DVW – Gesellschaft für Geodäsie,
Geoinformation und Landmanagement e.V.

Arbeitskreis 3 „Messmethoden und Systeme"

GNSS 2017 – Kompetenz für die Zukunft

**Beiträge zum 157. DVW-Seminar am
21. und 22. Februar 2017 in Potsdam**

Schriftenreihe des DVW
Band 87 / 2017

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Redaktion:
Michael Mayer
Alexander Born

Herausgegeber:
DVW – Gesellschaft für Geodäsie, Geoinformation und Landmanagement e.V.

Schriftenreihe des DVW
Band 87
Wißner-Verlag

The IGS Real Time Service

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1 Introduction

In April 2013, the International GNSS Service (IGS) has formally launched the IGS Real Time Service (RTS). This consists of GNSS data and products that are streamed from IGS data centres and are openly available to subscribed users with latencies of a few seconds.

The RTS is a collaborative effort from a large number of participating organisations and is provided on a "best efforts" basis, without any guarantees on performance, availability or user support. However, the service has been designed with a number of redundancies to maximise availability and minimise outages.

The IGS is an operational scientific service of the International Association of Geodesy and one of several services contributing to the Global Geodetic Observing System (GGOS). Data and products generated by the RTS contribute to the natural hazards theme within GGOS. Other applications for the service include GNSS constellation performance monitoring, weather forecasting and space weather monitoring.

This article is intended to inform about the IGS-RTS. The following topics will be discussed:

- a brief history of the evolution of the service,
- the IGS real-time infrastructure components of the RTS,
- user access to the data and products,
- the monitoring aspects of the service and typical results.

2 Historical Background

The development of the RTS has followed the traditional stages of development for a new IGS service. First, a working group was formed with responsibility for all real-time (RT) activities. In the second stage, the Real-Time Working Group initiated a pilot project and, on successful completion of the project, it recommended to the IGS Governing Board its readiness to launch an operational service.

The IGS Real-Time Working Group (RTWG) was established in 2001 with the goal to design and implement real-time infrastructure and processes for the delivery of real-time data to analysis centres, and the dissemination of real-time products to users. The working group's direction was set at the IGS workshop held in Ottawa in the spring of 2002, titled "Towards Real Time". At that time, the design for a prototype real-time service was adopted.

In June 2007, the IGS announced a Call for Participation in the IGS Real-Time Pilot Project with a three-year target to accomplish the following goals:

- manage and maintain a global IGS real-time GNSS tracking network,
- enhance and improve selected IGS products,
- generate new real-time products,
- investigate standards and formats for real-time data collection, data dissemination and delivery of derived products,
- monitor the integrity of IGS predicted orbits and the GNSS status,
- distribute observations and derived products to real-time users, and support Network DGPS/RTK operations,
- encourage cooperation among real-time activities, particularly in IGS densification areas.

In 2009 the pilot project was extended to March 2011, and in August 2011 the working group declared that the pilot project had reached the additional goal of Initial Operational Capability (IOC) and that it would be recommending to the IGS Governing Board the launch of an official Real-Time Service. The RTS was announced as operational in April 2013 with the release of a web site (www.igs.org/rts) containing links for user registration and extensive information on how to access the service.

3 RTS Infrastructure

3.1 Formats and Standards

Stemming from the recognition that RT services rely on the development of open standards and data formats, the IGS community has teamed up with the Radio Technical Commission for Maritime Services (RTCM), who are responsible for developing standards for differential GNSS applications. Over the course of the last eight years, this forum, which brings together GNSS service providers, users and receiver manufacturers, has made significant progress in:

- developing new multi-GNSS standards for RT high precision observations and for broadcast ephemeris dissemination,
- agreeing to standards for RT orbit and clock correction messages for GPS and GLONASS in state space representation (SSR) format (orbit and clock corrections),
- aligning the IGS RINEX format for batch data and ephemeris messages with the RTCM Real Time formats, aided by the formation of a joint IGS/RTCM

RINEX working group with overall responsibility for the RINEX format development.

Significant challenges still remain, particularly in the area of SSR correction format development to cover the remaining constellations and to provide a mechanism for disseminating phase biases and corrections needed for PPP integer ambiguity resolution.

