Modelling Studies of Metal Layers in the Upper Atmosphere

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The Earth's atmosphere is changing from the surface through to the thermosphere (up to 500 km) in response to increases in greenhouse gases (Nossal et al., 2016). The upper atmosphere (50-150 km) is a particularly sensitive region which is affected both by anthropogenic activities from the surface and space weather above. It is also potentially involved in climate feedback processes. One unique feature in the upper atmosphere is the presence of thin layers of neutral metal atoms which were first observed in 1929 (Slipher, 1929).

A variety of metals (e.g. Na, Fe, Mg, K, Ca and Si) are deposited in the mesosphere and lower thermosphere (MLT, ~70-120 km) through the process of meteoric ablation. Ablation occurs because cosmic dust particles enter the atmosphere at high velocities (11-72 km s^{-1}), which causes sputtering and flash heating through collisions with air molecules, followed by rapid evaporation of metal atoms and oxides once the particles melt (Plane et al., 2015). This source of metals gives rise to layers of metal atoms between 80 and 105 km which can be observed by the ground-based lidar (laser radar) techniques, as well as by satellite-borne optical spectroscopy. Metallic ions are also measured by mass spectrometry on sub-orbital rockets. These metals provide a unique tracer of the physics and chemistry of the atmosphere at the interface with geospace (Plane et al., 2015).

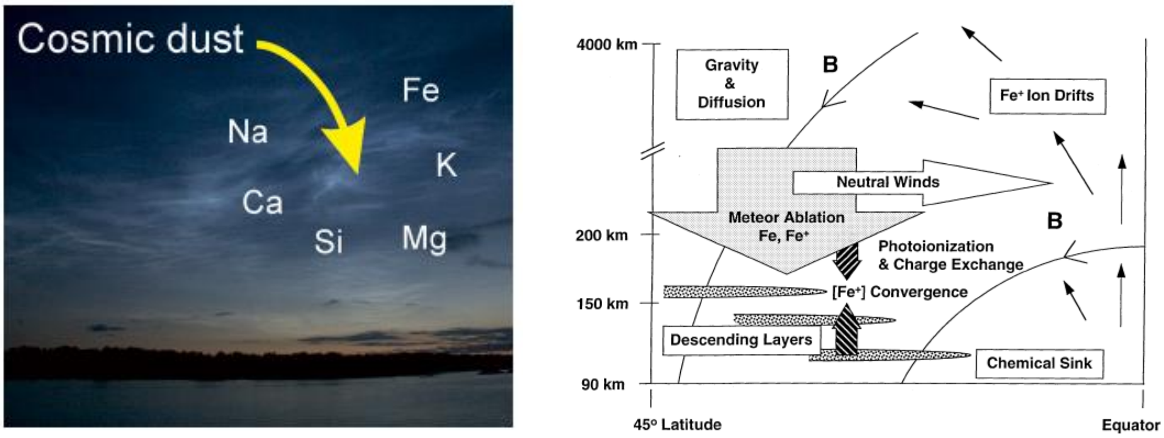

Figure 1. Left-hand panel: metals released from cosmic dust form meteoric smoke particles which provide condensation nuclei for noctilucent ice clouds at an altitude around 82 km (Plane et al., 2015). Right-hand panel: the physical and chemical processes which affect the

distribution of metal atoms and ions in the upper mesosphere and lower thermosphere (Carter and Forbes, 1999).

At the University of Leeds, in close collaboration with the US National Center for Atmospheric Research (NCAR) and NASA Goddard Space Flight Center (GSFC), we have added the chemistry of six metals (Na, Fe, K, Mg, Si and Ca) into the three-dimensional Whole Atmosphere Community Climate Model (WACCM) (e.g. Marsh et al., 2013; Feng et al., 2013, 2015; Plane et al. 2014, 2015, 2016; Langowski et al. 2015, Carrillo-Sánchez et al., 2015). This is the first global atmospheric model of meteoric metals, which allows us to better understand the meteor astronomy, chemistry and transport processes that control the different metal layers in the MLT. The other significant implement in WACCM is the inclusion of a detailed scheme of ion chemistry in the D region and lower E region from the Sodankylä Ion Chemistry (SIC) model (Kovacs et al., 2016).

