# Selected Results from Testing the IVS INT01 BA 50 Balanced Scheduling Strategy

**Karen Baver and John Gipson**

NVI, Inc., Greenbelt, MD, USA

## Introduction

The International VLBI Service for Geodesy and Astrometry (IVS) observes one-hour sessions called INT01s that provide quick, preliminary UT1-TAI (UT1) estimates, are scheduled by the United States Naval Observatory (USNO), and usually observe with two stations, Kokee (Hawaii, USA) and Wettzell (Germany). The original "STN" source set used for scheduling the INT01s is strong but has bad sky coverage that leads to high UT1 formal errors at times of the year. Our 2009 alternative, the "MSS" strategy, offers good sky coverage but weak sources that increase the UT1 formal errors at other times of the year. Our 2016 "BA 50" strategy balances sky coverage and source strength. Here we compare the BA 50 to the MSS through six R&Ds and three months of operational INT01 observing.

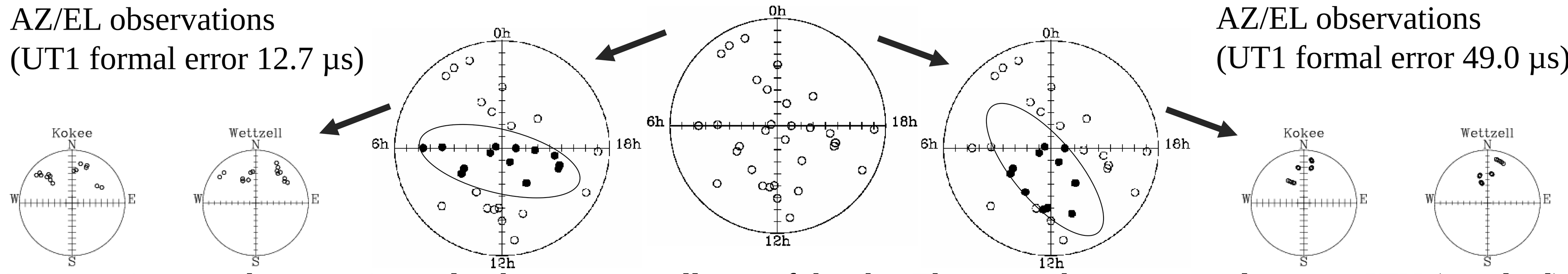
## High UT1 Formal Errors: Source Set Problem and Solutions

**Problem:**

2000: STN source set

mid November sources — early October sources

AZ/EL observations (UT1 formal error 12.7 µs) — AZ/EL observations (UT1 formal error 49.0 µs)

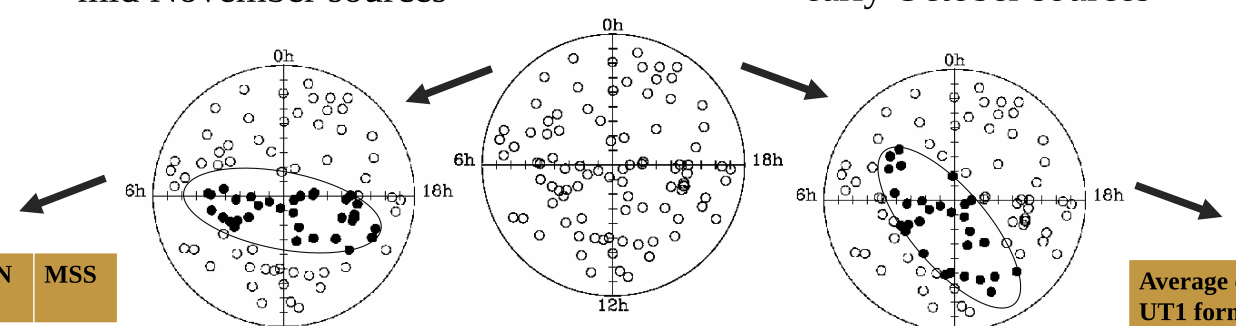


A two station, one-hour session only observes a small part of the sky. The strong but sparse and uneven STN (standard) set of sources (quasars) leads to good source coverage (dark circles in oval) and in turn good AZ-EL observation coverage (width) at some times of the year, such as early to mid November, but bad coverage at other times, such as early to mid October. Narrow AZ-EL observation coverage leads to high UT1-TAI (UT1) formal errors[1].

