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Direção-Geral do Território

# Sistemas de Referência Locais e Globais

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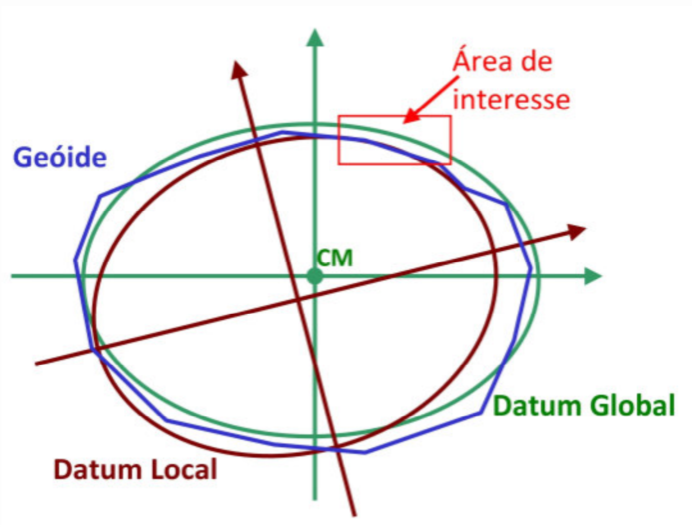
Lisboa, 25 de Maio de 2017

## Datum Local e Datum Global

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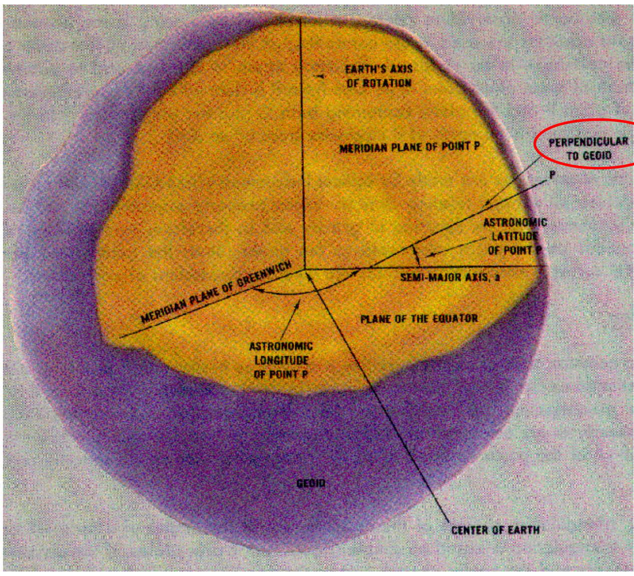
## Coordenadas Astronómicas




[DMA, 1983 "Geodesy for the Layman"]

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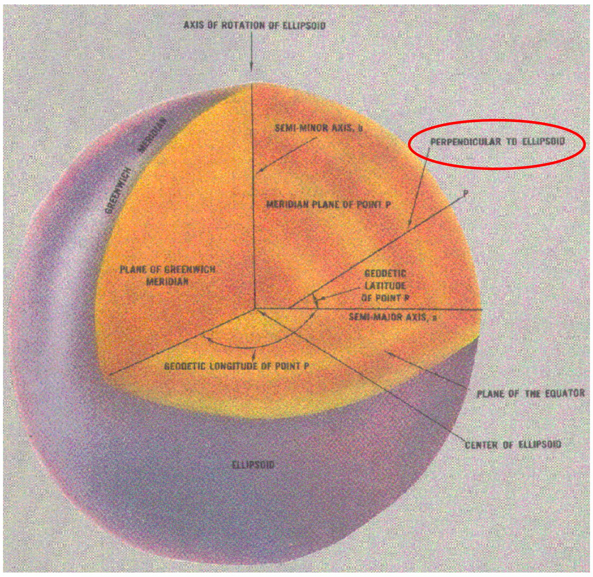
## Sistema de Referência Elipsoidal




[DMA, 1983 "Geodesy for the Layman"]

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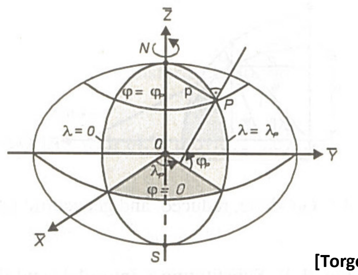
## Sistemas de Referência Elipsoidais




[Torge, 2001]

- Concebidos para apoiar o desenvolvimento das Redes Geodésicas
- Sistema de eixos tri-ortogonal directo
- Origem coincidente com o centro do elipsóide de revolução
- Eixos paralelos aos do Sistema Terrestre Convencional definido pelo BIH (*Bureau International de l'Heure*)



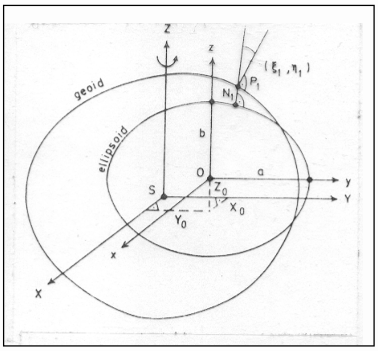
## Datum Geodésico Clássico

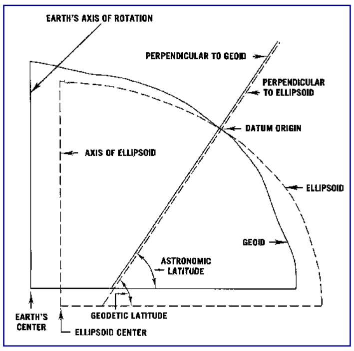
**Conjunto de parâmetros que define o posicionamento do elipsóide de referência relativamente à Terra**

- Escolha do elipsóide
- Baseado em observações astronómicas
- Estabelecimento de um ponto origem definindo:
  - as coordenadas geodésicas ($\varphi_{1G}$ , $\lambda_{1G}$)
  - as componentes do desvio da vertical ($\xi_1$ , $\eta_1$)
  - a ondulação do geóide ($N_1$)
  - um azimute geodésico (equação de Laplace):

  $\alpha_{1G} = \alpha_{1A} - (\lambda_{1A} - \lambda_{1G}) \text{ sen } \varphi$

## Parâmetros do Datum




- $\varphi_{1G}$ , $\lambda_{1G}$ -> fixam uma normal
- $\xi_1$ , $\eta_1$ -> fixam essa normal relativamente à Terra
- $N_1$ -> fixa a separação entre o elipsóide e o geóide
- equação de Laplace -> fixa a orientação

