Refining the Uniform Sky Strategy for IVS-INT01 Scheduling

Karen Baver[1] and John Gipson[1]

[1] NVI, Inc., Greenbelt MD, 20771

Background

Problem: Better sky coverage is empirically linked to better UT1 estimate precision and accuracy. But the original, standard ("STN") scheduling strategy uses only the strongest sources, and because strong sources are unevenly distributed, IVS-INT01 sessions have limited source availability and bad sky coverage at some times of the year. The worst source availability occurs in October, but source availability at other times of the year could also use improvement.

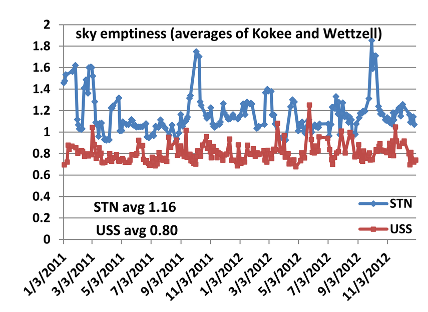
Initial solution: The USS (Uniform Sky Strategy) uses all geodetic sources that are mutually visible at the regular IVS-INT01 stations, Kokee and Wettzell. The IVS NEOS Operation Center began continuous use of this strategy on alternating days in late 2010.

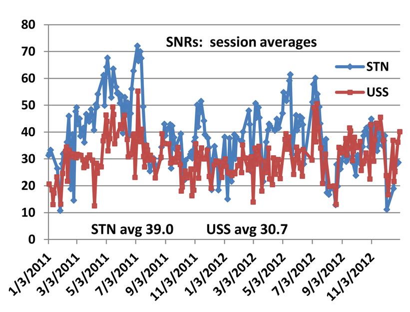
Drawbacks: The USS introduces weaker sources that take longer to observe and reduce the number of observations. Lower source strength and a lower number of observations increase the UT1 formal error, creating trade-offs.

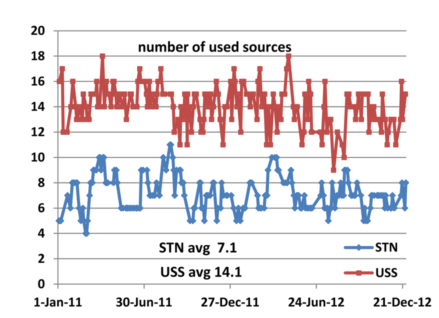
Overview: In 2012 we evaluated the first full year (2011) of alternating STN and USS sessions. The STN and the USS were each superior in some ways. The 2011-2012 data confirms the initial study, indicating a need to refine the USS. Here we present the 2011-2012 data, examine factors that affect schedule performance, and explore ways to use the Sked scheduling program to improve schedule performance.

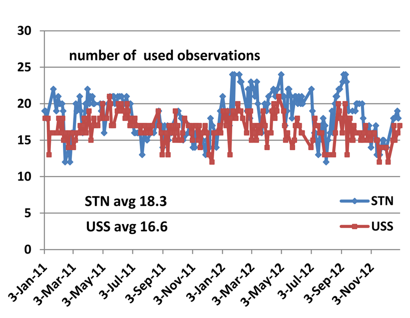
2011-2012 Data: Accuracy and Results

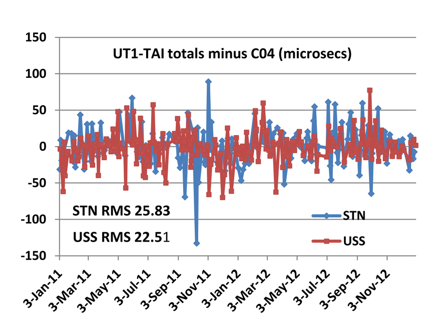
Analysis of the 2011-2012 data confirms the results from the initial study of the 2011 data. On the one hand, the USS has better sky coverage. On the other hand it has, on average, higher UT1 formal errors. The October UT1 formal errors are greatly improved, except for one noisy session, but the UT1 formal errors at some other times of the year could still use improvement. Please note that the first plot indirectly shows sky coverage by showing sky emptiness; a smaller value means less emptiness, or more coverage).

