Reduction of the IVS-INT01 UT1 Formal Error Through New Sked Algorithms

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General Information

Our past work has yielded information about spatio-temporal criteria for scheduling IVS-INT01 sessions' observations in order to try to improve the sessions' UT1 formal errors. We have added two new algorithms to the *Sked* scheduling program on a trial basis to use what we have learned to try to reduce the UT1 formal errors of test INT01 schedules. Here we report on the application of the following algorithms:

- Spatial algorithm • Temporal algorithm (four variations) • Combination

to the following INT01 types:

- MSS (operational (SX)) • BA 50 (SX type being tested in R&Ds) • Proposed VGOS INT

Sked selects observations in two stages. First it discards bad (e.g., too long) observations. Then it ranks the remaining observations according to sky coverage or covariances and selects the best N %, where N is user-specified. The second stage scores these trial observations using *minor* commands and develops a cumulative score over all of the commands for each observation. The observation with the highest score is scheduled. The test algorithms are stage 2 commands.

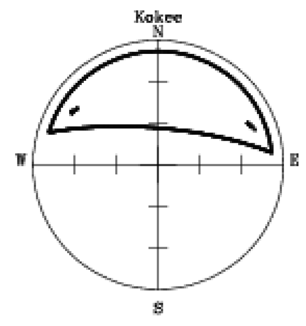
Temporal criterion: Our 2013 work[1] showed that UT1 formal errors are improved.when observations cycle evenly through sections of the sky instead of repeating in one area of the sky.

Sky Section Algorithm (SSA): divides the sky into 2, 3, 4, or 6 sections and scores observations by how long it has been since an observation has been scheduled in the trial observation's sky section. A longer time results in a higher score.

Observation order near elevation 30° L = azimuth 315°, C = azimuth 0°, R=azimuth 45°	UT1 Formal Error (µs)
LRC LRC LRC LRC LRC	10.27
CCCCC LLLLL RRRRR	16.06
LLLLL CCCCC RRRRR	23.51

Spatial criterion: Our 2015 minimization work[2] showed that UT1 formal errors are minimized when observations cluster near 303.2° or 67.1° azimuth at Kokee (290.7° or 54.7° at Wettzell) at 18.7° elevation.

Minimization Target Algorithm (MTA): Calculates the distance from the trial observations to the target spots. A shorter distance results in a higher score.



Approach:

- test a) 2, 3, 4, and 6 sky section SSA, b) MTA, and c) MTA with 2 section SSA, passing 25% of the stage 1 observations (the operational INT01 percentage) to stage 2. Test at 26 days of the year using 11 flux catalogs to test a variety of source distributions and strengths.
- Enhance the algorithms' impact by passing 50%, 75%, or 100% of the observations from stage 1 to stage 2.
- Evaluate the schedules' UT1 formal errors through a quick, approximate method (*Mini_fe* program) to pick promising case(s) for more review.
- More fully evaluate these cases using more time-consuming Solve superfile simulations.

Superfile metrics:

- UT1 formal error (using the more detailed Sked-Calc/Solve code). Lower values are better.
- Sensitivity to atmospheric turbulence (RMS about the mean of UT1 estimates from 300 Solve solutions that apply random noise simulating atmospheric turbulence). Lower values are better.
- Sensitivity to source loss (RMS about the mean of UT1 estimates from Solve solutions in which each source in a schedule is deleted in turn). Lower values are better.

