First International Symposium on

Lightning Physics and Effects

and

Third International Workshop on

EM Radiation from Lightning to Tall Structures

April 3rd- 4th , 2006
Palais Eschenbach,
Eschenbachgasse 11
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BOOK of ABSTRACTS

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SYMPOSIUM TIMETABLE

Monday April 3, 2006

Morning Sessions

09:00-09:50		**Registration (Coffee)**
09:50-10:00	Opening Session	**Welcome message of R. Thottappillil, COST P18 Chair, W. Janischewskyj, IPLT Chair, G. Diendorfer, OC Chair**
10:00-12:30	Session 1	**Lightning and Climatology** (**Chair: C. Price**)
	10:00-10:20	**T. J. Tuomi (Finland)** Rain and Flash Cells in July 2003
	10:20-10:40	**A. Mäkelä (Finland)** Some Comparisons between Weather Radar and Lightning Data in Finland in the Summer of 2005
	10:40-11:00	**C. Price and M. Asfur (Israel)**, Lightning and Climate – The Water Vapor Connections
	11:00-11:20	**C. Price and B. Federmesser (Israel)**, Lightning-Rainfall Relationships in Mediterranean Winter Thunderstorms
	Session 2	**Lightning Measurement** (**Chair: G. Diendorfer**)
	11:20-11:40	**M.M.F. Saba, M.G. Ballarotti, O Pinto Jr. (Brazil**) Possibility of High Peak Current Strokes Followed by Long Continuing Current in Ground Flashes
	11:40-12:00	**H. Pichler G. Diendorfer, M. Mair and W. Schulz (Austria)** Offset Compensated Integrator for the Measurement of Lightning Electric Fields
	12:00-12:20	**H.D. Betz, W.P. Oettinger, K. Schmidt, B. Fuchs, H. Höller (Germany)** Total Lightning Utilizing VLF/LF Networks: Procedures, Results and Open Questions
	12:20-12:40	**F. Heidler (Germany)** Resumption of the Lightning Current Measurement at the Peissenberg Tower in Germany
12:40-13:30	***Lunch Break***	

Monday April 3, 2006
Afternoon Sessions

13:30-15:30	Session 3	**Lightning Phenomenology and Modeling (Chair: M. Rubinstein)**
	13:30-13:50	**M. Arrayás, M.A. Fontelos and J.L. Trueba (Spain)** Notes on Negative Ionization Fronts
	13:50-14:10	**E.A. Mareev, A.V. Biryukov, S.S. Davydenko, A.A. Evtushenko, S.A. Yashunin (Russia)** Quasi-Stationary and Lightning Currents in the Global Atmospheric Electric Circuit
	14:10-14:30	**A.G. Keul, A. Geiswinkler and O. Stummer (Austria)** European Ball Lightning Research Focus
	14:30-14:50	**J. Cvetic, M. Raickovic, M. Buljan, V. Novakovic, B. Mijovic, I. Gligorijevic, M. Stefanovic, Z. Celicanin (Serbia and Montenegro)** Optical Signal Radiated from the Lightning Channel: Comparison of Different Return Stroke Models
	14:50-15:10	**R. Thottappillil (Sweden) and V.A. Rakov (USA)** Far Fields at an Elevation from Lightning Return Strokes
	15:10-15:30	**G. Maslowski (Poland)** Estimation of Lightning-Induced Effects in Complex Systems using Engineering Return Stroke Models
15:30-16:00	***Coffee Break***	
16:00-17:20	Session 4	**Lightning to Tall Structures (Chair: F.Rachidi)**
	16:00-16:20	**G. Berger and S. Aït-Amar (France)** Lightning Attraction of an Elevated Building
	16:20-16:40	**I Boev, W. Janischewskyj (Canada)** Current Reflections and Reflection Coefficients Related to Lightning at Tall Structures
	16:40-17:00	**D. Pavanello, F. Rachidi (Switzerland), W. Janischewskyj (Canada) M. Rubinstein (Switzerland), A.M. Hussein, E. Petrache (Canada), V. Shostak (Ukraine), C.A. Nucci (Italy), J.S. Chang, I. Boev, W.A. Chisholm (Canada), M. Nyffeler (Switzerland)** Three-Station EM Field Measurements of CN Tower Lightning Strikes
	17:00-17:20	**V. Shostak (Ukraine), W. Janischewskyj (Canada), F. Rachidi (Switzerland), A.M. Hussein, J.S. Chang, E. Petrache (Canada), M. Rubinstein, D. Pavanello (Switzerland) and W.A. Chisholm (Canada)** Suggestion on Experimental Estimation of Current Portion Measured by Rogowski Coil at the 474-m Level of the CN Tower

Tuesday April 4, 2006

08:30-10:30	Session 5	**Lightning Observations and Inverse Source Problems** **(Chair: P. Laroche)**
	08:30-08:50	**P. Baranski, M. Loboda (Poland)** Electric Field (E) Waveform Signatures of the First and Subsequent Return Strokes in Cloud-to-Ground (CG) Lightning Flashes Recorded during Summer'2005 Thunderstorms in Poland
	08:50-09:10	**G. Satori and J. Bor (Hungary)** Studying Individual and Global Lightning by Schumann Resonances
	09:10-09:30	**V. Djurica and J. Kosmac (Slovenia)** Comparison of Lightning Data Collected by LLS and RLDN
	09:30-09:50	**E. Defer (France) and D. Lalas (Greece)** Lightning Activity sensed by the National Observatory of Athens VLF ZEUS European Network
	09:50-10:10	**C. Price, Y. Yair, M. Ganor, E. Greenberg, Y. Sherez, R. Yaniv, A. Devir, B. Ziv and E. Katz (Israel)**, Ground-based observations of Sprites and other Transient Luminous Events in Eastern Mediterranean winter thunderstorms
	10:10-10:30	**P. Laroche, P. Lalande, P. Blanchet (France)**, Lightning Physic information deduced from Lightning Mapping System
10:30-11:00	***Coffee Break***	
11:00-11:40	Session 6	**Lightning Return Stroke Modeling and Effects** **(Chair: V. Shostak)**
	11:00-11:20	**R. Thottappillil and N. Theethayi (Sweden)** Realistic Sources for Modeling Lightning Interaction with Towers
	11:20-11:40	**F. Napolitano, M. Bernardi, A. Borghetti, C.A. Nucci, M. Paolone (Italy), F. Rachidi (switzerland)** Voltages induced by cloud discharges on overhead power lines
11:40-12:30		**Open Discussion and Conclusive Remarks** **(Chair: R. Thottappillil)**
12:30-13:30	***Lunch Break***	
13:30-17:00	**COST P18 Working Group Meetings**	

Session 1

Lightning and Climatology

Rain and Flash Cells in July 2003

Tapio J. Tuomi
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In July 2003, a period of one week produced unusually intense, almost stagnant air-mass thunderstorms in a limited area in Finland. The ground flash density was high and the number of positive flashes exceeded that of negative flashes. In the area of abundant lightning, the radar echo generally exceeded 40 dBZ, and in many places also 48 dBZ.

Flashes were grouped into cells with a previously developed algorithm. The most abundant flash cells (about 70 cells, up to about 260 flashes per cell) well correspond to the precipitation-cell cores in place and time. However, representative (mature-stage) 40 or 48 dBZ top heights or widths correlate only weakly with the flash density or +/- flash ratio. Closer comparisons of the time development of some individual cells will be presented.

Some Comparisons between Weather Radar and Lightning Data in Finland in the Summer of 2005

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One key element for the sufficient electrification of thunderclouds is the formation of large graupel in the cloud. Weather radar is a very good tool to observe the particle size distribution and hence to predict the possibility of lightning.

