Evaluation of the KOKEE12M/ONSA13NE Baseline as a KOKEE12M/WETTZ13S Backup

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Abstract USNO's IERS Rapid Service/Prediction Center (RS/PC) uses the KOKEE12M/WETTZ13S (K2/Ws) baseline for its combination solutions. It would be useful for the RS/PC to be able to use backup baselines in case K2 or Ws is not available. Here we evaluate the KOKEE12M/ONSA13NE (K2/Oe) baseline as a possible backup. We find that the K2/Oe differences with respect to extrapolated R1/R4 UT1–TAI estimates (-5.3 ± 13.5 µs) are smaller than the K2/Ws differences (7.7 ± 15.1 µs) when Ws is scheduled normally and comparable when Ws is scheduled with elevated SEFDs. Based on this, and other factors, we conclude that the K2/Oe baseline could be a viable backup for the K2/Ws baseline.

Keywords Intensives, VGOS, scheduling, UT1

1 Introduction

The International VLBI Service for Geodesy and Astrometry (IVS) observes several series of one-hour ("Intensive") sessions that provide rapid UT1 estimates. One series is the VGOS-INT-A series. The KOKEE12M (K2) and the WETTZ13S (Ws) antennas typically observe these sessions, and this is the only VGOS-INT-A baseline that USNO's IERS Rapid Service/Prediction Center (RS/PC) accepts for its combination solutions. It would be useful for the RS/PC to be able to use backup baselines in case K2 or Ws is not available.

While Ws underwent repair from mid-December 2022 to mid-March 2023, ONSA13NE (Oe) replaced Ws, to provide immediate UT1 for IVS products but also to begin building a data set for the RS/PC to eventually use to "characterize" (assess and approve) the K2/Oe baseline for use in its solutions. The RS/PC needs 60 sessions spread over four months to be able to characterize a baseline (Nick Stamatakos, RS/PC, 5/12/2022 USNO/GSFC VGOS Intensive meeting), and the data from the repair period provided 58 sessions, with three multi-baseline K2/Oe sessions being observed in November 2023. The RS/PC might prefer the data to be more evenly spread over the evaluation period, but meanwhile this paper looks ahead to see if the K2/Oe baseline could be a viable candidate for characterization. The paper evaluates the performance of the K2/Oe baseline itself and also compares the performance of the K2/Oe and K2/Ws baselines.

Section 2 describes the K2/Oe and K2/Ws data sets used in the evaluation. Section 2 also describes factors that affect the scheduling of the two baselines, specifically the mutual visibility for each baseline and the parameters used by the *Sked* scheduling program for each baseline. Section 3 evaluates the observed K2/Oe sessions using three types of metrics, comparing the sessions to observed K2/Ws sessions. Section 4 uses a year of hypothetical schedules to evaluate three schedule-based metrics. VGOS-INT-A sessions observe a small slice of sky containing a small set of quasars ("sources") that change throughout the year. Each session's performance depends on the available sources, so it is ideal to evaluate a year of schedules to predict how the baseline might perform when it observes a variety of source sets. Section 5 summarizes and concludes that the K2/Oe baseline could be a viable backup for the K2/Ws baseline.

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2 Data Sets and Scheduling Factors

VLBI stations observe radio signals from quasars ("sources"). The single baseline VGOS-INT-A sessions observe for only one hour and only a small slice of the sky. The distribution of sources is uneven throughout the sky. So, to meaningfully compare two VGOS-INT-A schedules, the schedules should observe the same part of the sky. This can be done by comparing schedules that start at the same day of year and time of day [1]. We did not plan a session-by-session comparison, but we at least wanted a comparison of sets of sessions from the same time frame. 57 single baseline K2/Oe sessions ran from December 19, 2022 (V22353) through March 24, 2023 (V23083). The only available K2/Ws sessions at corresponding times of the year were observed in December 2023/January 2024 and February/March 2022. But, while normal Ws SEFDs were used to schedule the February/March sessions, Ws was scheduled with elevated SEFDs in the December/January sessions to compensate for Ws having two defective LNAs. So the data are split into K2/Oe and K2/Ws December/January (ELEV) and February/March (NORMAL) data sets. Table 1 shows the data sets used in the evaluation, and Table 2 shows the Ws SEFDs. Multi-baseline K2/Oe sessions (sessions with tagged along stations) are omitted from the study for simplicity. We disclose that the K2/Ws NORMAL data set did not extend far enough to match the final K2/Oe session, which started 15 minutes after the final K2/Ws session and was the equivalent of a session a few days later.

