Geodesy and Geodetic Reference Frame

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Outline

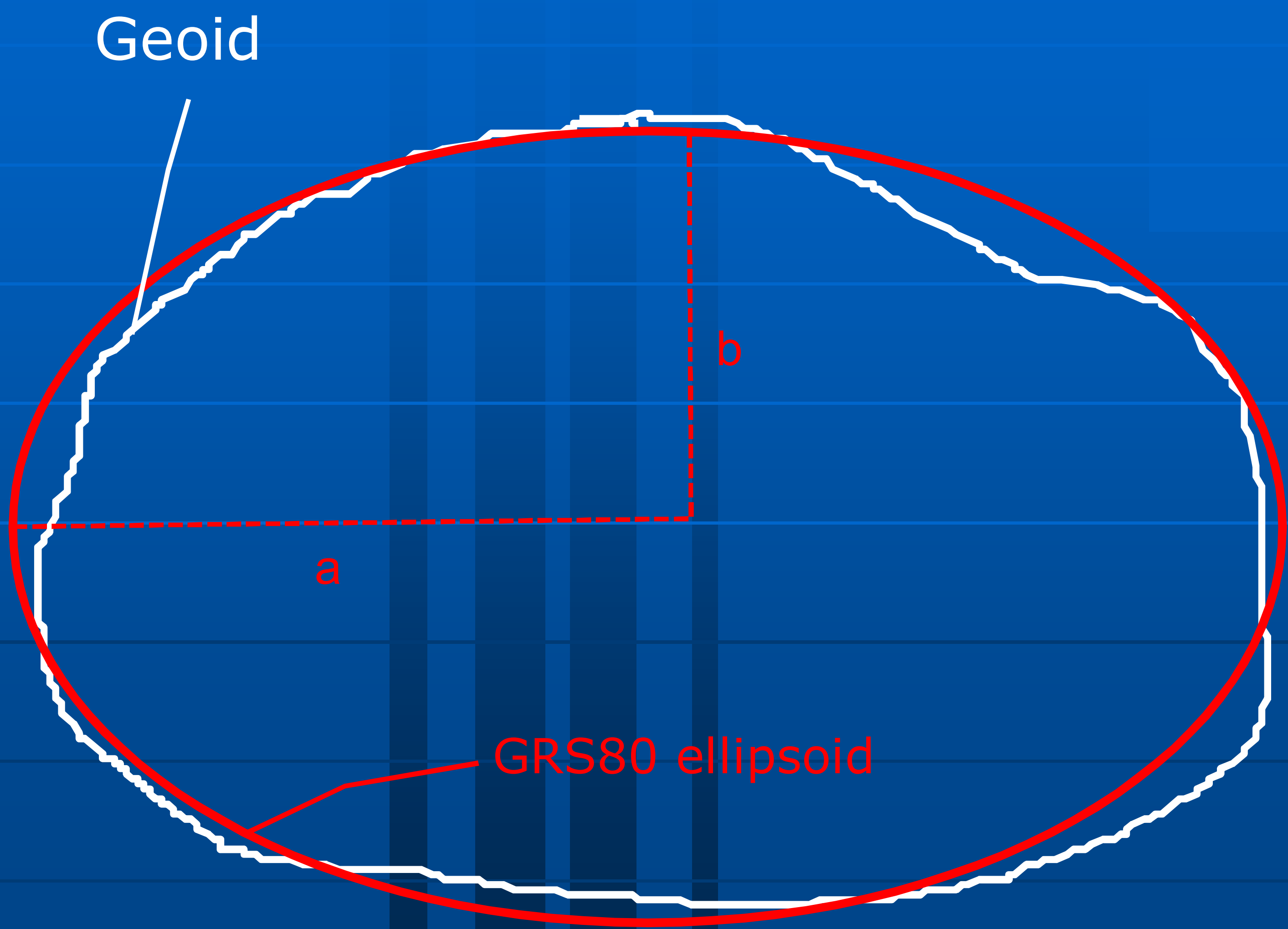
- Geodesy
- Reference frames
- Japan
- Asia-Pacific

Geodesy

- Geodesy studies the earth’s
  - Surface geometry and its changes
  - Gravity field
  - Rotations
  - Reference systems/frames

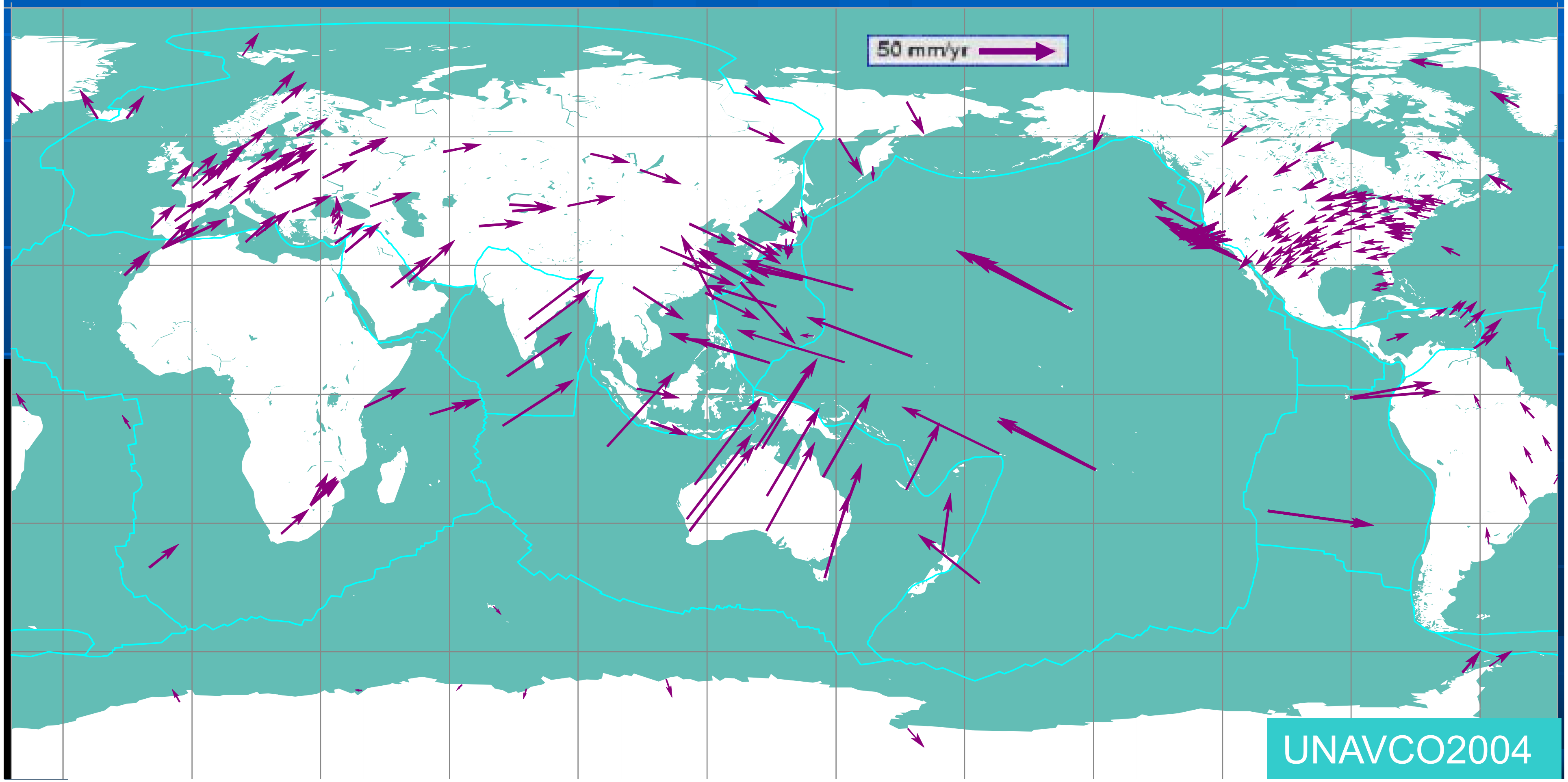
  - With measurement techniques
  - applications include surveying, mapping, navigation, timing, etc.

