Exploring the Effect of Aerosols on the Arabian Peninsula's Changing Climate

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Scientia

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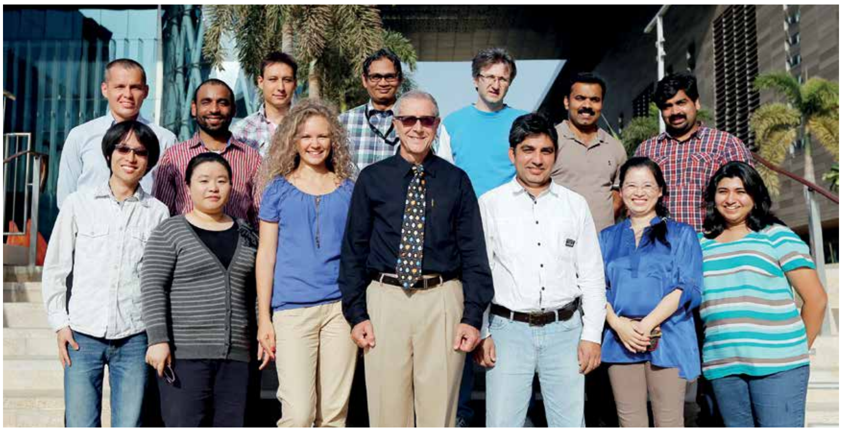
Today, the Arabian Peninsula already faces a more daunting array of environmental challenges than most other regions on Earth. Yet as the climate changes, it is now expected to feel these adverse effects even more strongly in the coming decades. Using the latest modelling techniques, combined with ground-based observations, **Dr Georgiy Stenchikov** at King Abdullah University of Science and Technology in Saudi Arabia aims to make better predictions of how these changes will unfold. His work now provides critical guidance on how governments in the region should prepare for future shifts in climate and air quality.



The Arabian Peninsula's Climate

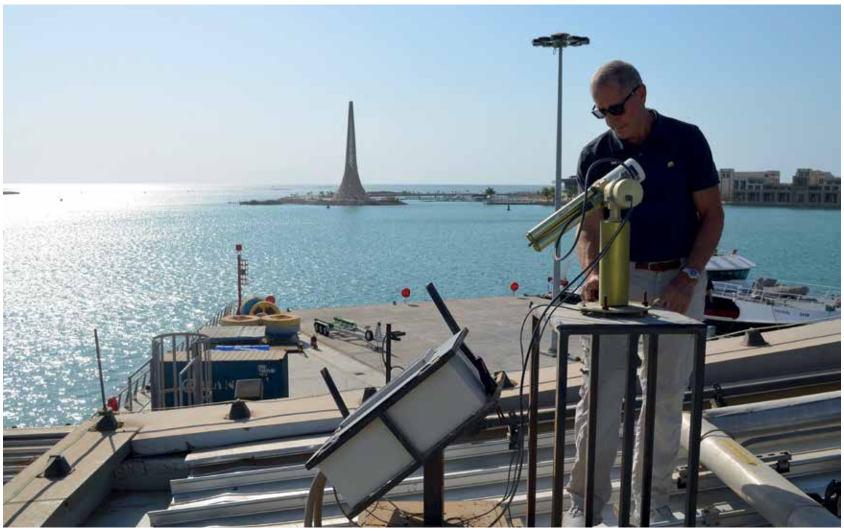
The Arabian Peninsula is well known for its harsh natural environments. Not only are large swathes of the region covered in inhospitable desert; it is also one of the most water-scarce regions on Earth, with many communities relying on the desalination of seawater for their survival. On top of this, the peninsula's climate is highly sensitive to a phenomenon named 'radiative forcing'. Radiative forcing describes the change in Earth's energy balance (the difference between the sunlight absorbed by Earth, and the infra-red light radiated back into space), which is associated with greenhouse gas emissions, desertification, urbanisation, and shrinking vegetation cover. This effect is strongly influenced by an abundance of particulates including sand, dust and anthropogenic pollutants suspended in the air – together named 'aerosols'.

Over the past three decades, both observations and computer simulations have shown that the Arabian Peninsula's average temperature has increased by about 0.5°C per decade exceeding almost twice the trend observed in the northern hemisphere as a whole. This means that effects including an increasing frequency of extreme weather events, such as heat waves, sandstorms and flash floods, are now being felt increasingly strongly.

