P2.1 WEIGH GAUGE ALGORITHMS

Harry H. Lamb*, Yves Durocher*
Meteorological Service of Canada

1. INTRODUCTION

Weighing gauge algorithms in common use by meteorological services and others traditionally apply a fixed threshold to the difference between the most recent and previous measurements to determine whether precip has occurred. The threshold, intended to eliminate noise primarily caused by wind pumping, will vary from gauge to gauge and region to region.

Some algorithms allow the measured weight to decrease as well as increase where others permit increases only. Where decreases are permitted, evaporation becomes a factor unless prevented with a layer of oil. Where decreases are not permitted, the diode effect will allow any noise which exceeds the threshold to appear as increases in weight. Depending on the characteristics of an algorithm, light precip which does not exceed the threshold may be lost completely or may eventually be counted much later than the actual event.

Normally, the data logger program at Environment Canada autostations takes measurements every five seconds and calculates minutely averages. The weighing gauge output that is reported is 15 minute data. To do algorithm development, we require minutely data. In late November of 2002, Quebec Region provided Surface Weather and Climate Division with minutely data from their Quebec City site covering the period from September 12 at 14:30 through November 22 at 09:00. An independent data set is then required to verify and, if necessary, refine the algorithms. In September of 2004, Quebec Region provided the Division with minutely data from the same site covering the period from May 1 at 00:01 through June 15 at 12:15.

This effort was made necessary with the incorporation of the very sensitive Geonor weighing gauge into the Environment Canada surface weather/RCS network. However, the results of the effort may be applied to other gauges, such as the Belfort (Fischer & Porter). Algorithms developed here will not be applied to the Pluvio as that gauge is a smart sensor with a built in algorithm and MSC wishes to gain experience with its performance.

2. RAW DATA

2.1 *First Raw Data Set*

The first raw data set, provided in an EXCEL workbook and containing numerous flaws, was put through a two stage automatic quality assurance test which set limits on the rate of change for the minute and the previous minute. If the test passed for the present minute, then the previous minute was tested. A failure of either test failed the data for that minute, in which case, the last accepted raw data was maintained for that minute. This eliminated all serious amplitude change flaws.

There were other problems with the data of a much more serious nature:

1) From September 12 to October 9, the data was 15 minutely for 22 hours per day from 17:00 to 15:00 and minutely from 15:00 to 17:00. This created a severe accordion effect in the time scale as well as distorting any precip events that occurred during that period.

2) There was a gap of missing data on October 9 from 17:00 to 21:00.

3) There was a gap of missing data from Oct 10 @ 19:00 to Oct 11 @ 03:00.

4) Data is erratic and zero or negative on October 11 from 03:00 to 15:11.

5) There was a six day gap from October 18 to October 24.

6) Where there was minutely data, at minutes 0, 15, 30 and 45, the data occurred twice. This flaw represents about 12% of the data and is distributed throughout the data.

Although the original data file is retained, the QA'd file discards all data from September 12 to October 11 at 15:15. Additionally, there is no precipitation activity after late afternoon on November 20 and all data after this point was discarded. Therefore, this report covers the period

Harry H. Lamb, Meteorological Service of Canada, Downsview, Ontario, harry.lamb@ec.gc.ca
Yves Durocher, Meteorological Service of Canada, Downsview, Ontario, yves.durocher@ec.gc.ca

from October 11 at 15:15 through November 21 at 02:12.

The QA'd raw data is adequate for algorithm development and data containing selected precipitation events is shown in the GRAPHS – FIRST RAW DATA SET section. These algorithms were tested against an independent data set.

2.2 *Second Raw Data Set*

The second raw data set, provided in an EXCEL workbook and containing no flaws, was subjected to the same quality control as the first data set. There was no precipitation activity after late evening on June 2 and all data after this point was discarded. Therefore, this report covers the period from May 1 at 00:01 through June 2 at 21:57.

From the results obtained with the first data set, a preferred algorithm was chosen and is the only algorithm presented with the second data set. This QA'd raw data verifies the chosen algorithm and data containing selected precipitation events is shown in GRAPHS – SECOND RAW DATA SET section.

3. FILTER METHOD

This method was created by Surface Weather and Climate Division while developing the first versions of the standard data logger program before receiving the Quebec City data set. Minutely means are produced from 5 second samples. The averages are input to a 3 minute boxcar (running) average. The output of the 3 minute boxcar is input to a 9 minute boxcar, whose output is taken as the measured weight. If a step is applied to the weight in the gauge, it will take the measured weight output 12 minutes to reach full value.

Because the 9 minute boxcar is a smooth version of the minutely means, it can decrease should evaporation occur. An evaporation correction is calculated by inputting the measured weight to a 30 minute boxcar which is input to a 90 minute boxcar. This gives a very slow response smooth output which can be used to determine if evaporation has taken place.

The algorithm, updated minutely, may be expressed as follows:

```
box 1(i) = avg last 3 minutes

box 2(i) = avg [box 1(i), box 1(i-1), , , box 1(i-8)]

box 3(i) = avg [box 2(i), box 2(i-1), , , box 2(i-29)]

box 4(i) = avg [box 3(i), box 3(i-1), , , box 3(i-89)]

if box 4(i-15) – box 4(i) > 0.08
  then evap(i) = [box 4(i-15) – box 4(i)]/15
  else 0

acc(i) = box 2(i) + evap(i)
```

The 15 minute amounts were taken as acc(i) – acc(i-15).

After the Quebec City data set was received, it was found that the accumulation of the 15 minute amounts considerably exceeded the accumulation, acc(i), due to the low level of noise that still remained on box 2. A longer boxcar could not be used because of the excessive time response.

A significant improvement was made to the 15 minute amounts by sychronizing them to the hourly amount. The algorithm is as follows:

```
if acc(15) – acc(0) > 0.2
  then amt(15) = acc(15) – acc(0)
  else 0

if acc(30) – acc(0) > 0.35
  then amt(30) = acc(30) – acc(0) – amt(15)
  else 0

if acc(45) – acc(0) > 0.5
  then amt(45) = acc(45) – acc(0)
                  – amt(30) - amt(15)
  else 0

if acc(60) – acc(0) > 0.65
  then amt(0) = acc(60) – acc(0) – amt(45)
                 - amt(30) - amt(15)
  else 0

acc(0) = acc(60)
```

4. NOISE THRESHOLD METHODS

4.1 *Introduction*

Noise threshold methods take some combination of average, maxima, minima and a noise related term over some length of time to test against a previous accumulation to determine if accumulation should be updated. With these methods, noise does not appear in the results so the accumulation of 15 minute amounts is the same as the accumulation.

4.2 *Swedish Method*

In May of 2003, Surface Weather and Climate Division obtained a copy of an algorithm, recently developed by the Swedish Met Institute, which is a noise threshold method. The algorithm, performed minutely and providing a 15 minutely update, is as follows:

```
if T = 0 minutes into a 15 minute interval
  then max = corr(0)  and  min = corr(0)

if acc(i) > max
  then max = acc(i)  and  min = acc(i)

if acc(i) < min
  then min = acc(i)

if T = 0 minutes into a 15 minute interval
  if min > corr(0) + x(max – min)
    if acc(15) – acc(0) > y
      then corr(15) = min
      else  corr(15) = corr(0)
```

useful range of x, y; 0 to 2, 0 to 0.05

This algorithm resets at the beginning of each 15 minute interval. Each minute during the interval, the algorithm checks for maxima and minima. If there is a maximum, the minimum is reset to the maximum. The algorithm is looking for the minimum that occurs after the maximum. At the end of the 15 minutes, if the minimum is greater than the sum of the corrected accumulation at minute 0 and a noise dependent term and if the difference in measured accumulation over the 15 minutes is greater than a fixed threshold, then the corrected accumulation is set to the minimum.

