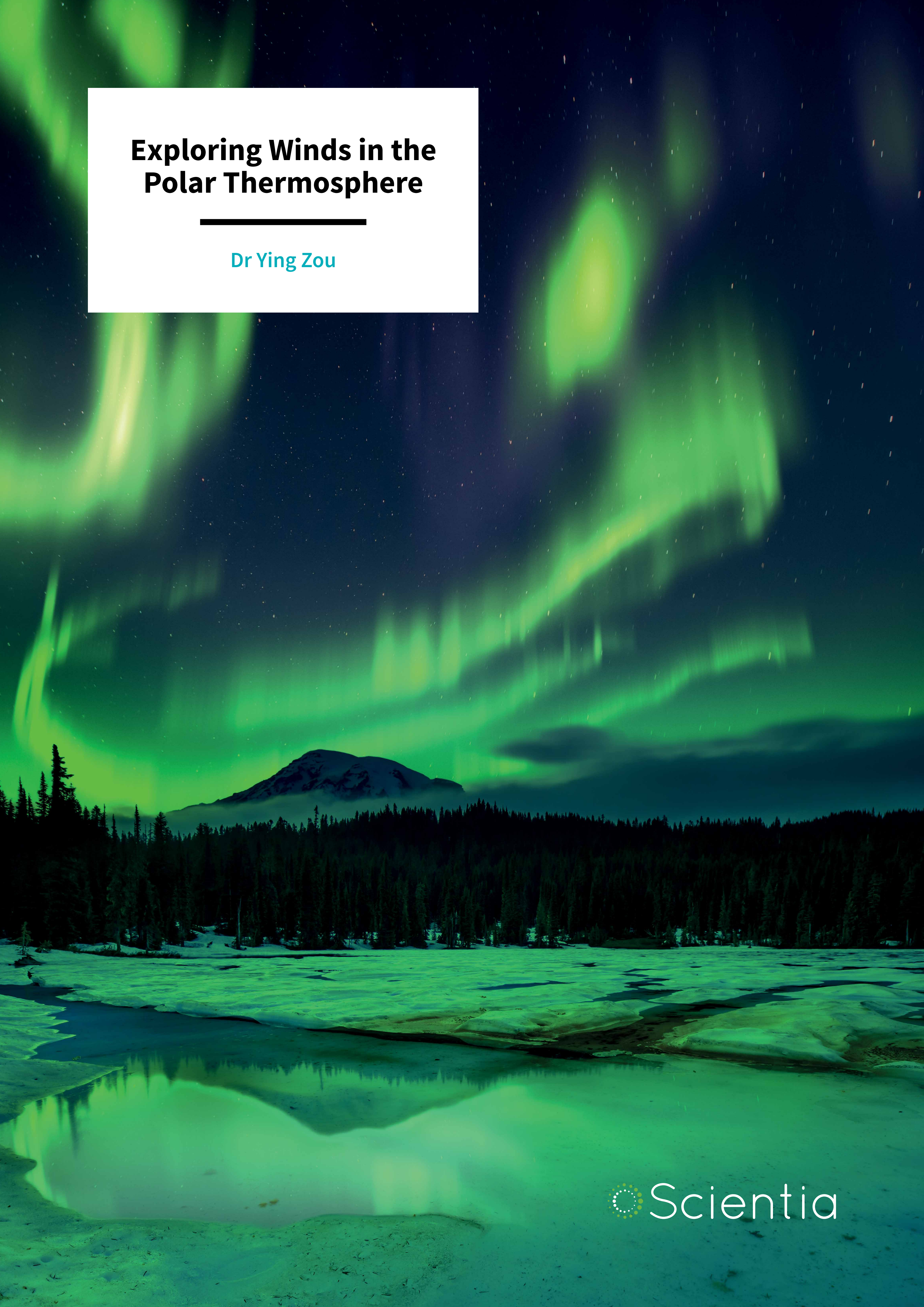
Exploring Winds in the Polar Thermosphere

Dr Ying Zou



Scientia

EXPLORING WINDS IN THE POLAR THERMOSPHERE

Beginning 80 kilometres above Earth's surface, and extending to the edge of the atmosphere, the thermosphere occupies a large proportion of Earth's upper atmosphere. So far, studies of this expansive region have largely focused on how the air it contains flows over global scales. Now, **Dr Ying Zou** at the University of Alabama in Huntsville has explored how the thermosphere is also significantly influenced by 'mesoscale' interactions with Earth's magnetosphere, creating flows spanning just hundreds of kilometres. Her team's work could greatly improve our knowledge of how the upper atmosphere behaves.