Shape and size of the earth

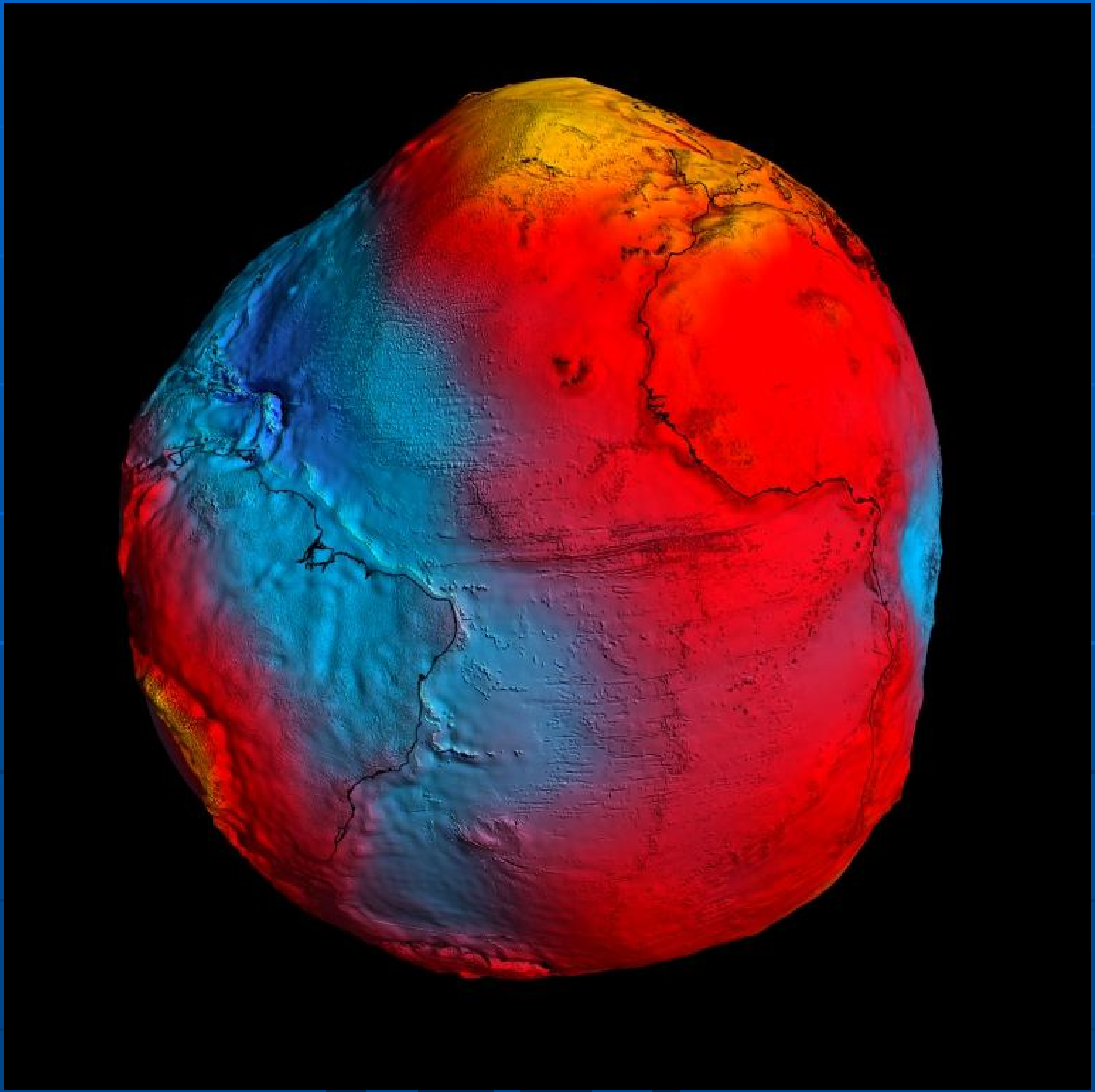


Surface movements

REVEL-2000(ref:ITRF97)
http://jules.unavco.org/



Gravity Field

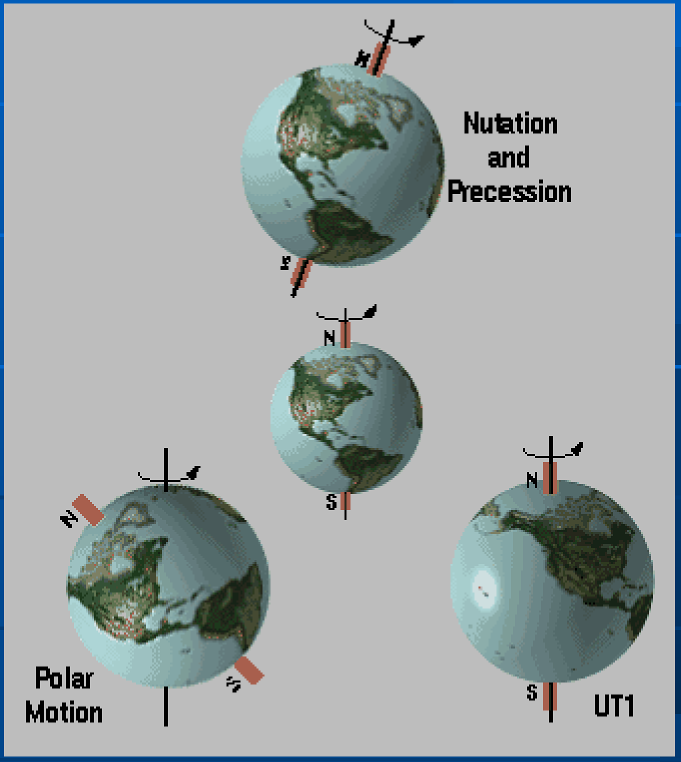


GOCE Geoid

by ESA

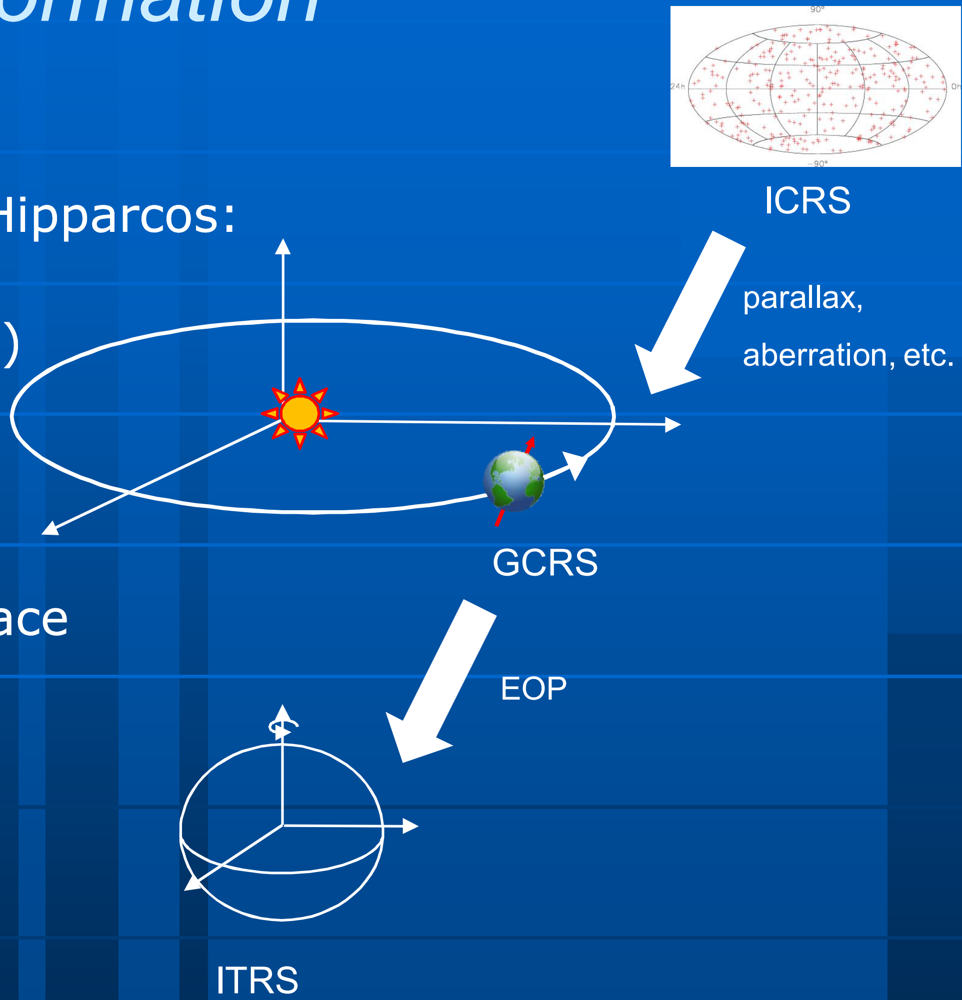
Earth Rotation: EOP (Earth Orientation Parameters)

- Link between terrestrial and celestial worlds
  - Nutation/Precession
  - UT1
  - Polar Motion



Reference Systems/Frames: hierarchy and transformation

- Celestial
  - ICRS/ICRF (VLBI), HCRF (Hipparcos: optical satellite)
  - GCRS (Geocentric Celestial)
- Terrestrial
  - Global
    - ITRS/ITRF, WGS84 (space geodesy)
  - Regional frame
  - National frame
- Time
  - UTC, TAI

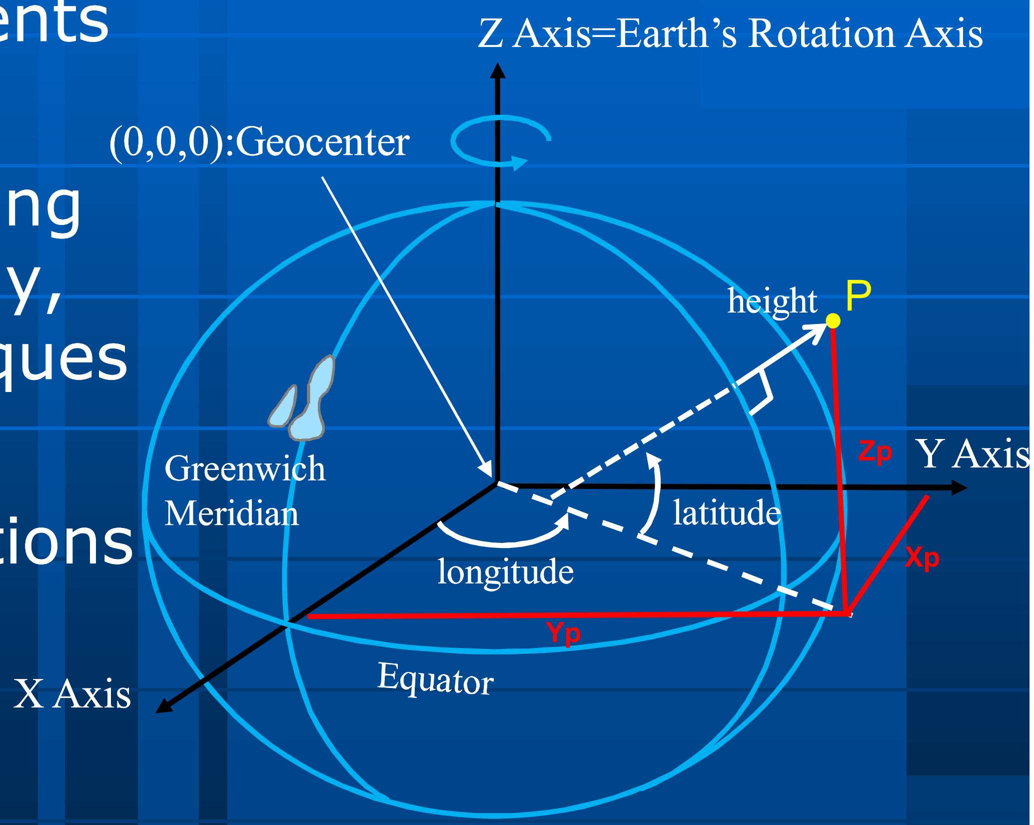


Reference Frames: roles & requirements

- Supporting science
  - Foundation of measurements/observations
  - Accurate, consistent, pursuing precision
  - Continuously revised (improved), reflecting earth’s dynamics
- Service to society
  - Accessible by users
  - Serve as standards (cf. metrology)

Geodetic Reference Frames

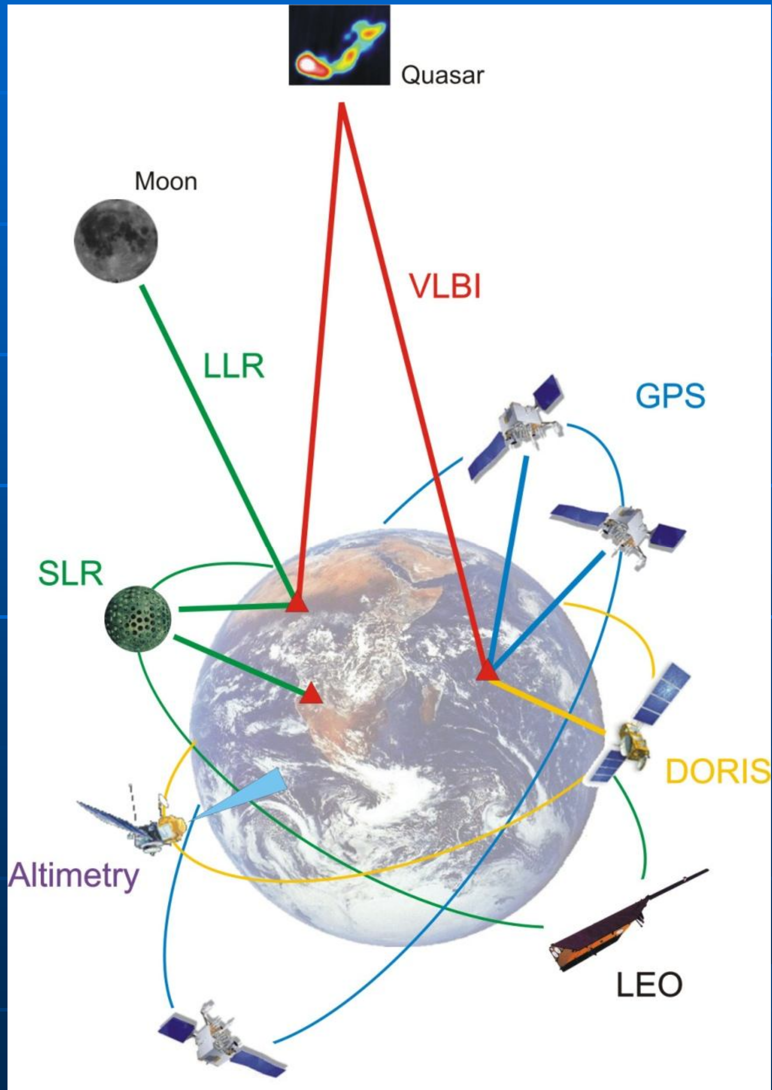
- Cornerstone of all geospatial measurements
- Evolving with positioning technologies, especially, space geodetic techniques
- Wide range of applications via GNSS



Global Terrestrial Reference Frames and Space Geodetic techniques

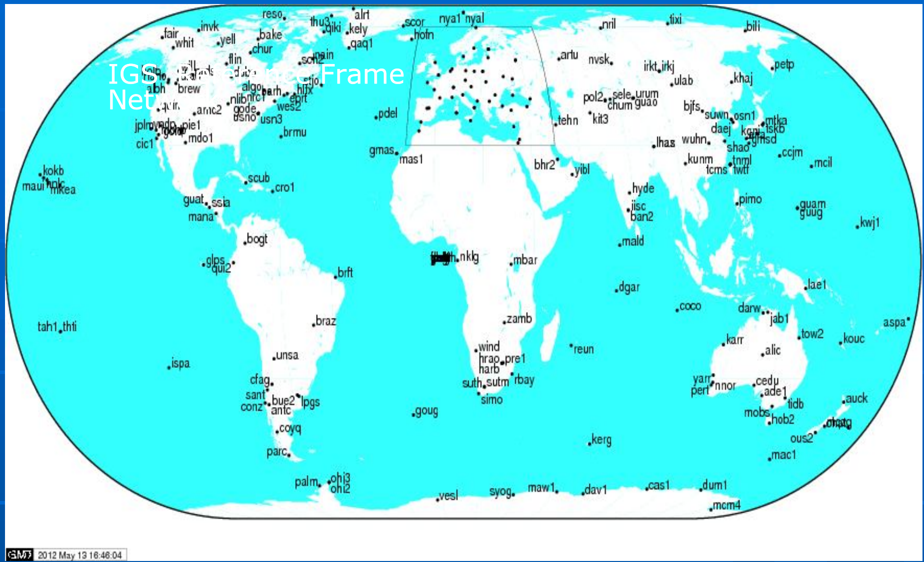
- VLBI
- GNSS (GPS and others)
- SLR, LLR
- DORIS
- …

- WGS84 ver.x.x.:GPS (U.S)
- ITRFxx: combination of techniques (IERS), since 1989, present standard of scientific community



