NGVLA Memo 49

Snapshot UV Coverage of the ngVLA: An Alternate Configuration

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Introduction

The current (June 2018) reference configuration for the ngVLA has 94 antennas in a tight central core, 74 antennas in a 5 arm spiral on the Plains of San Agustin, and 46 antennas, including 4 VLBA stations, extending out to roughly 600 km from the core. The configuration gives good UV coverage for long track observations, which was the design specification. It had been concluded, from the science cases, that snapshot coverage was not of interest. As a result, the snapshot coverage of the outer portion of the array has weaknesses. My own belief, and that of others I have consulted, is that it is a mistake not to design in decent snapshot coverage. The experience with the VLA and other instruments is that such a capability will be used even if hampered by not being part of the design. And it is not difficult to design for good snapshot coverage with as many antennas are available for the ngVLA. In this document, I present, as a proof of concept, an alternate configuration for the 46 outer antennas that gives reasonable snapshot coverage. The antenna locations are all in places that look reasonable on Google Earth, but I have not done the detailed site investigations required for a final configuration. I am not suggesting changes to the inner core and the 5 arm spiral of the reference configuration since they already have good snapshot coverage.

Tools

For a quick study the ngVLA configuration, I used a tool with which I am very familiar - namely the configuration study options in the VLBI scheduling program SCHED (see the SCHED manual for details). I added those capabilities to SCHED while working on the New Mexico Array portion of the second phase of the EVLA project. Unfortunately, that phase was not funded. Those capabilities were based on my experience while establishing the configuration of the VLBA. With SCHED, I can plot the station locations on a rough map and move them around using the cursor. Then I can plot the UV coverage for multiple sources - in this case, fake sources at 4 widely spread declinations. For this ngVLA project, I added a capability to write a new SCHED station catalog file and a comma-separated-values (.csv) file using the locations after the drag and drop operations, something that was not too important when looking at 10 station arrays. The SCHED file can be used to save the modified configuration for future use in SCHED. The .csv file is used to add placemarks to Google Earth Pro at the locations of the stations.

Google Earth Pro allows one to see easily where stations are located relative to features on the ground. One can then move the placemarks within Google Earth Pro to locations that might make more sense, such as near roads. The resulting placemark positions can be written back out to a .kml file. I wrote a very simple program to extract the name, latitude, and longitude from the .kml file and write a SCHED station catalog file. With the .csv output from SCHED and the .kml output from Google Earth Pro, I could iterate between looking at reasonableness on the ground and resulting UV coverage.

Note that there are other tools, including GIS tools, in the ngVLA project that combine the functions of SCHED and Google Earth as used here. Someone not as immersed in SCHED as I or in need of more extensive information on anything from horizons to power and fiber lines to land ownership should probably use that other software. The .csv files can be used to transfer the station positions.

For a centrally condensed array, such as the ngVLA when using the inner spiral and/or core with the outer antennas, much of the sensitivity is concentrated in tight clusters of baselines between each outer antenna and the core region. Therefore, producing an array with good snapshot coverage is a matter of trying to obtain good coverage with only those clusters of core baselines and their conjugate pairs on the opposite side of the core. All the isolated baselines between outer antennas are of significantly less importance unless using a much less sensitive subarray of only the outer antennas.

The New Configuration

My proof-of-concept configuration is called CW_CG[1]. It continues the idea of a 5 arm spiral to the larger scales using the same number (46) of antennas as ngvla-revB, the reference configuration. Those arms are distributed east and west of the core, but all are to the south. In a typical spiral configuration, with an odd number, N, of arms evenly distributed around the core, the snapshot UV coverage has 2N arms of UV point clusters, N for the actual baselines from N arms to the core alternating with N for the conjugate points on the opposite side of the core. An odd number of arms is used to prevent the conjugate points from falling on top of an opposing arm's actual points. But there is no reason, other than losing some isolated long baselines in one direction, not to put all of the actual arms of antennas on one side with the conjugate arms filling on the other side. It turns out that, for infrastructure and geographic reasons, it is better not to try to go significantly north from the VLA site, so that is what I have done.

My experience doing the VLBA and EVLA2 configurations was that regular patterns, such as spirals, do not work when only dealing with 10 antennas. Even with only 3 arms, you only get 3 antennas per arm. But here we have 46 antennas and you can use 5 arms of 9 antennas per arm which is much more useful.

The new configuration has not received much optimization effort. I used a spreadsheet to calculate the approximate positions based on a power law increase in core distance and an even angle difference between adjacent antennas on an arm. These template arms were spaced to give an even spacing, around the full circle, of all 10 arms of core baselines and their conjugates (36 degrees between arms). The power laws and angles were tweaked to allow the VLBA stations, except VLBA_LA, to be antennas in the arms and to conform to some other constraints. The power law indices ended up ranging from 1.79 to 2.22 (the current VLA uses an index of 1.72) and the angle step between arm elements is 10°. I then used Google Earth Pro to try to find sites that looked logistically reasonable near the desired positions. In practice, I was able to place nearly all sites near paved roads with the main exceptions being near the VLA. I do not have the information at hand to determine if they are near fiber or power, although I know some about that because of the effort expended on the EVLA2 configuration (Frazer Owen and I visited many of the locations at the time of that project). This process was iterated with looking at the UV coverage. In a later section, I give comments on a few individual

1 A very similar array, CW_BG, appeared in a draft and online so might be encountered. The differences are only a few kilometers for 6 sites.

