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Proposal for a new COST Action

COST P18

"The Physics of Lightning Flash and Its Effects"

Contact Person : **Prof. Rajeev Thottappillil**
Division for Electricity and Lightning Research,
Ångström Laboratory, Uppsala University
Box 534
751 21 Uppsala, Sweden
Tel: +46 18 471 5806
Fax: +46 18 471 58 10
rajeev.thottappillil@angstrom.uu.se

COST National Coordinator: **Ms. Birgitta Boman**
Swedish Agency for Innovation Systems
101 58 Stockholm, Sweden
Tel: +46 8 473 30 17
Fax: +46 8 473 30 05
birgitta.boman@vinnova.se

Rapporteur TC Physics: **Prof. Etienne Goovaerts**.
Universiteit Antwerpen - UIAUniversité de Liège
Department Natuurkunde
Universiteitsplein 1
2610 Wilrijk-Antwerpen, Belgium
Tel: +32 3 820 24 46
Fax:+32 3 820 22 45
Etienne.Goowaerts@uia.ua.ac.be

Rapporteur TC Meteorology: **Prof. Sylvain Joffre**
Finnish Meteorological Institute - FMI
PO Box 503
01101 Helsinki, Finnland
Tel: +358 9 1929 22 50
Fax:+358 9 1929 41 03
sylvain.joffre@fmi.fi

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Memorandum of Understanding

For the implementation of a European Concerted Research Action
designated as

COST P18

"The Physics of Lightning Flash and Its Effects"

The Signatories to this Memorandum of Understanding, declaring their common intention to participate in the Concerted Action referred to above and described in the Technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 400/01 "Rules and Procedures for Implementing COST Actions", the contents of which the Signatories are fully aware of.
2. The main objective of the Action is to increase the knowledge of the physics of the lightning discharge and of its effects on natural and man-made systems.
3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at Euro 96 million in 2004 prices.
4. The Memorandum of Understanding will take effect by being signed by at least five Signatories.
5. The Memorandum of Understanding will remain in force for a period of four years, calculated from the date of first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter 6 of the document referred to in Point 1 above.

Technical Annex

COST P18

"The Physics of Lightning Flash and Its Effects"

A. Background

The research in lightning is as old as the research in electricity. In 1750 Benjamin Franklin suggested an experiment that later proved lightning is an electrical discharge. Two years later the experiment was first successfully performed in France, followed by England and Belgium. The Franklin rod for protecting buildings from the effects of lightning strike was one of the first electrical devices. From the very beginning lightning research was interdisciplinary, attracting scientists from different branches of science. It was C.T.R. Wilson, recipient of the Nobel Prize for Physics in 1927 for the invention of the cloud chamber, who first determined the amount of electrical charges involved in lightning and thunderstorms by remote electric field measurement. The present knowledge and status of research on lightning is detailed in the following three recent books [Rakov and Uman, 2003; Cooray (ed.), 2003; Bazelyan and Raizer, 2000]. A brief introduction to the lightning phenomenon and important research questions are given below.

General description

Lightning is a transient electric discharge, which lasts, on average, half a second and exhibits a path length of some kilometers. The most common source of lightning on Earth is the cumulonimbus cloud in which the majority of charges are generally modeled as separated into upper positive and lower negative regions, although the charge structure is more complex. Lightning between the cloud and earth is called cloud-to-ground (CG) lightning. All other discharges that do not involve the ground are called cloud lightning or cloud discharges. The complete lightning, whether it is cloud-to-ground or cloud lightning, is called a lightning flash. Recently transient luminous events between top of the thunderclouds and ionosphere are observed, which are called sprites, elves, and blue-jets.

There are four types of CG lightning, based on the polarity of charge effectively lowered to ground and the direction of propagation of the initial leader. Lightning which effectively lowers a net negative charge to ground is known as negative lightning, and lightning that effectively lowers a net positive charge to ground is called positive lightning. The upward-initiated flashes usually occur from tall man-made objects or objects of moderate height from mountaintops. The possibility of artificially initiating lightning from thunderclouds by firing small rockets with trailing grounded wire was first demonstrated in the late 1960's. Since the late 1970's, this technique has been widely used for studying lightning discharges.

Lightning research has to be carried out on real lightning in nature and the difficulties associated with this is probably the main reason, why there is still very limited understanding of the detailed physical processes involved in lightning. The longest man made spark discharges in laboratory are still shorter than the average length of a single step in a downward propagating leader. Besides, attempts to initiate lightning in the laboratory, as it would in nature, are not very successful.

A description of the common processes in cloud-to-ground (CG) lightning is given in the Section Additional Information.

Issues in lightning research

Even though lightning is a very common natural phenomenon, mankind's knowledge of the physics of this phenomenon and its effects on natural and man-made systems is not complete and unanimity in opinions is lacking. Some of the important questions in lightning research at present are the following, but not limited to them: What is the phenomenology of processes in the lightning flash? How is lightning initiated in thunderclouds? What is the mechanism of lightning stepped leader and dart leader? What is the mechanism of lightning attachment to objects? What is the mechanism of lightning return stroke? What is the mechanism of X-rays and gamma-rays emission associated with lightning? How can ball lightning be observed and what is the mechanism of ball lightning? How lightning initiates the transient luminous events, called sprites, elves, and blue jets, in the mesosphere and ionosphere? What is the mechanism of the production of the trace gas species in the atmosphere by the hot plasma channel and corona in lightning discharge? How can the properties of lightning processes be inferred from remote measurements of electromagnetic radiation from lightning? How is lightning linked with the associated weather phenomena in which it occurs? A summary of the status of research on the above topics is given next. Important references are given in the Section Additional Information.

Several researchers around the world have performed experiments to determine the properties of lightning using photography, spectroscopy, electromagnetic field measurements, and direct measurements of currents when lightning strikes tall objects. However, knowledge of the phenomenology of processes in the lightning flash is not complete. Part of the reason could be the large natural variability of one lightning flash to the other and partly the availability of better technology for observing lightning with every passing decade.

The detailed physics of the preliminary breakdown in the clouds in an ambient electric field that is too small for direct spark breakdown and the initiation of lightning is not well understood. There are several competing theories for the mechanism of lightning initiation, such as a system of positive streamers developing from a point on a hydrometeor, bi-directional streamer development assisted by a chain of precipitation particles, and the role of 'run away' electrons, that is, electrons gaining more energy from the electric field between collisions with air particles than it loses in a collision.

Stepping is observed in lightning negative leaders regardless of whether it is initiated in the cloud or in the grounded object. There appears to be a qualitative similarity between a negative stepped leader in lightning and laboratory long sparks (several meters gap length). However, lightning stepped leaders are not studied experimentally as thoroughly as stepping in leaders of laboratory sparks. Different theories are advanced for lightning stepped leader.

