PRACTICAL EXERCISE

VLBI Scheduling - VO6259

Generating, optimizing, and understanding VGOS scheduling with VieSched++

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PURPOSE
This exercise introduces the complete scheduling workflow: import an official IVS session, create a baseline schedule, diagnose weaknesses, apply targeted changes, and use simulations to compare alternative schedules.

Session code	vo6259
Session type	VGOS-OPS
Nominal start	16 September 2026, 00:00 UTC
Duration	24 hours
Software	VieSched++

Learning objectives

1. Load official IVS session metadata and inspect the station and source pools.
2. Explain the difference between a station, a site, a scan, a baseline, and an observation.
3. Generate a schedule and identify the files needed for operations and reproducibility.
4. Improve scheduling parameters, calibration, and source sampling with targeted constraints.
5. Use the VieSched++ Analyzer, multi-scheduling, and Monte Carlo simulations to compare alternatives.
6. Select a final schedule based on scientific performance and operational robustness, not on a single number.

KEEP A BASELINE
Do not overwrite your first result. The most useful part of the exercise is comparing each modified schedule with the baseline under otherwise identical settings.
By default, each run will be stored in its own subfolder.

1. Background: what does a VLBI scheduler do?

In a VLBI experiment, geographically separated radio telescopes observe the same compact extragalactic radio source. The correlation process determines the difference in signal-arrival time between stations. These delay observables contain information about Earth orientation, station coordinates, clocks, the atmosphere, source positions and more.

A VLBI scheduler must decide which source is observed, when it is observed, which stations participate, and how long the scan lasts. Every decision is subject to source visibility, antenna slew limits, recording constraints, signal strength, and the scientific goals of the session. Consequently, there is no single universally optimal schedule: improving one aspect can make another worse.

Term	Meaning in this exercise
Station	One telescope and its observing system.
Site	A physical observing location. Two co-located twin telescopes are two stations located at the same geodetic site.
Scan	A time interval during which a selected set of stations observes the same source simultaneously.
Baseline	The vector between a pair of stations. One delay observation is formed for each participating station pair, provided data are recorded and correlated successfully.
Observation	A simulated or measured VLBI delay on one baseline within one scan.
Sky coverage	The distribution of observations over azimuth and elevation at a station or site. Distributed coverage helps separate geometric parameters from clocks and tropospheric delays.
SNR-based duration	A scan length selected to reach a target signal-to-noise ratio, bounded by the configured minimum and maximum durations.

FROM STATIONS TO OBSERVATIONS

A scan with N participating stations can produce at most $\frac{N\cdot(N-1)}{2}$ baseline observations. More stations therefore increase the number of observations quickly, but only if they add useful geometry and can observe the source simultaneously.

1.1 What characterizes a useful geodetic schedule?

- A high number of usable observations, without excessive slew or idle time.
- Good sky coverage at every station and observations distributed throughout the full session.
- Strong and geometrically diverse baselines, including intercontinental and long north-south (polar motion, nutation) and east-west (UT1-UTC) baselines.
- Sufficient repetition of important sources and adequate coverage of the celestial sphere.
- Operational feasibility: realistic slews, adequate SNR, valid station availability, and good mix between subnetworks.

VieSched++ balances these goals by applying hard constraints first and then ranking the remaining candidate scans with configurable weight factors. The following steps illustrate both mechanisms.

2. Create your first schedule

2.1 Start VieSched++ in VGOS mode

1. Start VieSched++ and wait until the catalog status at the bottom of the window confirms that the downloads have finished.
2. Click “*VGOS Catalogs”*.
3. Click “*VGOS mode”* to load a predefined set of parameters suitable for a standard VGOS session.

WHY USE PRESETS?

The catalog button loads the station, source, antenna, and equipment information needed by the scheduler. VGOS mode provides a sensible starting configuration so that this exercise can focus on scheduling concepts rather than on every low-level parameter.

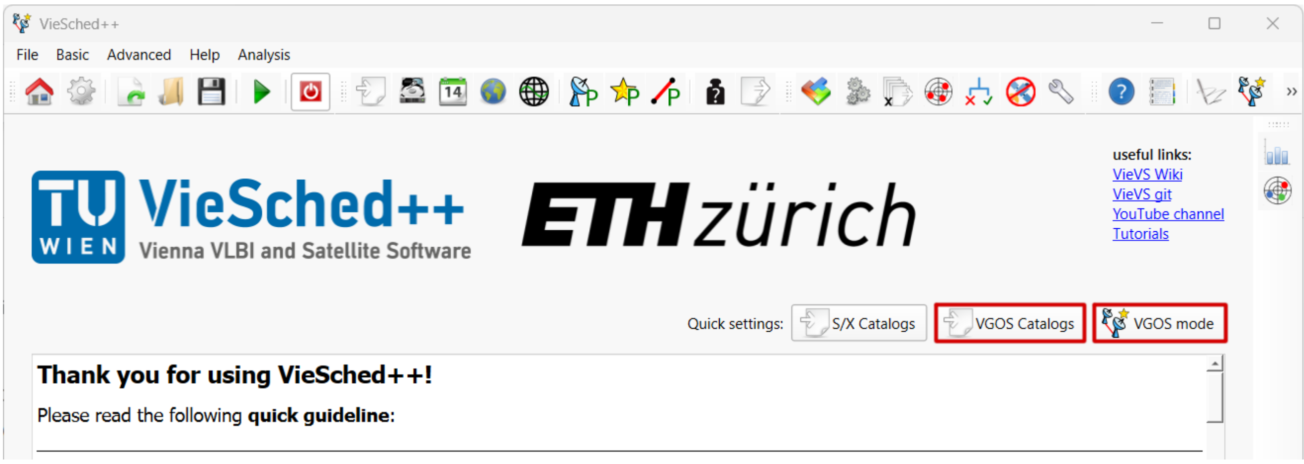

Figure 1. Load the VGOS catalogs and activate VGOS mode.

2.2 Import the official session

Official IVS session information is listed at [IVS 2026 session list]

1. Click the calendar icon to open the session page.
2. Click "*list next*", locate "*vo6259*", select it, and click "*OK*".
3. Verify the imported session code, description, start time, duration, and station network before continuing.

The import avoids input errors and ensures that the exercise starts from the metadata distributed for the official IVS session. Manual entry remains useful for experimental or non-IVS sessions.

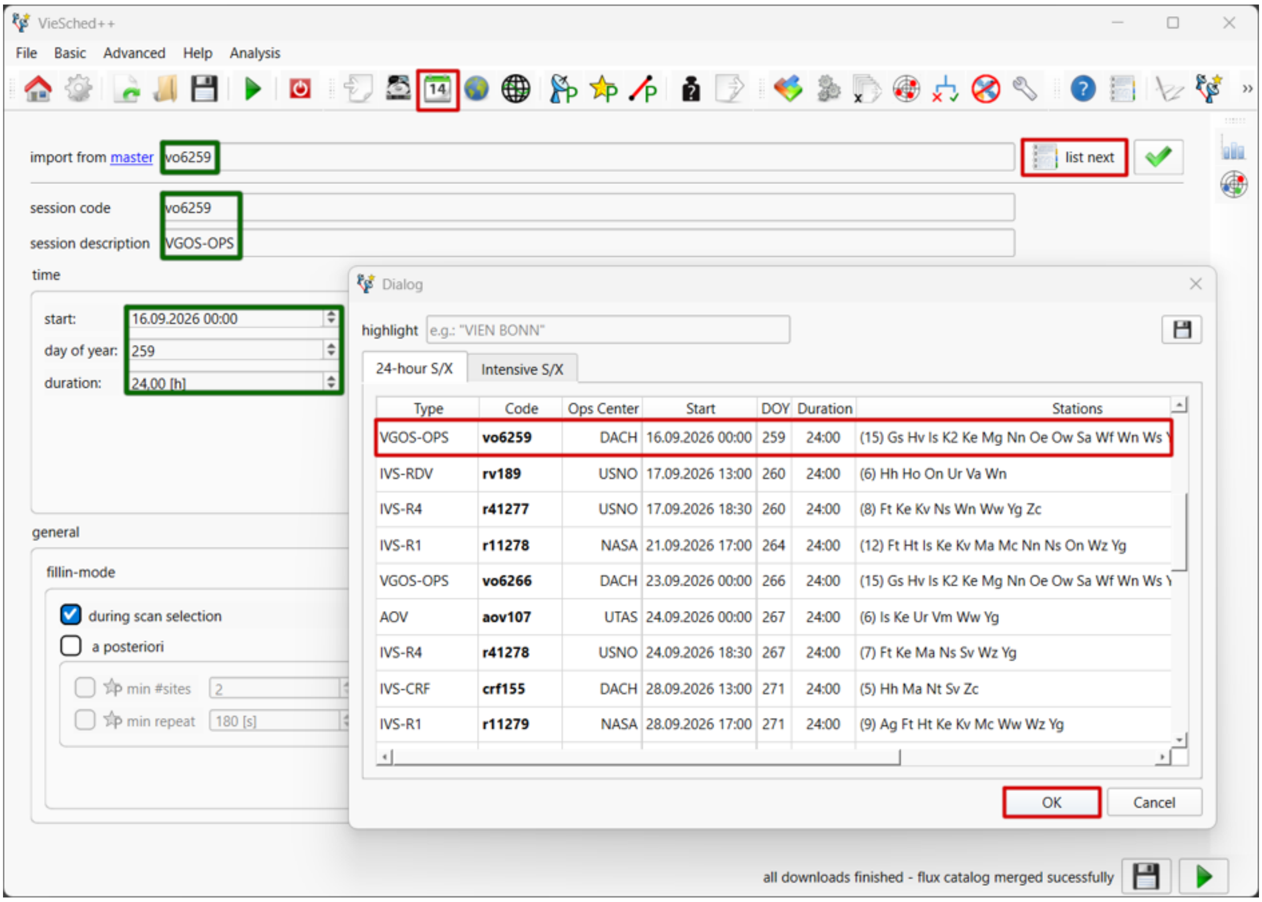

Figure 2. Select vo6259 from the list of upcoming 24-hour sessions.

2.3 Review the station network

Click the world-map icon. The left list contains available stations and the right list contains the selected network. Click a station on the left list to add it. Click a station on the right list to remove it. The map provides a first check of the network geometry and available baselines.

> **STATION VERSUS SITE**
>
> A network can contain two antennas at one observatory. They increase operational flexibility and provide a short local baseline, but they do not add a new geographic location. This distinction becomes important when the scheduler applies a minimum number of sites per scan.

