Clock and Timing Data Analysis for GNSS Products and Applications

Civil GPS Service Interface Committee
Timing Sub-Committee Meeting
Convened with ION GNSS+
Monday 19 September 2022

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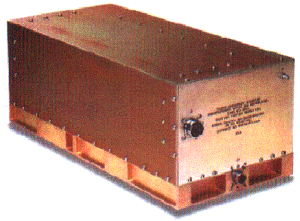
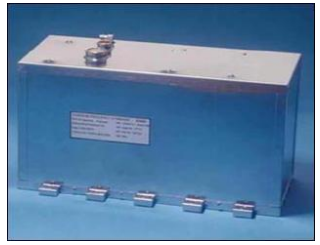
GPS Extended Clock Life Testing

Life testing serves as a baseline for GPS on-orbit clock performance.

- Provides long term (multi-year) testing that cannot be performed in the manufacturer's environment.
- Installation duplicates satellite mount.
- Environmental controls mimic temperature and pressure experienced on orbit.
- Evaluation of performance parameters.
  - Clock phase output and telemetry monitors.
  - Local environmental measurements.
- Identify and report on premature failure modes.
- Validate performance ahead of actual flights.



Cs AFS



Rb AFS

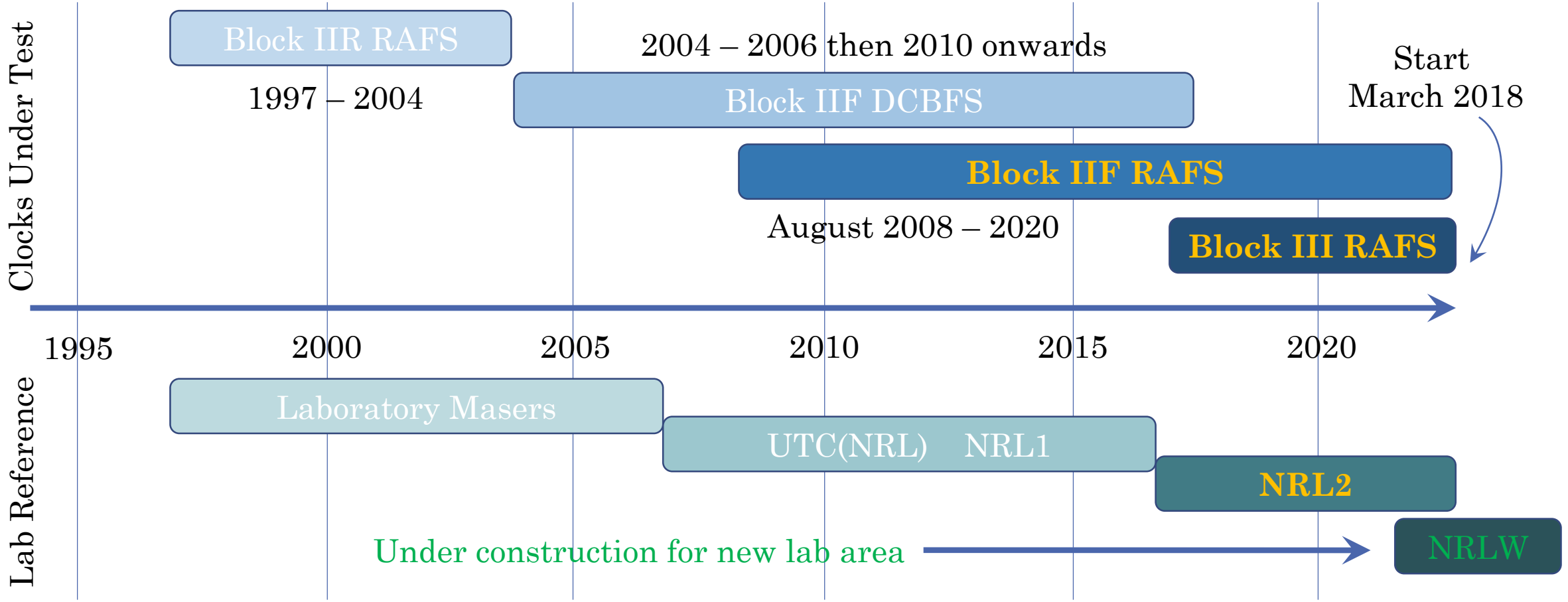
Precise Clock Eval Facility

Joint collaborative effort involving:

NRL USSF Clock & Satellite manufacturers

GPS Extended Clock Life Testing

Series of GPS satellite clocks have been tested over the past few decades.



