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Evaluation of thunderstorm warnings in Belgium

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***Abstract*—A first attempt is made to evaluate thunderstorm warnings issued by the forecasters of the Royal Meteorological Institute of Belgium (RMIB) in between Jan 2011 and Dec 2016 by comparing those to the lightning activity as observed by the Belgian Lightning Location System (BELLS). The results serve as useful feedback to the forecasters in order to further improve future warnings. Overall, it is found that the warnings attributed to the south and southeastern provinces of Belgium are of somewhat higher quality compared to those in the west. This could result from the fact that the lightning density is observed to increase on average towards the south and southeast of Belgium; augmenting the chance of actually observing electrical activity when a warning is issued for those particular areas. The annual warning quality is rather stable, with an observed minimum in 2013. Furthermore, it is found that the forecasts tend to be better during the summer compared to the winter months, inherently related to an increased occurrence of thunderstorms in summer. Finally, warning performance increases with the severity of the observed thunderstorms.**

***Keywords*—thunderstorms, forecasting**

I. INTRODUCTION

In recent years, the prediction of severe and hazardous weather has grown in importance to ensure public safety and to protect property. In addition, forecasting of extreme weather is regarded as highly beneficial as well for instance for aviation and the electric power industry, transportation and agriculture. In general, severe weather is short lived and due to its meso-scale character affects typically local areas, while adjacent regions are left untouched. Therefore, one of the core tasks of the forecasters at the Royal Meteorological Institute of Belgium (RMIB) is to issue province-specific severe weather warnings. Those encompass warnings for instance for the occurrence of heavy rain, high winds, fog, slippery conditions, heat waves and last but not least thunderstorms. Depending on the severity of the event happening and the impact it may have on society, a specific warning level is assigned indicating the severity of the forecasted event.

A range of different observational instruments and numerical models help the forecasters assessing the need to warn for severe weather on a short and/or medium time scale. For instance, precipitation observations from the radar network, together with satellite imagery provide a good idea of the horizontal and vertical extent of a developing thunderstorm at a certain moment. Furthermore, wind, temperature and humidity measurements of the automatic weather stations complement the latter. However, in the end, the forecaster must weigh up the possible severity of the weather conditions and the likelihood of their occurrence to make a correct judgment. On top of that, there is the issue when to send out the warning to the public. If the lead time is too small, there may be no time to take action, whereas a warning with a too large lead time may become forgotten.

Knowledge of the quality of the warnings is the key to further improve upon. For this, an objective verification of thunderstorm warnings in Belgium is computed.

II. DATA

RMIB has been operating the Belgian Lightning Location System (BELLS) since 1992. BELLS processes in real-time as of September 2017 VHF data of four SAFIR sensors and LF data of five LS7002 sensors, located in Belgium and owned by RMIB. In addition, raw data from sensors owned by neighboring partners and located in France, the Netherlands and Germany are shared in real-time; increasing the amount of LS7002 sensors in BELLS by eight. In this way, intracloud (IC) as well as cloud-to-ground (CG) electrical activity are monitored in high quality over Belgium and its surroundings. The locations of the sensors in the neighborhood of Belgium are displayed in Fig. 1, together with the abbreviations used to denote the nine different provinces which will be used in some of the figures throughout the paper.

Each warning is linked to an individual province with among others an indication of the validity period in hours and time stamp of the start of the warning. However, in this study the warning valid time is taken to be 24h for simplicity. This implies that when a warning is issued for instance from 0400 UTC to 2100 UTC, the warning period is modified to be valid

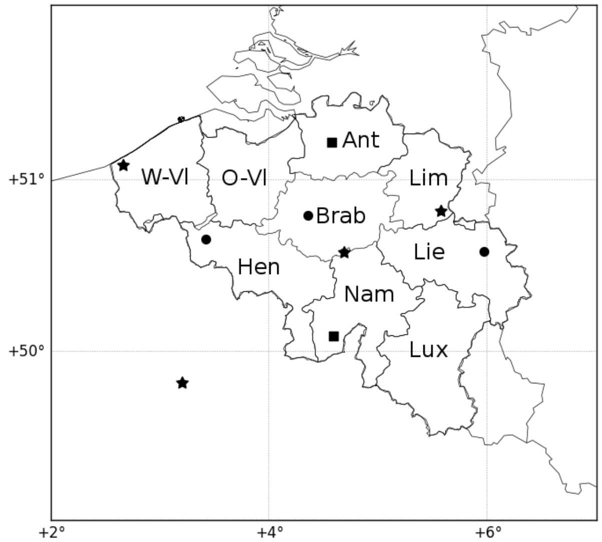

Fig. 1: Locations of some of the BELLS sensors in and within the neighborhood of Belgium (● = SAFIR, * = LS7002, ■ = SAFIR & LS7002).

