Views from the top

An expert in the science of the upper atmosphere, **Dr Astrid Maute** outlines her research on atmospheric tides and describes how it will help improve space weather prediction capability.

**Can you introduce yourself and your academic background? How have your research investigations evolved since you first joined the High Altitude Observatory in Colorado, USA?**

When I first started working at the Observatory – part of the National Center for Atmospheric Research – Dr Arthur Richmond, who is one of the leading experts on ionospheric electrodynamics, introduced me to the science of the upper atmosphere. Together we worked on different aspects of simulating ionospheric electrodynamics effects, including plasma pressure gradient and gravity driven current, observed by the Challenging Mini-Satellite Payload satellite. Several years ago, I was fortunate to begin working with Dr Maura Hagan, whose research focuses on the generation and propagation of tidal and planetary waves and their impact on the upper atmosphere. The focus of my research is still reflected by these collaborations, with an interest in using numerical models to explore the effects, coupling mechanisms and the importance of atmospheric tides and global scale waves on the ionosphere.

**You participate in NASA’s Living With a Star Targeted Research & Technology (LWS-TR&T) programme about Atmosphere-Ionosphere Coupling During Stratmospheric Sudden Warmings. What are its central goals?**

Its overarching aim is to further our understanding of vertical coupling and its importance for space weather variability while improving our forecast capabilities by focusing on atmosphere-ionosphere coupling during stratospheric sudden warmings (SSWs).

In recent years, Hagan and her colleagues have made progress by going from climatological specification of a limited subset of solar tides to the implementation of daily varying global perturbations. Correctly representing the middle atmosphere during SSWs with numerical models is challenging, since the models cannot resolve all spatial scales and therefore depend on parameterisation of smaller scale waves. Colleagues at the National Center for Atmospheric Research developed a scheme to correct the middle atmosphere, which makes it possible to examine SSW effects in the ionosphere. We could reproduce these events and analyse the model for the important tidal components responsible for the electrodynamic changes in the low latitude ionosphere.

**What is the purpose of the NASA Ionospheric Connection (ICON) explorer mission?**

The ICON explorer mission, led by Principal Investigator Dr Thomas Immel and scheduled to launch in 2017, is dedicated to exploring the thermosphere-ionosphere (TI) system and its boundary between Earth and space. One aspect of the project is to shed light on the coupling mechanism between Earth’s weather and space weather. ICON is focused on the low-latitude region, where neutral winds in the ionosphere can push plasma around and establish electric fields that map along the geomagnetic field line of the Earth and can lead to changes of the ionospheric plasma distribution. In addition, the ionospheric variability depends on the neutral composition that will be measured by ICON. The mission was confirmed in October 2014 by NASA headquarters and is proceeding as scheduled. Excitingly, it includes a strong numerical modelling component, and comparisons with the observations to examine the important vertical coupling mechanisms.

**Are large collaborative projects such as ICON and LWS-TR&T necessary for achieving real insights into the Earth’s TI system?**

This system is strongly influenced by the solar wind conditions as well as those from the lower atmosphere. It is necessary to bring together researchers from the different domains (the magnetosphere and upper, middle and lower atmosphere) to work on the problem as a whole. In addition, observers and numerical modellers must collaborate to interpret observations and simulations fully, generate ideas about possible underlying physical mechanisms and highlight important factors influencing the system. These can then be tested by models and verified by observations.

**How do you see your work progressing in the coming years?**

Progress in understanding the TI system depends very much on available observations, which are sparse compared with meteorological observations. The NASA ICON project has the potential to advance the field, not only by solving the questions we can formulate now, but also by discovering new phenomena and possible mechanisms not yet imagined by the research community.

In general, numerical modelling tends to go in the direction of increased resolution and novel coupling of different regimes – the plasmasphere, magnetosphere and troposphere, for example. As models become more sophisticated, the increasing complexity necessitates larger multidisciplinary collaborations to elucidate the physics fully and interpret the results accurately. It will be exciting for me to contribute and collaborate on the numerical modelling effort and use its results for observational interpretation.
Space weather: The long-range outlook

Scientists at the High Altitude Observatory of the National Center for Atmospheric Research, USA, are attempting to understand the complex Sun-Earth connection and thus reduce damage to terrestrial technological systems on Earth, but also long-term trends and their primary triggers. Despite significant recent developments in research tools and equipment, such as observing systems and quantitative models, fundamental questions about solar-terrestrial science remain unanswered.

Although it is rarely broadcast to the general public, space weather can have a huge effect on human life. First used in the 1990s, the term is defined by NASA as the dynamic and often fast-developing conditions within the solar system – on the Sun and in the solar wind, magnetosphere, thermosphere and ionosphere – that can influence the performance and reliability of space-borne and ground-based technological systems and endanger human life or health. It has long been known that the Sun’s energy output determines these interplanetary conditions, although recent NASA missions have shown that weather on Earth can also influence conditions in the upper atmosphere. The ability of space weather to affect terrestrial systems – including communications, transportation and electrical power networks – can lead to significant environmental, social and economic costs and disruption.

