WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

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WMO AIR QUALITY AND CLIMATE BULLETIN

Introduction

Ongoing climate change, caused by the accumulation of greenhouse gases in the atmosphere, is happening on a timescale of decades to centuries and is driving environmental changes worldwide. In contrast, the air pollution that occurs near the Earth's surface happens on a timescale of days to weeks, and across spatial scales that range from local (for example, urban centres) to regional (such as the eastern United States of America, northern India or the Amazon). Despite these wide-ranging differences, air quality and climate change are strongly interconnected. The *WMO Air Quality and Climate Bulletin* reports annually on the state of air quality and its connections to climate change, reflecting on the geographical distribution of and changes in the levels of traditional pollutants.

Traditional pollutants include short-lived reactive gases such as ozone – a trace gas that is both a common air pollutant and a greenhouse gas that warms the atmosphere – and particulate matter – a wide range of tiny particles suspended in the atmosphere (commonly referred to as aerosols), which are detrimental to human health and whose complex characteristics can either cool or warm the atmosphere.

Air quality and climate are interconnected because the chemical species that affect both are linked, and because changes in one inevitably cause changes in the other. Human activities that release long-lived greenhouse gases into the atmosphere also lead to the enhancement of concentrations of shorter-lived ozone and particulate matter in the atmosphere. For example, the combustion of fossil fuels (a major source of carbon dioxide (CO_2)) also emits nitrogen oxide (NO) into the atmosphere, which can lead to the photochemical formation[1] of ozone and nitrate aerosols. Similarly, some agricultural activities (which are major sources of the greenhouse gas methane) emit ammonia, which then forms ammonium aerosols. Air quality in turn affects ecosystem health via atmospheric deposition (the process by which air pollutants settle from the atmosphere to Earth's surface), which therefore also links air quality to climate. Deposition of nitrogen, sulfur and ozone can negatively affect the services provided by natural ecosystems such as clean water, biodiversity and carbon storage, and can impact crop yields in agricultural systems.

The United Nations Intergovernmental Panel on Climate Change (IPCC) recently released its Sixth Assessment Report (AR6) outlining the causes of observed climate change, the impact of climate change on society and the Earth system, and a range of solutions to mitigate climate change (https://www.ipcc.ch/reports/). The report includes scenarios on how air quality may evolve as the climate warms throughout the twenty-first century. These scenarios range from the possibility of increased emissions of air pollutants in developing regions of the world, to a carbon-neutral scenario in which urgent and effective policies to limit emissions of greenhouse gases (such as CO_2 and methane) provide the co-benefit of rapidly reducing emissions of air pollutants (such as NO, black carbon or sulfur dioxide (SO_2)).

The present edition of the *WMO Air Quality and Climate Bulletin* provides an update on the global distribution of particulate matter for 2021, highlighting the contribution of extreme wildfire events. In response to the growing frequency and intensity of wildfires, and the projected increase of wildfire activity in some parts of the world as the climate warms (UNEP, 2022), this edition of the Bulletin explores the impacts of smoke (from wildfires and crop burning) on air quality. The present Bulletin also explores a range of possible air quality outcomes as the climate continues to warm throughout the twenty-first century under high- and low-emissions scenarios, and concludes with an overview of the implications of atmospheric deposition for air quality, ecosystem health and climate.

Global particulate matter concentrations in 2021 recorded by the Copernicus Atmosphere Monitoring Service

Inhaling particulate matter smaller than 2.5 micrometres ($PM_{2.5}$) over long periods is a severe health hazard (WHO, 2021). Human and natural sources contribute to $PM_{2.5}$ pollution in varying proportions at the global scale. Sources include emissions from fossil fuel combustion, wildfires and wind-blown desert dust.

[1] Photochemical formation is a chemical reaction in which a molecule is formed in the presence of sunlight.