The RTS products are all provided using the RTCM standard. Observation streams use both the older RTCM 3.1 (RTCM 10403.1) formats for GPS and GLONASS and the newer RTCM 3.2 (RTCM 10403.2) standard that defines multi-signal and multi-constellation messages. Product streams for GPS and GLONASS use the SSR RTCM format which is defined in RTCM 3.2. The SSR formats for the other constellations have not yet been finalised, but some Analysis Centres are providing products based on a draft version of the standard. Dissemination is via Network Transport of RTCM by Internet Protocol (NTRIP). The NTRIP protocol has been developed by the German Federal Agency for Cartography and Geodesy (BKG) and is defined in RTCM standard 10410.1.

3.2 Network Infrastructure

The RTS network comprises a number of globally distributed real-time stations which transmit their observations to data centres operating NTRIP casters. IGS casters that allow user access are operated by the IGS Central Bureau at JPL, by BKG in Germany and by the NASA Crustal Dynamics Data Information System (CDDIS). Some stations send their data directly to the IGS casters but the majority transmit to regional casters operated by their host agency. In this case the IGS casters access the regional casters in order to relay the station data.

Fig. 1 illustrates the distribution of real-time tracking stations in the IGS network. The network is currently made up of over 200 GNSS receivers maintained by a wide variety of local and regional operators. They deliver one Hertz observations to real-time data centres with typical latencies of three seconds or less, along with ephemeris data that are refreshed every ten seconds.

The operational network is using RTCM 3.1 messages and provides GPS or GPS+GLONASS observations. A parallel network, formerly part of the IGS Multi-GNSS Experiment (MGEX), allows experimentation with data from all available GNSS constellations (GPS, Galileo, GLONASS, BeiDou, QZSS and SBAS) using RTCM 3.2 messages. In this network, the majority of the streams are received in receiver proprietary binary formats at BKG and converted to RTCM for dissemination. Multi-GNSS streams are not used in the operational service unless they are provided in RTCM format directly from the station receiver.

Fig. 1: GNSS tracking stations in the IGS real-time network

Global coverage is essential for the success of the RTS, and the presence of redundant stations in geographical regions enhances the reliability of data available from these regions. This goal has been a challenge in some areas of the globe, for example the South Pacific or large parts of Asia.

IGS station operators are required to adhere to a minimum set of standards and are encouraged to adopt best practices for real-time operations. Examples of best practices are:

- Real-Time data should be transmitted to a minimum of two separate real-time data centres.
- Stations that contribute to the realisation of the IGS reference frame should be operated in real-time in order to guarantee a reliable alignment of the real-time products to a stable reference frame.

3.3 Analysis infrastructure

The analysis infrastructure includes a number of individual Analysis Centres (AC) which process the RT observations and compute epoch-wise orbit and clock products. These are formatted using RTCM SSR encoding software and transmitted to the NTRIP casters at the IGS data centres. Orbit products are available either with respect to the satellite centre of mass (CoM) or the antenna phase centre (APC). The clock products are transmitted with an update interval of five seconds. The AC streams and NTRIP mountpoint designations are listed in Tab. 1.

Tab. 1: RTS analysis centre products

Centre	Description	NTRIP Mountpoint
BKG	GPS and GPS+GLONASS orbits and clocks using IGU orbits (CoM/APC)	CLK00/10 CLK01/11
CNES	GPS+GLONASS orbits and clocks based on IGU orbits (CoM/APC) GPS+GLONASS+GAL+BEI orbits and clocks (CoM/APC)	CLK90/91 CLK92/93
DLR	GPS orbits and clocks based on IGU orbits (CoM/APC) GPS+GLONASS orbits and clocks	CLKC0/A0 CLKC1/A1
ESOC	GPS orbits and clocks using NRT[1] batch orbits every hour which are based on IGS batch hourly files (CoM/APC) GPS orbits and clocks using NRT batch orbits every hour which are based on RINEX files generated from the RT streams (CoM/APC)	CLK50/51 CLK52/53
GFZ	GPS orbits and clocks and IGU orbits (CoM/APC)	CLK70/71
GMV	GPS+GLONASS orbits and clocks based on NRT orbit solution (CoM/APC)	CLK81/80
NRCan	GPS orbits and clocks using NRT batch orbits every hour (APC)	CLK22
WUHAN	GPS orbits and clocks based on IGU orbits (CoM/APC)	CLK15/16

The coordination of the Analysis Centre activities is the responsibility of the Real Time Analysis Centre Coordinator (RTACC). This role has been fulfilled by ESOC since the start of the Pilot Project in 2008. The RTACC is responsible for monitoring the individual AC streams and for generating and assessing the quality of combined real-time orbit and clock products.

