P4.9

OBSERVATIONS OF 1-MINUTE RAIN RATES USING A VIBRATING-WIRE WEIGHING-BUCKET RAIN GAUGE

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1. INTRODUCTION

Both precipitation amount and rate of precipitation are climatological variables useful for assessing climate change. One of the goals of the U.S. Climate Reference Network (USCRN) is to monitor precipitation across the U.S. from, potentially, 250 stations. The goal of this paper is to show that the Geonor vibrating-wire weighing-bucket all-weather precipitation gauge, the primary precipitation gauge employed by the USCRN, can be used to accurately estimate 1-minute liquid or frozen precipitation over a wide range of precipitation rates. Rain rates calculated from a Geonor 3-wire gauge are compared to rain rates measured by a collocated 2-dimensional video disdrometer (2dvd). The Geonor precipitation gauge was manufactured by the Norwegian Geotechnical Institute, Oslo, Norway, and the 2dvd by Joanneum Research, Graz, Austria.

2. FIELD SITE

The field site is located on the north campus of the University of Oklahoma in north Norman between the Oklahoma Mesonet Norman site and the National Severe Storms Laboratory. Fig. 1 is a photo of the field site looking NW with the pit in the foreground that houses the Geonor and the 2dvd. There is good exposure in all directions.

Fig. 1 Photo of the field site with the pit in center. The rain gauge and 2dvd are located in the pit.

The rim of the Geonor gauge orifice and rim of the rectangular opening of the 2dvd are about 1 cm above the surrounding raindrop splash-prevention fabric as shown in Fig. 2. The uncovered parts of the grillwork provide ventilation and means for raising the 8 grills to access the interior of the pit. Fig. 3 shows the inside of the pit with the 2dvd sensing unit (SU) in the middle foreground, its outdoor electronics unit (OEU) to the upper right of the SU, the associated junction box to the lower right and the Geonor gauge in the background and its enclosed data logger attached to the rear wall. The dimensions of the interior of the pit are 1.8 m x 3.7 m x 1.4 m deep (3 ft x 6 ft x 4.5 ft).

Fig. 2 Close-up view of the pit gauge showing the openings for the rain gauge (foreground) and 2dvd (background).

Bakkehoi et al. (1985) and Duchon et al. (2003) describe the operation of the Geonor gauge. In brief, inside the case in Fig. 3 is a bucket that contains a mixture of antifreeze, mineral oil, and

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Fig. 3 The inside of the pit showing the disdrometer (front) and Geonor gauge (back).

precipitation. The bucket is suspended from 3 vibrating-wire transducers that each transmit a resonant audio frequency in proportion to the total mass in the bucket. The frequency is converted to depth of accumulated precipitation through a quadratic formula. In the analysis in this paper, the measure of accumulated precipitation was the average accumulation of the 3 wires.

The 2-dimensional video disdrometer contains two orthogonal horizontal slits below the top of the rectangular rim. Light passes through each orthogonal slit from a transmitter to a receiver. As raindrops fall through the two narrow beams of light, the shadow of each drop is recorded at each receiver. This information is a used to construct a drop drop-size distribution from which the mass of water is calculated and used for comparison with the weight measurement from the Geonor gauge.

3. CASE STUDY: 30 August 2003

There are many events available for joint analysis of rain rates determined from the Geonor gauge and the 2dvd. The rain event on 30 August 2003 was chosen because of the wide range of rain rates and the 100 mm (almost 4 in) accumulation over a 19-hour period that contained an 8-hour period with no rain.

A series of 24 figures will be given that show the important features of the event and highlight the comparison of rain rates from the Geonor gauge and the 2dvd. The 1-minute rain rates from the disdrometer are a direct output from the computer program that calculates and integrates the drop-sized distribution. The rain rates from the rain gauge, on the other hand, are simply successive differences of 1-minute rainfall accumulations. Thus the estimates of rain rate from the two instruments are completely independent. Unfortunately, time is not synchronized between the rain gauge and the disdrometer but they are believed to be within one minute. The result is that one likely source of differences between coincident estimates of rain rates is the time disparity.

Fig. 4 shows the 1-minute accumulations for each wire and their average for 30 August 2003. As noted earlier, there are two rain periods, the first beginning about 0500 (all times are in UTC) and ending 1500, the second beginning about 2300 and ending about one-hour into the next day. The highest rain rates occur early in the first rain period. Fig. 5 again shows the average accumulation of the 3-wires and a comparison of 24-hour totals from the Geonor gauge and 3 tipping-bucket gauges located in a group about 80 m from the pit. The differences among the 4 gauges varied from 1.6 to 3.4 mm, the total from the Geonor always higher. In addition, the Geonor gauge total was 4.2 mm higher than the 2dvd total of 96.0 mm.

Fig. 6 is a summary of the rain rates from Geonor gauge and 2dvd for the entire day. The maximum rain rate was over 100 mm/h recorded by the Geonor. Because green is the dominant color, the appearance of red means the Geonor rain rate is higher that that of the disdrometer.