MSS: Operational SX INT01 Case

MSS UT1 formal error (µs) from schedules	control	SSA-2	SSA-3	SSA-4	SSA-6	MTA	MTA /SSA-2
Best 25%	8.29	8.06	7.81	7.70	7.77	7.93	7.94
Best 50%	8.77	7.90	7.64	7.44	7.53	7.48	7.43
Best 75%	9.13	8.09	7.38	7.21	7.30	7.65	6.69
Best 100%	9.14	8.80	7.27	7.05	7.04	7.33	6.35

MSS number of choices for each new observation in stage 2	Average overall
Best 25%	4.3
Best 100%	16.6

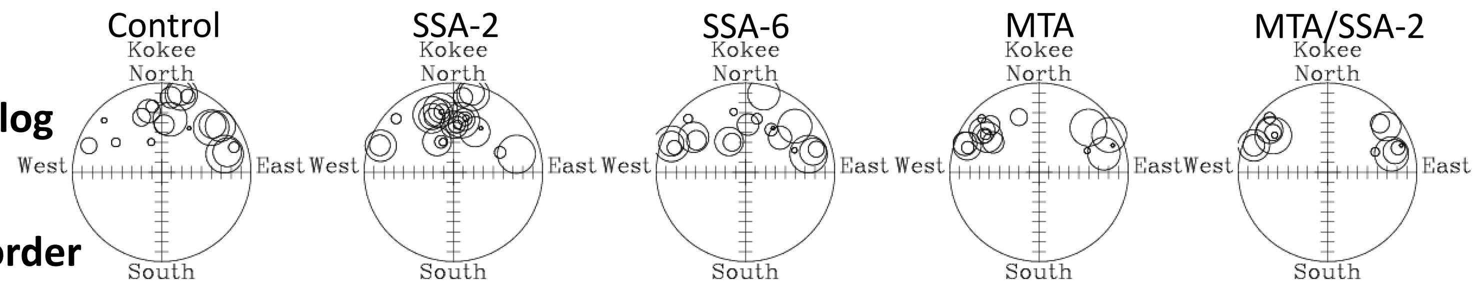
Schedule results: The algorithms' UT1 formal error range increases as the percentage of observations passed to stage 2 increases (from 0.36 µs for best 25%, through 0.47 and 1.4 µs to 2.45 µs for best 100%). The algorithms need choices to operate, and passing all observations to stage 2 provides 16.6 source choices per observation instead of 4.3 for best 25%. The UT1 formal error generally decreases as the percentage of observations passed increases. SSA-2 is the exception; increasing the percentage decreases stage 1 sky coverage optimization, substituting the SSA-2, which seems to be weak. SSA-4 is the best temporal algorithm. MTA/SSA-2 tends to be the strongest case overall. The most promising case for UT1 formal error reduction is the MTA/SSA-2 with best 100%, which combines and maximizes the temporal and spatial algorithms.

MSS metrics from superfile simulations	Avg Number Sources	Avg Number Observations	Avg UT1 formal error, µs	Avg Sensitivity to Atm Turb, µs	Avg Sensitivity to Source Loss, µs
Control, best 25%	16.70	19.83	7.37	16.35	12.08
MTA/SSA-2, best 100%	9.02	17.40	5.96	12.43	12.79
SSA-4, best 100%	15.03	21.21	6.17	13.76	10.67

Superfile metrics: MTA/SSA-2 reduced the superfile-based UT1 formal error from 7.37 to 5.96 µs, but it increased the sensitivity to source loss from 12.08 to 12.79 µs. This metric is linked to the number of sources, which dropped to 9.02, but it is also linked to sky coverage, so we tried the best non-spatial algorithm, SSA-4, with best 100%. This improved all metrics except the average number of scheduled sources with respect to the control case.

Kokee az/el plots 16May23 flux catalog DOY 108

Increasing size shows observing order



The control Kokee northwest quadrant is only observed near the start. The SSA-2 observing is temporally even between both quadrants but clusters spatially in the center. The SSA-6 is more spatially even. The MTA observes mostly near the targets but observes the northeast quadrant near the start and end only. The MTA/SSA-2 is more temporally even. This example is not necessarily typical, but it shows what the algorithms can do.

