Report of the IGS Clock Products Working Group

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IGS Combined Clock Products

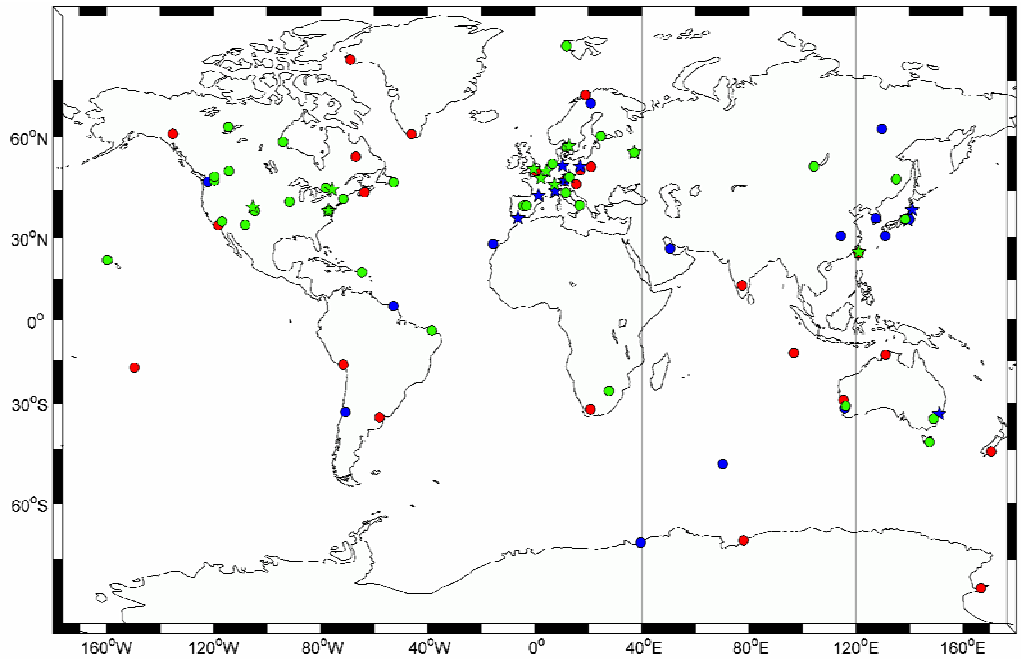
- IGS Analysis Centers contributing clocks since Nov. 2000:
  - CODE *Center for Orbit Determination in Europe, AIUB, Switzerland*
  - ESOC *European Space Operations Center, ESA, Germany*
  - GFZ *GeoForschungsZentrum, Germany*
  - JPL *Jet Propulsion Laboratory, USA*
  - NRCan *Natural Resources Canada, Canada*
  - USNO‡ *U.S. Naval Observatory, USA*
  - MIT† *Mass. Institute of Technology, USA*
- 5-minute intervals for all satellites & ~175 stations
- Supports global autonomous PPP
  - cm-level positioning/dissemination of IG(R)ST
  - dissemination of UTC < 50 ns
- Final, Rapid, & Ultra-Rapid products w/ latencies of 13 d to 3 h
- IGS Reanalysis underway 2006/2007
  - will reanalyze data back to 1994
  - clock densification a high priority
  - PPP using IGS products still an option for obtaining geodetic estimates for non-combination or non-IGS stations