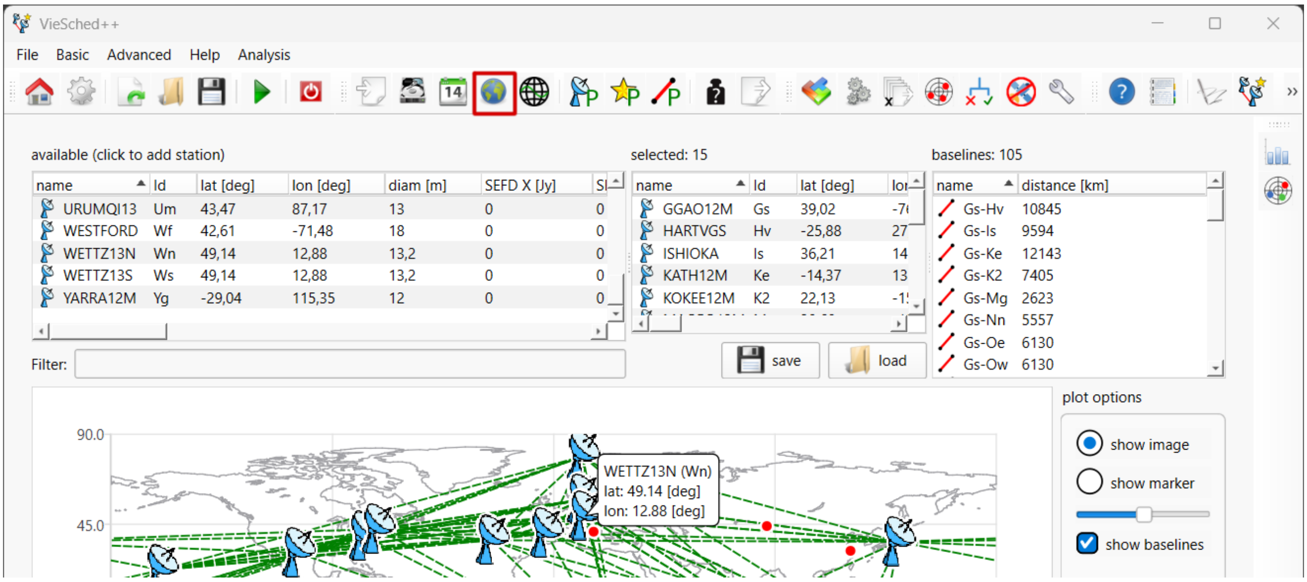

Figure 3. Review the selected station network and its baselines.

2.4 Review the candidate sources

Click the celestial-map icon to inspect the source pool. The selected list contains candidate sources: VieSched++ may consider them during scheduling, but it is not required to schedule every source. Visibility, source strength, network geometry, and the scoring logic determine which candidates are eventually used.

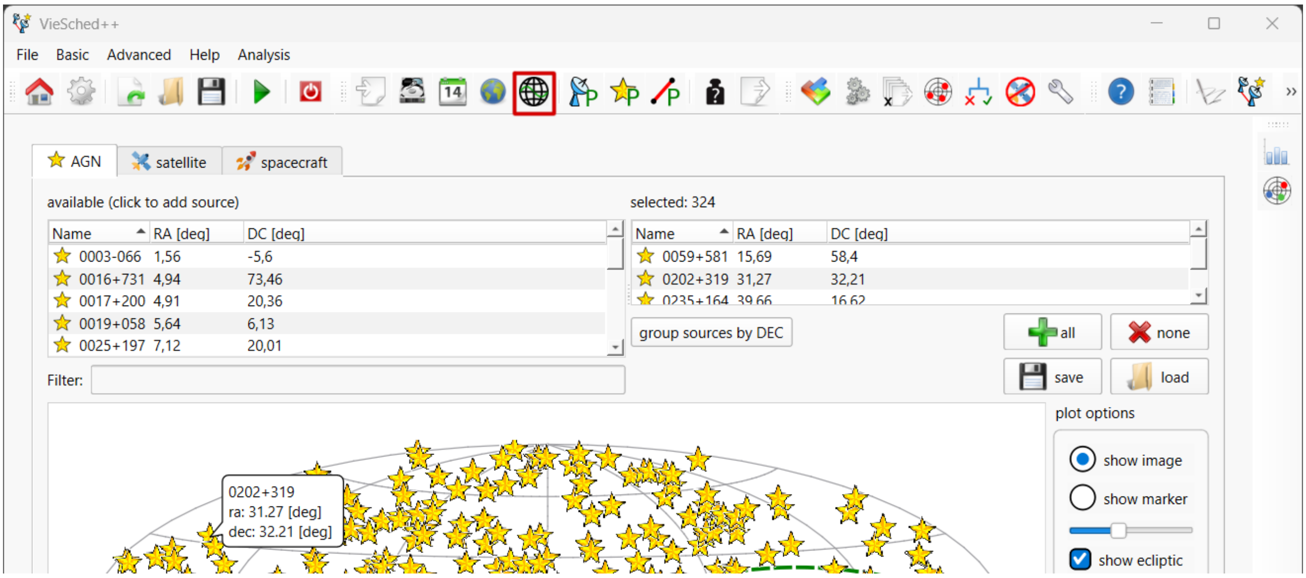

Figure 4. Inspect the selected candidate sources on the celestial map.

2.5 Run the first schedule

1. Click the green *"Run"* button in the lower-right corner.

2. When asked whether the XML configuration should be stored, click *"Yes"*. The XML file records the complete configuration and is essential for reproducing the schedule.
3. In the second dialog, click *"Open"* to open the output directory in your file browser.
4. Wait until the status bar reports everything finished before inspecting the files.

Figure 5. The Run button and completion status are located at the bottom right.

BASELINE RESULT

Keep the first output directory unchanged. Later runs should be compared with this baseline so that the effect of each parameter change remains visible.

3. Understand the generated files

VieSched++ writes several plain-text files to the output directory. They serve different purposes: station and correlator operations, schedule diagnostics, reproducibility, and simulation. The following files are the most useful in this exercise.

File	Purpose
vo6259.skd	Traditional IVS schedule representation containing the planned scans, sources, and participating stations.
vo6259.vex	Machine-readable experiment description used by VLBI station and correlation systems. It contains schedule and observing-configuration information.
VieSchedpp.xml	Complete VieSched++ configuration. Keep it with the schedule so that the run can be reproduced or modified.
vo6259_iteration_0.txt	Detailed log of the first scheduling iteration, including candidate-scan evaluation and scan-by-scan decisions.
vo6259.txt	Operations notes and human-readable schedule diagnostics, including station, source, scan, baseline, and network statistics.
statistics.csv	Machine-readable summary statistics suitable for comparisons or further analysis.
*.snr	Predicted signal-to-noise information for the scheduled observations.
*.log	Program messages that help diagnose warnings or failures.

OPERATIONAL FORMATS

The .skd and .vex files are both important operational products. Their precise use can differ between networks and control systems. Within the IVS, the .skd files distributed to the stations while the .vex files are distribute to the correlator.

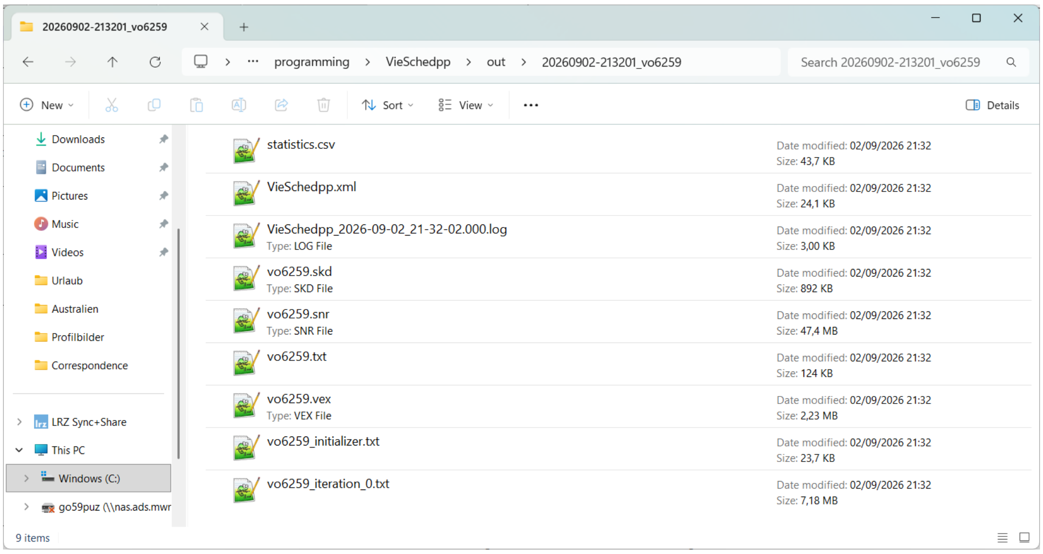

Figure 6. Example output directory after the baseline schedule has finished.

3.1 Inspect the iteration log

Open *"vo6259_iteration_0.txt"* in a text editor. This human-readable log shows the scheduler's progression through the session. For each selected scan, it records scheduling information, participating stations, times, slews, idle periods, elevations, and other quantities. Use it when you want to understand why a particular scan was or was not feasible.

```
.------------------------------------------------------------------------------------------------------------------------------------.
| depth:  0                                                                               considered single scans 183, subnetting scans 210 |
| scan:   no0000   (id: 705)                                                                             duration: 00:00:00 - 00:00:10 |
| source: 1057-797 (id: 157)                                                                       type: target subnetting scan (0.43) |
|------------------------------------------------------------------------------------------------------------------------------------|
|     station  | delay |  slew |  idle | preob |  obs  |        duration         |         az [deg]        |        unaz [deg]       |      el [deg]       |
|              |  [s]  |  [s]  |  [s]  |  [s]  |  [s]  |      start - end        |       start - end       |       start - end       |    start - end      |
|--------------|-------|-------|-------|-------|-------|-------------------------|-------------------------|-------------------------|---------------------|
|     HARTVGS  |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 173.6933 - 173.6872 |  173.6933 -  173.6872 | 18.0286 - 18.0328 |
|     KATH12M  |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 173.5662 - 173.5721 |  533.5662 -  533.5721 | 22.0315 - 22.0360 |
|     YARRA12M |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 170.3461 - 170.3504 |  530.3461 -  530.3504 | 34.3957 - 34.4018 |
|------------------------------------------------------------------------------------------------------------------------------------|
| scan:   no0001   (id: 706)                                                                             duration: 00:00:00 - 00:00:10 |
| source: 1803+784 (id: 259)                                                                       type: target subnetting scan (2.23) |
|------------------------------------------------------------------------------------------------------------------------------------|
|     GGAO12M  |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 357.3966 - 357.3837 |  357.3966 -  357.3837 | 50.4037 - 50.4022 |
|     ISHIOKA  |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 |   9.2490 -   9.2561 |    9.2490 -    9.2561 | 27.7448 - 27.7502 |
|     KOKEE12M |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 |  12.2436 -  12.2419 |  372.2436 -  372.2419 | 24.7400 - 24.7482 |
|     MACGO12M |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 |   4.9506 -   4.9402 |  364.9506 -  364.9402 | 41.4989 - 41.5020 |
|     NYALE13N |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 316.8824 - 316.9041 |  316.8824 -  316.9041 | 73.1284 - 73.1230 |
|     ONSA13NE |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 340.1274 - 340.1331 |  340.1274 -  340.1331 | 54.3044 - 54.2968 |
|     ONSA13SW |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 340.1275 - 340.1333 |  340.1275 -  340.1333 | 54.3041 - 54.2964 |
|     RAEGSMAR |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 346.5256 - 346.5215 |  346.5256 -  346.5215 | 42.0071 - 41.9993 |
|     RAEGYEB  |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 344.7660 - 344.7664 |  704.7660 -  704.7664 | 41.1183 - 41.1099 |
|     WESTFORD |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 355.4223 - 355.4088 |  355.4223 -  355.4088 | 53.7369 - 53.7345 |
|     WETTZ13N |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 343.3583 - 343.3625 |  343.3583 -  343.3625 | 46.2879 - 46.2801 |
|     WETTZ13S |     0 |     0 |     0 |     0 |    10 | 00:00:00 - 00:00:10 | 343.3585 - 343.3627 |  343.3585 -  343.3627 | 46.2874 - 46.2795 |
|------------------------------------------------------------------------------------------------------------------------------------|
| depth:  0                                                                               considered single scans 181, subnetting scans 199 |
| scan:   no0002   (id: 1106)                                                                            duration: 00:00:32 - 00:00:42 |
| source: 0308-611 (id: 38)                                                                        type: target subnetting scan (0.43) |
|------------------------------------------------------------------------------------------------------------------------------------|
|     HARTVGS  |     2 |    13 |     5 |     2 |    10 | 00:00:32 - 00:00:42 | 160.9613 - 160.9872 |  160.9613 -  160.9872 | 51.1463 - 51.1586 |
|     KATH12M  |     2 |    17 |     1 |     2 |    10 | 00:00:32 - 00:00:42 | 210.1488 - 210.1495 |  570.1488 -  570.1495 | 17.5739 - 17.5536 |
|     YARRA12M |     2 |    18 |     0 |     2 |    10 | 00:00:32 - 00:00:42 | 213.4406 - 213.4443 |  573.4406 -  573.4443 | 38.2167 - 38.1966 |
|------------------------------------------------------------------------------------------------------------------------------------|
| scan:   no0003   (id: 1107)                                                                            duration: 00:00:36 - 00:00:51 |
| source: 1044+719 (id: 152)                                                                       type: target subnetting scan (2.07) |
|------------------------------------------------------------------------------------------------------------------------------------|
|     GGAO12M  |     2 |    22 |     0 |     2 |    10 | 00:00:36 - 00:00:46 | 340.9280 - 340.9370 |  340.9280 -  340.9370 | 29.4036 - 29.3930 |
|     ISHIOKA  |     2 |    18 |     4 |     2 |    10 | 00:00:36 - 00:00:46 |  13.5647 -  13.5475 |   13.5647 -   13.5475 | 51.9129 - 51.9208 |
|     KOKEE12M |     2 |    14 |     8 |     2 |    15 | 00:00:36 - 00:00:51 | 347.5906 - 347.5714 |  347.5906 -  347.5714 | 37.0983 - 37.0858 |
|     MACGO12M |     2 |    14 |     8 |     2 |    10 | 00:00:36 - 00:00:46 | 338.7427 - 338.7452 |  338.7427 -  338.7452 | 29.4215 - 29.4085 |
|     NYALE13N |     2 |    15 |     7 |     2 |    10 | 00:00:36 - 00:00:46 |  15.6851 -  15.7121 |  375.6851 -  375.7121 | 61.1631 - 61.1653 |
|     ONSA13NE |     2 |     7 |    15 |     2 |    14 | 00:00:36 - 00:00:50 |   9.8415 -   9.8647 |  369.8415 -  369.8647 | 40.1117 - 40.1171 |
|     ONSA13SW |     2 |     7 |    15 |     2 |    10 | 00:00:36 - 00:00:46 |   9.8412 -   9.8577 |  369.8412 -  369.8577 | 40.1111 - 40.1150 |
```

