Statistics Netherlands

2016 Scientific Paper

Trend changes in ground subsidence in Groningen

update May 2016

The views expressed in this paper are those of the author and do not necessarily reflect the policies of Statistics Netherlands.

Frank Pijpers
D. Jan van der Laan

Contents

Nederlands

Deze rapportage behelst een voortzetting van onderzoek dat is uitgevoerd sinds midden 2014 in het kader van een onderzoeksproject door het CBS in opdracht van Staatstoezicht op de Mijnen (SodM). Dit onderzoek is ten behoeve van een statistische onderbouwing van het meet- en regelprotocol voor gasexploitatie in de provincie Groningen. Het onderwerp van dit rapport is een heranalyse van trends in de bodemdaling in de provincie Groningen, gerapporteerd in December 2014 en in Mei en November 2015. Voor de voorliggende analyse is de tijdreeks voor de GPS gegevens aangevuld tot aan 3 Maart 2016.

Zoals ook bleek uit de eerdere analyses is er een statistisch significante trendbreuk in de bodemdaling ongeveer 2 maanden nadat de productie sterk was gereduceerd. De trendwijziging kan zich geleidelijk gemanifesteerd hebben over een periode van enkele weken, en er is daarom een onzekerheid van ruwweg een week of twee over de centrale datum van deze overgang.

English

This report is a continuation of research, commenced in 2014, which is part of a research project being carried out by Statistics Netherlands and commissioned by State Supervision of Mines (SodM). This research is part of the underpinning of the statistical methods employed to support the protocol for measurement and regulation of the production of natural gas in the province of Groningen. The subject of this report is to re-analyse the trends in the ground subsidence in and around that region, first reported in December 2014 and later in May and November 2015. For this re-analysis the time series of the GPS data has been updated with more recent measurements up to March 5, 2016.

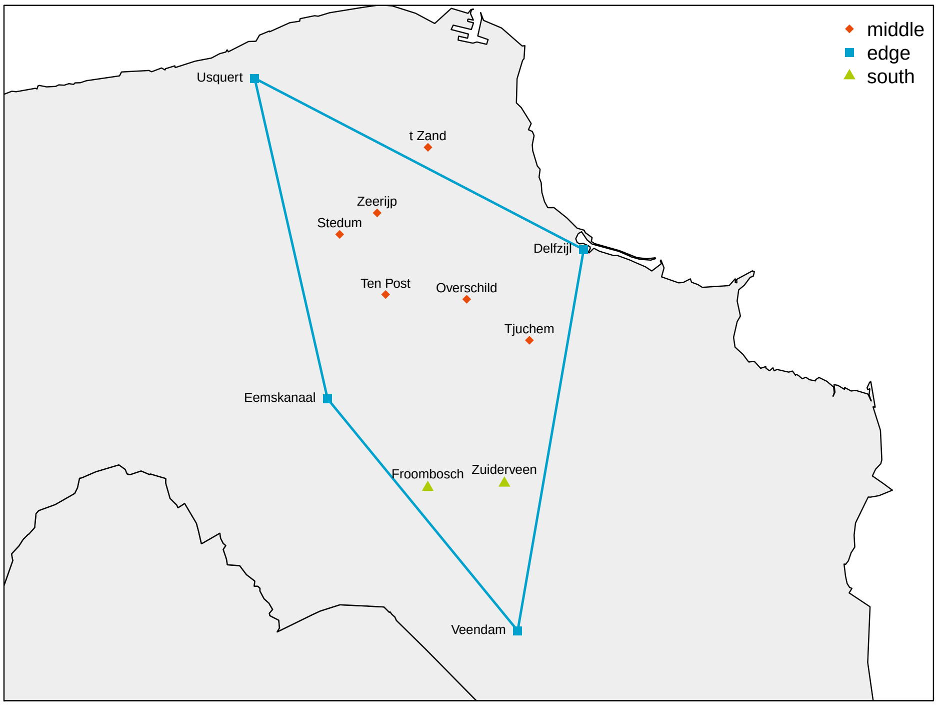
In accordance with the earlier report, it is found that there has been a significant change in the ground subsidence. The changeover in the trend of ground subsidence can have become manifest gradually over a period of several weeks, which implies that the central date of the transition is also uncertain by roughly a week or two.