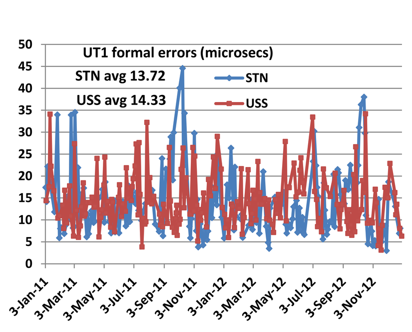




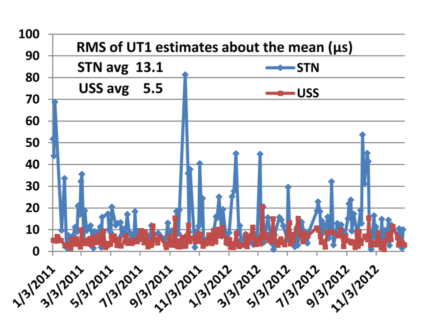


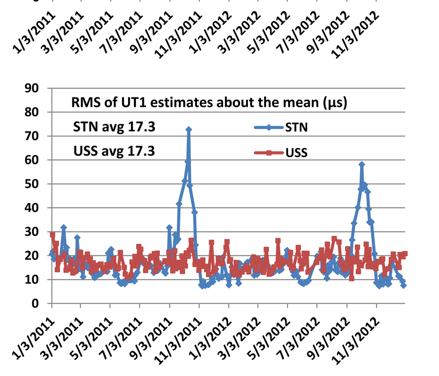






2011-2012 Data: Simulations





Test 1: Effect of source loss on UT1 estimates.

Method: For every session, we ran solutions that removed every source, one at a time.

Conclusion: As in the 2011 data set, the USS provides much better protection against source loss than the STN does.

Test 2: Effect of noise on UT1 estimates.

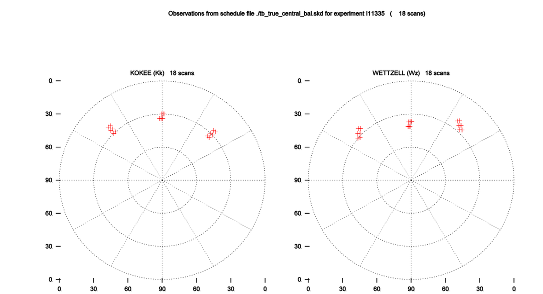
Method: We ran 5000 solutions for every session, adding noise each time.

Conclusion: The STN's protection against noise improved this time and tied the USS's. The USS's only benefit was protection against spikes such as in October of each year. Its protection against noise must still be improved.

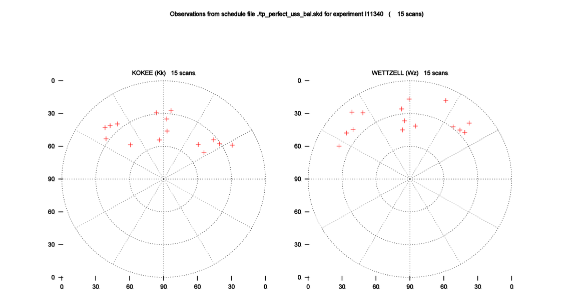
Effect of Temporal Distribution on Performance

Goal: Investigate the effect of temporal distribution on the RMS about the mean of the UT1 adjustments and on the unscaled UT1 formal error.

Method: We used Sked to make an STN-style schedule (three observations each of six sources) and a USS-style schedule (15 observations of 15 sources) with equal numbers of left quadrant (L), central (C), and right quadrant (R) hypothetical sources. The schedules cycled through the three areas evenly. We created two variations of each schedule to a) observe all of the C, then L, then R sources and b) all of the L, then C, then R sources. We ran 5000 solutions per schedule, adding noise to simulate atmospheric turbulence.



STN-style: Kokee (left), Wettzell observations



USS-style: Kokee (left), Wettzell observations

Results: The test supports the idea that temporal distribution matters. Balanced distribution gives continuous temporal coverage and good results. The CLR and LCR leave areas uncovered for long periods of time and give bad results.

