Exploring the Weather of Titan and Mars

Dr Scot C. R. Rafkin

Scientia

EXPLORING THE WEATHER OF TITAN AND MARS

The moons and rocky planets of our Solar System may be remote, unfamiliar worlds, but even on the very strangest of them, the weather on those with atmospheres is not wholly unlike our own. **Dr Scot Rafkin**, a planetary scientist at the Southwest Research Institute, believes that the small-scale patterns their atmospheres exhibit are directly comparable with Earth's weather. Based on the results of computer models simulating the atmospheres of Titan and Mars, he argues that these local and regional behaviours are significantly underappreciated in planetary science.

Familiar Yet Foreign Worlds

When we look at images of the moons and rocky planets with atmospheres in our Solar System, they can simultaneously seem completely alien to us, and yet strangely familiar. Clouds of sulphuric acid on Venus, Pluto's neatly layered atmosphere, and Mars' global dust storms are unlike anything we can find on our own planet, but the physical laws that shaped those worlds also apply to Earth. This means that planetary scientists can draw clear parallels between our Earth and the atmospheres of other bodies in the Solar System.

This principle is central to the research of Dr Scot Rafkin, a planetary scientist at the Southwest Research Institute in Boulder, Colorado. 'I study the weather and climate of other worlds using the same computer models, appropriately adapted, used to study and forecast the weather and climate of Earth,' he explains. 'There are many planetary bodies in our solar system with atmospheres overlying a rocky surface – Mars, Venus, Pluto, Titan – that behave in ways that are both familiar and foreign to us.'

Using computer models to study such a diverse range of bodies might seem like a mammoth task at first glance, but as Dr Rafkin explains, the laws of physics are on his side. 'These so-called terrestrial atmospheres are described by and are constrained by the same physics that governs the Earth's terrestrial atmosphere,' he says. 'Therefore, the same modelling framework that allows us to predict the weather and study the climate of Earth can be applied to other terrestrial atmospheres.' In building these models, Dr Rafkin aims to incorporate a crucial element that he believes is missing from many comparable simulations: the small- and regional-scale behaviours of planetary atmospheres.

Zooming into the Details

When simulating the atmospheres of Mars, Venus, Pluto and Titan, the models that most scientists use provide data that is averaged in space and time, removing details that are present at specific locations and times. Furthermore, many of these models are incapable of simulating the small scales, meaning that they fail to highlight potentially important effects. However,

CREDIT: NASA

if meteorologists only ever told us how the Earth's atmosphere was behaving on average, neglecting to mention any smaller-scale weather patterns, the weather forecast would be of very little use to us. Instead of providing local areas with important information about storms, showers and sunny spells, everyone would be subjected to the same, ultimately useless forecast. Dr Rafkin argues that to truly understand how planetary atmospheres work, scientists need to look at these small-scale features.

‘There are many planetary bodies in our solar system with atmospheres overlying a rocky surface – Mars, Venus, Pluto, Titan – that behave in ways that are both familiar and foreign to us.’

‘In the big picture, my work shows that details matter,’ he explains. ‘It is common in the planetary science community to think about how atmospheres behave on the large or global scale, often with little thought to the importance of processes operating at smaller scales. These smaller details can be extremely important, and if you neglect to take their effects into account, you will not fully capture the reality of how terrestrial atmospheres behave.’

Therefore, Dr Rafkin uses his computer models to analyse how local and regional weather patterns behave on different bodies – paying particular attention to how they can affect the properties of their atmospheres as a whole. Two particular worlds have been the subject of several of his recent studies: Saturn’s largest moon, and one of our closer planetary neighbours.

Titan’s Methane Cycle

At first glance, the weather on Saturn’s moon, Titan, appears to be remarkably similar to our own, with clouds, rain and storms, all fuelled by a global patchwork of lakes and seas. Here, however, all traces of water have been frozen as hard as rock, meaning a completely different substance must be cycling between liquid and gas on this world.

‘Titan has a very dense and cold atmosphere composed primarily of nitrogen with a small amount of methane that can condense into liquid or ice,’ says Dr Rafkin. ‘Earth has a similarly dense atmosphere of nitrogen, but it is much warmer, and water rather than methane is the trace gas that condenses. Both atmospheres produce clouds, and both atmospheres support storms.’

