# Intensive Sessions with the Mauna Kea VLBA Station


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## Introduction

Due to its location on the Hawaiian Islands in the middle of the Pacific Ocean, the Mauna Kea station (MK-VLBA) of the Very Long Baseline Array (VLBA) is well positioned for Intensive sessions with stations in the continental United States, Western Europe, and East Asia, similar to the Kōke'e Park Geophysical Observatory (KPGO). Recently, the IVS and the United States Naval Observatory (USNO) initiated characterization sessions on the MK-VLBA:WETTZELL and MK-VLBA:WETTZ13N baseline to explore their potential as operational backup baselines for IVS Intensives. The USNO has also been using MK-VLBA in similar sessions with other VLBA stations, particularly PIETOWN, in our efforts to develop a VLBA-based, consistent, high quality UT1−UTC series for use in EOP combination. We present the status and performance of these sessions, including the detection of the MK-VLBA station displacement due to the Kilauea eruption and associated earthquake, and our plan to account for this displacement in the measurement of UT1−UTC.

## The W-Series: Characterizing the Baseline from Mauna Kea to Wettzell

The IVS supports the IERS Rapid Service / Prediction Center (RS/PC) by observing Intensive sessions on a daily basis. Only three stations are currently used to make these observations (KOKEE, WETTZELL, and ISHIOKA). If more than one station is unavailable at a given time no Intensive will be observed, resulting in a degradation in the value of UT1−UTC reported by the RS/PC. Such a situation could occur this year as both KOKEE and ISHIOKA will be unavailable for extended periods of time due to upgrades and maintenance, and these outages may overlap. To ensure a high-quality UT1-UTC product from the RS/PC, additional stations need to be prepared to be alternates.

Before a station can be considered part of the Intensive network, it must first make at least 60 test observations with another station in the network over the course of at least four months to characterize that baseline for use by the RS/PC.


**Figure 1.** The Geodetic Observatory Wettzell, with 'Wz' on the right and 'Wn' in the middle.

The VLBA station on Hawai`i at Mauna Kea (MK-VLBA) is at the eastern end of the Hawaiian Islands ~500 km south-east of KOKEE, and would therefore be a good substitute for KOKEE when it is unavailable. Similarly, Wettzell North (WETTZ13N) is very close to WETTZELL and could act as an alternate to WETTZELL. With the goal of adding MK-VLBA and WETTZ13N to the network of Intensive-ready stations, the RS/PC, USNO Analysis Center, and IVS Coordinating Center developed a series of test Intensives in coordination with the Geodetic Observatory Wettzell (Figure 1) to characterize the MK-VLBA:WETTZELL (MkWz) and MK-VLBA:WETTZ13N (MkWn) baselines.

The IVS Coordinating Center determined that these sessions would be named wYYDOY with the DBC code of XW (the "w-series"). The backends of the VLBA and IVS S/X system are different, preventing the standard IVS Intensive observing setup from being used. The proven setup of the IVS RDV sessions was thus employed. To ensure that the sessions would perform sufficiently for the RS/PC in the limited time allotted by the USNO VLBA Time Allocation Committee, these sessions were merged with the 90-minute Intensives that the USNO observes daily with the MK-VLBA and PIETOWN stations. This results in a four-station network of MK-VLBA, PIETOWN, WETTZ13N, and WETTZELL, illustrated in Figure 3. Simulations showed that a 90-minute session with the Wettzell stations added to the MkPt observations would likely be sufficient to continue to meet the USNO's standards for the MkPt baseline; extending the sessions to 120 minutes ensures the data quality while staying within the time allotted. Sessions are scheduled for MkWz and then Pt and Wn are tagged along. The Geodetic Observatory Wettzell is able to support the sessions three times per week (only twice per week on WETTZ13N) and they are observed regularly at fixed times. Specifics can be found in the IVS Master File.

