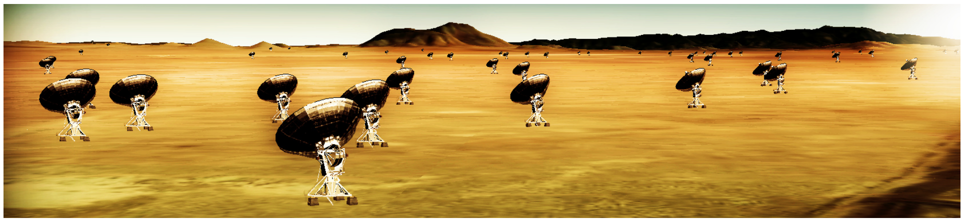

Next Generation Very Large Array Memo No. 82

Configuration: Reference Design RevC.01 Description and Alterations

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Abstract

We update the configuration to fix some minor errors in the original Rev C reference design, adopt a more specific station naming convention, and incorporate other project changes. We also present a more detailed description of the primary components of the ngVLA configuration as incorporated in the Rev C Reference Design.

1 Introduction

The Rev C reference design configuration has been extensively exercised through science simulations, and thus far, meets the requirements to fulfill the key science goals for the project, as documented in the ngVLA memo series. The configuration group continues to explore changes that may improve science return, taking into particular attention the subarray capabilities for the multi-scale ngVLA. We felt it important to document the well-tested Rev C configuration, before considering any significant alterations. Also, we have made small alterations to the Rev C configuration, based on changes dictated by the project, and to fix minor errors found in the original configuration files.

Much of the basic information on the Rev C configuration can be found in the Reference Design configuration description (020.23.00.00.00-0002-DSN). This memo describes the Rev C.01 configuration, which is a slight revision of the Rev C design. The primary alterations expressed in the latest work are:

- The original core configuration assumed a minimum baseline of 30m, set by initial notions of antenna design. This minimum has increased to 38m with the latest off-axis-low antenna design. Hence, a few antennas had to be moved in the core, and one LBA station antenna.

- The LBA XYZ files in the current ngVLA web configuration tools did not include the elevations in the conversion from longitude and latitude to Earth-centered XYZ files. The stations on the Hawaiian Islands were also adjusted.

- The SBA has been moved 700m east, out of the center of the Core, to avoid shadowing by the 18m antennas. It has also been rotated by 30° to reduce shadowing when observing low and high declination sources.

- We have renamed the stations in the .cfg files to reflect the subcomponents of the array to which an antenna belongs. We have found that knowing the antenna origin is convenient when investigating subarrays with antennas pulled from different parts of the full array, to achieve a science goal (Rosero 2019).

None of these changes have major impact on the science capabilities, or alter the results of the science simulations. The one marginal exception is the new minimum baseline for the Core, which does change conclusions concerning the maximum scales accessible.

2 Process

For reference, we review the process. The initial configuration tables are in longitude, latitude, and elevation. These tables are incorporated into the GIS software. Preliminary investigation was performed of real-world issues, such as roads, buildings, power, land access, fiber, RFI environment, and related. These investigations will need to become more detailed, as we advance toward a final configuration, likely requiring site visits to ensure accurate information.

When changes have to be made to an antenna position, the longitude, latitude, elevation values are adjusted in the Geographic Information System (GIS) software. These are then exported as an ascii table. We have written a python script, incorporating the standard CASA configuration tool: simutil.long2XYZ, to convert the (long, lat, el) values to Earth-centered XYZ coordinates. We employ CASA tools in order to maintain consistency with the CASA norms, given that our array testing is done in CASA. We have done extensive checks to see that this conversion provides the same XYZ results as was found for the current .cfg files on the ngVLA tool webpage. Agreement is typically much better than a meter.

We adopt the World Geodetic System 84 (WGS84) for the reference XYZ coordinate system. WGS84 includes correction for the Earth as a oblate spheroid, and is the standard for the GPS system, and for CASA. In this system, the Z axis is along the Earth's rotation axis, passing through the Earth's center of mass, and the X axis is a line passing through the Earth's center of mass and zero longitude and latitude.

Table 1 lists the basic parameters for each sub-component of the ngVLA. Note that the current configuration tools on the ngVLA webpage include some configurations that are combinations of the major subcomponents, such as the 'Plains array', which is a sum of the Core and Spiral. The general exploration of combining antennas from different components, such as the Spiral plus 10% of the Core, is of paramount importance, given the extreme spatial dynamic range ($\sim 10^5$), of the ngVLA full array, from the Core to the LBA (Rosero 2019, ngVLA memo 72).

3 Core

The Core is a semi-random antenna distribution, from 38m to 1.2km baselines. We have adjusted the minimum baseline up to 38m in the latest .cfg file. We have renamed stations in the .cfg file to 'corZZZ', where ZZZ = a number from 001 to 094.

Figures 1 and 2 shows the properties of the configuration. These figures, and subsequent figures, include: (1) the antenna layout, including local terrain and roads, (2) the uv snapshot coverage, (3) a histogram of the number of baselines vs. baseline length.

In terms of future work, we have begun assessing alterations to the core, such as taking 30 antennas from the random core, and adding them to the inner parts of each spiral, following the same logarithmic spacing down to baselines approaching 38m. A second investigation will look into increasing the number of shorter baselines, between 38m and 100m. The current random core is sparse on these spacings, as can be seen in Figure 1c.

