Balancing Sky Coverage and Source Strength in the Improvement of the IVS-INT01 Sessions

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Introduction

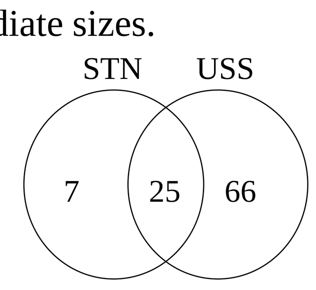
Two source sets are used for IVS-INT01 scheduling, the STN (a smaller but stronger set) and the USS (which has better sky coverage but includes weaker sources). Including weaker sources improves sky coverage, which should improve the UT1 formal errors, but it decreases source strength, which should degrade the UT1 formal errors. Evaluating the two source sets against three metrics gives mixed results. This poster examines two alternative series of source sets of comparable and intermediate sizes to see if better balancing of source strength and sky coverage improves performance.

Method

Algorithm: The bestsource (best) command of Sked, the program used to schedule the IVS-INT01 sessions, was used to pick source sets of different sizes for use in generating schedules. Bestsource selects the best N sources for a time period set by the schedule's span. Bestsource considers both source strength and sky coverage. Bestsource has two arguments. After preliminary simulations, we picked bestsource 2 3 as the most promising combination of values.

Goal: Test subsets of the geodetic source catalog of sizes comparable to the STN, sizes comparable to the USS and intermediate sizes.

Control source sets:



The STN and USS are source sets that are infrequently updated.

The STN has 19 additional sources with declinations too low to be observed.

The bestsource command reselects the source fluxes, so source fluxes were reselected for the STN and the USS.

Test source sets:

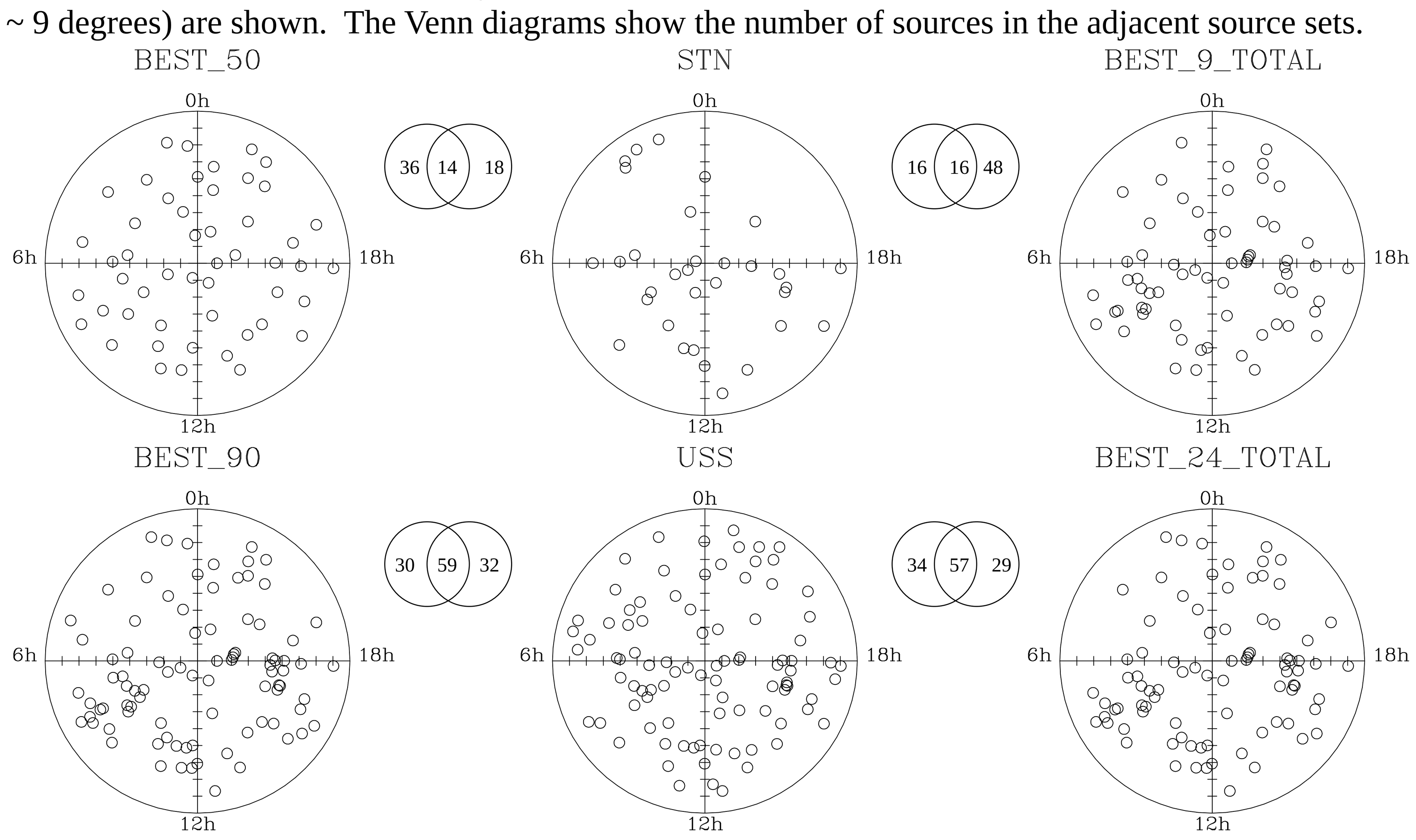
Strategy A: Pick the N geodetic sources that are best for a specific day of the year (set N = 9, 12, 15, 18, 21 and 24 with a time span of one hour). Test 26 days of the year spaced two weeks apart Pros: tailored to the day of the year of the session. Cons: picks some inferior sources..