Figure 7. The iteration log provides a scan-by-scan view of the scheduling logic.

3.2 Inspect the operations notes

Open *"vo6259.txt"*. This is the quickest source for an overall assessment of the schedule. Review the total numbers of scans and observations, station participation, network combinations, source usage, sky coverage, scan durations, and gaps. The text-based plots are deliberately compact and can be searched or compared between runs.

> **DIAGNOSTIC QUESTION**
> Do not ask only whether the schedule has many observations. Ask where those observations occur, which sites contribute, which sources dominate, and whether the geometry is balanced throughout the 24 hours.

4. Treat twin telescopes as one physical site

The network-combination table in the operations notes may reveal scans containing an Onsala twin pair plus only one remote station, or a Wettzell twin pair plus only one remote station. Such a scan has three antennas but only two independent geographic sites. The short intra-site baseline is valuable for local ties and system checks, but it contributes little to the global geometry of a geodetic scan. We will now adjust the settings to ensure that no three-station scans with twin telescopes are scheduled. The easiest way to do this is by telling the software that both stations belong to the same site.

network			network			network		
HvKeYg	413	(10.62%)	GsIsK2MgNnOeOwSaYjWfWnWs	312	(8.02%)	IsKeK2Yg	297	(7.64%)
GsMgNnOeOwSaYjWfWnWs	214	(5.50%)	HvIsKeYg	161	(4.14%)	GsHvMgNnOeOwSaYjWfWnWs	111	(2.85%)
GsK2MgNnOeOwSaYjWfWnWs	105	(2.70%)	GsHvNnOeOwSaYjWfWnWs	88	(2.26%)	NnOeOwSaYjWnWs	81	(2.08%)
GsIsMgNnOeOwSaYjWfWnWs	78	(2.01%)	IsKeK2MgYg	77	(1.98%)	KeK2Yg	66	(1.70%)
OeOwSa	64	(1.65%)	HvOeOwSaYjWnWs	56	(1.44%)	GsK2MgWf	45	(1.16%)
GsHvMgOeOwSaYjWfWnWs	43	(1.11%)	OeOwSaYj	41	(1.05%)	GsMgNnOeOwSaYjWfWn	41	(1.05%)
HvNnOeOwSaYjWnWs	39	(1.00%)	KeK2MgYg	39	(1.00%)	GsIsK2MgNnOeOwSaYjWnWs	37	(0.95%)
GsHvIsNnOeOwSaYjWfWnWs	34	(0.87%)	OeOwYj	33	(0.85%)	HvIsKeNnOeOwSaYjWnWsYg	33	(0.85%)
IsKeYg	30	(0.77%)	IsK2Mg	30	(0.77%)	GsIsK2MgNnWf	29	(0.75%)
HvOeOwSaYjWnWsYg	28	(0.72%)	MgNnOeOwSaYjWnWs	28	(0.72%)	GsMgNnOeOwSaYjWnWs	27	(0.69%)
OeOwSaYjWnWs	26	(0.67%)	GsK2MgSaWf	25	(0.64%)	NnOeOw	24	(0.62%)
GsHvOeOwSaYjWfWnWs	22	(0.57%)	GsHvMgNnOeOwSaYjWnWs	22	(0.57%)	GsIsKeK2MgWf	21	(0.54%)
HvIsKeOeOwYjWnWsYg	21	(0.54%)	GsHvMgSaYjWf	21	(0.54%)	HvSaYj	21	(0.54%)
GsNnOeOwSaYjWfWnWs	20	(0.51%)	K2MgWf	20	(0.51%)	HvIsKeNnOeOwYjWnWsYg	20	(0.51%)
IsKeK2NnYg	17	(0.44%)	GsHvNnOeOwSaYjWnWs	16	(0.41%)	NnOeOwSaYj	15	(0.39%)
HvKeOeOwYjWnWsYg	15	(0.39%)	HvIsNnOeOwSaYjWnWsYg	14	(0.36%)	HvSaYjWnWs	14	(0.36%)

Figure 8. Network-combination statistics can expose scans with a twin pair and only one remote site.

1. Open the *"Station setup"* page and select the *"Sites"* tab.
2. Assign the same Site ID to *ONSA13NE* and *ONSA13SW*.
3. Assign another common Site ID to *WETTZ13N* and *WETTZ13S*.
4. Do not assign the Onsala and Wettzell antennas the same Site ID: they are different physical sites.
5. Run the schedule again and inspect the network-combination statistics.

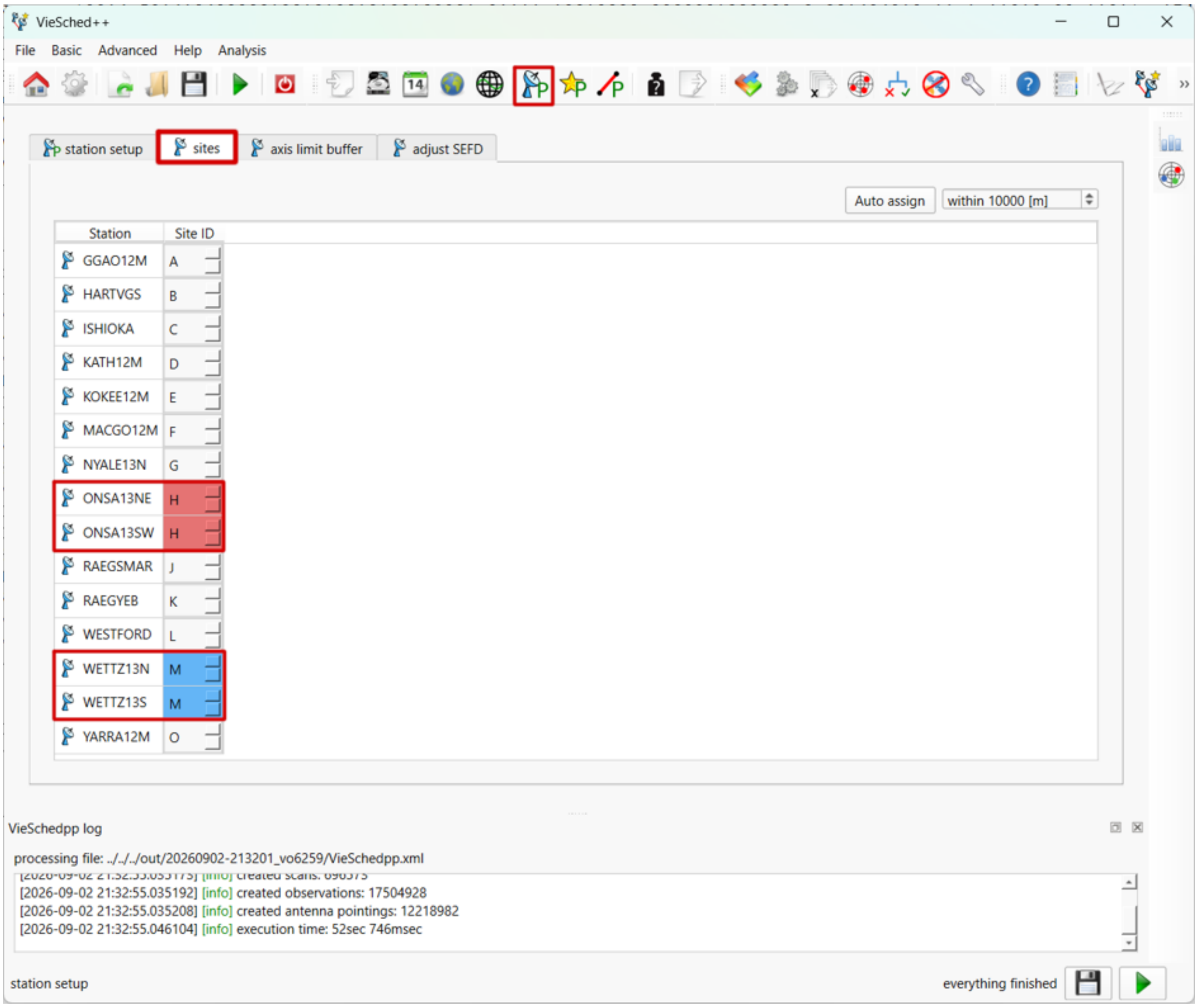

Figure 9. Give each co-located twin pair a common Site ID.

EXPECTED EFFECT

A minimum of three sites now means three independent geographic locations. Scans consisting of one twin pair and only one remote site should disappear, although both twins may still participate when at least two additional sites are present.

5. Add longer calibration blocks

The VGOS preset uses SNR-based scheduling with short scan durations, bounded here by approximately 10 and 30 seconds. Short scans increase temporal sampling and the number of observations. A small number of longer scans on strong, compact calibrator sources can nevertheless provide high-SNR data for fringe detection and observing-system checks.