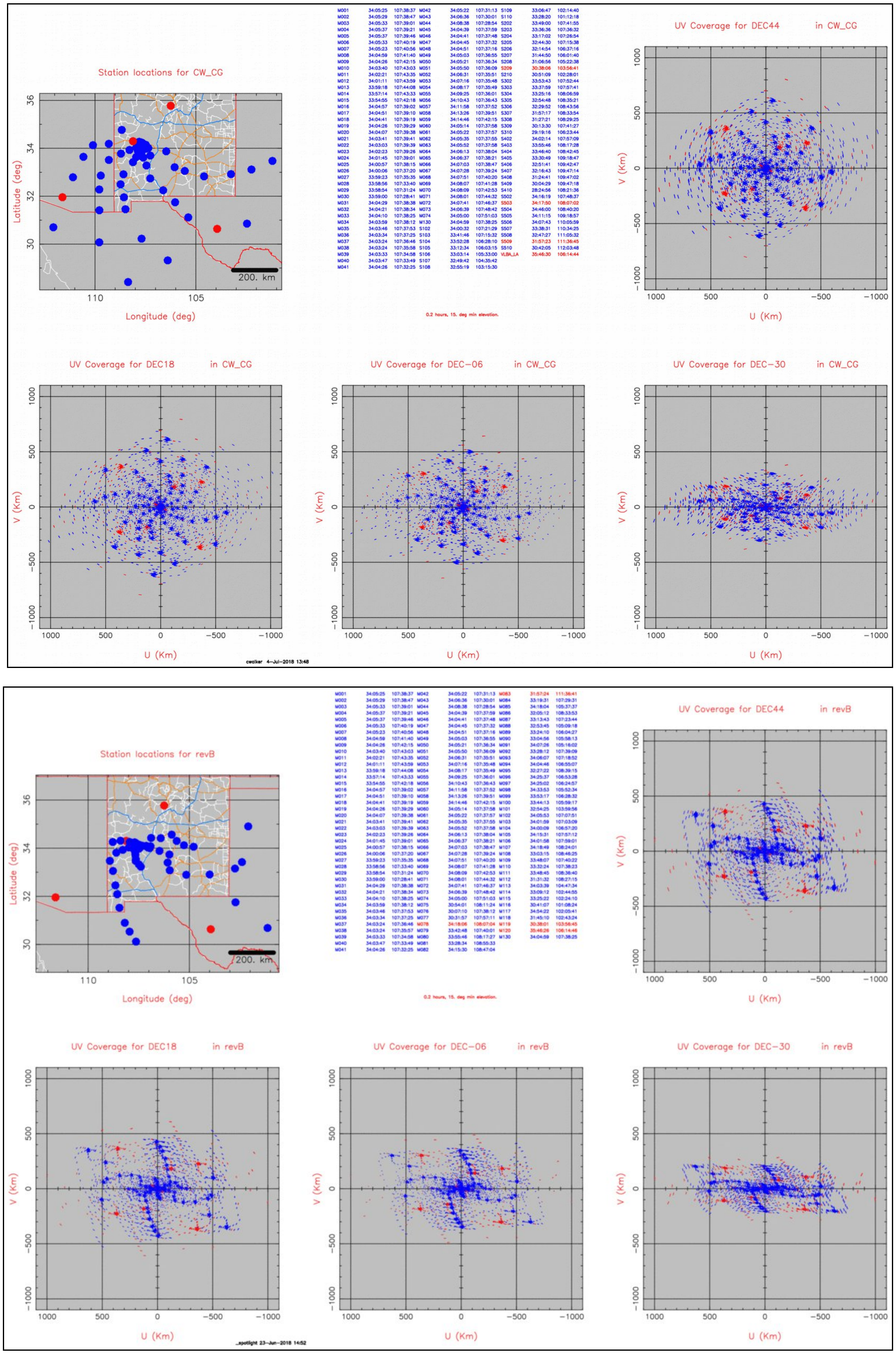

Figure 1: Comparison of snapshot coverage for the CW_CG configuration (top) and the ngvla-revB configuration (bottom) on scales to 1100 km. Both include the 74 antennas of the 5 arm spiral on the Plains of San Agustin that are part of ngvla-revB.

sites.

While I have avoided White Sands Missile Range, big wilderness areas such as the Gila, and Indian reservations, I have not tried hard to be on government land. This is partly a result of the VLBA experience. The easiest site acquisitions involved purchasing a small amount of land from a farmer. The sites on government land or land belonging to other institutions generally involved a lot more paperwork and overhead.

Figure 1 shows plots from SCHED that compare the full-resolution, snapshot coverage of CW_CG and ngvla-revB. More plots are in the Figures 2 to 7 at the end of this memo. The characteristics of each plot are shown in the table. The plots show six panels. The first is an outline map showing the stations with state boundaries plus major roads in New Mexico. Stations that are red will show red baselines in the UV plots. The red stations are the VLBA stations. Yellow stations (usually the San Agustin spiral here) are stations not included in the UV plot. They have been turned off interactively in SCHED. The second panel is a list of stations and latitude/longitude coordinates. The other four plots are the UV coverage for +44, +18, -6, and -30 degrees declination. All UV plots here include one antenna in the center of the central ngVLA core (M130 from ngvla-revB). The U axis in the plots has been reversed from normal so that the distribution of the core baseline clusters looks like the distribution of antennas looking at a map. This aids in relating UV coverage features to station locations whereas the normal convention helps relate UV coverage to features in images. The snapshot plots are for a single 12 minute scan, which is enough to extend the tracks slightly. This makes the "points" look slightly bigger at larger UV distances in the higher resolution plots. The long-track plots have been made assuming a minimum elevation of 15 degrees and a maximum time of 12 hours.