Strategy B: Pick the best N sources from the entire geodetic catalog (set N = 40, 50, 60, 70, 80 and 90 with a time span of 24 hours). Apply these sets to the same 26 days of the year as in A. Pros: picks the best overall sources. Cons: some days of the year may have fewer sources.

Simulations: For each source set (e.g., best 40) and each of the 26 days of the year, we created a schedule template and determined the initially available sources. We created one schedule per source by selecting each source in turn, then running Sked's autosked mode to complete the schedule. This was an effort to provide more test cases per source set and day of the year. If a schedule's final observation began less than 55 minutes into the schedule, the schedule was discarded for being too short.

Developed Source Sets

Plots of six of the source sets. Only sources that are visible in the IVS-INT01 sessions (declination > = ~ 9 degrees) are shown. The Venn diagrams show the number of sources in the adjacent source sets.



Metrics	STN	BEST 9	BEST 12	BEST 15	BEST 18	BEST 21	BEST 24	BEST 40	BEST 50	BEST 60	BEST 70	BEST 80	BEST90	USS
Average number of sources at mid-session	8.1	7.8	10.3	12.8	15.2	17.6	19.6	11.4	14.6	16.4	18.5	21	23.5	17
Average sky gap	12.6	11.0	9.9	9.5	9.4	9.2	9.1	9.5	9.1	9.0	8.9	8.9	9.0	9.5
Average scan length	126.5	130.3	135.1	137.5	139.9	140.9	141.5	132.8	137.7	142.7	144.0	143.1	143.2	145.7

With two exceptions, the sources added within each series are, on average, weaker than the previous sources and increase the average scan length. **S**ky gap measures sky emptiness, approximating the average number of degrees between observations. The USS sky gap is comparable to the sky gap values of the best 15 and 40 source sets, because some of the sources it adds are close together.

Results of Simulations Using Schedule Files

Caveat: T-tests have not been applied, so the statistical significance of the results is unknown.