1. Open the *"Rules page"* using the icon with three gears.
2. Enable "*schedule calibration scans*".
3. Set number of blocks to 25. Across a 24-hour session, this places a calibration block approximately once per hour.
4. Set the default duration to 60 seconds, leave the number of scans per block at 2, and restrict allowed sources to the *"CALIB"* group. More about groups in the following.
5. Use the block list items to modify individual entries if desired. For example, make one block every three hours contain a 120-second scan.
6. Run the schedule again and confirm in the scan list that the calibration blocks were inserted.

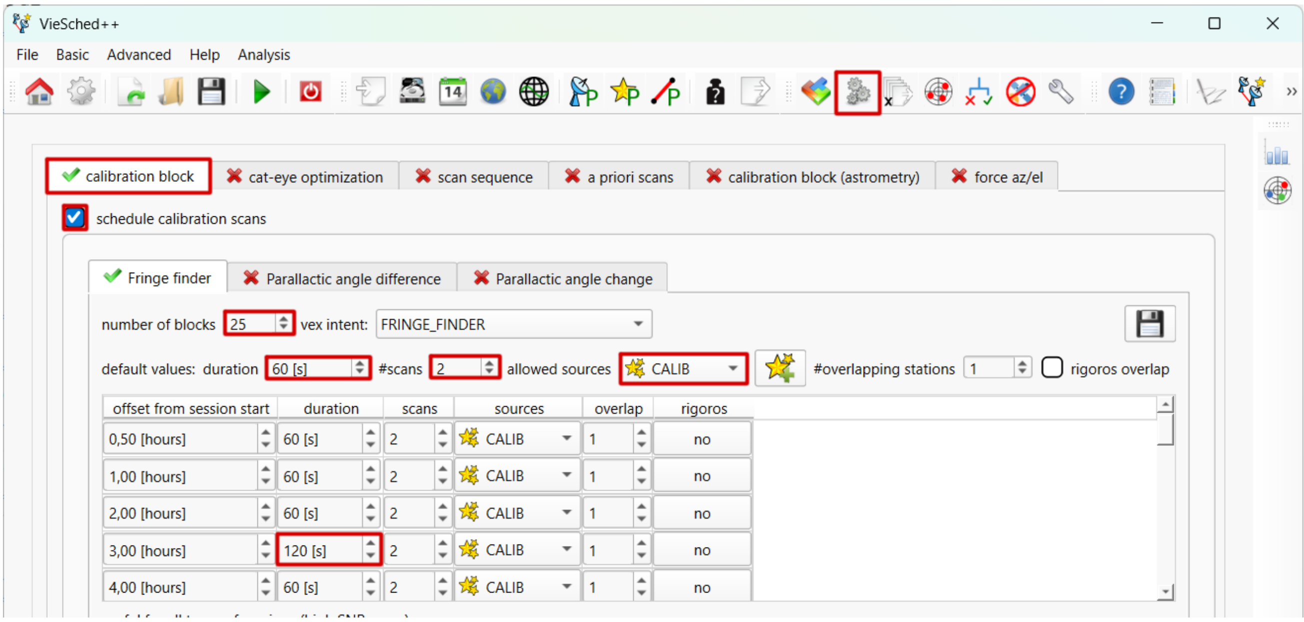

Figure 10. Configure approximately hourly calibration blocks using sources from the CALIB group.

> **A BLOCK IS NOT NECESSARILY ONE SCAN**
> The number of blocks controls how often calibration periods occur. The #scans field controls how many scans each block contains. With 25 blocks and 2 scans per block, the setup is approximately one calibration block with two calibration scans per hour. Have a look at the operation notes to see a summary of the calibration scans.

> **TRADE-OFF**
> Longer calibration scans consume observing time and may reduce the total number of scans. However, it is typically worth to have calibrator scans for improved correlation and fringe fitting.

6. Require repeated observations of each source

The source section of the operations notes may show several sources with only a few scans. Sparse sampling is inefficient when the scientific goal requires source-wise parameters: a reliable source position or time-dependent source assessment needs repeated observations at different times and geometries. Even when source positions are held fixed, a long tail of rarely observed sources may add complexity without much benefit.

SOURCE	time since session start (1 char equals 15 minutes) 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23	#SCANS	#OBS	OBS Time [s] sum	OBS Time [s] average	independ closures
0003-066	1 1 1 1 1 1 1 1 1 1 1 1 11 1 1 1 11 1 1 1 1	23	374	264	11.5	509
0016+731	1 1 1 1 1 1 1 1 1 1 11 1 1 1 1 11 1 1 1 1 1 1 11 1	27	1244	558	20.7	1985
0017+200	11 1 1 11 11 11 11 1 1 11 1 1 1 1 1 1 1 1 1 1	26	1017	516	19.8	1590
0019+058	1 1 11 11 1 1 1 1 1 1 1 11 1 11 1 1 1 1 1 11 1 1 1 11 1 1 1 1	34	820	360	10.6	1200
0059+581	1 11 1 11 11 11 11 11 11 11 1 11 11 111 11 1 11 11 11 11 1 11 11 11 1 1 1 1 11 1 1 1	53	2629	573	10.8	4237
0104-408	1 1 1 1 1 1 1 11 2 1 1 1 11 11 1 1 1 1 11	24	99	323	13.5	60
0106+013	11 1 1 1 1 1 1 1 1 1 1 1 1 1	15	307	175	11.7	441
0109+224	11 1 11 11 1 11 11 11 11 11 1 1 1 1 1 1 1 1 1 1 1	29	1025	472	16.3	1585
0113-118	1 1 1 1 1 1	6	43	69	11.5	42
0116-219	1 1 1 1 1 1 1 1 11 11 11 11 1 1 1 1 1 1 11 1 1 1 11 1 11 1	33	370	593	18.0	449
0119+041	1 1 1 1	4	34	40	10.0	36
0119+115	1 11 1 1	5	114	50	10.0	285
0123+257	1 11 1 11 1 1 1 1 1 1 1 1 1 1 1 1 1	19	685	455	23.9	1061
0131-522	11 11 11 1 11 11 11 11 1 11 11 11 11 11 11 111	31	93	372	12.0	31
0133+476	11 1 11 1 1 1 1 1 11 11 11 11 11 11 111 1 11 1 1 1 1 1 1 1 11 1	38	1982	585	15.4	3194
0159+723	1 11 1 1 1 1 1 11 1 1 1 1 1 1 1 1 11 1 1 1 111 1	27	1091	623	23.1	1719
0202+319	11 1 11 1 11 1 111 1 1 1 1 11 1 11 1 1 1 1 1 1 1 11 1 1 1 1 1 111 1 11 1	42	1532	734	17.5	2380
0202-172	1 1 1 1 11 11 1 1 1 11 1 1 1 11 1 1 1	21	286	393	18.7	363
0215+015	1 1 1 1 1 11 1 1 1 1 1 1 1 1 1 1 1	18	382	180	10.0	540
0219+428	11 1	3	58	67	22.3	83
0221+067	1	1	55	30	30.0	89
0227+403	1 1 1 1 1 1 1	7	258	159	22.7	399
0229+131	1 11 1 11 11 1 1 11 1 1 1	15	325	200	13.3	469
0234+285	1 1 1 1 11 1 1 1 1 1 1 1 1	14	358	179	12.8	526
0235+164	1 1 11 1 11 1 11 1 1 1 1 1 1 1	17	431	187	11.0	637
0300+470	1 1 1 1 1 1 1 1 1 1 1	11	80	127	11.5	81
0308-611	111 1 1 11 11 11 11 11 1 11 11 11 11	24	72	240	10.0	24
0322+222	1 1 1 1 11 11 11 11 1 11 1 1 11 11 1 11 1 1 1 11 11 1	32	1385	691	21.6	2190
CTA26	1 1 1 1 11 1 1	8	161	97	12.1	222
0346-279	1 1 1 1 1 1 1 11 1 11 11 1 1 1 11 1 1 1 1	23	159	315	13.7	151
NRAO150	1 1 1 1	4	16	40	10.0	12
0402-362	1 1 1 1 1 1 1 1 1 1	10	30	141	14.1	10
0403-132	1 1 1 11 1 1 1 1 1 1 1	12	201	312	26.0	274
0420+022	1	1	3	10	10.0	1
0420+417	1 1	2	9	28	14.0	6

Figure 11. Source-by-time statistics reveal sources that occur in only a few scans.

1. Open the *"Conditions"* page.
2. Set minimum number of scans per source to 10 and click *"Add"*. The condition should appear in the list on the right.
3. Set stop if number of reduced sources below to 5. This permits the iterative process to stop when no more than five sources remain below the threshold.
4. Keep a finite maximum number of iterations, for example 10, to prevent an excessive sequence of schedules.
5. Run the schedule and inspect the generated iteration files and final source statistics.

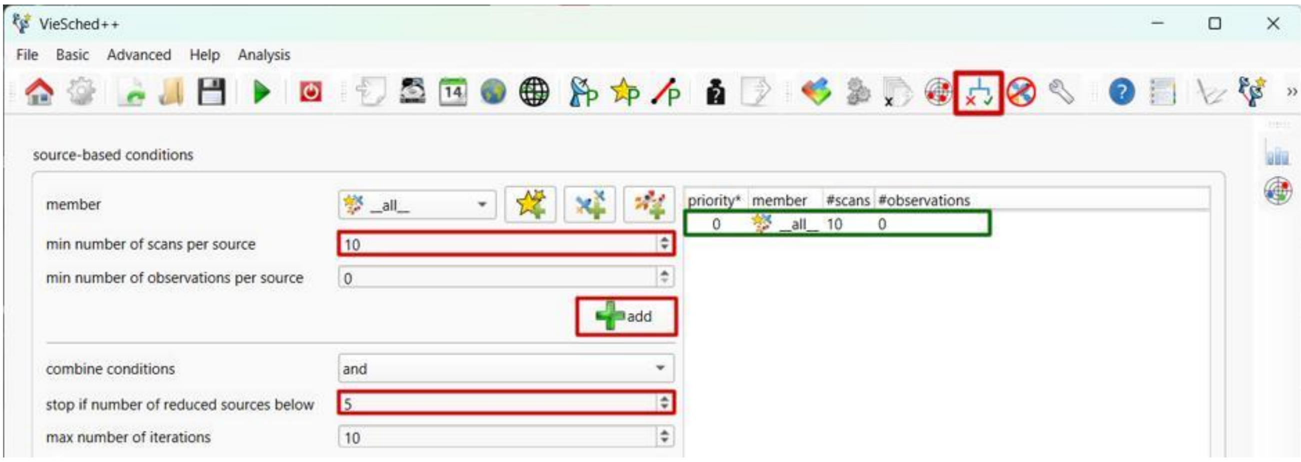

Figure 12. Add the minimum-scan condition and a stopping criterion.

HOW THE ITERATION WORKS

The condition does not simply force extra scans onto every weakly sampled source. VieSched++ first creates a schedule, identifies sources that fail the condition, reduces the candidate list, and schedules again. The source pool becomes progressively more concentrated until the condition or stopping rule is met.

CHECK THE CONSEQUENCE

A strict threshold can remove sources that are visible only briefly, especially in the far south. Record the final number of sources and verify that the desired celestial coverage is adequate.

7. Explore the schedule with VieSched++ Analyzer

The text files are useful for detailed checks, while the VieSched++ Analyzer provides an interactive view. It is particularly helpful for recognizing gaps, uneven sky coverage, repeated source patterns, and station-specific behavior.