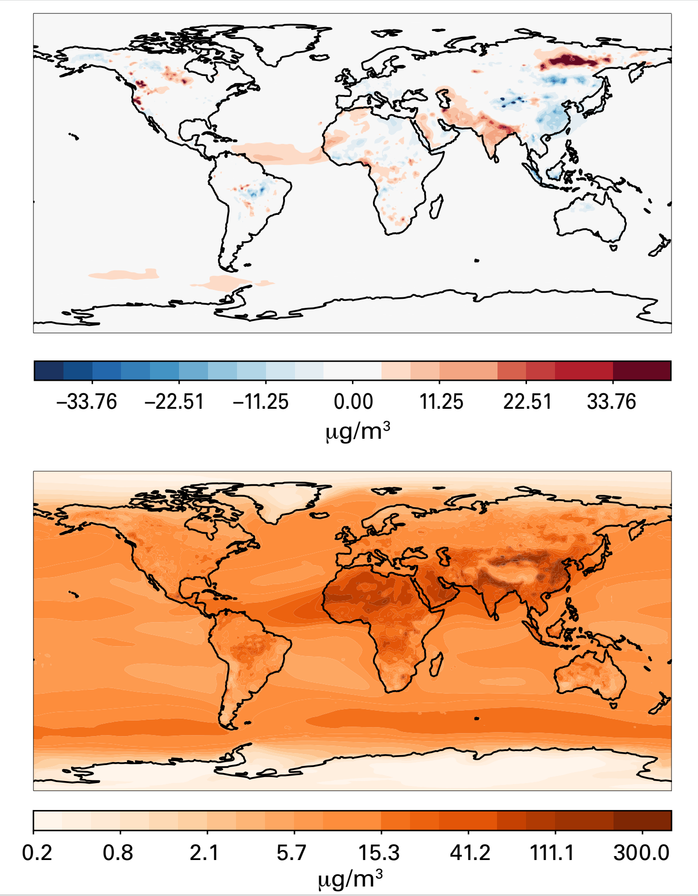

Figure 1. Anomaly (absolute difference) of the mean $PM_{2.5}$ surface concentrations (µg/m³) in 2021 of the CAMS reanalysis (top panel) compared to the average for the period 2003–2020 (bottom panel). Low concentrations across the oceans are largely due to naturally occurring sea salt particles. The CAMS reanalysis assimilates satellite-detected aerosol optical depth (AOD), from a Moderate Resolution Imaging Spectroradiometer (MODIS) and an Advanced Along-Track Scanning Radiometer (AATSR), with Global Fire Assimilation System (GFAS) wildfire emissions data. *Source*: ECMWF/CAMS

Intense wildfires generated anomalously high $PM_{2.5}$ concentrations in Siberia and Canada in July and August 2021. $PM_{2.5}$ concentrations in eastern Siberia reached levels not observed before, despite a continuous increase in wildfires in previous years driven mainly by increasingly high temperatures and dry soil conditions (Romanov et al., 2022). The $PM_{2.5}$ data from the Copernicus Atmosphere Monitoring Service (CAMS) reanalysis (which combines observations and model output to fill the gaps) indicates large anomalies (absolute differences) in the annual 2021 $PM_{2.5}$ surface concentrations (top panel, Figure 1) compared with the mean values for the period 2003–2020 (bottom panel, Figure 1), highlighting the large emission sources associated with wildfire areas in Siberia, Canada and western USA.

$PM_{2.5}$ anomalies caused by wildfires are the result of a series of additional factors, such as human activity, fire management, fire ignition (lightning or human-caused) and spread, in addition to meteorology. The positive $PM_{2.5}$ anomaly over India and the negative anomaly over China in 2021 were mainly manifestations of increased or decreased anthropogenic (human-caused) emissions in those two regions, respectively. In contrast to the positive $PM_{2.5}$ anomalies caused by wildfires in summer, the anomalies of the mainly anthropogenic $PM_{2.5}$ occurred mostly in winter, when cold and stable conditions with light winds trapped pollutants near the surface. Anthropogenic emissions from heating and local agricultural waste burning practices also peaked in the winter months in India and Southern Asia.

Growing air pollution hazards from wildfires

Wildfires, which encompass large-scale biomass burning, including forest fires, bush fires and savanna fires, are an integral and inevitable feature of the natural landscape. While wildfires that occur under natural conditions or are managed by traditional indigenous practices have a range of ecosystem benefits (Pausas and Keeley, 2019), increasingly intense wildfires can be devastating to the environment, wildlife, human health and economies (UNEP, 2022). Since wildfire smoke is a complex and dynamic mixture of gases and very small particles, it can irritate the human respiratory system. Exposure to this pollution, especially $PM_{2.5}$, is of great concern. At the global scale, observations of the annual total burned area show a downward trend over the last two decades as a result of decreasing numbers of fires in savannas and grasslands (*WMO Aerosol Bulletin, No. 4*). However, at continental scales, some regions are experiencing increasing trends, such as, but not limited to, parts of Western North America, the Amazon and Australia (UNEP, 2022).