The remaining figures have a common time axis of 60 minutes in order to observe minute-to-minute changes in rain rate. The vertical axis is always rain rate in mm/h but the scale changes to accommodate the wide range in rain rates, including zero rain rate. Fig. 7 is a comparison of rain rates for the first hour. The correspondence between the two measurements is very good.

Fig. 8 captures the highest rain rates of the day. The most notable feature is the reduced rain rate of the 2dvd relative to the Geonor gauge during the middle 25-minute period. The explanation may be as follows. The design of the intake throat of the 2dvd is such that the orthogonal optical planes are located at a sufficient vertical distance from the rim that shadowing can occur. That is, with 2-m wind speeds greater than about 4 m/s, trajectories of smaller drops have zenith angles that carry them beyond the optically active rectangle in the middle of intake throat and, therefore, are not observed. Fig. 9 is the same as Fig. 8 with the addition of the 2-m wind speed measured 4 meters from the pit. Wind speeds above 4 m/s are associated with the reduced rain rate of the 2dvd. During this 25-minute period there is a difference of 4.7 mm, more than enough to account for the difference in the 24-hour totals from the Geonor and 2dvd. There is no other period during the day with sustained wind speed greater than 4 m/s.

Figs. 10 and 11 provide a continuous comparison between the Geonor gauge and the 2dvd, now with a rain rate scale one-half that of the previous 4 figures. Again, the correspondence between rain rates is very good. The scale of the rain rate in Figs. 12-17 is further reduced by a factor of 6 relative to Figs. 10 and 11. The good correspondence continues. In fact, the absolute differences are typically less than 1 mm/h. There appears to periods in which the Geonor rain rates are smoother than the 2dvd rain rates and times when the opposite is true.

The length of the vertical axis in the next 6 figures (Figs. 18-23) is 1 mm/h. The purpose is to show the magnitude of the noise in the Geonor when there is no precipitation. Thus in Fig. 18 the rain rate diminishes to zero. When no raindrops pass the optical window in the disdrometer, the output is zero. The Geonor gauge, however, always presents a signal (the frequency from each vibrating-wire). Usually, the 1-minute absolute values of noise are less than 0.05 mm/h. One can see in Figs. 19-22 that the noise can generally be of one algebraic sign, here negative. This is due to the negative temperature coefficient (Duchon 2004) coupled with the steady rise in temperature from 0960 to 1140 seen in Fig. 4.

The purpose of Fig. 20 is to show the effect of averaging the noise from three wires. The black curve in Fig. 20 is the same as the red curve in Fig. 19, except that it has been displaced downward to accommodate the noise curves of the individual wires. So that these curves are discernible, they have been offset from each other by 0.2 mm/h, as shown in Fig. 20. Now consider computing the variance of each of the 4 time series. It can be shown, theoretically, that if the noise series from each wire is white (serial correlation is zero), the variance of the averaged series (black curve) is 1/3 the average of the variances of the individual noise series. That is, using three wires and averaging their accumulations should reduce the noise variance by 2/3 or 67% relative to using one wire if the noise is white.

For the time period in Fig. 20, the reduction is 52%, less than expected for white noise, but nevertheless substantial. One can visually observe the reduction in noise by comparing the bottom curve to the others. Analyses of other time periods showed that the variance reduction ranged from 48% to 59%. Noise reduction is very important for rain rate calculations because differencing amplifies the errors.

Fig. 24 shows that there is a considerable disagreement of the rain rates for the brief shower that is shown The integrated total from the 2dvd is 0.22 mm (0.009 in) and from the Geonor 0.09 mm (0.004 in), less than one-half that from the disdrometer. There is no obvious explanation. Interestingly, almost the identical situation occurs later in Fig. 27 between 1387 and 1395. The Geonor collected 0.08 mm (0.003 in) and the 2dvd 0.22 mm (0.009 in). Again, the reason for difference, although small, is not evident.

Figs. 25 and 26 show the continuation of Geonor noise with zero output from the disdrometer. With the exception of the brief shower just noted, we see in Fig. 27, once more, good agreement between the two rain rates.

4. SUMMARY AND CONCLUSIONS

The analysis in this paper shows that very comparable 1-minute rain rates can be measured by two independent instruments: the 3-wire Geonor vibrating-wire weighing-bucket rain gauge and the 2-dimensional video disdrometer, a state-of-the-art research grade instrument capable of measuring drop-size distribution from which rain rate in computed.

Because rain rate is considered to be a sensitive measure for assessing climate change, the author recommends that the management of the U.S. Climate Reference Network consider recording and transmitting 1-minute precipitation rates to take full advantage of the capabilities of its primary precipitation gauge. In this way, the first step can be taken toward developing a nationwide climatology of precipitation rates.

