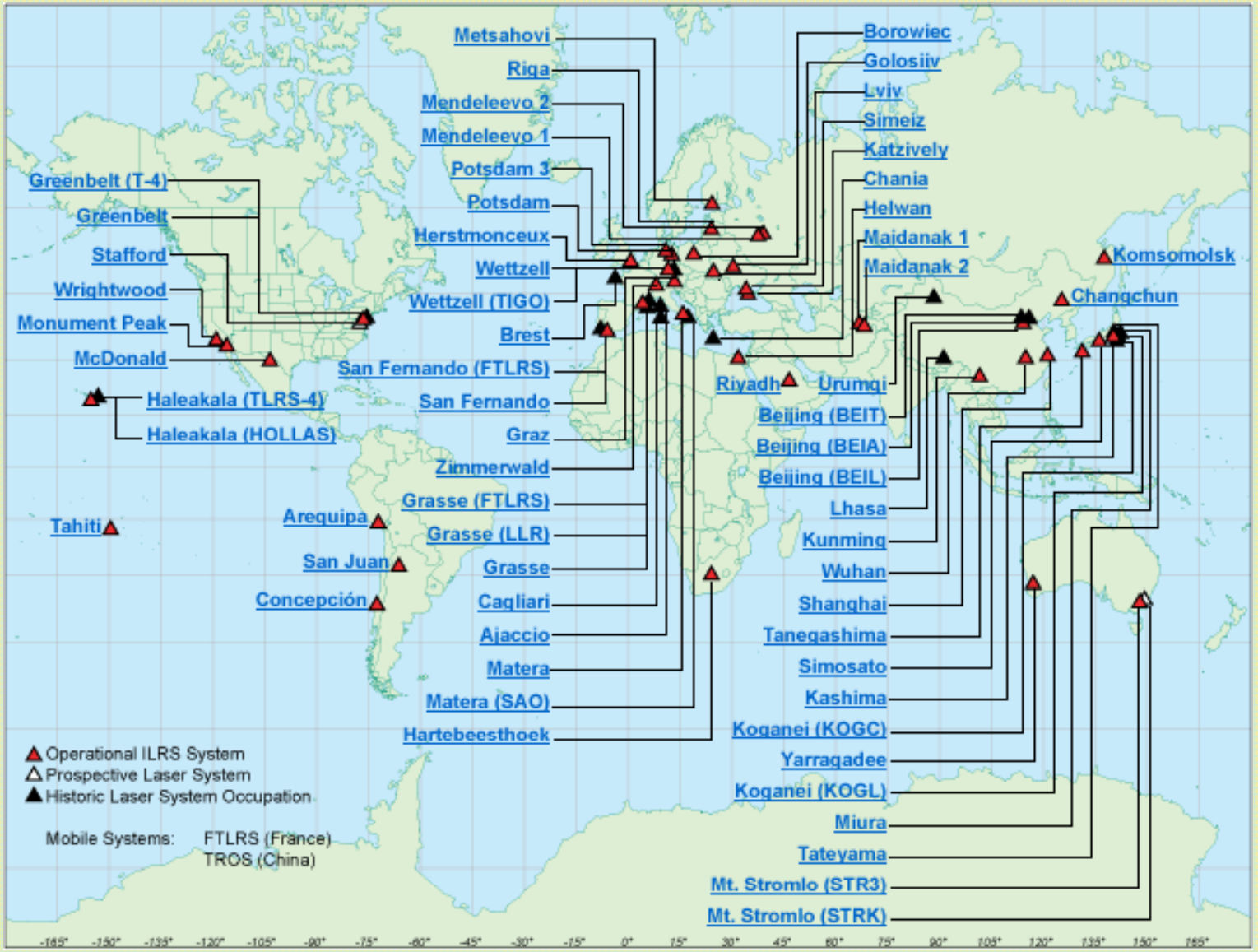


(http://ivscc.gsfc.nasa.gov/)

ILRS – Contributions

- study of the solid Earth - atmosphere – hydrosphere - cryosphere
- fundamental support to altimetric satellites
- contribution to the monitoring of the sea and ice levels
- long-term dynamics of the solid Earth, oceans and atmosphere
- study of tectonic motions
- contribution for the research in fundamental Physics

ILRS –Global network



(http://ilrs.gsfc.nasa.gov/)

IGS – International GNSS Service

Created from a IUGG resolution in 1991 (Vienna)

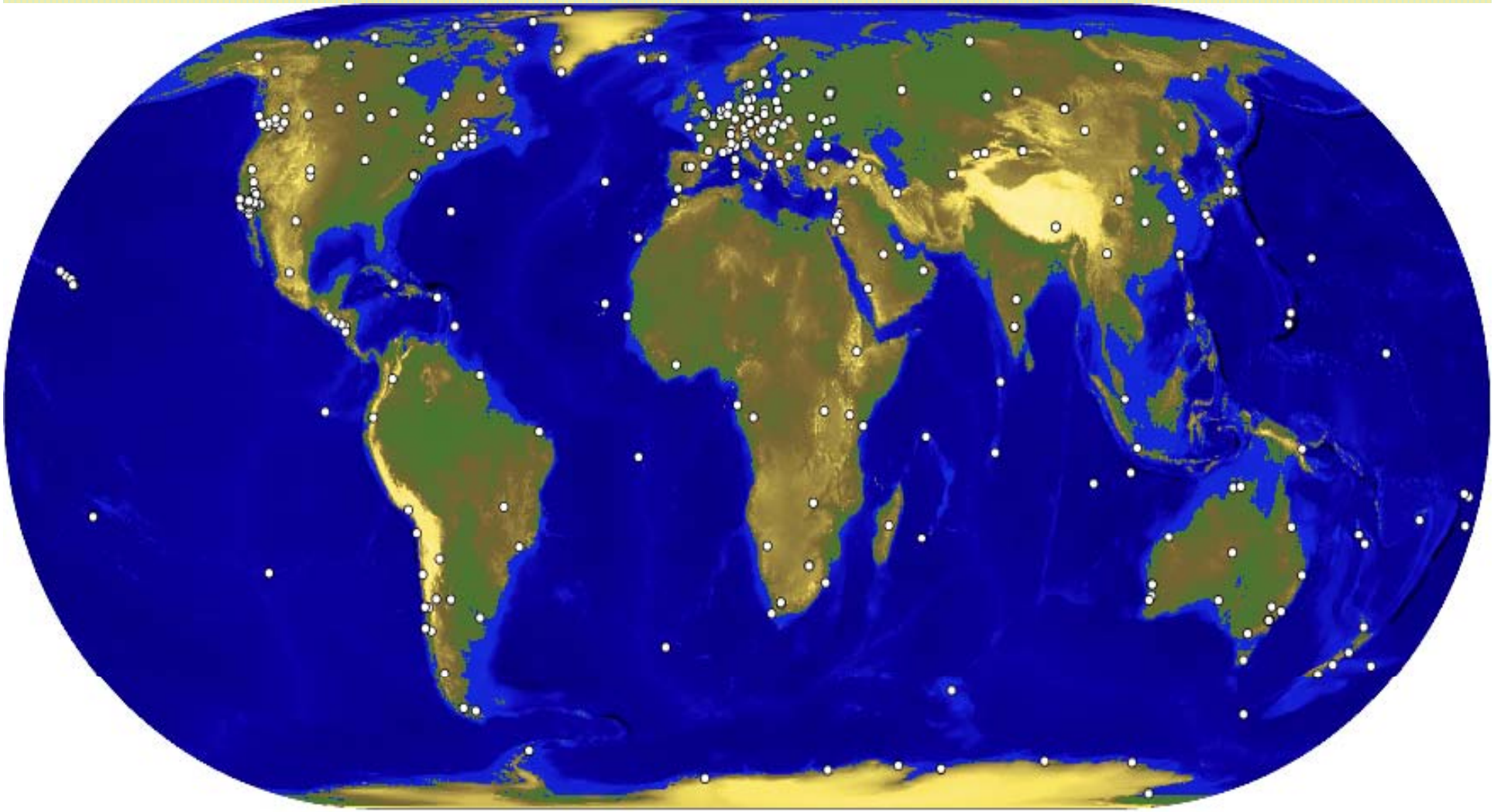
Activities started officially in 1994

SET OF GPS (+GLONASS) PERMANENT STATIONS

(***presently more than 380, some inactive***)