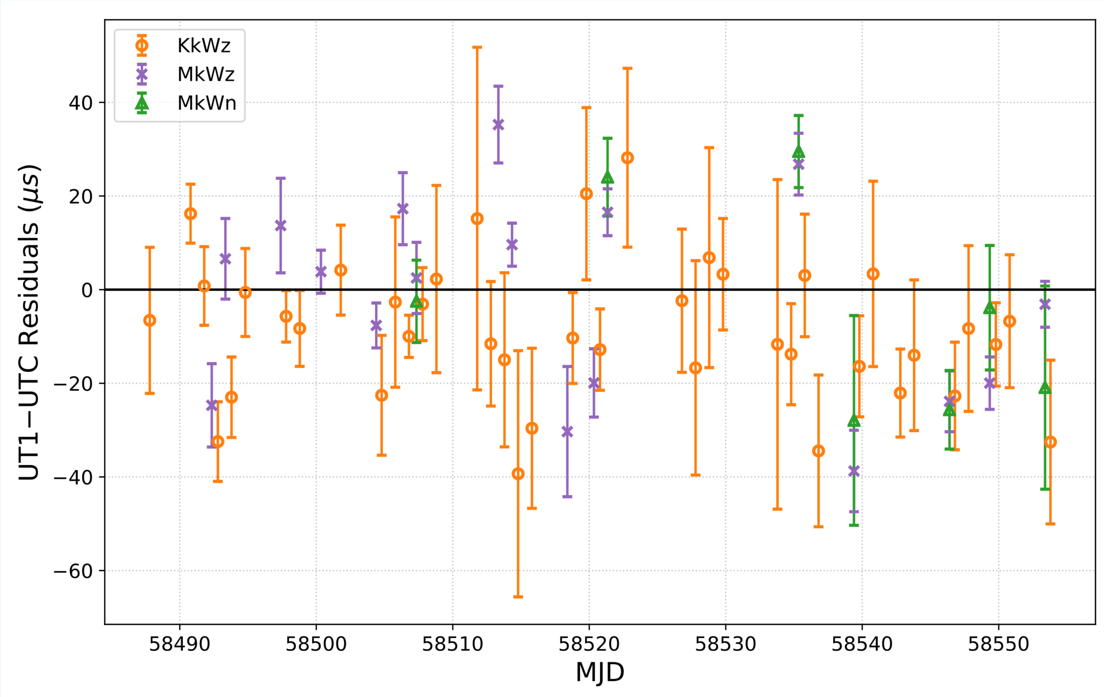


**Figure 2.** The residuals of the UT1−UTC measurements from the USNO intensive series with respect to the finals.all series from the IERS Rapid Service / Prediction Center. The w-series baselines (MkWz in purple, MkWn in green) are shown with KkWz (in orange) as a reference. No systematic characterization has been applied to the data in this diagram.


**Figure 3.** The locations of the stations involved in the w-series observations.

Thus far, 19 successful observations have been made. The first few sessions had some issues, and as a result fringes were not found on baselines including WETTZ13N. The observations will continue into mid-year to accumulate the 60 observations required for characterization. Table 1 shows the expected performance and the results from the w-series sessions. Residuals of the USNO Analysis Center's UT1−UTC measurements from the w-series with respect to the reported values from the RS/PC are shown in Figure 2 along with residuals from the KkWz baseline intensives as a reference. All indications from this are that the baselines from the Wettzell stations to MK-VLBA will be viable for use as backup baselines.

| Baseline | 90 minute Simulation | | 120 minutes Sessions | | |
|---|---|---|---|---|---|
| | # Scans | UT1-UTC Formal Error (μs) | # Sessions | Median # Scans per Session | Median UT1-UTC Formal Error (μs) |
| MkPt | 48 | 21.0 | 17 | 47 | 36.4 |
| MkWn | - | - | 7 | 18 | 8.8 |
| MkWz | 41 | 5.5 | 17 | 43 | 7.3 |
| PtWn | - | - | 6 | 22 | 16.4 |
| PtWz | 71 | 4.8 | 16 | 45 | 12.8 |

**Table 1.** The comparison of the number of scans and the formal errors from the simulation of a 90-minute schedule of MkPtWz to medians of those values from the 18 120-minute w-series sessions observed and analyzed to date.

## Mauna Kea Displacement: Detection through Mauna Kea – Pie Town Intensives

The USNO has been using the MK-VLBA station (Figure 4) to monitor the earth's rotation for several years, primarily in conjunction with the PIETOWN station (Geiger et al. 2019). The UT1−UTC measurements resulting from these sessions have proven to be difficult to incorporate into the products produced by the RS/PC. As a result, the USNO AC has been evaluating the VLBA Intensive baselines to optimize a product that can be utilized by the RS/PC. In addition to exploring alternative frequency setups in different bands (Dieck et al. 2019), the Analysis Center is actively developing a collection of Python scripts and functions called the General Repository of EOP Analysis Tools (GREAT).