4 Spiral

We have made no changes to the spiral positions, but we have renamed the stations to indicate the spiral arm on which an antenna lies: the arms are designated spaZZZ, spb, spc, spd, spe, with a through e increasing clockwise from north (at origin), and antenna numbers, ZZZ, increasing along each spiral arm from 001 to 015.

We provide here a more detailed mathematical description of the spiral. The python code is available, on request.

The spiral is a modified version of the SKA logarithmic spiral, described in SKA Configuration Design document: WP3-050.020.000-R-002. The spiral has the form:

$$R = a \times exp\left[\frac{b\theta^3}{(\theta+\phi)^2}\right]$$

where R is the antenna distance to the center of the array (radius), a is the minimum radius (0.9km), $b = 1.5$ rad^{-1}, θ is the azimuth angle, and $\phi = 4.5$, in radians (all angle units could be in degrees, since the exponent is a ratio). The antennas are located at regular increments in azimuth of $\delta\theta = 0.17$rad (10^o), covering a total range in azimuth of 140^o for the 15 antennas along a given arm. This leads to a logarithmic radial distance distribution for the antennas along the spiral arms. Note that one arm to the East has only 14 antennas due to terrain limitations.

Our realization of the SKA spiral also includes a random dither that scales with distance along the arm, with a range of approximately $\pm\frac{500}{19000} = 0.025\times$ the antenna radius, in the current implementation. The dither helps fill-in the uv-plane.

Note that the Plains configuration on the ngVLA tools page is a combination: Spiral + Core.

In the future, we plan to explore alterations to the spiral, such as increasing the dither scale to 'widen' the arms, or taking 30 antennas from the core to make a 7 arm spiral, or to be placed as a ring around the Plains, (Clarke & Brisken 2015, ngVLA memo 3; Conway 2000, ALMA memo 283).

5 Mid

We have made no changes to the Mid stations. The Mid configuration is a very rough approximation of the five arm spiral from the plains. The arms are irregular in both length and form, driven by the need to obey real-world constraints, such as road access and power, and many outer antennas do not conform to any arm. The Mid configuration prioritizes antenna locations extending south of the Plains, to improve beam response for southern objects. The Mid antenna station code is: 'midZZZ', where ZZZ is a number from 001 to 046. Three of the Mid antennas are in Mexico (044, 045, 046).

Note that the Main Configuration on the ngVLA tool page is a combined: Mid + Spiral + Core.

In the future, we may investigate alterations to Mid that optimize uv-coverage (see Walker 2019, ngVLA memo 49). We are also considering sociological factors, such as bringing broad band fiber to under-served communities in New Mexico, and beyond, while not sacrificing scientific capabilities.

6 Long Baseline

The LBA consists of 10 stations of 2 to 4 antennas each, from Hawaii to Saint Croix. Half of the installations are at existing VLBA sites. The others are arranged to improve UV-coverage, in particular when including some of the Mid stations. Note that a few of the existing VLBA stations (Pie Town, Los Alamos, Kitt Peak, Fort Davis), are included in the Mid configuration.

The addition of multi-antenna stations will help in calibration, including the capability of paired-antenna calibration, where calibration transfer is done continuously between an antenna pointing at the target, and the neighboring antenna pointing at the calibration source (Carilli & Holdaway, Radio Science, 34, 817). For the longest baselines, the design incorporates a relatively nearby station, within a few hundred km. Experience shows that having a relatively close station helps to anchor the gain calibration for the longest baselines.

We have moved one antenna in the North Liberty station to comply with the 38m minimum baseline specification. We have also added elevations for all the stations, since these were omitted in the first conversion from long,lat,elev to the XYZ.cfg file in the ngVLA toolbox. For the station on the island of Hawaii, consisting of three antennas, the locations were somewhat arbitrary. We have moved these to one site in a 100m equilateral triangle. The final location for the HI station remains under investigation. On the Island of Kauai, there are three antennas in the Kokee Park Geophysical Observatory park. One of the antennas was about 1km from the other two. We have moved this antenna to within 100m.

7 Short Baseline

The short baseline array is an approximate hexagonal, compact grid, with minimum spacing set by antenna structure of 11m. The grid is dithered to mitigate grating lobes. This configuration is designed for excellent surface brightness sensitivity to structures on scales up to $\sim 1'$ at 32 GHz, and to provide adequate sensitivity to large scale structure for inclusion with eg. the core array, with modest integration times. The array is 10% elongated North-South, to obtain a rounder beam at low and high declinations. The array is described in detail in Mason et al. (2018, ngVLA memo 43; 2019, ngVLA memo 67), to which we refer the interested reader. In the design documents, the SBA also incorporates four 18m antennas optimized for stable total power measurements.

We have changed the SBA in two ways. First, we have rotated the array by 30° to avoid having antennas on adjacent east-west rows located due north-south of each other. This rotation allows for more visibility south and north during transit, leading to less shadowing. Second, we have translated the whole structure 700m to the east, outside of the Core. This was done to avoid shadowing by the 18m Core antennas.

We quantified the impact of shadowing on the original (Rev.C) SBA configuration and the new, rotated configuration using simulations of a target at -27° (the approximate declination of Sgr A*, an important science target). These simulations used the same observing strategy as described in ngVLA memo 67, comprising a 1h15m observation of a grid of mosaic pointings centered on transit.

