NGVLA Memo 102

Enhanced Central Condensation Options for the Configuration of ngVLA MID

R. Craig Walker (NRAO)

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Abstract

Modifications to the MID portion of the current reference configuration, Rev D, of the ngVLA are considered to in an effort to achieve a higher degree of central condensation and a smoother transition between CORE and MID. The main mechanism is to switch from a power law to a more scale-invariant exponential distribution of distances to the center. The effects of two choices are considered. One is whether there should be one or two antennas per arm inside the position Pie Town. The other is whether Ford Davis and Kitt Peak should be the last, or second to last, antenna on their arms, affecting the resolution. The project still needs to decide especially about the resolution. The author's preferred option is given.

Introduction

The current reference configuration for the ngVLA is called Rev D. The MID segment of Rev D is based on the proposal in ngVLA Memo 49 which addressed poor snapshot coverage in the previous reference configuration. Two issues have been identified with the Rev D MID. The first is that a histogram of baseline lengths, based on all ngVLA antennas, has a big dip just beyond the maximum length of the SPIRAL baselines. Therefore the available UV coverage is not scale invariant – some resolutions are covered better than others which is not considered desirable for the ngVLA. That dip can only be addressed by moving some or all MID antennas inward. The second issue is that the project requirements specify that MID covers baselines to 500km. Rev D is noticeably larger, even for just the clusters of baselines between MID antennas and the core. But there are some projects that want that resolution. Also, with the extra resolution, the interface to LONG will be better.

This memo presents four alternative MID configurations that use an exponential, rather than power law, distribution of distances from the core for the antennas on the spiral pattern. That provides more central condensation and is more scale-invarient. The four options are the combinations of two options for the innermost antennas and two for the maximum resolution. All are constrained by having the VLBA stations at Pie Town, Kitt Peak, and Fort Davis be included. All of these options also use more “twisted” arms than Rev D to achieve a more uniform distribution of the main clusters of baselines from MID antennas to the SPIRAL antennas. This was done by putting the Pie Town VLBA site on the second most western arm (arm 4), not the most western.

Finally a personal preference for the longer baseline option on both small and large scales is explained and a slightly tweaked version of the theoretical spiral with Pie Town on station 2 and Fort Davis and Kitt Peak on station 8 (of 9) is presented. Note that the configurations presented have not been adjusted for geographic constraints. That is a separate project for once the general parameters of the configuration are chosen.

Tools

For a description of the tools I use, see ngVLA Memo 49. Since then, I have started using Caltopo and Gaia GPS to supplement Google Earth for checking the reasonableness of sites, although very little of that was done for this memo. The theoretical station positions are calculated in an OpenOffice spreadsheet (SpMID_CW_Configs.ods) which provides position data tables that can be cut and pasted into .csv, .cfg, and .dat files. Google Earth can read the .csv files. The ngVLA projects and my program, GETHIST, that calculates the histograms, read the .cfg files. SCHED, the VLBA scheduling program and the main tool I use to display array coverage, uses .dat files. One can shift station positions in Google Earth and write .kml files, which can be read by CalTopo and Gaia GPS. CalTopo has a public lands layer that is useful and Gaia GPS has somewhat more extensive road information. GETHIST has been tested and, with the right input parameters, produces the same histogram numbers as those shown in ngVLA Memo 92 (the Rev D description) Figure 3. Note that, while GETHIST calculates the numbers, the histograms are actually plotted in OpenOffice. For this memo, I am using different histogram parameter than were used in Memo 92.

The New Configurations

There are 5 new configuration shown in this memo. They are listed in Table 1. They look much like the CW_CG configuration of ngVLA Memo 49, being 5 arm spirals extending from just outside ngVLA SPIRAL on the Plains of San Agustin westward into Arizona, eastward into Texas and southward into Mexico. The big difference between all of these configurations and CW_CG is that the antennas of the new configurations are spaced along each arm according to exponentials of the form $D_m = D_n\, a^{(m-n)}$. The array of ngVLA Memo 49 was based on power laws of the form $D_m = D_n\, (m-n)^{a}$ which are less centrally condensed. Here a is the scale factor which, in the exponential case, is the ratio of the distance from the array center (average position of CORE antennas) between adjacent antennas on a spiral arm. The antenna number along the arm is m and D_n is the distance to antenna n. The angle, seen from the array center, of successive antennas of an arm are constant. In practice, the positions of two antennas on each arm were fixed and the parameters a and the angle changes between antennas were derived to match those antenna positions separately for each arm. The arms are placed at 36 degree angle increments about the center at the distance of Pie Town. The angle increment between antennas along each arm are very similar, but vary a bit in order to hit both Kitt Peak and Fort Davis. The range of values of the scale factor and angle increment are included in Table 1.

To set the size and location of the arms, a constraint was used that seems to work well, but the necessity of which could be debated. That constraint was that the Pie Town (VLBA_PT; PT), Kitt Peak (VLBA_KP; KP), and Fort Davis (VLBA_FD; FD) VLBA sites should each be an integral part of an arm. This was done by choosing the pre-existing VLBA site as one of the two fixed positions for the appropriate arm. Using the existing sites allows reuse of existing infrastructure and gives continuity in measurement of geodetic parameters. Los Alamos (VLBA_LA; LA) is included in MID,

Name	PT Station	KP Station	FD Station	Minimum Center Distance (km)	Maximum Center Distance (km)	Maximum Baseline (km)	Scale Factor “a”	Angle increment along arm (deg)
MID28	T42	T58	T28	34	631 - 767	1187	1.435 - 1.476	15.0 - 16.0
MID38	T43	T58	T28	18	678 - 830	1275	1.543 - 1.595	18.0 - 19.2
MID29	T42	T59	T29	36	439 - 520	828	1.363 - 1.396	12.9 - 13.7
MID39	T43	T59	T29	23	439 - 520	828	1.435 - 1476	15.0 - 16.0
28MOD	T42	T58	T29	34	628 - 723	1228	1.434 - 1.476	15.0 - 16.4

Table 1: Properties of the configurations considered in this memo. The station naming convention is that the first digit is the arm number, increasing east to west, and the second is the station number along the arm. The "Center" is the average position of the Rev D CORE antennas. Where a range is given, the parameter varies by arm and that is the range seen over the arms.

but is just too far from any of the arms to be used in this manner. So it stands by itself, not part of any arm. Perhaps it should be considered to be part of LONG – that will be considered again in a future memo focused on LONG.