SCHED UV plots shown in this memo				
Figure	Array	Inner spiral?	Max baseline	Snapshot or long track
Figure 1, top	CW_CG	Yes	1100 km	Snapshot
Figure 1, bottom	ngvla-revB	Yes	1100 km	Snapshot
Figure 2, top	CW_CG	No	1100 km	Long
Figure 2, bottom	ngvla-revB	No	1100 km	Long
Figure 3, top	CW_CG	No	1100 km	Snapshot
Figure 3, bottom	ngvla-revB	No	1100 km	Snapshot
Figure 4, top	CW_CG	Yes	300 km	Snapshot
Figure 4, bottom	ngvla-revB	Yes	300 km	Snapshot
Figure 5, top	CW_CG	No	300 km	Snapshot
Figure 5, bottom	ngvla-revB	No	300 km	Snapshot
Figure 6, top	CW_CG	Yes	300 km	Long
Figure 6, bottom	ngvla-revB	Yes	300 km	Long
Figure 7, top	CW_CG	No	300 km	Long
Figure 7, bottom	ngvla-revB	No	300 km	Long
Not shown. Like Fig 2.	CW_CG	Yes	1100 km	Long
Not shown. Like Fig2.	ngvla-revB	Yes	1100 km	Long

Plots were made for both arrays for all combinations of long tracks and snapshots, just the outer antennas and outer antennas plus the Plains of San Agustin spiral, and for maximum scales of 1100 km and 300 km. For most of the 300 km plots, the map is somewhat zoomed in although not by the same amount for both arrays. Figures 1 above and 2 through 7 at the end of the memo show these plots in pairs for the CW_CG and ngvla-revB configurations with matching scale, observation duration, and presence of the San Augustin spiral. The table lists all the plots and indicates which figure they are in. High resolution versions of the plots can found on my web page at this link. Note that the full track, long-baseline plots with and without the San Agustin spiral with scales to 1100 km look almost identical so only the ones without the spiral are shown. For this scale and long tracks the coverage is sufficiently dense that most of the track lines overlap. It is apparent from these plots that the long-track UV coverage of both arrays is good with rather complete coverage.

However, the snapshot coverage for CW_CG is better, especially when the San Agustin Plains spiral is included. As noted earlier, when any significant number of antennas from the central region (core and San Agustin spiral) are included, they dominate the sensitivity. So a good distribution of those clusters of baselines and their conjugates is important. The ngvla-revB array has a very uneven distribution of such clusters which will hamper the snapshot imaging capability.

Comments about the array and about specific stations.

This section gives some generic comments about the configuration, and some specific details about individual antennas. For bookkeeping purposes, I have named the stations in CW_CG "S" followed by a number between 1 and 5 for the arm (east to west) followed by a number from 2 to 10 for the sequence along the arm. The antennas along the arms start with sequence 2 and go to 10. Sequence 1 of the power law sequence was always deep inside the San Agustin Plains spiral so was not used.

An impact of having all 5 arms on one side is that the long baselines between the tips of arms on opposite sides of the center are not there for one dimension, north-south in this case. For a centrally condensed array where the sensitivity is concentrated in the baselines to the core, I don't believe this is significant Note that, if one put all the arms on the east or west side of the core, you would get somewhat more N-S resolution at low declination from these isolated baselines at the cost of logistic problems.

One can cheat on the spiral for a few antennas to deal with problematic locations by putting them at the conjugate points. I have used this method to solve two tricky geographic problems. Arm 1 wants to have a station in the middle of White Sands Missile range, which is not thought to be a good idea. By placing an antenna north of Quemado (which is along Rt. 60 west of Pie Town), one gets similar UV coverage of the core baselines. In a matching move, I relocated the Quemado station of arm 5 to Rt 380 on the north side of White Sands to avoid a big gap in the line of antennas of arm 1. The other case was the result of the template spiral placing an antenna of arm 1 in the middle of the San Mateo mountains (near Mt. Withington), which is a bad idea. By moving it northeast and also moving the first antenna of arm 5 north from Rt. 60, I was able to retain about the same UV coverage for the baselines to the core from the innermost 5 antennas.

The array has 5 antennas in Mexico, 9 in Arizona, and 6 in Texas. Several more antennas could easily go to Mexico by moving ones close to the border to the other side.

The configuration, as it stands, has a bit more space than desirable at middle distances between arms 2 and 3. That makes for some open space in the coverage from core baselines to the north and south for low declinations. Moving those arms somewhat closer to each other would be useful. That might be done by moving some of the arm 2 stations across the border to Mexico. But that reduces the number in Texas, which might not be politically desirable.

