Sprite above lightning in a thunderstorm. Courtesy of Nippon Hoso Kyokai (Japan Broadcasting Corporation). © NHK

Lightning **reflexes**

Previously unobserved electrical events occurring above storm clouds have highlighted a stark lack of knowledge about thunderstorm activity. Here, **Dr Torsten Neubert** discusses the European Science Foundation's TEA-IS programme's explorations beyond the troposphere

What originally triggered your interest in the environmetal sciences and the field of atmospheric electricity in particular?

I am interested in understanding Nature and the role played by human life and civilisation. Life has developed in this very thin atmospheric layer enveloping our beautiful planet, which rushes through the Solar System at an incredible 30 km/s. The iconic photo of Earth taken by astronauts from the Moon during the Apollo mission has always fascinated me. It gave me a different perspective on my life and illustrated the absurdity of wars and conflicts.

I was astonished by the first published images of sprites in the mesosphere. Sprites are electric discharge 50-80 km above thunderstorms. They are huge – up to 100 km horizontally and 30-40 km vertically. It seemed fantastic that such events had gone unnoticed by scientists. Of course, we subsequently discovered many anecdotal statements dating back in time of people that had seen sprites. I am sure airline pilots have seen them because they are quite common and can be seen with the naked eye. One has to look above the storms and not at the lightning below.

Can you explain the holistic approach of the Thunderstorm Effects on the Atmosphere-Ionosphere System (TEA-IS) programme? Why is collaboration essential in your study?

A host of questions arise when studying a process like sprites in the mesosphere. For instance, what is required for the thunderstorm cloud to power such discharge? This question takes us into the realm of meteorology and cloud physics, and perhaps charge transfer processes in clouds. As lightning creates ozone, another question is what happens to the mesosphere when there is a sprite. This line of enquiry requires knowledge of atmospheric chemistry. To gain a proper understanding, several fields of physics must be brought into play.

Are you working with any groups or projects beyond the main consortium?

The TEA-IS consortium only includes a subset of collaborators in Europe and not our international collaborators. Our main project is the Atmosphere-Space Interactions Monitor (ASIM) for the International Space Station which launches in early 2016. It is developed within the European Space Agency (ESA) and is built by partners in Spain, Norway, Poland and Italy. ASIM is backed by a large International Science Team of more than 80 groups from 30 countries. We also participate in the French microsatellite project TARANIS, which is set to launch in the same timeframe.

Can you provide an insight into ASIM and TARANIS? What preparatory activities are to be undertaken?

The spacecrafts carry instrumentation to observe lightning in the clouds, high altitude lightning in the stratosphere, and sprites, jets and giants in the mesosphere. We have cameras and photometers in various bands, and X- and gamma-ray detectors. TARANIS also carries other sensors including electromagnetic wave receivers to measure lightning emissions.

It is very costly to transport instruments into space, so we only carry sensors that require a space platform. Since we are interested in the high altitude discharges and the atmosphere is very thin. This allows us to observe spectral bands that are not useful from the ground because atmospheric absorption is too strong. On the other hand, important observations are taken from the ground that place the space measurements in a context. The most important information concerns the lightning that often triggers the events above the clouds.

Not all of the scientifically interesting regions of the Earth are covered by such systems, although global networks today give useful information. We are therefore proactively contacting groups in a variety of interesting countries to encourage them to deploy field instrumentation and measure new parameters. In return, we invite them to join the science teams of the space missions, which provide access to valuable space data.

You touched upon the fact that the cost of space-related research can be prohibitively expensive. Do you feel that the TEA-IS projects offer an opportunity for less wealthy nations to gain from the latest technological developments?

Yes, I feel good about the possibility that the lesser developed countries in thunderstorm regions can participate in the ASIM and TARANIS missions. The only requirements are power and an internet connection. It is a good way of bringing young people and scientists of these countries online in cutting-edge science with rather simple means.

Cooking up a storm

Comprising a network of researchers from various disciplines, the **TEA-IS** project is striving to better our understanding of the mechanisms of thunderstorms and their effects on climatic variability

AN OBSERVABLE PHENOMENON since life began on Earth, thunderstorms still provide scientists with surprises that underscore how little they are understood. Dramatic flares of lightening naturally draw the attention of the eye during an electrical storm, but high above them transient luminous events (TLEs) of enormous dimensions flash towards the edge of space. They take many forms, like the 'giant' – a lightning bolt shooting upwards from the cloud tops to the edge of the ionosphere at 80 km altitude – or 'sprites', that are discharges within the mesosphere at 40-80 km altitude.

Despite annual occurrences estimated at several million, TLEs such as blue jets, sprites, elves and giants had long gone unnoticed by professional spectators in the meteorological community. Observations from the ground cannot penetrate cloud coverage, the majority of planes cannot fly high enough and satellite orbits are too high to take measurements.

Likewise, there are the flashes of gamma-rays from thunderstorm discharges. They are bremsstrahlung (electromagnetic radiation) from electrons and positrons reaching up to 100 MeV energies. Their discovery was a surprise; not just that discharge processes generate radiation, but that the energies are so high and that antimatter is created.

The serendipitous capture of these events – the first sprite was accidentally caught on video by a graduate student in 1989 and the gamma-ray bursts were first observed from the Compton Gamma-ray Observatory in 1994 – have sparked new momentum into studies of the gas discharge and of thunderstorm electricity, prompting major advances in techniques of observation, simulation and analysis. The study of these electrical phenomena will help scientists reach a far greater understanding of the processes behind thunderstorms and hopefully elucidate their effects on climate variability.