3- Space geodetic observing system

IGS – Global network



(http://igscb.jpl.nasa.gov/)

3- Space geodetic observing system

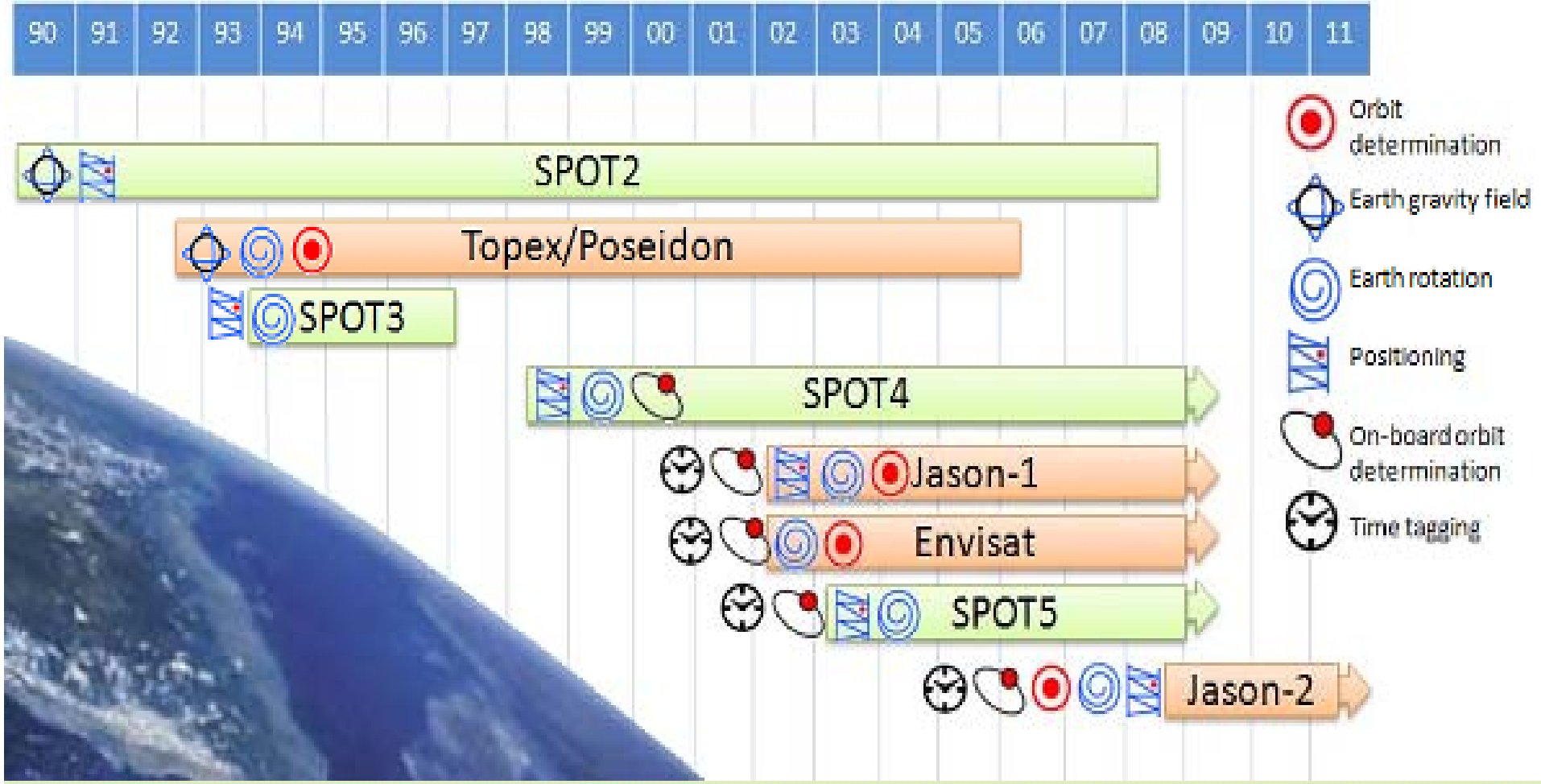
DORIS

Doppler Orbitography and Radiopositioning Integrated by Satellite

- ***Doppler System for satellite tracking***
  - ***precise orbit determination***
  - ***precise location on the terrain***

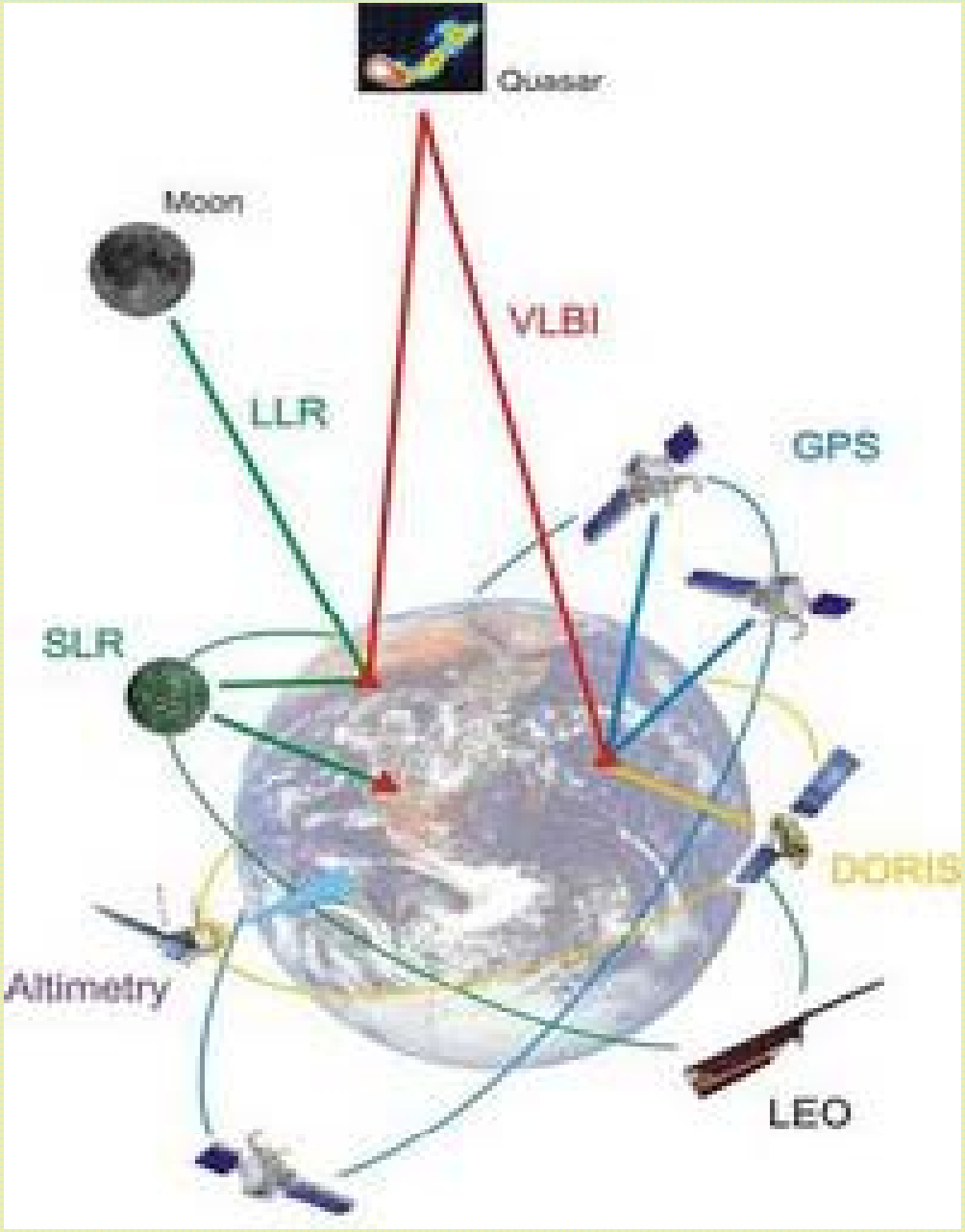
- ***altimetric satellites Jason-1 and ENVISAT (TOPEX/POSEIDON)***
- ***remote sensing satellites SPOT-2, SPOT-4 and SPOT-5 (SPOT-3)***