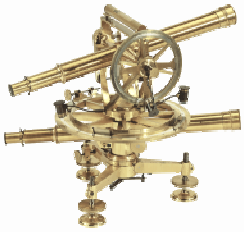


## Sistemas de Referência Clássicos

- **Origem** – estabelecida através de observações astronómicas
- **Orientação** – observações astronómicas
- **Escala** – medição de distâncias
- **Elipsóide** – tangente ao ponto origem
- **Observações** – ângulos
- **Projecção Cartográfica**

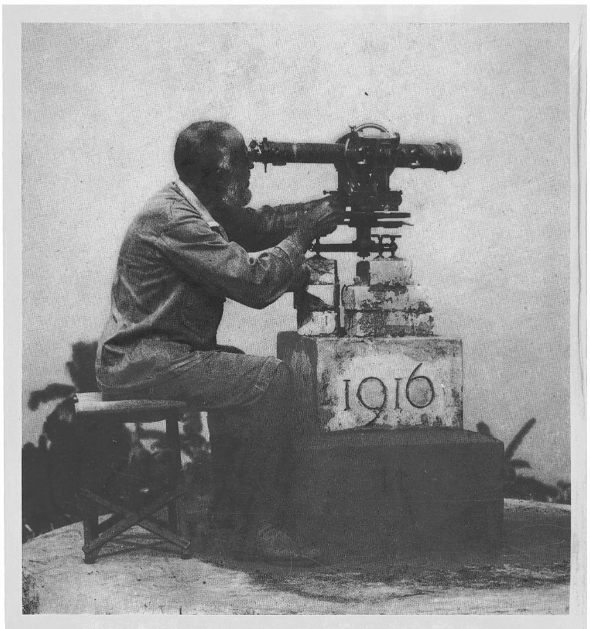
Existiram diferentes sistemas, com:
- Diferentes origens
- Diferentes elipsóides
- Diferentes projecções cartográficas

# Redes Clássicas



- Cadeias de triângulos
- Medições de ângulos (e distâncias)







## Evolução dos Elipsóides

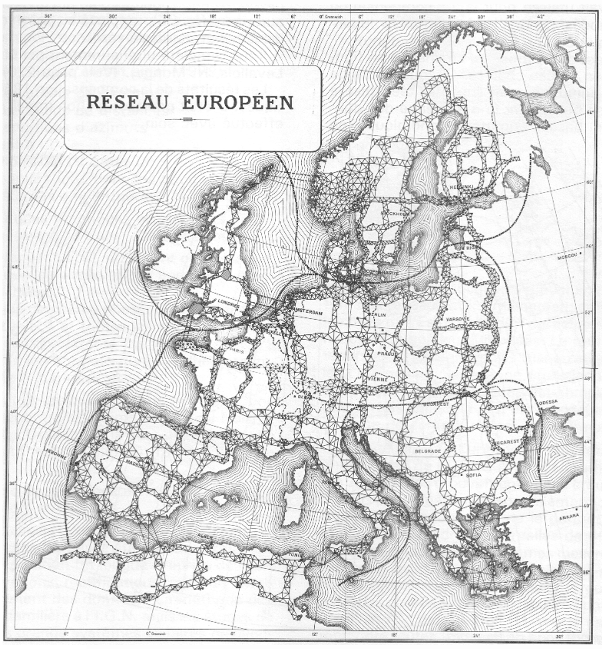
| autor | data | a (m) | 1/f |
|---|---|---|---|
| Eratóstenes | 230 A.C. | 6 250 000 | ∞ |
| Bouguer, Maupertuis | 1744 | 6 397 300 | 207 |
| Delambre | 1810 | 6 376 985 | 308.64 |
| Everest | 1830 | 6 377 276 | 300.8 |
| Airy | 1830 | 6 377 563 | 299.3 |
| Bessel | 1840 | 6 377 397 | 299.15 |
| Clarke | 1880 | 6 378 245 | 293.5 |
| Hayford | 1910 | 6 378 388 | 297 |
| Jeffreys | 1948 | 6 378 097 | 297.28 |
| GRS80 | 1980 | 6 378 137 | 298.26 |



## Datum Europeu

- reconstrucão da Europa depois da 2.ª guerra mundial motivou a integração dos diferentes data num datum comum
- selecção das cadeias de triangulação primárias (Réseau Européen 1950)
- cálculo realizado pelo United States Coast and Geodetic Survey
- conjunto de coordenadas ED50 (European Datum 1950)
- ponto origem na Helmertturm em Potsdam, Alemanha.
- Elipsóide International (Hayford) adoptado pela IUGG em 1924: a = 6 378 388 m, f = 1/297

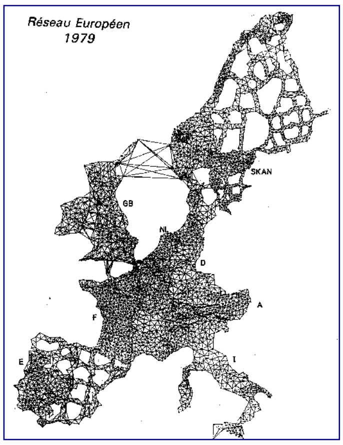
## Rede do ED50





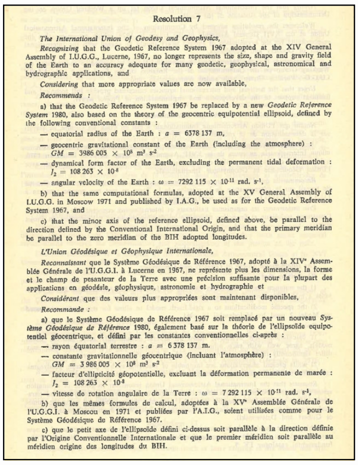

## Evolução do Datum Europeu

- criação pela IAG em 1954 da Sub-comissão RETrig (Réseau Européen Trigonométrique)
- continuar o cálculo da rede geodésica europeia e aumentar a sua qualidade incluindo novas e mais precisas medições
- nova versão do Datum Europeu (ED79) adoptada em 1979, baseada em redes de triangulação densas
- reconhecida a importância de incluir observações Doppler na fase seguinte
- nova versão (ED87) adoptada em 1987



# GRS80


Adoptado na Assembleia Geral de 1979 da IUGG (International Union of Geodesy and Geophysics)



Resolution 7

*The International Union of Geodesy and Geophysics,*

*Recognizing* that the Geodetic Reference System 1967 adopted at the XIV General Assembly of I.U.G.G., Lucerne, 1967, no longer represents the size, shape and gravity field of the Earth to an accuracy adequate for many geodetic, geophysical, astronomical and hydrographic applications, and