There are 2 antennas in the backcountry south of the VLA. One is at the Beaverhead Forest Service camp along Rt. 59. Note that, unlike nearly all roads in the region, Rt. 59 is paved to Beaverhead. The other, somewhat further north, is on a dirt road.

There are some antennas in the southern Rio Grande Valley that may present issues finding good RFI environments. I've tried to be reasonable, but this will need to be explored much more carefully.

The 46 outer antennas, perhaps with one core antenna as in the plots, make a rather good stand-alone array that can be used as a subarray when the core and San Agustin spiral are in use for lower resolution work.

I have not tried to optimize sites for high frequency observations. However most sites are at 3000' or above (mostly significantly above). The main exception is the one in Mexico south of Kitt Peak. It is at around 1000', but in an area that looks very dry. The other Mexican stations are in the mountains and fairly high. The easternmost one in Texas is at around 2500' but sites near 3000' are about 6 km away.

Note that, if NRAO installs its own fibers, paths along the arms make a natural way to configure the system. The total fiber distance has not been calculated yet, but it is likely that it will be significantly longer than for ngvla-revB. Just eyeballing the maps, the fiber distance for ngvla-revB may be equivalent to about 3 of the 5 arms of CW_CG.

Conclusion

I have made a quick, proof-of-concept effort to make a configuration for the outer antennas of the ngVLA that has good snapshot coverage. The result of that effort is shown in this memo. The new configuration appears to have significantly better snapshot coverage than ngvla-revB on the outer spacings where they differ. But be aware that this configuration is very preliminary. The availability of land and infrastructure, the nature of the horizons and RFI, and winter access, have not been explored. Also the cost of any communications infrastructure we build may be higher than for the reference array.

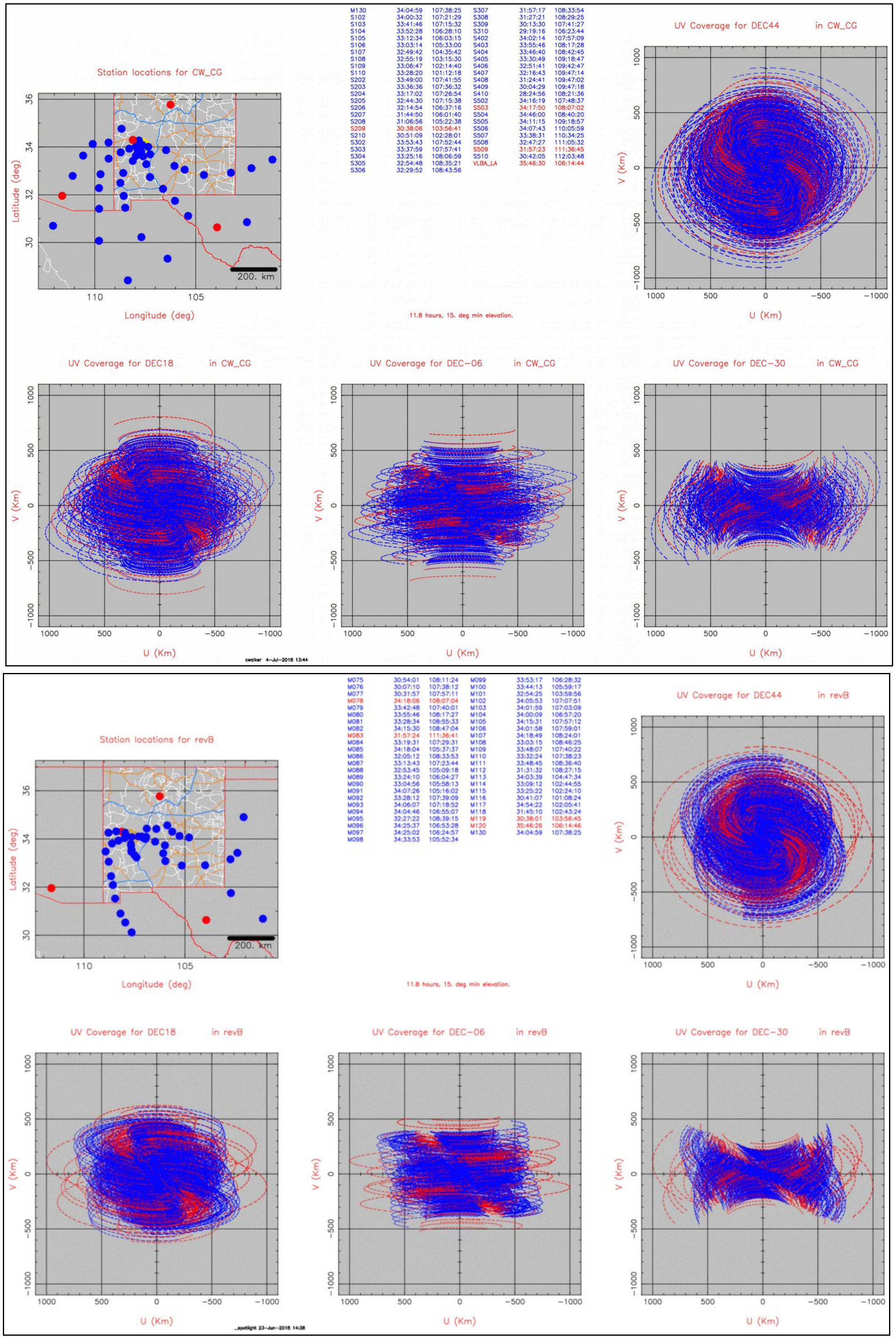

Figure 2: Comparison of full track coverage for the CW_CG configuration (top) and the ngvla-revB configuration (bottom) on scales to 1100 km. The antennas of the San Augustin spiral are not included. Including them does not visibly change these plots due to the dense coverage so plots with them on this scale are not included.