UTC(NRL) Reference

Key benefits of clock ensemble reference:

- Improved stability against high performing GPS clocks.
- Continuity in event of a maser requiring service.

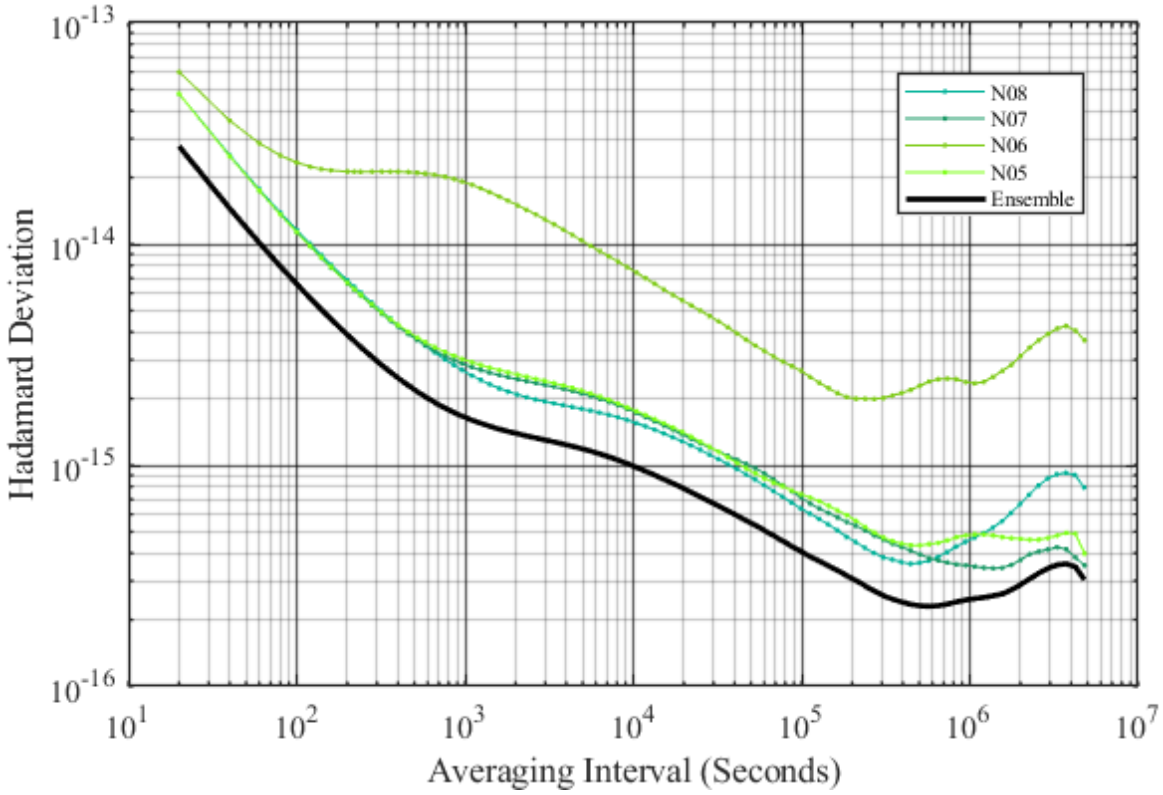
Members of the NRL clock ensemble:

- 6 Hydrogen Masers
- 3 Cesium (5071A)
- Link to UTC(USNO)

