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ACADEMIA

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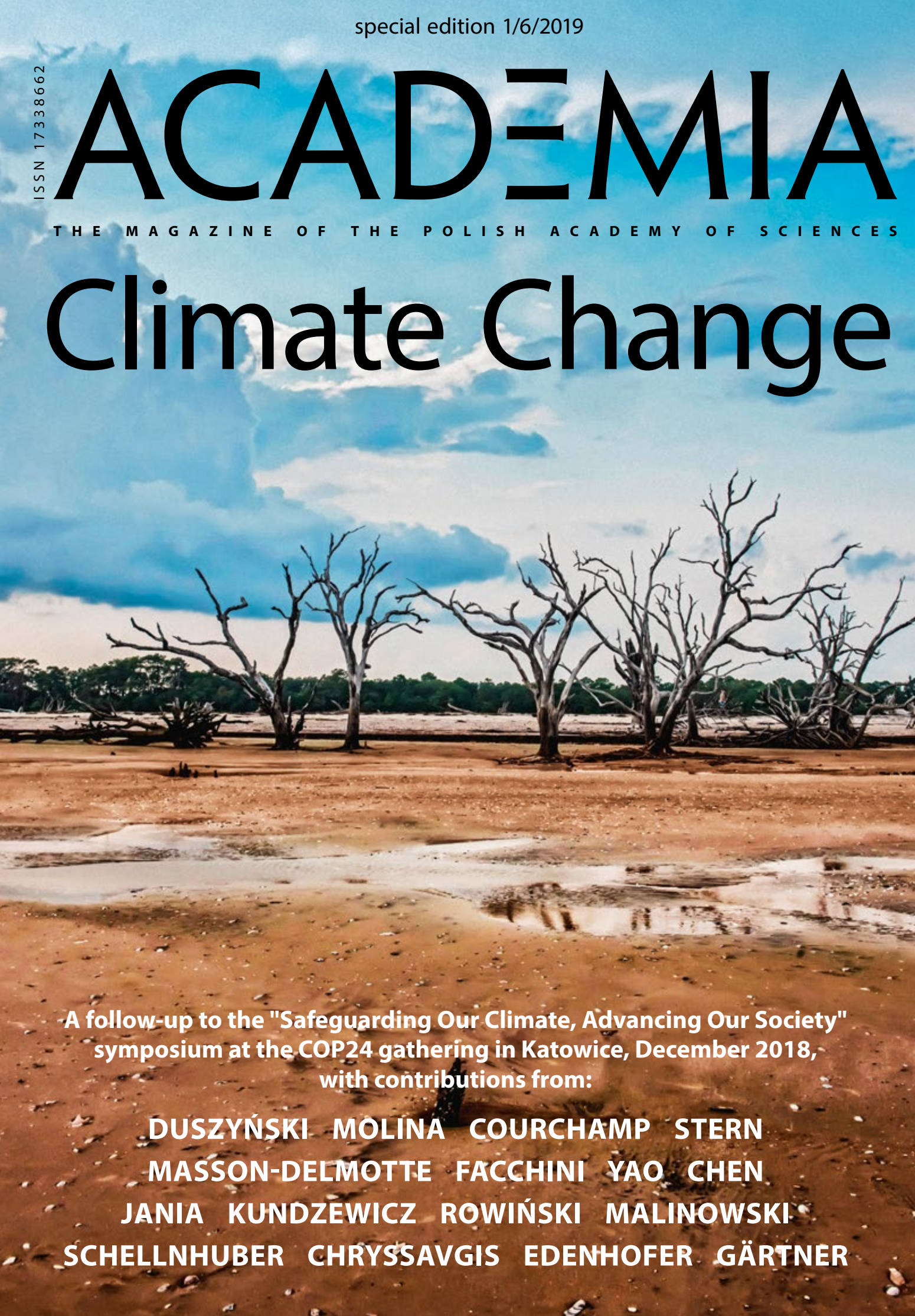
Climate Change

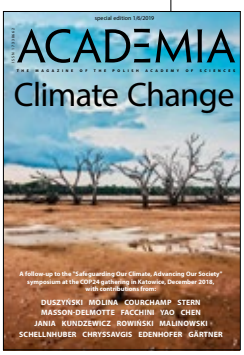


A follow-up to the "Safeguarding Our Climate, Advancing Our Society" symposium at the COP24 gathering in Katowice, December 2018, with contributions from:

DUSZYŃSKI MOLINA COURCHAMP STERN MASSON-DELMOTTE FACCHINI YAO CHEN JANIA KUNDZEWICZ ROWIŃSKI MALINOWSKI SCHELLNHUBER CHRYSSAVGIS EDENHOFER GÄRTNER

ACADEMIA | Climate Change

Table of Contents



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A World Gone Awry?

Scientists are carefully observing the rapid, ongoing changes in the Earth's climate. We already know for certain that these processes are caused by human activity, by the emission of greenhouse gases, chiefly carbon dioxide and methane, from industry, heat plants, power stations, agriculture, and households. Consequently, scientists continue to posit increasingly dire and alarming forecasts. Like all scientific projections, these scenarios are expressed in terms of their likelihood. However, science already says that there is a 60% chance that, within a decade or two – in other words during the lifetime of most of us alive now – the world will witness significant floods, heatwaves, typhoons, rising sea and ocean levels, and in their aftermath, increasingly widespread famine, shortages of drinking water, and migrations of entire nations.

However, the voice of scientists continues to resonate poorly with societies and decision-makers. Why is that the case?

In his short story *The Lady with the Dog*, Anton Chekhov describes a scene in which the main character in the story, a man named Gurov, unable to share with anyone the pain he feels deep in his soul, finally explodes at an unexpected moment:

One evening, whilst emerging from the doctors' club together with his card-playing partner, a public official, he could not help himself and said: "If only you knew what a fascinating woman I became acquainted with in Yalta!" The official got into his sleigh and drove away, but then turned back suddenly and shouted: "Dmitri Dmitritch!" "Yes?"

"What you said earlier was right: the sturgeon had indeed gone a bit off!"

In Chekhov's short story, Gurov feels insulted by this remark about the sturgeon, thinks of it as trivial and shallow, terribly off-topic. Compared to the intense drama he is experiencing in his own mind, the bureaucrat's down-to-earth comment seems absurd.

Scientific scholars and religious leaders alike harbor no illusions about the causes, pace, and directions of climate change and its dramatic consequences. This was particularly audible during the joint symposium organized by the Polish Academy of Sciences, the French National Centre for Scientific Research (CNRS), and the Pontifical Academy of Sciences during the United Nations Climate Change Conference COP24, held in Katowice in December 2018. The threats and potential means of preventing them are discussed in the Katowice Memorandum, the final document adopted by the participants in the symposium. In this special issue of *Academia* magazine, we are proud to present the positions of a number of the prominent thinkers and researchers that were involved.

Their warnings are indeed very much down-to-earth, but the serious problem is that to many members of society, they may seem terribly off-topic and trivial, compared to the day-to-day concerns they are absorbed with. However, a failure to pay heed to those warnings may have a very profound effect on entire societies in just a few years. The whole world may then realize that scientists were indeed right, that the world has not just "gone a bit off" but indeed gone profoundly awry.

Prof. Jerzy Duszyński,
President of the Polish Academy of Sciences

A Joint Call for Action

A Declaration of the Joint Symposium on Climate Change
"Safeguarding Our Climate, Advancing Our Society"
10 December 2018.

The Polish Academy of Sciences, the Pontifical Academy of Sciences and the National Centre for Scientific Research (CNRS) convened the joint symposium 'Safeguarding Our Climate, Advancing Our Society' during the 24th UN Conference of the Parties to the UN Framework Convention on Climate Change (COP 24) in Katowice, Poland. At the event, eminent researchers, intellectuals and spiritual leaders formulate a joint call for swift and just climate action. This call to action is addressed to all members of the scientific, cultural and spiritual communities and is based on our collective insight – a sober consideration of climate science and an ethical commitment to a viable future for our common home.

There is compelling scientific evidence that

(i) the Earth is rapidly warming and is already 1°C warmer than in pre-industrial times;
(ii) greenhouse gas emissions from human activities are the dominant driving force of climate change;
(iii) many of the impacts so caused are already negative for society at large and increase social vulnerabilities and
(iv) there is still a window of opportunity to take full responsibility and avoid an all-out climate crisis. However, this window is rapidly closing (Intergovernmental Panel on Climate Change, AR5).

Should it close completely, human progress across our planet would be thwarted, thus turning the immense historical benefit of fossil fuel use into an outright curse for our civilization. This must not happen.

Already today, we are witnessing species extinction and potentially irreversible transformations of ecosystems. Billions of humans are suffering under intensified extreme weather events, such as heat waves, droughts, or flooding. Without a rapid and profound transformation, sea-level rise, water scarcity and other climate impacts will force more and more people to leave their homes or perish.

Scientific and spiritual leaders have responded to these scientific findings by calling on the ethical responsibility of every person living on this planet, urging us to start now to steer Earth toward our children's future.

The international community gathering at COP 24 needs to heed these appeals and substantiate the pivotal Paris Agreement by creating a set of universal rules for national actions that will ensure that global warming is confined to "well below 2°C" A stable climate is one of the most precious common goods in our shared home; it belongs to and

JAKUB OSTAŁOWSKI

Some of the symposium participants in action: Laurence Tubiana – CEO of the European Climate Foundation, Jerzy Duszyński – President of the Polish Academy of Sciences, Stéphanie Thiébault – director of the CNRS Institute of Ecology and Environment, and Prof. Hans Joachim Schellnhuber – Director Emeritus of the Potsdam Institute for Climate Impact Research (PIK).

supports all life on Earth. Scientists, spiritual leaders and civil society need to take care of this good together and must mobilize all efforts to avoid climate chaos.

Rapid decarbonisation of all economic sectors is crucial for preserving the environmental conditions that allowed humanity to thrive. The energy sector is critical in this context, since power and heat are still predominantly generated from fossil fuels – and especially from coal, which has damaging effect on the climate and public health. A move towards renewable energy sources is imperative to protect workers and economies, independent of climate change. For the sake of climate stability, this move needs to happen much sooner than sheer market considerations would suggest.

The answers given by our symposium clearly demonstrate the feasibility for such a transition. The phase-out of fossil fuels provides many co-benefits such as improved air quality and the creation of novel jobs in a progressively digitalized world. Public education can form a strong backbone to the required rapid and deep transformation of our economies and lifestyles.

Climate change intensifies existing inequalities. In addition, transition to a climate neutral economy is more challenging for certain regions than for others. It is therefore necessary to strengthen support to the former, and share knowledge, practices, innovations and resources.

We support the European Union's long-term ambition to lead an innovation process that makes the world fossil-free. To this end, the 'carbon law', a plan to halve emissions every decade, provides a scientifically sound and simple roadmap. A crucial step of this roadmap is a rapid and human-centred transition away from the critical coal sector, no later than 2030, which will be instructive to many fossil-fuel dependent and poorer regions of the world. This is a vital step, which will pave the way to safeguard our climate and advance our society. ■

Done on the 10th of December 2018 during the COP 24 in Katowice, Poland

Evidence Comes From Scientists

Prof. Mario Molina, a Nobel Prize winner, talks about his experience in making the harmful effects of chlorofluorocarbons (CFCs) known to scientists, the general public, manufacturers and politicians.

Prof. Mario Molina
is an American chemist known for his pivotal role in the discovery of the Antarctic ozone hole. He was a co-recipient of the 1995 Nobel Prize in Chemistry for his role in elucidating the threat to the Earth's ozone layer of chlorofluorocarbon gases (or CFCs).
In 2004 he accepted the positions of professor at the University of California, San Diego and the Center for Atmospheric Sciences at the Scripps Institution of Oceanography.
Prof. Molina is also Director of the Mario Molina Center for Energy and Environment in Mexico City.

ACADEMIA: **How did you originally get into atmospheric science?**
MARIO MOLINA: I first became interested in science when I was a child, mainly by reading biographies of scientists. I also liked to do chemistry experiments when I was a kid and wanted to be a scientist from a very young age. When I finished school and started college in Mexico, I already knew I liked chemistry and physical chemistry. Although there were no physical chemistry courses as such, I studied chemical engineering, which uses a lot of physical chemistry. I got my PhD from the University of California in Berkeley for work in fundamental science, looking at speeds of chemical reactions, understanding quantum mechanics and so on. I decided to stay on as a postdoc to continue doing research with a colleague, which also involved fundamental science. He was using different techniques to study chemical reactions. We decided to do something which still involved fundamental research but which was more connected to problems faced by society as a whole. We chose to move into atmospheric chemistry, because it allowed us to continue with fundamental chemistry while looking at something more practical: the atmosphere.

> It has taken a long time for the results of our CFC discoveries to gradually become accepted.

The community working in the new field of atmospheric chemistry was then still quite small. We chose to investigate what happens to some industrial chemicals that were being accumulated in the atmosphere: chlorofluorocarbons (CFCs). We thought these small molecules, similar to ones we studied in the laboratory, would be a good starting point for learning about the atmosphere. So that was how it all started – basically out of curiosity, shifting from basic science to more applied science – and the rest happened relatively fast.

I was investigating chemicals and reactions which can be found in the atmosphere. CFCs are very stable and were designed to be safe to breathe. It was at this point that my colleague and I realized that these compounds cannot be destroyed through natural processes that commonly break down air pollutants; CFCs would eventually reach the stratosphere, and we knew that at sufficiently high altitudes they would be destroyed by ultraviolet radiation. This destruction mechanism was the logical conclusion, and what was important was not finding out that it happens per se, but whether there would be any consequences. We realized that parts of the molecules that were being broken down would be very reactive – chlorine atoms or free radicals, for example – and we knew from fundamental chemistry that chlorine atoms react rapidly with ozone molecules.

Drawing on my background in fundamental chemistry, I saw that there was potential for the process to be catalytic, meaning that a very small amount of chlorine atoms would be able to destroy a significant amount of ozone molecules. Since that was just a theory at the time, we talked to other colleagues and thought it would be important to work with more researchers to make sure we could test the hypothesis. That's the historical account.

So you came from a background in basic science, moved into an applied field, and discovered something fundamental about life and the planet. How long did it take from you realizing the significance of your results to the moment when they became politically important?
It's hard to tell exactly how long it took, although it was many years. We first checked with other atmospheric chemists and their response was "Sure, it makes a lot of sense," but in the wider scientific community people thought the idea might be exaggerated. We were very careful to publish our results in one of the best-known journals, *Nature*, because as you know to publish in *Nature* or *Science* you have to wait for your research to be reviewed and published before you can put out a press release. The main worry expressed by other scientists was that we just wanted to make noise. We ended up waiting for quite a while for the paper to be published because no reviewers were available. Following publication, the research was gradually accepted by the scientific community, although industry was more reluctant to accept the results.

In the end, we decided that we had a responsibility to communicate the results to the public. That's when we started to talk to the media, decision-makers, politicians, members of the US Congress and so on. That took a considerable length of time. We found that the best way to speed up the process was to get the US National Academy of Sciences involved. They published a couple of stories indicating that our work was in fact scientifically sound and the results were worrying, which made people pay attention. The US Congress started considering the idea of banning the use of CFCs in spray cans – their main application was as a propellant for aerosol hairspray, cleaning products and so on. And of course they were used as refrigerants, because they were significantly safer than ammonia or sulfur dioxide.

Next, we had to take on manufacturers. Fortunately, there were only five or six major chemical companies producing these chemicals, and we were able to

talk to them. Initially they said they would not stop making CFCs based on just our theory. DuPont in particular had a tradition of research – not our type of research, but development of materials such as Teflon. They said that if the science were to be confirmed, they would halt manufacturing. When we were able to reproduce our results, they said "OK, you're right, we will stop making these compounds." By then they had already started investigating other compounds that could replace CFCs as propellants and refrigerants and that would not reach the stratosphere. This allowed them to make the switch, but the process took at least a decade.

Was it frustrating?

It was, because even the press had accepted our results by then. It took a long time for the United Nations to look at the problem and to begin preparing an international agreement to do something about it, so although things were happening, they were slow. Then the Antarctic ozone hole was discovered; we had not predicted that, so that accelerated the response. At the beginning, even the scientific community said, "Wow, that's a spectacular phenomenon, and it's not clear that it has anything to do with CFCs!" However, accurate measurements revealed that the ozone hole over the Antarctic was definitely caused by chlorine from CFCs. This speeded things up again, resulting in the drafting of the Montreal Protocol, which was instrumental in solving the problem.

Did you have any regrets about how you managed to communicate the science?

Only towards the beginning. The aerosol industry in particular claimed we were exaggerating the problem as a way of getting publicity, but it was actually surprising that most scientists and industries believed us. We were much luckier than, say, with climate change, which became very politicized very quickly. Part of the reason was that we were dealing with a small number of fairly responsible chemical manufacturers which accepted our research. In contrast, with climate change you are dealing with huge numbers of industries and political groups; it has become a matter of politics, especially with the Republicans in the US. CFCs were a more minor issue, which made it easier to solve. The story is an example of societies coming together to solve a global problem. But one similarity between CFCs and climate change is that it doesn't matter which country the emissions come from – all countries need to work together.

There's a difference between the hole in the ozone layer and climate change in terms of perceptions, though. Climate is something we all experience every day, and the ozone hole is not. How do you think the danger of this really huge planet-wide problem we are facing should be communicated?

I believe that we in the scientific community have not done a good job in communicating the issue to the public. Some of it has been conveyed by groups which are not scientists but environmentalists, and some points may have been exaggerated. The most important thing is that there has been a very strong response, driven by politics, from people we call deniers – people who don't trust science. And to us in the scientific community that's totally unacceptable. Of course, we acknowledge that there are uncertainties in science, because climate is a complex system. The accuracy of our projections of the future depends very much on how society responds. We can still talk about probabilities and risks, but to the scientific community it is totally unacceptable to deny the science itself. Unfortunately, for political reasons the Republican Party in the United States has been against government interference in industrial or commercial activities, feeling that the Democrats seek too much intervention of this sort. But then with the Tea Party movement, the question became to be seen as a matter of belief, and that's completely irrational.

I could draw an analogy with vaccines. Humans are also complex systems, and the original development of vaccines wasn't perfect. However, science has evolved, and documenting and measuring outcomes makes it very clear that vaccines have saved many lives of young children who would otherwise get infectious diseases. That's well established. But this has also become politicized; there are groups which believe scientists shouldn't interfere with nature, and this extends to vaccines. This happened with the Republicans and climate change at the level of US policy, and to us it is completely unacceptable and absurd. It shows ignorance of science, even though science has had an enormous impact on our lives and life expectancy has more than doubled over the years. Obviously science has changed the way we live and has improved our quality of life – scientific progress has resulted in the development of technologies such as the cell phones which we all use every day – so it's absurd not to trust science or to think that science is all about politics. That comes from ignorance. But unfortunately, that's the way things are developing in the United States with the Republican Party. We work with some Republicans and they understand there are limits to what they can say due to the political implications, but the most extreme case is President Trump who just ignores the science because of his beliefs.

We have the same problem in Poland.

And that's total nonsense. We should be able to explain that this is nonsense, driven by irrationality, and that science is rooted in the scientific method, in evidence. Evidence comes from scientists being able to

reliably reproduce results. When an apple falls from a tree, it's not that sometimes it falls and sometimes it doesn't; it happens every time. That's why we trust airplanes to fly across oceans from Europe to the States: we know they are extremely safe because the science is reproducible. That's why this stance makes no sense to scientists; it's pure politics.

There is obviously some sociology behind this, and I try to understand it. Some people's income depends on not believing climate change, for example. It has such an important influence on their mentality that maybe they honestly end up believing climate change is not real. We can invoke psychology to show they are exhibiting irrational behavior. This shouldn't be the case for the US President, but unfortunately it is.

Do you have any idea how to inspire scientists to disseminate information and how to make this information more accessible to the general public?
First let me give you a historical precedent. When we discovered the problem of CFCs, it was generally believed that communicating research results to the public was not the duty of the scientific community; it should be done by somebody else. But as society has changed and come to face new challenges, it is now widely accepted that scientists have a responsibility to the public. We believe that that's also very important in education. College students have to be taught not just what science is and how it works; we believe it is important to teach scientists and engineers ethical and social components as well. And the way to do that is not by teaching them more subjects, but by having them engage with real problems facing society. We have had some very good experiences at MIT and in Mexico with students responding very positively to such teaching. We think that's the way for society to advance, and we have high hopes that younger people are becoming more responsible for ethical reasons. That's why we invest in elementary education, even though it's not an investment which produces instant results – it takes decades for it to show economic improvement. It is a matter of social responsibility. In the long run, it is about education, but we also have to do something on a shorter scale. We have to become better communicators, and we have managed to get some groups of scientists to work with us on publishing reports. I work with the American Association for the Advancement of Science (AAAS), which publishes the journal *Science*, and together we produced a report on climate change. But we have to do more. It's not just a matter of putting out publications; we have to communicate with politicians as well. And I think we should be able to do a better job in the coming years.

> As society has changed and come to face new challenges, it is now widely accepted that scientists have a responsibility to the public.

Politicians want to improve the way science and technology are transferred to industry and the economy. But we also have a problem with transferring science to politics?
It's essential for governments to realize that investment in science and innovation is crucial. In particular, applied science is very important for developing countries. On the other hand, the national academies have established very clearly that besides applied science you also need to fund fundamental science because that way you get excellent educators and professors who communicate how science and research should be taught to their students. So, you cannot draw a line between applied and fundamental science, you have to fund both; it's a matter of culture.

The story of your research is fascinating. Your natural curiosity helped you solve a major problem faced by society which we never recognized before. So, it's not just an issue of scientific progress, but also one of protecting our planet and ensuring humankind's wellbeing.
I am lucky in that I have been able to become friends with many Nobel Prize winners over the years. Let me tell you a story. When I first went to Berkeley as a student, I found it extremely crowded and it was very hard to find a parking space on campus. There were some free spaces marked with name plaques, one of the names being Charles Townes. I thought, "Who the hell is that?" When I met him at his lab later, I realized he was allocated his own parking spot because he was a Nobel Prize winner. We went on to become very good friends as we were both members of the Pontifical Academy of Sciences. He passed away a few years ago, aged 99. I remember clearly people in meetings asking him what he'd won his Nobel Prize for, and he would simply answer, "Oh, the laser." He was very humble, even though the laser is an incredibly important piece of fundamental science. It was first postulated by Einstein, and I used Einstein's laser equations in my PhD. This is an example of very fundamental science which has made its way to the mainstream – lasers are all around us, as they are used in CD players and pointers and so on. They are very common now, but the technology took a long time to investigate and demonstrate. The first laser was highly complicated in comparison with those we use now. And science is

full of such examples. When quantum mechanics was first developed, it appeared to be too complex for any practical applications, but it is now an essential component of solid state physics, chemistry, etc.

That's right – it is used in cellphones and so on.
There are so many applications. From an economist's perspective, countries that invest a certain proportion of their GDP in fundamental science are more successful – it benefits their economy. In Mexico we invest too little, only 0.5% of our GDP.