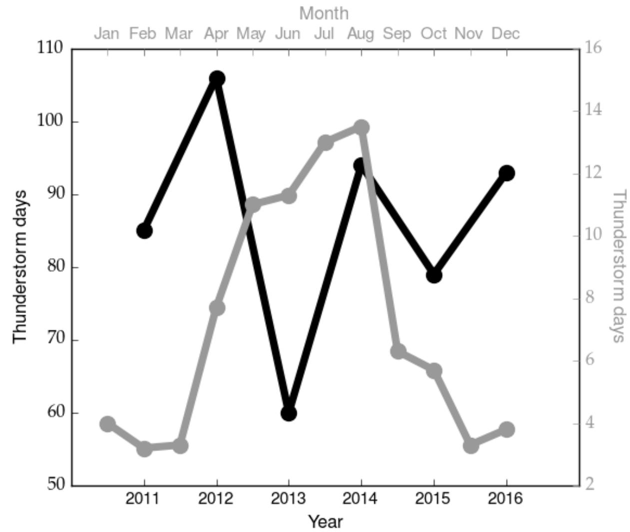

Fig. 2: Distribution of the annual and monthly average amount of thunderstorm days observed in Belgium.

during the entire day from 0000 UTC to 2400 UTC. In addition, in case multiple warnings are given for a specific day, the most recent issued one is used. Furthermore, each warning receives a so-called warning level (ranging from 1 to 3) related to the forecasted severity of the event. However, no distinction is made between the warning levels in the remainder of the paper. Thus, all warnings are evaluated as equal.

III. Methodology

The lightning observations of BELLS and thunderstorm warnings by the forecasters are dichotomous, meaning it is either 'yes' or 'no'. Hence, it is straightforward to produce a 2x2 contingency table (see Table I) in which a hit (A) is defined as a yes/yes event, meaning lightning was observed and a thunderstorm warning was in effect. A miss (C) is defined as a yes/no event: lightning was observed, but without a thunderstorm warning. A no/yes event is known as a false alarm (B), indicating that there was no observed lightning, but a thunderstorm warning was in effect. In general, thunderstorm warnings and occurrence can be considered as rare events. As a result, the total amount of 'no' warning and 'no' observation (D) outweighs the other elements in the contingency table. It is thus wisely to neglect the latter when measuring the warning quality. Hence, focus is on the Probability of Detection (POD), False Alarm Ratio (FARatio), Bias, and Critical Succes Index (CSI), defined as:

Table I.

2x2 Contingence table		Event observed	
		Yes	No
Warning	Yes	A (hits)	B (false alarms)
	No	C (misses)	D (correct negatives)

$$POD = A/(A+C) \quad (1)$$

$$FARatio = B/(A+B) \quad (2)$$

$$Bias = A+B/(A+C) \quad (3)$$

$$CSI = A/(A+B+C) \quad (4)$$

From the equations, it follows that POD is the fraction of the number of hits and the total number of lightning events observed. The FARatio divides the number of false alarms by the total number of warned events. Therefore, the FARatio is conditioned on warnings rather than observations. The Bias

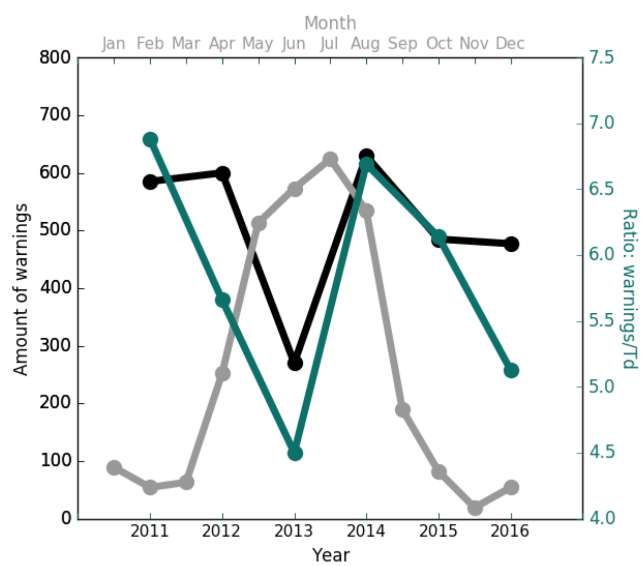

Fig. 3: Distribution of the annual (black) and monthly amount of thunderstorm warnings (grey), as well as the ratio of the amount of warnings and thunderstorm days (green).

measures the ratio of the frequency of warned events to the frequency of observed events. It indicates whether the warning system has a tendency to under-warn (Bias < 1) or over-warn (Bias > 1). Finally, CSI measures the fraction of observed and/or warned events that were correctly predicted, and gives a sense of accuracy when correct negatives (D) are not considered.

