Real Time GNSS Processing at ESOC: Infrastructure and Initial Results

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ESOC Navigation Support Office

IGS Workshop 2008

Miami

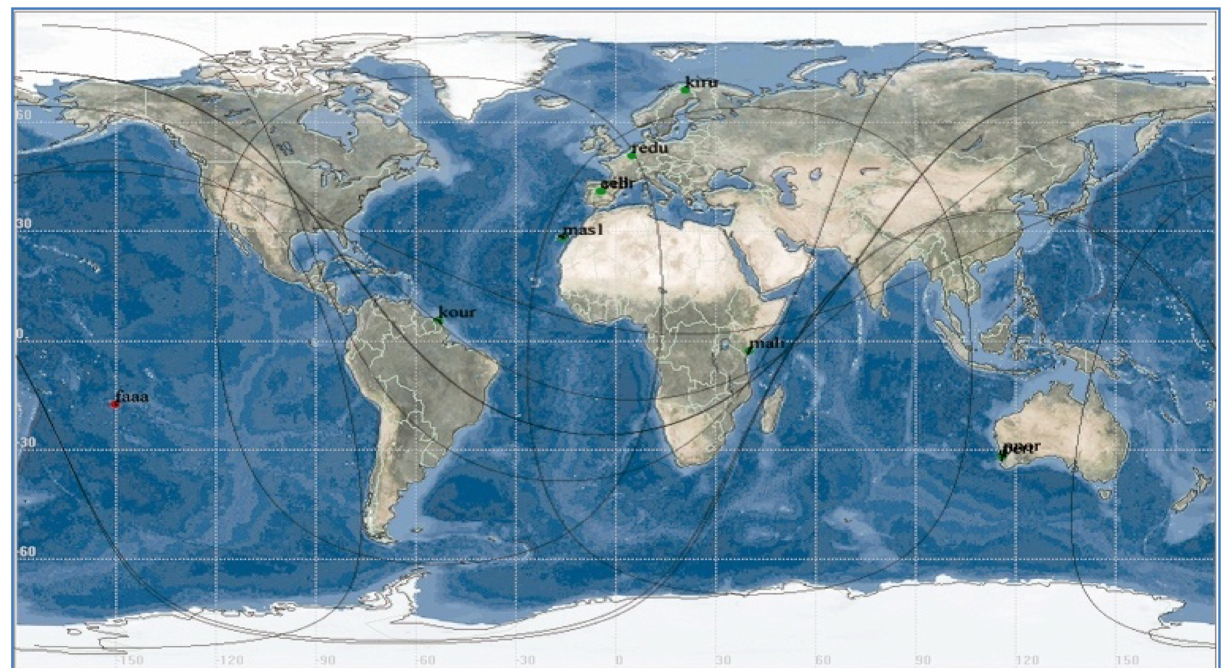
Introduction

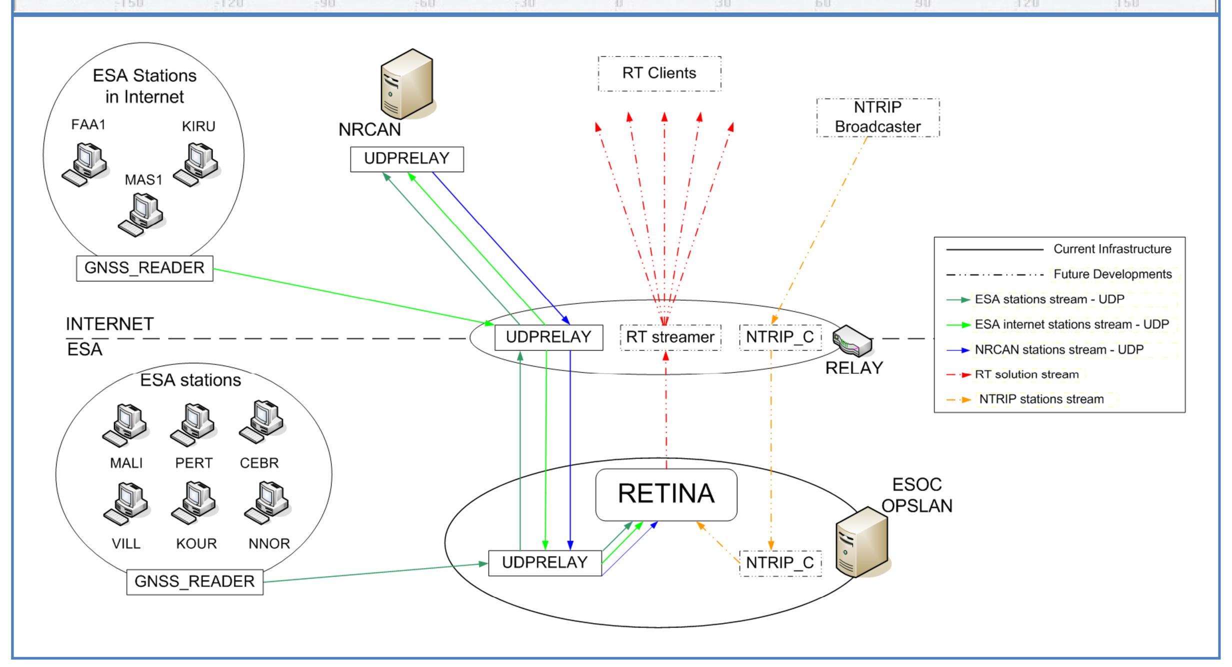
ESOC has been working over the last six years in establishing a Real Time GNSS capability. In the network area, ESOC has a well-established commitment for the installation of GNSS reference stations at all the ESA Ground Stations.