Earth's Thermosphere

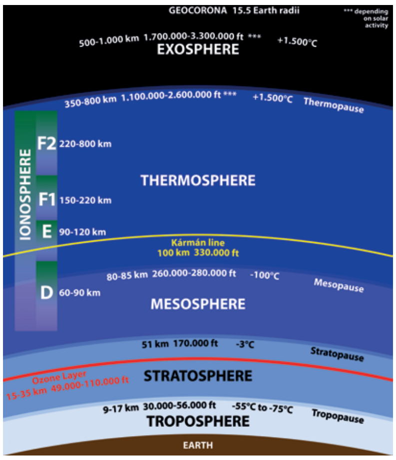
Within the Earth's thermosphere, atoms and molecules are subjected to extremely different conditions to those closer to the surface. Here, ionisation and heating are triggered as particles interact with the Sun's powerful radiation, creating plasmas with exceedingly high temperatures. In addition, the region is strongly influenced by Earth's magnetosphere – the region surrounding its atmosphere whose properties are governed by the shape and strength of its magnetic field and the flow of the solar wind.

'The thermosphere can be highly variable, since the sun and the magnetosphere deposit large amounts of energy on a wide range of temporal and spatial scales into this layer,' explains Dr Ying Zou, researcher at the University of Alabama in Huntsville. 'The science community is now actively examining some fundamental properties of the thermosphere, including its density, temperature, and velocity.'

One major challenge to these studies is the wide range of scales at which processes can occur – both in space and time. While some energy depositions can occur on scales comparable to the Earth itself, other 'mesoscale' processes can measure just hundreds of kilometres across – the size of some small countries. Moreover, processes can either unfold over timescales of several hours, or just a few minutes.

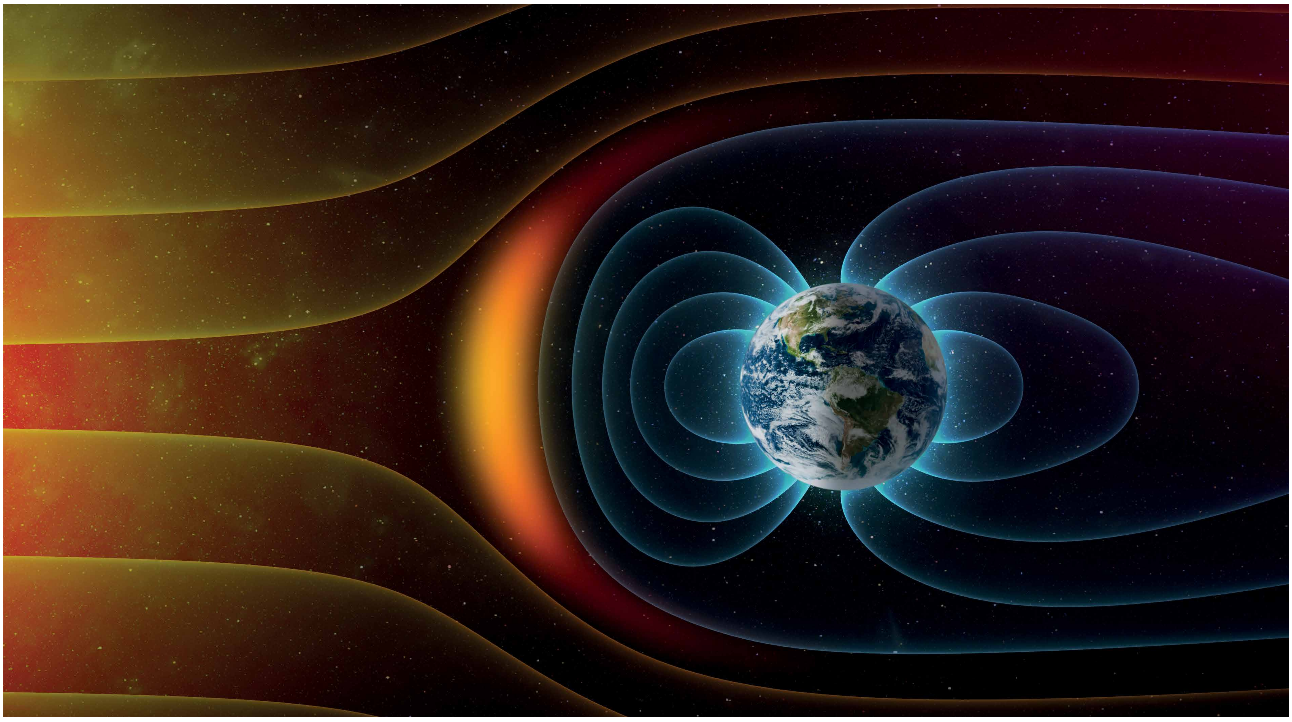
The nature of these depositions is particularly important to consider during geomagnetic 'storms' and 'substorms'. Storms are major disturbances that occur when there is a very efficient exchange of energy from the solar wind into the magnetosphere. They inject energy into the thermosphere across a broad range of latitudes and last for several days, creating the well-known natural light displays known as the aurora borealis in the northern hemisphere, and aurora australis in the south.