The process of lightning leader attachment to ground or objects is very poorly documented and understood. From time-resolved photographic observations it appears that in response to the downward moving leader, one or more upward leaders are launched from the ground, one of which make contact with the downward leader. The attachment process in the first stroke, which is through virgin air, and in the subsequent strokes, which is through warm-air channel, may be different. Lightning strikes to aircrafts in flight are usually initiated by the aircrafts itself. There were attempts at modelling the sweeping of the lightning attachment point along the aircraft in flight. Observations show that the return stroke current causes extensive branched arcing along the soil surface and also under the soil. The fulgurites, glassy hollow tubes, formed by lightning in soil have zigzagged and branched appearance. The mechanism of lightning current dissipation into soil is not well understood.

Of all the lightning processes, the return stroke is the most energetic and most investigated. Physical properties of the return stroke channel, such as temperature, electron density, and pressure has been determined from time resolved optical spectroscopy. There are several classes of models for the lightning return stroke, depending on the purpose of the model. However, there is no comprehensive model of the lightning return stroke that could reconcile most of the observed characteristics of the return stroke.

C.T.R. Wilson in 1925 has hypothesized that high fields in thunderstorms could produce runaway electrons. Runaway electrons could produce X-rays and gamma rays in collision with air particles. However, reliable measurements of runaway electrons, X-rays, and gamma rays attributable to lightning processes are not that many. Recent observations with triggered lightning shows that bursts of X-rays in the 30-250 keV range are produced by dart leaders in 73% of the strokes. Intense bursts of gamma rays in the MeV range, hypothesized to be originating in the in-cloud processes, were also observed in triggered lightning. Models for the origin of these X-rays and gamma rays in lightning processes are not available.

Ball lightning is a fascinating and mysterious phenomenon and there are several theories. Some of these theories involve heated spheres of air or air mixed with trace materials at atmospheric pressure, dust, droplets, aerosols, aggregations, chemical reactions or combustion, very high density plasma which exhibits quantum-mechanical properties characteristic of the solid state, closed-loop current contained by its own magnetic field, air vortex that provides containment for luminous gases, electromagnetic fields contained within a thin spherical shell of plasma, nuclear reactions, matter-antimatter annihilation, miniature black holes, maser theory, focused atmospheric high-frequency electromagnetic fields, steady and locally focused current flow from cloud to ground, focused cosmic rays, antimatter meteors etc. 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 recording of the luminous phenomena above the tops of the thunderclouds were obtained by accident in 1989 while testing a new low-light video system. The low luminosity, but colorful, transient optical events in the clear air above thunderclouds are classified as blue jets, red sprites, and elves. It has been established that there is a connection between cloud-to-ground lightning and these luminous events, even though the exact mechanism of this connection is still under investigation.

Atmospheric electrical discharges, including corona, different processes in lightning discharge, sprites, blue jets and elves between cloud tops and ionosphere, produce new trace molecules from the constituents of the atmosphere. Nitric oxide, NO, is the most important molecule produced by electric discharges because it facilitates production of ozone. Atmospheric ozone absorbs infrared radiation and is therefore acting as a greenhouse gas. There is wide disagreement on the percentage of the contribution of

NOx in the atmosphere due to lightning, varying from 3-20 % of the total. This disagreement may be due to the differences in the estimation of number of molecules of NOx per unit energy in corona and other discharge channels, the difficulty in estimating the energy in various processes of lightning flash, and the difficulty in estimating the total number of global lightning.

Lightning is a highly variable event and no two lightning discharges are the same. Even though measuring the time varying electric and magnetic fields in lightning is relatively easy, estimating the spatial and temporal distribution of sources that give rise to these fields are not so easy. This type of problem is sometimes called the inverse source problem in lightning. As electromagnetic fields travel along the earth it suffers from attenuation and dispersion due to the electromagnetic property of earth. Simple models that can predict the peak currents in the lightning channel from remotely measured fields are available. Simultaneous measurements of fields at different stations can locate the point of lightning strike. Also, interferometric techniques can give information on the development and progression of lightning discharge inside the clouds. Development of better theoretical models is required to infer the properties of lightning processes from remote measurement.

The effects of lightning on natural and man-made systems:

A strong need exists today in Europe to understand the way in which the lightning flashes interact with power systems, telecommunication systems, railway signalling systems, wind turbines, aircraft, and special structures. This knowledge will lead to finding optimised protection measures to safeguard these man-made systems against lightning.

Recent research indicates the intertwining relationship between lightning, rainfall and severe weather. Data from the NASA’s Tropical Rainfall Measuring Mission (TRMM) satellite, launched in 1997, is used to investigate the relationship between rainfall and lightning. Among other instruments this satellite has precipitation radar and Lightning Imaging Sensor. Convective rainfall is well correlated to lightning activity, although the relationship varies from region to region. Improving the understanding of these relationships in Europe may allow the use of lightning data to estimate rainfall amounts for nowcasting purposes. Downbursts and microbursts, the strong winds blasting down from thunderstorms, are major hazards to civil aviation. The time of occurrence of microbursts is closely related to the occurrence of lightning flashes in the thundercloud and a knowledge on the connection between them would aid in the prediction of the occurrence of microbursts. It has recently been shown that increases in the positive CG flash rate often occur shortly before the onset of severe weather (tornados, wind damage, hail, etc.). Knowledge of the physics of lightning, especially the mechanism of initiation of lightning in thunderclouds, will help to link statistics of lightning occurrence and characteristics with particular weather phenomena.

The global lightning studies are also related to the Earth's climate. Recently, studies have shown strong connections between regional/global lightning activity and important climate parameters, such as surface temperature and upper tropospheric water vapour. It has been suggested that global lightning activity (measured from a single ground station via the Schumann resonance) may be used as a "global thermometer" to track changes in the Earth's climate. The quantification of the contribution of the lightning flashes in the production of nitrogen oxides in the atmosphere is an important piece of information in finding the effects of man made nitrogen oxides on the global environment changes. There are now satellites looking down on the Earth continuously, supplying information on the temporal and spatial variability of lightning and thunderstorms. This would facilitate the study of the relationship between lightning and the global electrical circuit.

Reason for co-operation:

From the above description, the interdisciplinary nature of lightning research is very clear. Effective communication and exchange of information between groups working on diverse aspects of lightning are essential for the success of the research of each group involved in this proposal. Up to now the research related to lightning in Europe is carried out largely in isolation using national funding of different groups, and a COST Action is the ideal instrument to co-ordinate all these national research activities in Europe.

B. Objectives and Benefits

The main objective of the Action is to increase the knowledge of the physics of the lightning discharge and of its effects on natural and man-made systems. This will include the following sub-objectives, but not limited to them.

(a) To understand and model the different physical processes in the lightning channel.
(b) To understand and model the lightning attachment to objects.
(c) Measurement of characteristics of lightning flashes in Europe and an establishment of a data bank on the lightning parameters, including a databank on the characteristics of the electromagnetic radiation of lightning from ELF to gamma rays.
(d) Develop models for the inverse source problem in lightning, that is, inferring the characteristics of the processes in the lightning channel from remote measurements of the electromagnetic waves associated with lightning.
(e) To understand the mechanism of the production of the trace gas species in the atmosphere by the hot plasma channel and corona in lightning discharge.
(f) To understand the connection between the particular characteristics of lightning flashes and the associated observation of luminous events in the mesosphere and the lower ionosphere.