In this simulated observation with the original configuration, 29.8% of integrations are affected by shadowing (evaluated using `flagcmd(vis=vis,mode='shadow')`). The same observation using the rotated SBA results in only 6.4% of integrations being affected by shadowing. The beam is also slightly rounder, with an axial ratio of 1.69 *vs.* 1.79 for the original Rev.C SBA configuration. In general for the current (feed-low) SBA antenna design, flagging comes into play below 30° elevation. This corresponds to the elevation at which a source at $\delta \sim -26^\circ$ transits.

For reference, the major to minor axis ratio of the NA weighted snapshot beam vs. declination is: 1.69 (N-S) at -27^o, 1.08 at 0^o (NW-SE), 1.09 (E-W) at $+45^o$, and 1.33 (N-S) at $+80^o$.

Table 1: Rev C Configuration Components

Component	Station code	N ants	D_{ant} meters	B_{min} meters	B_{max} meters	Description
Core	cor	94	18	38.2	1340	random on Plains of San Augustin
Spiral	sp[a-e]	74	18	274	36450	SKA 5 arm exponential spiral on Plains
Mid	mid	46	18	7800	1005000	broken 5 arm spiral over US SW and Mexico
Long Baseline	lb	30	18	40	8856000	10 stations of 2 to 4 ants
Short Baseline	sba	19	6	10.9	59.7	close-packed pseudo-grid

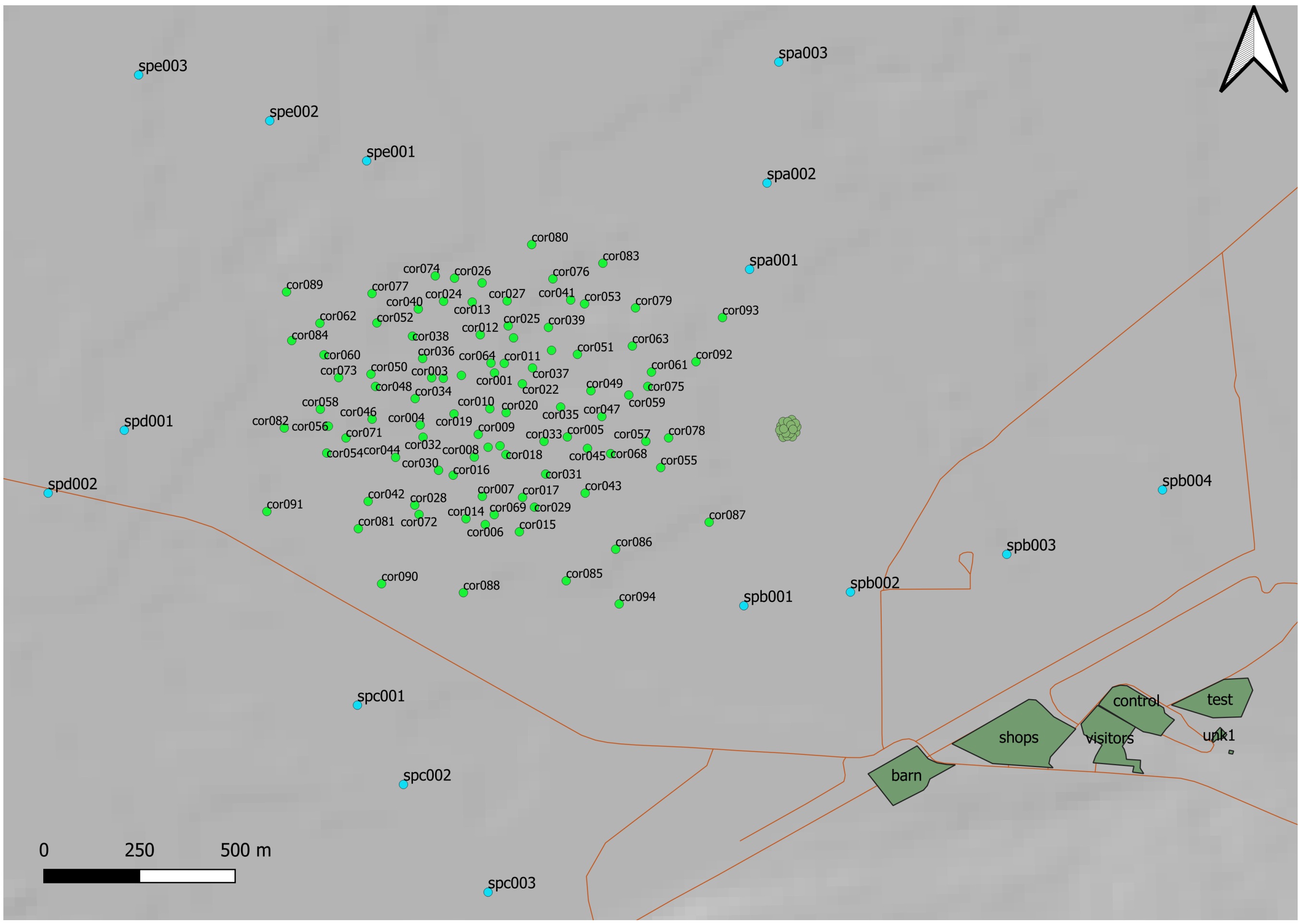


Figure 1: The Core configuration shown as light green circles. The inner spiral antennas are shown as cyan, to demonstrate the relationship. The SBA antennas are shown as darker green, about 700m east of the Core center. Also shown in this, and subsequent, figures is the terrain, and some of the roads and buildings.

