Physicist Risto Makkonen explores the climatic conditions which prevailed thousands of year ago. For this purpose, he uses a powerful tool - paleosimulations - which help to understand the future atmosphere

Opening the prehistory of climate

About 6,000 years ago, there were lakes and vegetation in the Sahara, now known as the largest desert in the world. The cause of the change was Nature itself: the position of the globe with respect to the Sun varies with time, thus influencing the conditions prevailing on the Earth.

But this is not the whole story. Several open questions remain, and to answer them may help us to understand the future climate, too. This is why young physicist Risto Makkonen has recently been awarded a research grant to study the patterns of the ancient Green Sahara further.

Makkonen works as a researcher in the Finnish Centre of Excellence in Atmospheric Sciences. The center has many laboratories and offices, part of which are located inside the University of Helsinki. Makkonen and his colleagues are specialists in aerosol physics and air chemistry – fields which offer the key knowledge needed to make better climate predictions over the coming years.

"The draught periods in the Sahara follow the well-known variations of the axial tilt in the orbit of the Earth", explains Makkonen. "The climatic changes caused by the orbital forces are clear-cut and predictable. They are also extremely slow from the point of view of a human, as they take thousands of years. There is, however, record of the holocene era indicating that the change from Green Sahara to a desert was abrupt compared to orbital timescales. Now, we want to find out why."

Aerosol particles and paleosimulations

Makkonen wishes to explore one intriguing explanation for the rapid desertification: the feedback mechanisms acting via aerosol particles.

There are myriad tiny liquid and solid particles suspended in the air called 'aerosol particles'. They are borne not only by human action like industry and traffic, but also by the Nature itself, for example as a by-product of photosynthesis. This is why the atmosphere and the vegetation of the Earth are strongly interlinked.

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Risto Makkonen is a physicist, but does a lot of scientific coding, too

> The Holocene was one of the geological periods which prevailed about 11,000-5,000 years ago.

"The feedback loops are complex, non-linear phenomena in the ecosystem, not yet well-known by scientists", clarifies Makkonen. Particularly, it is the aerosol particles which loom behind many of the loops, making all climate predictions uncertain: the aerosol effects may either cool or warm the environment.

"As far as we do not know the formation process of the aerosols or their interaction with clouds and radiation, we do not understand the current climate either," says Makkonen. In other words, to see the bigger picture, we have to drill down to the molecular level.

The ancient conditions of the Sahara cannot be brought into the laboratory, of course. Yet there is a special tool which can be used to look 6,000 years into the past. With the help of a few colleague physicists, geologists and scientific coders, Makkonen performs paleosimulations. For this purpose, he uses a special Earth System Model, which he has also developed further.

The equations of the Earth

It has often been argued by science sceptics that computer simulations are a misleading way of exploring the climate: "Computer programs and simulations are no better than the ideas of a human who made them up," some have argued.

This is, of course, partly true. However, what is less known is that the models developed by physicists, chemists, and other scientists are not based on defaults or subjective assessments. On the contrary, the Earth System Model consists of thousands of empirically tested equations and laws of Nature. The equations may look like the ones in our high school physics textbooks describing the connections of, say, pressure, gravitation, flows and fluxes of gaseous and liquid substances, temperature etc.

