Tests of WVRs at OSF/AOS July/August 2009*

B. Nikolic and R. E. Hills

27th August 2009 (r260)

1 Summary of main findings

1. The WVRs generally performed well from a functional perspective. The main shortcomings that were identified was the lack of facility to monitor internal diagnostics of the WVR while observing and the lack of any capability to check the lock of the LO subsystem

2. No issues were found with operating the radiometers at the AOS

3. The atmospheric fluctuations measured by the two radiometers during side-by-side tests (i.e., when they looked through the same atmosphere) both at the AOS and OSF were generally very close to each other. The two possible concerns that we found are:

   (a) The difference between the fluctuations observed by the radiometers do not have the characteristic of random Gaussian noise (e.g., Figure 17). This could be due slight misalignment of the units in our tests, or due to other more significant issues

   (b) In one of the tests at the AOS, the relationship between fluctuations observed in channel 4 did not have the expected slope of close to unity. This may be due to the dry conditions at the time producing a low temperature in this channel (around 30 K)

4. The absolute calibration measurements we were able to do did not suggest problems with the calibration of the WVRs

5. The two short atmospheric experiments done at the AOS suggest the majority of the turbulence was at a height of 400 m and moved as a frozen screen at a speed of 15 m s$^{-1}$

6. Solar scans did not have a good detection of the spillover past the sub-reflector and so did not to allow measurement of the alignment of the WVR beam

7. Preliminary analysis of sky dips indicate forward efficiency of 97% for DV02 and WVR-SN102 and 98% for DV01 and WVR-SN104 with indications that the discrepancy is statistically significant

Contents

1 Summary of main findings 1

2 Introduction & Overview 4

3 Notes 5

*Please do not republish or reproduce parts of this report without permission
4 Individual WVR tests
4.1 OSF tests .......................................................... 5
4.2 AOS tests ........................................................... 12
   4.2.1 Allan variance ................................................. 12
   4.2.2 Absolute calibration check ................................. 12
   4.2.3 Water vapour retrievals ............................... 17

5 Two WVR tests ....................................................... 18
5.1 OSF, looking at same sky .................................... 18
5.2 AOS, looking at the same sky ................................. 20
5.3 AOS, tilted radiometers ....................................... 24
5.4 AOS, separated radiometers ................................ 27

6 Single WVR+Antenna tests ..................................... 30
6.1 Sky dips ............................................................... 30
6.2 Solar scans .......................................................... 33

7 Two WVR+Antennas tests ....................................... 37
7.1 Simultaneous sky-dips ........................................ 37
7.2 Crossed beams ..................................................... 41

List of Figures

1 View of the two WVRs just outside the OSF interim AIV lab. One of the back-end electronics fans used to keep the units cool can be seen above the left-hand WVR in the picture. The WVRs were placed in cardboard boxes lined with foam (but with holes cut on the sides for the central structure cooling fan) to thermally insulate them from the ambient air. .......................................................... 6
2 Tests of radiometer SN102 in the lab at OSF on 30th July. The top panel shows the four channel temperatures as a function of time for the duration of the test. Lower-left is the plot of Allen variance for each of the channels and lower-right is the plot of the spectral distribution of power for each of the channels. ........................................ 7
3 Tests of radiometer SN104 in the lab at OSF on 30th July. The panels are arranged as in Figure 2. ........................................................... 8
4 Comparison of water vapour retrievals for data from the two radiometers when they were side by side on 30th July, i.e., corresponding to data shown in Figures 2 and 3. ............... 9
5 Absolute calibration load tests with the radiometers outside the provisional AIV lab at the OSF on 30th July. The ambient load was an Eccosorb cone. The cold load was a styrofoam box, filled with LN2 and with an absorber inside it. The loads were alternatively placed on the two WVRs. ........................................ 10
6 Section of data from one of the WVR units while observing the ambient external load at the OSF. Drift on about one minute timescales can be seen, but that is likely to be due to change in temperature of the external cone. ............................ 11
7 Section of data from one of the WVR units while observing the cold liquid nitrogen external load at the OSF. ........................................ 11
8 Allan variances computed from test observations at the AOS. ....................... 12
9 Absolute calibration checks with an Eccosorb cone at the AOS on 31st July. The cone was placed alternatively at the two units and then left on each of the units for a longer period of time. ........................................ 13
10 Data from the previous plot (Figure 9), but only showing sections with the hot load on each of the WVRs. 