Microsemi HMH2020

Cesium 5071 A

Stability of Selected Hyrodgen Masers versus Ensemble

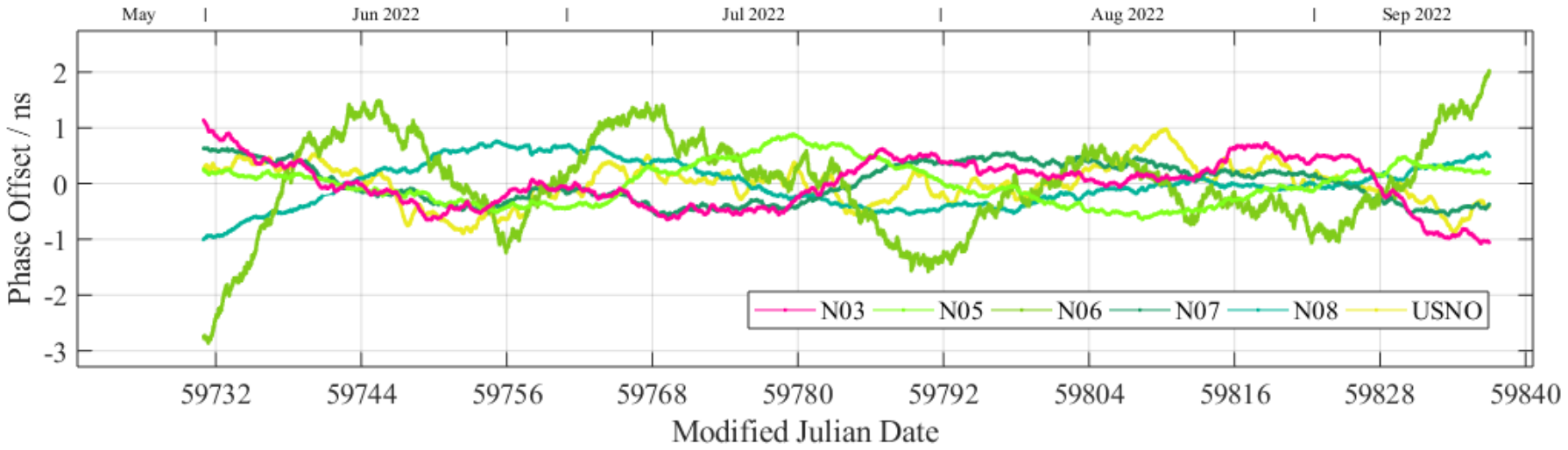


UTC(NRL) Reference

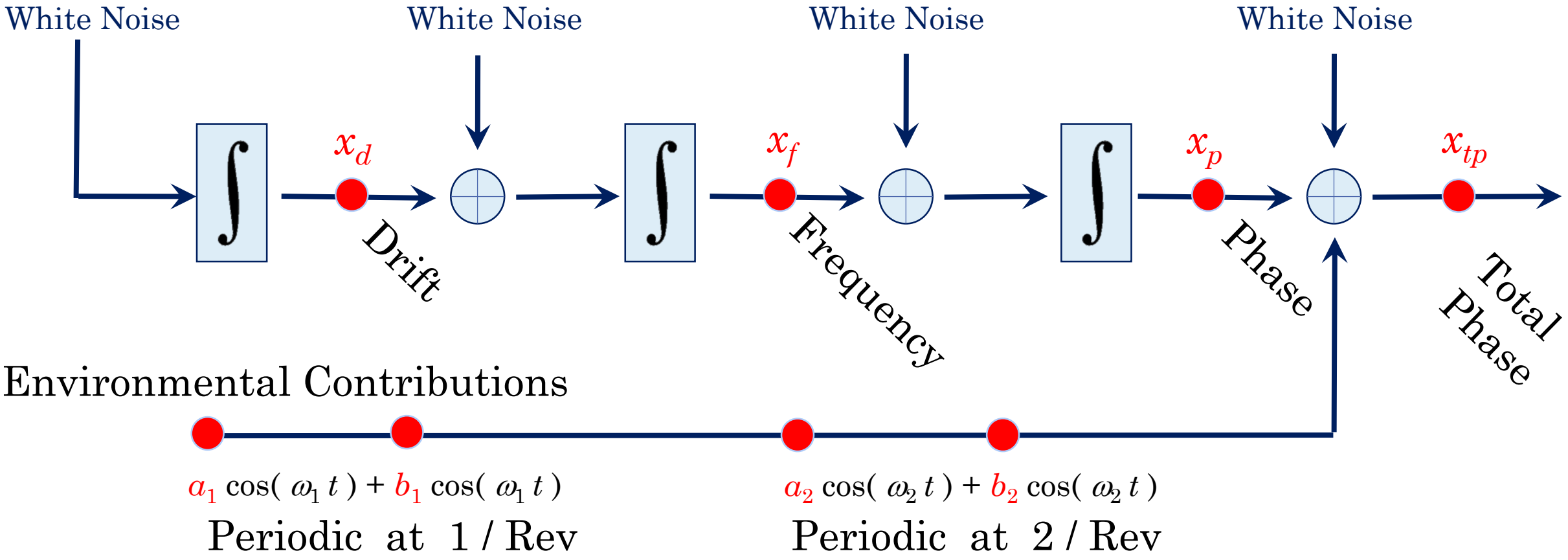
Contributions to UTC and IGS Network facilitated by:

- Septentrio PolaNT antenna
- Septentrio PolaRx5TR receiver
- Microsemi Auxiliary Output Generator

Maser phase offsets vs NRL Local Ensemble



Clock Model Basis



A small random walk process is modeled for each environmental state allowing sufficient flexibility in the filter for the states to converge to each clocks' periodic components.

New GPS Timescale

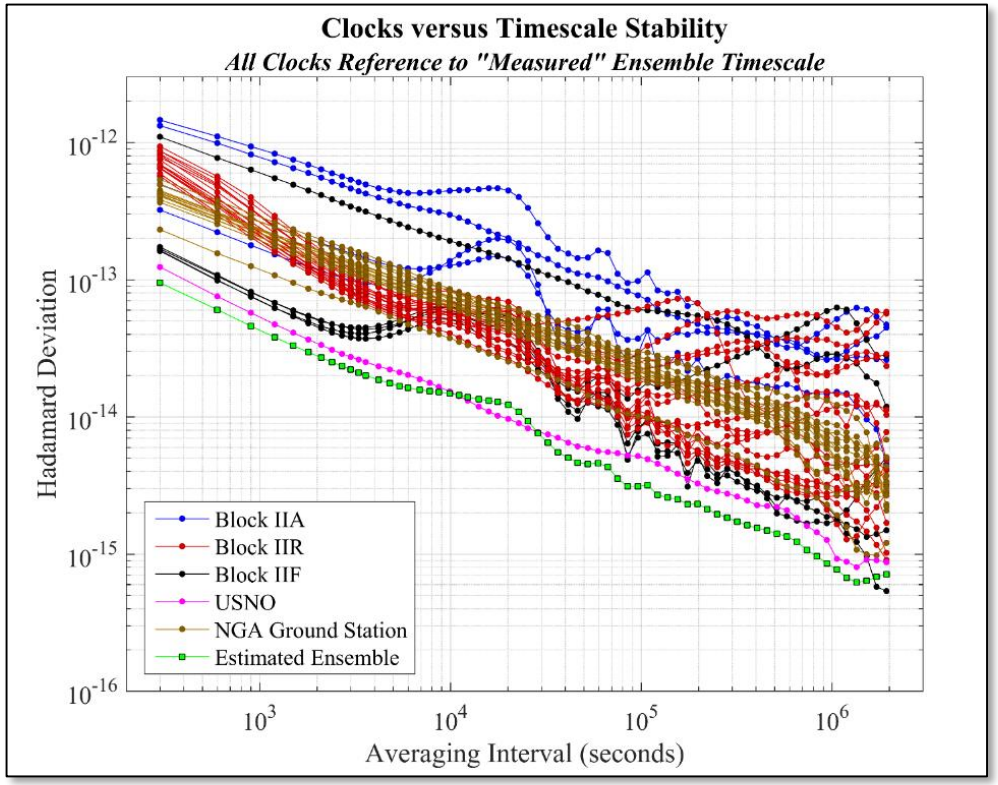
Scope: Generate an ensemble reference time that: estimates phase, frequency and drift of member clocks, is not solely dependent on one clock as master, and is capable to steering to any identified source."

Completion Milestones

- Installation to OCX enterprise mostly complete as of 2020.
- First stage of testing has passed requirements.
- Several rounds of testing remain to exercise other capabilities.

Capabilities

- Multi-weighting (one set of clock weights for each noise process) yields a more stable ensemble over a wider range of averaging intervals.
- Autonomous break detection allows self correction of clock states for several types of clock anomalies.
- Independent measurement weight reduces impact of outliers or excessive noise on measurements.
- Linear Quadratic Gaussian steering control parameters



Ground Control Segment

Raytheon

NASA JPL Jet Propulsion Laboratory California Institute of Technology

Naval Center for Space Technology NCST

L3HARRIS™ FAST. FORWARD.

Data In

Raw L-Band Data

Orbit and Clock Filter
< Jet Propulsion Lab >

Solves for all system clocks with respect to reference clock R.

