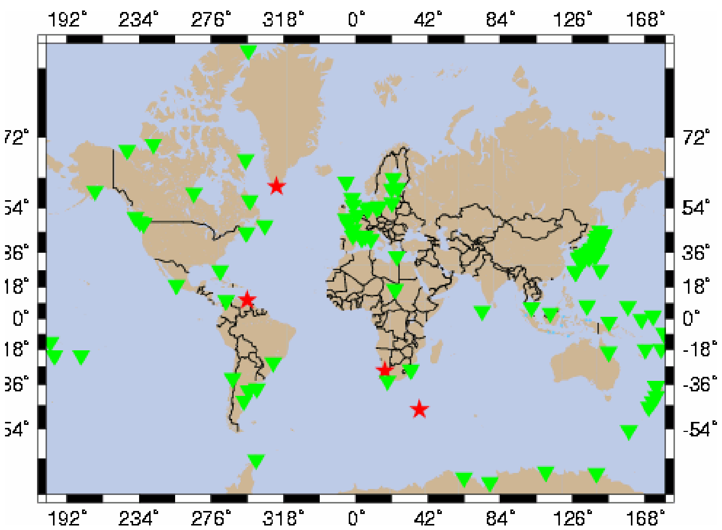
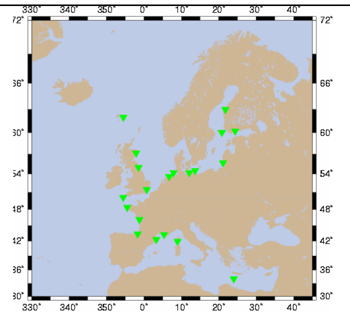
Status of TIGA, June 2007

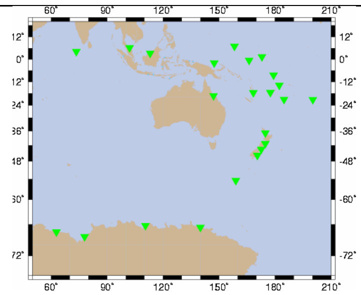
TIGA Observing Stations (network)

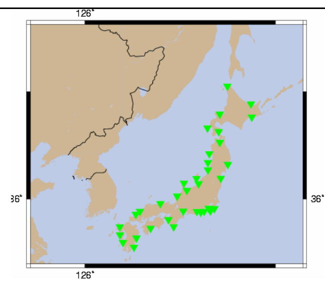
The number of stations contributing to TIGA remains constant. About 100 stations currently have submitted site information. The network is lacking sufficient coverage in large parts of the world. Currently TIGA members are involved in the (technical) densification of the network in Africa parts of the Indian Ocean, which will result in a regional densification.



Map of TOS (green triangles) where the complete information is available. Red stars are proposed, but not yet installed. Also the situation around the Indian Ocean will improve due to UNESCO/IOC efforts to install an Indian Ocean Tsunami Warning System.







Tide Gauge data is stored at sea level Services (e.g. PSLMS, UHSLC, NTF). GPS data is distributed to dedicated data centers; however, not all of the stations are providing data continuously. Dedicated data centers are at the University of La Rochelle and CDDIS.

Recently the GLOSS office at IOC requested its member states and individual experts to submit cGPS@TG stations, but so far no feedback (except for some personal communications) arrived. Also recently for GLOSS an update about cGPS@TG was made available by Guy Wöppelmann (see http://www.sonel.org/stations/cgps/surv_update.html).

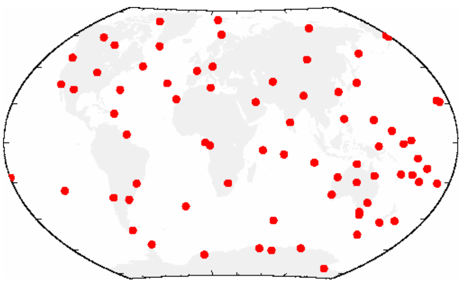
TIGA Analysis Centers

Currently six TIGA analysis centers are processing GPS data of TIGA stations. This is done on a best-effort basis. Only EUREF is providing a short-latency solution on a regular basis. All other centers are providing their solutions in batches on different intervals.

With the switch of the IGS to absolute phase center variations, the solutions submitted so far became outdated. The corresponding files have been removed from the TIGA-FTP server. A survey among the TAC's about the provision of updated solutions gave positive feedback. So it was decided to switch the processing strategy to using absolute phase center variations. So far, reprocessed solutions have been already provided by Deutsches Geodätisches Forschungsinstitut, Geoscience Australia, and University of La Rochelle. EUREF provides a short latency solution; recent solutions are passed on absolute PCV's. The CTA-TAC announced the provision of a reprocessing; GFZ has started to process TIGA data as well.