Fulfilling the above objectives would increase knowledge of the most important scientific issues in lightning research, as listed in Section A, namely, the phenomenology of processes in the lightning flash, lightning initiation in thunderclouds, mechanism of lightning stepped leader and dart leader, mechanism of lightning attachment to objects, mechanism of lightning return stroke, mechanism of X-rays and gamma-rays emission associated with lightning, mechanism of ball lightning, mechanism of trace gas species production by lightning, and the connection between lightning and upper luminous events in the atmosphere. In addition, increased knowledge of the physics of lightning would help several scientists and engineers in devising better strategies for protecting sensitive systems from the deleterious effects of lightning and to understand the impact of lightning on the chemistry of the atmosphere and on the global electric circuit. The advance in the physics of lightning would also allow better ways to forecast and observe lightning in connection with specific weather structure or processes.

C. Scientific Programme

The most important research tasks to be carried out for achieving the objectives are described below. For clarity, the research tasks are grouped under different headings, which naturally will become the focus of each Working Group. The Working Groups are:

WG1. Measurement of properties of various types of lightning discharges
WG2. Phenomenology and modelling of the processes in the lightning flash
WG3. Physics and models for the lightning attachment to objects
WG4. Inverse source problems in lightning

Summary of the activities of each Working Group are described below.

WG1. Measurement of properties of various types of lightning discharges

To advance the knowledge of the properties of the various physical processes in lightning, several measurements will be performed, some of which are: 1) Time domain measurements of electric and magnetic fields from lightning using sensors with bandwidth from a few hertz to a few hundred megahertz (step response rise time in several nanoseconds and fall time in fraction of a second) for the whole duration of the lightning flash, from its initiation in the clouds to the end of the last return stroke. 2) Measurements of lightning current in triggered lightning and lightning strike to towers, correlated with fields at different distances from lightning. 3) Time resolved optical measurements of the lightning channel from close distances in triggered lightning and lightning strike to towers and correlated with the current and fields measurements. 4) Measurements of X-rays and gamma rays from triggered lightning and lightning strike to towers, correlated with current, fields, and optical radiation. 5) Measurements of ELF (Schumann resonance) from the same lightning at different stations around the globe, correlated with wide-band measurements of fields near to the lightning.

At the planning stage of the measurements a dialogue has to be established with WG2 and WG3 to decide the most important parameters required for modelling the lightning processes. The meteorologists taking part in this Action will provide the meteorological parameters associated with those storms during which lightning measurements are to be carried out. For carrying out the above time-correlated measurements using primarily the national funds, several groups have to co-ordinate their measurement campaigns under the COST Action.

In Europe, the tower on Mount Gaisberg in Austria is struck by lightning on average 65 times in a year and at present the tower is instrumented to measure lightning currents and plans are there for measuring electric fields also. Also, the tower on Mount Peissenberg in Germany is struck by lightning on average 30 times in a year and this tower also will be instrumented for measuring currents and fields in year 2005 using national funds. Every year in summer, triggered lightning experiments are conducted at the Camp Blanding facility at University of Florida, Gainesville in USA. All the above three groups participated in preparing this COST Action. Besides, correlated remote measurements have to be carried out on natural CG lightning striking ground, even if current measurements may not be possible.

The measurements described above are essential for establishing the phenomenology of the processes in the lightning flash (WG2), for modelling the various processes in the lightning flash (WG2), for developing models of lightning attachment to objects (WG3), and for estimation of the characteristics of lightning processes from remote measurements (WG4). Besides, these measurements will contribute to the establishment of a data bank on the characteristics of lightning processes and the characteristics of electromagnetic radiation of lightning from ELF to gamma rays. This data bank is beneficial for physicists trying to understand lightning phenomena, radio communication industry for avoiding the disturbances caused by the spectrum of frequencies from lightning, meteorologists who could possibly use information about lightning in climate change and severe weather studies, and engineers wanting to protect electrical and electronic systems from the deleterious effects of lightning. The data bank also contributes to several international and European standards related to lightning protection.

WG2. Phenomenology and modelling of the processes in the lightning flash

Detailed analysis of the measurements carried out in WG1 will fill the gaps in the present understanding of the phenomenology of the processes in the lightning flash. New undiscovered processes from the analysis of measurements (WG1) cannot be ruled out. A theory has to be developed for lightning initiation in electrified clouds. The reasons for the stepping of the lightning leader in virgin air and its zigzag path have to be understood. The conditions required to sustain the leader all the way to ground has to be modelled. The remote measurements of electric and magnetic fields (WG1) associated with the later stage of the initiation of lightning will be helpful in verifying the predictions of the lightning initiation models. The stepped-leader pulses in electric and magnetic field records, time-resolved photographic observations, and measurements of X-rays and gamma rays associated with the leader (WG1) will help in the modelling of the leader process.

Even though considerable effort has been done in return stroke modelling, there is no single model that is consistent with all the observed parameters of the lightning return stroke. At present there are no models that could explain the large variations in the peak current, charge, and optically measured speed between return strokes. Present models are not able to explain why some negative CG lightning flashes are single stroke flashes while majority of them are multiple-stroke flashes. For some strokes there is more than one termination on ground, separated by a few meters to a few kilometres, and there are no models to explain this. The physics of negative return stroke is different from positive return stroke, and a better understanding of this difference can explain why most of the positive lightning has only one stroke while negative lightning usually have more than one stroke. Also, positive lightning produces the most energetic return strokes in terms of the largest value of peak currents and largest value of effective charge lowered and physical models of positive return strokes will be able to explain this behaviour. In developing the physics and models for all the above lightning processes, measurements in WG1 are necessary.

Different lightning processes giving rise to impulsive or quasi-static field changes are instrumental in causing the transient luminous events, blue jets, sprites, and elves, in the upper atmosphere. Therefore models of the processes in lightning that can give reliable estimates of the fields in the upper atmosphere are useful in the study of transient luminous events.

The hot plasma channel of the lightning return stroke, and the corona produced during the pre-breakdown processes reacts with the molecules in air and produce trace gas species, most importantly NO and NOx, which are important in environment studies. Better models for lightning processes would also help the global estimation of NOx produced by lightning.

WG3. Physics and models for the lightning attachment to objects

It is generally thought that the beginning of attachment process decides the strike point of lightning and therefore this process has great significance in the practical task of lightning protection. The existing models for lightning leader attachment, used in lightning protection are very crude and does not involve the proper physics of leader attachment. The international organisation CIGRE (International Council on Large Electric Systems) has recognised this and has formed a Task Force C4.4.05 'Lightning interception' to review the situation and activities of WG3 are complementary. The factors that determine the striking distance, the relationship between striking distance and measurable parameters like charge and current, the differences in the attachment process when upward leaders are initiated from insulated objects (e.g., trees, rotor of windmills) as opposed to from grounded conducting objects (e.g., air terminals on top of buildings, towers), the conditions necessary for a tall object (e.g., tall tower, mountain top) to initiate long upward leader all the way to the cloud, the physics of triggering of lightning by flying objects (e.g., air planes, rocket carrying trailing wire in triggered lightning experiments) etc. are some of the questions, that this WG will try to find an answer for.

