NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Know the Earth... Show the Way... Understand the World

# ICG-9 Working Group D
# Transformations to Classical Horizontal Mapping Datums

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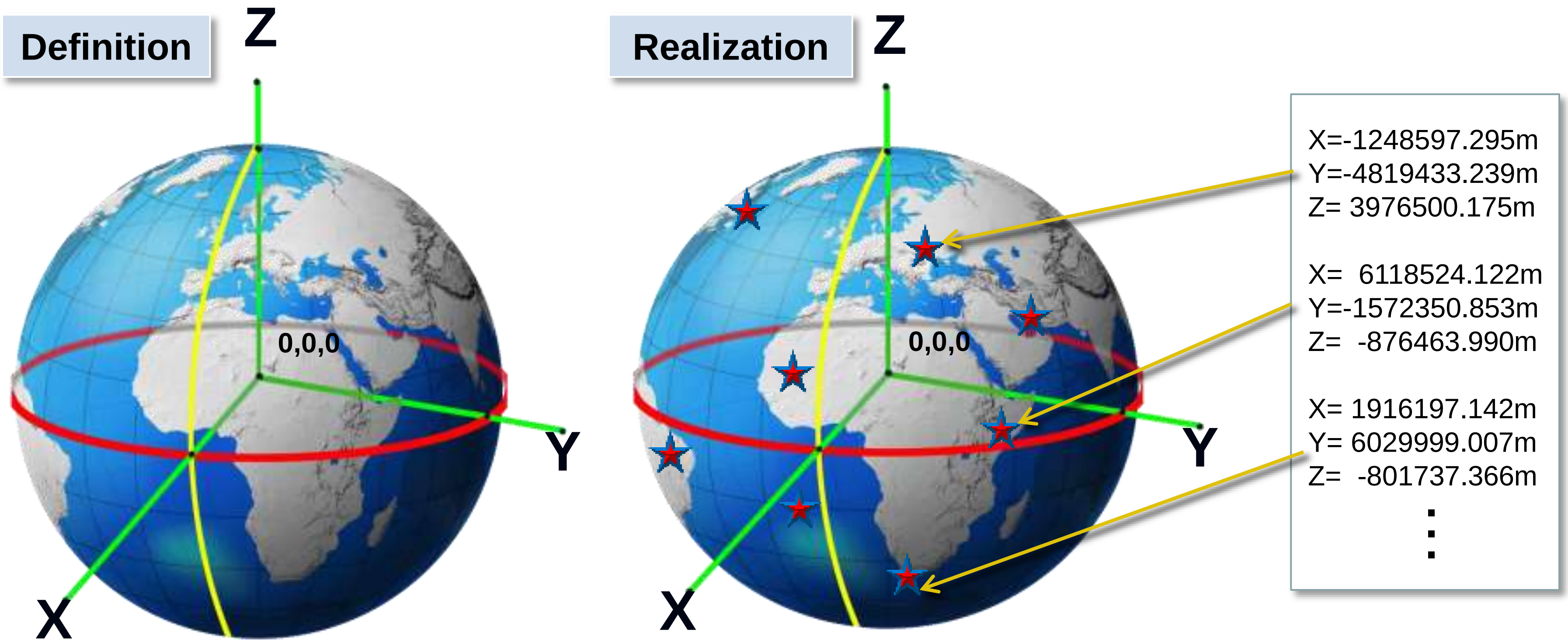
# The 'Realization' of an Earth-Centered, Earth-Fixed Global Reference Frame

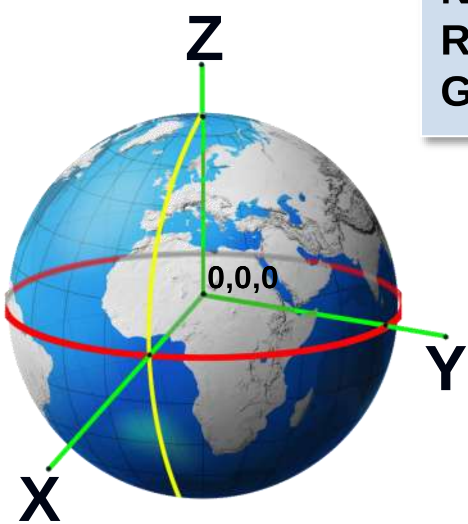



A globally-distributed set of station coordinates

- Infer the location of the ORIGIN
- Infer the ORIENTATION of a set of ECEF Axes
- Infer the SCALE of the reference frame

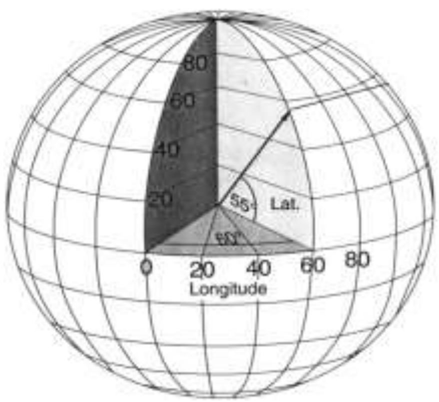
# World Geodetic System 1984

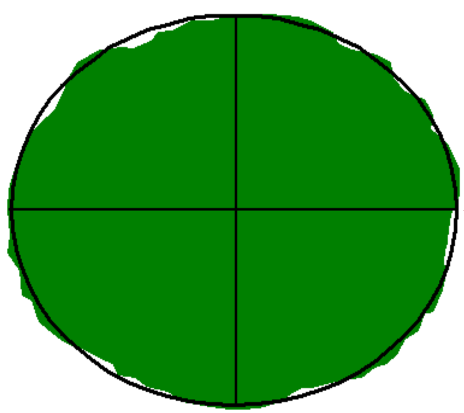
**NGA – Developed the First Series (1958) of Global Reference Frames and Geophysical Models for Modern Geospatial Information**




