Measuring slew rates of VLBA antennas

VLBA Antenna Memo 91

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Abstract: In this memo a novel technique for measuring VLBA antenna slew rates is presented and updates to catalogs are suggested. The most notable finding was the Mauna Kea azimuth rate being almost 10% under specification.

1 Antenna motion

This memo discusses speed slew from one source to another and does not consider tracking, where the antenna stays on one source as the Earth's motion is compensated. To first order a slew has three phases which occur separately on the two axes of motion (azimuth and elevation): acceleration, constant speed motion, decceleration.

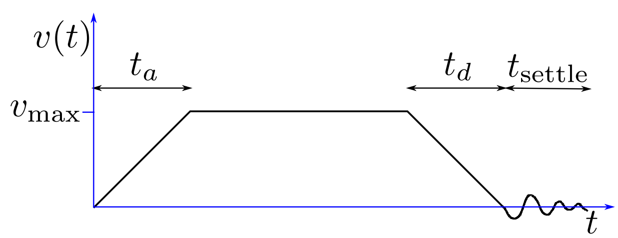
It is most convenient to parameterize motion in terms of time to reach full speed, t_a, rather than acceleration directly as this is most closely related to the specification of the antennas (see below). Unfortunately, the effects of acceleration, decceleration, and settling cannot be distinguished by the simple measurement technique used here so a combined effective acceleration time, t_0, is used to account for all of these times:

$$t_0 = \frac{t_a + t_d}{2} + t_{\mathrm{settle}}. \tag{1}$$

The distance that can be slewed in time t, $\theta(t)$, valid for slews that reach full speed (e.g., $t > t_a + t_d + t_{\mathrm{settle}}$ can be expressed as:

$$\theta(t) = v_{\mathrm{max}}(t - t_0) \tag{2}$$

where v_{max} is the slew speed. The velocity as a function of time for the second of these cases is shown below.



In the analysis that follows, the average speed over a slew of a given angle will be studied. Only slews longer than 15 seconds will be considered, allowing the slew length condition to be met in all cases. The average speed, $\bar{v}$, in this case can be written as a function of the slew distance as:

$$\bar{v}(\theta) = \frac{1}{1/v_{\mathrm{max}} + t_0/\theta} \tag{3}$$

This form allows for simple comparison with monitor data.

2 VLBA specifications

The specification for VLBA slew rates as stated in the VLBA Project Book is 90 deg/min in azimuth and 30 deg/min in elevation. The specification for acceleration time is two seconds. The Operations and Maintenance Manual notes that settling time is 3.1 sec for azimuth and 2.86 sec for elevation as designed. The servo loops have bandwidths of 0.8 Hz and 0.56 Hz in azimith and elevation, respectively. These numbers are related to the lowest oscillation frequencies of the antenna relevant to the two axes.

3 Measurements

Commanded and measured azimuths and elevations are monitored by the VME-based VLBA control computer. The values are infrequently dumped into the monitor stream but are available at ≈ 1.5 second intervals via the `rscreen` operator interface. A version of `rscreen` was created which logs to a disk file a timestamp and the four angle values each time their values are updated. Modifying `rscreen` for this task was non-trivial as the data coming to that application originate inside the VME control computer and are sent as updates to a VT100 terminal emulator rather than as complete numbers. A VT100 emulator with just sufficient capability was built into the modified `rscreen` program (called `rscreen2`). The source code for this is available within the NRAO SVN at https://svn.aoc.nrao.edu/repos/VLBA/legacy/obsprgms. In order for the program to do its job, a single ACU screen must be enabled and it must be in the top left corner of the `rscreen2` window. A file will be produced in the directory where `rscreen2` was started with a filename based on the current Unix time and the hostname of the VME control computer.