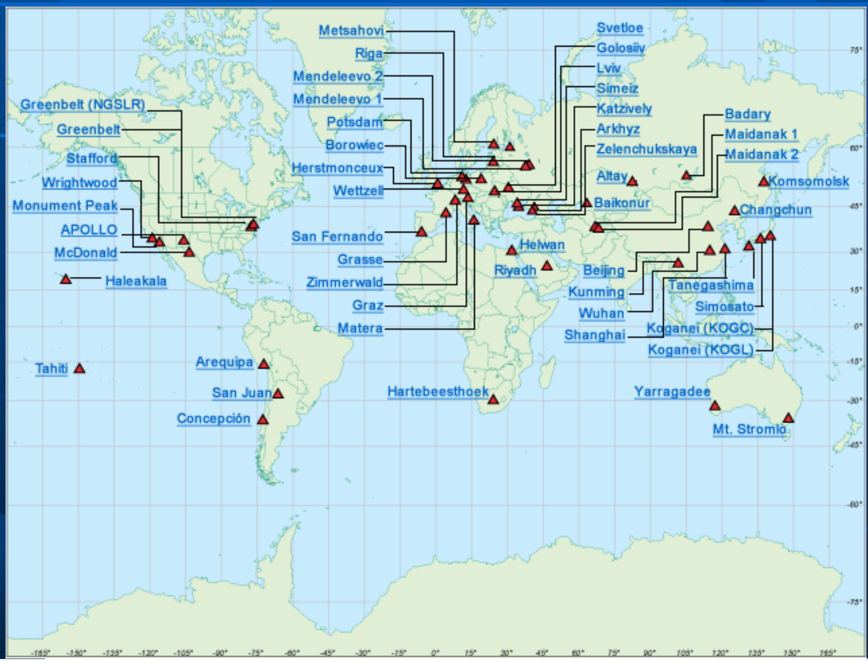
4 techniques to Realize ITRF

IGS Reference Frame Network

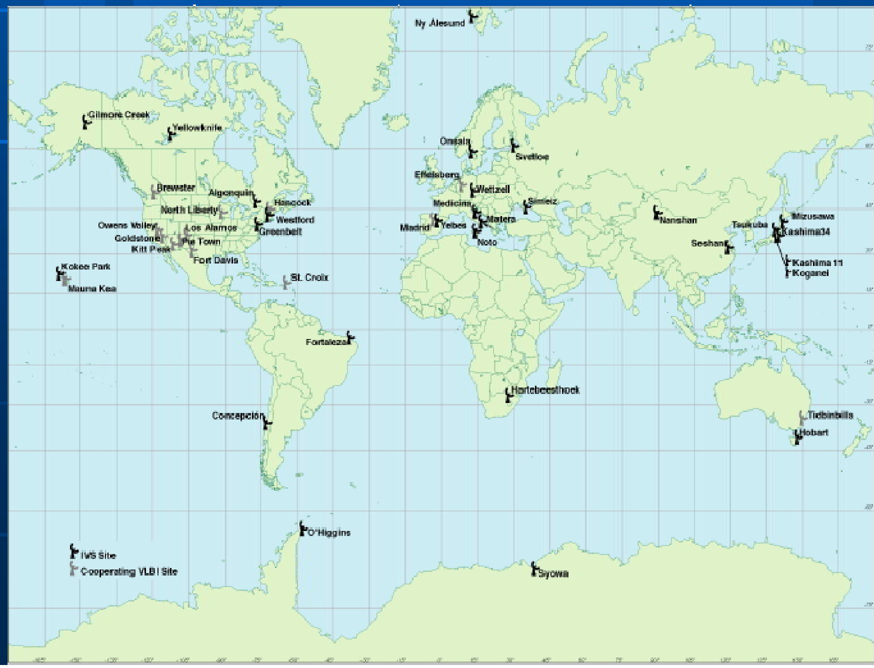


DORIS stations

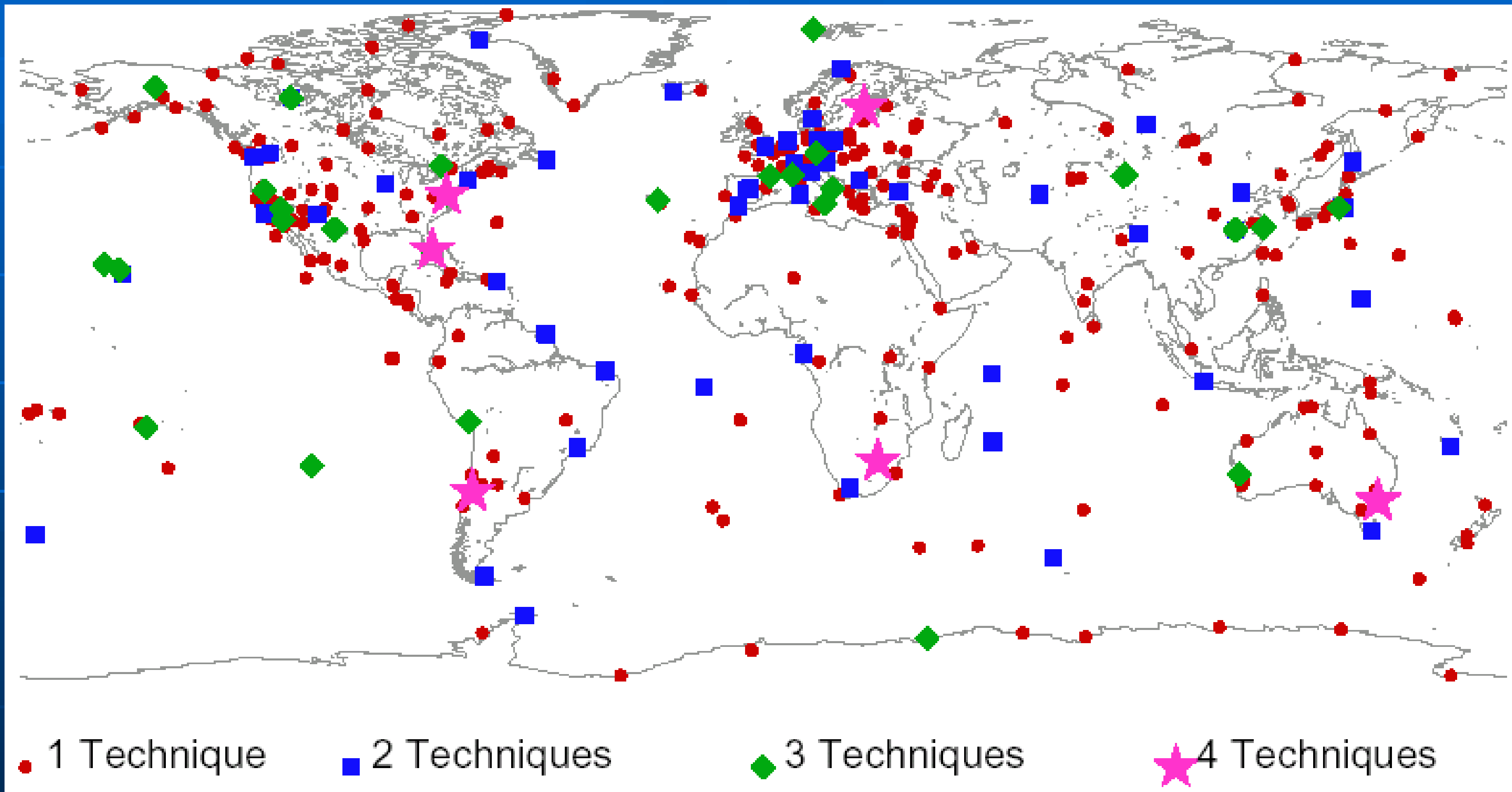
SLR stations



IVS Network



ITRF Network



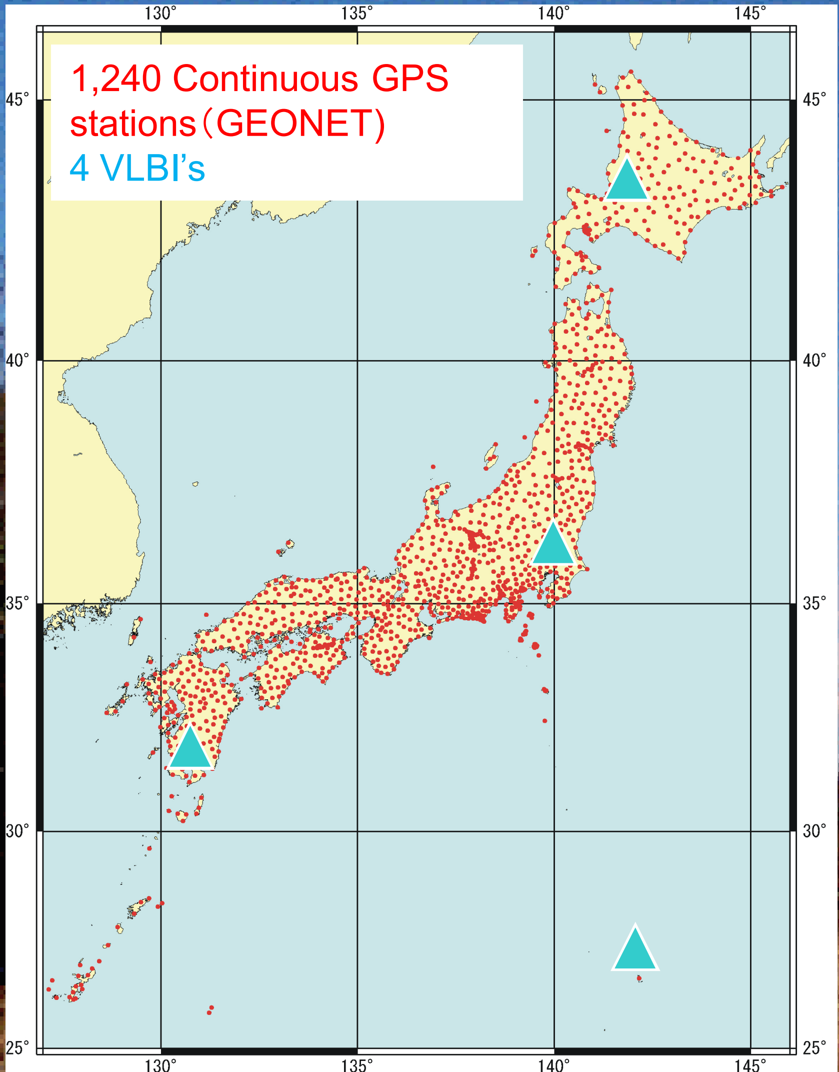
Reference Frames for regions and nations

- Underpin geospatial activities
  - Foundation of surveying and mapping, navigation and timing, across the region and in each country
  - High quality connection to a global geocentric frame to gain full benefit of GNSS and its applications
- National Frame
  - Authoritative source of station coordinates in a nation
  - Land, utility and asset management
  - Emergency and disaster management
- Regional Frame
  - Link between national datum and global standard (ITRF), overcoming differences in geodetic ability of each nation
  - Possible by sharing data and analysis

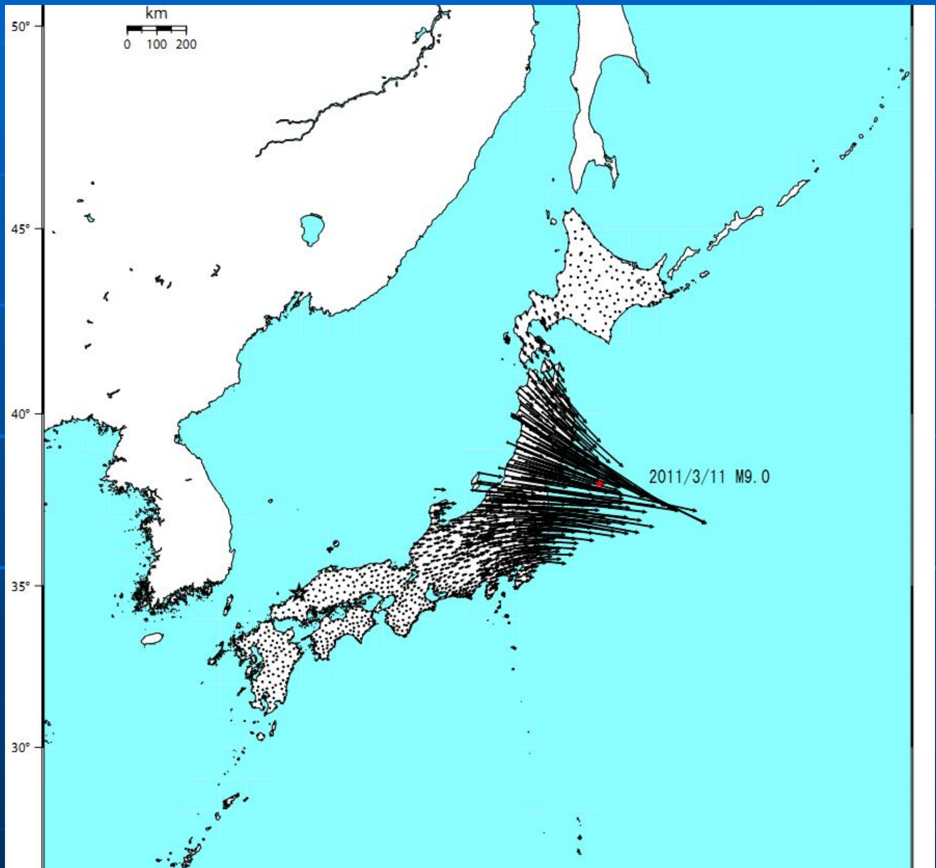
Case study 1: Geodetic Reference of Japan and its Revision after Great East Japan Earthquake

- Tokyo datum(late 19th century)
  - Infrastructure for surveying, mapping for modern Japan
  - Survey act
- JGD2000 (2002, Geocentric datum referred to ITRF)
  - Improvements of geodetic observations with space geodetic techniques
  - Global trend of satellite positioning/navigation by GNSS
  - Infrastructure for geospatial information
  - Based on VLBI and GPS observations
  - Revised Survey act
- JGD2011 (2011)
  - First major revision necessitated by Great East Japan earthquake