That's exactly the same situation as here in Poland.
That's right. And scientists have to say, "Look, I know this will take a while to convert into tangible benefits, but it's a really good investment and we should get started as soon as possible." The economy in Mexico has been struggling, so this investment is being postponed, and there is not enough pressure from scientists. But you're absolutely right – we have to improve how we communicate the importance of funding for fundamental research.

Let me ask you a different question. As you already mentioned, you are a member of the Pontifical Academy of Sciences. The Academy has had some influence on Pope Francis' highly influential "Laudato si'" encyclical, in which he calls for "swift and unified global action" on issues including climate change. How were you able to impart your scientific knowledge not to a political body but to this very different kind of community?
The Pontifical Academy of Sciences in the Vatican comprises around 50 scientists, most of whom are not themselves Catholic. It's an international body of scientists. We have been working hard and have succeeded in bringing various religious groups up to date with important scientific works, such as those of Galileo and so on – it only accepted them relatively recently. We were able to push further to a positive response, and we knew early on that it's important for the Catholic Church to understand climate change. We were worried initially, because there were a few high-level leaders inside the Church who doubt climate change, but we decided we would try anyhow. We were greatly helped by Marcelo Sánchez Sorondo from Argentina, Chancellor of the Pontifical Academy; he heads the group communicating with the public and the Pope, and he is a wonderful man. We were very lucky in that the Pope wrote his very strong encyclical which supports scientific consensus instead of climate change deniers. It's clear that the Pope realized this is important for the benefit of all of humanity.

Here at the Climate Change Conference in Katowice we held a meeting organized by the Polish Academy of Sciences and the Pontifical Academy of Sciences. The Pontifical Academy has written reports based on the latest scientific understanding, stressing that religion doesn't have to be in conflict with science. I have past experience working with religious groups; when I was a professor at MIT, I was involved with various religious groups at Harvard, mainly their medical school because MIT doesn't have one, and with the Public Institute of Health. Our work on climate change is a great example of the scientific community working with religious groups. But on the flip side, we have yet to learn how to work with the Republican Party in the US. That's only beginning to happen, but yes, it can be done.

It's surprising that even though the Republicans were responsible for the original environmental-protection legislation, they are now reversing their position. Since their views are largely conservative, it should follow that they should be interested in conservation of the environment, of nature.
We worked closely with former Republicans, with William Riley, with George Shultz. Even President Nixon was very much in favor of environmental protection. But these Republican collegues have a problem communicating with the current Republican leadership. That's finally beginning to change – not with President Trump, unfortunately, but within the Republican Party.

So you hope they can pass on this information to conservatives.
Yes, that's right. In some extreme cases, certain Republicans have narrow "religious" views; I am talking about creationists who believe that according to the Bible, creation literally happened in five days. The Catholic Church doesn't believe that, nor do most Protestants, but certain Republicans are extremely narrow minded, and they are in Congress. Unfortunately they are hopeless cases.

We come back to the problem of communication between science and politics. What else would you like to share with the readers of *Academia* magazine?
The most important message is that I believe in rationality. I believe we should be able to convince society that climate change is real. But it's also very important for the scientific community to develop social responsibility and to communicate to society that making fundamental changes in how we interact with the environment benefits all humankind. That's our goal: to make sure that what we do is for the benefit of all people, not just certain groups.

Interview by **Prof. Szymon Malinowski**
Photography by **Jakub Ostałowski**

EKAMELEV/WWW.PIXABAY.COM

DR. FRANCK COURCHAMP

Eating Biodiversity

Dr. Franck Courchamp of France's National Center for Scientific Research (CNRS) explains why a reduction in meat consumption would be good for everyone, lists the catastrophic consequences of biological invasions, and suggests what could be done to protect giraffes.

ACADEMIA: **What research question is currently keeping you awake at night?**
FRANCK COURCHAMP: It's difficult to say, because I work on many different topics at the same time and conduct many projects. I'm now recruiting six master's students, each will be working on a different topic. But biological invasions are the leading topic for me. I'm trying to predict biological invasions based on global scenarios for climate change. This poses a gigantic environmental problem, the most serious one, only closely behind habitat destruction. It's even more important than pollution. It's linked to the death of many people, because invasive species carry different viruses and parasites. That's a very important topic, but we don't have tools at our disposal that would allow us to prepare for the consequences.

Why are such invasions dangerous?
If a species is introduced and spreads into a new region, it can cause enormous damage, because the ecosystem isn't prepared for its presence. There may be no predators or parasites that control it. So it can take over the entire ecosystem and cause damage in a biologically uncontrollable way. There are plenty of such species all over the world, starting from microbes, through plants, marine and terrestrial species, insects, birds, mammals... In each country, there are hundreds of invasive species, and this poses a major problem for ecology, economies, and human health. Climate change has a huge impact on the distribution of invasive species. For example, insects are cold-blooded animals and therefore highly dependent on climate. Currently, winters in Europe are too cold for many species, so they can't stay for the whole year, but as winters get warmer, they gradually become more established, year after year, and invade new territories, which were previously inaccessible.

Could we compare this phenomenon to climate-induced human migrations?
In this field it is very hazardous to compare biological invasions by plants and animals, which are ecological processes, to human population movements, for several reasons but primarily because of the xenophobic connotations. There is no reason to fear human migrations, unless of course they are from conquering armies, but there are plenty of reasons to fear biological invasions, because by definition these species are ones that are introduced into new ecosystems by human activities and cause ecological and economic damage. Not all introduced species pose a threat, in fact a low percentage do, but given that there are now so many such introductions with global trade, the end result is many biological invasions and much impact.

But invasive species could be also dangerous to humans, right?
Yes, in many different ways at that. First of all, they cause sanitary problems. Let's take mosquitoes, for example. The tiger mosquito transmits around thirty different viruses and therefore poses a direct danger to humans. But there's also damage that is done to economies. For example, many insects eat crops or

agricultural products. This means gigantic costs for societies – if a large portion of crops is destroyed by invasive species, people will have to pay a lot more to buy food in stores. Our recent research showed that invasive insects cost the world over 70 billion dollars annually.

> The situation of wild species like giraffes and lions is dramatic. They are threatened by extinction, but people don't realise it because images of them are everywhere. That's paradoxical, because these are the animals we love most.

Do insects form the largest group of invasive species?

Yes, they are very problematic, but we also have problems with larger animals as well as plants and microorganisms, such as fungi – they could have a gigantic impact on the destruction of crops. In France, we have recently observed many flatworms that come from tropical regions. More and more fish species are attacking other fish, causing enormous losses for humans and ecosystems.

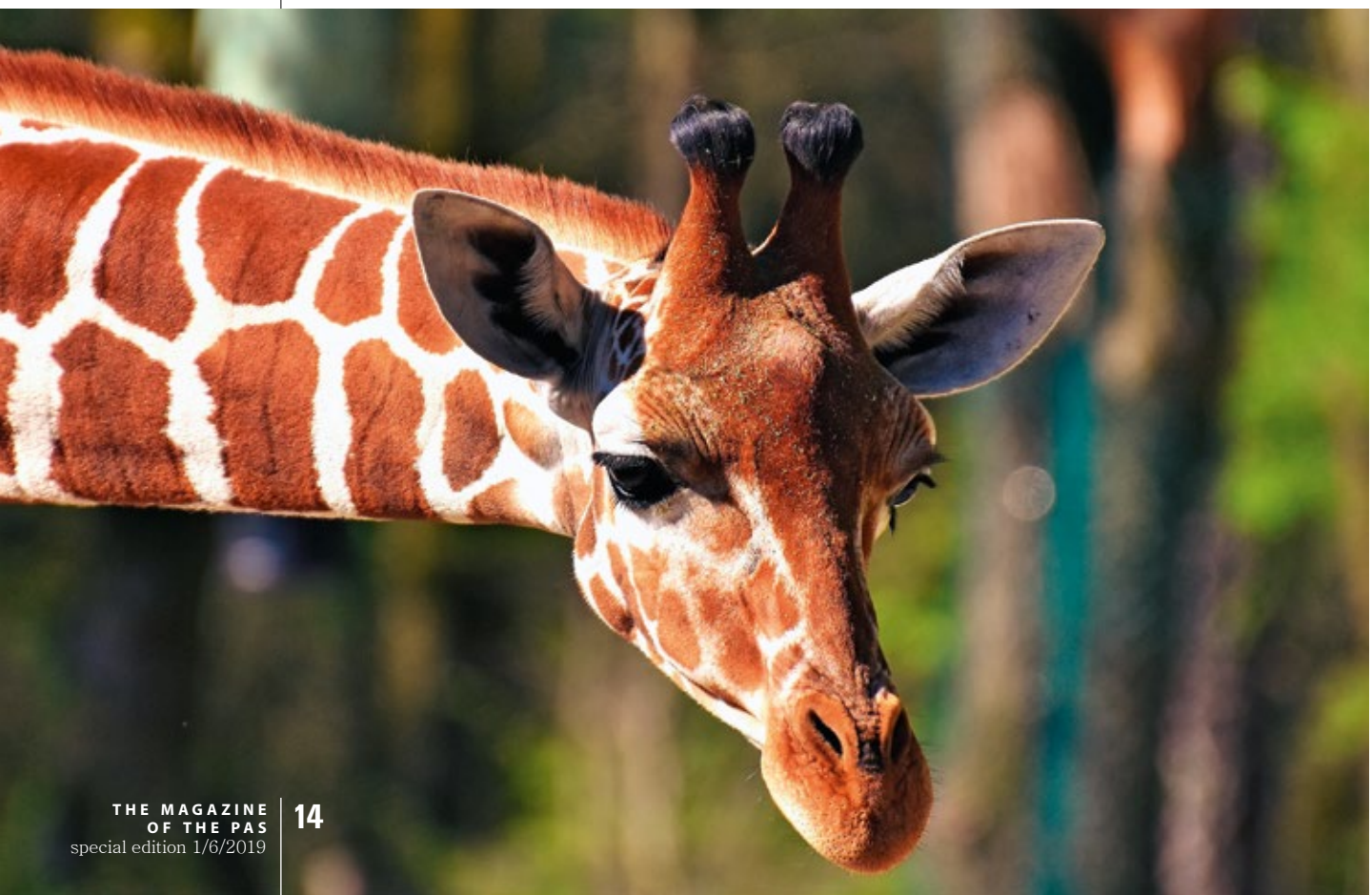
I'm currently trying to establish the costs of the introduction of all invasive species for people and economies. We have difficulty attracting the attention of politicians as decision-makers to this topic. People are aware of climate change, the exploitation of animals, and pollution, but biological invasions are the worst. We must do something to increase awareness of this issue, especially among the public and decision makers. In order to do so, we must measure the scale of the problem and add the financial aspect. And the amounts are staggering!

What do you mean?

I can't reveal that yet, because we're about to publish an article in *Nature*. I suspect this will cause a stir in the media, because these are really mind-blowing amounts.

All the things you are talking about sound terrifying. Are you working on any topics that are more optimistic?

No. That's because this is really a disastrous period for biodiversity. I've just submitted a paper in which I list megafauna species, or large animals, that are threatened. We have demonstrated that 70% of all large animals, which means 200 species, are declining, and 59% are threatened by extinction. This situation is largely caused by the fact that we eat them. We're eating bio-



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DR. FRANCK COURCHAMP

Dr. Franck Courchamp

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diversity, which means large fish, turtles, mammals. There's only one bird among the large animals, namely the ostrich, and people also eat this species, both the meat and eggs. That's very sad. We depend on biodiversity, and people don't even realize that.

Would it be better if we only ate farm animals?

No, it would be better if we ate meat only three or four times a week. By nature, we're omnivorous, not herbivorous, but this doesn't mean that we need to eat meat two or three times a day. When agriculture was developing in Europe after World War II, governments encouraged people to eat meat. So, this is now a very strong habit. People think that if there's no meat in a meal, it is not fully nutritious. If you tell parents that children will get some vegetarian meals at school, they will worry that their kids will be hungry or have nutrition deficiencies. We've completely overlooked the fact that they should not eat meat every day, because that's simply bad for health. We know many diseases that follow from the excessive consumption of meat. In addition, reducing meat consumption would be hugely beneficial for the environment.

You're also involved in science popularization and environmental protection. Have you noticed any changes in people's awareness, in societies?

I can definitely see positive changes. People are increasingly aware, there are more and more environmentally friendly products in stores, for example ready vegetarian meals, which were not there two years ago. Also, more and more people are trying to reduce meat consumption. I've recently talked to a person that was not linked to environmental protection in any way. That person told me that she and her colleagues at work talk about that, try to change their habits. It seems to me that this is a general trend. I think that's one of many positive aspects of science popularization.

Are such changes visible only in the capital or also in towns and rural areas?

Ecological-friendly products, for example mock meat or meat substitutes, are now available in chain stores in the whole of France. I see that as an example of changes that are taking place in the whole of the country.

You're also studying population dynamics. What does this area involve specificity?

It's about relations between species, for example a predator and its prey. In this case, their population sizes are mutually dependent. If there are more prey, there will be more predators because they will be well fed and will reproduce more. In turn, that will increase predation and therefore cause a drop in the prey population. And if the prey population declines rapidly, there will be fewer predators, too, because they will die of hunger. The same holds true for host-parasite relationships, competitive relationships, and so on. Population numbers are interlinked with those of other species, forming complex patterns that we try to understand and predict.

However, at present I'm mainly studying the population dynamics of species in the context of conservation biology. For example, I want to know why a specific population is declining and what we can do to stop this process. Unfortunately, such phenomena are usually anthropogenic, which means that I study the influence of human activity on biodiversity.

I'm also involved in a project on how people perceive charismatic species such as lions and elephants. I'm checking if this helps in their conservation. For this type of studies, we sometimes work together with psychologists. I have created a list of the most charismatic wild animal species. Most of them are threatened by extinction. That's paradoxical, because these are the animals we love most. The situation of giraffes and lions is dramatic, but we've hypothesized that people don't realize that, because images of those animals are everywhere – in company logos, on cereal boxes, T-shirts. For this reason, people have a biased perception of the size of their populations. Several months ago, we suggested that companies that use the images of such threatened animals should pay for copyrights, and the money could be allotted to the protection of those species. Maybe something like this could be done.

INTERVIEW BY **JUSTYNA ORŁOWSKA**

A Story of Growth

The transition to a zero-carbon economy is the inclusive growth story of the twenty-first century. It needs to be managed with effective and cohesive policies, whilst recognizing that sustainable development, inclusive growth and climate action are interwoven and mutually supportive.

JAKUB OSTAŁOWSKI

This photograph shows a sight panelists were actually confronted with when leaving the building where the climate symposium took place.

PROF. NICHOLAS STERN

Prof. Nicholas Stern

London School of Economics

The latest Intergovernmental Panel on Climate Change (IPCC) Special Report regarding a 1.5°C increase in average global surface temperature (measured against the conventional benchmark, as of the end of the 19th century) re-emphasizes the urgency of strong action on climate change. The report highlights the immense dangers to lives, livelihoods, ecosystems and the global economy if there is further delay. Action is intensely urgent and must be on a large scale.

Current global greenhouse gas (GHG) emissions are around 50 GtCO2e per annum (50 billion tonnes of carbon dioxide equivalent – which includes other GHGs in addition to CO_2, including energy, industry and land use). While there have been some signs of a plateauing of annual emissions in recent years there were worrying increases recorded in 2016, 2017 and projected for 2018. Rates of increase in GHG emissions have been slowing, but the trajectory is still in the wrong direction. The slowing rate of increase is being led by a plateau in GHG emissions in China and decreases in the European Union and the United States. However, GHG emissions in other countries continue to increase, including in many developing nations.

The focus should now be on recognizing the consequences of inaction and realizing the opportunities of inclusive growth.

While we may be close to a plateau (with some "bouncing around"), the overall window for making the right choices is shrinking, and the need to peak and decline becomes ever more urgent. If the world is to have a 50% chance of meeting a 1.5°C target, the IPCC report argues that we have space for only a cumulative 500 $GtCO_2$ (approximately) of further CO_2 emissions. At current emission rates, this space would be exhausted in 10 to 12 years. After this period, the arithmetic says that the total for the world would have to be net-zero emissions; since there would likely be very few significant negatives, that would mean effectively net-zero for all countries.

If GHG emissions were to decline along a smoother downward trajectory, the world would have to reach net-zero emissions by around 2050 to remain within the allowed space. For a 2°C target temperature, the allowed space would be around 800 $GtCO_2$, or about 20 years of emissions at current rates. If emissions peak in the next few years and then steadily decline, the world would need to achieve net zero around 50 years from now. The more the world delays in reducing annual GHG emissions and uses up the remaining space, the steeper the required decline becomes later in time. Such delay would also likely require substantial negative total emissions later this century, something which may be technically infeasible or very expensive.

Decisive action is hampered by some unique elements from the science of climate change that make taking collective action difficult. First, the causes of climate change are "public," in that we all contribute to emissions; second, consequences are uncertain; third, they appear with lags; fourth, many of the consequences could be way out of human experience. People are generally not very good at handling any one of these problems, let alone all of them simultaneously. Given this circumstance, it is striking that there is a widespread readiness to act.

Current GHG concentrations in the atmosphere are already on the edge of the experience of Homo sapiens. Likely future concentrations will be at levels not seen for millions of years. The impacts could redefine where people can live and work. Poor people are likely to be hit earliest and hardest. We are currently on track for 3°C or more, temperatures not seen for three million years or more. That would likely involve hundreds of millions, or billions, of people having to move with major risk of severe and extended conflict. The stakes for lives and livelihoods are immense.

The "costs of action"

The notion of "costs of action" is being rapidly transformed by major technological advances, offering hope and optimism for the future. Action, investment and innovation across the world have rapidly lowered the costs of alternative energy sources. Solar PV and battery prices have both fallen by nearly 80% since 2010. These decreases have already made power generation with renewables (including storage) competitive with fossil fuels (without subsidy or carbon tax) in many parts of the world. The world has seen rapid

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increase in installed renewable capacity and the costs continue to fall.

Road transport is being transformed and we can see the end of the era of the internal combustion engine within the next two or three decades. Zero-carbon electricity will power the electric vehicles of the future. Hydrogen, created in a zero-carbon way, is also likely to play a strong role.

Digital advances have and will transform the efficiency and productivity of our power and other systems, including cities. The Internet of Things and the circular economy will transform efficiency across the economy.

Recent reports have also shown that it is now technically possible to cost-effectively reduce GHG emissions in sectors previously thought to be considered as difficult; including cement, steel, plastics, shipping and air transport (see the work of the Energy Transition Commission). Using a combination of existing technologies, including prioritizing energy efficiency and electrification where possible, combined with carbon capture and storage (CCS), where necessary, industrial sectors could reduce emissions across the economy to net-zero by mid to late century.

It is remarkable that so much of this progress has been made in the last 10–15 years (remember that the iPhone was released in 2007). There is so much more discovery to come. This progress has occurred with only a broad sense of direction and with fairly mediocre policies. We could do so much more, and more quickly with stronger commitment and better policies.

These new technologies and actions have also demonstrated that it is possible to de-couple economic growth and development from GHG emissions. Indeed, the story is stronger than "de-coupling." Discoveries, innovations and investment are now drivers of growth. It is a form of growth that is not only strong and sustainable but also inclusive. Evidence from the UK, EU and the USA all point in this direction (see the work of the New Climate Economy). The understanding has, in large measure, moved on from 'costs of action'; rather, focus should now be placed upon recognizing the consequences and costs of inaction, together with realizing the opportunities and benefits of the inclusive growth story of the twenty-first century.

Opportunities of coming decades

If global growth continues at around 3% a year, global output will double in 20 years or so. Alongside this growth, the urban population will approximately double in 40 years and the urban area in the next two to three decades. During the next two decades, cumulative investment in infrastructure will likely more than double the existing stock, to enable and support this growth and manage urbanization. The future of our towns and cities will be shaped in the next twenty years.

Most of the growth and investment in new infrastructure will be in developing countries. How we manage these doublings will determine the future of our world. We can either lock in high-carbon and polluting investments, putting ourselves and our descendants in great danger, or we can set off in a new and very attractive direction.

To meet the Paris climate change targets of "well-below 2°C," GHG emissions will have to decrease by 25% by 2030 and reach net zero around 50 years from now. For 1.5°C targets, GHG emissions will have to fall by around 45% by 2030, and reach net-zero by mid-century.

If our growth and investment follow the past and current models, then reaching the Paris Agreement targets will be near impossible. The choices made now, particularly on infrastructure and urban design, could make 3°C or 4°C and their terrible consequences very likely.

To reach the Paris goals, strong action in the five key sectors of energy, cities, food and land use, water and industry will be key (see the work of the New Climate Economy, 2018). In all of these sectors the main focus must be on investing in sustainable infrastructure. Sustainability means giving future generations opportunities at least as good as those we had, assuming they behave in a similar way to their successors.

That involves investing "wisely" in all the relevant forms of capital: physical, human, natural and social. Sustainable infrastructure, and investment in all these types of capital, are at the heart of reaching the whole set of Sustainable Development Goals (SDGs), including those on climate.

Sustainable development, inclusive growth and climate action are interwoven and mutually supportive. There is no horse-race between them.

Managing the transition cohesively

The deep structural and systemic change required for the zero-carbon transition will come with disruptions to some existing industries and livelihoods. This transition will also occur following, and during a period of other large changes and disruptions to economic structures, over many decades, past and future. These include: increasing shifts to service-based economies; labor-saving technologies (with robotics and artificial intelligence moving quickly); and increased globalization. At the same time we need to deal with the consequences of past economic shocks including the impacts of the recent global financial crisis. Persistent global inequality adds to the challenges.

Sustainable development, inclusive growth and climate action are interwoven and mutually supportive. There is no horse-race between them.

All of these processes have to be managed together; how they are managed will be central to building support for strong, sustainable action on climate change. The tools and finance are available now. A just and inclusive transition is, in large measure, about investing in people and bringing employment opportunities to them.

Designing public policy

The necessary urgency and scale of action make it very clear that climate policy is not about incremental initiatives that can be attached to existing development plans; it requires deep structural and systemic change, implemented over many decades, starting strongly now. Seizing this opportunity requires radical change; much of what we currently do will have to be done differently.

On policy we must recognize that there are multiple market failures that limit or distort investment and activities more generally beyond the fundamental externality associated with the emission of GHGs. To overcome these failures we must use a collection of different, but mutually reinforcing, instruments. Policies should stretch across the pricing of negative externalities, in particular GHG emissions, removal of fossil fuel subsidies, supporting research and development, managing key networks (power grids, transport…), providing increased information to consumers and producers, managing risk in capital markets and developing systems to value non-market rewards, including reduction in air pollution. The quantity and quality of investment will be determined by the soundness of policy and of government signals.

The collection of policies should both send long-term signals to all players but also be "predictably flexible." That is, policies should include clear, transparent mechanisms and processes for review and revision. The overall set of policies and strategies should provide clarity and confidence on the long-term direction. For example, policies to encourage new technologies could be phased out as diffusion and cost-reduction take place, but the criteria that guide review and revision should be set out ex ante.

Finance for these investments can come from the mobilization of domestic public revenue, private investment (both national and international), development banks, and concessional finance or overseas development assistance (ODA) (in the case of developing countries). We have to use all sources, targeted to where they are most effective. Bringing down the cost of capital, through reducing policy related risk and the management of risk, is essential.