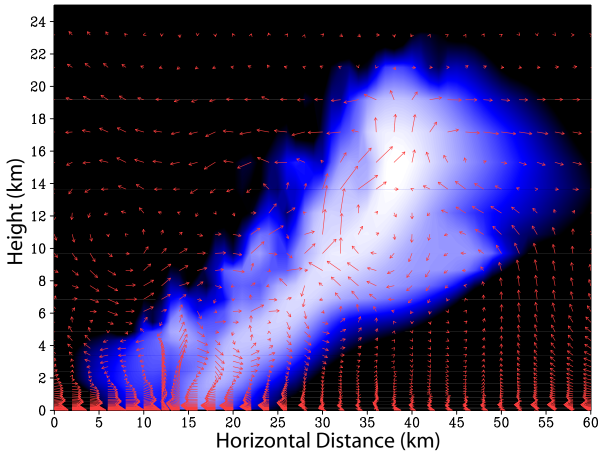
On Earth, storms arise when large amounts of energy are stored in evaporated water, which is rapidly released when the water condenses to produce rain, strong winds, and lightning. Because Titan’s methane cycle appears to be so remarkably similar to the water cycle on Earth, Dr Rafkin modifies the techniques used by more conventional meteorologists who study these violent weather phenomena.

‘By adapting Earth cloud models to Titan, I can understand the conditions under which Titan’s storms form, and importantly, I can learn more about the characteristics and behaviour of the storms than is possible from the very limited observational data,’ he explains. Through these studies, Dr Rafkin has concluded that the very same physical processes responsible for the dynamics, shapes and lifetimes of our own storms can be directly compared with those on Titan.

‘For example, in the absence of strong wind shear, Titan’s storms have a short lifetime and produce heavy rain in a local area,’ he adds. ‘When wind shear increases, the storms evolve into longer-lived and more severe storms similar to those seen on Earth. These storms also produce heavy rain, but it is spread over a larger area along the path of the storm.’

Cold Sea Breezes

In further research, Dr Rafkin and his colleagues studied another Earth-like weather phenomenon visible on Titan: exchanges of vapour and



A simulated Titan storm: the cloud is shown by the shading and the red vectors indicate the circulation and flow of the atmosphere

energy between lakes and seas, and the lower layers of the atmosphere. This process creates a steady wind flowing inland, named a 'sea breeze', which can be impacted by factors including the size and depth of the lake, the strength of the background wind, and the difference in temperature between the lake and the atmosphere.

Since the breezes appear to form on both Earth and Titan, Dr Rafkin could again adapt existing computer models used to study sea breezes on Earth to discover how they behave on Titan. 'Our recent work shows that properly representing the amount of evaporation from Titan's methane lakes requires attention to the details of the local scale circulations,' he says. 'Just like on Earth, Titan's lakes produce sea breezes and marine microclimates of cool and moist air.'

Through these results, Dr Rafkin and his colleagues have shown that smaller-scale weather patterns cannot be ignored when studying planetary atmospheres. 'The circulations and the local marine layer strongly affect the amount of methane evaporated from the lakes, and this, in turn, affects Titan's global methane budget,' explains Dr Rafkin. 'Failure to account for these localised details results in an inaccurate picture of how methane is globally recycled through clouds, rain, and lakes on Titan.' So far, this line of research has already provided scientists with critical insights into how one of the most active terrestrial worlds in the outer Solar System can be properly studied.

Dust Storms on Mars

Closer to home, Dr Rafkin and his colleagues are also studying the atmosphere of Mars, whose mass is now greatly diminished through aeons of gas molecules escaping from the planet's weak gravity, and being stripped away by unshielded solar winds. When looking at images of the planet's desolate surface, especially those gathered by NASA's *Curiosity* rover, it is easy to draw parallels with the more barren parts of our own planet. As Dr Rafkin explains, such comparisons can indeed be useful in studying the Martian atmosphere, though not in an immediately obvious way.

'Mars has enigmatic dust storms,' he says. 'While dust storms occur on Earth too, the characteristics and behaviour of Mars' dust storms is, in many ways, more similar to Earth's thunderstorms, squall lines, and hurricanes. We know this because computer models provide insight into how atmospheres work.'

In recent studies, Dr Rafkin and his team have also used their computer models to interpret data gathered by *Curiosity*, now located in the Gale Crater, to characterise the seasonal changes observed throughout the Martian year. This research has now revealed a complex, small-scale meteorological landscape inside the crater, complete with features including thermal tides, regular flows of dust down the slope of the crater, and atmospheric waves breaking on the surrounding mountain tops. Such discoveries represent crucial advances in our understanding of the Martian atmosphere, and its similarities with our own.