1 Introduction

This is an update to the previous report studying ground subsidence in Groningen. The calculations performed in previous reports (Pijpers, 2014; Pijpers and van der Laan, 2015a,b) are redone using more recent GPS data. The time series being analysed in this report contain the entire period that was analysed in the previous reports, but is now extended forward to cover the epoch up to March 5 2016. The same methodology is used as in previous reports.

In addition a fitting procedure is carried out using smooth functions, through which the effects of more modest increases and decreases in gas production rates might become visible in GPS ground subsidence measurements, rather than focus just on the very substantial decrease in gas production rate of January 2014.

Figure 2.1 The locations of the GPS stations from which data are available.



2 Data

Data are available for 13 stations for the period 2013-09-13 to 2016-03-05. Not all stations have data available for the complete period. From March 2014 GPS data is available for most stations. Early in 2016 there is a small gap in the data for all locations. The stations can be divided into three groups as indicated in figure 2.1. A group ‘middle’; these are in the production field in which the production has been reduced in January of 2014, although at a later time some level of production was resumed. A group ‘edge’: these are outside the main field, although at the station Eemskanaal (eems) there are wells in production. Finally, a group ‘south’ where production has not been reduced. At all production locations there is some seasonal variation in production levels throughout the year.

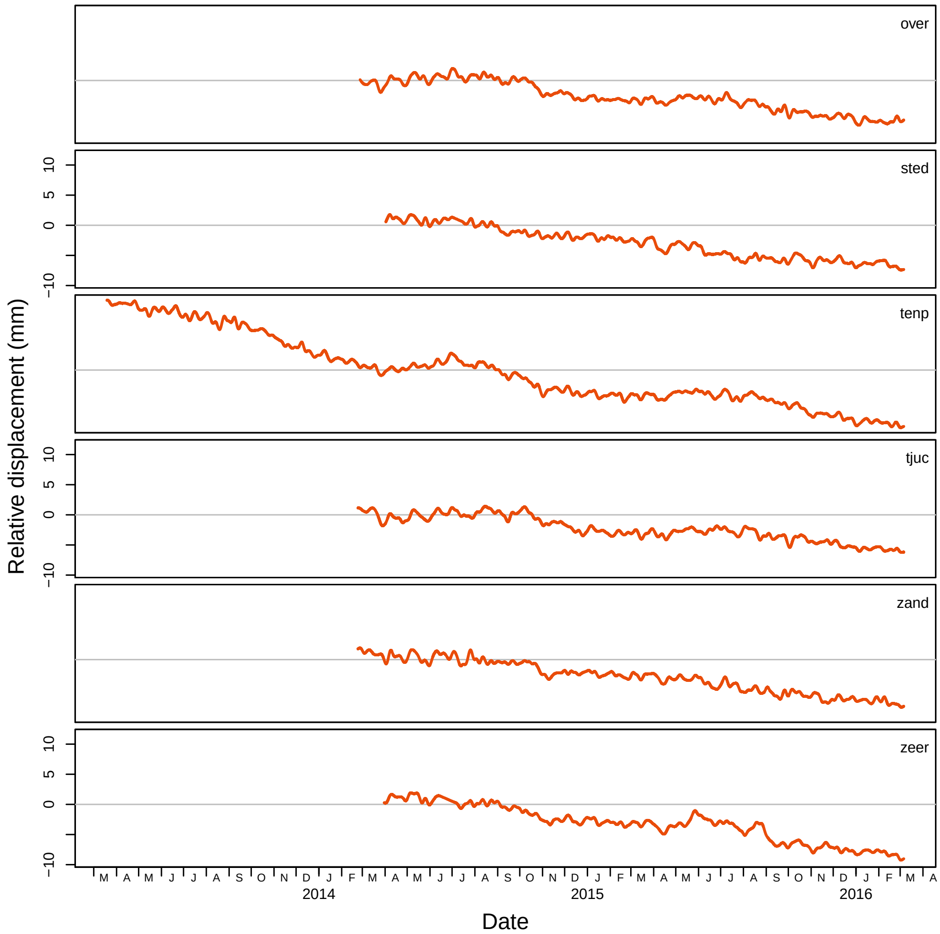
Figure 2.2 shows the filtered time series for each of the stations in ‘middle’ and ‘edge’. The time series were filtered using a moving average filter as described in Pijpers (2014) to remove the high frequency noise, which is not of interest for current research. Since the absolute height of the stations is not of interest, the height has been normalised by subtracting the average height in the period 2014-02-19--2014-11-15.

