[updated 26 December 2001]

This is the IGS clock analysis plan that has been developed among the IGS Analysis Centers, together with Jan Kouba and Tim Springer. The purpose is to describe long-term plans and actions related to clock solutions. The main goal is to try to define reasonable objectives for the IGS and begin to identify other broader objectives that should probably be left to the IGS/BIPM Timing Project.

Goal 1. -- Submit station (& satellite) clock results

There are several important reasons for the IGS to add station clock products to its output, in addition to these being part of the Terms of Reference: (1) As noted by Springer, Zumberge, and Kouba (1998) in their Darmstadt position paper, the availability of clock estimates from stations equipped with high-performance frequency standards (H-masers mostly) would allow a more precise alignment of the clock solutions (currently including only satellites) from the ACs relative to one another and would allow better relative weightings. The current restriction of only using satellite clocks for weighting and alignment limits the IGS combined precision to roughly 0.2 ns. (2) As discussed at the IGS/BIPM meeting at Sevres in June, linkage of the IGS clock products to TAI/UTC is highly desirable (just as station coordinates are linked to ITRF). This is most directly done by using IGS station clock results from timing lab receivers together with local time transfer (calibration) data. Until this is feasible (the Timing Project must develop the calibration techniques with the labs and BIPM), the IGS must continue to link its clock products to GPS time. (3) The station clock results have intrinsic value and interest to a wide user community for a variety of applications.

* Action 1.A -- Develop clock data exchange format [DONE]

  Within the Timing Project, the initial RINEX extension has been develop and is available at .

* Action 1.B -- ACs adopt common satellite antenna offsets [DONE]

  In consultation with the ACs, the AC Coordinator should distribute a set of values for the antenna phase center offsets from the center of mass of each satellite. The ACs are urged to adopt these values in their analysis solutions as soon as feasible in order that all the IGS clock solutions are referred to a common set of physical points within the spacecraft.

* Action 1.C -- ACs adopt common biases values [DONE]

  The (C1,P2') pair available from cross-correlation style receivers (e.g., AOA TurboRogue and Trimble 4000) have satellite-dependent biases compared with the (P1,P2) observables provided by newer generation receivers (e.g., Ashtech Z-XII, AOA Benchmark/ACT, etc.) To avoid mixing data with different satellite biases, which would degrade the IGS satellite clock products, the ACs are asked to use a common pseudorange bias convention by modifying data from the older receivers to be compatible with the newer generation observables. The background and history of bias values are documented at .

* Action 1.D -- ACs begin to submit weekly clock solutions [DONE]

ACs are encouraged to develop clock RINEX software and start submitting "cccwwwwd.clk" solution files, weekly with other IGS Finals submissions and daily with other IGS Rapids results. The results should be for 5-minute intervals and should include the (redundant) satellite clock information in order to simplify the IGS combination effort.

In addition to including all global tracking stations used in the orbit adjustment, ACs are asked to "densify" their clock submissions using the precise point positioning method to estimate consistent clock values for as many other stations as possible, especially for the "fiducial clock" sites (see below).

* Action 1.E -- AC Coordinator develops tools to use clock solutions [DONE]

As soon as clock solution files become available the Coordinator needs to develop the ability to read and manipulate the clock information from the ACs in order to develop a combined clock product.

Goal 2. -- Use station clocks to improve IGS alignment/weighting
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The improved inter-AC clock alignment and weighting described above can only be accomplished if there is a sufficient number of station clocks in common among the ACs. If too few stations are common, then the results will not improve over the current use of ~26 satellite clocks. To improve the alignment strategy, ACs are encouraged to include as many sites as possible from a list of "fiducial clock" stations. The list should include primarily sites from the set of Reference Frame stations which have stable frequency standards and all stations equipped with H-masers. In addition, suitable IGS sites at timing labs should be included to prepare for eventual linkage of the IGS clock results to TAI/UTC.

* Action 2.A -- Develop list of "fiducial clock" sites [DONE]

The list of "fiducial clock" sites is at
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* Action 2.B -- ACs consider using fiducial clock sites [DONE]

ACs are asked to examine the list above and attempt to include as many stations as possible in their analyses, either as part of their global tracking network or included in a separate "clock densification" solution using the precise point positioning method.

ACs should choose a station as reference clock which is equipped with an H-maser standard (only) and has a history of reliable, stable performance.

* Action 2.C -- AC Coordinator evaluates effectiveness [DONE]

Based on this approach, the AC Coordinator will need to evaluate the effectiveness and usefulness of the fiducial selection. The Coordinator will need to develop new combination software, in close cooperation with the ACs. If the set of common stable clock sites is insufficient, then the use of satellite clock results for inter-AC alignment and weighting must continue.

Goal 3. -- Distribute IGS clock products

Once Goals 1 and 2 have been met, then the IGS can begin to distribute its combined station clock products (initially as part of the Final products but soon afterwards also with the Rapids), as well as improved satellite clocks. The satellite clocks will continue to be adjusted to account for differences between AC orbit solutions and the IGS combined orbits in order to ensure that consistency is maintained. All of the clock products (stations and satellites) will be consistent with other IGS products, particularly the orbits, and will be expressed in a common timescale (eventually, linked to TAI/UTC).

It should be made very clear to the user community that the epoch offsets of these station clock products refer to the internal "clock" of each GPS receiver and not to the external standards (at least not until local time transfer calibrations become available).

* Action 3.A -- AC Coordinator adds new clock products [DONE]

* Action 3.B -- Develop improved IGS time scale [DONE]

  Because the traditional time scale of IGS clock products uses a linear alignment to broadcast GPS time for each day individually, the stability is very poor at about 1-d intervals. This can be improved by forming an an internal time scale based on a weighted ensemble of the frequency standards in the IGS network.

Goal 4. -- Linkage of IGS clock products to TAI/UTC

For now, the IGS clock products will continue to be aligned with the GPS time scale. However, it is desirable for the IGS to become more closely connected to the UTC/TAI time scales maintain by the BIPM. Indeed, the IGS is poised to contribute significantly to the maintenance of UTC by improving global time/frequency transfer. However, to accomplish this will require the development of accurate local calibration techniques that can be applied at timing labs which contribute to TAI. This is a major effort of the IGS/BIPM Timing Project, which must also validate the calibrations using independent techniques.

* Action 4.A -- Develop local GPS time calibration techniques
  [IGS/BIPM Timing Project, in progress]

* Action 4.B -- IGS apply calibrations to effect TAI link [later]

Goal 5. -- High-rate satellite clocks

As also described by Springer, Zumberge, and Kouba (1998) in their Darmstadt position paper, there are applications which require satellite clock results more frequently than the 15-minute interval currently provided by the IGS. To permit interpolation of the satellite clocks affected by SA, it is necessary to have clock results tabulated every 30 seconds. The new RINEX clock format now allows such results to be exchanged.

* Action 5.A -- ACs indicate willingness to contribute 30-s clocks [TBD]

  To determine how well ACs are prepared for this, each is asked to respond to Jan Kouba with an estimate of when/if they expect to contribute satellite clock solutions at 30-s intervals in RINEX format.

* Action 5.B -- AC Coordinator assess combination impact [TBD]

  The task for the Coordinator to handle this new task must be assessed against other IGS priorities. Based on the ACs' responses and this assessment, a plan for IGS implementation can be developed.

* Action 5.C -- 30-s satellite clocks as IGS products [TBD]

  Depending on Actions 5.A and 5.B, 30-second satellite clock values will eventually become a standard product of the IGS.