1. Click the Analyzer icon on the right side of VieSched++.
2. Browse to the output directory, select a .skd file, and load it. A parsed schedule summary should appear.
3. Click *"run session analyzer"* to open the interactive VieSched++ Analyzer window.
4. Use the lower sliders to restrict the display to a selected time interval. Compare the full session with several shorter intervals.

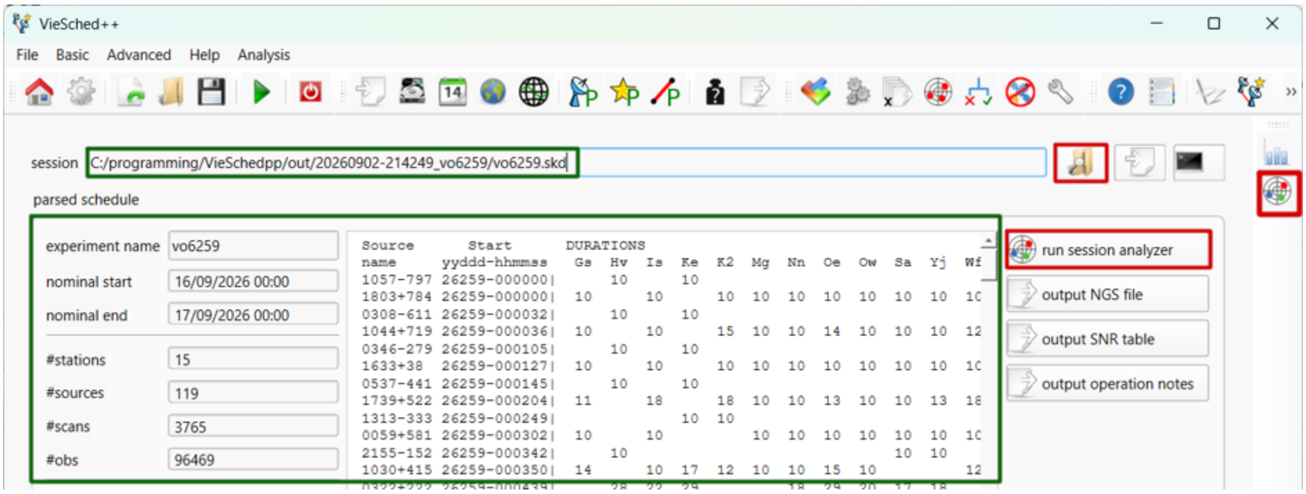

Figure 13. Load a .skd file and start the session Analyzer.

Figure 14. Interactive station sky plots and time-range controls in the Analyzer.

7.1 What should you inspect?

- Are all stations represented throughout the session, or are there long gaps?
- Does each station sample a broad range of azimuths and elevations?
- Are low- and high-elevation observations reasonably balanced?

- Do a few sources or network combinations dominate the schedule?
- Are the scan durations, slews, and idle periods operationally plausible?
- Can you identify the longer calibration blocks in the time sequence?

8. Apply source-specific settings in the deep south

The current VGOS network contains substantially more stations in the Northern Hemisphere than in the Southern Hemisphere. Sources at low southern declinations are therefore visible to fewer stations at the same time. A global minimum of three sites per scan may prevent many of these sources from being scheduled at all.

We will relax the rule only for sources south of -25 degrees declination. This demonstrates an important scheduling principle: apply exceptions to a well-defined group instead of weakening a useful global constraint.

> **SCIENTIFIC TRADE-OFF**
> A two-site scan provides only one baseline observation and has no internal redundancy. It is more vulnerable to data loss and contributes less network geometry, but it may be the only practical way to improve coverage of far-southern sources.

8.1 Create a declination group

1. Open the source-selection page using the celestial-map icon.
2. Click *"group sources per DEC".*
3. Enter a new threshold of -25.00 degrees and click *"Add".*
4. Confirm with *"OK"*. VieSched++ creates groups on either side of the threshold, including DEC_-90.00_-25.00.

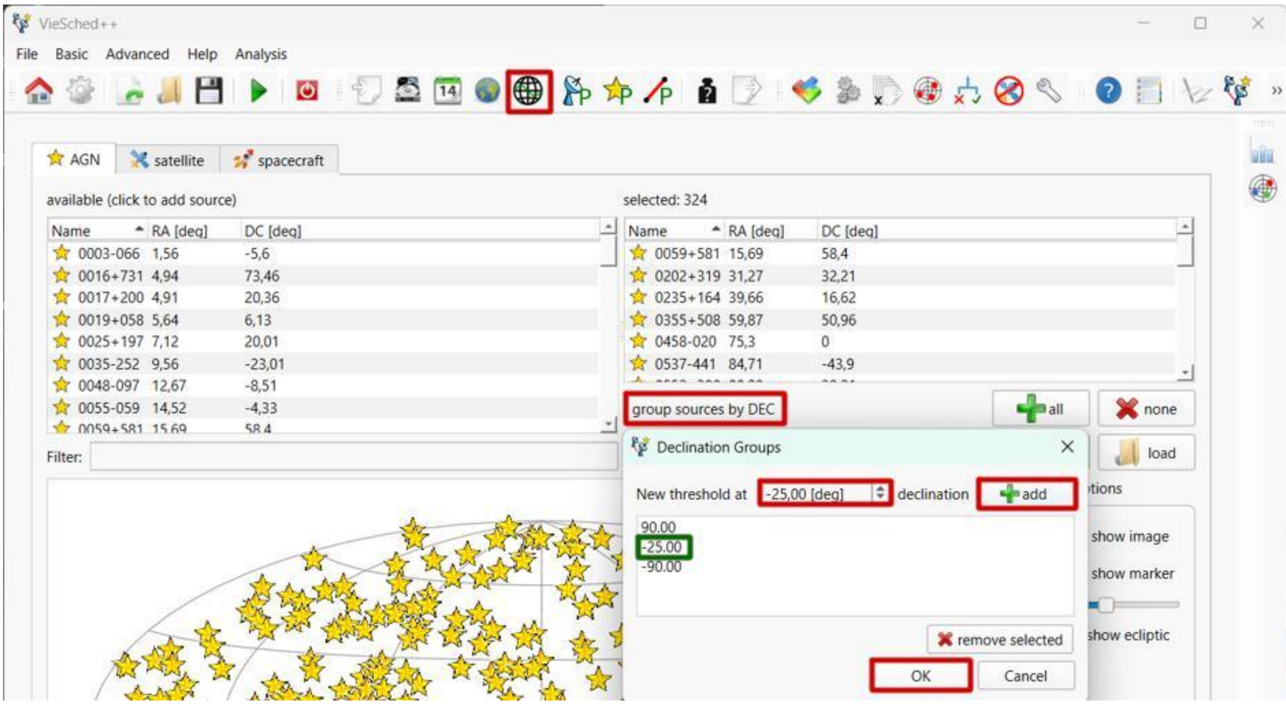

Figure 15. Create source groups separated at -25 degrees declination.

8.2 Alternative: construct a group manually

Stations, sources, and baselines each have an *"Add group"* button marked by a green plus at various places within the GUI. The group editor lets you select members manually, import a list, reuse existing groups, or combine groups through set operations such as intersection and difference. This is useful when a group cannot be described by a single numerical threshold.

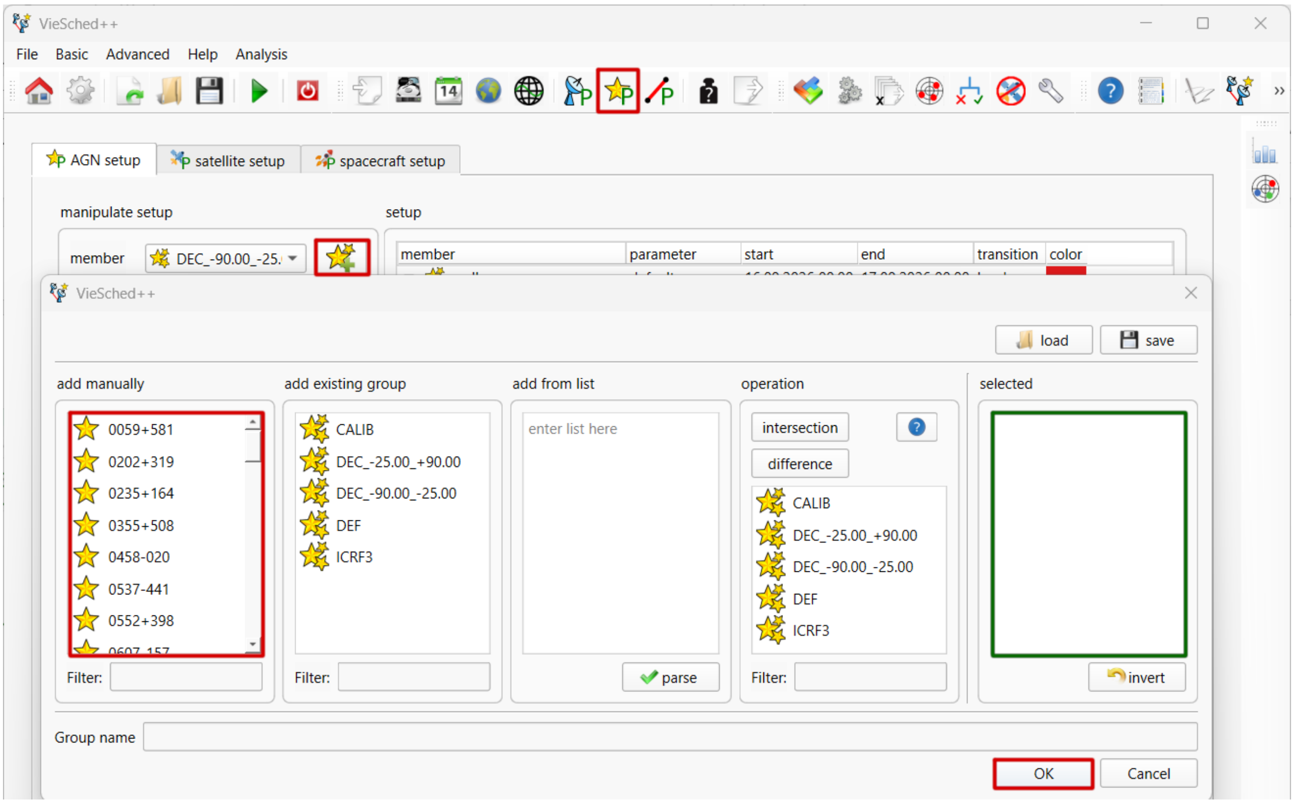

Figure 16. The general group editor supports manual selection, imported lists, and set operations.

8.3 Assign a source-specific parameter set

1. Open the Source setup page and select "*DEC_-90.00_-25.00*" as the member group. This is one of the automatically generated groups you have by introducing the declination threshold. There is also a corresponding group for *"DEC_-25.00_90.00"*.
2. Click the large green plus beside *"Parameter"* to create a parameter set.
3. Enable min *"#sites"*, set it to 2, and name the new parameter set *"min_2_sites"*.
4. Click *"OK"*, verify that *"min_2_sites"* is selected as the parameter, and click add setup.
5. Confirm that the setup appears in the list on the right for the full session interval, then run the schedule again.
6. Use the operations notes or Analyzer to verify that two-site scans occur for the southern group and that the default remains unchanged for other sources.

