# GPS Tide Gauge Benchmark Monitoring. Some Results


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# Overview

- Purposes of reprocessing of GPS data at tide gauges
- TIGA and IGS networks
- The main models, algorithms and parameterization used
- Some results of reprocessing
- Conclusions

# Purposes of reprocessing

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- We live on the changing Earth
- Investigations of sea level variations are very important for the mankind
- Tide gauge (TG) measurements are one of the primary tools to determine sea level variations
- Analysis of TG measurements requires a well defined reference frame
- Such a reference frame can be realized through precise positions of GPS stations located near tide gauges (TIGA stations)
- TIGA: IGS Tide Gauge Benchmark Monitoring Pilot Project
- The purpose of the Project: to provide precise positions and vertical motion of tide gauge benchmarks
- Required accuracies: position: ~5–10 mm, vertical motion: < 1 mm/yr
- TIGA GPS network (end of 2007) processed at GFZ Potsdam: globally 403 GPS stations: 216 IGS stations and 187 – TIGA-only stations
- Reprocessing of GPS data (1994-2008) from TIGA stations using recent models
- EPOS-Potsdam software package (version PDM7, GFZ Potsdam) used

# Sea level changes

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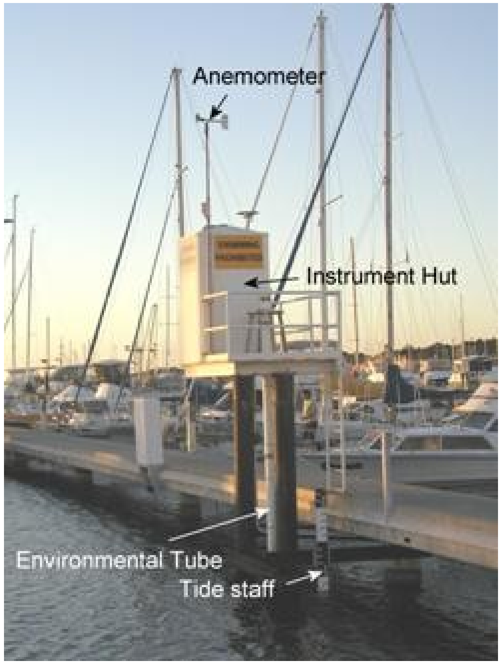
Photo courtesy Hobby destinations

- The global mean sea level change (Nerem et al., 2006):
- +1.8 ± 0.3 mm/y in 1955-2005, from tide gauges
- +3.1 ± 0.4 mm/y in 1993-2005, from TOPEX/Poseidon and Jason-1 data analysis

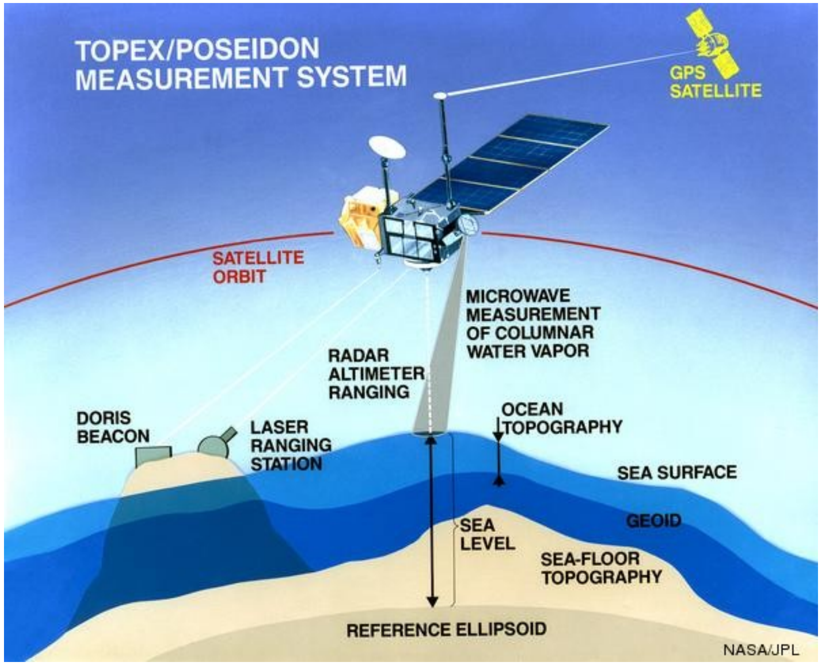
- The main sources of the the sea level rise (Cazenave et al., 2006):
- Land ice melting (Glaciers, Greenland, Antarctica)
- Increased ocean warming, change of salinity => change of sea water density
- Land waters