Table 1 Data sets used in the evaluation. 57 K2/Oe and 59 K2/Ws sessions were used.

	December/January schedules (elevated Ws SEFDs were used in scheduling)	
	K2/Ws	K2/Oe
Sessions	V23353–V24031	V22353–V23031
Dates	12/19/2023–1/31/2024	12/19/2022–1/31/2023
#Sessions	24 good, 2 failed	25 good, 1 failed
	February/March schedules (normal Ws SEFDs were used in scheduling)	
	K2/Ws	K2/Oe
Sessions	V22032–V22083	V23033–V23083
Dates	2/1/2022–3/24/2022	2/2/2023–3/24/2023
#Sessions	35 good	32 good, 1 failed, 1 canceled

The relative positions of two stations determine which sources they can mutually observe. Figure 1 shows the mutual visibility of the K2/Ws and K2/Oe baselines. The maximum mutual visibility is limited by obstacles on the horizon at each station, as well as by any minimum observing elevation imposed during scheduling. The plots include both stations' horizon masks plus the 8° elevation minimum imposed on both baselines during scheduling. The Ws and Oe longitudes differ by less than 1°, and their latitudes differ by approximately 8.5°. This causes the baselines' mutual visibilities to be slightly offset, giving each baseline a slightly different set of sources to observe. The roughly semi-circular indentation in K2's northwest quadrant is due to the Kokee 20-m antenna, which blocks the sky and significantly limits observing for both baselines.

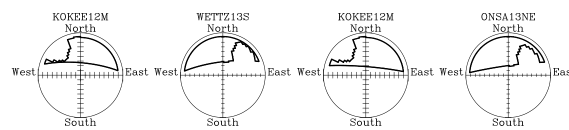

Fig. 1 Mutual visibility at K2/Ws (left) and K2/Oe (right).

Table 2 Station SEFDs used in scheduling (in Jy).

	December/January			
	K2	ELEV Ws	K2	Oe
X-band	3000	3000	2500	3000
S-band	3000	3000	2500	3000
	February/March			
	K2	NORMAL Ws	K2	Oe
X-band	2200–2900	1400–1800	2500–3100	3000
S-band	2800–3300	1300–1900	2500–3500	3000

Most of the scheduling parameters important to this study were common to both the K2/Ws and K2/Oe baselines. Both were scheduled through a combination of the *Sked* automated and manual modes by the same scheduler. The source fluxes used differed but were updated approximately weekly. The "S/X" SNR targets were set to 15, and the SNR margins were set to 0 so that *Sked* could not lower the SNR targets. The minimum and maximum scan lengths were set to 20 and 60 seconds, respectively. Three 120-second calibrator observations were scheduled. But the station SEFDs used in scheduling differed. Table 2 shows details.

3 Observed K2/Oe Session Evaluation

This section evaluates the K2/Oe observed sessions using three types of metrics: UT1–TAI estimates, metrics related to observation counts, and SNR-based metrics.

3.1 UT1–TAI Estimates

Figure 2 compares the K2/Oe and K2/Ws Intensive sessions' UT1–TAI estimates in µs to estimates from temporally close R1 and R4 sessions. Each R1 or R4 estimate was extrapolated to the closest Intensive epoch. R1 and R4 sessions with epochs more than a day from the closest Intensive epoch were omitted, because the extrapolation errors grow rapidly. Table 3 shows the averages (means) and the standard deviations of the differences between the Intensive estimates and the extrapolated R1 and R4 estimates. In February/March, with normal Ws SEFDs, the standard deviation and the absolute value of the mean of the K2/Oe differences (-5.3 ± 13.5 µs) are smaller than the K2/Ws values (7.7 ± 15.1 µs). The results are mixed in December/January, with K2/Oe values of -3.6 ± 19.2 µs vs. K2/Ws values of 0.6 ± 27.7 µs (the largest standard deviation of all four data sets). But the K2/Oe performance in both cases seems reasonable.

