# THE BENEFITS OF GLD360 LIGHTNING LOCATION DATA IN OPERATIONAL WEATHER FORECASTING

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# I. INTRODUCTION

Besides weather radars, lightning location system (LLS) is one of the most efficient tools to pinpoint the location of thunderstorms and to estimate their intensity. Traditionally LLS, operated typically by the national meteorological services, covers areas critical to lightning like airports or the area of the country. However, the LLS may also have a global coverage like Vaisala's operated Global Lightning Dataset GLD360. A global LLS has several practical benefits in storm detection. First of all, the large detection area makes possible to detect thunderstorms at the further range than national LLS. It can also give an early warning of approaching severe weather way before the national weather radar network or LLS. Typically, weather radars in operational weather radar networks have measurement ranges of 250 km. This is specifically the case in cold climates, where precipitation occurs in a shallow layer limiting the detection range. The situation is different in the tropics, where the height of the tropopause can be more than 15 km and deep convection with thunderstorms can reach extreme altitudes. The combination of lightning and radar data tells more about the type, severity and life cycle of the phenomena compared to the measurement done with a single instrument.

In this paper we compare GLD360 measurement to NORDLIS lightning detection network situated in Scandinavia showing the GLD360 performance in northern Europe, i.e., at the boundary region of the GLD360 detection area. The results indicate that although the GLD360 detection efficiency is lower than the NORDLIS network (which also detects cloud flashes), GLD360 still provides usable lightning data even at high latitudes. We also introduce new way of enlarging severe storm detection that can applied anywhere in the world based on GLD360 data set and weather radar data. The case studies show that combined GLD360 lightning and radar data could give up to an hour or more of lead time beyond the range of available weather radar measurements.

# II. COMPARISON OF GLD360, NORDLIS AND WEATHER RADAR

An example of how a wide-coverage LLS complements severe weather detection of both a typical national weather radar network (here the Finnish Meteorological Institutes, FMI) and a smaller-coverage LLS is shown in Fig 1. The efficient detection area of the weather radar network is shown with light-grey colour, and the dark grey colour indicates the coverage of the NORDLIS LLS.



FIG. 1: GLD360 lightning locations on July 21, 2011. The color bar on the left shows the UTC hour of the lightning activity. The lightgrey color indicates the FMI weather radar coverage, and the darkgrey color the coverage of the NORDLIS LLS. A total of 62980 located flashes on the area.

The GLD360 area of detection covers both of these and beyond, as can be seen from the located flashes on July 21, 2011. It shows clearly the benefit of severe weather observations from multiple sources. When measuring precipitation the weather radar data is the most informative source of data, but relatively small coverage does not allow the detection of storms until they arrive close enough to the network i.e. less than 250 km from the nearest radar in this case. A national-scale LLS provides data from a larger area, but still the efficient area of detection is limited. However, if we combine the data set from a global lightning location system like GLD360 (Demetriades 2009), we can monitor severe storms way before they arrive to the monitored area. Actually the detection area is unlimited, but the occurrence of lightning is of course needed.

Validating the accuracy of the GLD360 data, we have compared it against the data from the NORDLIS LLS (Tuomi 2008). The NORDLIS data includes three categories: (i) first cloud-to-ground (CG) strokes (usually termed as flashes), (ii) all CG strokes, and (iii) all events. The category (iii) contains also cloud flashes, because they are also detected by NORDLIS to some degree. In this comparison we have used only category (i) data of NORDLIS. Also, we have filtered from the NORDLIS data all positive flashes with peak current below 10 kA, because their nature (i.e., whether they are cloud or ground flashes) is not always clear. We also tested 15 kA limit for the peak current and it gives almost the same results. The comparative data set contains lightning location data from a total of 97 days (May 5 – August 9 2011). We must note that all the comparisons in this study are relative to NORDLIS; NORDLIS performance is considered to be better in its efficient coverage area, because the sensors density is high and the sensors baselines much smaller than those of GLD360. However, like any other LLS, the NORDLIS detection efficiency is not 100%.

# **III. RESULTS AND CONCLUSIONS**

## a) Relative Detection Efficiency

The relative detection efficiency (RDE) of GLD360 has been calculated by dividing the number of GLD360 lightning locations by the number of NORDLIS first-stroke lightning locations from the same area. The area used here is narrowed to 59-70°N, 21-31°E to ensure that the NORDLIS data is as homogenous as possible. We have also calculated the GLD360 RDE on day-to-day basis, to show the daily variation during the study period.

The total number of GLD360 and NORDLIS firststroke lightning locations from the study period is 154336 and 197695, respectively. This leads to a GLD360 RDE of 78%. However, the day-to-day variation is large (Fig. 2): for some days the GLD360 RDE is close to 100%, but values as low as a few percent and above 100% also exist. The variation is most likely due to some combination of individual storms characteristics, hourly dependence of storm occurrence, and current sensor redundancy in the region. Additional GLD360 sensors are currently being installed in the region to improve redundancy.



FIG. 2: Day-to-day variation of the GLD360 relative detection efficiency (RDE) May 5 - August 9, 2011. Blue bars indicate the number of NORDLIS first strokes (values in the left y-axis), red indicate GLD360 RDE (percentages, second y-axis).

