A radar-based lightning nowcasting system in the Netherlands

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Introduction

Lightning is a serious weather hazard that has to be considered with every outdoor activity. Specifically, it has a major impact on aviation, not only in-flight, but also on airside operations at an airport. If thunderstorms are active at or near an airport, fuelling and handling are suspended to ensure the safety of ground personnel, and this can seriously affect the operation of an airport as a whole. The aviation meteorologists at KNMI issue Aerodrome Warnings for four airports in the Netherlands: Amsterdam Airport Schiphol, Rotterdam The Hague Airport, Maastricht Aachen Airport and Groningen Airport Eelde. Lightning that is expected to occur – or has just occurred – at or near one of these airports, be it cloud-cloud or cloud-ground, is one of the criteria for the issue of such a warning. The aviation meteorologist is then to contact the Airside Operation Manager by telephone. The AOM is responsible for informing all parties on airside when handling is to be stopped and then started again. After this has been done, other parties, such as Air Traffic Control, are informed as well.

Lightning activity is monitored in the Netherlands by FLITS (Flash Localization by Interferometry and Time of arrival System). If thunderstorms have already formed upstream of an airport, this information is often sufficient to assess the risk of lightning occurring at or near the airport, also making use of forecast radar imagery. Until recently, when large-scale meteorological conditions could not rule out the development of thunderstorms and a cumulonimbus cloud was developing near the airport, it was hard for the meteorologist to tell whether (and when) it would produce lightning. In this paper, a new radar-based lightning nowcasting system is introduced with the name Preflits ("flits" is the Dutch word for flash). Preflits has been developed to increase the warning time for the first lightning strike within developing thunderstorms by using three-dimensional radar reflectivity data to monitor the charge separation process that is taking place within developing storms. The objective is to increase thunderstorm forecast skill, e.g., for TREND forecasts and Aerodrome Warnings produced by the aviation meteorologists. Preflits consists of two radar-derived fields acting as a set of two thunderstorm nowcasting predictors. Both predictors are based on volumetric reflectivity data from the radar combined with isothermal height data from direct numerical weather prediction model output. In April 2012, meteorologists at KNMI started using Preflits on an experimental basis. In December 2012 Preflits was integrated into the RADIS radar software already in use at KNMI (RADar DISplay, a dedicated Java application for displaying radar data), thus acquiring an operational status. The tool has been found to add significant added value for nowcasting and for distinguishing thunderstorms from ordinary showers.

Theoretical Basis

The most common theory on charge separation within cumulonimbus clouds is by collisions between hydrometeors in the vertical layer between -10 and -40°C. In particular the presence of graupel roughly between -10 and -20°C is strongly associated with the "charging" process within a storm cloud. Three-dimensional radar information can thus help identify the storm cells in which the process of charge separation is sufficiently taking place to produce lightning. Mosier et al. (2011) have tested several radar-based lightning nowcast predictors. They were the first to objectively analyze an enormous number of unique storm cells (67,384) and lightning flashes (1,028,510) to determine the best forecast criteria based on radar-derived lightning predictors. Earlier studies had been based on only used a few tens of hand-picked storm cells. Based on the study by Mosier et al. (2011), the Vertically Integrated Ice (VII) and a dimensionless Criteria-Index (CI) were chosen as radar-derived lightning nowcasting predictors for Preflits. By using both a vertically integrated and a radar reflectivity forecast method, we follow the recommendation of Mosier et al. (2011): "A combination of the radar reflectivity forecast method and the VII forecast method can potentially be used to provide better results." Although we acknowledge that there may be regional differences in the quantitative interpretation of their results, we do expect that the results of their study will indeed apply qualitatively for the Netherlands.