As mentioned above, the 2021 fire season in Western North America was intense, with the annual total estimated emissions ranking among the top five years of the period 2003 to 2021, and causing widespread air pollution. Figure 2 shows that the May to September

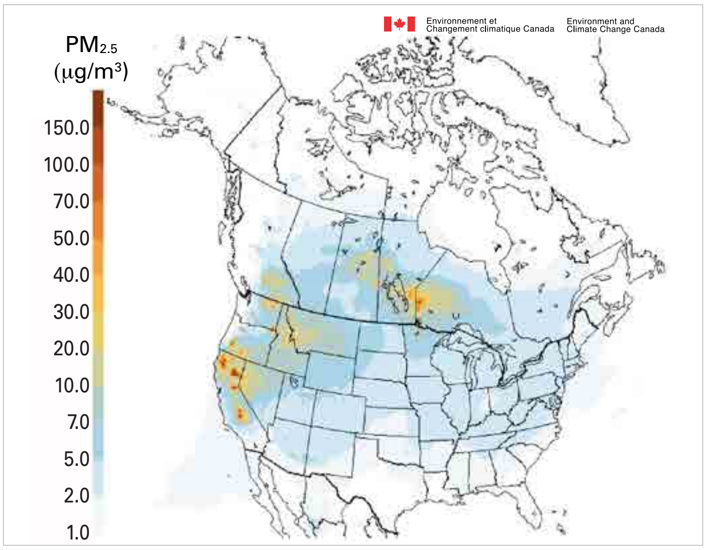

Figure 2. Seasonal (May to September mean) fire $PM_{2.5}$ contribution to total forecasted surface $PM_{2.5}$ concentrations (µg/m³) for 2021 over North America. These means were calculated using Environment and Climate Change Canada operational air quality systems: FireWork and Regional Air Quality Deterministic Prediction System (RAQDPS) (Moran et al., 2014; Pavlovic et al., 2016). The FireWork system is identical to the RAQDPS, except for the inclusion of satellite-derived, near-real-time wildfire emissions information. In order to estimate the direct contribution of fire $PM_{2.5}$ to the total $PM_{2.5}$ concentration, the RAQDPS $PM_{2.5}$ concentration field (valid at the same hour) was subtracted from the FireWork field.

mean contribution of wildfire emissions to total ambient $PM_{2.5}$ concentrations exceeds 10 μg/m³ and even 20 μg/m³ in some areas. To put this in context, the World Health Organization (WHO) annual recommended exposure limit for $PM_{2.5}$ is 5 μg/m³. The spatial distribution of adverse health risks attributable to this emission source was evaluated by applying the NASA GEOS atmospheric composition forecast system (GEOS-CF; Keller et al., 2021) with a multi-pollutant health-based air quality index designed for children with respiratory risks (Gladson et al., 2022) over North America. This analysis confirmed that the extreme $PM_{2.5}$ concentrations are largely driven by wildfire emissions and are primarily responsible for the highest adverse health risks in parts of Western and Northern North America.

Looking to the future, regional air quality may become increasingly influenced by wildfires, especially in light of regional climate change impacts. A measurable effect of climate change on a regional scale, affecting the frequency and intensity of wildfires, can already be observed in different parts of the world (UNEP, 2022), which hinders the achievement of WHO air quality targets. According to a recent UNEP report (UNEP, 2022), an increase of 50% in the number of wildfires is expected by 2100, a scenario not yet considered by existing air quality control strategies.

A detailed global quantification of characteristics of forest fires and their associated driving mechanisms is critical for developing robust air quality management strategies, particularly in fire-prone regions. The examples shown in this section illustrate the importance of evaluating air quality standards through a regional prism, of considering regional factors and mitigation possibilities and of integrating them into a global vision to improve air quality.

Future air quality under a high-emissions scenario

At the Earth's surface, ozone is an air pollutant that adversely affects health, crops and ecosystems. Changes in ozone can occur due to changes in both precursor emissions such as nitrogen oxides (NO_x, that is, nitrogen oxide plus nitrogen dioxide) and volatile organic compounds (VOCs) associated with the burning of fossil fuels or wildfires, or as a consequence of changes in weather patterns. Heatwaves are associated with poor air quality because the stable atmospheric conditions and low wind speeds allow pollutants to accumulate near the surface, while the hot, dry conditions are associated with intense sunlight which exacerbates the photochemical production of ozone. According to IPCC, an increase in the frequency, intensity and duration of heatwaves is virtually certain in the twenty-first century, which could favour an increase in episodes of poor air quality over and downwind of highly polluted areas.

In the framework of the latest IPCC assessment (IPCC, 2021), simulations were carried out using the latest generation of chemistry-climate models to quantify future changes in ozone levels. It is worth mentioning, however, that even the latest generation of chemistry-climate models cannot achieve the necessary resolution to fully capture emission hotspots and realistic NO_x and VOC regimes for ozone creation. Results of these simulations must therefore be interpreted with care. Nonetheless, according to these simulations, under a scenario in which air pollutant emissions increase in developing regions of the world, surface ozone levels are also projected to increase. Ozone increases are mainly due to increases in precursor emissions; however, increasing temperature and changes in mixing condition (as attributes of climate change) can also have an impact. If only the impact of the latter is considered, ozone concentration is predicted to decrease across the oceans and many land areas of the world. This is because warmer air typically contains more water vapour, which diminishes ozone concentrations through chemical reactions. However, the decreases on land are predicted to be small, and if greenhouse gas emissions remain high, such that global temperatures rise by 3 °C from pre-industrial levels by the second half of the twenty-first century, surface ozone levels are expected to increase across heavily polluted areas, particularly in Asia (Figure 3). For example, under this scenario, future ozone could increase by 20% across the region encompassing Pakistan, northern India and