DORIS Missions



(http://www.aviso.oceanobs.com)

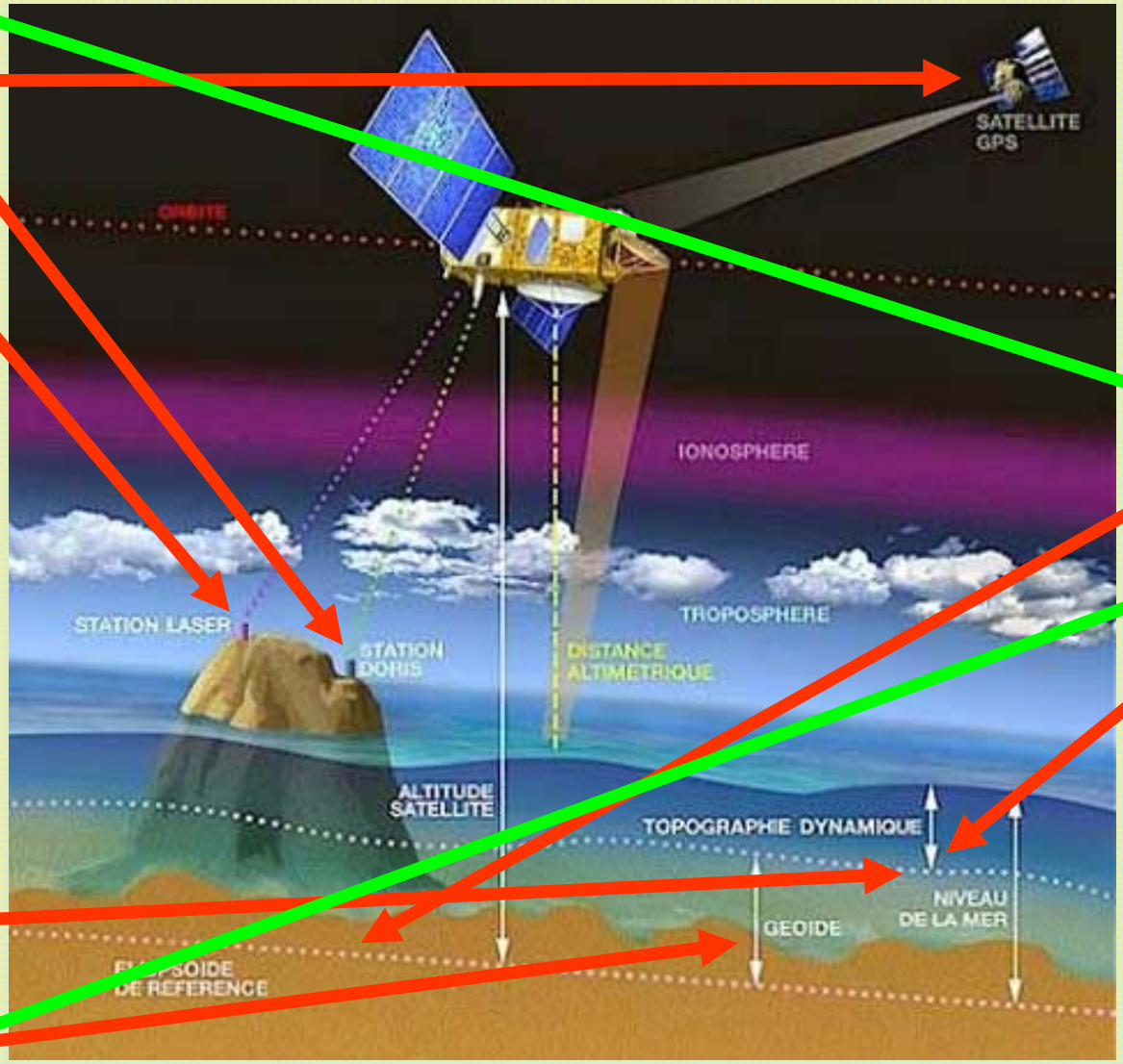
3- Space geodetic observing system



3- Space geodetic observing system

Earth rotation

Geodetic techniques



Reference systems

Gravity field

(CNES/NASA)

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TRS - TERRESTRIAL REFERENCE SYSTEM

- *Spatial reference system co-rotating with the Earth in its diurnal motion in space*
- *Mathematical model for a physical Earth in which point positions are expressed and have small temporal variations due to geophysical effects (Plate motion, Earth tides, etc.)*

  - **Mathematical and physical definition**
  - **Tridimensional system of axes defined by an origin, a unit of lenght and an orientation**
  - **Associated physical constants:**
    time*, *speed of light in vacuum*, *GM

TRF - TERRESTRIAL REFERENCE FRAME

- *Realization of the reference system*
- *Set of geodetic references (physical points)*
- *Coordinates estimation based on space geodetic techniques*
- *Each technique and data analysis realizes its own TRS*
- *Multitude of TRF exist*

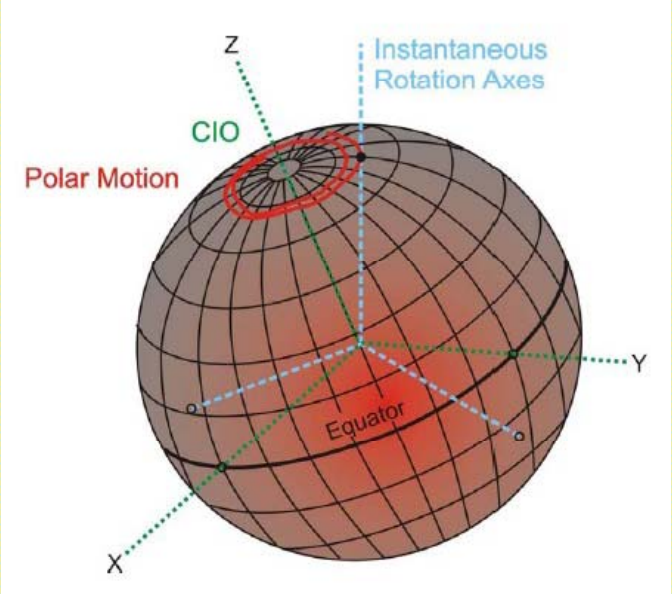
REFERENCE SYSTEMS: TERMINOLOGY

- **Ideal Reference System**

  theoretical definition (not accessible to the users)
- **Reference Frame**
  - *Set of physical objects with their coordinates*
  - *Realization of an Ideal Reference System*
  - *Accessible to the users*
- **Coordinate System**

  cartesian (X,Y,Z), geographic (λ, φ, h),...

ITRS - INTERNATIONAL TERRESTRIAL REFERENCE SYSTEM



ADOPTED IN 1991 (VIENNA) BY THE IUGG

DEFINITION, REALIZATION AND PROMOTION BY THE IERS (successor of the BIH)

(International Earth Rotation and Reference Systems Service)

ITRS

- *Origin at the Earth's centre of mass (considering the mass of the solid part, liquid part and atmosphere)*
- *Unit of lenght: meter (SI) consistent with TCG (Geocentric Coordinate Time)*
- *Orientation of axes consistent with the BIH definition at epoch 1984.0*
- *Non-rotation condition wrt horizontal tectonic motions*

ITRF - INTERNATIONAL TERRESTRIAL REFERENCE FRAME

- *Set of geodetic references*
- *Coordinates estimation based on space geodetic techniques*
  - **VLBI** *(Very Long Baseline Interferometry)*
  - **SLR** *(Satellite Laser Ranging)*
  - **GPS** *(Global Positioning System)*
  - **DORIS** *(Doppler Orbitography Radiopositioning Integrated by Satellite)*

ITRF AND SCIENCE REQUIREMENT

- *Long-term stable ITRF: 0.1 mm/yr*
- *Stable: linear behaviour of the TRF parameters, i.e. with no discontinuity :*
  - *Origin Components: 0.1 mm/yr*
  - *Scale 0.01 ppb/yr (0.06 mm/yr)*
- *Current situation: probably not better than 1 mm/yr*