## Recent WGS 84 Frame Realizations

| | |
|---|---|
| TRANSIT (1 - 2 m) | Jan 1987 |
| G730 (10 cm) | Jun 1994 |
| G873 (5 cm) | Jun 1997 |
| G1150 (1-2 cm) | Jan 2002 |
| **G1674 (1 cm)** | **Feb 2012** |
| **G1762 (1 cm)** | **Oct 2013** |

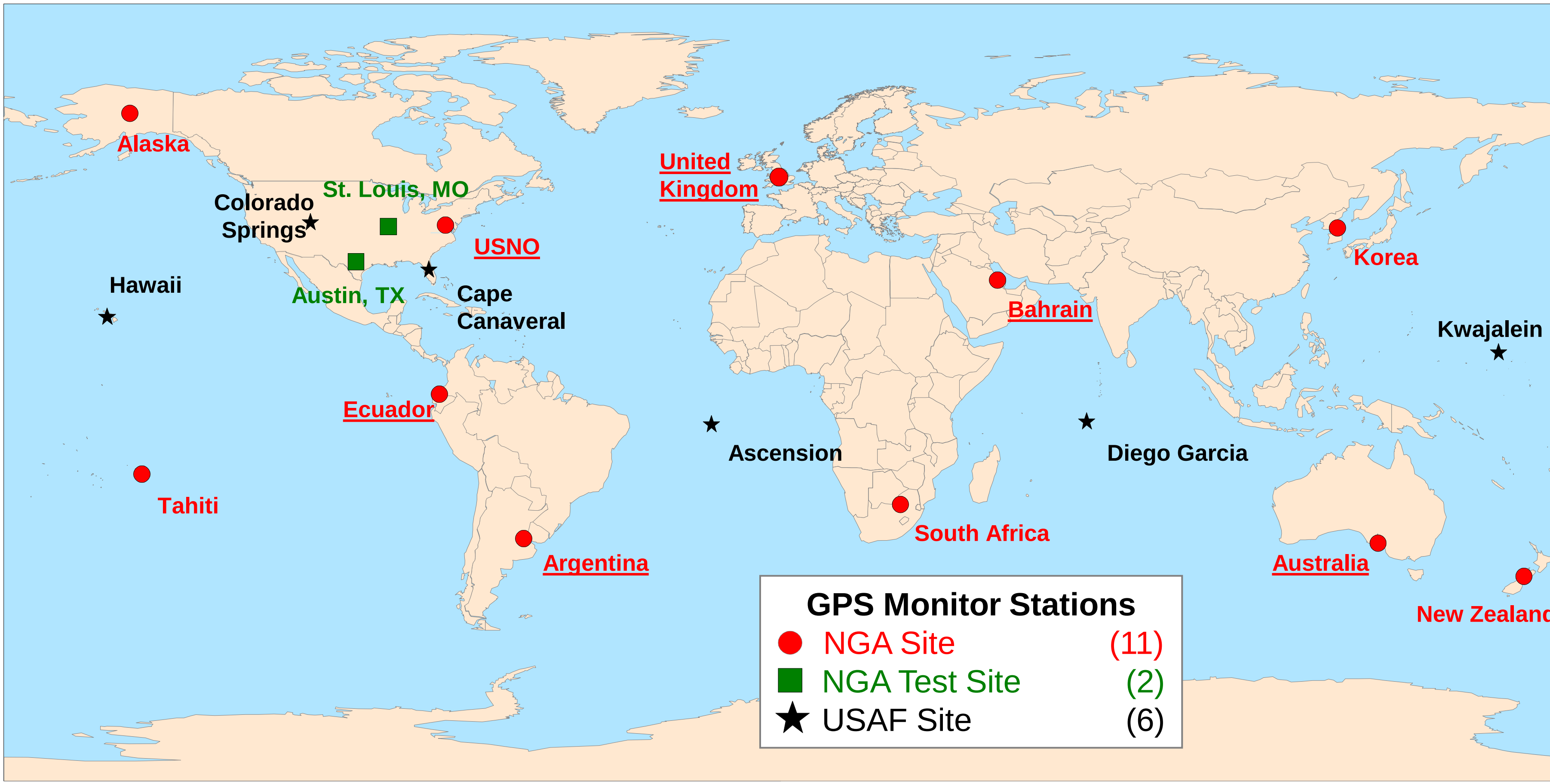


**The geoid is used as a surrogate for mean sea level, the vertical datum for traditional “elevations” (EGM08)**

WGS 84 Ellipsoid: a = 6378137, f = 1/298.257223563

# US GPS Monitor Station Network



# Verification of WGS 84 Reference Frame Accuracy: Comparisons to IGS GPS Orbits

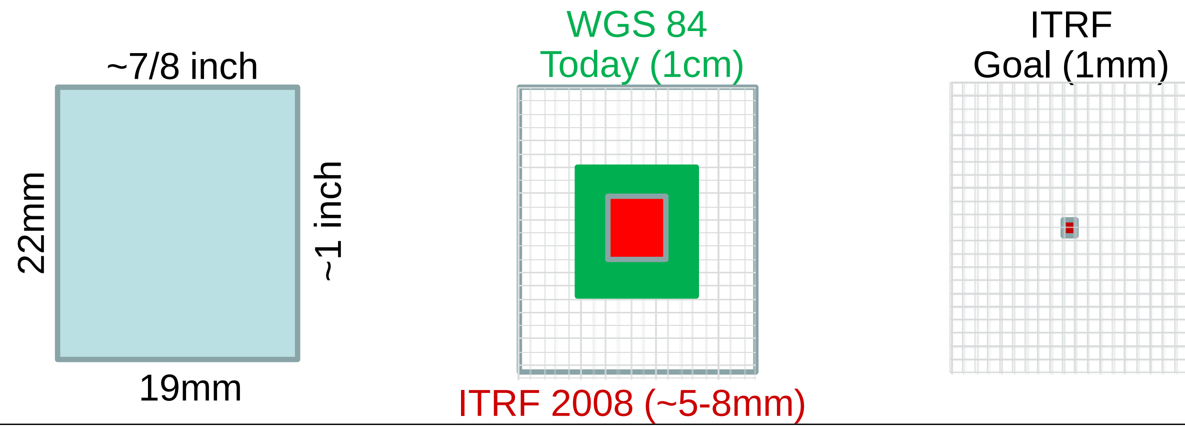
- Transformation parameters are computed daily between NGA and IGS GPS orbits
- These transformations are a metric for the alignment of the WGS TRF to the ITRF
  - Mean results from first 242 days of 2014
  - All values ***in the vicinity of 1 cm*** at surface of Earth

| | ΔX(cm) | ΔY(cm) | ΔZ(cm) | Rx(mas) | Ry(mas) | Rz(mas) | Scale (ppb) |
|---|---|---|---|---|---|---|---|
| Mean | 0.0 | -0.0 | -1.0 | -0.08 | 0.07 | 0.04 | -0.55 |
| Std Dev | 0.0 | 0.0 | 1.0 | 0.08 | 0.09 | 0.13 | 0.14 |

- WGS 84 (G1762) is coincident with ITRF2008 (IGb08) at the 1cm level

# Goals for a Future ITRF

*2010 National Research Council Study: *The ITRF must be both accurate and accessible at the 1-millimeter level, with a stability of 0.1 millimeters per year*