Radar data

KNMI operates two identical Meteor 360AC C-band Doppler weather radars from SELEX, formerly known as Gematronik. They are located at KNMI in De Bilt (5.17834E 52.10168N) and at a naval base in Den Helder (4.78997E 52.95334N), 98.5 km apart. The radars use a parabolic antenna with diameter of 4.2 meter, offering a 1 degree beam width. The operational scanning of the KNMI weather radars generates a 14-elevation volume every 5 minutes. Figure 1 displays the Volume Coverage Pattern of the KNMI weather radars. For the calculation of the VII and the CI, both radar scans are combined for each 1x1 km pixel in the radar template.

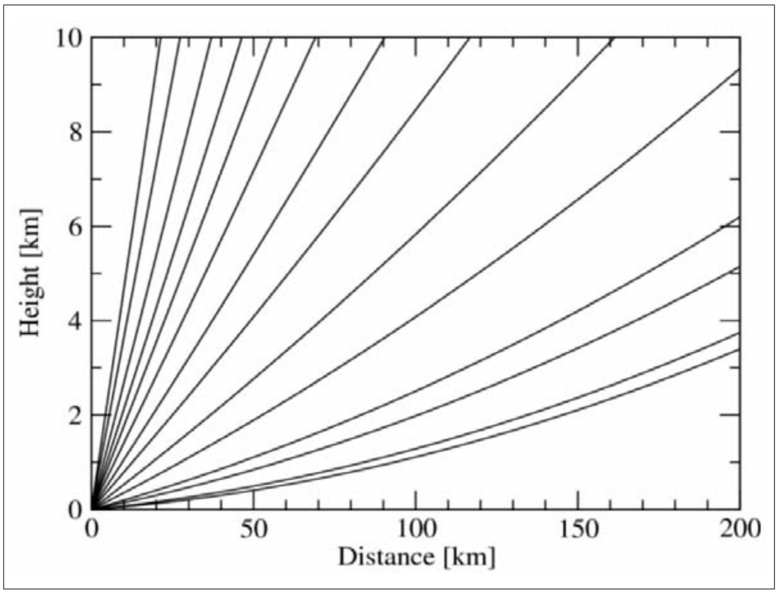

Figure 1: volume Coverage Pattern of both KNMI radars with 14 elevation angles: 0.3, 0.4, 0.8, 1.1, 2, 3, 4.5, 6, 7, 10, 12, 15, 20, and 25°.

VII and CI

The VII is an estimation of the airborne "ice mass" per square metre in the vertical layer between the -10 and -40°C isotherm levels, based on merged 3D radar information. The height of these isotherm levels are calculated with the most recent output of the 3-hourly HiRLAM 11 km NWP model. They are determined for each 1x1 km pixel in the radar template, using the nearest-neighbour model grid point and interpolating between time steps of 1 hour.

The CI combines six dichotomous radar-based lightning nowcast predictors, that were all tested by Mosier et al. (2011), see their Table 3:
35 dBZ/-10°C | 40 dBZ/-10°C | 30 dBZ/-15°C | 35 dBZ/-15°C | 40 dBZ/-15°C | 30 dBZ/-20°C

In the dimensionless CI, "35 dBZ/-10°C" contributes 1 if a reflectivity of ≥35 dBZ is encountered by at least one of the two radars at or higher than the -10°C level, otherwise it contributes 0. Likewise, all six predictors contribute either 0 or 1 to the CI. Each radar pixel can therefore have a value of 0 to 6. The VII and CI are left undefined where the distance to both radars exceeds 240 km. In rare cases of very cold air, the -10°C isotherm may be close to the surface, causing an underestimation of the VII and the CI, as can be seen from Figure 1.

Figure 2 shows an example of the VII and the CI, for a case of clustered wintertime thunderstorms. Lightning activity was mostly confined to the areas with VII ≥ 1.0 kg/m² and CI ≥ 4.