Observation order L=left quadrant, R=right quadrant, C= center (near azimuth 0)	RMS about the mean of the UT1 adjustments (µs) STN style	RMS about the mean of the UT1 adjustments (µs) USS style	Unscaled UT1 formal error (µs) STN style	Unscaled UT1 formal error (µs) USS style
LRC LRC LRC LRC LRC	9.89	13.35	7.45	10.27
CCCCC LLLLL RRRRR	38.42	23.64	17.58	16.06
LLLLL CCCCC RRRRR	36.41	40.29	18.44	23.51

Effects of Spatial Distribution on Schedule Performance

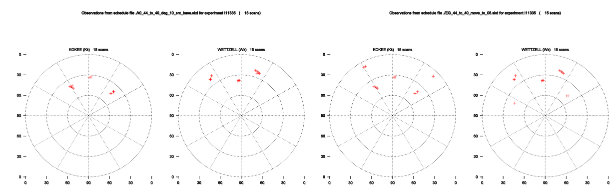
Low elevation observations:

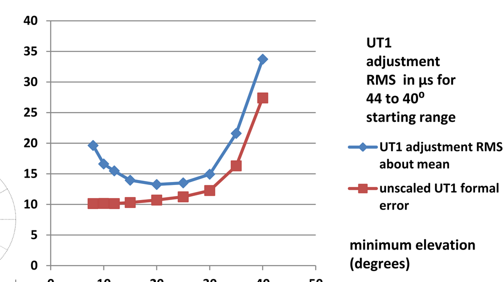
Goal: Study the effect of low elevation observations on the UT1 adjustments' RMS about the mean and the unscaled UT1 formal error.

Method: We used Sked to create 15 baseline cases with maximum elevations of 44, 40, 35, 30, and 25° and minimum elevations of 40, 35, 30, 25, and 20° (i.e., 44-40 , 44-35, …, 44-20, 40-35, …, 25-20°). For each case, we generated a set of schedules that moved four observations from the minimum elevation to a series of lower elevations (35, 30, 25, 20, 15, 12, 10, and 8°), along azimuths 45° and 330/332° at Kokee (i.e, for the baseline case 44-30°, the observations moved to 25, 20, 15, 12, 10, and 8°). We limited azimuth coverage to isolate the effects of elevation. We used hypothetical sources to achieve the desired positions. We then ran 5000 solutions on each schedule, adding noise to simulate atmospheric turbulence.

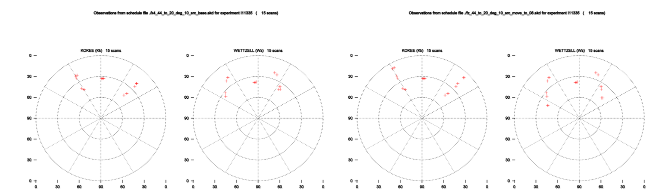
Results: For high starting elevations, adding low elevation observations first decreases, then increases the RMS. Probably these cases start with such limited elevation coverage that the decrease helps until a transition point is reached (~20° for the azimuths studied). More normal, lower starting elevations start near the transition point, so adding lower elevation observations tends to hurt the RMS. 8° observations hurt the RMS for all but one severely limited case (starting range 44-40°). Low elevation observations decrease the UT1 formal error.

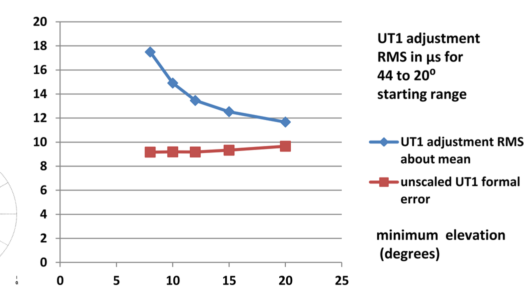
44-40° case: LEFT: baseline sky plots at Kokee (left) and Wettzell (right); MIDDLE: 8° minimum sky plots at Kokee and Wettzell; RIGHT: statistics for all 44-40° cases.