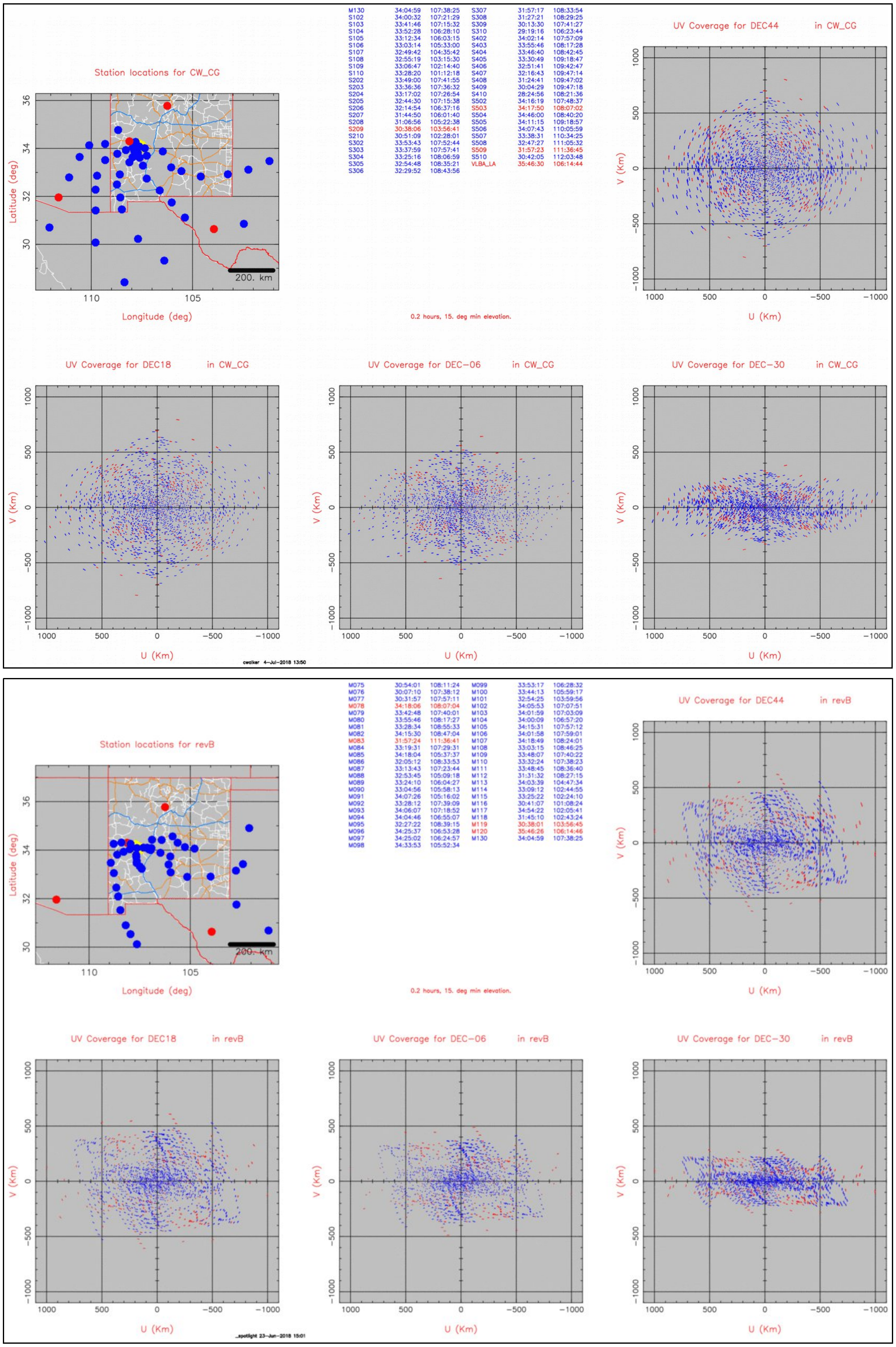

Figure 3: Comparison of snapshot coverage for the CW_CG configuration (top) and the ngvla-revB configuration (bottom) on scales to 1100 km. The antennas of the San Agustin spiral are not included. The effect of including the spiral is seen in Figure 1.