In this study the weather radar and lightning location system data were compared from 90 cases (i.e. convective cells in which lightning activity had been observed) to obtain information about time differences between the observation of certain radar reflectivity values (24, 32, 40 and 48 dBZ) and the first cloud discharge and ground flash. Every case was associated with at least one cloud flash, but in 17 cases no ground flash was observed. Also, in every case the reflectivity value of at least 40 dBZ was observed, but the 48 dBZ value was not observed in every case. So, it seems that the 40 dBZ value can be considered as a good requirement for the occurrence of lightning.

The time differences vary in quite a wide range. Some cases develop very rapidly, some cases very slowly. The mean of the time differences between 40 dBZ and the first observed cloud discharge was 19.2 minutes (median 15 minutes; positive value indicates that the radar signal was observed first), and between 40 dBZ and the first observed ground flash 21.2 minutes (median also 15 minutes). The corresponding values for 48 dBZ were 6.8 minutes (median 6 minutes) for cloud discharges and 10.4 minutes (median 8.5 minutes) for ground flashes.

The frequency distribution of the time differences shows the greatest frequency for 40 dBZ at class interval 0...9 minutes (29 cases) for cloud discharges and at 10...19 minutes (23 cases) for ground flashes. For 48 dBZ the greatest frequency is at 0...9 minutes for both cloud discharges (28 cases) and ground flashes (18 cases).

When considering only those 17 cases in which only cloud discharges were observed, the time differences are substantially larger. This could mean that in these cases convection is weaker so that enough charge for the occurrence of ground flash is not acquired. However, 17 cases are too small a sample for making solid conclusions.

Comparison between the observation times of cloud and ground flashes was also made. 56.2% of the cases were such that the first cloud discharge and the first ground flash were observed almost instantaneously. The mean time difference for these two is 3.2 minutes (cloud discharge appears first). One interesting thing was that there were some cases in which the first ground flash preceded the first cloud discharge by several minutes. This of course can't be the real truth because in every ground flash there has to be some in-cloud processes which the sensors should detect.

Lightning and Climate – the Water Vapor Connections

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Lightning activity in thunderstorms is closely related to the intensity of vertical updrafts in deep convective clouds that also transport large amounts of moisture into the upper troposphere. Small changes in the amount of upper tropospheric water vapor (UTWV) can have major implications for the Earth's climate. We present new evidence showing a strong connection between the daily variability of tropical lightning activity and daily upper tropospheric water vapor concentrations from the NCEP/NCAR reanalysis. Our results over the African continent show that the NCEP upper tropospheric water vapor peaks one day after intense lightning activity in the tropics. Given the many caveats related to the NCEP UTWV product over Africa, these results need to be interpreted with caution. However, since global lightning activity can be monitored from a few ground stations around the world via the Schumann resonances, we suggest the possible use of continuous lightning observations for studying the daily variability of upper tropospheric water vapor. Whether lightning is related to UTWV on other spatial and temporal scales needs further investigation.

Lightning-Rainfall Relationships in Mediterranean Winter Thunderstorms

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Space-based instruments on the Tropical Rain Measuring Mission (TRMM) have been used to study rainfall and lightning over the central and eastern Mediterranean Sea. Data from six winters (1998 until 2003) were analyzed. Rainfall amounts increase during the winter months, with the maximum precipitation occurring during December, while lightning activity has a maximum during November. Analysis of seasonal rainfall and lightning activity showed a strong correlation with ENSO events. Instantaneous (90 second) analysis of the rain and lightning in individual storms reveals a strong correlation between rain rate and total flash rate. Monthly and seasonal correlation coefficients between rainfall and lightning were found to vary between 0.81 and 0.98, with the rainfall yield (kg/flash) found to vary between $2.5\text{x}10^8$ and $9.\ 7\text{x}10^8$ kg/flash. Due to these high correlations we suggest the possibility to use lightning data over the Mediterranean Sea as a proxy for instantaneous rain rate in thunderstorms.

Session 2

Lightning Measurements

Possibility of High Peak Current Strokes Followed by Long Continuing Current in Ground Flashes

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We consider the possibility of existence of high peak current strokes followed by long continuing current in ground flashes, a combination that would offer an appreciable threat to protection systems. The observation of 454 negative strokes followed by continuing currents from 4 ms to 542 ms reveals that negative strokes combining both high peak current and long continuing current are very improbable to occur. However this possibility is real for positive strokes. This study was performed using a high-speed camera (1,000 frames/s), a slow electric field flat antenna and data from the Brazilian Lightning Location Network (RINDAT). All data was GPS synchronized allowing the matching and the comparison between stroke peak current and initial electric field peak with the duration of continuing current. The detection efficiency for stroke followed by very-short, short and long continuing currents were respectively 62.1, 57.4 and 35.7%.

Offset Compensated Integrator for the Measurement of Lightning Electric Fields

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Lightning discharges are one of the major reasons for service interruptions in electric power supply and cause significant damage to electric and electronic installations every year. Detailed knowledge of lightning parameters is the fundament for the appropriate design and testing of lightning protection measures. At the communication tower on Gaisberg near Salzburg a multitude of parameters are measured:

- Direct measurement of current with current viewing resistor
- di/dt with Rogovsky coil
- Electrostatic field with fieldmill
- High speed video recording of lower section of the lightning channel

These measurements are now extended by recording the vertical transient electrical field. To analyse both, the near and far electrical field, two stations are necessary. One station is located ~200 m next to the tower; the other station will be located in Wels at a distance of ~80 km. Because of the elementary physical model a flat plate antenna is used to measure the vertical electrical field of lightning pulses. To avoid local field enhancement, the border of the inner circular plate is surrounded by a small concentric air gap extended by a conductor at reference ground potential. The measured current is proportional to the change of the electrical field. To provide an output signal proportional to the electrical field the amplifier must have an integrative behaviour which can be achieved by a capacitor in the feedback loop of an inverting amplifier as shown in Fig. 1.

Because of the offset voltage of a typical operation amplifier, which mainly depends on the temperature, we have designed and tested an automatically offset compensation. Compared to the fast measurement signal (millisecond time scale) the change of the temperature and the offset voltage of the OPA are very slow (minutes). This allows controlling the output voltage of the amplifier to zero. If the time constant of the controller circuit is within the range of a few seconds the transient measurement signal from the lightning discharge will not be affected by the controller.

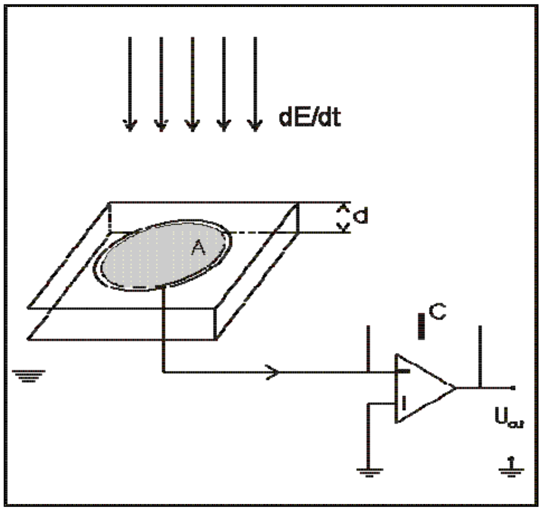

Fig. 1: Plate antenna with amplifier

Total Lightning Utilizing VLF/LF Networks: Procedures, Results and Open Questions

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For several decades numerous networks exist for lightning detection in the VLF/LF regime, whereby both scientific and commercial applications have been pursued. In particular, measurement of cloud-to-ground strokes (CG) has been optimised; control was derived from VHF observations, video recordings, strikes into towers, and artificially triggered lightning.

Although basic VLF/LF antenna techniques allow simultaneous measurement of both CG and intracloud (IC) discharges, IC events have received little attention in the past. In fact, the usefulness of comprehensive IC measurements for both the study of discharge mechanisms and meteorological applications has been greatly underestimated.