Photo courtesy Richard Dunbar

# Measurements of the sea level changes




Tide gauge at Hillarys, Western Australia

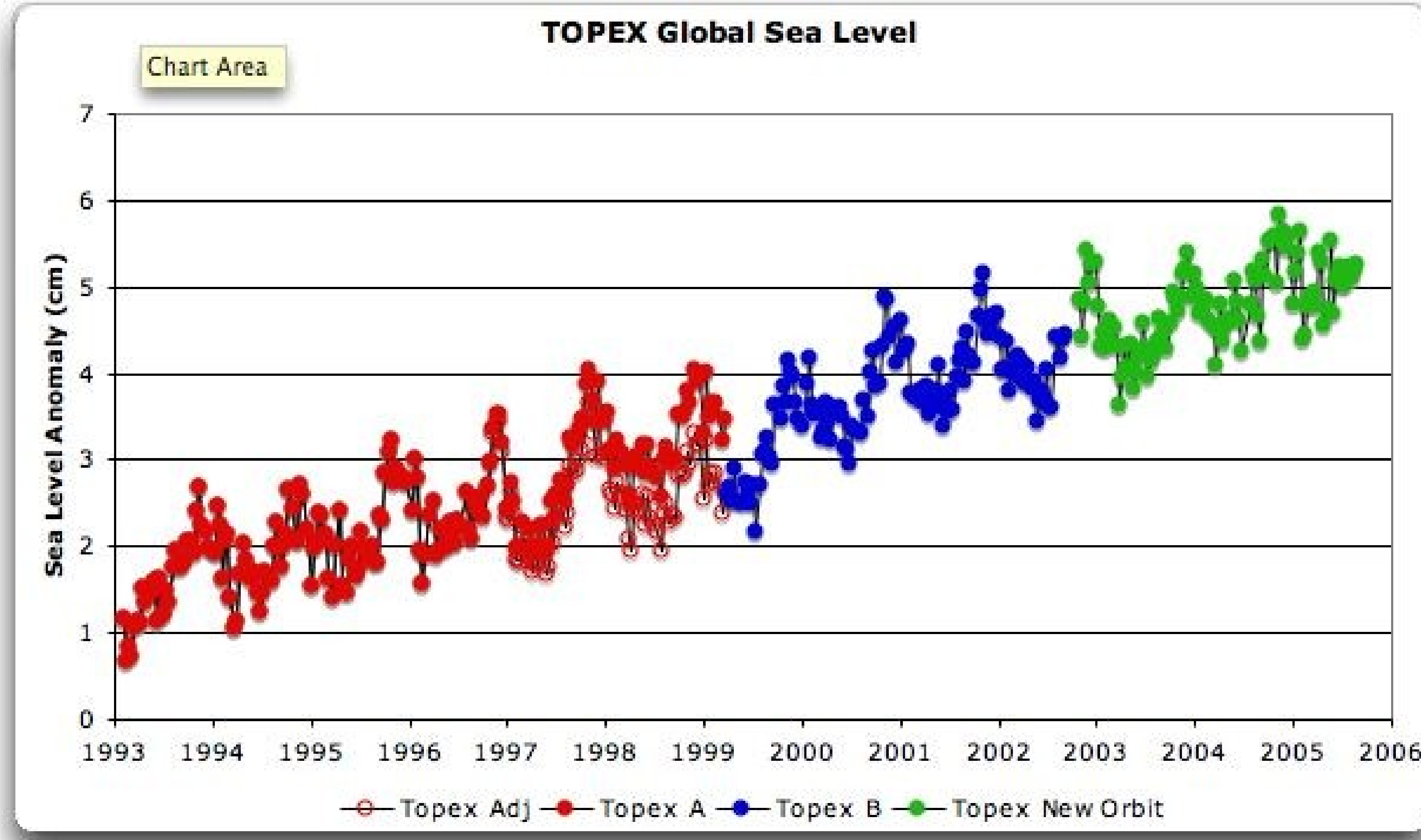



Radar altimetry principle (courtesy NASA)

- Tide gauges – devises for measuring (relative) sea level:
- – long time series (> 120 years),
- – over 1750 stations worlwide
- Radar altimetry measures absolute sea level:
- – last 30 years,
- altimetry satellite missions: GEOS3, SEASAT, GEOSAT, ERS-1, ERS-2, GFO, TOPEX/Poseidon, Jason-1, ENVISAT