Clock Solution $z_i^R(t_k)$

Estimates Returned

(ETF) Ensemble Timescale Filter

Filter

Clock Model

Calculates reference time E and returns clock estimates with respect to E.

Clock Estimates $x_i^E(t_k)$

Clock Predictions $x_i^E(t_k + \delta)$

IGS Clock Products

NRL contributes to the International GNSS Service (IGS) in several ways.

- Maintains NRL2 site for IGS network.
- Performs daily clock exchange for reference time to IGS clock products.
- Evaluate day boundary jumps in clock phase to smooth rapid products over longer time series periods.

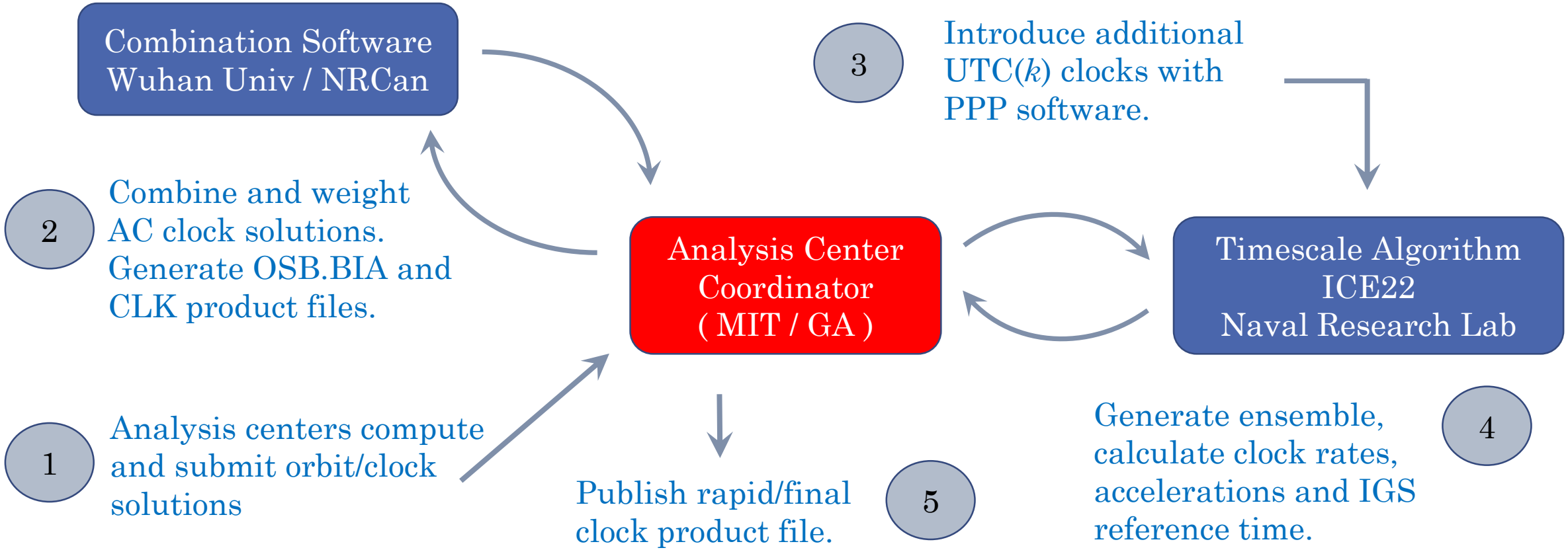
New Multi GNSS Clock Combination

- Analysis Centers (AC) mostly performing multi-GNSS orbit and clock solutions.
- Wuhan University and NRCan developed new combination software to handle multi-constellation solutions.
- IGS2.0 timescale to be replaced by ICE22 (IGS Clock Ensemble) developed at NRL for future IGS ref. time.

IGS Sites equipped with external receiver clocks

Clock Product Processing

Combination is re-referenced to IGS Clock Ensemble (ICE22) output forming IGST.