In parallel to the receiver deployment activities, we have embarked on a program to build a Real Time software infrastructure. RETINA (System for Real Time Navigation) has been modelled after ESOC's experiences in Real Time satellite control systems and includes many elements for data processing and visualisation that are common to such systems.

ESA Real Time Network

ESA's GNSS Real Time receiver network currently comprises stations at Tahiti, Kourou, Malindi, Maspalomas, Cebreros, Villafranca, Kiruna, Perth and New Norcia. New Norcia is connected to a local time generator driven by a hydrogen maser. A hydrogen maser has also been procured for Kourou and the GNSS receiver will be connected to it. The remaining sites have local Cesium or Rubidium atomic oscillators available.





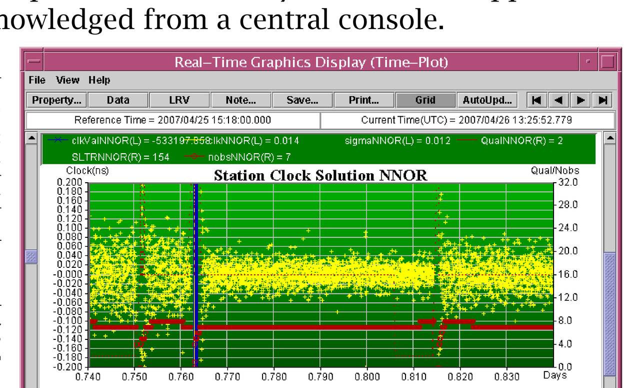
The schematic above shows the current and planned communication and software infrastructure for real time GNSS data transfers. The current system is based on the RT-IGS software tools, which have been integrated into ESOC's processing software. Data from ESA's stations is received at ESOC, combined with external streams from NRCan and relayed to ESOC's operational system. In parallel, the ESA data are relayed to NRCan for further dissemination to Pilot Project participants.

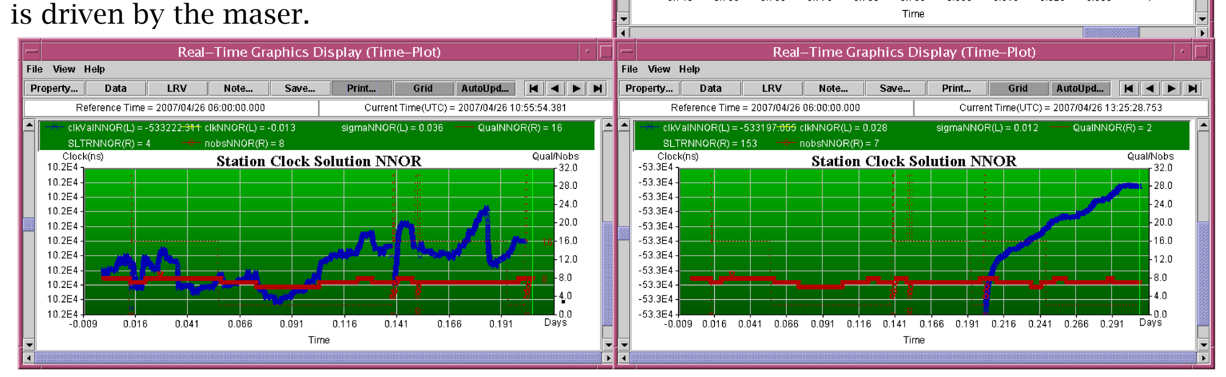
RETINA

RETINA (System for Real Time Navigation) is a suite of algorithmic, infrastructure and visualisation elements to enable the processing, distribution and archiving of both Real Time and Near Real Time GNSS data and results. The RETINA system has been developed for ESOC by UK-based Symban Ltd. Its objective is to integrate batch and Real Time processing under a single system with centralised facilities for monitoring and control of the Real Time tasks and batch processes.