If these policies and finance are managed well, then the consequential investments in the new economy will generate large and long-term benefits. Much of this investment will be focused on sustainable infrastructure. Such investment would, in the shorter term, boost demand and sharpen supply, create new opportunities, and contribute strongly to growth and reducing poverty. In the medium term this would unleash a wave of innovation, creativity, unlock new markets and employment opportunities, and drive growth forward. We are already seeing this process moving strongly. This new path is the only feasibly long-term option; any attempt at high-carbon growth over the longer term will self-destruct through the devastating impacts on our climate and environment.

The transition to a zero-carbon economy is the growth story of the twenty-first century. Analysis suggests (New Climate Economy, 2018) that, if this path is followed, by 2030 it is possible to generate over

65 million new jobs, and to avoid 700,000 premature deaths, as a result of reduced air pollution. This is in addition to the immense economic and social benefits of protecting lives and livelihoods in the future by avoiding the worst impacts of climate change.

Multilateral institutions are critical

We have some important favorable conditions which can help foster the change necessary. Political direction has been provided by international agreements and commitments, particularly the Paris climate agreement of December 2015 and the adoption of the Sustainable Development Goals at the UN in September 2015. Rapid technological change and falls in costs have provided the evidence that the new growth path is feasible and attractive. And the falls in costs and arrivals of technologies are likely still in the early stages. Further, we are in a period of historically low real interest rates which is likely to continue for some time. Notwithstanding these favorable conditions we are moving far too slowly.

The necessary acceleration of the transition to zero-carbon growth will require strong action at the country level and collaboration and cooperation across the world. International institutions are key players in both shaping and delivering this agenda, with the multilateral development banks (MDBs) of special importance. The MDBs are central to the generation of the necessary flows of sustainable financing, but are also key enablers of learning and cooperation between countries and can help foster the sound and credible policies necessary to incentivize investment and manage risk.

The MDBs, however, must expand and reform if they are to perform their role in delivering on this crucial challenge. This will require not only additional financial contributions from shareholders, but also reform to operations to work more cohesively and raise the priority of sustainability still further. Part of this will be the joint creation, led by countries themselves, of in-country platforms for investment and cooperation.

The bulk of the finance for the necessary investment will come from the private sector. Government-induced policy risk is the biggest deterrent to private sector investment and finance worldwide. Bringing down the cost of capital, through reducing and managing risk, is essential and can be achieved with sound policies and institutions and stronger development banks, both national and multilateral. The MDBs have a set of financial tools, including guarantees, that can help reduce risks and their involvement in a program itself reduces risk. But key to success will be the presence of a set of long-term, clear, coherent and credible public policies that guide markets and capital. The MDBs and national development institutions can play a powerful catalytic and multiplicative role. Working together national governments and MDBs could play a critical role in mobilizing the "trillions" needed.

Powerful and continuing declines in renewable energy costs, and increasing roll out, including solar PV and wind, are critical examples of how a sense of direction and public policy, combined with global collaboration, and innovative financing can support rapid change. And the strong changes we have seen have followed from modest commitment and policies; much more could be achieved with a greater sense of purpose and urgency and clearer and stronger policies.

Decisions will determine the trajectory

The current nationally determined contributions (NDCs) submitted under the Paris Agreement put us on a high-carbon growth path, likely to result in 3°C of warming or more by the end of the century. At such temperature increases the world would likely experience catastrophic impacts, ranging from extreme weather events, to desertification, to inundation, to sea-level rise, to intolerable heat and so on. Together they would redefine where people could live, work and be productive.

These impacts would damage or destroy lives, property, infrastructure, and undermine economies and societies, reversing growth and development and pushing large numbers of vulnerable people into poverty. The impacts could also lead to hundreds of millions or billions of people moving, and could lead to large-scale, severe and extended conflict.

The task of the twenty-fourth meeting of the Congress of the Parties meeting in Poland in 2018 was to set the rules for how all countries report and measure climate action and thus help in the ramping up of ambitions under the Paris climate change agreement. The actual commitments to increase ambition will be made in 2020. These two years will be a critical period. The investments in the next two decades are decisive, and the decisions of 2020, in large measure, will determine whether change on the urgency and scale necessary will be realized.

The choices made on infrastructure and capital now will either lock us in to high emissions, or set us on a path to net-zero emissions which will embody strong sustainable and inclusive growth. There is a new way to growth and development that we can now see; and it is highly attractive. We have begun; we have momentum. But the scale and rate we need requires much stronger commitment and action, starting now.

Nicholas Stern

Further reading:

Energy Transitions Commission (2018). *Mission Possible*. Available at: http://www.energy-transitions.org/mission-possible

New Climate Economy (2018). *Unlocking the Inclusive Growth Story of the 21st Century: Accelerating Climate Action in Urgent Times*. September 2018.

Every Half a Degree Matters

Key messages from the IPCC Special Report on Global Warming of 1.5°C


DR. VALÉRIE MASSON-DELMOTTE

Valérie Masson-Delmotte

Co-Chair, IPCC Working Group I for the Sixth Assessment Cycle

- Climate change is already affecting people, ecosystems and livelihoods all around the world.
- In terms of climate-related risks, there are clear benefits to keeping warming to 1.5°C compared to 2°C, or higher. Every half a degree matters.
- Limiting warming to 1.5°C is not impossible but would require unprecedented transitions in all aspects of society. Every year matters.
- Limiting warming to 1.5°C can go hand-in-hand with achieving other world goals, such as achieving sustainable developments and eradicating poverty. Every choice matters.

Context

This IPCC Special Report has been prepared in response to an invitation by governments, through the Decision of COP21 of the United Nation Framework Convention on Climate Change in December 2015. This request arose out of the concerns of about 100 countries that the long-term goal of the Paris Agreement, keeping global warming to well below 2°C above pre-industrial levels, may not be sufficient to prevent dangerous climate change, and from the lack of scientific knowledge on differences in impacts for 1.5°C and 2°C of global warming, and differences in compatible greenhouse gas emission pathways.

The invitation was accepted by the Panel during its spring 2016 Plenary, where government delegates defined the full mandate of this report to be "An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty." The IPCC decision to strongly link the assessment not just to climate change but also to the multiple aspects of sustainability has guided the design of the structure of the report, and shaped novel aspects of the assessment of the state of knowledge, for instance the systematic exploration of synergies and trade-offs between mitigation and adaptation response options, and sustainable development goals.

The enthusiastic response of the international research community to produce and publish timely new knowledge has been instrumental in the new information provided in the report. There has also been extraordinary motivation shown by scientists worldwide to participate in the scoping, preparation and review of the report.

The report has been prepared by 91 authors from 40 countries, with support from 133 contributing authors. They have performed an assessment of about 6,000 scientific, technical and socio-economic publications, 75% of them published in the last 3 years. The IPCC strives to perform assessments of the state of knowledge that are rigorous, exhaustive, transparent and objective. More than 42,000 review comments received by 1,131 reviewers in the three-step review process fully contributed to the quality of the final report.

Where are we?

Since pre-industrial times, approximated in this report as 1850–1900, human activities have caused approximately 1.0°C of global warming, with a *likely* range of 0.8°C to 1.2°C.

We are already seeing the consequences of 1°C of global warming through more extreme weather such as heat waves and heavy rainfall events, rising sea levels and diminishing Arctic sea ice extent, among other changes.

If the world continues to warm at its current rate, at 0.2°C per decade, global mean surface temperature is *likely* to reach 1.5°C between 2030 and 2050.

Although past emissions from pre-industrial times to the present will continue to cause further changes in the climate system and committed future sea level rise, these past emissions alone are *unlikely* to cause global warming of 1.5°C.

There is still a window of opportunity to stabilise global warming to 1.5°C, depending on the pathway of global greenhouse gas emissions and primarily emissions of CO_2 due to the combustion of fossil fuels in the next decade.

Reducing emissions of CO_2 to net zero is key for climate stabilisation, due to the relationship between the level of global warming and cumulative CO_2 emissions. Faster immediate CO_2 emission reductions limit cumulative emissions. The future peak level of warming is determined by cumulative net CO_2 emissions, and by net non-CO_2 radiative forcing (impact on the

Where is the full report?

The full report is available here : www.ipcc.ch/report/sr15. It includes a Summary for Policy Makers, 10 Frequently Asked Questions, a Glossary and 5 chapters.

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Earth's radiative budget) due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents. Reducing the net climate effect of non-CO_2 emissions is also crucial for climate stabilisation.

Where do we want to go?

Global climate models project robust differences in climate between present-day and global warming of 1.5°C, and between 1.5°C and 2°C. In all cases, the intensity of warming is larger over land than oceans, and amplified in the Arctic region.

Changes in precipitation are spatially heterogeneous. Climate models project an increase in annual mean precipitation in cold regions, where a warmer atmosphere can hold more moisture, and a decrease in precipitation in areas with a Mediterranean climate today, due to changes in large-scale atmospheric circulation. The projections of reduced annual precipitation amounts for each additional 0.5°C of warming are particularly clear around the Mediterranean Sea, in South Europe, the Middle East, and North Africa.

Climate models also project a marked increase in the number of hot days, especially in tropical areas, an increase in the temperature of hottest days, especially over land areas, and in the temperature of coldest nights, especially in north Europe and around the Arctic region. In several regions, climate models project an increase in the severity of heavy rainfall events, and an increase in the probability of drought.

Regional climate change hotspots have been identified, and they are projected to intensify with the level of global warming. These regions include the Arctic sea-ice and land areas, with losses of habitats for specific species and biome shifts; Alpine regions, with biome shifts; the Mediterranean area, with increased risks of extreme drought, runoff decrease and water deficit; the tropics, with increases in heat waves and risks for livestock heat stress and human health, key crop yields, and loss of biomass in some rainforests; South East Asia, with increased risk of flooding due to sea level rise and intensification of heavy precipitation, as well as projected crop yield reductions; West Africa and the Sahel, with increased risks associated with heatwaves as well as projected reductions in areas suitable for maize and sorghum production, implying increased under-nutrition risks; Southern Africa, with projected reductions in water availability, heat stress, increased mortality from heat waves, and high risk of under-nutrition for population depending on dryland agriculture and livestock. Small islands are exposed to compound risks of land exposed to inundation, enhanced coastal flooding, freshwater stress, increased number of warm days and persistent heat stress for cattle; and severe degradation of coral reefs and loss of their ecosystem services.

> The pledges that governments have made over the last three years about their mitigation ambitions are not enough to keep warming below 1.5°C.

Based on new evidence, the report has revised upwards climate-related risks for warm water corals, mangroves, small scale low latitude fisheries, terrestrial ecosystems, coastal flooding, fluvial flooding, reduced crop yields, tourism (including snow tourism), and heat related morbidity and mortality for a global warming between 1°C, 1.5°C and 2°C. By 2100, global mean sea level rise would be around 10 cm lower with global warming of 1.5°C compared to 2°C. This would mean up to 10 million fewer people exposed the risk of rising seas, but still around 100 million people facing related adaptation needs.

Loss of biodiversity and species extinction are projected to be lower with global warming of 1.5°C compared to 2°C. Limiting warming to 1.5°C compared with 2°C would mean smaller reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub Saharan Africa, Southeast Asia, and Central and South America. The proportion of the world population exposed to climate-change induced water shortages would be up to 50% less with global warming of 1.5°C compared to 2°C.

Importantly, this special report highlights how all of these things affect people's lives and livelihoods around the world. For example, the impacts of climate change in the ocean are increasing risks to fisheries and livelihoods that depend on them. Limiting global warming to 1.5°C compared to 2°C could reduce the number of people exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050. It would imply lower risks for health, livelihoods, food security, water supply, human security and economic growth, especially in tropical regions. At 1.5°C of global warming, disproportionately high risk is identified for Arctic, dryland regions, small-island developing states and the least developed countries.

A wide range of adaptation options can reduce climate risks, if implemented. Adaptation needs are less at 1.5°C compared to 2°C. There is a lack of scientific knowledge about the costs of adaptation, and about the costs of losses and damage when adaptation limits are exceeded.

To limit global warming to 1.5°C, global emissions of carbon dioxide would need to reach "net zero" around 2050. This means that any remaining emissions would need to be balanced by removing carbon dioxide from the air.

How to get there?

The trajectories of greenhouse gases compatible with limiting warming at 1.5°C and 2°C are diagnosed from a database of published emission pathways, in open access for transparency and traceability (https://data.ene.iiasa.ac.at/iamc-1.5c-explorer).

Limiting global warming to 1.5° implies reducing emissions of carbon dioxide by about 50% by 2030, compared to 2010 levels. For comparison, in most pathways that limit global warming to below 2°C, carbon dioxide emissions decline by about 25% by 2030

To limit global warming to 1.5°C, global emissions of carbon dioxide would need to reach "net zero" around 2050. This means that any remaining emissions would need to be balanced by removing carbon dioxide from the air. For comparison, pathways that limit global warming to 2°C reach net zero around 2070.

As part of limiting warming to 1.5°C, reducing emissions of substances other than carbon dioxide such as methane and black carbon would improve air quality and have direct and immediate health benefits. Pathways compatible with climate stabilisation to 1.5°C without any overshoot have CO_2 emissions decrease in the next decade. Pathways with delayed reduction in CO2 emissions, starting at the end of this decade, imply the large-scale deployment of negative CO_2 emissions in the second part of this century.

Limiting warming to 1.5°C implies rapid, far-reaching and unprecedented changes in all systems (energy; land, including agriculture, forestry and food systems; urban, including changes in urban planning practices; industrial; and infrastructure). It means deep emission reductions in all sectors, the use of a wide range of technologies, behavioural changes, and a 5- to 6-fold increase in investment in low carbon options by 2050. The use of coal declines steeply in all pathways. Rapid progress is already being made in some areas, notably renewable energy. This progress would need to be picked up in other sectors such as transport and land management.

There are many different 1.5°C-consistent pathways, with different near-term patterns in the reduction of emissions of CO_2 from fossil fuels and industry (with small residual emissions after around 2050), major shifts from agriculture, forestry and land use carbon fluxes (reaching either neutrality or net negative emissions after around 2050), and various scales of deployment of bioenergy with carbon capture and storage.

To limit warming to 1.5°C, we would need to start taking carbon dioxide out of the atmosphere during the 21st century. Methods for doing this include: planting trees; bioenergy combined with carbon dioxide capture and storage; rehabilitation of degraded ecosystems; changed land management as well as some other approaches that are at very early stages of development. Carbon dioxide removal on a large scale based on biomass energy would have implications for food security, ecosystems and biodiversity.

The pledges that governments have made over the last three years about their mitigation ambitions are not enough to keep warming below 1.5°C, even with

A summary for urban policy makers (adaptation of SR1.5°C):
https://www.globalcovenantofmayors.org/wp-content/uploads/2018/12/Summary-for-Policy-Makers_Final_Online.pdf

A summary for teachers (prepared by the Office for Climate Education, supported by the French Academy of Sciences):
http://www.oce.global/resources/

ambitious and very challenging efforts after 2030. They place us on a trajectory of global warming of 3°C or more by 2100.

Carbon dioxide emissions would need to decline substantially before 2030 to avoid warming of more than 1.5°C in the middle of the 21st century, with the associated overshoot climate-related risks, followed by large scale carbon dioxide removal, and implications. Climate change risks and how we respond to them are closely linked to sustainable development and the UN sustainable development goals. These goals balance social well-being, economic prosperity and environmental protection.

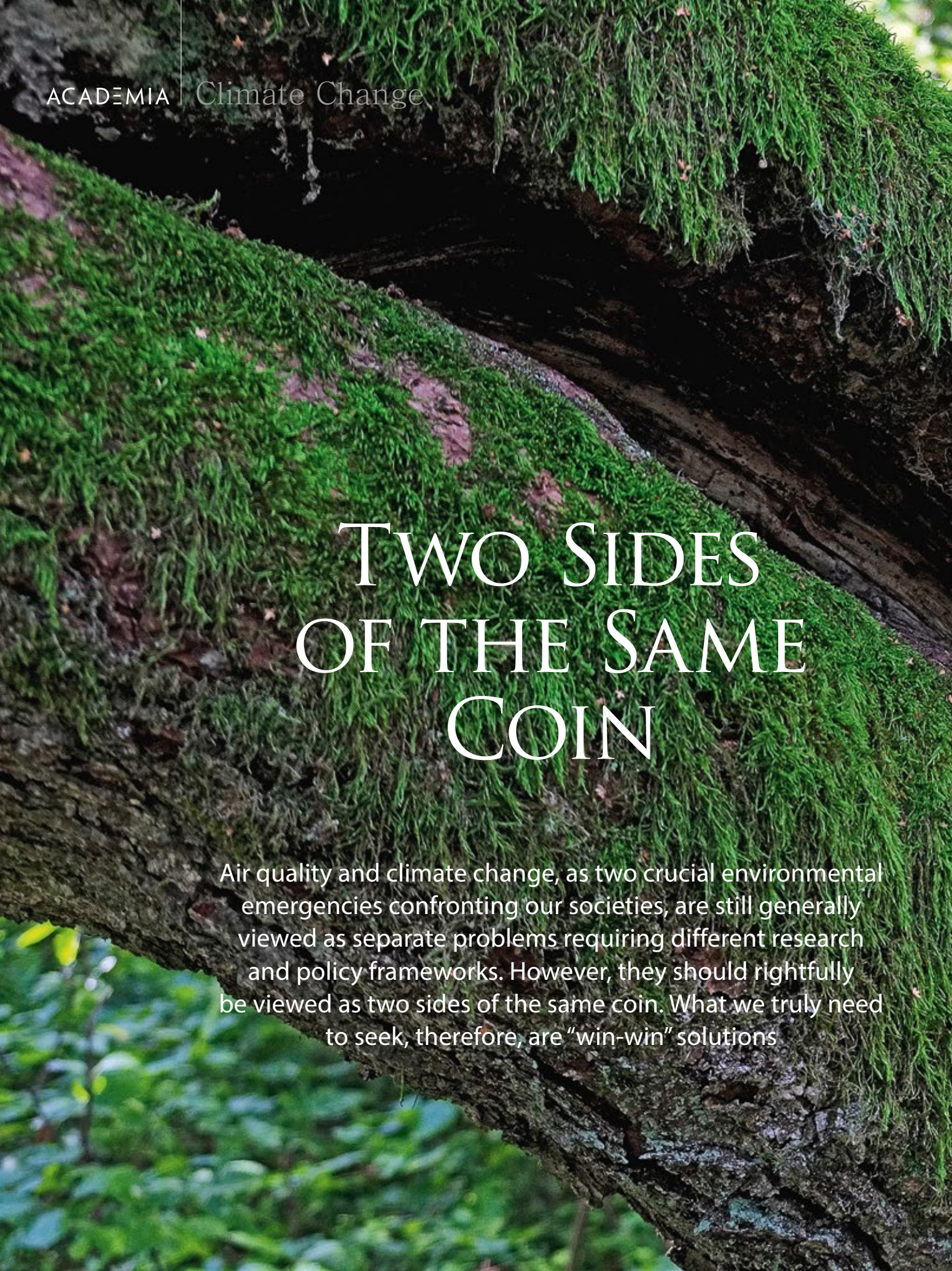
As part of limiting global warming to 1.5°C, a mix of measures to adapt to climate change and options to reduce emissions will, if carefully selected, have benefits for meeting the sustainable development goals. In each context, ethical, fair and just transitions can be designed, by placing attention upfront to protect those most vulnerable to the impacts of climate change, and to climate policies. This is most effective when local and regional governments and decision makers are supported by national governments, and when participatory mechanisms are put in place. Strengthening the capacities of national and sub-national authorities, civil society, the private sector, indigenous peoples and local communities can support the ambitious actions that would be required to limiting global warming to 1.5°C.

What is next for the IPCC?

In 2019, the IPCC will release an update of the methodological report on guidelines for emission inventories (May 2019); a Special Report on Climate Change and Land (August 2019); and a Special Report on the Oceans and the Cryosphere in a Changing Climate (September 2019). The main Working Group reports are scheduled for 2021 (WGI, the Physical Science Basis; WG2, Impacts, adaptation and vulnerability; WGIII, mitigation of climate change). They will contribute to the Synthesis report, scheduled for April 2022.
Scientists can contribute to the assessment of the state of knowledge by participating to the expert review of the main Working Group reports, which will start in spring 2019 for Working Group 1. Information on timelines is available from the IPCC web site and on social media.

International cooperation and mobilisation of finance is critical for this to be achieved in all countries and for all people, especially for developing countries and vulnerable regions. The feasibility of ambitious climate response is also strongly linked to education and innovation, with a strong role for the academic role to support societal transformation and transitions.

Valérie Masson-Delmotte
Photography by **Jakub Ostałowski**



Two Sides of the Same Coin

Air quality and climate change, as two crucial environmental emergencies confronting our societies, are still generally viewed as separate problems requiring different research and policy frameworks. However, they should rightfully be viewed as two sides of the same coin. What we truly need to seek, therefore, are "win-win" solutions

JAKUB OSTAŁOWSKI

Incentivizing wood-burning for household heating in lieu of fossil fuels (gas, oil), on the grounds that biomass combustion can be considered carbon-neutral, is actually a "win-lose" solution due to the large emissions of soot particles and other gaseous species so released.

Dr. Maria Cristina Facchini

Institute of Atmospheric Sciences and Climate
National Research Council, Italy

According to the World Health Organization (WHO) air pollution is the second leading cause of non-communicable diseases that are on the rise worldwide, and 4.2 million people die every year of causes attributable to air pollution. The latest WHO reports provide strong evidence in this respect, clearly linking especially long-term exposure to fine particles ($PM_{2.5}$) with deaths due to cardiovascular, respiratory diseases and cancer, as well as increased morbidity, particularly in children and asthmatics. According to the European Environmental Agency (EEA), more than 80% of the urban population in the EU Member States is exposed to particulate matter (PM) levels above the WHO guidelines.

