Addendum to:
Hazard Assessment for the Eemskanaal area of the Groningen field

Eemskanaal Cluster with rig drilling Eemskanaal-13

Contents

Introduction

In discussion on the report "Hazard Assessment for the Eemskanaal area of the Groningen field" a number of questions were posed. Some of these required additional evaluation.

Clarification Production

The production forecasts have been made for the period from 1/1/2014, until the next anticipated ministerial decision based on winningsplan 2016 which is expected at 1/1/2017. Production from the field during this period is within the production limitations announced mid-January 2014. For the period up to October 2014 actual realised production volumes have been used in the history match.

Table of the hazard for city of Groningen and the eastern most outskirt of the city (labels GRON and GRON1 have been used as in the KNMI analysis).

Tables 1 and 2 below provide the PGA hazard values at these two addition surface locations.

Production Plan	Compaction Model	Seismological Model	PGA Hazard 0.2%/year	2%/year	10%/year
WIPLA STD	TD	AR	0.30g	0.09g	0.02g
Prod Restriction	TD	AR	0.28g	0.08g	0.02g
WIPLA STD	RTCiM	AR	0.32g	0.10g	0.02g
Prod Restriction	RTCiM	AR	0.29g	0.08g	0.02g
Model 2 (Str38) Ekl 5mln	RTCiM	AR	0.33g	0.10g	0.02g
Model 1 (Str40) Ekl 5mln	RTCiM	AR	0.29g	0.08g	0.02g
Model 2 (Str38) Ekl 8mln	RTCiM	AR	0.35g	0.10g	0.02g
Model 2 (Str38) Ekl 8mln	TD	AR	0.33g	0.10g	0.02g
Model 1 (Str40) Ekl 8mln	TD	AR	0.28g	0.08g	0.02g
Model 2 (Str38) Ekl 3mln	RTCiM	AR	0.33g	0.10g	0.02g
Model 2 (Str38) Ekl 3mln	TD	AR	0.32g	0.10g	0.02g
Model 1 (Str40) Ekl 3mln	RTCiM	AR	0.29g	0.08g	0.02g
Model 1 (Str40) Ekl 3mln	TD	AR	0.30g	0.08g	0.02g
Model 1 (Str40) Ekl 8mln	RTCiM	AR	0.30g	0.09g	0.02g
Model 2 (Str38) Ekl 5mln	TD	AR	0.32g	0.10g	0.02g
Model 1 (Str40) Ekl 5mln	TD	AR	0.28g	0.08g	0.02g
WIPLA STD	TD	SP	0.29g	0.08g	0.02g
Prod Restriction	TD	SP	0.27g	0.08g	0.02g
WIPLA STD	RTCiM	SP	0.28g	0.08g	0.02g
Prod Restriction	RTCiM	SP	0.23g	0.07g	0.02g
Model 2 (Str38) Ekl 5mln	RTCiM	SP	0.28g	0.09g	0.02g
Model 1 (Str40) Ekl 5mln	RTCiM	SP	0.24g	0.07g	0.02g
Model 2 (Str38) Ekl 8mln	RTCiM	SP	0.29g	0.09g	0.02g
Model 2 (Str38) Ekl 8mln	TD	SP	0.31g	0.10g	0.02g
Model 1 (Str40) Ekl 8mln	TD	SP	0.27g	0.07g	0.02g
Model 2 (Str38) Ekl 3mln	RTCiM	SP	0.28g	0.09g	0.02g
Model 2 (Str38) Ekl 3mln	TD	SP	0.30g	0.10g	0.02g
Model 1 (Str40) Ekl 3mln	RTCiM	SP	0.23g	0.07g	0.02g
Model 1 (Str40) Ekl 3mln	TD	SP	0.27g	0.08g	0.02g
Model 1 (Str40) Ekl 8mln	RTCiM	SP	0.23g	0.07g	0.02g
Model 2 (Str38) Ekl 5mln	TD	SP	0.31g	0.10g	0.02g
Model 1 (Str40) Ekl 5mln	TD	SP	0.27g	0.08g	0.02g

Table 1: Comparison of PGA hazard for different scenarios. TD, RTCiM denote the Time-Decay and Rate Type Compaction Isotach models. AR and SP denote the Activity Rate and Strain Partitioning models. PGA is evaluated at the location referred to as GRON1 by KNMI. This is located at (237.981, 583.850).