11 Absolute calibration checks at AOS on 1st August when the two radiometers were separated by about 45 metres. (There might have been additional cooling of the cone while it was out in the wind being during the move between the two units).

12 Data from the previous plot (Figure 11), but only showing sections with the hot load on each of the WVRs.

13 Retrieved water vapour during a stretch of observations at the AOS on 31st July.

14 Retrieved water vapour during the first side-by-side observations on 1st August at the AOS.

15 The longest of the side-by-side test obtained at the OSF lab with SN 102 and SN 104 radiometers. Weather was getting wetter and probably warmer (it was about the time of the daily coordination meeting).

16 Correlation between outputs of the two radiometers in side-by-side tests on 30th July. Channels 1 and 2 are shown in the top row and channels 3 and 4 are in the bottom row. The data correspond to figure 15. The slope of channel 1 correlation is 1.049 while the other channels have slopes closer to unity at 0.998, 0.996 and 0.996.

17 Residual of the side-by-side tests in Figure 16, computed by subtracting the signals from the radiometers after multiplying with the best-fitting linear relationship between them. The RMS fluctuation in each of the channels are 0.11, 0.17, 0.28, 0.30 K.

18 Side-by-side test at the AOS, on 31st July 2009.

19 Correlations between the radiometer signals for the test in Figure 18. The slopes were 0.969, 1.001, 0.996, 0.995 for channels 1 through 4 respectively. Note that the reversal of connections to the ABM at the AOS caused the WVRs to be renamed, and for these tests, and the tests the day after, “WVR” was SN104 and “WVR2” was SN102. This is presumably the reason for the change in slope of channel 1 correlation from above unity to below unity.

20 Residual difference between the signal from the two radiometers for data shown in Figure 19, taking into account the constant offset and linear scale difference. The RMS of the residuals are 0.24, 0.29, 0.2, 0.2 K.

21 Side-by-side test at the AOS, on 1st August 2009.

22 Correlations on 1st August. The slopes were 0.986, 1.000, 0.984, 1.068 for channels 1 through 4 respectively. The units were named: “WVR” for SN104 and “WVR2” for SN102.

23 Setup of the radiometers during tilted observations test. The direction along which the units were tilted was east to west. They units were positioned outside the side door of the AOS building which is located to the east of the main observing area.

24 Channel-by-channel data taken during the tilted observation tests on 1st August at the AOS (i.e., in configuration shown in Figure 23).

25 Cross correlation of data from the tilted observation tests (Figure 24). The four colours represent the four channels of the radiometers. High values of time offset in fact represent negative time offset (due to the usual FFT effect of negative frequencies appearing in the second half of the output). The maximum cross correlation occurs at 10 second offset.

26 Setup of the separated radiometers tests on 1st August at the AOS. The units were separated by about 45 meters in the east-west direction. They were pointed toward zenith.

27 Channel-by-channel data taken during the separated radiometer tests on 1st August at the AOS (i.e., in configuration shown in Figure 26).

28 Cross correlation of the data during separated radiometers tests (Figure 27). The maximum cross correlation occurs at 3 seconds. (Note: timestamps in this analysis are standard CORBA time stamps).
29 Overview of the data taken during evening of 2nd August on DV02.  

30 Difference of adjacent WVR timestamps for a long stretch of data obtained with WVR SN102 mounted on antenna DV02 during the night of 2nd August.  

31 Overview of a sky dip on 3rd August with DV02/WVR SN102. The sky dips were done at three different azimuths, avoiding the direction of the PM03 antenna which may have contaminated earlier dips.  