ITRF2005

ITRF2005 STATION POSITIONS AT EPOCH 2000.0 AND VELOCITIES
GPS STATIONS

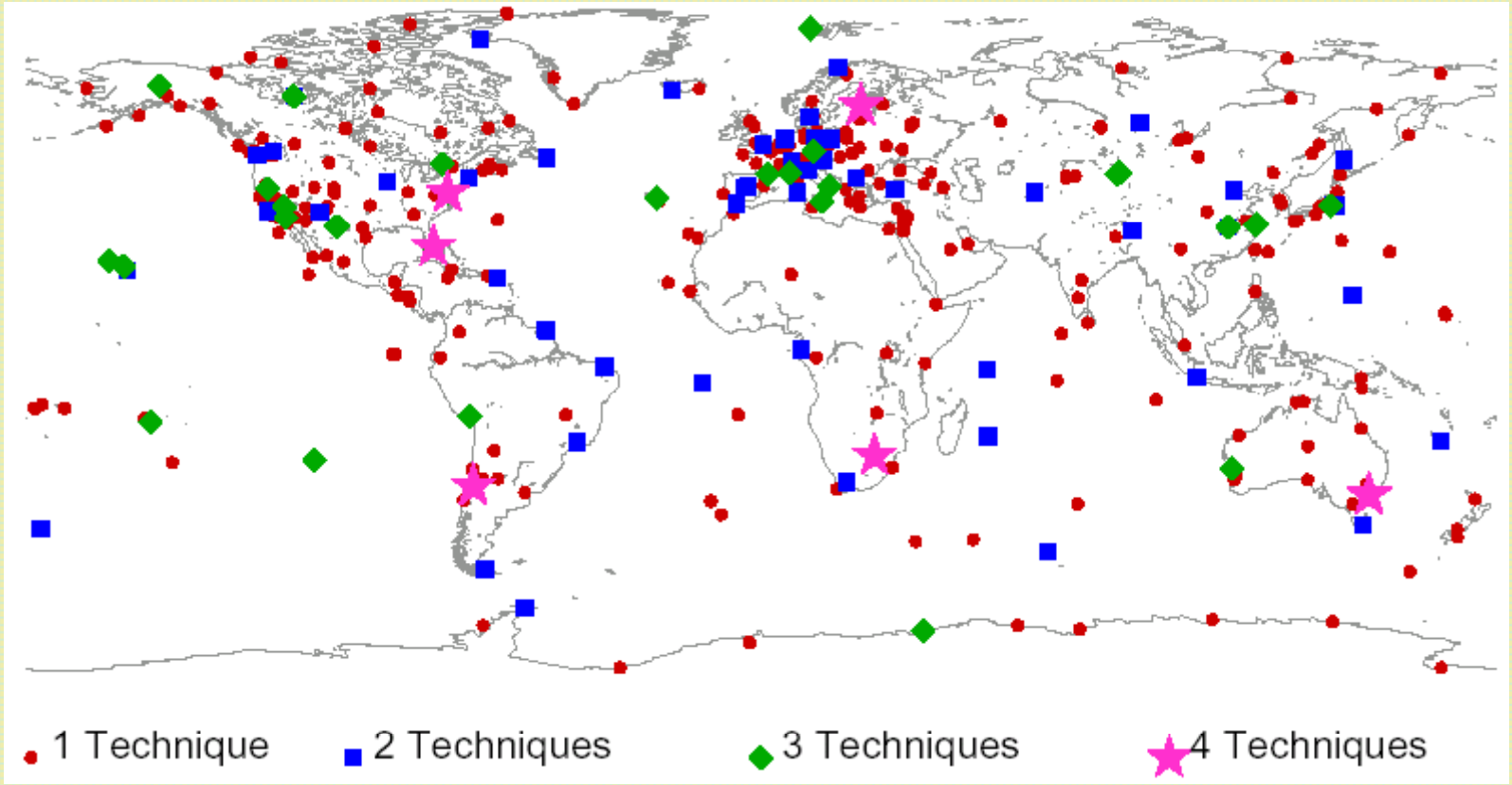
DOMES NB.	SITE NAME	TECH. ID.	X/Vx	Y/Vy	Z/Vz	Sigmas		
			----------m/m/y----------					
10002M006	GRASSE	GPS GRAS	4581690.974	556114.744	4389360.739	0.001	0.001	0.001
10002M006			-.0139	0.0186	0.0116	.0001	.0001	.0001
13909S001	CASCAIS	GPS CASC	4917536.986	-815726.310	3965857.316	0.006	0.003	0.005
13909S001			-.0069	0.0201	0.0141	.0014	.0006	.0011

Available: ITRF88, 89,…,2000

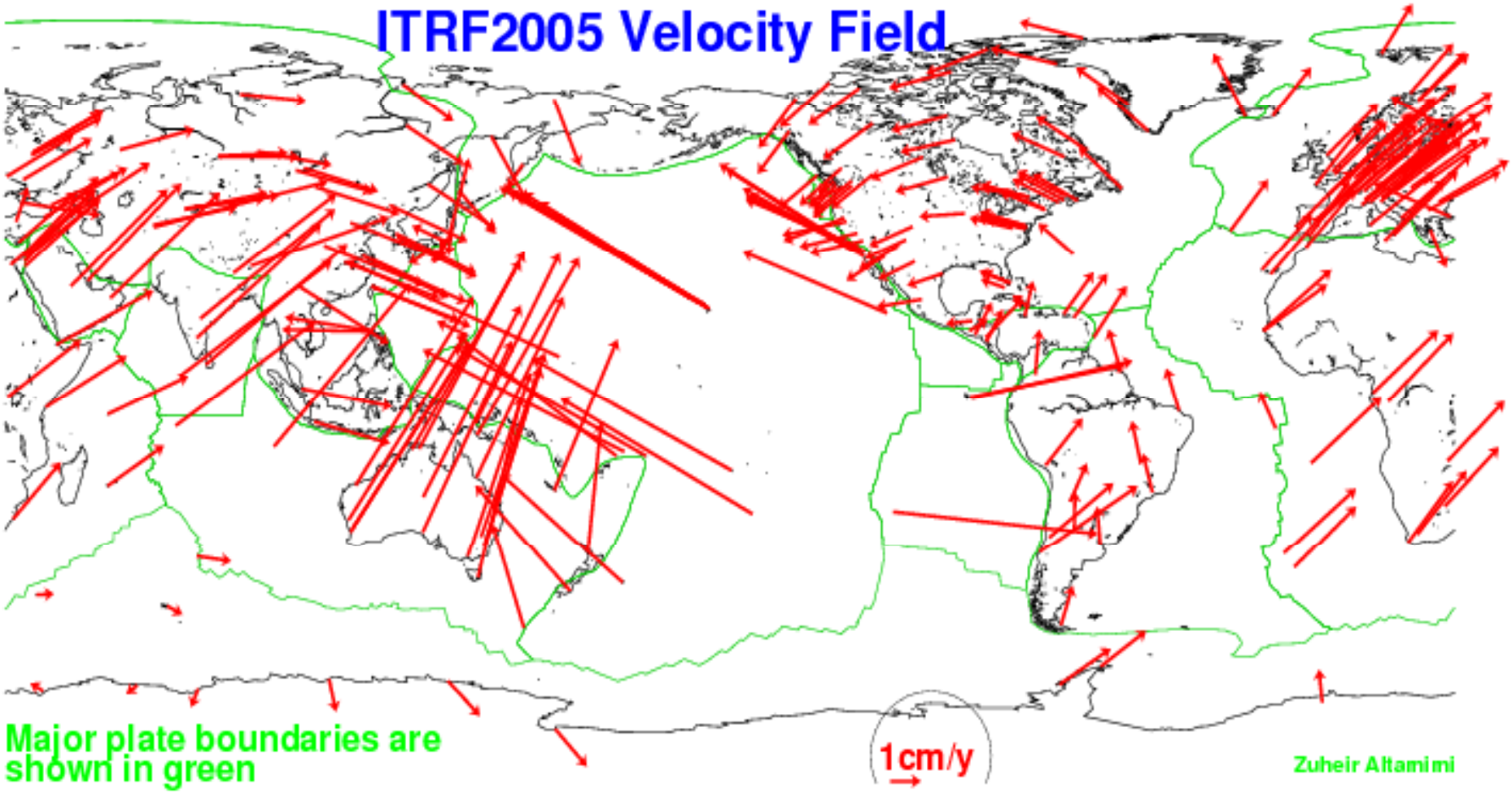
Latest: ITRF2005

(http://itrf.ensg.ign.fr)