Metric 1: Unscaled UT1 formal error

Bestsource 9-24 over one hour with STN and USS

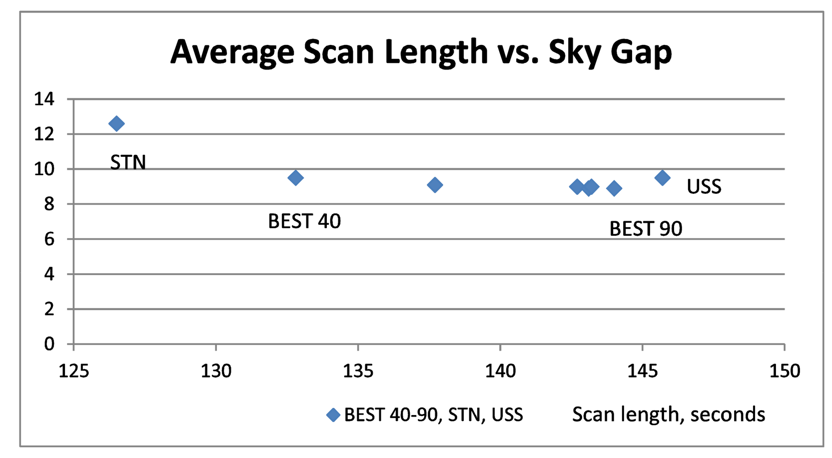
DOY	STN	BEST 9	BEST 12	BEST 15	BEST 18	BEST 21	BEST 24	USS
10	7.0	7.0	**6.9**	6.9	8.3	7.6	7.5	8.3
24	9.5	6.1	**6.3**	6.8	7.2	7.4	7.2	6.7
38	6.5	6.4	**5.6**	5.9	6.3	7.0	7.2	6.5
52	7.8	7.1	**7.8**	7.9	7.9	8.0	8.3	7.9
66	8.1	6.4	**7.1**	7.6	7.6	7.7	7.7	7.8
80	9.8	8.5	**7.3**	8.0	8.5	7.7	7.9	9.9
94	8.9	8.0	**7.3**	7.2	7.7	7.9	8.1	8.1
108	7.7	6.7	**6.6**	6.5	7.1	7.5	7.5	7.9
122	6.8	6.1	**6.8**	7.1	7.6	7.7	7.9	7.0
136	6.9	6.4	**6.1**	6.0	6.7	7.7	7.4	7.3
150	5.8	5.0	**5.5**	5.5	6.1	6.2	6.6	7.6
164	5.7	8.6	**9.0**	8.6	9.1	8.3	7.8	8.0
178	6.3	6.5	**7.0**	7.0	6.9	7.2	7.4	7.7
192	7.4	5.9	**6.2**	6.6	6.5	6.9	7.1	8.5
206	8.9	6.2	**6.8**	7.6	7.0	7.7	7.8	8.0
220	8.0	6.5	**6.1**	6.2	6.5	6.8	7.2	7.5
234	8.4	5.4	**5.5**	5.6	6.0	6.2	6.0	7.4
248	7.8	7.7	**6.6**	5.4	5.5	5.9	6.2	6.7
262	8.1	5.7	**6.5**	6.5	7.1	7.1	7.1	7.7
276	11.7	11.6	**9.2**	8.9	9.0	8.6	8.6	8.4
290	11.1	8.4	**9.4**	9.7	10.9	10.4	10.3	12.8
304	7.6	10.6	**12.2**	11.3	10.8	10.6	10.9	12.0
318	7.0	8.5	**7.3**	7.8	7.0	8.0	8.6	8.7
332	7.9	7.6	**7.3**	7.4	8.3	7.9	8.0	8.9
346	8.0	9.0	**8.3**	9.5	8.5	8.3	7.9	8.6
360	6.6	6.8	**6.7**	7.3	6.9	7.6	7.5	8.2
average	7.9	7.3	**7.2**	7.3	7.6	7.7	7.8	8.2
st. dev.	1.4	1.5	**1.4**	1.4	1.3	1.0	1.0	1.4

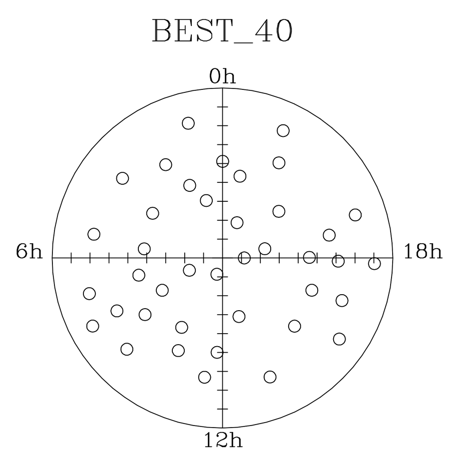
Bestsource 40-90 over 24 hours with STN and USS