32 Preliminary analysis of the full sky dip observation shown in Figure 31. The left panel is the probability distribution of the coupling parameter from this observation. The free parameters in this case were the coupling coefficient, opacity, and the physical temperature of the water vapour, with the constraint that this last temperature is between 247 and 297 K (i.e., 272 ± 25 K). The right panel shows the observed temperature against air-mass and a representative model chosen at random from the Markov Chain near the peak of the distribution.  

33 Sky dips in four directions close to azimuth of 90 degrees, done to check the apparent offset at greater than 90 deg.  

34 Overview of Solar observations on 5th August with both DV01 (top) and DV02 (bottom). A number of scans were carried out, at 0, 45 and 90 degrees inclination to the horizontal.  

35 Horizontal solar scans on DV01 on 5th August. The horizontal axis is units of degrees with the zero azimuth position defined by the maximum observed temperature within the scan.  

36 Horizontal solar scans on DV02 on 5th August.  

37 Two of the scans from DV01 with atmospheric fluctuations suppressed by subtracting the signal from channel 1 scaled by 0.25.  

38 Simultaneous sky dips on 4th August with DV01/WVR-SN 104 and DV02/WVR-SN 102 at azimuth around 35 (to give DV01 reasonably clear line of sight).  

39 Motion of DV01 antenna during observations shown in Figure 38.  

40 Preliminary analysis of a simultaneous skydip observation on DV01 and DV02. There is a significant discrepancy between the measured coupling for the two antennas. The coupling retrieved for DV02 is however consistent with the coupling measured the previous day under different conditions (see Figure 32). See also the caption to Figure 32 for explanation of retrieval methodology.  

41 Crossed beam observations taken on 4th August. Movement of the ACD contaminated short section of the observations.  

42 Crossed beam observation at 70 degree elevation, which has the highest correlation between the two radiometers.  

2 Introduction & Overview  

The tests consisted of three main stages:  

1. First, at the OSF, side-by-side tests of the radiometers by themselves (i.e., no relay optics or mirrors) were done on 30th July  

2. Then the radiometers were moved to the AOS, where they were tested both in the side-by-side configuration and separated by about 45 m in the East-West direction. These tests were done on 31st July and 1st August  

3. Finally, the radiometers were returned to the OSF and mounted on the two Vertex antennas (DV02 and DV01). Testing of the complete system of WVRs with relay optics and antennas were then done from 2nd to 5th August
The main goals of the testing were:

- Identify any functional problems with WVRs or the interface to them while they are easily accessible in the lab
- Check the calibration of the units and that they measure the same fluctuations when looking through the same atmosphere
- Try experiments to determine the height of the turbulent layer of the atmosphere
- Measure the coupling to the ALMA antennas through sky-dips
- Measure the centering of the WVR beam on the sub-reflector through solar scans

3 Notes

- LO lock? Functionality to determine the lock of the LO does not at the present exist in the WVRs. ESO are aware of the issue
- Clearing of the clock bit without reboot: Need to issue the `wvr.SET_WVR_STATE([2,2])` command
- Most monitors do not update when in operational mode. Need to observe in the “configuration” mode to get to them. Modified the observing script to be able to do that? Tested the script at AOS
- WVR fans can only turn on at minimum 33% or more power – could be some implications on stability but didn’t see any.
- Cooling with extra fans was required at the OSF on warm day – used the back-end electronics rack fans
- Repeated values read into the text file – usually three values repeat. Tracked down to caching within the ICD-to-CORBA layer. Do not use the “.TEMP” method – use the raw methods
- To observe in configure mode must first go into operational mode
- Set bit 0 in SET_STATE command to reset the internal clock within the WVR so that timestamps are synchronised

4 Individual WVR tests

4.1 OSF tests

These tests were done as part of side-by-side tests at the OSF on 30th July. A photograph of the arrangement of these tests is shown in Figure 1. The extra fans were used because the ambient temperature was quite warm (around 20°C) and we thought that the radiometers may not cool down well without the extra heat sink normally provided by the FES structure. The location of the tests was just outside the back door of the interim AIV lab.

For these tests as well as the AOS tests the two WVRs were connected to the same ABM on different ports. They were named by the software “WVR” and “WVR2”. The ABM was named “LA01”.