In this memo a slew is identified as a period of time when the commanded and measured values for a particular axis differ by more than 10 arcseconds. A naive algorithm such as this will label some events as slews incorrectly (such as stow events), but the vast majority of identified slew events correspond to actual source changes. The uncertainty in slew time, introduced by the periodic sampling of encoders and the update cycle of `rscreen`, dominates the measurement uncertainty. A uniform time uncertainty of 1 second is adopted here. Data were collected between 2016 April 9 and 2016 April 12. A "χ-by-eye" approach was used to find best values of slew speed, v_{max}, and t_0 for each axis of each antenna. Uncertainties in the measured v_{max} values are thought to be less than 0.5 deg/min and uncertainties in the measured t_0 values are approximately 0.5 s.

Measurements of average slew speed vs. slew angle and the corresponding fit to Eqn. 3 are tabulated below and shown in Figures 1 through 10.

Antenna	$v_{\mathrm{max,az}}$ (deg/min)	$t_{0,\mathrm{az}}$ (s)	$v_{\mathrm{max,el}}$ (deg/min)	$t_{0,\mathrm{el}}$ (s)
BR	84	7.5	29	7
FD	85.5	5	29.7	7
HN	82	5	28.5	6
KP	82.5	3.5	29.5	6
LA	89.5	3.5	29.5	6
MK	~~79~~ 83	6	30.8	6
NL	81.5	5	28.0	6.5
OV	83	4.5	29.5	6.3
PT	85	4.5	30.0	6.3
SC	85	5.5	28.5	7

Note above that the azimuth value for MK has been updated to 83 deg/min from 79 deg/min during the editing of this memo. Values of azimuth and elevation rates (`AX1RATE` and `AX2RATE` respectively) in the 2015Mar03-18:50:14 version of `sched`'s `stations_RDBE.dat` file are:

Antenna	`sched AX1RATE` (deg/min)	`sched AX2RATE` (deg/min)
BR	83.6	29.0
FD	84.3	30.5
HN	81.3	26.7
KP	80.8	29.3
LA	82.0	29.5
MK	86.8	28.3
NL	82.5	28.7
OV	84.5	28.7
PT	82.3	29.3
SC	84.5	28.5

Within `sched`, the settling time is catalogued as 6 seconds for all axes of all VLBA antennas, which is seems fairly conservative given the measured values of t_0.

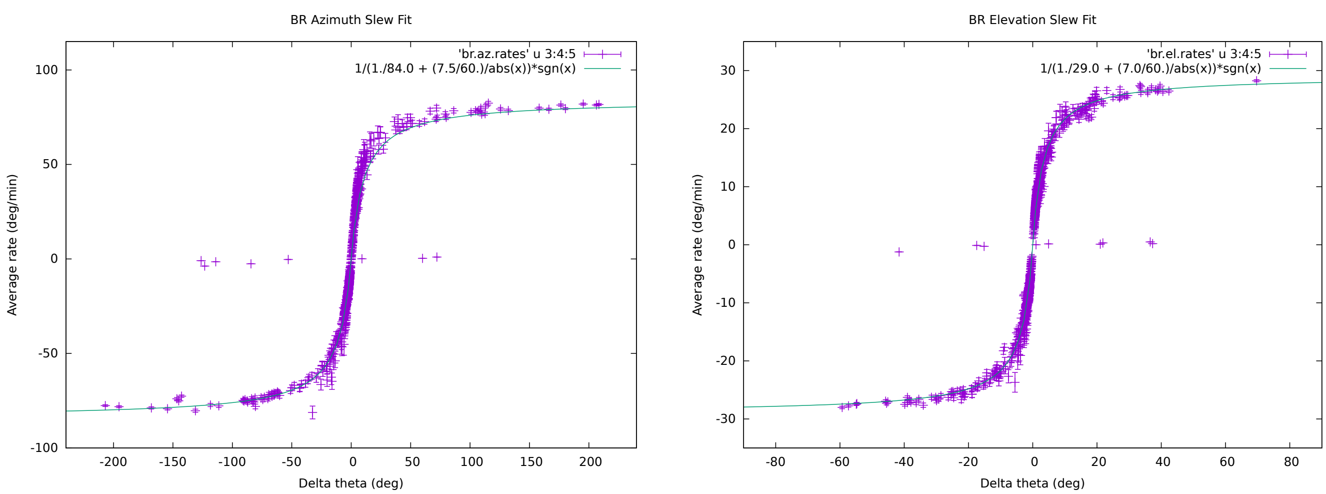


Figure 1: Slew data and fit in azimuth (left) and elevation (right) for Brewster. The highly discrepant points that lie closer to the x-axis than the bulk of points, are related to stow and other non-slew events and can be ingnored.