DOY	STN	BEST 40	BEST 50	BEST 60	BEST 70	BEST 80	BEST 90	USS
10	7.0	**7.2**	7.3	7.4	7.5	7.8	7.7	8.3
24	9.5	**5.5**	6.8	6.3	6.8	6.6	6.9	6.7
38	6.5	**6.5**	5.9	6.6	7.2	7.6	7.4	6.5
52	7.8	**6.8**	7.5	7.5	7.7	7.9	7.7	7.9
66	8.1	**6.2**	6.6	7.1	7.1	7.1	7.4	7.8
80	9.8	**6.6**	7.2	8.3	7.6	7.9	7.8	9.9
94	8.9	**7.0**	6.7	7.4	7.4	7.4	7.4	8.1
108	7.7	**6.4**	6.2	6.8	6.8	7.4	7.8	7.9
122	6.8	**6.0**	6.5	7.3	7.1	6.8	6.9	7.0
136	6.9	**5.9**	6.5	6.8	6.9	7.1	7.1	7.3
150	5.8	**5.7**	5.8	6.3	6.7	6.7	6.8	7.6
164	5.7	**6.3**	6.8	7.4	8.0	7.7	8.2	8.0
178	6.3	**6.2**	7.0	6.9	7.2	7.6	7.5	7.7
192	7.4	**6.5**	6.8	6.8	7.2	7.1	7.1	8.5
206	8.9	**6.5**	7.1	7.1	7.4	7.6	7.6	8.0
220	8.0	**6.0**	6.6	6.7	6.8	6.8	6.8	7.5
234	8.4	**4.9**	5.4	5.6	5.4	5.8	5.8	7.4
248	7.8	**5.0**	5.3	5.9	6.0	6.0	6.0	6.7
262	8.1	**6.4**	6.9	7.2	7.2	7.1	7.1	7.7
276	11.7	**8.5**	8.5	8.2	8.2	8.1	8.1	8.4
290	11.1	**8.3**	8.8	9.3	9.8	10.1	10.5	12.8
304	7.6	**9.9**	10.7	11.0	10.3	10.7	12.0	12.0
318	7.0	**6.8**	6.9	7.4	7.8	8.1	7.9	8.7
332	7.9	**6.2**	6.0	6.6	7.2	7.3	7.7	8.9
346	8.0	**6.4**	6.9	7.6	7.2	7.2	7.8	8.6
360	6.6	**7.0**	7.0	7.5	7.7	8.0	7.8	8.2
average	7.9	**6.6**	6.9	7.3	7.4	7.5	7.6	8.2
st. dev.	1.4	**1.0**	1.1	1.1	1.0	1.0	1.2	1.4

It is hard to directly compare cases from the best 9-24 and best 40-90 series, because no two pairs of cases are of comparable size (that is, have the same average number of sources available at mid-session). The best 40-90 series yields a lower range of UT1 formal errors (6.6—7.6 μs vs. 7.2—7.8 μs). Investigation of the reason has not yet begun, but lower sky gap values (8.9—9.5 vs. 9.1 to 11.0) is probably a factor.

As expected, in each series, scan length increases in each successive source set, while sky gap decreases due to the addition of sources that are weaker. But new sources are often adjacent to previous sources, so source strength weakens faster than sky gap decreases. So as sources are added in a series, the UT1 formal error worsens. The best UT1 formal errors come from the source sets in the series with the lowest or second lowest number of sources.





The best average UT1 formal error of the source sets under consideration comes from the best 40 set, which has good sky coverage and strong sources. On average, the STN has the strongest sources of any set, but it also contains many gaps and has the worst sky coverage. This leads to times of the year with few available sources, which drives up the UT1 formal error. The STN average UT1 formal error of 7.9 μs is comparable to the best 24 average UT1 formal error of 7.8 μs, suggesting that the combinations of strong sources with bad sky coverage and weak sources with good sky coverage can be comparable. The USS has the weakest sources as well as elevated sky gap values comparable to the best 15 case, and the USS has the worst average UT1 formal error.

Metric 2: Protection against random noise--- RMS about the mean of UT1 estimates from a series of simulations that apply random noise to a solution. A lower value indicates better protection from random noise.