There are some evidences that interaction of lightning with the tower influences the measured parameters of lightning. This issue requires more investigation. Also, there are some indications that parameters of return stroke that strike sea water are different from those that strike the shore, as measured by remote electric and magnetic fields. Seawater has electrical parameters very different from that of the sand of the shore. Understanding the physics of lightning attachment will shed more light into these issues.

The mechanism of arcing along soil surface and the mechanism of soil ionisation and breakdown in the soil, especially the role of moisture and air pockets, are important issues to be investigated.

WG4. Inverse source problems in lightning

The electromagnetic radiation from processes in lightning is not confined to the radio frequency spectrum, but also extends to microwave, infrared, visible light, ultraviolet, X-ray and gamma ray regions of spectrum. When compensated for the propagation effects, the radio waves from lightning can give information on the magnitudes of the currents and charges, its position and its time variation at the source region of lightning. Radiation at the high frequency end of the spectrum can give information about the processes at the atomic level. The commonly used radio-frequency locating technique of the lightning processes are the magnetic direction finding usually applicable to the return stroke process, the time of arrival of the pulse technique, applicable to any process in lightning that give rise to an impulsive radiation pulse, and the interferometric technique at higher frequencies. The lightning location networks, that continuously monitor time and position of lightning strikes works based on one of the above three principles, the first two being the most common. Lightning location networks cover the whole of North America, and most parts of Europe. These systems use some models to convert the measured peak field amplitudes into peak field currents of the return stroke. A consistent difference is observed between such estimated return stroke peak current distribution and the peak current distribution given by lightning protection standards used today. Better models that can estimate the source characteristics are required to resolve the reason for this difference. Accurate models for radio wave propagation over different types of terrain are also required to correct the measured remote impulsive fields for propagation effects. More research is required for deriving the properties of the sources in lightning from the high frequency radio signals.

Schumann resonance from lightning is routinely measured at several locations in Europe. Satellite-based optical observations of lightning are also available. These global measurements of lightning occurrence have to be calibrated against the more local, but more accurate, lightning location data from the European Lightning Location network. This calibration allows reliable estimation of global frequency of lightning flashes based on Schumann resonance, which is quite useful in getting information about lightning over regions where there are no ground-based lightning location networks (e.g., Oceans, large parts of Africa and Asia).

Some of the models for lightning processes (WG2), where electromagnetic waves occur as one of the outputs of the model, and simultaneous measurements of lightning processes with different types of instruments (WG1) would be useful in the inverse source problem also.

D. Organisation

Management Committee:

The Management Committee (MC) will be responsible for co-ordinating all the activity within the Action and will take advice from the Technical Committee Physics to liaison with other COST projects. The MC will comprise delegates from signatory countries and will meet once every half year. To reduce cost, these meetings will be conducted in connection with the workshops and international conferences. At the beginning of the Action, a website dedicated to the Action will be established for better information exchange.

Working Groups:

For convenience the research will be organised around four Working Groups. These Working Groups are: WG1 – Measurements of properties of various types of lightning discharges, WG2 - Phenomenology and modelling of the processes in the lightning flash, WG3 - Physics and models for the lightning attachment to objects, WG4 - Inverse source problems in lightning. The scientific programme of these Working Groups are as given under the same titles in Section C.

At the end of the preparatory phase, the expressed interests of the countries in the activities of the Working Groups are as in Table 1, but this could change as the Action progresses and more groups and countries join the Action.

Table 1. Expressed interest of countries in Working Groups at the end of the preparatory phase.

	COST Countries																		Non-COST Countries				
	Austria	Denmark	Finland	France	Germany	Hungary	Israel	Italy	Macedonia	Netherland	Poland	Portugal	Serbia and Mo.	Slovenia	Spain	Sweden	Switzerland	UK	Canada	Japan	Russia	Ukraine	USA
WG1	X	X	X	X	X			X			X			X	X	X	X		X	X			X
WG2	X	X	X	X	X	X	X	X		X			X	X	X	X	X	X	X	X	X	X	X
WG3	X	X		X	X		X	X	X	X	X	X	X			X	X		X	X	X	X	X
WG4	X		X	X	X	X	X	X						X		X	X	X					X

The MC will appoint Working Group Co-ordinators (WGC) responsible for the activities of each group and will have a joint meeting at the beginning of the Action.

Workshops and Symposiums:

Following the initial establishment of the Action, the MC together with respective WGC will organise a series of workshops on the subject area of each Working Group for better information flow and also to link this Action with the national research projects. Following this, at least one yearly workshop in the subject area of each Working Group (total 4) will be organised. In addition, there will be several cross-group workshops, the details of them will be decided later as the Action progresses.

Once each year, a symposium covering all the Working Groups will be held. At the end of each workshop and symposium, the proceedings will be published.

Joint Technical Actions:

In addition to the workshops, the MC will encourage development of Joint Technical Actions (JTAs) to enhance the existing national research programmes contributing to the Action. These are minimal cost activities mostly funded by the national research programmes of the groups. One particular type of JTA that could be mentioned at this stage is simultaneous measurements on natural lightning at the unique European facilities in Gaisberg, Austria, and at Piessenberg, Germany by several groups using diverse equipments to cover the entire spectrum of electromagnetic waves. Such simultaneous measurements of the entire spectrum of electromagnetic waves from lightning processes have never been attempted before. Simultaneous measurements are desired because of high variability from one lightning to the next. Other JTAs will be initiated as the Action progresses.

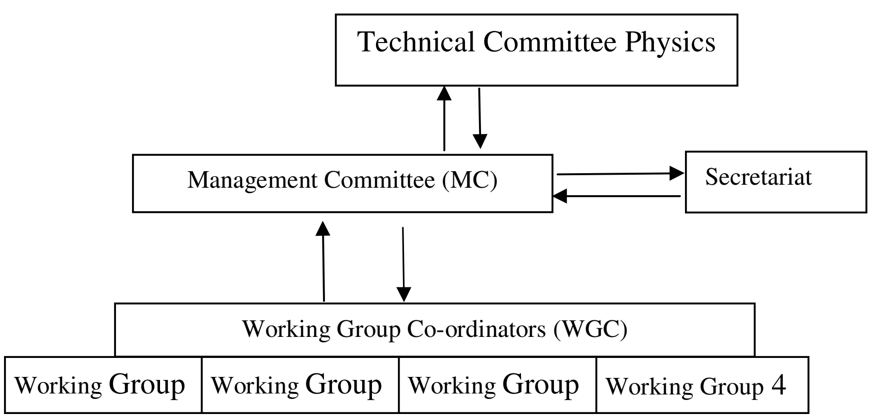
Short-Term Scientific Missions:

Short-Term Scientific Missions (STSM) will be used for the movement of researchers between groups so that they can work together closely on specific problems and exchange expertise. Some of the STSM's could be in connection with the JTAs mentioned above, some in connection with use of advanced numerical models of lightning processes, and some in connection with sharing of special equipments.