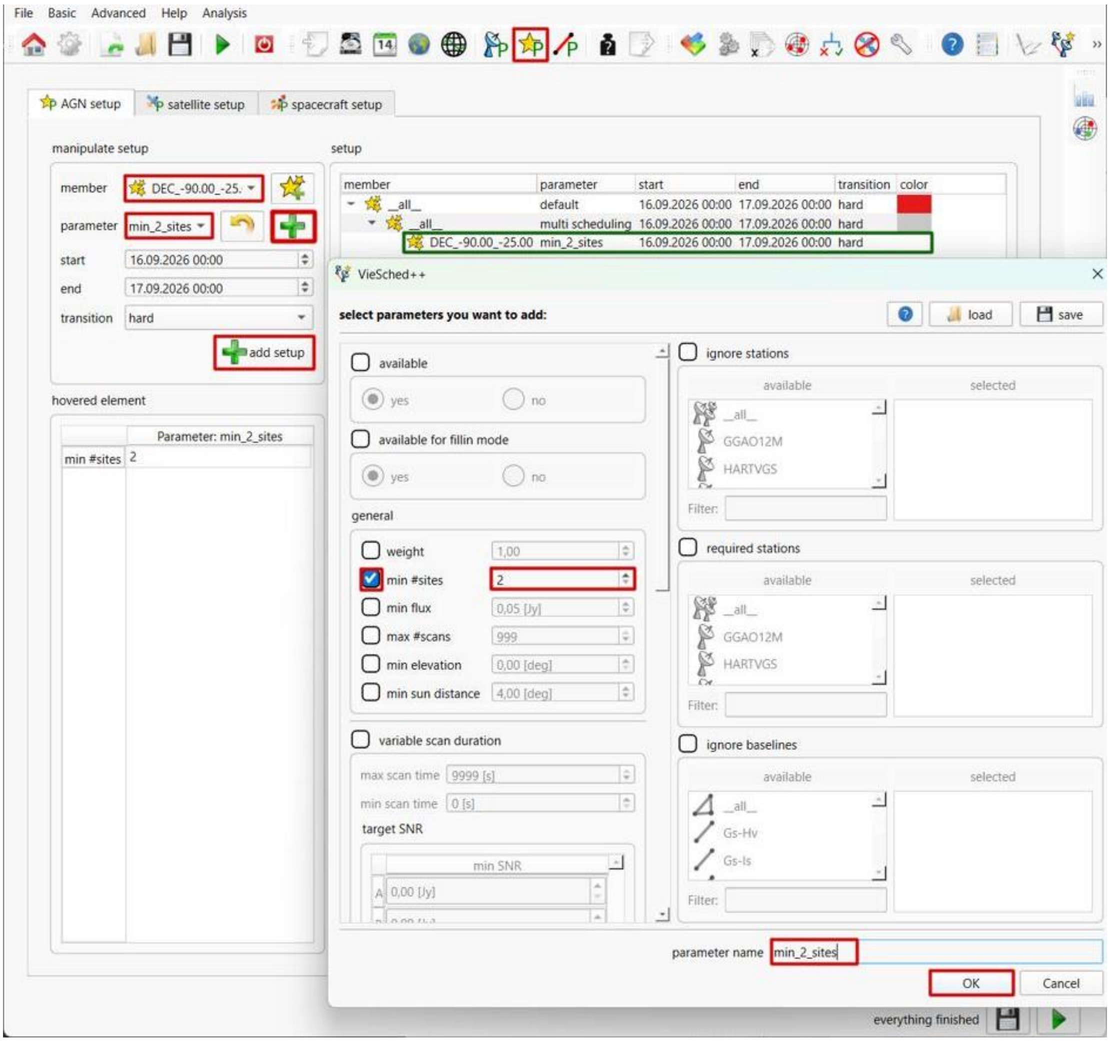

Figure 17. Create min_2_sites and assign it to the deep-southern source group.

EXPLORE THE HIERARCHY

The yellow curved arrow edits an existing parameter set. The green plus creates a new one. Equivalent setup mechanisms exist for stations and baselines. Group-based setups let you preserve general defaults while changing only a defined subset.

THE POWER OF VIESCHED++

The possibility of defining groups and assigning individual parameters to them is one of the main benefits of VieSched++. This allows you to very flexibly adjust your settings and tune the schedule based on your desires. Take time to explore all the parameters and also experiment with various settings.

9. Understand weight factors

All previous changes modified the set of admissible scans through constraints: site definitions, calibration blocks, source-selection conditions, and group-specific minimums. Weight factors act at a different level. Among the candidate scans that satisfy the hard constraints, VieSched++ ranks alternatives according to a weighted combination of scheduling objectives.

Examples include improvement in station sky coverage, number of observations per scan, scan duration, idle time, source balance, and other criteria. The weights express relative priorities; they are not physical probabilities. Increasing one weight can indirectly change many schedule statistics because the selected scan also changes the candidates available later.

INTERPRET WEIGHTS COMPARATIVELY

A larger sky-coverage weight tells the scheduler to value that criterion more strongly relative to the others. It does not guarantee that every station's final sky plot will improve, nor does it guarantee better geodetic repeatability.

Open the Weight factors page and inspect the available criteria before continuing.

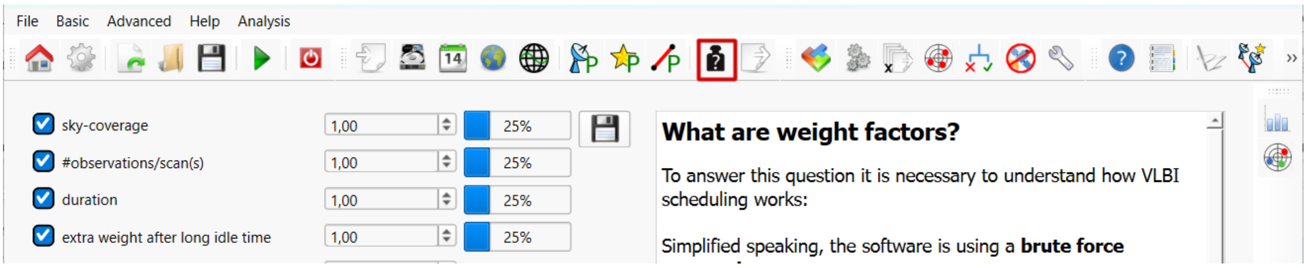

Figure 18. Configure four schedules with different sky-coverage weights.

10. Compare weight choices with multi-scheduling

Multi-scheduling generates several schedules from one configuration while varying selected parameters. Here, we vary only the sky-coverage weight. Holding all other settings constant makes the comparison easier to interpret.

1. Open the Multi-scheduling page and enable *"multi-scheduling"*.
2. In the parameter tree, look for the weight factor list and select "sky-coverage".
3. Click *"add selected"*.
4. In the value dialog, keep the generated range from 0.00 to 1.00 with a step of approximately 0.33. This produces four values: 0.00, 0.33, 0.67, and 1.00.
5. Confirm with *"OK"* and verify that the maximum number of schedules is 4.

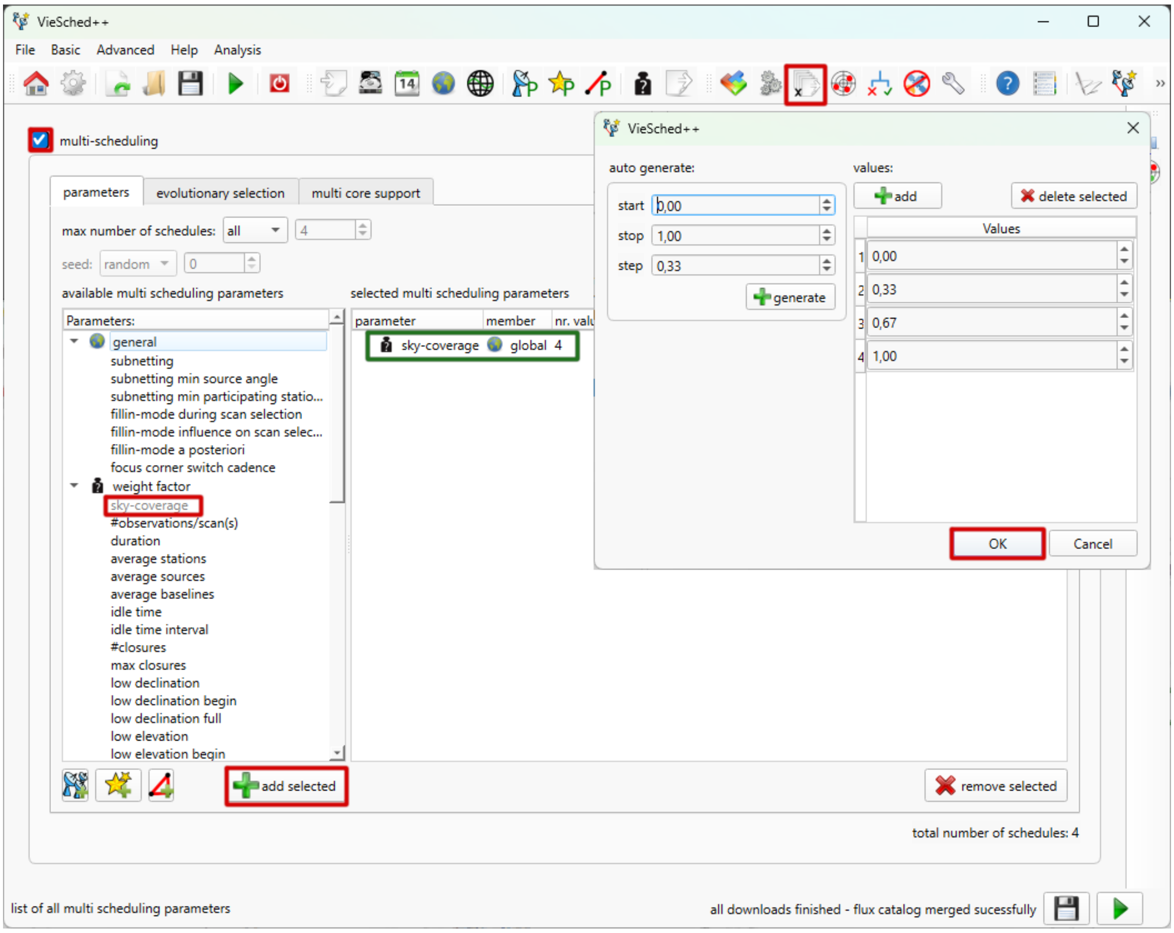

Figure 19. Configure four schedules with different sky-coverage weights.

11. Simulate the candidate schedules

Schedule statistics describe what is planned, but they do not directly show how well geodetic parameters can be recovered. VieSched++ can generate synthetic delays for each schedule, add realistic error processes, estimate selected parameters, and repeat the experiment many times. The dispersion of the estimated parameters across realizations is a measure of expected repeatability under the assumed simulation model.

The simulation can include observation white noise, clock variations, and spatially and temporally correlated tropospheric delays. These components represent important error sources, but they remain a model: unmodeled instrumental problems, radio-frequency interference, weather, and actual station failures are not predicted automatically.

1. Open the Simulations page and enable *"simulate schedules"*.
2. Click *"Load"* and select *"24_hour_VGOS"*.
3. Inspect the loaded noise, clock, and troposphere settings and the list of estimated parameters. Keep the preset values for this exercise.
4. Also inspect the parameters that will be estimated by browsing to the *"Solve"* tab.
5. Use 1,000 simulations in a Monte Carlo manner to compute repeatability values.