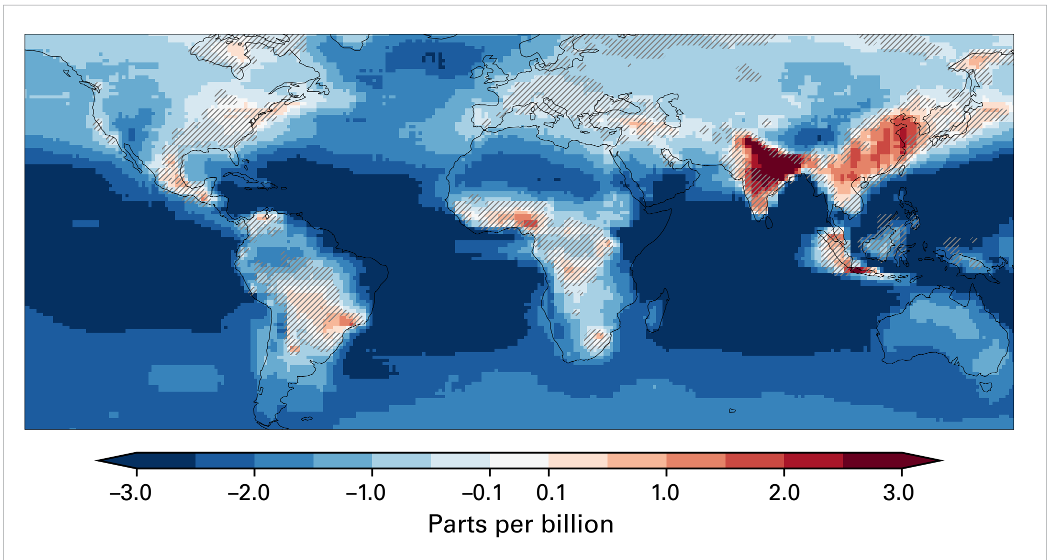

Figure 3. Projected changes in surface ozone levels due to climate change alone in the late part of the twenty-first century (2055–2081), if average global surface temperature rises by 3.0 °C above the average temperature of the late nineteenth century (1850–1900). This projection assumes increasing air pollutant emissions in developing regions and is based on simulations from five global chemistry-climate models. Hatching indicates regions where less than four out of five models agree on the projected changes, therefore greater confidence is placed on the regions without hatching. See Zanis et al. (2022) for further details.

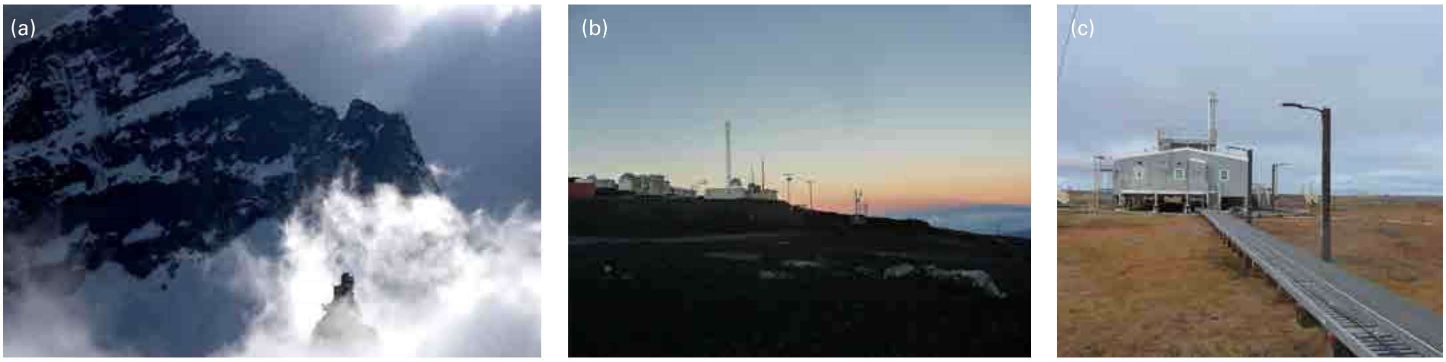

Figure 4. WMO Global Atmosphere Watch (GAW) Programme sites that have measured atmospheric constituents since the 1970s: (a) Sphinx Observatory station, Jungfraujoch, Switzerland (photo: Paul Scherrer Institute); (b) Mauna Loa Observatory, Hawaii (photo: Betsy Andrews); and (c) Barrow Atmospheric Baseline Observatory near Utqiagvik, Alaska (photo: Betsy Andrews).