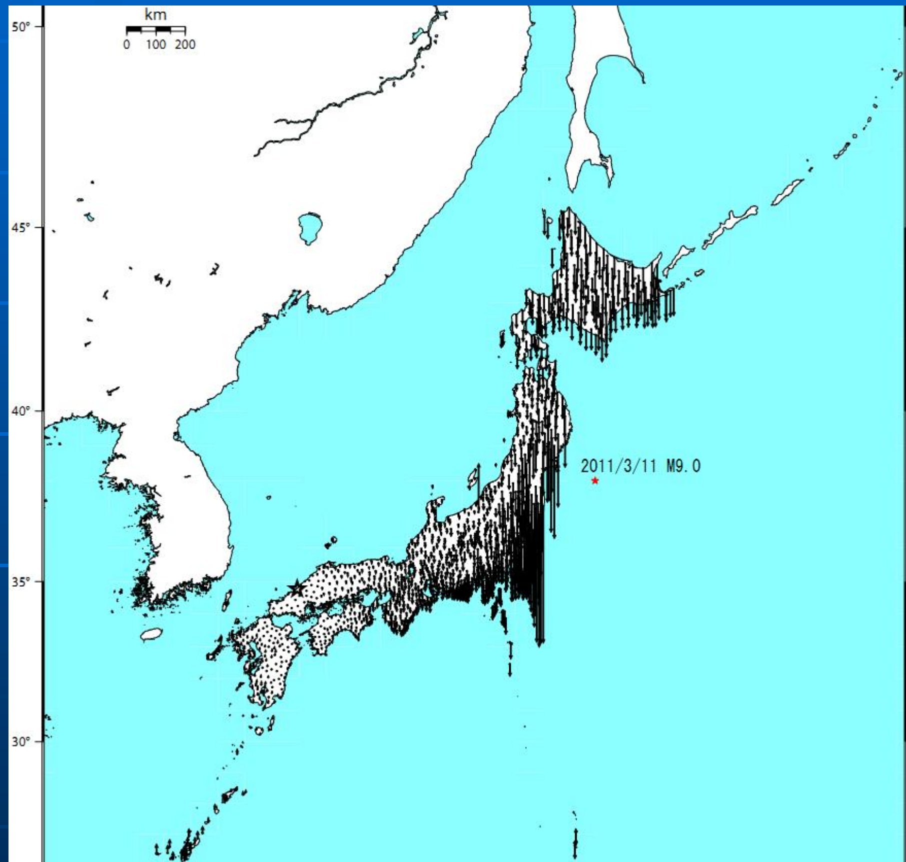
Space geodetic Network by GSI, Japan



Deformations caused by the Great East Japan Earthquake (March 11, 2011)