The RETINA Real Time processing concepts and techniques borrow heavily from those used in Satellite Control systems where ESOC has many years of experience: GNSS data and results are treated in much the same way as spacecraft Telemetry Streams and application messages and alarms are displayed and acknowledged from a central console.

RETINA is used extensively for visualisation and monitoring of receiver data and status. The example plot on the right shows the effect on the New Norcia receiver clock between switching from internal clock steering to the external maser (decrease in the noise of the clock corrections) and back. The plots below show the clock solution with and without clock steering, indicating the smoother behaviour when the receiver is driven by the maser.





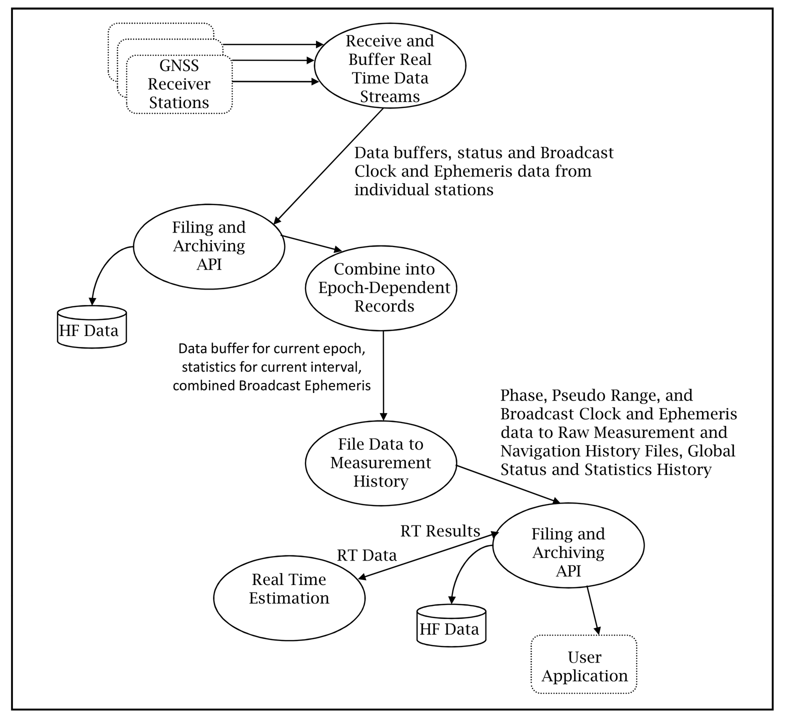
The RETINA subsystems belong to one of three functional categories:

Infrastructure
The main components are C++ applications and middleware elements for History Filing and Archiving, Event Logging and Job Scheduling. All middleware elements have C++, Java and FORTRAN interfaces.

Application
Software is written in FORTRAN 90 or C++. It incorporates ESOC's NAPEOS application suite for Batch GNSS processing and new applications for Real Time estimation and for generation of products and comparison statistics between results sets.

Visualisation
Software is entirely written in Java for portability. It includes Real Time graphical and alphanumeric display applications and the RETINA Graphical User Interface

Filing and Archiving provides the tools for streaming and archiving of Real Time data. The API is used by the RETINA applications for filing data to (time) key indexed circular **History Files** (HFs), update of existing HF records, and retrieving 'live' or archived data. Derived retrieval by parameter name e.g. phase bias between s/c x and receiver y is also possible. All applications support seamless processing of historical and live data, allowing the processing to start from the past and continue in Real Time mode.