Mutli-GNSS Product Status

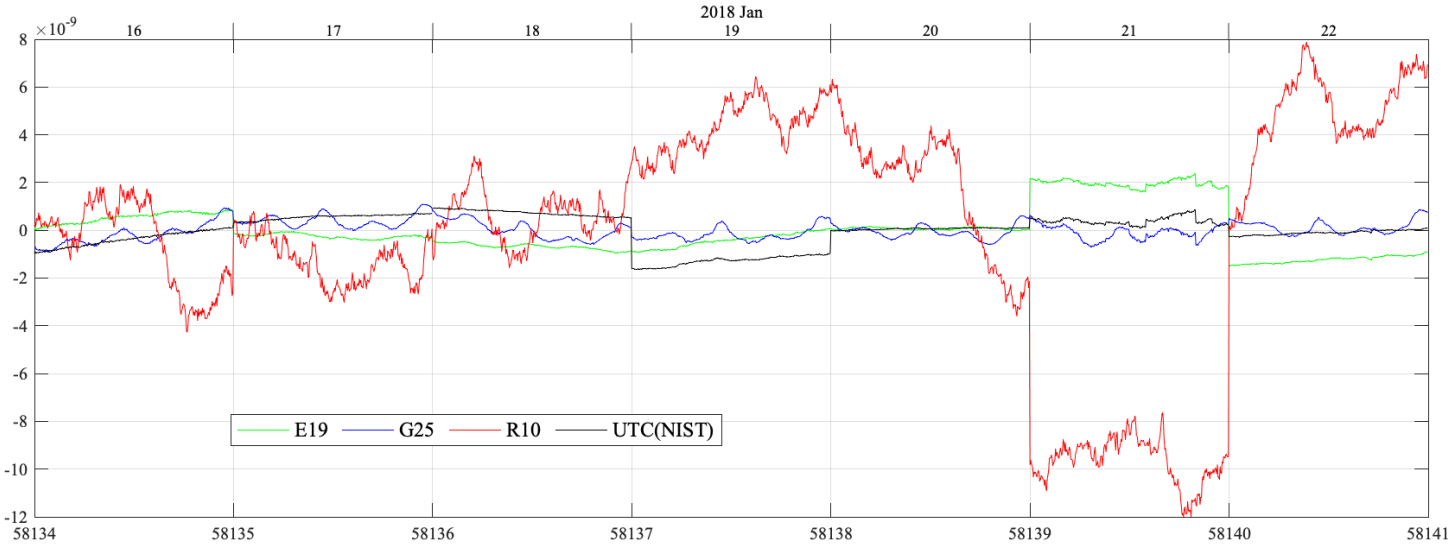
Product Changes

- IGS core products are expanding to include orbit and clock solutions for GPS, GAL and GLO.
- Rinex format updated to v4.00 to accommodate new updates.
- Clock Rinex format undergoing updates as well.

Satellite Clocks	2018	2020
• Galileo	16	24
• GPS	31	32
• GLONASS	23	21
Total	70	77

Product Updates

- Clock combination reprocessing effort completed earlier this summer.
- Timescale reprocessing underway now. Image right shows earlier first stage solution.
- Un-corrected day boundary jump shown around 21 January 2018.



Support for Future of WGS – 84

ITRF has been evolved for last ~30 years

- Updated every ~4-5 years using more recent data and models.
- Most recent update ITRF2020 in April 2022.
- Easier access to the latest frame using GNSS.
- Precision and stability has been improving over time.
  - Improved geophysical models
  - Longer time series
  - Adding more stations
  - Improved processing technique

Main Contact:
Kevin Choi
Naval Research Lab

WGS84 has been loosely aligned to ITRF

- World Geodetic System 1984 (WGS84): Reference Frame for GPS system
- WGS 84 is using subset of IGS core stations + NGA stations