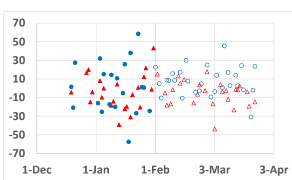

Fig. 2 Comparison to R1/R4 UT1–TAI estimates in µs. Circles represent K2/Ws, and triangles represent K2/Oe. Closed symbols represent December/January (elevated Ws SEFDs), and open symbols represent February/March (normal Ws SEFDs).

Table 3 Means and standard deviations of the differences between the Intensive and R1/R4 UT1–TAI estimates (µs).

	December/January elevated Ws SEFDs	February/March normal Ws SEFDs
K2/Ws	$+0.6 \pm 27.7$	$+7.7 \pm 15.1$
K2/Oe	-3.6 ± 19.2	-5.3 ± 13.5

3.2 Observation Count Related Metrics

Figure 3 (left) shows the number of scheduled observations. The February/March K2/Oe sessions have generally fewer scheduled observations (57 to 70) than the K2/Ws sessions (61 to 70). This represents the normal scheduling case. But, in the December/January sessions, where Ws was scheduled with elevated SEFDs, the K2/Oe sessions have generally more scheduled observations (60 to 70) than the K2/Ws sessions (54 to 62). Also, the minimum overall K2/Oe observation count (57) exceeds the minimum overall K2/Ws count (54). The number of achieved observations is not shown, but all K2/Oe sessions achieved at least 47 observations, which slightly exceeds the K2/Ws minimum of 46.

Figure 3 (right) shows the average (mean) number of scheduled observations per source. Smaller values show more robustness: if a source fails, fewer observations will fail. The K2/Oe sessions generally have a smaller mean number of scheduled observations per source than the K2/Ws sessions in both the December/January and February/March cases. The actual ranges are 2.6 to 4.3 (K2/Oe) vs. 2.9 to 4.1 (K2/Ws), in the case in which Ws was scheduled normally, and 2.7 to 3.5 (K2/Oe) vs. 3.2 to 4.5 (K2/Ws), in the case in which Ws was scheduled with elevated SEFDs.

The station SEFDs used in scheduling influence the number of scheduled observations and observations per source. The two metrics track with the SEFDs to a degree, but other factors such as the source fluxes also play a role. We started to analyze the metrics and scheduling factors but found their relationships to be more complicated than expected. So here we only say that the K2/Oe baseline's performance seems acceptable for the metrics related to observation counts.

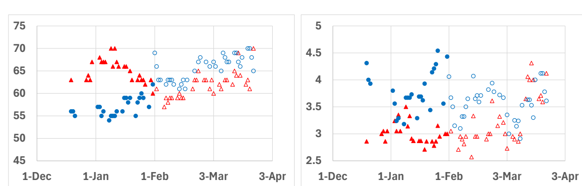

Fig. 3 Number of scheduled observations (left) and mean number of scheduled observations per source (right). Circles represent K2/Ws, and triangles represent K2/Oe. Closed symbols represent December/January (elevated Ws SEFDs), and open symbols represent February/March (normal Ws SEFDs).

3.3 SNR-based Metrics

Signal-to-noise ratios (SNRs) are important in evaluating a session's success. 3,602 (99.9%) of the K2/Oe observations succeeded (i.e., were correlated with an SNR of at least 7). Figure 4, which plots the averages (means) of each session's observed to scheduled SNR ratios by session date, shows that the means of the ratios were also good. All means exceeded our preferred lower limit of 0.9. We prefer the means to be no larger than 1.1; higher means indicate SNR underestimation that kept additional observations from being scheduled. But we consider the maximum of 1.45 acceptable. NB: the observations' ratios were halved because observed SNRs are based on four bands, while scheduled SNRs are based on one band.