Individual TAC reports are provided below. Recently University Newcastle offered to contribute to the TIGA goals as well. The report is attached as an external contribution.

Australian Universities (ANU, Canberra, and Tasmania)



The Australian Universities analysis center consortium was established in 2002 initially to process GPS data from sites co-located with tide gauges only in the Australasian region. In 2007 we have commenced processing global data, using 2 x 40 station interwoven networks. The data analysis is performed using the GAMIT/GLOBK software (King and Bock, 2007; Herring, 2005).

Significant effort has been made to incorporate new models into the GAMIT software in order to achieve the highest possible accuracy, especially in the vertical component. We use the VMF1 mapping function (Boehm et al., 2006) interpolated from a global grid, with a priori zenith hydrostatic delays derived from ray-tracing through the ECMWF numerical weather model. The wet tropospheric delay is modelled as a piecewise linear function with knots every hour, and one N/S and E/W gradient per day. GPS satellite orbits were estimated using a 15 parameter orbit model (position, velocity, direct, y- and b-bias plus 1/rev parameters for each perturbing parameter), using IGS final orbits as a priori values. Atmospheric pressure loading deformation is accounted for at the observation level (Tregoning and van Dam, 2005). Station-dependent, elevation-dependent weighting was applied and we used the absolute satellite transmitter and antenna phase centre variation models.

The analysis is performed on the 128-node linux cluster at ANU. We have chosen to commence our analysis with data from 2000 onwards, since data prior to 2000 recorded by turborogue receivers prior to a firmware upgrade lacks significant numbers of observations below 20 degrees (Tregoning et al., 2004). To date, daily solutions from 2000-2007.4 have been computed and are currently being combined into loosely-constrained weekly SINEX solutions for inclusion in TIGA combination solutions.

Deutsches Geodätisches Forschungsinstitut (DGFI)

DGFI contributes to the TIGA project of the International GNSS Service (IGS) by operating permanent GPS stations at six tide gauges and by processing a network of about 60 GPS stations covering the entire North and South Atlantic Ocean. It contains also a few sites along the Pacific Ocean coastline, where the vertical datum of some Latin American countries is realized. In addition to the coastal sites, a number of IGS global stations are included in order to improve the geometry of the network, and to serve as fiducial points for realizing the reference frame. The selected reference stations are included in the IGS Reference Frame 2005 (IGS05) and their selection is based on their geographical distribution and on the accuracy of their velocities in the ITRF2005 solution. The regional stations (i.e. those that are not included in the global IGS network) belong to the permanent networks of the European Reference Frame (EUREF) and of the Reference Frame for the Americas (SIRGAS). The analysis strategy is based on the double difference approach and the Bernese GPS Software Version 5.0 is used for the daily data processing. The main characteristics of which are: The elevation mask and the data sampling rate are set to 3° and 30 s, respectively.

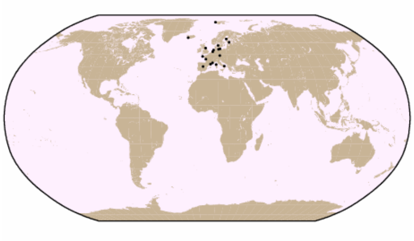
The absolute calibration values for the antenna phase centre corrections published by the IGS in November 2006 are applied. In this step, the radomes covering the antennae are taken into account. Satellite orbits, satellite clock offsets, and Earth orientation parameters are fixed to the final IGS solutions. The earlier orbits are transformed from ITRF97 or ITRF2000 to ITRF2005. The quasi ionosphere free (QIF) strategy is applied for solving the L1 and L2 phase ambiguities. The applied *a priori* ionosphere models correspond to the daily global ionosphere maps (GEM) derived at the CODE analysis centre. The periodic site movements due to ocean tide loading are modeled according to the FES2004 ocean tide model. The zenith delay due to the tropospheric refraction (wet part) is estimated at a 2 hour interval within the network adjustment. The *a priori* delay values (dry part) correspond to the Niell model. No gradients are taken into account. The free normal equations obtained from the daily network adjustments are combined to generate free weekly solutions, which are provided to the TIGA Associated Analysis Centres (TAAC) and to other users through SINEX files at the web site http://adsc.gfz-potsdam.de/tiga/index_TIGA.html.

At present, SINEX files for the GPS weeks 1096 (January 2, 2000) until 1411 (January 21, 2007) are available. The analysis for the coming weeks (after 1411) will routinely be carried out.