*Considering* that more appropriate values are now available,

*Recommends* :

a) that the Geodetic Reference System 1967 be replaced by a new *Geodetic Reference System* 1980, also based on the theory of the geocentric equipotential ellipsoid, defined by the following conventional constants :

— equatorial radius of the Earth : $a = 6378\,137$ m,

— geocentric gravitational constant of the Earth (including the atmosphere) : $GM = 3986\,005 \times 10^8$ m³ s⁻²

— dynamical form factor of the Earth, excluding the permanent tidal deformation : $J_2 = 108\,263 \times 10^{-8}$

— angular velocity of the Earth : $\omega = 7292\,115 \times 10^{-11}$ rad. s⁻¹,

b) that the same computational formulas, adopted at the XV General Assembly of I.U.G.G. in Moscow 1971 and published by I.A.G., be used as for the Geodetic Reference System 1967, and

c) that the minor axis of the reference ellipsoid, defined above, be parallel to the direction defined by the Conventional International Origin, and that the primary meridian be parallel to the zero meridian of the BIH adopted longitudes.

*L'Union Géodésique et Géophysique Internationale,*

*Reconnaissant* que le Système Géodésique de Référence 1967, adopté à la XIV[e] Assemblée Générale de l'U.G.G.I. à Lucerne en 1967, ne représente plus les dimensions, la forme et le champ de pesanteur de la Terre avec une précision suffisante pour la plupart des applications en géodésie, géophysique, astronomie et hydrographie et

*Considérant* que des valeurs plus appropriées sont maintenant disponibles,

*Recommande* :

a) que le Système Géodésique de Référence 1967 soit remplacé par un nouveau *Système Géodésique de Référence* 1980, également basé sur la théorie de l'ellipsoïde équipotentiel géocentrique, et défini par les constantes conventionnelles ci-après :

— rayon équatorial terrestre : $a = 6\,378\,137$ m.

— constante gravitationnelle géocentrique (incluant l'atmosphère) : $GM = 3\,986\,005 \times 10^8$ m³ s⁻²

— facteur d'ellipticité géopotentielle, excluant la déformation permanente de marée : $J_2 = 108\,263 \times 10^{-8}$

— vitesse de rotation angulaire de la Terre : $\omega = 7\,292\,115 \times 10^{-11}$ rad. s⁻¹,

b) que les mêmes formules de calcul, adoptées à la XV[e] Assemblée Générale de l'U.G.G.I. à Moscou en 1971 et publiées par l'A.I.G., soient utilisées comme pour le Système Géodésique de Référence 1967.

c) que le petit axe de l'ellipsoïde défini ci-dessus soit parallèle à la direction définie par l'Origine Conventionnelle Internationale et que le premier méridien soit parallèle au méridien origine des longitudes du BIH.

- Destinado a representar a Terra nos seus aspectos geométricos e dinâmicos e adequado a aplicações nos domínios da geodesia, geofísica e hidrografia
- Sistema de referência oficial para os trabalhos geodésicos
- Baseado na teoria do elipsóide equipotencial
- Inclui toda a massa da Terra e da atmosfera

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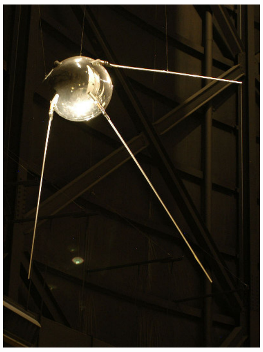
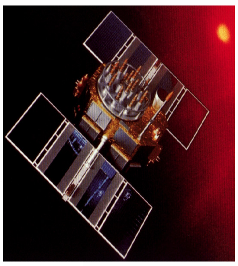
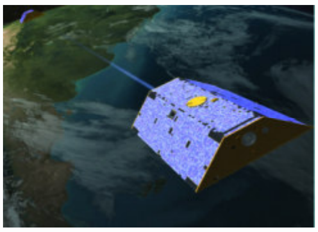
# Técnicas Geodésicas Espaciais





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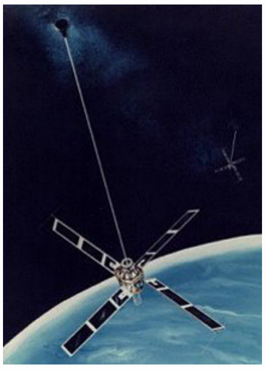
## Primeiros Satélites de Navegação

**TRANSIT Navy Navigation Satellite System**



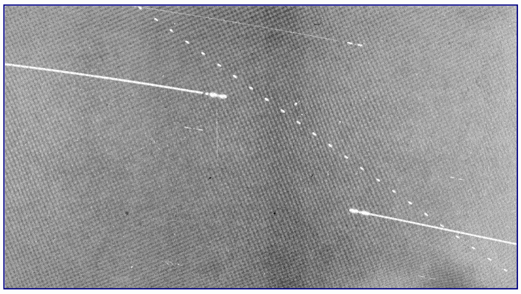
- Primeiro sistema de navegação por satélite operacional mundial
- Desenhado em 1960s para apoiar frota de submarinos com misseis balísticos
- Observações Doppler
- Último Satélite lançado em Agosto 1988
- Programa terminado em 31/12/1996

[Mendes, 2004]



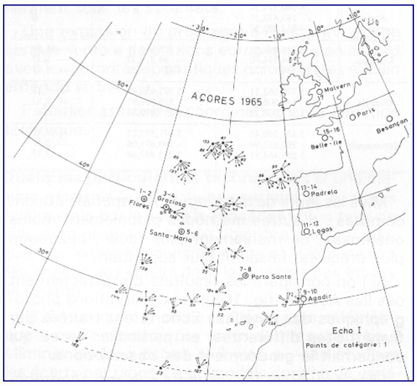
## Posicionamento com câmaras balísticas

**Ligações geodésicas a longas distâncias com recurso a satélites artificiais**
**Uniformização do Referencial Geodésico**



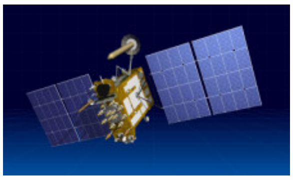
- Satélite passivo ECHO1
- Fotografia com câmaras balísticas sobre fundo de estrelas

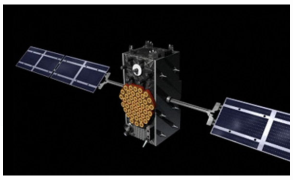
**Precisão do posicionamento com câmaras balísticas:**
**~100 m (absoluto)**
**~20 m (relativo)**