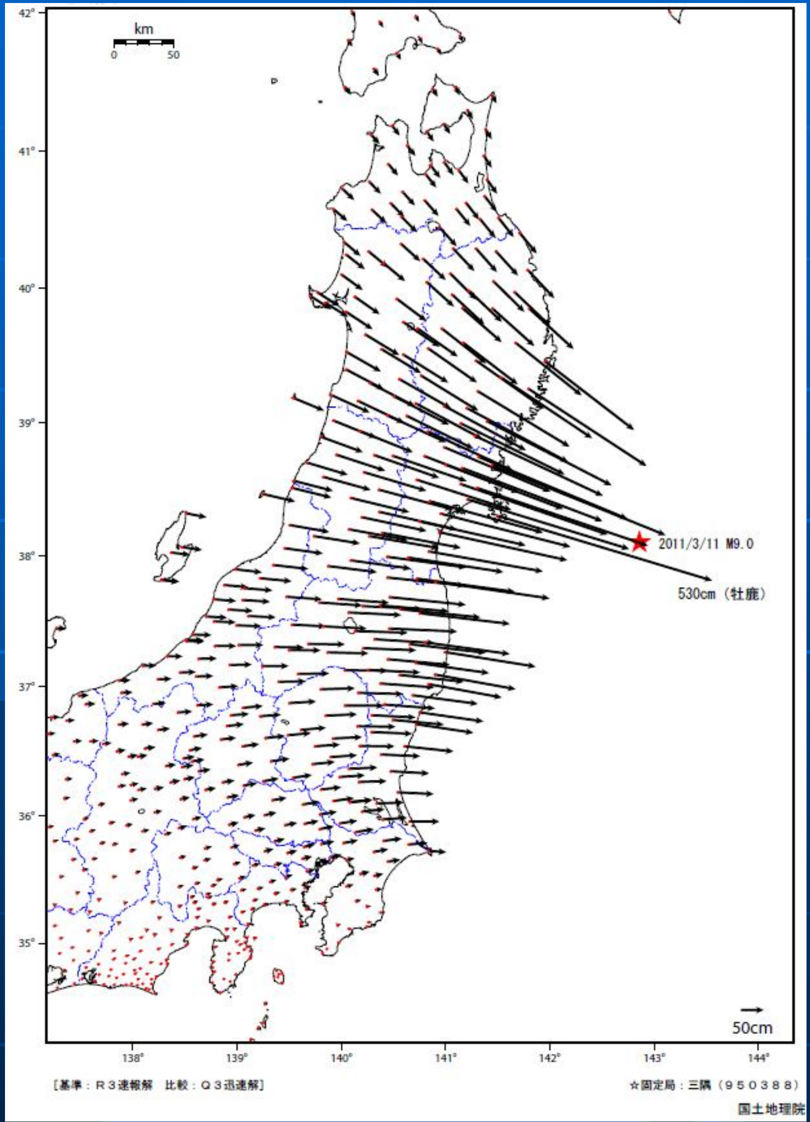


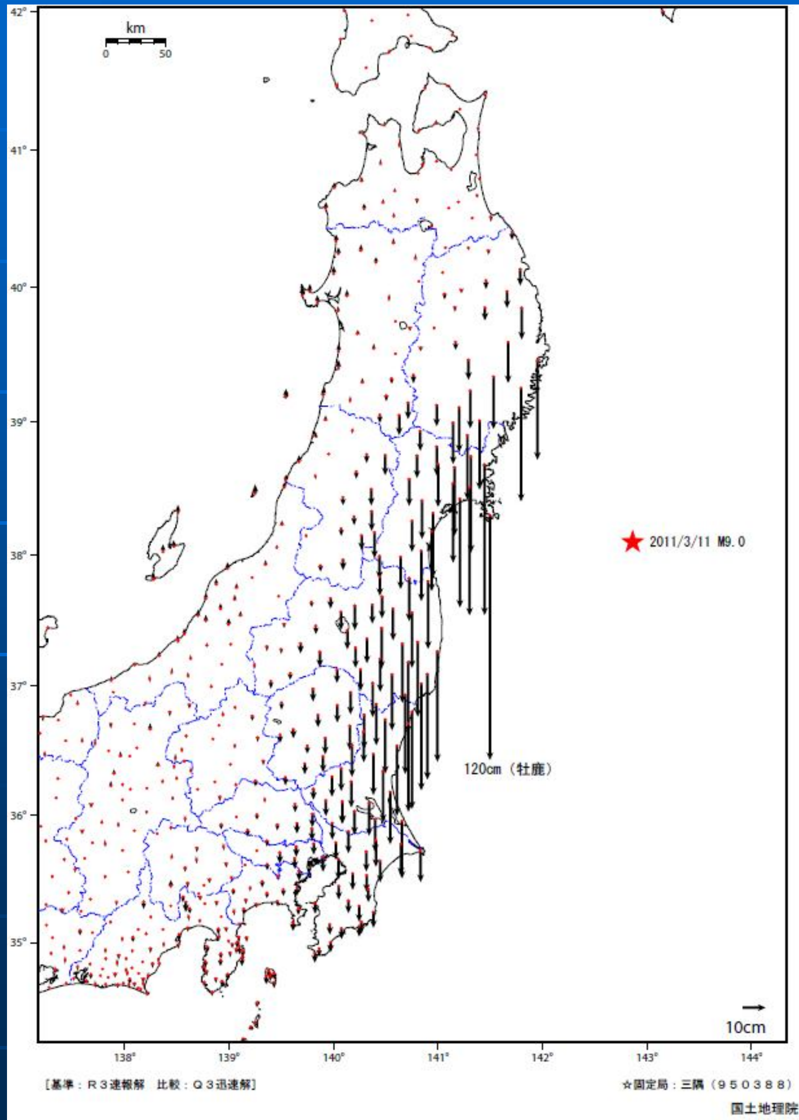
Horizontal up to 5.3m



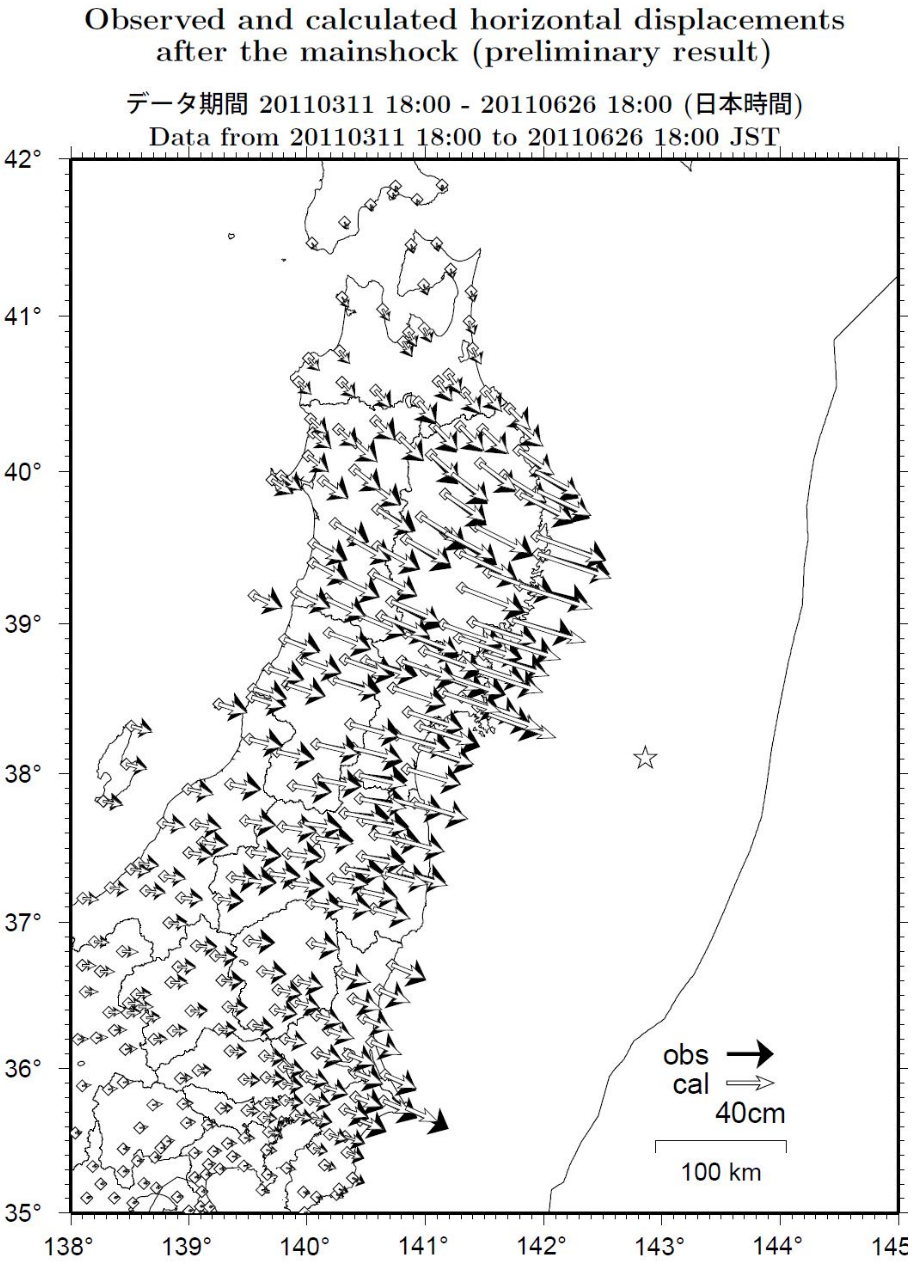
Subsidence up to 1.2m

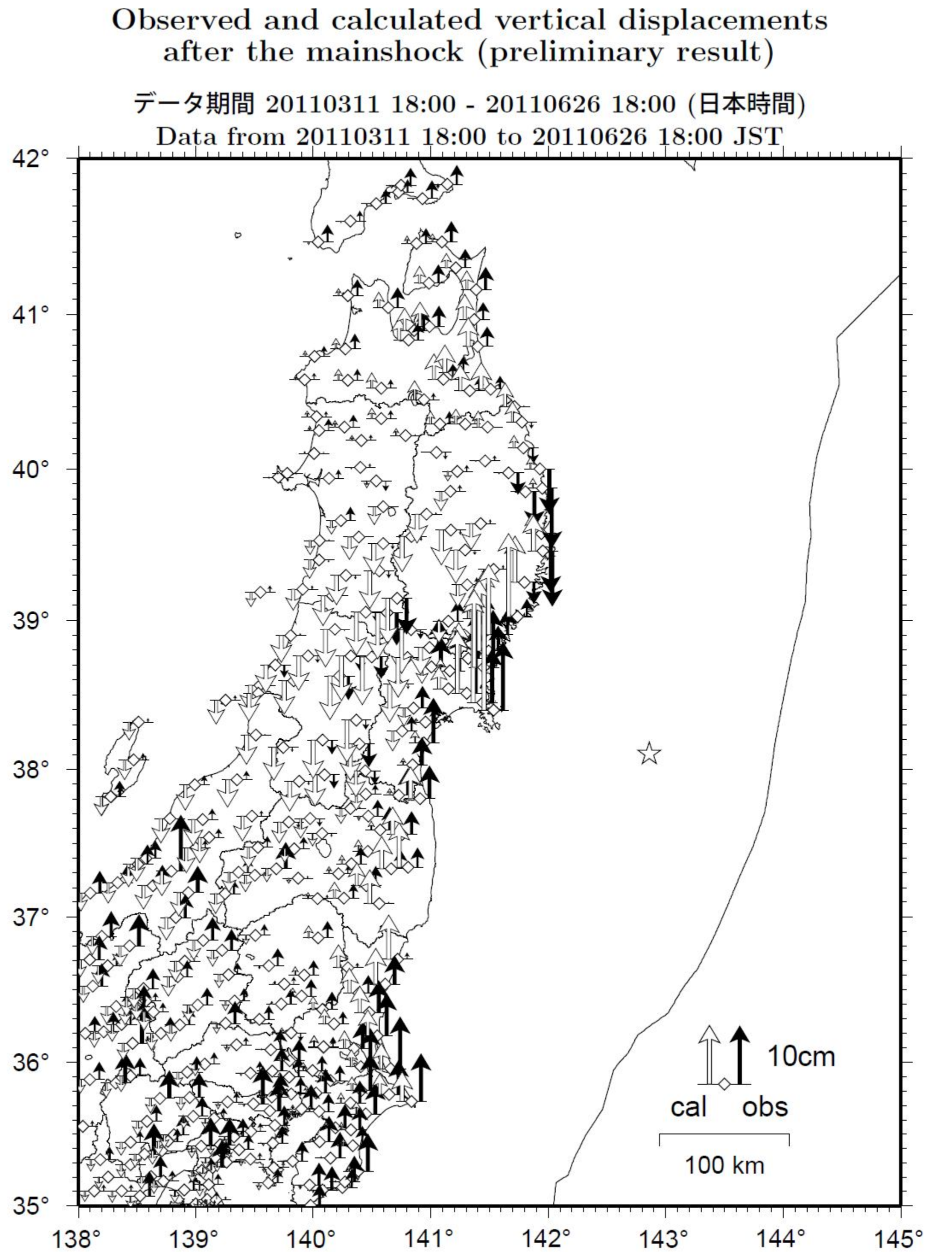
Coseismic deformation





Post-seismic deformation (After Slip)





Revision of JGD in 2011

- Quick evaluation of crustal movements (including after slip) by GEONET
- More than 1/3 (>40,000 pts.) of the positioning data revised
- Shifts of Origins (in Tokyo for horizontal/vertical; designated by Survey Act) by VLBI(IVS) and leveling followed by GEONET observations and parameter corrections
- Completed in 7 months
- Enabled by nationwide positioning infrastructure with international cooperation

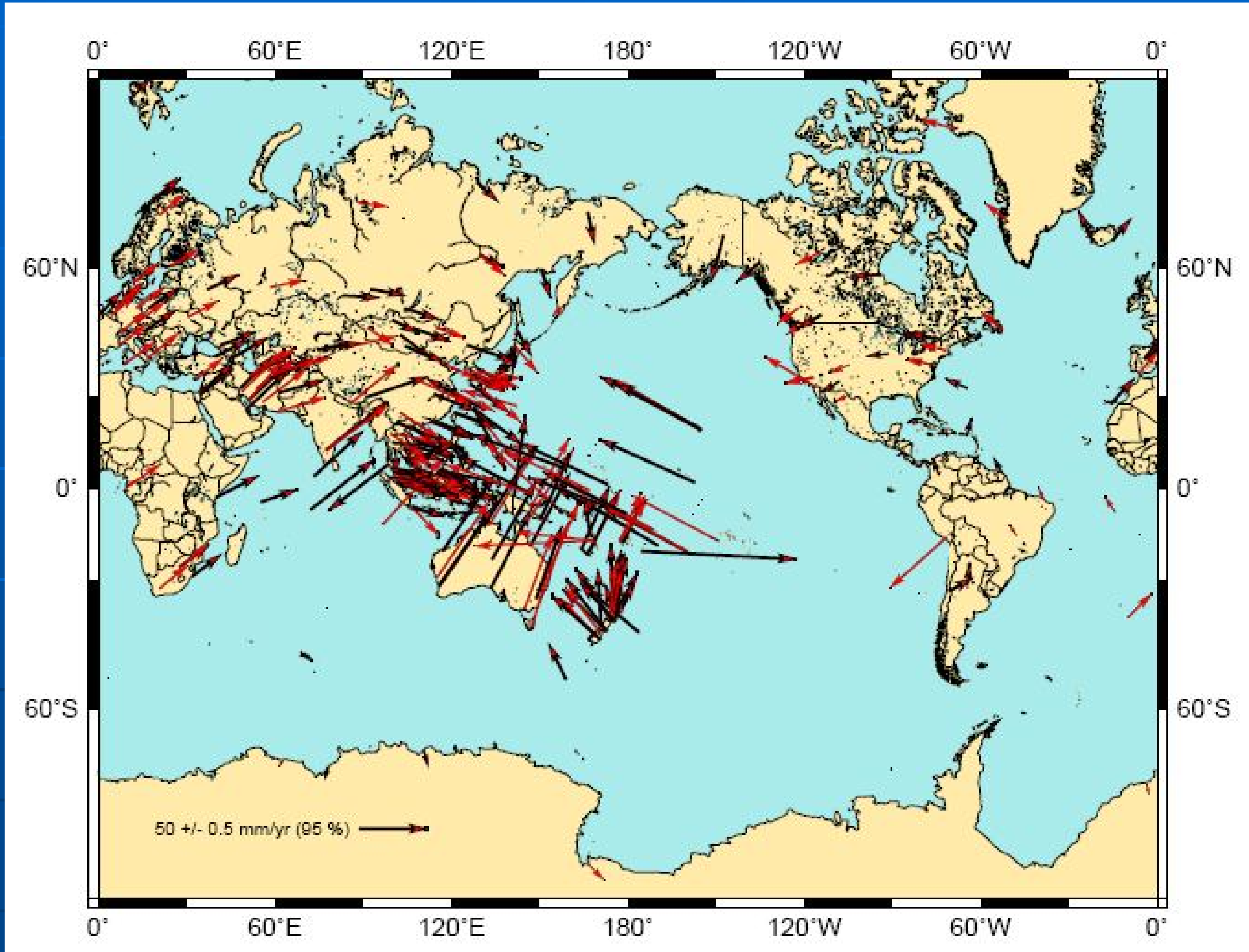
Case study 2:The Asia-Pacific Reference Frame (APREF) Project (2010-)

- Concepts:
  - Development and evolution of the current campaign-based APRGP activity (1997-, by PCGIAP WG1),
  - To overcome the geodetic situation of the region complicated by frequent earthquakes and continuous deformations
  - By establishing a precise and reliable reference based on continuous observations.

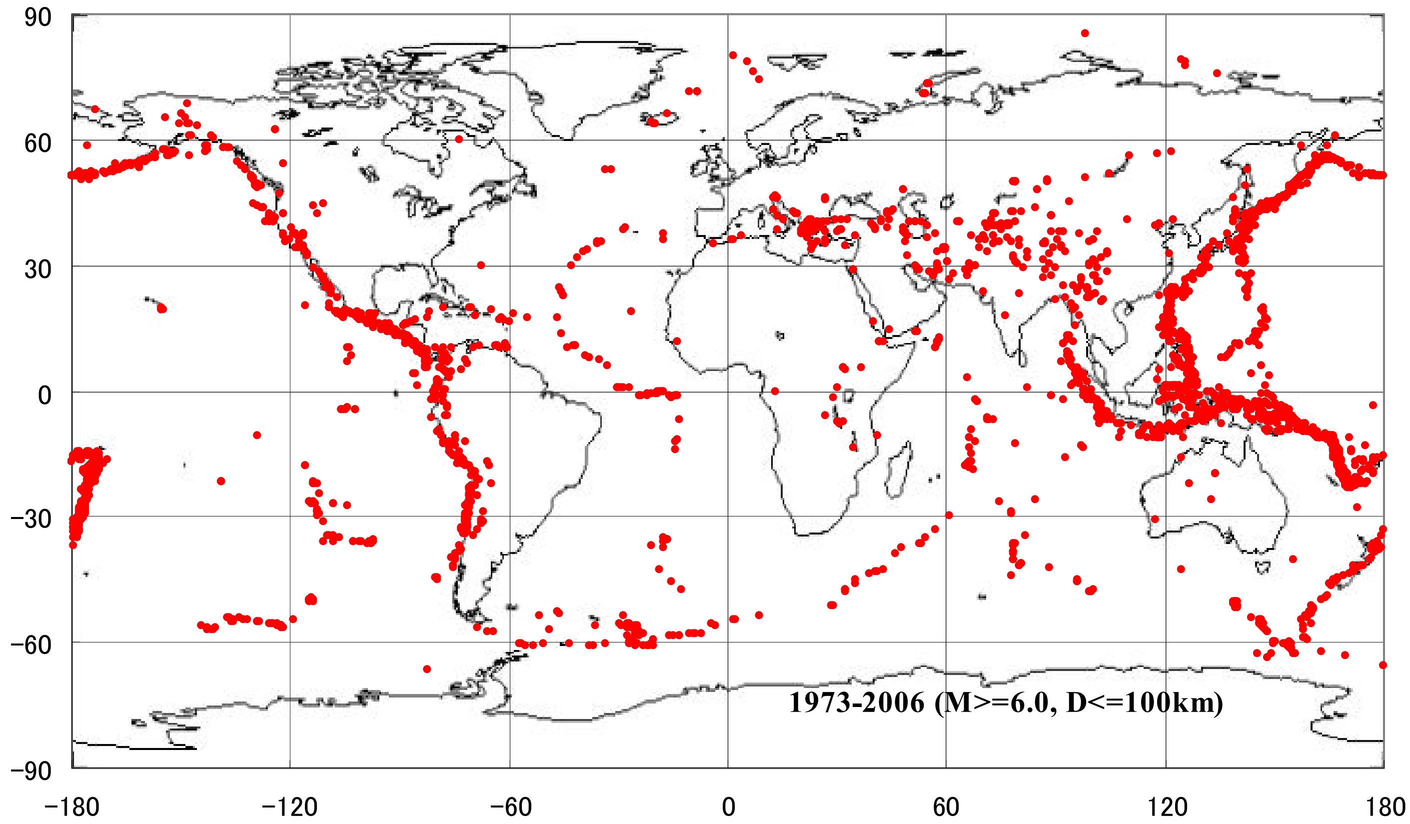
APREF: Objectives

- Create and maintain an accurate and densely realised geodetic framework, based on continuous observation and analysis of GNSS data;
- Encourage the sharing of GNSS data from CORS in the region;
- Share experiences and encourage regional consultation in regards to CORS GPS/GNSS networks;
- Develop the APREF Permanent Network, as a contribution to the ITRF and as infrastructure to support other relevant projects;
- Provide an authoritative source of coordinates and their respective time-series for geodetic stations in the region in near real-time with high quality connection to ITRF; and
- Establish a dense velocity field model in Asia and the Pacific for scientific applications and the long-term maintenance of the Asia-Pacific reference frame.

Velocity Field for the PCGIAP APRGP Stations



Distribution of Earthquakes



Current APREF Network including IGS stations (420 stations, 28 countries)

http://www.ga.gov.au/earth-monitoring/geodesy/asia-pacific-reference-frame.html

Sustainable System for the Future

- Long-term maintenance with improvements of observational infrastructure (geodetic network)
- Coordination, assistance and cooperation with the help of international community
  - PCGIAP-AP
  - UN
  - International organizations and Academic community

Thank you for your attention

THE GLOBAL GEODETIC OBSERVING SYSTEM

Geodesy's contribution to Earth Observation

THE GLOBAL GEODETIC OBSERVING SYSTEM (GGOS)

GGOS is the Observing System of the International Association of Geodesy (IAG). GGOS was established by IAG in July 2003. Since April 2004, GGOS represents IAG in the Group on Earth Observation (GEO) and GGOS is IAG's contribution to the Global Earth Observation System of Systems (GEOSS).