ITRF2005 CO-LOCATIONS



(Zuheir Altamimi, 2006)



(Zuheir Altamimi, 2008)

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WGS84

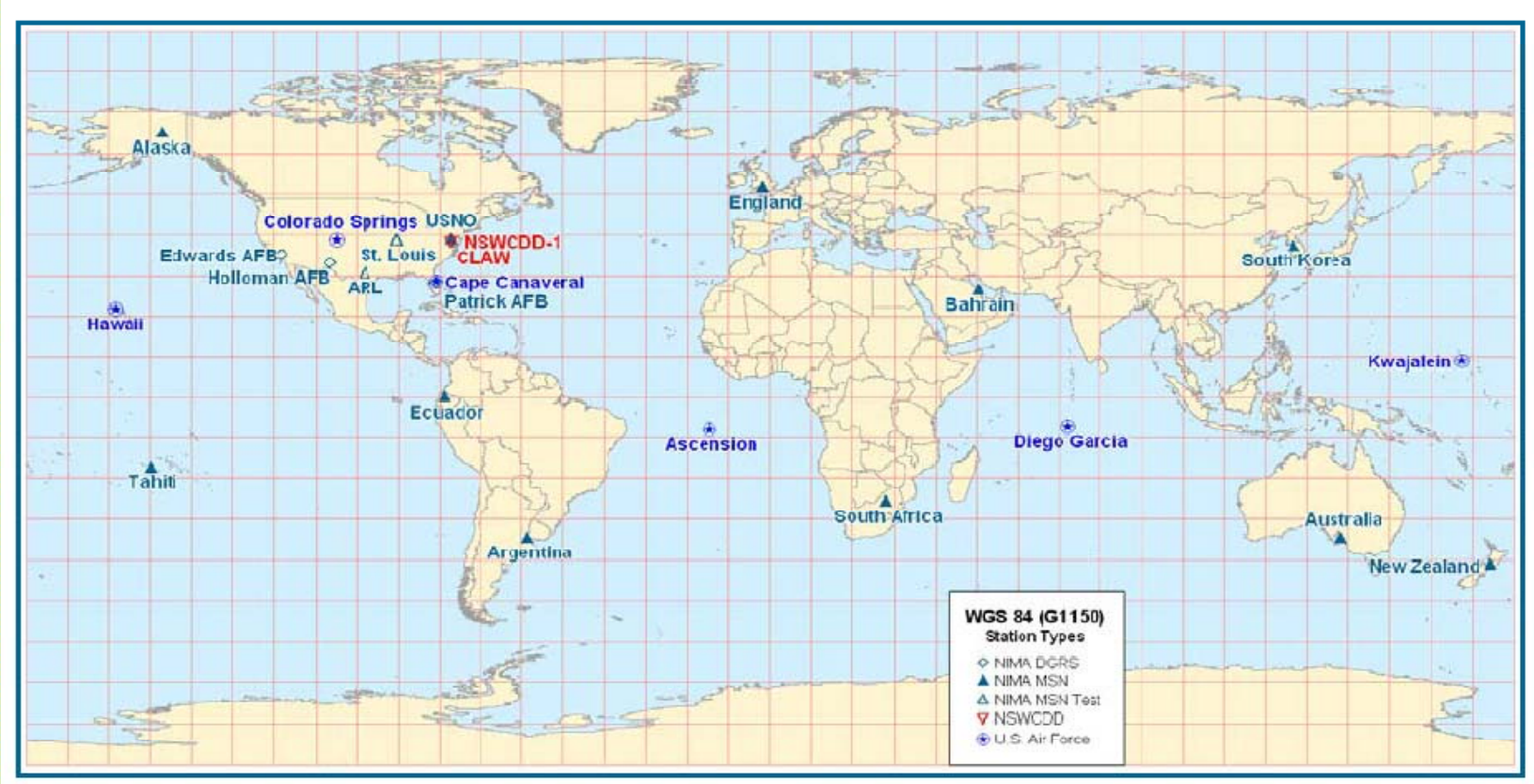
- *Evolution from WGS72 (60…66), used with the TRANSIT satellite system, percussive of NAVSTAR GPS*
- *Collection of models including Earth Gravitational model, geoid, transformation formulae and set of coordinates of permanent DoD GPS monitor stations*
- *It's a geocentric conventional terrestrial system (Earth Centered Earth Fixed)*
- *The orientation is consistent with the BIH's at epoch 1984.0*
- *Associated with a reference ellipsoid, with the same name*
- *Associated with a reference frame*

THE WGS84 ASSOCIATED REFERENCE FRAME

- *The realization of the system is based on a consistent set of station coordinates (TRF)*
- *The original set of stations had a consistency in the coordinates at the 2 m level*
- *In 1994 (GPS week 730) and 1996 (GPS week 873) new realizations based on the ITRF were adopted:*
  WGS84 (G730) and WGS84 (G873)
- *In 2002 (GPS week 1150) the present realization (G1150) based on the ITRF2000 was adopted*
- *Present consistency with ITRF2000 ≈10 cm*

5- Relationship with other systems

WGS 84-(G1150)