- Campanhas em 1963-1965
- Comparações com Doppler e GPS mostram precisão melhor que 10 m em distâncias de 1500 km

# GNSS





**NAVSTAR GPS**

- Criado em 1973 pelo DoD dos EUA com o objectivo de garantir navegação de precisão, continua e globalmente, em tempo real e sob quaisquer condições atmosféricas
- Totalmente operacional em 17/07/1995
- Actualmente: 31 satélites operacionais

**GLONASS**

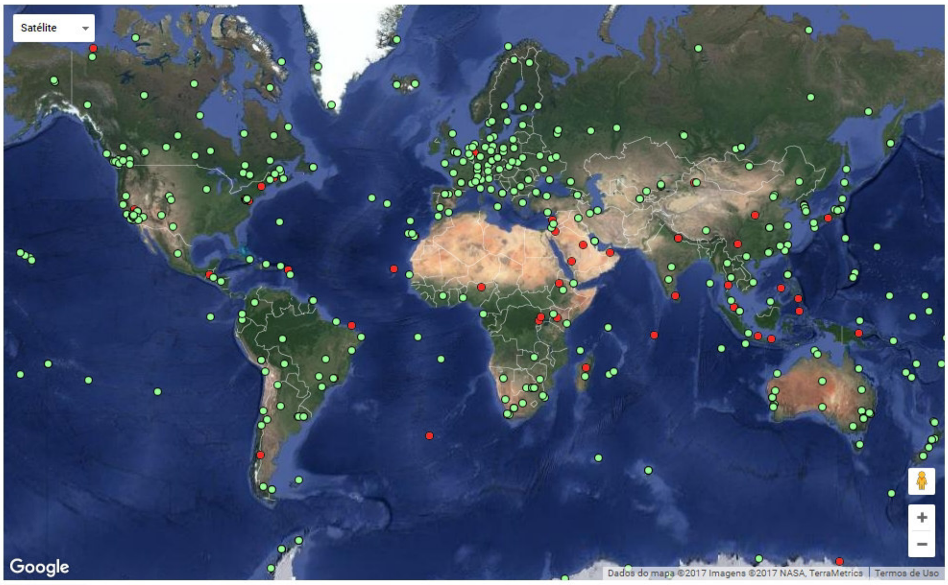
- Sistema Russo análogo ao GPS
- Primeiro lançamento em 1982
- Actualmente: 24 satélites operacionais

**GALILEO**

- Sistema Europeu
- Primeiros lançamentos: Dez2005, Abr2008
- Actualmente: 18 satélites em órbita



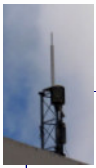
# Rede GNSS

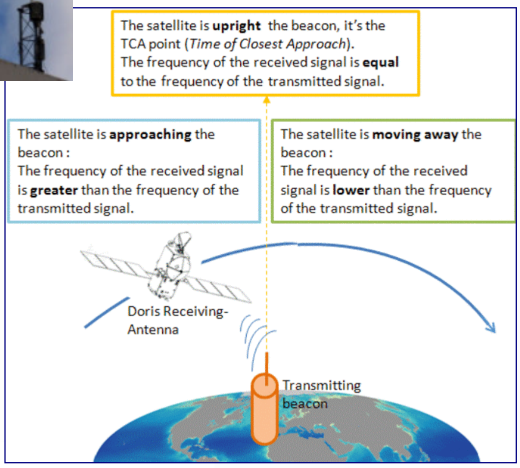



http://www.igs.org

# DORIS

## Détermination d’Orbite et Radiopositionnement Intégrés par Satellite






[CNES]

- Desenvolvido pelo *Centre National d’Etudes Spatiales* (CNES)
- Sistema de posicionamento de comunicação ascendente
- Objectivos:
  - determinação das órbitas precisas de missões de altimetria por satélite
  - posicionamento de precisão em Terra
- Missões equipadas com receptores DORIS: SENTINEL-3A, CRYOSAT-2 SPOT-5, …

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# Rede DORIS


https://ids-doris.org/

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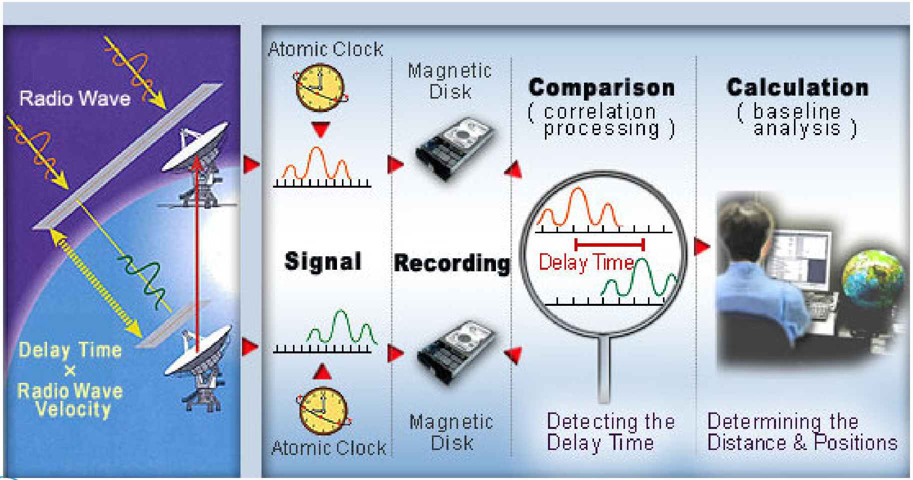
## VLBI - Very Long Baseline Interferometry

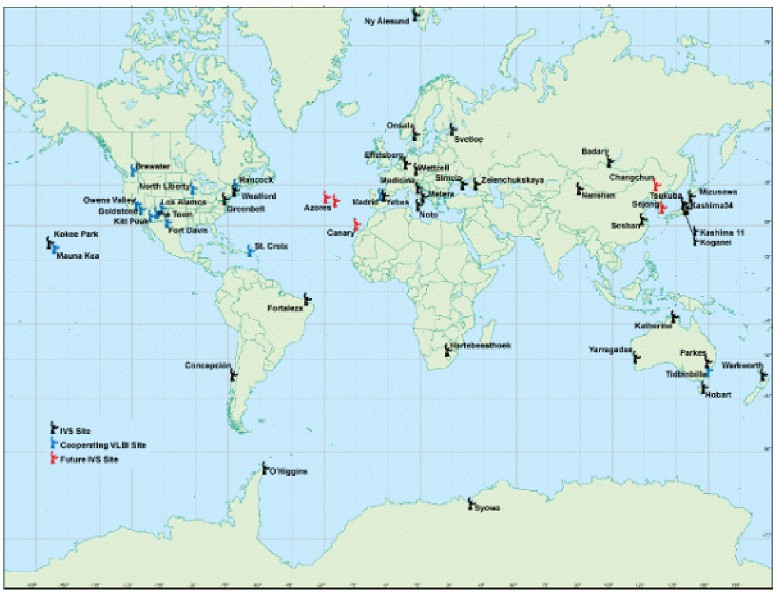
Observações de VLBI (Very Long Baseline Interferometry):