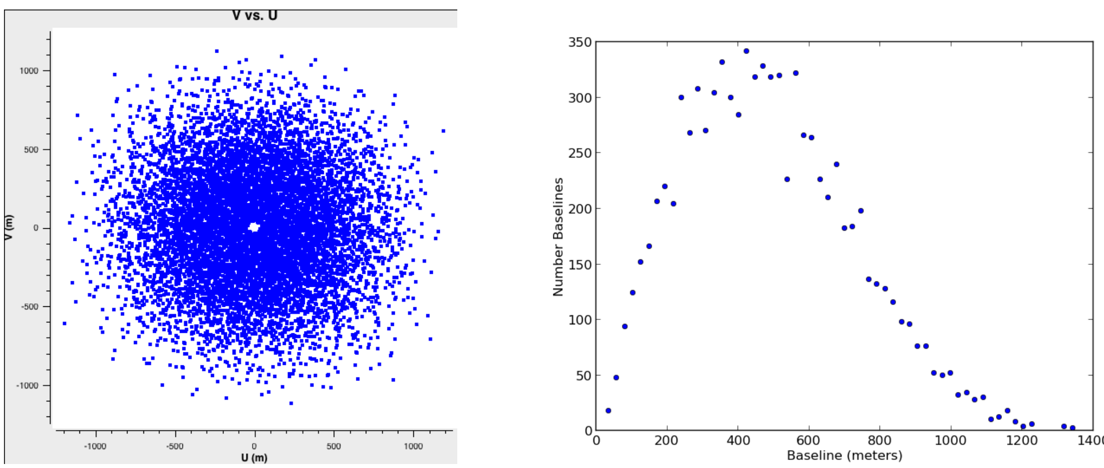


Figure 2: Left: Snapshot uv-coverage of the Core. Right: Histogram of baseline distribution.

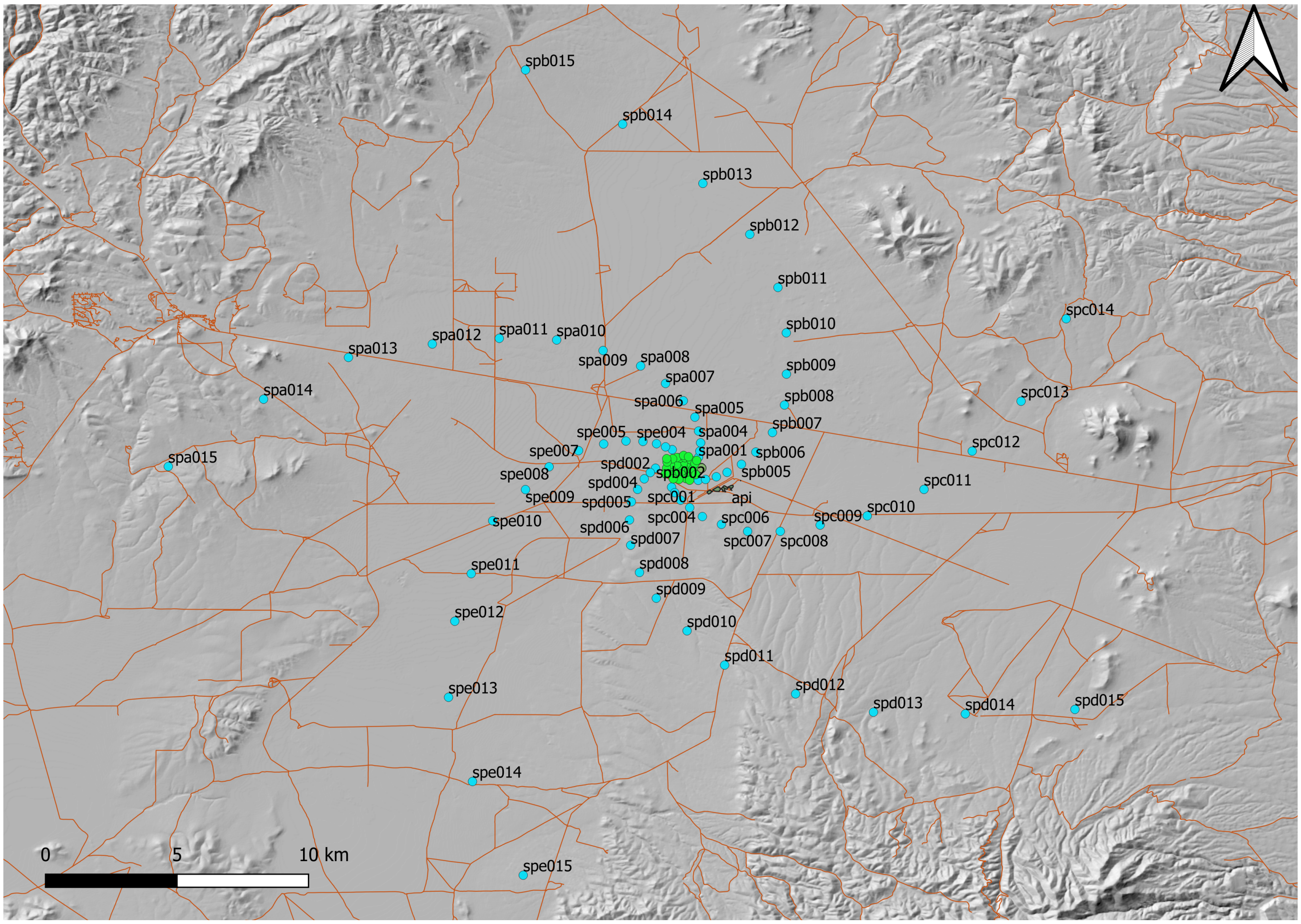


Figure 3: The Spiral configuration shown as cyan circles. The Core antennas are shown as green, to demonstrate the relationship.