4 Update to azimuth rate

During the editing of this memo the azimuth slew rate at MK was updated. Current fits (as of 2016 May 1) put this rate at 83 deg/min. The elevation speed was not adjusted and no change in performance was observed. An updated fit is shown in Fig. 11.

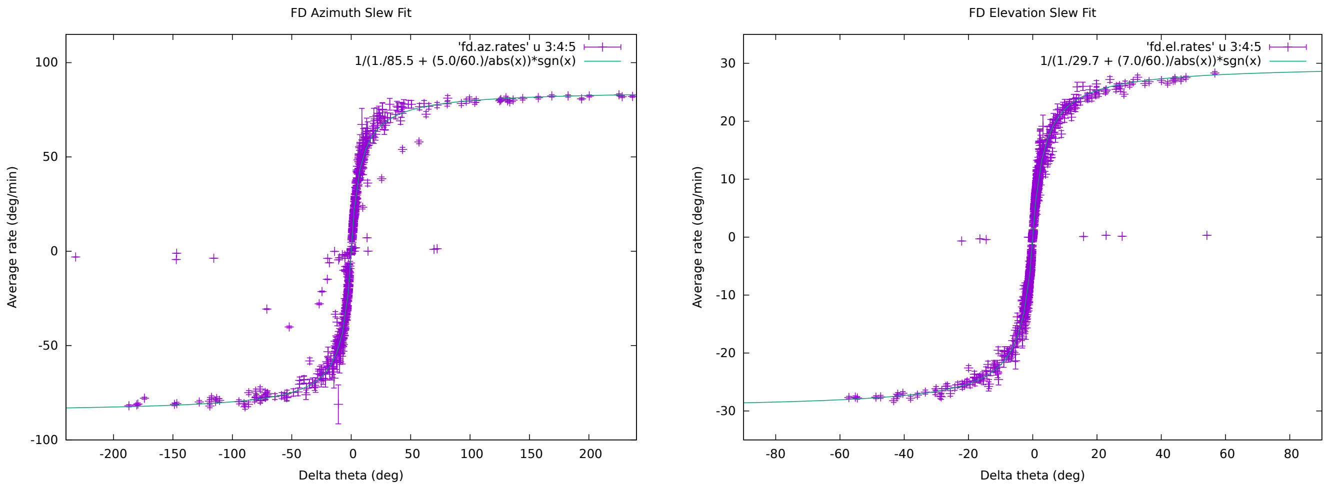


Figure 2: Slew data and fit in azimuth (left) and elevation (right) for Fort Davis.