Bangladesh, and by 10% across eastern China. Most of the ozone increase would be due to an increase in emissions from fossil fuel combustion; however, roughly a fifth of this increase would be due to climate change, most likely realized through increased heatwaves, which intensify air pollution episodes. This climate change effect on ozone pollution is referred to as the "climate penalty". While the regions with the strongest projected climate penalty cover a relatively small proportion of the Earth's surface, they are home to roughly one quarter of the world's population, and therefore climate change could exacerbate ozone pollution episodes, leading to detrimental health impacts for hundreds of millions of people.

Unlike in a high-emissions scenario, where most of the projected increase in surface ozone would be due to ozone precursor emission increases rather than as the direct effect of climate change, in a worldwide carbon neutrality emissions scenario the future occurrence of extreme ozone air pollution episodes would be limited. This is because efforts to mitigate climate change by eliminating the burning of fossil fuels (carbon-based) will also eliminate most human-caused emissions of ozone precursor gases (particularly NO_x, VOCs and methane). However, in terms of mitigating the air pollution produced by wildfires, reducing fossil fuel emissions will have limited success because wildfires would continue to occur. Even under a low-emissions scenario, the Earth's atmosphere would continue to warm slightly because the climate has not yet fully responded to the greenhouse gases that have already been accumulating in the atmosphere. IPCC has assessed that the probability of catastrophic wildfire events – like those observed in central Chile in 2017, in Australia in 2019 or in the western United States in 2020 and 2021 – is likely to increase by 40%–60% by the end of this century under a high-emissions scenario, and by 30%–50% under a low-emissions scenario.

The interplay between climate and air quality in a low-carbon future

Atmospheric aerosol particles (such as dust and black carbon) come from both natural sources and human activities. Particle amounts vary in space and time because of their multiple sources and relatively short residence time in the atmosphere. High aerosol amounts are an attribute of poor air quality. Not only do they have a negative impact on human health but they can also induce atmospheric cooling by reflecting sunlight back to space, or by absorbing sunlight in the atmosphere so that it never reaches the ground. Satellite observations are one of the ways to assess global aerosol levels. Another way is through detailed aerosol measurements made at surface sites, such as the WMO Global Atmosphere Watch (GAW) Programme stations around the world (Figure 4). Both types of observations provide long-term (>10 years) data sets from which aerosol trends can be derived. The measurements indicate that atmospheric aerosol amounts continue to decrease (see Figure 5), consistent with the decrease in the light extinction by particles (that is, the collective impact of aerosol particles reducing the amount of sunlight that reaches the ground, whether by absorbing or reflecting sunlight) that began in the 1980s for Central Europe and North America and in the 2000s for Northern Asia, South America and

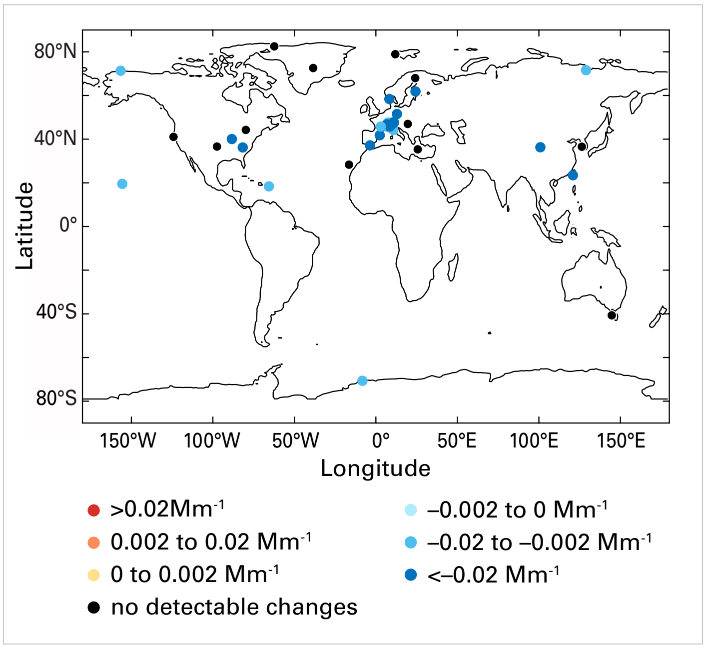

Figure 5. Long-term trends of light absorption by black carbon and mineral dust, as measured at surface stations around the world from 2009 to 2018. Units are inverse megametres (Mm^{-1}), a standard measure of light absorption in the atmosphere by particles or gases. Blue and orange symbols correspond to negative and positive trends, respectively. *Source*: Adapted from Collaud Coen et al. (2020)

most of Africa (IPCC, 2021). This decrease indicates the effectiveness of air quality policies in reducing atmospheric aerosol particles and their precursors; however, such reductions also increase the amount of sunlight (and thus heat) reaching the Earth's surface. Regions which adopted the earliest air quality control policies now exhibit less atmospheric cooling potential due to changes in aerosol concentration and composition.