5. ACKNOWLEDGEMENTS

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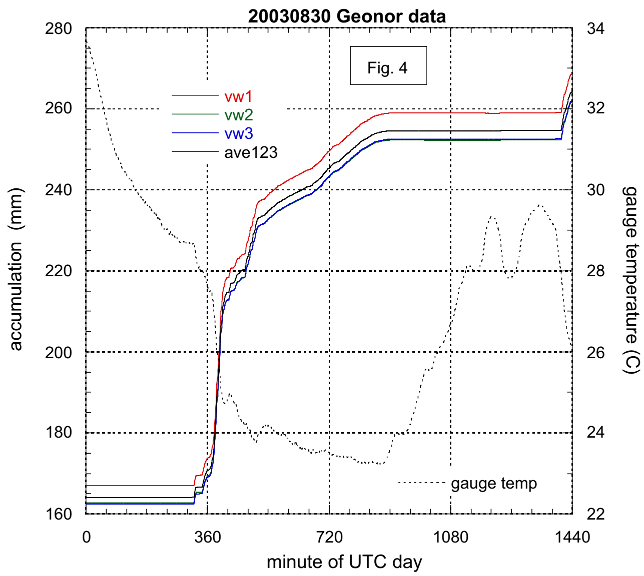
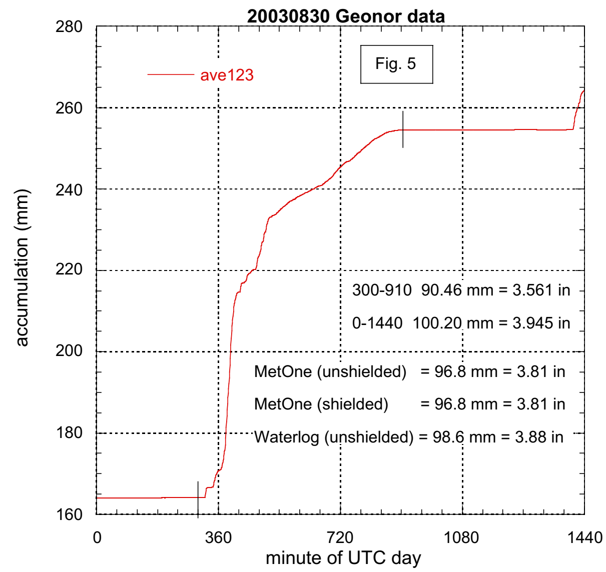
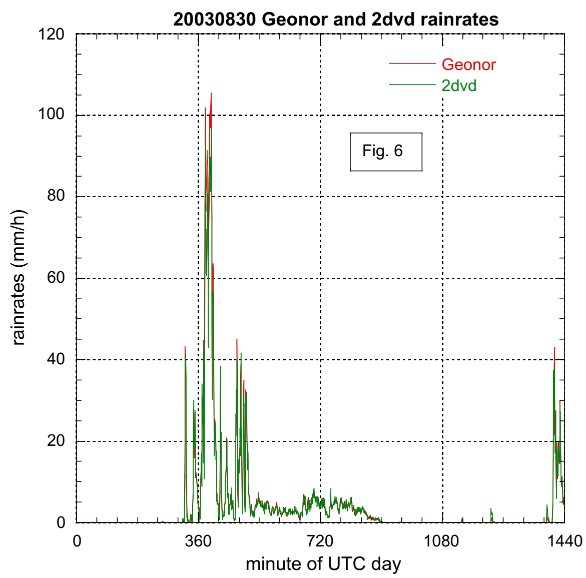

20030830 Geonor data
Fig. 4
vw1
vw2
vw3
ave123
gauge temp
accumulation (mm)
gauge temperature (C)
minute of UTC day
280
260
240
220
200
180
160
34
32
30
28
26
24
22
0
360
720
1080
1440


20030830 Geonor data
Fig. 5
ave123
300-910 90.46 mm = 3.561 in
0-1440 100.20 mm = 3.945 in
MetOne (unshielded) = 96.8 mm = 3.81 in
MetOne (shielded) = 96.8 mm = 3.81 in
Waterlog (unshielded) = 98.6 mm = 3.88 in
accumulation (mm)
minute of UTC day
280
260
240
220
200
180
160
0
360
720
1080
1440


20030830 Geonor and 2dvd rainrates
Fig. 6
Geonor
2dvd
rainrates (mm/h)
minute of UTC day
120
100
80
60
40
20
0
0
360
720
1080
1440