One change from the MID configuration of Rev D is that Pie Town is placed on arm 4 (numbering east to west) rather than arm 5. Kitt Peak is on arm 5 in both cases while Fort Davis is on arm 2. The result is an increased curvature, or “twist”, to the arms – the angle change between arm elements is larger. The snapshot coverage of Rev D had obvious, somewhat straight arms. Long experience with VLA snapshots shows the disadvantage of straight arms. With the higher twist, the arms are less apparent and the coverage, especially by the clusters of CORE-MID baselines, is more uniform.

Four of the configurations considered are the combinations of two binary choices. The first is whether to place Pie Town on station 2 or 3 of arm 4. When it is on station 3, the innermost antennas of MID almost overlap with the outermost antennas of SPIRAL. This gives a high concentration of baseline lengths, mainly to the big concentration of antennas at the array center, at distances of of about 15-40 km. With Pie Town on the second station, there is more of a gap between CORE and SPIRAL antennas and there is not such a concentration of baselines in that range. The other binary choice is whether to put Kitt Peak and Fort Davis on the last, or the second to last station of their arms. That makes about a 200 km difference in the center distances of the outer antennas and nearly a 400 km difference in the longest baseline. Therefore, there is a significant resolution effect although, with a centrally condensed array, the actual effect will depend on the weighting scheme used.

All of these factors can be seen in Table 1. The columns are: 1.) The name given to the configuration which includes the station numbers for the inner and outer VLBA stations. 2.) The station name for Pie Town. The station name gives the arm number and station number along the arm. 3, 4.) The same for Kitt Peak and Fort Davis. 5.) The approximate minimum core distance. There are variations of about 1 km between arms. 6.) The maximum center distances with the range accounting for differences between arms. The fairly large variation is the result of Fort Davis being about 100 km farther from the core then Kitt Peak, but they are in the same sequence position on their arms. Note that the offsets from the center set the UV positions of the big clusters of baselines which will be the most important factors determining array performance. 7.) The maximum baseline which is typically between the tips of arms 1 and 5. These are much longer than the maximum center distance, but they only apply to a few baselines to the tips of opposite arms. To get the full resolution implied would require seriously down weighting most of the data. 8.) The scale factor *a* of the exponential for the arm. The range is over the arms with variation required to include Kitt Peak and Fort Davis. Note that *a* is the ratio of center distance between adjacent antennas on an arm. Larger values imply more widely spaced antennas and a sparser array. 9.) The angle increment between antennas on each arm. As with *a*, they vary to accommodate Kitt Peak and Fort Davis and to cover the full 180 degrees appropriately (the rest of the circle is covered by conjugate positions).

The lengths of arms 2 and 5 are fixed, and different, in order to include Fort Davis and Kitt Peak respectively. But there is some freedom to choose the lengths of the other arms. For these configurations, the station corresponding to the ones Kitt Peak and Fort Davis are on (8 or 9) were set to 520 km for arms 3 and 4 and to 439 km for arm 1. For reference, Kitt Peak is at 439.42 km and For Davis is at 516.46 km. The tips of arms 3 and 4 are mainly to the south of the center so the somewhat larger distance stretches the north-south coverage a bit which can help with southern sources. A larger stretch could be chosen if that is desired. The length of arm 1 was chosen to match arm 5 which is set by Kitt Peak. This shrinks the east-west coverage a bit. As one can tell, there is considerable freedom to tweak these parameters even in the theoretical configuration, let alone when trying to accommodate the geographic constraints.

After examining the four MID configurations, I decided I preferred MID28 for reasons given later. But it is somewhat extended in a northwest – southeast direction. So I tweaked the positions of the outer antenna somewhat to make it rounder. For arms 2 and 5, I only changed the outermost antenna, the one beyond Fort Davis or Kitt Peak. For the other arms, I changed the position of the outer fixed antenna used in the spiral calculation. The result is configuration 28MOD. These actions again suggest that the exact spirals should not be considered to be unchangeable.

Geographic Realities:

The calculated antenna positions used for this study have a significant probability of falling somewhere inappropriate. In fact, for an early draft of this memo that was based on an array similar to MID39, but with Pie Town on arm 5, a lot of stations fell in rather inaccessible places. I made a quick effort to find more usable substitutes using Google Earth and the other mapping programs. I moved outer stations up to 18 km and inner ones up to 4 or 5 km. For the inner stations, I did not make a serious attempt to get near infrastructure other than roads. The plan is to lay new fibers to all stations within 300 km so that means they don't have to be near existing fiber. If power is not available nearby, it should be possible to install it along with fiber although I have not checked that.

