EVLA Memo #215
The Distribution of Observed Azimuth and Elevation Angles for the Pre-upgrade VLA

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1. Introduction

The distribution of azimuth and elevation angles while observing with the VLA is of some interest to antenna designers. They may want to know, for example, if some azimuths are observed more than others, to aid in gear or structure design. While the VLA may not be exactly the same as other arrays in this respect, it will likely be similar enough that the distributions will be of broad use. I have access to the full legacy VLA archive (Butler 2021), and as such, the azimuth and elevation for all observations in the period from 1976 to 2010, since these quantities were stored in the EXPORT data files. I have used these data to determine the distributions of azimuth and elevation for all observations with the VLA in that period. While it is possible to do a similar thing for the post-upgrade VLA, the data are not as simply organized or accessed, so I have not completed that exercise here. I do not believe it would substantially change the distributions in any case.

2. Retrieving the quantities from the raw EXPORT files

A massively trimmed-down version of the software (in Python) used in Butler (2021) was used to parse the individual EXPORT files. The quantities of interest in the raw EXPORT files are, for each stored record (see Hunt & Sowinski [1996] for a full description of the EXPORT file format and the various quantities available):

- Sine and cosine of azimuth and elevation (words 88-95 of the SDA)
- Antenna Control Bits (words 1-2 of each ADA)
- Integration time (word 19 of the SDA)
- Number of antennas (word 17 of the RCA)
- Program ID (words 11-13 of the SDA)

While not strictly needed, the Program ID allows for distinguishing between science observing and all other observing, at least after the naming convention for Program IDs was put into place (some time in 1982). It is not always perfect, as users were allowed to put whatever they wanted in for the Program ID in their OBSERVE files, but it is a reasonable way to try to determine this and mostly gives the desired answer.

The sine and cosine of azimuth and elevation were stored for computational economy (per Ken Sowinski) – the MODCOMPs had to have those quantities on-hand anyway, so they were stored directly. The VLA antennas could (and can) go over-the-top (OTT) to encoder "elevations" of up to 122 degrees; the online system calculated the physical azimuth and elevation for the array center and stored the sines and cosines of those values in the SDA. Then, after adding pointing model and refraction offsets for each antenna, if OTT had been enabled, it would calculate whether to go OTT or not for each antenna (which was the shortest path). If OTT was indicated, the azimuth and elevation sent to the antenna ACU would be modified (encoder azimuth = 180° + physical azimuth; encoder elevation = 180° – physical elevation), and the appropriate bit (bit 7) in the Antenna Control Bits (ACB) words would be set. Knowing sine and cosine of physical azimuth (only one is needed, of course, since it is constrained to be in the range 0-90°), and the state of the OTT bit, both physical and encoder elevation can be determined. For azimuth, the physical azimuth can be determined from the sine and cosine (using the atan2() function). For directions to the North, the antennas could (and can) be on either wrap (CW or CCW, or R or L), so the encoder azimuth might be different than the physical azimuth. Unfortunately, there is no way to ascertain this from the information in the EXPORT files.

The important quantity for each record of each EXPORT file is the product of the number of antennas times the integration time. The distribution of the sum of that quantity over time gives an aggregate idea of where the VLA antennas pointed.

3. Amount of data

In total, 118367916 records were parsed in EXPORT data files, and a row written to a CSV file for each, containing: MJD, azimuth, elevation, integration time, number of antennas, program ID, source name (informational only), an indicator of whether it is science observing or not, and an indicator of whether it is OTT or not. Table 1 shows the overall numbers from the data, broken into everything, science only, and OTT only. What I call "Array Days" in Table 1 is just Antenna Days (which is the summed number of antennas times the integration time in units of days) divided by 27, so, if the full array was observing (all 27 antennas) this is how many days were accumulated. So, there is roughly 23.3 years of VLA observing contained in the resulting overall histograms.

Table 1. Total number of records and antenna time used to calculate histograms.