The quantity of interest is the ‘sagging’ of the stations in group ‘Middle’ and in group ‘South’ with respect to those in group ‘Edge’. It is this differential displacement over a spatial scale of the order of, or smaller than, the field that traces the ’subsidence bowl’ which is due to compaction of the layer from which gas is extracted. Therefore the displacements, averaged for each group, are subtracted in the sense ‘Middle’ minus ‘Edge’ and ‘South’ minus ‘Edge’. The result is shown in figure 2.3.

To assess the extent to which correlations might still be present in the differential displacement, two additional differential time series are shown in figure 2.4. One measure concerns the

Figure 2.2 The time series of the GPS height after filtering out intermediate time scale variations. The average of its time series over the period from 2014-02-19 (day 50) to 2014-11-15 (day 319) is subtracted.

(a) GPS stations in group `middle'



(b) GPS stations in group `edge'

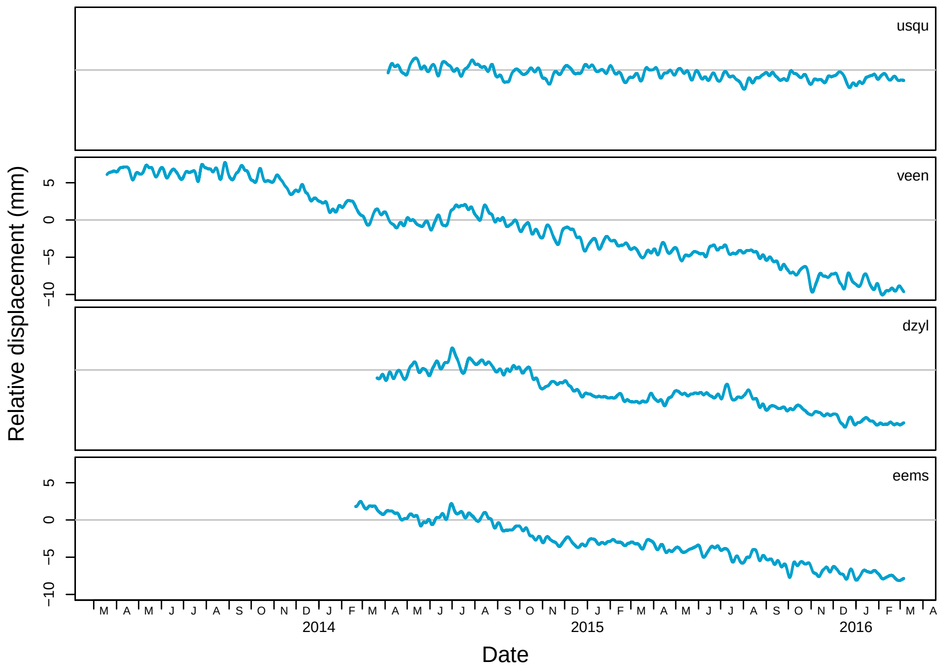
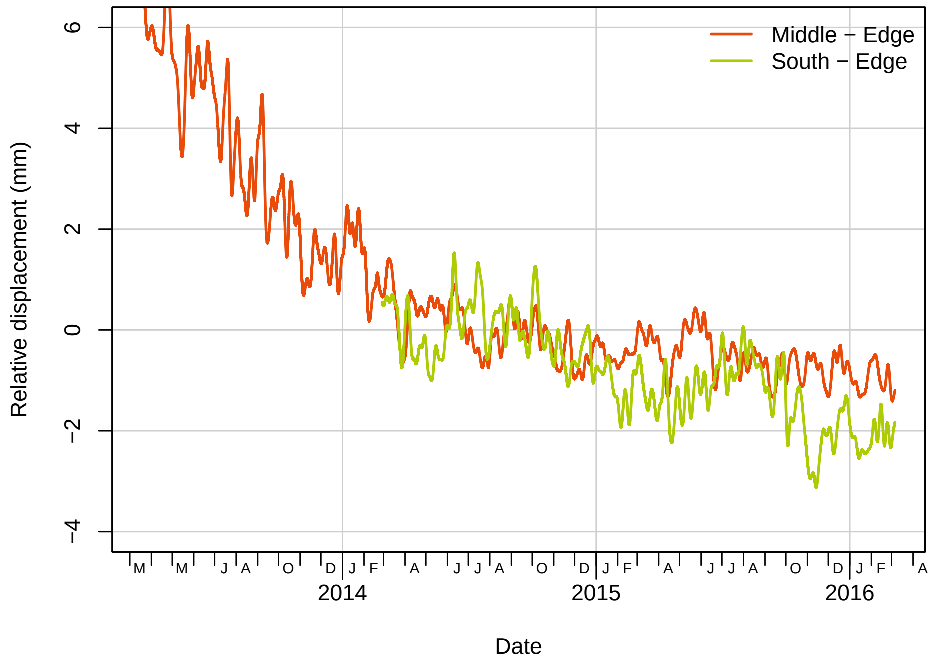
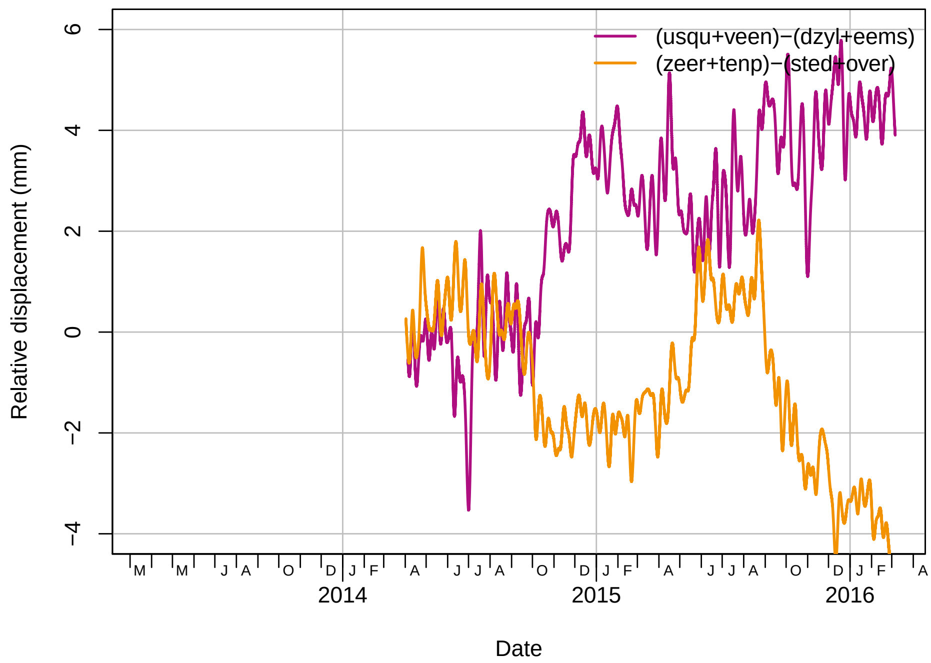