Global climate models are generally able to reproduce the observed regional trends in aerosol amounts; however, the simulated magnitude and uncertainties of the trends differ among models and from observations. In light of this, models can be used to complement satellite measurements for estimating aerosol trends in places without observations, but with lower confidence. The lack of long-term observations in some regions (for example, in much of the southern hemisphere) limits our ability to understand some key air quality and climate forcing[2] components (such as black carbon concentrations) which are difficult to detect with satellite and other remote sensing instruments.

As mentioned in the previous section, the Sixth Assessment Report (IPCC, 2021) uses models to evaluate a range of mitigation scenarios in order to understand their potential impact, both on air quality and climate. One such mitigation scenario is the low-carbon pathway (SSP1-1.9), which assumes that carbon dioxide emissions are cut to net zero around the year 2050. The cutting of carbon dioxide emissions will also affect concentrations of atmospheric aerosol particles and their precursors because these are co-emitted with greenhouse gases such as carbon dioxide. The Sixth Assessment Report (IPCC, 2021) suggests that the low-carbon pathway will be associated with a small, short-term warming prior to temperature decreases. This is because the effects of reducing aerosol particles, that is, less sunlight reflected into space, will be felt first, while the temperature decrease in response to reductions in carbon dioxide emissions will take longer to manifest. However, natural aerosol emissions (such as dust and wildfire smoke) are likely to increase in a warmer, drier environment due to desertification and drought conditions, and may cancel out some of the effects of the reductions in aerosols related to human activities. How such changes would impact regional and global air quality and climate is rather uncertain.

There are trade-offs between the health effects and climate effects of atmospheric aerosols (high loads are bad for health, but good for cooling). The Sixth Assessment Report (IPCC, 2021) notes that "Some options for improving air quality cause additional climate warming, and some actions that address climate change can worsen air quality." The low-carbon pathway appears to help with both issues – quickly lowering the aerosol concentrations to which people are exposed, while also accelerating the removal of key warming agents.

[2] Climate forcing is the physical process of affecting the Earth's climate through a number of forcing factors, such as by increasing the levels of greenhouse gases in the atmosphere.

Atmospheric deposition connects air quality, ecosystem health and climate

Deposition and ecosystem impacts

Gases and particles are deposited from the atmosphere to ecosystems via dry deposition (when gases or airborne particles leave the atmosphere by coming into contact with the surface of the Earth) or via scavenging by precipitation, also known as wet deposition (when gases or particles are removed from the atmosphere by raindrops or snowflakes). While deposition of many pollutants (such as ozone) is important, the present discussion will focus on other pollutants that can also be harmful. For example, nitrogen (N) and sulfur (S) compounds alone and in combination are sources of acidity in ecosystems and, in the case of N, also cause effects related to availability of excess nutrients, that is, eutrophication.[3] Acidification of soils and waters can increase plant and aquatic life mortality and increase vulnerability to other ecosystem stressors (such as climate change). Additionally, N deposition can harm lichen, reduce soil microbial diversity and alter plant community composition. These impacts affect the quality of services provided by healthy ecosystems, including biodiversity, clean drinking water, food and forest products, and carbon storage. Critical loads (CL), which are deposition amounts above which harmful effects might be expected, link ecosystem exposure to air pollution (that is, air quality), via deposition. CLs have been developed for a range of ecosystem components, and impacts from acidification and eutrophication are used to assess risk from current pollution and inform policy and management.

Trends in air quality and deposition

In Europe[4], emissions of S and N from fossil fuel combustion (namely, oxidized forms such as SO_x and NO_x) have decreased over the past two decades (2000–2019) by approximately 75% (SO_x) and 40% (NO_x) with associated reductions in air concentrations and deposition. Emissions of ammonia (NH_3), a form of reduced N that originates primarily from agriculture, have decreased by only about 10% over the same domain (EMEP, 2021). In the USA, emission reductions (approximately 90% for NO_x and SO_x since 2000: U.S. EPA, 2022) have also led to decreasing N and S deposition. In China, emissions of SO_x and NO_x have also been reduced (by approximately 62% and 17%, respectively) since 2010 (2010–2017) (Zheng et al., 2018), along with deposition of oxidized N and S (Zhao et al., 2021), while emissions and deposition of reduced N (that is,

[3] Eutrophication is the enrichment of an ecosystem with a limiting nutrient. It can occur in both land-based (terrestrial) and aquatic ecosystems. For example, too much nitrogen in aquatic ecosystems can lead to algal blooms, dead zones and fish kills.

