

WEATHER,
CLIMATE
AND THE AIR WE
BREATHE



World
Meteorological
Organization

Weather • Climate • Water

WMO-No. 1035

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FOREWORD



Michel Jarraud, Secretary-General

In 1873, when the First International Meteorological Congress met in Vienna, Austria, to establish the International Meteorological Organization, which preceded the World Meteorological Organization (WMO), the key objectives were to establish networks of meteorological observing stations. These were appropriately linked, thanks to Samuel Morse's recent development of the telegraph, so that progress could be made in weather forecasting and thereby contribute to the safety and efficient operation of shipping.

Over the years, the range of meteorological services dramatically expanded and the requirements became more exacting, most notably with the advent and rapid growth of aviation. However, weather forecasting and the meteorological statistics that soon led to an exciting new discipline—climatology—were principally concerned with assisting the efficiency and safety of operations taking place in the environment, rather than the protection of this environment.

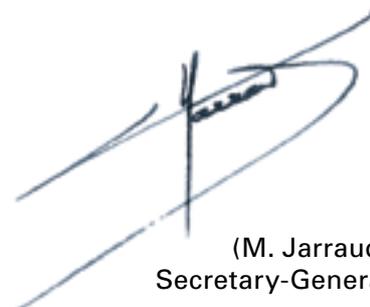
On 23 March 1950, IMO became WMO and it was later decided that WMO and the international meteorological community would celebrate World Meteorological Day on this date every year under an appropriate

theme. On the occasion of its 59th session (Geneva, May 2007), the WMO Executive Council decided that the theme for World Meteorological Day in 2009 would be "Weather, climate and the air we breathe", in recognition of the integration of environmental issues that has been achieved within the framework of WMO's activities.

It is especially stimulating to note that a large share of our atmospheric composition data was accumulated and stored by meteorologists even while the potential applications were not yet clear. For example, long before the ozone hole became an issue, meteorologists were using Dobson spectrophotometers for stratospheric circulation studies, which permitted WMO to play a key role in the Vienna Convention for the Protection of the Ozone Layer and its landmark Montreal Protocol, as well as at the Earth Summit—the United Nations Conference on Environment and Development (Rio de Janeiro, June 1992).

I am confident that this publication will be especially welcomed by those seeking an introduction to the increasingly prominent relationship between the composition of our atmosphere, weather and climate, particularly after the release of the Fourth Assessment Report by the WMO co-sponsored Intergovernmental Panel on Climate Change, which received the prestigious Nobel Peace Prize in 2007.

I wish to congratulate all WMO Members on the occasion of World Meteorological Day 2009.



(M. Jarraud)
Secretary-General



INTRODUCTION

The air we breathe is constantly changing. Urban growth, land-surface modification and climate change, all spurred by an explosion in global population, are altering the composition of our air. Those changes can dramatically affect weather and climate and, in turn, our health and that of ecosystems.

Numerous scientific studies link air pollution to respiratory and cardiovascular illnesses, cancer and nervous system disorders, as well as airborne and heat-related diseases. The atmosphere deposits contaminants in our waterways and on our land, harming not only people but also animals and plants. Such environmental problems include erosion, acidification of oceans, lakes, streams and forests and the accumulation of toxic compounds in plants and wildlife. The emission of gases and aerosols into the atmosphere also impacts long-term climate change. Meteorologists, hydrologists and climatologists offer invaluable information and services to help mitigate these health and environmental problems.

As scientists collect more data on our ever-changing air, they increasingly see how intimately air quality is connected to the weather-climate system. Wind, rain, snow, sunlight and temperature variations all control the transport and longevity of pollutants

around the globe. The more scientists understand the weather-climate system, the better they are able to forecast the distribution of potentially harmful atmospheric particles and gases. At the same time, pollutants themselves influence our weather-climate system. For example, particles and gases in the atmosphere can change the way the planet absorbs or reflects heat and can delay or spur precipitation. Understanding the composition of the atmosphere substantially improves scientists' ability to make short-term weather forecasts and long-term climate predictions.