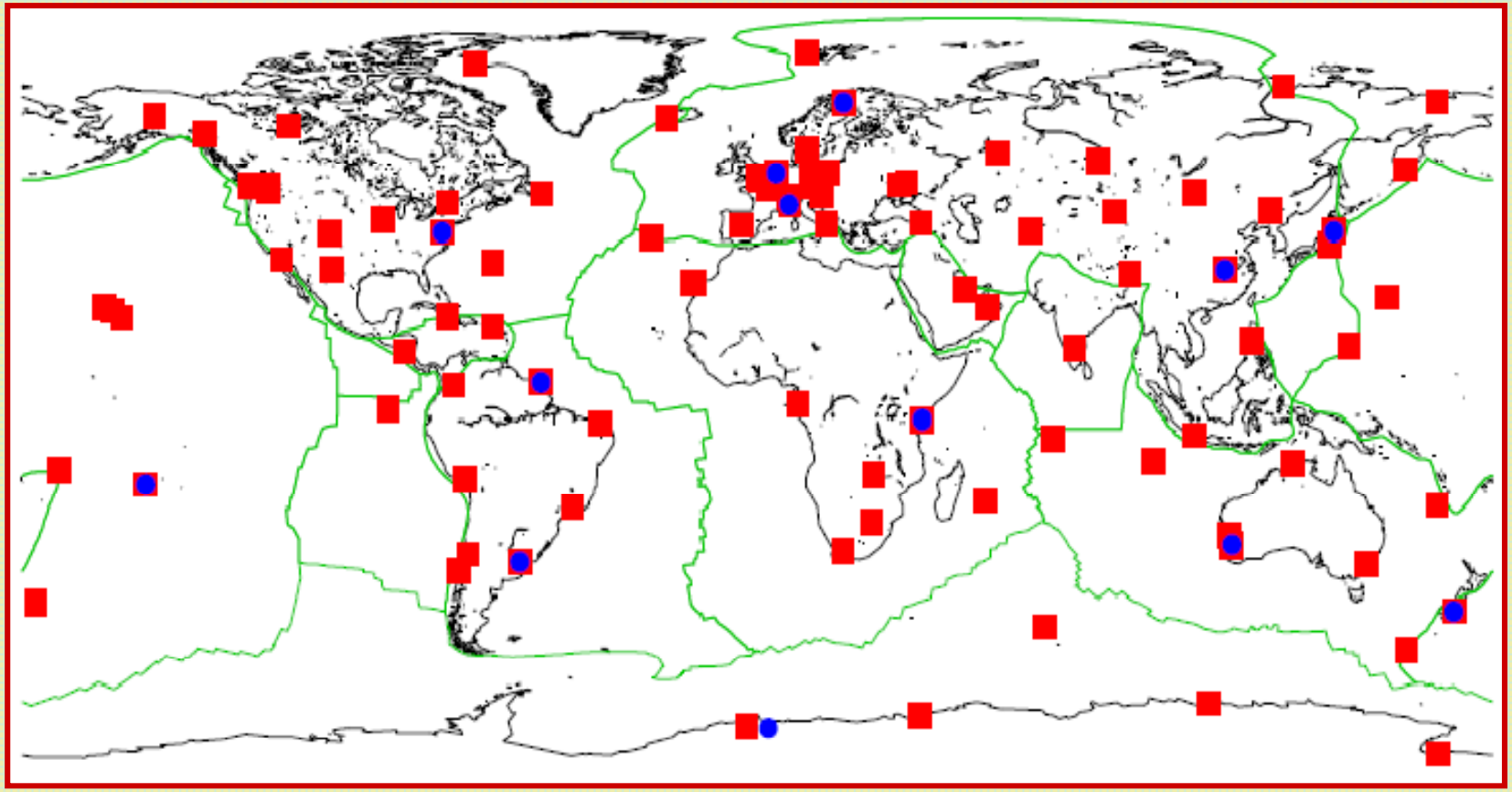


- *Coordinates of ~20 stations fixed to ITRF2000*
- *No station velocities*

GALILEO TERRESTRIAL REFERENCE FRAME (GTRF)

- *Galileo Geodesy Service Provider (GGSP)*
  - *Define, realize & maintain the GTRF*
  - *GTRF is compatible with the ITRF*
  - *GTRF is fully aligned to ITRF*
- *GTRF is a realization of the ITRS*

GTRF PROVISIONAL NETWORK



GESS IGS station

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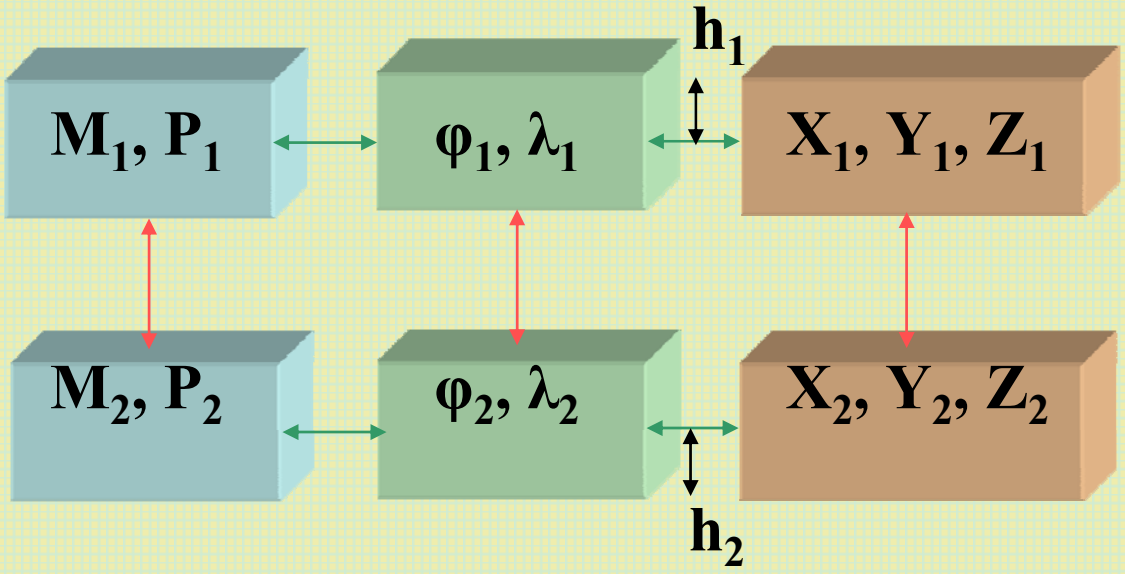
Relationship between the different types of coordinates and different reference systems

Geodetic system 1

Geodetic system 2



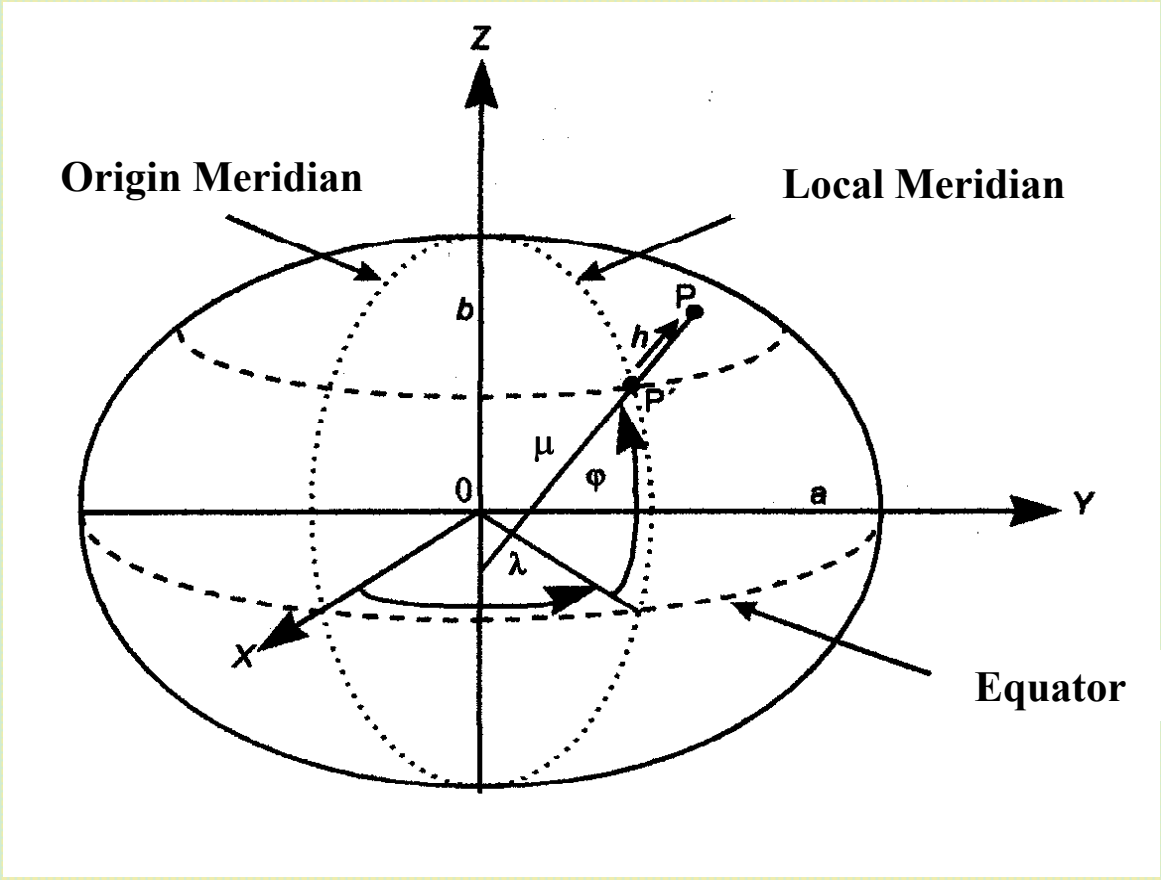
M_i, P_i	*Plane cartesian coordinates*
$\varphi_i, \lambda_i, h_i$	*Geographic coordinates and ellipsoidal height*
X_i, Y_i, Z_i	*Spatial cartesian coordinates*

INTRODUCING THE REFERENCE ELLIPSOID

$$X = (\mu + h) \cos \varphi \cos \lambda$$

$$Y = (\mu + h) \cos \varphi \operatorname{sen} \lambda$$

$$Z = (\mu (1 - e^2) + h) \operatorname{sen} \varphi$$



$$h = f(\varphi, \lambda)$$

$$\tan \lambda = Y / X$$

$$\tan \varphi = (Z / Y) ((\mu + h) \operatorname{sen} \lambda) / (\mu (1 - e^2) + h)$$