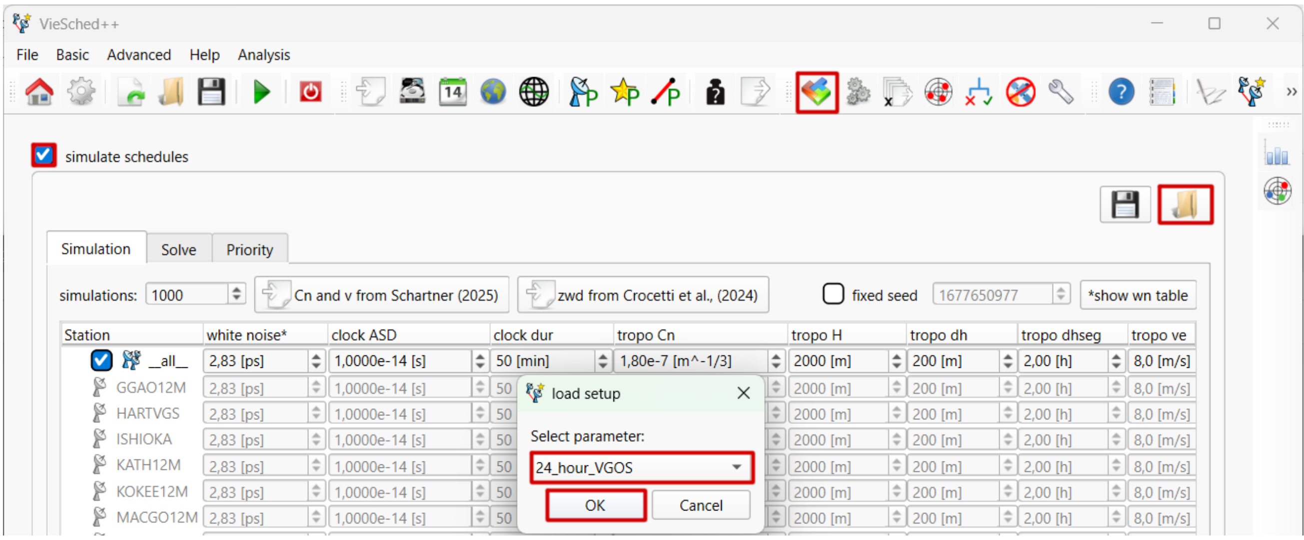

Figure 20. Load the 24_hour_VGOS simulation preset and inspect its stochastic models.

11.1 Run and inspect the four variants

Click Run. VieSched++ creates four schedule variants, usually identified by version suffixes such as *v001* to *v004*, and simulates each one. Depending on the number of realizations and the available processor cores, this step can take substantially longer than a single scheduling run.

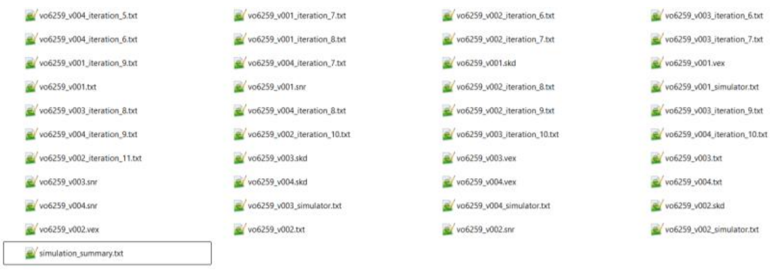

Figure 21. Multi-scheduling creates separate schedule, log, and simulator files for every variant.

Detailed results for each variant are written to files such as *"vo6259_v*_simulator.txt"*. The cross-schedule summary is stored in *"simulation_summary.txt"*.

```
repeatability:
.-----------------------------------------------------------------------------------------------------------------------
|   v  |   score    |   #obs     |    XPO     |    YPO     |   dUT1     |   NUTX     |   NUTY     |  avg. sta.  |
|      |     []     |     []     |   [muas]   |   [muas]   |   [mus]    |   [muas]   |   [muas]   |    [mm]     |
|------|------------|------------|------------|------------|------------|------------|------------|-------------|-
|    1 |   1.0000 |      98451 |    20.9145 |    23.4552 |     0.8472 |    13.5420 |    13.0012 |      3.5498 |
|    2 |   0.0000 |      96611 |    20.6144 |    23.7443 |     0.8293 |    13.8888 |    13.5996 |      3.4710 |
|    3 |   0.2783 |      95509 |    20.5121 |    22.7909 |     0.8105 |    13.5363 |    13.2380 |      3.4889 |
|    4 |   0.5794 |      94494 |    19.6508 |    22.9442 |     0.7744 |    13.1224 |    12.9727 |      3.4596 |
'-----------------------------------------------------------------------------------------------------------------------
```

Figure 22. The simulation summary compares observation counts and parameter repeatabilities.

11.2 Select a schedule

Term	Meaning in this exercise
Schedule score	A summary of the configured scheduling objective. It is useful for comparing hundreds of variants generated in the same run, but it is not a universal quality measure.
Number of observations	More observations can improve precision, but only when geometry, sky-coverage, and network participation remain useful.
EOP repeatability	Scatter of the recovered Earth-orientation parameters across simulations. For the same parameter and units, smaller values indicate better expected repeatability.
Station repeatability	Summary of coordinate scatter across simulations. Smaller values are generally preferable when station-coordinate precision is a goal.
Operational diagnostics	Station gaps, subnetwork composition, calibration coverage, source balance, scan durations, and other practical checks that may not be captured by a single simulation statistic.

DECISION RULE

Choose the schedule that best supports the scientific objective while remaining operationally robust. A variant with the smallest value in one simulation column is not automatically the best overall schedule.

MODEL LIMITATION

Simulation results are conditional on the adopted noise, clock, troposphere, and estimation models. They compare candidate schedules consistently. They do not guarantee the precision of the real experiment.

12. Include satellite scans for Genesis

Conventional geodetic VLBI observes compact extragalactic radio sources. At Earth-scale distances, these sources can be treated as fixed directions at effectively infinite distance. A satellite is different: it is nearby, moves rapidly relative to each station horizon, and may be visible simultaneously from only part of the network. VieSched++ must therefore propagate an orbit, evaluate time-dependent visibility, and identify stations that can track the spacecraft at the same time.

This extension adds Genesis as a moving target to the existing quasar schedule. The purpose is to understand how an orbit catalog and satellite-specific scheduling rules alter the candidate scans. The supplied orbit is an exercise data set; it is not intended to define an operational mission schedule.

WHAT AN ORBIT FILE DOES - AND DOES NOT DO

The orbit file tells the scheduler where the satellite is expected to be. It does not define the observing frequency, signal structure, recording mode, tracking capability, correlation setup, or near-field analysis model. Those elements must also be coordinated for a real satellite-VLBI experiment.

12.1 Preserve the previous result and simplify the run

- Disable multi-scheduling so that only one satellite-inclusive schedule is generated.
- Disable simulate schedules. The 24_hour_VGOS preset used above was selected for the quasar-schedule comparison and is not needed for this extension.

COMPARISON STRATEGY

Keep the final quasar-only schedule as the reference case. After adding Genesis, compare both schedules to determine which quasar scans, observations, and sky-coverage opportunities were displaced by the satellite scans.

12.2 Prepare a two-line element orbit file

A two-line element (TLE) set describes a satellite's mean orbital elements at a stated epoch. An orbit propagator uses these elements to predict the spacecraft position during the session. The first two digits of the epoch field identify the year, while the following value gives the day of year and its fractional part. In the example below, 26259 identifies day 259 of 2026, close to the start of vo6259.

1. Open a plain-text editor and create a new ASCII file.
2. Copy the three lines below exactly, preserving their spaces and line breaks:

```
Genesis
1 00000U 00000AAA 26259.198761574 .00000000  00000+0  00000-0 0  0000
2 00000  95.0000   0.0000 0000000 000.0000  28.1881  6.30950882000000
```

3. Save the file as "genesis_2026-09-16.tle" in an accessible folder.

USE A CURRENT ORBIT FOR REAL OBSERVATIONS

TLE accuracy degrades as the propagation interval from its reference epoch increases. The example also uses the placeholder catalog number 00000. For an operational experiment, obtain an authoritative element set or precise ephemeris valid near the observing epoch and verify the predicted passes before distributing the schedule.

12.3 Load the satellite catalog

1. Open the Input catalogs page.
2. In the source section, click *"Browse"* beside *"satellites".*
3. Select the previously generated *"genesis_2026-09-16.tle"* file and click *"Open".* Confirm that its path appears in the Satellites field.
4. Click *"Reload"* so that VieSched++ reads the new catalog (at the bottom of the source block, not in picture).

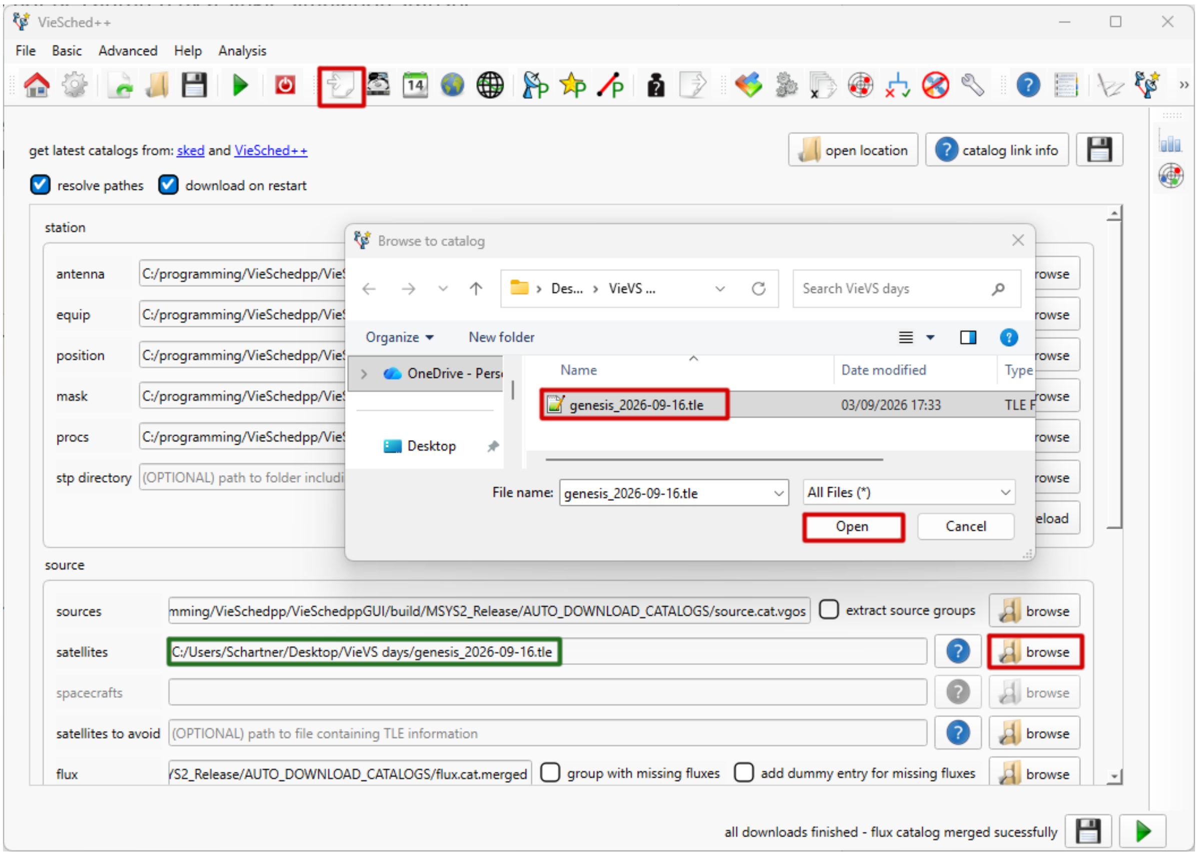

Figure 23. Select the Genesis TLE file on the Input catalogs page and reload the catalogs.