Figure 2.3 The difference between the average heights for the groups `middle' and `south' and the group `edge'.



differential displacement between stations that are all within group ‘Middle’, in the sense (Zeerijp+ten Post) - (Stedum+Overschild) which is shown as an orange line. The other concerns the differential displacement between stations that are all within group ‘Edge’, in the sense (Usquert+Veendam) - (Delfzijl+Eemskanaal) shown as a purple line. In the absence of remaining biases these differential measurements should not show any trends. However, if the rate of gas production is different as a function of time between the four GPS locations in group Middle, this could potentially affect the differential measurement as well.

Figure 2.4 The difference between the average heights for stations all within the group `middle' and all within the group `edge'.



While it is clear that for most of 2014 no trend is present in these sets of differential displacements, in October there is a sudden change in particular in the group ‘Edge’, but also to some extent in the group ‘Middle’. In the report of May 2015 (Pijpers and van der Laan, 2015a,b) it is seen that a different calibration procedure and processing as performed by the TU Delft, produced clearly different results that are also closer to 0 for the period October 2014 to January 2015. In the course of May 2015 the differential displacements within group middle appear to jump back to 0, but after August 2015 another displacement occurs. In this period there are also variations in gas production rates at various locations. It is possible that these GPS trend changes reflect the time varying production rate. or alternatively there are still some issues that require resolving in the standard processing. From figure 2.2(b) it appears that of the GPS stations in the group ’edge’, Usquert appears not to follow the trend of the other stations in that group which could produce the result seen in figure 2.4.

