Striking Lightning

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Will we ever harness the power of lightning? Probably yes, but first we need to answer some fundamental questions, because we've really just begun to tap into the secrets of atmospheric electricity

People are not commonly aware that the air we breathe contains thousands of charged aerosol particles per cubic centimeter, or that we live in a persistent natural electric field creating a voltage of more than 200 volts between the levels of our feet and head, even during fair weather conditions. In 1920, C. T. R. Wilson hypothesized that the permanent electric potential of 250 thousand volts between the upper conducting layer of the atmosphere – the ionosphere – and the Earth's surface is maintained by the worldwide thunderstorm activity, a thousand storms active at every moment, transferring negative charges to the ground and

Courtesy of Nathan Lounds, stockexchange@nathanlounds.com

Once initiated, a discharge can sequentially drain electricity from a large portion of a thundercloud

Spectacular cloud-to-ground lightning flash shot in July 2005

positive charges to the conducting ionosphere. Now scientists know that this picture is a lot more complex, with additional extraterrestial and atmospheric factors, e.g. the solar wind influencing the global electric circuit, exerting a direct impact on cloud microphysics and others dynamic processes taking place in the troposphere.

Flashing clouds

One of the longest-standing questions in atmospheric science is how lightning actually becomes initiated. Although some experiments imply that runaway electrons from cosmic rays may touch off lightning discharges, it is believed that the main initiating role is played by inhomogeneities in the electric charge distribution within a thundercloud. When two or more oppositely charged regions of a cloud grow close to each other, preliminary short-range discharges (initial breakdown discharges) within tens of microseconds set off a cascade of increasingly powerful intracloud flows of current called "streamers," a spectacular swarm of lightning inside the cloud. The change in electric fields due to the neutralization of a large part of the cloud creates a favorable situation for draining more nearby charges. Then, if enough charge gets concentrated, it protrudes from the cloud towards the ground in a form of a "stepped leader," which is the precursor to a cloud-to-ground discharge, or "flash." The "flash" itself is usually a series of discharges (up to 11 observed), reusing the plasma channel created by the stepped leader. Most lightning bolts drain positive charge from earth to the negatively charged base of a thundercloud, but sometimes one of the discharges connects to a large region of positive charge in the cloud (i.e. the cloud top), producing the much more powerful and dangerous phenomenon of "hot" lightning. In rare situations, such a positive "hot" discharge can occur as part of a series of negative discharges. Called a "bipolar flash," this phenomenon is now being researched at the Institute of Geophysics as a part of the COST P18 Action entitled "The Physics of Lightning Flash and Its Effects."

The exact mechanism of charge generation in an initially neutral cloud is not yet known, but two competing hypotheses have been proposed. According to the convective hypothesis, the positively charged, close-to-ground air is sucked into the cloud by updraft currents. The precipitation hypothesis, on the other hand, suggests that cloud particles (water droplets, ice needles etc.) get positive and negative charges by colliding with each other inside fast air currents (up to 180 km/h) in the cloud. In thunderclouds, precipitation often plays the role of a charge carrier. A high-speed fall of rain or hail can almost instantly transport huge charge from the top of the cloud to its base, creating a region of positive charge in a negatively charged environment - a guaranteed lightning bolt in the making, as shown simultaneously by radar observations and the detection of radio wave emissions in a thundercloud during its high electrical activity.

Swedish supercells

The Laboratory of Atmospheric Electricity at the Institute of Geophysics, Polish Academy of Sciences, focuses its research activity on two areas: studying fair weather electricity, and studying thunderstorms with regard to the lightning discharge initiation processes. The research on thunderstorms and lightning has already led to major breakthroughs in our understanding of atmospheric electricity.

Current research on thunderstorm electricity builds upon the work of Stanisław Michnowski, started at our Institute in the early 1950s. He proposed a method for describing the transient variation of an electric field after a sudden discharge on an electrical pole set above a conductive plane in a non-homogeneous medium, like the atmosphere. Michnowski obtained a simplified solution for the general equations, one which under certain circumstances makes it possible to calculate the decrease in the recovery time of field variation with increasing distance, and to ascribe the behavior of that variation to the effect of charge distribution formed in the medium.