CHANGE OF SETTINGS AFTER RELOADING

Reloading catalogs can invalidate settings derived from the previously loaded source catalog, including source groups and group-specific parameter assignments. In general, it is always recommended to first define all your input files before adjusting any settings. We only do it like this now for education purposes.

12.4 Add Genesis to the candidate targets

1. Open the source-selection page using the celestial-map icon.
2. Select the *"Satellite"* tab.
3. Click *"Genesis"* in the available list on the left. It should move to the selected list on the right.
4. Confirm that the displayed epoch and orbital elements agree with the file you loaded.

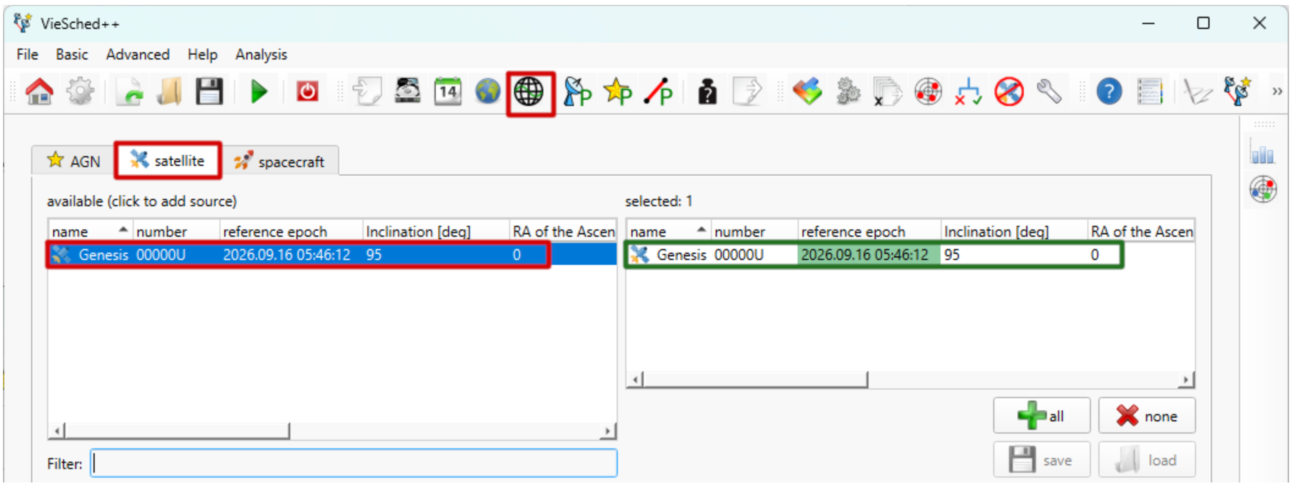

Figure 24. Add Genesis from the available satellite list to the selected targets.

12.5 Define satellite-specific scheduling parameters

The default AGN settings aim to distribute scans among many sources and normally use flux information to determine an SNR-based duration. For this exercise, Genesis should be revisited frequently, but no satellite flux model is available. We therefore assign a high source priority and deterministic timing rules.

1. Open the source setup page as before and select the *"satellite setup"* tab.
2. Because Genesis is the only loaded satellite in this exercise, click the yellow curved arrow beside *"Parameter"* to edit the default parameters.
3. Enable and adjust the four parameters from the table below, then click *"OK"*.

Satellite parameter	Value	Reason in this exercise
Source weight	999	Makes feasible Genesis scans strongly preferred relative to ordinary source candidates.
Minimum number of sites	2	Allows a pass to be used when only two independent sites have simultaneous visibility.
Fixed scan duration	60 s	Provides a defined duration because this exercise has no satellite flux model for SNR-based scheduling.
Fixed minimum time between scans	60 s	Permits frequent revisits and denser sampling along the visible orbital arcs.

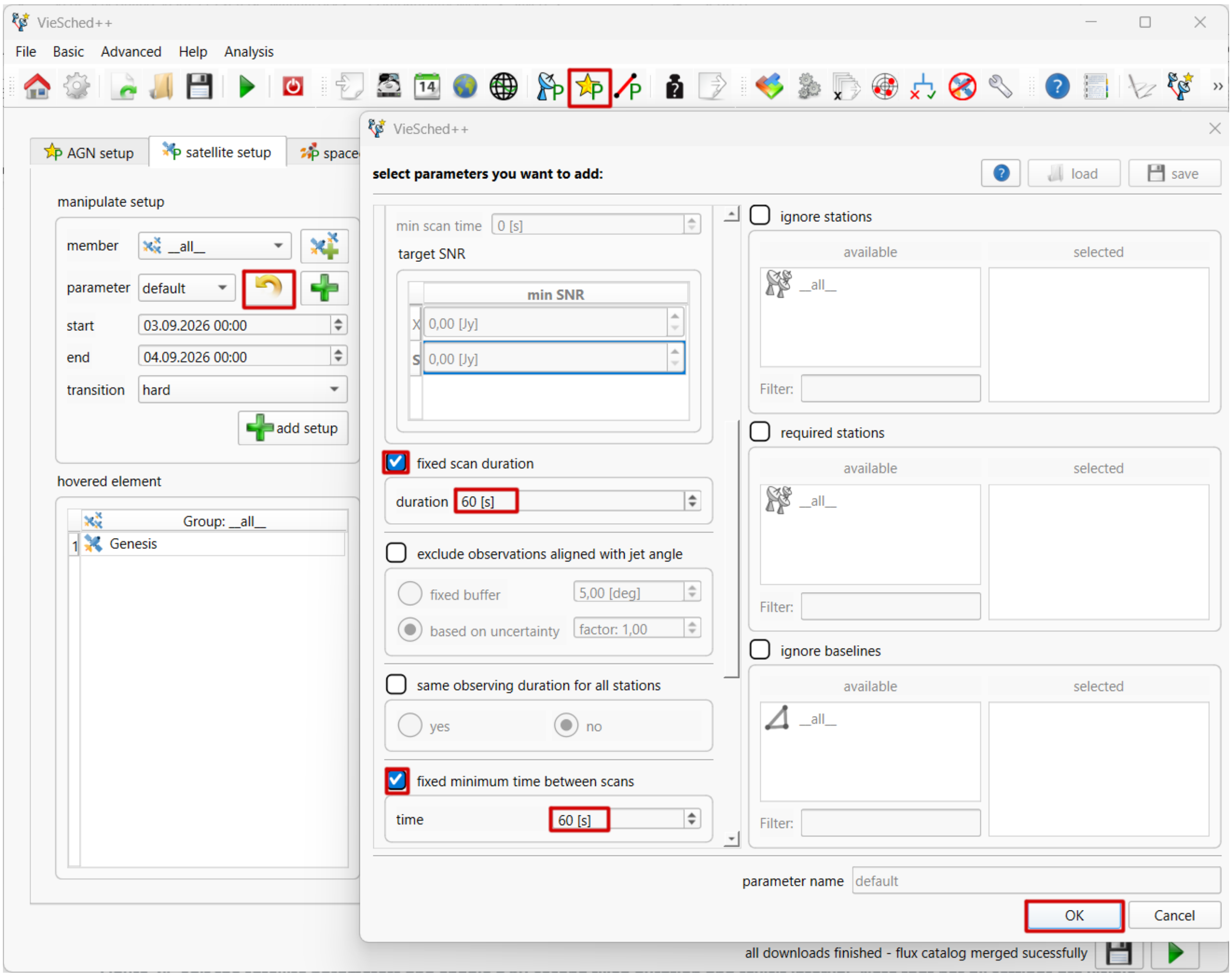

Figure 25. Edit the satellite parameters and enable a 60-second fixed duration and revisit interval. Note that not all settings are visible.

HOW TO INCREASE GENESIS SCAN SEQUENCE

A weight of 999 does not force an impossible scan. The value only changes the ranking of feasible candidates. The satellite must still be visible, stations must meet their elevation and tracking limits, and all slew, cable-wrap, timing, and network constraints must be satisfied, including minimum repeat time and minimum number of sites. Alternatively, it can also help to use a custom scan sequence rule which you can define in the Rules page.

INTERPRET TWO-SITE SCANS CAREFULLY

Two sites provide one baseline and no internal network redundancy. This can extend the sampled satellite arc, but it also makes the scan more vulnerable to the loss of either station. The setting is appropriate for this exercise, not a universal recommendation.

12.6 Run and diagnose the satellite-inclusive schedule

Click Run and wait for everything finished. Open the operations notes and locate the Genesis row in the source statistics. A scheduled row confirms that at least one feasible satellite scan was found. The time-distribution symbols show when the common-visibility windows occurred.

```
| 2351-154 |        1      1 1                        1  11 1                  1           1         1      |    10  164 |   268      26.8 |       218 |
| 2355-106 |              1                                                                                    |     1    3 |    10      10.0 |         1 |
| 2355-534 |                                      1 11 1 1  1 1         11 1    11 1 1 1 1   1 11 1 11 1       |    23   69 |   230      10.0 |        23 |
| 2357-318 |      1                        1                                                                   |     2    6 |    31      15.5 |         2 |
|----------|+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---|------------|----------------|----------|
| Genesis  |  654666155561    255556336454    155546754      2552645651    255643755553    56436756454       356|   316 3960 | 18960     60.0 |
'------------------------------------------------------------------------------------------------------------------------------------------------'
```

Figure 26. The source statistics show the scheduled Genesis scans and their distribution through the session.

1. Record the number of Genesis scans and observations.
2. Check whether the scans occur in distinct visibility windows rather than uniformly through the day.
3. Inspect how many independent sites participate in each satellite scan and which stations dominate.
4. Verify that the scheduled Genesis scans use the intended 60-second duration.
5. Compare the total quasar scans, observations, source balance, and station sky coverage with the saved quasar-only schedule.
6. Look for excessive slewing, long station gaps, or a single satellite pass that displaces too much of the geodetic program.

EXPECTED EFFECT

Genesis should appear repeatedly during periods of common visibility. Because telescope time is finite, increasing the number of satellite scans will normally reduce some part of the quasar program. A useful mixed schedule balances satellite arc coverage against the geodetic quality of the remaining AGN observations.

12.7 From scheduling to simulation and analysis

The generated schedule files can be imported into compatible VLBI simulation and analysis software, such as VieVS configured for satellite observations. Unlike a quasar, a spacecraft is at finite distance. The delay model must therefore use near-field geometry and an orbit or ephemeris that is consistent with the observation times. The TLE used for scheduling is adequate for this classroom exercise, but it is not automatically a sufficiently precise orbit model for high-accuracy analysis.

A complete experiment also requires a compatible satellite signal, station receiver and recording setup, antenna tracking commands, correlation model, and analysis configuration. The schedule provides the observing timeline. It does not replace these technical interfaces.

FINAL EVIDENCE TO RETAIN

Keep the satellite TLE together with the VieSched++ XML, .skd, .vex, operations notes, and any external simulation or analysis configuration. This records both the assumed orbit and the scheduling choices used to generate the mixed session.

Further reading

VieSched++ overview: [Schartner and Boehm (2019), Publications of the Astronomical Society of the Pacific, 131, 084501]