Production Plan	Compaction Model	Seismological Model	PGA Hazard 0.2%/year	2%/year	10%/year
WIPLA STD	TD	AR	0.23g	0.06g	0.01g
Prod Restriction	TD	AR	0.22g	0.06g	0.01g
WIPLA STD	RTCiM	AR	0.24g	0.07g	0.02g
Prod Restriction	RTCiM	AR	0.21g	0.06g	0.01g
Model 2 (Str38) Ekl 5mln	RTCiM	AR	0.29g	0.08g	0.02g
Model 1 (Str40) Ekl 5mln	RTCiM	AR	0.22g	0.06g	0.01g
Model 2 (Str38) Ekl 8mln	RTCiM	AR	0.29g	0.08g	0.02g
Model 2 (Str38) Ekl 8mln	TD	AR	0.28g	0.08g	0.02g
Model 1 (Str40) Ekl 8mln	TD	AR	0.21g	0.06g	0.01g
Model 2 (Str38) Ekl 3mln	RTCiM	AR	0.28g	0.08g	0.02g
Model 2 (Str38) Ekl 3mln	TD	AR	0.27g	0.07g	0.02g
Model 1 (Str40) Ekl 3mln	RTCiM	AR	0.22g	0.06g	0.01g
Model 1 (Str40) Ekl 3mln	TD	AR	0.22g	0.06g	0.01g
Model 1 (Str40) Ekl 8mln	RTCiM	AR	0.23g	0.06g	0.01g
Model 2 (Str38) Ekl 5mln	TD	AR	0.26g	0.07g	0.02g
Model 1 (Str40) Ekl 5mln	TD	AR	0.22g	0.06g	0.01g
WIPLA STD	TD	SP	0.21g	0.06g	0.01g
Prod Restriction	TD	SP	0.20g	0.05g	0.01g
WIPLA STD	RTCiM	SP	0.19g	0.06g	0.01g
Prod Restriction	RTCiM	SP	0.16g	0.04g	0.01g
Model 2 (Str38) Ekl 5mln	RTCiM	SP	0.25g	0.08g	0.02g
Model 1 (Str40) Ekl 5mln	RTCiM	SP	0.16g	0.04g	0.01g
Model 2 (Str38) Ekl 8mln	RTCiM	SP	0.25g	0.08g	0.02g
Model 2 (Str38) Ekl 8mln	TD	SP	0.25g	0.08g	0.02g
Model 1 (Str40) Ekl 8mln	TD	SP	0.19g	0.05g	0.01g
Model 2 (Str38) Ekl 3mln	RTCiM	SP	0.24g	0.07g	0.02g
Model 2 (Str38) Ekl 3mln	TD	SP	0.25g	0.08g	0.02g
Model 1 (Str40) Ekl 3mln	RTCiM	SP	0.16g	0.04g	0.01g
Model 1 (Str40) Ekl 3mln	TD	SP	0.19g	0.05g	0.01g
Model 1 (Str40) Ekl 8mln	RTCiM	SP	0.16g	0.04g	0.01g
Model 2 (Str38) Ekl 5mln	TD	SP	0.26g	0.08g	0.02g
Model 1 (Str40) Ekl 5mln	TD	SP	0.19g	0.05g	0.01g

Table 2: As Table 1 except for the location referred to as GRON by KNMI. This is located at (233.737, 582.054).

Additional discussion on the hazard response in the Eemskanaal area

PGA hazard values assessed in the vicinity of the city of Groningen do show some evidence of reductions due to reduction in the Eemskanaal production rate. The question is does the lower rate of closer seismicity within the Eemskanaal region or the higher rate of more distant seismicity around Loppersum govern the seismic hazard experienced within the city of Groningen? Groningen city is located 5-10 km from Eemskanaal and 10-20 km from the region of greatest seismicity around Loppersum. Disaggregation of the hazard results helps to answer this question by revealing the different contributions made by these different regions of seismicity. Figure 1 shows the hypocentral distance that contributes most to the PGA hazard in the city of Groningen is 10-20 km. At shorter hypocentral distances the contributions to the hazard are less due to the lower rates of seismic activity in these regions. At greater hypocentral distances the contributions to the hazard are less due to the greater distances. Similar effects are revealed in Figure 2 that shows the average hypocentral distance responsible for the hazard around the city of Groningen is about 15±5 km. Notably, this is twice the average hypocentral distance responsible for the maximum hazard around Loppersum. These disaggregation results demonstrate most of the seismic hazard experienced in the city of Groningen is due to seismic activity in the central region and not primarily due to seismic activity in the region of Eemskanaal.

