The First Year of KOKEE12M-WETTZ13S VGOS Intensive Scheduling: Status and Efforts Towards Improvement

Karen Baver[1], John Gipson[1], Frank Lemoine[2]

Abstract The KOKEE12M-WETTZ13S (K2-Ws) VGOS Intensive series began on January 4, 2021. Evaluation of the first year of schedules has shown that the series is performing reasonably well, but the schedules could be improved. For example, the number of scheduled scans in a typical K2-Ws session is approximately half those of the first few MACGO12M-WETTZ13S Intensive sessions, and scheduling fewer scans negatively impacts UT1 results. Also, preliminary analysis of the K2-Ws scans' scheduled and achieved SNRs and their ratios shows examples where the achieved SNRs are either too high, indicating long scans that could have been replaced by a greater number of shorter scans, or too low, indicating a lack of robustness that could lead to scan loss. In this paper, we discuss the areas of concern and the status of efforts to make improvements in these areas.

Keywords VGOS, Intensives, scheduling

1 Introduction

The International VLBI Service for Geodesy and Astrometry (IVS) observes several series of one-hour single baseline ("Intensive") sessions that provide rapid UT1-TAI estimates. One of these series is the "V-series" (e.g., V21004), in which the WETTZ13S (Ws) and the KOKEE12M (K2) VGOS antennas observe. This series began on January 4, 2021. Scheduling of the K2-Ws series is done by the Sked program, mainly through automated scheduling. Manual scheduling is used as a supplement to insert three calibrator scans at least 15 minutes apart at times when Sked has automatically selected the target calibrator source or a source at a similar right ascension and declination, if possible. Manual scheduling is used as needed for other reasons, such as adding scans when Sked's automated mode fails.

Scheduled scan (observation) lengths are very important in an Intensive session due to the session's short duration. Scheduled scan lengths determine the number of scheduled scans and, in turn, the maximum number of achieved scans. This metric then directly affects the session's UT1 formal error, which decreases as 1 over the square root of the number of scans. With only one hour of observing time in an Intensive session, the number of potential scans in an Intensive session is limited; so it is important to keep the scheduled scans short to increase the number of scheduled scans. But scans must also continue for enough time to achieve a minimum SNR that will enable the scan to be correlated and included in the final set of a session's data. This is especially important in a one-hour session, in which the loss of a source and its scans will remove a greater percentage of the data. So the scheduled scan lengths must be balanced between being short enough to provide many scheduled scans but long enough that the scans will be successful.

Three aspects of scheduling significantly affect the scheduled scan lengths. The greatest impact comes from the values of the minimum and maximum permitted scan lengths. During 2021 these values were set to 40 seconds and 200 seconds, respectively. The values were a carryover from the S/X INT01 schedules, and they were retained in the 2020 V-series schedules,

1. NVI, Inc.
2. Goddard Space Flight Center

which included three additional antennas whose baselines sometimes needed longer scan lengths. The minimum and maximum scan lengths should have been reduced when the 2021 K2-Ws series began, but, due to an oversight, the reduction was not made. The oversight was realized during comparison of the K2-Ws series to the first MACGO12M-WETTZ13S (Mg-Ws) VGOS Intensives. The Mg-Ws series was initiated in December 2021 by NASA GSFC, Geodetic Observatory Wettzell, and ETH Zurich as a research program to test improvements to Intensive scheduling using the VieVS software and to commission a “backup” VGOS baseline for UT1 determination whenever the K2-Ws baseline might be unavailable. The first Mg-Ws sessions averaged 60 to 65 scans per hour, roughly 50% more than in the 2021 K2-Ws series. This motivated us to look for ways to increase the scan count for the K2-Ws series. The smaller K2-Ws scan counts were traced to the excessively large minimum and maximum scan lengths, and plans were quickly made to reduce the minimum and maximum scan lengths to values that would generate more scans but make sure that the scans would be strong enough to be correlated.

The other two factors that affect a scan’s scheduled length are the system equivalent flux densities (SEFDs) of the antennas in the scan and the flux density (flux) of the source being observed. The SEFDS and flux used to a schedule a scan contribute to the scan’s scheduled length according to the following equation [2]:

$$ScanLength = \left(\frac{SNR}{\eta \times F}\right)^2 \times \frac{SEFD_1 \times SEFD_2}{SR \times NC} \quad (1)$$

where SNR is the scan’s target SNR, η is the degradation in SNR due to digital sampling multiplied by a constant that corrects approximations made during correlation, F is the flux density of the source being observed, $SEFD_1$ and $SEFD_2$ are the SEFDs of the two observing antennas, SR is the sampling (recording) rate (double the bandwidth (per channel)), and NC is the number of channels (the total number of tracks recorded (excluding fan-out)) [2]. When the schedule is observed, the scan length from Equation 1 and the actual SEFDs and fluxes at the time of the scan then provide a scan’s achieved SNR according to the following inversion of the first equation [2]:

$$SNR = \frac{\eta \times F \times \sqrt{SR \times NC \times ScanLength}}{\sqrt{SEFD_1 \times SEFD_2}} \quad (2)$$

If the achieved SNR from Equation 2 is less than 7, the scan will not be correlated, reducing the session’s final scan count. So, it is important to use antenna SEFDs and source fluxes during scheduling that will provide good scan lengths that during observing will generate high enough SNRs so that the scans will be correlated.