Type	$N_{records}$	Antenna Days	Array Days
All	118367916	230035	8520
Science	81245203	164081	6077
OTT	3071816	3556	132

4. Results

From all of the data, I form histograms of azimuth and elevation, with two constraints: should I account for OTT explicitly, or just use physical elevation, and should I only include science. I calculate the histograms with 1° bins, then Hanning smooth them (so effectively 2° width). Then I normalize them to the largest bin in the histogram.

a. Everything

If everything is included, the distributions in Figures 1-3 are the result. Figure 1 displays physical azimuth, Figure 2 displays physical elevation (ignoring OTT), and Figure 3 displays encoder elevation (including OTT). The azimuth distribution is quite symmetric, as might be expected. The broad hump centered near azimuth 180° is undoubtedly from southern sources. The sharp peak at 0° is almost certainly from system observations of the North Celestial Pole (NCP), which was (and is) used for many types of system checkouts (notably RFI). The two sharp peaks near azimuth 60° and 300° are likely from sources near +40° declination, as those are their rise and set azimuths. In many system or operations observations, the sources 3C 84, 3C 273, or 3C 345 were used, two of which are at those declinations (and 3C 273 is contributing to the southern hump). The elevation distribution is as expected: broad and peaked near 55°, with little observing at very high and very low elevations. The small peak near 28° is likely due to obervations of the galactic center, which transits at that elevation.

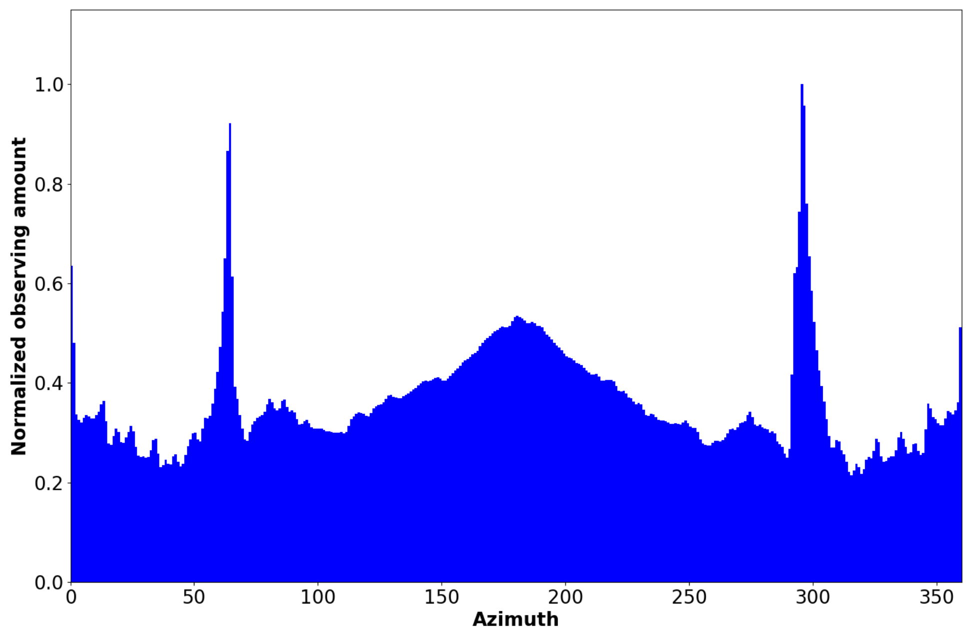

Figure 1. The distribution of azimuth of VLA observations in the period 1976-2010 for all observations. Sharp peaks are seen at 0°, 60°, and 300° from system observations, and a broad hump centered at 180° from observing southern sources.