At the National Space Institute of the Technical University of Denmark (DTU Space), Dr Torsten Neubert is Head of the Solar System Physics Department and Chair of the steering committee on the Thunderstorm Effects on the Atmosphere-Ionosphere System (TEA-IS) project. Established in 2011, this five-year study is the first of its kind to bring together such a wide range of scientific disciplines and nations to investigate thunderstorms both from the ground and space. As a research networking project of the European Science Foundation (ESF), through which TEA-IS receives the majority of its funding for collaborative opportunities, a framework of collaboration is created for the space missions ASIM and TARANIS which will be the first with specially fitted instruments dedicated to observing lightning, TLEs and terrestrial gamma-ray flashes (TGFs).

A VIEW FROM ABOVE

With launches currently set for 2016, the ASIM and TARANIS space missions will employ a combination of optical cameras, optical photometers, X-ray and gamma-ray detectors and electromagnetic wave receivers to help answer questions about the links between TLEs and TGFs, the mechanisms that generate them, and the effects they have on the Earth's atmosphere and radiation belt.

The ASIM mission, headed by Neubert, will dock with the European Space Agency Columbus module on the International Space Station (ISS). The ISS is in the lowest available, permanent orbit with an orbit inclination of 51.6 degrees relative to the equatorial plane, covering all the major thunderstorm regions and providing ASIM with the closest proximity to thunderstorm activity possible from a space platform. The Modular Multispectral Imaging Array (MMIA) module will be measuring this activity with two light-sensitive optical cameras to capture the spatial structure of emissions, and three optical photometers for measuring the total photon flux in a high time resolution to record rapid time variations. The instruments observe in different bands to measure the energetic properties of the high altitude discharges.

The main instrument of the ASIM platform is the Modular X- and Gamma-ray Detector (MXGS) which measures photon energies up to 20 MeV. For the first time, scientists will measure the direction at the source of the emissions and will be able to pinpoint the exact altitude and thunderstorm electric discharge event that generates the emissions.

The ASIM instruments face downward in order to minimise the atmosphere between the instruments and thunderstorms as they occur directly below. To capture the vertical dimension, the first Dane ever to go into space, astronaut Andreas Mogensen, who was recently selected to fly on the ISS, will be equipped with scientific cameras and take images at angles slanted towards the Earth's limb of thunderstorm activity. The focus of this activity is to observe what happens at the top and above thunderstorms – flash activity, storm cloud formation and penetration into the stratosphere. The observation will be taken from the Cupola of the Space Station, which is a bell of thick glass windows facing towards the Earth, much like in the window to the deep waters of the Nautilus submarine of Captain Nemo in the Jules Vernes science fiction *20,000 Leagues Under the Sea*.

Early morning on the top of Monte Corona, Corsica. A helicopter has left optical equipment which the researchers later install for observations of sprites over southern Europe (DTU Space).

INTELLIGENCE

TEA-IS

THUNDERSTORM EFFECTS ON THE ATMOSPHERE-IONOSPHERE SYSTEM

OBJECTIVES

To understand the role of thunderstorms in the atmosphere-ionosphere-magnetosphere system and also anthropogenic influences on thunderstorms.

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TORSTEN NEUBERT received his PhD from the University of Copenhagen in 1982. His research focus is on the plasma physics of the magnetosphere, ionosphere and atmosphere. In 2000, he documented electric discharges in the mesosphere over Europe from the Observatoire Midi Pyénées. Neubert is leading the ASIM mission to the International Space Station which launches in 2016.

A VIEW FROM BELOW

As a networking project eliciting considerable cooperation, the data transmitted to the ground from ASIM and TARANIS will benefit a whole raft of scientific communities along the way. TEA-IS aims to get relevant, less developed countries on board, encouraging collaboration on the ground in exchange for highly useful space data, because these regions are home to violent thunderstorms. The project's ground observation strategies are also turning southern Europe into a natural discharge laboratory through a network of sophisticated lightning detection systems and optical instruments for high-altitude discharge.

> The ASIM and TARANIS space missions will be the first with specially fitted instruments dedicated to observing lightning, and associated phenomena

Heading toward the tropical climes and into what Neubert calls the 'engine room' of the most powerful thunderstorms, further ground observations are expected to shed light on the processes of atmospheric circulation and its effect on the climate. Due to their strength, thunderstorms in the tropics act like funnels transporting trace gases from the lower troposphere into the stratosphere where they can remain for several months. As one of the most effective greenhouse gases, understanding the circulation of water vapour around the atmosphere is a key concern in unravelling climate variability. This powerful pumping mechanism of gases into the stratosphere could be both a contributor to global warming and a symptom, increasing in frequency as the climate warms.

NETWORK OF NEIGHBOURS

Reaching its conclusion in 2016, Neubert hopes that TEA-IS will provide the programme's numerous participants with a better understanding of cloud formation, electrification and transport, which could help scientists produce improved climate models and perhaps even proxy data from lightning measurements to describe storm development. It is hoped that the strengthened collaborations will pave the way for scientists to be in position – and ready – to mine the science data of the ASIM and TARANIS missions. "It is our obligation to try to maximise the scientific output of the missions, both to ourselves and to the public who in the end funded our adventure," Neubert remarks. Meanwhile, TEA-IS has already helped elucidate the micro-processes of electrical discharge beyond what was known prior to the project's commencement in 2011, and has advanced current understanding of streamer discharge and X-ray generation.

Crucial to the project's success to date is its inherent collaborative nature: "It is absolutely wonderful to see Europe coming together and collaborating, preparing for the ASIM and TARANIS missions," states Neubert. As a research networking project TEA-IS has benefited hugely from the ease with which instruments have been fielded and observational campaigns conducted by members of the network. With continuing cooperation appearing to outstrip old fashioned ideas of competition in space, TEA-IS looks set to deliver on its objective of significantly improving understanding of thunderstorm effects on the atmosphere-ionosphere system.