The present contribution demonstrates that total lightning can be measured by means of adequately designed VLF/LF networks, provided that they allow simultaneous and effective recording of both CG- and IC events. As an example, results are presented from a 21-sensor network (LINET) operating in southern Germany. Due to its high efficiency for the detection of low-amplitude events massive occurrence of IC discharges was established. For many thunderstorms this novel data was used to identify severe weather conditions with the inclusion of super cells.

Owing its 3D-capability LINET allows detailed detection of IC discharges. In most cases even the sign of the current amplitude can be extracted, based on the well-known and accepted procedure established for CG strokes. Characteristic differences between positive and negative IC's may indicate features of the charge separation processes and subsequent discharge mechanisms.

Open questions still tangle the precise succession of various discharge steps, especially for IC events, and the relative radiation power in VLF/LF- and VHF bands during the respective steps. Since VLF/LF observations are limited to currents in relatively long channels, whereas VHF measurements reflect short discharge distances in associated processes, simultaneous observations with powerful VHF networks might be helpful to i) cover the entire evolution of lightning events and their successive occurrence within a complete flash, and ii) provide independent data for scaling and verification purposes.

Resumption of the lightning current measurement at the Peissenberg tower in Germany

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The Peissenberg tower is located about 60 km south-west of Munich, Germany. The 160 m high tower is situated on a ridge rising about 250 m above the surrounding open ground. At this tower, the lightning currents have been measured since 1978. Initially, only a di/dt-probe was installed in order to measure the current derivatives and the integrated impulse currents. Then, in 1992 a current monitor was installed also at the tower top. With this current monitor, the continuing currents could be measured with a bandwidth from 0.15 Hz up to 200 kHz. Later on the measuring system was completed by two sensors measuring the current and the current derivative close to the tower base. In April 1999 the various measurement programs ended and the Peissenberg Lightning Measurement Station had to be shut down.

Meanwhile, the German telecommunication company being the owner of the tower consented to resume the lightning current activities at the Peissenberg. Objective of the paper is to give an overview about the measuring concept and to inform about the status of preparations.

The top of the Peissenberg tower will be equipped with a current shunt (company: Hilotest, type: ISM 500) having an upper cut-off frequency of 50 MHz. Also at the tower top, a di/dt – probe (company: EG&G, type: IMM-4) with an upper cut-off frequency of 1,3 GHz will be installed. Meanwhile, both sensors are combined in a common metal cage and tested in the high current laboratory of the University of the Armed Forces Munich. The metal cage is shielded to protect against the electric and magnetic field in case of lightning. Furthermore, a special design is required to avoid the penetration of insects and to withstand the various natural influences as the pollution and the different weather conditions.

Further, it is planned to install a second set of sensors close to the tower base. This second set of sensors comprises a current probe to measure the lightning current via the magnetic field and a di/dt-probe to measure the lightning current derivative via the magnetic field derivative.

From the sensors located at the tower top and at the tower base, the measured quantities will be transferred to a measuring cabin using coaxial cables. The cabin is located inside the tower near ground level. The cabin will be equipped with a controller working like a PC with Microsoft Windows. The controller uses a PXI-bus with 8 slots where different PXI-cards can be inserted. The first slot is used for the GPS-clock to get the time stamp. In the second slot, a two channel 14-bit digitizer card (Type: NI PXI-5122) with 512 MByte/channel is inserted. With this card, it is possible to record the currents at the tower top and at the tower base with 10 ns sample interval and a duration up to 2,56 s. In the third slot a two channel 12-bit digitizer card (Type: NI PXI-5124) with 512 MByte/channel is installed. With this card the current derivatives at the tower top and at the tower base will be recorded with 5 ns sample interval and a duration up to 1,28 s.

The program LABVIEW is used for the data acquisition. For each event, the data comprise more than 2GByte exceeding the memory of the controller-RAM being 1GByte. Due to this huge amount of data a special data management is necessary.

Session 3

Lightning Phenomenology and Modeling

Notes on negative ionization fronts

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We are interested in the investigation on the physical principles of electrical breakdown. We study the phenomena of streamer formation and spontaneous branching in terms of a fluid description based on kinetic theory. Particular attention is paid to a minimal model which is suitable for non-attaching gases.

We have studied anode-directed ionization fronts in curved geometries [1]. From the minimal streamer model, a Burgers type equation which governs the dynamics of the electric shielding factor is obtained when electron diffusion is neglected. A Lagrangian formulation is then derived to analyze the ionization fronts. Power laws for the velocity and the amplitude of streamer fronts are found numerically and calculated analytically by using the shielding factor formulation. We have found that a new phenomenon, called geometrical diffusion, appears and a universal self-similar asymptotic behavior is derived.

Branch-like patterns of streamers have been observed in anode directed discharges. We have explained a mechanism for branching [2] as the result of a balance between the destabilizing effect of impact ionization and the stabilizing effect of electron diffusion on ionization fronts. If D is the ratio between the dimensionless electron diffusion coefficient and the dimensionless intensity of the external electric field, and it satisfies $D << 1$, then the dispersion relation for transversal perturbation of a planar negative front can be obtained analytically. From the dispersion relation, we have estimated the spacing λ between streamers, and deduce a scaling law $\lambda \sim D^{1/3}$.

[1] M. Arrayás, M. A. Fontelos and J. L. Trueba, Phys. Rev. E. 71, 037401 (2005).
[2] M. Arrayás, M. A. Fontelos and J. L. Trueba, Phys. Rev. Lett. 95, 165001 (2005).

Quasi-Stationary and Lightning Currents in the Global Atmospheric Electric Circuit

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Quasi-stationary and fast transient processes connected with large-scale thunderstorm systems and powerful lightning discharges are analyzed. The correct modeling of these processes implies the use of proper boundary and initial conditions determined, in turn, by the state of the global electric circuit. Therefore, success in the modeling depends to high degree on the account for spatial and temporal structure of different subsystems forming the global electric circuit. Another important factor of model development is the use of modern nonlinear methods of analytical and numerical consideration.

We address two aspects of the global electric circuit conception, particularly important from the viewpoint of lightning research. First is a classical aspect of the global circuit as the quasi-stationary current contour supported by the operation of thunderstorm generators over the globe. Another aspect is connected to the energy deposition and dissipation into the circuit, treated as an open dissipative system.

Energetic estimates of lightning flashes and thunderstorms are presented. It should be noted in this connection that development of gas-dynamic models of return strokes is necessary not only for understanding physical processes in the lightning channel, but for estimating correctly percentage of input lightning energy converted to the kinetic, internal energy, and electromagnetic radiation, as well as for different technical applications. At the moment there are models, which allow calculating such physical parameters of the lightning channel as temperature, pressure, density as functions of time and channel radius in assumption of axial symmetry of the channel. They predict percentage of input lightning energy converted into light radiation, kinetic and internal energy, while these predictions vary substantially from one model to another, and agree only partially with experimental measurements. We discuss in particular some ideas about further progress of gas-dynamic models.

An importance of global circuit conception in terms of the modeling of sprites and sprite-producing clouds is particularly recognized. It was shown recently that stratiform regions of mesoscale convective systems (MCSs) make an especially large current contribution to the global circuit, serving either as an effective generator or as a discharger of the circuit depending on the polarity, magnitude and thickness of the layers of external current. On the other hand, stratiform regions of MCS are characterized by enhanced rate of positive flashes. In a case of MCS the big narrow layers, generated near the 0°C isotherm serve as the source of electric charges for positive CG flashes. We develop a model of a positive charge layer near the 0°C isotherm, based on the hypothesis that the melting-charging mechanism plays a principal role in the formation of the layer. A role of light ions in this model is discussed. A concept of lightning discharge development through the hydrometeor and cloud particle system in the active part of thunderclouds is suggested.