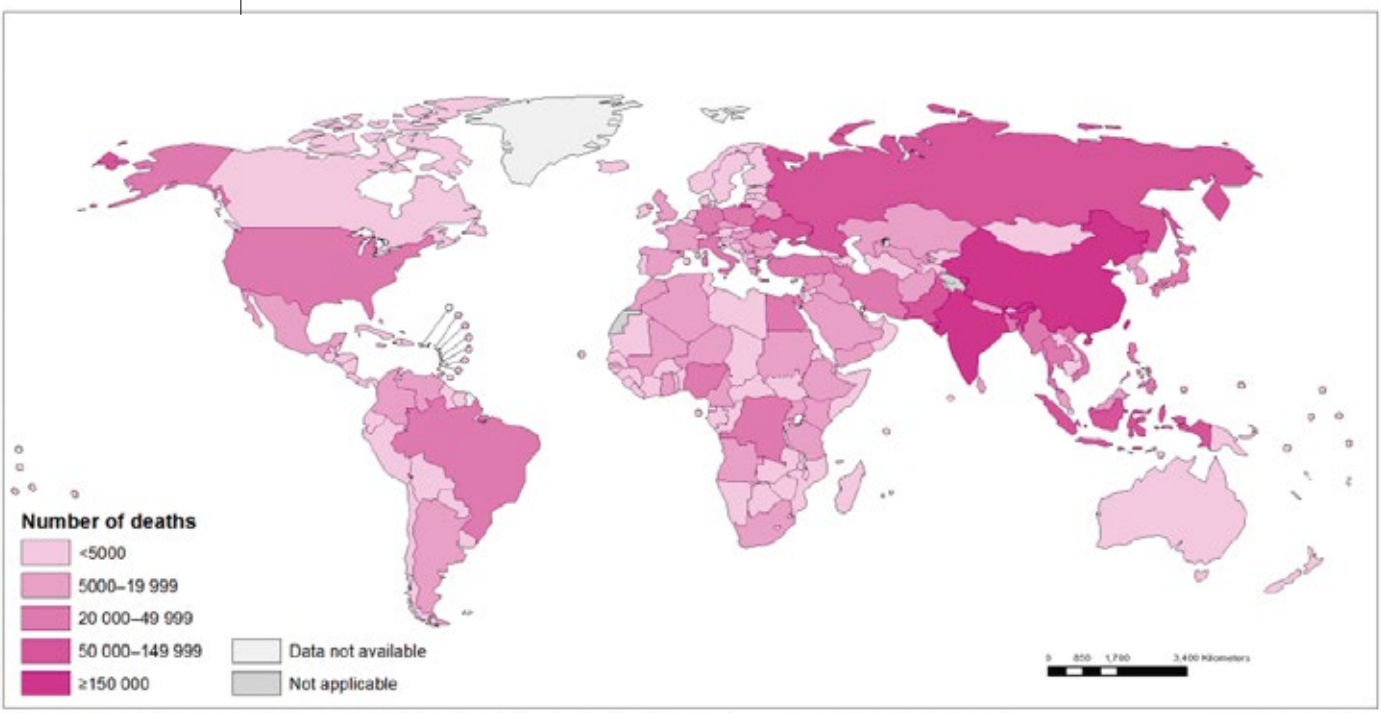
This translates into a decrease of life expectancy of more than eight months on average in Europe, and up to two years in the most polluted areas. Air pollution also causes significant damage to ecosystems and the environment. Ground level ozone (O_3), besides being harmful for human health, damages agricultural crops and vegetation. Nitrogen oxides (NO_X), sulfur dioxide (SO_2) and ammonia (NH_3) contribute to the acidification of soil, lakes and rivers, causing loss of biodiversity. NH_3 and NO_X also negatively impact upon water ecosystems by introducing excessive amounts of nutrients, in turn causing algal blooms and water hypoxia, a process known as "eutrophication."

On the other hand, as the recent Special Report of the Intergovernmental Panel on Climate Change (IPCC) "Global Warming of 1.5°C" (SR15) states, human activity is estimated to have already caused approximately 1.0°C of global warming above pre-industrial levels and global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate.

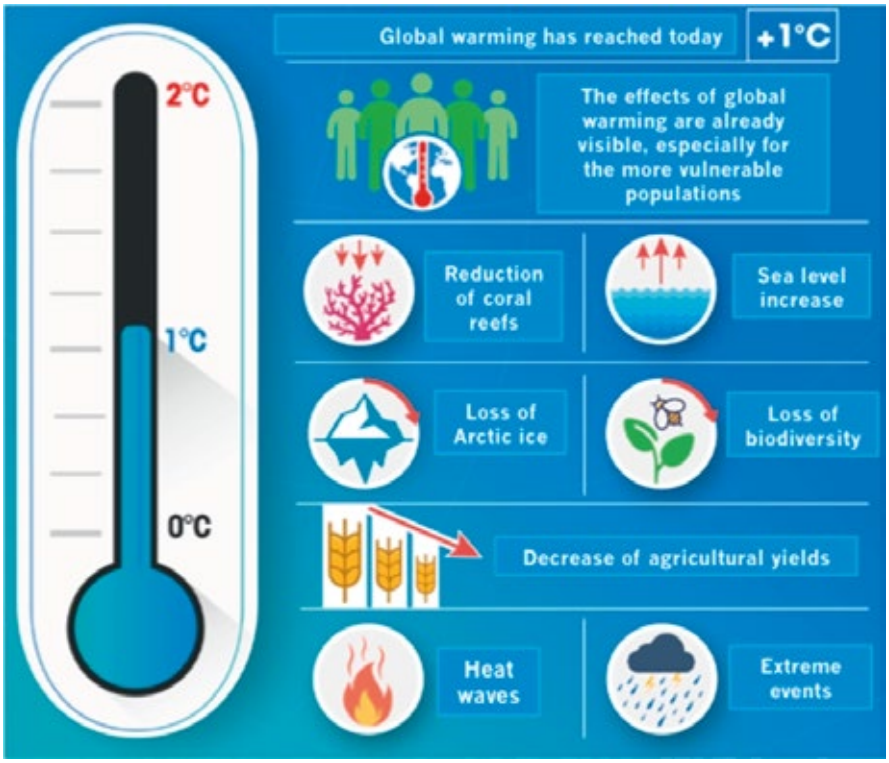
The SR15 also reports that impacts on natural and human systems from global warming have already been observed and that many land and ocean ecosystems, together with some of the services they provide, have already changed due to global warming. Sea levels have already risen by approx. 20 cm since pre-industrial times, Arctic sea ice continues to shrink, agricultural yields have already decreased in many parts of the world, and heath waves and extreme events are becoming more and more frequent in many parts of the world.

Atmosphere in the Anthropocene

Atmospheric pollution and climate warming both result from changes in chemical composition of the atmosphere due to anthropogenic activities. In fact,



Deaths attributable to ambient air pollution in 2012, by country, as reported by the WTO.



GRAPHICS BY CMCC FROM THE IPCC SPECIAL REPORT SR15

Effects of global warming that are already being observed.

anthropogenic activities of all sorts (energy production, transportation, industry, agriculture, waste management) are responsible for the emission of gaseous and particulate pollutants that modify the atmospheric composition. Such changes are, in turn, responsible for the degradation of air quality at the regional/local scale as well as for the warming of the climate.

Over the past millennia of human history, the environmental changes induced by man have been negligible, given the small number of people on the planet and the very limited technologies available. Today, the magnitude, the spatial scale and the speed of the environmental changes induced by our societies have reached an unprecedented level, never before experienced in human history. The environmental processes induced by anthropogenic activities equal, and sometime exceed, the natural ones, their spatial extent extends at this point to the global scale and the speed at which the environmental changes proceed is on the order of years to decades, compared to a temporal scale of millennia that is typical of natural changes.

Some simple numbers provide a clue as to the causes of the recent environmental changes occurring at the global level:

- the global population more than doubled over the second half of the past century,
- cereal production tripled over the same period,
- energy production quadrupled,
- global production of goods increased five times.

In view of all theis evidence, the Nobel Laureate Paul Crutzen and the biologist Eugene Stoermer recently proposed that the Holocene, the geologic era that began ca. 12,000 years ago at the end of the last glaciation, should be seen as concluded and that the Earth should be viewed as having entered a new geologic era, called the Anthropocene, in recognition of the overwhelming role of mankind in the geology and the ecology of the planet.

Over six billion people now live on the planet, all of them with such fundamental needs as clean water, food, health, mobility, etc. The way in which these needs are met determine the environmental consequences at the global level (see Table 1). Most of the accelerated economic activity and energy consumption over the past decades have occurred in the developed parts of the world, but the new economies (e.g. China,

Recent research has shown that there are opportunities for "win–win" scenarios that benefit both air quality and climate, while there are also measures that would benefit only one or the other ("win-lose" scenarios).

TABLE 1
Schematic representation of the anthropogenic activities responsible for the global environmental changes in different compartments of the Earth System and the individual and societal needs that induce these changes. Human needs are, in turn, also a function of social factors as the market, institutions, legislation, political systems and cultural values typical of each society

Compartment	Anthropogenic activities	Individual and societal needs determining global environmental changes
Terrestrial ecosystems	Deforestation, agriculture, land management	Food, recreational activities, shelter
Atmosphere	Fossil fuel combustion, land use change, industrial activities, waste management	Mobility, food, production of goods
Water	Water management, waste management	Water for human consumption, agricultural activities, industrial needs
Marine and coastal ecosystems	Land management, fishing, waste management, urbanization	Food, recreational activities, shelter
Biodiversity	Destruction of natural habitats, introduction of allochthonous species	Food, recreational activities, shelter

India, etc.) are now also having an increasing impact on the global environment and on atmospheric composition change.

Air quality and climate

Air pollution and climate change are, therefore, two intimately interconnected environmental issues. However, these two environmental challenges are still generally viewed as separate problems, dealt with by different research communities and within different policy frameworks. Indeed, many mitigation options offer possibilities to improve air quality and mitigate climate change but, at the same time, mitigation options that may provide benefits to one aspect are worsening the situation in the other. Therefore, coordinated action taking into account the air quality-climate linkages is urgently required.

In fact, it is not possible to unambiguously separate anthropogenic emissions into two distinct groups – atmospheric pollutants vs climate-forcing species (see the Table 2) – and moreover many of the same sources inject both climate-forcing species and air pollutants into the atmosphere. One straightforward example is the tailpipe of our car, which simultaneously emits CO_2 (a climate forcer), NO_X (an air pollutant) and PM (both a pollutant and a climate forcer).

Synergies and trade-offs

It has become clear through recent research that there are opportunities for "win–win" scenarios that would benefit both air quality and climate, while there are also measures that would benefit only one or the other ("win-lose" scenarios).

TABLE 2
Pollutant properties and climate effects of the main atmospheric trace compounds deriving from anthropogenic activities.

Compound	Pollution effect(s)	Climate effect
Carbon dioxide (CO_2)	Ocean acidification, affects photosynthesis	Long-lived climate forcer (warming)
Methane (CH_4)	Precursor of tropospheric ozone	Medium-lived climate forcer (warming)
Ozone (O_3)	Health and vegetation damages	Short-lived climate forcer (warming)
Sulfur dioxide (SO_2)	Health damages, ecosystem acidification	Precursor of PM sulfate (cooling)
Nitrogen oxides (NO_X)	Health damages, precursor of tropospheric ozone, ecosystem acidification, water eutrophication	Precursor of PM nitrate (cooling)
Ammonia (NH_3)	Ecosystem acidification, water eutrophication	Precursor of PM ammonium (cooling)
Particulate matter (PM)	Health damages	*Either cooling or warming
Volatile organic compounds (VOC)	Health damages, precursors of tropospheric ozone	Precursor of tropospheric ozone (warming)

*PM can, depending on particle composition, either absorb or scatter solar radiation, thus warming or cooling the climate.

DR. MARIA CRISTINA FACCHINI

Dr. Maria Cristina Facchini

is Director of the Institute of Atmospheric Sciences and Climate, National Research Council, in Bologna, Italy. She studies the interactions between climate and air pollution, physical and chemical processes in multiphase atmospheric systems (aerosols and clouds) and their effects on atmospheric composition and climate change.

The vast majority of climate change mitigation options will, at the same time, promote health and sustainable development. Win-win solutions are represented, for example, by placing a price on CO_2 emissions or by removing subsidies on fossil fuels. Also promoting greater use of renewables for electricity and household energy brings both air quality and air quality benefits.

One example of a win-lose solution, on the other hand, can be found in the incentives assigned by some countries to substituting wood burning for the use of fossil fuels (gas, oil) in household heating, on the basis that biomass burning can be considered carbon-neutral, since trees accumulate the same amount of CO_2 that is released when wood is burned. This may represent an advantage in terms of climate mitigation, but does not take into account the large emissions of soot particles and other gaseous species during wood combustion, which are extremely harmful for human health.

A schematic summary of synergies and trade-offs between air quality and climate change is represented in Fig. 1, where the upper-right and the lower-left quadrants represent win-lose policy options that benefit one aspect but that are detrimental for the other (air quality and climate, respectively, in the two cases), while only the upper-right quadrant represents win-win measures that mitigate both air quality and climate warming. The lower-left quadrant should, of course, not be considered since it clearly implies disadvantages for both climate change and air quality.

Emission abatement strategies are frequently intended only in terms of technological measures, such as any end-of-pipe technologies. Equally important are, however, the behavioral measures for which active citizen involvement is key (commuting habits, energy choices, waste disposal, dietary habits, etc.). To pursue individual behavioral changes of this type, social acceptability is key – there therefore needs to be reliable information provided to citizens, in addition to proper policy actions that favor the desired changes of lifestyles.

Maria Cristina Facchini

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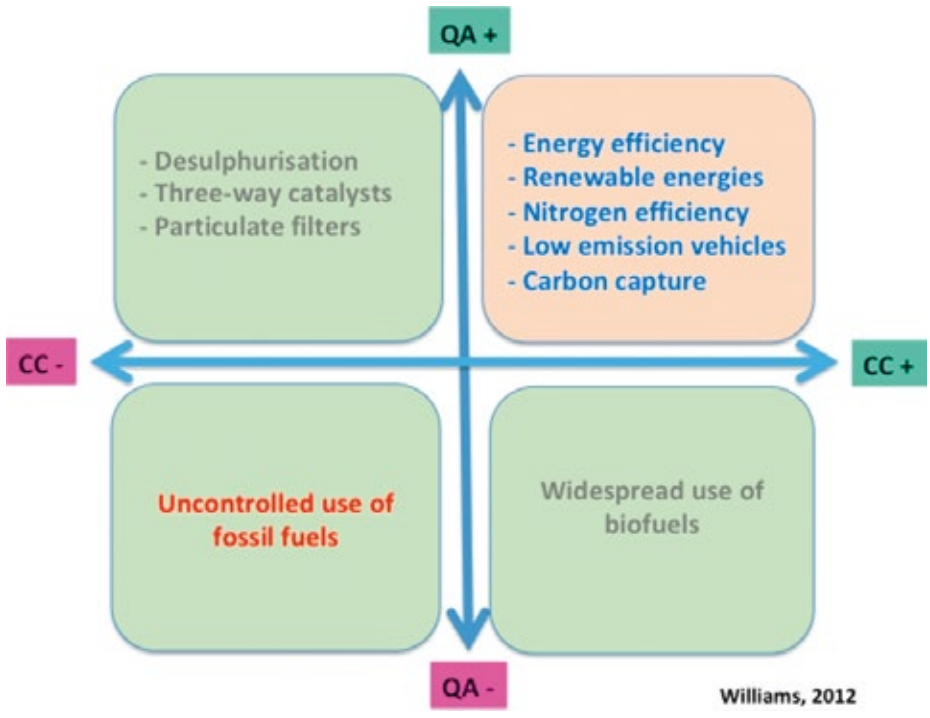


Schematic representation of synergies and trade-offs from policies and technologies that address climate change and air quality.

Along the Silk Road

BEW

Prof. Tandong Yao and **Prof. Fahu Chen** describe our growing understanding of climate change impacts in the "Pan-Third Pole" region, discussing both coping strategies and research initiatives focusing on the region.

Prof. Tandong Yao
Prof. Fahu Chen

Institute of Tibetan Plateau Research
Chinese Academy of Sciences

The Pan-Third Pole region, which stretches from the Tibet-centered "Third Pole" westwards to the Carpathians and includes Pamir, Hindu Kush, the Iranian Plateau, and the Caucasus (see map), covers more than 20 million square kilometers and contains more than 20 countries. The region has a population of more than 3 billion people. Historically, as a key corridor connecting western and eastern cultures and economies, this region has propelled the development of human civilization, and nowadays has become the core area of the Silk Road Economic Belt. Research into environmental changes in the Pan-Third Pole region is essential to overcome some of the challenges faced by countries along the Silk Road, and thereby safeguard the implementation of the Belt and Road Initiative, which aims to realize sustainable growth for common development and shared prosperity across the continents of Asia, Europe and Africa.

The Pan-Third Pole region is generally characterized by a dry and relatively cool climate, and has becomes a hotspot in terms of the rate of recent climate change. A comparison with historical climate recon-

structions reveals that the observed twentieth century warming in the Pan-Third Pole has exceeded any natural temperature variations in the past 2000 years. Furthermore, the warming rate in the region in the last few decades has been twice as fast as the global average, which means it may face a temperature increase of 4°C if the Earth gets 2°C warmer in the future. In contrast, precipitation in the region displays a large spatial heterogeneity. This drastic climate change, characterized by extraordinary warming, has already triggered a series of environmental issues, and poses significant threats to local resources and ecosystems in the Pan-Third Pole region. To achieve a green and healthy Pan-Third Pole, it is a scientific imperative to understand climate change and its impacts on human and natural systems.

Past climate change and human civilization

The Pan-Third Pole region is currently the largest mid-latitude arid area in the Northern Hemisphere. Some 6000 calendar years before the present (cal yr BP), the climate over the Pan-Third Pole region became relatively warm and wet, favoring the expansion of grass and mountain forests, and facilitating the development of human civilizations. The humid climate, and the introduction of new agriculture and animal husbandry techniques, promoted the rapid development of civilization and the emergence of trans-Eurasia exchange in the Central Asian Steppes during the subsequent two millennia. The millet and wheat-barley crops that were first domesticated in both the east and west of Eurasia spread out and encountered one another in central Asia in ~4500 cal yr BP. The agro-pastoral innovations made under the warm-wet conditions in the central Eurasian Steppes may have contributed to the extensive expansion of the Yamnaya culture (~5600–4200 BP), which profoundly influenced cultural and genetic patterns in Eurasia during the late Neolithic and early Bronze Age.

The trans-Eurasia culture exchange intensified after the fourth millennium BP, and further reshaped the evolution of civilization in the old world. For example, barley and wheat were introduced into northwest China around 4000 BP. The adoption of these cold-tolerant western crops facilitated permanent human settlement on the Tibetan Plateau since ~3600 BP. Although the influence of climate change in the Pan-Third Pole region on the formation of the proto-Silk Road has not been examined in detail, the major highway for trans-Eurasia exchange shifted from the Eurasian Steppes to the beaded oasis route in the third millennium BP, when the climate in the Xinjiang area was much wetter than before 4000 BP. That transformation in the spatiotemporal pattern for west-east culture exchange across Eurasia laid the foundation for the formation of the Ancient Silk Road, which has been named as one of the major centers of world civilization in the past 2000 years. The rise and fall of the ancient civilizations along the Silk Road was also influenced by climate change. It has been suggested that favorable climate conditions were an important factor for facilitating unprecedented communications of ancient civilization and technology along the Silk Road across the Pan-Third Pole region, while the collapse of the well-developed agriculture oasis such as in the region of the famous Luolan Kingdom (176 BC-630 AD) may resulted from strongly human-impacted environmental changes.

Recent impacts on water resources

The Tibetan Plateau, described as the Asian Water Tower, forms the core of the Pan-Third Pole region, and comprises numerous glaciers, lakes and rivers. It hosts the largest glacier area (>100,000 km^2) outside the North and South Pole regions. Warming-induced glacier retreat, floods and lake expansion or shrinkage are destabilizing the water tower, affecting human welfare all along the Belt and Road. The impacts of dramatic climate change have been witnessed in glaciers on the Tibetan plateau. The extraordinary warming has led to the severe decline of most of glaciers over the last several decades. For example, the mass of the Tien Shan glacier, which is a vital water resource for Kazakhstan, Kyrgyzstan, Uzbekistan and the Xinjiang Uyghur Autonomous Region, has declined by 27±15% from 1960 to 2012. Even worse, the glaciers in this region are retreating so fast that 64 percent of glacier mass is projected to disappear by 2100 under the worst-case emission scenario. Such rapid glacier melting could have devastating impacts. In arid and semi-arid regions, water from glacier melt could create a buffer for water stress in dry seasons or drought years, but the buffering capacity is projected to be severely reduced in a future warming world. Furthermore, the rapid glacier melting could also lead to catastrophic ice avalanches. To adapt to more commonly occurring climate extremes in the future, early warning systems must be designed to support decision-makers and local authorities in their response to these unprecedented types of natural hazards.

Compared to glaciers, the response of lakes in the Pan-Third Pole region to climate change displays large spatial variations. The lakes in the Tibetan Plateau show expansion, but those in the Central Asia are shrinking rapidly. For example, the area of lakes in the Tibetan Plateau has expanded from 29,278 to 37,867 km^2 over the last 40 years, and the mean water

level has increased by 0.20 m per year. In contrast, the Aral Sea in Central Asia, once the fourth-largest inland sea in the world (66,000 km^2 in 1960s), lost more than 90% of its area before 2010. The Aral Sea shrinkage has been described as "probably the biggest ecological catastrophe of our time" by António Guterres, Secretary-General of the United Nations. An in-depth understanding of the patterns of water resource changes under rapid climate change and the underlying mechanisms is required. More research efforts need be made to enable scientifically sound projections and to support science-based policy making for the Pan-Third Pole region.

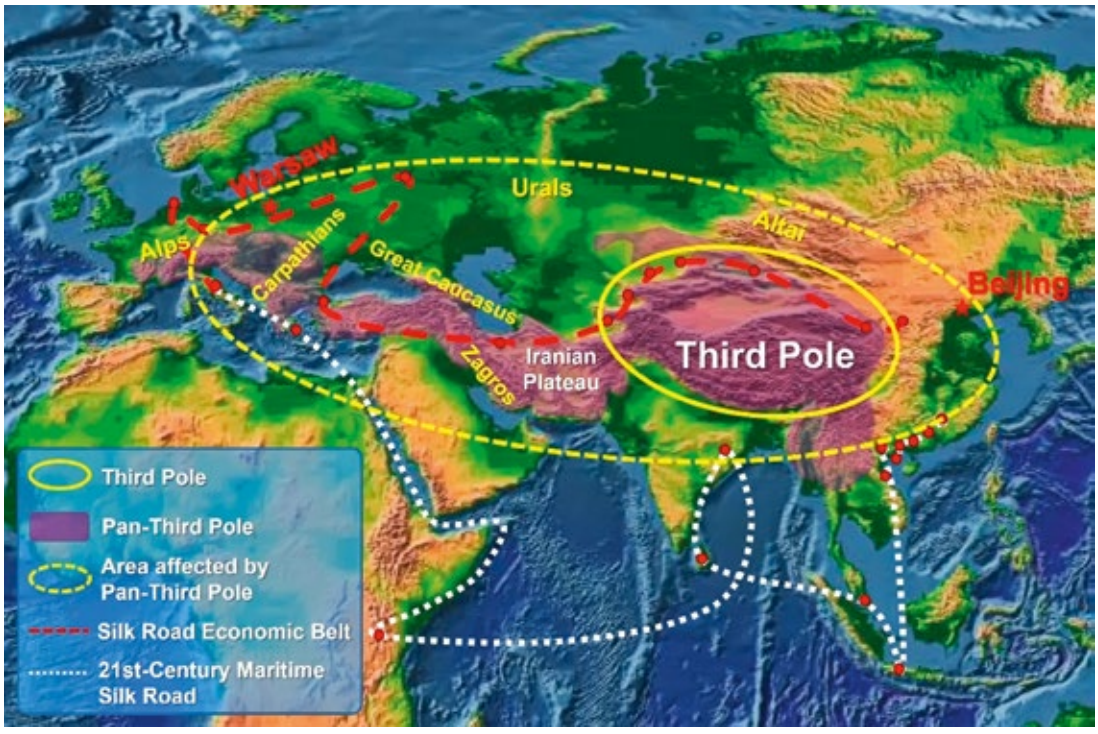
Impacts on ecosystems and biodiversity

Warming, together with elevated atmospheric CO_2 concentration and increasing nitrogen deposition, generally stimulates vegetation growth and enhances carbon uptake in the high mountain ranges in the Pan-Third Pole region. For example, net primary productivity in the Tibetan Plateau increased by 13.3% in the last 30 years. This warming-induced increase in production could enhance ecosystem services that are essential to livelihood and social development. However, the Tibetan plateau hosts the largest area of permafrost outside the Polar Regions. Continued warming will accelerate permafrost thawing and release "old carbon" buried beneath the permafrost, which will potentially overturn the warming-induced increase in carbon uptake. Moreover, grasslands in some key areas, being an important ecosystem type over the Pan-Third Pole region, are plagued by human-induced degradation. It is essential to understand how ecosystem services will respond to future climate change, to be able to guide the population to keep their activities within the ecosystem carrying capacity.