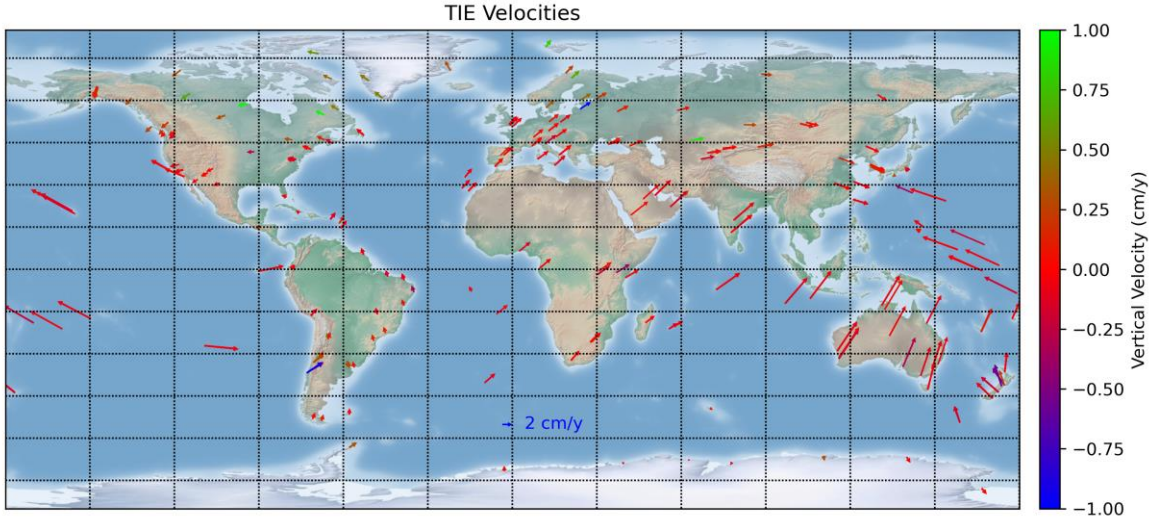
Support for Future of WGS – 84

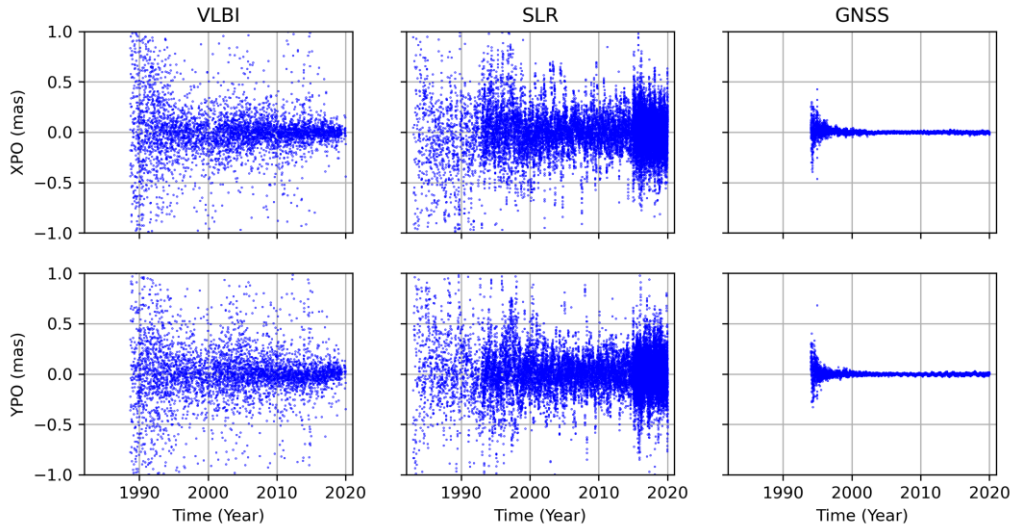
Working on WGS84 to be fully consistent with ITRF

- Developing a new system to realize a global TRF to be more tightly consistent with ITRF (Equivalent algorithms)
- Use of consistent metadata information, Post-Seismic Deformation (PSD) model parameters.
- Enables to monitor the frame evolution of the frame though time.

Preliminary Results (G55C-0271, AGU Fall mtg. 2021)

- Comparable results on EOPs and PV of stations with ITRF.