European Ball Lightning Research Focus

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The Technical Annex of the European COST Action P18 mentions ball lightning (BL) as unusual lightning discharge. Its reality is not in doubt, but research remains underdeveloped due to a paucity of empirical data and missing theoretical consensus regarding the physical mechanisms. COST Action P18 summarizes Chapter 20 of "Lightning" (Rakov & Uman, 2003) with its overview of various BL theories, stating: "Perhaps the number of likely theories on ball lightning would dramatically reduce, if there were even a single reliable photographic or other instrumental recording of ball lightning".

The first author, a meteorologist and psychologist, shares the COST Action P18 position that scientific progress on BL will depend upon valid empirical data collection, laboratory simulation, empirically fruitful explanatory theories, and the interaction of the three fields. A private Austrian project collected and field investigated BL cases since 1974, which resulted in a data bank of 500 entries from Central Europe (300 from Austria, 200 from Germany). 405 entries were analyzed with the support of ALDIS and Siemens in 2001. Since Tokyo 1988, the Austrian project is affiliated with the International Committee on Ball Lightning (ICBL), a network with meetings every two years. Its 1993 conference took place at Salzburg, Austria. In 2002/2003, a European Survey on BL research was done covering 15 countries.

Further project aims to be developed in contact with COST Action P18 are
1. Coordination of European BL research in Austria, Germany, Sweden, Finland and Italy on a north-south axis. Collection and analysis of three BL data bodies (Europe North, Central, South) against regional climatology, EUCLID lightning data, population, and topography.
2. Identification of BL "hot spots" for photographic and instrumental documentation. Preferably, in-depth analysis of cases with Natural Scientific value (photographs, videos, traces), further estimation of ball lightning energy densities.

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Optical Signal Radiated from the Lightning Channel: Comparison of Different Return Stroke Models

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The intensity of the light pulse radiated from the lightning channel during the return stroke phase is analyzed. The time dependence of the apparent height and the apparent average speed are calculated by the causality consideration. The experimentally observed decrease of the apparent return stroke speed along the channel of more than 25% is partially explained. Accepting the linearity connection between the current along the lightning channel and the emitted optical signal during rise time of the channel base current, the total light intensity along the channel is calculated. Six return stroke models are considered and compared: Bruce-Golde, transmission line, modified transmission line, traveling current source, Diendorfer-Uman and the generalized traveling current source model.

Far Fields at an Elevation from Lightning Return Strokes

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Electromagnetic fields at high altitudes from lightning return stroke in cloud-to-ground lightning are often calculated in studies related to transient luminous events in the mesosphere. Two commonly used return stroke models are: 1) the modified transmission line model with exponential decay (MTLE) of the current in the channel and 2) the modified transmission line model with linear decay (MTLL) of the current in the channel. The relationship between the channel-base current and the channel current at height *z*' in these models are defined by (e.g., Rakov and Uman, 1998)

$$i(z',t) = i(0,t-z'/v)\cdot e^{-z'/\lambda} \qquad (1) \qquad \text{MTLE}$$

$$i(z',t) = i(0,t-z'/v)\cdot (1-\frac{z'}{H}) \qquad (2) \qquad \text{MTLL}$$

where, *t* is the time, *v* is the return stroke speed, λ is the decay constant for current, and *H* is the height of the total channel.

In this manuscript, simplified expressions are derived for calculating the far fields at an elevation from lightning return stroke using the MTLE and MTLL models. These expressions are given by,

$$\overline{E}_{farMTLE} = \hat{\theta}\frac{1}{4\pi\varepsilon_0 c^2 r}\frac{v\sin\theta}{1-\frac{v}{c}\cos\theta}\left[i(0,t-\frac{r}{c}) - \frac{1}{\lambda}\int_0^{L'(t)} i(0,t-\frac{z'}{v}-\frac{R(z')}{c})\cdot e^{-\frac{z'}{\lambda}}dz'\right] \qquad (3)$$

$$\overline{E}_{farMTLL} = \hat{\theta}\frac{1}{4\pi\varepsilon_0 c^2 r}\frac{v\sin\theta}{1-\frac{v}{c}\cos\theta}\left[i(0,t-\frac{r}{c}) - \frac{1}{H}\int_0^{L'(t)} i(0,t-\frac{z'}{v}-\frac{R(z')}{c})dz'\right] \qquad (4)$$

where *c* is the speed of light and other quantities are as defined in Fig. 1. *L*'(*t*) is the height of the return stroke channel contributing to the fields at P at time *t*. Equations (3) and (4) are derived without including the effect of the ground plane, which can be easily added by considering similar expressions from image channel. Equations (3) and (4) are readily reduced to corresponding equation for Transmission Line (TL) model when λ or *H* is set at infinity. Validity of (3) and (4) are verified by comparing the numerically calculated results from (3) and (4) with the calculated results from exact field expressions for these models. Fields predicted by these two models at 100 km distance for various speeds and elevations are presented and discussed.

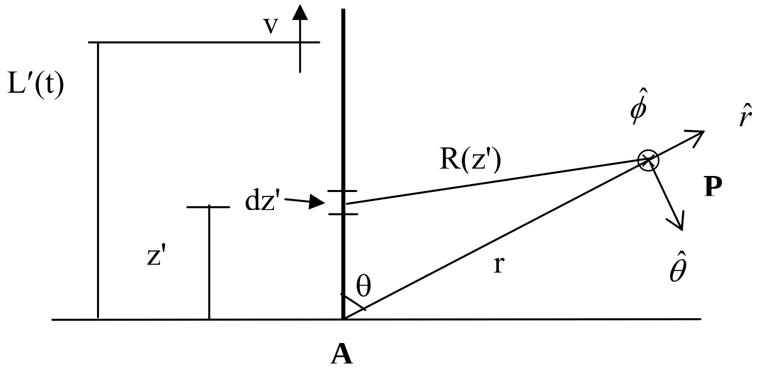

Fig.1 Geometry of the problem defining the symbols used in (3) and (4)

Estimation of Lightning Induced Effects in Complex Systems using Engineering Return Stroke Models

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We can define four classes of lightning return-stroke models, that is, the gas dynamic (or "physical") models, the electromagnetic models, the distributed-circuit models, and, so-called, the engineering return-stroke models. The electromagnetic, distributed-circuit, and engineering models can be used during calculation of the lightning electromagnetic impuls (LEMP). Probably, the engineering models are most popular, in which the spatial and temporal distribution of the channel current is chosen in the arbitrary manner. However, defined variation in time as well as the specific attenuation with height of this current reflect such observed lightning return-stroke characteristic as the current at the channel base, the speed of the upward-propagating front and the channel luminosity profile. Hence, the electromagnetic field predicted by these models in wide range of distances (from tens of meters to hundreds of kilometers) is generally in fairly good agreement with observations. These models also contain information about the radial corona current.

Engineering return-stroke models are usually used to determine lightning induced voltages in long overhead and underground transmission lines. First, vertical and horizontal electric fields are calculated based on well known analytical formulas, and then, induced voltages and currents can be determined using Agrawal et al. field-to-transmission line coupling equations.

Unfortunately, it is difficult to use the engineering models to determine induced currents and voltages in complex system for case of direct and nearby lightning strikes. Therefore, we can presently observed the fast development of the electromagnetic models which are based on the antenna theory and enable to calculate the induced effects in the cylindrical conductors freely situated in space. For such models ground with finite conductivity can be also considered according with the Sommerfeld solution. The return-stroke channel is represented by the lossy antenna situated above the ground surface and forced by the current or voltage source at the channel base. For such structure the return-stroke velocity is practically the same as velocity of light in vacuum. This disadvantage can be eliminated using additional inductive loads distributed along the whole channel. However, in order to obtain the appropriate remote electromagnetic field using these return-stroke models we have to apply the enough long antenna. Then, relatively long time of computation is required to determine longitudinal current along the lightning channel, especially, when the lossy ground is taken into account.