E. Timetable

Total estimated duration of this COST Action is 4 years.

General organisation and timetable of the Action are given below.



Year 1		**Year 2**		**Year 3**		**Year 4**	
1st Half	**2nd Half**	**1st Half**	**2nd Half**	**1st Half**	**2nd Half**	**1st Half**	**2nd Half**
Start							
MC+WGC meeting	MC meeting	MC+WGC meeting	MC meeting	MC+WGC meeting	MC meeting	MC+WGC meeting	MC meeting
Workshop WG 1		Workshop WG 1	Special effort at widening the Action network to include more countries and groups	Workshop WG 1		Workshop WG 1	
Workshop WG 2		Workshop WG 2		Workshop WG 2		Workshop WG 2	
Workshop WG 3		Workshop WG 3		Workshop WG 3		Workshop WG 3	
Workshop WG 4		Workshop WG 4		Workshop WG 4		Workshop WG 4	
	Sympo-sium		Sympo-sium		Sympo-sium		Concluding Symposium
	10 STSMs		10 STSMs	Intermediate Progress Report	10 STSMs	10 STSMs	**Final report**

Note: Several groups are involved with more than one Working Group. Therefore, for convenience and to reduce cost effort will be made to conduct the joint MC and WGC meetings and the group workshops at the same place and in the same week. All Working Groups present their national research at the symposium.

F. Economic dimension

The following 18 COST countries have actively participated in the preparation of the Action or otherwise indicated their interest:

Austria
Denmark
Israel
Finland
France
Germany
Hungary
Italy
Macedonia
The Netherlands
Poland
Portugal
Serbia and Montenegro
Slovenia
Spain
Sweden
Switzerland
United Kingdom

On the basis of national estimates provided by the representatives of these countries, the economic dimension of the activities to be carried out under the Action has been estimated, in 2004 prices, at roughly Euro 96 Million.

This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

In addition to the 18 COST countries, the following institutions from 5 non-COST countries have expressed their interest in joining the Action at their own cost.

University of Toronto, Toronto, Canada

Ryerson University, Canada

McMaster University, Hamilton, Canada

Central Research Institute of Electric Power Industry (CRIEPI), Tokyo, Japan

University of Tokyo, Japan

Doshisha University , Japan

The Institute for Problems in Mechanics, Russian Academy of Science, Moscow, Russia

National Technical University of Ukraine ”Kyiv Polytechnic Institute”, Ukraine

Usikov Institute for Radio Physics and Electronics, Ukraine

University of Florida, Gainesville, USA

G. Dissemination Plan

The results of the Action will be disseminated to the target audience of researchers working with the physics of lightning. In addition, some parts of the research results will be of interest to other researchers in the field of meteorology and electromagnetic compatibility. Provision will be made for contacts with TC-Meteorology of COST. Besides, international standard making bodies concerned with lightning protection, national and regional policy makers and planners concerned with weather and environmental issues related to lightning, insurance industry and service providers concerned with risk of damages and accidents due to lightning, and manufacturing and service industry concerned with effective lightning protection would also be interested in some of the research results.

A website dedicated to this Action will be created where all public information regarding the Action proceedings of the workshops and symposiums will be put, accessible to everyone. Working documents will also be put at the website protected by username and password. The Action website will be linked to the websites of other scientific associations such as International Commission on Atmospheric Electricity (ICAE), International organisation of Electrical and Electronic Engineers (IEEE), International Conference on Lightning Protection (ICLP), Institute of Physics (IoP) etc.

Information about this COST Action will be provided at international conferences.

Scientific articles on the results of the Actions will be published in international conferences and journals.

Where applicable, the Management Committee will delegate individual researchers to National and International Standards making bodies.

Research on lightning started in the late 18th century, with Benjamin Franklin, in the area of electricity, which was part of Physics. As physics developed, different specialisations with in physics branched out. Like all natural large-scale phenomena, researchers from different branches of physics (and other sciences) contribute to research on lightning phenomena. Therefore research articles on the physics and effects of the lightning phenomena are scattered across diverse journals. Examples of these journals are Journal of Geophysical Research, Journal of Physics D: Applied Physics, Physics Letters, Radio Science, Geophysical Research Letters, Nature, Science, IEEE Transactions on Plasma Science, IEEE Transactions on Electromagnetic Compatibility, IEEE Transactions on Power Delivery, IEE Proceedings, American Journal of Physics, Journal of Electrostatics, Monthly Weather Review, Atmospheric Research, Physica Scripta, Physics of Fluids, Lancet, Journal of Trauma, Icarus etc. Therefore it was decided to launch a new peer reviewed journal called 'Journal of Lightning Research', under the initiative of Prof. Vernon Cooray, Sweden, an expert taking part in this COST Action. The scientific committee of the International Conference on Lightning Protection (ICLP) has agreed to sponsor this journal and negotiations are going on with publishers for the journal production. The editor of the journal will be Prof. Vernon Cooray and a team of associate editors, who are experts in different aspects of lightning research, have been put together. This journal will be a prominent vehicle in bringing the research results of this COST Action to the target audience.

COST P18

"THE PHYSICS OF LIGHTNING FLASH AND ITS EFFECTS"

ADDITIONAL INFORMATION
NOT PART OF THE MOU

History of the proposal:

This proposal emerged as a natural outcome of informal research contacts between different groups within Europe on issues related with lightning. There are two international conferences on lightning that originated in Europe, namely, International Conference on Lightning Protection (ICLP), and the International Workshop on Physics of Lightning (IWPL). Since its inception more than 50 years ago (Germany, 1951) as a pan-European conference, the ICLP has grown as a truly international conference covering both theoretical and practical aspects of lightning and attracting delegates from North and South America, and Asia. The 27th ICLP that was held in Avignon, France during September 13-16, 2004 has attracted about 270 delegates from more than 30 countries. The International Workshop on Physics of Lightning was first held in Vitrac, France in year 1993. Since then it was held once every two years, totally numbering six. These two conferences helped to establish informal contacts between several research groups in Europe and a strong need was felt to have a research network within Europe devoted to the Physics of Lightning Flash and its effects. Such a research network can overcome several difficulties associated with research on Lightning phenomena. A big disadvantage in lightning research is the difficulty of making experiments on lightning under controlled conditions. It is impossible to predict when and where lightning is going to strike. There are several constraints in extending the results from laboratory experiments with long sparks to natural lightning. No single research group in Europe have all the expertise or all the equipments or the resources required to thoroughly study lightning. The high variability of one lightning discharge to the other adds to the problems. A research network will be able to coordinate the experimental observations on lightning, data analysis, and theoretical modelling. The Gaisberg tower in Austria is struck by lightning on average 65 times in a year and the Peissenberg tower in Germany is struck by lightning on average 25-30 times in a year. Even though these lightning are due to upward initiated leaders from the towers, several later processes in a lightning flash can be studied by coordinated experiments by different groups at these facilities. Since University of Florida, Gainesville, where there is a rocket-triggered lightning experimental facility at the International Centre for Lightning Research and Testing, is part of this COST initiative, fruitful exchange of information and experience across the Atlantic are possible.

