Draft Statistical Note: Regional Seasonal Patterns in Earthquake Rates

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1 Introduction

In our report "Statistical Methodology for Investigating Seasonal Variations in Rates of Earthquakes in the Groningen Field" we observed that for the Groningen field as a whole, there are seasonal patterns in the event rate. Strong evidence of seasonality was found for rates of events with associated magnitudes M<1, and some evidence for rates of events with 1 < M <1.5. No evidence was found of seasonality in rates of events with magnitudes M>1.5. This note seeks to investigate if there is a spatial dependence to these seasonal patterns.

2 Method

For the purposes of this note we divide the Groningen Field into four production areas; Loppersum, Oost, Zuidwest and Eemskanaal. The division is shown in Figure 1.

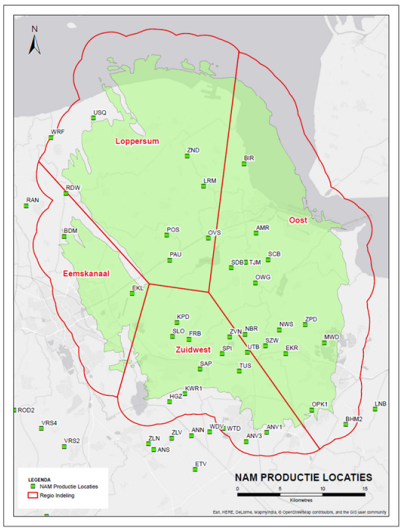

Figure 1: Map of the Groningen gas filed divided into four regions. The red lines show the division of the field into four production areas.

We have chosen this division based on discussion with NAM and other stakeholders. Next, a catalogue of events that have been recorded is downloaded. The download date was 9th September 2015. Each

event in the catalogue is assigned to a region based on the event's coordinates. We consider the events recorded between the 1st of January 1991 and the 31st of December 2013 for the purpose of this note. To demonstrate the seasonal variation we take a simple count of the events grouped by calendar month. We do this separately for events with a magnitude, M, greater than 0.5, 1.0 and 1.5.

We note that the probability that an earthquake with an associated magnitude $M \leq 1.0$, when it occurs within the Groningen field, is detected by the geophone network and included in the events catalogue (the so-called "inclusion probability") cannot be assumed to be unity nor to be spatio-temporally invariant. In this note we have assumed, in line with recent advice from the Dutch Meteorological Society (KNMI), that inclusion probabilities for events with magnitudes $M \geq 1.5$ can be assumed to be 1 or close to 1 throughout the Groningen field and throughout the time-series under consideration. We therefore use the terminology "Earthquake rate" or "Earthquake count" for observed counts or estimated rates of events with magnitudes $M \geq 1.5$. We use the terminology "Catalogue Rate" or "Catalogue Count" for observed counts or estimated rates of events with magnitudes $M \leq 1.0$.

3 Results

3.1 Spatial dependence: Catalogue rateM ≥ 0.5

Figure 2 shows the total number of seismic events across the entire field with a magnitude greater than 0.5. These are grouped by calendar month and includes all events from 1st January 1991 to 31st Dec 2013. This figure suggests that there is a seasonal pattern with fewer events in September and October and more in May and June.

Figure 3 shows the same data broken down by production area. This figure suggests some regional dependence to the seasonality. The Oost region appears to have the strongest seasonal pattern with a noticeable dip in the number of events around August and September. The Loppersum region shows a slight decline in number of activities towards the end of the year but this may be by chance. Eemskanaal and Zuidwest do not show any clear pattern. However these regions are smaller and so contain fewer data points.