3 Analysis of trend changes

3.1 Linear fit through average trends

Since the reduction of the gas production at some locations near stations in the group ‘Middle’ has been rapid, it is of interest to explore whether a break can be found in the linear component of the downward drift for the time series for ‘Middle’ minus ‘Edge’. To this end one can fit not only a single straight line, using standard least-squares fitting, but also introduce a break-point with a different straight line fit before and after that point. Two types of breaks are modelled: a continuous break which we will call a ‘kink’ and a discontinuous break which we will call a ‘jump’.

Figure 3.1 shows the Akaike Information Criterion as a function of the position of the break. The minimum for the model with a ‘kink’ is at 2014-02-22 and that of the model with the ‘jump’ is a 2014-04-04. Figure 3.2 shows the time series with the three models (the two with break and the one without break). It is clear that the linear model without break doesn’t describe the time series. The rate of relative descent has decreased after the first quarter of 2014.

It should be noted that while this type of fitting with a breakpoint is useful in order to asses whether subsidence trend is different between the start and the current end of the measured time series, it does not necessarily imply that in reality the changeover is as abrupt as this. A more gradual change in trend is allowed by the data.

3.2 Alternative model

One possible issue with the previous fit of the break in the trend, is that the number of measurements contributing to each of the average lines changes with time. Before Februari 2014 there is only one measurement station contributing to each of the lines. The previous model does not take this into account: one would expect the model to give more weight to differences at later dates as more measurement stations are contributing to the averages.

One possibility to avoid this problem is to not calculate the difference, but to model all time series combined. The difference in slopes between the two groups can be modelled explicitly and it is possible to test if this difference is significant.

Figure 3.1 AIC as a function of the position of the break in the linear model fit of the time series of the difference between the average of the group `middle' and `edge'. The minimum of the `kink' is at 2014-02-27 and that of the `jump' is at 2014-04-04.

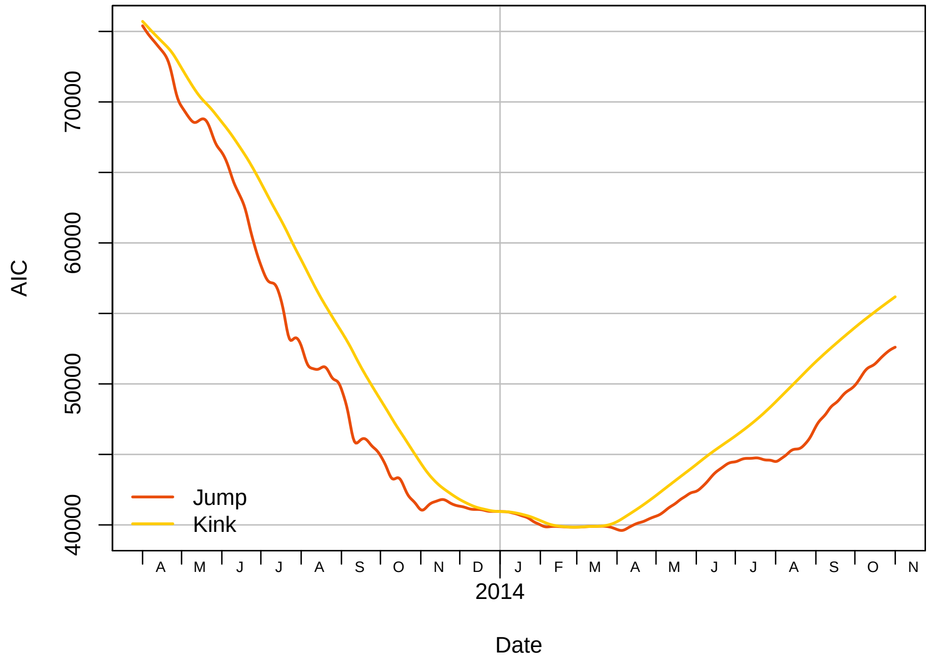


Figure 3.2 The trends fitted to the difference between the group averages of `middle' and `edge'.