As these changes have unfolded, the population of Saudi Arabia alone has exploded from just 4 to 34 million in only half a century. Combined with rapid social and economic development, and urbanisation in the region, these effects are now imposing an unprecedented strain on the region's water resources, agriculture, air quality, and natural ecosystems.

A Need for Better Predictions

To tackle these mounting challenges, detailed evaluations of changes in the Arabian Peninsula's climate and air quality have never been more critical. Ideally, a robust basis for supporting environmental policy in this way would enable regional, national and international policymakers to carry out long-term planning and sustainable developments, and to utilise renewable energy more effectively. This would require advanced, science-based decision making from governments as



they decide how to mitigate and adapt to climate change, with judgements centred around the outcomes of robust observations and predictive models.

Twenty to thirty years ago, there were significant shortcomings in the techniques used by researchers to predict these changes, creating critical oversights in existing climate predictions for the Arabian Peninsula. 'Before, we did not know the optical properties of aerosols, their microphysical behaviour, or their emission sources,' says Dr Georgiy Stenchikov at King Abdullah University of Science and Technology in Saudi Arabia. 'The spatial resolution of our models was very coarse. In many models, aerosols were not included in the radiative transfer calculations, meaning they couldn't affect solar and terrestrial radiation.' Over decades of research, Dr Stenchikov has used cutting-edge simulations, combined with ground-based and satellite observations, to discover how these predictions can be improved.

Diverse Tools for Regional Climate Modelling and Monitoring

Dr Stenchikov and his colleagues have a wide array of techniques at their disposal for achieving these research goals, based around cutting-edge computer simulations of circulations in Earth's atmosphere and oceans. Alongside high-resolution global atmospheric simulations, they now use the regional Weather Research Forecasting WRF model with chemistry and aerosol module (WRF-Chem). The main shortcoming of regional climate models is that without considering how the oceans are influenced by the atmosphere, and vice versa, their individual prediction abilities are limited.

To alleviate this issue, Dr Stenchikov has introduced novel techniques for coupling atmospheric and oceanic simulations together on a regional scale, greatly improving the accuracy of their predictions. He used WRF as an atmospheric component for regional models, and the Regional Ocean Modelling System (ROMS) for the oceanic component. In addition, he implemented NASA's satellite observations in the model, which monitor dust aerosols over the Arabian Peninsula and the Red Sea from space. By running this regional coupled ocean-atmosphere modelling system, Dr Stenchikov and his colleagues have gained critical insights into how aerosols have influenced the Red Sea and the Arabian Peninsula's climate in the past, and how they can be expected to transform it in the future.

Aerosol Catastrophes

When Dr Stenchikov first started out in his career, our perceived threat of climate change was dwarfed by the very feasible prospect of another global catastrophe: an international nuclear conflict between global superpowers. If such an event had ever occurred, vast quantities of smoke from urban and forest fires, as well as dust from ground bursts, would have been injected up into the atmosphere, triggering devastating rapid drops in temperature, precipitation, and sunlight.

Together known as 'nuclear winter', these effects were widely studied through simulations at the time, producing predictions of a brief yet devastating shift in the Earth's climate. Dr Stenchikov and his colleague Dr Aleksandrov, then at the Computer Center of the USSR Academy of Sciences, conducted the first general circulation model simulation of climate perturbations following the hypothetical nuclear war based on TTAPS (group of American Scientists Turco, Toon, Ackerman Polack, and Sagan) scenarios.

Later on, Dr Stenchikov was involved in research exploring the climate effects of volcanic explosions. He also studied how particulates spread through New York and the surrounding area following the 2001 attacks on the World Trade Centre, conducted simulations of the hypothetical nuclear conflict between India and Pakistan, and investigated the feasibility of Solar Radiation Geoengineering to counteract global warming. As Dr Stenchikov describes, nuclear winter studies heavily influenced his subsequent research, as well as that of many other world leaders in the wider field of aerosol research.

'Problems including the effects of volcanic eruptions on climate; dust storms; the effect of dust on air quality and radiation transfer; and transport of the World Trade Centre fire's plume are all physically related to the effects causing nuclear winter,' he says.

Impacts of Volcanic Eruptions

In 1991, the eruption of Mount Pinatubo in the Philippines exerted the largest volcanic climate impact in the 20th century. The globally averaged volcanic cooling exceeded 0.5°C and this was twice as strong in the Middle East.