4.3 *MaxMin Method*

At the same time the filter method was being developed, Surface Weather and Climate Division was also developing a method utilizing the properties of the noise on the minutely means. While not originally a noise threshold method, it was a precursor. The algorithm, updated minutely, is as follows:

```
acc(i) = min{(max last 15),
              max[(min last 15), acc(i-1)]}
```

Although noise does not appear in the result, it does affect the result and accumulation increases significantly faster than it should.

The algorithm was then modified to a noise threshold method by retaining only the second term in the outer brackets and adding a noise related term, with dramatic improvement in results. The algorithm, updated minutely, is as follows:

```
acc(i) = max{[min last 15 – x(max last 15
               – min last 15)], acc(i-1)}
```

useful range of x, 0 to 0.5

Running boxcars are maintained on both the minima and maxima of the last 15 minutes. Whenever the minimum, reduced by a noise related term, exceeds the previous accumulation, the accumulation is set equal to the new value.

4.4 *Boxcar Method*

This method, developed by Surface Weather and Climate Division, is a derivation of the filter method where the 3 minute boxcar and the evaporation correction have been dropped. Only the 9 minute boxcar has been retained and a noise related term added, which considerably improves results and reduces the response time from 12 to 9 minutes. The algorithm, updated minutely, is as follows:

```
if avg last 9 – x(max last 15 – min last 15)
   > acc(i-1)

  then acc(i) = avg last 9
  else acc(i) = acc(i-1)
```

useful range of x, 0 to 0.5

Running boxcars are maintained on both the minima and maxima of the last 15 minutes. Whenever the 9 minute boxcar, reduced by a noise related term, exceeds the previous accumulation, the accumulation is set equal to the new boxcar value.

5. RESULTS

The results are given in the the various GRAPH sections. All the algorithms perform well and are very close to each other and to the raw data. Because of this, the curves have been given negative offsets of -1, -2, -3, -4, -5 and -6 mm relative to the raw data, larger offsets being assigned to curves with larger time delay to minimize crossovers.

In GRAPHS – FILTER METHOD – FIRST DATA SET, five curves are shown:

- QA'd raw data one minute means.
- Nine minute boxcar and accumulation of 15 minute amounts at 100% duty cycle.
- Nine minute boxcar and accumulation of 15 minute amounts at 20% duty cycle. In this case, the sensor was powered only for the last three minutes of each 15, the minutely means remaining constant for the first 12 minutes.

In GRAPHS – NOISE THRESHOLD METHODS – FIRST DATA SET, seven curves are shown:

- QA'd raw data one minute means.
- Max Min, Swedish and Boxcar accumulations at 100% duty cycle.
- Max Min, Swedish and Boxcar accumulations at 20% duty cycle.

In GRAPHS – NOISE THRESHOLD METHOD – SECOND DATA SET, three curves are shown:

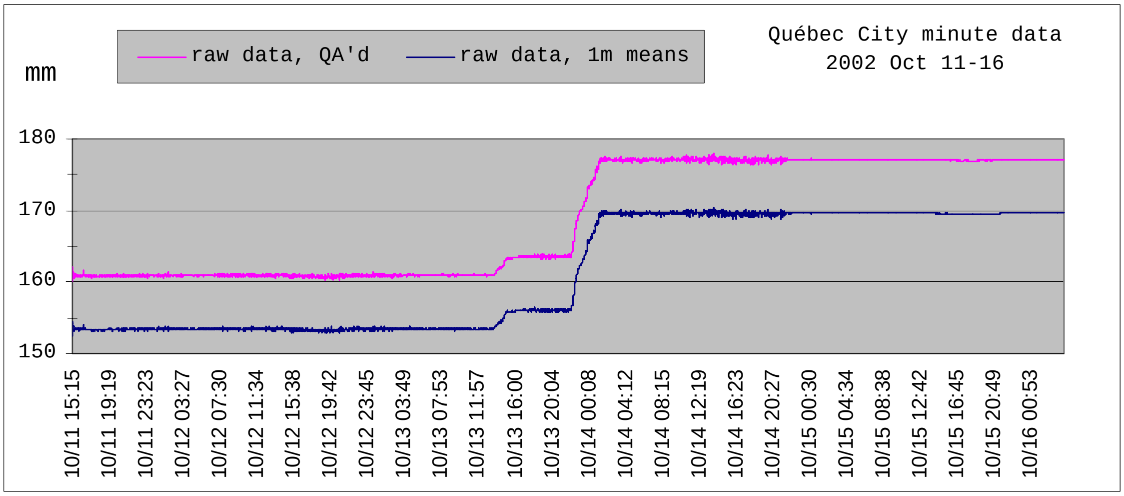
- QA'd raw data one minute means.
- Boxcar accumulation at 100% duty cycle.
- Boxcar accumulation at 27% duty cycle.