- permitem a monitorização de movimentos de placas
- precisão melhor que 0,002 ppm (1 cm/5000 km)



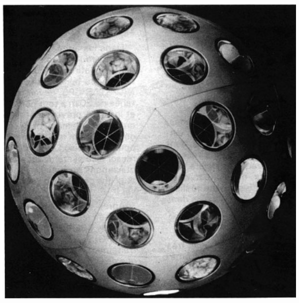



## Rede VLBI




https://ivscc.gsfc.nasa.gov/index.html

# SLR – Satellite Laser Ranging



- estudo do sistema Terra sólida - atmosfera – hidrosfera - criosfera
- apoio fundamental aos satélites altimétricos
- contribuição para a monitorização dos níveis do mar e do gelo
- dinâmica a longo prazo da Terra sólida, oceanos e atmosfera
- apoio ao estudo dos movimentos tectónicos
- contribuição para a investigação em Física fundamental

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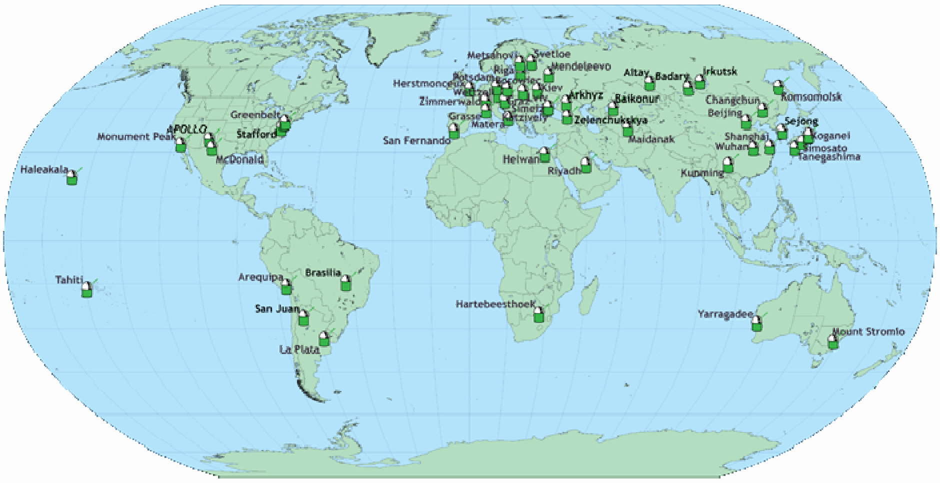
# Rede SLR




https://ilrs.cddis.eosdis.nasa.gov/index.html

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## Sistemas de Referência Globais

- Evolução “natural” dos sistemas de referência
- Desenvolvimento das técnicas geodésicas espaciais
- Exigência de maior rigor por parte da comunidade científica
- Uniformização dos sistemas e referenciais a nível global



## TRS – Terrestrial Reference System

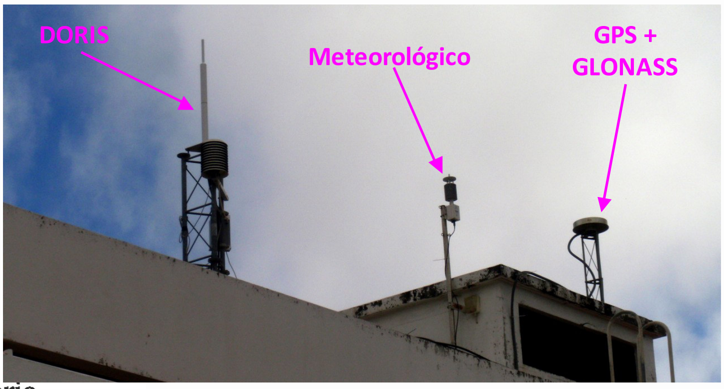
**Sistema de referência espacial que acompanha a rotação da Terra no seu movimento diurno no espaço**

- Definição Matemática e Física
- Sistema de eixos tridimensional definido por:
  - origem
  - unidade de comprimento
  - orientação
- Constantes físicas associadas:
  - tempo
  - velocidade da luz no vácuo
  - GM (constante gravitacional geocêntrica)

## TRF – Terrestrial Reference Frame

**Realização do Sistema de Referência**

- Conjunto de Estações Geodésicas de Referência
- Coordenadas resultantes de observações de técnicas de geodesia espacial

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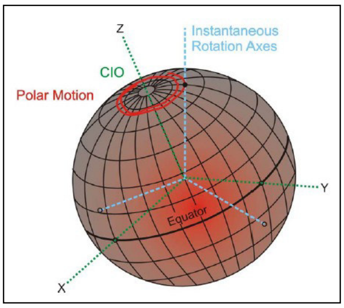
## ITRS – International Terrestrial Reference System




- Adoptado pela IUGG em 1991
- Definição, realização e manutenção a cargo do IERS (*International Earth Rotation and Reference Systems Service*)

International Earth Rotation and Reference Systems Service

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## ITRS – International Terrestrial Reference System

Vienna - 1991

CLOSING PLENARY SESSION

The Closing Plenary Session of the XX General Assembly of the IUGG was held in Hall G of the Messepalast, at 9:00 a.m. on Saturday, 24 August 1991.

President V. Keilis-Borok introduced the presidents of the associations, who gave brief reports on the activities of their respective associations during the Assembly.

Prof. P. Melchior read the resolutions adopted by the Union. These are reported elsewhere in this volume.

President Keilis-Borok introduced the new Bureau.

The incoming President, Prof. H. Moritz, made a short address and then he closed the Assembly.