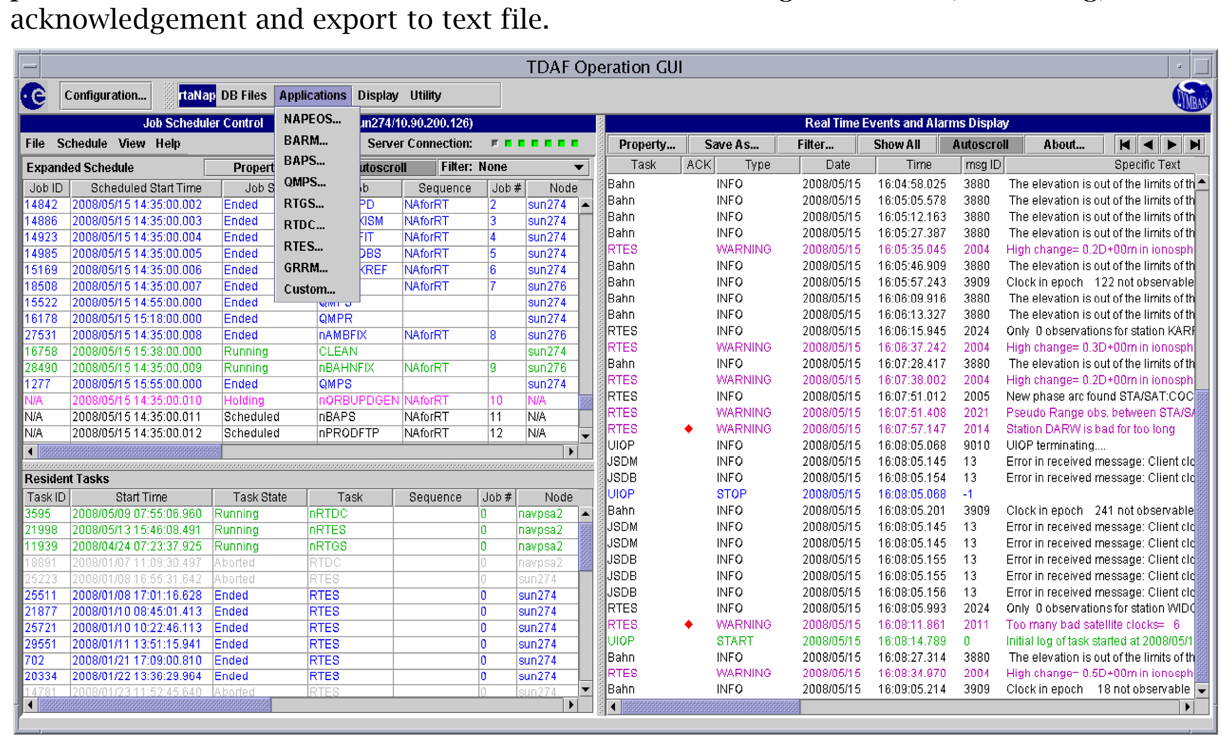
The use of the Filing and Archiving infrastructure in RETINA is illustrated by the data flow diagram on the right, which shows the processing stages for estimating the GNSS Real Time clocks from the receiver measurement streams.

Event Logging and Alarm Management software allows applications to log error, warning and information messages. The messages are collected by a Logging server via TCP, allowing tasks to log messages even if running on different nodes. The server also detects abnormal process termination and generates an alarm, alerting the RETINA operator.

The RETINA **Job Scheduler** is used for automating and monitoring the execution of both Batch and Real Time tasks. It is used for scheduling Batch jobs and sequences and for monitoring and automatically restarting the Real Time Resident Tasks. Jobs are submitted on any machine on the network and all functions are configured and monitored centrally via a Java Job Scheduling display application. The User can intervene to cancel, abort, suspend or reschedule selected jobs and can also view messages and output from a selected job.

All application GUIs are integrated into a single RETINA desktop, the **TDAF Operation GUI** (see below). A scenario menu bar provides access to the individual application GUI panels and allows the display of Real Time graphical and alphanumeric displays. Additional scenarios can be launched in parallel, providing the capability of controlling multiple individually configured projects.

The **Events and Alarms** display, on the right, shows the log messages from the running processes and includes functionalities for message retrieval, filtering, alarm acknowledgement and export to text file.



The **Job Scheduling** display on the left, shows the status of the RETINA scheduled applications, with the Batch jobs and sequences in the top window and the Real Time processes in the bottom.

Three Real Time tasks are always running:

RTGS receives the UDP receiver streams and writes out an individual Measurement and Navigation HF per receiver