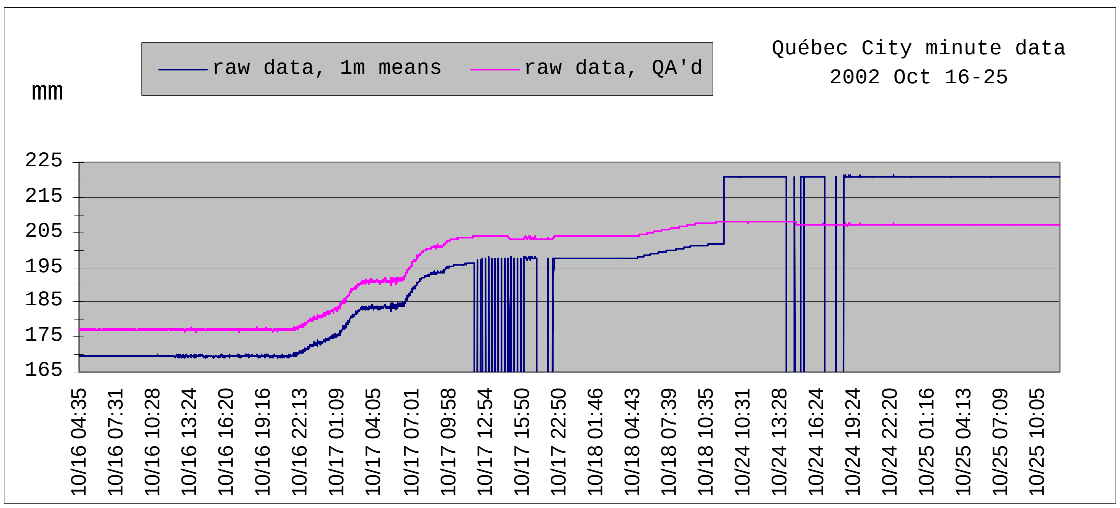
6. CONCLUSION

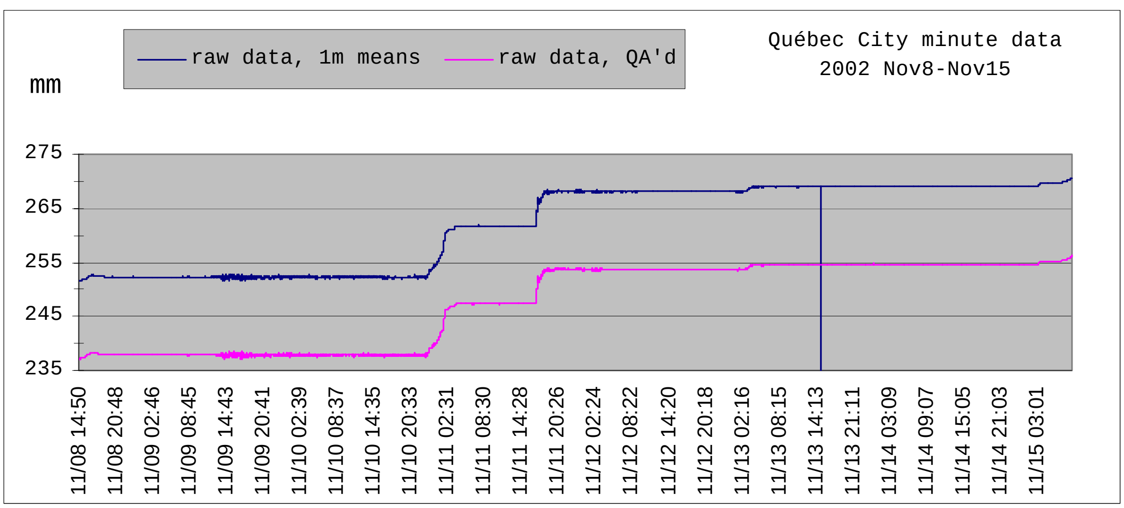
For the algorithms developed with the first data set, it was concluded that the preferred algorithm would be the boxcar method. The results with the second data set confirm that the preferred algorithm performs the same as when it was developed.

	Filter		Noise Threshold		
	accumulation	15 min amts	Swedish	MaxMin	Boxcar
Noise sensitivity	some	more	less	less	less
Delay	less	some	some	some	less
Event reproduction	good	fair	fair	good	good
Degradation from full to part duty	some	some	some	more	less
Difference: accumulation & 15 minute amounts	yes	yes	no	no	no