GGOS HISTORY

The international cooperation fostered by IAG has led to the establishment of the IAG Services, that provide increasingly valuable observations and products not only to scientist but also for a wide range of non-scientific applications. Considering this development in geodesy, the requirements of Earth observations, and the increasing societal needs, IAG initially created GGOS as an IAG Project during the IUGG meeting in 2003 in Sapporo, Japan. After the first two years devoted to the definition of the internal organizational structure of GGOS and its relationship with external organizations (the "Design Phase"), the Executive Committee of the IAG at its meetings in August 2005 in Cairns, Australia, decided to continue the Project. In the "Implementation Phase" from 2005 to 2007, the GGOS Steering Committee, Executive Committee, Science Panel, Working Groups, and Web Pages were established, and the Terms of Reference were revised. Finally, at the IUGG meeting in 2007 in Perugia, Italy, IAG elevated GGOS to the status of a full component of IAG as the permanent observing system of IAG.

THE TWO MEANINGS OF GGOS

GGOS has two very distinct aspects, which should not be confused: the "organization GGOS" consisting of components such as committees, panels, working groups, etc., and the "observation system GGOS" comprising the infrastructure of many different instrument types, satellite missions, and data and analysis centers. While GGOS as an organization has established its structure from essentially new entities and will, over the next years, add new entities where needed, the observational infrastructure for GGOS as the system is being largely provided by the IAG Services.

GGOS THE ORGANIZATION

GGOS as an organization is a unifying umbrella for the IAG Services and an interface between the Services and the "outside world". Internally, the GGOS Committees, Science Panel and Working Groups focus on cross-cutting issues relevant for all Services. The research needed to achieve the goals of GGOS influences the agenda of the IAG Commissions and the GGOS Working Groups. Externally, GGOS provides the links between the IAG Services and the main programs in Earth observations and Earth science. It constitutes a unique interface for many users to the geodetic Services. In particular, GGOS participates on behalf of IAG in large international programs focusing on Earth observations.

According to the IAG By-Laws, GGOS "works with the IAG Services and Commissions to provide the geodetic infrastructure necessary for the monitoring of the Earth system and global change research." This statement implies a vision and a mission for GGOS. The implicit vision for GGOS is to empower Earth science to extend our knowledge and understanding of the Earth system processes, to monitor ongoing changes, and to increase our capability to predict the future behavior of the Earth system. Likewise, the embedded mission is to facilitate networking among the IAG Services and Commissions and other stakeholders in the Earth science and Earth Observation communities, to provide scientific advice and coordination that will enable the IAG Services to develop products with higher accuracy and consistency meeting the requirements of particularly global change research, and to improve the accessibility of geodetic observations and products for a wide range of users. The IAG Services, upon which GGOS is built, benefit from GGOS as a framework for communication, coordination, and scientific advice necessary to develop improved or new products with increased accuracy, consistency, resolution, and stability. IAG benefits from GGOS as an agent to improved visibility of geodesy's contribution to the Earth sciences and to society in general. The users, including the national members of IAG, benefit from GGOS as a single interface to the global geodetic observation system of systems maintained by the IAG Services not only for the access to products but also to voice their needs. Society benefits from GGOS as a utility supporting Earth science and global Earth observation systems as a basis for informed decisions.

GGOS THE OBSERVING SYSTEM

GGOS as an observing system is built upon the existing and future infrastructure provided by the IAG Services. It aims to provide consistent observations of the spatial and temporal changes of the shape and gravitational field of the Earth, as well as the temporal variations of the Earth's rotation. In other words, it aims to deliver a global picture of the surface kinematics of our planet, including the ocean, ice cover and land surfaces. In addition, it aims to deliver estimates of mass anomalies, mass transport and mass exchange in the Earth system. Surface kinematics and mass transport together are the key to global mass balance determination, and an important contribution to the understanding of the energy budget of our planet. Moreover, the system aims to provide the observations that are needed to determine and maintain a terrestrial reference frame of higher accuracy and greater temporal stability than what is available today. By combining the "three pillars" into one observing system having utmost accuracy and operating in a well-defined and reproducible global terrestrial frame, GGOS adds to these pillars a new quality and dimension in the context of Earth system research. The observing system, in order to meet its objectives, has to combine the highest measurement precision with spatial and temporal consistency and stability that is maintained over decades.

GGOS AND ITS CHALLENGES

The observing system GGOS faces two types of scientific and technological challenges:

1. GGOS and the geodetic technologies need to meet the demanding user requirements in terms of reference frame accuracy and availability, as well as in terms of spatial and temporal resolution and accuracy of the geodetic observations. Developing an observing system capable of measuring variations in the Earth's shape, gravity field, and rotation with an accuracy and consistency of 0.1 to 1 ppb, with high spatial and temporal resolution, and increasingly low time latency, is a very demanding task. Accommodating the transition of new technologies as they evolve in parallel to maintaining an operational system is part of this challenge.

2. The Earth system is a complex system with physical, chemical and biological processes interacting on spatial scales from micrometers to global and temporal scales from seconds to billions of years. The integration of the "three pillars" into a system providing information on mass transport, surface deformations, and dynamics of the Earth therefore requires a "whole Earth'" approach harnessing the expertise of all fields of Earth science.

GGOS: AN OBSERVING SYSTEM OF LAYERED INFRASTRUCTURE

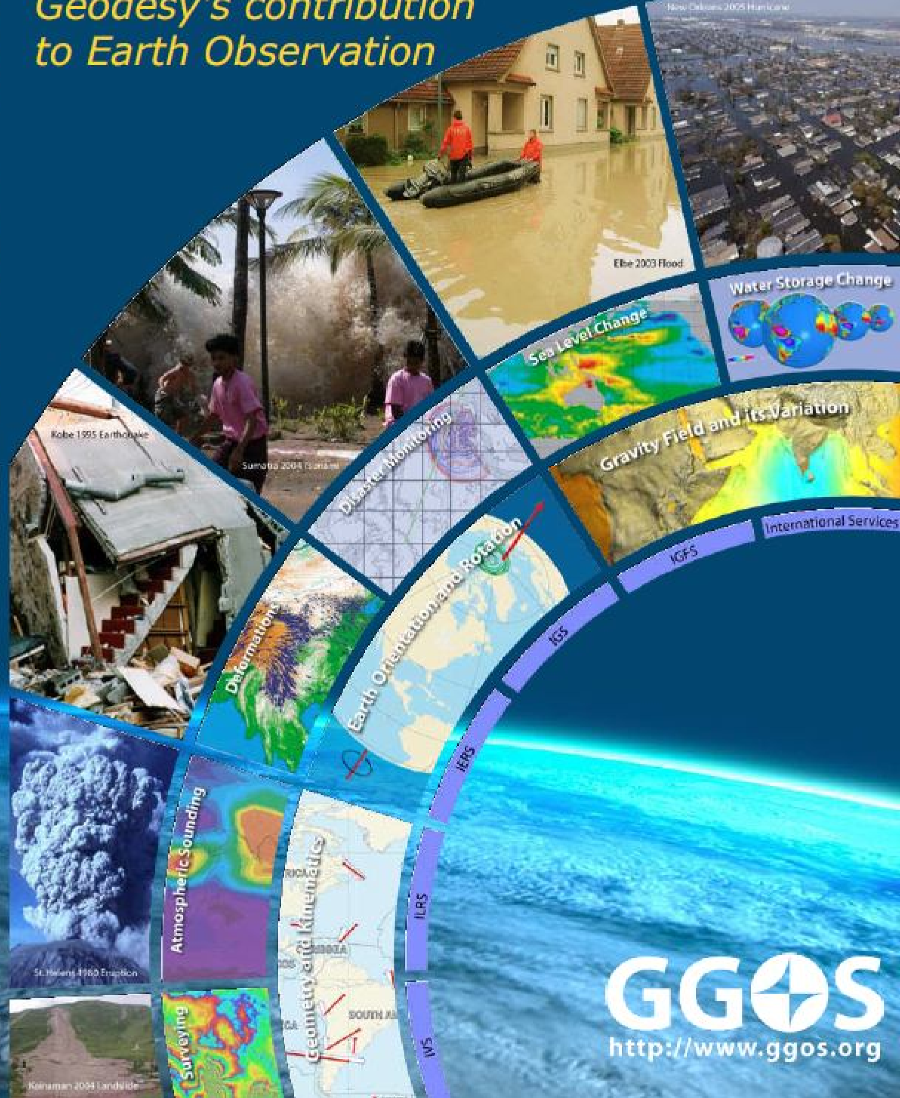
GGOS as an observing system has five major levels of instrumentation and objects that actively perform observations, are passively observed, or both. These levels are:

- Level 1: the terrestrial geodetic infrastructure;
- Level 2: the LEO satellite missions;
- Level 3: the GNSS and the Lageos-type SLR satellites;
- Level 4: the planetary missions and geodetic infrastructure on Moon and planets;
- Level 5: the extragalactic objects.

These five levels of instrumentation and objects, independent of whether they are active or passive, receivers or emitters or both, are connected by many types of observations in a rather complex way to form the integrated GGOS observing system. In this system, the major observation types at present are:

1. observations of the microwaves at the ground and at the LEO satellites emitted by GNSS satellites;
2. laser ranging to LEOs, dedicated laser ranging satellites, GNSS satellites and the Moon;
3. microwave observation of extragalactical objects (quasars) by VLBI;
4. instrumentation onboard the LEO satellites measuring accelerations, gravity gradients, satellite orientation, etc.;
5. radar and optical observations of the Earth's surface (land, ice, glaciers, sea level, ect.) from remote sensing satellites;
6. distance measurements between satellites (K-band, optical, interferometry, etc.).

In the future, new measurement techniques will evolve and be included into the system. Different parts of the overall system are cross-linked through observations and inter-dependent. All these techniques are affected by and measure the "output" of the same unique Earth system, that is, the various geodetic fingerprints induced by mass redistribution and changes in the system's dynamics. Therefore, consistency of data processing, modeling, and conventions across the techniques and across the "three pillars"is mandatory for maximum exploitation of the full potential of the system.