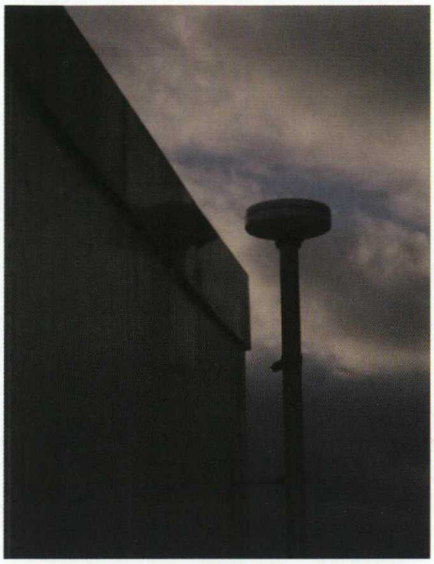
His next achievement was to analyze the evolution of thunderstorms in a mesoscale convection system that developed over southern Sweden on May 18, 1982. Mesoscale convective systems, also called "supercells," are now being intensively studied in the US, where they produce some of the most violent tornado-generating thunderstorms, although a similar situation is also present in Scandinavia where the warm air of the Gulf Stream meets cold polar air from the Arctic. Michnowski used the records provided by the lightning location system of the Institute of High Voltage Research in Uppsala, as well as routine meteorological observations, to show that some practical possibilities of lightning discharge monitoring may exist for "now-casting" (short-time forecasting) of the evolutionary stages of the mesoscale thunderstorm systems.

Subsequently, together with Nguyen Manh Duc of the Vietnamese Institute of Atmospheric Physics, Michnowski studied the poorly known processes of lightning initiation in the thundercloud on the basis of collective streamer discharges between cloud particles, and proposed a new hypothesis for explaining these phenomena.

Building upon this research, in the years 1994-1996 the Institute of Geophysics took part in the international research project "CESAR" aiming to design and produce a prototype of a thunderstorm detector able to operate from a low orbit satellite. The efforts to build new electric field measurement devices for lightning detection from a satellite and ground based platforms are being continued in cooperation with the Space Research Center of the Polish Academy of Sciences.

Validating discharges

Since autumn 2001, data about the spatiotemporal distribution and some electrical properties of lightning discharges for the whole territory of Poland is being provided by the Polish SAFIR network (an interferometric network for the two-dimensional detection and location of lightning). The Polish SAFIR system, now called PERUN, is operated by the Institute of Meteorology and Water Management. In order to validate its lightning detection efficiency it urgently needs to cooperate with at least one additional "reference measuring point" to supply independent detections of the electric field and current changes associated with lightning discharges.



Piotr Barański

Reference measuring point for the SAFIR system, located at the Institute of Geophysics

We aim to obtain a method to validate the SAFIR data for the 100x100 km area around Warsaw, using the reference point at the Institute of Geophysics. Simultaneous observations of thunderstorm discharges would make it possible to improve the detection efficiency of the SAFIR system in Poland, and introduce some discrimination criteria for different types of lightning discharges. The ability to assess rapid changes in total lightning activity may provide short-time forecasts of severe wind (microbursts) and severe precipitation (heavy gushes with hail), crucial to aviation. They are characteristic for particular development stages of thunderclouds and seem to take place in certain parts of a cloud system, especially in mesoscale systems. We have already begun observations of these unquestionably important processes. ■

Courtesy of Ante Vesić, ante.vesic@gmail.com

Cloud-to-ground lightning is usually a series of several discharges reusing the same plasma channel

Further reading

Barański, P., Bodzak, P., Maciążek, A. (2003) *The complex discharge lightning events observed simultaneously by the SAFIR, radar, field mill and Maxwell current antenna during thunderstorms near Warsaw.* Proceedings of the 12th ICAE Conference, 9-13 June 2003, Versailles, France, 1, p. 161-164.

Rakov V. A., Uman M. A. (2003) *Lightning: Physics and Effects.* Cambridge University Press, Cambridge, United Kingdom.