ADOPTION OF THE GRS80

- *Adopted at the 1979 General Assemby of the IAG, as successor of the GRS67*
- *For representing the Earth (geometry and dynamics)*
- *For applications in the domains of geodesy, geophysics and hydrography*
- *Official for geodetic works*
- *Based on the theory of the equipotential ellipsoid*

ELLIPSOID
WGS84 VERSUS GRS80

WGS84		*GRS80*	
a	6 378 137 m	a	6 378 137 m
1/f	298. 257 223 563	J_2	108 263 x 10^{-8}
ω	7 292 115 x 10^{-11} rad s^{-1}	ω	7 292 115 x 10^{-11} rad s^{-1}
GM	3 986 004.418 x 10^8 m^3 s^{-2}	GM	3 986 005 x 10^8 m^3 s^{-2}

IAG REGIONAL INITIATIVES

Commission 1 - Reference Frames

- *SC1.1: Coordination of Space Techniques*
- *SC1.2: Global Reference Frames*
- *SC1.3: Regional Reference Frames*
  - *SC1.3 a: Europe (EUREF)*
  - *SC1.3 b: South and Central America (SIRGAS)*
  - *SC1.3 c: North America (NAREF)*
  - *SC1.3 d: Africa (AFREF)*
  - *SC1.3 e: Asia-Pacific*
  - *SC1.3 f: Antarctica*

EUROPEAN TERRESTRIAL REFERENCE SYSTEM 89 (ETRS89)

Definition

The IAG Subcommision for the European Reference Frame, following its Resolution 1 adopted in Firenze in 1990, recommends that the terrestrial reference system to be adopted by EUREF will be coincident with the ITRS at the epoch 1989.0 and fixed to the stable part of the Eurasian Plate.

It will be named European Terrestrial Reference System 89 (ETRS89).

REALIZATION OF ETRS89

- *Expression in $ITRF_{YY}$ at the central epoch (t_c) of the observations*
- *Expression in ETRS89 using 14 transformation parameters (some are zero)*

(Altamimi, Z., 2007)

Positions

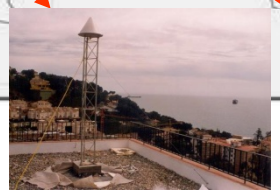
$$X^E(t_c) = X^I_{YY}(t_c) + T_{YY} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c).(t_c - 1989.0)$$

Velocities

$$\begin{pmatrix} \dot{X}^E_{YY} \\ \dot{Y}^E_{YY} \\ \dot{Z}^E_{YY} \end{pmatrix} = \begin{pmatrix} \dot{X}^I_{YY} \\ \dot{Y}^I_{YY} \\ \dot{Z}^I_{YY} \end{pmatrix} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times \begin{pmatrix} X^I_{YY} \\ Y^I_{YY} \\ Z^I_{YY} \end{pmatrix}$$

EUREF Permanent Tracking Network

204 permanent stations (1 inactiv)

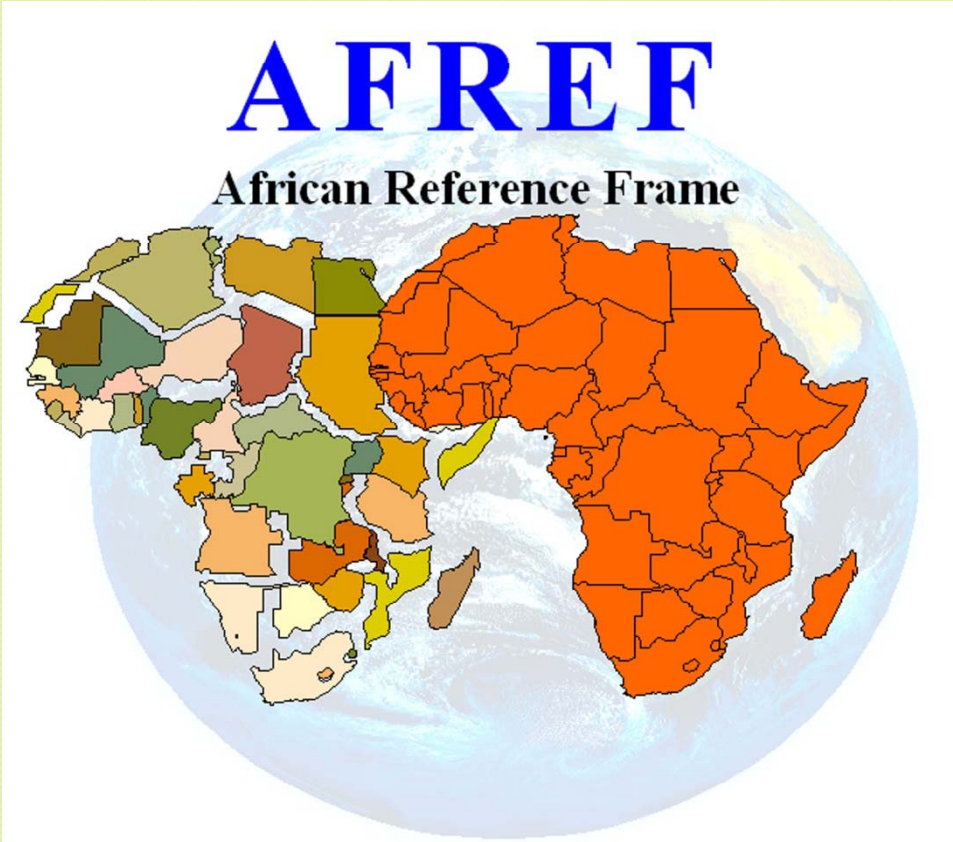


GMT 2008 May 31 02:31:07

http://www.epncb.oma.be/

ADOPTION OF ETRS89 (2005)

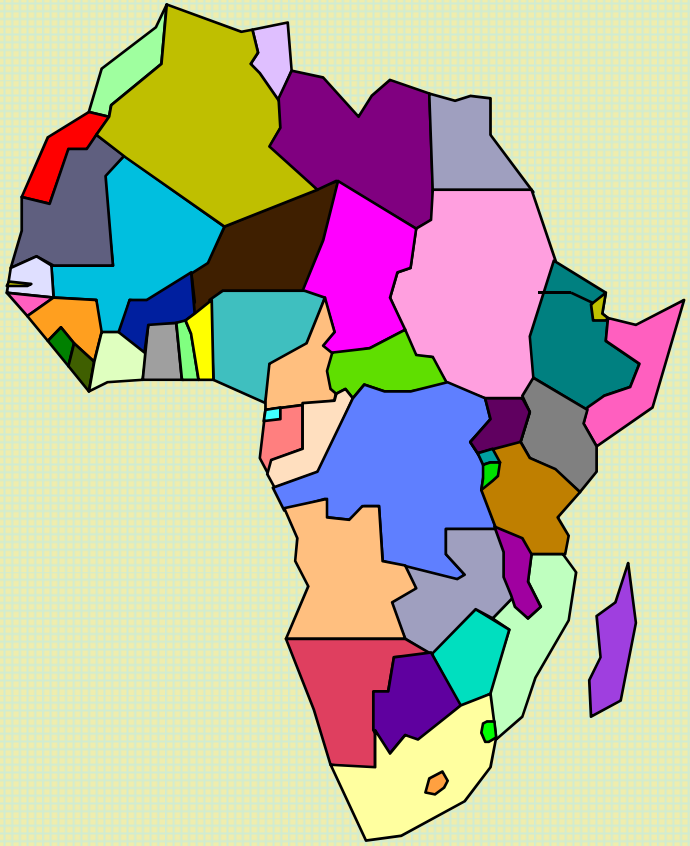
Countries to whom the questionnaire was sent	41
Countries who answered	27
Countries that adopted already ETRS89	21 (78%)
Countries willing to adopt ETRS89	4 (15%)
Countries that will not adopt ETRS89	2 (7%)
Oficial support: law	10
Oficial support : standard	6
Oficial support : recommendation	9
Conditions of use: mandatory	6
Conditions of use: in specific situations	13
Conditions of use: complementary	16



AFREF is an effort carried out by the international community, in particular the African countries, to establish a continental reference system, consistent and homogeneous with the global reference system (ITRS) as a basis for the national reference networks.