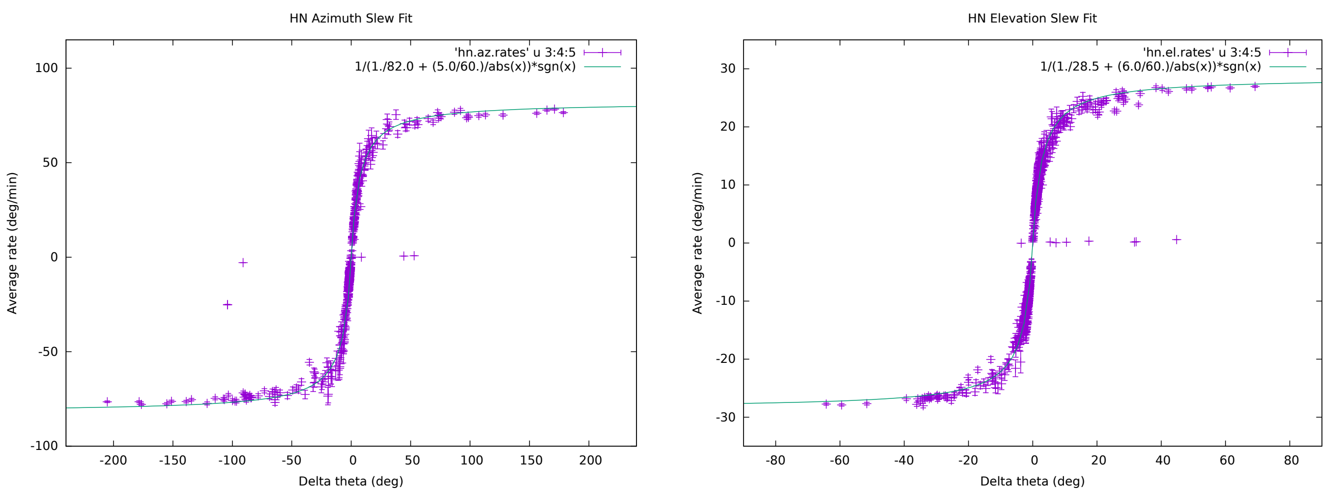


Figure 3: Slew data and fit in azimuth (left) and elevation (right) for Hancock.

5 Impact

A few slew rates, most notably the azimuth rate at Mauna Kea and the elevation rate at Hancock, have diverged significantly from the most recently catalogued values. The consequence of an underperforming antenna is unexpected time off source, which can impact calibration and even cause scans to be completely missed. Cases of late-on-source and even some never-on-source events in daily UT1-UTC observations were in fact the motivation for this study. These observations are perhaps the most sensitive to underperforming antennas due to typically long slews and short scans. The consequences of a catalogued slew rate that is slower than the antenna is not beneficial either as it will limit the amount of observing that a user can achieve in a give amount of assigned telescope time.

The slew rates derived here will be used to update NRAO `sched`'s catalogues. A second piece of scheduling software is used outside NRAO when scheduling geodetic VLBI observations is the Goddard `sked` (ftp://gemini.gsfc.nasa.gov/pub/sked/) program; a notice to the maintainer of