BA 50: SX Type Being Tested in R&Ds

BA 50 UT1 formal error (µs) from schedules	control	SSA-2	SSA-3	SSA-4	SSA-6	MTA	MTA /SSA-2
Best 25%	7.17	7.14	7.12	7.07	7.07	7.25	7.30
Best 50%	7.43	7.16	7.10	7.01	6.98	7.09*	7.03
Best 75%	7.80	7.54	7.13	6.99*	7.04	6.78	6.61
Best 100%	7.81*	8.14*	7.03*	6.97*	6.99*	6.20	6.24

BA 50 number of choices for each new observation in stage 2	Average overall
Best 25%	2.2
Best 100%	8.1

* Schedule(s) are too short for 1+ flux catalogs or DOYs using *Sked*'s autosked mode.

Schedule results: The BA 50 source list has as good sky coverage as the MSS', but it has ~ half the sources (50 vs. 90), giving ~ half the choices at each observation (2.2 vs. 4.3) With best 25%, the UT1 formal error range is only 0.23 µs, and the MTAs raise the formal error. The MTAs improve the UT1 formal error with best 100% but only by a modest ~ 1 µs. Best 100% produces too short schedules in the SSA cases. Only the best 75/100% MTAs are promising, and they are only somewhat promising.

BA 50 metrics from superfile simulations	Avg Number Sources	Avg Number Observations	Avg UT1 formal error, µs	Avg Sensitivity to Atm Turb, µs	Avg Sensitivity to Source Loss, µs
Control, best 25%	13.78	20.76	5.99	13.67	11.67
MTA, best 100%	9.35	20.71	5.36	12.57	14.20
MTA/SSA-2, best 100%	8.47	18.65	5.44	11.92	13.56

Superfile metrics: The two most promising cases (MTA cases with best 100%) only lower the UT1 formal error by ~ 0.6 µs, and, as with MSS, lower the number of scheduled sources and raise source loss sensitivity. The third best case, MTA/SSA-2/best 75%, is similar. The algorithms fail for BA 50.

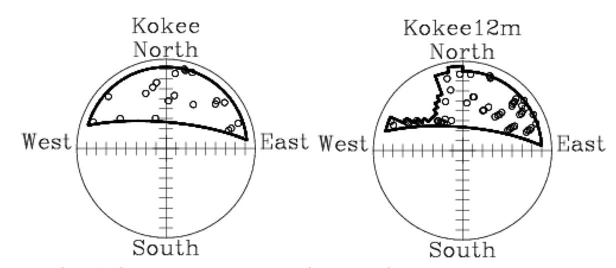
VGOS INT (Proposed Type with KOKEE12M and WETTZ13S)

VGOS INT UT1 formal error (µs) from realistic schedules	control	SSA-2	SSA-3	SSA-4	SSA-6	MTA	MTA /SSA-2
Best 25%	5.59	5.54	5.42	5.45*	5.43	5.59*	5.54*
Best 100%	4.91*	4.89	4.91	4.86	4.88	5.06	4.51

VGOS number of choices at each new observation	Average overall
Best 25%	2.2
Best 100%	7.6

* Schedule(s) are too short for 1+ flux catalogs or DOYs using *Sked*'s autosked mode.

Realistic schedules: VGOS INT schedules have as many sources as MSS schedules, but the KOKEE20M antenna blocks much of KOKEE12M's northwest horizon, eliminating some sources and reducing the effectiveness (and viability) of the algorithms. On average, the algorithms have only 2.2 sources to choose from when scheduling each new observation (best 25%). Best 100% raises this to 7.6 and lowers the UT1 formal error by up to 1 µs.



SX (left) and VGOS (right) area of mutual visibility with Wettzell at Kokee Park (area inside the dark lines).