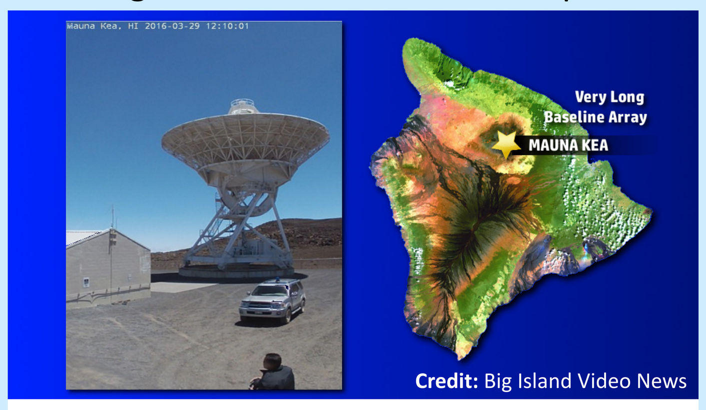


**Figure 4.** The VLBA station at Mauna Kea (left) and the location of the station on Hawai'i. Note that the Kilauea volcano is on the southeast coast of the island.

The existing tools in GREAT revealed statistically significant impacts on the UT1−UTC time series due to motion of the MK-VLBA station. To see these impacts, the software first calculates the residuals of the time series with respect to one of three model series: *eopc04.62-now* from the Paris Observatory, *latest_midnight.eop* from the NASA Jet Propulsion Lab, or, as is used in these analyses, *finals.all* from the USNO. Then an offset and a rate is calculated by doing a least squares minimization fit and the resulting first order polynomial is subtracted from the residuals, resulting in a time series with a mean residual of zero. This process is similar to the RS/PC characterization of a baseline.

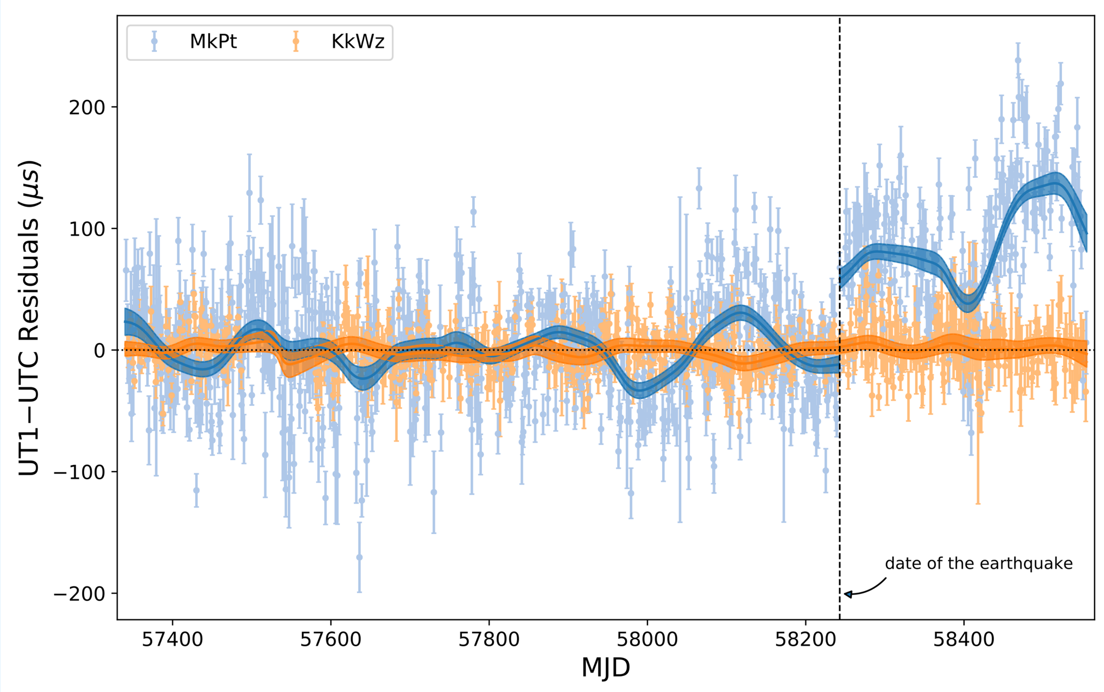


**Figure 5.** The residuals of the UT1−UTC measurements from the USNO intensive series with respect to the finals.all series from the IERS Rapid Service / Prediction Center. These series have systematic corrections applied so that the mean residual is zero prior to the time of the earthquake, marked by the vertical dashed line. The MkPt VLBA intensive series is in blue and the KkWz series is in orange. The light points are the residuals with errorbars for each session and the solid line is the gaussian kernel smoothed estimate with the shaded region around the line denoting the 3-sigma confidence interval of the calculation of the estimate. The discontinuity in the MkPt residual estimate demonstrates that the position of the station did move as a result of the earthquake.