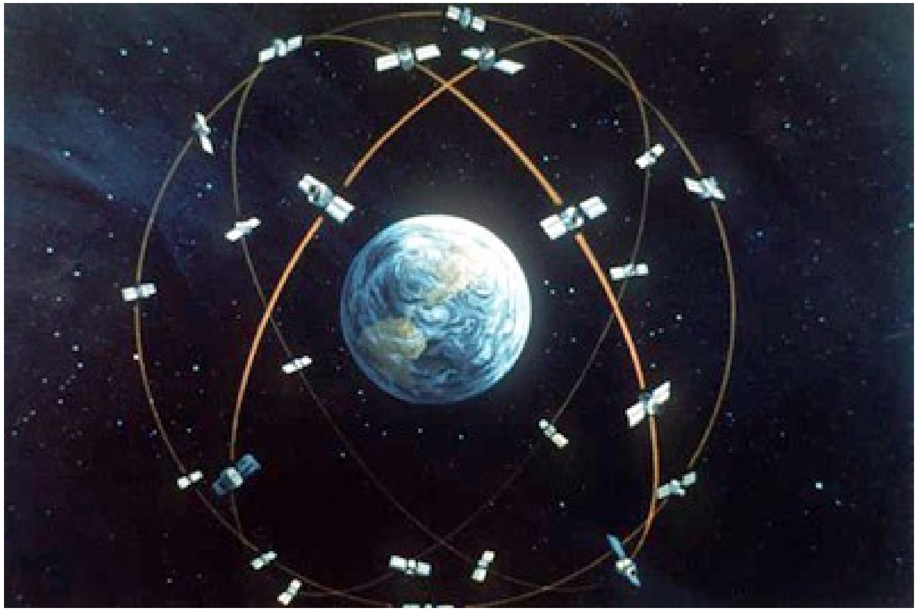
# Global sea level changes from TOPEX/Poseidon






Courtesy S. McIntyre

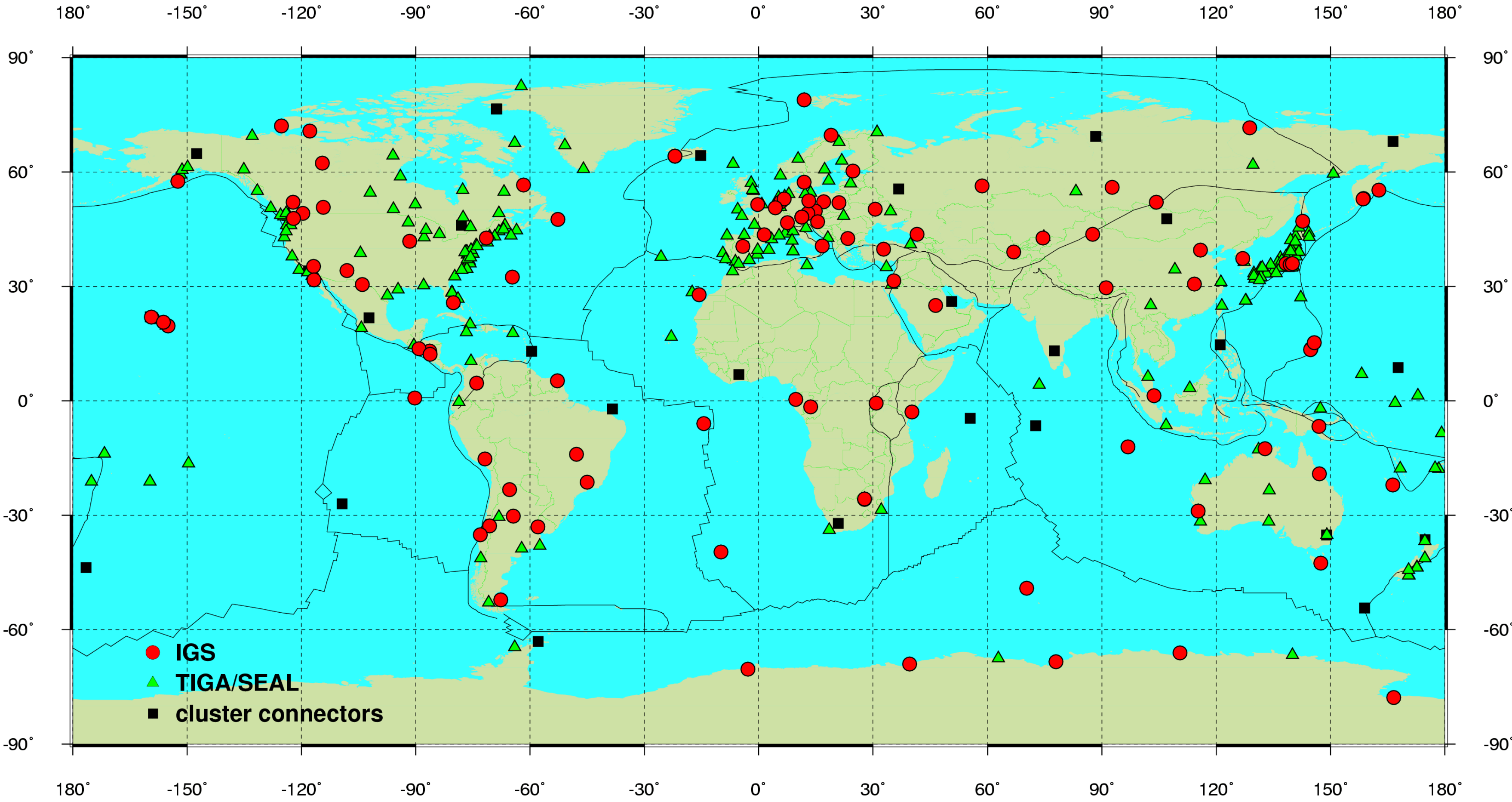
# Global Positioning System (GPS)