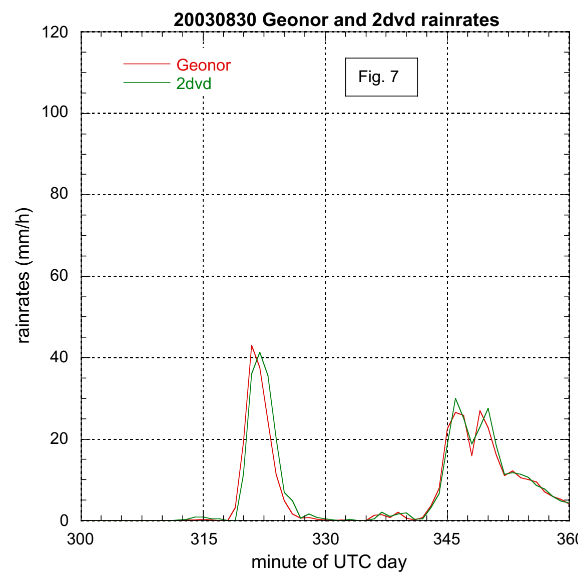

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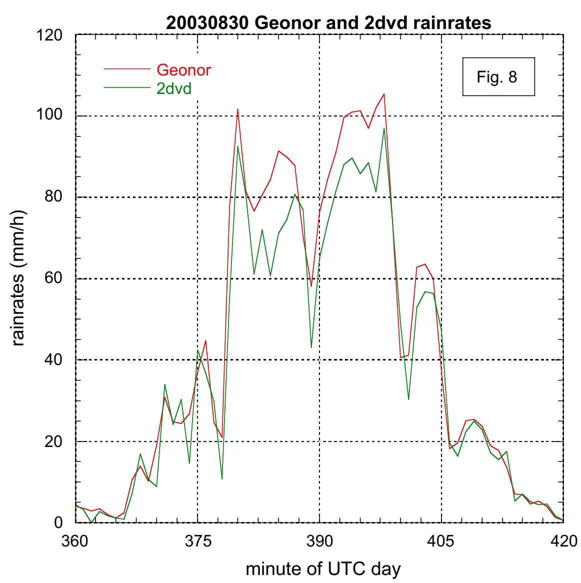
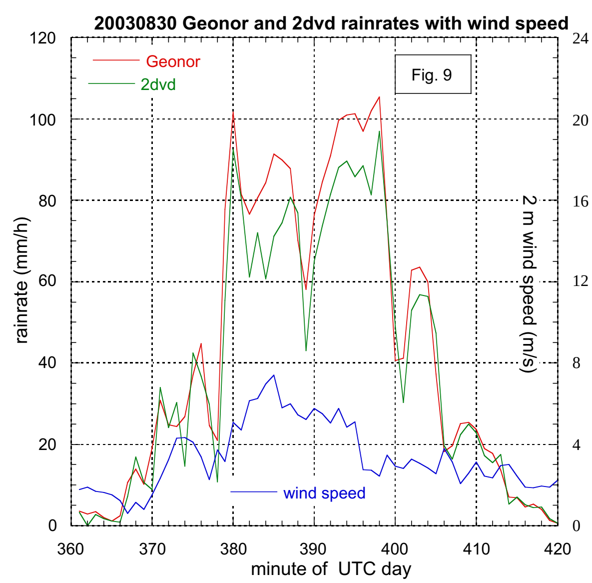
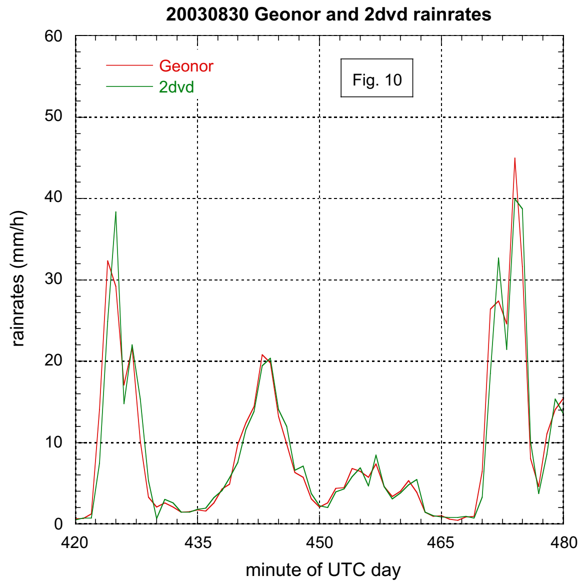
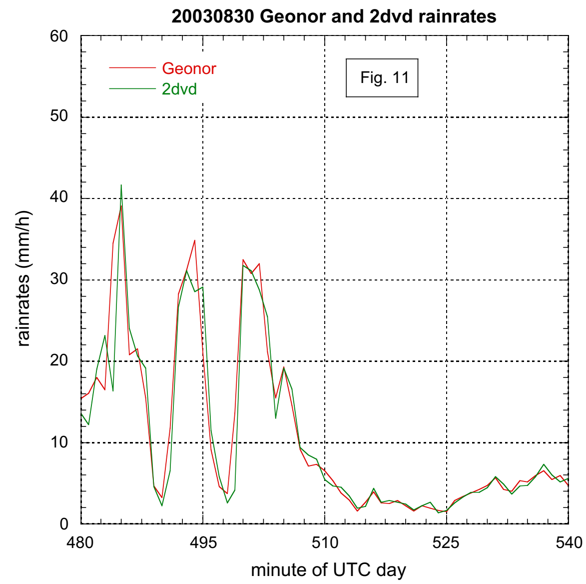
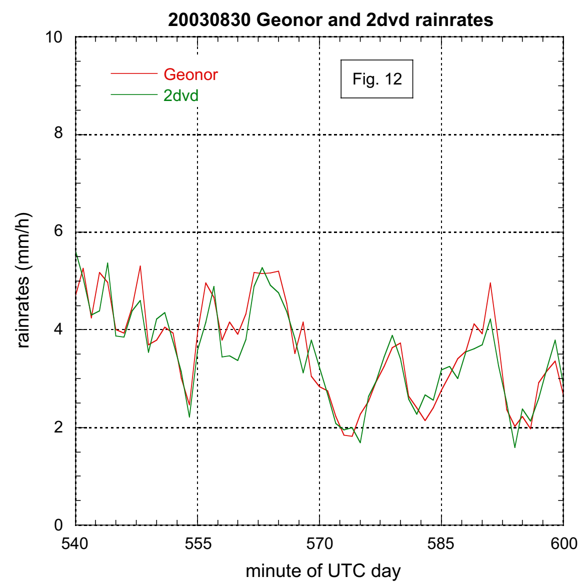
Fig. 7
Geonor
2dvd
rainrates (mm/h)
minute of UTC day
120
100
80
60
40
20
0
300
315
330
345
360