**Solution 1:**

2009: MSS strategy

mid November sources — early October sources



| Average observed UT1 formal error (µs) | STN | MSS |
|---|---|---|
| first half November 2011, 2012 | 10.0 | 12.0 |

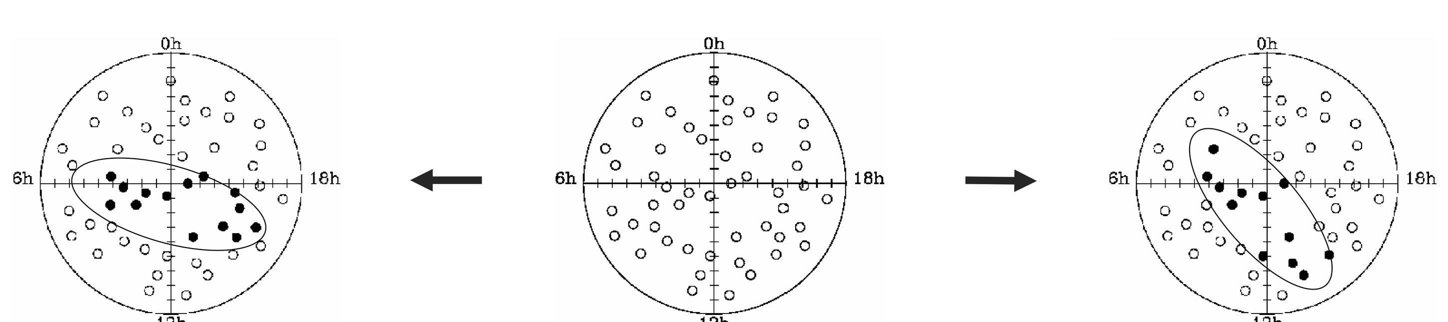
| Average observed UT1 formal error (µs) | STN | MSS |
|---|---|---|
| first half October 2011, 2012 | 32.0 | 15.1 |

We tested the use of all available geodetic sources (Maximal Source Strategy or MSS) in nine 2009/2010 R&Ds, and USNO alternated the MSS with the STN in IVS-INT01 operational sessions from mid 2010 to mid 2016, when USNO discontinued the STN. The MSS source coverage is good (wide) throughout the year, and its use reduced the average UT1 formal error in the first half of October in 2011 and 2012 by over 50%[2]. But the MSS introduces weak sources that lead to longer and fewer observations, and the average UT1 formal error in the first half of November in 2011 and 2012 was raised by 20%[2]. The MSS source set also shows redundancy (multiple, close sources, indicating weak sources with no gain in sky coverage).

**Solution 2:**

2016: BA 50 strategy

mid November sources — early October sources

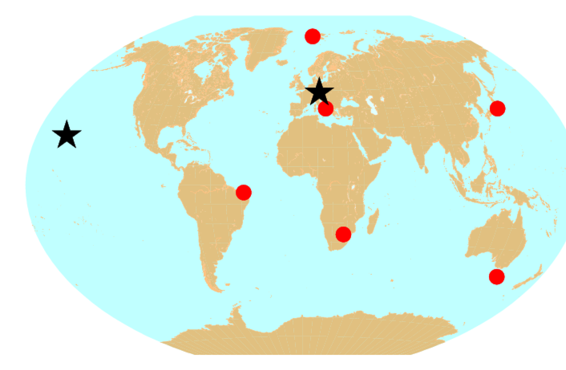


We used our Sked program's Bestsource command to balance sky coverage and source strength and create source sets of varying sizes (30, 40, …, 90 sources). All source sets led to schedules with a lower average UT1 formal error than the STN and MSS schedules' UT1 formal errors in simulations. A 50 source ("Balanced 50" or "BA 50") set worked best when other metrics (e.g., sensitivity to the loss of all observations of a source) were considered. The BA 50 source set had good, even coverage without redundancy. The IVS allotted six R&D sessions for us to test the BA 50 strategy.

## R&D Tests

**Design**

Six 2016/2017 R&Ds with two independent networks per R&D




**24-hour network:** One 24-hour session with approximately six varying stations. Provided a UT1-TAI (UT1) offset and rate for extrapolation to the 24 Intensive epochs. Comparison of the Intensive UT1 estimates to the 24-hour extrapolated values assessed the accuracy of the Intensive estimates (not shown in this poster).

**Intensive network:** 24 one-hour Intensives that observed with Wettzell and Kokee starting at the same 24 evenly spaced GSTs to test the BA 50 against the MSS at 24 areas of the sky as shown in the table below. This provided 12 MSS and 12 BA 50 UT1-TAI (UT1) formal errors per R&D for a total of 72 MSS and 72 BA 50 formal errors, with three MSS and three BA 50 formal errors per GST. A new BA 50 source set was generated for each R&D to use up-to-date source fluxes (strengths).