Courtesy Solmeta Technology Co., LTD

- 27 Earth orbiting satellites (24 operational, 3 spare)
- 6 orbital plains, altitude ~ 20200 km, inclination ~ 55°
- 1978 – the first development satellite launched
- 1989 – the first operational satellite launched
- Signals: L1 = 1575.42 MHz, L2 = 1227.60 MHz

# GPS network of IGS and TIGA stations



# TIGA Observing Stations (Responsible Agencies)

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- Australian Surveying and Land Information Group (Australia)
- Bundesamt fuer Kartographie und Geodaesie (Germany)
- Department of Survey and Mapping (Malaysia)
- Deutsches Geodaetisches Forschungsinstitut (Germany)
- Finnish Geodetic Institute (Finland)
- Geodetic Survey Division, NRCan (Canada)
- HartRAO Space Geodesy Programme (South Africa)
- Institute of Geological and Nuclear Sciences (New Zealand)
- National Coordination Agency for Surveys and Mapping (Indonesia)
- Technical University of Crete (Greece)
- University La Plata (Argentina)
- University La Rochelle (France)
- Universidad Politecnica de Cataluña (Spain)

# TIGA Analysis Centres

- Geoscience Australia (Australia)
- CTA: The University of Canberra, The University of Tasmania, The Australian National University (Australia)
- Deutsches Geodaetisches Forschungsinstitut (Germany)
- EUREF Subcomission (Belgium)
- GeoForschungsZentrum Potsdam (Germany)
- University La Rochelle (France)

# Why TIGA GPS data reprocessing is necessary?

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- Use of absolute phase centre variations (PCV) instead of relative ones
- More data from TIGA GPS stations became available in the recent years, e.g. from stations in Japan, Great Britain etc.
- Not all TIGA GPS stations were included in the previous GFZ solutions, e.g. some stations in Great Britain, new stations, gaps in time series
- Implementation of new models and algorithms in the EPOS-Potsdam software allows us to get better results
- Use of a new (ITRF2005) reference frame as an a priori one

# The main steps of daily processing

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- Retrieval of data from Data Centres for IGS and TIGA stations
- Restoration of existing IGS products: initial orbit elements, orbit files, clock files, Earth shadow files, yaw attitude files, data cleaning information files (“log files”)
- RINEX-level data pre-processing: data sampling, receiver-dependent corrections, single-station-oriented data editing by removing outliers, detection and repair of cycle slips
- Data cleaning station by station by analyzing residuals from precise point positioning (PPP) analysis using orbit and clock products
- Data cleaning by analyzing the residuals from the network solution
- Ambiguity fixing to resolve integer double-difference ambiguities
- Final network solution with resolved integer ambiguities
- Combination of cluster normal equations to get a daily solution
- Combination of daily normal equations as 3-day normal equation (to stabilize the orbit of GPS satellites) and generation of a weekly SINEX solution