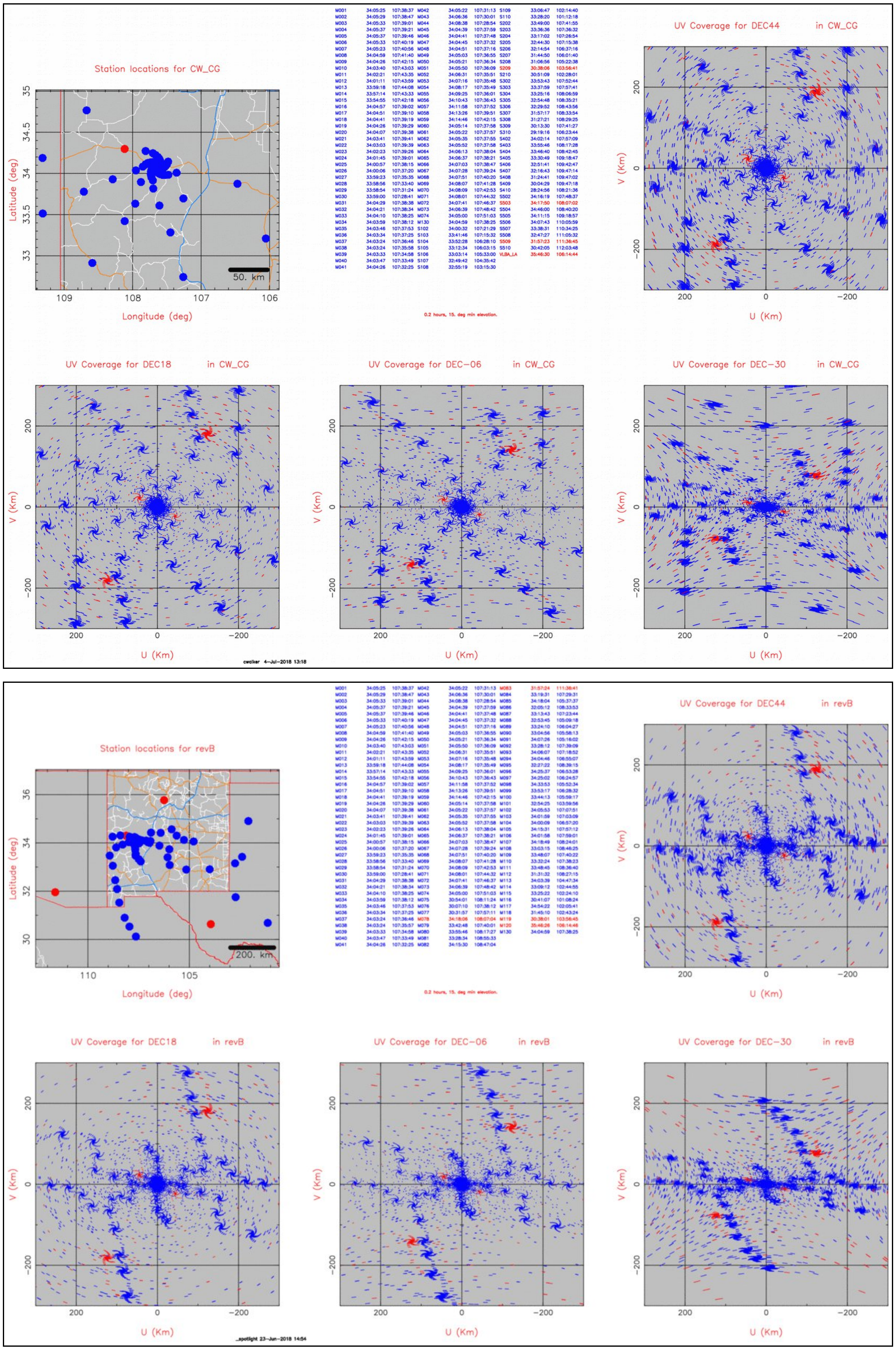

Figure 4: Comparison of snapshot coverage for the CW_CG configuration (top) and the ngvla-revB configuration (bottom) on scales to 300 km. The antennas of the San Agustin spiral are included, providing the dense clumps of baselines.