The impact of rapid climate change is not only seen in ecosystem changes, but also in biodiversity changes. The Pan-Third Pole region carries a huge number of endemic species, harbors 7 of the total 36 biodiversity hotspot regions in the world, and forms a unique natural gene bank in the high mountain ranges. But in the past decades, about 10.6% of western Asia's endemic species have come under threat because of drastic climate change and increasing human intervention. Besides the shrinkage of the number of endemic species, the abundance of invasive alien species is steadily increasing. For example, the tree line position in the eastern Himalayas has risen 110 m over the past century. This expansion of lowland tree species will create a further favorable niche for species invasion under rapid climate change. However, current knowledge on biodiversity and its response to climate change is still fragmented, and more thorough studies are needed.

Coping with climate challenges

As climate change has become more severe in recent years, climate-induced drastic ecosystem changes and



The geographic range of the Pan-Third Pole region.

Prof. Tandong Yao

is a Chinese glaciologist, a member of the Chinese Academy of Sciences (CAS) and Honorary Director of the Institute of Tibetan Plateau Research. He is the first Asian scientist to win the prestigious Vega Medal in 2017 in the fields of anthropology and geography for his contribution to research on glaciers and the environment on the Tibetan Plateau.

Prof. Fahu Chen

is Director at the Institute of Tibetan Plateau Research, Chinese Academy of Sciences. He mainly studies climate change and environmental archaeology in arid central Asia and monsoonal China. His major contributions include the Westerly climate regime in arid central Asia; early human colonization of the Tibetan Plateau and sub-orbital scale abrupt climate change in Northwestern China.

natural disasters such as drought, flood, sand storms and ice avalanches have started to pose great threats to countries along the Belt and Road routes. To gain a better understanding of climate and environment changes and their impacts on ecosystem and human activities in the Third Pole, the Chinese Academy of Sciences (CAS) initiated the Third Pole Environment (TPE) program in 2009. This program is designed to encourage world-known scientists and institutions to investigate the processes and mechanisms of the interactions among atmosphere-water-ice-vegetation-human activities in the Third Pole region. In 2011, TPE received funding of 0.12 billion RMB from the CAS, in the name of the Strategic Priority B Research Program "Multi-sphere interaction of the earth system in the Tibetan Plateau and its effects on resources and the environment."

As TPE research grows further, there is an increasing recognition that Third Pole environmental changes could have far-reaching impacts on regions that are not limited to the Third Pole. In 2016, the TPE proposed "Pan Third Pole" research that should also cover the regions affected by the Third Pole including East Asia, South Asia, Central Asia, East Europe etc. The proposed Pan-Third Pole region covers the Silk Road Economic Belt, and includes all the countries of the Belt and Road region. Soon after it was proposed, Pan-Third Pole research received large amounts of funding from both the Ministry of Science and Technology and CAS. In 2017, CAS instigated the Second Comprehensive Scientific Expedition to the Third Pole, followed by the Chinese Ministry of Science and Technology announcement in 2018 that 4.4 billion of research funding will be invested in the next five to ten years, with the aim of achieving a comprehensive understanding of changes in climate, water resources, ecosystem, biodiversity and human activities in the Third Pole and surrounding areas. Recently, CAS initiated the Strategic Priority A Research Program "Pan-Third Pole Environment Change Study for Green Silk Road Development," with financial support of 1.68 billion RMB. The overall objective of this program is to serve green growth in the Pan-Third Pole region, by clarifying the conditions of natural resources and environmental carrying capacity, revealing the mechanisms of environmental change and proposing a scientific strategy for green Silk Road development. Avoiding the worst impacts of climate change will also require deep international cooperation among scientific institutions and countries in the Pan-Third Pole. To ensure green growth, the CAS established the Alliance of International Science Organizations (ANSO) in the Belt and Road region in November 2018. The establishment of ANSO will bring together the international scientific community and mobilize efforts in jointly addressing the climate change challenges.

In the symposium "Safeguarding Our Climate, Advancing Our Society" held in Katowice on 10 December 2018, scientists suggested that we still have a window of opportunity to take full responsibility and avoid the climate crisis, but that this window is rapidly closing. The Third Pole together with the North and South Poles are the most vulnerable and sensitive regions to rapid climate change. There is compelling scientific evidence that the three poles (north, south, and third) are rapidly warming, and many of the climate change impacts are already negative for ecosystems and human beings e.g. irreversible ecosystem transformation, species extinction and sea-level rises. It is thus imperative to have a solid scientific base so that the climate actions can be understood and shared. Excitingly, the Chinese government is now promoting the Tri-Polar Environment and Climate Change (TPEC) program that will focus on the climate changes of the Three Poles, their impacts on the regional/global environment and the linkages among the Three Poles through establishing multi-dimension observation systems. The implementation of this project will help us to provide scientific and technological support for addressing climate-induced disaster, safeguarding polar security and eventually building "A community with a shared future for mankind."

Tandong Yao, Fahu Chen

Further reading:

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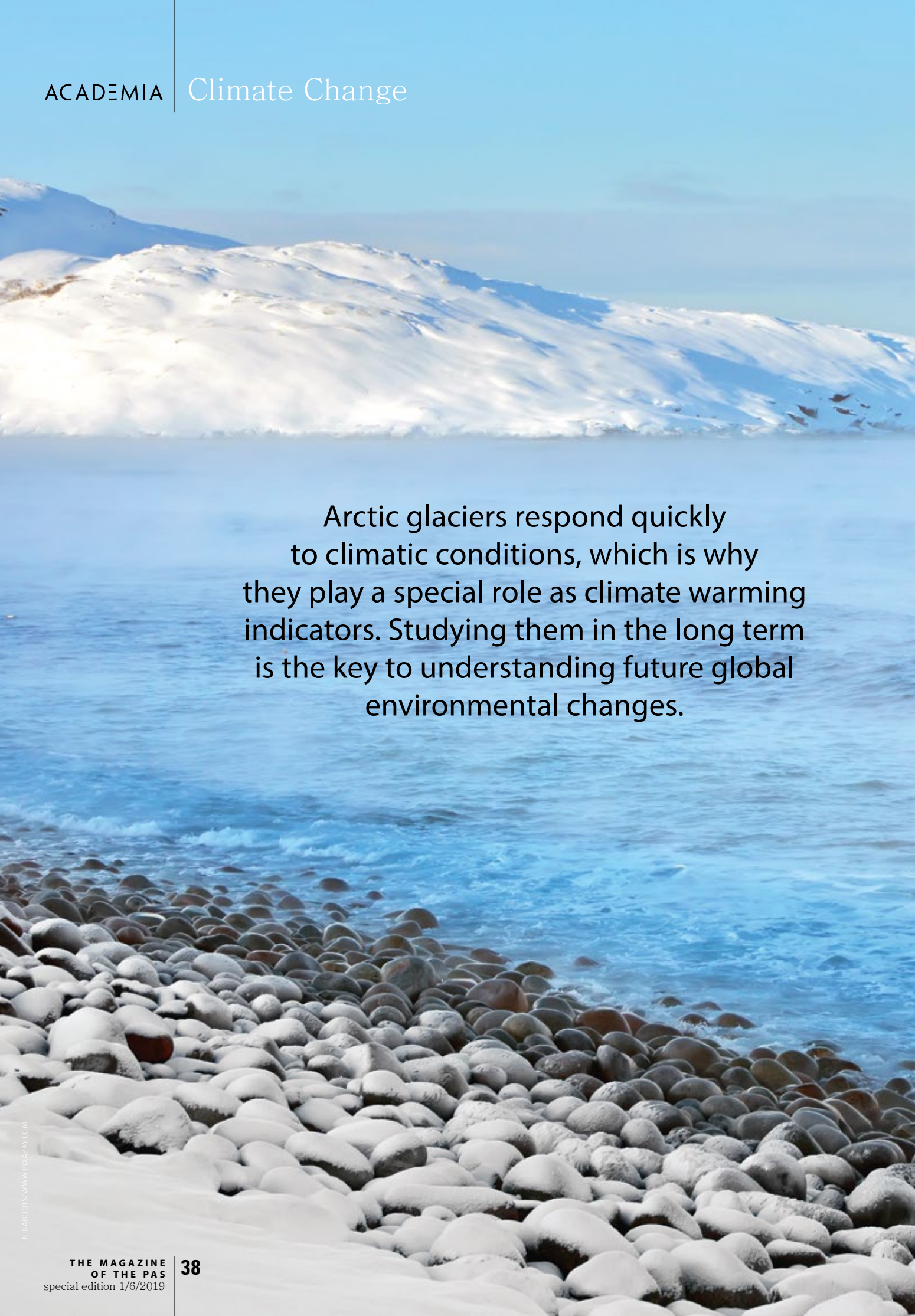

Arctic glaciers respond quickly to climatic conditions, which is why they play a special role as climate warming indicators. Studying them in the long term is the key to understanding future global environmental changes.

NINAMOOTS/WWW.PIXABAY.COM

PROF. JACEK JANIA

Telling the Future from Ice

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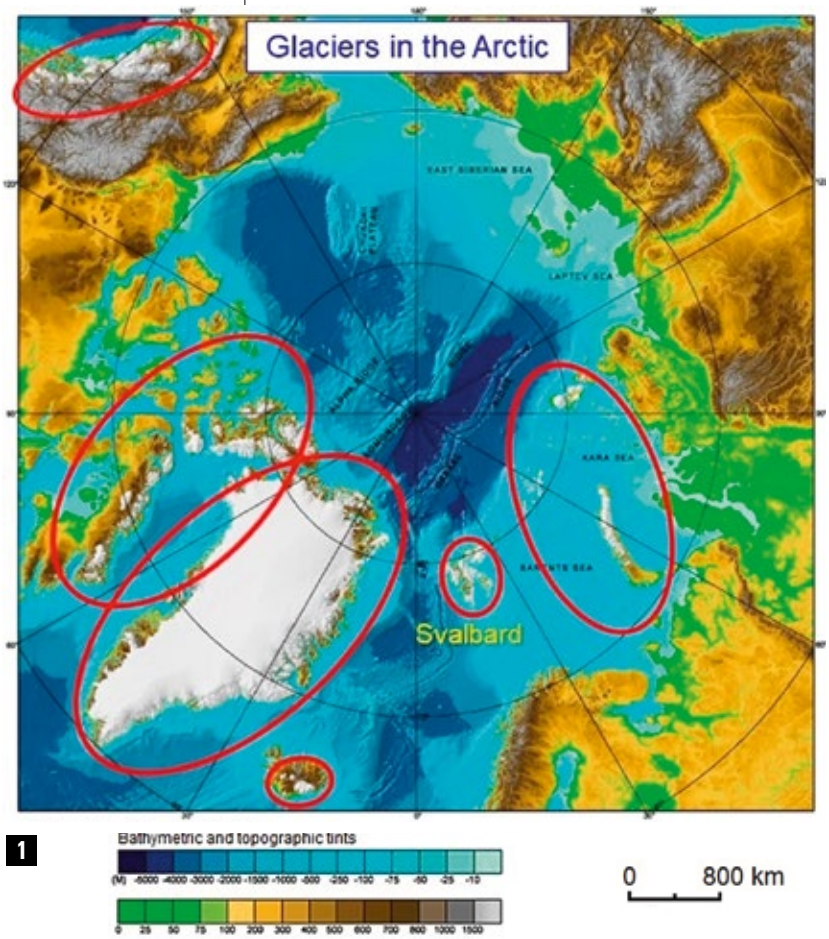
Committee on Polar Research,
Polish Academy of Sciences

Glaciers are masses of ice formed on land due to accumulating annual snowfalls. These include the major glaciers in Antarctica and Greenland, the ice caps in many Arctic regions, and smaller mountain and valley glaciers around the world. They are in constant, usually slow motion under the influence of gravity. They vary in terms of size, shape, thickness and thermal structure. A very important differentiating factor is the tip of their tongue. Most glaciers (usually the smaller ones) terminate on land, whereas ones that terminate in the ocean, known as tidewater glaciers, transport ice from the largest glaciated areas.

The climate influences glaciers by affecting the main factors contributing to the ice mass balance: the magnitude of winter snowfalls (the rate of accumulation) and the rate of melting (surface ablation). In the classic approach to the mass balance of glaciers, the loss of mass on the front of the glacier terminating in the sea is not taken into account. This frontal ablation is the combination of melting on contact with sea water and glacial calving (when icebergs break off the edge of a glacier). Global warming both increases the melting process as well as boosts the formation of icebergs, which can significantly affect the length and thickness of glaciers.

Monitoring the mass balance of glaciers enables us to identify more precisely how they react to climate change. Out of the nearly 200,000 glaciers in the world, only a few are being studied long-term, and a similar problem applies for the Arctic ice cover. Studying frontal ablation, as opposed to surface ablation, is very difficult. Only a handful of tidewater glaciers have their mass balance, including calving, regularly measured. For others, estimates are made using various kinds of satellite data. Researchers from the University of Silesia and the United States Geological Survey were among the first to study tidewater glaciers. Back in the late 1970s, research began on the Columbia glacier and other glaciers in Alaska, and a few years later on the Hans glacier in southern Svalbard near the Polish Polar Station on the Hornsund fjord.

In this article, we will illustrate how Arctic glaciers serve as indicators of global warming and examine the



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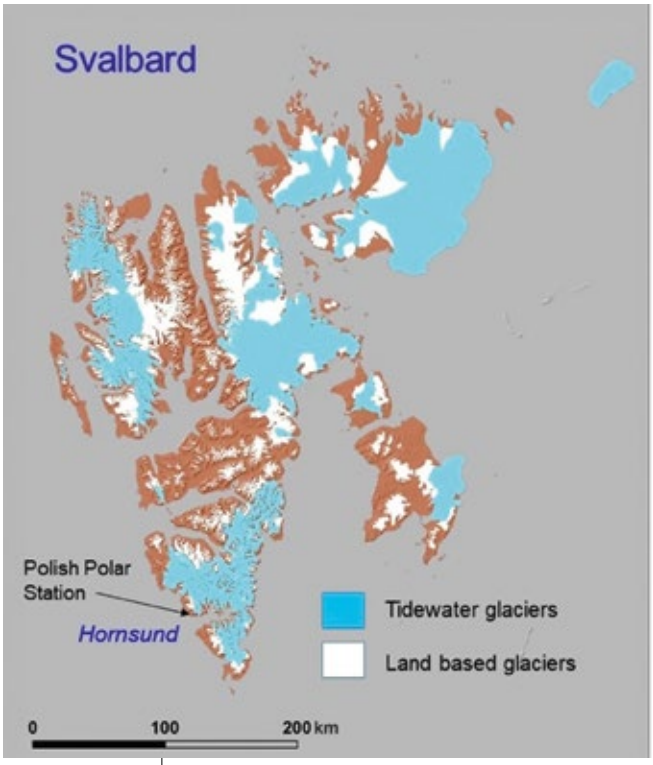
Glacierized regions of the Arctic (Fig. 1) and tidewater glaciers in the Svalbard archipelago. The location of the Polish Polar Station is marked on the northern shore of the Hornsund Fjord (Fig. 2).



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SOURCES: THE INTERNATIONAL BATHYMETRIC CHART OF THE ARCTIC OCEAN (IBCAO)
HTTPS://WWW.NGDC.NOAA.GOV/MGG/BATHYMETRY/ARCTIC/ARCTIC.HTML
MAP PREPARED BY M. BŁASZCZYK (DEPT. OF GEOMORPHOLOGY, UNIVERSITY OF SILESIA)

special role played by ice masses flowing into the sea. The latter are still poorly researched, which is why the Polish research initiatives are important for fostering a better understanding of global environmental changes.

On the move

In the Arctic part of the Northern Hemisphere, apart from the great Greenland Ice Sheet (about 1.71 million km²) and its surroundings, glaciers are found in Svalbard, the archipelagos of the Russian Arctic, the Canadian Arctic, as well as in the Sub-Arctic in Iceland, Alaska and Scandinavia. With the exception of Iceland and Scandinavia, tidewater glaciers account for a majority of surface area. In Svalbard, the main area of Polish research, the total area of glaciers is about 33,800 km², of which 68% are tidewater glaciers.

The Arctic is warming up faster than the climate in middle latitudes and the rest of the globe, a phenomenon known as Arctic amplification. For example, over the last three decades, the average annual air temperature in the Polish city of Katowice increased at the rate of 0.4°C/10 years, whereas on Svalbard, during the same period it increased by 1.1°C/10 years in Hornsund (77°N) and 1.4°C/10 years in Longyearbyen (the capital, 78°N). This means the Arctic is warming up about three times faster.

This increases the melting of glaciers, affecting the mass balance on their surface. The resulting meltwaters penetrate deep into the glaciers through crevasses and caves in the ice, reaching the floor. The increase in the amount of the sub-glacial waters, and therefore their higher pressure, reduces friction on the substrate and facilitates the sliding of glaciers along the floor, which makes them flow faster. This is glacers' dynamic reaction to global warming. The fronts of the tidewater glaciers experience a lifting force due to the hydrostatic displacement of seawater, in accordance with Archimedes' law. This further reduces friction and accelerates the advancement of glaciers.

The lower part of the ice tongue becomes stretched out, which results in the formation of numerous slits parallel to the ice cliff. These slits loosen the frontal structures, which leads to the formation of icebergs. This process, called "calving," is influenced by a combination of many factors. Although no general "calving law" has yet been determined, it is obvious that the key factors controlling the intensity of calving include: the depth of seawater in relation to the thickness of the ice, the speed of the flowing glaciers and the temperature of the seawater washing the ice cliff (it affects the intensity of underwater melting, and thus the stability of the glacial front). With the exception of the first factor, which mainly

JAKUB OSTAŁOWSKI

PROF. JACEK JANIA

Prof. Jacek Jania, PhD, DSc

is a geographer studying glaciers and the polar environment and their response to climate change since 1972. Internationally known for his research on Arctic tidewater glaciers, he is a member of the European Polar Board (EPB), Chairman of the Committee on Polar Research of the Polish Academy of Sciences, and Head of the Centre for Polar Studies – a Leading National Research Centre in Poland. He is a full professor at the Faculty of Earth Sciences, University of Silesia, where he lectures on geodesy, cartography, glaciology and climate change problems. The author of numerous papers and three books.

depends on the topography of glacial substrates, the remaining ones are related to the changing climate. Put simply, the warmer the climate, the more intensive the calving, especially in deep water at the front of the glacier.

Tidewater glaciers are spatially dominant in the Arctic, and at the same time are more sensitive to global warming.

Retreat

Longer-term observations of the mass balance of Arctic glaciers are rare and focus on Svalbard. They include land glaciers, which are easier to be measured directly. Polish research on the Hans glacier (since 1989) is one of the few long-term studies involving tidewater glaciers. The surface mass balance of this glacier is slightly negative. Measuring mass loss due to calving requires hard-to-obtain data: the cross-sectional area through the ice tongue at the front, the average annual speed of the glacier at the front, and changes in the location of the glacier front (the amount of recession or possibly advancement).

It is necessary to measure the topography of the front and the thickness of the ice (very difficult at the ice cliff due to the crevices), as well as the depth of the sea at the front, the average speed of the glacier, and to track changes in cliff position during the year. The results for the period 2009–2014 showed that calving is responsible on average for 38% of the overall mass loss of the Hans glacier (the rest is due to surface melting). At the same time, significant inter-annual variability of the impact of frontal ablation is observed (25–54%). Subtracting the icebergs from the glacier mass balance, the cumulative sum is dramatically negative, more than 4 times more negative than for land glaciers. This means that calving is an extremely important process in the current accelerated Arctic deglaciation. This points to a persistent long-term global warming of the region.

An example of accelerated Arctic deglaciation is the Hornsund fjord in the south of Svalbard, studied by M. Błaszczyk's a team from the University of Silesia. Using historical maps, aerial photographs and satellite images, they tracked the recession of glaciers since the beginning of the 20th century. In the first four decades, glacial surface decreased at a rate of 0.8 ± 0.2 km^2/year. In the period 1936–1976, the rate of surface recession increased to about 1.6 km^2/year, and then to 2.6 km^2/year after 2000, to 3.5 km^2/year in recent years. This points to the dramatic acceleration of deglaciation in the twenty-first century.

Glacial thickness studies conducted by the same team from the University of Silesia (M. Grabiec et al.) using radar has shown that the Horn glacier substrate, which closes off the fjord from the east, lies 40 m below sea level. This means that its further recession will lead to the opening up of a sea link between the Greenland Sea and the Barents Sea in the future. The Hornsund Fjord will become a strait, probably around the middle of the twenty-first century. So the southern part of Spitsbergen – Sørkapp Land – will become a new island in the Svalbard archipelago.

Studies in the Atlantic part of the Arctic (JR Carr et al.) showed that the average rate of recession of tidewater glaciers has increased by 3.5 times between 1992–2000 and 2000–2010 (from 30.5m/year to almost 106m/year, respectively), albeit with differences between the regions studied. These results confirm observations from Svalbard that deglaciation is occurring swiftly and has been significantly accelerating in recent decades.

Changes

Glacier recession affects the surroundings. The land becomes exposed, but above all the water surface of the fjords increases. In both cases, because land and sea surfaces reflect less solar radiation than glaciers (from 50% for glaciers to approx. 30% for land and 10% for water), the average albedo of the region decreases. Higher absorption of solar radiation causes local and regional acceleration of global warming and melting of ice. This positive feedback increases the warming

The front of Hansbreen, a tidewater glacier flowing into the Hornsund Fjord.

M. MICHALSKI

of the Arctic's glaciated regions. Although the dominant positive feedback involves the disappearance of the sea ice cover across vast areas of the Arctic Ocean, the disappearance of glaciers is also of considerable regional significance.

Work by various authors, including studies conducted by the Dutch-Polish team on the Hans glacier (J. Oerlemans, J. Jania and L. Kolondra), shows that the accelerated deglaciation of tidewater glaciers is irreversible over the course of many centuries. It appears that depending on climate change scenarios, due to the deepening of the bottom of the glacial valley to 60–100m below sea level, by the end of this century the glacier will decrease to 10–12 km in length, and by 45–65% in volume.