RESOLUTIONS OF THE UNION ADOPTED AT THE
XX GENERAL ASSEMBLY, Vienna 23 August 1991

**Resolution N°2**

The International Union of Geodesy and Geophysics

Considering the need to define a Conventional Terrestrial Reference System (CTRS) which would be unambiguous at the millimetre level at the Earth's surface and that this level of accuracy must take account of relativity and of Earth deformations, and

Noting the resolutions on Reference Systems adopted by the XXI General Assembly of the International Astronomical Union (IAU) at Buenos Aires, 1991,

Endorses the Reference System as defined by the IAU at their XXI General Assembly at Buenos Aires, 1991, and

Recommends the following definitions of the CTRS:

1) CTRS to be defined from a geocentric non-rotating system by a spatial rotation leading to a quasi-Cartesian system,
2) the geocentric non-rotating system to be identical to the Geocentric Reference System (GRS) as defined in the IAU resolutions,
3) the coordinate-time of the CTRS as well as the GRS to be the Geocentric Coordinate Time (TCG),
4) the origin of the system to be the geocentre of the Earth's masses including oceans and atmosphere, and
5) the system to have no global residual rotation with respect to horizontal motions at the Earth's surface.

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## ITRS – International Terrestrial Reference System

Boulder - 1995

CLOSING PLENARY SESSION

Friday, July 14, 1995, 17:00 - 19:00

Introduction (H. Moritz) Resolutions: read in French and in English (G. Balmino)
Introduction of New President (P. Wyllie) by H. Moritz Presentation of the new Bureau Members, the new Finance Committee and the new Association Presidents (P. Wyllie) Announcement about the next General Assembly Formal Closing of XXI General Assembly

RESOLUTIONS OF THE UNION
ADOPTED AT THE XXI GENERAL ASSEMBLY
Boulder, July 13,1995

**Resolution N°1**

The International Union of Geodesy and Geophysics

Recognizing that:

1. since its establishment in 1988, the International Earth Rotation Service (IERS) has successfully developed a comprehensive observation and analysis system to realize the International Terrestrial Reference System (ITRS) and the International Celestial Reference System (ICRS), and to permanently link them by monitoring the Earth's orientation,
2. IERS achievements are entirely due to the contributions of national agencies in terms of technical development, network operation, and data analysis;

Noting that:

1. the IERS-published reference systems are of high quality and are used in a wide range of research and applications in geodesy and geophysics to provide quantities that the user would otherwise have to determine for himself and at his own expense,
2. the IERS Directing Board has published a strategy statement describing the optimal combination of the astronomical and space techniques to fulfil the IERS missions.

Recommends that national agencies and institutions contribute to the operation of IERS by providing observations and products in compliance with the IERS Strategy.

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## ITRS - Definição

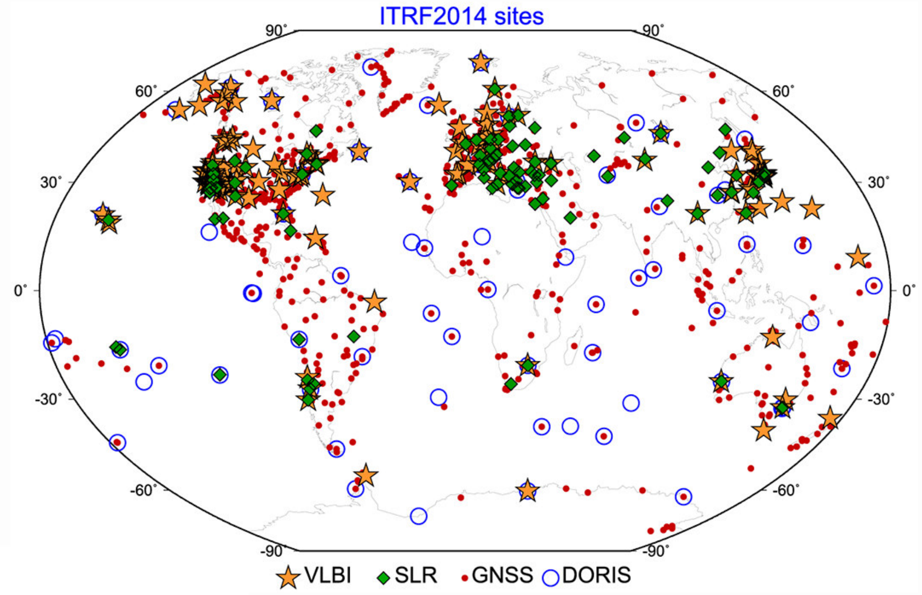
- Origem: Centro de Massa da Terra (incluindo as partes sólida e líquida e a atmosfera)
- Unidade de comprimento: metro (SI)
- Orientação dos eixos: consistente com a definição do BIH (*Bureau International de l'Heure*) para a época 1984.0
- Condição de não rotação relativamente a movimentos tectónicos ("No Net Rotation")



## ITRF – International Terrestrial Reference Frame

- São as realizações do ITRS
- Conjunto de referências geodésicas
- Coordenadas resultantes de observações de geodesia espacial (GNSS, VLBI, SLR, DORIS)
- Cada realização é designada por ITRFyyyy
- As técnicas actuais permitem determinar também as variações temporais das coordenadas – velocidades e translações

# ITRF2014 – Rede de Estações




[Altamimi, 2015]

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# ITRF2014 – Dados e Definição

**ITRF2014 : Input data**

Input data

Space geodesy solutions. The used time series of solutions of space geodesy are summarized in the following table, indicating for each one, the time span and the type of constraints

| TC - AC | Time span | Type of constraints/solution | Description |
|---|---|---|---|
| IVS | 1980.0 - 2015.0 | Free / Normal equation | Summary |
| ILRS | 1983.0 - 2015.0 | Loose / variance-covariance | Summary |
| IGS | 1994.0 - 2015.1 | Minimal / variance-covariance | Summary |
| IDS | 1993.0 - 2015.0 | Minimal / variance-covariance | Summary |

**ITRF2014 : Frame Definition**

Origin:

The ITRF2014 origin is defined in such a way that there are zero translation parameters at epoch 2010.0 and zero translation rates between the ITRF2014 and the ILRS SLR long-term solution obtained by tacking the ILRS time series.

Scale:

The ITRF2014 scale is defined in such a way that there are zero scale and scale rate between ITRF2014 and the average of VLBI and SLR scales/rates.