IV. RESULTS

Fig. 2 plots in black the annual distribution of thunderstorm days (T_d) over the years 2011 until 2016. As expected, the distribution of T_d experiences a natural annual variability, with an observed maximum of 110 days in 2012 and a minimum of 60 days in 2013. The distribution of the average monthly amount of T_d is shown in Fig. 2 in gray. The amount of T_d is highest in between May to August. This is not surprising since about 95% of all the observed lightning activity occurs within those months (Poelman et al., 2014).

Fig. 3 plots the total amount of warnings sent out as a function of year (black), i.e. the sum of the warnings for each of the nine provinces. It is found that 2013 received the least amount of warnings, being 270, whereas the year after, in 2014, this amount increases to 629 warnings. However, it is expected that the amount of warnings is somewhat proportional to T_d. Hence, the ratio of the amount of warnings and T_d is supposed to be similar over the years. However, this ratio is plotted in green in Fig. 3 and varies between 4.5 and 6.8. This ratio is at a minimum in 2013 and has an average of 5.9, i.e. approximately six out of nine provinces received a warning for each observed thunderstorm day in Belgium. The monthly distribution of warnings is shown as well in Fig. 3. Not surprisingly, this distribution mimics the behavior as in Fig. 2, with the highest amount of warnings found in July.

The annual variability of POD, BIAS, FARatio and CSI, color-coded by province, is plotted in Fig. 4 a–d, respectively. In addition, the average of all the regions is plotted in red. Average POD values range in between 0.6 and 0.7, except in 2013 with a minimum of approximately 0.4. This minimum in 2013 results from the fact that more thunderstorms were not warned for compared to the other years, as can be seen from the lower ratio of the amount of warnings and thunderstorm days as plotted in Fig. 3. Nevertheless, even when neglecting 2013, an average POD of about 0.65 can be perceived as rather moderate. However, as mentioned earlier, the forecasters do not send out warnings for every expected thunderstorm but only for those that have the potential to cause disruption at ground. Hence, this will influence the value of "C" considerably and consequently has a decreasing