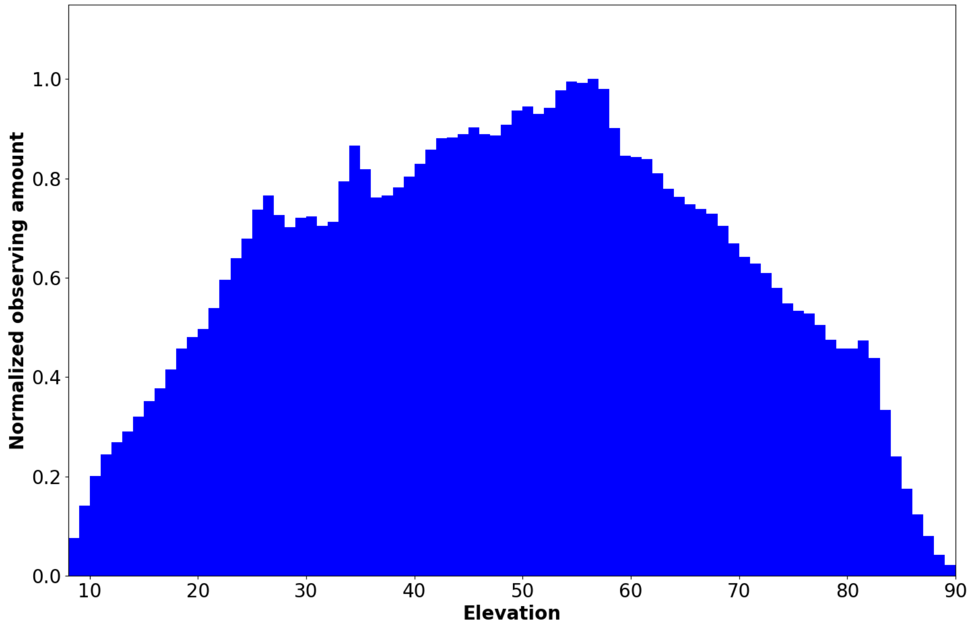

Figure 2. As Figure 1 but for elevation, ignoring OTT.

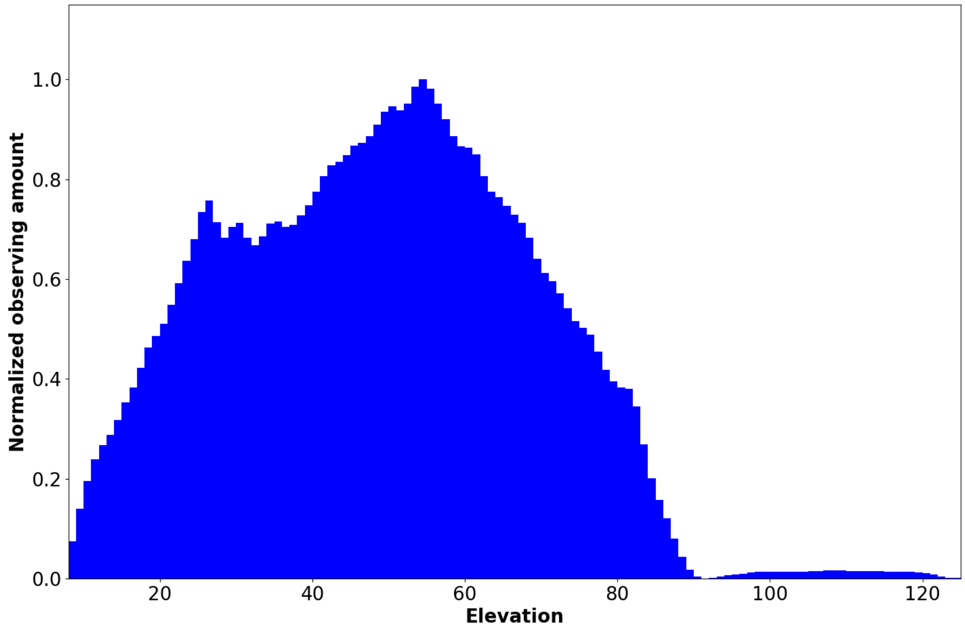

Figure 3. As Figure 2, but including OTT elevations (so encoder elevation instead of physical elevation).

b. Science only

If only science observing is included (as can be ascertained from the Program ID), the distributions in Figures 4-6 are the result. Figure 4 displays physical azimuth, Figure 5 displays physical elevation (ignoring OTT), and Figure 6 displays encoder elevation (including OTT). The azimuth distribution still shows sharp peaks near 60° and 300°, but far lower in magnitude than the distribution in Figure 1. The sharp peak at 0° is gone, as expected (the system observations of the NCP are not included). The elevation distributions are quite similar to those where all of the data is included.