[4] This includes the 27 European Union members, the European Free Trade Association members, the United Kingdom of Great Britain and Northern Ireland, Monaco and the Western Balkans

mainly gaseous NH_3, aerosol ammonium (NH_4^+) and wet deposited ammonium) have remained at a relatively high level. Due to regulations on fossil fuel combustion, but not on agriculture, N deposition in Europe and the USA has shifted toward a predominance of reduced rather than oxidized N, while a more equal distribution is observed across China.

Status of deposition and critical load exceedance in different regions

Across Europe, CLs for eutrophication are exceeded in most countries (Figure 6(d)). In contrast, CLs of acidity are exceeded in a much smaller area (Figure 6(b)) due to sharp declines in S deposition (Figure 6(a)). In the USA, decreasing S deposition has confined exceedances of the CL for surface water acidity to relatively small areas in the east, although many surface water systems are still impaired due to historic high deposition. Similar to Europe, exceedance of the CL for eutrophication is more widespread in the USA, with lichen communities, alpine surface waters and some plant species being particularly sensitive (Geiser et al., 2019; Lynch et al., 2020). Though emissions are declining, rates of S and N deposition are greater in China compared to Europe and the USA, with highest CL exceedances for N and S deposition occurring in the south-west and central regions of China (Zhao et al., 2021).

Path forward

Deposition of S and N and their resulting impacts on ecosystems are highly variable around the globe. Based on current CL assessments, exceedance of healthy levels of deposition is widespread, particularly for N. Maps indicating deposition and CL exceedance, such as those presented in Figure 6, are important tools for the management of air quality and ecosystem health. However, more advanced methods that fuse measurements and atmospheric models to generate total deposition maps with global coverage (Fu et al., 2022) are urgently needed to reduce uncertainty in CL exceedances and better evaluate risk of ecosystem harm. To improve these methods and the underlying models, more measurements of wet and dry deposition (Figure 7) are needed, particularly where monitoring remains geographically sparse (Africa, India, South America). Looking ahead, steps toward better management of air quality to protect ecosystem health will play an important role in the development of sustainable nature-based climate solutions.[5]

[5] Nature-based climate solutions involve conserving, restoring and better managing ecosystems to remove carbon dioxide from the atmosphere and reduce greenhouse gas emissions.