To get better (by 2030?), measurement and modeling of <u>geocenter motion</u> becomes necessary.

Examples surface mass transport causing geocenter motion include snow and water changes over continents, including melting glaciers, ground water changes; annual hemispheric water mass exchange in oceans (N. hemisphere has more mass in N. winter); and polar ice sheet variations

* *Precise Geodetic Infrastructure, National Requirements for a Shared Resource, National Research Council of the National Academies, The National Academy Press, 2010*

# Sample Modern Geocentric Terrestrial Reference Frames

WGS 84 (G1762)
PZ90.11 (Earth Parameters 1990 – Parametry Zemli 1990)
CTRF 2000/CGCS 2000 (China Terrestrial Reference Frame/China Geodetic Coord. System)
GDA94 (Geocentric Datum of Australia)

IAG Commission 1 Reference Frames

- Europe — EUREF
- South and Central America — SIRGAS
- North America — NAD83
- Africa — AFREF
- Asia-Pacific — APREF
- Antarctica — ITRF2000, RSRGD2000

These frames may also have national sub-realizations

- SWEREF (Sweden)
- MAGNA SIRGAS (Colombia)

Geocentric National datums include that cover a limited geographic area

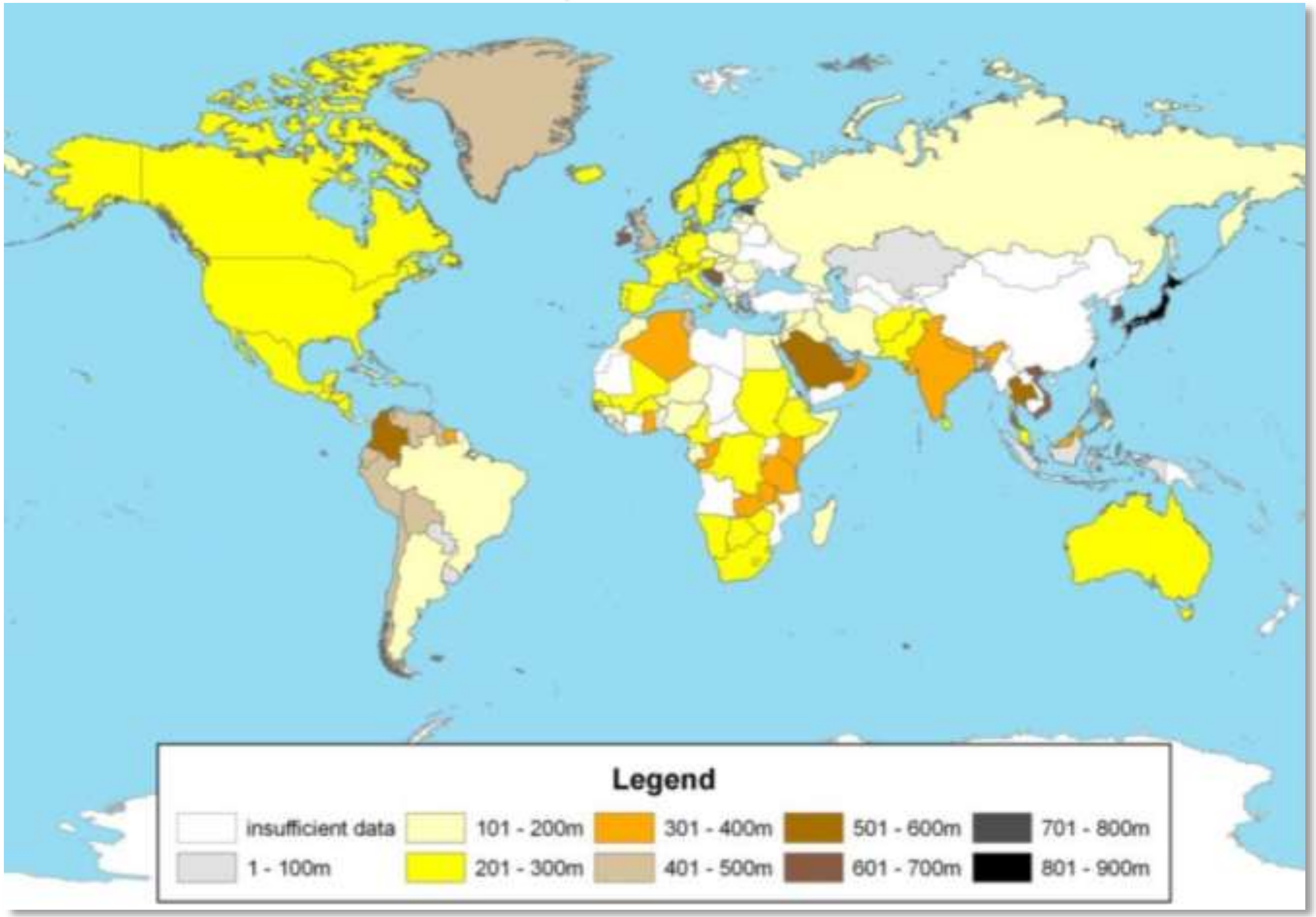
- Hartebeesthoek 94 (South Africa)
- New Zealand Geodetic Datum 2000