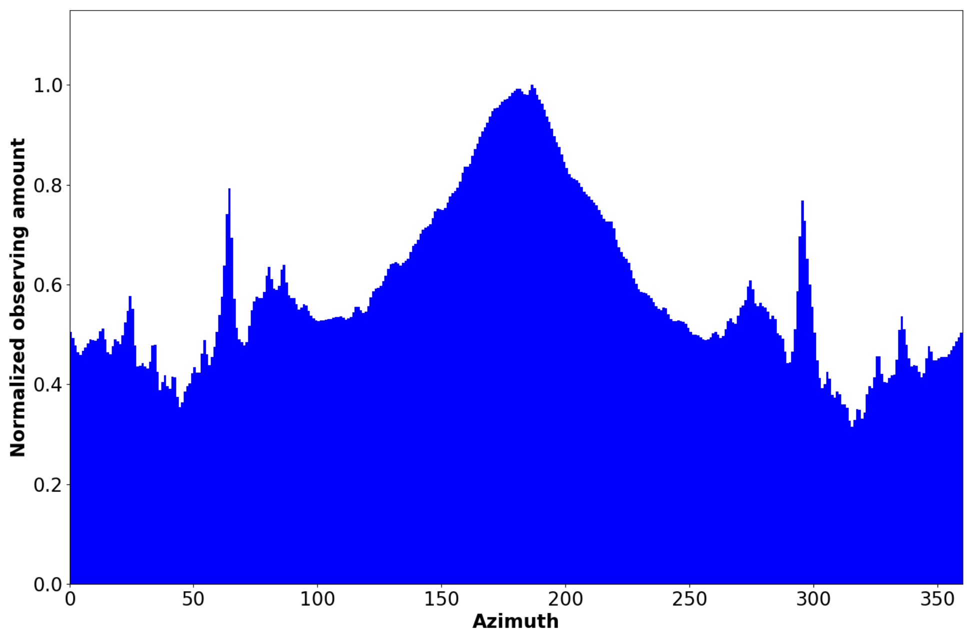

Figure 4. As Figure 1 but only counting science observations. The sharp peaks at 60° and 300° are substantially reduced, and the sharp peak at 0° is gone entirely.

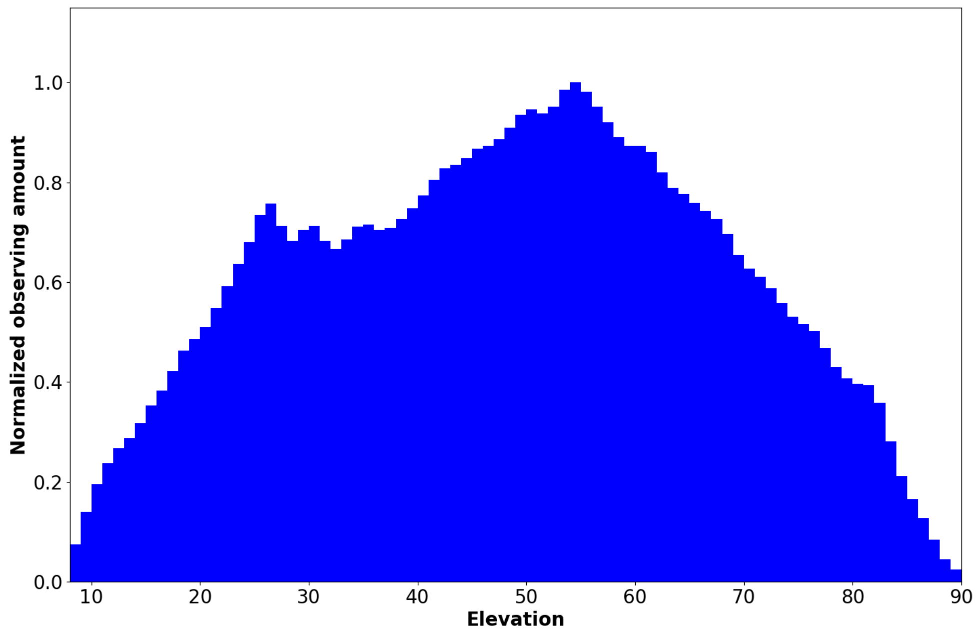

Figure 5. As Figure 2 but only including science observations.