A much more serious effort with the tools available in the ngVLA project and likely site visits will be needed to find final locations. When I plotted the UV coverage of the theoretical array and the modified described above, they were difficult to distinguish without very careful examination. That indicates that the array is tolerant of fairly significant adjustments to reflect reality on the ground. Since they are hard to distinguish, I'll only plot the coverage of the theoretical array and leave publication of the actual coverage for after final sites are chosen. Also, the centers for the search areas for final sites based on this work should start with the calculated positions, not my adjusted positions to avoid "double dipping" offsets.

One small concern is that some sites are likely to be above 2500m elevation which is the nominal limit. That is apparently an HVAC limitation (Rob Selina, Private Communication). It should be possible to take special measures at a few sites. But care should be taken to avoid the almost-problem we had on the VLBA when the contract allowed for one site above some elevation, probably 2000m, that was

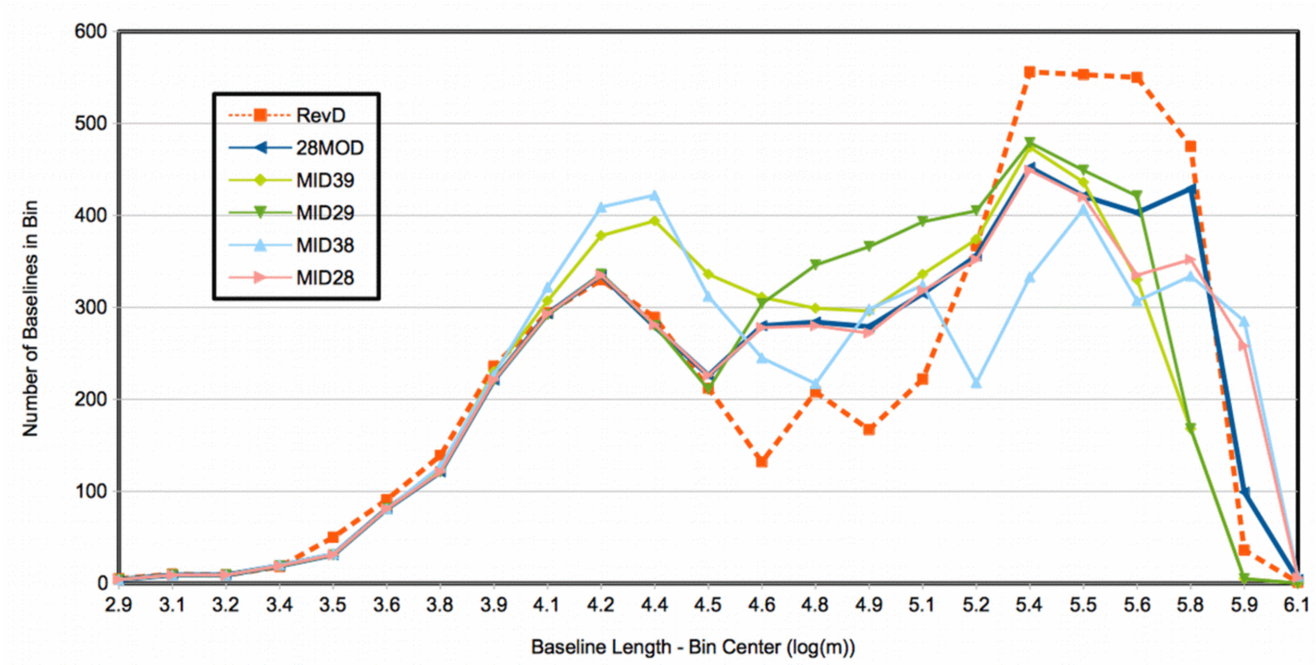

Figure 1: Histograms of number of baselines vs baseline lengths for Rev D (red, dashed) and five versions exponential spiral configurations. Only stations from SPIRAL and MID are included. See Table 1 for the differences between the various configurations. The bin labels are the log10 of the bin center in meters. The bin boundaries are at 720, 1000, 1390, 1931, 2683, 3728, 5180, and 7197 m and 10.0, 13.9, 19.3, 26.8, 37.3, 51.8, 72.0, 100, 139, 193, 268, 373, 518, 720, 1000, and 1389 km. All of the exponential configurations show flatter distributions than Rev D which makes them more scale invariant.

meant to cover Mauna Kea. But Pie Town was also slightly above the specified value so the contractor could have hit us for more expenses. As I recall, they were nice about it.

Histograms

This project was triggered by the histogram of Figure 3 of ngVLA Memo 92 on Rev D. It shows a significant dip in the number of baselines in the two bins between 30 and 127 km – the shorter end of the baselines dominated by MID. Note that the baseline length scale is logarithmic so, if the goal is to have scale-independent capability, the histogram should be flat. For this memo, I have made new histograms that attempt to show more clearly what is happening in the interface between SPIRAL and MID. The new histograms have higher resolution in baseline length – there are more bins across a given baseline range. The original only had about 4 bins for a whole ngVLA segment. I have also removed both the CORE and LONG antennas from the station list from which the histograms were made. Including the CORE baselines produces tight clusters of many baselines between the CORE and any more distant stations (already apparent with SPIRAL present). It turns out that, with the higher resolution histogram, a resolution comparable to the radial separation of the MID antennas, this produced some pronounced strobing effects. Adjacent bins could have very different amplitudes depending on whether a few antennas were just above or just below the bin boundary in center distance. This effect is somewhat smoothed when the clusters only contain baselines to SPIRAL. As for LONG, there are clear issues in the interface between LONG and MID that are not the subject of this memo – they will be addressed in a future memo. So I left out LONG for the histograms. Besides these practical issues, including just SPIRAL and MID probably reflects most common way the array will actually be used.