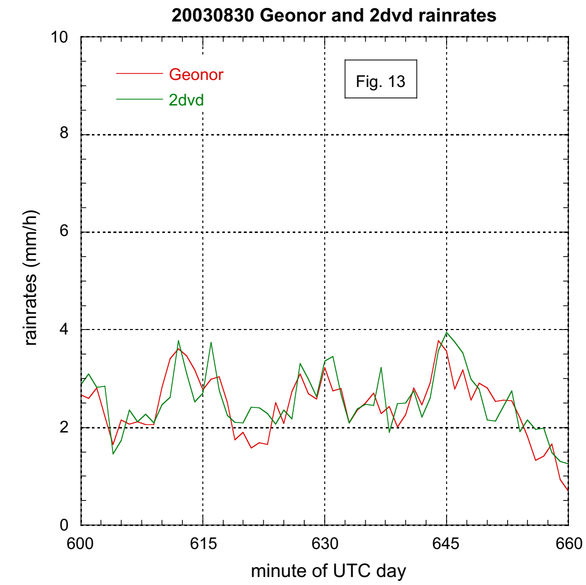

20030830 Geonor and 2dvd rainrates
Fig. 8
Geonor
2dvd
rainrates (mm/h)
minute of UTC day
120
100
80
60
40
20
0
360
375
390
405
420

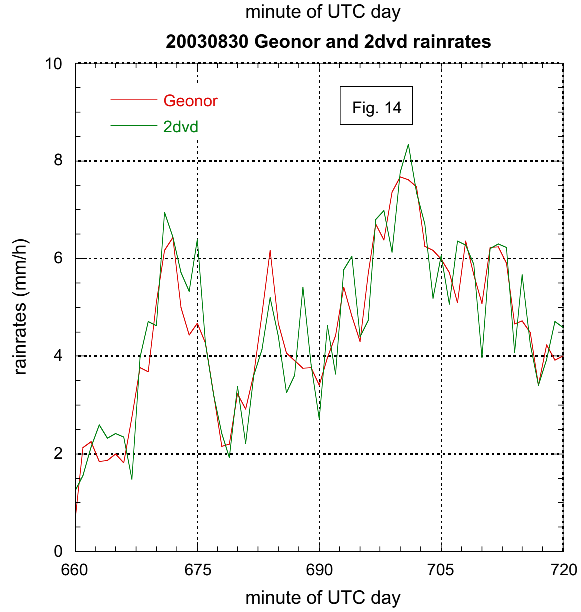

20030830 Geonor and 2dvd rainrates with wind speed
Fig. 9
Geonor
2dvd
wind speed
rainrate (mm/h)
2 m wind speed (m/s)
minute of UTC day
120
100
80
60
40
20
0
24
20
16
12
8
4
0
360
370
380
390
400
410
420

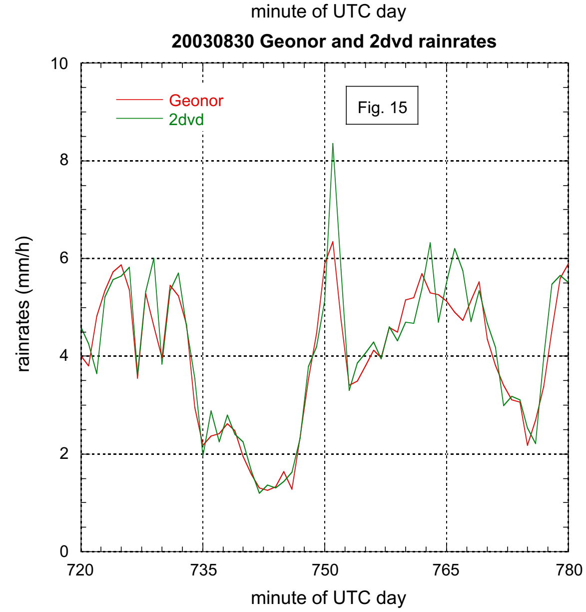

20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 10
rainrates (mm/h)
minute of UTC day
0
10
20
30
40
50
60
420
435
450
465
480


20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 11
rainrates (mm/h)
minute of UTC day
0
10
20
30
40
50
60
480
495
510
525
540