But a complicating factor is that a schedule is expected to be submitted to the IVS seven days before the schedule is observed, and the SEFDs and fluxes can change greatly during that time. Therefore, the antenna SEFDS used in the 2021 K2-Ws scheduling were calculated for each schedule based on the averages of SEFDs from Ws and K2 ready, start, and stop messages (when available). SEFD averages from the past day, week, two weeks, and month were considered. Source fluxes were updated approximately once per week, based on four to six weeks of the most recent R1 and R4 data. This provided some averaging of the source fluxes. But it should be noted that the flux information at the time of scheduling was out-of-date because it generally takes two to three weeks for a correlator to receive and correlate the data from an R1 or R4 session.

Feedback about the accuracy of the SEFDs and the fluxes used in scheduling comes from looking at the SNRs from the observed sessions and also at the ratios of the observed to the scheduled SNRs. Preliminary analysis of these metrics in the 2021 K2-WS schedules shows examples in which the ratios are either too high, indicating long scans that could have been replaced by a greater number of shorter scans, or too low, indicating a lack of robustness that could lead to scan loss. This indicates a need to look more closely at the determination of the antenna SEFDs and source fluxes for use in scheduling.

This paper discusses the areas of concern and the status of efforts to make improvements in these areas. Section 2 discusses efforts that have already been made to reduce the minimum and maximum scheduled scan lengths. These efforts are assessed by comparing six weeks of sessions scheduled with the new schedule configuration to six weeks of sessions scheduled with the original configuration. Section 3 provides a preliminary assessment of the antenna SEFDs and source fluxes used for scheduling during 2021 using all of the

2021 data. It then briefly discusses initial future plans. Section 4 presents conclusions.

2 Minimum and Maximum Scheduled Scan Lengths

In December 2021, we noticed that the number of scans in the 2021 K2-Ws sessions were approximately half those of the initial MACGO12M-WETTZ13S (Mg-Ws) sessions. We identified the cause as the fact that the Mg-Ws schedules had short scans that lasted mostly 30 to 48 seconds with a few 120 second scans of calibrator sources. In contrast, the K2-Ws schedules had scans ranging from 40 to 200 seconds. Steps were quickly taken to run simulations to determine new, reduced minimum and maximum scan lengths that would generate more scans in the K2-Ws schedules but not weaken the scans enough that they would not be correlated. Several combinations of shorter minimum and maximum scan lengths were tested. A 20/60 second minimum/maximum scan length combination was promising, but the combination generated some short schedules in Sked's automated mode due to a reduction of the list of sources that could be observed. Reducing the target SNRs from 20 to 15 did not help. But the configuration with 20/60 second minimum/maximum scan lengths and target SNRs of 15 provided the most scans and the best UT1 formal errors as discussed in [1]. Short schedules can be finished manually; so, on January 31, 2022, testing of the new schedule configuration began in the daily K2-Ws sessions.

The remainder of this section evaluates the effects of the new scheduling configuration. Source availability has a large impact on one-hour sessions. So, this section compares the first six weeks of the new-style sessions (January 31 to March 15 in 2022) to old-style sessions from the corresponding six weeks in 2021 to ensure that the two session sets observed the same areas of the sky. Due to a change in scheduling frequency, there are 12 old-style sessions and 29 new-style sessions.

Figure 1 (left) shows that the new schedule configuration increases the number of scheduled scans. The scan counts range between 60 and 70, which is closer to the Mg-Ws scan counts. But Figure 1 (right) shows that the new configuration also increases the average number of scheduled scans per source. This increase could have a mixed effect. On the one hand, having more scans per source decreases robustness because if a source is observed more times, its scans will make up a greater percentage of the schedule, and therefore the loss of the source will have a greater impact on the session. On the other hand, there is some concern within the IVS that if a source is observed only once in a session, the source's scan might not connect well within the session's solution. The GSFC Analysis Center has not investigated this possibility, but we consider it as a minor factor when generating the K2-Ws schedules. Figure 2 shows that the new schedule configuration reduces the average number of sources observed once in a session from eight in the old-style sessions to 3.5. On the other hand, the new-style sessions have more sources with four scans per session, significantly more sources with five or six scans per session, and a few sources with seven scans per session, in contrast to the old-style sessions, which have no sources with seven scans. So the new configuration has a mixed effect on the number of scans per source in a session, and this effect should be studied further.