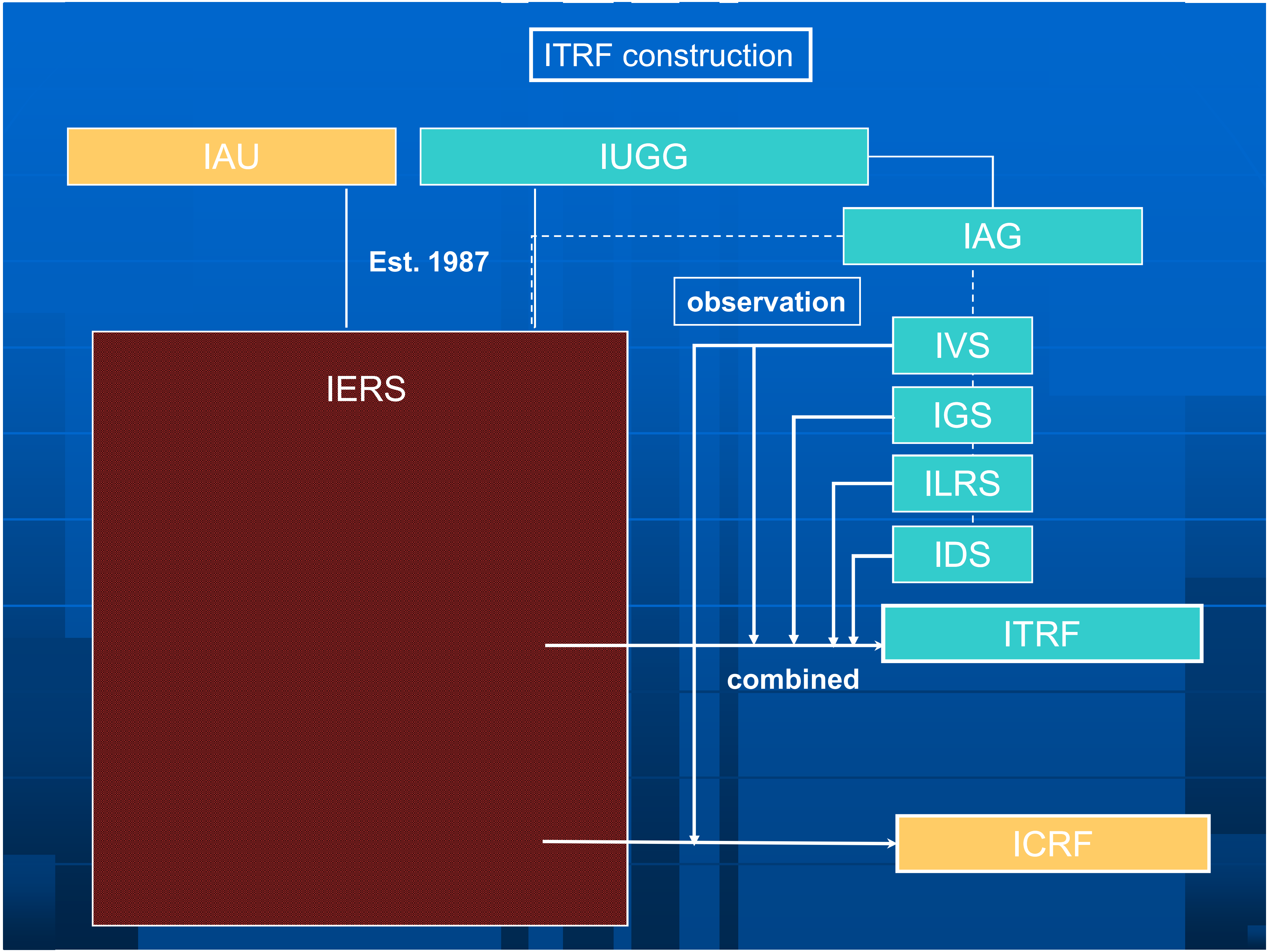


GGOS
http://www.ggos.org

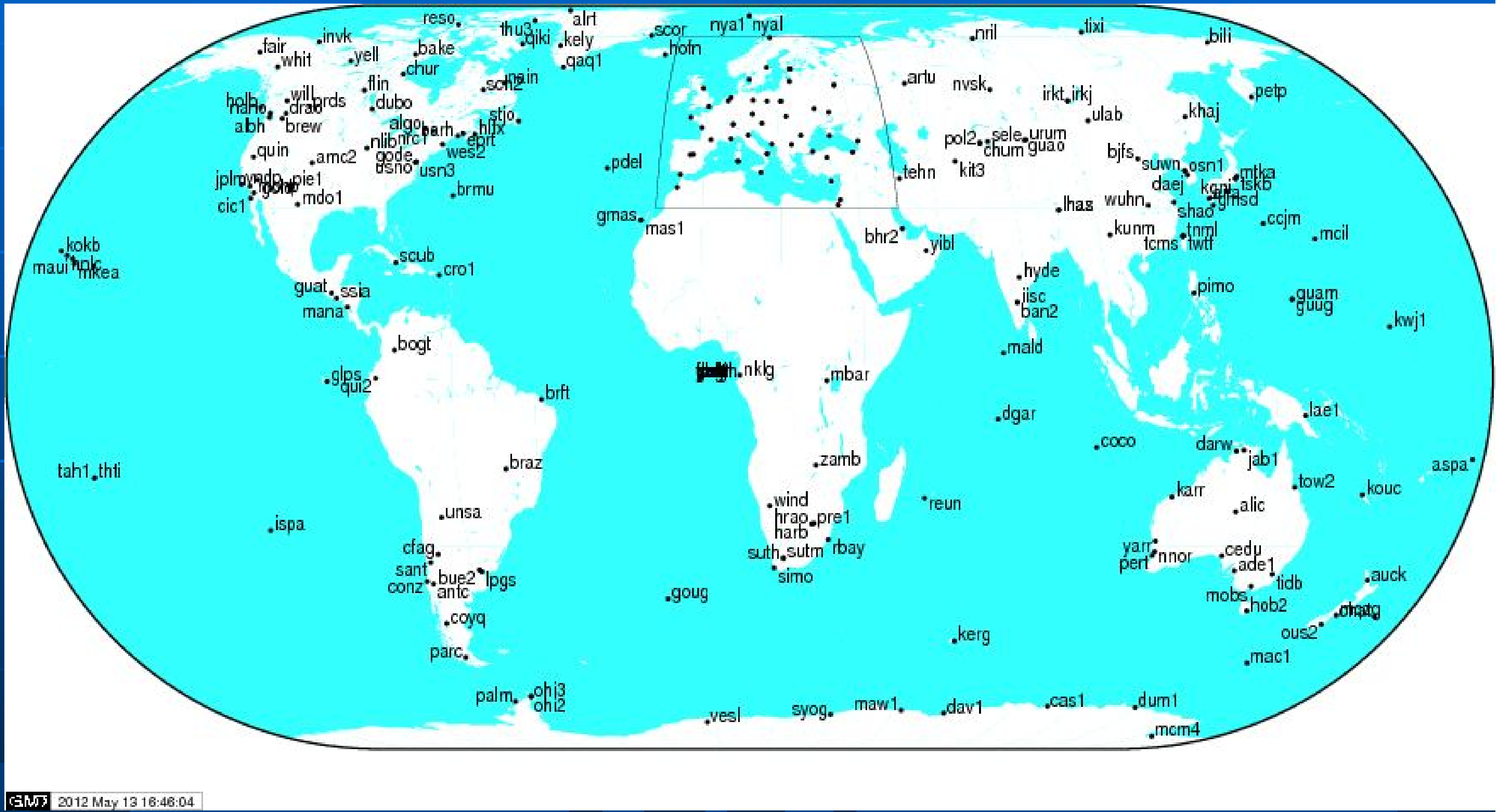
Supplements

IERS (International Earth Rotation and Reference System Service)

- Est. by IAU and IUGG (1987)
- ICRS (Concept)→ ICRF (Realization)
- ITRS (Concept)→ ITRF (Realization)
- EOP
- Standards and models

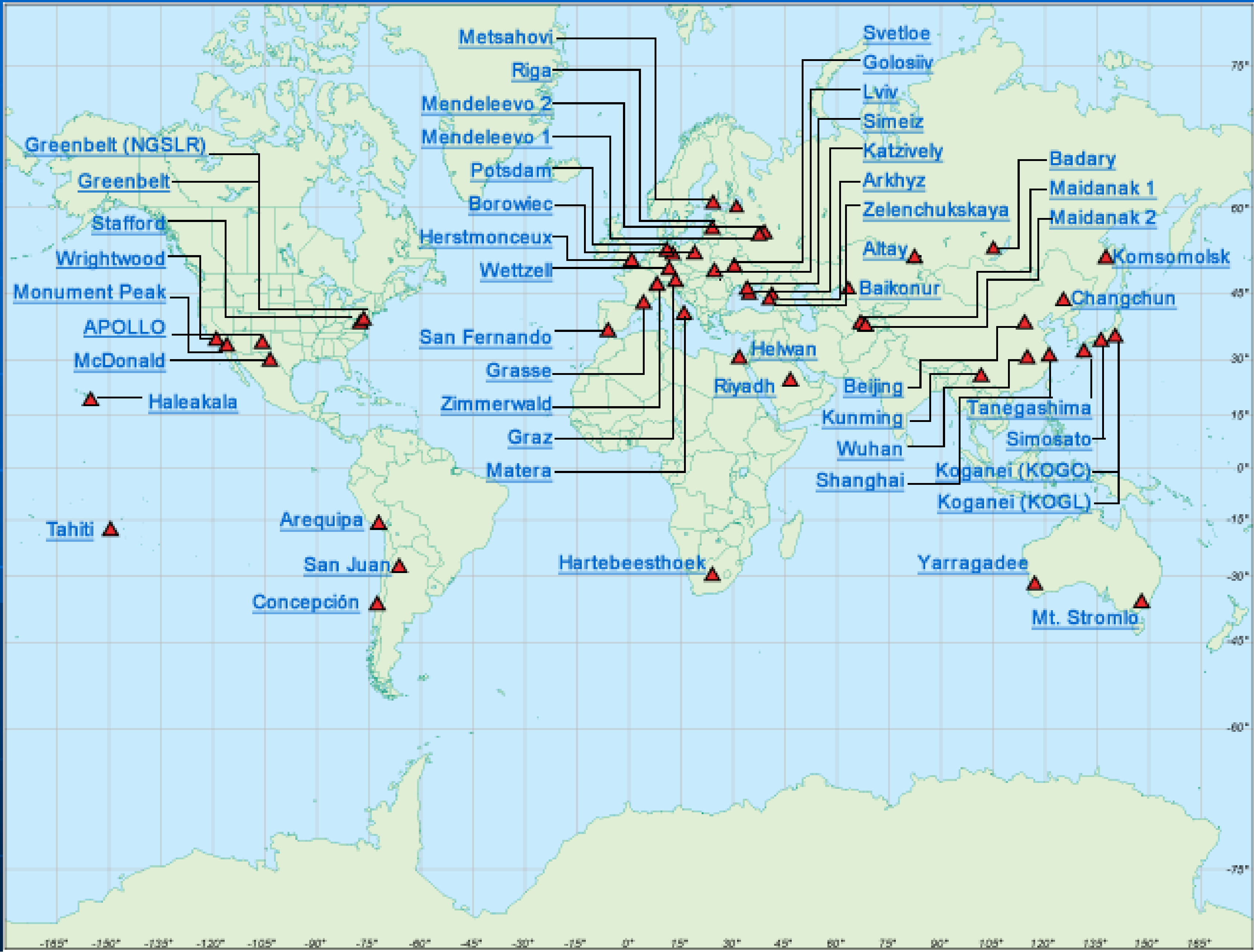

ITRF construction
IAU
IUGG
IAG
Est. 1987
observation
IERS
IVS
IGS
ILRS
IDS
ITRF
combined
ICRF

IGS Reference Frame Network

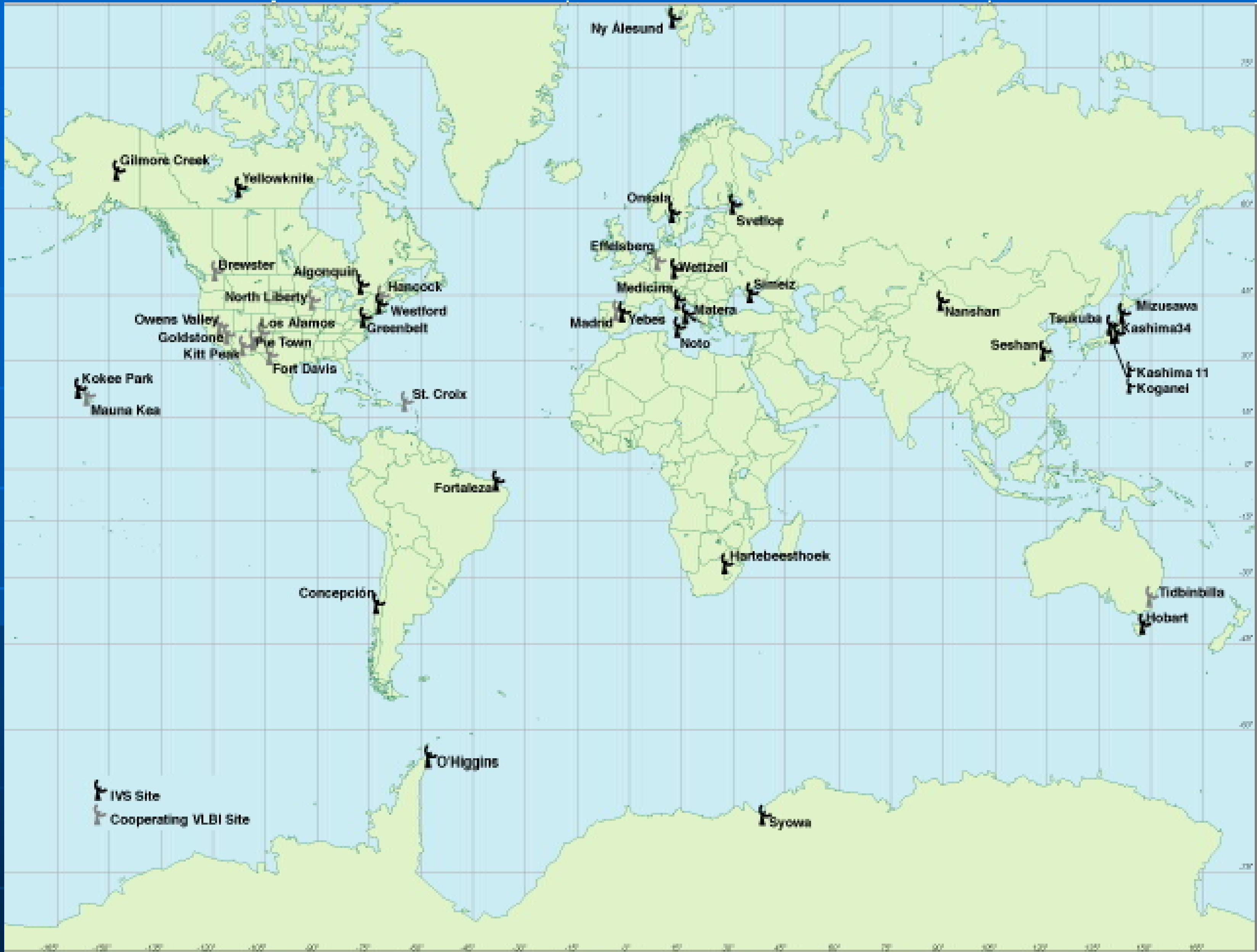


DORIS stations

SLR stations



VLBI Network



Datum Accuracy
(Ray, Dong & Altamimi, 2004)

Table 1. Estimated accuracy of ITRF2000 datum

Attribute	Offset error (at 1997.0)	Instability	Datum Specification
origin translations (per component)			physical:
equatorial	0.5 mm	0.1 mm/yr	geocenter
axial	0.9 mm	0.3 mm/yr	
scale	0.2 ppb	0.03 ppb	physical:
	1.2 mm	0.2 mm/yr	Earth's radius
orientation rotations (per component)			conventional:
	0.018 mas	0.065 mas/yr	no net surface
	0.6 mm	2.0 mm/yr	rotation
station coordinates (3D relative to each other at mean epoch)	2 - 5 mm	0.5 - 2 mm/yr	

Note: These estimates are based on internal agreement of submitted global solutions (see Altamimi et al., 2002) except that the rotational stability is given by Altamimi et al. (2003) based on the level of agreement among the few available no-net-rotation models.