The interdependence of the weather-climate system and global pollution is a critically important field of study for the 21st century. National Meteorological and Hydrological Services (NMHSs) of WMO Members and their partners are at the forefront of this work. By observing the changes in the atmosphere, analysing the relationship between pollutants and the weather-climate system and then making air-quality forecasts and climate predictions, NMHSs provide vital information to policy-makers and the public. Working with national, regional and international public health and environmental services, they help reduce risk of pollution-related death and injury, protecting us and our planet.



SHIFTING SKIES

For thousands of years, people have left their mark on the atmosphere, filling the skies with gases, dusts and other particles. In 1661, John Evelyn noted the “impure and thick” vapours “corrupting” the lungs of London’s inhabitants. Two hundred and fifty years later, the situation would be even worse. Increased industrialization around the turn of the 20th century profoundly changed the air we breathe.

The Industrial Revolution brought new sources of air pollution. The widespread burning of coal sent a toxic combination of smoke particles and sulphur dioxide into the air. Dense fogs often trapped these pollutants, causing them to accumulate in great quantities—so-called smog. The hazardous mixture would also form corrosive sulphuric acid droplets that irritated people’s respiratory tracks and caused pervasive environmental damage.

As population growth has accelerated since the beginning of the 20th century, so too has the scale of air pollution. Booming populations are fuelling the growth of megacities worldwide: about half of the six billion people on Earth now live in cities. That population growth has resulted in a significant increase in vehicle usage and electricity demand—both of which largely require the combustion of fossil fuels, releasing reactive gases into the atmosphere.

Since the middle of the 20th century, vehicles, along with industrial processes, have been spewing carbon monoxide, nitrogen oxides, sulphur dioxide and small particles called particulate matter into the atmosphere. Nitrogen oxides and other substances called volatile organic compounds combine with sunlight to create surface ozone, which has a marked effect on respiratory health. Most smog now refers to this combination of sunlight and reactive gases—so-called photochemical smog—rather than the London smog at the turn of the century. Cars and industries also emit greenhouse gases, such as carbon dioxide, that alter the climate over time, affecting people in a variety of ways: changing the weather, raising sea level, melting glaciers and ice sheets,

increasing vulnerabilities to natural disasters and altering the water and food cycles, to name just a few. Other current sources of human-made pollution include forest and vegetation burning and waste incineration. These different sources of pollution present new challenges for protecting human health.

The World Health Organization (WHO) estimates that two million people die prematurely every year due to air pollution. The primary culprits are ground-level ozone and related smog pollutants, particulate matter, sulphur dioxide and carbon monoxide. These pollutants are responsible for large numbers of death and injury due to respiratory and heart disease, particularly in developing nations. Even relatively low concentrations of these pollutants can cause a range of adverse health effects. Fortunately, advances in science and technology, particularly in the field of air-quality forecasts, have given us new opportunities to reduce risks from air pollution.

Improving the outlook

The Olympic Games bring the world’s best athletes together. In the past decade, they have also provided a beneficial side-effect: pioneering measures to improve air pollution during the Games and to increase awareness of air-quality issues. For the 1996 Olympics in Atlanta, Georgia, USA, the city



An early impetus for action was the Great Smog of London in December 1952.

implemented a number of measures to reduce traffic and decrease levels of ozone and other harmful pollutants. The strategy included new forms of public transportation, adding 1 000 buses to the existing fleet, altering delivery schedules, closing city streets to private cars and promoting flexible work schedules and telecommuting. Medical studies have found that these measures resulted in a dramatic drop in asthma during the Games. For the Sydney Summer Olympics in 2000 and the Beijing Summer Olympics in 2008, similar efforts tailored to each area were implemented to keep the air quality higher for athletes and tourists. They have left a legacy in each location, namely improved air quality and a public sensitive to the benefits thereof.