The histograms for Rev D and the 5 configurations considered here are shown in Figure 1. For this figure, connected symbols were used rather than a bar chart to make tracing what is happening with each configuration easier. Rev D is shown in red and clearly shows the strong bias against baselines in the transition region with emphasis on the longer spacings. For the other configurations, the effects of the two choices can be seen. The two configurations, MID38 and MID39, with the smaller inner ring caused by having PT on station 3, have significantly more baselines in the transition region (near log(baseline length)=4.4). The two with longer baselines, MID28 and MID38, with Fort Davis and Kitt Peak on station 8 rather than 9, clearly have more resolution. The light blue line of MID38 shows both high density in the transition region and high resolution. To achieve that with the same number of antennas as the others, the antennas are more spread out as indicated by the low number of baselines through much of the range. The 28MOD configuration is based on MID28 with the outer stations moved to adjust the envelope of the UV coverage. The effect of that can be seen in the somewhat lower resolution than MID28, but otherwise the 28MOD histogram tracks the one for MID28 rather closely. All of these histograms show some lumpiness that is probably the result strobing between the the finite number of baseline clumps and the bins.

UV Coverage

Sample UV coverages are shown in Figures 2 through 6. The first two compare the new configurations, specifically MID28 (large inner ring, high resolution) with Rev D.

Figure 2 is on a scale covering to 200 km to show the region of the interface to SPIRAL. The relatively low density of baselines in this region in Rev D is clear. Fixing that was the point of the changes suggested in this memo. The comparison array is MID28 which, with Pie Town on station 2, has a lower density of inner baselines than those with Pie Town on station 3, but is still much better than Rev D.

Figure 3 shows the full coverage, with axes extending to 1300 km of Rev D and MID28. Here the impact of moving antennas toward the center is clear as the MID28 has reduced coverage on the long baselines. It also has a bit more resolution because the fractional spacing between the outer antennas of the exponential distribution is larger than for the power law of Rev D.

Figure 4 shows the impact of the choice of the large or small inner ring. In practice, this is the choice of whether Pie Town is on the second or third station of its arm. When it is on the third station (MID38), the density of inner baselines is somewhat higher. As seen in the map insert, the inner MID antennas are at almost the same center distance as the outer SPIRAL antennas, so there is some redundancy which is likely not the best use of antenna resources. Backing off the inner MID ring, by putting Pie Town on station 2 still gives much better UV coverage in the transition region than Rev D but leaves more antennas for the longer spacings. Note that there is clearly an out-of-place looking pair of clusters of baselines near the top edge of MID38 toward the right side. It is also there in MID28 but less visible because of more overlap. One of that pair is baselines to Los Alamos, which is not part of the systematic spiral pattern.

Figure 5 shows the impact of ending the arms at Kitt Peak and Fort Davis, or having one more station beyond those on each arm By then the stations are rather far apart since the scale factor *a* is near 1.45 (see Table 1) so the difference in longest spacings is on that order. Note that the difference in achieved resolution will depend on weighting schemes, which, for a centrally condensed array, can be dramatic. The difference is not just resolution. Since both configurations have the same number of antennas and Pie Town is in the same position on both, there is one more antenna on each arm inside of Kitt Peak and Fort Davis on each arm leading to somewhat denser coverage. This same effect applies for the choice of station number for Pie Town. When it is on station 3, there is one less antenna beyond Pie Town on each arm compared to when it is on station 2. This density is reflected in the values of *a*.

Figure 6 shows the UV coverage on 200 km and 1300 km scales for 28MOD. This is basically MID28 with the outer antennas adjusted for somewhat rounder beams as described earlier. This is the configuration whose station coordinates are in the Appendix and which I am suggesting the project use as the starting point to find actual locations. I know at least the southern-most Mexican station will need to be moved significantly based on Google Earth.

Finally, a .cfg file of the stations of 28MOD is given in Appendix A.

Conclusions

This memo presents alternative configurations to Rev D for the ngVLA MID antennas. The changes are much more subtle than those presented in ngVLA Memo 49, which formed the basis of MID in Rev D. The new configuration provides a more centrally condensed distribution of antennas so that it blends more smoothly with ngVLA SPIRAL, avoiding the large dip in the baseline length histogram seen for Rev D. This is accomplished by using an exponential, rather than power law, distribution of distances to the center. The impacts of two choices relating to the central condensation and the maximum spacings are considered. Those choices, in practice, are whether Pie Town is the second or third antenna on arm 5 and whether Fort Davis and Kitt Peak are the ends of their arms or the second to last on the arms. The new configurations also have somewhat more tightly wound spirals than Rev D to reduce a tendency for the arms to be more radial than desired. Finally, a slightly modified version of the configuration with Pie Town on station 2 and Fort Davis and Kitt Peak on station 8, of 9, is offered as a favorite. But the decision about the desired maximum resolution is still to be made by the project.

