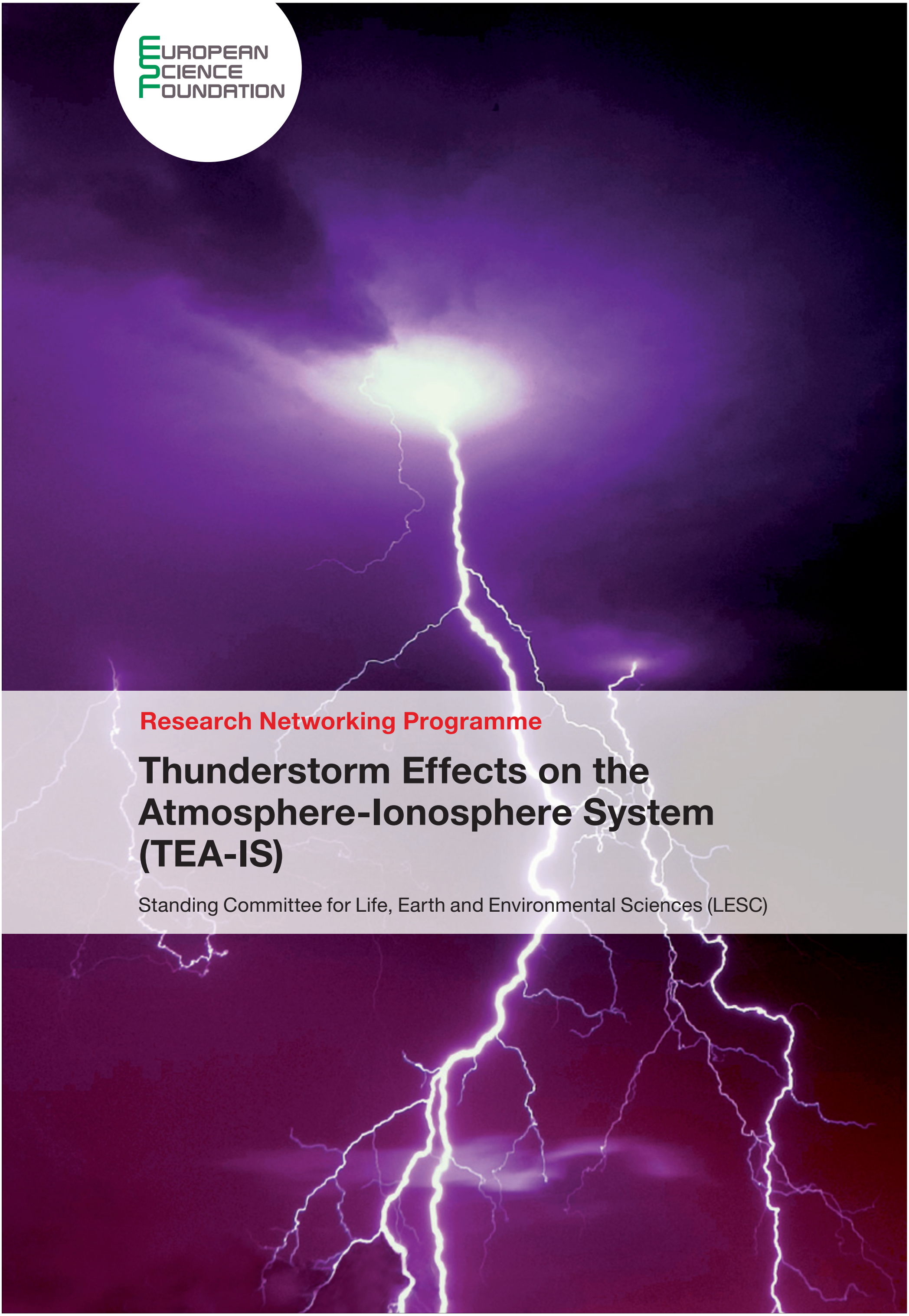

Research Networking Programme

Thunderstorm Effects on the Atmosphere-Ionosphere System (TEA-IS)

Standing Committee for Life, Earth and Environmental Sciences (LESC)

The past 20 years have seen the discovery of two surprising phenomena above thunderstorms: one is the huge electric discharges in the stratosphere and mesosphere, and the other the energetic bursts of gamma radiation with energies reaching 100 MeV observed on astrophysical satellites. Their late discovery demonstrates that our understanding of thunderstorms, and of processes in the atmosphere above them, is limited. The discoveries further underscore the point that thunderstorms power energy exchange between the troposphere and upper atmospheric layers and near-Earth space, and that several research fields must combine to advance our knowledge of the effects of thunderstorms on the atmosphere-ionosphere system.