Substorms are also disruptions in the Earth's magnetosphere, but they



are much briefer and release less energy than storms. Both storms and substorms cause extra drag on satellites in low-earth orbit, modify the path of radio signals, disrupt navigation systems, and create harmful geomagnetic induced currents in the power grid and pipelines.

Such storms and substorms can lead to features including fleeting surges and streams of particles, as well as longer-lived arcs of auroras. However, one particular aspect of these features has remained notably unexplored until now.



Considering Global Circulations

So far, studies of winds in the thermosphere have been dominated by the exploration of global-scale circulations. Researchers have drawn their conclusions using satellite and ground-based observations of how these large-scale air flows are altered during different levels of geomagnetic activity, revealing characteristic patterns in their intensification. However, Dr Zou argues that this picture does not tell the whole story. Rather, it downplays the full influence of the magnetosphere as it interacts with the thermosphere, generating far more localised winds at high latitudes.

As Dr Zou explains, this oversight means that previous studies have left a significant gap in our knowledge of the thermosphere. 'Traditionally, it has been assumed that to drive the thermosphere in motion, forcing or energy originated from outer space must be long lasting, considering the large inertial of the thermosphere,' she says. 'In other words, if the forcing is transient, the thermosphere would exhibit little change. My research suggests that the assumption fails around aurora borealis.'

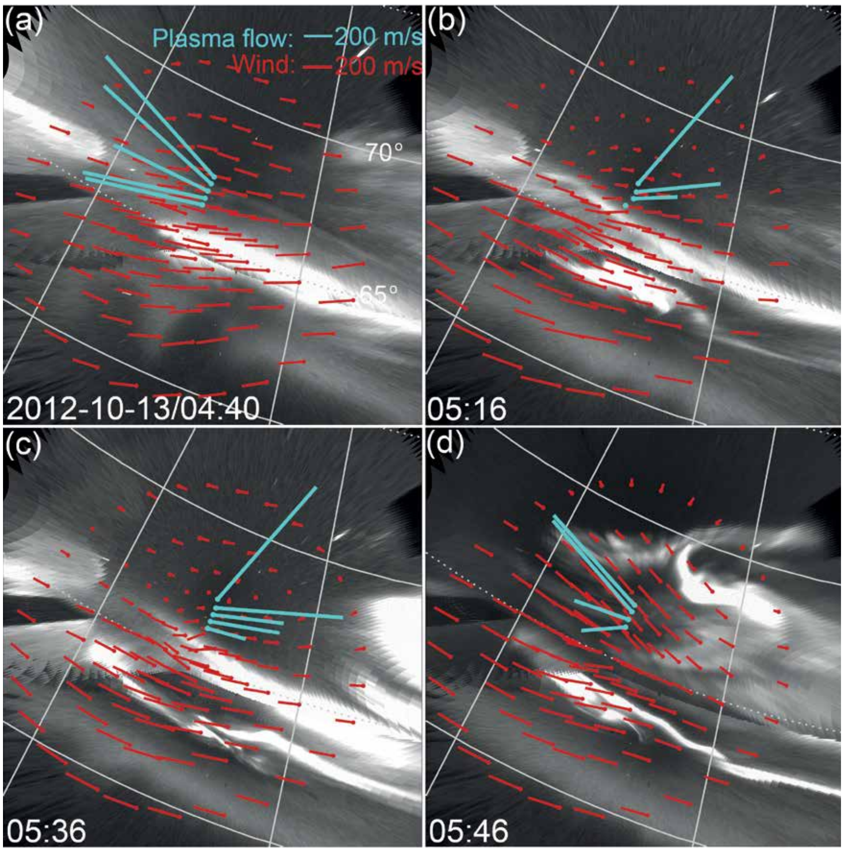
With no measures in place to account for the smaller, more fleeting motions of the aurora on top of the global-scale features it is embedded in, previous studies have produced sketches of air flow that are over-simplified. However, these shortcomings are by no means insurmountable. Using the latest monitoring tools and analytical techniques, Dr Zou and her colleagues could draw out a roadmap towards a better understanding of the interaction between thermosphere and magnetosphere.

Setting Out New Goals

Winds in the thermosphere are crucial in several aspects – all of which can benefit from a thorough analysis of the mesoscale processes found in the aurora. 'Firstly, the winds transport atoms and molecules from one place to another,' Dr Zou explains. 'This means that given a disturbance in air at one certain location, air circulation can cause it to spread, occasionally all the way to the opposite hemisphere.' Therefore, her team's findings would provide critical insights into how mesoscale processes affect the transport throughout the entire thermosphere, beyond simpler, more uniform processes.