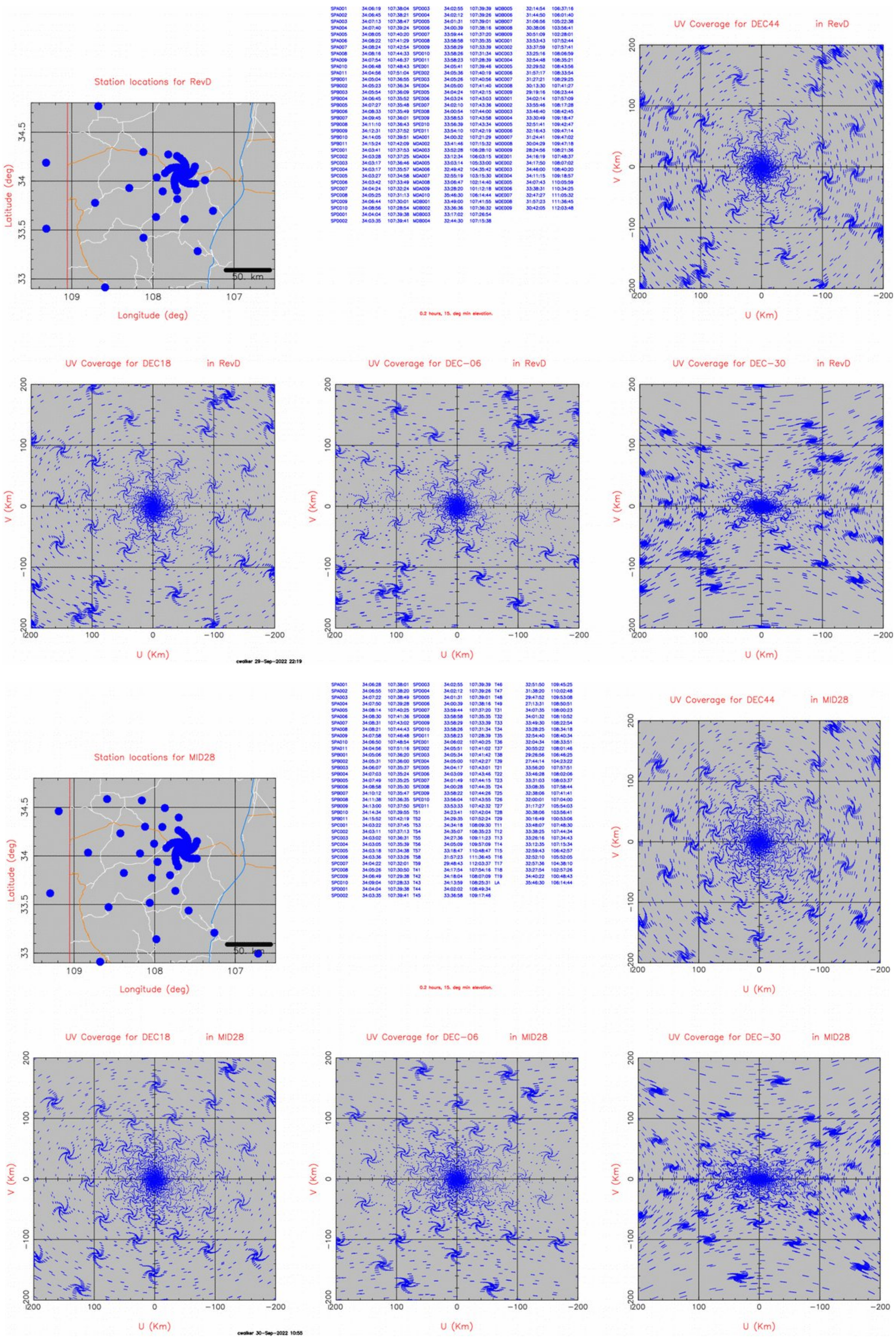

Figure 2: UV coverage on a 200 km scale for Rev D (top) and MID28 (bottom).