Two European space missions are planned for studies of thunderstorms and atmospheric coupling. They are the "Atmosphere-Space Interactions Monitor" (ASIM) of the European Space Agency (ESA) and the French satellite "Tool for the Analysis of RAdiation from lightNIng and Sprites" (TARANIS) developed by the French space agency Centre National d'Études Spatiales (CNES). To be launched in 2013 and 2014, the missions will study electric discharges above thunderstorms, thunderstorm-generated atmospheric waves, and thunderstorm cloud properties.

Preparatory activities include deployment of new ground instrumentation for observing thunderstorms, organisation of balloon campaigns to study the atmosphere above thunderstorms, laboratory experiments, and development of theory and models. These activities will provide an essential context for the satellite measurements. This networking programme will help to coordinate the activities, and structure and expand the European research community behind the space missions towards the common goal of studying the fundamental thunderstorm processes and their impacts. This task requires a multidisciplinary approach of geosciences and physics through the development of long-term observations, specific experiments and theoretical work. The applications are as diverse as the science, ranging from the industrial use of electric discharges to improved understanding of the role of thunderstorms in a changing climate. The programme will stimulate the exchange of methods and results between the European and international communities involved.

The running period of the ESF TEA-IS Research Networking Programme is for five years from May 2011 to April 2016.

Scientific Background

The courageous lightning experiments of Benjamin Franklin and Jacques de Romas in the 18th century led to discoveries of fundamental aspects of electricity and began our journey of exploration into gas discharge phenomena. After many years of research the very process of lightning initiation is still debated, and surprises are still in store. Consider the chance discovery in 1989 of flashes in the mesosphere at 50–80 km altitude above thunderstorms, now known as "sprites". Although electrical breakdown between thunderclouds and the ionosphere was discussed by the Nobel laureate C.T.R. Wilson in 1925, its discovery came as a surprise to scientists. Consider another serendipitous discovery a few years later, in 1994, of sub-millisecond duration bursts of γ–rays from the atmosphere above thunderstorms with energies exceeding 300 keV. These terrestrial gamma-ray flashes (TGFs) were observed by detectors on the Compton Gamma Ray Observatory (CGRO) satellite designed to observe such radiation from space. The discovery of new phenomena above thunderstorms continued in 2002 with observations of the longest electric discharge on planet Earth, a gigantic jet reaching from thunderstorm clouds – through the stratosphere and mesosphere – to the bottom of the ionosphere, at 90 km altitude. These discoveries have given extra momentum to research in atmospheric electricity and, more generally, on how thunderstorms interact with the atmosphere and ionosphere.

1. The physics of atmospheric electricity

It is generally accepted that non-inductive collisions between graupel and smaller ice crystals, in the presence of liquid water, represent an efficient charging mechanism of thunderstorm clouds and that the combination of this microphysical process and of large-scale cloud dynamics lead to electric dipole and/or tripole structures in clouds. The ambient electric field measured from instrumented balloons may reach more than 100 kV/m; however, this is not enough to cause electrical breakdown. Mechanisms for lightning triggering that have been suggested include relativistic electrons created by cosmic rays or local electric field enhancements produced by hydrometeors. Alternatively, the relatively few *in situ* observations may not have captured the maximum electric field.

The sprite discharge is driven by the quasi-electrostatic (QE) field in the mesosphere following a positive cloud-to-ground (+CG) flash in a thundercloud below, jets are formed by space charge fields at cloud tops and elves are the signature of heating of the atmosphere at the lower ionosphere by the lightning electromagnetic pulse. Together these phenomena are known as transient luminous events (TLEs). As with lightning, the triggers of sprites and jets are under discussion (suggested candidates include cosmic rays, meteors, gravity waves). The processes of TGF generation are also under intense investigation, but still remain unknown. The discoveries of TLEs and TGFs have increased our understanding of the electric discharge. TGFs have pointed to the importance of high-energy electron production, which is now known also to be common in tropospheric lightning. Because the discharge time-scales of sprites are longer in the tenuous mesosphere, imaging instruments with high frame rates can resolve the dynamics of streamer formation and propagation, so providing new information on the basic physics of the gas discharge.