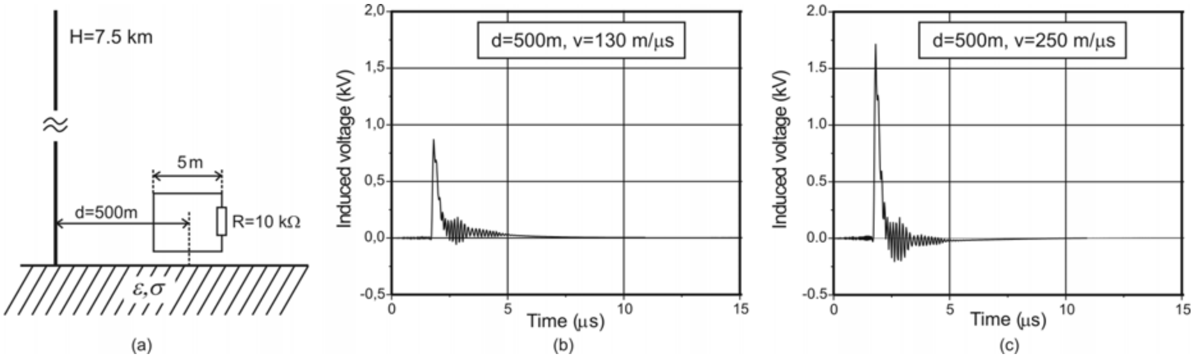

Fig.1. Geometrical and physical parameters of the analyzed system a) and lightning induced voltages inside the square loop situated above the lossy ground ($\sigma = 0.01$ S/m, $\varepsilon_r = 10$) obtained during full-wave frequency domain calculation for the MTLL model and different speed v of upward propagating return stroke front, b) $v = 130$ m/μs, c) $v = 250$ m/μs.

It can be shown that the lightning channel with the arbitrary defined longitudinal current, which is consistent with the engineering return-stroke models predictions, can be applied during full-wave frequency domain calculations. For example, lightning induced voltages inside the square loop can be calculated using frequency domain implementation of the MTLL and MTLE return stroke models (Modified Transmission Line model with Linear and Exponential current attenuation with height). Obtained results show that the lightning voltages induced inside the square loop depend significantly on speed of upward propagating return-stroke front (see Figure 1). Different attenuation of lightning current predicted by the MTLL and MTLE models gives difference during lightning induced voltages calculation less than 3%.

Further study of the presented issue should be continued, especially, influence of lossy ground and distance from the lightning channel on the voltages induced in different complex systems will be investigated.

Session 4

Lightning to Tall Structures

Lightning Attraction of an Elevated Building

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Lightning protection of an elevated building is not straightforward. International lightning protection standards consider only structures lower than 60 m. The classical Electrogeometrical Model (Rolling Sphere Model) is no more applicable for such high structures and numerical modelling of lightning interception has to be used. We developed a 3D Leader Progression Model, the principles of which have been firstly presented at ICLP 2004 in Avignon. This model takes into account the actual geometry of the structure to be protected, the downward and upward leaders propagation and their relative mean velocities. The computation can be performed for any incoming downward leader trajectory (vertical or oblique). Conditions of competition between several upward leaders may be exhibited.

It is shown that corners and edges of the building are more frequently struck by lightning than other parts of the structure. This is perfectly correlated with observations of the damages due to the lightning protection system by-pass. Attractive radii of corners and edges of the roof have been calculated as function of the structure height for various transverse dimensions of the building. Examples are shown for a 10 kA flash.
If the roof is protected by a lightning rod according to the standards, the downward leader is liable to terminate on a corner or an edge of the roof, except if the lightning rod is largely increased in height. Placement of short rods close to a corner or an edge is often not sufficient to avoid the structure striking.
When the incoming downward leader is oblique, some parts of the structure below the roof may be submitted to sideflashes, as observed in real conditions.

As a conclusion, limitations of the Electrogeometrical Model may have critical consequences on the reliability of the lightning protection of a high building, which differs strongly with the case of normal low structures for which it is adequate.

Current Reflections and Reflection Coefficients Related to Lightning at Tall Structures

Based on the 2006 MASc Thesis by Ivan Boev (University of Toronto) entitled:
"Development of a Five-Section Model for Computing Lightning Current in the CN Tower"

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Introduction

In considering lightning current oscillations within Tall Structures, it could be easily accepted that values of Reflection Coefficients at structure discontinuities, barring any variations with frequency or skin effects, may be uniquely responsible for the ratios of incident to reflected waves. Conversely it then may be argued that values of measured Reflected Signals may be used to compute unique values of Reflection Coefficients. The proposed contribution to the Workshop will examine this situation for the CN Tower, and will indicate complications that exist in the process of determining Reflection Coefficients from measured data.

The Study

In order to be able to closely follow the process of reflections within the structure, the reported study has used a transparent form of modeling the CN Tower developed in the MASc Thesis quoted above, where individual sections of the tower are represented by transmission lines with constant impedances. Such representation assures that Reflection Coefficients remain constant throughout the computation. For the reported study, two models were used to represent the CN Tower: a Single-Section Model and a Five-Section Model. In both models losses were excluded and propagation within the tower at speed of light was assumed. Reflections from the front of the return stroke channel were included and propagation at speed of light was assumed within the ionized portion of the lightning channel and that at 1/3 speed of light for the partially ionized portion. Three different waveforms, with identical peak values, were utilized as excitations applied at tower top: a Square Wave, a Heidler Function and a Double Exponential. Results of the study (waveshapes computed for the observation point at the 509 m AGL) are analyzed in Tables 1 and 2.

Discussion and Conclusion

On the basis of the performed analysis it is found that, irrespective of the model used, the observed amplitude of the wave reflected from ground is different for each excitation. It is largest for the Square Wave, next in size for the Heidler Function and smallest for the Double Exponential. On closer examination it is recognized that the primary reason for the differences in results computed for each of the three excitations lies in the rate of rise of each waveform. Due to peculiarities of the CN Tower shape and because of the location of the observation point, even for the overly simplified Single-Section Model, only in case of the Square Wave the reflection from ground has the chance to rise to its full value. For the other two waveforms, depending on the steepness of their fronts, a reflection from tower top "cuts off" the rise of the reflected wave at a different level. Additionally, the overall shape of the incident wave influences the value of the Absolute Peak. The situation becomes even more complicated when the much more realistic Five-Section Model is used. In that case, due to reflections at intermediate points of the CN Tower, except for the Square Wave, it is virtually impossible to recognize the real shape of the incident wave, and already the First Peak is different for each applied waveform.

Consequently, in case of lightning wave shapes observed at Tall Structures, one must be very careful when attempting to use the simple ratio of Absolute to First Peak for derivation of Reflection Coefficients. Additional information about the complete shape of the incident lightning current and its possible distortions due to reflections within the Tall Structure must be fully taken into account.

Excitation	*First Peak (FP), p.u.*	*Absolute Peak (AP), p.u.*	*AP/FP*
Square Wave	1.00	1.50	1.50
Heidler Function	1.00	1.20	1.20
Double Exponential	1.00	1.12	1.12

Table 1. Single-Section Model

Excitation	*First Peak (FP), p.u.*	*Absolute Peak (AP), p.u.*	*AP/FP*
Square Wave	1.00	1.47	1.47
Heidler Function	1.07	1.17	1.09
Double Exponential	1.05	1.10	1.05

Table 2. Five-Section Model

Three-Station EM Field Measurements of CN Tower Lightning Strikes

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Simultaneous measurements of return stroke current and the corresponding electric and magnetic field at three distance ranges associated with lightning strikes to the CN Tower (CNT), Toronto were performed for the first time during the Summer of 2005. The lightning current was measured using a 40-MHz Rogowski coil installed at a height of 474 m. The coil is connected to the recording system located at 372-m AGL (above ground level). The recording system consists of a 4-ns 8-bit two-channel digitizer and a computer controller.