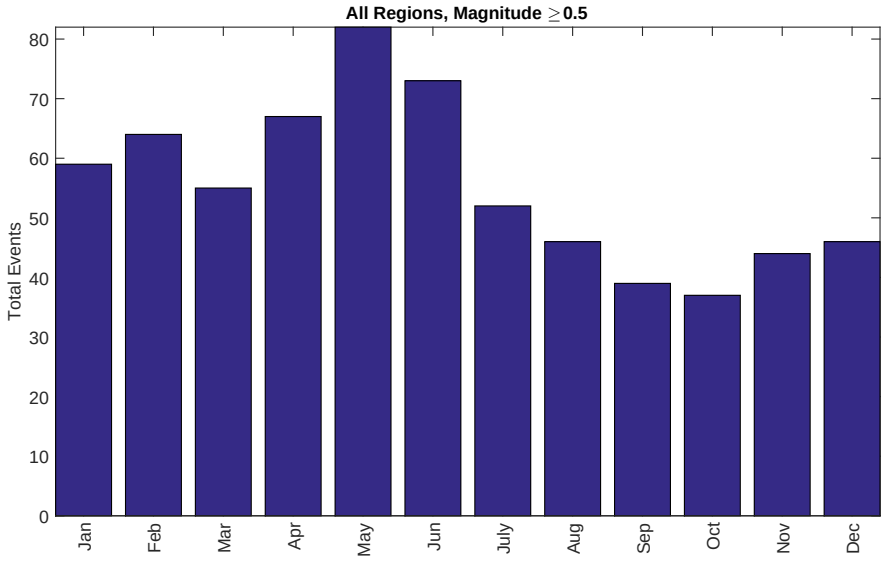

Figure 2: Seasonal pattern in activity rate broken down by region for events with M ≥ 0.5.

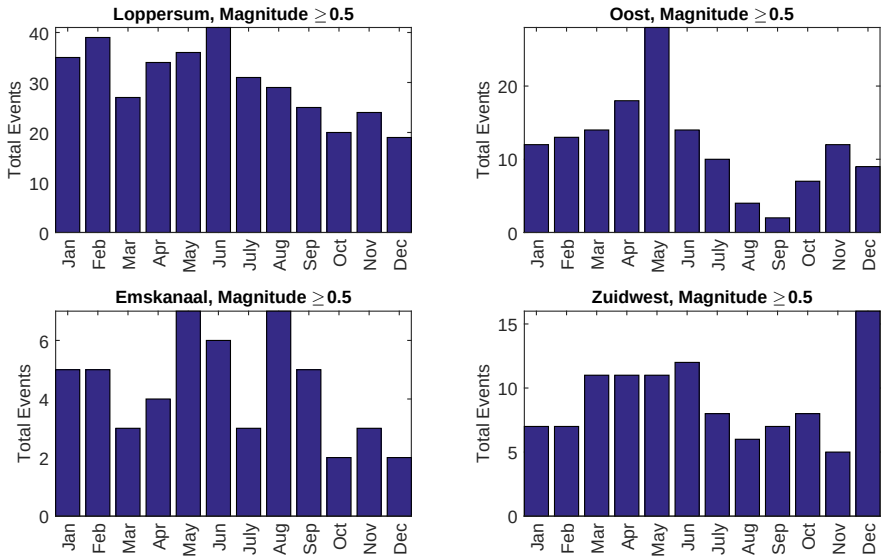

Figure 3: Seasonal pattern in activity rate broken down by region for events with M $\geq$ 0.5.

3.2 Spatial dependence: Catalogue rate. M$\geq$ 1.0

Figures 4 show the count by month for the overall field with M$\geq$ 1.0. This figure suggests that it is much more difficult to pick out a seasonal pattern in number of events for the whole field. However, looking at figure 5 which now shows the same data split by regions, we see that Oost again shows the clearest seasonal pattern with a dip in August and September. In this case the other three regions do not show any clear seasonal pattern.