2. Lightning field-induced perturbations to the atmosphere-ionosphere

Lightning couples energy *directly* to the mesosphere and lower ionosphere through QE and electromagnetic pulsed (EMP) fields. The fields heat the partly ionised atmosphere and cause additional ionisation, thereby changing the atmospheric conductivity. Electromagnetic waves from lightning discharges may also have an *indirect* effect on the lower ionosphere via reflection effects or interactions with radiation belt electrons that can be precipitated from the magnetosphere into the upper atmosphere. Perturbations to the ionosphere are observed as perturbations to the amplitude and/or phase of signals from very low frequency (VLF) transmitters used for submarine communications. Quantitative estimates of ionisation and heating by TLEs are still lacking but can in principle be modelled. They hold the promise of new insights into the properties and microphysics of the mesosphere.

Chemical perturbations include the production of nitric oxide (NO) by lightning. It is of the order of 5 Tg N/year, corresponding to 10% of the total emissions today and 40% of pre-industrial emissions. However, in the upper troposphere, lightning is the major source of nitrogen oxids (NOx). NO in the troposphere is important because it modifies the ozone (O_3) and methane (CH_4) chemistry, increasing the concentration of the former and lowering that of the latter. Some important challenges remain, such as improving the quantification of NO production by lightning and understanding better the roles of lightning in global change. Likewise, the local effects of TLEs on upper atmospheric chemistry are not well understood. Better observations and kinetic models of the electric discharge are needed to answer these and other important questions.

3. Convection-induced perturbations to the atmosphere-ionosphere

Thunderstorms in the tropics are powerful fountains that pump trace gases from the lower to the upper troposphere and into the stratosphere where they may reside for several months. Water vapour is one of the most effective greenhouse gases in the atmosphere, and understanding its transport in the atmosphere is crucial for understanding climatic variability. However, the non-uniform mixing of water vapour, and changes between ice, water and water vapour, make its behaviour much harder to understand than that of carbon dioxide. Some important processes in the hydrological cycle, such as the formation of cloud condensation nuclei and cirrus clouds in the lower stratosphere, are not well understood. With global warming at the Earth's surface, tropical deep cumulus convection is expected to become even more powerful and frequent, and global troposphere/stratospheric water vapour transport enhanced, leading to further heating of the atmosphere on a global scale.

Gravity waves in the mesosphere produced by thunderstorms are observed in the hydroxyl (OH) nightglow layer by ground-based cameras and by microbarometer networks. Observations in the different atmospheric night-glow layers are needed to determine the penetration of such waves into the upper atmosphere and to assess their impact on the global stratospheric and mesospheric circulation. It is known that forcing by wave activity in the stratosphere contributes to the upward and poleward large scale circulation in the stratosphere and mesosphere. However, observations are still rare, and our present understanding of the effect of these phenomena on the upper atmosphere is limited.

Aim and Objectives

The objectives of this programme are to understand the role of thunderstorms in the atmosphere-ionosphere-magnetosphere system and also anthropogenic influences on thunderstorms. The holistic approach adopted here leads us to study a multitude of processes and their interdependencies; some processes are of such a fundamental nature that the insights gained are expected to have impacts beyond the field of atmospheric science. The scientific topics to be studied are summarised as follows:

1. The physics of atmospheric electricity
   a. Fundamentals of thundercloud formation and electrification
   b. Fundamentals of atmospheric electric discharges

2. Lightning field-induced perturbations to the atmosphere-ionosphere
   a. Ionisation and conductivity perturbations, and their larger scale effects
   b. Perturbations to atmospheric chemical composition

3. Convection-induced perturbations to the atmosphere-ionosphere
   a. The upper-troposphere/lower stratosphere interface
   b. Gravity wave perturbations to the stratosphere, mesosphere, ionosphere

4. Applications
   a. Technological plasma systems
   b. The Earth's atmosphere, weather, climate and climate change

The programme will help prepare the European and international research community for the ASIM and TARANIS missions (see www.electricstorms.net). Planned for launch in 2013 and 2014, the missions will study electric discharges above thunderstorms, atmospheric gravity waves and thunderstorm cloud properties. The missions are the first simultaneously to observe lightning, TLEs and TGFs with dedicated instruments, thus allowing studies of the inter-relationships between these phenomena. Preparations already underway include the fielding of new instrumentation for observing thunderstorms and TLEs from the ground or balloons, laboratory experiments on electric discharges, and developing improved models of the electric discharge and various effects in the atmosphere.