The interdisciplinary nature of Lightning Research was well appreciated and therefore groups working with all different aspects of lightning, namely, those working with physics and models of lightning processes, those working with measurements and phenomenology, those working with lightning attachment, and those working with inverse source problems are part of this proposal.

Lightning is a prominent natural phenomenon and the results of the research described in this proposal will benefit not only the physics community, but also people from several other related disciplines. Some of these are mentioned below.

The database on the characteristics of the spectrum of electromagnetic waves from lightning (WG1) will also be beneficial for radio and communication engineers, and engineers trying to protect electrical and electronic networks from deleterious effects of lightning. This database and better knowledge of the physics of lightning attachment (WG3) and new models based on that will help engineers to design better lightning protection methods for wind farms, communication towers, rail networks and airborne vehicles. Also, it will be useful to the pre-standardisation work of CIGRE (Conference on large electric systems), the standardisation work of IEC (International Electricity Commission) and CENELEC related to lightning protection.

Having better models for the remote estimation of lightning parameters (WG4) will also help the European lightning detection network to associate parameter values with detected lightning. This can be useful in lightning risk assessment and lightning accident investigations. The models for calculating the electromagnetic fields from lightning processes (WG2) and remote estimation of lightning parameters (WG4) will be helpful to EU FP5 Research Training Network 'Coupling of Atmospheric Layers' aiming at understanding the mechanisms of sprites, elves, and bluejets and their role in global electrical circuit.

Several people are trying to develop using Schumann resonance as a "global thermometer" to track changes in the Earth's climate. Measurements of lightning currents and radio waves (WG1) can be used to calibrate the occurrence of the Schumann resonance with lightning.

The conditions under which a lightning is initiated in the thundercloud are influenced by meteorological parameters. Knowledge of the physics of lightning initiation (WG2) and the measurement of the characteristics of radio waves associated with lightning initiation (WG1 and WG4) will be valuable inputs to those who wants to study the connection between lightning and several weather related phenomena.

List of Experts:

Prof. Dr. Rajeev Thottappillil, Sweden is the co-ordinator of this proposal.

The President of International Conference on Lightning Protection, Prof. Dr. Carlo Mazzetti, Italy, and Vice-president Prof. Dr. Z. Flisowski, Poland and five of the members of the scientific committee, namely, Prof. Dr. Vernon Cooray, Sweden, Prof. Dr. Farhad Rachidi, Switzerland, Prof. Dr. Carlo Alberto Nucci, Italy, Prof. Dr. Fridolin Heidler, Germany, and Prof. Dr. Vladimir Rakov, USA are taking part in this proposal.

Prof. Dr. Serge Chauzy, France, Dr. Gerhard Diendorfer, Austria, and Dr. Takatoshi Shindo, Japan are three of the members of the scientific committee of the International Workshop on Physics of Lightning who are also taking part in this proposal.

The experts who have been consulted and who have contributed during the drafting of this Action proposal or who have expressed interest in joining this COST Action are given below. All experts are listed country-wise.

Dr. Gerhard Diendorfer **Austria**
Dr. Wolfgang Schulz
OVE-ALDIS
Austrian Electricity Association
Kahlenberger Str. 2A
1190 Vienna
Austria
Tel.: +43-1-370 58 06/215
G.Diendorfer@ove.at
W.Schulz@ove.at

Dr. Torsten Neubert **Denmark**
Senior Scientist
Danish Space Research Institute
Juliane Maries Vej 30
2100 Copehagen O
e-mail: neubert@dsri.dk
Phone: +45 3532 5731
Fax: +45 3536 2475

Dr. Troels Sorensen **Denmark**
Energi E2,
Att.: Troels Sørensen
Teglholmsgade 8, DK-2450
Copenhagen SV, Denmark.
Phone: + 45 24883868
E-mail: slt@e2.dk

Dr. Tapio Tuomi **Finland**
Head of Research Group
Finnish Meteorological Institute (FMI),
Earth Observation
P.O. Box 503
FIN-00101 Helsinki
Finland
telephone: +358-9-19291
telefax: +358-9-1929 4603
tapio.tuomi@fmi.fi

Prof. Dr. Serge Chauzy **France**
Prof. Dr. Serge Soula
Dr. Sylvain Coquilla
Laboratoire d'Aerologie
OMP - 14 av Edouard Belin 31400 Toulouse
+33 561 33 27 74
+33 561 33 27 90
serge.chauzy@aero.obs-mip.fr
sous@aero.obs-mip.fr
sylvain.coquillat@aero.obs-mip

Dr. Pierre Laroche **France**

ONERA
29 avenue Division Leclerc 92322 Chatillon
France
+33 1 46 73 47 23, +33 1 46 73 41 48
Pierre.Laroche@onera.fr

Dr. Martin Fullekrug **Germany/UK**

Telecommunications, Space and Radio Group
Department of Electronic and Electrical Engineering
University of Bath
Bath, BA2 7AY
United Kingdom

phn: +44 1225 386053
fax: +44 1225 386305
elm: eesmf@bath.ac.uk

Dr.-Ing. habil. Fridolin Heidler **Germany**
University of the Federal Armed Forces Research Munich
Institute of Electrical Power Supply, EIT7
Werner-Heisenberg-Weg 35
D-85577 Neubiberg
Germany
Fridolin.Heidler@unibw-muenchen.de
Phone: ++49 89 6004 - 3736
Fax: ++49 89 6004 – 3723

Dr. Gabriella Sátori **Hungary**

Head of the Department of Aeronomy
Geodetic and Geophysical Research Institute
of the Hungarian Academy of Sciences
Csatkai u. 6-8.
H-9400 Sopron
Hungary
+36-99-508379 +36-99-508355 satori@ggki.hu

Prof. Dr. Carlo Mazzetti **Italy**

Dept. of Electrical Engineering
University of Rome "La Sapienza"
Via Eudossiana
18-00100 Roma, Italy
mazzetti@elettrica.ing.uniroma1.it

Prof. Dr. Carlo-Alberto Nucci **Italy**

Professor
Department of Electrical Engineering
University of Bologna - Faculty of Engineering
v.le Risorgimento 2 - 40136 Bologna BO
Italy
tel: +39.051.2093479
fax: +39.051.2093470
e-mail: carloalberto.nucci@unibo.it

Dr. Marina Bernadi **Italy**

CESI SIRF
Via Rubattino 54, 20134 Milano, IT
Tel: +39-02-21255163
Fax:+39-02-21255150
Cell:+39-329-3741394
Email: Mbernardi@cesi.it

Prof. Dr. Colin Price **Israel**

Department of Geophysics and Planetary Science
Tel Aviv University
Ramat Aviv, 69978
Israel
tel: 972-3-6406029 fax: 972-3-6409282
e-mail: cprice@flash.tau.ac.il

Prof. Dr. Zev Levin **Israel**

The Goldemberg Chair in Atmospheric Physics
Department of Geophysics and Planetary Science
Tel Aviv University, Ramat Aviv 69978, Israel
Tel: Geophysics private office: 972-3-6408274 fax: 972-3-6409282
E Mail: zev@hail.tau.ac.il