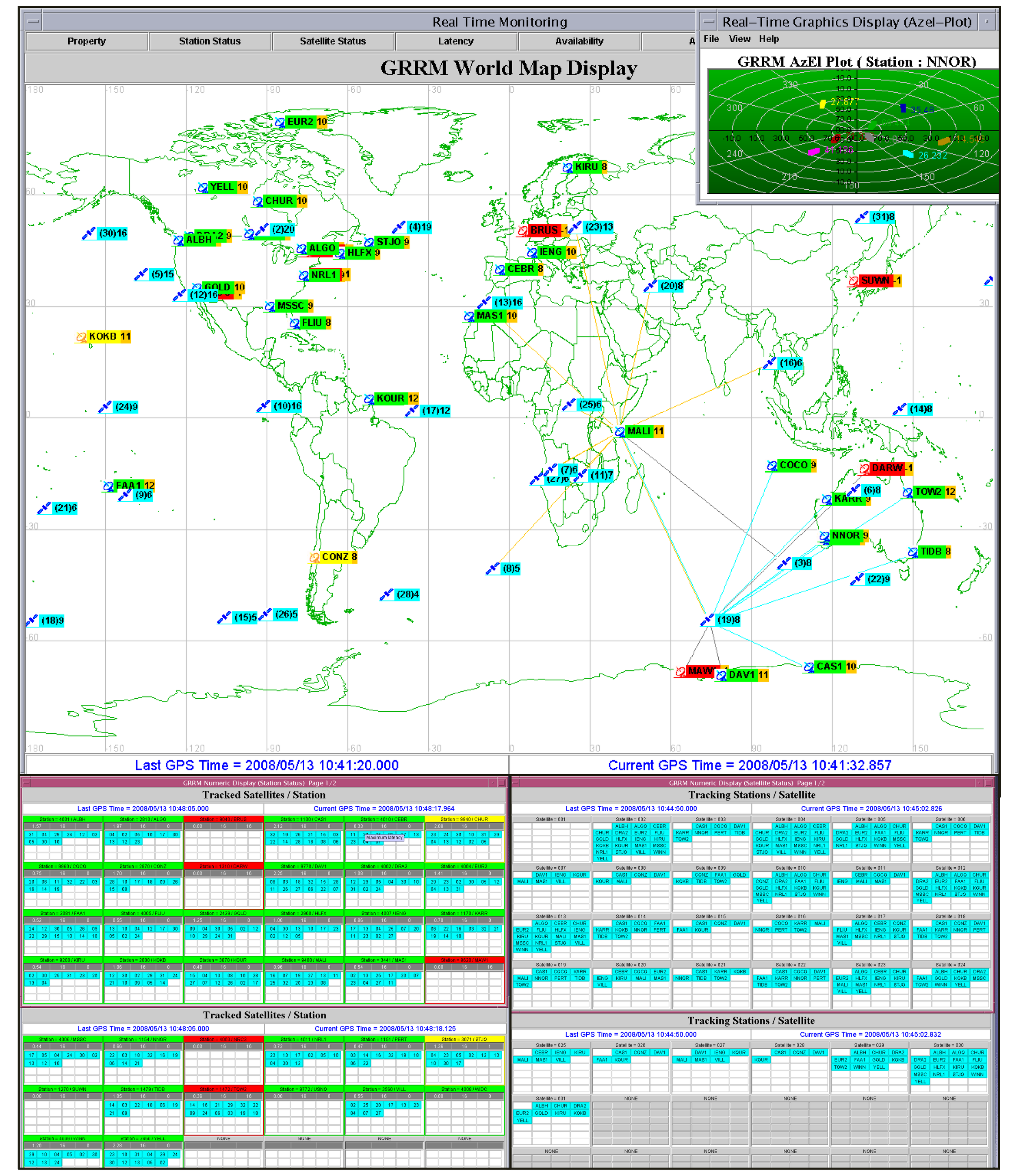
RTDC combines the individual receiver HF records and writes out a global Measurement HF and a global Navigation HF

RTES processes the global Measurement and Navigation HFs and estimates the s/c and receiver clocks, TZDs and phase biases using a Kalman Filter. The results are streamed to a Results HF, containing the satellite and receiver clock solutions, the TZD solution and solution quality flags.

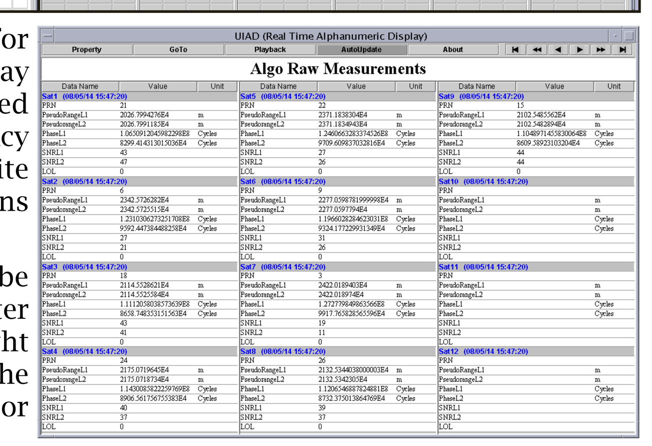
A batch sequence (**NAforRT**) is executed automatically by the Scheduler every 2 hours. It runs a number of NAPEOS and RETINA applications in a specified order, in order to estimate precise GNSS orbits using a process similar to the generation of the ultra-rapids and using IGS RINEX observation files. The latest predicted orbit information is then made available to the Real Time estimation by updating an Orbit History File.

RETINA

RETINA allows visualisation of Real Time data and results with a range of easily configurable graphical and alphanumeric displays. The status of the network is monitored using the World Map Display below. Stations receiving data are shown as green markers, while data drops are indicated in yellow. Red markers imply complete loss of data over a monitoring interval. The user can activate links for individual stations or satellites. Actual data links are shown in colour, while links with geometric visibility but no data are indicated in grey. It is also possible to launch real time plots for any station or satellite, to display the history of tracked satellites or tracking receivers, as well as horizon plots.