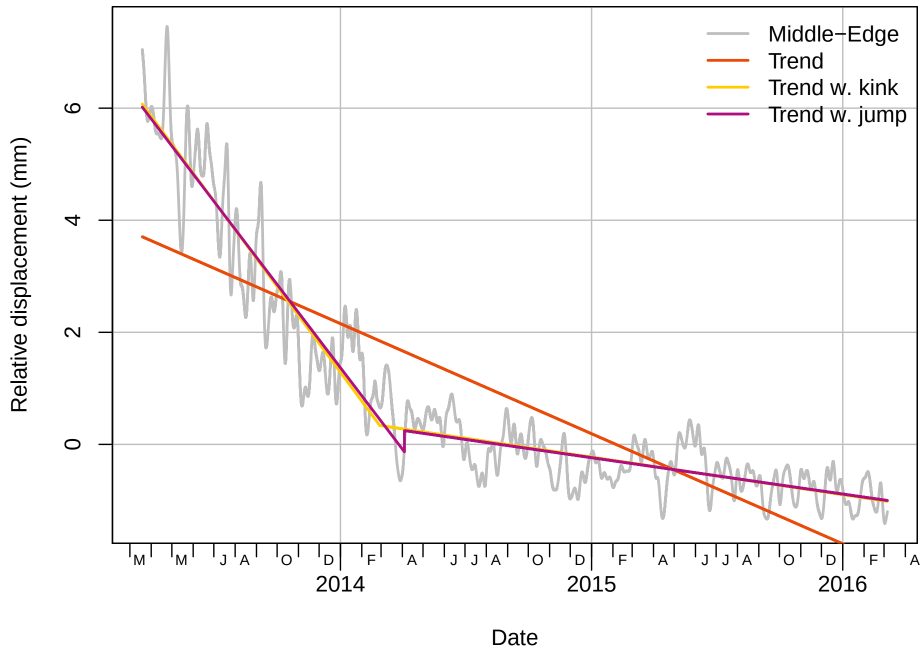
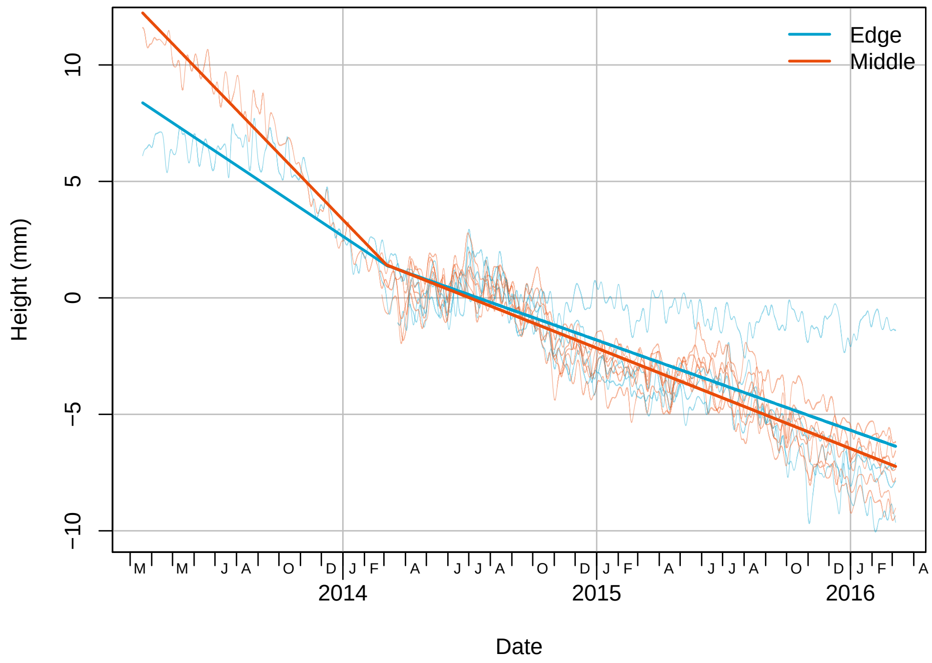


Figure 3.3 Filtered time series of each of the measurement stations in `edge' and `middle' with the fitted model. The break is located at 2014-03-05.