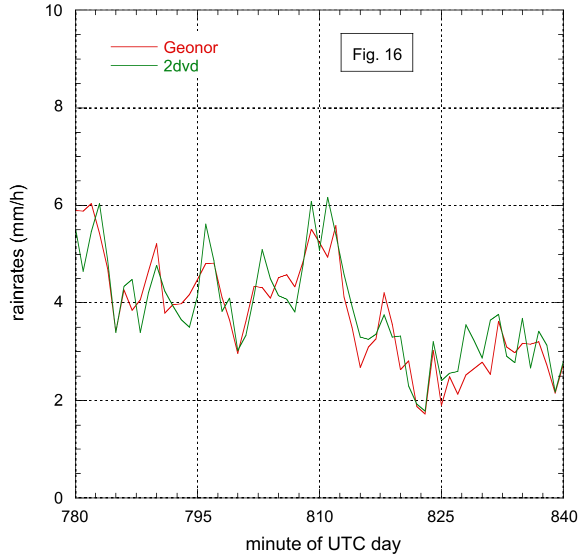

20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 12
rainrates (mm/h)
minute of UTC day
0
2
4
6
8
10
540
555
570
585
600


20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 13
rainrates (mm/h)
minute of UTC day
0
2
4
6
8
10
600
615
630
645
660

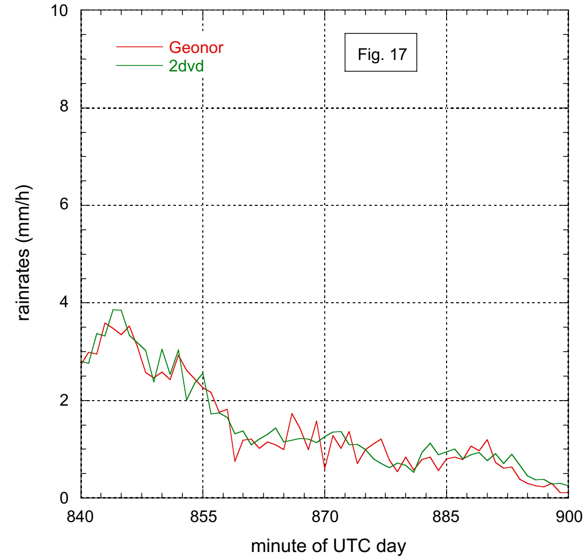

20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 14
rainrates (mm/h)
minute of UTC day
0
2
4
6
8
10
660
675
690
705
720


20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 15
rainrates (mm/h)
minute of UTC day
0
2
4
6
8
10
720
735
750
765
780

20030830 Geonor and 2dvd rainrates



20030830 Geonor and 2dvd rainrates



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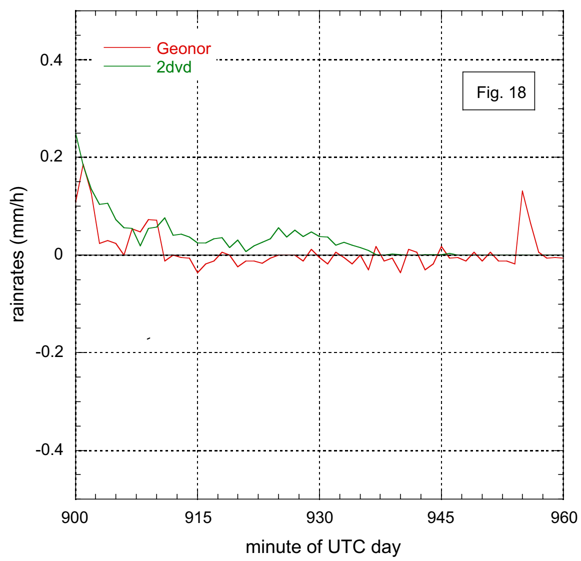
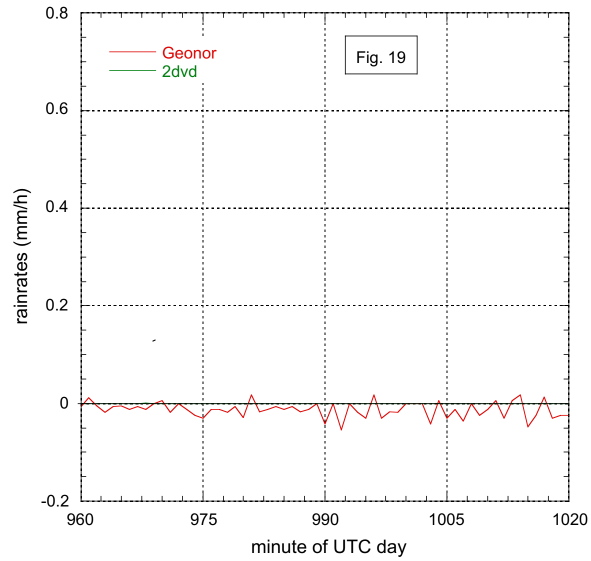