‡Rapids & Ultra-rapids only †Finals only

IGS High Performance Clocks

Time Labs

IGS Site	Time Lab	Freq. Std.	Location
AMC2	AMC	H-Maser	Colorado Springs, CO USA
BOR1	AOS	Cesium	Borowiec, Poland
BRUS	ORB	H-Maser	Brussels, Belgium
IENG	IEN	Cesium	Torino, Italy
KGN0	CRL	Cesium	Koganei, Japan
MDVJ	VNIIM	H-Maser	Mendeleevo, Russia
MIZU	NAO	Cesium	Mizusawa, Japan
NISU	NIST	H-Maser	Boulder, CO USA
NPLD	NPL	H-Maser	Teddington, UK
NRC1	NRC	H-Maser	Ottawa, Canada
NRC2	NRC	H-Maser	Ottawa, Canada
OBE2	DLR	Rubidium	Oberpfaffenhofen, Germany
OPMT	OP	H-Maser	Paris, France
PENC	SGO	Rubidium	Penc, Hungary
PTBB	PTB	H-Maser	Braunschweig, Germany
SFER	ROA	Cesium	San Fernando, Spain
SPT0	SP	Cesium	Boras, Sweden
SYDN	NMI	Cesium	Sydney, Australia
TLSE	CNES	Cesium	Toulouse, France
TWTF	TL	Cesium	Taoyuan, Taiwan
USNO	USNO	H-Maser	Washington, DC USA
USN3	USNO	H-Maser	Washington, DC USA
WAB2	CH	H-Maser	Bern, Switzerland
WTZA	IFAG	H-Maser	Wettzell, Germany
WTZR	IFAG	H-Maser	Wettzell, Germany