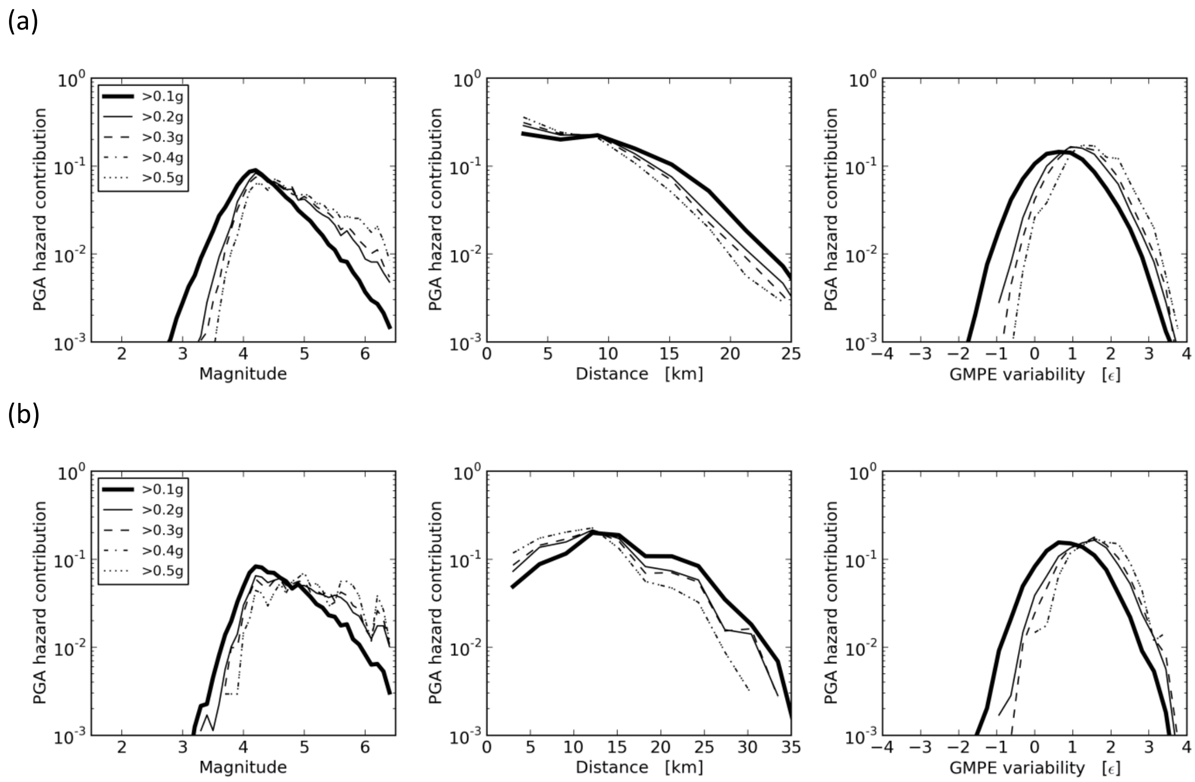


Figure 1: Comparison of hazard disaggregation curves obtained at two different surface locations (a) the location of maximum assessed hazard, and (b) the location of Groningen city.