20030830 Geonor and 2dvd rainrates



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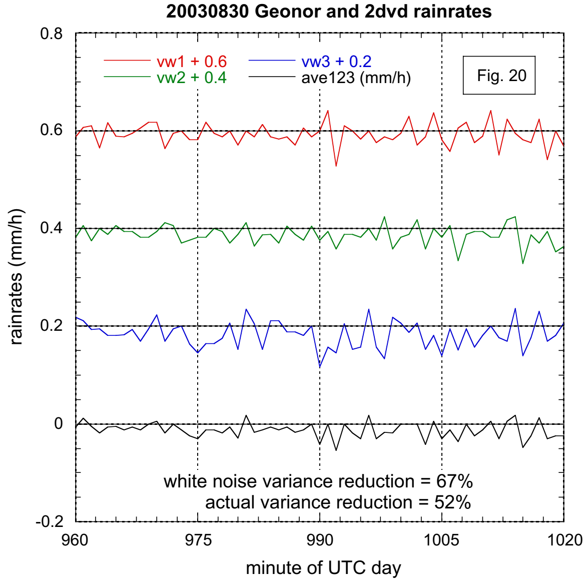

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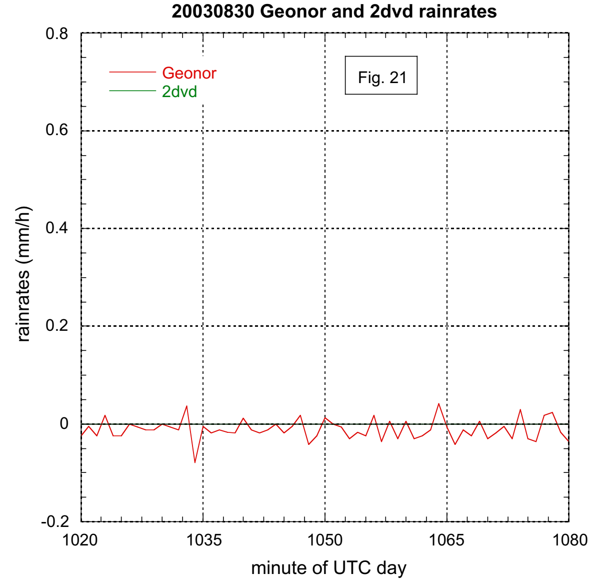
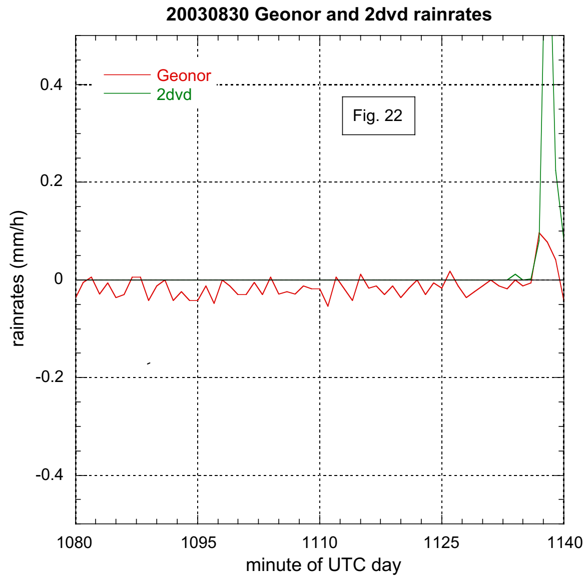
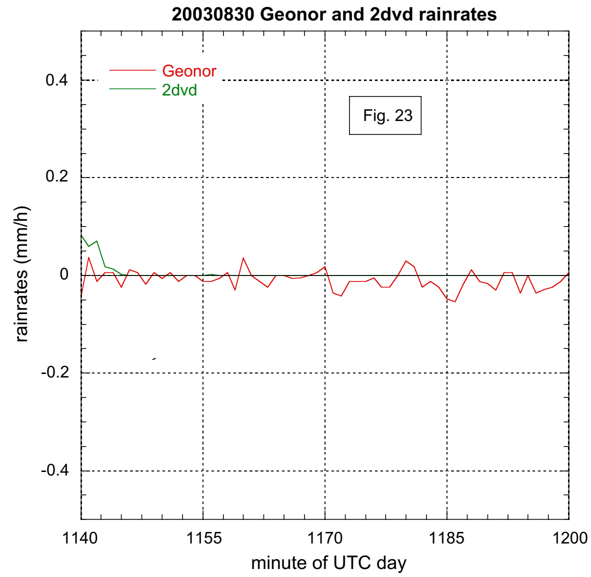
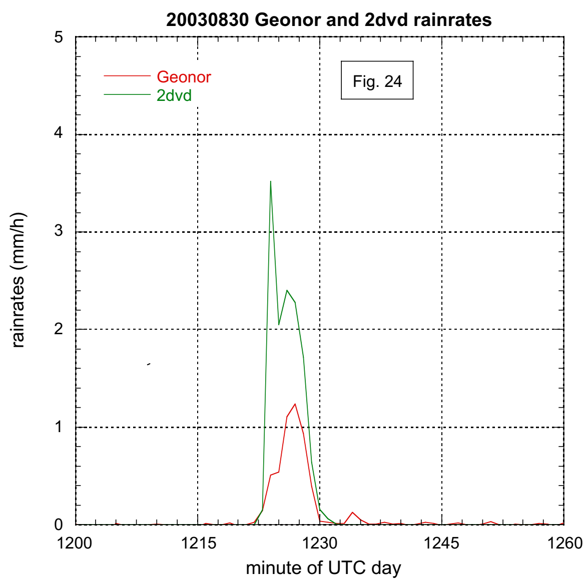