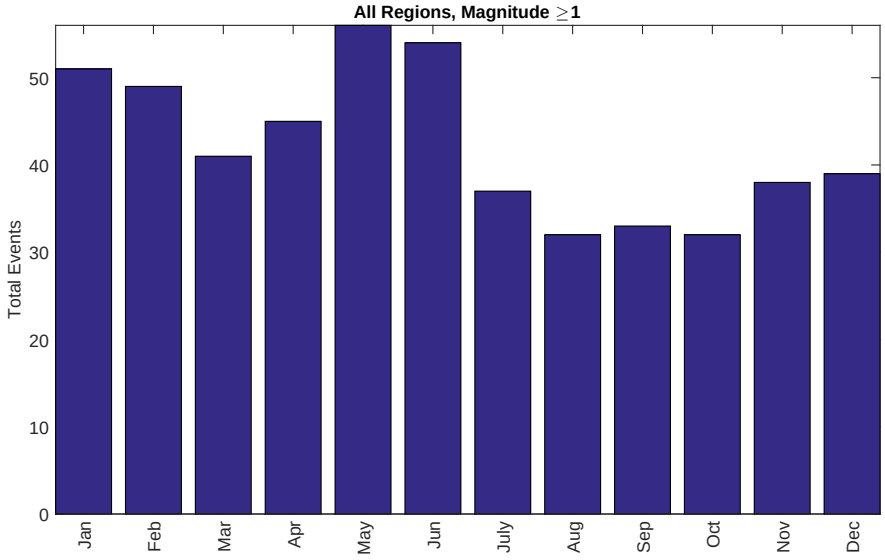

Figure 4: Seasonal pattern in activity rate for events with M$\geq$ 1.

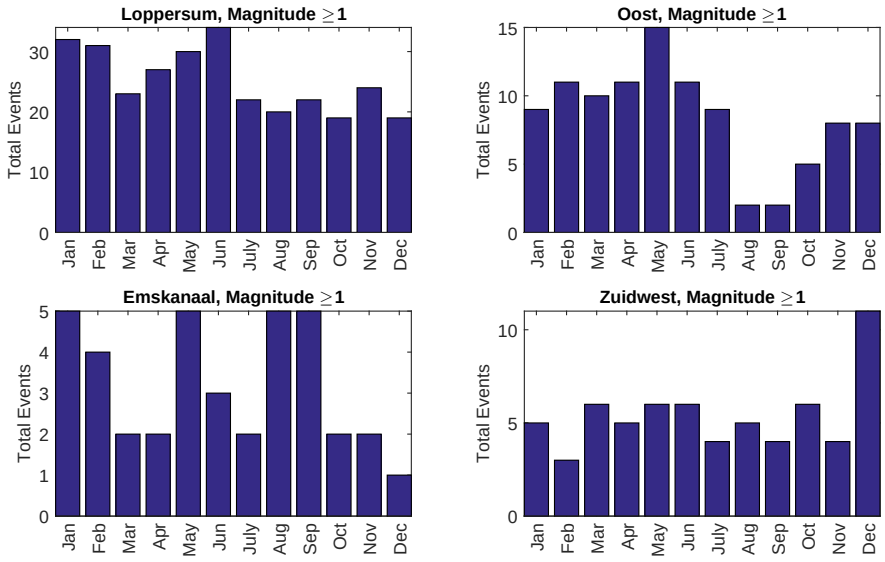

Figure 5: Seasonal pattern in activity rate broken down by region for events with magnitudes $\geq$ 1.

3.3 Spatial dependence: Earthquake rate M$\geq$ 1.5

Figures 6 shows the count by month for the overall field with M$\geq$ 1.5. It is evident that for the whole field, we do not see any seasonal pattern. Figure 7 show the plots for events with magnitude $\geq$ 1.5 broken by regions. Looking at a regional level we again see no clear seasonal pattern for any region. This is, in part at least, due to the lack of data as there are fewer events with M$\geq$ 1.5.