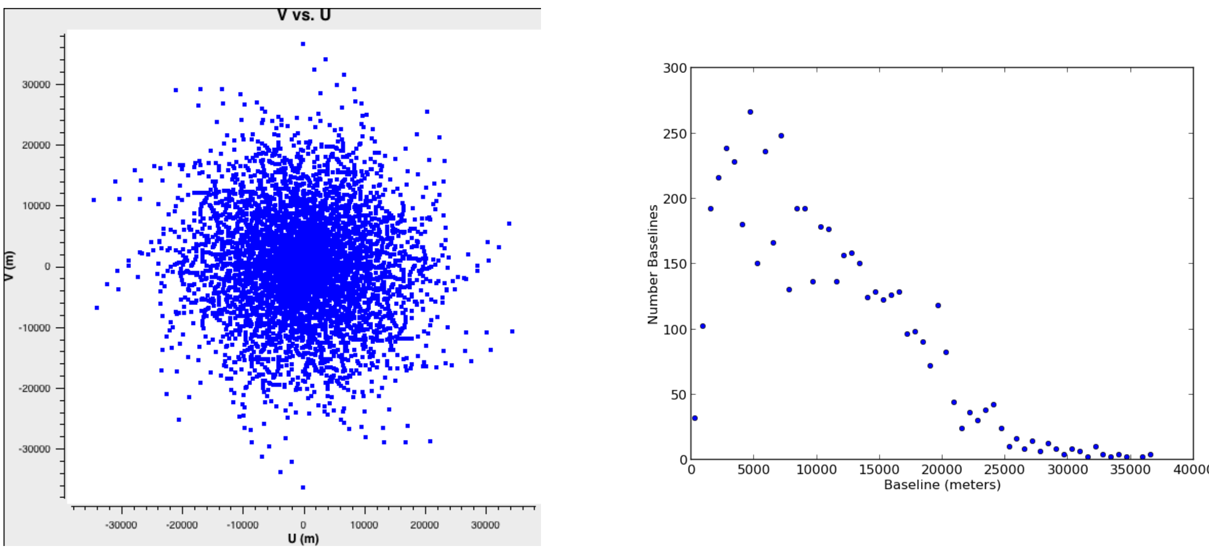


Figure 4: Left: Snapshot uv-coverage of the Spiral. Right: Histogram of baseline distribution.

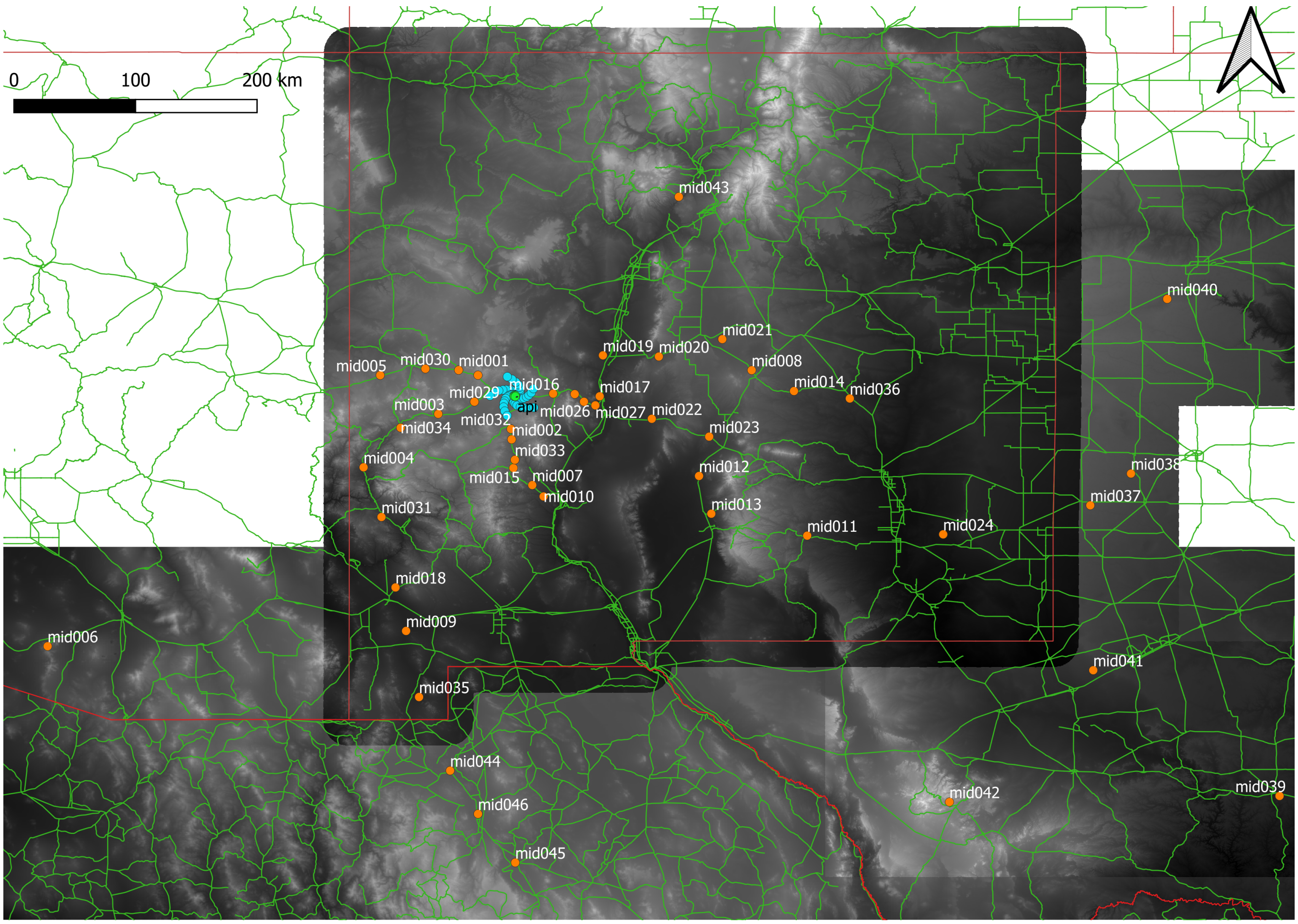
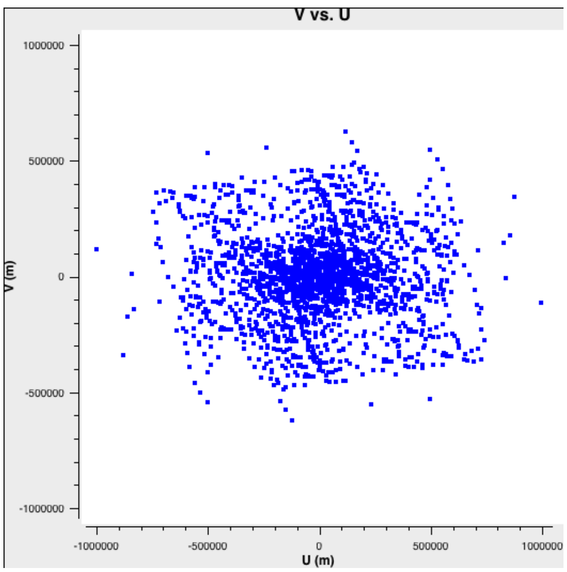