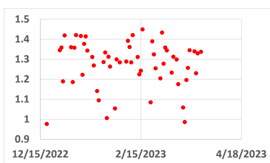

Fig. 4 Observed to scheduled SNR ratios averaged over each session and plotted by session date.

Figure 5 (top left) shows the observed to scheduled SNR ratios for the individual observations in both K2/Oe data sets, with the X-axis plotting the declinations of the observations' sources. Many ratios are outside our preferred range of 0.9 to 1.1. But Figure 5 (top right) plots the individual SNR ratios of the K2/Ws observations (also by source declination), and a visual comparison of the two plots shows that the K2/Oe ratios are slightly better (closer to the preferred range) than the K2/Ws ratios. The actual ranges are 0 to 2.7 (K2/Oe) and 0 to 2.9 (K2/Ws).

Figure 5 also resolves an issue revealed in a 2022 report on the K2/Ws sessions [2]. In the 2021 K2/Ws sessions, all 130 observations of sources with declinations less than or equal to 17.2° had SNR ratios less than 1 [2]. Although Figure 5 (top right) shows that all 12 December/January and February/March K2/Ws observations with declinations under 17° have SNR ratios under 1, plotting all 19,356 2022–2023 K2/Ws observations scheduled with normal Ws SEFDs and the current schedule configuration (Figure 5, bottom) shows that some K2/Ws observations with declinations under 17° have SNR ratios over 1. So the problem seen in [2] was possibly due to a smaller data set and/or an earlier schedule configuration used through January 31, 2022. But Figure 5 (bottom) shows some K2/Ws ratios that exceed our ideal of 1.1 and in fact have a maximum value of 10.3. This issue is under investigation.

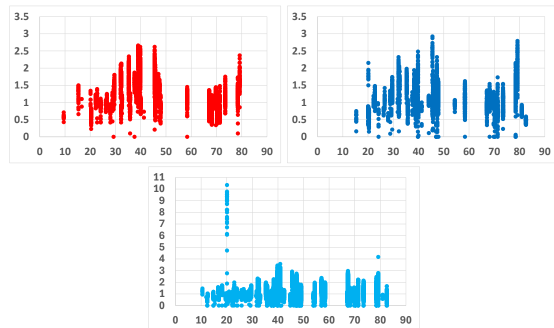

Fig. 5 Observed to scheduled SNR ratios vs. source declinations for individual observations: K2/Oe data sets (top left), K2/Ws data sets (top right), and 19,356 K2/Ws ratios from February 1, 2022 through November 13, 2023 (bottom).

4 Year of Hypothetical Schedules

Only three months of single-baseline K2/Oe data are available, but the observable sources change during a year and affect scheduling [1]. So we wrote a year of hypothetical schedules. The information from the schedules is limited, because they were not observed, and so we cannot evaluate their actual performance. But it is possible to evaluate the schedules themselves.

Figure 6 shows 52 schedules, spaced a week apart, plotted by day of year. The schedules are based on a single source flux catalog. Figure 6 (top left) shows that the number of scheduled observations ranges from 57 to 73. The minimum of 57 is the same as in the observed K2/Oe data set. Figure 6 (top right) shows that the average (mean) number of scheduled observations per source ranges from 2.3 to 6.6. The maximum is close to the maximum from the 2022 and 2023 K2/Ws schedules (6.3), although larger. The K2/Oe values for these two metrics seem to be reasonable.