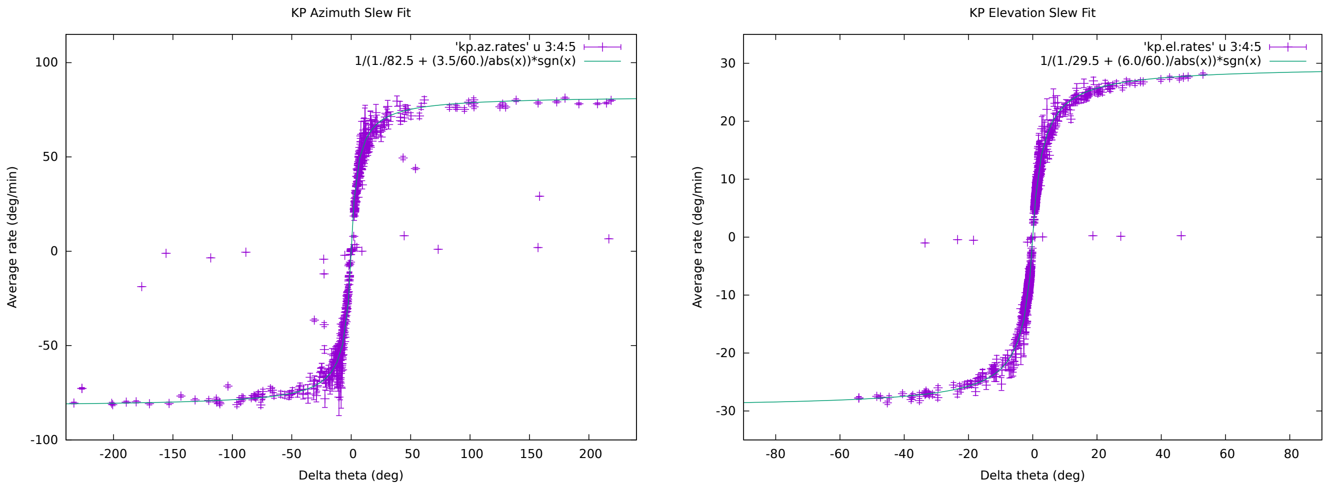


Figure 4: Slew data and fit in azimuth (left) and elevation (right) for Kitt Peak.

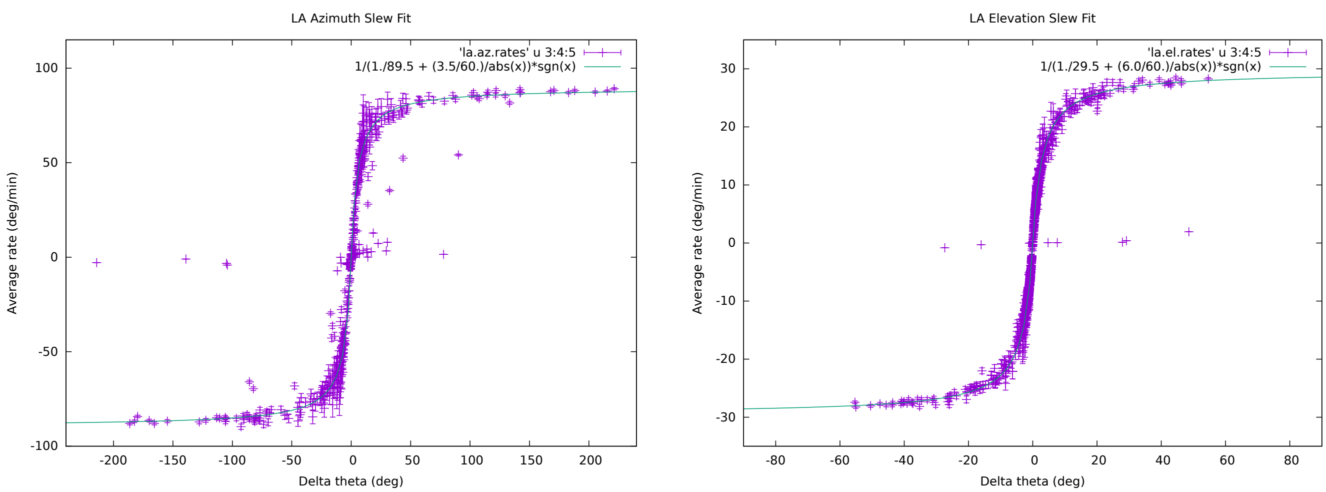


Figure 5: Slew data and fit in azimuth (left) and elevation (right) for Los Alamos.

that software will be made as well. It should be emphasized that anytime slew rates of VLBA antennas are adjusted corresponding measurements should be made and relevant catalogs maintainers should be informed.

6 Acknowledgements

Thanks to Rob Selina, Ephraim Ford, Eric Carlowe, Craig Walker, and Mark Alfero for useful input.