Maps & Charts based on any of these modern Geocentric Reference Frames Do NOT Require a Transformation for any practical application and are

**INTEROPERABLE** for all Practical purposes

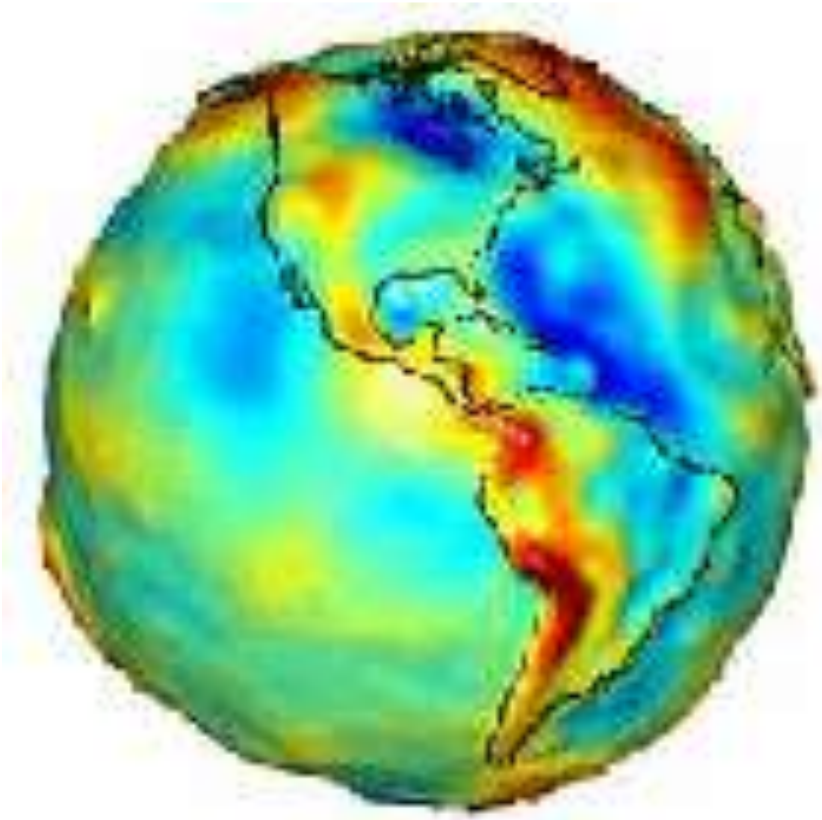
# Classical (non-Geocentric) Horizontal Mapping Datums

## DATUM SHIFTS IN UTM X, Y GRID FROM LOCAL TO WGS84




NGA maintains a set of Horizontal Datum Transformations to/from WGS 84 for more than 226 datums

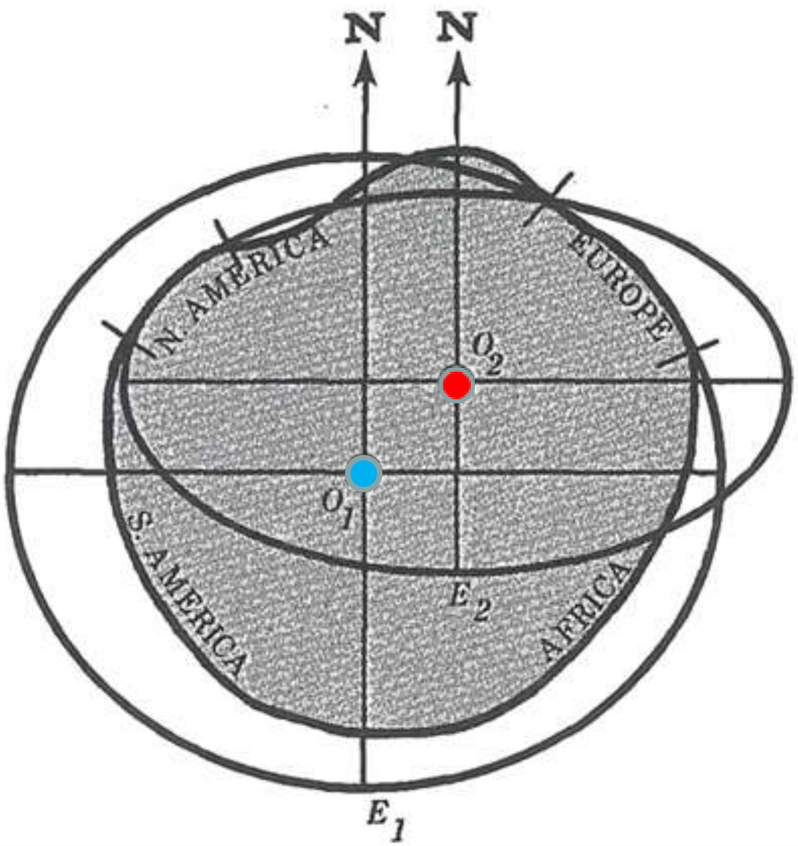
# The Earth's Gravity Field and the Geoid