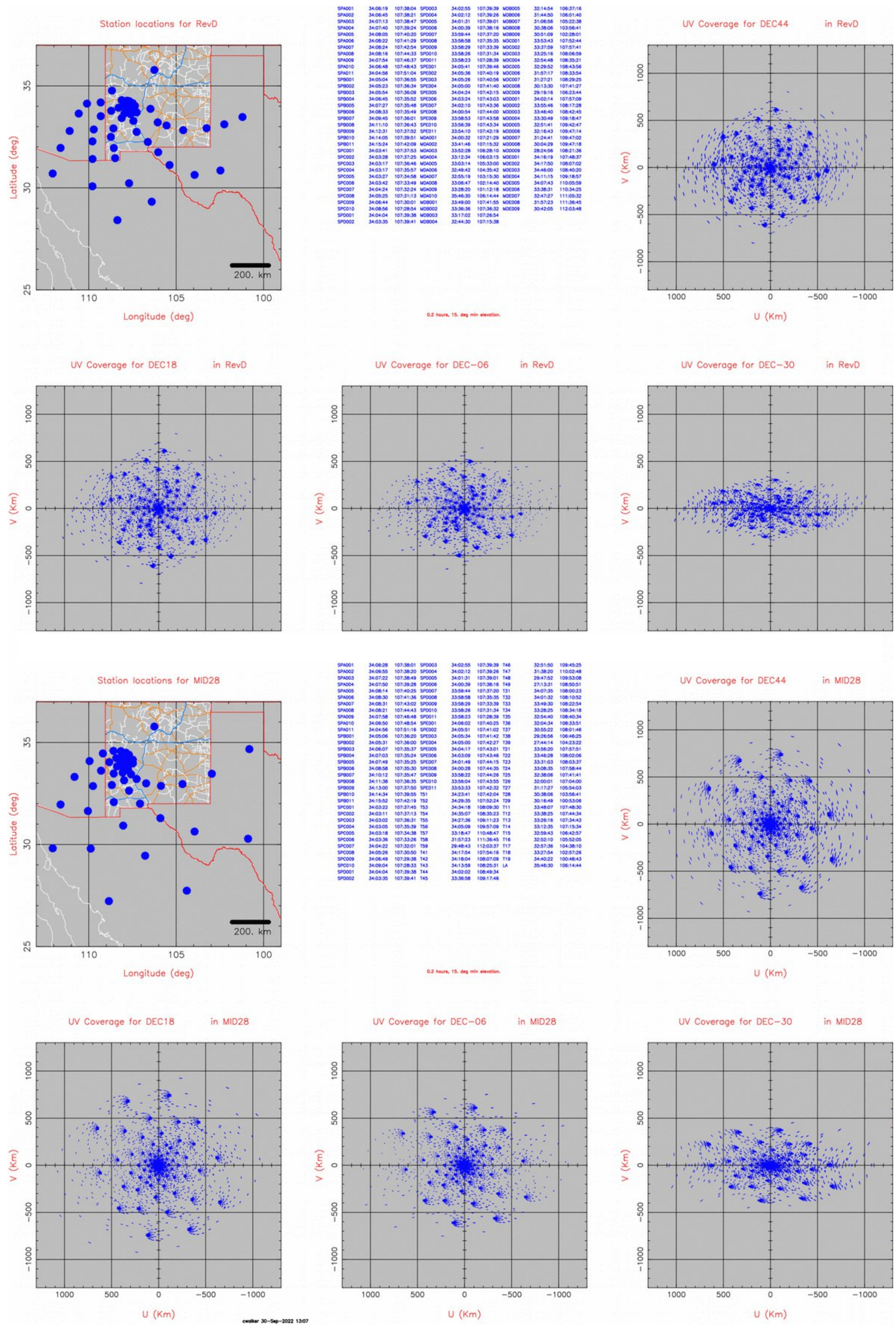

Figure 3: UV coverage on a 1300 km scale for Rev D (top) and MID28 (bottom).

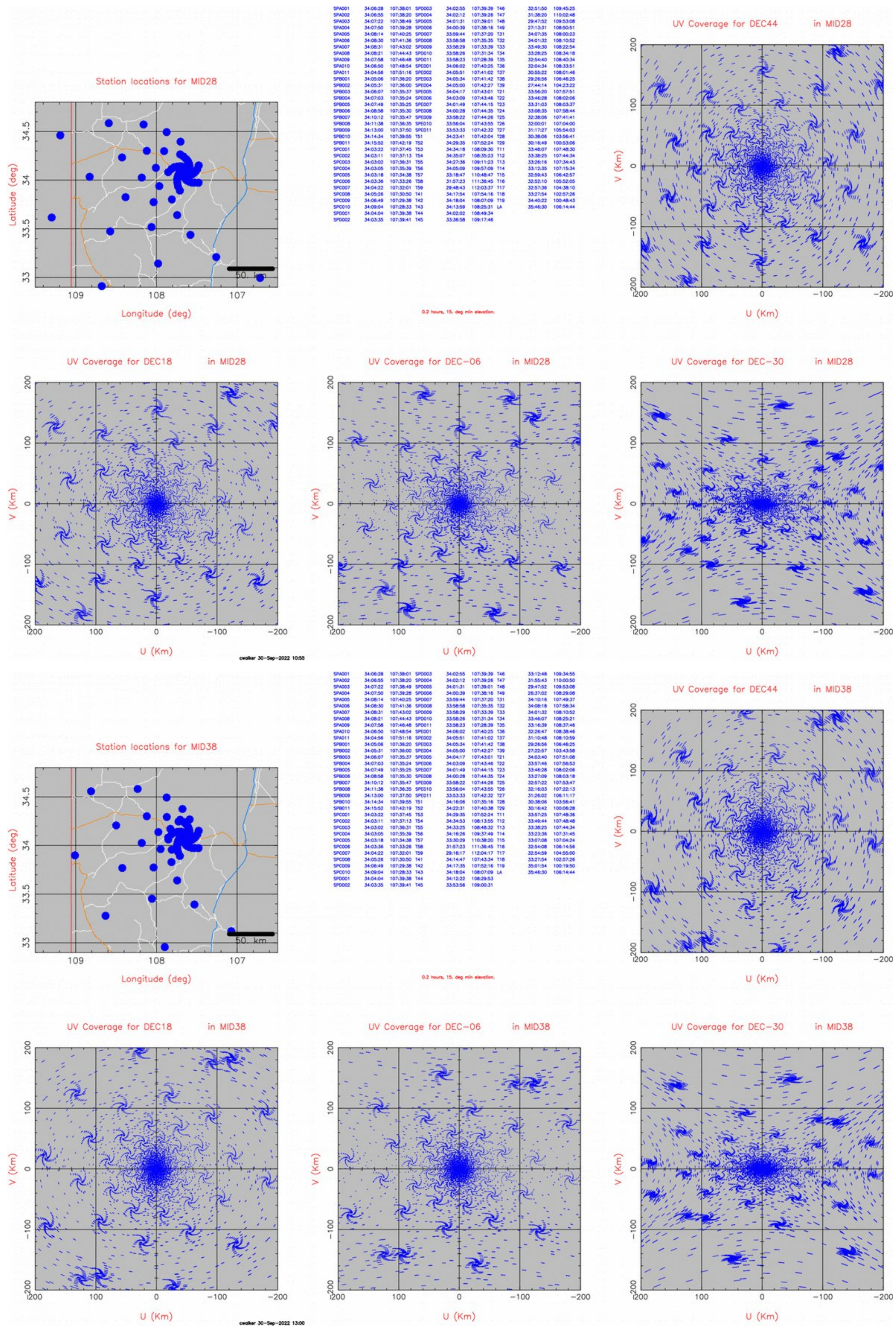

Figure 4: UV coverage on a 200 km scale for MID28 (top) and MID38 (bottom).