Bestsource 9-24 over one hour with STN and USS

DOY	STN	Best 9	Best 12	Best 15	Best 18	Best 21	Best 24	USS
10	11.6	**11.2**	14.5	16.1	17.0	15.2	15.2	18.6
24	14.9	**13.8**	12.9	16.1	17.3	16.2	14.7	14.4
38	16.9	**15.2**	13.2	13.0	17.2	17.6	18.3	14.5
52	17.2	**11.7**	16.0	16.4	19.0	18.8	19.1	20.8
66	20.8	**16.2**	14.9	15.0	13.9	14.7	16.2	18.4
80	20.7	**14.9**	13.8	14.2	15.2	14.3	15.0	17.5
94	13.1	**14.0**	12.6	12.2	13.3	13.0	13.8	15.1
108	15.4	**10.5**	12.1	12.3	13.2	13.5	13.7	13.2
122	17.7	**12.6**	13.3	16.4	16.7	16.8	16.5	17.0
136	11.4	**14.3**	12.0	14.4	15.4	17.8	15.7	14.6
150	9.0	**14.1**	14.1	14.2	15.6	15.5	15.4	17.0
164	8.4	**12.0**	13.9	14.6	15.7	15.3	14.8	14.1
178	14.8	**12.3**	13.0	13.5	14.5	14.9	16.4	16.8
192	17.8	**11.9**	13.0	14.2	14.2	17.2	16.8	20.0
206	16.7	**11.0**	13.8	14.6	14.4	15.6	16.9	18.4
220	13.7	**14.1**	14.1	13.3	13.3	13.5	15.2	14.4
234	17.7	**11.6**	12.6	11.5	12.1	12.3	12.6	15.9
248	17.9	**18.2**	12.8	12.6	13.4	14.2	15.0	14.9
262	19.1	**12.8**	14.3	14.4	16.2	16.3	15.9	16.4
276	30.9	**19.6**	22.3	19.1	21.9	22.4	23.4	24.0
290	17.3	**23.0**	24.7	25.5	22.9	20.4	22.0	27.6
304	10.9	**15.5**	17.9	16.4	16.4	16.7	16.7	17.3
318	14.2	**15.0**	15.4	13.5	14.1	15.1	15.1	16.4
332	11.3	**13.5**	12.2	12.0	13.9	13.5	13.7	14.6
346	13.6	**14.4**	13.8	15.3	16.2	16.1	18.5	15.6
360	10.3	**12.1**	13.2	14.3	14.0	16.0	15.6	16.9
average	15.5	**14.1**	14.5	14.8	15.6	15.9	16.2	17.1
st. dev.	4.6	**2.8**	2.9	2.7	2.5	2.2	2.4	3.2

distance	STN	Best 9	Best 12	Best 15	Best 18	Best 21	Best 24	USS
average	17.4	18.5	18.6	18.4	18.3	18.4	18.5	18.6
st. dev.	2.3	1.5	1.3	1.1	1.0	1.1	1.0	1.2

Bestsource 40-90 over 24 hours with STN and USS

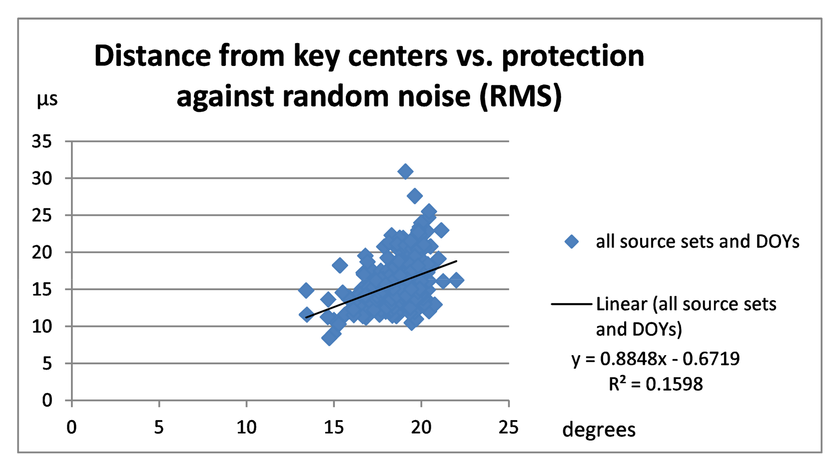
DOY	STN	Best 40	Best 50	Best 60	Best 70	Best 80	Best 90	USS
10	11.6	**12.3**	15.6	16.0	16.9	17.5	16.5	18.6
24	14.9	**13.5**	16.5	14.1	14.3	14.5	16.1	14.4
38	16.9	**11.6**	13.8	15.7	18.1	18.6	18.8	14.5
52	17.2	**18.2**	16.9	18.5	19.0	20.4	19.5	20.8
66	20.8	**16.8**	16.9	17.5	17.9	17.8	18.4	18.4
80	20.7	**13.4**	14.2	15.3	14.4	14.7	14.9	17.5
94	13.1	**14.5**	14.0	15.1	14.8	15.4	14.8	15.1
108	15.4	**12.0**	11.8	12.5	12.5	13.8	14.7	13.2
122	17.7	**13.8**	16.1	17.5	17.1	17.0	16.7	17.0
136	11.4	**13.8**	14.4	15.9	15.9	16.0	16.4	14.6
150	9.0	**13.1**	13.6	14.1	15.4	15.3	16.2	17.0
164	8.4	**12.5**	13.9	15.2	15.6	15.6	16.1	14.1
178	14.8	**15.9**	16.6	16.4	17.3	16.7	17.0	16.8
192	17.8	**15.6**	17.1	16.9	18.1	18.4	18.4	20.0
206	16.7	**13.1**	16.0	16.2	17.1	17.4	17.3	18.4
220	13.7	**13.1**	13.6	14.8	14.6	14.9	14.1	14.4
234	17.7	**11.9**	14.0	14.7	14.1	15.2	15.1	15.9
248	17.9	**13.1**	13.3	14.1	14.1	15.1	15.0	14.9
262	19.1	**15.3**	15.9	16.7	16.7	16.3	16.4	16.4
276	30.9	**18.7**	21.3	21.2	21.0	23.0	22.7	24.0
290	17.3	**20.4**	20.7	19.8	20.5	21.5	21.1	27.6
304	10.9	**15.4**	16.8	16.4	16.1	16.8	19.3	17.3
318	14.2	**14.5**	14.0	15.9	15.5	15.1	15.7	16.4
332	11.3	**11.4**	11.5	12.3	14.3	14.4	14.2	14.6
346	13.6	**15.2**	16.8	18.0	18.3	19.1	18.2	15.6
360	10.3	**12.2**	13.7	16.8	15.7	17.0	16.9	16.9
average	15.5	**14.3**	15.3	16.1	16.4	16.8	16.9	17.1
st. dev.	4.6	**2.3**	2.3	2.0	2.0	2.2	2.1	3.2