Operational use at KNMI

Based on the operational experience of over one year, we can give a reasonable estimate of lightning risk within 20 minutes for a storm cell in which the VII exceeds certain thresholds:

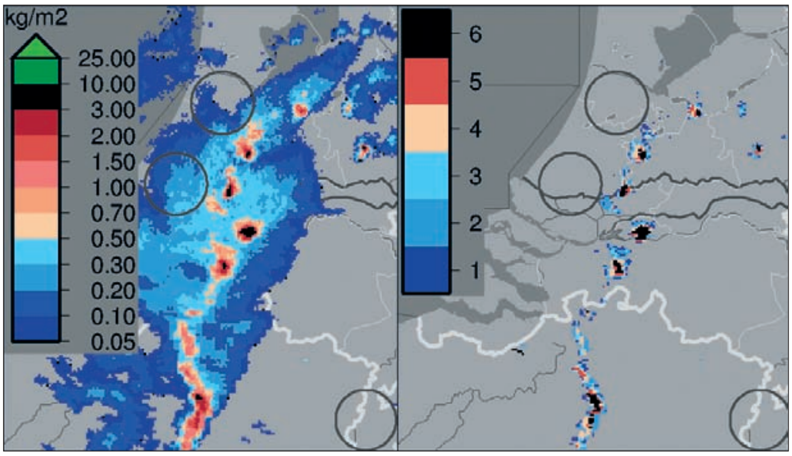

Figure 2: example of the VII (left) and the CI (right) for the SW- and S-part of theNetherlands, 3 Jan 2014 at 1600 UTC. From north to south, the dark grey circles mark the 15km radius around Amsterdam Airport Schiphol, Rotterdam The Hague Airport and Maastricht Aachen Airport.

VII	Indication for next 20 minutes
0.5 kg/m^2	10% risk of lightning (yellow)
1 kg/m^2	50% risk of lightning (orange-red)
2 kg/m^2	90% risk of lightning (dark red)
≥ 10 kg/m^2	Summer hail diameter ≥ 0,5 cm likely (dark green)
≥ 25 kg/m^2	Summer hail diameter ≥ 2,0 cm likely (light green)

Our experience with the CI is, that generally at least 4 out of 6 criteria need to be met for the onset of lightning within a storm. So on average, the best condition for lightning seems to be VII ≥ 1.0 kg/m² and CI ≥ 4. The equations to calculate the estimated VII are based on assumptions about precipitation type et cetera. This partly explains why the best VII and CI thresholds vary on different days. Therefore, if there is a mix of thundery and non-thundery showers, it is best to determine a 'VII of the day'. VII is used as the main predictor, mainly because the overall storm structures are better visible than with the CI, as can be seen from Figure 2. The CI tends to function as a 'second opinion'.

Once lightning is occurring within a thunderstorm, the meteorologist wants to predict the cessation of lightning within that storm. The VII and the CI do give information about the (re)charging that is taking place within a storm, but well-organized thunderstorms (especially Mesoscale Convective Systems) tend to produce lightning long after the VII and the CI have dropped to values below the optimum thresholds. However, Preflits does enable the meteorologist to better monitor the (re)charging process within a thunderstorm.

A particular type of lightning discharge is Aircraft-Induced Lightning (AIL). This is lightning caused by aircraft charging up and 'triggering' the lightning. We have had a few incidences of AIL since Preflits has been in use, and a lightning strike often seemed very unlikely according to Preflits. This result confirms that AIL can occur within storms that are much less charged than the storms that produce natural lightning strikes and that the meteorologist should not rule out AIL based on Preflits, if conditions for AIL are favourable, see Wilkinson et al. (2013).

References:

Mosier, Richard M., Courtney Schumacher, Richard E. Orville, Lawrence D. Carey (2011), Radar Nowcasting of Cloud-to-Ground Lightning over Houston, Texas. Wea. Forecasting, 26, 199–212. doi: http://dx.doi.org/10.1175/2010WAF2222431.1

Wilkinson, J. M., Wells, H., Field, P. R. and Agnew, P. (2013), Investigation and prediction of helicopter-triggered lightning over the North Sea. Met. Apps, 20, 94–106. doi: http://dx.doi.org/10.1002/met.1314