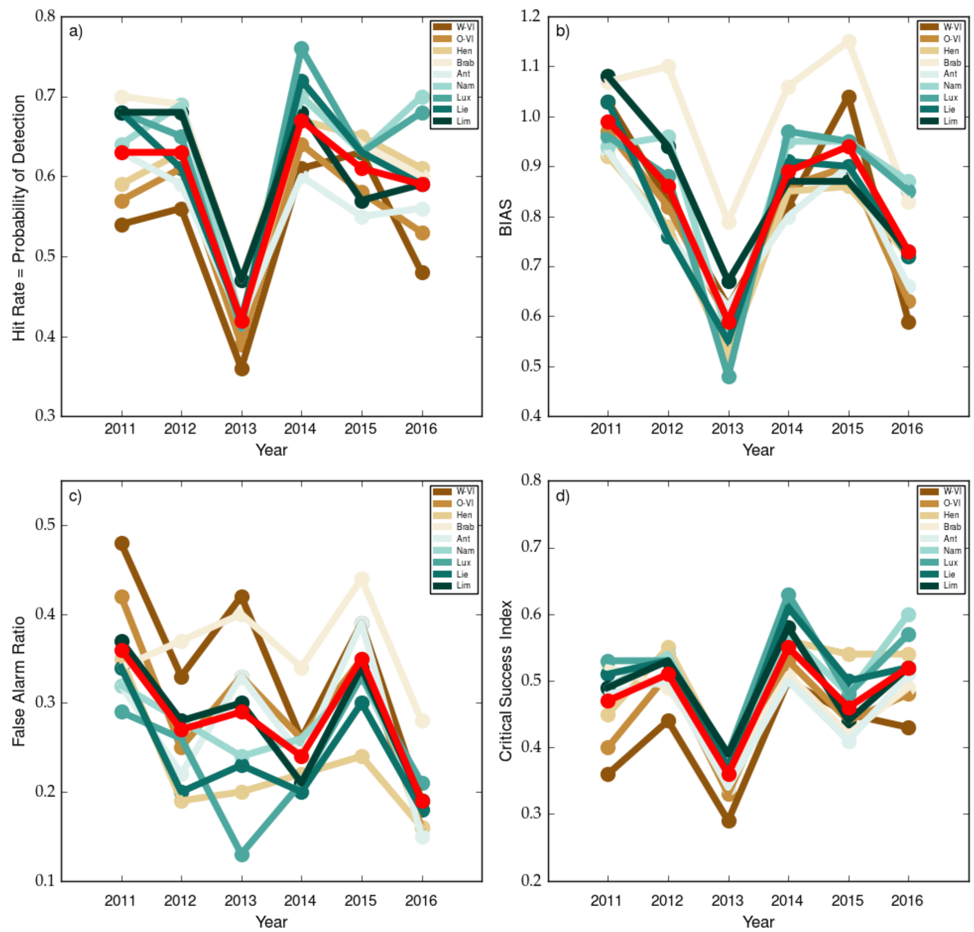

Fig. 4: Annual distribution of a) POD, b) Bias, c) FARatio and d) CSI. Each province is given a specific color. In addition, the average value over all the provinces is plotted in red.

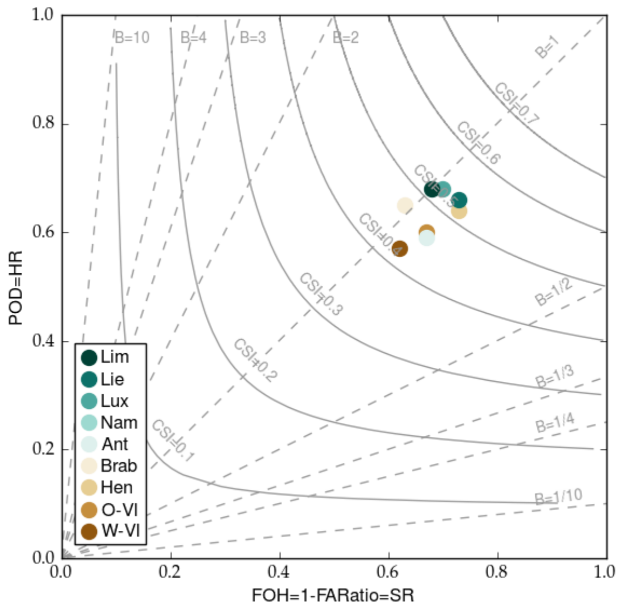

Fig. 5: Roebber plot, assigning a single quality value per province averaged over the period 2011−2016.

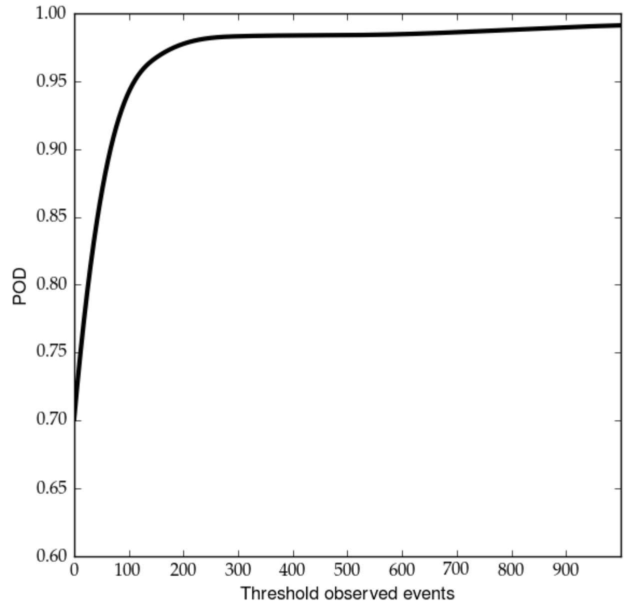

Fig. 6: Change of POD when a threshold for the amount of observed lightning discharges is introduced.

effect on POD. A similar trend is found for the Bias with an observed minimum in 2013. Averaging over the years, the bias is about 0.9, close to unity. The FARatio, plotted in Fig. 4c, shows a gradual decrease from 2011 to 2016, with an average value of approximately 0.3. Such a low FARatio is desired, since it limits the generation of unwanted alarms. Finally, CSI varies around 0.5. Overall, it is found that the provinces in the west of Belgium (brownish colors) perform slightly worse compared to the ones in the east (greenish colors) over the years. This will be made clearer later on.