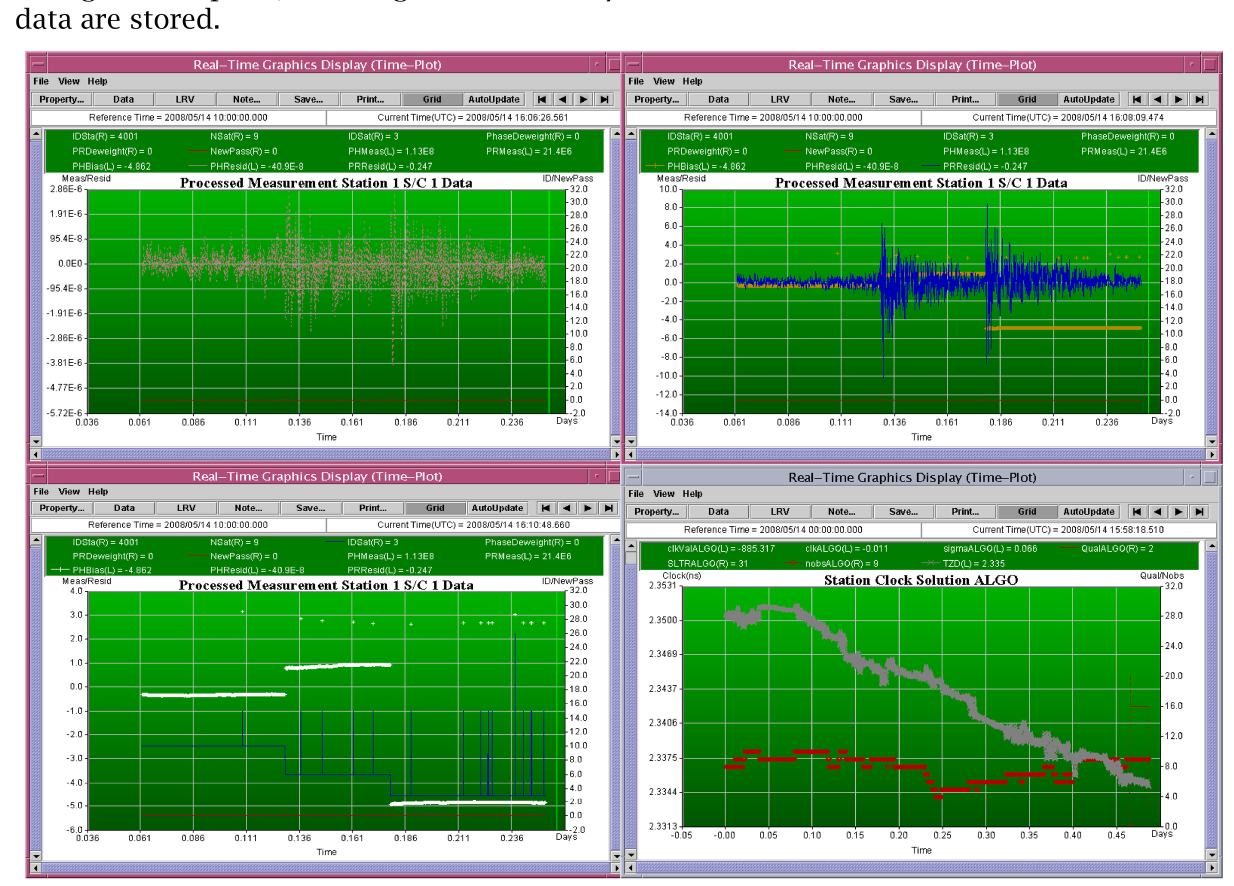


Customised displays are available for monitoring the network. The station display (above left) shows the satellite IDs received at each station, along with latency information for the last interval. The satellite display (above right) shows the stations tracking each satellite.