The vertical component of the electric field and the azimuthal component of the magnetic field were measured at distances of 2.0 km (Pratt building), 16.8 km (Environment Canada Building), and 50.9 km (Grimsby, accross the lake Ontario) from the tower (across the Ontario Lake), respectively (see Fig. 1).

Fig. 1. Location of the electromagnetic field measuring stations Environment Canada and Place Polonaise (Grimsby). The Pratt building location (not shown in the picture) is 2.0 km north of the CN Tower.

At Pratt building, the sensors (belonging to the University of Toronto) were located on the roof of the building. The system consisted of one hemispheric E-field sensor (bandwidth 50 Hz – 150 MHz) and one H-field small loop antenna (bandwidth 600 Hz – 150 MHz) connected via 50 Ω triaxial cables to a digitizer operating at 250 Msamples/sec. Simultaneously, vertical electric and azimuthal magnetic field components were also measured at the Environment Canada Building and at Grimsby using Mélopée field systems (belonging to the Swiss Federal Institute of Technology and Armasuisse) relayed via fiberoptic cables to LeCroy digitizing oscilloscopes operating at 100 Msamples/sec. The Mélopée field sensors consisted of one spherical E-field and one H-field (loop antenna) sensors manufactured by Thales, France. The overall bandwidth of the system was 1 kHz to 150 MHz. In addition to the field measuring system, a video recording system was also operational. All mentioned measuring systems have a GPS time stamping.

In this contribution, we present a detailed analysis of the obtained experimental data and comparisons with numerical simulations. The obtained results are useful for characterizing electromagnetic radiation from lightning return strokes to tall towers and to validate theoretical models.

Suggestions on Experimental Estimation of Current Portion Measured by Rogowski Coil at the 474-m Level of CN Tower

V. Shostak[1], W. Janischewskyj[2], F. Rachidi[3], A.M. Hussein[4], J.-S. Chang[5],
E. Petrache[2], M. Rubinstein[6], D. Pavanello[3], W.A. Chisholm[7],
[1]Kyiv Polytechnic Institute, [2]University of Toronto, [3]Swiss Federal Institute of Technology, [4]Ryerson University, [5]McMaster University, [6]Yverdon University of Applied Sciences, [7]Kinectrics

As one of the means of measuring lightning current parameters (*di/dt, I, T*, etc.) of strikes to the CN Tower (CNT) in Toronto, for many years a 3-m long Rogowski Coil located at the 474-m level of the CNT [1] has been used. This Coil encircles (1/5)th of the metallic pentagonal structure of the tower. On this basis, when experimental data were processed, it was assumed that this Coil measures approximately one fifth of the total current, and coefficient $K=5^x$ was applied.

During the use of this Coil some doubts were raised about the value of K, and there still a need exists to estimate the accuracy of this approach. It should be taken into account that, beside the metallic pentagonal core structure, there are some elements at the CNT designed to hold the weather shield outside of the core. Also inside and outside the core various devices are installed, such as antennae, cables and other engineering means for communication. One can expect that these additional elements can influence the actual distribution of lightning current between parts of the metallic core and other parallel paths. Moreover, it should be considered, that these additional elements may have been mounted and dismounted during the years, and, thus, their configuration might have been changed.

In view if these factors, present contribution is devoted to some suggestions on the possible procedure for a more accurate estimation of lightning current parameters from the waveform measured by the Rogowski Coil. The goal of this presentation is to initiate a preliminary discussion for the calibration and to take into account possible comments for improvements of the proposed procedure. The main idea is to design a circuit with generator connected to two points, some meters (like 5-10 m) above and below the Coil, then to measure the whole current injected into tower's structure (using Pearson transformer (PT) and Fluke) and its portion measured by the Coil and relevant digitizing-recording station at CNT. Preparation for this procedure includes analysis of CNT structure and additional elements in the vicinity of discussed level 474 m, selection of connection points, calculations of generator and test schemes (to get steep impulse in case of long wires; if needed, to modify the existing portable generator), preliminary tests of generator and circuits at the UofT laboratory.

Additionally, it is suggested that such calibration procedure should be performed each year at the beginning of the lightning season (together with the regular Coil calibration – current from generator, measurements by PT-Fluke and the Coil) or after reports from CN Tower personnel on changes in engineering equipment/communications near the discussed CNT level. Some other possible approaches for estimation of the above mentioned current distribution should also be discussed.

[1] Hussein, A.M., W. Janischewskyj, J.-S. Chang, V. Shostak, W.A. Chisholm, P. Dzurevych and Z.-I. Kawasaki, Simultaneous measurement of lightning parameters for strokes to the Toronto Canadian National Tower, Journal of Geophysical Research - Atmosphere, Vol. 100, No. 5, pp.8853-8861, May 1995.

Session 5

Lightning Observations and Inverse Source Problems

Electric Field (E) Waveform Signatures of the First and Subsequent Return Strokes in Cloud-to-Ground (CG) Lightning Flashes Recorded during Summer'2005 Thunderstorms in Poland

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The presentation gives a brief outlook of several cases on negative and positive return stroke (RS) electric field signatures of CG flashes of some Polish active summer thunderstorms on 15 June, 7 July and 12 September, 2005. All these RS waveforms were recorded with a 40 ns resolution by 2-channel A/D PC 12-bit card having on its board a 64 MB memory buffer in each channel and triggered by ($\partial E/\partial t$) pulse obtained from external Maxwell current antenna. This acquisition system gives us a possibility to collect waveform RS signatures for close cg flashes, i.e., located in the range of about 50 km from our measuring point. One channel of our A/D card was connected to the LF (low frequency) antenna, i.e., PAD 04 unit with charge amplifier AD 825, the same as that used in the SAFIR network systems for discrimination of cg discharge events. On the other hand, the second channel of A/D card was fed by additional LF sensor, with charge amplifier AD 711 having frequency band a little different from the first one, but with lower slew rate. The feedback time constants of these antennas were similar (equal to 6,7 ms and 5 ms, respectively). The time interval of 0.4 s, taken as a whole duration of lightning discharges, was applied to be in accordance with the SAFIR time domain limits allowed by that system for cg discrimination processing.

The general time behaviour of particular RS waveform is similar to the one described by Weidman and Krider (1978), i.e., after some separated in time leader steps or dart leader steps pulses which appear near the beginning of the slow front, a very fast-transition to the peak value of electric field has occurred. During the decay stage a distinct additional structure, i.e., secondary and subsidiary peaks can be easily distinguished and counted. But sometimes, as it was noted by Murray et al. (2005) also the fast-transition phase may have such additional structures, i.e., the "γ-peaks" or "γ-shoulders".

The time characteristic of our recorded RS waveform signatures can be summarized as follows:

- for 16 distinguished cases of the first return stokes (1 RS_-) transferring negative charge to ground, the mean rise time (t_r) of their waveforms was equal to $(2.9\pm0.6)\mu s$ and their mean decay time (t_d) was equal to $(32.2\pm29.2)\mu s$, whereas the mean number of their secondary and subsidiary peaks was equal to 3.9 ± 1.4
- for 8 distinguished cases of the second return stokes (2 RS_-) transferring also negative charge to ground, we obtained $<t_r>=(3.3\pm0.9)\mu s$ and $<t_d>=(29.5\pm12.6)\mu s$, and the mean number of their secondary and subsidiary peaks was equal to 3.6 ± 1.5
- for 2 distinguished cases of the first return stokes (1 RS_+) transferring positive charge to ground, $<t_r>=0.7\mu s$ and $<t_d>=(6.8\pm1.7)\mu s$, and the mean number of their secondary and subsidiary peaks was equal to 5.