The concept of a 'geoid' was introduced by J.B. Listing (1872)

- The Earth's gravity field is not uniform around the planet.
- A surface of equal potential of the gravity field, that is close to Mean Sea Level, is called *Geoid*.
- The departures of the geoid from the surface of an ellipsoid of revolution are called geoid undulations.

# Spatial Relationship of the Geoid with Two "Regional Best-fitting" Ellipsoids




*Based on: Irene Fischer, Defense Mapping Agency Topographic Center, Wash DC, The Figure of the Earth – Changes in Concepts, Geophysical Surveys 2 (1975) 3-54*

# Ellipsoids 1830-2014

Table 10.1
Ellipsoid Parameters

| Ellipsoid Name (Year Computed) | Semi-Major Axis a(m) | Inverse Flattening 1/f |
|---|---|---|
| Airy (1830) | 6378563.396 | 299.324964 |
| Bessel (1841) | 6377397.155 | 299.152813 |
| Clarke 1866 | 6378206.4 | 294.978698 |
| Clarke 1880 (modified) | 6378249.145 | 293.4663 |
| Clarke 1880 | 6378249.145 | 293.465 |
| Everest (1830) | 6377276.345 | 300.8017 |
| International (1924) | 6378388 | 297 |
| Krassovski (1940) | 6378245 | 298.3 |
| Mercury 1960 | 6378166 | 298.3 |
| Modified Mercury 1968 | 6378150 | 298.3 |
| Australian National | 6378160 | 298.25 |
| South America 1969 | 6378160 | 298.25 |
| Geodetic Reference System 1967 | 6378160 | 298.2471674273 |
| WGS72 | 6378135 | 298.26 |
| Int. Assoc. of Geodesy (1975) | 6378140 ±5 | 298.257 ±.0015 |
| Geodetic Reference System 1980(WGS84) | 6378137 | 298.257222101 |
| Int. Assoc. of Geodesy (1983) | 6378136 ±1 | 298.257 |

Still used today

*Table Ref: Rapp, R.H., Geometric Geodesy, Part I, Ohio State University, 1984*

A classical (pre-satellite era) <u>horizontal mapping datum</u> was defined by 5 parameters

An Initial Point ($F_0$, $l_0$)
An initial Azimuth ($a_0$)
and
An ellipsoid (a, 1/f)

<u>Example</u>:
North American Datum 1927
($F_0$, $l_0$) at Meades Ranch, Kansas
Ellipsoid was Clarke 1866

# Sample Datum Transformation Parameters

For use with standard Molodensky transformation formulas

**Continent: ASIA**

| Local Geodetic Datums | | Reference Ellipsoids and Parameter Differences | | | No. of Satellite Stations Used | Transformation Parameters | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Name | Code | Name | Δa(m) | Δf x $10^4$ | | Cycle Number | Pub. Date | ΔX(m) | ΔY(m) | ΔZ(m) |
| **AIN EL ABD 1970** | AIN | International 1924 | -251 | -0.14192702 | | | | | | |
| Bahrain Island | AIN-A | | | | 2 | 0 | 1991 | -150 ±25 | -250 ±25 | -1 ±25 |
| Saudi Arabia | AIN-B | | | | 9 | 0 | 1991 | -143 ±10 | -236 ±10 | 7 ±10 |
| **DJAKARTA (BATAVIA)** | BAT | Bessel 1841 | 739.845 | 0.10037483 | | | | | | |
| Sumatra (Indonesia) | | | | | 5 | 0 | 1987 | -377 ±3 | 681 ±3 | -50 ±3 |
| **EUROPEAN 1950** | EUR | International 1924 | -251 | -0.14192702 | | | | | | |
| Iran | EUR-H | | | | 27 | 0 | 1991 | -117 ±9 | -132 ±12 | -164 ±11 |
| **HONG KONG 1963** | HKD | International 1924 | -251 | -0.14192702 | | | | | | |
| Hong Kong | | | | | 2 | 0 | 1987 | -156 ±25 | -271 ±25 | -189 ±25 |
| **HU-TZU-SHAN** | HTN | International 1924 | -251 | -0.14192702 | | | | | | |
| Taiwan | | | | | 4 | 0 | 1991 | -637 ±15 | -549 ±15 | -203 ±15 |
| **INDIAN** | IND | Everest | | | | | | | | |

# Sample Local or Regional Datums Possibly Still in Use or Likely to be Encountered by a GNSS User

Sierra Leone 1960
Liberia 1964
Djakarta
Ireland 1965
Hjorsey 1955
Naparima
Provisional South American 1956
Ordnance Survey of Great Britain 1936
Hu-tzu-shan
Corrego Alegre

Yacare
European (1950)
Qornoq
Tananarive Obsv 1925
Luzon
Tokyo
Indonesia 1974
Campo Inchauspe
Chua Astro
Geodetic Datum 1949