distance	STN	Best 40	Best 50	Best 60	Best 70	Best 80	Best 90	USS
average	17.4	18.1	18.6	18.7	18.8	18.9	18.9	18.6
st. dev.	2.3	1.2	1.0	1.0	0.8	0.9	0.9	1.2

According to [1] the RMS is tied to coverage of three key points (~ azimuths 315, 0 and 45 at elevation 30). The new key center distance metric is the first cut at measuring this. For each observation, the key point closest to the observation is identified, and the distance to the point is calculated. Then all of the distances are added. But this measure fails to consider temporal distribution, and it fails to model the coverage of azimuths 315 and 45 at double that of azimuth 0. The plot below assesses the new metric's correlation with the RMS in its initial form.

The best average RMSs are best 9 and 40, and the worst is the USS.

Adding sources should spread out coverage, moving it away from key points and increasing the RMS [1]. The RMS does increase within each series. Fewer sources allow observation concentration, possibly away from the key points but possibly near them, providing a low or high RMS depending on the day of year and its available sources. The specific sources might make the average RMS low or high, but the standard deviation should be higher in source sets with fewer sources, or in a set with more sources, but worse sky coverage, such as the USS. This occurs.



The best 40—90 series' RMS values are worse (14.3—16.9 μs) than the best 9—24 values (14.1—16.2 μs). The reason is unknown, but [1] shows that the random noise RMS increases and the UT1 formal errors decrease with a greater number of low elevation observations. The best 40--90 series is worse for the random noise RMS but better for the UT1 formal error, so a line of inquiry might be whether best 40—90 provides more low elevation observations..

Metric 3: Protection against loss of a source

RMS about the mean of UT1 estimates from simulations that delete each source in a session, one by one, to test the effect of source loss. A lower value shows better protection against source loss.