A piecewise linear continuous fit can be written as

$$y_i = \beta_0 + \beta_1 t_i + \beta_2 s(t - t_0) t_i + e_i, \tag{1}$$

with $s(t)$ the step function ($s(t) = 1$ for $t \geq 0$ and 0 otherwise). We can then fit each of the time series with a piecewise linear continuous fit:

$$y_i = \begin{cases} \beta_0 + \beta_1 t_i + \beta_2 s(t - t_0) t_i + e_i & \text{if 'Edge',} \\ (\beta_0 + \beta_3) + (\beta_1 + \beta_4) t_i + (\beta_2 + \beta_5) s(t - t_0) t_i + e_i & \text{if 'Middle'.} \end{cases} \tag{2}$$

We can then test if the coefficient β_5 is zero.

The position of the break (t_0) is estimated using the same method as above: estimate the model for each break point and select the model with the smallest value of the AIC.

The resulting fit is shown with the time series of each of stations in figure 3.3. The coefficient β_5 differs significantly from zero. Furthermore, also in 'Edge' the discontinuity is significant ($\beta_2 \neq 0$). Therefore, both 'Edge' and 'Middle' decrease in time and for both this decrease is reduced from approximately 2014-03-05. However, for 'Middle' this decrease is much stronger than for 'Edge', suggesting that this difference is related to the gas production.

3.3 A smooth higher-order fit

As the time series is extended forward, attempting to capture the behaviour of the subsidence in terms of one or two linear trends with a single break or kink is likely to be increasingly inappropriate. Subsequent to January 2014 the gas production in the clusters at or near the more central GPS stations has varied substantially, and was increased, sometimes temporarily, even at those locations where a substantial reduction was implemented in Januari 2014. If the subsidence does respond to the gas extraction, its time behaviour must therefore similarly show

Figure 3.4 The unfiltered differenced time series of `edge' - `middle' with the fitted model : the lowest three Fourier components without a break.

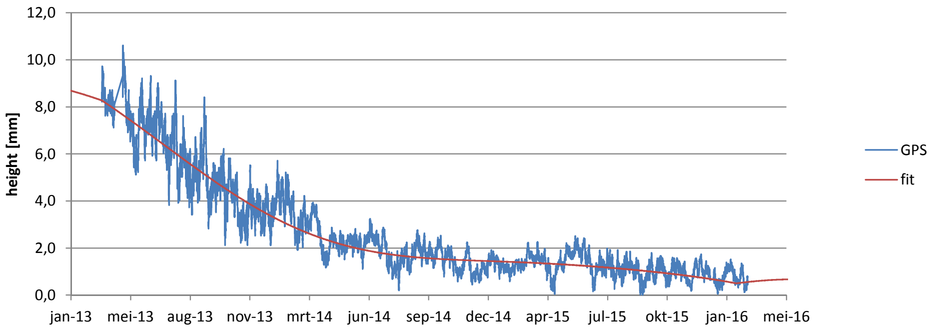
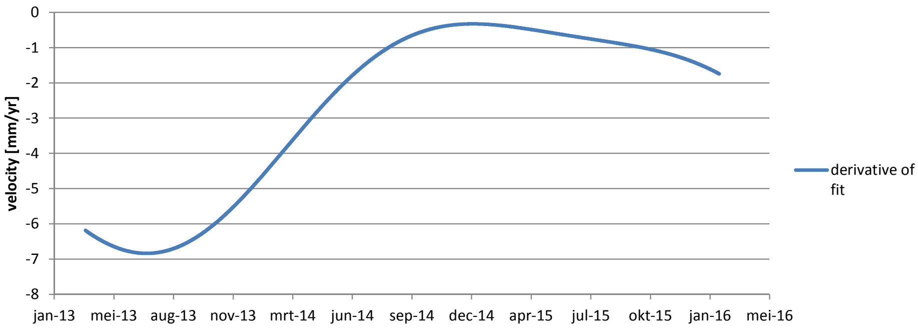


Figure 3.5 The derivative of the fitting function of Fig. 3.4 .