The planned activities provide an excellent and essential context for the satellite measurements which would not be of nearly the same value unless the wider context is considered and better understanding obtained. The network will permit objectives that are not directly studied by the space missions, such as the effects of thunderstorms on atmospheric circulation and their role in a changing climate.

The programme will structure the European research community to take full advantage of the space mission data when they become available. Even if either mission is later postponed or fails on launch, this programme will generate a wide range of important and fascinating results.

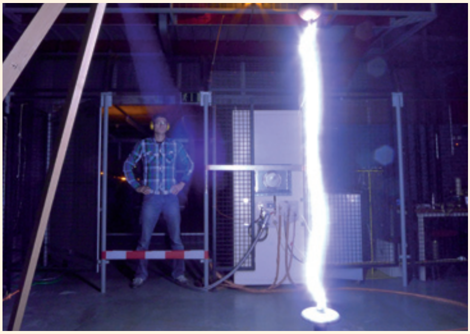

Figure 1. A large spark is generated in a laboratory at the Technical University of Eindhoven, the Netherlands. Experiments with sparks are used to study X-ray and gamma-ray photons from relativistic electrons, accelerated in the electric field of sparks and natural lightning. The photons are "bremsstrahlung" from the interaction of the electrons with the air. Bursts of gamma radiation are observed from satellite above thunderstorms. The precise source mechanism is unknown.
Courtesy of Cung Vuong Nguyen, Technical University Eindhoven, NL

Activities

The programme will accelerate the exchange of ideas and scientific collaborations through networking, workshops and through young scientists working on cross-institutional topics. The training of young scientists will be supported by two dedicated summer schools. A showcase conference with associated outreach activities will be held in year 4 when ASIM and TARANIS are operating in space.

Steering committee meetings

These annual meetings will be held in connection with the meeting of the European Geosciences Union (EGU) where the network at large comes together.

Focused scientific workshops

Workshops will be held on sub-themes, either within the three subject areas or across area boundaries. Workshops are also foreseen in connection with the scientific planning of observational campaigns or around larger laboratory and modeling activities. Programme-wide workshops will be held annually in connection with the EGU meeting. The first will discuss the organisation of the programme activities, the status of the science in each country and plans to bring new members on board in areas which need strengthening.

Conferences

One conference will be held during the project lifetime when the ASIM and TARANIS missions have been launched and data are in hand. The conference will showcase the scientific results of the network and communicate results to the public. The conference will be open to the many international partners outside Europe that participate in the collaborations around ASIM, TARANIS and associated projects. The conference is expected to be co-sponsored by ESA.

Summer schools

The young scientists associated with the network are its lifeblood, linking the research groups at the participating institutions and collaborating across topic boundaries. To achieve this goal, the young scientists will be educated in the wide variety of topics covered by the network, at two summer schools. The first will be in year 2, when the programme has gained momentum and the second in year 4. At post-graduate level, the schools will be conducted by experts both from Europe and from the international community. The schools will build on the experience and material of two summer schools held in this discipline area during 2004 (under CAL Research Training Network of FP5), and in 2008 (under ESA and the French E-CANES GDRE), which led to two books being published.

Short-term visits

For this highly cross-disciplinary programme, visits between participants are essential to build up new collaborations, and to educate and train young scientists. Scientists may spend up to six months

Figure 2. An optical imaging system for observation of sprites, the electric discharges in the mesosphere above thunderstorms. The system is located on Mount Corona in Corsica and can observe the atmosphere above thunderstorms reaching from Spain in the West, over Southern France in the North and to Italy in the East. It has its own power system and is controlled via a satellite link.
Courtesy of Olivier Chanrion, DTU Space, Denmark

at another research institution to learn and collaborate on topics that cannot be handled locally. Scientists will be asked to apply for such grants, priority being given to cross-disciplinary activities and to young scientists.

Publicity, webpages and publications

Public outreach is integral to the project because of the central role of the ASIM and the TARANIS space missions, which provide an excellent platform from which to communicate the scientific topics in general and the scientific achievements of the network in particular. The outreach activities will peak at the time of launch of the space missions and will be coordinated with the activities of CNES, ESA and others involved.

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For the latest information on this Research Networking Programme consult the TEA-IS website:
www.esf.org/tea-is

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