Dr. Yoav Yair **Israel**

The Open University of Israel
16 Klauzner Street Ramat-Aviv, 61392 Tel-Aviv
Israel
+972-3-6465579, +972-3-6465410
yoavya@openu.ac.il

Prof. Dr. Arie Braunstein **Israel**

Tel Aviv University
Ramat Aviv, 69978
Israel
aribraun@eng.tau.ac.il

Prof. Dr. Leonid Grcev **Macedonia**

Elektrotehnicki fakultet
Karpos II BB, P.O. Box 574
1000 Skopje, Macedonia
Phone (work): +389-2-3099128
Phone (home): +389-2-3127274
Fax: +389-2-3064262
Email: lgrcev@etf.ukim.edu.mk

Prof. Dr. Ute Ebert **The Netherlands**
CWI, P.O.Box 94079, 1090 GB Amsterdam, The Netherlands
second affiliation: Dept. Physics, TU Eindhoven, The Netherlands
ebert@cwi.nl, tel (+31) 20-5924206, fax (+31) 20-5924199

Prof. Dr. Zdobyslaw Flisowski **Poland**

Institute of Power Engineering and High Voltage Technology
Warsaw University of Technology
ul. Koszykowa 75, 00-662 Warsaw - Poland
Phone: +48.22.625.19.14
Fax: +48.22.625.19.14
E-mail: zdobyslaw.flisowski@ien.pw.edu.pl

Dr. Marek Loboda **Poland**

Warsaw Institute of Technology
Poland
marek.loboda@ien.pw.edu.pl

Dr. Mariusz Neska **Poland**

Centralne Obserwatorium Geofizyczne
05-622 Belsk Duzy
POLAND
nemar@igf.edu.pl

Doc. Dr. Stanislaw Michnowski **Poland**
M. Sc. Piotr Baranski
Laboratory of Atmospheric Electricity, Institute of Geophysics,
Polish Academy of Sciences, 01-452 Warsaw, Ks. Janusza 64, Poland
phone: (48 22) 6915 872, 867
fax: (48 22) 6915 915
e-mail: baranski@igf.edu.pl
e-mail: smichn@igf.edu.pl

Eduarda Pedro **Portugal**
Instituto Superior Técnico/Technical University of Lisbon
Lisbon
Portugal
d2527@mail.ist.utl.pt

Dr.-Ing. Jovan Cvetic **Serbia and Montenegro**

Associate professor
Faculty of Electrical Engineeering
Kralja Aleksandra 73, PO Box 35-54
11120 Belgrade, Serbia and Montenegro
tel: + 381 11 3370 156
+ 381 11 3218 393
fax: + 381 11 324 86 81
E-mail: CVETIC_J@ETF.BG.AC.YU

Dr. Janko Kosmac **Slovenia**
Dr. Vladimir Djurica

Electroinstitut Milan Vidmar
1000 Ljubljana
Slovenia
janko.kosmac@eimv.si
Vladimir.Djurica@eimv.si

Dr. Joan Montanyà **Spain**
Associated Professor
Electrical Engineering Department
Technological University of Catalonia (UPC)
EUETIT - ETSEIT
Colon,1
08222 Terrassa
(Barcelona)
SPAIN
tel.: + 34 93 739 80 71 / 81 56
fax.: + 34 93 739 82 36
montanya@ee.upc.es

Prof. Dr. Rajeev Thottappillil **Sweden**

Division for Electricity and Lightning Research
Ångström Laboratory
Uppsala University
Box 534
S-751 21 Uppsala, Sweden
Tel.: +46 18 471 5806
Fax.: +46 18 471 5810
E-mail: Rajeev.Thottappillil@angstrom.uu.se

Prof. Dr. Vernon Cooray **Sweden**

Division for Electricity and Lightning Research
Ångström Laboratory
Uppsala University
Box 534
S-751 21 Uppsala, Sweden
Tel.: +46 18 471 5806
Fax.: +46 18 471 5810
E-mail: Vernon.Cooray@angstrom.uu.se

Mr. Göran Unden **Sweden**

FMV:KC Sensor & Telekom
Box 1165, 581 11 Linköping
Tfn: 013-378176, 070-6234989
E-post: goran.unden@fmv.se

Dr. Mats Bäckström **Sweden**

Research Director, Electromagnetic Effects
Swedish Defence Research Agency, FOI
Box 1165
SE-581 11 Linköping
SWEDEN
Tel: +46 13 378430
Fax: +46 13 378170
email: **mats@foi.se**

Dr. Anders Larsson **Sweden**

Associate Professor
Research Director, Electrophysics and Pulsed Power
FOI – Swedish Defence Reseach Agency
Weapons and Protection Division
Grindsjön Research Centre
SE-147 25 TUMBA
Sweden
Tel: +46 8 5550 3506, Fax: +46 8 5550 4144,
Mobile: +46 709 27 7468
Anders.Larsson@foi.se

Ms. Caje Jacobsson **Sweden**
Swedish Meteorological Services (SMHI)
Box 40
190 45 Stockholm
Tel: +46 11 - 495 80 00
Fax: +46 8 - 593 616 21
Caje.Jacobsson@smhi.se

Dr. F. Rachidi **Switzerland**

Maître d'enseignement et de recherche
Swiss Federal Institute of Technology
EMC Group
EPFL-LRE
CH-1015 Lausanne
Switzerland
Phone: +41-21-693 26 20
Fax: +41-21-693 46 62
Email: Farhad.Rachidi@epfl.ch

Prof. Dr. Marcos Rubinstein **Switzerland**

Institut TCOM
Ecole d'ingénieurs du Canton de Vaud
Route de Cheseaux 1
1400 Yverdon-les-bains
Switzerland
Tél: +41 (0)24 423 2289
Cel: +41 (0)79 430 1977
marcos.rubinstein@eivd.ch

Prof. Jean-Francois Affolter **Switzerland**

HES-SO / EIVD / IESE
Prof. JF Affolter (M.Eng)
CP/Rte de Cheseaux 1
CH 1401 Yverdon
affolter@eivd.ch tel +(0)24 - 423 21 11 FAX +(0)24 - 425 00 50

Prof. Dr. Clive Saunders **UK**
UMIST
Physics Department
Sackville Street
Manchester
M60 1QD
UK
Tel: 44 (0) 161 200 3909, Fax: 44 (0) 161 200 3941
clive.saunders@umist.ac.uk

Non-COST countries

Prof. Dr. Wasyl Janischewskyj **Canada**

Department of Electrical and Computer Eng.
University of Toronto
10 King's College Road, Toronto, Canada.
Phone: +1 416 978-2274.
Fax: +1 416 971-2325
wasyl.janischewskyj@utoronto.ca

Prof. Dr. Ali M. Hussein **Canada**

Electrical and Computer Engineering Department
Ryerson University
350 Victoria Street, Toronto, Ontario
Canada M5B 2K3
Phone: +1 416.979.5052
Fax: +1 416.979.5280
<ahussein@ee.ryerson.ca>