It is possible to relate POD, FARatio, Bias and CSI in a single plot in order to visualize the warning quality at one glance. This is can be done in a so-called Roebber plot, which assigns along the X-axis the Success Rate (SR) and along the Y-axis POD (Roebber, 2009). Note that SR is simply 1−FARatio. As such, moving to the right in the plot means a reduction in FARatio, while moving up is an increase in POD. It follows that a perfect score would then lie in the upper right corner of the figure. In Fig. 5 a single value is calculated, averaged over the years 2011−2016, and assigned to each of the provinces. Note that the solid contours represent CSI, while the dashed lines display the Bias. It is clear that the three most eastern provinces in Belgium, being “Lim”, “Lie” and “Lux” have a POD which is about 0.1 higher compared to “O-Vl” and “W-Vl” located in the west. The same holds for SR. This could result from the fact that the lightning density is observed to increase on average towards the south and southeast of Belgium (Poelman et al., 2014); augmenting the chance of actually observing electrical activity when a warning is issued for those particular areas.

Let’s come back now once more to the value of POD. Up to now, POD has been measured taken into account all days with lightning activity. This includes days for which only a single lightning discharge was observed within a certain province. Introducing a minimum threshold on the amount of lightning events that needs to be observed during a single day per region makes it possible to monitor the effect on POD since days with lightning activity below the threshold are excluded and no longer taken into account in the contingency table. This is done in Fig. 6, where the threshold ranges from 1 to 1000 lightning discharges. It is found that POD increases sharply when the threshold is increased from 1 to 200, whereas after that the increase is moderate with increasing threshold. Thus, larger electrically active thunderstorms tend

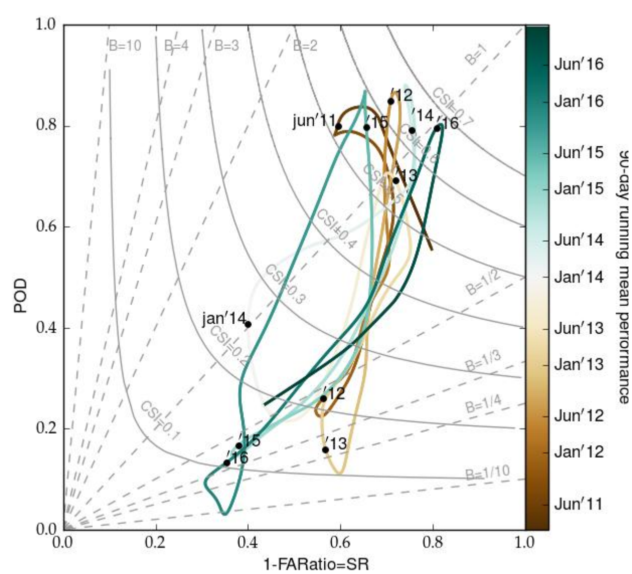

Fig. 7: Roebber plot, applied over the entire period from 2011−2016, showing the smoothed three month running mean.

to have a better POD compared to weaker ones. This is again related to the strategy of the forecasters to only send out warnings for potentially dangerous events.

Finally, Fig. 7 illustrates the trend in warning quality when a moving three months average (of all the provinces combined) is applied over the entire period 2011−2016. Additionally, a local regression with a light smoother is used to remove sudden irregularities in the behavior. Along the line in the plot January and June of each year is indicated for clarity. Overall, a better performance during summer is noticed, compared to the winter months. A minimum (maximum) in the warning quality is the result from a larger fraction of low (high) POD, BIAS and SR warnings, respectively, during winter and autumn (spring and summer). This is not surprising since during the warm season thunderstorms tend to be larger and are potentially more dangerous. Hence, forecasters anticipate by sending out warnings more frequently during summer compared to winter; decreasing the amount of misses.

V. SUMMARY AND CONCLUSIONS

The impact of severe weather on society and the economy cannot be underestimated and will increase even further in the future with the ongoing growth of cities and associated infrastructure. Whether or not located in high-risk areas, accurate forecasts and warnings, both in space and time, are therefore in high demand.

In this paper, six years of thunderstorms warnings in between 2011 and 2016 over Belgium have been evaluated. It is found that the warnings in summer are of considerable higher quality than in winter. However, this is related to the forecasters' strategy to warn solely for those thunderstorms that have a high probability to cause damage at ground, occurring primarily in summer. On the level of the individual provinces, it becomes evident that there is a discrepancy between the western and eastern provinces, with a higher quality for the latter.

REFERENCES

Poelman, D. R. (2014), A 10-year study on the characteristics of thunderstorms in Belgium based on cloud-to-ground lightning data, Mon. Wea. Rev., 142, 4839-4849, doi:10.1175/MWR-D-14-00202.1.

Roebber, P. J. (2009), Visualizing multiple measures of forecast quality, Weather Forecasting, 24, 601-608, doi:10.1175/2008WAF2222159.1