Comparing these time parameters of particular RS waveform signature to the one obtained for the same detected return stroke in cg flash by the PERUN (SAFIR) system, one can see that the SAFIR detection algorithms delivered by manufacturers have resulted in overestimation of the value of t_r and underestimation of the value of t_d, and gave no information about occurrence of secondary, subsidiary or γ-peaks.

Moreover, it is worth to note that for real positive return stroke in cg flash we recorded t_r of less than 1 μs.

Studying Individual and Global Lightning by Schumann Resonances

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Schumann resonances (SR) are electromagnetic eigenfrequencies of the Earth-ionosphere cavity [Schumann, 1952]. They are excited by lightning strokes and maintained by worldwide thunderstorm activity. The conductive Earth's surface and the conductive ionosphere together bound an insulating atmosphere forming a global spherical resonator for electromagnetic waves with wavelengths comparable with the Earth's circumference. The fundamental resonance frequency is close to 8 Hz, with higher-order modes spaced at intervals of about 6 Hz.

The SR parameters (actual peak frequency, amplitude etc.) observed a single station are controlled by the global lightning activity, which in turn, is related to different climate variables in the troposphere. Therefore SR parameters can be used to study global climate variability. The SR parameters depend also on the physical parameters of the Earth-ionosphere waveguide, especially on the upper diffusive wall of the cavity, namely the ionospheric D-region. In this way Schumann resonances can be used to study global processes both of tropospheric and ionospheric (extraterrestrial) origins.

ELF (Extremely Low Frequency: 3 Hz – 3 kHz) transient events are initiated by individual energetic lightning strokes. These ELF wave packages circumpropagate around the globe several times before decaying to background levels and can excite electromagnetic resonances in the Earth-ionosphere cavity. These transient events appear as coherent signals in the vertical electric E_Z and azimuthal magnetic field $H\varphi$ components and they are detectable in very large distances (in principle up to 20 Mm) from the lightning discharge. From these SR transients, one can determine the position and the polarity of a lightning discharge, even from a single SR station, and estimate the charge moment (CM) change. CM is relevant in quantifying the ability of a flash to generate TLEs (Transient Luminous Events).

Some results are presented based on the transient and background Schumann resonance observations in the Széchenyi István Geophysical Observatory, at Nagycenk, Hungary.

Schumann, W. O. Über die strahlungslosen Eigenschwingungen einer leitenden Kugel, die von einer Luftschicht und einer Ionosphärenhülle umgeben ist. Z. Naturforsch., 7a, 149-154, (1952).

Comparison of Lightning Data Collected by LLS and RLDN

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The paper compares high accuracy data collected by Reference Lightning Detection System (RLDN) and possible application of data in improvement of LLS accuracy.

After years of data exploitation we came to the conclusion that some kind of systematic errors exists in LLS, which become evident when large datasets are evaluated. We show two examples of high resolution flash density maps for two different locations which clearly show an south-east shift of the lightning data.

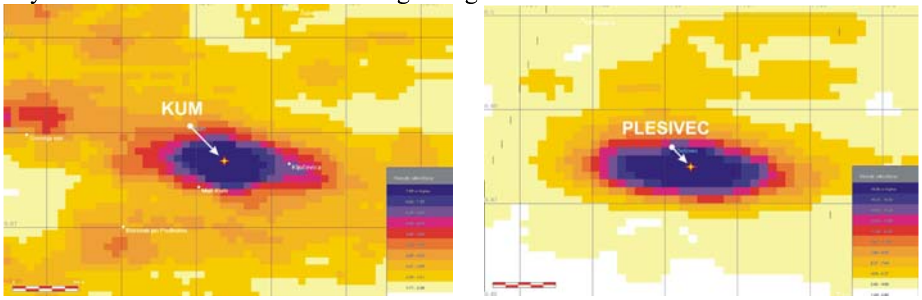

Figure 1: Shift of the highest flash density to the south-east of the towers Kum and Plešivec

Spatial and temporal comparison of lightning events located by LLS SCALAR-EUCLID and RLDN was performed. The RLDN is a network of 10 (Direct Lightning Analyzer - DLA) DLA-FlashCounter sensors located allover Slovenia. The DLA-FlashCounter sensor consists of lightning probe (LP) and direct lightning analyzer (DLA). The LP serves as a main detection element and could be installed either on the top of tower or on the ground termination system (Fig. 1), thus determining the exact location of detected lightning event.

Figure 2: Lightning probe

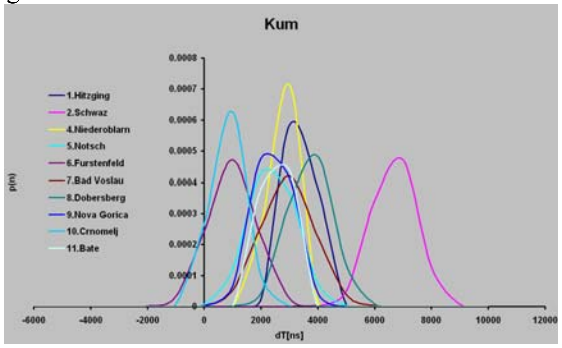

Figure 3: Distribution of time differences Δt for LLS sensors as seen from RLDN sensor Kum

Time differences were calculated between events detected by RLDN and LLS and based on the differences time corrections were applied to location analyzer software.

If no time correction is performed in processing of the raw data then the average error is 467 m and 659 m for RLDN locations Nanos and Kum respectively. We calculated also the mean dissipation of the data set from the average distance error point.

	original LL data		***time corrected LL data***	
RLDN sensor	***average distance error [m]***	***mean distance dissipation [m]***	***average distance error [m]***	***mean distance dissipation [m]***
Nanos	467	483	53	400
Kum	659	336	135	410

Table 3: Distance measurements between LL data and true lightning location

The results presented above indicate that using the above described corrections improve the accuracy of the LLS. Changes in location accuracy are significant, and range from 400 to 500 m, while dissipation is practically unchanged.

Lightning Activity sensed by the National Observatory of Athens VLF ZEUS European Network

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The National Observatory of Athens is operating the long-range VLF ZEUS network composed of five stations located in Portugal, UK, Denmark, Romania and Cyprus, with the central processing in Athens (Greece). ZEUS provides a full temporal and spatial coverage of the lightning activity over Europe and the Mediterranean Sea. It

ZEUS observations for 2005 have been analyzed to study the regional distribution of lightning activity over Europe. As expected, lightning activity in summer was located predominantly over land while in winter the lightning activity was located over the Mediterranean Sea. We will present regional distributions of lightning flashes and diurnal cycles per season. Intensities of the lightning activity will be also reported. We will also present some typical ZEUS observations for continental and Mediterranean storms in combination with measurements of the cloud content, structure and extension from ground based radar and space born sensors such as METEOSAT IR sensor or Tropical Rain Measurement Mission (TRMM) Microwave Imager (TMI) and Precipitation Radar (PR).
We will also discuss on ZEUS detection efficiency and location accuracy based on the results of the comparison of ZEUS observations to the University of Munich LINET (Betz *et al*., this symposium) measurements for a storm located in Germany on the 29th of July 2005.
We will finally present some preliminary results on the use of ZEUS data to investigate NOx production over the European continent and the Mediterranean Sea.

Acknowledgments. This work was financed by the European Union (75%) and the Greek Ministry of Development (25%) in the framework of the program "Competitiveness - Promotion of Excellence in Technological Development and Research - Excellence in Research Centers, Action 3.3.1”.