# The main models and algorithms used in TIGA GPS data reprocessing in EPOS-Potsdam PDM7 software

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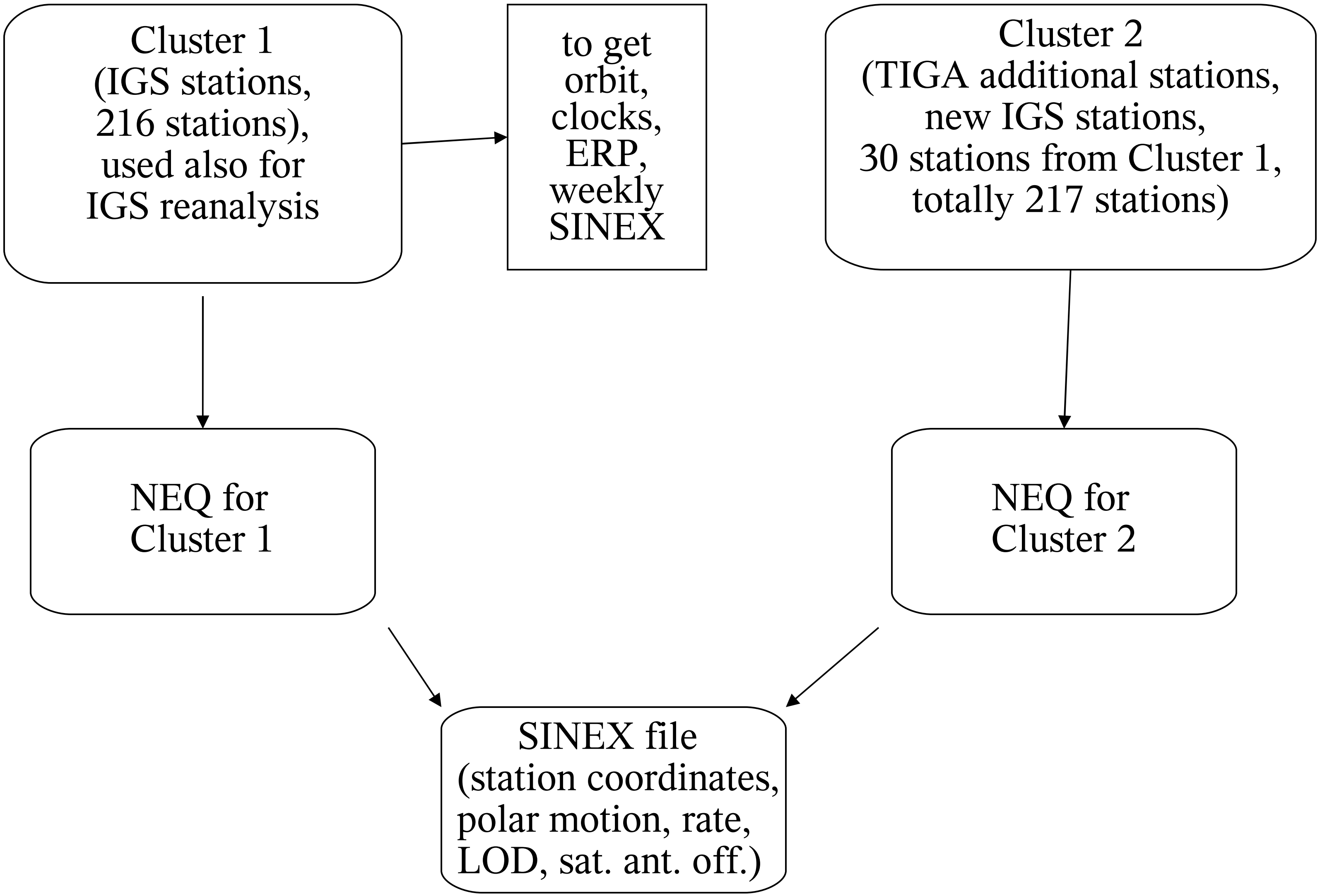
- EIGEN-GL04S1 geopotential model (up to n=m=12), with time variations for C20, C30, C40
- ITRF2005 as a priori reference frame
- IERS Conventions 2003
- FES2004 ocean tide loading model
- IAU2000A nutation model, subdaily nutation
- Earth Orientation Parameters (initial): IERS EOP 05 C04
- Absolute phase centre variation model
- PCV for receiver and satellite, radom calibration: igs05.atx file
- Tropospheric modeling: Global Pressure and Temperature (GPT) model and Global Mapping Function (GMF)
- A new ambiguity fixing scheme (95% versus 80% ambiguities fixed)
- A new data processing strategy for huge GNSS networks (Ge, M. et al., 2006) implemented allowing to process GPS data from a few hundred stations

# Parameterization

| Estimated parameters | Period of estimation, comment |
| --- | --- |
| Satellite clocks | Each epoch (white noise process) |
| Station clocks | Each epoch (white noise process), once clock fixed |
| Orbital parameters | Position and velocity, Cr scale, y-bias, yaw rate, stochastic impulses /day |
| Tropospheric zenith delay | Once per 1 hour |
| Ambiguities | Real value. Integer ambiguity in the final step in global network |
| Station X,Y,Z coordinates | Once per week |
| Satellite antenna offset | Once per day |
| Polar motion, rate, LOD | Once per day |
| Troposphere gradients | In elevation and azimuth: once per 12 hours |