Figure 5: The Mid Array with antennas labeled, as orange circles. The spiral array is also shown as cyan circles.



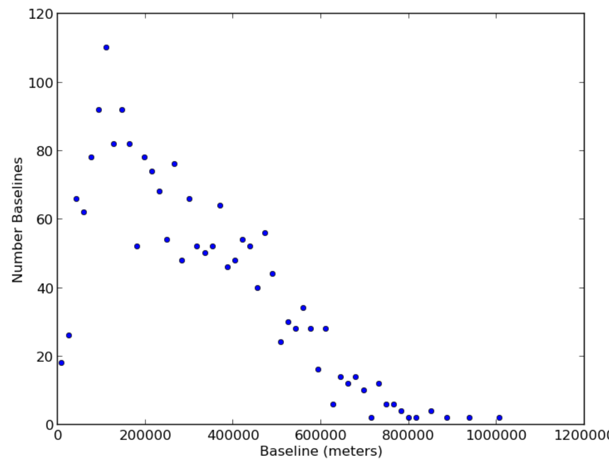


Figure 6: Left: Snapshot uv-coverage of the Mid. Right: Histogram of baseline distribution.

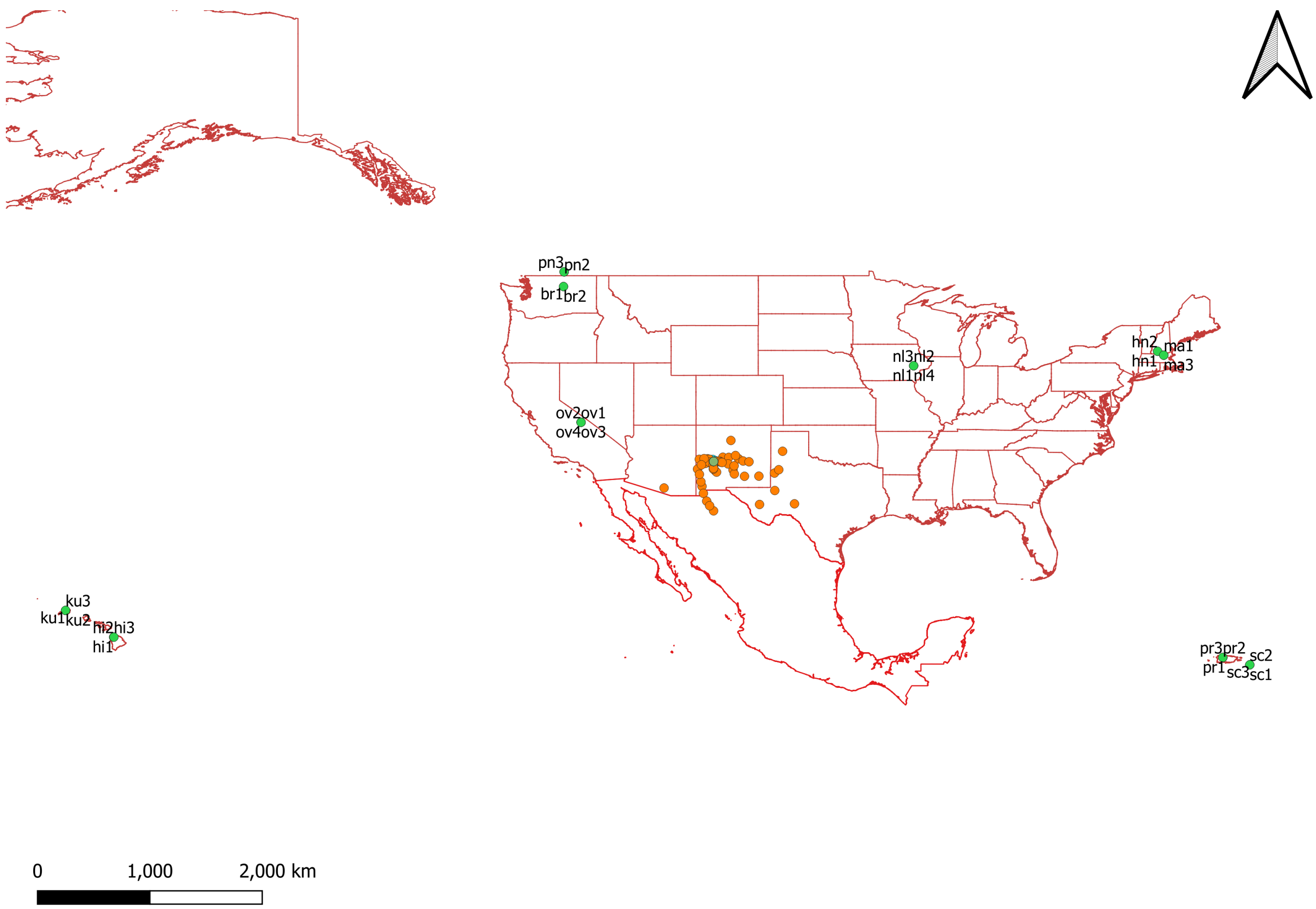