Tab. 2 shows combined product streams available within the RTS. Both a single epoch combination product developed by ESOC and a Kalman Filter combined product, developed collaboratively by BKG and Czech Technical University (CTU), are available. A GPS+GLONASS Kalman Filter combined product has also been developed at BKG and CTU.

1 Near Real-Time

Tab. 2: RTS combination products

Centre	Description	NTRIP Mountpoint
ESOC	RT GPS epoch combination from NRCan, BKG, CNES, DLR, ESOC, GMV and GFZ streams	IGS01 (APC) IGC01 (CoM)
BKG	RT GPS Kalman-generated combination from NRCan, BKG, CNES, DLR, ESOC, GMV, GFZ and WUHAN streams	IGS02 (APC) IGC02 (CoM)
BKG	RT GPS+GLONASS Kalman-generated combination from BKG, CNES, DLR and GMV streams	IGS03 (APC)

The solution epochs in the single-epoch combination (IGS01/IGC01) product are completely independent of each other, which has the advantage that the full accuracy is available as soon as product generation starts. The combination process removes a common offset from all satellite clocks at each epoch, computed by processing pairs of Analysis Centre solutions, in order to align the clocks in each contributing solution. The aligned clocks are then screened for outliers and combined by calculating a weighted average clock value for each satellite. The orbit states are combined by using the average value from all contributions.

The Kalman Filter solution (IGS02/IGC02) requires a few minutes convergence time to reach full accuracy. Once converged, the accuracy is maintained unless there is a reason to restart the software. A mechanism is in place to avoid publishing results during the convergence period. The orbit information is extracted from one of the incoming ultra-rapid solutions. In the Kalman Filter approach satellite clocks estimated by individual AC are used as pseudo observations within the adjustment process. Each observation is modelled as a linear function of three estimated parameters: AC specific offset, satellite specific offset common to all AC, and the actual satellite clock correction which represents the result of the combination. These three parameter types differ in their statistical properties. The satellite clock offsets are assumed to be static parameters while AC specific and satellite specific offsets are stochastic parameters with appropriate white noise. The solution is regularized by a set of minimal constraints. A recursive algorithm is used to detect orbit outliers. The greatest difference between AC specific and mean satellite positions is computed. If this is greater than a threshold, then corrections of the affiliated AC are ignored for the affected epoch.

To improve the robustness of the RTS products, combination solutions are performed on more than one host. The redundancy concept for the IGS01/IGC01 streams is shown in Fig. 2. The two combination solution servers are located in different geographical locations and are processing AC solution streams from two separate NTRIP casters. Each solution is then uploaded to both casters using the same mountpoint designation. The caster design is such that it accepts the first of the two streams and rejects the second stream. If the first stream is interrupted then the caster seamlessly switches to the other stream.

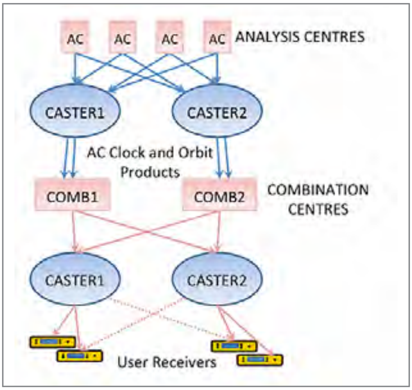

Fig. 2: Combination stream generation

3.4 User Access and Software

Information on user access and software is provided on the RTS website at www.igs.org/rts/access. Users can register separately at one or more of the three agencies operating the IGS RT data centres, must accept the terms of service and complete the online subscriber registration. After a brief processing period, users will be contacted with login and further information for connecting to the RTS streams.