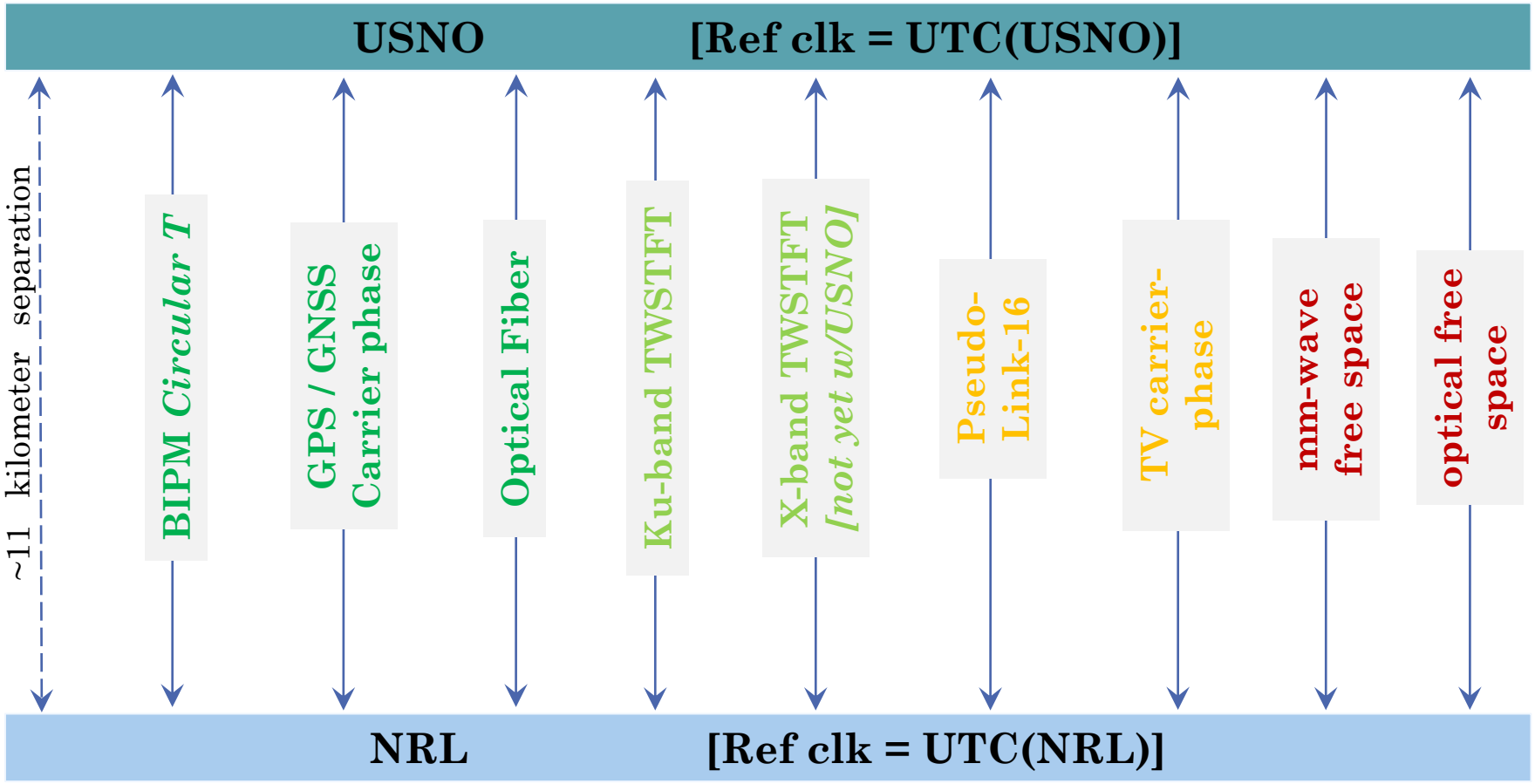




NRL – USNO Time Transfer Test Bed

- NRL and USNO are unique in that they are independent timing laboratories with line of sight availability.
- Long term goal of this test bed is to maintain a suite of known time transfer techniques between these two sites.
- Techniques or clocks can be compared between sites.
- New techniques could be precisely evaluated against any subset (or all) of existing operational techniques.

NRL – USNO Time Transfer Test Bed



Operational

Recently Started

Needs Repair

In Development

Other sites involved: APL, NIST

Main Contact:
Christine Hackman
Naval Research Lab

ION / PTTI 2023 Meeting

Long Beach, CA

23 – 26 January 2023

Topics:

Advanced and Future Clocks

Environmental Impacts on Clocks and Time Transfer

Low SWaP Clocks and Oscillators for 5G and Beyond

Mathematical Models and Algorithms for Timing Applications

Novel Methods in Time and Frequency Transfer

Present and Future Space Clocks

Recent Innovations at Time Laboratories and NMIs

Novel Methods in Time and Frequency Transfer

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Recent Innovations at Time Laboratories & NMIs

Role of Timing and its Maintenance in Present and Future GNSS Architectures

Time Transfer and PNT from Proliferated LEO Constellations

Time Transfer over Comms and Unconventional Methods

Dr. Sven-Christian Ebenhag, General Chair

Research Institute of Sweden

Dr. Daphna Enzer, Program Chair

Jet Propulsion Laboratory

Abstracts Due: 07 October 2022