These are just samples

226 Horizontal Datums Appear in our NGA Publication on WGS 84

# More than 1200 Distinct Horizontal Mapping and Charting Datums Have been Created in Human History

- Which of these datums are still in practical use?
- Which can be categorized as ‘for office use’ (by mapping agencies/orgs)?
- Which can be retired to history and declared extinct?
- Practical issue for many GNSS Receivers
  - Compatibility of datum lists among receivers
  - Agreement on transformation parameters among receivers
  - A common, authoritative list would reduce confusion over these transformations
  - Promote use of GNSS in numerous developing countries that still use classical datums
- **Proposed Working Group D Goal:** Develop and maintain a Multi-National, Authoritative list of Horizontal Mapping and Charting datums that are still in use and therefore may be encountered by a GNSS user
  - A corresponding authoritative set of datum transformation parameters would also be of significant value to the world-wide GNSS user community

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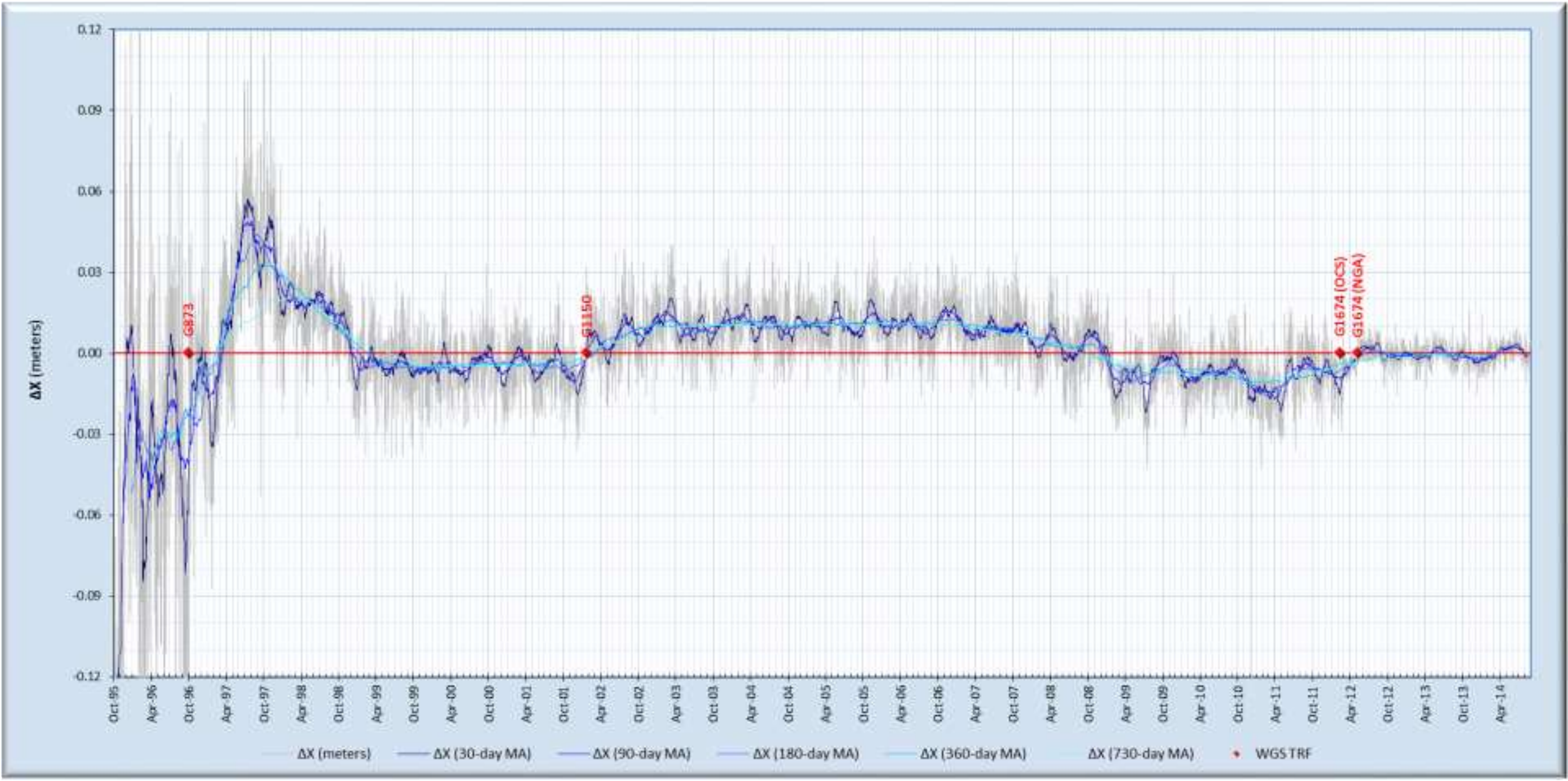
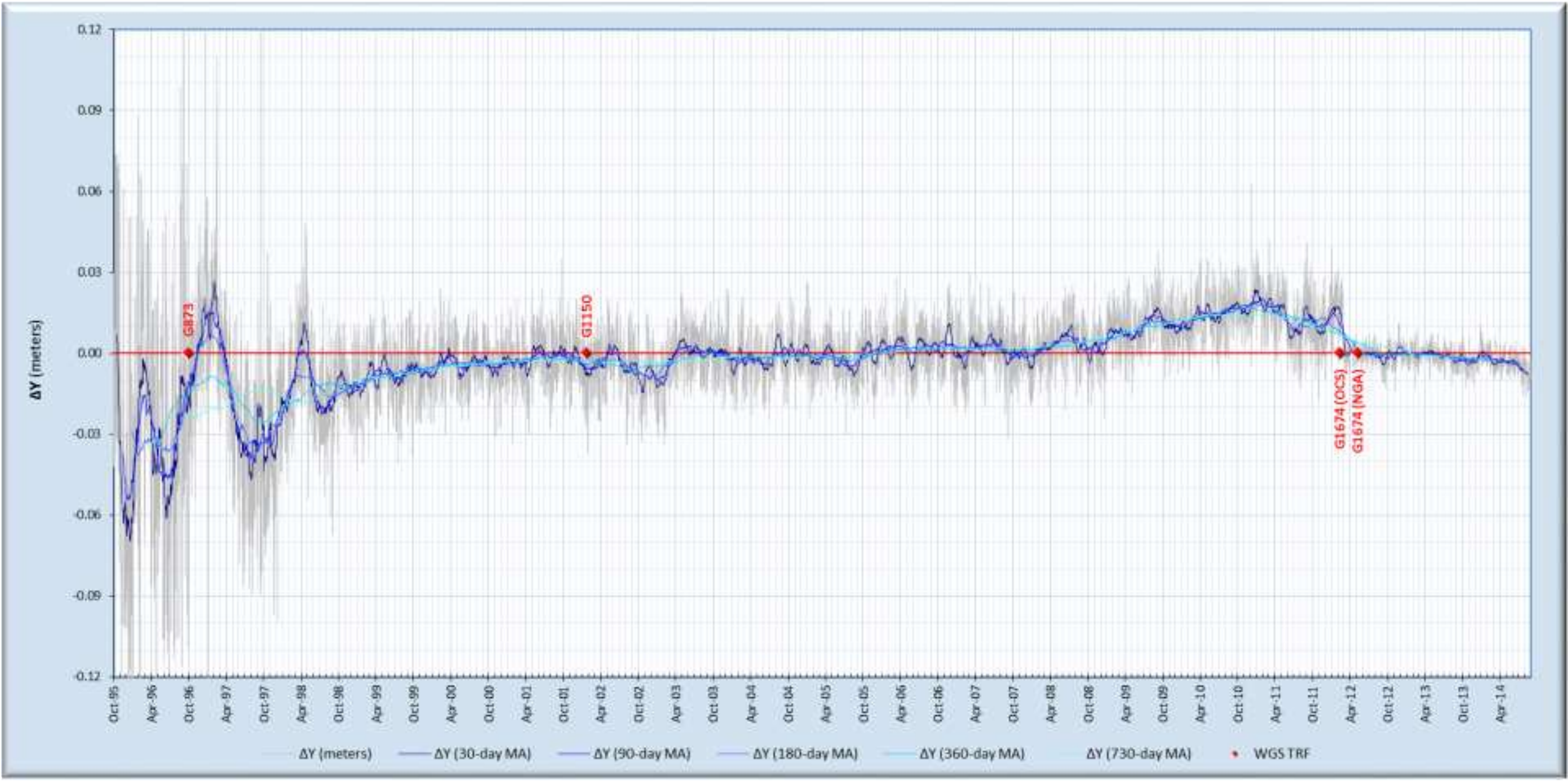
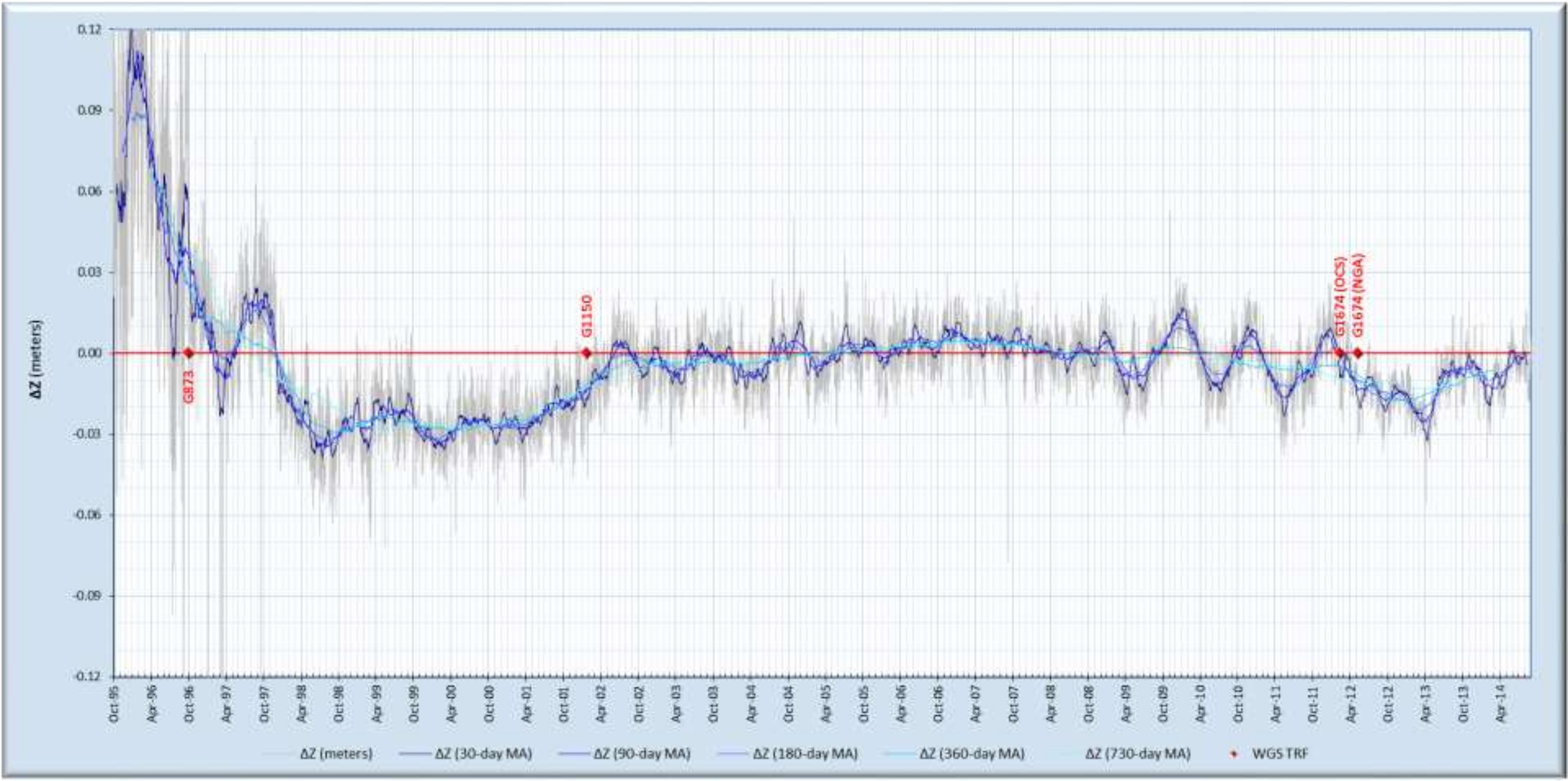
# ΔX Transformation Parameter