A multi-year solution (DGF07P01_TIGA), based on the accumulation of more than 2500 daily free network normal equations, has been computed. The possible discontinuities or systematic effects to be modeled in the combination are pre-analysed by generating time series of stations coordinates. Stations with short time series (less than 2 years) were excluded. The epoch coordinates and velocities for all stations are estimated defining the geodetic datum by constraining ten IGS stations of the IGS05 network to their *a priori* values. The obtained coordinate time series and vertical velocities are compared with those derived from tide gauge registrations in order to distinguish secular sea level variations from vertical crustal movements. Since the reference surface (the zero height level) of the classical height datum is realized by the mean sea level measured at different fixed periods, the combination of these two kinds of data (continuously GNSS positioning + tide gauge records) with satellite altimetry is useful to reduce the different levels to the same reference epoch, and consequently, it allows the consistent unification of the existing height datums in a global vertical reference system. It should be mentioned that at the coastal sites, the distance between the tide gauge and the GPS station has not been taken into account because the local ties (and their variation with time) between tide gauge benchmarks and GPS antennae are not known at all stations. So, we assumed that the difference between the vertical displacements of these relatively closed observation points (tide gauge and GNNS site) are under the mm-level per year. Please see:

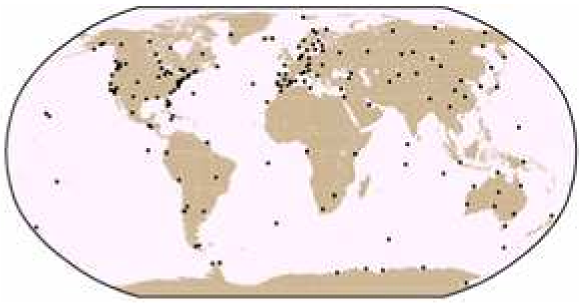
Sanchez L., Krügel M. (2006). The role of the TIGA project in the unification of classical height systems. Presented at the International IAG/FIG Symposium on "Geodetic Reference Frames", GRF 2006, 9-14 October 2006. Munich, Germany. (In press).
Sánchez, L. (2007). Vertical motion control of tide gauges in the Atlantic as a part of the TIGA Project. To be presented at the IUGG General Assembly, Joint Symposium JGS002: Global sea-level change: Altimetry, GNSS and tide gauge measurements, July 2 – 13, 2007. Perugia, Italy.

EUREF



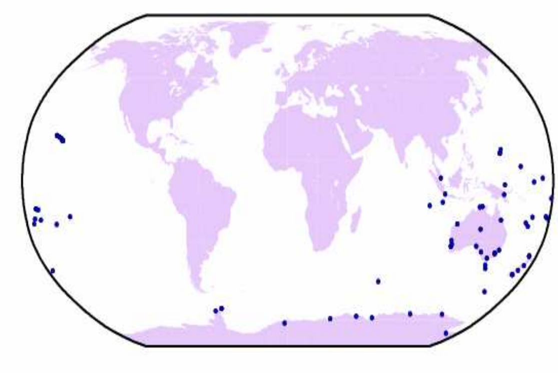
- Latest submission: GPS week 1422
- Based on IGS05/ITRF2005 coordinates
- Absolute phase center variations since GPS week 1400 (change with IGS)

GeoForschungsZentrum Potsdam (GFZ)



Current processing stopped at GFZ TIGA Analysis Center in March 2005 due to man-power restrictions and was resumed in February 2007, since man-power became available. GFZ processes GPS data from about 370 stations, about 180 of which are TIGA observing stations. Presently, positions of TIGA stations are available for GPS weeks 785 – 1430 (up-to-date) with some gaps in year 1997 using GFZ "EPOS Potsdam-6" software using relative phase center corrections and for GPS weeks 1411 – 1430 using the latest version of GFZ "EPOS Potsdam-7" software using absolute phase center corrections in the ITRF2005 reference frame. The processing is performed in the same way as by the GFZ IGS Analysis Center. The formal RMS errors of 1-D station coordinates are about 7 mm. The preparation for backward reprocessing TIGA data for the period from 1994 till 2007 using "EPOS Potsdam-7" software is currently underway. It is planned to perform reprocessing twice until the end of 2007. Cleaned GPS data obtained during routine processing will be used in the first reprocessing using the new software and models. A study has been performed to find gaps in TIGA station coordinate time series and missing stations. More GPS data from some missing stations and time spans will be used during the second reprocessing. Data cleaning will be performed in this case from the very beginning. It is planned to process data from as many TIGA stations, as possible. The current activities are supported within third-party funded project "GEOTECHNOLOGIEN".