Data from about an hour-long stretch of observation during the OSF tests are shown in Figures 2 and 3. Also plotted are the Allan variances and the power spectral distribution for these data sets.

The Allan variance plots show that the fluctuation on one second timescales are in the region consistent with the thermal noise of radiometers being less than 0.08 K, as expected from their measured performance when looking at external loads.
Figure 1: View of the two WVRs just outside the OSF interim AIV lab. One of the back-end electronics fans used to keep the units cool can be seen above the left-hand WVR in the picture. The WVRs were placed in cardboard boxes lined with foam (but with holes cut on the sides for the central structure cooling fan) to thermally insulate them from the ambient air.

Figures 4 and 5 show the retrieved water vapour columns as function of time for the two radiometers. The retrieval of water vapour was made using the approach of [Nikolic(2009)], i.e., the free parameters were the temperature, pressure and water-vapour column. The horizontal axes on these plots represent time, the vertical axes represent the water vapour column and the colour scale is probability assigned by the retrieval. A separate retrieval was in this case done at intervals of 10 seconds. The vertical spread of each column in the plot is the uncertainty in water vapour due to retrieval errors.

We also performed basic absolute calibration tests of the radiometers while they were outside the OSF lab. We used an Eccosorb cone for the ambient load and a box filled with liquid nitrogen for the cold load. The results of these are shown in Figure 5 which shows the overview of the whole observation, Figure 6 which shows the enlarged plot of a section when the ambient load was observed and 7 which shows an enlarged plot when the cold load was observed.

Slight drifts can be in both the cold and ambient load observations but given the relative crude nature of the loads that we used we can not determine if these were due to the loads (most likely) or the WVRs. It can also be seen that the four channels of the radiometers see similar absolute temperatures when observing the external load, with the spread always smaller than 2 K and hence consistent with absolute calibration requirements of the WVRs.
Figure 2: Tests of radiometer SN102 in the lab at OSF on 30th July. The top panel shows the four channel temperatures as a function of time for the duration of the test. Lower-left is the plot of Allen variance for each of the channels and lower-right is the plot of the spectral distribution of power for each of the channels.
Figure 3: Tests of radiometer SN104 in the lab at OSF on 30th July. The panels are arranged as in Figure 2.
Figure 4: Comparison of water vapour retrievals for data from the two radiometers when they were side by side on 30th July, i.e., corresponding to data shown in Figures 2 and 3.
Figure 5: Absolute calibration load tests with the radiometers outside the provisional AIV lab at the OSF on 30th July. The ambient load was an Eccosorb cone. The cold load was a styrofoam box, filled with LN2 and with an absorber inside it. The loads were alternatively placed on the two WVRs.
Drift on about one minute timescales can be seen, but that is likely to be due to change in temperature of the external cone.

Figure 7: Section of data from one of the WVR units while observing the cold liquid nitrogen external load at the OSF.
4.2 AOS tests

4.2.1 Allan variance

Allan variance plots for representative data collected on both days at the AOS are shown in Figure 8. On 1st August the one-second Allan variances are below 0.01 K^2, indicating that the raw sensitivity of the radiometers was consistent with the specification. On 31st August, the Allan variances are all higher than 0.01 K^2, presumably due to very unstable weather on this day (e.g., see Figure 13).

4.2.2 Absolute calibration check

At the AOS we were only able to check the absolute calibration with the ambient load (Eccosorb cone). The results are shown in Figures 9, 10, 11 and 12. The findings were the same as the OSF, namely that within the relatively crude accuracy of the experiments the WVR units performed within the absolute calibration specifications.
Figure 9: Absolute calibration checks with an Eccosorb cone at the AOS on 31st July. The cone was placed alternatively at the two units and then left on each of the units for a longer period of time.
Figure 10: Data from the previous plot (Figure 9), but only showing sections with the hot load on each of the WVRs.
Figure 11: Absolute calibration checks at AOS on 1st August when the two radiometers were separated by about 45 metres. (There might have been additional cooling of the cone while it was out in the wind being during the move between the two units).
Figure 12: Data from the previous plot (Figure 11), but only showing sections with the hot load on each of the WVRs.
4.2.3 Water vapour retrievals

