GROUND-TRUTH FROM THE LIGHTNING DETECTION NETWORK LINET IN EUROPE FOR THE INTERPRETATION OF THUNDERSTORM-RELATED DATA COLLECTED BY SPACE-BORNE SENSORS

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Abstract

The lightning location network LINET has started continuous operation early in 2006 and covers large parts of Europe, approximately the area from longitude 10°W - 26°E to latitude 35°N - 66°N. It has been developed by the atmospheric research group in the Physics Department of the University of Munich, and undergoes permanent evaluation, partly in co-operation with scientific partners and national weather services. nowcast GmbH organizes the network operation as exclusive provider of continuous real-time lightning data for the German Weather Service, and continues to expand the covered area; as of May 2008, a total of 90 sensors are utilized.

Since the network is able to report total lightning (cloud-to-ground and cloud strokes), electrical activity of thunderstorms can be investigated in great detail. Tests in Brazil have shown that LINET detects and locates cloud lightning better than the Tropical Rainfall Measuring Mission (TRMM) Lightning Imaging Sensor (LIS). Due to high detection efficiency and the ability to monitor cloud activity, LINET allows recognition of severe weather conditions. Moreover, nowcasting becomes possible even with relatively simple algorithms.

At present, the combination of lightning with other meteorological data sources is examined. Special attention is given to the comparison between lightning data from LIS and LINET, with the aim to contribute to the planning basis for future space-born lightning sensors. Especially satellite data from the different Meteosat Second Generation (MSG), TRMM and A-train sensors are utilized to examine correlations between lightning observations and microwave brightness temperature, IR radiance, cloud top temperatures, vertical structure of the clouds, and precipitation fields. It is investigated to what extent various satellite data can be utilized to derive thunderstorm features in areas where no high-quality ground-based lightning detection network is available.

LIGHTNING LOCATION WITH LINET IN EUROPE

LINET has been developed to achieve high performance standards by means of an easy-to-handle and economic 4-part modular design, employing up-to-date technology in all components (Betz et al., 2008). Module 1 consists of two crossed loops that serve as passive sensor for magnetic field components without making use of any active electronics. Two sensor loops oriented orthogonal to each other measure the components Bₓ(t) and Bᵧ(t) of the magnetic flux directly as a function of time in the frequency range of interest without having the need for subsequent integration. This feature is helpful for the treatment of small signals close to the noise level. Signal timing is achieved by means of a GPS clock with an accuracy of better than 100 ns (module 2). Special and partly sophisticated measures are taken to transport this level of basic accuracy as far as possible to the actual event timing. Signal amplification, filtering, AD-conversion and data processing are performed with a single plug-in device (module 3) in a separately positioned processing unit (module 4). No allowance for rearm time must be provided (zero dead-time). As regards signal rates, usually a rate of less than 100 strokes/s has been observed, even during storms in central Africa.
Figure 1: Location of 90 LINET sensor sites as of May 2008.

Figure 2: Example for a large storm detected with LINET (02 June 2008).
All signals are treated irrespective of their waveform; notably, discrimination between cloud-to-ground (IC) and cloud (IC) strokes is performed not by means of finding shape differences between IC and CG pulses, but by a specially adopted 3D-algorithm in the central processing unit. While smaller versions of LINET have produced real-time data for more than 10 years, especially in southern Germany, the international European network started operation on 01 May 2006 and presently comprises some 90 sensors (Fig. 1); in southern Germany the sensor density is relatively large because of continued research with respect to extremely weak lightning signals and other open issues in lightning research. Otherwise, the concept aims at a baseline of 200 – 250 km in order to enable 3D discrimination between CG and IC, reasonably well fulfilled within Germany and several other countries, but some areas await completion and expansion of the network geometry. Fig. 2 shows lightning locations retrieved during a storm that extended from northern Great Britain to southern Greece. In areas near and beyond the network borders, and also over the Sea, the detection efficiency decreases so that only stronger strokes will be located; still, storms can be identified far away and traced over long paths.

RECOGNITION OF SEVERE WEATHER

It is well known that IC activity and especially large increases of the IC flash rate within a short time often correlate with the advent of severe weather (Williams et al., 1999). In a significant number of storms particularly strong convection rapidly develops and, in rare cases, leads to supercells (Tessendorf et al., 2008). For many practical applications it is advantageous to both recognize a severe cell at an early stage and predict cell development in time and space. Fig. 3 shows the time evolution of CG and IC stroke rates for two cases, a typical cell (left) and a more rare situation (right) indicating severe weather conditions.

Figure 3: Example for the stroke evolution in normal (left) and strong (right) storms, detected with LINET.

Corresponding information can be visualized from 3D-plots of LINET strokes. Since IC strokes are reported with their individual emission height, differences between weak and strong storm can be seen quite easily: Fig. 4 presents an example for the two cases. We note that these images can be extracted in near real time, including ‘flights’ around the storm cells.

Figure 4: Example for the visualization of normal (left) and strong (right) storms, detected with LINET (Betz et al., 2008).
COMPARISON BETWEEN LINET AND LIS DATA IN BRAZIL

During an international campaign DLR has temporarily set up a 6-sensor LINET version around Bauru in Brazil. Lightning data was measured in order to correlate with storm-induced NOx production in the atmosphere. Since LIS passes over Brazil a data comparison could be made.