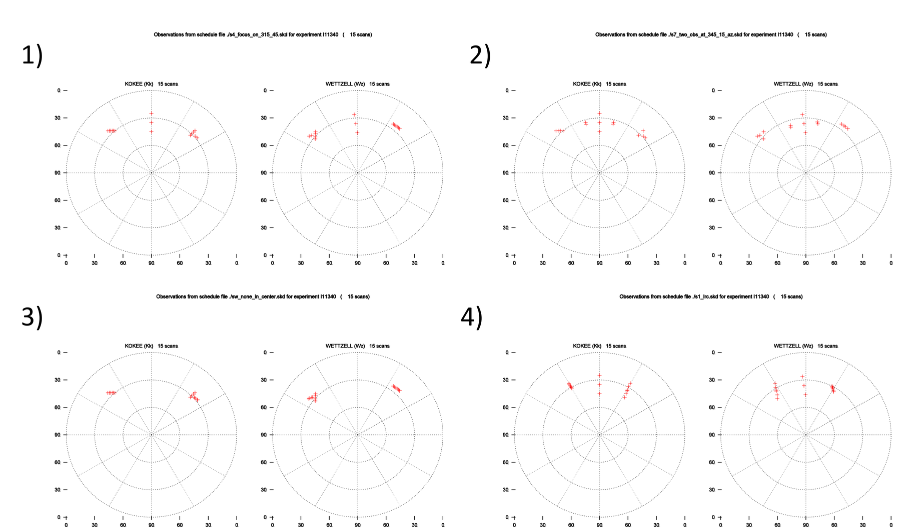
44-20° case: LEFT: baseline sky plots at Kokee (left) and Wettzell (right); MIDDLE: 8° minimum sky plots at Kokee and Wettzell; RIGHT: statistics for all 44-20° cases.





Coverage of key areas (azimuth 0° and the centers of the mutually visible quadrants):

Working with the 2011 data indicated that low values for the RMS about the mean of the UT1 adjustments might be tied to covering the quadrant centers and, to a lesser extent, azimuth 0° roughly near elevation 30°. We used Sked to create a schedule with hypothetical sources that covered only the key areas. Then we moved observations away from the areas and ran 5000 solutions that added noise.



Pairs of azimuth-elevation observation plots (Kokee left, Wettzell right)

Case	RMS about the mean of the UT1 adjustments (µs)	Unscaled UT1 formal error (µs)
1) Fully covers all three areas at a ratio that has been empirically identified as desirable (2-1-2 where 1 represents the coverage of azimuth 0°).	11.82	9.90
2) All areas are covered, but the quadrant centers are only partially covered because some observations have moved.	13.50	10.84
3) Coverage of azimuth 0° is missing.	14.09	11.96
4) All quadrant center observations have moved, leaving the quadrant centers uncovered.	26.40	22.75

More testing is necessary, but these cases support the idea that covering the three key areas might help the RMS (as well as the UT1 formal error), with the quadrant centers having more importance than azimuth 0°.

Using Sked to Improve Schedule Performance

Next we investigated applying the above information to 26 real IVS-INT01 USS source sets spaced two weeks apart. We changed a series of parameters or small sets of related parameters (e.g., an elevation cutoff) to simulate manual scheduling done above. We also tried to improve source strength. Then we ran 5000 solutions for each schedule, adding noise.

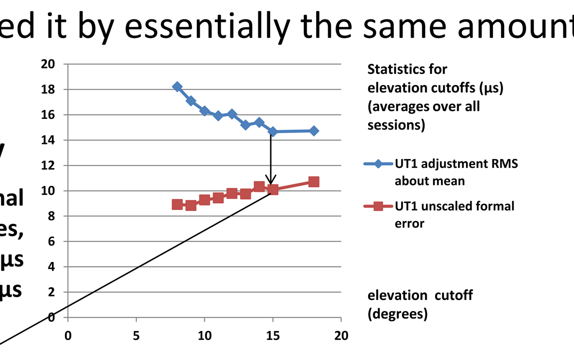
Effect of individual parameters:

Goal for improvement	Sked parameters tested	Purpose	Values tried	Values that gave significant improvement
Stronger sources	Endscan weight	Preferentially selects scans that end sooner. These tend to be stronger sources.	2.0, 3.0, 4.0	None
	Maxscan Snr Margin	Maximum allowed scan time. Reducing this excludes weaker sources that cannot achieve an acceptable SNR in the allotted time. Target minimum SNR Snr minus Margin = absolute minimum SNR	Various combinations; only one produced viable schedules for all 26 cases	Maxscan 200 seconds (standard) X/S Snr 20/15 X/S Margin 4/4
Reduction of low elevation observations	Elevation cutoff	Minimum elevation allowed for observations.	9, 10, 11,12,13,14,15,18°	10° and higher
Coverage of key areas	Horizon mask (STATION section H line)	Specifies an elevation cutoff for ranges of azimuths. We set the cutoff to 0° outside key areas. Then we varied the cutoff starting at 8° within key areas. We used this to force Sked to only schedule observations in the key areas.	For azimuth ranges 300-330°, 350-10°, 30-60° Kokee only: elevation cutoff 8,10,12,15° Kokee and Wettzell: elevation cutoff 8, 10° (elevation cutoff was 0° elsewhere)	Kokee only: elevation 10° and higher Kokee/Wettzell: none
Better temporal distribution	Minangle	Minimum sky angle between two successive observations. We raised this in an effort to spread observations (at least successive ones) around.	20,25,30,35,40° Also 45° (but it did not produce viable schedules for all 26 cases)	30° only

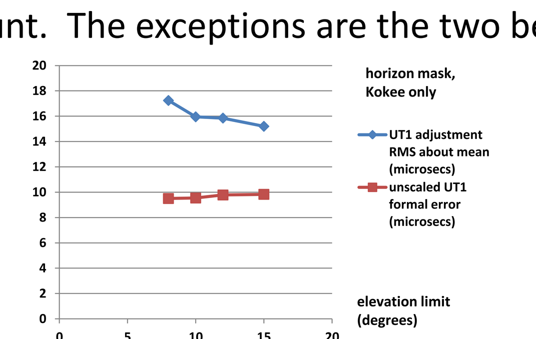
Some parameters made no significant improvement and are not mentioned below. Most parameters that significantly improved the RMS improved it by essentially the same amount. The exceptions are the two best parameters, elevation cutoffs of 15° and 18°.

Cases by category

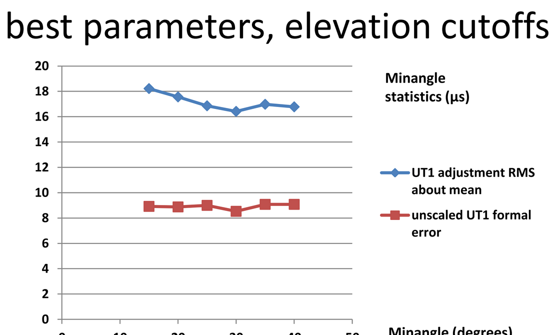
With normal Sked values, RMS = 18.2 µs F.E. = 8.92 µs



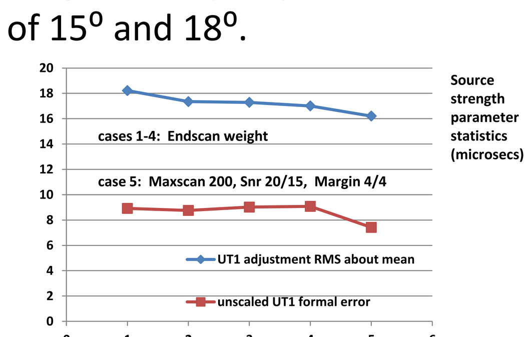
As the **elevation cutoff** rises, the RMS falls, but the UT1 formal error rises, probably due to changes in azimuth coverage. This might require a trade-off.



More testing is needed to separate the effect of the **horizon mask**'s azimuth and elevation components.