# The general scheme of reprocessing



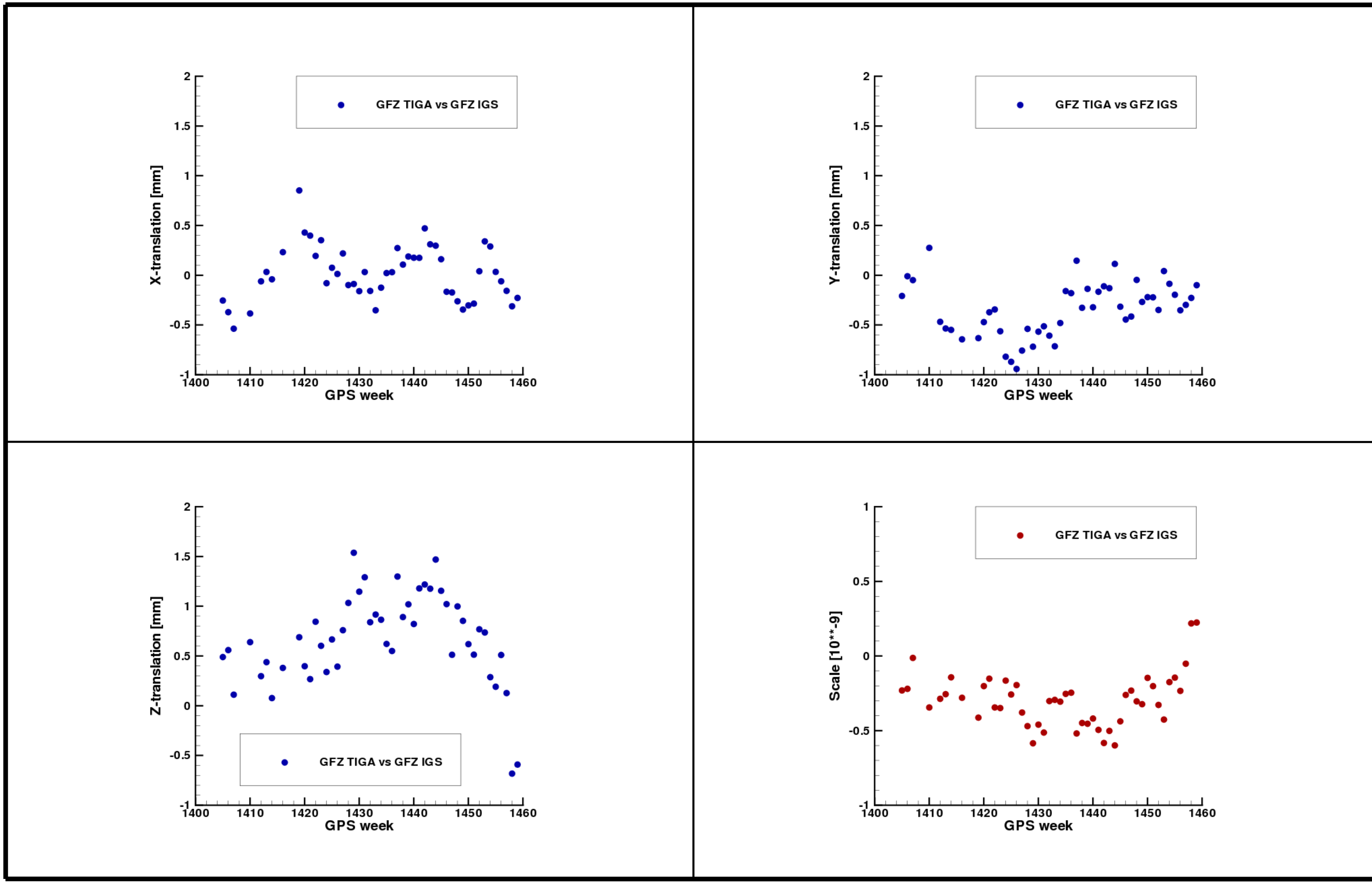
# Parameters present in SINEX files

- Satellite antenna X, Y, Z offset [m]
- Station coordinates X, Y, Z [m] – once a week
- X and Y polar motion [mas] – once a day
- X and Y polar motion rate [mas/d] – once a day
- Delta time UT1-UTC [ms] – once a day
- Length of day [ms] – once a day