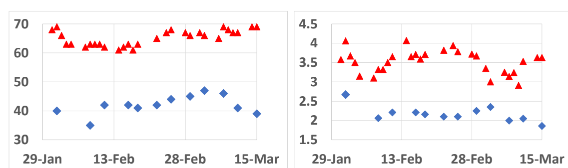

Fig. 1 Old-style (2021) sessions (blue diamonds) vs. new-style (2022) sessions (red triangles): number of scheduled scans (left) and number of scheduled scans per source (right).

Finally, observation loss as measured by the individual scans' observed SNRs and the sessions' average observed-to-scheduled SNR ratios are considered. In its first six weeks, the new schedule configuration did not hurt the individual observed SNRs. In fact, the SNRs slightly improved. Only 0.2% (3) of the new-style schedules' scans failed, in contrast to 1.2% (5) of the scans made with the old schedule configuration during the six weeks in 2021. The SNR ratios averaged over a session also show no problems. There is no obvious difference between the old-style and new-style average ratios, as shown in Figure 3, and the average of each session type's average ratios is 1.1.

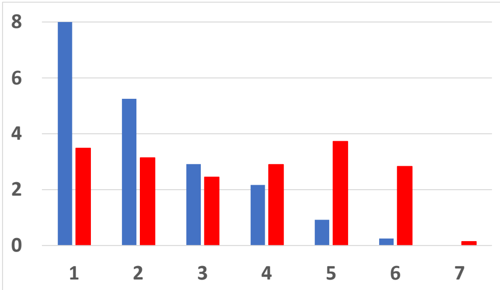

Fig. 2 Average number of sources per session (y-axis) that were scheduled N times in the session (x-axis). E.g., on average, 0.9 sources were scheduled five times in the old-style sessions, and 3.7 sources were scheduled five times in the new-style sessions. Old-style (2021) values are represented by the blue (left) bar in each pair, and new-style (2022) values are represented by the red (right) bar in each pair.

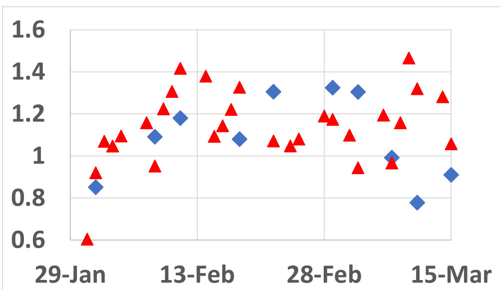

Fig. 3 Observed-to-scheduled SNR ratios averaged over all scans in a session: old-style (2021) (blue diamonds) vs. new-style (2022) (red triangles).

3 Antenna SEFDs and Source Fluxes

The observed SNRs and the ratio of the observed SNRs to the scheduled SNRs provide feedback about the antenna SEFDs and source fluxes used for scheduling. The observed SNRs from the entire set of 2021 (old-style) K2-Ws sessions indicate that the antenna SEFDs and the source fluxes used for scheduling were reasonable. 4,816 (97.8%) of the 4,925 scans in 2021 had an SNR of at least 7 and were successfully correlated. Where scans failed, the failures seemed to be generally unrelated to the schedule. Only four (0.1%) of the scans seemed to be related to the schedule (specifically to the source fluxes used), although we admit that the causes of the failures of 16 (0.3%) of the scans are not known.

But the averages of each session's observed-to-scheduled SNR ratios indicate some problems. Figure 4 plots the ratios of the observed-to-scheduled SNRs (averaged over all scans in a session) for all of the sessions in 2021. Lower averages show an overestimation of antenna and source strength (that is, an underestimation of SEFDs and an overestimation of fluxes) that could lead to scan loss. Higher averages show an underestimation of strength (an overestimation of SEFDs and an underestimation of fluxes) that kept additional scans from being scheduled. We think that it is best to have SNR ratios between 0.9 and 1.1. It should be noted that the ratios have been cut in half because observed SNRs are based on four bands while scheduled SNRs are based on one band.

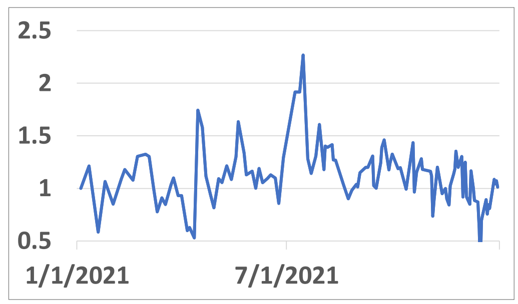

Fig. 4 Ratios of the observed-to-scheduled SNRs (averaged over all scans in a session) for all sessions in 2021.