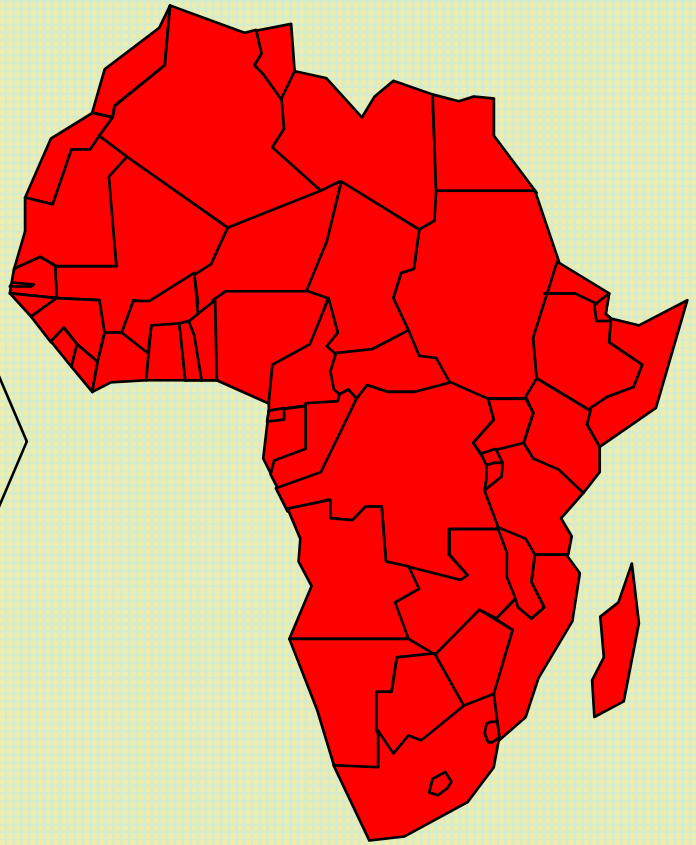
6- GRS for geo-spatial referencing; regional initiatives

Non-uniform systems



GNSS stations + ITRS

Uniform system

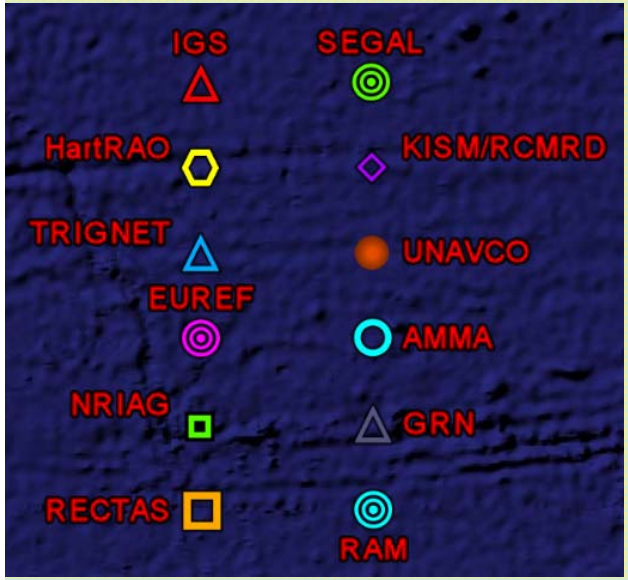


- *GNSS stations will realize and maintain AFREF*
- *AFREF will be based on the ITRS*

(Fernandes, R., 2008)

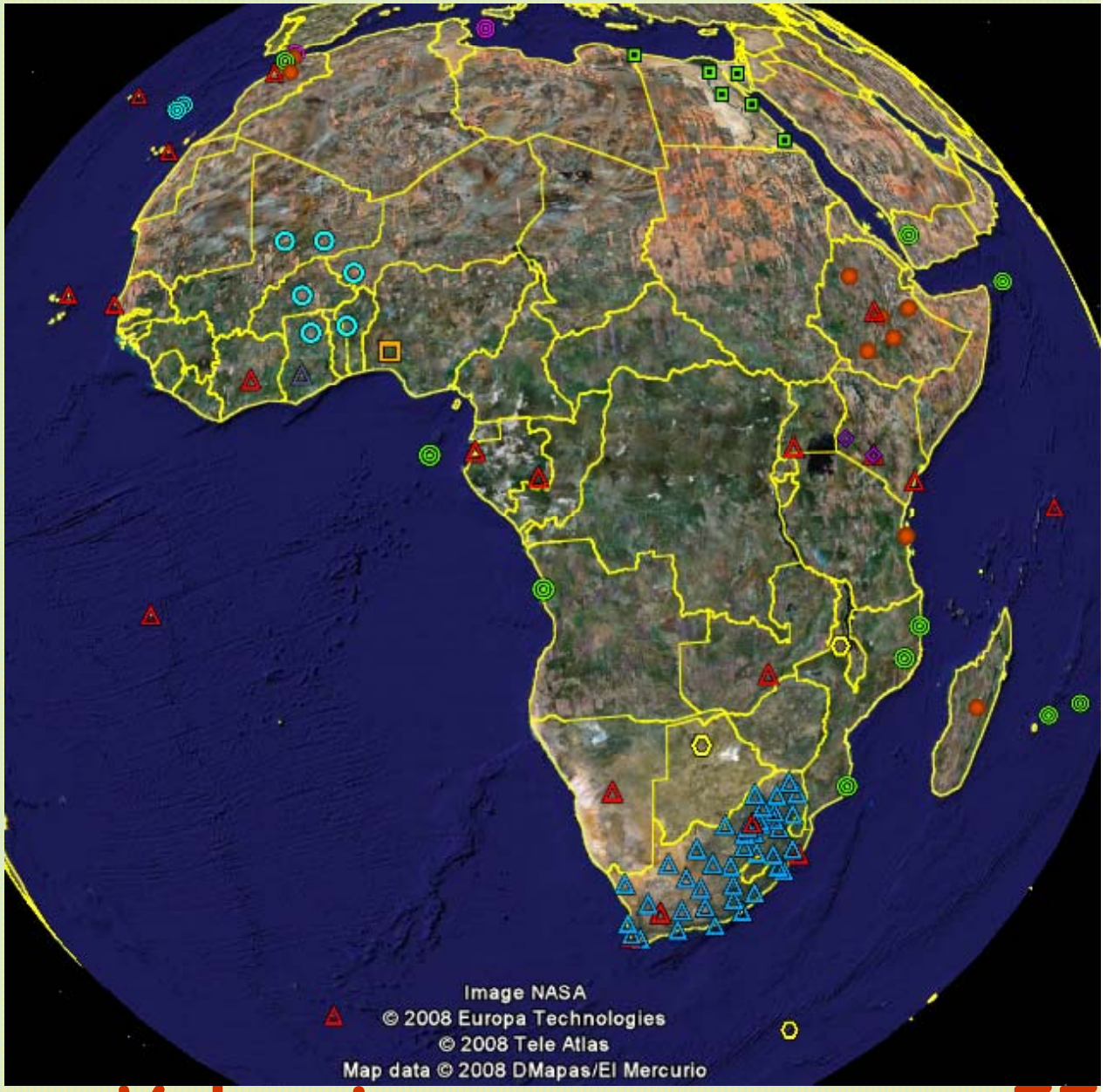
Current Situation

- *Survey of CGPS sites:*
- *101*



Note:
Many stations belong to more than one network.

(Fernandes, R., 2008)



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- *The present geo-referencing systems are realized through an observing system based on geodetic space techniques*

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- *There is a strong international effort and cooperation for the maintenance of the global and regional geodetic reference frames*

7- Conclusions

- *The present geo-referencing systems are realized through an observing system based on geodetic space techniques*
- *There is a strong international effort and cooperation for the maintenance of the global and regional geodetic reference frames*
- *The description of geodetic reference systems is the aim of the ISO 19111 Geographic Information – Spatial referencing by coordinates*

7- Conclusions

- *The present geo-referencing systems are realized through an observing system based on geodetic space techniques*
- *There is a strong international effort and cooperation for the maintenance of the global and regional geodetic reference frames*
- *The description of geodetic reference systems is the aim of the ISO 19111 Geographic Information – Spatial referencing by coordinates*
- *WGS84, ETRS89, PZ90, GTRF are all connected to (compatible with) a Unique System: the ITRS*