Orientation:

The ITRF2014 orientation is defined in such a way that there are zero rotation parameters at epoch 2010.0 and zero rotation rates between the ITRF2014 and ITRF2008. These two conditions are applied over a core network (see section transformation parameters between ITRF2014 and ITRF2008)

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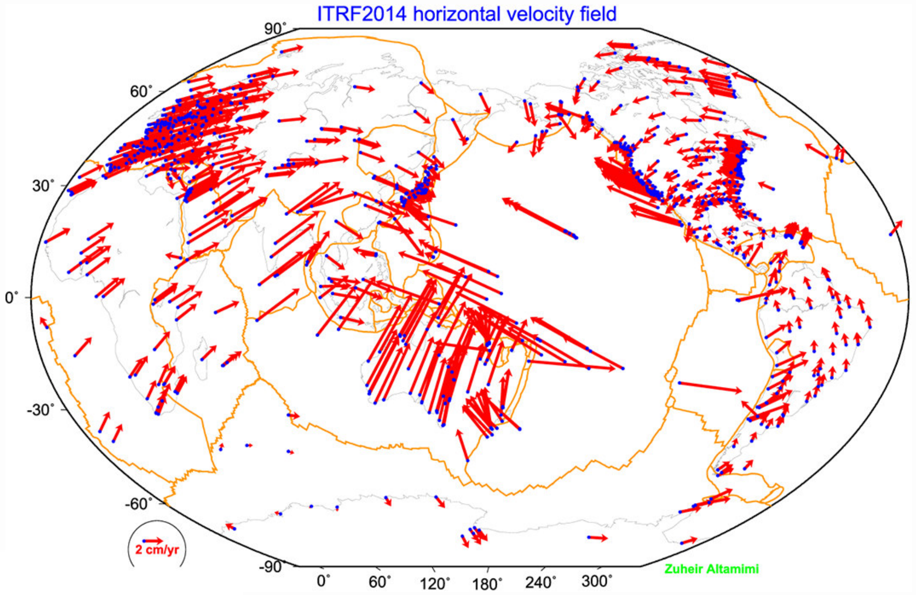
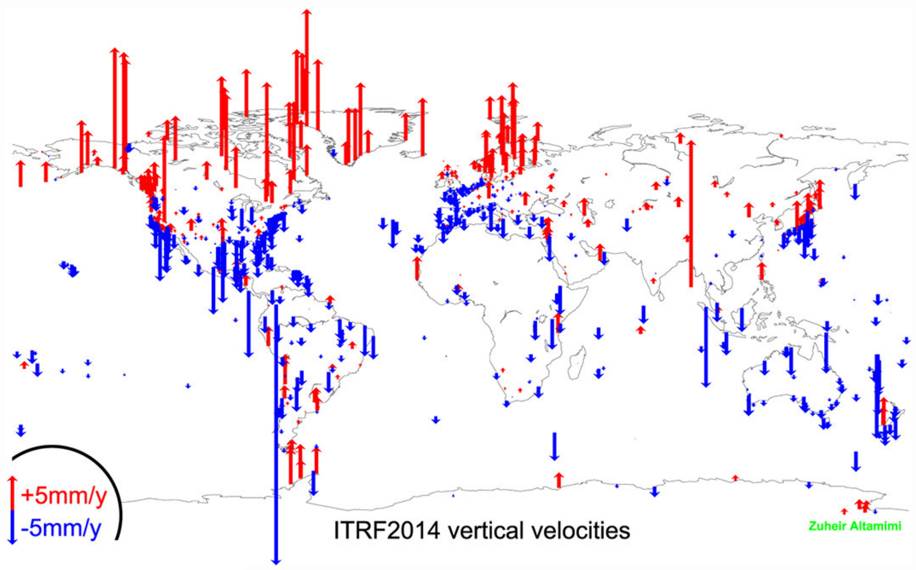
## ITRF2014 – Campo de velocidades




[Altamimi, 2015]



## ITRF2014 – Campo de velocidades




[Altamimi, 2015]

# Parâmetros de Transformação entre ITRF

Transformation parameters from ITRF2014 to past ITRFs.

| SOLUTION | Tx | Ty | Tz | D | Rx | Ry | Rz | EPOCH |
|---|---|---|---|---|---|---|---|---|
| UNITS----------> | mm | mm | mm | ppb | .001" | .001" | .001" | |
| RATES | Tx | Ty | Tz | D | Rx | Ry | Rz | |
| UNITS----------> | mm/y | mm/y | mm/y | ppb/y | .001"/y | .001"/y | .001"/y | |
| ITRF2008 | 1.6 | 1.9 | 2.4 | -0.02 | 0.00 | 0.00 | 0.00 | 2010.0 |
| rates | 0.0 | 0.0 | -0.1 | 0.03 | 0.00 | 0.00 | 0.00 | |
| ITRF2005 | 2.6 | 1.0 | -2.3 | 0.92 | 0.00 | 0.00 | 0.00 | 2010.0 |
| rates | 0.3 | 0.0 | -0.1 | 0.03 | 0.00 | 0.00 | 0.00 | |
| ITRF2000 | 0.7 | 1.2 | -26.1 | 2.12 | 0.00 | 0.00 | 0.00 | 2010.0 |
| rates | 0.1 | 0.1 | -1.9 | 0.11 | 0.00 | 0.00 | 0.00 | |
| ITRF97 | 7.4 | -0.5 | -62.8 | 3.80 | 0.00 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |
| ITRF96 | 7.4 | -0.5 | -62.8 | 3.80 | 0.00 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |
| ITRF94 | 7.4 | -0.5 | -62.8 | 3.80 | 0.00 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |
| ITRF93 | -50.4 | 3.3 | -60.2 | 4.29 | -2.81 | -3.38 | 0.40 | 2010.0 |
| rates | -2.8 | -0.1 | -2.5 | 0.12 | -0.11 | -0.19 | 0.07 | |
| ITRF92 | 15.4 | 1.5 | -70.8 | 3.09 | 0.00 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |
| ITRF91 | 27.4 | 15.5 | -76.8 | 4.49 | 0.00 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |
| ITRF90 | 25.4 | 11.5 | -92.8 | 4.79 | 0.00 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |
| ITRF89 | 30.4 | 35.5 | -130.8 | 8.19 | 0.00 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |
| ITRF88 | 25.4 | -0.5 | -154.8 | 11.29 | 0.10 | 0.00 | 0.26 | 2010.0 |
| rates | 0.1 | -0.5 | -3.3 | 0.12 | 0.00 | 0.00 | 0.02 | |

Note : These parameters are derived from those already published in the IERS Technical Notes and Annual Reports. The transformation parameters should be used with the standard model (1) given below and are valid at the indicated epoch.

$$\begin{pmatrix} XS \\ YS \\ ZS \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} Tx \\ Ty \\ Tz \end{pmatrix} + \begin{pmatrix} D & -Rz & Ry \\ Rz & D & -Rx \\ -Ry & Rx & D \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \qquad (1)$$

Where X,Y,Z are the coordinates in ITRF2014 and XS,YS,ZS are the coordinates in the other frames.