ITRF2000 datum definition

- **Scale and rate:** weighted average of the following VLBI and SLR solutions
- VLBI: GIUB, GSFC, SHA
- SLR: CGS, CRL, CSR, DGFI, JCET
- **Origin** (translations and rates): weighted average of SLR solutions (CGS, CRL, CSR, DGFI, JCET)
- **Orientation** : insured upon a selection of ITRF sites with high geodetic quality
- Rotations: ITRF97 at 1997.0 epoch
- Rotation rates: No Net Rotation w.r.t. NNR-NUVEL1A

The criteria retained for site selection are

1. continuously observed during at least 3 years
2. located on rigid plates and far away from deforming zones
3. velocity formal error (as result of ITRF combination) better than 3 mm/y
4. velocity residuals less than 3 mm/y for at least 3 different solutions

The International Terrestrial Reference System (ITRS)

The ITRS definition fulfills the following conditions:

1. It is *geocentric*, the center of mass being defined for the whole earth, including oceans and atmosphere.
2. The *unit of length* is *the metre* (SI). This scale is consistent with the TCG time coordinate for a geocentric local frame, in agreement with IAU and IUGG (1991) resolutions. This is obtained by appropriate relativistic modelling.
3. Its orientation was initially given by the BIH orientation at 1984.0.
4. The *time evolution of the orientation* is ensured by using a *no-net-rotation condition* with regards to horizontal tectonic motions over the whole earth.

See the IERS Conventions (2003), especially Chapter 4, for a detailed description of the ITRS.

The ITRS is realized by estimates of the *coordinates and velocities* of a set of stations observed by VLBI, LLR, GPS, SLR, and DORIS. Its name is International Terrestrial Reference Frame (ITRF).

General documentation on terrestrial reference systems and frames is available at the ITRS Centre of the IERS.

The ITRS can be connected to the *International Celestial Reference System* (ICRS) by use of the IERS *Earth Orientation Parameters* (EOP).

The International Celestial Reference System (ICRS)

At its 23rd General Assembly in August 1997, the International Astronomical Union (IAU) decided that, **as from 1 January 1998, the IAU celestial reference system shall be the International Celestial Reference System (ICRS)**, in replacement of the FK5 (Fricke et al. 1988). The consequences of this new situation for accuracy needs more stringent than 0.05" are summarized by Feissel and Mignard (1997).

By *Reference System* it is meant the set of prescriptions and conventions together with the modeling required to define at any time a triad of axes.

The ICRS is accessible by means of coordinates of reference extragalactic radio sources, the **International Celestial Reference Frame (ICRF)**.

The ICRS complies with the conditions specified by the **1991 IAU Recommendations**. Its **origin** is located at the barycenter of the solar system through appropriate modelling of **VLBI** observations in the framework of General Relativity. Its **pole** is in the direction defined by the conventional IAU models for precession (Lieske et al., 1977) and nutation (Seidelmann, 1982). Its **origin of right ascensions** was implicitly defined by fixing the right ascension of 3C 273B to the Hazard et al. (1971) FK5 value transferred at J2000.0. See Arias et al. (1995) for more details.

The **Hipparcos** star positions and proper motions and the **JPL Solar System ephemerides** are expressed in the ICRS.

The directions of the ICRS **pole and right ascensions origin** are maintained fixed relative to the quasars within +/- 20 microarcseconds. Thanks to the fact that the Hipparcos catalogue includes all the FK5 stars, the location of the FK5 pole and right ascensions origin is known with an uncertainty of a few mas (Mignard and Froeschlé 1997). Using a state of the art precession-nutation model, the analysis of long VLBI series of the observed motion of the celestial pole allows to derive the coordinates of the mean pole at J2000.0 in the ICRS: 17.3 +/- 0.2 mas in the direction 12 h and 5.1 +/- 0.2 mas in the direction 18 h.(IERS 1997). Comparing VLBI and LLR earth orientation and terrestrial reference frames, Folkner et al. (1994) estimated the frame tie between the IERS celestial system and the JPL planetary ephemeris, and concluded that the mean equinox of J2000.0 is shifted from the ICRS right ascension origin by 78 +/- 10 mas (direct rotation around the polar axis).

The ICRS is realized by VLBI estimates of equatorial coordinates of a set of extragalactic compact radio sources, the **International Celestial Reference Frame (ICRF)**.

The ICRS can be connected to the **International Terrestrial Reference System (ITRS)** by use of the **IERS Earth Orientation Parameters (EOP)**.

Measuring the irregularities of the Earth's rotation

The **variability** of the earth-rotation vector relative to the body of the planet or in inertial space is caused by the gravitational torque exerted by the Moon, Sun and planets, displacements of matter in different parts of the planet and other excitation mechanisms. The observed oscillations can be interpreted in terms of mantle elasticity, earth flattening, structure and properties of the core-mantle boundary, rheology of the core, underground water, oceanic variability, and atmospheric variability on time scales of weather or climate. The understanding of the coupling between the various layers of our planet is also a key aspect of this research.

Several space geodesy techniques contribute to the **permanent monitoring** of the earth's rotation by IERS. For all these techniques, the IERS applications are only one part of their contribution to the study of planet earth and of the rest of the universe.

The measurements of the earth's rotation are under the form of time series of the so-called **Earth Orientation Parameters** **(EOP)**. Universal time **(UT1)**, **polar motion** and the **celestial motion of the pole** (precession/nutation) are determined by **VLBI**. The satellite-geodesy techniques, **GPS**, **SLR** and **DORIS**, determine polar motion and the rapid variations of universal time.

The satellite-geodesy programs used in the IERS give access to the time variations of the earth's gravity field, reflecting the evolution of the earth's shape, as well as the redistribution of masses in the planet. They have also detected changes in the location of the centre of mass of the earth relative to the crust. This makes it possible to investigate global phenomena such as mass redistributions in the atmosphere, oceans and solid earth.

Universal time and polar motion are available daily with an accuracy of 0.5 mas and celestial pole motion are available every five to seven days at the same level of accuracy - this estimation of accuracy includes both short term and long term noise. Sub-daily variations in Universal time and polar motion are also measured on a campaign basis. Past data, going back to the 17th century in some cases, are also available.

EOP series are provided by the IERS in **bulletins** and as **permanently updated series** (long term earth orientation data).

The International Celestial Reference Frame (ICRF)

The International Celestial Reference Frame (ICRF) realizes an ideal reference system,the International Celestial Reference System (ICRS), by precise equatorial coordinates of extragalactic radio sources observed in Very Long Baseline Interferometry (VLBI) programmes. The Hipparcos catalogue which includes all the FK5 stars was astrometically aligned to ICRF and provides the primary realization of ICRS at optical wavelengths.

Contents Equatorial coordinates of 608 extragalactic radio sources in J2000.0 observed with VLBI.

Accuracy Uncertainties are given in the file.

R.A. [s] 0.000017- 0.092072

Dec. ["] 0.00026- 0.946

Updates First extension of the ICRF (ICRF-Ext.1)

Publicaccess

ICRF http://hpiers.obspm.fr/webiers/results/icrf/icrfrsc.html
or ftp://hpiers.obspm.fr/iers/icrf/iau/icrf_rsc/icrf.rsc

ICRF + ICRF Ext. 1 http://hpiers.obspm.fr/webiers/results/icrf/icrfext1rsc.html
or ftp://hpiers.obspm.fr/iers/icrf/iau/icrf-Ext.1/icrf-Ext1.rsc

Format For format description see contents of the data file.

Documentation

- IERS Technical Note No. 23 (out of print!)
- C. Ma et al.: The International Celestial Reference Frame as Realized by Very Long Baseline Interferometry (*AJ, 1998, 116, 516-546*)
- http://hpiers.obspm.fr/webiers/results/icrf/Icrf.html
- http://rorf.usno.navy.mil/ICRF/

Product Centre IERS ICRS Centre

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.

Contents - cartesian stations coordinates and velocities- site catalogue- DOMES identification numbers (see "Documentation")- local ties (see "Documentation")- realizations: ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97, ITRF2000, ITRF2005 (in preparation)

Accuracy Uncertainties are given in the solutions.

Updates Almost every year.

Public access ftp://lareg.ensg.ign.fr/pub/itrf or http://itrf.ensg.ign.fr/ITRF_solutions/index.php

ITRF1992 Primary ITRF1992 station positions/velocities
ITRF1993 Primary ITRF1993 station positions/velocities
ITRF1994 Primary ITRF1994 station positions/velocities
ITRF1996 Primary ITRF1996 station positions/velocities
ITRF1997 Primary ITRF1997 station positions/velocities
ITRF2000 Primary ITRF2000 station positions/velocities Local ties used in ITRF2000
ITRF2005 ITRF2005 description

Format

ITRF92-00: simple tables
ITRF94-00: SINEX-Format

Documentation ITRF homepage

ITRF89: IERS Technical Note No. 6
ITRF90: IERS Technical Note No. 9
ITRF91: IERS Technical Note No. 12
ITRF92: IERS Technical Note No. 15
ITRF93: IERS Technical Note No. 18
ITRF94: IERS Technical Note No. 20
ITRF96: IERS Technical Note No. 24
ITRF97: IERS Technical Note No. 27
ITRF2000: IERS Technical Note No. 31
IERS Network: Domes number description Domes number request Site information and selection

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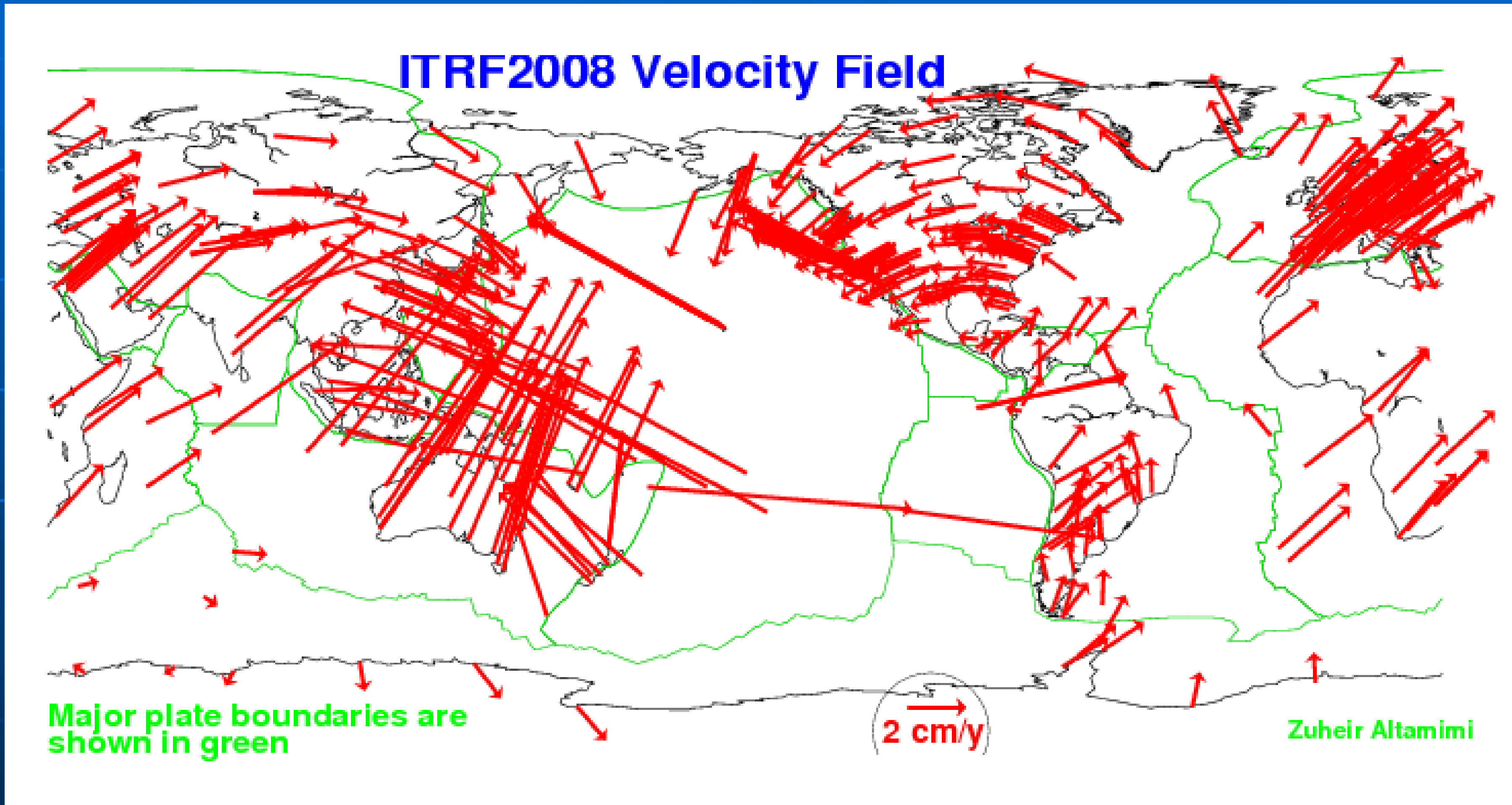
ITRF2008 Velocity Field
Major plate boundaries are shown in green
2 cm/y
Zuheir Altamimi