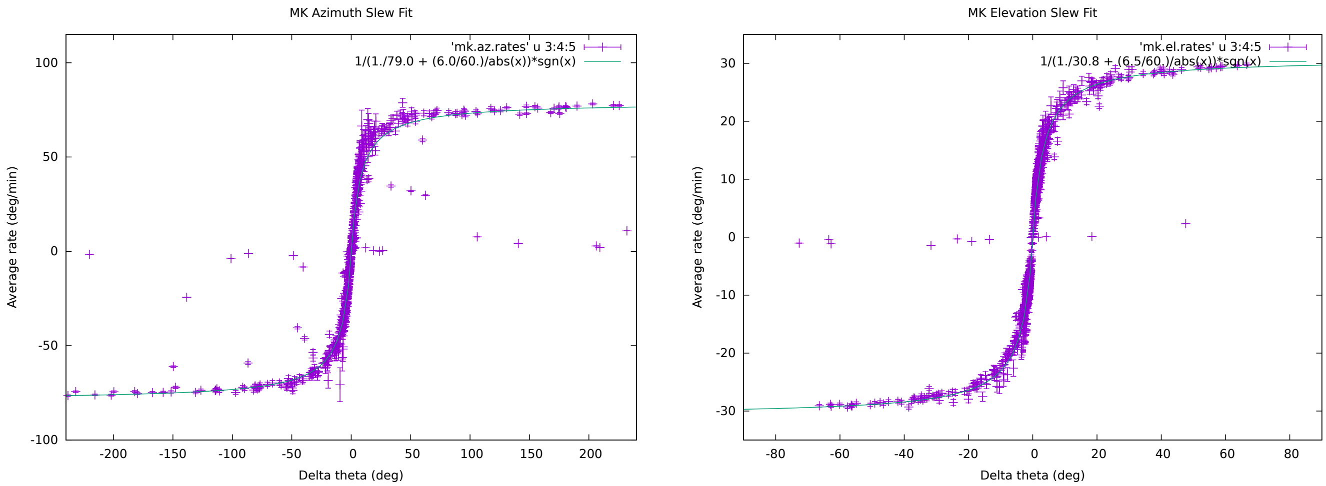


Figure 6: Slew data and fit in azimuth (left) and elevation (right) for Mauna Kea.

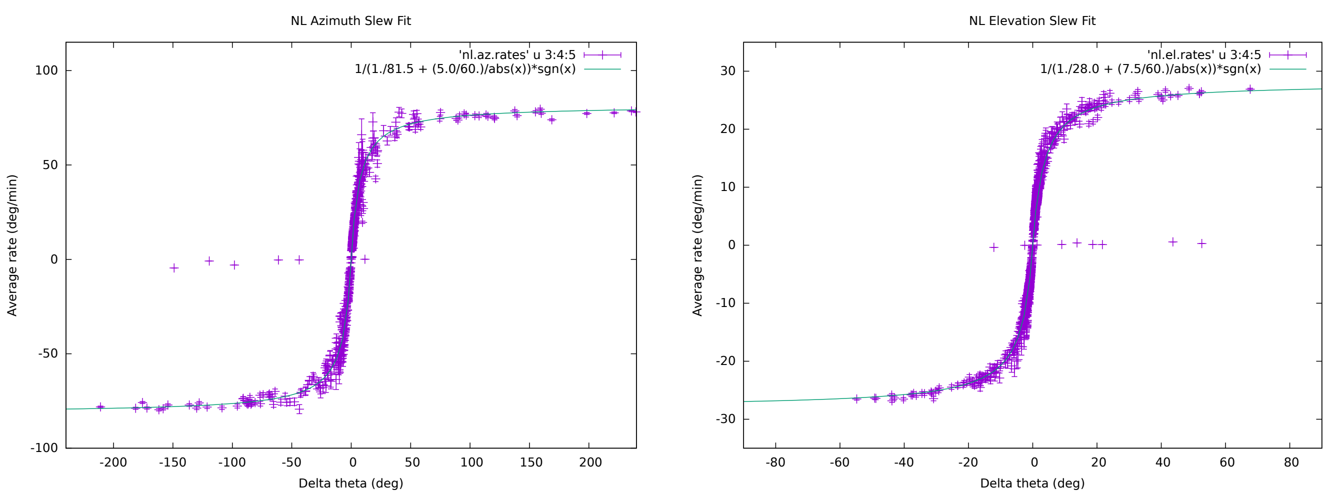


Figure 7: Slew data and fit in azimuth (left) and elevation (right) for North Liberty.