'Secondly, the velocity affects how frequently thermospheric particles collide with charged particles from the ionosphere, and therefore how much heat is created due to frictional heating,' Dr Zou continues. 'Generally speaking, a blowing thermosphere will produce less heat than a stagnant one.' While temperatures in the thermosphere can reach up to 1,700°C, they are known to fluctuate widely with the Sun's activity, which varies the amount of energy transferred into the magnetosphere. Therefore, the team's studies could explain more accurately how these variations will unfold.

Having identified each of these aspects, Dr Zou and her colleagues next set out several objectives to determine how mesoscale winds are associated with different types of features in the aurora, and how their occurrence and properties can change. The first of these objectives involved measuring how mesoscale winds are distributed around longer-lived auroral arcs on hour-long timescales, while the second considered how winds evolve and distribute around more transient arcs. Finally, the team's third objective involved measuring how mesoscale winds vary with the activity of the Sun, and Earth's magnetosphere.



Monitoring from Ground and Space

Dr Zou's team has a wide range of instruments at their disposal to achieve each of these goals. The first of these is a chain of ground-based Fabry-Perot interferometers named Scanning Doppler Imagers (SDIs), which are positioned over the skies of Alaska. By continually monitoring thermospheric wind speeds in this region, these interferometers can produce mosaics of wind disturbances induced by the aurora at varying times. Secondly, THEMIS All-Sky Imagers are a constellation of NASA cameras, which monitor how auroral features intensify during substorms. With imaging areas spanning thousands of kilometres, these cameras can readily capture mesoscale features in their entirety as they occur.

Finally, the Poker Flat Incoherent Scatter Radar facility, also in Alaska, sends radio signals into the atmosphere, enabling researchers to monitor the energy input originating from the magnetosphere. In their latest research, Dr Zou and her colleagues have combined over a decade of data gathered using these instruments, and analysed them using cutting-edge statistical techniques. Through this approach, the researchers were able to address each of their goals, without the need to gather any new data. Their results have revealed unprecedented insights into some of the most mysterious characteristics of Earth's upper atmosphere.

Revealing Mesoscale Winds

As Dr Zou describes, the researchers have now clearly demonstrated how the thermosphere's behaviour is influenced by mesoscale processes. 'When auroras occur, the thermosphere responsively adjusts,' she says. 'Within 20 minutes, the thermosphere velocity field can exhibit spatial structures that mimic the forms and evolution of the auroras. Such results suggest that one should not treat the thermosphere as a slowly-varying and spatially smooth fluid. Instead, the thermosphere is dynamic and structured.'

This crucial result has led the team to make key discoveries in their following projects. Firstly, they have shown that substorms can significantly alter wind circulation in the polar thermosphere, altering flow speeds by as much as 200 metres per second. Secondly, they have provided new insights into the formation of a wide ribbon of hot plasma found in the thermosphere, which flows as rapidly as 6 kilometres per second. Named STEVE, this feature was first spotted in a citizen science project in 2016, and has widely mystified researchers since.

Together, these results provide corrections to a variety of long-standing misconceptions, which assume that winds in the thermosphere are only relevant on global scales. By considering how mesoscale winds are also driven by magnetospheric interactions with widely differing sizes and strengths, researchers could gain a far better understanding of the thermosphere as a whole.

A New Understanding of the Thermosphere

As well as improving our understanding of a large proportion of Earth's upper atmosphere, the findings of Dr Zou and her colleagues could shed new light on the surroundings of the many satellites that occupy the thermosphere. These include the International Space Station (ISS), as well as many other spacecraft in low-Earth orbit, which provide crucial infrastructures for global communications systems. Therefore, the team's results could lead to better predictions of the environments surrounding these satellites, and how their operation could be affected.

Through further research, Dr Zou's team now hopes their groundbreaking work will soon lead to models that accurately incorporate the mesoscale interactions between thermosphere and magnetosphere for the first time – potentially enabling greater predictions of how the Earth's atmosphere behaves as a whole.

Meet the researcher

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Dr Ying Zou completed her PhD in Space Physics at the University of California, Los Angeles in 2015. She has since occupied research positions at UCLA and Boston University, before taking her current role as Assistant Professor at University of Alabama in Huntsville in 2019. Her research interests are focused on processes that occur in Earth's magnetosphere, ionosphere, and upper atmosphere, and how they depend on the solar wind, which she observes using a variety of cutting-edge ground- and space-based instruments. Dr Zou has also been the recipient of several prestigious awards and fellowships, including the Jacob Bjerknes Award for academic excellence, and the NASA Living With a Star Jack Eddy Postdoctoral Fellowship

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FUNDING

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FURTHER READING

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