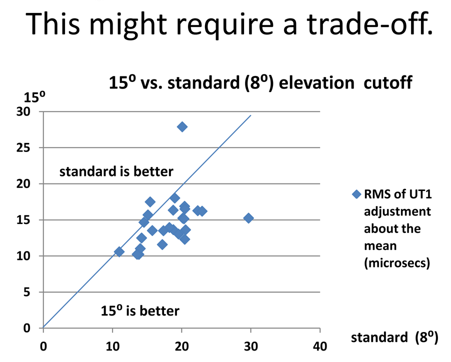


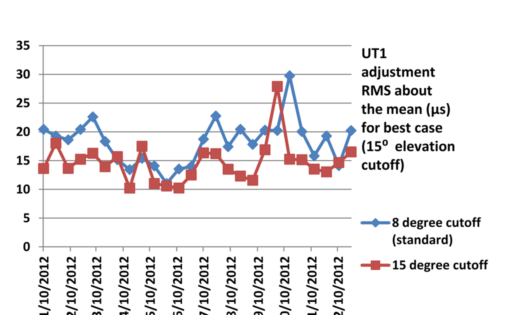
Minangle only separates successive observations, so the third observation can be close to the first. A Sked option that provides more separation might lower the RMS.

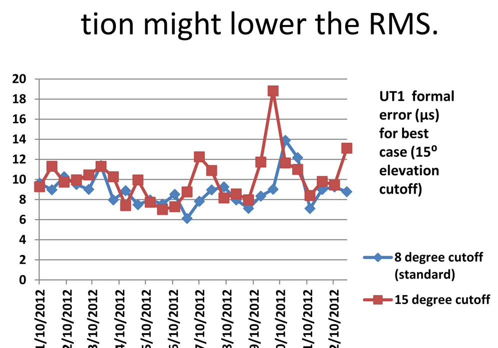


The **Endscan** weight did not significantly improve the RMS. The **Maxscan** parameter set did, but not as well as the 15° elevation cutoff did.

Best case (15° elevation cutoff)



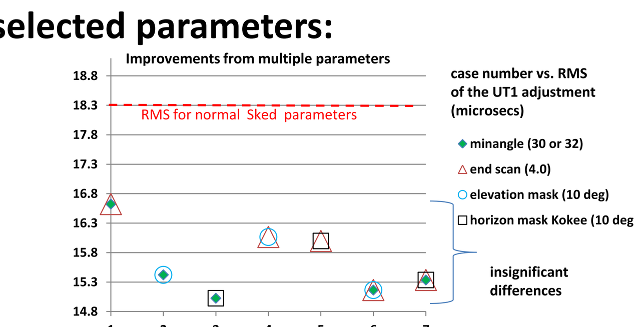




Comparison of the **15° elevation cutoff** to standard parameters for the 26 cases. The largest RMS spike is on 10/2, which has pathological sky coverage. Removal of its low elevation sources leaves Wettzell with no sources below 32° in one quadrant. Early October might need special handling if an elevation cutoff is used. Other sessions also need improvement.

Effect of combining selected parameters:

Averages over 26 source sets:



- •All seven cases had essentially the same effect.
- •The use of the Endscan weight did not greatly change the effect of the parameters with which it was paired. It can be discarded.
- •The combinations did not improve the RMS more than the two best individual cases (the 15° and 18° elevation cutoffs) did.

Conclusions and Acknowledgements

- The need to refine the USS remains. Target areas are removing low elevation observations, improving temporal distribution, improving coverage of key areas, and improving source strength.
- The best Sked parameter identified so far is an elevation cutoff of 15°, but this raises the UT1 adjustments' RMS in early October sessions. These sessions might require special handling.
- The 15° elevation cutoff improves the average RMS from 18.2 to 14.7 µs, but additional improvement would be desirable.
- New Sked parameters should be tested or developed to improve the USS.

We thank Merri Sue Carter (NEOS Operation Center, USNO Flagstaff Station) for her continued generation of alternating schedules.

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Contact author: Karen Baver
NVI, Inc.
Greenbelt, MD 20771, USA
karen.d.baver@nasa.gov