Even if the emission of anthropogenic greenhouse gases is significantly reduced or stopped, the recession will not be halted, due to the calving of the glacier into deep water. In addition, even if the climate cools down and snowfall increases significantly (resulting in a positive mass balance of the glacier), the tongue will not flow into deep sea water. The frontal ablation in the deeper water will counterbalance the increased inflow of ice. Only a considerable shallowing of the fjord as a result of sedimentation of minerals from the surrounding land will allow the tongue to advance and stabilize itself on the piled-up bottom sediments. This is shown by the results of C^{14} dating of peat, which melted into the surface of the Hans glacier. They prove that there were no glaciers in the Hansbreen valley approx. 7,200–5,200 years ago BP (warm period during the Holocene era with temperatures 2°C higher than present). The marine sedimentation observed on Svalbard at a rate of 1cm per year is high. Despite that, the shallowing of about 50 m, which must have lasted about 5,000 years, enabled the glacier to advance during the Little Ice Age.

Considering the aforementioned fact that a large part of the Arctic glaciers flow into the recessed fjord valleys, we should expect further accelerated deglaciation. For glaciers to potentially return to their current state will take millennia, so we need to understand that the impact global warming will not stop within decades or even centuries after the end of the anthropogenic emissions of greenhouse gases into the atmosphere.

Increased melting of glaciers and formation of icebergs causes a global increase in sea levels. It is estimated at approx. 3.0–3.5 ± 0.5 mm/year (according to different authors). According to the latest work by

J. Box et al., Arctic glaciers are responsible for over 1/3 of this increase, constituting its largest regional source. Greenland's share in this is about 50 percent. The thermal expansion of seawater is the source of about 1/3 of the increase in ocean levels, and Antarctica along with other glaciers on Earth and reduced land water retention is responsible for the rest (less than 30%).

Between the years 1986–2005 and 2006–2015, the contribution of Arctic glaciers to raising global ocean levels increased threefold. Thus, Arctic glaciers play an important role in global environmental changes. The accelerated recession of Greenland outlet glaciers could threaten to bring about an accelerated rise in the global ocean level, which over a decade ago was estimated to be as much as 2 m through the end of the twenty-first century. W.T. Pfeffer et al. have shown that this number is not very realistic, because this glacier is surrounded on all sides by mountains, and the glaciers carrying the ice into the ocean squeeze through the narrow gates of the fjords.

We should remember, however, that increased ocean levels and sea water temperatures around West Antarctica are contributing to the slow disintegration of ice shelves and the acceleration of glaciers moving out of the West Antarctic Ice Sheet. Unlike Greenland, the largest of these glaciers (Pine Island Glacier and Thwaites Glacier, as well as the ice streams supplying the Ronne Shelf Iceberg) have wide gates with floors well below sea level. Many models show that with the significant instability of the Western Antarctic Ice Sheet, global ocean levels may rise by up to 3.3 m in a relatively short time, even over decades. Thus, the clear but limited impact of the Arctic glaciers on global ocean levels could contribute to a catastrophic sea level rise caused by glaciers on the other side of the Earth, in Antarctica, as suggested by the relatively numerous scenarios of global warming consequences.

A slow rise in sea level is also being observed on the Polish coast, caused by storm surges. The frequency of autumn and winter storm surges (>70 cm) has increased threefold in the last 60 years. This is also the result of global warming causing more intensive atmospheric circulation from the west. The destruction of beaches, erosion of cliff and dune coasts, and damage to coastal infrastructure are its consequences.

Responsibilities

- Arctic glaciers are exhibiting accelerated recession, confirming that global warming has been occurring for a long period of time.
- Increased melting accelerates the movement of tidewater glaciers, and consequently increases calving, which dramatically increases the negative mass balance of glaciers.
- This causes a positive feedback for further climate warming.
- Due to the fact that most tidewater glaciers are clearly below sea level, their recession will remain irreversible for several centuries, even if the warming stops and snowfall increases.
- The increased melting and calving of the Arctic glaciers plays a significant role in increasing global ocean levels. Their rise will not cease even if anthropogenic emissions of greenhouse gases are reduced.

We should therefore swiftly reduce greenhouse gas emissions in an effort to mitigate global warming. However, we should bear in mind that the glacier response will be delayed, even for millennia. Therefore, we should focus on adapting to life with a clearly warmer climate and rising sea levels.

Overall, work on tidewater glaciers highlights the complexity of climate research. It is particularly important to intensify international research efforts on studying the relationship between the atmosphere and the oceans and cryosphere.

Jacek Jania

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Keeping Our Heads Above Water

Prof. Zbigniew Kundzewicz from the PAS Institute of Agricultural and Forest Environment in Poznań talks about the negative impact of climate change on our lives and what we can do to save ourselves.

ACADEMIA: **What does climate change mean for the average Pole?**

ZBIGNIEW KUNDZEWICZ: It is already affecting the average Pole. Hardly anyone is aware of the fact that high temperatures are the main natural phenomenon responsible for killing Poles. A study conducted on this very issue at my Institute showed that in the years in which heat waves were particularly severe, there were more than 1,000 additional deaths in Poland's ten major cities, whereas in Europe overall the figure reached 70,000 in 2003. Two factors contributed to this: high air temperatures, including at night, and the effect of the urban heat island – sun-heated roofs, sidewalks and streets gave off heat at night. Typically there are less deaths in Poland in the summer months than in the winter. However, record high

temperatures turn everything upside down. In the coming decades, hot summers will become more frequent in Europe, occurring nearly every year. In addition, societies are aging, and people aged 65+ can't tolerate heat. In the summer of 2003 France saw a record number of deaths in Paris, with many of its elderly, sick and lonely residents dying. The health minister resigned because he underestimated the threat. Meanwhile, many of these deaths could have been prevented by taking simple preventive steps, such as trying to ensure that the elderly stay hydrated (seniors don't always feel thirsty, and this is the first step to dehydration).

Global warming is inevitably causing the glaciers to melt. How will rising sea levels affect Poland?

One can see with a naked eye that the mountain glaciers are shrinking. The melting of the Greenland and Antarctic ice sheets is responsible for half of the sea level rise, which is approximately 3mm per year on average. The other half is caused by rising water temperatures, which increases the water volume.

Poland is very sensitive to a rise in sea level. Even a small rise increases the probability of storm surges and backwater floods, which happened in the past and continue to happen, except that in this case even a few centimeters can lead to a significant increase of the frequency of storm surges.

A sea level rise of 4 meters will cause the Hel Peninsula to become a small island, the Żuławy region will simply disappear, and part of the Vistula valley will become flooded. This gloomy scenario, however, will not happen any time soon. Certainly not in the 21st century.

Couldn't we protect ourselves against flooding the way the Dutch have?

The Netherlands are located in a depression, and this is a bit different. In 1953, 2,000 people lost their lives in the Netherlands as a result of a great storm surge. Since then the government has invested enormous resources in protecting the country against flooding. It takes protection against floods much more seriously than other countries. The embankment on the sea side is the strongest construction of this type in the world, as it must withstand 10,000-year water (meaning exceeded once every 10,000 years, on average, so the annual probability of exceeding is 0.01%).

Also inland, on seemingly irrelevant brooks, there are protective structures built to protect against 125-year flood, which is more than many countries have on large rivers, where 100-year protective structures are considered to be really good. In the Netherlands, all protective structures are built to protect against 125-year flood, followed by 250, 400, 1250, and 4000 years, depending on the area.

So we can certainly learn from the Dutch, but it will not help us save Hel, because even the Dutch will not come up with a solution to this problem. I have been to the Netherlands many times, visiting Scheveningen near The Hague, where the beach is not as attractive as our beaches on the Baltic Sea. The embankment is extremely high, but for the people living there it is a serious matter.

So it is the lowest areas, like the Baltic coast, Żuławy or the Vistula valley that are most at risk. Is the rest of the country safe for now?

If the sea level increases by 40 meters, a large part of Poland will be flooded. The melting of the entire Greenland ice sheet would increase the sea level by 7.36 m, and the melting of the entire Antarctic ice sheet by 58.3 m. With significant warming, the high-

er areas will probably become islands, and in the long term, ultimately submerged islands.

In addition to the destructive pressure of rising sea waters, there are other types of floods. River floods, such as the floods of 1997 and in 2010 in Poland, are gaining momentum. More and more problems are caused by "urban floods" and "flash floods" caused by intense rain, which are too much for the sewage system to handle. Until recently, these were very rare, and now they occur in many cities, including Warsaw.

There are several reasons for this. Increasingly dense urban construction takes away ground space, which means that the water can't freely seep into the ground. Intense rain is becoming even more intense.

How are they related to global warming?

According to the laws of physics, warmer atmosphere can hold more water vapor, which increases the chances of intensive and more frequent rainfall. Prof. Tadeusz Niedźwiedź, a climatologist from the University of Silesia, clearly observed an increase in the occurrence of atmospheric circulation systems, which are associated with the risk of intense rainfall. It's true that rainfall projections are quite uncertain, and different models say different things, generally suggesting that humid locations will become even more humid (northern Europe – Sweden, Norway, Finland), and dry areas will become even drier (southern Europe – Spain, Portugal, Italy, southern France, Greece). And drier weather means more forest fires.

> Record high temperatures will turn everything upside down. In the coming decades, hot summers will become frequent in Europe, occurring nearly every year. Societies are aging, and older people tolerate heat poorly.

The year 2003, which I already mentioned as a record year for deadly heat waves in Europe, was also extremely dry, to the extent that nuclear power plants had to be shut down because there was not enough water for cooling.

When temperatures rise, we don't need to heat our homes, so we burn less fossil fuel. Shouldn't climate warming therefore decrease the consumption of coal and oil, and consequently lead to lower greenhouse gas production?

But in the summer we increasingly need air conditioning, which is more expensive and effectively cancels out the positive aspects of using less heating during winter. Air conditioning, which is good for adapting to climate change, is terrible when it comes to preventing it – power generation produces carbon dioxide emissions, contributing to global warming. But it is becoming more widespread and I'm afraid there is no escape from it, also for Poland.

We keep coming back to climate, talking about droughts and rainfall, but how can global warming effect the fauna and flora?

The academic answer to this question is that all living creatures seek out the right climate for themselves, including humans, so there is a threat of climate migrations. Species of flora and fauna change location, migrating north and to higher elevations. We are observing thermophilic species moving to new habitats. One example of this is the moth known as the Horse-chestnut leaf miner (*Cameraria ohridella*) originating in the Lake Ohrid area on the Balkan Peninsula, where the climate is warmer than in our country. But for years now this insect has been attacking chestnut trees in Poland, causing leaves to prematurely wither and fall. Also, unwanted species posing a direct risk to humans, such as ticks, have been clearly extending their range, appearing in places they never have before, including the far north areas of Scandinavia.

There are significant changes to biological systems, including phenological changes of plants, such as accelerated blooming or fruit ripening, as well as fauna activity, like the appearance of butterflies, or the migrating times of birds.

The growing season has extended, affecting the timings of crops and agricultural practices. The course of the weather observed in recent years in Poland, the result of climate change, has contributed to crop yield variability, as well as the emergence of new threats to crops from pests, diseases and weeds. In Poland, as in all of Europe, agriculture is subject to increasing climatic risks. We are afraid that unfavorable climatic conditions will continue for decades, increasing the variability of yields from year to year.

I once reviewed a study on truffles, whose future in the south of Europe is very uncertain. About 70% of the French production of truffles comes from cultivations, meaning you buy a grafted seedling that you need to water in order for it to grow. During a drought year, there isn't enough water. Each sector needs water. The only way is to ration it, but it still will not be enough for everyone, so truffle cultivation may begin

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PROF. ZBIGNIEW KUNDZEWICZ

Prof. Zbigniew Kundzewicz, PhD, DSc

is a hydrologist and climatologist. His work deals with system hydrology, the relations between climate and water resources, hydrometeorological extremes (especially intense rain events, floods and heat waves), as well as issues of global adaptation to changes and sustainable development. He has been involved in numerous scientific studies of the Intergovernmental Panel on Climate Change (IPCC).

to dwindle. This will give a chance to other countries with sufficient water supply. We have already seen an example of this in the successful introduction of truffles in England. How abut Poland? The truffle does not like frost, but who knows?

Who is to blame for climate change?

Almost all climatologists and everyone at the Katowice conference agree with the conclusion that anthropogenic greenhouse gas emissions are most responsible for the current global warming. The atmospheric concentration of carbon dioxide increases every year. There haven't been any Major annual fluctuations since the measurements began. The fuel crisis of the early 1970s did somewhat slow down the growth rate, but the level of concentrations continued to rise. Politicians from many countries gather every year at the climate summit, debating on how to reduce emissions. There is a lot of talk, but no effective action. The atmospheric concentration of greenhouse gases is gradually increasing.

Poland's economy is based on coal, of which we have a lot, but I'm not sure we can say that "we have coal reserves for 200 years" because it may soon become the most expensive energy source in Europe.

Perhaps the government should consider nuclear or renewable energy?

In my opinion, renewable energy has enormous potential in Poland. We're talking about energy taken from biomass, as well as geothermal, wind and solar energy. Although in Poland the sun does not shine as often and as intensely as it does in the south of Europe, the amount of solar radiation reaching the Earth's surface at our latitude should be utilized. Even Norway has introduced photovoltaic systems. There is still a lot to do in terms of improving energy efficiency. We should look for negawatts of energy saved, not just megawatts of energy produced.

I think we should take a look at Germany's energy policy. They are definitely moving away from nuclear energy, and gradually from coal energy. That only leaves renewable energy.

What can we do individually to produce less carbon dioxide?

We should try to reduce our "carbon footprint" as much as possible, reducing our energy consumption, which in most of Poland comes from the combustion of coal, oil and gas. Both direct consumption (the heating system, domestic electricity consumption, vehicle fuel consumption), as well as for manufacturing and transporting goods that we consume and use.

I think that we should look at coal consumption in more broad terms, taking into account many aspects, such as energy, employment, health, environment and climate. Historically, coal, "black gold," was a valuable resource for Poland, but it is also one of the causes of smog. According to the European Environment Agency, every year about 48,000 people in Poland die prematurely due to poor air quality.

Taking steps to mitigate climate change will therefore also contribute to reducing smog, because smog is caused by the burning of coal, which at the same time increases the atmospheric concentration of carbon dioxide, which in turn leads to global warming. We need a strong public campaign to reduce smog and carbon emissions. It should be strong enough to encourage drivers to start using public transport instead. If the weather is nice, we should cycle or walk to school, work or to the store. If we leave the car and walk instead, it will be better for the environment, for the climate, and for our health. Not to mention for our wallets, as it will not cost us anything.

Reducing the emission of pollutants from old, inefficient furnaces, in which all kinds of things are burned, would significantly improve air quality. Many cities in Poland subsidize the replacement of old furnaces with newer generation ones. A campaign has been launched promoting green energy through subsidizing home photovoltaic systems. These are steps in the right direction and I hope they will continue.

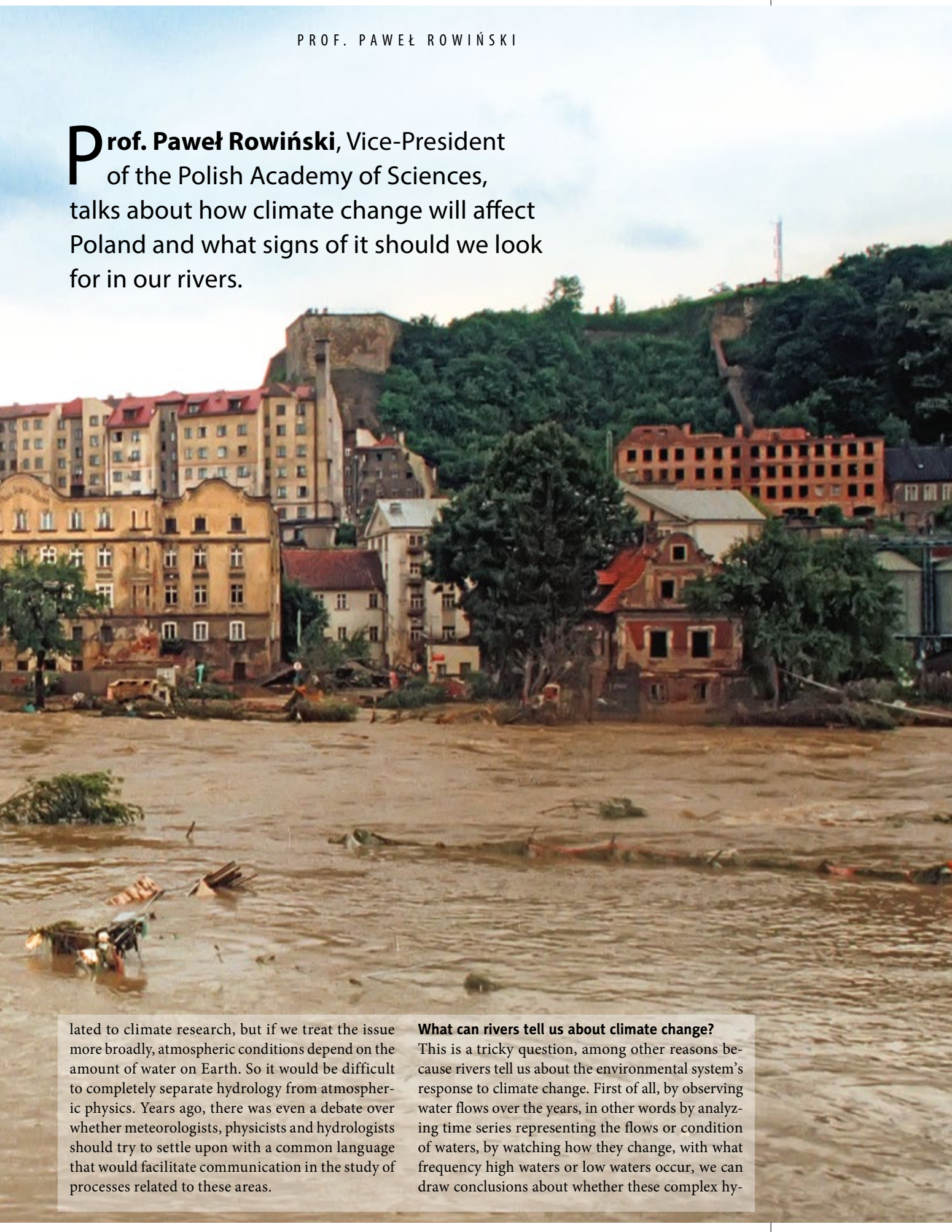
INTERVIEW BY **JOLANTA IWAŃCZUK**
PHOTOGRAPHY BY **JAKUB OSTAŁOWSKI**

Too Much Feedback

ACADEMIA: **What exactly is environmental hydrodynamics, the field in which you specialize, and what is its relation to the climate?**

PAWEŁ ROWIŃSKI: The word hydrodynamics has two parts: "dynamics" indicates movement, and "hydro," of course, means water. So hydrodynamics deals with everything that is related to the movement of water. I mainly study rivers, which are extremely complex. For example, turbulence, something we know from airplane travel, for instance, can be observed in rivers and better understood. Such turbulence in rivers is one of the least understood problems in science, even though it influences many processes occurring in the aquatic and natural environment. Among other things, it affects the status of habitats in river ecosystems, the development of benthic flora, the transport of pollutants and sediment, and also flood waves. This is not directly re-

Prof. Paweł Rowiński, Vice-President of the Polish Academy of Sciences, talks about how climate change will affect Poland and what signs of it should we look for in our rivers.



lated to climate research, but if we treat the issue more broadly, atmospheric conditions depend on the amount of water on Earth. So it would be difficult to completely separate hydrology from atmospheric physics. Years ago, there was even a debate over whether meteorologists, physicists and hydrologists should try to settle upon with a common language that would facilitate communication in the study of processes related to these areas.

What can rivers tell us about climate change?

This is a tricky question, among other reasons because rivers tell us about the environmental system's response to climate change. First of all, by observing water flows over the years, in other words by analyzing time series representing the flows or condition of waters, by watching how they change, with what frequency high waters or low waters occur, we can draw conclusions about whether these complex hy-

Previous page: flooding experienced by the Polish town of Kłodzko in 1997

drological systems react to climate change. Rivers are in large part responsible for catastrophic phenomena, i.e. floods and droughts, which have a huge impact on our lives. No one needs to be persuaded that a flood or drought can have dramatic effects, and it seems that in the future we will witness many more extreme phenomena like these. This is the main direct impact of climate change in Poland, which will not be as drastic as in tropical countries, which will experience extreme high temperatures. The climate in Poland will slowly shift towards a two-season year: a cool, rainy season and a dry, hot season. There will definitely be long periods when there will not be enough water. Droughts usually last longer than floods. If there is no snow, there will be no snowmelt flowing into rivers. Indeed, springtime snow-melt floods are occurring less and less often. This, in turn, has many economic consequences, such as in river transport and agriculture. On the other hand, we are observing more and more dangerous summertime precipitation-related floods.

No one needs to be persuaded that a flood or drought can have dramatic effects, and it seems that in the future we will witness many more extreme phenomena like these. This is the main direct impact of climate change in Poland.

Is historical data on rivers helpful in making predictions?

Definitely. This is the broad subject of study known as statistical hydrology. It teaches us how rivers react at times of low water, and when high water comes. Such historical situations recur, and so they can be predicted with a certain likelihood. Added to this is complex analysis of how all these processes vary over time. Back in the 1990s, I was part of a group led by Prof. Zdzisław Kaczmarek, which took part in the US Team Country Study. That was more or less at the time when the Intergovernmental Panel on Climate Change (IPCC) received the Nobel Peace Prize and he coordinated the Polish involvement in those projects. We then created models that answered the question of how river systems will react to various climate change scenarios. Such scenarios are devised based on a model of the global atmospheric circulation, and as time goes on these models account for more and more processes, they are becoming more and more precise. Back then these scenarios were posited on the basis of tools that were far from perfect, without answering questions regarding water relations under changing conditions, and such models were devised in Poland as well. Today, these models are more accurate, because computers are becoming more efficient ad we better understand all the processes, and so we can achieve better quality results. Compared to those of today, the methods we used back in the 1990s were far from ideal. This is probably why there was then a strongly audible voice of skeptics, who did not believe that climate change was actually taking place.

I should once again stress that the phrase "climate change" is a kind of a useful oversimplification. In fact, we are talking about different climate scenarios. Vast, complex models are built depicting what will happen to the climate, and then, by positing various likely scenarios, we try to determine what will happen with many other systems, for example with water resources. But the answer is not black-and-white. Depending on which climate scenario actually comes to pass, we can determine what will most likely happen to the rivers. I say "most likely," because even the IPCC report points to different scenarios. We are certain about the ongoing trends, but quantitative processes may proceed in various ways.

Is unpredictability the biggest problem?