Geoscience Australia



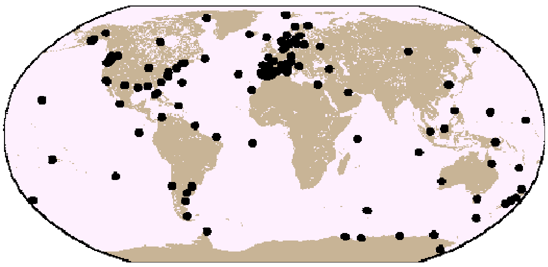
The Geoscience Australia (GA) TIGA pilot project data and analysis centre was established in 2001. Since then 11 new CGPS stations were installed at and near tide gauges for South Pacific Sea Level and Climate Monitoring Project (SPSLCMP, http://www.ga.gov.au/geodesy/slm/spslcmp).

Another 7 CGPS stations adjacent to tide gauges exist in Australia and its territories including Antarctica. They are part of Australian Regional GPS Network (ARGN) and were installed between 1992 and 1995.

The centre processes the GPS data from more than 70 sites from a regional network including Southeast Asia, Australia, South Pacific, New Zealand and Antarctica. The data processing is performed using Bernese software version 5.0 (Dach et al. 2007) for daily solutions and weekly combined solutions with 7 parameters minimum constraint to IGb00 and recently IGS05 reference frames. Further CGPS time series analysis is performed using CATREF software (Altamimi et al. 2004) and CATS software (Williams 2003). All data (1997-present) were reprocessed using absolute antenna phase centre corrections for both GPS satellites and receivers (e.g. Ge et al. 2005, Gendt 2005). The centre contributed to the TIGA pilot project by providing weekly solutions (from 1997 to present).

In next 3 years Geoscience Australia will install another 12 CGPS stations at and near the tide gauge sites for the Australian Baseline Sea Level Monitoring Array Project (ABSLMAP, http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml) which have no existing CGPS stations. The centre will further improve its solutions by using a global network with some improved strategies such as the new troposphere mapping functions (Boehm et al. 2006).

University La Rochelle (ULR)



The ULR analysis center consortium was established in 2002 to process GPS data from stations at or close to tide gauges. It contributes to the TIGA pilot project since October 2002 by providing weekly solutions with 460 days latency. The data analysis is performed using: (i) GAMIT software (King and Bock 2005) for processing on a free network approach the GPS measurements that are split into several global clusters, each with at most 50 stations and (ii) CATREF software (Altamimi et al. 2004) for combining the cluster solutions into daily solutions, and then into weekly solutions. Wöppelmann et al. (2004) present the rationale for the ULR analysis consortium and provide details on the initial processing strategy.

Studies were carried out to investigate the best strategy to implement the terrestrial reference frame and to align the station position solutions at the millimeter level (Wöppelmann et al. 2007a). The results led to an extension of the GPS stations processed at ULR to include the 92 IGb00 reference frame stations of the IGS (IGSSTATION-352, Ferland 2005). The ULR processing infrastructure is now coping with a network of up to 223 GPS stations. In parallel, major advances were made in absolute antenna phase centre corrections for both GPS satellites and receivers (e.g. Ge et al. 2005, Gendt 2005). Both the network extension and the new antenna model corrections encouraged ULR to reprocess backwards the GPS data. The reprocessing started in January 2006. Weekly SINEX solutions with the new strategy have satisfactorily been processed from 1999.0 up to 2005.7 (GPS weeks 0992 to 1341), replacing the former solutions which covered the period 1997.0 to 2004.0 (GPS weeks 0887 to 1250). The new strategy also includes the troposphere GMF mapping function from Boehm et al. (2006), as well as the atmospheric pressure loading corrections from Tregoning and van Dam (2005).

In addition ULR has carried out analyses to assess the quality of its solutions, and to construct coherent time series of station positions. An exercise of combining tide gauge and GPS results was undertaken for the World Climate Research Program workshop on "Understanding Sea-level Rise and Variability" which took place in June 2006, in Paris (Wöppelmann et al, 2006). The idea was to reproduce Douglas (2001) and Peltier (2001) analysis by using GPS land motion estimates instead of the glacio-isostatic adjustment (GIA) corrections to derive GPS-corrected tide gauge trends. The results were quite encouraging. They showed that GPS corrections reduce the dispersion of sea-level trends, either regionally and globally, compared to GIA corrections. The results are now published in Wöppelmann et al (2007b)