Prof. Dr. Jen-Shi Chang **Canada**

Department of Engineering Physics
McMaster University
1280 Main Street West, Hamilton
Ontario, Canada L8S 4L7
voice: +1 905 525-9140 x 24924
fax: +1 905 527-5222
changj@mcmaster.ca

Dr. Takatoshi Shindo **Japan**

Director
Electric Power Engineering Research Laboratory
Central Research Institute of Electric Power Industry (CRIEPI)
2-6-1, Nagasaka, Yokosuka-shi, Kanagawa Prefecture
240-0196 JAPAN
Tel. +81-46-856-2121
Fax. +81-46-856-3540
e-mail: shindo@criepi.denken.or.jp

Prof. Dr. Masaru Ishii **Japan**
Department of Electrical Engineering
University of Tokyo 7-3-1
Hongo, Bunkyo-ku
Tokyo 113-8656, JAPAN
ishii@iis.u-tokyo.ac.jp

Dr. Yoshihiro Baba **Japan**
Department of Electrical Engineering
Doshisha University
1-3 Miyakodani, Tatara
Kyotanabe, Kyoto 610-0321, Japan
ybaba@mail.doshisha.ac.jp

Dr. Yuri Raizer **Russia**
The Institute for Problems in Mechanics, Russian Acad.Sci
101 Vernadsky prospect, 119526, Moscow, Russia
e-mail: raizer@ipmnet.ru

Dr. Volodymyr O. Shostak **Ukraine**

Volodymyr Shostak
Dept. of High Voltage Engineering and Electrophysics
National Technical University of Ukraine "Kyiv Polytechnic Institute"
KPI-1670
03056 Kyiv
Ukraine
volod@shostak.kiev.ua

Prof. Dr. Alexander Nickolaenko **Ukraine**

Department of Remote Sensing
Usikov Institute for Radio-Physics and Electronics
National Academy of Sciences of the Ukraine,
12, Acad./ Proskura street,
Kharkov, 61085,
The UKRAINE
Phone +38 (057) 744-8369 (work) +38 (057) 705-3020 (home)
Fax: +38 (057) 744-1105
E-mail: <sasha@ire.kharkov.ua>

Prof. Vladimir A. Rakov **USA**
Prof. Martin A. Uman
University of Florida
Department of Electrical and
Computer Engineering
553 Engineering Building #33
Gainesville, FL 32611-6130
Tel. (352) 392-4242
FAX: (352) 392-8381
E-mail: rakov@ece.ufl.edu
E-mail: uman@ece.ufl.edu

Additional description of lightning processes pertaining to the issues in lightning research

In this section, additional description of lightning processes, that will help to understand the terminology used in Section A: Background of Technical Annex, is given. Besides, important references pertaining to the issues in lightning research are also given.

Processes in cloud-to-ground (CG) lightning

The negative CG lightning is the most studied type of lightning and the processes in lightning are described with reference to this type of lightning. A negative CG lightning event can be subdivided into several different processes starting from its inception in the cloud. The measured electric fields in the thunderclouds are typically 1-2x10^{5} V/m which is much lower than the electrical breakdown value of 3x10^{6} V/m between parallel plates in dry air at sea level although the break-down fields at elevated altitudes (lower pressure) in clouds containing particulate can be expected to be lower than the value at sea level, for example 1.6x10^{6} V/m at an altitude of 6 km. Under certain conditions, not well understood, the electric field in some region can exceed the ambient breakdown value and local breakdown occurs, possibly between the negative charge region and a small positive charge region in the lower part of the cloud. This stage is known as the *preliminary breakdown* and culminates in the initiation of a downward-moving *stepped leader* that is negatively charged. Photographically observed stepped leaders are 1 μs in duration and several tens of meters in length, with a pause time between steps of 50 μs. Stepped leader travels towards the general direction of ground in a zigzag manner. The potential at the tip of the stepped leader when it nears the ground is thought to be of the order of 10 million volts. A fully developed stepped leader can effectively lower 10 C or more of negative charge towards the ground in tens of milliseconds. The stepped leader has an average downward speed of about 2x10^{5} m/s and impulsive stepped currents in excess of 1000 A. As the stepped leader approaches ground, the electric field around sharp objects and irregularities on ground exceeds the breakdown value of air and positive streamers propagate upward, one of which will meet the stepped leader a few tens of meters above ground, a sequence called the attachment process, bringing the bottom of the stepped leader to ground potential. Thereafter a ground potential wave called the *return stroke* propagates upward at about one third the speed of light, discharging the leader channel. The return stroke is observable to the naked eye as a bright flash of light. The first return stroke typically produces a peak current near the ground of 30 kA that falls to half value in about 50 μs. The return stroke heats the channel to about 30,000 K, so that it emits light, and the high-pressure channel expands producing shock waves that become thunder. The return stroke current generally ceases to flow within a few milliseconds. If no other stroke follows, the discharge is called a *single-stroke flash*. Studies in Florida indicate that about 17% of all the negative CG flashes are single-stroke flashes. If sufficient charge is made available to the top of the channel in the cloud, a *subsequent leader* (*dart leader*) will follow the decaying first stroke channel causing another return stroke. The sequence of leader and return-stroke, together called *stroke*, may occur a number of times. The mean number of strokes in a flash is 4 to 5 and the mean time interval between strokes in the same channel is about 50 ms and therefore when observed with naked eye, the multiple stroke flash appear to flicker. Up to 26 return strokes has been observed in a lightning flash and the interval between strokes can vary widely, sometimes as low as three milliseconds. Usually, the subsequent return-stroke current peaks are smaller than the first stroke current peaks, but have faster rise time to peak. Often a current of the order of 100 A continues to flow for many milliseconds to tens of milliseconds after the return stroke. This current flow is called a *continuing current*. Continuing current produces a slow, more or less linear, change in electric field measured at close range and a continuing luminosity of the channel in optical records. Sometimes during continuing current the channel brightens for a millisecond or so due to additional transport of negative charges to ground, a process called an *M component*. Between the end of the return stroke (or continuing current) and the beginning of the following dart leader a slow variation of electric field at the ground can be observed. Step-like field changes with duration of about a millisecond, called *K changes*, indicative of charge motion within the cloud, occur during this time.

Positive lightning effectively lowers positive charge from cloud to ground. This type of lightning is quite interesting because the highest directly measured lightning currents (near to 300 000 A) and the largest charge transfers to ground (a few hundreds of coulombs) are associated with positive lightning. Usually positive flashes have only one leader-return stroke sequence, followed by a continuing current.

Ball lightning

There are some unusual lightning discharges. Ball lightning is the name given to the luminous spheres that appears to be associated with the location of lightning strike point of a CG flash. The balls, having a size ranging from an orange to a basketball, have a lifetime of about 1 second during which time they move horizontally and maintain a roughly constant luminosity. They appear outdoors, inside houses, and inside all-metal airplanes. Even though the reality of ball lightning is not in doubt, it has never been photographed or produced in the laboratory and there is no consensus regarding the physical mechanisms responsible for ball lightning. In spite of that, or probably because of it, a significant fraction (more than 2400 papers) of all the literature on lightning is related to ball lightning.