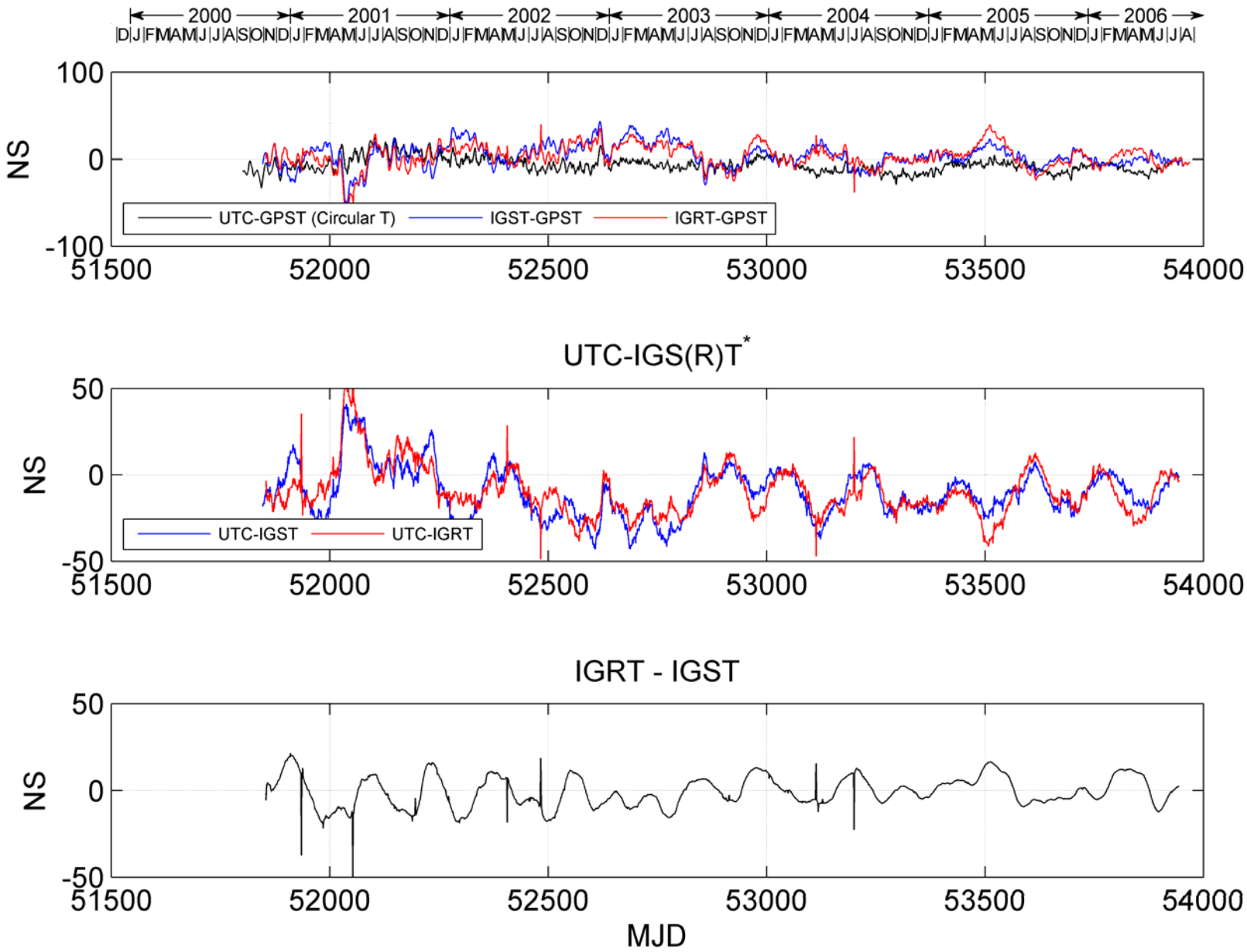


masers (54)
cesiums (32)
rubidiums (27)

★ time lab stations (25)

+ GPS space clocks …

IGS Timescales

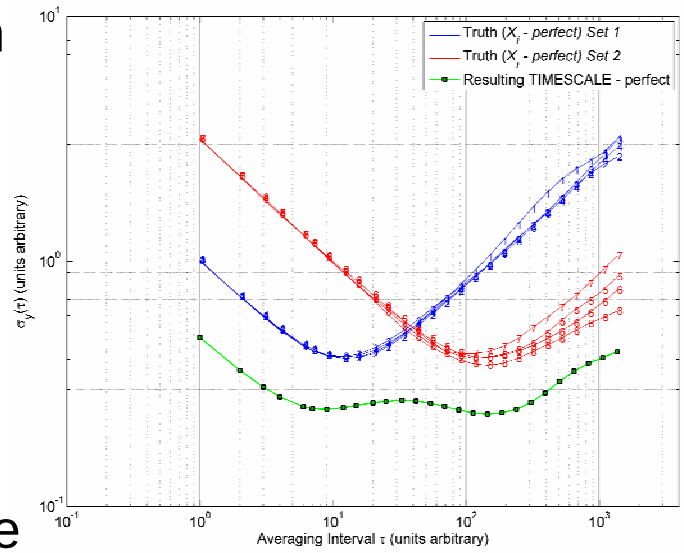


IGS Timescales *(cont.)*

- Kalman continuous filter implementation
  - formulated as a frequency ensemble
  - deterministic models for rates & drifts
  - process noise capabilities: WHFM, RWFM, RRFM,
  - inputs from ~54 H-maser, 32 Cs, & 27 Rb clocks
  - ~25 stations at timing labs
- Can support IGS move to real-time operations
- Instability ~1×10^{-15} at 1 d
- Suffers in longer term by steering to GPS Time
- Implemented for Final (IGST) & Rapid (IGRT) clocks
- Has run autonomously since 2001, officially adopted in 2003 as reference for IGS Rapid & Final Combined Clock Products

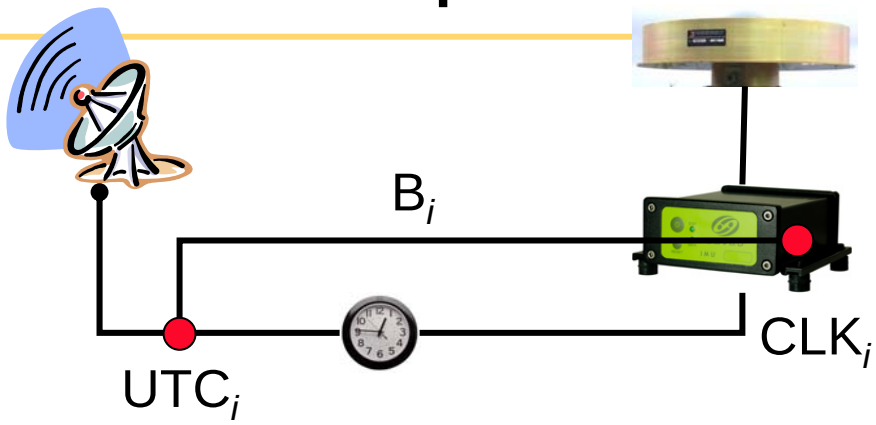
New Timescale Expected (~ 2006/2007)