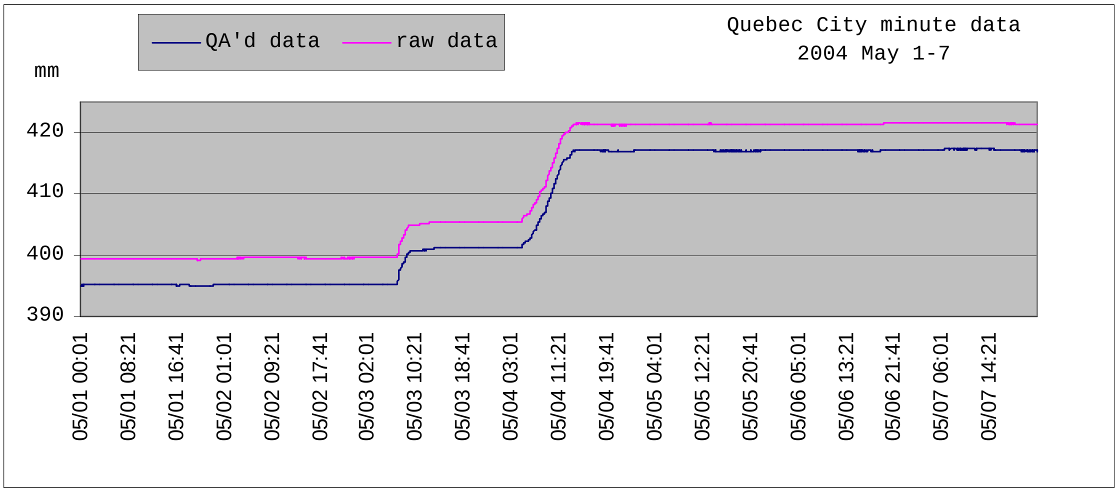
GRAPHS – FIRST RAW DATA SET

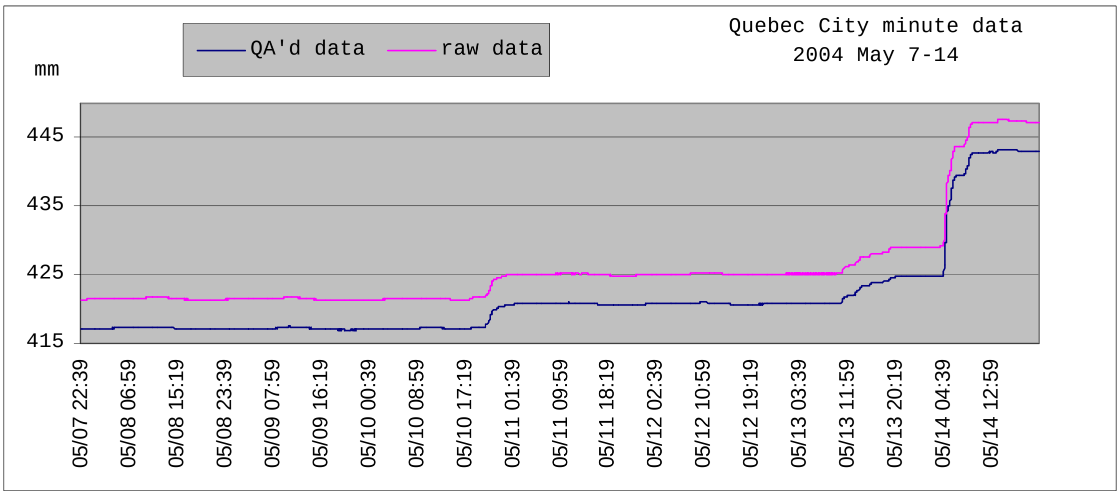


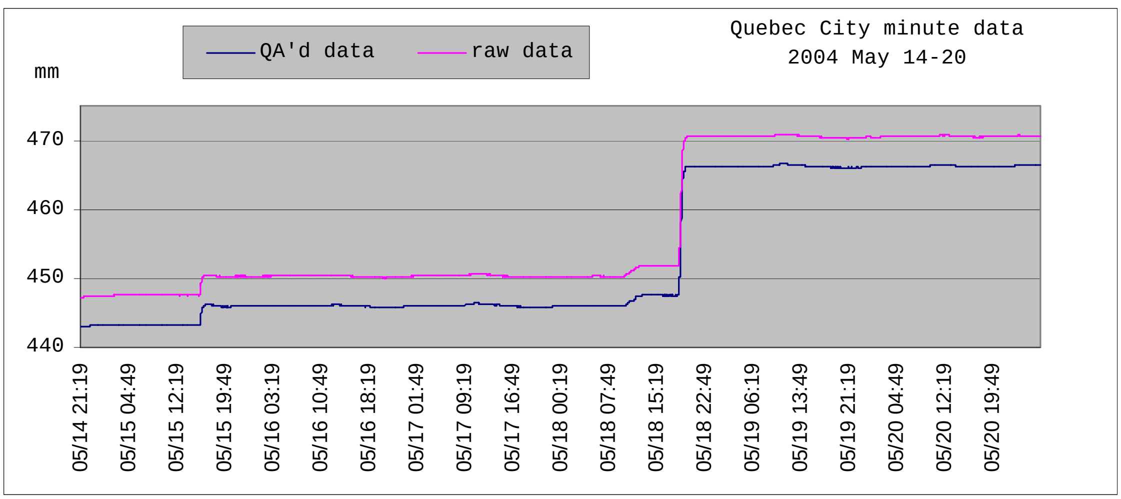


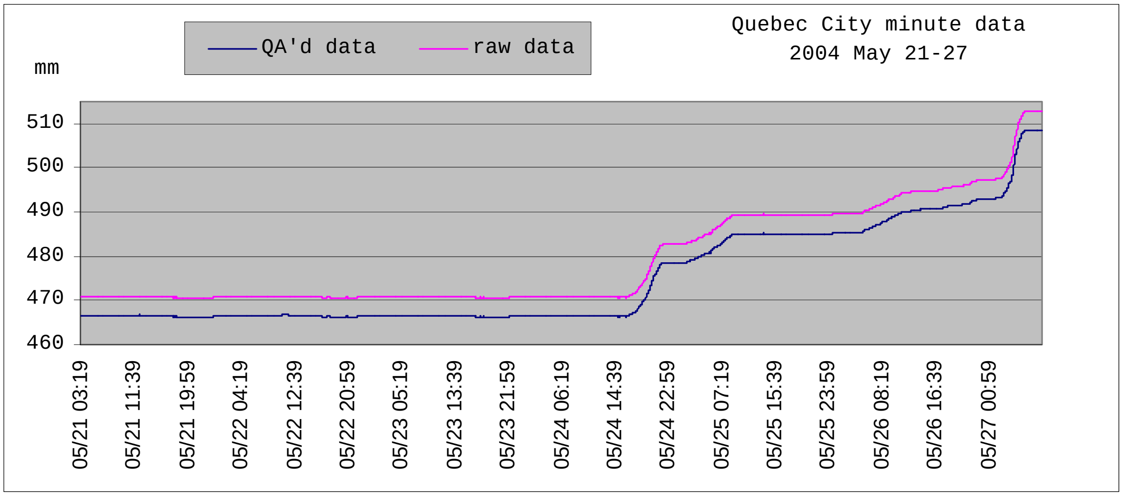


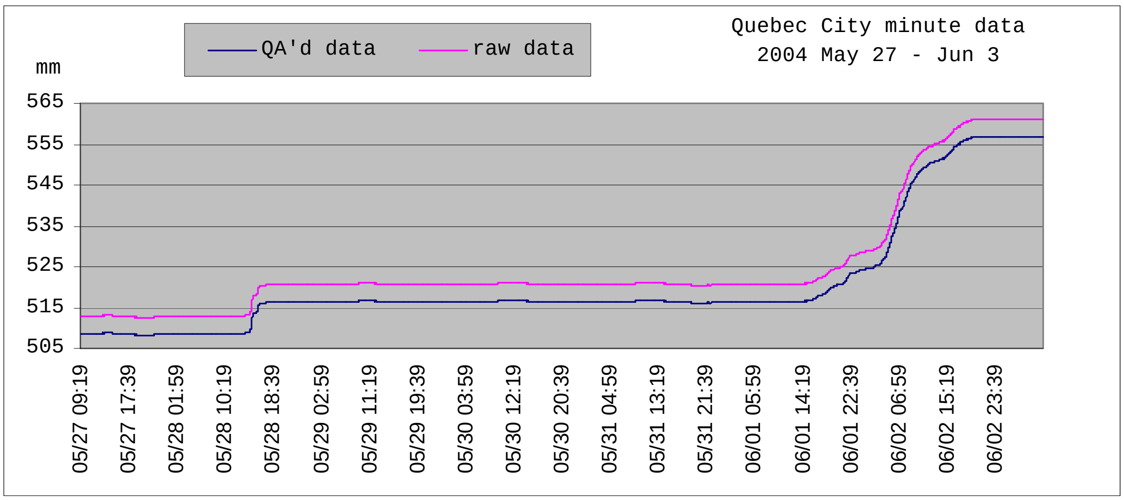
GRAPHS – SECOND RAW DATA SET



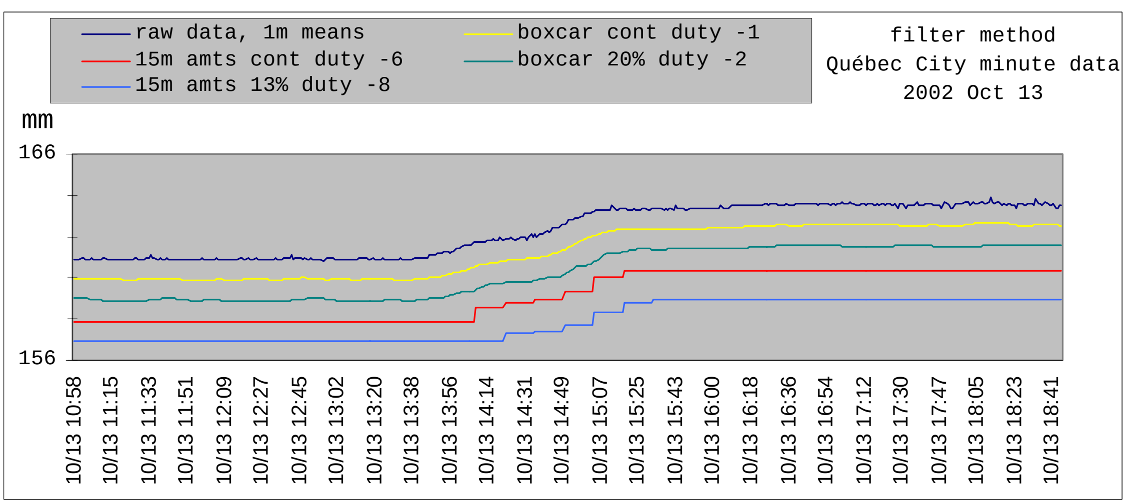


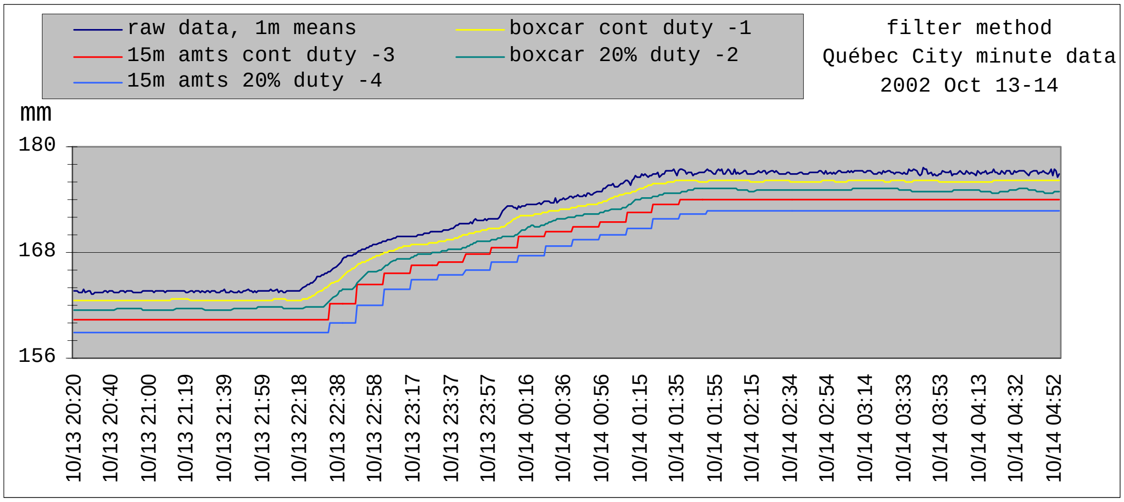






GRAPHS – FILTER METHOD – FIRST DATA SET

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boxcar cont duty -1
15m amts cont duty -3
boxcar 20% duty -2
15m amts 20% duty -4
filter method
Québec City minute data
2002 Oct 13-14
mm
180
168
156
10/13 20:20
10/13 20:40
10/13 21:00
10/13 21:19
10/13 21:39
10/13 21:59
10/13 22:18
10/13 22:38
10/13 22:58
10/13 23:17
10/13 23:37
10/13 23:57