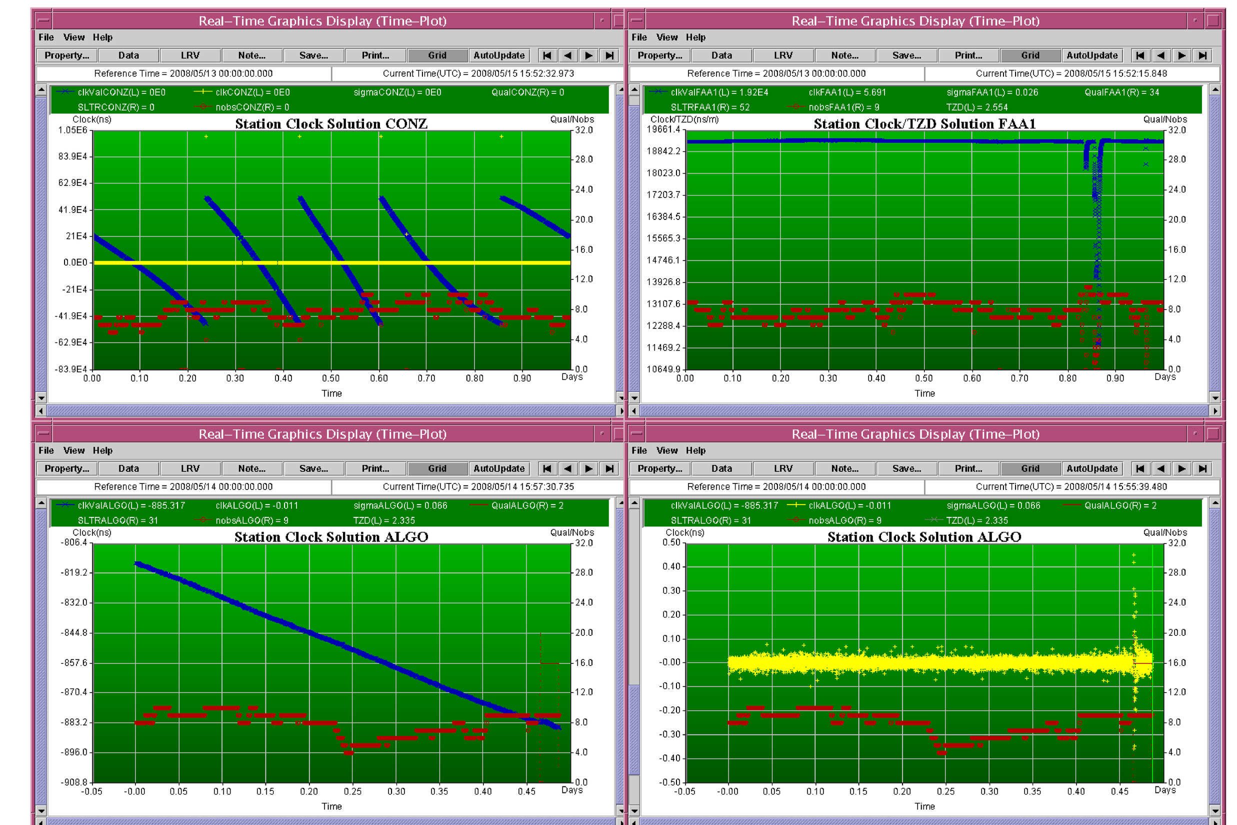
Configurable alphanumeric displays can be easily created to monitor any parameter stored in a HF. The example on the right shows the raw measurements from Algo. The display can be set to update in Real Time or it can be used to play back Historical data.

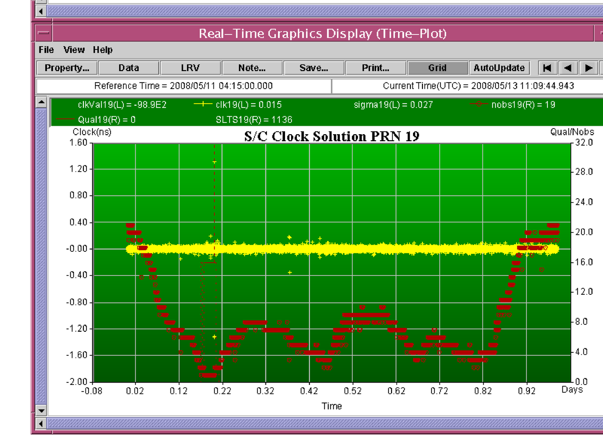
Similarly, graphical displays can be used to plot any HF variable. The plots below show Real Time Estimation results: Phase and pseudo-range residuals and the phase bias and Tropospheric Zenith Delay solutions. Dedicated configuration GUIs allow the user to easily configure new plots, selecting HF variables by name and without the need to know how the data are stored.



Real Time Results

One of the challenges in the generation of Real Time results is the tuning of the Kalman filter to allow it to cope with the widely varying behaviour of individual clocks. The examples below show the clock solutions for three receiver clocks (Conz, Faa1 and Algo). It can be seen that the Conz clock suffers frequent 1 ms resets over the course of a day. The Faa1 clock is stable except for occasional instances of data corruption, likely due to local signal interference. On the other hand, the Algo clock is highly stable with clock corrections between filter epochs of the order of 10 ps, as seen by the lower right plot. The larger corrections near the end of the day are due to a filter reset after a data gap.