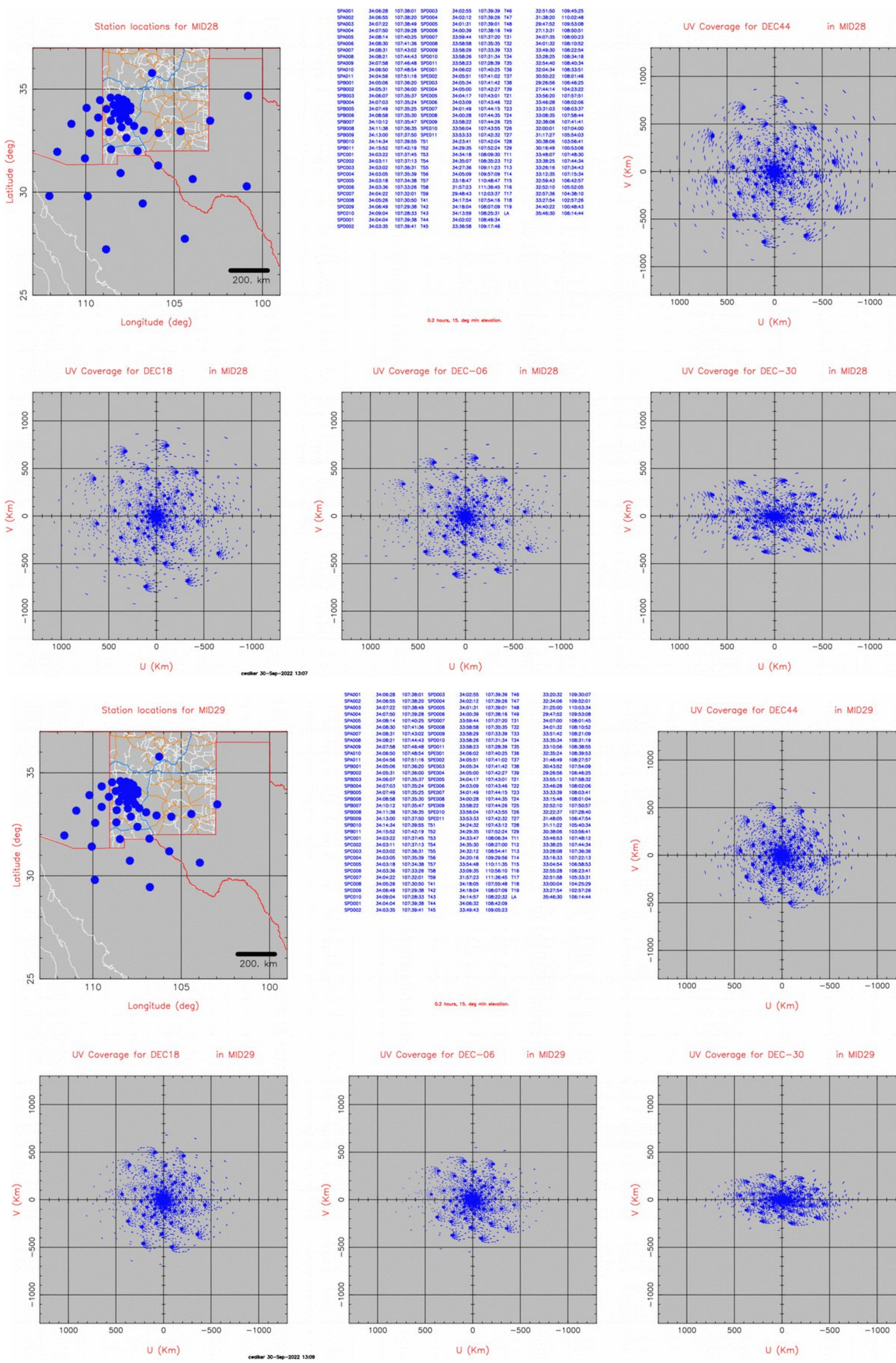

Figure 5: UV coverage on a scale of 1300 km for MID28 (top) and MID29 (bottom).