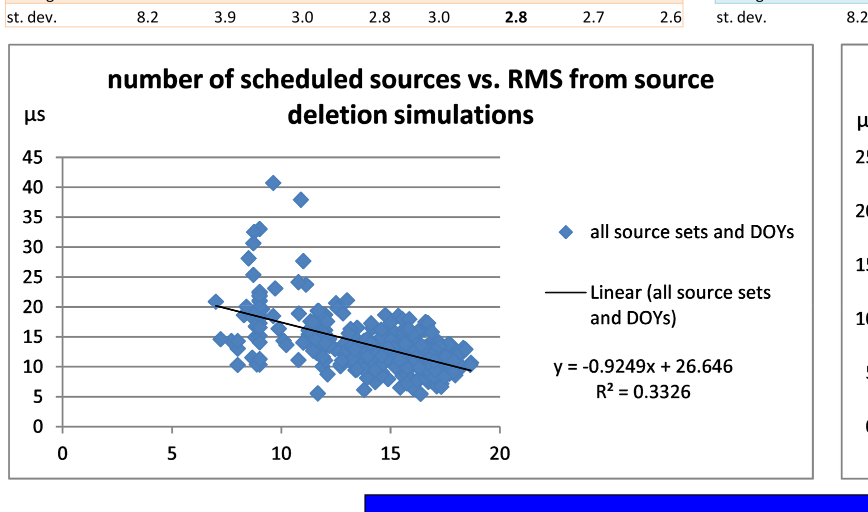
Bestsource 9-24 over one hour with STN and USS

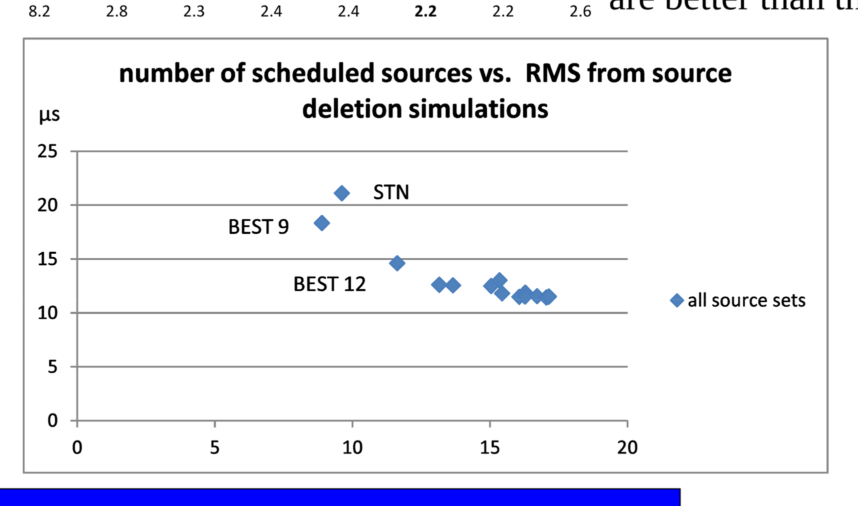
DOY	STN	Best 9	Best 12	Best 15	Best 18	Best 21	Best 24	USS
10	14.3	10.4	13.4	13.1	15.0	**11.8**	10.4	12.0
24	25.4	19.4	12.6	12.0	13.2	**14.4**	12.3	11.8
38	23.1	18.6	17.9	11.4	16.1	**16.5**	18.0	13.2
52	13.0	14.9	15.4	15.2	12.9	**13.3**	13.9	18.7
66	33.0	19.7	16.1	14.6	12.5	**10.9**	13.5	15.1
80	23.8	20.9	13.7	13.7	15.1	**10.4**	13.0	12.9
94	14.3	10.4	5.5	6.1	6.5	**6.3**	5.5	8.0
108	32.5	19.3	12.8	11.0	11.6	**9.8**	10.3	13.6
122	16.4	21.1	19.4	14.1	13.5	**12.3**	10.4	13.5
136	20.9	22.4	15.1	14.3	12.9	**11.8**	12.0	11.0
150	10.3	17.3	15.4	13.5	12.3	**12.0**	12.2	14.0
164	14.3	15.2	16.1	11.6	14.1	**9.3**	9.6	8.1
178	27.7	21.8	13.8	10.9	11.4	**11.3**	13.8	10.9
192	18.9	18.6	14.9	12.4	13.1	**11.0**	10.8	12.0
206	40.7	18.5	17.6	13.6	10.5	**12.9**	12.3	13.3
220	24.1	18.1	10.1	9.3	11.3	**10.3**	10.4	13.2
234	20.6	22.5	18.7	12.0	10.0	**10.4**	10.4	15.3
248	12.7	20.0	12.4	9.2	7.5	**7.5**	8.0	10.8
262	16.1	14.1	11.1	8.9	9.2	**9.4**	9.7	11.3
276	37.9	19.0	14.3	12.4	17.5	**17.9**	17.9	16.1
290	18.5	11.3	16.7	19.8	21.1	**17.3**	15.7	16.5
304	11.5	16.8	14.1	14.6	12.4	**10.2**	11.9	13.8
318	13.6	28.1	15.6	11.0	8.5	**9.9**	12.5	12.0
332	14.6	20.0	11.1	8.8	11.3	**7.5**	8.6	9.5
346	30.7	16.6	17.4	16.3	11.5	**11.1**	12.5	13.7
360	19.6	21.9	18.5	16.5	14.4	**13.7**	13.3	18.5
average	21.1	18.3	14.6	12.6	12.5	**11.5**	11.9	13.0
st. dev.	8.2	3.9	3.0	2.8	3.0	**2.8**	2.7	2.6