20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 22
rainrates (mm/h)
minute of UTC day
0.4
0.2
0
-0.2
-0.4
1080
1095
1110
1125
1140


20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 23
rainrates (mm/h)
minute of UTC day
0.4
0.2
0
-0.2
-0.4
1140
1155
1170
1185
1200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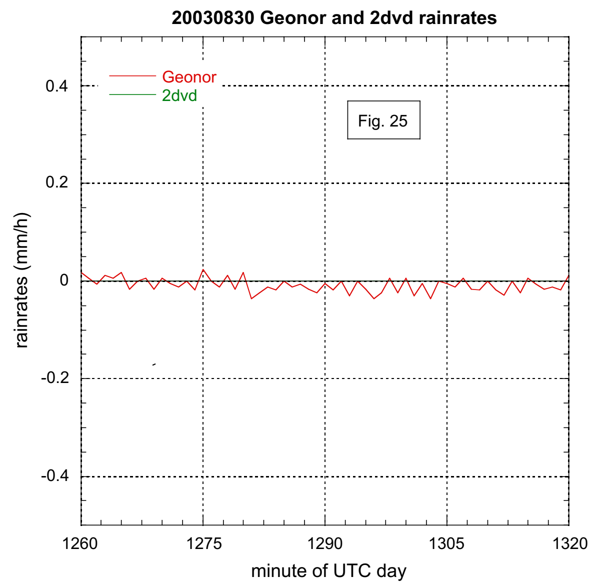
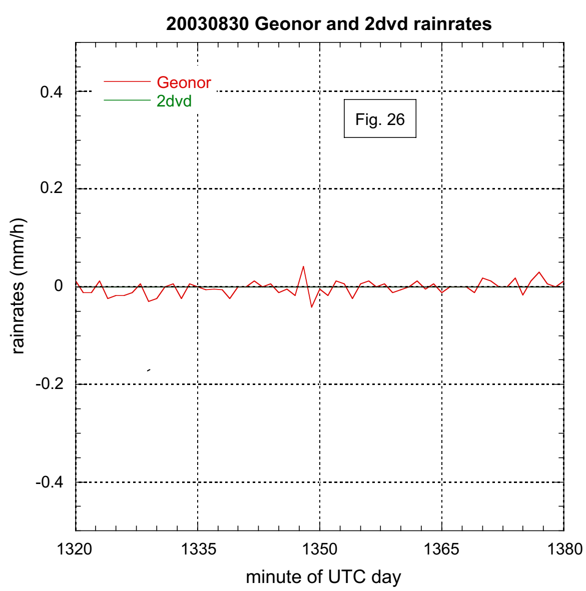
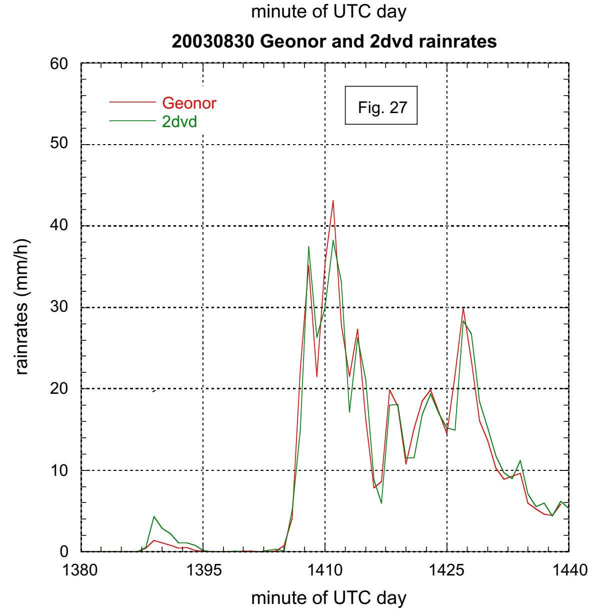
Geonor
2dvd
Fig. 24
rainrates (mm/h)
minute of UTC day
5
4
3
2
1
0
1200
1215
1230
1245
1260


20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 25
rainrates (mm/h)
minute of UTC day
0.4
0.2
0
-0.2
-0.4
1260
1275
1290
1305
1320


20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 26
rainrates (mm/h)
minute of UTC day
0.4
0.2
0
-0.2
-0.4
1320
1335
1350
1365
1380


20030830 Geonor and 2dvd rainrates
Geonor
2dvd
Fig. 27
rainrates (mm/h)
minute of UTC day
60
50
40
30
20
10
0
1380
1395
1410
1425
1440