# ΔY Transformation Parameter



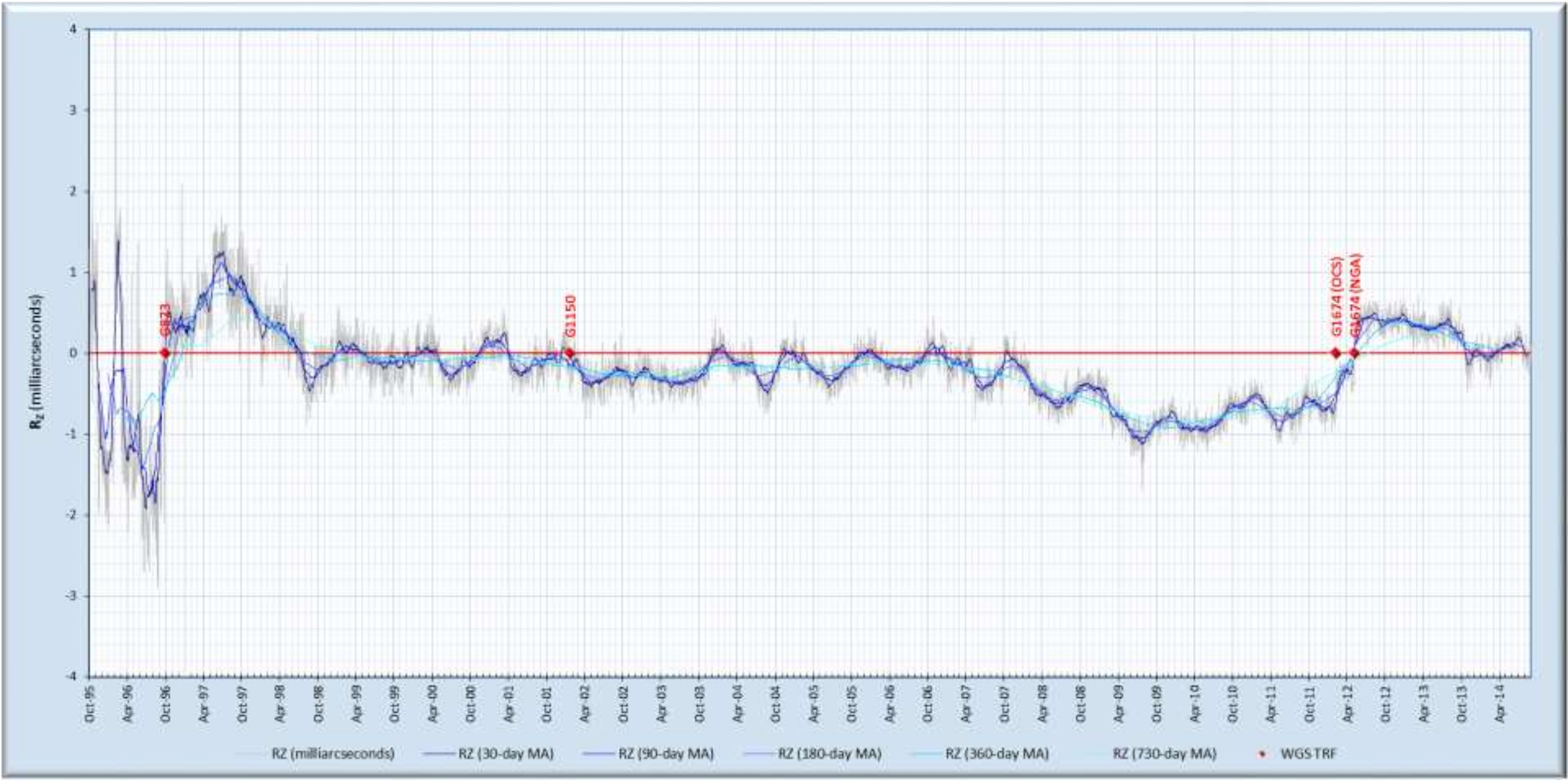
# ΔZ Transformation Parameter



# $R_X$ Transformation Parameter

# $R_Y$ Transformation Parameter

# $R_Z$ Transformation Parameter



# Scale Transformation Parameter