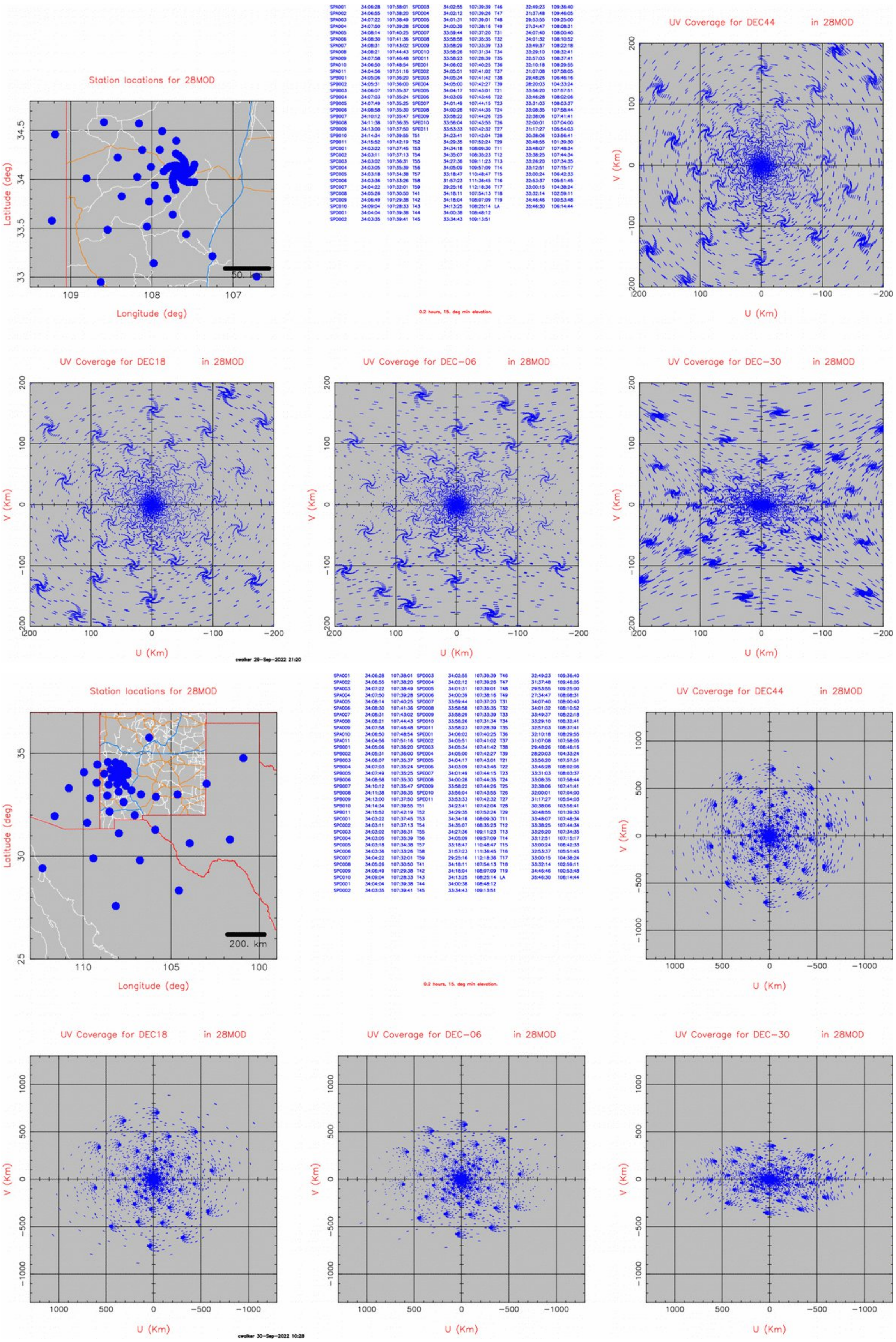

Figure 6: UV coverage for 28MOD on scales of 200 km (top) and 1300 km (bottom).

Appendix A: The Station Locations

Below is a listing of a .cfg file containing the xyz coordinates of the 28MOD configuration. This is a theoretical configuration that has not been adjusted for geographic realities. So most stations will need to be moved.

```
# File Name:    SpMID_CW_28_MOD.cfg
# VLBA_KP on Arm 5, Station      8
# VLBA_FD on Arm 2, Station      8
# VLBA_PT on Arm 4, Station      2
# Exponential spacing.
# Extracted from file     ~/NGVLA/Configuration/SpMID_CW/SpMID_CW_ModConfigs.ods
# This is meant to match a hand edited (in SCHED) version of SpMID_CW_28

-1602460.02  -5020855.85  3583855.82  18.0  T51
-1615651.69  -5010140.78  3592856.54  18.0  T52
-1639027.14  -4997342.91  3600036.41  18.0  T53
-1676322.85  -4984058.67  3601268.98  18.0  T54
-1731026.21  -4973669.31  3589808.68  18.0  T55
-1805043.54  -4972157.37  3555506.72  18.0  T56
-1896413.61  -4988944.48  3484178.23  18.0  T57
-1995672.85  -5037298.57  3357314.47  18.0  T58
-2111301.47  -5145351.93  3115568.85  18.0  T59
-1621963.89  -5020633.53  3575439.83  18.0  T41
-1640954.08  -5014816.18  3575411.85  18.0  T42
-1668828.82  -5010701.76  3568318.03  18.0  T43
-1706473.52  -5011784.19  3548595.17  18.0  T44
-1752612.13  -5024087.94  3508749.08  18.0  T45
-1801302.62  -5055578.42  3438620.89  18.0  T46
-1839018.41  -5117034.39  3326667.79  18.0  T47
-1840256.38  -5220848.49  3161665.46  18.0  T48
-1762141.71  -5377947.03  2936263.48  18.0  T49
-1634769.63  -5027973.15  3559365.35  18.0  T31
-1651737.61  -5029336.79  3550130.33  18.0  T32
-1672312.84  -5035500.19  3531835.92  18.0  T33
-1694127.66  -5050091.48  3500195.68  18.0  T34
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-1715122.68  -5126412.26  3377687.52  18.0  T36
-1686481.70  -5200357.88  3278265.45  18.0  T37
-1598773.82  -5305054.43  3152881.51  18.0  T38
-1412522.73  -5439658.51  3010138.75  18.0  T39
-1634275.69  -5040471.16  3541989.64  18.0  T21
-1643709.74  -5048324.96  3526985.61  18.0  T22
-1650823.27  -5062621.33  3503250.33  18.0  T23
-1650614.08  -5086455.59  3468401.06  18.0  T24
-1634674.32  -5123726.87  3421084.20  18.0  T25
-1589458.33  -5177320.78  3361581.24  18.0  T26
-1495087.81  -5248300.16  3294579.77  18.0  T27
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-1324003.31	-5332162.77	3231948.82	18.0	T28
-1108160.86	-5370716.76	3249105.80	18.0	T29
-1623246.03	-5052931.22	3529370.57	18.0	T11
-1620463.47	-5064498.07	3514617.95	18.0	T12
-1609479.23	-5080955.67	3495987.10	18.0	T13
-1584927.22	-5102782.65	3475006.39	18.0	T14
-1539877.14	-5129683.39	3455729.42	18.0	T15
-1465777.08	-5158435.71	3445203.17	18.0	T16
-1353689.19	-5182079.39	3455486.18	18.0	T17
-1196311.40	-5187358.78	3504913.28	18.0	T18
-991708.65	-5151501.43	3618968.09	18.0	T19
-1449752.33	-4975297.46	3709123.01	18.0	LA