Figure 7: The Long Baseline Array with antennas labeled, as light green circles. The Mid array is also shown as orange, with the spiral as darker green.

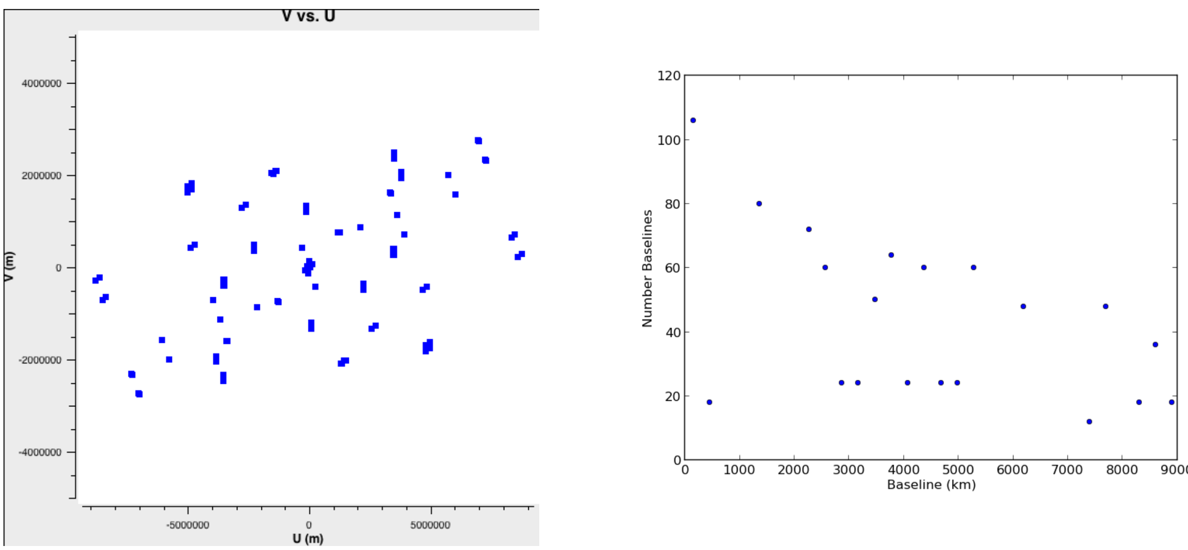


Figure 8: Left: Snapshot uv-coverage of the LBA. Right: Histogram of baseline distribution.