### b) Hour-to-hour variation

Figure 3 shows the hour-to-hour variation of located GLD360 and NORDLIS events. The same features are visible for both networks, i.e., most of the events are located on average at 12 UTC (15 local time), which is simply related to the occurrence of most of the storms at this time. The GLD360 hourly RDE (yellow) shows mostly only some minor variation, but a larger drop is at 8-9 UTC. The reason for this needs to be explored further and may depend on sample size during this time period and/or changes in the earth-ionosphere waveguide as a function of time of day. The mean RDE is 78%.

#### c) Relative location accuracy

GLD360 compared to NORDLIS, we have studied a subset of temporally matched events (time difference between GLD360 and NORDLIS first stroke at most 1 ms). In this comparison we have used only the most accurate and reliable NORDLIS first strokes (estimated location uncertainty below 500 m). The total number of common events decreases to 23945, but is still statistically representative. However, the results are not straightforward to interpret, because we do not have exact information about the NORDLIS absolute location accuracy.



FIG. 3: The hourly distribution of located GLD360 events and NORDLIS first strokes. Blue: NORDLIS, red: GLD360, yellow: GLD360 hourly RDE (triangles) and its mean value (horizontal line).

In Figure 4 we have plotted all the GLD360 temporally matched events (red) relative to the corresponding NORDLIS first strokes (origin). There is an interesting Southwest-Northeast oriented pattern, which is most likely caused by a systematic error produced by one sensor covering the region. A combination of (1) identifying and removing this systematic sensor error and (2) additional sensor installations in the region will improve location accuracy in the NORDLIS region. However, the mean (median) location difference is good 9.4 km (7.5 km). About 5% of GLD360 events are within 1 km, 15% with 2 km, 37% within 5 km, and 90% with 16 km.



FIG. 4: Spatial differences of temporally matched GLD360 (red) and NORDLIS (origin) lightning locations.

To study the relative location accuracy (RLA) of

#### d) GLD360 Overall Performance in Scandinavia

Finally, we show how the performance of GLD360 varies regionally, and vice versa, how the NORDLIS performance varies relative to GLD360. In Figure 5 we have calculated the relative detection efficiency of GLD360 (as in Section a) in 10 km x 10 km squares in the whole NORDLIS coverage area. However, in this comparison we have used all the NORDLIS events, i.e., including also subsequent CG strokes and cloud flashes. This way we can determine especially the outer boundaries of the NORDLIS coverage area.

As is seen in Figure 5, there is a sharp boundary in the NORDLIS performance: for example, at the eastern border of Finland and in southern Sweden, the GLD360 RDE jumps above 100%, indicating that GLD360 is detecting more events. Figure 5 clearly shows that the smallor medium-coverage LLS such as NORDLIS, is efficient especially inside the network coverage area, but the efficiency drops rapidly when approaching the network boundaries.



FIG. 5: The relative detection efficiency (percentages) of GLD360 versus all NORDLIS events in 10 km x 10 km squares from May 5-August 9 2011. Purple color indicates RDE above 100%.

#### e) GLD360 Combined with Weather radar data

Finally we show an example of the combination of weather radar and GLD360 data. In Fig. 6 on left panel is shown the storm situation indicated in red 3 hours before the radar is detecting the storm first time. At first, the cluster of GLD360-detected strokes is not accompanied by radar returns outside the 450-km range on the bottom of the left panel in Fig. 6, but then the storm moves over Latvia and Lithuania within radar range as seen in Fig. 6 on right panel.

As a result, GLD360 data provides lead time for thunderstorms of interest within the radar's range, in this case three hours. Also additional strokes in other storms were apparent in these 15-minute time segments. Since lightning does not always directly correspond with radar reflectivity, the thunderstorm lifecycle and threat information from the combined dataset is greater than either dataset shown separately. The GLD360 as a global data set can be applied like this anywhere in the world.

#### f) Conclusions

We have shown some performance characteristics of the Vaisala global lightning detection system (GLD360). The performance analysis has been made relative to the NORDLIS lightning location system, situated in the northern Europe (Norway, Sweden, Finland, Estonia). NORDLIS is considered to be a stable and well-performing system, so that its data can be considered as a ground truth in the study.



FIG. 6: Reflectivity measured by Vaisala WRM200 weather radar combined with the lightning strokes of 15 minutes accumulation indicated in red measured by GLD360. The first detection of the storm approaching Scandinavia was detected by the GLD360 in the bottom of the left panel. In right panel, 3 hours afterwards, storm reaches the radar coverege.

The overall performance of GLD360 based on the NORDLIS comparison is giving the similar results compared to the comparison with National Lightning Detection Network (NLDN) data in USA. The detection efficiency of ground flashes is better than 70%, although there is some day-to-day variation, and location accuracy is 5 to 10 km. This comparison on the northern location is showing that GLD360 has nearly uniform performance globally. If the performance is checked against all NORDLIS events (i.e., including all CG strokes and cloud flashes), the efficiency drops, which is not a surprise because NORDLIS or any other local network detects a large number of weak events which in practice can not be detected with a global network with sensor baselines of thousands of kilometres.

Our results suggest that GLD360 is especially useful for providing lightning location data outside of the coverage of the national lightning location network giving more timeliness for the detection severe weather. Also, for areas to which it is not practical or feasible to implement a smallscale LLS network, GLD360 is capable of providing efficient lightning location data.

## **IV. REFERENCES**

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