10/14 00:16
10/14 00:36
10/14 00:56
10/14 01:15
10/14 01:35
10/14 01:55
10/14 02:15
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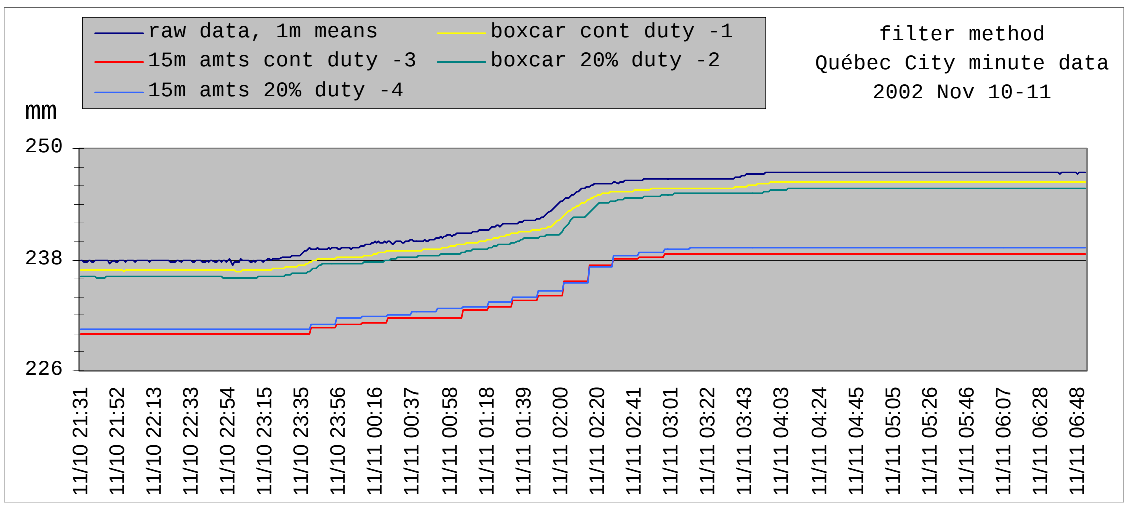
10/14 04:32
10/14 04:52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boxcar cont duty -1
15m amts cont duty -3
boxcar 20% duty -2
15m amts 20% duty -4
filter method
Québec City minute data
2002 Nov 10-11
mm
250
238
226
11/10 21:31
11/10 21:52
11/10 22:13
11/10 22:33
11/10 22:54
11/10 23:15
11/10 23:35
11/10 23:56
11/11 00:16
11/11 00:37
11/11 00:58
11/11 01:18
11/11 01:39
11/11 02:00
11/11 02:20
11/11 02:41
11/11 03:01
11/11 03:22
11/11 03:43
11/11 04:03
11/11 04:24
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11/11 05:05