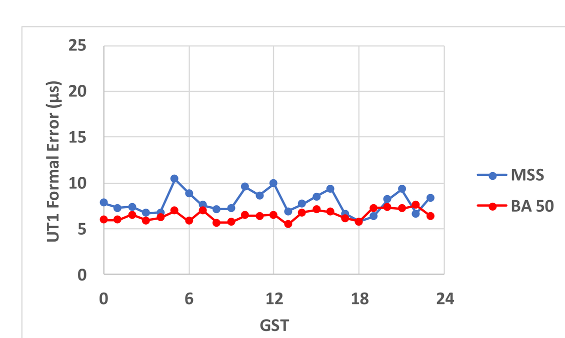
| GST | = observing around | RD 1608 | RD 1610 | RD 1701 | RD 1702 | RD 1706 | RD 1707 |
|---|---|---|---|---|---|---|---|
| 00:00 | December 13 | MSS | BA 50 | MSS | BA 50 | MSS | BA 50 |
| 01:00 | December 28 | BA 50 | MSS | BA 50 | MSS | BA 50 | MSS |
| | | | | … | | | |
| 19:00 | September 27 | BA 50 | MSS | BA 50 | MSS | BA 50 | MSS |
| 20:00 | October 13/14 | MSS | BA 50 | MSS | BA 50 | MSS | BA 50 |
| 21:00 | October 28/29 | BA 50 | MSS | BA 50 | MSS | BA 50 | MSS |
| 22.00 | November 12 | MSS | BA 50 | MSS | BA 50 | MSS | BA 50 |
| 23:00 | November 27 | BA 50 | MSS | BA 50 | MSS | BA 50 | MSS |

**Results[3]**

Predicted (unweighted) UT1 formal errors from schedules

| µs | MSS | BA 50 |
|---|---|---|
| Avg | 7.9 | 6.5 |
| STDev | 1.5 | 1.0 |

Improvement: average 1.4 µs (18%)
standard deviation 0.5 µs (33%)

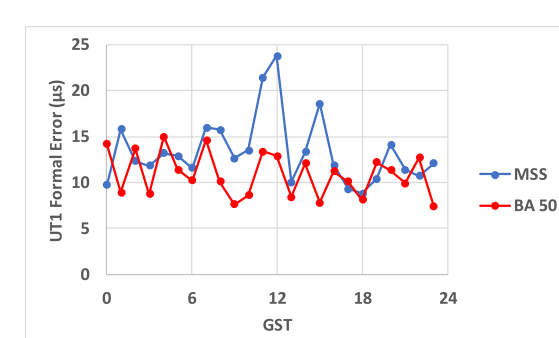



The average BA 50 UT1 formal error is lower at 21 of the 24 GSTs.

Observed (weighted) UT1 formal errors from data

| µs | MSS | BA 50 |
|---|---|---|
| Avg | 13.4 | 10.8 |
| STDev | 6.3 | 5.2 |

Improvement: average 2.6 µs (19%)
standard deviation 1.1 µs (17%)




The average BA 50 UT1 formal error is lower at 18 of the 24 GSTs.

**Summary:** The BA 50 strategy provides a lower average UT1 formal error over all R&D data and at most GSTs. USNO agreed to use it in the operational INT01 sessions for a three month trial, in alternation with the MSS strategy.

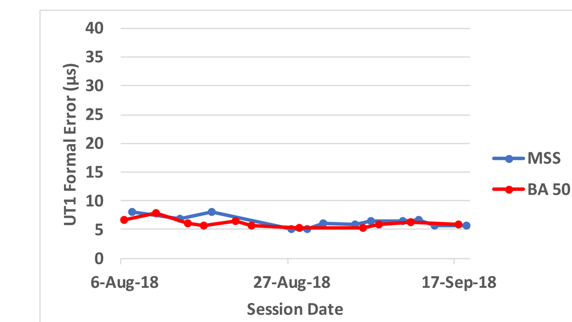
## First Operational INT01 Results (Three Month Trial)

**Data Set 1: Normal operating conditions**

**i18218 to i18264 (18AUG06 through 18SEP21): 12 MSS sessions, 11 BA 50 sessions**

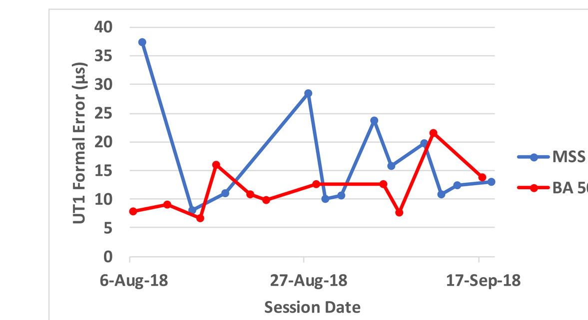
Predicted (unweighted) UT1 formal errors