Ground-based observations of Sprites and other Transient Luminous Events in Eastern Mediterranean winter thunderstorms

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We present results from the 2005-6 winter sprite campaign conducted in Israel. Optical ground-based observations were conducted from two sites, aiming to detect transient luminous events (TLEs) above winter thunderstorms approaching the eastern coastline of the Mediterranean Sea. We used 2 WATEC cameras, mounted on a pan-and-tilt unit with GPS time-base and event-detection software (UFO-Capture). The system was remote-controlled via the Internet and targets were chosen in real-time based on lightning locations derived from a BOLTEK system stationed in Tel-Aviv. Detailed weather forecasts and careful analysis of lightning probability allowed us to choose between the two observation sites: one near the coast in central Tel-Aviv, and the other from the Wise astronomical observatory in the Negev desert (Mizpe-Ramon). The optical observations were accompanied by ELF and VLF measurements from the existing TAU array (Price et al., 2004). In 4 different storms we detected 29 events - 22 sprites, 6 elves and 1 sprite halo; detection ranges varied from 250 to 450 km. Sprites were found to occur in the height range 50-80 km, with lengths varying from 10 to 35 km. We used the LPATS data of the Israeli Electrical Company to determine the ground location of the parent lightning. All TLEs were accompanied by distinct ELF transients. The relationship between meteorological parameters, storm size, vertical cloud development, lightning properties and charge moment is being investigated.

Lightning Physic information deduced from Lightning Mapping System

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Several types of LMS (Lightning Mapping System) are used world wide to monitor and analyze the lightning activity produced by storm. Most of those systems detect the electromagnetic radiation emitted by lightning flashes. Depending of the principle and the performances of LMS, relevant information about storm activity can be derived from the observations. Several Weather Services use those observations to identify storm cells and to nowcast their evolutions. But LMS applications are not limited to weather or climate studies.

If the physic of the return stroke process of the cloud to ground flash (CG) can be investigated from ground electrical and optical observations, intra cloud flash process and intra cloud part of a CG flash are more difficult to observe. For this type of lighting events, the LMS are important investigation tools.

In the first part of this paper, we give a review of existing systems and of their main field of application. Electromagnetic as well as optical systems at ground, airborne and in space are considered.

In the second part we discuss the capabilities of LMS for scientific studies on physic of lightning. Finally, we'll give a short description of the performances of a LMS designed for scientific studies, which is under development at Onera to monitor lightning activity over Paris area.

Session 6

Lightning Return Stroke Modeling and Effects

Realistic sources for modeling lightning interaction with towers

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Lightning interaction with towers is usually modeled as a parallel current source connected at the tower top (e.g., Rachidi et al., 2002; Bermudez et al., 2003). According to this model the undisturbed current source is divided into two parts, one part going into the channel and the other part going into the tower, the current division controlled by the surge impedances of the channel and the tower. This implies that the current that goes into the tower, being measured by instruments at the tower top, is affected by the presence of the tower. On the other hand Baba and Rakov (2005) modeled the lightning interaction with the tower as a series voltage source placed at the top of the tower. Such a voltage source injects equal currents into the channel and the tower, and this current is given by the series voltage source divided by the sum of channel surge impedance and tower surge impedance.

In both the above models of parallel current source and the series voltage source, the current that would be injected initially into the tower is a function of the surge impedances of the tower and the channel. Both models imply that the presence of the tower and its characteristics has an influence on the initial return stroke current that would be measured at the tower top, even before the time the ground reflections comes back.

From a physical perspective what would be the model closer to reality and have minimum inconsistencies? Let us look at the process of attachment of lightning to the tower. The downward leader is negatively charged and the upward leader from the tower top is positively charged. These two leaders will meet at some height above the tower top, and this height could be several tens of meters above tower top. Once the two leaders meet a current wave (voltage wave) travels in both directions as in a transmission line. The upward wave effectively neutralizes the negative charge and the downward wave neutralizes the positive charge of the upward leader from the tower, the tower, and the grounding network. The upward current can be treated as due to positive charge flow and the downward current can be treated as due to negative charge flow, giving rise to current vectors in the same direction in the channel and the tower initially.

According to the above picture, the undisturbed current source is in SERIES with the lightning channel and can not be in parallel with ground as reference. In the present work we model the lightning interaction with the tower as a series current source that has negligible series internal impedance (can be viewed also as a point current source) at the top of the tower or at the top of the upward connecting leader. This source injects the same current into the channel and the tower as the reflection coefficient is still unaffected. In contrast to the earlier models (parallel current source, and series voltage source) the series current source characteristics are not influenced by the surge propagation characteristics of the tower or the channel. This implies that the initial current measured by tower top instruments are not different from the current that would be measured if the lightning were to attach ground, in the absence of the tower. The current distributions on the tower and in the channel predicted by the series current source model is compared with that from the parallel current source model.

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Voltages Induced by Cloud Discharges on Overhead Power Lines

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Lightning-induced voltages in overhead power lines are generally analyzed in the literature by taking into account only cloud-to-ground (CG) discharges. Aim of this study is to extend such an analysis to the estimation of lightning-induced voltages to the case of LEMP (Lighting Electromagnetic Pulse) radiated by cloud-discharges (CD).

To achieve such an estimation, a procedure for the calculation of the LEMP associated to generally-oriented CD discharge paths has been developed. The procedure is based on the integration of the Master and Uman' equations adapted to the case of a generally-oriented lightning channel above a perfectly conducting plane [1-4]. Concerning the spatial-temporal distribution of the lightning current the Trasmission Line model is assumed, the adopted LEMP-to-transmission line coupling model is the Agrawal et al one [5-8].

The study presents a sensitivity analysis of CD-induced voltages against different quantities which characterize this specific problem, namely: amplitude and time to peak of the CD current, speed of the pulse wavefront, length, height and orientation of the CD path relevant to the position of the illuminated overhead line.

According to the geometry reported in Fig.1, where CD path and overhead line lie in the same plane perpendicular to the ground, Fig. 2 is reporting, for different velocity of the lightning wavefront, an example of the voltages calculated in the center of the line induced by a CD current waveshape having the following characteristics: 30 kA amplitude, 1.9 μs time-to-peak and 50 μs time-to-half.

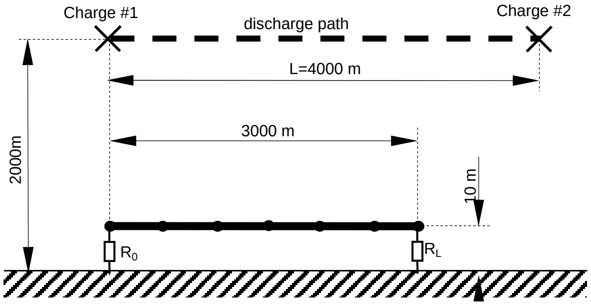

Fig. 1. Geometry of the problem discharge.

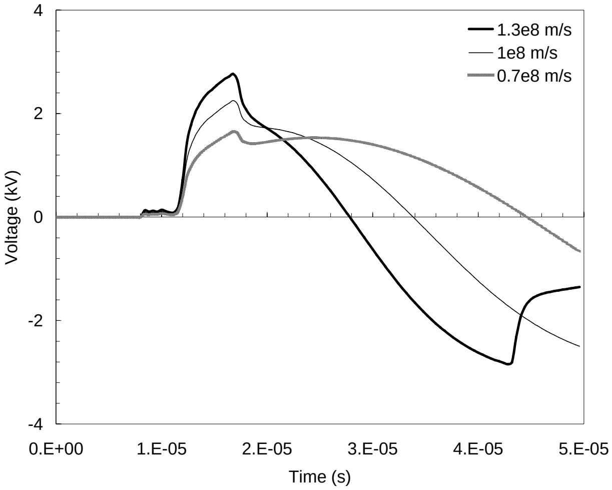

Fig. 2. Induced voltages in the medium point of the line, for the geometry illustrated in Fig.1, for three velocity of propagation of the stroke.

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