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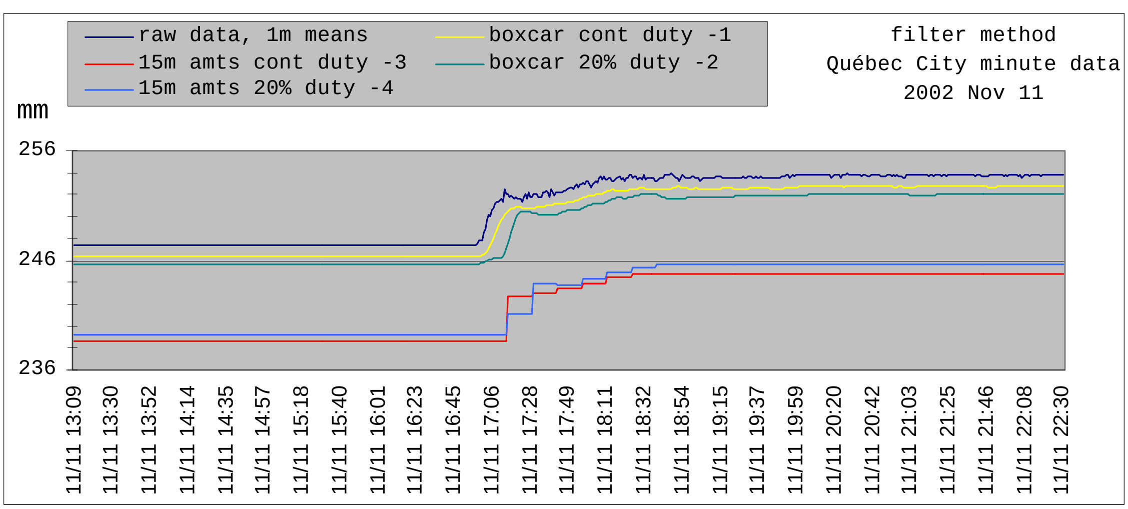
11/11 06:28
11/11 06:48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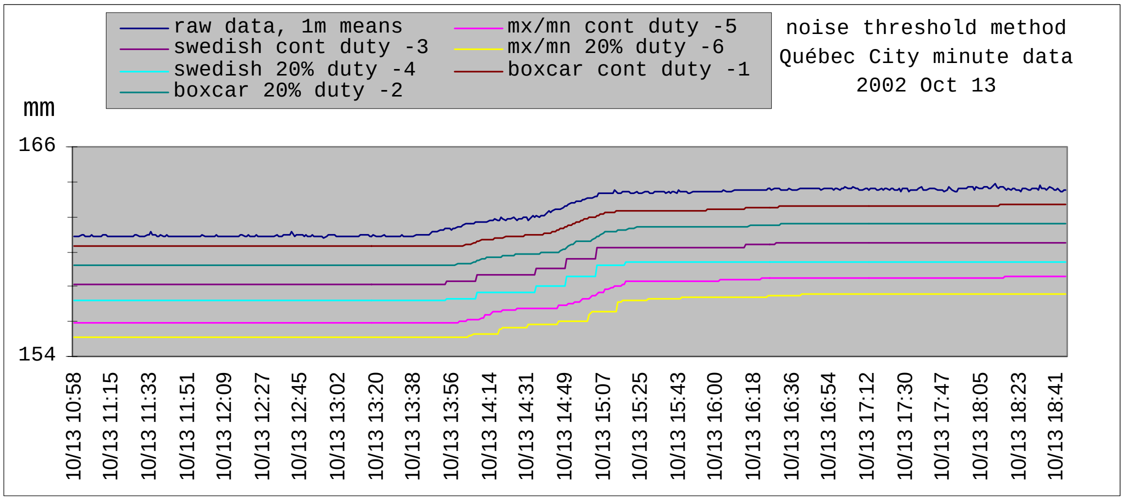
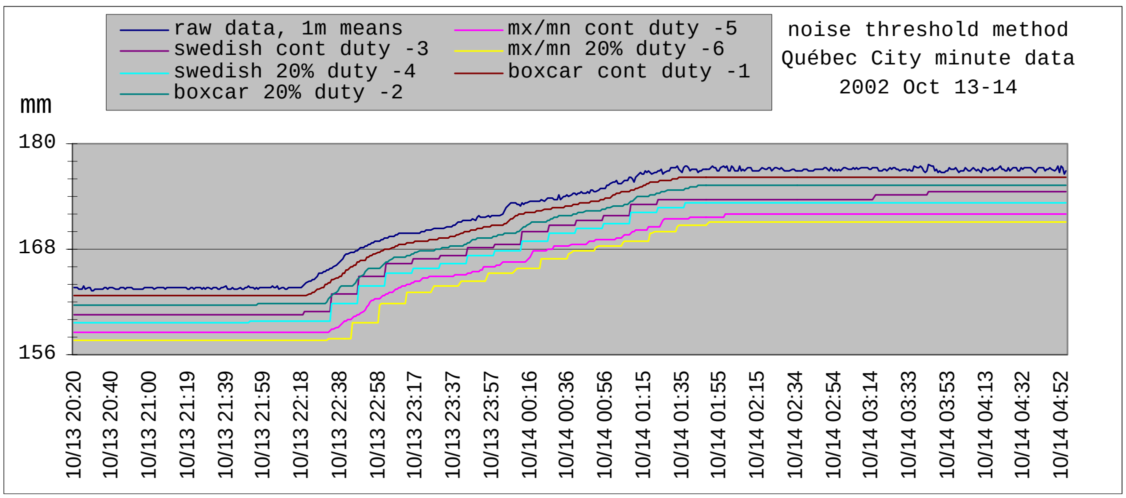
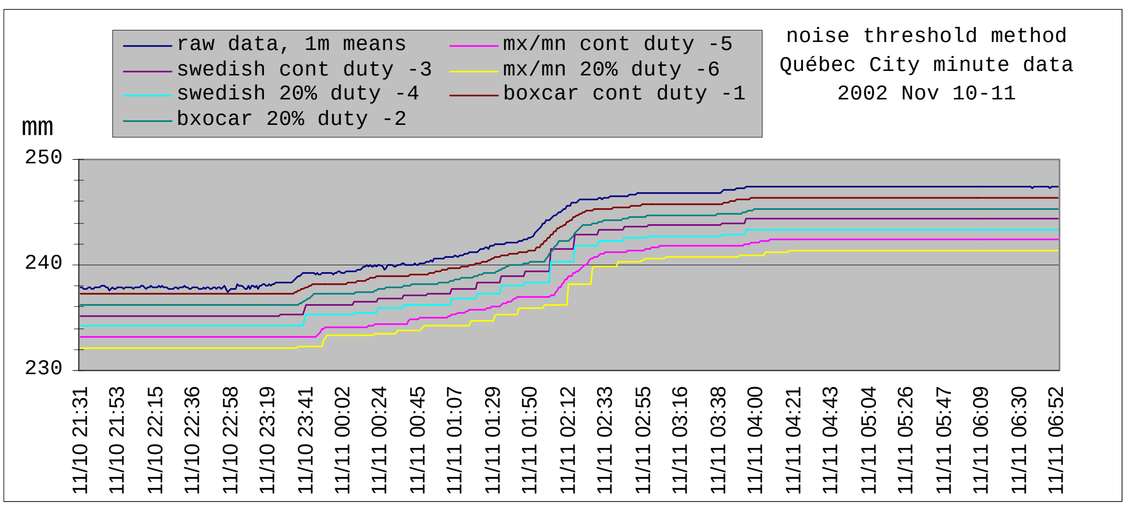
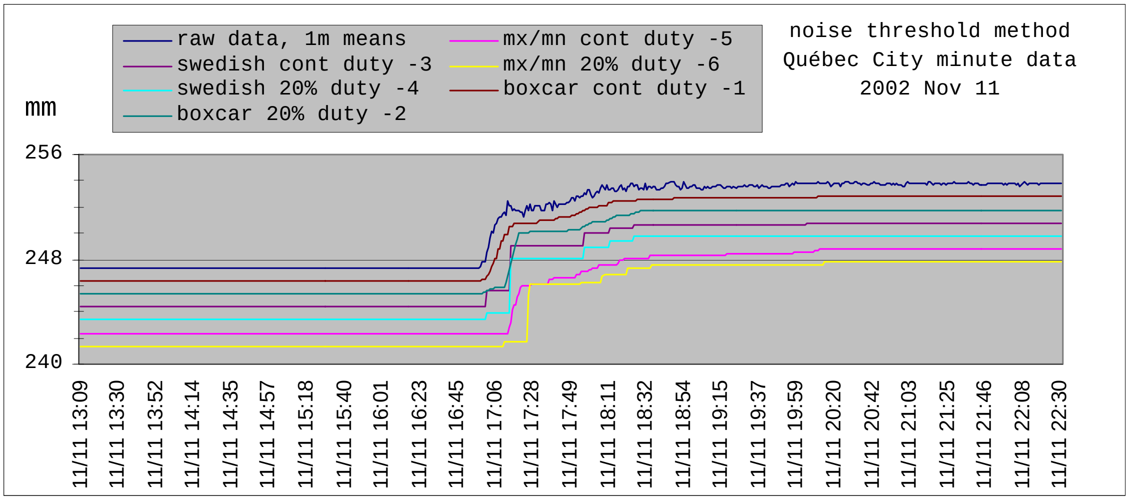
boxcar 20% duty -2
15m amts 20% duty -4
filter method
Québec City minute data
2002 Nov 11
mm
256
246
236
11/11 13:09
11/11 13:30
11/11 13:52
11/11 14:14
11/11 14:35
11/11 14:57
11/11 15:18
11/11 15:40
11/11 16:01
11/11 16:23
11/11 16:45
11/11 17:06
11/11 17:28
11/11 17:49
11/11 18:11
11/11 18:32
11/11 18:54
11/11 19:15
11/11 19:37
11/11 19:59
11/11 20:20
11/11 20:42
11/11 21:03
11/11 21:25
11/11 21:46
11/11 22:08
11/11 22:30