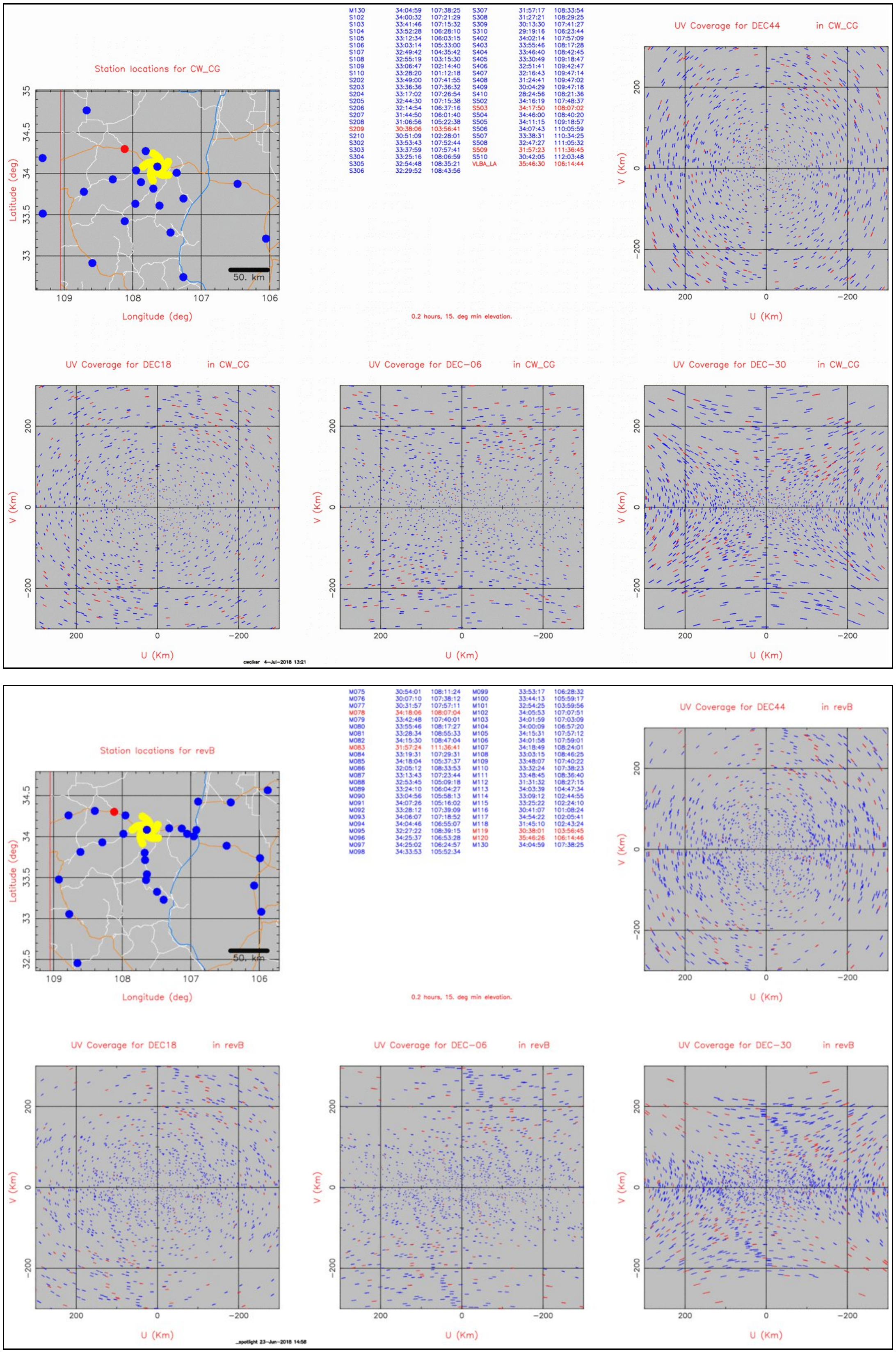

Figure 5: Comparison of snapshot coverage for the CW_CG configuration (top) and the ngvla-revB configuration (bottom) on scales to 300 km. The antennas of the San Agustin spiral are not included. The effect of including the spiral is seen in Figure 4.