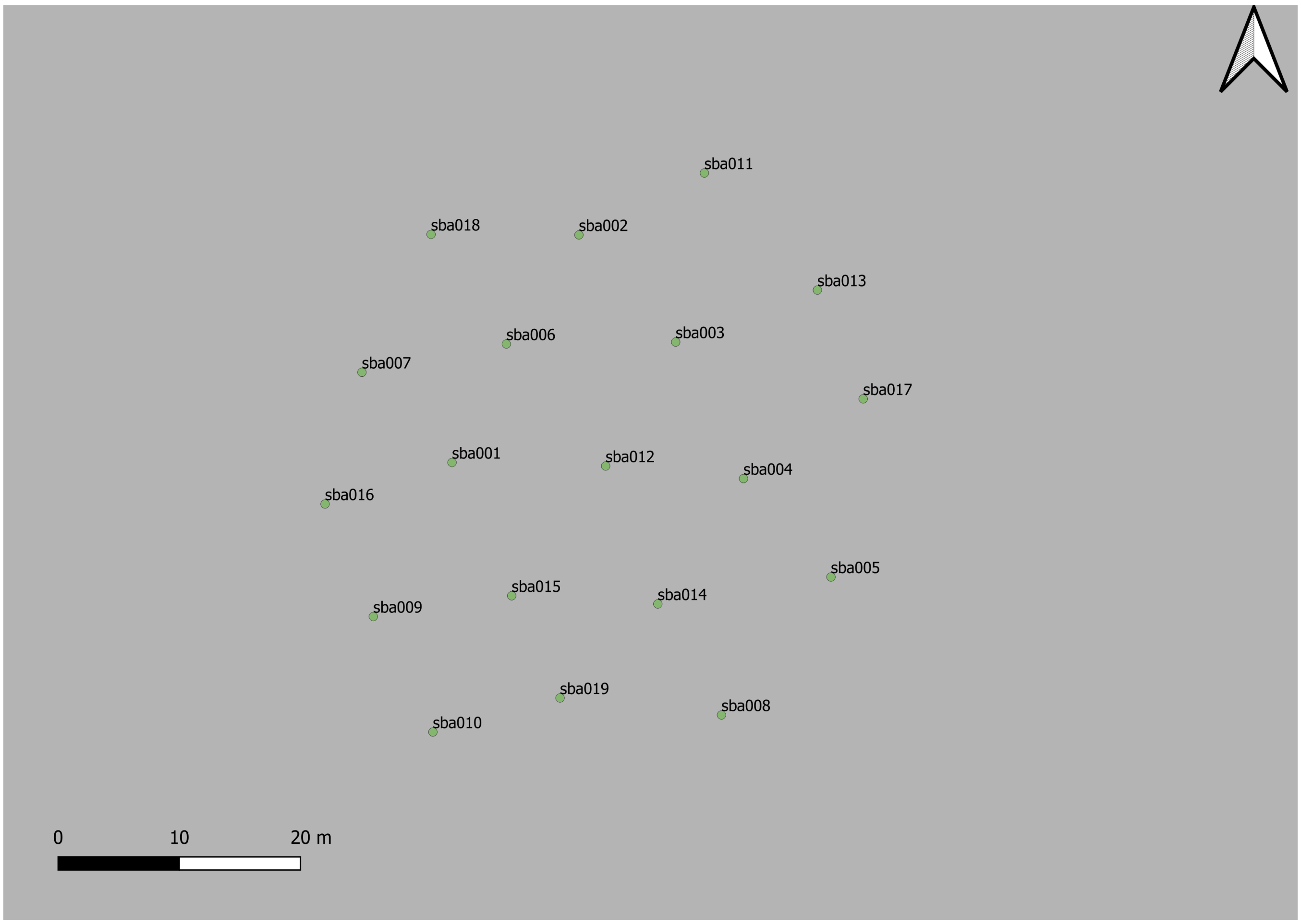


Figure 9: The Short Baseline array configuration shown as green circles.

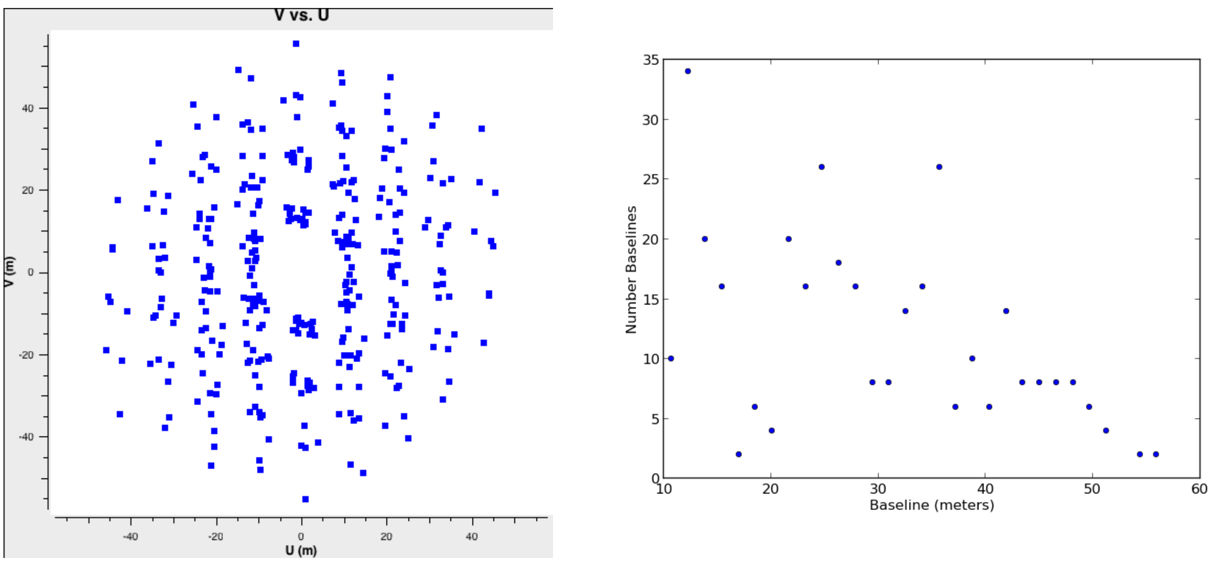


Figure 10: Left: Snapshot uv-coverage of the SBA. Right: Histogram of baseline distribution.