We also used the data collected at the AOS to make a retrieval of the water vapour column. The results of this analysis are shown in Figure 13 (for a stretch of data on 31st July) and Figure 14 (for a stretch on 1st August). One notable feature of the data is that the weather on 31st July was very unstable, showing a change in water vapour column of 0.5 mm in only two to three minutes. The weather on 1st August was much more stable with peak-to-peak fluctuation over 20 minutes of about 0.1 mm.
Figure 15: The longest of the side-by-side test obtained at the OSF lab with SN 102 and SN 104 radiometers. Weather was getting wetter and probably warmer (it was about the time of the daily coordination meeting).

5 Two WVR tests

5.1 OSF, looking at same sky

The longest stretch of side-by-side data collected at the OSF is shown in Figures 15 (where the data from two radiometers are plotted as a function of time) and 16 (where the output of one of the radiometers is shown as a function of the output of the other radiometer at the same time). It can be seen from the plots that there is generally a close correlation between the data recorded by the two radiometers. The approximately 2 K offset between channel 1 data from the two radiometers can be explained by the frequency difference between filter centres of this channels in the two units.

Using the side-by-side data we computed the slope of the best-fitting line when the output of one of the radiometer is regarded as a function of the output of the other one. This slope is a check that the magnitudes of the fluctuations of the two radiometers are close to each other. The results of the fitting are given in the caption to Figure 16. The slope of channel 1 is significantly different from unity, but this can be attributed to the difference in the channel 1 centre frequencies between the two units. The other channels have a proportionality constant very close to unity.

Figure 17 shows the residual difference of fluctuation between the two radiometers, after taking into account the difference in offsets and linear scale of the WVRs found by fitting a straight line to the correlations shown in Figure 16. The RMS of the residual fluctuations is also given in the caption to Figure 17. It is notable that the residual between channel 1 fluctuations appear to have properties of thermal noise, while the remaining channels show structure related to the fluctuations of the atmosphere. Additionally the magnitude of residual fluctuations in channels 2, 3 and 4 is significantly higher than what would be expected form the intrinsic noise of the radiometers.
Figure 16: Correlation between outputs of the two radiometers in side-by-side tests on 30th July. Channels 1 and 2 are shown in the top row and channels 3 and 4 are in the bottom row. The data correspond to figure 15. The slope of channel 1 correlation is 1.049 while the other channels have slopes closer to unity at 0.998, 0.996 and 0.996.

Figure 17: Residual of the side-by-side tests in Figure 16, computed by subtracting the signals from the radiometers after multiplying with the best-fitting linear relationship between them. The RMS fluctuation in each of the channels are 0.11, 0.17, 0.28, 0.30 K.
5.2 AOS, looking at the same sky

We repeated the side-by-side tests at the AOS on 31st July and 1st August. The data were analysed in the same way as at the OSF. The results from 31st July are shown in Figures 18, 19 and 20; the results from 1st August are shown in Figures 21 and 22.

The results of these experiments are generally the same as found the OSF. The one exception is the channel 4 data from 1st of August (lower right panel of Figure 22). In this case the correlation between the two radiometers is not very good and the slope of the best fitting line is 1.06, i.e., significantly higher than unity.
Figure 19: Correlations between the radiometer signals for the test in Figure 18. The slopes were 0.969, 1.001, 0.996, 0.995 for channels 1 through 4 respectively. Note that the reversal of connections to the ABM at the AOS caused the WVRs to be renamed, and for these tests, and the tests the day after, “WVR” was SN104 and “WVR2” was SN102. This is presumably the reason for the change in slope of channel 1 correlation from above unity to below unity.
Figure 20: Residual difference between the signal from the two radiometers for data shown in Figure 19, taking into account the constant offset and linear scale difference. The RMS of the residuals are 0.24, 0.29, 0.2, 0.2 K.