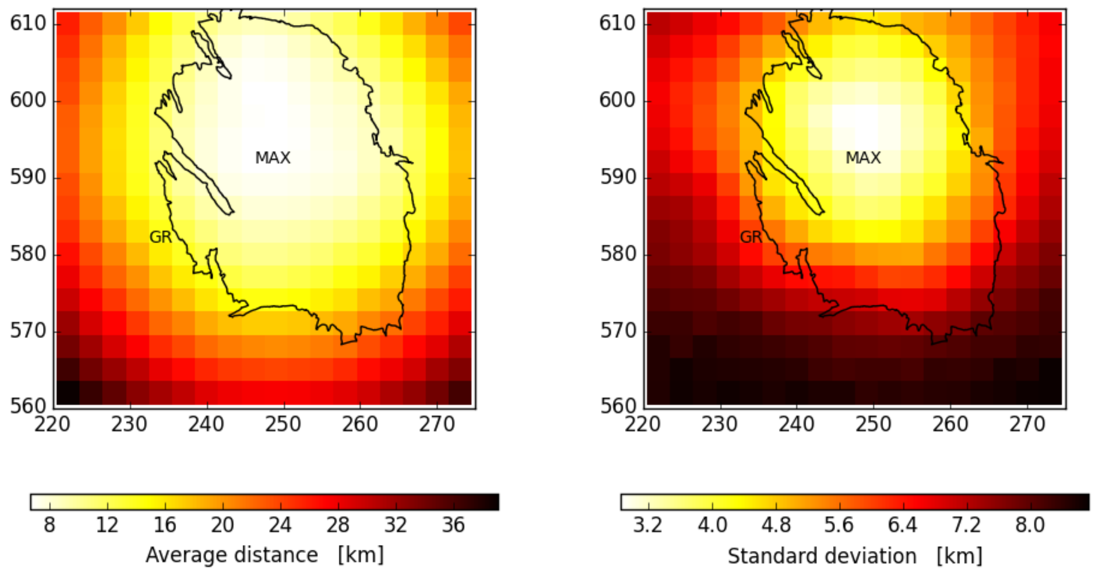
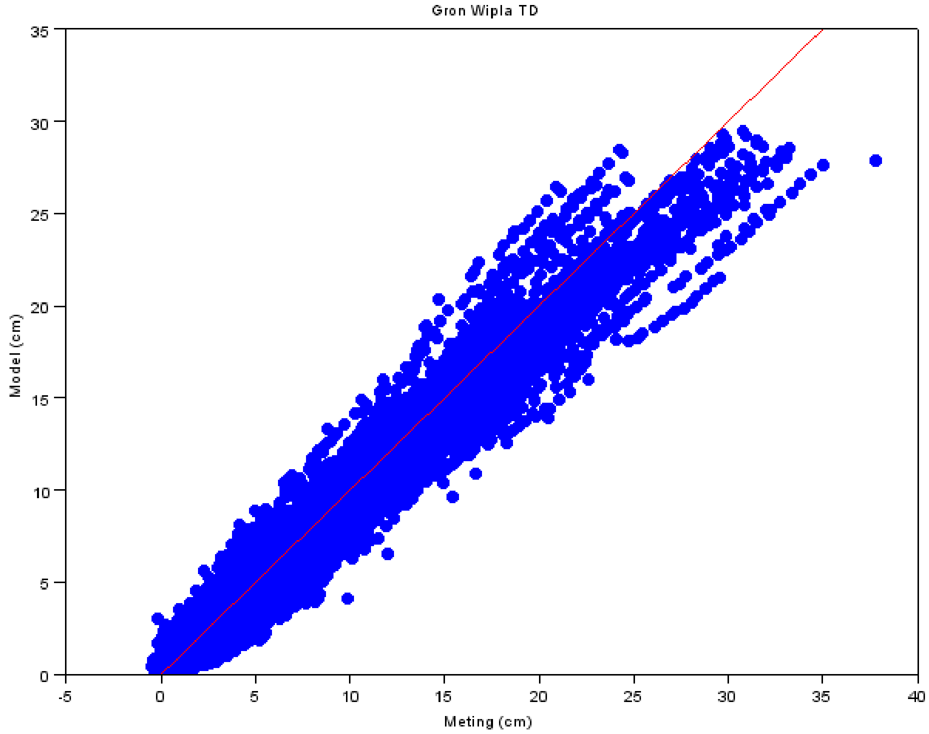


Figure 2: Hazard disaggregation maps showing the average the average hypocentral distance that contributes to the seismic hazard assessed at each map location (left), and the standard deviation in this average distance (right). Labels denote the locations of the maximum assessed hazard and Groningen city.