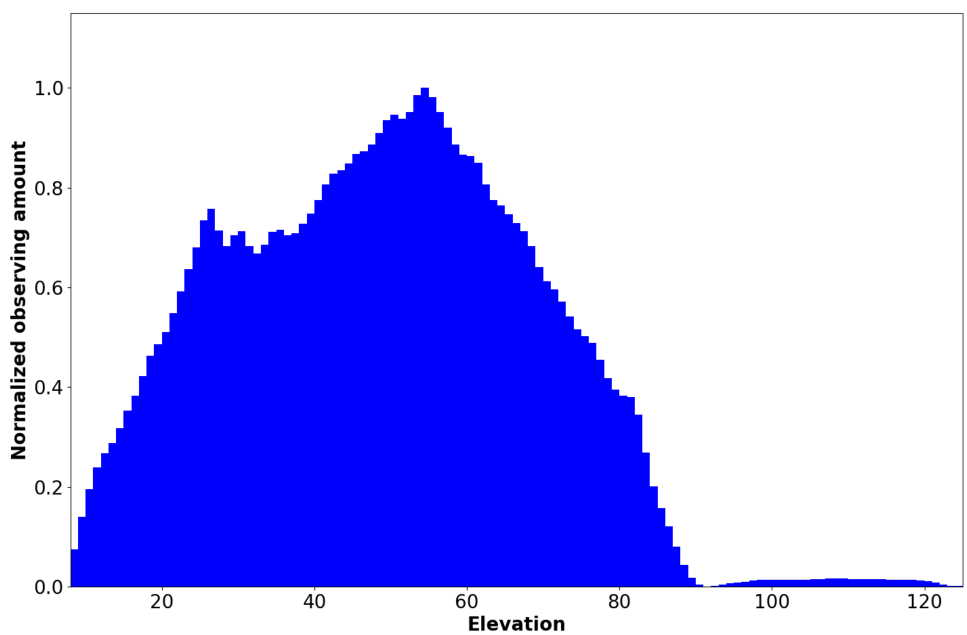

Figure 6. As Figure 3, but only including science observations.

5. Conclusions

While the derived histograms are mostly as expected (broad hump in azimuth centered at 180° from southern sources, and broad distribution in elevation centered near 55°), they are clearly not uniform. Notably in the azimuth histogram, the use of particular sources for system and observatory observations clearly drove the antennas to azimuths near 60° and 300° for significantly more time than other azimuths. We can expect a similar distribution for ngVLA, though the sharp peaks can be smoothed out by choosing from a broader range of sources (at various declinations) for system observations. The difficulty, of course, is finding sources that are strong enough and compact enough to allow for the ability to perform whatever function the system observation was meant to perform (delays, bandpasses, polarizations, etc.). For many such observations, however, the constraints are not particularly strong, so the selection of source is not as important; we have just chosen from a small list of sources (for both pre- and post-upgrade VLA) out of expediency. Similar distributions are likely for any interferometer that is designed for a broad range of open PI science; for more focused arrays (which may have particular regions of sky to look at more often, for example) there may be different distributions. For southern arrays, the broad hump in azimuth will be moved to the North from the South (near 0°).

Acknowledgements

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References

Butler, B., Preparing the VLA Legacy Archive Data for New Archive Access Tool Ingestion, EVLA Computing Memo #51, 2021.

Hunt, G. C., and K. P. Sowinski, VLA Archive Data Format, VLA Computer Memo 188, 1996.