To evaluate the schedules' predicted accuracy, we used the GSFC analysis program *SimpleSimul* [3]. *SimpleSimul* constructs the normal equations in the ab-

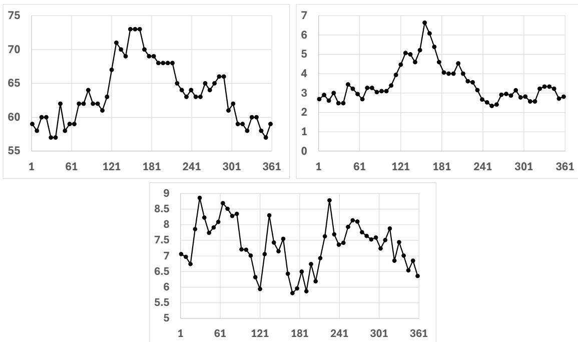

Fig. 6 Number of scheduled observations (top left), mean number of scheduled observations per source (top right), and simulated UT1–TAI estimate RMS values in µs (bottom) from hypothetical schedules plotted by day of year.

sence of noise, modifies the "O–C" vector by adding noise, and calculates the effect on the estimated UT1. This process is repeated an arbitrary number of times, and the RMS of the UT1 estimates is used as a proxy for the accuracy of UT1. Figure 6 (bottom) shows simulated UT1–TAI estimate RMS values for the hypothetical schedules for 1000 *SimpleSimul* iterations. The values range from 5.8 µs to 8.9 µs, with a mean of 7.3 µs. For reference, for the 2022 K2/Ws schedules made with the current schedule configuration and normal Ws SEFDs (V22032 through V22348), the values range from 7.7 µs to 11.6 µs, with a mean of 9.6 µs. The K2/Ws schedules do not cover January, correspond exactly to the dates of the K2/Oe hypothetical schedules, or use the K2/Oe source flux catalog, but the comparison indicates that the K2/Oe schedules are likely to perform as well as or better than the K2/Ws schedules.

5 Conclusions

The IERS Rapid Service/Prediction Center uses the VGOS-INT-A KOKEE12M/WETTZ13S (K2/Ws) baseline for its combination solutions. It would be useful for the Center to have backup VGOS-INT-A baselines. This paper has evaluated the KOKEE12M/ONSA13NE (K2/Oe) baseline.

We looked at 57 K2/Oe sessions from December 19, 2022 through March 24, 2023, comparing them, with one caveat explained above, to 59 K2/Ws sessions from the same time of the year. The K2/Oe differences with respect to extrapolated R1/R4 UT1−TAI estimates (-5.3 ± 13.5 µs) are smaller than the K2/Ws differences (7.7 ± 15.1 µs) for the case where Ws was scheduled with normal SEFDs and comparable for the case where Ws was scheduled with elevated SEFDs. K2/Oe has fewer scheduled observations than K2/Ws (for the normal Ws case), but the overall minimum number of K2/Oe scheduled observations (57) is larger than the K2/Ws overall minimum (54). The minimum number of achieved K2/Oe observations (47) is slightly larger than the K2/Ws minimum (46). The mean numbers of scheduled observations per source in the K2/Oe sessions are generally smaller than the K2/Ws means, with a smaller overall K2/Oe range (2.6 to 4.3) than the K2/Ws range of 2.9 to 4.5. Almost all the K2/Oe observations were successfully correlated. The means of the ratios of the observed K2/Oe SNRs to the scheduled K2/Oe SNRs are larger than our preferred lower limit of 0.9 for each session, and the range of individual K2/Oe ratios (0 to 2.7) is smaller than the K2/Ws range (0 to 2.9). These metrics are generally promising.

We wrote 52 hypothetical K2/Oe schedules one week apart to evaluate schedules throughout a year of source availability. The schedules have a minimum of 57 observations, the same as in the observed K2/Oe data set, and a maximum mean of 6.6 scheduled observations per source, which is comparable to the maximum operational 2022/2023 K2/Ws mean (6.3). The K2/Oe schedules have smaller simulated UT1–TAI estimate RMS values (5.8 µs to 8.9 µs) than values from operational K2/Ws schedules (7.7 µs to 11.6 µs). We predict that the K2/Oe schedules should be okay for all available source sets throughout a year.

We conclude that the K2/Oe baseline could be a viable backup for the K2/Ws baseline.

References

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