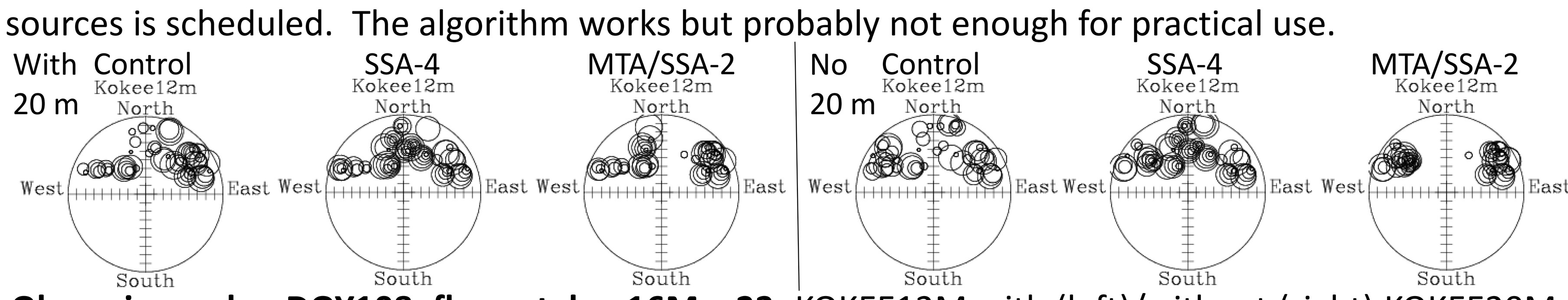
VGOS INT UT1 formal error (µs) from hypothetical schedules	control	SSA-2	SSA-3	SSA-4	SSA-6	MTA	MTA /SSA-2
Best 25% no KOKEE20M	4.01	3.98	4.06	4.06	4.05	4.08	4.06
Best 100% no KOKEE20M	3.97	3.92	3.83	3.83	3.90	3.31	3.27

VGOS number of choices at each new observation	Average overall
Best 25%, no 20M	3.6
Best 100%, no 20M	13.0

Hypothetical schedules: Removing the 20-m antenna improves sky coverage and the algorithms' effectiveness. It raises the number of choices for each observation from 2.2 to 3.6 (best 25%) and from 7.6 to 13.0 (best 100%). It results in the lowest VGOS UT1 formal errors in all seven categories.

VGOS INT metrics from realistic superfiles	Avg Number Sources	Avg Number Observations	Avg UT1 formal error, µs	Avg Sensitivity to Atm Turb, µs	Avg Sensitivity to Source Loss, µs
Control, best 25%	20.29	56.44	3.38	13.84	9.24
MTA/SSA-2, best 100%	16.89	59.88	2.72	10.54	9.07

Realistic superfiles: MTA/SSA-2, best 100% improves the UT1 formal error, but only by 0.66 µs. But sensitivity to source loss is reduced (although only slightly), perhaps because an average of ~ 17 sources is scheduled. The algorithm works but probably not enough for practical use.



Observing order, DOY108, flux catalog 16May23: KOKEE12M with (left)/without (right) KOKEE20M. With many observations, the observing order is probably less important than for MSS. MTA/SSA-2 with KOKEE20M deflects observations to the north and center and without it behaves as intended.

Conclusions

- The algorithms lower the UT1 formal error best when they have more sources to choose in the *Sked* stage that chooses the observations. The algorithms work best with the MSS, which has 90 sources and full sky coverage, and worse with the BA 50 (smaller source list) and the VGOS INT (worse sky coverage). Passing more observations to the selection stage helps the UT1 formal error.
- The maximized spatio-temporal combination MTA/SSA-2/100% generally gives the best UT1 formal error, but it schedules fewer sources and only slightly lowers (or even raises) source loss sensitivity.
- The most promising case tested is use of the SSA with four sky sections and 100% of the Sked first stage observations for the MSS. The best VGOS INT case tested lowers the metrics but not by enough for practical use. Usage of the algorithms for the BA 50 does not seem viable.

References

1. Baver, K. and Gipson, J., Refining the Uniform Sky Strategy for IVS-INT01 Scheduling, Proceedings of the 21st Meeting of the European VLBI Group for Geodesy and Astrometry, pages 205-209.
2. Gipson, J. and Baver, K., Minimization of the UT1 Formal Error through a Minimization Algorithm, Proceedings of the 22nd Meeting of the European VLBI Group for Geodesy and Astrometry., pages 230-234.

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