# Time span presently processed

- 923 days of the years 2005-2008

# Comparison of weekly station coordinates from GFZ TIGA and GFZ IGS solutions: Helmert transformation parameters



# Comparison of weekly station coordinates from GFZ TIGA and GFZ IGS solutions: Helmert transform. param. (continued)

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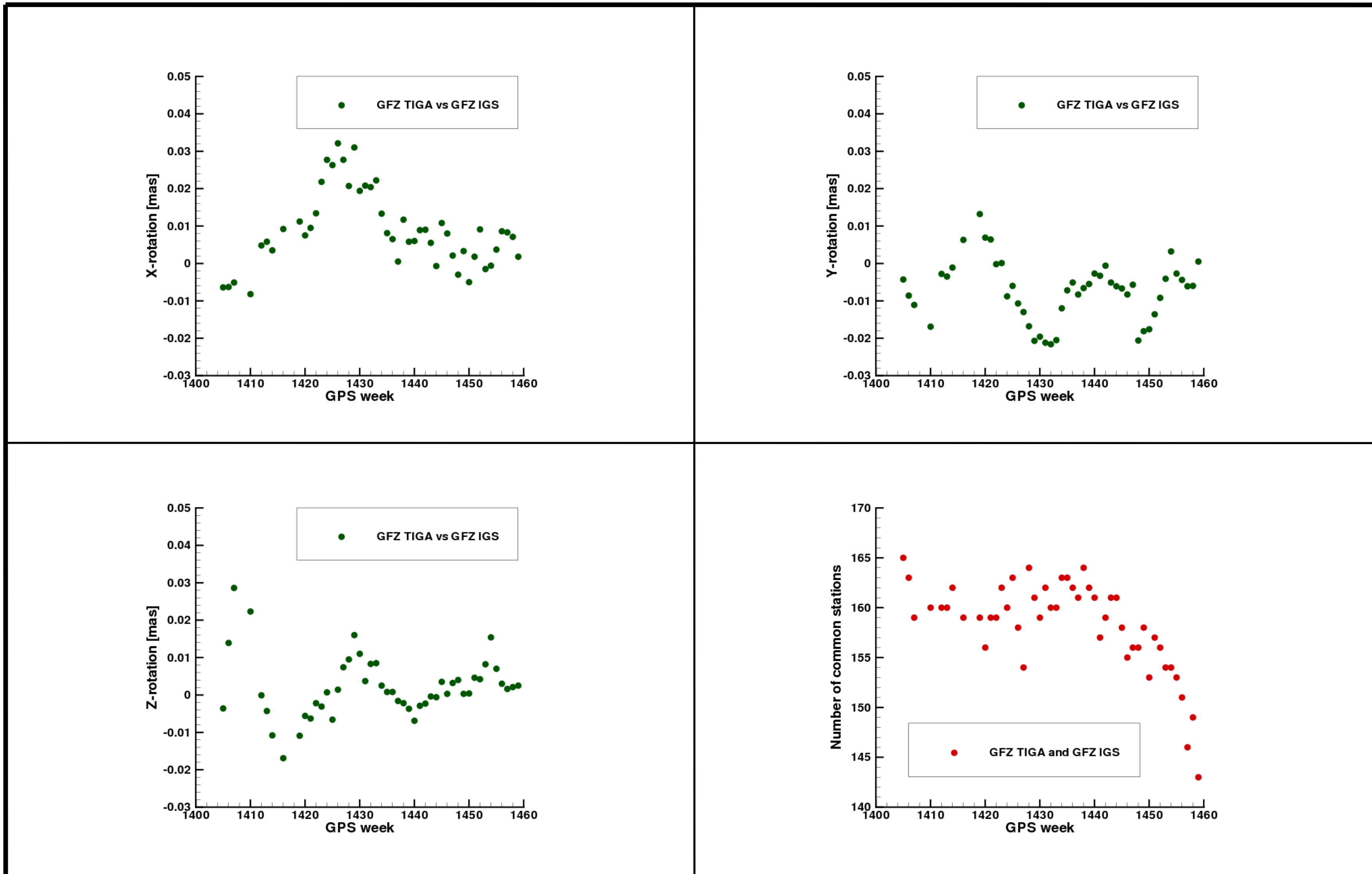
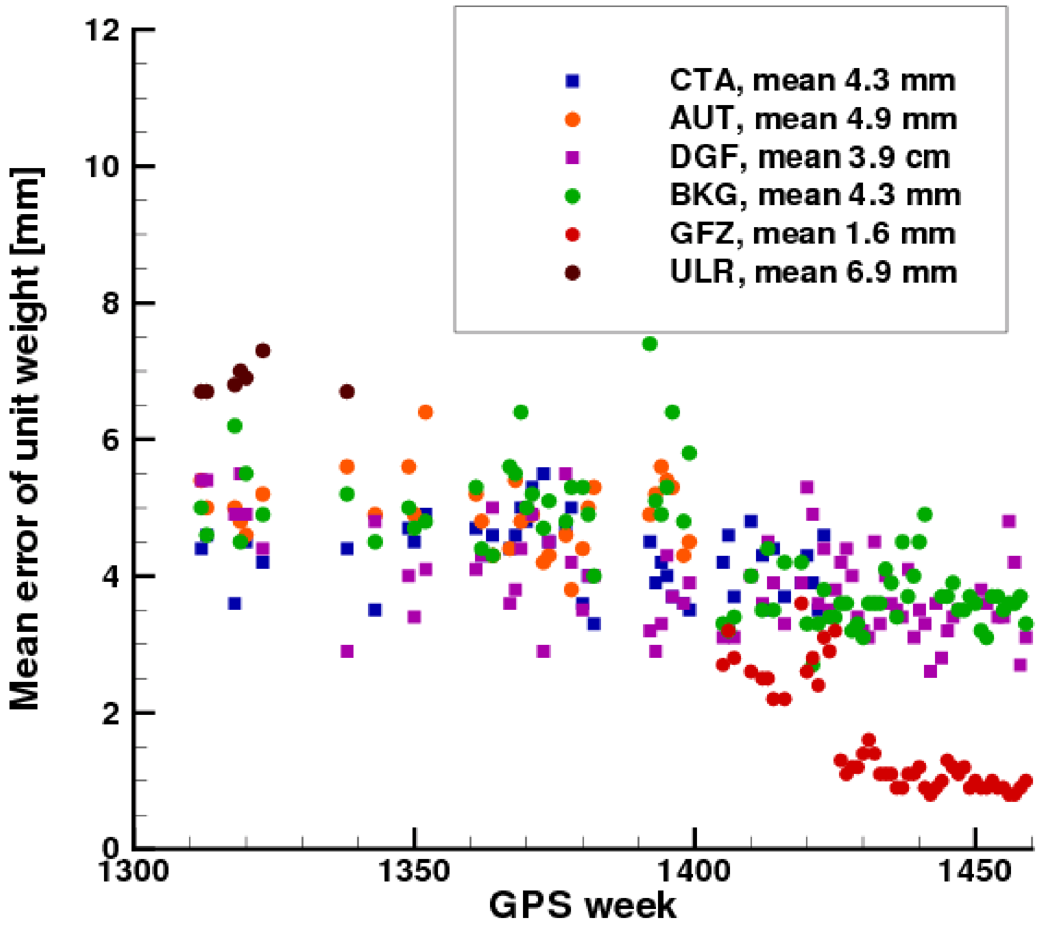