It is an inherent part of natural science, including climate science. Speaking in mathematical terms, most of the phenomena we are talking about here are described by nonlinear equations. Often we do not know precisely what will happen because we are dealing with so-called unstable systems. Different elements of a system mutually influence one another, and there are many feedback loops within the system. We can only try to visualize what might happen based on observation, how the Earth's system will, colloquially speaking, go crazy. There is a danger that once a certain threshold is crossed, for instance in terms of temperature, the situation may go out of control. But we do not exactly know where that threshold lies. Will it be 1.5°C or perhaps 2°C? And then what? Certainly, in our geographicsl latitudes, the frequency of floods or droughts will surely increase, but all of this will have further consequences, and we don't know exactly what kind, because it depends on the extent to which individual elements of the system influence each other.

Ticks are a good example. They were once only a summer pest, but with warmer weather lasting longer, ticks now appear from March to November. This has led to increased cases of tick-related meningitis and borreliosis in Poland and throughout Europe. What will happen if the temperature rises by 1°C? We don't know, it's difficult to predict. Perhaps the tick

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PROF. PAWEŁ ROWIŃSKI

Prof. Paweł Rowiński, PhD, DSc

is a hydrologist working at the Department of Hydrology and Hydrodynamics, PAS Institute of Geophysics, where for many years he held the post of Director. His research involves mathematical modeling of turbulent flows, processes of pollutant and sediment dispersion in flowing surface waters, experimental research on turbulence and pollutant concentration zones in rivers, the impact of climate change on the water balance in catchments, adaptive evaluation and environmental management. He is Vice President of the Polish Academy of Sciences.

season will be all year round, but how will that affect human and animal health? It's difficult to estimate.

And that's just the biological aspect. What about the social one, such as migrations?

We can certainly expect human migrations, as people will want to escape from destructive weather phenomena. And the recent migration crisis has shown that we don't even know what to do with a small inflow of people to our area.

Many people think that a degree or two is insignificant.

Yes, they think the weather will simply be warmer, but more pleasant, that we may have a Mediterranean climate here in Poland. But even the tick example shows that changes will not be pleasant. We are not used to insects from different climates that cause malaria, for instance, and if it gets warmer, they may appear in Poland.

Because Poland is among the more wealthuy societies, there is a chance that we will manage to adapt to such changes. But it will be difficult to come to terms with the fact that if the sea water level increases by several meters, at some point we may find the sea reaching as far inland as the Polish town of Płock. We still don't fully realize what possible geographic changes may occur.

Taking all this into account, it would be cheaper and easier for people to make changes to their lifestyles rather than worry about an inevitable catastrophe.

Habits are hard to break, but actually if everyone in the world suddenly stopped eating meat, it would significantly reduce the emission of harmful gases into the atmosphere.

Unfortunately, the opposite is happening. Soon developing countries may be eating a lot more meat, as this is what happens when societies become richer. It is a problem of mentality, education, and contradictory signs aimed at young people. If politicians say that climate change is so-called "leftist talk" and there is nothing to worry about, some people will choose to believe it. But although the COP24 regulations are not yet binding enough to change the world, we are standing on the threshold of very serious decisions.

This is where trust in scientific research pointing to climate change comes in. It turns out that even among the scholars themselves, there are many people who doubt this research or try to interpret the finding differently. Geologists, for example, look differently at the Earth system than hydrologists. Did you also notice that there are more or fewer skeptics in particular scientific disciplines?

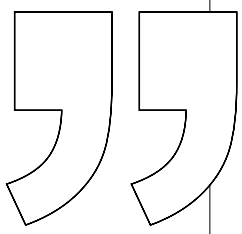
The number of skeptics is definitely on the decline, because it is hard to refute facts. But you are right, various things happen in Poland. You mention geology; there was for instance a resolution passed in 2009 by the PAS Committee on Geological Sciences, which perhaps did not exactly call climate change into question, but it showed great skepticism with respect to the anthropogenic causes of climate change. At the same time there was a resolution passed by the PAS Committee on Geophysics, which in fact supported the IPCC's position, not mincing words in presenting a rather pessimistic scenario. The position of this latter committee was in fact updated last year. The point at issue was the previously observed increases in CO_2 concentrations in the atmosphere, based on ice-core data, but we know after tall that they never attained today's levels. To this we need to add the incredibly rapid growth in CO_2 levels. In defense of the geological community here, we should stress that geologists are engaged in intensive debate about whether the current geological era should be called the Anthropocene, in recognition of the human impact on the Earth.

At the water festival sponsored by the Polish Academy of Sciences back in October 2018, someone said that water could become a luxury at some point. What can we do to prevent this from happening?

Water is the most precious commodity we have and it cannot be replaced. At the same time, we are not

used to viewing it in economic terms. These days, with water meters installed in our homes and having to pay water bills, we do know that it has its value. Of course this value varies depending on the region of the Earth. There are places, many at that, with no access to clean drinking water at all, and this affects significantly more than one billion people. But here in Poland, we also do not have too much of it, either. In terms of annual precipitation, Poland ranks in one of the last places in Europe.

Also, it is not just water quantity that matters, but quality as well. We still don't have enough quality water. On the world scale, more than 5 million people die each year because of poor water quality. We should also remember that with decreased supply, the quality of water dwill drop further. This can lead to many disasters, including armed conflicts. Water can't be replaced. We can look for solutions to replace coal, but nothing will replace water.



We constantly hear that there are nearly inexhaustible amounts of groundwater in Poland, but we don't realize that this water is also polluted. This is partially due to the revolting habit of building septic tanks that are leaky, so that they have to be emptied less often.

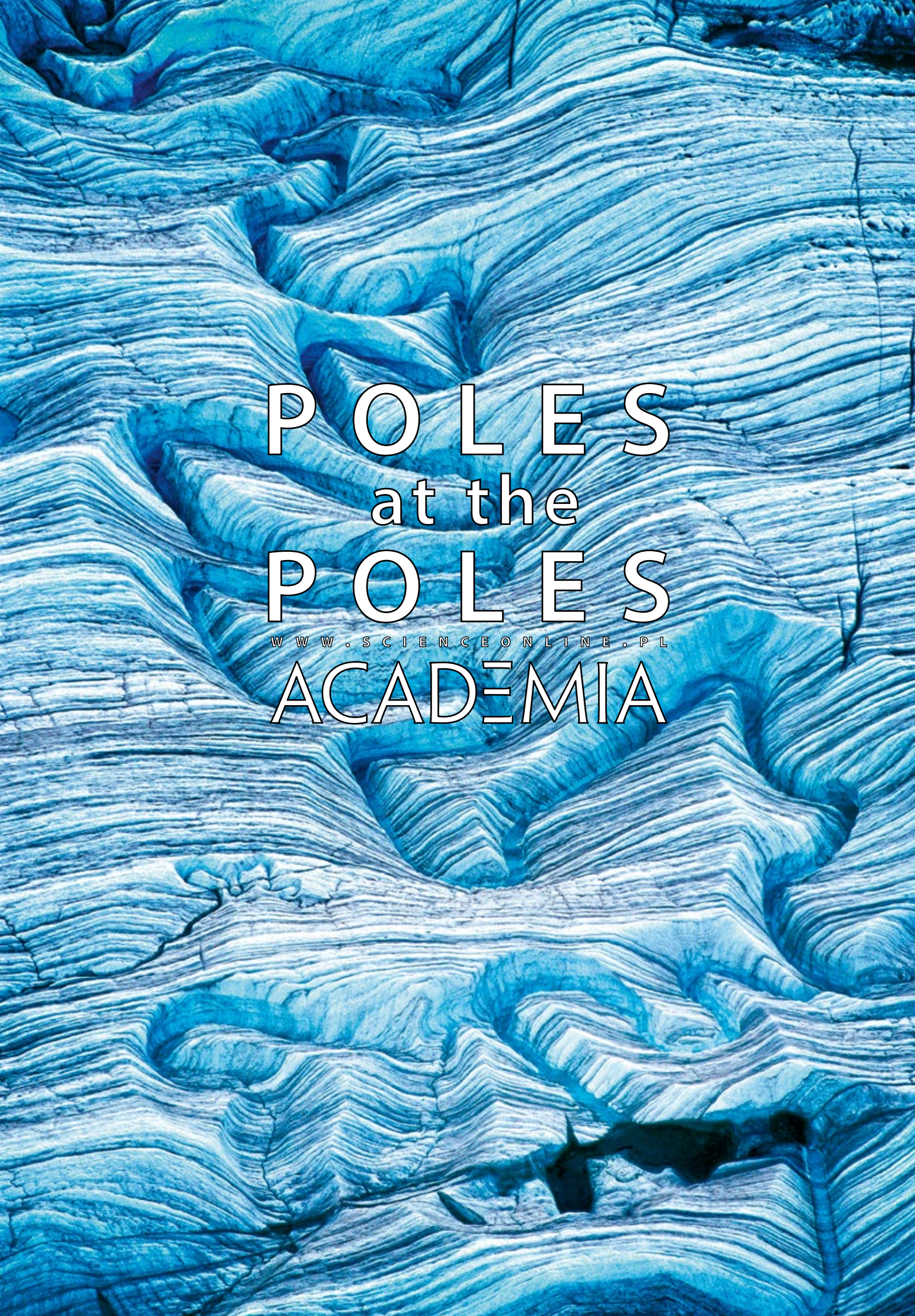
Which countries have plenty of clean water?
In Europe, Scandinavia is an excellent example. Its people understand the importance of water. They are best at adapting to climate change, just look at their hydropower systems, although technically some of the praise should go to Mother Nature as the mountains help derive energy from the gravitational force of water. But a lot depends on effective, balanced policy.

Is there an antidote to the upcoming water crisis? Is it possible to desalinate, purify and treat water on a large scale to make it drinkable?
It is, but it's still quite expensive. Plus there is a cultural aspect to consider. In many countries there is a tendency to treat rivers as sewage dumps, disposing of everything possible in them. In Poland, too, we have not fully managed to cope with this problem. The draining of waste from private farms is very common. We constantly hear that there are nearly inexhaustible amounts of groundwater, but we don't realize that this water is also polluted. This is partially due to the revolting habit of building septic tanks that are leaky, so that they have to be emptied less often. People don't realize that by doing so they are poisoning themselves as they are also drinking this contaminated water. For years now, there has been discussion about the problems with water quality in the Vistula River, or also in the Baltic Sea. Although we have to admit that these days things are improving, as more and more sewage treatment plants are appearing. But we're far from a satisfactory state of affairs. As I see things, education remains the most important factor here.

One of the main missions of the Polish Academy of Sciences is to use scientific research in practice. How does it look from your perspective? What's working and what could be improved?
Many scientists often study fundamental processes. And it is a good thing, because without solid research, good science is out of the question. But a huge number of studies are in applied research, and it would be a good thing if the findings obtained were garnered greater attention. A good example is coal power in Poland. Research clearly shows that we should not be using coal, but the topic is treated politically. After all, the closing of coal mines can in fact stimulate development, technologies, science, and the national economy. Much research carried out within the Polish Academy of Sciences head in this direction, to just mention the ultra-modern PAS Research Center for Energy Conversion and Renewable Energy Sources (KEZO) in the Warsaw suburb of Jabłonna. Discovering new technological solutions is an important driving-force of innovation. Science shows that all areas of life really comprise one great big system, and that only this holistic way of seeing things will allow us to take proper action. Problem solving only in emergencies will never bring long-term results.

So what we need is an interdisciplinary dialogue involving politicians?
Unfortunately, in Poland we have never had good cooperation between scientists and politicians. The voice of science gets ignored. Maybe because it deals with long-term issues, while politicians are mostly concerned about winning the next elections. But of course the answer to your question is: yes.

Interview by **Justyna Orłowska**
Photography by **Jakub Ostałowski**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Not To Be Ignored

Global warming is not a myth, there is solid scientific evidence for it. If humanity opts to ignore it, it will come to a catastrophic end.

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Prof. Szymon Malinowski

University of Warsaw

Global and local temperatures are breaking record after record. Extreme weather is wreaking havoc, leaving behind trails of devastation. Ice is disappearing in the Arctic, the snow cover continues to decline, and groundwater levels are decreasing. Intense heat waves and droughts are causing lower crop yields, forcing people to migrate. In Poland, limited rainfall and the continuous drop in groundwater levels are affecting crops and forests. Increasingly more violent storms are destroying property, sometimes even causing death. These are facts.

The forecast

The scientific world knows and understands the reasons for this state of affairs. Nearly 200 years ago, based on observational data and his understanding of the planet's energy balance, the French mathematician and physicist Joseph Fourier proposed the existence of a phenomenon known to us today as the greenhouse effect. Over 150 years ago, the pioneer Irish physicist and naturalist John Tyndall discov-

ered that the key greenhouse gases are carbon dioxide, methane and water vapor. He hypothesized that changes in the concentration of these gases in the atmosphere were responsible for the occurrence of ice ages. In the late nineteenth century, the Swedish chemist and physicist Svante Arrhenius, realizing that the amount of carbon dioxide in the atmosphere was increasing due to the combustion of fossil fuels, estimated changes in the surface temperature of the planet when the concentration of CO_2 increased and decreased by a factor of two. Using measurements provided by American physicist and engineer Samuel Langley on the transfer of solar and infrared radiation through the atmosphere, Arrhenius showed that the biggest changes would occur at high latitudes, a phenomenon that today we refer to as polar or arctic amplification. In the 1930s, the English engineer and inventor Guy Stewart Callendar showed that the temperature rise already observed was most likely due to the increased concentration of carbon dioxide in the air. These were pioneering works in the field of climate physics.

In Poland there is insufficient understanding of the problem, its scale and likely dramatic consequences, which, in the event of further neglect, will affect all people and the natural world as a whole.

During the Cold War, numerous research projects sponsored by the military, especially by the US Naval Research Office, made it possible to better understand how we are heating up the planet by increasing the greenhouse effect. Scientists then began to measure and calculate the radiative transfer of energy through the atmosphere. Observing the spread of radioactive isotopes after nuclear explosions, scientists studied ocean circulation and heat transport by sea currents. Studying the isotopic composition of carbon in CO_2 present the air and in ocean waters helped prove beyond any doubt that the burning of fossil fuels is responsible for its increased concentration in the atmosphere and hydrosphere. Studying the isotope composition of oxygen in marine sediments and ice cores confirmed the sensitivity of our planet's climate to even the slightest forcing. All these studies led to the conclusion that mankind is conducting a unique geophysical experiment, something that is beyond the capabilities of nature itself. By emitting carbon dioxide into the atmosphere at a huge rate, rapidly releasing carbon that had been accumulated in sedimentary rocks over millions of years, humans are disturbing the natural carbon cycle in the atmosphere, ocean and biosphere on a vast, planetary scale, causing changes to the climate unprecedented in the natural history of our planet.

The alarm

Concerned about possible consequences, researchers began to warn politicians and the public against this threat. This began with a report submitted to US President Johnson in 1965, which stated that a further increase in emissions over several decades could lead to enormous and rapid changes in air temperatures at the surface and sea level.

The report dealt with the state of the environment in general, the chapter on the climate change being just one of many, but it initiated many positive responses. It made us aware of our impact on the environment and inspired us to attempt to control it in order to minimize the negative effects. Today, emitting sulfur oxides, nitrogen oxides and many other substances to the atmosphere does not go unpunished in developed countries. We are no longer draining toxic waste into rivers, lakes and seas. One thing remains unchanged, however: the fact that we continue to treat the atmosphere as a free dump for carbon dioxide.

Despite the overwhelming evidence that by strengthening the greenhouse effect we are destabilizing the climate on which we depend 100%, we are not stopping these emissions, or even slowing them down. Reports by the specially-established Intergovernmental Panel on Climate Change (IPCC) show that we are quickly approaching a climatic catastrophe. Recent publications, including the IPCC Special Report on the global warming of 1.5°C, show that we have no time to lose and need to rapidly reduce our CO_2 emissions to zero.

The price of ignorance

In Poland, meanwhile, there is unfortunately insufficient understanding of the problem, its scale and likely dramatic consequences, which, in the event of further neglect, will affect all people and the natural world as a whole. In the media, politicians and publicists either avoid mentioning this issue or sweep it under the carpet. They often hold views completely contrary to the well documented evidence. The scien-

JAKUB OSTAŁOWSKI

PROF. SZYMON MALINOWSKI

Prof. Szymon Malinowski, PhD, DSc

is the Director of the Institute of Geophysics at the Faculty of Physics, University of Warsaw. He specializes in physics of clouds and precipitation, atmospheric turbulence, numerical modeling of atmospheric processes, and non-linear processes in the atmosphere. An active promoter of science, author of the climate-science blog "*Nauka o klimacie*" and co-author of a book of the same title. Winner of the 2017 Science Popularization contest in the "team" category.

tific community also has its share of global warming deniers, widely propagating their views, contradicting the knowledge about how the climate system works. No "cycles" or "galactic cosmic ray interactions" can explain the phenomena we are observing at the moment. Measurements of the planet's energy balance, radiation spectra, and ocean temperatures provide an unambiguous explanation, confirmed by many independent studies, of current global warming, while calculations based on the laws of physics and collected data provide information on the potential future.

However, in Poland the threat of a climate disaster is not seen as an important argument in favor of striving for a zero-emissions society. The priority is, instead, to preserve the current state of the economy, and emissions. What is the background of this absurdity? One of the most serious problems is the lack of scientific consultation in the field of modern physical climatology.

Many descriptive climatology specialists in the country are working independently or in small groups at numerous universities and institutes providing information on the changing climate. What we lack are strong, well-organized and properly equipped research groups in the field of physical climatology, numerical modeling of atmospheric processes, and basic research in the field of atmosphere physics. They should provide an understanding of the cause-and-effect relationships based on the basic laws of physics, propagate this knowledge to the public, and provide sensible advice to politicians, public administration, and businesses.

We have no research institutions able to provide specialized modern climate services to decision-makers. Various types of reports are published, but this usually happens through individual grants or projects financed from foreign research funding, and so it fails to ensure continuity or to build up scientific or consultative potential in this respect. The underfunded Polish Institute of Meteorology and Water Management is barely coping with the country's weather services and basic weather forecasts, and the Institute of Environmental Protection is desperately looking for specialists. Meanwhile Polish universities lack the staff to train new meteorological and climate professionals in compliance with the international standards described in the guidelines of the World Meteorological Organization (WMO).

Poland does not have enough human resources and funding for research, development and responsible consultancy in the field of climate policy. It lacks the appropriate organizational structures, and there is also a lack of awareness of what modern science can offer in this area. As one of the consequences, public and private debate on the topic is quite limited, barring occasional mentions in news stories about natural disasters, or during political events like COP 24 in Katowice. Meanwhile, climate change is increasingly affecting us, and it will soon have a dire impact on Poland, as shown by the abovementioned reports.

It depends on us

Global warming is progressing. Poland, Europe, and the world must adapt to the accelerating climate change, while simultaneously doing everything to slow its pace and keep global warming from going beyond 1.5°C above pre-industrial levels. Recent studies from many research centers around the world show that this number is just below the "limit of climate safety," which is estimated to be warming above 2°C. Passing this threshold will unleash powerful natural forces that will further increase warming, due to uncontrolled and unstoppable emissions of greenhouse gases from the frozen organic matter in the Arctic. The margin of error is small. If we go beyond this margin, we are heading for a climate and biosphere disaster on a planetary scale, one which neither man nor nature known to man might survive.

In short: the climate will not be ignored. We can still stop this disaster from happening, albeit on one condition – we have to really want to do so.

Szymon Malinowski

Empathy is Key

We talk to the pioneering climate-change researcher **Prof. Hans Joachim Schellnhuber** about the role of decency in fighting climate change, and why excellent climate science requires freedom and trust.

ACADEMIA: **What is your biggest hope when it comes to climate change?**
JOHN SCHELLNHUBER: My biggest hope is that humankind, including politicians and businesspeople, will become aware of the crisis we are facing. It is a monumental challenge. I have worked in this field for 25 years now, and I have never been so worried. Scientists are constantly warning, "It is 5 min-

utes to 12!" "And now it is only 3 minutes to 12!" and all this is actually true. We need immediate action. I simply hope that people will finally wake up to the scientific evidence.

What would be needed to facilitate that waking up?

It would require a combination of things, which I call the "3 D Theory." The first D unfortunately stands for "disaster." People often say that climate action is too expensive, but that is not true. In Germany and Poland, we have just experienced enormous droughts and heat waves. Across Europe, we had crop failures. These disastrous climate impacts are harming the economy. Other 2018 examples include the deadly forest fires in California. The State Insurance Commissioner just reported that it caused more than 9 billion dollars in insured losses. Sadly, it seems to take a catastrophe, a disaster, to awaken people to the severity of the threat of climate change.

The second D stands for "discovery" and tells a more hopeful narrative. In this country, you still have some 100,000 people working in the coal sector. To avoid more climate disasters, this industry needs to close down soon, but millions of new jobs will emerge with cleantech and with digitalization. People have to be trained so they can become fit for the next industrial revolution that will usher in a new era of modernity. Discoveries, inventions and innovations are what we need to master this transformation towards sustainability. Science will change our world dramatically in the decades to come. We should not be afraid of innovations, but we should explore and embrace them. Renewable energy, for example, could replace coal in Poland. It would not only reduce the reliance on imported Russian coal, but also lower air-pollution-related diseases and premature deaths in Poland. And it would create new jobs. By taking advantage of discoveries, we can do much better.

The third and final D stands for "decency." We need to be empathic, empathic with our fellow human beings. One historic example can teach us a lot: the abolition of slavery. In the 18th century, it was argued that abolition would mean the end of the economy, in England, in the Caribbean, anywhere. The shipbuilders of Liverpool, the world center of the slave economy at that time, told people in London that so many jobs would be lost that it would actually be socially unjust to end slavery. However, this skewed economic rationale was overruled by public sentiment. Tens of thousands of ordinary British people argued that black people ought not to be enslaved, because they are our fellow human beings, created our equals by God. This overpowering movement swamped Parliament, which finally passed laws that abolished slavery.

Another historic example of how human decency can bring about positive change is the fall of the apartheid regime in South Africa. When I was at UC Berkeley in California in 1990, I listened to Nelson Mandela's speech about the importance of the global "boycott" movement. Millions in the developed world refused to purchase products from South Africa and pushed for economic sanctions against the apartheid regime. It was actually Berkeley students that triggered the avalanche of divestment that finally brought the system down. Mandela thanked his young "blood brothers and sisters." In the end, it was a moral issue. Of course, there are many intricacies to these complex historic turning points, but human decency and morals often play a crucial role.

I believe that climate action works in a very similar way. While we keep on doing business as usual, slowly but surely, people from low-lying islands and other vulnerable regions will be killed or displaced. We will also bring about heat stress in the tropics that is so severe that people without air conditioning will perish. In many already disadvantaged regions of our planet, climate impacts will worsen the situation through extreme weather events, like floods and cyclones. If the world continues to burn fossil fuels and refuses to support societies in vulnerable regions, people from Central America to sub-Saharan Africa will have to migrate to escape from hunger and thirst.

> If we cannot quickly abandon the business-as-usual trajectory, modernity will crash into a wall of fire.