On the other hand, for a given parameter P, its value at any epoch t is obtained by using equation (2).

$$P(t) = P(EPOCH) + \dot{P} * (t - EPOCH) \qquad (2)$$

where EPOCH is the epoch indicated in the above table (currently 2010.0) and $\dot{P}$ is the rate of that parameter.

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## ETRS89

Symposia - Resolutions

**Florence, 28 - 31 May 1990**

**Resolution No. 1**

The IAG Subcommission for the European Reference Frame

**recognising** the availability of the International Terrestrial Reference System (ITRS) which has been established by the International Earth Rotation Service (IERS) which is accepted worldwide and which uses SLR, LLR and VLBI observations and

**noting** that in such a system station positions in Europe have a common motion of the order of one centimetre per year

**recommends** that the system to be adopted by EUREF will be coincident with ITRS at the Epoch 1989.0 and fixed to the stable part of the Eurasian Plate and will be known as European Terrestrial Reference System 89 (ETRS 89) and

**accepts** that this geocentric system will coincide with the World Geodetic System 84 (WGS 84) at the one metre level and that, for most applications, the coordinates will have no time variation.



## ETRS89

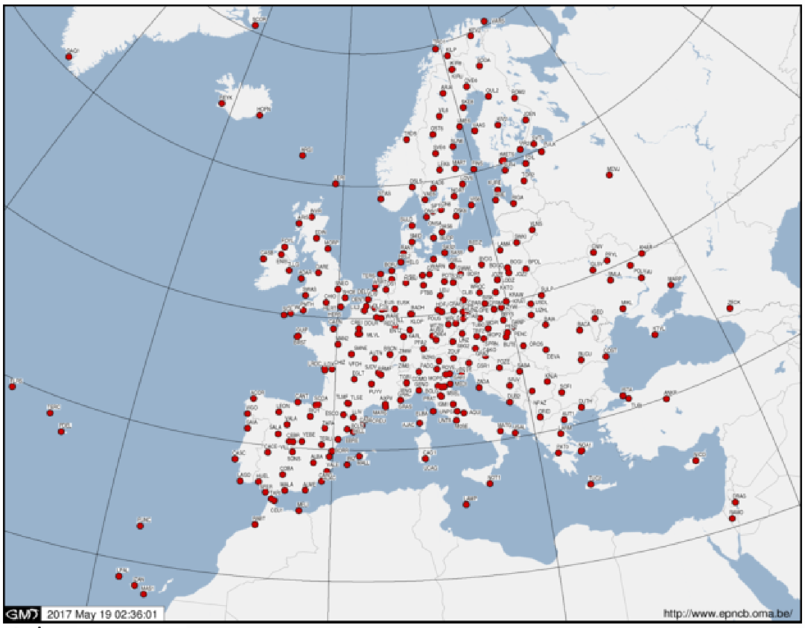
### Sistema de Referência

- ETRS89 roda em conjunto com a parte estável da Europa
- As posições relativas entre as estações europeias mantêm-se

### Referencial

- O ETRF89 é o subconjunto europeu das estações do ITRF89
- Cada novo ITRF tem o correspondente novo ETRF

# EPN – EUREF Permanent Network






# Realização do ETRS89

1. Processar os dados GNSS em ITRFyy para a época das observações ($t_C$)
2. Transformar as coordenadas de ITRFyy para ETRS89

Posições:

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

Velocidades:

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

[Boucher and Altamimi, 2011]

# Realização do ETRS89

**Table 1:** Transformation parameters from $ITRF_{YY}$ to ITRF89

| From | T1 cm | T2 cm | T3 cm | D $10^{-8}$ | R1 mas | R2 mas | R3 mas | $t_0$ y | Ref. IERS TN |
|---|---|---|---|---|---|---|---|---|---|
| ITRF90 | 0.5 | 2.4 | -3.8 | 0.34 | 0.0 | 0.0 | 0.0 | 88.0 | 9 |
| ITRF91 | 0.6 | 2.0 | -5.4 | 0.37 | 0.0 | 0.0 | 0.0 | 88.0 | 12 |
| ITRF92 | 1.7 | 3.4 | -6.0 | 0.51 | 0.0 | 0.0 | 0.0 | 88.0 | 15 |
| ITRF93 | 1.9 | 4.1 | -5.3 | 0.39 | 0.39 | -0.80 | 0.96 | 88.0 | 18 |
| ITRF94 | 2.3 | 3.6 | -6.8 | 0.43 | 0.0 | 0.0 | 0.0 | 88.0 | 21 |
| ITRF96 | 2.3 | 3.6 | -6.8 | 0.43 | 0.0 | 0.0 | 0.0 | 88.0 | 24 |
| ITRF97 | 2.3 | 3.6 | -6.8 | 0.43 | 0.0 | 0.0 | 0.0 | 88.0 | 27 |
| ITRF2000 | 3.0 | 4.2 | -8.7 | 0.59 | 0.0 | 0.0 | 0.0 | 97.0 | |
| ITRF2005 | 3.0 | 3.9 | -9.7 | 0.63 | 0.0 | 0.0 | 0.06 | 00.0 | |
| ITRF2008 | 2.80 | 3.81 | -10.17 | 0.724 | 0.0 | 0.0 | 0.060 | 00.0 | |

**Table 4:** Estimation of $\dot{R}_{YY}$

| $YY$ | $\dot{R}1$ mas/y | $\dot{R}2$ mas/y | $\dot{R}3$ mas/y |
|---|---|---|---|
| 89 | 0.11 | 0.57 | -0.71 |
| 90 | 0.11 | 0.57 | -0.71 |
| 91 | 0.21 | 0.52 | -0.68 |
| 92 | 0.21 | 0.52 | -0.68 |
| 93 | 0.32 | 0.78 | -0.67 |
| 94 | 0.20 | 0.50 | -0.65 |
| 96 | 0.20 | 0.50 | -0.65 |
| 97 | 0.20 | 0.50 | -0.65 |
| 00 | 0.081 | 0.490 | -0.792 |
| | $\pm0.021$ | $\pm0.008$ | $\pm0.026$ |
| 05* | 0.054 | 0.518 | -0.781 |
| | $\pm0.009$ | $\pm0.006$ | $\pm0.011$ |

[Boucher and Altamimi, 2011]