Bestsource 40-90 over 24 hours with STN and USS

DOY	STN	Best 40	Best 50	Best 60	Best 70	Best 80	Best 90	USS
10	14.3	11.6	11.9	14.0	11.5	**13.2**	10.7	12.0
24	25.4	12.5	11.7	10.2	12.0	**10.5**	10.7	11.8
38	23.1	12.7	15.9	15.9	16.8	**17.5**	17.3	13.2
52	13.0	19.3	11.6	12.0	12.7	**12.2**	12.9	18.7
66	33.0	14.0	16.2	13.7	14.1	**13.4**	12.8	15.1
80	23.8	17.6	14.9	14.9	11.2	**11.8**	11.2	12.9
94	14.3	10.1	8.8	7.7	6.8	**7.2**	6.7	8.0
108	32.5	12.3	10.0	8.5	8.4	**9.8**	11.5	13.6
122	16.4	10.6	10.9	12.0	12.5	**11.6**	11.8	13.5
136	20.9	15.6	11.4	10.8	10.0	**10.4**	10.0	11.0
150	10.3	14.4	12.4	12.1	13.8	**12.4**	13.2	14.0
164	14.3	10.2	10.2	8.8	9.0	**8.6**	9.1	8.1
178	27.7	12.5	11.8	12.5	11.6	**12.2**	12.9	10.9
192	18.9	10.4	10.7	9.7	10.3	**11.0**	11.0	12.0
206	40.7	13.6	12.4	12.3	12.0	**11.9**	11.9	13.3
220	24.1	10.0	11.4	11.0	9.6	**9.7**	11.2	13.2
234	20.6	18.9	10.9	11.4	10.7	**10.3**	10.3	15.3
248	12.7	8.1	7.2	7.5	8.3	**8.3**	8.3	10.8
262	16.1	10.8	7.7	8.2	9.5	**10.1**	10.1	11.3
276	37.9	12.9	12.2	13.8	16.4	**15.8**	15.8	16.1
290	18.5	13.5	14.0	14.3	16.2	**14.5**	13.2	16.5
304	11.5	14.6	13.9	12.9	11.7	**11.8**	13.2	13.8
318	13.6	10.7	11.4	10.0	11.2	**9.6**	9.4	12.0
332	14.6	11.1	9.6	9.4	11.1	**9.8**	9.9	9.5
346	30.7	10.3	11.6	10.5	10.3	**10.9**	11.0	13.7
360	19.6	9.7	16.4	15.5	12.9	**13.1**	13.6	18.5
average	21.1	12.6	11.8	11.5	11.6	**11.4**	11.5	13.0
st. dev.	8.2	2.8	2.3	2.4	2.4	**2.2**	2.2	2.6

Protection against source loss is tied to the number of sources. More sources give more protection by giving better coverage; a three-session simulation with 19 observations apiece confined to 90 degrees of azimuth gave RMSs of 20.7--24.6 μs instead of the ~ 10--12 μs implied by the plots below. Fewer sources gives uneven coverage and results. Best 80 gives the best average protection, but any source set other than STN or best 9 or 12 seems adequate. 10 source sets are better than the USS.





Conclusions

• In the source sets studied, adding sources improves protection against source loss but degrades the UT1 formal errors and decreases protection against random noise.

•. The best 9-24 series is better than best 40-90 for protection against random noise, but best 40-90 provides better UT1 formal errors. We have not investigated yet, but we think that different numbers of low elevation observations may be a factor.

•Selecting the best 40 sources gives the best results overall. The USS gives the worst results overall.

References

1. K. Baver and J. Gipson, Refining the Uniform Sky Strategy for IVS-INT01 Scheduling, *Proceedings of the 21st Meeting of the European VLBI Group for Geodesy and Astronomy*, N. Zubko and M. Poutanen (eds.), pp.205--209, 2013.

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