Of course, a combination of factors causes these crises. Economists simply say it is a matter of costs and benefits. You have the gigantic costs of the impacts of climate change across the planet. And you have the moderate costs of reducing greenhouse-gas emissions to create the huge benefit of avoiding catastrophe. The choice is self-evident…

So, disasters are the writing on the wall; they are becoming more frequent and more intense. Discoveries show us that we can do something about it, and in the end, we all need to be decent people with empathy for our brothers, sisters, and descendants. Not stopping climate change is a civilizational cul-de-sac. Unbridled

global warming would eventually bring the human enterprise to an end. I would not have said this some 20 years ago. When I set up the Potsdam Institute for Climate Impact Research back in 1991, the impacts of climate change were just an interesting academic topic, but today I tell you: if we cannot quickly abandon the business-as-usual trajectory, modernity will crash into a wall of fire.

So you envision that there's a chance climate change will be stopped, because of human decency. It is great to hear that you have such faith in humanity.

I do, but it is not just faith. Historical comparison helps us to remain hopeful. When you look back in human history, you have these types of movements, against slavery, against apartheid, or, of course, Solidarność in Poland. The victory of Solidarność was enabled by a combination of things: John Paul II played a role in the Vatican, Wałęsa played his role in Gdańsk, thousands of ordinary workers and citizens played their roles across the country. Amazingly, it was this very movement, which eventually sparked the fall of communist regimes all over Europe. It was just a small protest at the beginning and became so big by the end. That is why I have faith in human decency.

A group of protesters in front of the building where the COP24 symposium took place (also p. 44).

We are talking about compassion for other human beings. There is also a growing trend in Europe for showing compassion towards animals and stopping meat consumption. More and more people are turning vegetarian and vegan.

It is good that you raise this point. The whole problem of industrial agriculture is another important issue related to climate change. Even without considering the climate impacts of mass animal farming and the like, there are such cruel ways of treating other creatures involved: from practices in industrial slaughterhouses and the castration of little pigs without anesthesia, to the excessive use of antibiotics. Such a sin… We cram chickens, cattle, and fish into minute spaces and feed them lots of drugs to keep them "healthy." This creates resistant bacteria, resulting in antibiotics not working for humans anymore. A whole series of completely wrong and unethical steps.

In addition, this type of agriculture is harming the climate, because it takes so much energy to produce animal products like beef. It is cruel, it is nonsensical and it will kill the planet in the end, so it is nonsense in every conceivable way.

I grew up on a small farm in rural Bavaria. There are many farms like it in Poland. At most, we had a little piece of meat on Sundays, and yet I enjoyed everything I cared for. There is so much overconsumption nowadays. Being a little more modest would help our personal and planetary health. Some necessary changes require government policies, like switching from coal to renewable energy. But, just overnight, we could all change our behavior and it would have an immediate effect on the climate. Some say it is impossible, but we can do this. Within Europe, we could construct and take rapid trains instead of airplanes. Inaction is often just an excuse, because people want to keep sitting in their easy-chairs. Slowly, the first D of my theory – disaster – is making those chairs quite uncomfortable.

One part of the Earth system that is crucial to such extreme weather events is the Gulf Stream. I cannot miss this opportunity to ask: what is the real future of the Gulf Stream ocean currents?

There are two recent scientific studies on the Gulf Stream, one by our group at PIK and another by an international team. Both confirm that the Gulf Stream has weakened by about 15% since the 1950s,

Prof. Hans Joachim Schellnhuber

is a German theoretical physicist and Director Emeritus of the Potsdam Institute for Climate Impact Research (PIK). He is a member of the Pontifical Academy of Sciences, the German Leopoldina and the US Academy of Sciences. The many awards he has received include the German Environment Prize (2007), the Volvo Environment Prize (2011) and the Blue Planet Prize (2017).

even though this is just the beginning of global change. There is a significant risk that, if we follow a business-as-usual pathway, the North Atlantic deep water formation will shut down completely by the end of this century. If we warm the planet by more than 2°C, the Greenland ice sheet will start to melt irreversibly. When so much fresh water enters the Labrador Sea and other parts of the Arctic Ocean, it dilutes the salty water and hinders it to sink down. We know that this has happened in history, so we know it can happen again. To ensure that the Gulf Stream does not collapse, we definitely need to confine global warming to below 2°C.

And a collapse would spell tragedy for ocean ecosystems?

Precisely, and more. Atlantic ecosystems would be heavily damaged. Generally, above 2°C warming, Europe would experience more severe storms, and even droughts in the Sahel region would increase. We have also identified tipping points for other systems, such as the rainforests or the West African monsoon. Of all those entities, tropical coral reefs are the most vulnerable to climatic change.

The Potsdam Institute for Climate Impact Research (PIK), which you founded, has an impressive interdisciplinary approach to studying climate change. It studies climate change through oceanography, ecosystem sciences, economics and countless other disciplines. It is amazing that you have managed to bring all these people of very different backgrounds together in one place. Do scientists at PIK cooperate between the disciplines?

Absolutely, that was the plan from the very beginning. In 1991, I wrote down the concept of the institute on three pages and I emphasized: it has to be multidisciplinary, because climate change is a multifaceted, complex problem. This was almost revolutionary, since at that time doing interdisciplinary science was considered something only mediocre scholars do. Fortunately, I had already proven myself as a first-rate physicist, so I was freer to change course. Initially, I tried to build the institute like a miniature university with departments of biology, sociology, and so on. We soon realized that if we wanted to answer important questions, like how to make agriculture climate-proof, we had to be truly interdisciplinary. In 2006, I simplified the institute's make-up. We now have four departments, which are dedicated to very broad subjects. The first department deals with the complex Earth system as a whole, the second department looks at regional climate impacts and vulnerabilities, and the third looks into specific sustainable solutions to climate change. The fourth department is called "Transdisciplinary Concepts & Methods" and focusses on complex networks and dynamics. They can actually do almost whatever they like.

That sounds like a dream job...

Indeed. Beyond interdisciplinarity, freedom of research and trust are key. When I recently stepped down as director of PIK, we had an internal celebration where every second word mentioned by my colleagues was "freedom." People seemed grateful that I let them do their own thing. Many capable researchers apply to our institute, and if you employ them, you have to trust them. When you put good people together and allow them to cooperate freely, brilliant ideas emerge. For example, we recently found a new way to substantially improve the Indian monsoon forecasting. Knowing about the monsoon onset as early as possible allows people to prepare for the rains and saves hundreds of lives every year. In the end, our recipe for excellent climate science at PIK was freedom, trust and the belief in passionate young people. For the best of science, for the best of our climate, and hence for the best of people across the world.

Interview by **Justyna Orłowska**
Photography by **Jakub Ostałowski**

Religious and Spiritual Perspectives

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Any effective response to ecological crisis calls for collaboration of all parties involved.

Rev. Dr. John Chryssavgis

Archdeacon of the Ecumenical Patriachate

The crisis we face is – we all now know and we all now admit – not primarily ecological. It has less to do with the environment and more to do with us. In many ways, it has less to do with spending and more to do with spirituality. It is a crisis concerning the way we imagine and interact with the world. And in addressing this challenge, the world of faith can prove a powerful and persuasive ally in addressing it. We are treating our planet in an inhumane, godless manner because we fail to see it as a sacred gift. This means that, unless we radically change the way we perceive the world, we will continue to deal with symptoms, not their causes.

I believe that, in our relationship with creation, we are called to acknowledge and affirm our interconnectedness with the rest of the world. That is

what I like to refer to as the ecumenical imperative of creation care. This interconnectedness reminds us that, in a very peculiar and profound way, the earth unites us all – before and beyond any religious, political, racial, or other differences. We may or may not share doctrinal convictions or ethnic cultures. But we definitely share an experience of the natural environment: the air that we breathe, the water that we drink, the ground that we tread – albeit neither always equally nor always fairly.

The earth is what we all have in common; the earth is what we are made of and what we live from. Therefore, we cannot damage it without damaging those with whom we share it. By some mysterious connection that we do not always recognize (and sometimes choose to disregard), the earth reminds us of our fundamental calling to be humble and sensitive. That is arguably our greatest source of hope and joy.

If there is something we have learned from the ecological crisis, it is that our world constitutes a seamless whole, that our problems are universally shared-that no initiative or institution, no nation or corporation, neither science nor technology, can address this challenge alone. Any effective response calls for convergence and collaboration among civil leaders and religious believers, scientific thinkers and technological innovators, as well as all people of goodwill. What we desperately need is a model of cooperation, not a methodology of competition. We can no longer continue on an adversarial or partisan path, but instead learn to care and share-what in religious parlance we would call love and compassion.

> The earth unites us all – before and beyond any religious, political, racial, or other differences.

This is where the religious worldview converges with scientific research. For, if we consider ourselves as the center and meaning of the universe, then we are likely to search for meaning by scratching out an existence on this world and by exploiting the resources of this planet. But if we have a broader image of the universe, then the world ceases to be something I observe objectively and becomes something of which I am a vital part. In this larger panorama, I am no longer a stranger or threat to the world, but an ally and friend. This is how I interpret the Christian identity of being "in the world" but not "of the world" in the Gospel of John (17.14 and 16) How tragic it is that Christians have often construed these phrases as excusing and exonerating their exploitation of the earth's resources. How convenient it is that these same Christians omit or forget the verse between these two phrases, where Christ clarifies: "I am not asking you, Father, to take [my disciples] out of the world, but to protect them from evil." (John 17.15)

In order, however, to think and act like this, we must recognize that the earth is not something *else*, something *other* than or *external* to us. It *is* us – our body, our history, and our destiny. To paraphrase the popular refrain, we *are* the earth, we *are* the environment, we *are* creation. In this respect, the ecological crisis is compelling not as a vision for the future. As former co-chair of the IPCC Martin Parry once put it: "We are all used to talking about these impacts coming in the lifetimes of our children and grandchildren. Now we know that it's us." We need to address climate change as if confronting our very selves and our very lives-indeed our very survival. Otherwise, as science has long warned us and as current experience has made abundantly clear to us, ecological justice will follow suit with mathematical precision sooner or later; or, perhaps more accurately, sooner than later.

Far too often, however, we are sure that we have the solutions to the crisis that we face without first being still to listen to the earth that we have so burdened and blemished. We prefer to pursue tangible results in alternative energy or else are satisfied with more sustainable growth. Let us not forget that it is our actions that led us in the first place to the situation we are facing. In his now classic article on the roots of the ecological crisis, Lynn White Jr. already suspected – though he did not actually elaborate on – this truth:

> *The Greek saint [he wrote over half a century ago] contemplates; the Western saint acts. The Latins [...] felt that sin was moral evil, and that salvation was to be found in right conduct [...] The implications of Christianity for the conquest of nature would emerge more easily in the Western atmosphere.*

The present ecological crisis is not only the result of bad judgment or vicious greed on the part of some; it is largely a result of human effort and successful development. Nor should we somehow presume we are "good Samaritans" when religious believers and ideologies have long associated with "highway robbers."

Paradoxically, despite or precisely because of the urgency of the ecological crisis, ecological change, correction and conversion may begin with environmental inaction. It is not the inaction of inertia or indifference, but the discipline of silence and vigilance. It is a detachment that allows us to look at our world more humbly, to tread on our planet more lightly. This is precisely where the role and responsibility of

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Rev. Dr. John Chryssavgis

Archdeacon of the Ecumenical Patriarchate, was born in Australia, studied theology in Athens Greece, and completed his doctorate in Oxford England. He co-founded St Andrew's Theological College in Sydney and taught theology in Sydney and Boston. Currently he serves as theological advisor to Ecumenical Patriarch Bartholomew. He has authored over thirty books translated into many languages, including *Light Through Darkness: the Orthodox tradition* (Orbis), *In the Heart of the Desert: The Spirituality of the Desert Fathers and Mothers* (World Wisdom), *Toward an Ecology of Transfiguration: Orthodox Christian perspectives on environment, nature, and creation* (with Bruce Foltz, Fordham), and *On Earth as in Heaven: Ecological vision and initiatives of Ecumenical Patriarch Bartholomew* (Fordham). His book *Creation as Sacrament: Reflections on ecology and spirituality* will be published by Bloomsbury. He lives in Maine.

religion can prove invaluable. Drained of dogmatism and fanaticism, religion can link us mysteriously to the most ancient secrets of humankind and the universe.

There is a story in the *Sayings of the Desert Fathers* that relates how the devil once asked a monk, who looked like he was doing nothing: "What are you doing here?" The monk replied: "I am just *keeping* this place." This reminds me of the divine commandment given to Adam and Eve, "to till and keep the earth" (Gen. 2.15)-that I like to translate more literally as "serve and preserve the earth." And in every Divine Liturgy in the Orthodox Church, the deacon stands in the middle of the church and exclaims: "Let us stand in goodness; let us stand in awe." This sense of "goodness" reminds me of Genesis, when God looked upon creation and said: "Indeed, it is very good." (Gen. 1.31)

Before we can *act* responsibly, we are called to keep and preserve, to stop and see the world differently from the perspective not of what we *want* but what the world *needs*. But this will take no less than a crusade by religious leaders to force change among our political leaders, a movement as critically urgent and morally imperative as any campaign for fundamental human and civil rights, a movement that ultimately demands global service and personal sacrifice.

And here, I think, lies the heart of the problem. The truth is that we are unwilling to adopt simpler lives. If we are guilty of relentless waste, it is because we have lost the spirituality of simplicity and frugality. Again, at least to a large extent, the Christian church has regrettably opted for a more selfish, narcissistic worldview. Proof of this is that the almost two billion followers of Jesus, "who had no place to lay his head" (Matt. 8.20) and taught us "not to store up treasures on earth" (Matt. 6.19), today control more than two-thirds of the earth's resources and are three times better off than their non-Christian neighbors.

Still, for some reason, we are the ones doing the "deep ecology" thinking, and we are the ones refusing either to assume responsibility or else alter our patterns. In an article criticizing Pope Francis' Laudato Si', R. R. Reno, an American Catholic and editor of First Things, asserted:

It won't do to blame our difficulties on "those who consume and destroy," or to insinuate, as Francis so often does, that the rich and powerful stand in the way of ecological ideals and a just social order. This is cheap populism that falsifies reality. The global ecological movement is a rich country phenomenon funded and led by the One Percent.

The challenge is: How do I live in such a way that promotes harmony, not division? How do I live in such a way that communicates gratitude or generosity, not greed or arrogance? Because when we begin to understand that climate change is not just one in a long list of problems confronting politicians, we gain new insight and new perspective. Then, foreign policy looks quite different; then, threats to homeland security can be met by shipping technology instead of shipping weapons. Then, even the economy looks radically different; then, we can abandon the urge for unbridled expansion – for riches without risk and profit without price – and instead focus on the sustainability we so desperately need.

Mystics have always taught – what we have now learned all too painfully – that we are intimately and inextricably bound up with the history and destiny of our world. In my own tradition, in the seventh century, Maximus the Confessor spoke of the world as a "cosmic liturgy," a magnificent altar on which human beings worship in thanksgiving and a sacred song where the sun and moon, the trees and birds, praise God. And Isaac of Syria prayed for "a merciful heart, burning with love for all of creation: for humans, birds, and beasts." We have to recover this spirit of inclusion and spirituality of compassion, which allow us to see the world as God would see it and as God would have us see it. And if God saw the world as "very good" on that sixth day of creation, then we too can begin to sense in our world the promise of beauty and to see the world in its unfathomable interrelatedness. Then, we *shall* hear the grass grow and feel the seal's heart beat.

John Chryssavgis

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Climate and Christianity: The Legacy of Pope John Paul II

In 1979, Pope John Paul II spent just nine days in his home country, Poland. This historic pilgrimage lead to a 'spiritual revolution' that culminated in the peaceful collapse of the authoritarian regime in Poland, and eventually to the disintegration of the Soviet Union. Could leaders of the Christian churches today spark a similar 'spiritual revolution' to combat manmade climate change?

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The political legacy of Pope John Paul II went much beyond Poland. He strengthened the toppling of dictatorships, from Chile and Haiti to the Philippines. At the same time, the Christian effort to subvert Soviet oppression went far beyond John Paul II. The Pope was quintessential to the success of *Solidarność* in Poland – a powerful union of reason and faith that even Gorbachev acknowledged. However, an ecumenical spark of sorts existed between Poland and Germany, where the Protestant Church was a major catalyst for the fall of the Berlin Wall in 1989.

Ignorance is an important parallel between the political crisis then and the environmental crisis now. A parallel that heightens the importance of ethical guidance. The Communist era ignored fundamental economic principles, but modern-day capitalism ignores the most basic scarcities of today's world: the scarcity of natural resources in general, and specifically the limited capacity of our atmosphere, oceans and forests to capture and store carbon emissions. If we do not respect these fundamental natural scarcities, our Earth system will face the same destiny of collapse, although this time at a planetary scale.

At the heart of this threat to our common future lies the principle of the "global commons." Pope John Paul II highlighted this already in his 1987 encyclical

Sollicitudo rei socialis. He strongly supported democratic voices across the globe by proclaiming the universal right to human participation in the common good and the importance of solidarity with the poor and marginalized. Within Catholic doctrine, "this right to common use of goods is the 'first principle of the whole ethical and social order'" (John Paul II, 1981, §19). It "stems from the dignity, unity and equality of all people" (*Compendium,* §164). With particular relevance to climate change, the social doctrine states that "the universal destination of goods requires a common effort… in which progress of some will no longer be an obstacle to the development of others, nor a pretext for their enslavement"(*Compendium*, §175). Any ethical discussion of climate justice needs to engage with these principles of universal human dignity and solidarity. Principles in strong need of defence in a warming world, both within capitalist and communist systems. The "Polish Pope" himself, who stated, "there are many human needs which find no place in the market," was certainly not a champion of capitalism either.

His successor Pope Francis applies these central principles of the Social Catechism to climate change and continues the strong ecological legacy of John Paul II. In *Laudato si'*, he references this legacy several times. He echoes 'the ecological conversion' that John Paul II called for, and highlights that already "in his first Encyclical [John Paul II] warned that human beings frequently seem 'to see no other meaning in their natural environment than what serves for immediate use and consumption'" (§5). To protect the poor from adverse impacts of climate change, Pope Francis asks the world's community to establish an effective governance regime for the climate by declaring it "a common good, by all and for all." (§23, 174). Elevating the status of the climate to a global commons would entail a fair global sharing of the costs of mitigation, in particular by richer societies that are capable of doing so. This is an idea that some governments are obviously not keen to endorse, but which *Laudato si'* puts prominently on the table.

Moreover, *Laudato si'* opened new ground on two fronts: Never before has a Pope addressed the issue of climate change in such a systematic manner. And importantly, *Laudato si'* set out to soothe the age-old conflict between science and religion. The encyclical embraces the scientific consensus on climate change. It does not claim exclusive authority, but invites the scientific community to discuss possible paths forward together. Pope Francis here "embraces science while pointing out that ethical questions cannot be resolved by science alone" (Edenhofer et al., 2015, 907). He opened a dialogue between unusual partners: Scientists, diplomats, activists, politicians and those affected by climate change, all assembled around the encyclical as a platform to discuss climate justice. The resonance of *Laudato si'* within the scientific community was strikingly favourable: both *Nature* and *Science* – two leading scientific journals – published approving commentaries on the encyclical. Of course, our joint symposium on climate change, held on 10 December 2018 in Katowice, built on this very bridge that Pope Francis created between reason and faith.

Anticipating *Laudato si'*, John Paul II's ecological work was often ecumenical in spirit. In 2002, he published a joint declaration with the Ecumenical Patriarch Bartholomew I in which they argued that "the social and environmental crisis, which the world community is facing… is not simply economic or technical, it is moral and spiritual."(John Paul II and Bartholomew I, 2002). Together, they urged us all to foster more "ecological awareness, which is none other than responsibility towards self, towards other, and towards creation" (ibid.). Hence, a 'spiritual revolution' of the 21st century would need to promote what they call "a true culture of life" that respects "universal solidarity, social justice and responsibility" (ibid.) for our common home.

Drawing lessons from the Solidarność movement of the 20th century, only a union of reason and faith will be able to drive a 'spiritual revolution' strong and fast enough to limit global warming. Especially, since we have only about 30 years left to turn the wheels of history towards decided climate action. This task needs to be tackled by reason *and* faith, because it conjoins the entire human family and touches on a fundamental question that has occupied both scientific and religious communities for millennia: *How can we all live ethically and well together on this planet?*

It is important in this joint quest that we respect and affirm a plurality of truths, while seeking that which all of us share in common. Unity in diversity. Here, concepts like truth, freedom and dignity are nobody's exclusive dominion, but our common denominators, as central guiding principles. These powerful guiding principles are needed all the more in a world that is warming and again increasingly polarized along nationalist lines.

It is in this spirit of unity in diversity that we urge the scientific and religious communities to join forces in Poland, Europe and beyond. No 30-year-period in history has been as decisive as the one we are entering now. Let us walk in the footsteps of John Paul II and Pope Francis and foster a process of learning and transition that stabilizes the climate as our common good. Only together can we master the challenging task of decarbonizing the world economy until 2050. And only in a stable climate do our neighbours and children have a chance to live together in dignity, unity, and equality. Let us not squander it.

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Juliana Gärtner

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Core Concepts and Terms

- **Global mean surface temperature (GMST):** Estimated global average of near-surface air temperatures over land and sea ice, and sea surface temperatures over ice-free ocean regions, with changes normally expressed as departures from a value over a specified reference period. When estimating changes in GMST, near-surface air temperature over both land and oceans are also used.[19] {1.2.1.1}
- **Pre-industrial:** The multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850–1900 is used to approximate pre-industrial GMST. {1.2.1.2}
- **Global warming:** The estimated increase in GMST averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.
- **Net zero CO_2 emissions:** Net zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.
- **Carbon dioxide removal (CDR):** Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.
- **Total carbon budget:** Estimated cumulative net global anthropogenic CO_2 emissions from the pre-industrial period to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions.
- **Remaining carbon budget:** Estimated cumulative net global anthropogenic CO_2 emissions from a given start date to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions.
- **Temperature overshoot:** The temporary exceedance of a specified level of global warming.
- **Emission pathways:** In this Summary for Policymakers, the modelled trajectories of global anthropogenic emissions over the 21st century are termed emission pathways. Emission pathways are classified by their temperature trajectory over the 21st century: pathways giving at least 50% probability based on current knowledge of limiting global warming to below 1.5°C are classified as 'no overshoot'; those limiting warming to below 1.6°C and returning to 1.5°C by 2100 are classified as '1.5°C limited-overshoot'; while those exceeding 1.6°C but still returning to 1.5°C by 2100 are classified as 'higher-overshoot'.
- **Impacts:** Effects of climate change on human and natural systems. Impacts can have beneficial or adverse outcomes for livelihoods, health and well-being, ecosystems and species, services, infrastructure, and economic, social and cultural assets.
- **Risk:** The potential for adverse consequences from a climate-related hazard for human and natural systems, resulting from the interactions between the hazard and the vulnerability and exposure of the affected system. Risk integrates the likelihood of exposure to a hazard and the magnitude of its impact. Risk also can describe the potential for adverse consequences of adaptation or mitigation responses to climate change.
- **Climate-resilient development pathways (CRDPs):** Trajectories that strengthen sustainable development at multiple scales and efforts to eradicate poverty through equitable societal and systems transitions and transformations while reducing the threat of climate change through ambitious mitigation, adaptation and climate resilience.

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