Figure 21: Side-by-side test at the AOS, on 1st August 2009
Figure 22: Correlations on 1st August. The slopes were 0.986, 1.000, 0.984, 1.068 for channels 1 through 4 respectively. The units were named: “WVR” for SN104 and “WVR2” for SN 102.
5.3 AOS, tilted radiometers

After the side-by-side tests on 1st August we tilted the radiometers so that their beams diverge by approximately 20 degrees in the East-West direction. The setup of the experiment is shown in Figure 23.

The sky temperatures recorded by the two radiometers are shown in Figure 24. It can be seen that although there are clear correlations between the two signals there are also significant uncorrelated differences, indicating that a simple ‘thin-screen’ model is not accurate for the atmosphere at this time.

The cross-correlation of the signals from the two radiometers is shown in Figure 25, from which it can be seen that the highest correlation between the two radiometers occurs when the two signals are offset by 10 seconds of time. Assuming 15 m s\(^{-1}\) wind speed, this corresponds approximately to a height of 400 m.
Figure 24: Channel-by-channel data taken during the tilted observation tests on 1st August at the AOS (i.e., in configuration shown in Figure 23).
Figure 25: Cross correlation of data from the tilted observation tests (Figure 24). The four colours represent the four channels of the radiometers. High values of time offset in fact represent negative time offset (due to the usual FFT effect of negative frequencies appearing in the second half of the output). The maximum cross correlation occurs at 10 second offset.
5.4 AOS, separated radiometers

The last experiment at the AOS was to separate the radiometers by about 45 meters in the East-West direction and observe straight toward the zenith. The configuration of this experiment is shown in Figure 26. The data recorded by the units is shown in Figure 27. It can be seen that there is a very high correlation between the two signals. This suggests that the ‘frozen-screen’ approximation is reasonable in this case.

The cross-correlation of the signals from the two-radiometers is shown in Figure 28. The offset of maximum correlation occurs at 3 seconds, which indicates a wind speed of about 15 m s\(^{-1}\).
Figure 27: Channel-by-channel data taken during the separated radiometer tests on 1st August at the AOS (i.e., in configuration shown in Figure 26).
Figure 28: Cross correlation of the data during separated radiometers tests (Figure 27). The maximum cross correlation occurs at 3 seconds. (Note: timestamps in this analysis are standard CORBA time stamps).
Figure 29: Overview of the data taken during evening of 2nd August on DV02.

6 Single WVR+Antenna tests

6.1 Sky dips

The time during which only one of the antennas had a radiometer (WVR SN102 on DV02) was mostly spent performing sky dip observations. Two of the observations taken are shown in Figures 31 and 33.

The primary goal of the sky-dips was to measure the coupling between the WVR unit and the atmosphere. The sky dips consisted of multiple up-and-down scans, with the antenna rotating in azimuth between them. The scans included five second stare periods at each elevation step. If this were not the case, the relative accuracy of the time stamps on WVR and antenna position data would have to be very high.

The optimal way to analyse the sky dip is to include our knowledge of the atmospheric physics and use data from all four channels of the WVRs. However, as a preliminary analysis, we have made retrievals using single channels of the WVR only. In order to minimise the effect of the atmospheric lapse rate we used data from channel 4 only. The inference of the atmospheric coupling is shown in Figure 32.
Figure 30: Difference of adjacent WVR timestamps for a long stretch of data obtained with WVR SN102 mounted on antenna DV02 during the night of 2nd August.

Figure 31: Overview of a sky dip on 3rd August with DV02/WVR SN102. The sky dips were done at three different azimuths, avoiding the direction of the PM03 antenna which may have contaminated earlier dips.
Figure 32: Preliminary analysis of the full sky dip observation shown in Figure 31. The left panel is the probability distribution of the coupling parameter from this observation. The free parameters in this case were the coupling coefficient, opacity, and the physical temperature of the water vapour, with the constraint that this last temperature is between 247 and 297 K (i.e., 272 ± 25 K). The right panel shows the observed temperature against air-mass and a representative model chosen at random from the Markov Chain near the peak of the distribution.