| µs | MSS | BA 50 |
|---|---|---|
| Avg | 6.4 | 6.1 |
| STDev | 1.0 | 0.7 |




Observed (weighted) UT1 formal errors

| µs | MSS | BA 50 |
|---|---|---|
| Avg | 16.8 | 11.7 |
| STDev | 8.5 | 4.1 |



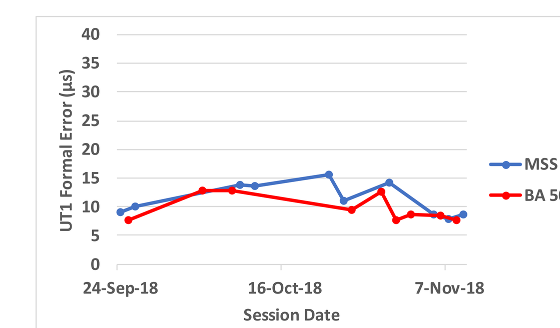

A BA 50 source set generated in June 2018 was used. The data's time frame does not experience notable UT1-TAI (UT1) formal error problems and is an "average" case. The BA 50 observed errors show a 30% reduction, but so do the session fits, which influence the UT1 formal errors. Our initial conclusion is that the predicted and observed BA 50 UT1 formal errors are comparable to the MSS formal errors for an average case and as scheduled in the R&Ds.

**Data Set 2: Kokee's scheduled SEFDs were raised due to a warm receiver**

**i18267 to i18313 (18SEP24 through 18NOV09): 10 MSS sessions, 9 BA 50 sessions**

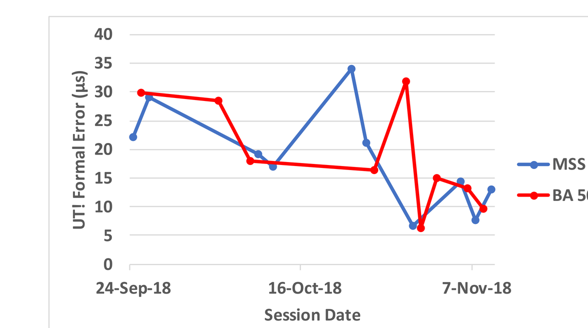
Predicted (unweighted) UT1 formal errors

| µs | MSS | BA 50 |
|---|---|---|
| Avg | 11.3 | 9.7 |
| STDev | 2.7 | 2.2 |




Observed (weighted) UT1 formal errors

| µs | MSS | BA 50 |
|---|---|---|
| Avg | 18.4 | 18.7 |
| STDev | 8.3 | 8.7 |




The June 2018 BA 50 source set was used. The data's time frame includes early to mid October (when the STN fails) and part of early to mid November (when the MSS UT1 formal errors increase). The BA 50's average predicted UT1 formal error shows a 13% reduction. Its observed average increases slightly, even with session fits considered, but the increase is acceptable. Our initial conclusion is that the BA 50 UT1 formal errors are acceptable for a case of equipment failure and for two critical times of the year.

**Outlook:** USNO considers the BA 50 UT1-TAI estimates to be acceptable so far, and USNO has continued the BA 50's use past the initial trial period for an indefinite length of time.

## Conclusions, References, and Acknowledgements

The BA 50 strategy was designed to balance sky coverage and source strength. The use of the BA 50 in six R&Ds reduced the average UT1 formal errors by ~20% when compared to sessions scheduled with the MSS strategy, which emphasizes sky coverage over source strength. The BA 50 UT1 formal errors were comparable to the MSS UT1 formal errors in three months of operational INT01 observing, even when a station had a warm receiver.

**1)** M. Uunila, A. Nothnagel, J. Leek, N. Kareinen, Influence of Source Distribution on UT1 Derived from IVS INT1 Sessions, Proc. 21st Meeting of the EVGA, 111-115. **2)** J. Gipson, K. Baver, Improvement of the IVS-INT01 Sessions by Source Selection: Development and Evaluation of the Maximal Source Strategy, Journal of Geodesy, 90(3), 287-303, DOI: 10.1007/s00190-015-0873-6. **3)** K. Baver, J. Gipson, UT1 Formal Errors from the BA 50 Balanced Scheduling Strategy INT01 R&Ds, IVS 2018 General Meeting Proceedings, in press.

We thank the IVS for the six R&Ds and Merri Sue Carter (USNO Flagstaff) for scheduling the BA 50 in the INT01s.

AGU 2018 Fall Meeting, Washington, DC, USA

**G31B-0660**

*E-mail contact: Karen Baver (karen.d.baver@nasa.gov)*