An overpass lasts approximately 90 sec; Fig. 5 presents the LINET and LIS counts recorded during a relatively strong storm: both systems detect active areas though LIS is sensitive to hot lightning channels while LINET measures the acceleration of neutralizing charges. It is important to note that the LINET graph contains mostly weak IC strokes, not seen effectively by other VLF/LF networks. When time-coincident events are selected (<~1 ms), the location difference becomes evident. Since it is known from other comparisons that LINET locates better than 500m, the LIS location error can be estimated; it amounts to several km. Likewise, the corresponding range-normalized current of LINET strokes can be extracted; it turns out that the coincident events are mostly weak and show a peak around 3 kA, a value that is smaller than the one found for all detected strokes (<~10 kA).

All together it may be stated that data from satellite-based lightning sensors can be tested quite well by means of ground-based networks, provided that these exhibit sufficient detection efficiency for both CG and IC lightning. This condition can be fulfilled with LINET, as long as sensor baselines do not exceed ~250 km; otherwise, low-current strokes are not recorded at as many sensors as required for locating. In addition, the network must be capable of reporting IC lightning with adequate efficiency.
CORRELATION BETWEEN DATA FROM LINET AND OTHER SPACE-BORN SENSORS

Apart from direct lightning detection by means of space-born sensors, a number of additional data sources are available that relate to convection and thunderstorms. In Fig. 7 (left) the base reflectivity is depicted for a thunderstorm area that has developed on 20 July 2007 (COPS experiment); for the corresponding area and time the right part of Fig. 7 shows ice scattering as sensed with AMSRE 89 GHz radiometer (cold brightness temperatures; Prigent et al., 2005). In both cases, excellent agreement is obtained with lightning data. Further work will be focussed on the detailed time-evolution of the shown phenomena. For example, the question can be studied with what probabilities can a region with depressed brightness temperature be regarded to indicate upcoming thunderstorm activity and what leading times can be achieved. For comparisons of this kind, lightning data as provided by LINET can be utilized, because it offers high detection efficiency with the inclusion of substantial amounts of cloud lightning.

Figure 7: Radar mosaic of base reflectivity (COPS campaign, left) and AMSRE 89 GHZ brightness temperatures recorded on 20 July 2007 between 12:37 and 12:39 UTC with concurrent overlaid LINET data (right).

Figure 8: 85 GHZ (vertical polarization) SSMI without (left) and with (right) LINET observations at 19:30 UTC over France on 04 July 2006 (only SSMI observations with longitudes East of Greenwich meridian are plotted).
Fig. 8 presents the microwave brightness temperatures sensed by the SSMI sensor at 85 GHz in vertical polarization. The presence of cloud ice in convective areas induces scattering, i.e. a depression of the brightness temperatures. When one overlays lightning activity one can readily identify the areas with significant scattering effects. Thus, extending the above, lightning data can be exploited to recognize convection and, moreover, it might help to distinguish convective and non-convective regions. As a further consequence, rain retrievals could be better interpreted when lightning-based discrimination of convective and non-convective regions is considered that are produced due to different cloud microphysical circumstances.

As a last example we present in Fig. 9a-e correlations between LINET, A-TRAIN observations, i.e. 89 GHz radiometric plots, infrared data, radar data, and cloud top levels. Panel a shows the lightning activity in a large area, whereby the colors indicate time intervals. The evolution of stroke rates is depicted in panel b. The other panels c, d and e focus on a small convective area near Genova: the brightness temperatures are clearly depressed (panel c), indicating deep convection, confirmed by LINET strokes in panel d and by the vertical cross section of radar reflectivity measured by CLOUDSAT. Also shown in panel e is the edge of the highest cloud level measured with the lidar CALIOP. The radar reflectivity suggests that the cloud top exceeds 10 km height. Obviously, lightning data can accurately pinpoint convective areas especially when overlaid on IR imagery.

**Figure 9:** Multi-instrumental observations on the 15th and 16th of August 2006. (a): spatial distribution of the lightning activity as sensed by LINET between 15/08/2006 12:00 UT and 16/08/2006 12:00 UT; (b): lightning total (IC+CG) fix rate per 5 min (in blue) and ratio of total negative strokes per 5 min (%. in green); (c): A-Train AMSRE 89 GHz V brightness temperatures over the Ligurian Sea at 01:40 UT on the 16th of August 2006; (d): A-Train IIR 10.6 µm radiances with overlay of LINET observations between 01:39 and 01:42 UT; (e): vertical cross section of reflectivity from A-Train CLOUDSAT radar and top (bottom) of the first cloud layer measured with A-Train CALIOP lidar in red (white). CLOUDSAT ground track is plotted as a solid line in panels (c) and (d).

**CONCLUSION**

A new European lightning detection network (LINET) has been briefly described. The most novel features are high detection efficiency, i.e. recording of weak discharges, and its ability to locate both ground strokes and cloud lightning over large areas. It has been discussed in which ways lightning
data with these qualities can be utilized to compare with and interpret data from various space-born devices, such as lightning sensors, microwave and IR imagers, and rain/cloud radar. Indications are given that allow further research with respect to better understanding of significance and potential of such sources. Since lightning data is available without time delay over large, though limited areas, it can be useful for complementing nowcasting procedures.

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