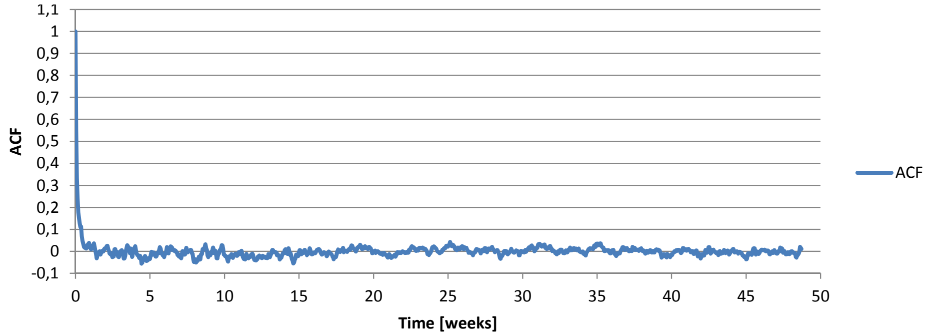


accelerations in subsidence as well as slowdowns. An alternative approach to the previous sections is to attempt a smooth fit and examine its slope.

Fig. 3.4 shows the data of the time series 'edge'- 'middle' without any filtering, in this case with an overall offset chosen to produce positive values for the entire series. Also shown is a fit, where the fitting function consists of the three lowest frequency Fourier components of a Fourier decomposition of this time series, with in Fig. 3.5 the time derivative of this fit, with units of [mm/year]. This shows that the rate of subsidence first decreases in absolute value, and after September 2014 slowly increases in absolute value to about −2 mm/yr in the most recent months. Evidently using only three Fourier components has the effect of broadening any transition in subsidence velocity both forward and backward in time. Even if the transition were sharper in reality, a fit such as this would not reflect this. The midpoint of the upward slope of the fit lies in March 2014, and the result is consistent with that of the previous sections.

The choice of using three Fourier components, rather than fewer or more, is guided by inspecting the autocorrelation function (ACF) of the residuals, after removing the fitted function from the unfiltered time series. This ACF is shown in Fig. 3.6. Using three Fourier components for the fit is the lowest number that produces an ACF for the residuals that drops to 0 within a week.

Figure 3.6 The autocorrelation function of the residuals when subtracting the fitted function from the unfiltered differenced time series of `edge' - `middle' .



4 Conclusion

In this paper an update is presented of the results obtained in previous reports (Pijpers, 2014; Pijpers and van der Laan, 2015a,b) using new, more recent data. The results obtained here are in line with the results obtained in the previous reports.

From the GPS data it can be concluded that there is continued subsidence of the ground in the area of the wells where production was reduced in the month of January of 2014. However, the rate of subsidence is lower some time after this reduction. The location of the break is around mid-March or very early in April, ie. approximately 9 weeks after the reduction in production, but there is a fair margin of uncertainty (some 2 weeks) around the exact value of the time gap.

While there is clear statistical evidence that a break has occurred in the subsidence rates, and the reduction in subsidence speeds is measurable with a high degree of precision, research is now in progress to perform a more systematic analysis of the correlation between the production time series and the GPS height time series. It is important to carry out more of such extensive correlation analyses in view of the fact that at all clusters the production rate continues to vary with time, even at clusters where production was substantially reduced in january 2014. The cluster of ten Post is an example where production was partially resumed towards december of that year. Also, over time there is likely to be a redistribution of gas throughout the field so that also the extraction of gas at locations quite distant from a particular GPS station near the middle of the subsidence bowl would have some delayed effect. It is recommended to continue monitoring of GPS signals, and attempt further improvements in the processing of GPS data.

References

Pijpers, F. (2014). Phase 0 report 1 : significance of trend changes in ground subsidence in Groningen. Technical report, Statistics Netherlands.

Pijpers, F. and D. van der Laan (2015a). Phase 1 update may 2015: trend changes in ground subsidence in Groningen. Technical report, Statistics Netherlands.

Pijpers, F. and D. van der Laan (2015b). Phase 1 update november 2015: trend changes in ground subsidence in Groningen. Technical report, Statistics Netherlands.

Publisher
Statistics Netherlands
Henri Faasdreef 312, 2492 JP The Hague
www.cbs.nl

Prepress: Statistics Netherlands, Grafimedia
Design: Edenspiekermann

Information
Telephone +31 88 570 70 70, fax +31 70 337 59 94
Via contact form: www.cbs.nl/information

Where to order
verkoop@cbs.nl
Fax +31 45 570 62 68
ISSN 1572-0314