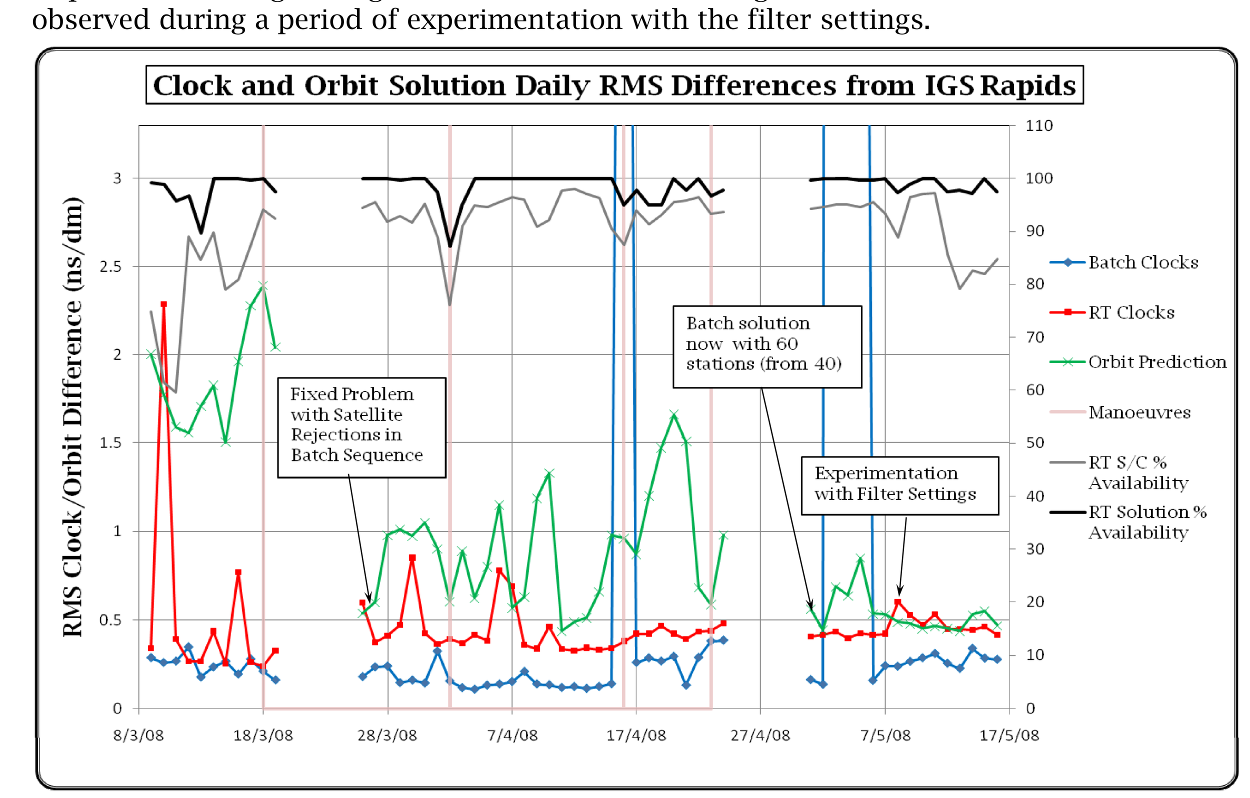


The graph on the left illustrates the limitations of the network by showing the clock corrections over the course of a day (in yellow). The red markers indicate the number of phase-locked observations used in the solution at each epoch. It can be seen that the network does not provide very good coverage for this satellite, with four intervals where the number of simultaneous measurements falls below 4. In these regions some clock instability is evident from the jumps in the solution.

The graph below presents a synthesis of the RETINA Real Time and Batch results between 9 March and 16 May 2008, through comparisons with the IGS Rapid solution. The black line represents the Real Time solution availability as a percentage (right scale), while the grey line represents the satellite availability in the solution. In March, the figure for satellite availability was low due to a problem in a batch application, resulting in the elimination of some satellites from the orbit solution. This in turn resulted in their elimination from the Real Time processing which explains the erratic behaviour of the Real Time clock solution (red line) and the high orbit prediction errors.

In the period between 26 March and 7 May, the batch sequence was running with 40 stations. Also, during this interval, the number of stations processed by the Batch subsystem was reduced due to a problem with one application. In the period after 7 May the batch sequence was running with 60 IGS stations, showing a marked improvement in the orbit prediction error (5 cm level). The batch clock solution does not seem to be correlated with the orbit quality and in fact it seems to degrade slightly when using 60 stations, with the more accurate orbits.

The plot shows that under normal circumstances the Real Time clock comparison is below 0.5 ns RMS. Excursions above 0.5 ns are due to network outages or problems in the batch sequence resulting in high orbit errors. A small degradation in the RT clocks is also observed during a period of experimentation with the filter settings.



Conclusions

ESOC has developed the infrastructure to allow the automated generation of GNSS Real Time products. RETINA applications are currently processing data from the IGS Real Time network, which includes 9 ESA stations. It is seen that with a stable network the target clock accuracy of 0.5 ns (Real Time Pilot Project target) is easily met. A higher density of stations in the Southern hemisphere is needed in order to further improve the solution.