GRAPHS – NOISE THRESHOLD METHODS - FIRST DATA SET

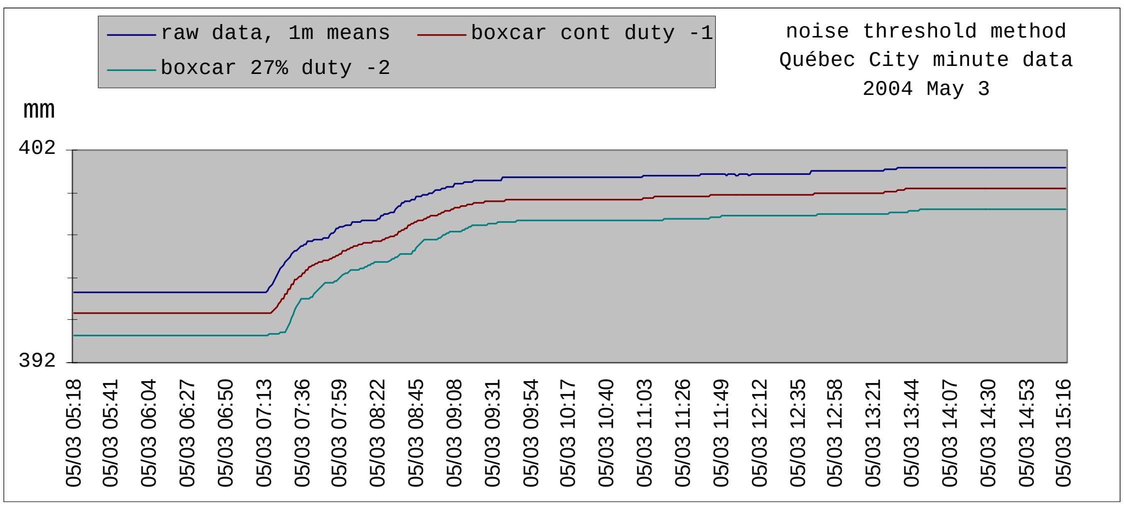


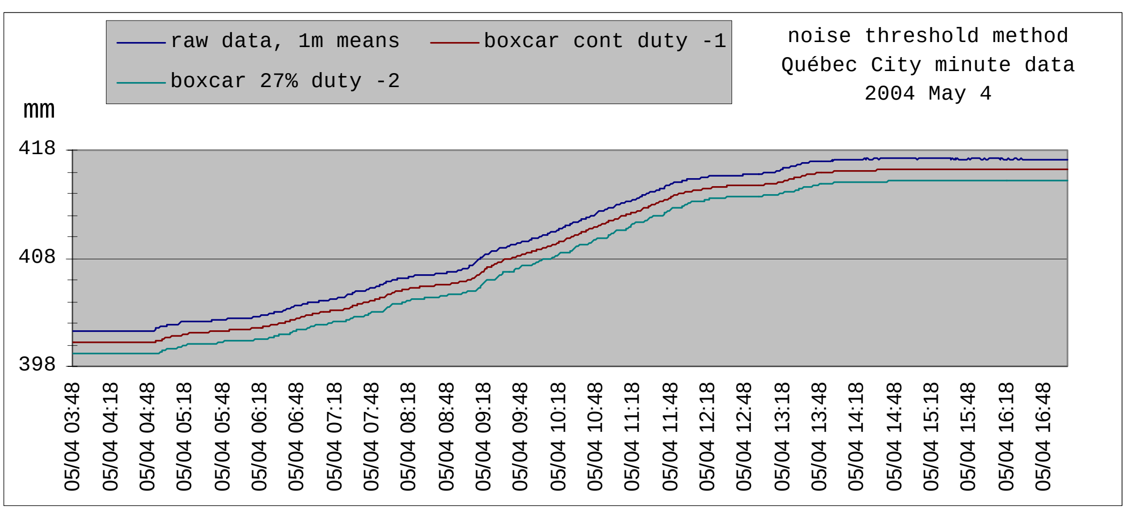


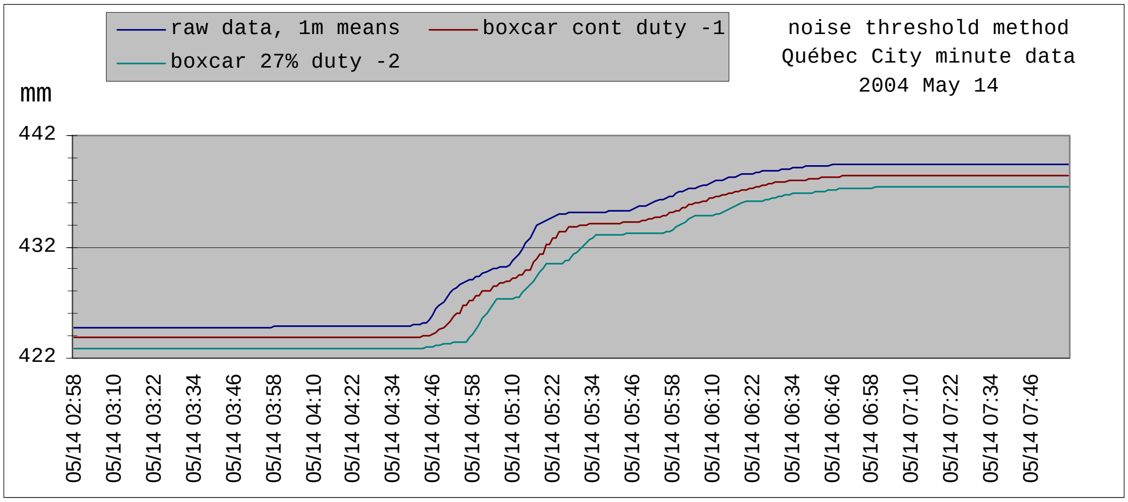




GRAPHS – NOISE THRESHOLD METHOD – SECOND DATA SET



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boxcar cont duty -1
boxcar 27% duty -2
noise threshold method
Québec City minute data
2004 May 14
mm
442
432
422
05/14 02:58
05/14 03:10
05/14 03:22
05/14 03:34
05/14 03:46
05/14 03:58
05/14 04:10
05/14 04:22
05/14 04:34
05/14 04:46
05/14 04:58
05/14 05:10
05/14 05:22
05/14 05:34
05/14 05:46
05/14 05:58
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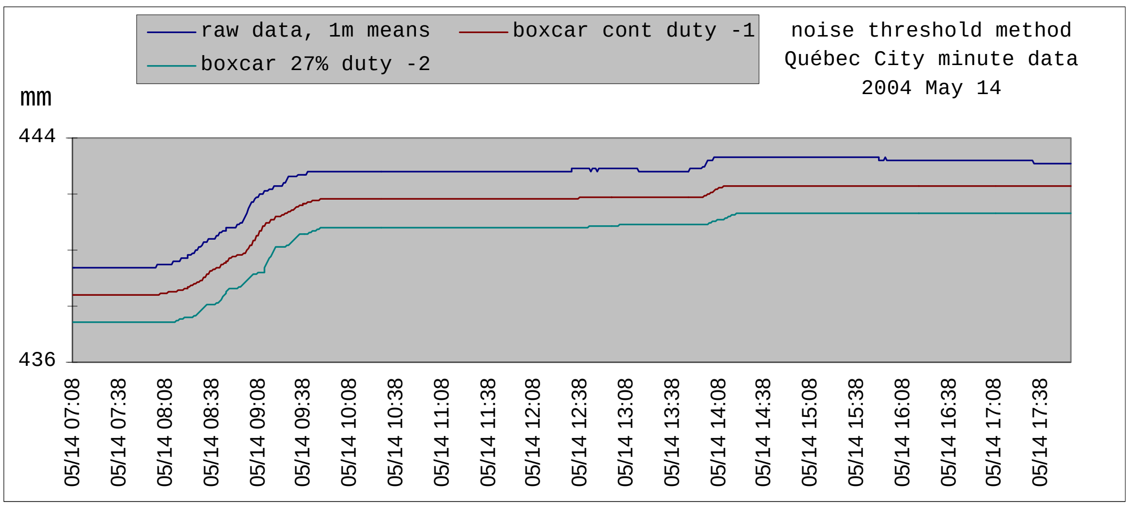
05/14 07:34
05/14 07:46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boxcar 27% duty -2
noise threshold method
Québec City minute data
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mm
444
436
05/14 07:08