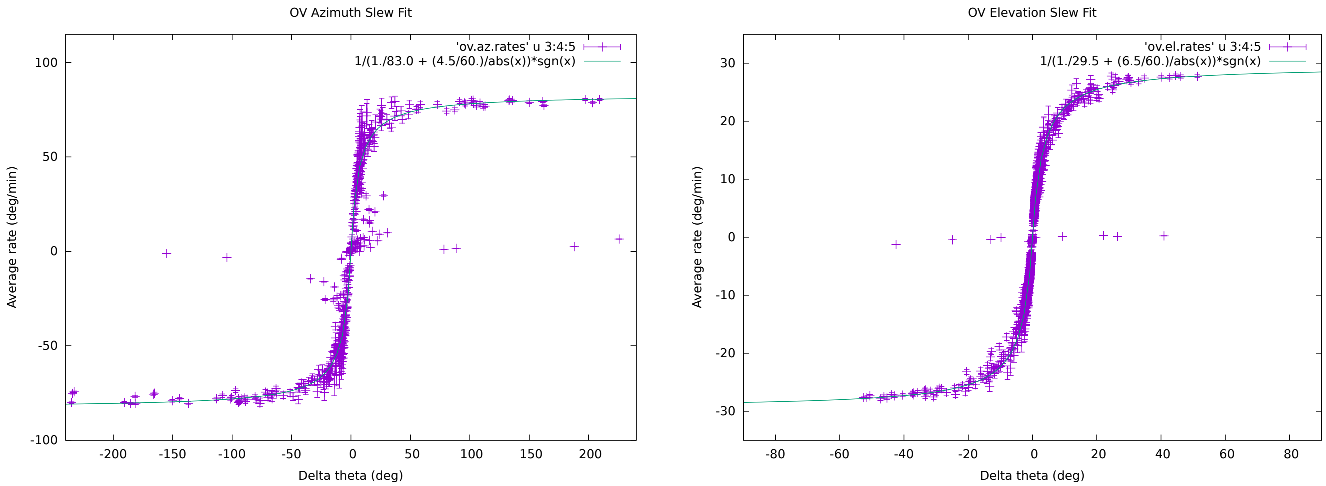


Figure 8: Slew data and fit in azimuth (left) and elevation (right) for Owens Valley.

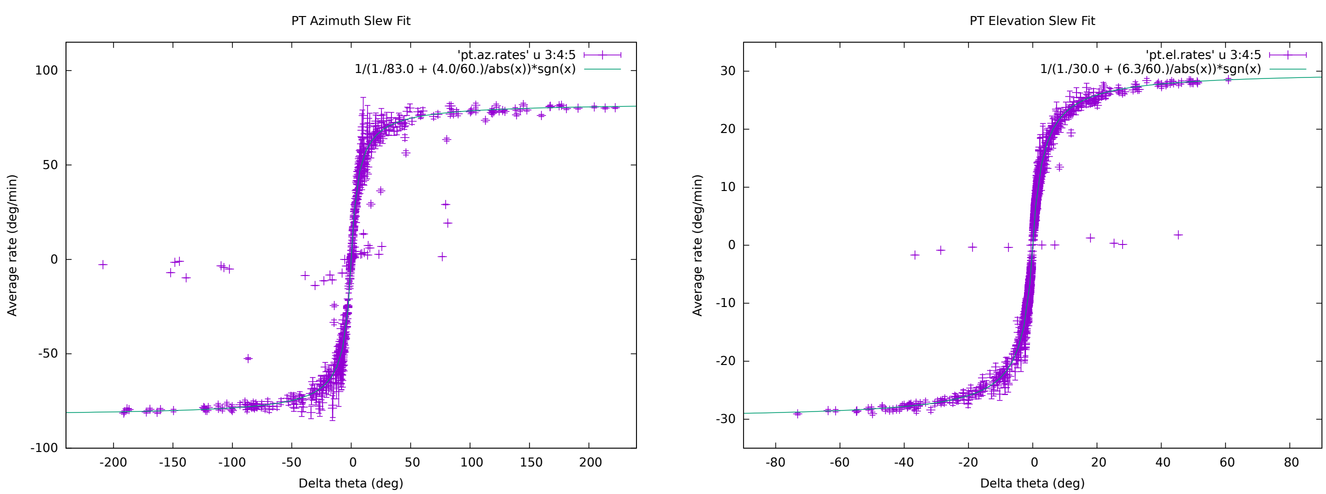


Figure 9: Slew data and fit in azimuth (left) and elevation (right) for Pie Town.