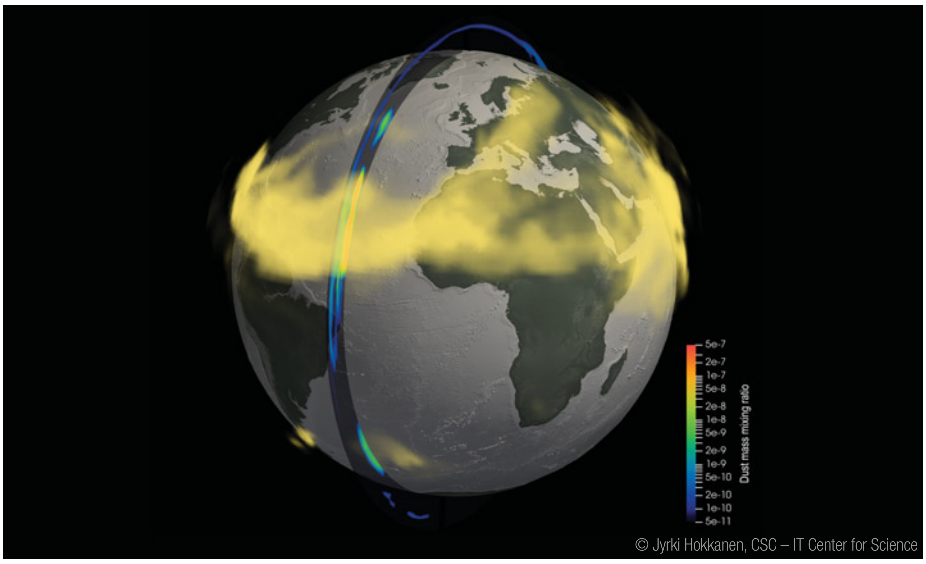
"Earth System Model includes several main blocks such as vegetation, oceans, land use, or aerosols. All of the components can be formulated mathematically", explains Makkonen. He also points to one of the equations describing the dynamics of photosynthesis, while another explains numerically the growth rates of aerosol particles.

"All formulas are well-known, empirically tested, and based on real data. During the simulation the components are coupled together, and the model begins to imitate Nature with given conditions including, orbital parametrs, Sun activity, amongst others. Thus, the model allows us to test our hypotheses of Earth System interactions."

For the actual simulation, equations need to be translated into computer languages. At the moment, there are millions of code lines in the Earth System model. "To construct a model like this required the contribution of more than 30 European research institutes", says Makkonen. "Our main input is to add the aerosol feedbacks into it."

World-class aerosol research

When it comes to expertise in aerosol research, Makkonen and his colleagues in the Finnish Centre of Excellence are probably the best in the world. The scientists of the center have published a tenth of all the scientific breakthroughs connected with the formation process of natural aerosols. They also have established two successful spin-off companies which produce industrial monitoring technology like particle counters.



The Earth System model simulation shows how Saharan dust is circulated by the wind over the Atlantic. The numbers and colours in the right corner of the Figure refer to the ratio of dust mass to air mass

Furthermore, the Finnish atmospheric scientists have founded specific observation stations called SMEAR (Station for Measuring Earth Surface-Atmosphere Relations) in Finland, Estonia and China. These are kinds of laboratories equipped with state-of-the-art instruments to explore the molecular interlinks of the ecosystem.

As a physicist, Makkonen enjoys being close to the core of these aerosol research entities with all their apparatus. "It is the way of putting models into real world context", as he puts it. After three years, his research team will hopefully have reconstructed the mid-Holocene aerosol fields above the Sahara.

"I should then be able to quantify, i.e. express in numbers, the effect of aerosols on the West African Monsoon and its changes", says Makkonen. "What I hope most is that I could pursue a more holistic understanding of what actually happens between climate and the vegetation of the Earth – and why."

The Institute for Atmospheric and Earth-System Research (INAR) is located in the science campus of the University of Helsinki, Finland. In total there are 300 scientists in INAR representing various fields of physics, chemistry, forest sciences, mathematics and computer sciences. The INAR-scientists conduct world-wide field research via specific observation stations. The SMEAR-stations measure the interlinks between the Earth's surface and the atmosphere, offering long-term data on versatile molecular-level phenomena of the ecosystem.

The INAR spin-off companies Airmodus Ltd and Karsa Inc. produce particle counters and special sensors respectively, and SMEAR Ltd develops and offers observational technology and knowledge.

The basic laws of Nature as well as the versatile phenomena of the ecosystem can be captured into mathematical formulas. The interconnected equations can, then, be further translated to computer languages, i.e. code lines. The Earth System Model includes millions of them

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