Examination of the UT1−UTC residuals at this stage suggested there was a jump in early May 2018 which is coincident with the eruption of the Kilauea volcano and associated 6.9 magnitude earthquake on Hawai`i. The volcano is ~59 km south-east of MK-VLBA and is thus sufficiently close to for the eruption and earthquake to cause a displacement in the position of the MK-VLBA station. Any significant displacement would directly translate into the estimate of UT1−UTC.

To confirm that the jump is statistically significant, a tool was added to GREAT that performs a weighted moving average over a time series by employing a gaussian kernel density estimator with the kernel bandwidth determined by leave-one-out cross validation (see Feigelson and Babu, 2012). An initial pass of this smoother over the UT1−UTC residual time series from November 14, 2015 (the resumption of MkPt sessions after major maintenance at MK-VLBA) to the present revealed that the residuals not only jumped at the time of the earthquake, but exhibit an unmodeled oscillation (with a primary period of ~193 days) throughout the baseline's history. Further smoothing was performed in two separate segments, divided at the time of the earthquake (May 4, 2018, MJD 58242.940), which demonstrates that the discontinuity in the MkPt UT1−UTC residuals is indeed significant (Figure 5).

## Future Work: Modeling an Updated A Priori Position for Mauna Kea with GPS

The MKEA GPS station is co-located with the MK-VLBA station at a separation of 87.8 m. We produced position solutions for the station which confirm, independently of VLBI, that there was a displacement of the Mauna Kea geodetic observation site down and to the south east with a total magnitude of ~15 mm (Figure 6). Because UT1−UTC estimates assume a fixed position, this position displacement must be corrected to utilize any Intensive observations made with MK-VLBA, including both the W-series and the USNO VLBA Intensives.

To generate new a priori positions, we will use the MKEA position information to extrapolate a position for each epoch of observation as was done for the TSUKUB32 station by MacMillan et al. (2012) following the 2011 earthquake in Japan. We expect this to eliminate the jump in the residuals. Additionally, it appears upon visual inspection that oscillations in the north component of the MKEA station are correlated with the oscillations in the VLBI UT1−UTC residuals. Such extrapolated positions would also correct for this, if the connection is real.

From the resulting position history of the MK-VLBA station after the earthquake we can develop parametric models such as one of the post-seismic deformation models now used in the ITRF 2014 (Altamimi et al. 2016). These could then be used to predict the station's motion and generate a priori positions for use with Intensives without relying on a priori positions extrapolated from GPS data.

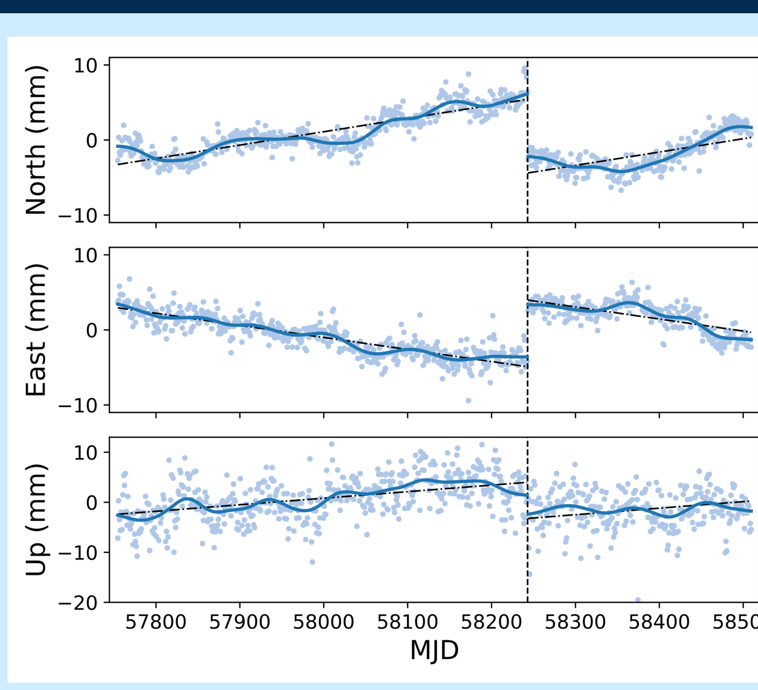


**Figure 6.** Relative GPS positions of the MKEA station in the North, East, and Up local tangent coordinates. These data start January 1, 2017 and are plotted with an arbitrary zero point. The individual measurements are showing in light blue circles with the solid blue line denoting the gaussian kernel weighted moving average. The dot-dashed black line is a linear fit model to the positions both before and after the earthquake, marked by the vertical dashed line.

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