# Availability of reprocessed TIGA solutions (absolute phase center variations used)

| Analysis Centre | From week | Until week | Week number | Station number | Software used |
|---|---|---|---|---|---|
| AUT, Australia | 887 | 1399 | 513 | ~80, regional | Bernese 5.0, CATREF |
| BKG, Germany | 1400 | 1465 | 65 | ~40, regional | Bernese 5.0 |
| CTA, Australia | 1201 | 1423 | 218 | ~80, global | GAMIT/GLOBK |
| DGFI, Germany | 1043 | 1459 | 414 | ~60, regional | Bernese 5.0 |
| GFZ, Germany | 1312 | 1459 | 82 | 403, global | EPOS PDM7 |
| ULR, France | 992 | 1341 | 308 | 223, global | GAMIT/CATREF |

# Comparison of weekly station coordinates from GFZ TIGA solution and solutions of other TIGA Analysis Centres and GFZ IGS solution



# Conclusions

- The GPS network processed by the GFZ TIGA Analysis Centre was extended by 31 new stations leading to totally 403 GPS stations
- EPOS-Potsdam PDM7 software was updated to include new models and algorithms
- GPS data from ~360 GPS stations have been processed for 923 days at the time span from January 1, 2005 till February 13, 2008 using EPOS-Potsdam PDM7 software
- 82 weekly SINEX files are available for GPS weeks 1312 – 1459 with some gaps
- The station coordinates from our (GFZ TIGA) solution have been compared with the station coordinates derived by GFZ Analysis Center of IGS at GPS weeks 1400 – 1459: mean error of unit weight is 1.6 mm
- The station coordinates from our solution have been compared with those from the solutions of 5 other TIGA Analysis Centres: mean error of unit weight is 3.9 – 6.9 mm
- GFZ TIGA reprocessing is ongoing

# References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