- New Kalman filter implementation (adaptive parameter estimation)
  - filters clock difference measurements, separating phase, freq., and drift shocks as well as fixed-phase sinusoid (WHPM, WHFM, RWFM, & RRFM capable)
  - Utilizes separate set of weights for each filter state
    - set of phase weights optimized for masers
    - set of frequency weights optimized for cesiums
  - LQG multiple-input steering filter utilizing (calibrated) IGS stations colocated at time labs (UTC(k) realizations)
  - Development complete, testing underway



"*in situ*" Calibration Technique

Senior K., Ray J., Petit G., EFTF 2004



$$B_i = \mathrm{CLK}_i - \mathrm{UTC}_i$$

CLK_i = GPS geodetic clock estimates at lab ***i***
UTC_i = local realization of **UTC** for lab ***i***

STATION CALIBRATION BIAS: includes internal GPS receiver/antenna calibration bias & intra-lab offset to **UTC_i**

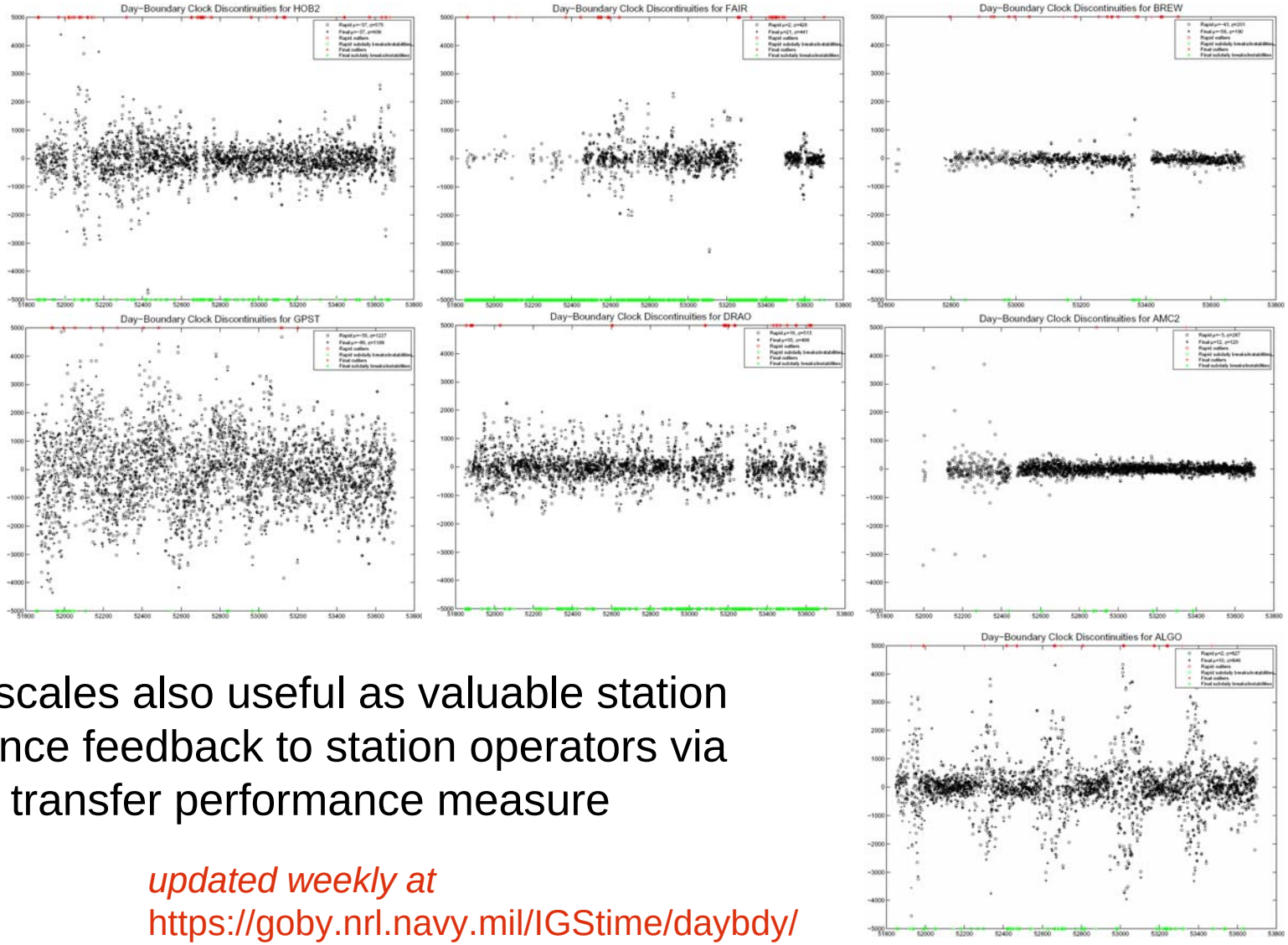
From IGS clock products & BIPM Circular T, can compute:

Method good to ~ 2 ns

$$\begin{aligned} B_i' &= \left(\mathrm{CLK}_i - \mathrm{GPST}\right)_{\mathrm{IGS}} - \left(\mathrm{UTC} - \mathrm{GPST}\right)_{\mathrm{T}} + \left(\mathrm{UTC} - \mathrm{UTC}_i\right)_{\mathrm{T}} \\ &= \left(\mathrm{CLK}_i - \mathrm{UTC}_i\right) + \left(\mathrm{GPST}_{\mathrm{T}} - \mathrm{GPST}_{\mathrm{IGS}}\right) \\ &= B_i + \Delta\mathrm{GPST} \end{aligned}$$

small corrections due to different methods of observing GPS time

Geodetic Time Transfer Accuracy



- IGS timescales also useful as valuable station performance feedback to station operators via new time transfer performance measure

updated weekly at
https://goby.nrl.navy.mil/IGStime/daybdy/

Clock RINEX Format

a. "RINEX VERSION / TYPE" header changed to 3.00 and to add satellite system designator.

b. "PGM / RUN BY / DATE" header date format elaborated.

c. "SYS / # / OBS TYPES" header added.

d. Added Galileo and Space-Based Augmentation System (SBAS) satellite designators in Section 5.

e. "TIME SYSTEM ID" header added.

f. The satellite antenna phase center offset information has been moved from a mandatory comment to the "SAT ANT PCO / PCV" header and now includes the associated phase center variation information also. It is expected that an external file will be referenced.

g. "SYS / DCBS APPLIED" header added. [NOTE: The format -- taken from RINEX 3.00 is not adequate to give DCBs for each satellite. Further changes are under discussion.]

h. Capability of handling inter-system timing biases (possibly as a new type of CR data record) are under consideration.

To view the pending revised version, please see: ftp://www.ngs.noaa.gov/dist/jimr/rinex_clock.30aug06 Send any comments to me and Werner Gurtner (werner.gurtner@aiub.unibe.ch).

CANVAS Software

***C**lock **AN**alysis **V**isualzation & **A**rchiving **S**oftware*

- NRL contribution through IGS Clock Products working group
- Built on Matlab®, though binaries available not requiring Matlab
- Source code available
- Standard Clock time & frequency domain measures
- Clock simulation
- Interactive Visualization (zooming)
- Opportunity to contribute/help with further development
- Download at https://goby.nrl.navy.mil/canvas/