Antenna SEFDs have a large impact on scheduling because they affect every scan and because the scheduled scan lengths vary as the product of each scan's two SEFDs, as shown in Equation 1 above. Unfortunately, SEFD measurements are currently only available through an antenna's ready, start, and stop messages, and antenna operators do not always have time to measure their antennas' SEFDs. Also, sometimes strong sources are not visible at an antenna, and the operators cannot take an SEFD measurement. During 2021, SEFD measurements were only available for both the WETTZ13S antenna and the KOKEE12M antenna on 79 of the 182 days on which a schedule was written and/or observed. On 73 of the days, SEFDs were only available for one antenna, and on 30 days, SEFDS were not available for either antenna. So it is currently hard to determine the SEFDs at the time of scheduling or to use the SEFDs at the time of observing to assess the accuracy of the SEFDs used during scheduling. The GSFC Analysis Center is discussing ways to obtain SEFD measurements more frequently.

The source fluxes only affect individual sources; so it will be easier to determine their quality and, if necessary, correct how they are generated once the systematic impacts of the antenna SEFDs are known and, as necessary, corrected. But preliminary analysis yields two insights. Figure 5 plots the observed-to-scheduled SNR ratios of the 4,925 successful scans in 2021 vs. the declinations of the sources observed in the scans. First, the SNR ratios greater than 4 come from underestimated fluxes of two sources in two catalog versions. This indicates that the worst underestimations came from a transient condition. Second, all 130 scans with source declinations less than or equal to 17.16° have SNR ratios less than 1. This behavior is not seen in the S/X KOKEE-WETTZELL Intensive sessions, so it might be due to the small data set. But this behavior should be watched to see if it continues.

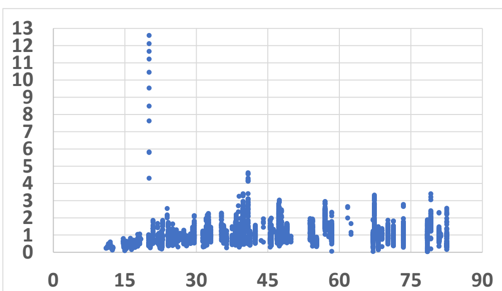

Fig. 5 Ratios of the individual scans' observed-to-scheduled SNRs in the 2021 sessions vs. the declinations in degrees of the sources that were observed in the scans.

4 Conclusions

Scheduled scan lengths are important in scheduling one-hour Intensive sessions. Three factors that contribute to the scan lengths are the minimum and maximum scan lengths allowed during scheduling and the antenna SEFDs and the source fluxes used during scheduling.

The 2021 K2-Ws schedules had minimum and maximum scan lengths that were too high (40 and 200 seconds, respectively). Starting with the January 31, 2022 schedule, the minimum and maximum scan lengths were reduced to 20 and 60 seconds, respectively, and the target SNRs were reduced from 20 to 15 to avoid excluding too many sources due to the reduction of the maximum permitted scan length. The new schedule configuration has improved the number of scheduled scans in a session without harming the session's observed SNRs or the average ratios of the session's observed-to-scheduled SNRs. But more scans are now scheduled per source during a session, which can have a mixed effect on the session.

The 2021 K2-Ws scans generally achieved good SNRs after correlation. But the observed-to-scheduled SNR ratios averaged over a session are sometimes too low or too high, indicating a need to look more closely at the antenna SEFDs and the source fluxes used during scheduling. Individual scans' observed to scheduled SNR ratios with values greater than 4 come from only two source fluxes in two catalogs, indicating a transient issue. Antenna SEFDs are not always available; so determination of the SEFDs to be used during scheduling, as well as the assessment of the SEFDs used during scheduling, can be difficult. The GSFC Analysis Center is discussing ways to improve SEFD determination for scheduling. Once this is accomplished, it will be easier to assess the quality of the source flux values generated by the GSFC Analysis Center and to determine how to improve them, if necessary.

Acknowledgments

We thank the KOKEE12M and WETTZ13S operators for providing SEFD measurements whenever possible. We also thank Andy Sargent (Washington Correlator) for providing information about the correlation of the K2-Ws sessions.

References

1. J. Gipson, K. Baver, S. Bolotin, F. Lemoine, P. Elosegui, C. Ruszczyk, D. Mondal, A. Sargent, P. Haftings, S. Hardin, C. Coughlin, C. Plötz, A. Neidhardt, T. Schüler, "Evaluation of the KOKEE12M-WETTZ13S VGOS Intensives with Calc/Solve", this volume.
2. J. Gipson, Sked manual, 2018-Oct-12 version, pages 180 and 181.