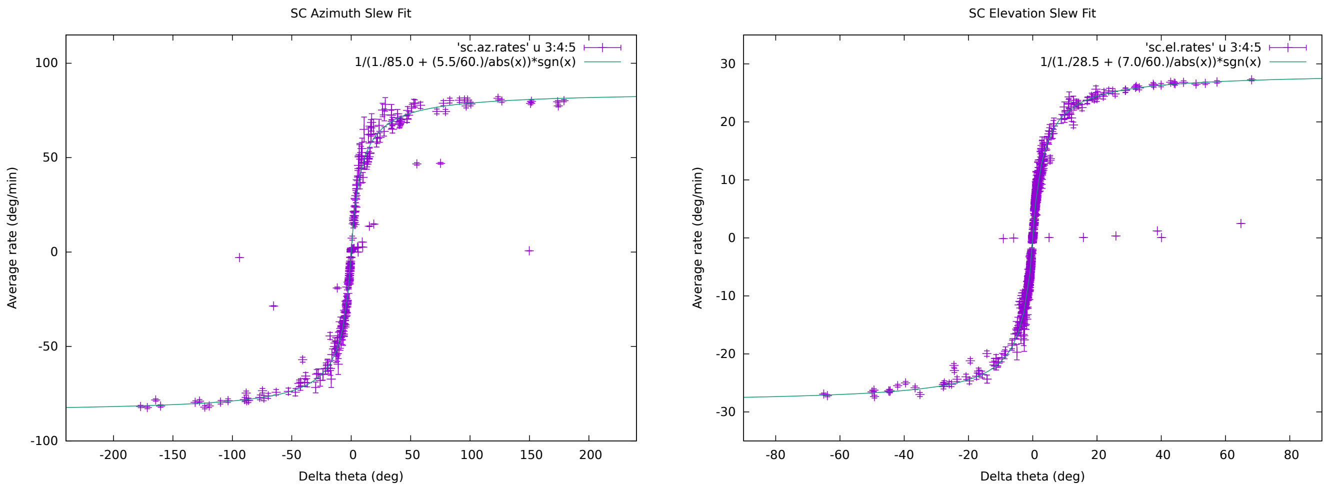


Figure 10: Slew data and fit in azimuth (left) and elevation (right) for Saint Croix.

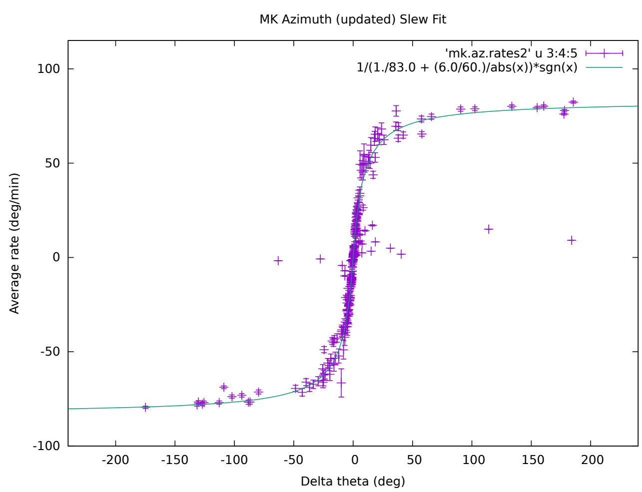


Figure 11: Updated slew data and fit in azimuth for Mauna Kea.