The reprocessing of 6.7 years of GPS data took 8 months with the computer facilities currently available at ULR. Solutions are being investigated to enhance the computing facilities in order to reduce the GPS processing time. This is a key technical issue for future backwards reprocessing of the entire GPS data set that is now available, when new models are available or new strategies are devised. National fundings have been asked to enhance the processing capabilities (CPER 2007-2013), and to support the PhD thesis that has started in January 2007 at IGN/LAREG to investigate and improve the GPS analysis strategy at the ULR consortium (GRGS/TOSCA 2008). We expect to start a fully consistent reprocessing of the entire GPS data set again at the end of 2007. Feissel et al (in press) indeed outline the importance and the benefits of a fully consistent GPS reprocessing: the noise level in the station position time series then drops to the VLBI level in horizontal and to the SLR level in vertical, with most time series showing a white noise instead of the usual flicker noise.

University of Newcastle, Newcastle upon Tyne, UK (external contribution)

Newcastle University (UK) has recently been funded by the Natural Environment Research Council (UK) to investigate 20th C sea level rise based on a new GPS reprocessing project. The entire TIGA and IGS time series will be reprocessed in updated GIPSY software. The project will commence in September 2007 and run until December 2010 in the first instance. In brief the project components relating to TIGA involve:

- The global reprocessing of GPS data from several hundred sites from the early 1990s until present
    - Joint Newcastle/NASA JPL GIPSY/OASIS observation model development
    - Data reanalysis at Newcastle University, including data from several hundred sites as archived in IGS, TIGA and national archives
    - Reference frame realisation at Newcastle University
    - Noise characteristics of reprocessed GPS time series at the Proudman Oceanographic Laboratory
- Use of improved GPS vertical rates to improve corrections for TG vertical motions at the University of Southern Florida and Newcastle University

Parallel efforts are already underway to perform global reprocessing in GAMIT, including the implementation of models of higher order ionospheric effects in GAMIT. The GAMIT reanalysis will have a smaller scope and different focus to the GIPSY analysis, but both data sets will be available in SINEX format.

Matt King (http://www.staff.ncl.ac.uk/m.a.king/)

TIGA Combinations of individual solutions

As reprocessed TIGA AC solutions using the new absolute modeling for antenna phase center variations became available for some ACs, the comparison and combination studies focused on these solutions, namely AUT, ULR and DGFI. The time span considered is about eight years of data and lasts from GPS week 0992 (i.e., January 10, 1999) until 1399 (i.e., November 4, 2006) because a minimum number of two contributions are available only for this period. For the GPS weeks 0992 until 1095 only AUT and ULR were combined, from 1096 until 1341 solutions from all three Analysis Centers are available, and only AUT and DGFI contribute to the combined solution for the weeks 1342 until 1399.

At present, the analysis of the individual contributions and the computation of a combined solution are done on a weekly basis instead of multi-year solutions. The computations are done with the Bernese GPS Software version 5.0. For the contributions by AUT and DGFI it is possible to derive datum-free normal equation systems from the information provided in the SINEX files. Unfortunately, this is not possible for the files provided by ULR as only the solution itself (i.e., estimated parameters and their variance-covariance matrix) is stored in SINEX, whereas the a priori information and the statistical information are missing. Therefore, seven Helmert parameters (three translations, three rotations and one scale parameter) were set up in the combination. The weekly combined solutions are aligned to the IGS realization of ITRF2005 using no-net-rotation and no-net-translation conditions for the IGS reference frame stations.

Based on the weekly solutions, detailed analysis of the coordinate time-series in view of detecting jumps in the time-series still has to be done. After finalizing these analyses, a multi-year solution will be computed in order to derive a terrestrial reference frame for TIGA.

Chairman's activities

The Chairman is involved in the installation of tide gauges and GPS in Indonesia and around the Indian Ocean. Efforts have been made to include stations of the future IOTEWS system to TIGA. A report was presented to the UNESCO/IOC meeting of GLOSS/GE (June 2007) (see http://www.ioc-goos.org/index.php?option=com_oe&task=viewEventDocs&eventID=104). The TIGA web page was updated.

Discussion with ESEAS was continued about the inclusion of a set of their stations into the TIGA solution. The discussion will be continued with the TIGA analysis centers.

Points for discussion (for the GB meeting in Perugia)

Within the IAPSO Commission on Mean Sea Level and Tides there is an ongoing discussion about a dedicated meeting about GPS at Tide Gauges and TIGA. The GB is kindly asked to support such a meeting.

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Tregoning, Paul; Australian National University, Australia (CTA)

Wöppelmann, Guy; University of La Rochelle, France (ULR)