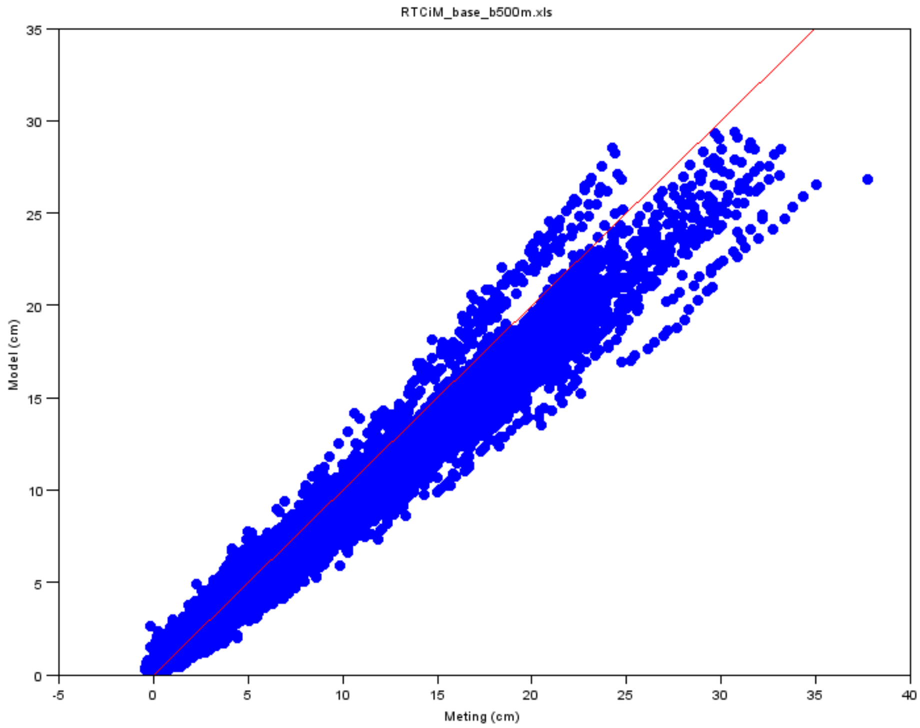
Crossplots of observed and calculated subsidence at the benchmark locations in the polygon area for the different subsurface models.

A Crossplots for contours plotted in Fig. 25 (Hazard Assessment for the Eemskanaal area of the Groningen field)

1) Measured vs modelled subsidence based on the G1 model used in de Winningsplan 2013 Time-decay compaction model for the period 1972 – 2012 (blue contour in fig. 25).

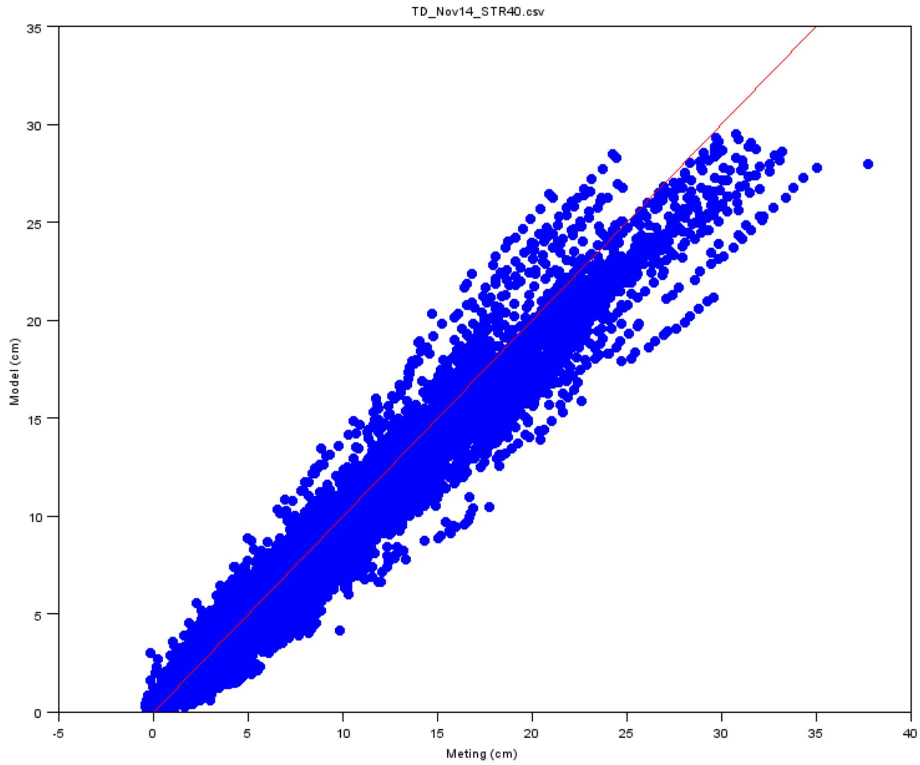


2) Measured vs modelled subsidence based on the G1 model used in de Winningsplan 2013 RTCiM compaction model for the period 1972 – 2012 (red contour in fig. 25).



B Crossplots for contours plotted in Fig. 26 (Hazard Assessment for the Eemskanaal area of the Groningen field)

1) Measured vs modelled subsidence based on subsurface model 1 (STR 40) and the Time-decay compaction model for the period 1972 – 2012 (red contour in fig. 26).



2) Measured vs modelled subsidence based on subsurface model 2 (STR 38) and the Time-decay compaction model for the period 1972 – 2012 (blue contour in fig. 26).