However, the standard version of WACCM only extends up to 140 km, and recent lidar observations have shown that neutral Fe, Na and K layers occur up to at least 170 km (e.g. Chu et al., 2011; Dou et al., 2013; Jiao et al., 2015; Tsuda et al. 2015). Furthermore, metal ions have been observed at heights of over 500 km (Carter and Forbes, 1999; Plane et al., 2015), and WACCM does not yet contain some important electodynamical processes. A new version of the next generation model (WACCM-X, an extended version of WACCM which couples the ionosphere up to 600 km (Liu et al., 2010)), is being developed at NCAR in Boulder, Colorado. One aim of this DTP project will be to include metal chemistry in WACCM-X which we have recently successfully incorporated the Fe chemistry into an earlier version of WACCM-X. The student will have the opportunity to work with Drs Daniel Marsh and Hanli Liu at NCAR on this aspect.

There are continuous high resolution lidar Na, K and Fe measurements being made at several locations in China under the Chinese Meridian Space Weather Monitoring Project (Dou et al., 2013). The Meridian project is designed to monitor the geospace environment and better understand the near-Earth space response to solar activity, and thereby improve space weather forecasts. A range of key atmospheric variables (over the altitude range 20 - 1000 km) are measured from a chain of 15 ground-based observatories located along 120ºE longitude and 30ºN latitude (Wang, 2010). The lidar and ancillary data will be made available for the DTP project in order to test aspects of WACCM-X. The student will work closely with Profs. Xiankang Dou and Xianghui Xue at the University of Science and Technoldgy of China (USTC, Hefei).

The project will therefore explore the coupling of atmospheric chemistry and dynamical processes in the mesosphere and thermosphere, as well as testing the accuracy of climate models in the whole atmosphere, and the impacts of space weather. The PhD student will have an opportunity to visit USTC and NCAR for collecting observations and model development, respectively.

Objectives:

The goal of this project is to answer a number key questions about the upper atmospheric metal layers: why do neutral metal atoms occur in the ionosphere above 100 km? What are the chemical and physical processes which control their distribution? How are the layers affected by long-term trends such as the solar cycle and climate change? Which important processes are missing in the current whole atmosphere model?

In this project, you will work with leading scientist at Leeds, NCAR and USTC to develop a comprehensive global model of the metal layers (WACCM-X with metal chemistry), and then validate the new model using available lidar and satellite measurements. Specific goals will include:

1) Learning to run the existing WACCM and WACCM-X models, analyzing model output and comparing with general observations of meteorology and chemical composition;

2) Incorporating metal chemistry into the WACCM-X model;
3) Collecting available lidar data from observatories in China, the US and Germany, and then comparing with the developing WACCM-X metal model;
4) Performing long-term simulations to investigate changes produced by greenhouse gases, ozone depletion, and the solar cycle.

Potential for high impact outcome:

This project addresses the coupling of the atmosphere to the geospace environment. Metallic species provide a unique tracer of dynamics in the neutral and ionized atmosphere, on a range of temporal (seconds to years) and spatial (400 km vertical, global horizontal) scales. The Chinese Academy of Sciences have recently recognized this as their highest priority research area in geophysics, and have made significant investments in a chain of lidar/radar stations at low geomagnetic latitudes. The data that they will provide for this project will be the first of its kind and - combined with a new state-of-the-science whole atmosphere model up to 600 km being developed at NCAR- will likely to lead to some high impact discoveries.

Training:

The student will work under the supervision of Dr Wuhu Feng, Professor John Plane and Professor Martyn Chipperfield at the University of Leeds, and also work with other researchers contributing to this project, including: Drs Daniel Marsh and Hanli Liuat the world-leading US National Center for Atmospheric Research (NCAR), USA; Profs. Xiankang Dou and Xianghui Xue at the University of Science and Technoldgy of China (USTC, Hefei), one of the top Universities in China. This project will provide a high level of specialist scientific training in: (i) the application of a world-leading atmospheric chemistry-climate model; (ii) analysis and synthesis or large datasets; (iii) use of advanced High Performance Computing facilities (e.g. the UK national supercomputer archer.ac.uk, and the N8 HPC n8hpc.org.uk). The successful PhD student will have an opportunity to visit USTC and NCAR for collecting observations and model development, as well as training organised by the Doctoral Training Programme, the National Centre for Atmospheric Science, and attendance at national/international conferences.

Further Reading:

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