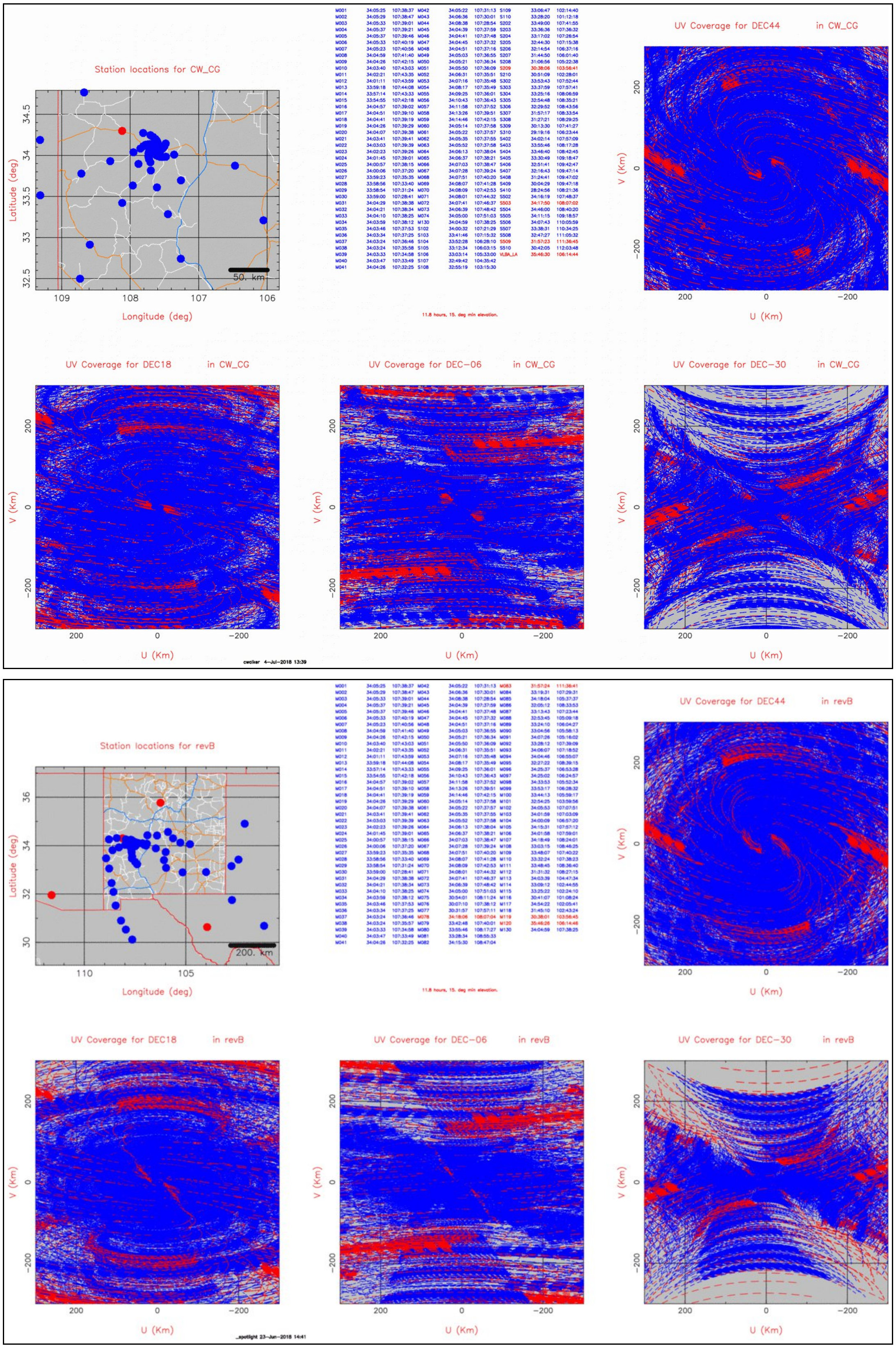

Figure 6: Comparison of long track coverage for the CW_CG configuration (top) and the ngvla-revB configuration (bottom) on scales to 300 km. The antennas of the San Agustin spiral are included.

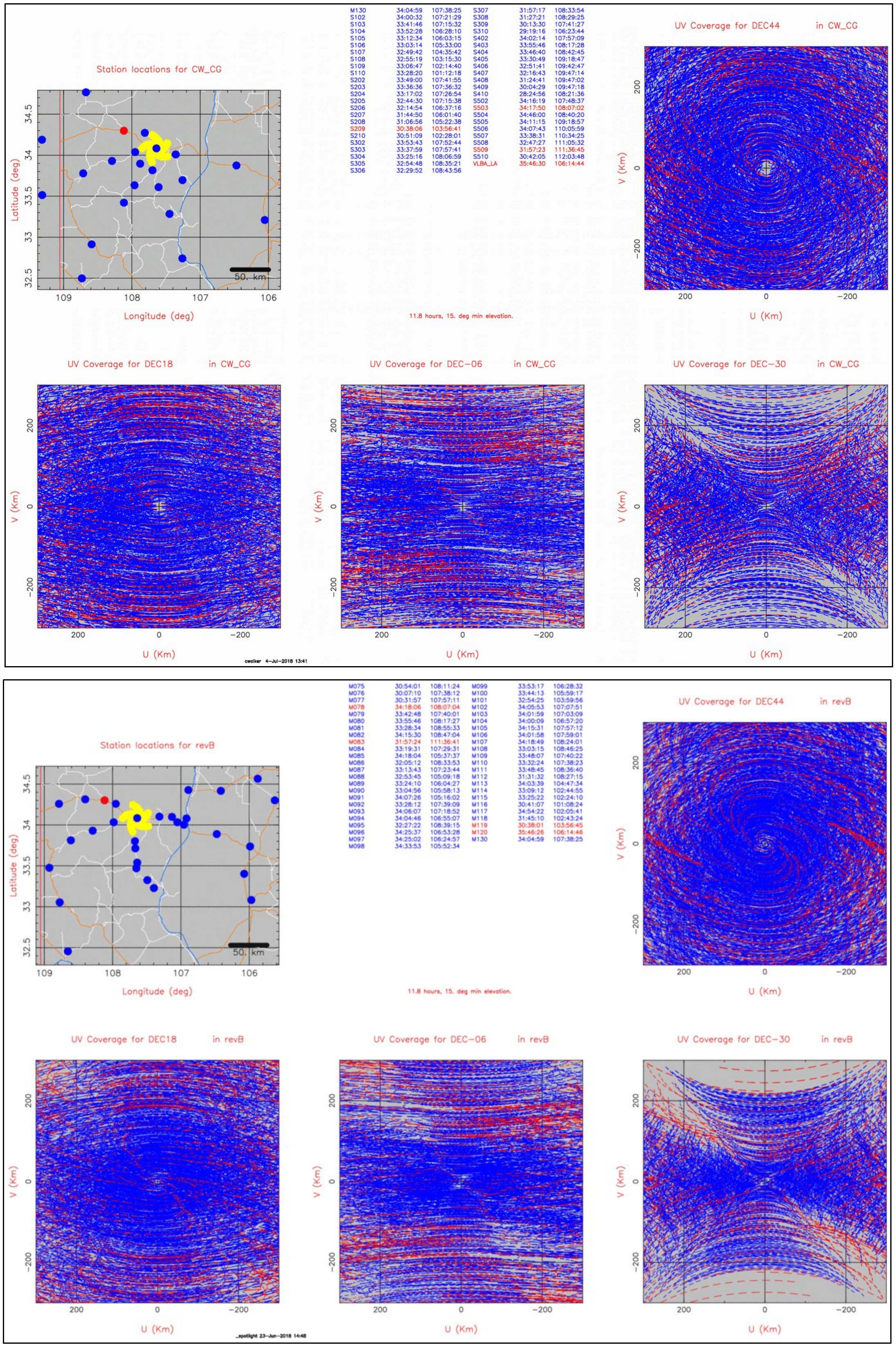

Figure 7: Comparison of long track coverage for the CW_CG configuration (top) and the ngvla-revB configuration (bottom) on scales to 300 km. The antennas of the San Agustin spiral are not included. Figure 6 shows the effect of including the spiral.