Human existence has become increasingly reliant on technology that is susceptible to damage from space weather. For society to limit the impact of such damage, natural hazards such as geomagnetic storms need to become more predictable. Upper atmosphere scientists face the challenge of evaluating not only the short-term impacts of space weather on Earth, but also long-term trends and their primary triggers. Despite significant recent developments in research tools and equipment, such as observing systems and quantitative models, fundamental questions about solar-terrestrial science remain unanswered.

Since 1940, it has been the mission of scientists at the High Altitude Observatory of the National Center for Atmospheric Research (NCAR) in Colorado, USA, to explore the coupled Sun-Earth system. They are currently focused on determining the structure and dynamics of Earth’s upper atmosphere, its response to the effects of the solar wind and the Sun’s radiation, and the coupling between regions, including with the lower atmosphere. Dr Astrid Maute is one such project scientist. She is using numerical modelling to study the upper-atmospheric effects due to geospace and meteorological forcing.

A Significant System

The thermosphere-ionosphere (TI) system is a priority area of research at the High Altitude Observatory. The thermosphere is the working environment of numerous satellites, including the International Space Station, and it is where the majority of

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space-based human activities occur. “Due to the low densities in the thermosphere, it is highly variable and easily influenced by confounding factors, for example, solar radiation, solar wind and lower atmospheric forcing,” Maute elaborates. Changes in density could affect the orbital routes and lifetimes of satellites, and variations in the ionospheric environment could disrupt global positioning systems (GPS) and radio communications.

“The thermosphere and ionosphere influence each other through ion-neutral collisions, advection and composition changes,” Maute explains. “Therefore, understanding the processes and their interaction is important for predicting space weather. Even on the ground, changes in the ionospheric currents that are part of the TI system can be measured in magnetic perturbations.”

### INTRINSICALLY TIED TOGETHER

**Living With A Star** is a NASA scientific programme aimed at advancing our understanding of the integral system coupling the Sun to the Earth, and identifying aspects that directly affect human life. A major component is a targeted research and technology programme in which the local processes and coupling between the lower and upper atmosphere, and their consequences on the TI system, are being studied using periods of highly disturbed space weather.

One such phenomenon that scientists at NCAR are focusing on is stratospheric sudden warming (SSW), characterised by strong planetary wave activity in the winter polar stratosphere. This is due to a distortion or split of the polar vortex, creating huge variations in the horizontal winds that lead to dramatic changes in temperature – rapid increases in the stratosphere and cooling in the mesosphere above. Although it can take several weeks for the disturbed middle atmosphere to recover, an advantage is that SSW events can be reliably forecast. Furthermore, the consequences of SSWs are not limited to the stratosphere and mesosphere; large ionospheric variations (changes of 50-100 per cent) can be measured lasting for several days.

Results from studies carried out by Maute and her colleagues have shown that these events are associated with various changes – in atmospheric tidal and wave components, lunar gravitational tides, ionospheric electric fields, and electron densities and temperatures, for example. Additionally, SSWs are accompanied by secondary tidal and planetary wave production and propagation into the lower thermosphere. Understanding the coupling mechanisms for SSWs – including the energy transfer resulting in lower-upper atmosphere coupling – under different geospace conditions is crucial for predicting the ionospheric variability.

NCAR is utilising the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM) to simulate SSW events. “Simulating these events can help allude to the origin of ionospheric disturbances and uncover possible coupling mechanisms that can then be tested against observations,” Maute expounds. “Despite this, comprehensive observations are still lacking, but the NASA Ionospheric Connection (ICON) explorer mission will provide the necessary measurements to enhance our understanding of the vertical coupling mechanisms.”

### ICONIC INVESTIGATIONS

The proposed space-based ICON mission, due to launch in 2017, will examine the extreme variability of Earth’s ionosphere by measuring the thermospheric winds, in situ electric fields, thermospheric composition and F-region plasma distribution. Its goals are to use observations to enhance understanding of the drivers of ionospheric variability to explain the propagation of energy between Earth’s atmosphere and space, and to understand extreme weather, such as geomagnetic storms.

Maute is responsible for the numerical modelling aspects of the project, focusing on the coupling and effects of global scale waves on the TI system. Using the first principal Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIME-GCM), it will be possible to simulate the TI system during the mission in order to conduct the numerical tests that are necessary to help explain and understand the observations.

### COMPLETING THE PICTURE

Elucidating the Sun’s complex influence on space weather is an area of increasing importance to society at large, as it is necessary for the accurate prediction of space weather events. Currently, the precision of space forecasting is comparable to terrestrial weather predictions approximately 50 years ago.

In particular, the ionospheric environment plays a huge part in understanding and predicting space weather effects and this needs to be better characterised. The research being carried out at the High Altitude Observatory will continue to support the development of observations, theories and models to study space weather effects. Combining numerical modelling with the observations that will undoubtedly be gained from the launch of the ICON mission will surely enable scientists to comprehend these ionospheric effects. Such research efforts hold great promise for improving our space weather predictions.