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05/14 08:38
05/14 09:08
05/14 09:38
05/14 10:08
05/14 10:38
05/14 11:08
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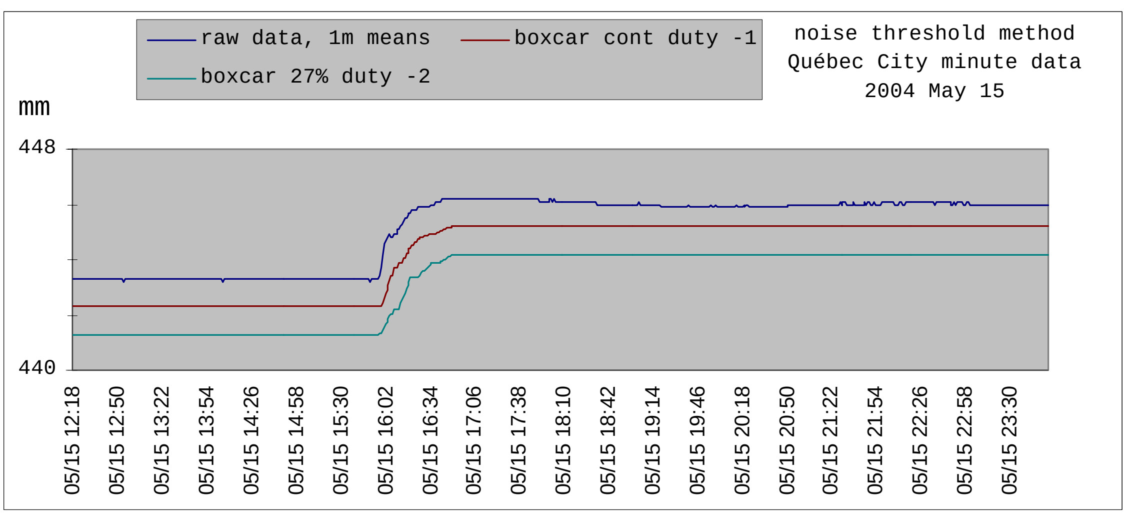
05/14 17:08
05/14 17:38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440
05/15 12:18
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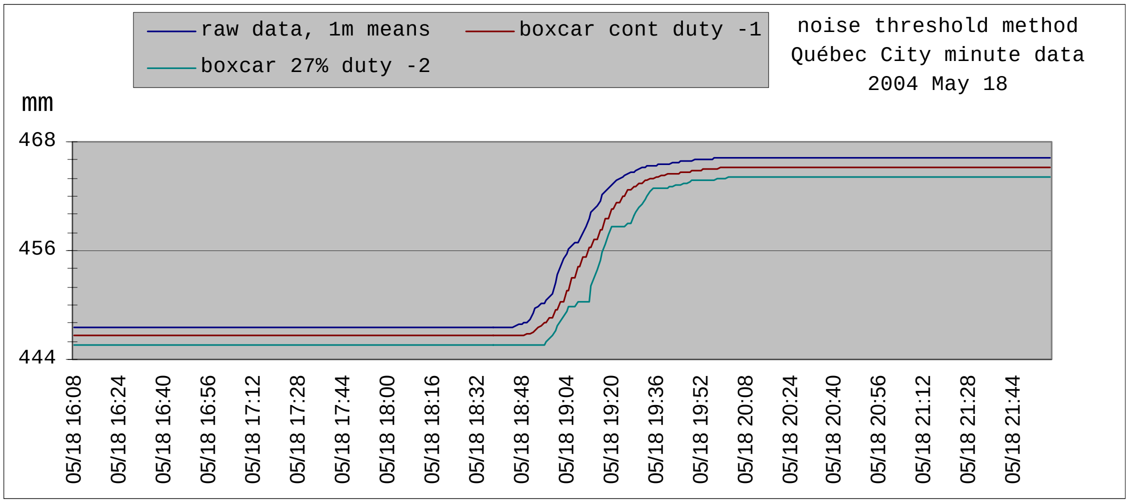
05/15 22:58
05/15 23:30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boxcar 27% duty -2
noise threshold method
Québec City minute data
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mm
468
456
444
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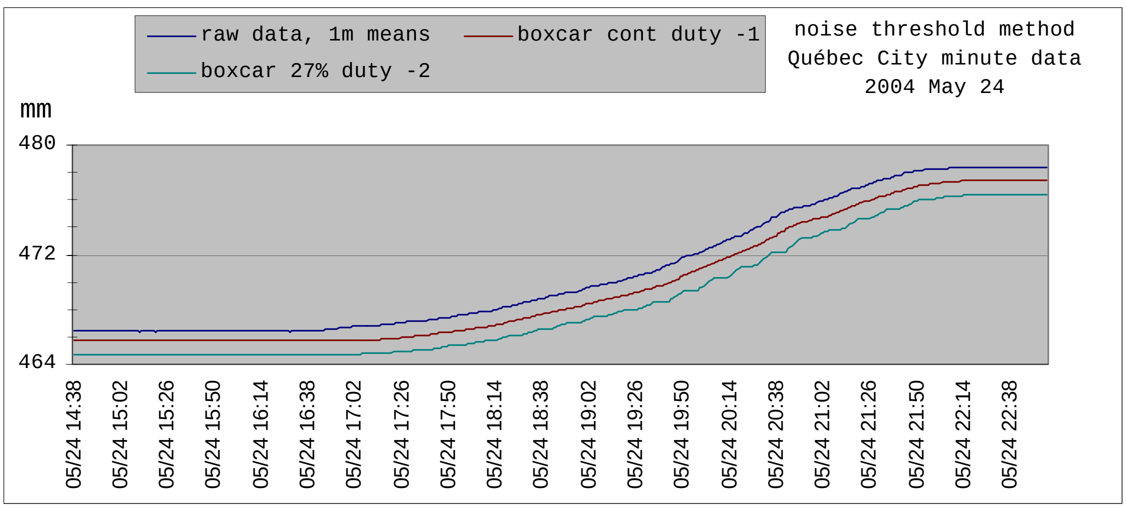
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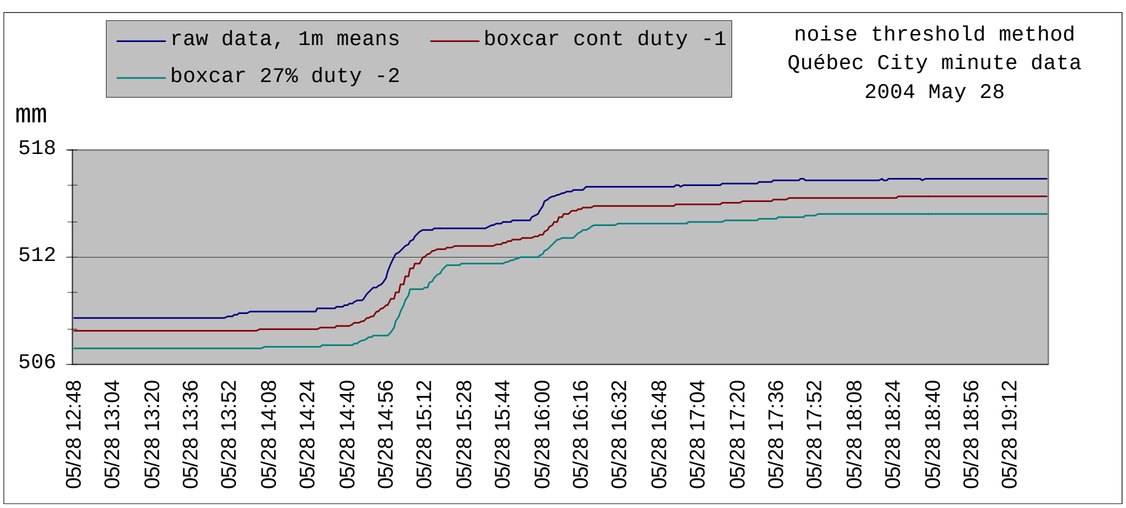
05/24 22:38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noise threshold method
Québec City minute data
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