It should be noted that all streams are not hosted at each caster. To find a particular stream, the user is advised to check the information on the hosting agency web pages, e.g.:

BKG: https://igs.bkg.bund.de/root_ftp/NTRIP/streams/streamlist_igs-ip.htm (data)
BKG: https://igs.bkg.bund.de/ntrip/orbits (products)
CDDIS: cddis.nasa.gov/Data_and_Derived_Products/Data_caster_streams.html (data and products)
IGS CB: igs.org/network?network=rts (data)

There are two open source software packages that can perform various functions using RTCM streams, the BKG NTRIP Client (BNC) and RTKLIB. BNC has extensive functions for RTCM stream decoding and encoding and for performing Precise Point Positioning (PPP). The PPP function requires an SSR product stream, a receiver observation stream and an ephemeris stream. The RTS provides a dedicated ephemeris stream with messages for all constellations with the designation RTCM3EPH. In addition there are single-constellation ephemeris streams.

4 RTS Performance Monitoring

4.1 Orbit and Clock Performance

The GPS individual AC and combination solutions are monitored by making daily comparisons of the decoded orbit and clock products against the IGS rapid solution. Results from the comparisons are published in daily reports that are emailed to the AC representatives with graphical summaries published on the RTS web site (www.igs.org/rts/monitor) and on the Pilot Project web site (www.rtigs.net/products.php).

The clock results for the individual AC since November 2010 are shown in Fig. 3 while Fig. 4 shows the performance of the IGC01 combination. Fig. 3 shows that there are significant daily variations in the statistics of the individual RTAC[2] solutions. These are usually due to a problem in a single satellite, which distorts the daily statistics. Fig. 4 shows that these distortions are effectively removed by the combination outlier detection logic. The IGC01 clock standard

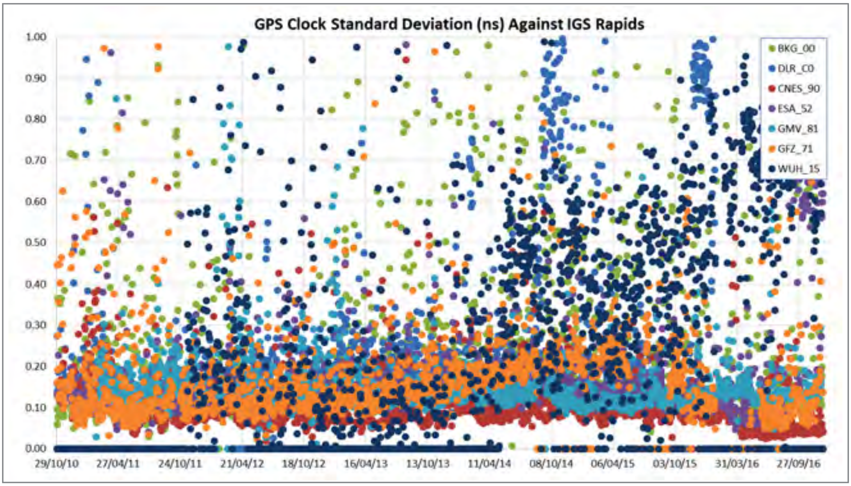

Fig. 3: RT AC clock standard deviation against IGS rapid product

deviation is normally at the 0.1 to 0.15 ns level. The best individual RTAC solution is normally better, but suffers from occasional outlier problems that the combination is designed to remove.

Fig. 5 shows the orbit comparison results of the IGC01 combination. The plot is of the daily 1-D RMS difference between the RT combination solution and