Figure 33: Sky dips in four directions close to azimuth of 90 degrees, done to check the apparent offset at greater than 90 deg.
6.2 Solar scans

We made scans across the Sun on 5th August with both the radiometers mounted on antennas. Figure 34 shows plots of WVR sky measurements as function of time as an overview of the observations. A number of scans were made, most in the horizontal direction (which are the easiest to analyse since the atmospheric emission changes the least) but some also at in the vertical and 45 degree directions.

The horizontal scans are shown in Figure 35 for antenna DV01+WVR104 and in Figure 36 for DV02+WVR102. The temperatures recorded by channel 4 of the WVR are shown to minimise the effect of the atmospheric fluctuations. The inner side-lobes are clearly detected in these data, however, there is no clear detection of spillover past the sub-reflector that should appear at around 4 degrees from the centre of the scan. This mean it won’t be possible to easily measure the centering of the beam from these data.

It should be possible to further suppress the atmospheric fluctuations in these measurements by subtracting the signal from channel 1 or channel 2 scaled by an appropriate amount. Some plots of this type are shown in Figure 37.
Figure 34: Overview of Solar observations on 5th August with both DV01 (top) and DV02 (bottom). A number of scans were carried out, at 0, 45 and 90 degrees inclination to the horizontal.
Figure 35: Horizontal solar scans on DV01 on 5th August. The horizontal axis is units of degrees with the zero azimuth position defined by the maximum observed temperature within the scan.

Figure 36: Horizontal solar scans on DV02 on 5th August.
Figure 37: Two of the scans from DV01 with atmospheric fluctuations suppressed by subtracting the signal from channel 1 scaled by 0.25.
7 Two WVR+Antennas tests

7.1 Simultaneous sky-dips

The simultaneous sky dips were made and analysed in a way similar to the single-antenna sky dips described in Section 6.1. Both the antennas were pointed in same azimuth but they did not in this case rotate in azimuth between up-and-down scans. The reason was the relatively restricted view to the horizon from the DV01 antenna.

The motion of one of the antennas during these sky dips is illustrated in Figure 39 while the actual data collected are shown in Figure 38. Finally the retrieved coupling and models are shown in Figure 40. It can be seen from this figure that the retrieved coupling of the WVR to antenna DV01 (most likely value around 0.982) is significantly different from the coupling to antenna DV02 (most likely value around 0.970). Although both of the couplings are relatively high, it is not obvious what could cause such an discrepancy and it would be worth collecting more data of this type to check the discrepancy is reproducible.
Figure 38: Simultaneous sky dips on 4th August with DV01/WVR-SN 104 and DV02/WVR-SN 102 at azimuth around 35 (to give DV01 reasonably clear line of sight).
Figure 39: Motion of DV01 antenna during observations shown in Figure 38.
Figure 40: Preliminary analysis of a simultaneous skydip observation on DV01 and DV02. There is a significant discrepancy between the measured coupling for the two antennas. The coupling retrieved for DV02 is however consistent with the coupling measured the previous day under different conditions (see Figure 32). See also the caption to Figure 32 for explanation of retrieval methodology.
7.2 Crossed beams

The overview of the crossed beam observations is shown in Figure 41. The observations were made at 10 degree elevation intervals starting from 40 degrees and finishing at 80 degrees. At each elevation, the observation time was 90 seconds. As can be seen some of the sections were contaminated by movement of the ACD through the beam.

The section with highest correlation between the radiometers was at 70 degrees and the data from this section are shown in Figure 42. A definitive interpretation of these however is prevented by problems with the data and the fact only one scan was made. In particular it is recommended the following steps are taken when taking future data to mitigate these problems:

- The low elevation scans can be eliminated since they correspond to very low heights and furthermore the volume of the overlap of the beams is so low that it is unlikely correlations can be detected
- Obviously, the ACD should be parked for the duration of the observation – significant fraction of the current data are contaminated
- The steps should be done in terms of height above ground where the beams cross rather than elevation, e.g., 50 m intervals starting with 100 m above ground level
- The length of observation at each scan should be made somewhat longer than 90 s

References

Figure 41: Crossed beam observations taken on 4th August. Movement of the ACD contaminated short section of the observations.
Figure 42: Crossed beam observation at 70 degree elevation, which has the highest correlation between the two radiometers.