Giant Vertical Plumes

As on Titan, Dr Rafkin argues that these intriguing behaviours play an integral role in the atmosphere on Mars, which cannot be ignored by simply studying the system as a whole. 'The evidence for the importance of small and regional circulations has continued to grow,' he says. 'For example, the dust distribution in the atmosphere of Mars strongly influences the temperature distribution, which then drives pressure gradients and winds.'

One particularly intriguing conclusion Dr Rafkin makes is the influence of deep and vigorous plumes of dust, which come and go in measurable life cycles. As he explains, the results indicate that these coherent, small-scale phenomena are a crucial element of larger patterns in dust dynamics. 'It turns out that small local scale atmospheric circulations are critical to the overall dust cycle,' he says. 'In particular, these atmospheric circulations are capable of rapidly injecting dust high into the atmosphere. The result is enhanced layers of dust at altitude, which cannot be explained by the global scale circulation alone. I've also shown, along with other colleagues, that local and regional dust storms have similar effects.'

Such discoveries are now transforming the ways in which researchers are viewing the moons and terrestrial planets of our Solar System – an advance that would not have been possible with large-scale atmospheric analysis alone. Dr Rafkin's research, therefore, could have a significant impact on the techniques used by planetary scientists in the future, potentially allowing us to study them in unprecedented levels of detail.

CREDIT: Rayna Tedford

Meet the researcher

Dr Scot C. R. Rafkin
Department of Space Studies
Southwest Research Institute
Boulder, CO
USA

Dr Scot Rafkin achieved his PhD in the Department of Atmospheric Science at Colorado State University in 1996. He then worked at the University Corporation for Atmospheric Research and San José State University in collaboration with the NASA Ames Research Center before moving to Southwest Research Institute in Boulder, Colorado in 2003. Here, he is currently Program Director in the Department of Space Studies. Dr Rafkin has extensive experience developing weather and research modelling codes and has applied these to the study of local-scale circulations, clouds, and aerosols for Earth and to several other terrestrial planetary atmospheres. His systems for modelling Mars and Titan are recognised as the premier tools for simulating local and regional atmospheric circulations. Dr Rafkin is a Co-Investigator on the Mars Science Laboratory Rover Curiosity mission and the recently selected New Frontiers Dragonfly mission to Saturn's moon Titan.

CONTACT

E: rafkin@boulder.swri.edu
W: https://www.boulder.swri.edu/~rafkin/

KEY COLLABORATORS

Dr Jorge Pla-Garcia, Centro de Astrobiología, Torrejon, Spain
Timothy I. Michaels, SETI Institute, Mountain View, California
Dr Alejandro Soto, Southwest Research Institute, Boulder, Colorado
Dr Erika Barth, Southwest Research Institute, Boulder, Colorado

FUNDING

NASA

FURTHER READING

SC Rafkin, J Pla-Garcia, M Kahre, J Gomez-Elvira, VE Hamilton, M Marín, S Navarro, J Torres, A Vasavada, The meteorology of Gale Crater as determined from Rover Environmental Monitoring Station observations and numerical modelling, Part II: Interpretation, Icarus, 2016, 280, 114–138.

SC Rafkin, EL Barth, Environmental control of deep convective clouds on Titan: The combined effect of CAPE and wind shear on storm dynamics, morphology, and lifetime, Journal of Geophysical Research: Planets, 2015, 120, 739–759.

B Charney, E Barth, S Rafkin, C Narteau, S Lebonnois, S Rodriguez, SC Du Pont, and A Lucas, Methane storms as a driver of Titan's dune orientation, Nature Geoscience, 2015, 8, 362.

SCR Rafkin, JL Hollingsworth, MA Mischna, CE Newman, MI Richardson, Mars: Atmosphere and climate overview, Comparative Climatology of Terrestrial Planets, 2013, 1, 55-89.

SC Rafkin, The potential importance of non-local, deep transport on the energetics, momentum, chemistry, and aerosol distributions in the atmospheres of Earth, Mars, and Titan, Planetary and Space Science, 2012, 60, 147–154.

SC Rafkin, A positive radiative-dynamic feedback mechanism for the maintenance and growth of Martian dust storms, Journal of Geophysical Research: Planets, 2009, 114.

SC Rafkin, MRS Maria, TI Michaels, Simulation of the atmospheric thermal circulation of a martian volcano using a mesoscale numerical model, Nature, 2002, 419.

SwRI
SOUTHWEST RESEARCH INSTITUTE