2 RTAC: Real-Time Analysis Centre

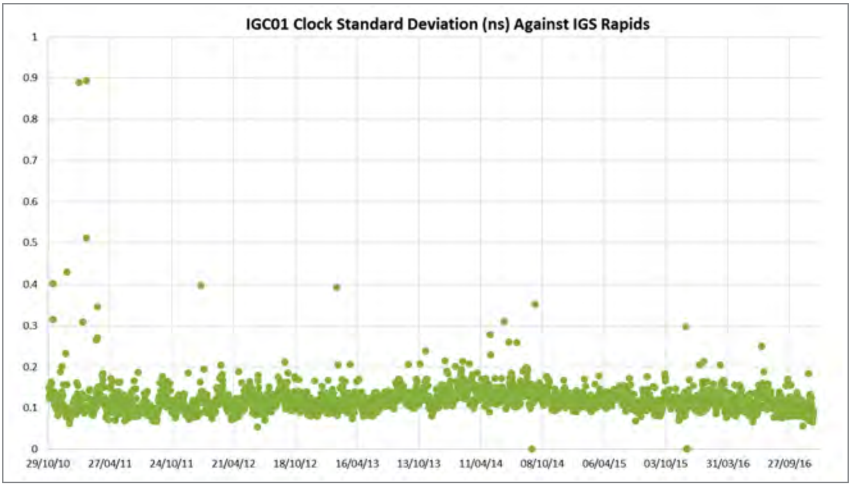

Fig. 4: RT combination clock standard deviation against IGS rapid product

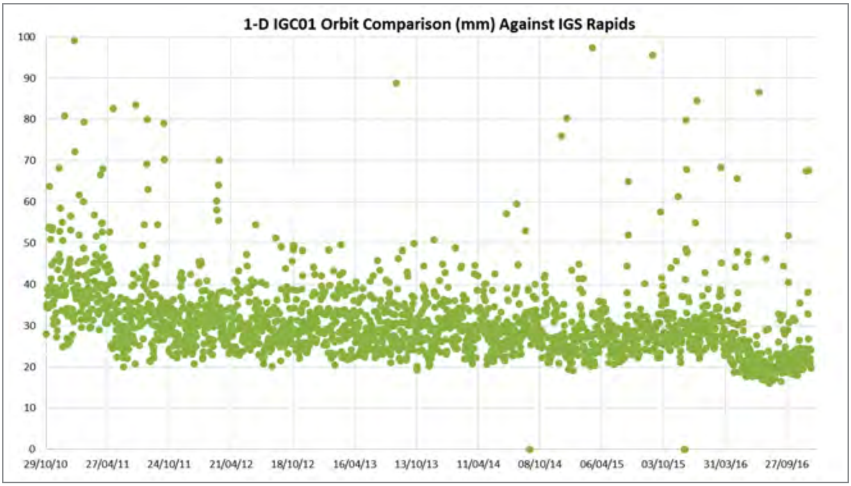

Fig. 5: RT combination orbit 1D RMS comparison against IGS rapid product

the IGS rapid product. Typical results since the second quarter of 2016 are at the 20 mm level.

4.2 PPP Monitoring

Continuous PPP performance results for all streams are available at https://igs.bkg.bund.de/ntrip/ppp and are displayed on a 24-hour sliding window. They are

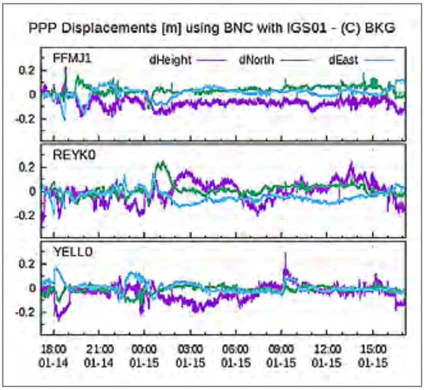

Fig. 6: PPP performance of IGS01 combination stream

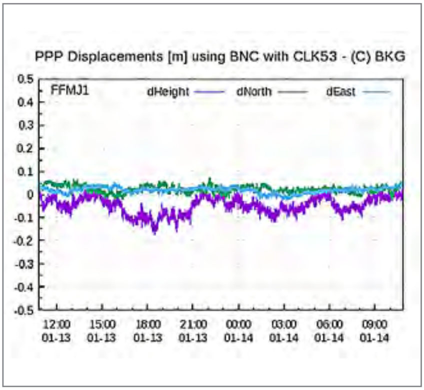

Fig. 7: PPP performance of AC solution stream

derived from the BNC PPP client, running in kinematic PPP mode and using observations from a number of receivers whose positions are precisely known. The chart in Fig. 6 shows the PPP monitoring of the IGS01 combination from three sites, while Fig. 7 shows the PPP monitoring of an individual AC solution (CLK53).

5 Conclusions

The IGS Real-Time GNSS Service has been operating since April 2013. However, it has to be clarified that this service is an open service that is offered to the public on a best efforts basis and without any guarantee on availability, quality, level of service or accuracy.

Through the use of international standards, a built-in level of redundancy and combined-products design, the IGS Real-Time GNSS Service is able to support high quality sub-decimetre (2-drms) real-time positioning on a global scale.

Acknowledgements

The authors wish to acknowledge the important contributions of the more than thirty agencies that participate in the IGS Real-Time Service. In particular the station operators, data and analysis centres who we rely on to deliver, day in and day out, high quality data products, and without whom the service would not be possible.

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