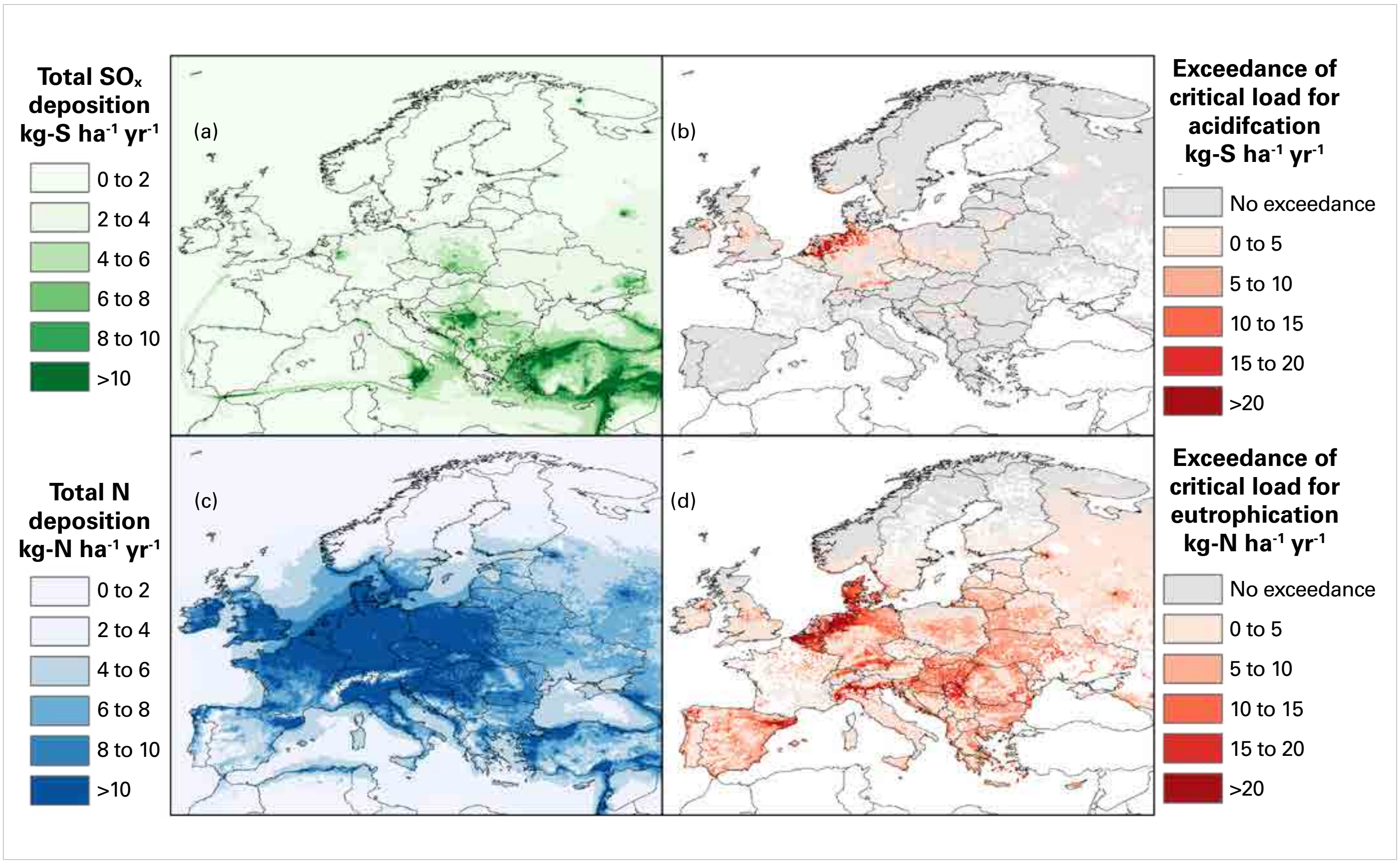

Figure 6. Atmospheric deposition of total oxidized sulfur (SOx) and total reactive nitrogen (N) (measured in kg per hectare per year) (EMEP, 2021) and associated critical load exceedances (that is, amount of deposition in excess of the critical load) for terrestrial acidification and eutrophication across Europe in 2019. In this map, total reactive nitrogen includes both oxidized and reduced forms of nitrogen. Methods for quantifying the critical loads shown here, and the spatial resolution of the critical loads data, vary by country (Hettelingh et al., 2017).

Figure 7. Examples of samplers for wet deposition ((a), Duke Forest, Chapel Hill, North Carolina, USA; photo: John Walker), wet and dry deposition (throughfall) beneath a forest canopy ((b), Duke Forest, Chapel Hill, North Carolina, USA; photo: John Walker), and dry deposition of total reactive N ((c), Bavarian Forest National Park, Germany, Wintjen et al., 2022; photo c/o Christian Brümmer). Methods for monitoring deposition range in complexity and cost, from relatively simple funnel type collectors for measuring throughfall, to the advanced systems that combine measurements of atmospheric turbulence and chemistry at higher temporal resolution that are needed to directly determine dry deposition (c).

Conclusions

This second edition of the *WMO Air Quality and Climate Bulletin* highlights the growing impact of wildfire smoke on air quality in many regions of the world. As in 2020, hot and dry conditions in 2021 exacerbated the spread of wildfires across Western North America, producing widespread increases in $PM_{2.5}$ that reached levels known to impact human health. As the climate warms during this century, wildfires and associated air pollution are expected to increase, even under a low-emissions scenario. In addition to human health impacts, increasing air pollution will also affect ecosystems via increased atmospheric deposition.

A warming climate is also expected to produce an increase in the frequency, intensity and duration of heatwaves in the twenty-first century. This could lead to increases in episodes of poor air quality over highly polluted areas, and a degradation of air quality in those areas where emissions are not necessarily high, a phenomenon known as the climate penalty. If fossil fuel burning continues to increase in developing regions of the world, surface ozone pollution will also increase in those regions, with a fifth of the ozone increase caused by climate change.

Long-term surface-based and satellite observations of atmospheric aerosol particles show aerosol amounts are decreasing in most places around the world, leading, on the one hand, to improved air quality, but on the other hand, to a decrease in the atmospheric cooling provided by these sun-shielding aerosol particles. However, if a low-carbon emissions scenario is achieved around the globe, the short-term warming due to lower aerosol amounts would eventually be cancelled out by the slower decreases in greenhouse gas concentrations, and the atmosphere would begin to cool.

A future world where a low-carbon emissions scenario is achieved would also benefit from reduced deposition of nitrogen and sulfur compounds from the atmosphere to the Earth's surface, where they can damage ecosystems through acidification and eutrophication. The response of air quality and ecosystem health to proposed future emissions reductions will be monitored by WMO GAW stations around the world, which can quantify the efficacy of the policies designed to limit climate change and improve air quality.

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