However, even 25 years afterwards, these effects were still not completely understood. Through his research, Dr Stenchikov improved our understanding of the physical mechanisms controlling climate responses to volcanic radiative forcing. To study the volcanic impact on the Middle East climate, Dr Stenchikov and his team coupled the regional atmospheric model, WRF, with the regional ocean model, ROMS, and comprehensively accounted for the radiative effects of volcanic aerosols. Critically, his team found that atmospheric circulation had a greater influence on the climate of the Middle East than direct regional cooling from aerosols.

In a further study, Dr Stenchikov produced new simulations of the Toba super-eruption: a particularly devastating event that occurred in Sumatra around 75,000 years ago and emitted about 2 billion tonnes of sulphur dioxide. By better accounting for the radiative effect of sulphur dioxide, his team found that the effects of volcanic winter following the super-eruption were softened by the greenhouse effect of sulphur dioxide. They also found that the development of sulphate aerosols was delayed by the ability of sulphur dioxide to absorb UV and to inhibit the breakdown of ozone developing an equatorial ozone hole.

Altogether, these studies suggested that major volcanic eruptions can significantly alter the Earth's climate, and should be carefully considered when assessing long-term climate variability and warming trends.

Calculating Anthropogenic and Natural Pollutants

Together, North Africa and the Arabian Peninsula are the two largest sources of dust in the world. Mixtures of mineral dust, sea salt, sulphate, black carbon and organic matter, when suspended in air, can profoundly influence air quality, radiative heating, and atmospheric circulations in the region. The size distribution, and chemical composition of aerosols are crucially important to evaluate these effects. However, as Dr Stenchikov describes, these cannot be effectively monitored using conventional observation techniques.

'It is a difficult problem for satellites to distinguish between different types of aerosols,' he says. 'Passive satellite instruments measure the aerosol optical effect, or depth, at different wavelengths. This helps to make some conclusions about the size distribution and compositions of aerosols. Active lidar instruments have better capabilities – but the composition and size distribution of atmospheric aerosols are still poorly observed, and not well modelled.'

To combat this issue on a regional basis, Dr Stenchikov established NASA AERONET and MPLNET sites at KAUST's campus – which enable his team to precisely determine the size distribution and thickness of the aerosol layer. The team also conducted first multi-year systematic measurements of aerosol deposition rates, mineralogy and size distribution of aerosol samples.

Combined with simulations, these empirical studies revealed how aerosols become concentrated over the southern Red Sea producing in this place world's largest radiative forcing– behaviour consistent with observations from satellites. In turn, Dr Stenchikov's discoveries have clearly revealed the extent to which natural and anthropogenic aerosols impact regional climate, solar panel efficiency, air quality and human health.

Informing Future Decisions

Climate change, combined with a rise in air pollution, are now severely threatening the livelihoods of many millions of people in the Arabian Peninsula – with potential disasters ranging from rising instances of respiratory diseases and lung cancer, to diminishing water resources for agriculture. 'The Middle East's climate is at the border of liveability,' Dr Stenchikov summarises. 'Global warming is faster here than the global average, so inevitably, adaptation and mitigation measures must be applied. Our work is meant to help in the planning and preparation of such actions and should be accounted for in environmental decision making.'

Dr Stenchikov's research has now clearly shown that a combination of coupled atmospheric and oceanic simulations, and ground-based aerosol measurements, are the best tools for informing governments as they make these critical decisions. Through future research, he now hopes to create more accurate climate forecasts for the Arabian Peninsula for both 2050 and 2100. He also aims to show how the elaborated distribution of solar panels over the Red Sea coastal plain could enhance breezes in the Red Sea – which are some of the strongest in the world – forcing precipitation in the most arid region on Earth.

Meet the researcher

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Dr Stenchikov completed his PhD in the Numerical and Analytical Study of Weak Plasma Turbulence at Moscow Physical Technical Institute in 1977. Afterwards, he headed a department at the Russian Academy of Sciences, which used computational analysis to carry out crucial early research into the impact of humans on Earth's climate and environmental systems. From 1992 until 1998, Dr Stenchikov worked at the University of Maryland in the USA, after which he held a position as a Research Professor in the Department of Environmental Sciences of Rutgers University for almost a decade. Since 2009, he been a Professor and a Chair of the Earth Sciences and Engineering Program at King Abdullah University of Science and Technology in Saudi Arabia. His work has brought about important advances in fields including climate modelling, atmospheric physics, fluid dynamics, radiation transfer, and environmental sciences. Dr Stenchikov also co-authored the Nobel Prize winning report from the Intergovernmental Panel on Climate Change IPCC-AR4 of 2007.

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