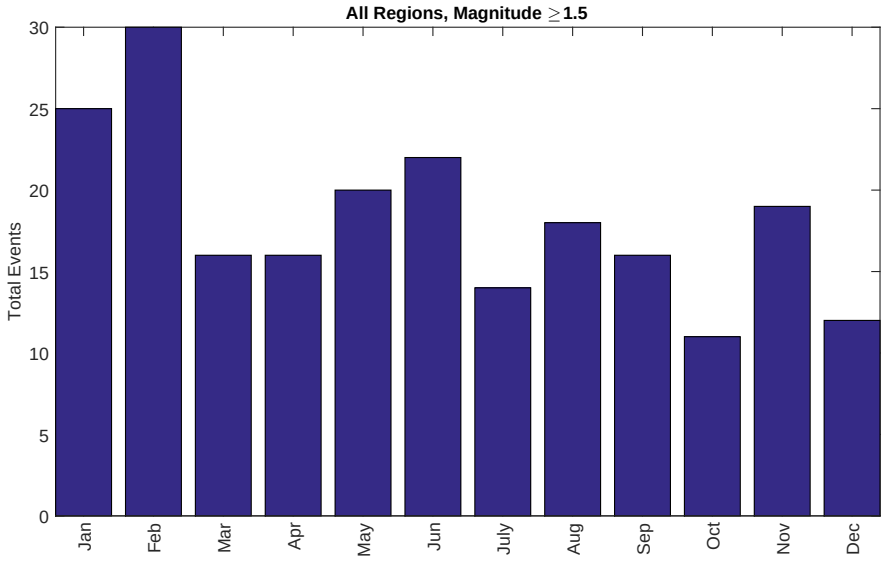

Figure 6: Seasonal pattern in activity rate for events with M $\geq$ 1.5.

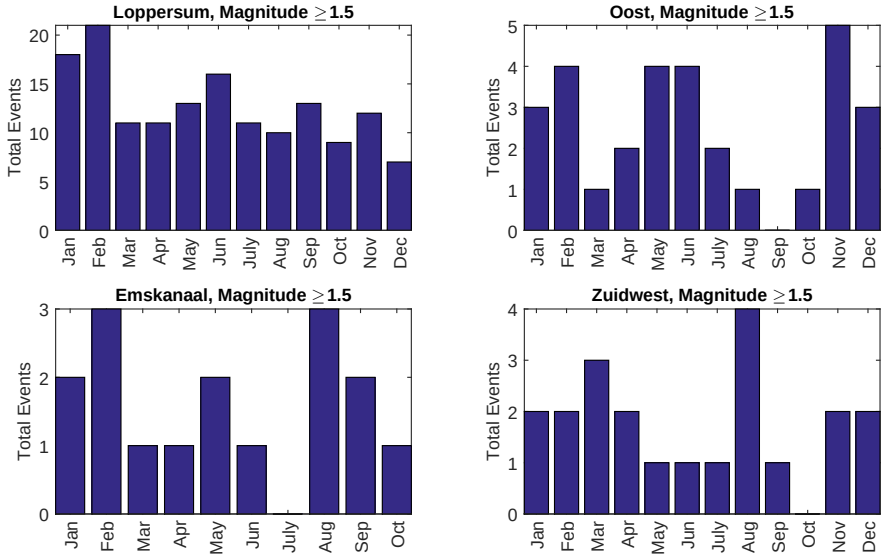

Figure 7: Seasonal pattern in activity rate broken down by region for events with M$\geq$ 1.5.

4 Conclusions

In conclusion, there is evidence for a seasonal pattern in the activity rates particularly for events with a M$\geq$ 0.5 and potentially for M$\geq$ 1.0 when the entire Groningen field is considered. There is evidence that this pattern is not constant spatially. The Oost region appears to have a more pronounced seasonal pattern than the other regions of the field. This evidence however is mostly qualitative. In order to establish the statistical significance of these patterns it will be necessary to take a quantitative approach. This may take the form of a significance test to establish how likely it is that this pattern has appeared by chance. It is also possible that this pattern can be explained by other variables such as the gas production rate. We note that it is unclear based on the current work, what the underlying cause(s) of these seasonal trends are, and the interpretation of this finding is made difficult in particular because of the possibility that this is partly or wholly caused by variability in probabilities that earthquakes with small event magnitudes are detected and recorded in the catalogue. More insight may be gained if in future a denser network of geophones is in operation.