The Olympic Games are but one example of the many ways in which increased understanding and awareness of air-quality issues can lead to greater protection of human health. Since the mid-20th century, governments around the world have been taking actions, large and small, to reduce the risk of injury and death from air pollution. An early impetus for action was the Great Smog in London of December 1952. More than 4 000 people died, leading to the 1956 Clean Air Act to control emissions of smoke from coal fires. The legislation worked: when a similar smog event occurred in 1962, 750 people died, less than 20 per cent of the figure in 1952. Slowly, smog levels decreased, increasing winter sunshine by more than 70 per cent between 1956 and the 1980s. The United Kingdom Clean Air Act led to similar legislation in other countries. In the USA, clean air legislation dramatically reduced the number of dangerous smog days in Los Angeles. Between the 1970s and 1999, bad ozone days in Los Angeles dropped from 200 to 41 days per year.

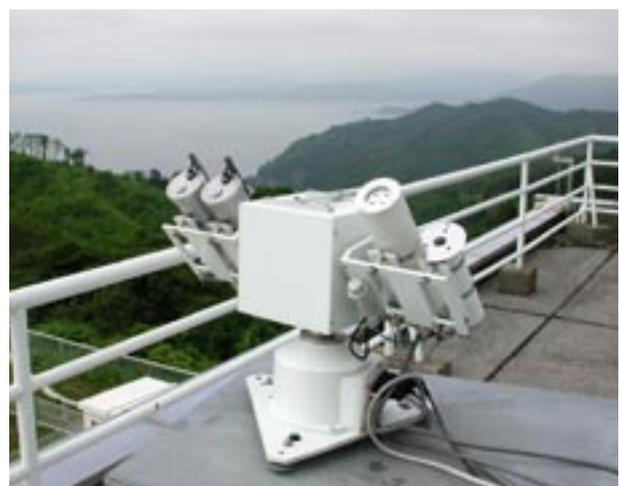
With rising populations throughout the world, particularly in developing countries, cities are increasingly coping with the effects of increased motor vehicle usage. Many cities are taking comprehensive approaches to reduce the effects. Mexico City, for example, recently introduced a programme of higher vehicle standards, driving

bans on poor air-quality days and factory improvements. That programme, combined with unusually strong winds, helped keep pollution levels down in the year 2000: the first year in a decade with no smog alert for the city.

Contributing to all these actions to curb air pollution are scientists at NMHSs and partner agencies. They play a critical role in observing, analysing and predicting air-quality conditions to inform policy-makers and the public. Without these services, cities would be ill-equipped to evaluate either the challenges or the effectiveness of policies to address them.

Observing our air

Virtually no place on the planet is far from an observation system designed to collect specific information about the air we breathe. On a clear evening, a satellite may be spotted, transmitting data back to Earth about a wildfire. On a clear day, a commercial or research aircraft or balloon may be spied, measuring the air quality. By the ocean, a ship on the horizon might be sampling



A sun-tracking aerosol photometer at GAW station Ryori, Japan, measures total atmospheric aerosol burden.



Layers of air

The air we breathe lies in the lowest layer of the atmosphere, called the troposphere. From the Greek word for “to turn,” the troposphere is where most of the world’s weather takes place. About 10 kilometres thick, the troposphere is home to a variety of gases, largely nitrogen and oxygen, with smaller amounts of the greenhouse gases carbon dioxide and methane.

Combined with invisible water vapour, which is a natural greenhouse gas, and a powerful set of mixing processes involving clouds, lightning and rain/snow formation, the troposphere is an atmospheric powerhouse. Notably, interactions of the troposphere and the surface and the troposphere and the stratosphere, one atmospheric layer up, can change the fate of atmospheric pollutants.

the composition of the air above and the sea below. Every day, more than 10 000 manned and automatic surface weather stations, more than 1 000 upper-air stations, some 3 000 commercial aircraft, more than 1 000 ships, 1 000 drifting ocean buoys, 3 000 ocean profiling floats and hundreds of weather radars take measurements of the atmosphere, land surface and oceans. These are coupled with observations of the chemical state of the atmosphere. Closely coordinated meteorological and chemical composition observations enable scientists to better understand and forecast weather, climate and air quality.

WIGOS (WMO Integrated Global Observing Systems) acts as an umbrella for global observations supported by NMHSs and their partners. The goal of WIGOS is to maintain high data-quality standards across those Services. In addition to the core observational systems it facilitates, WIGOS supports a number of international efforts to improve the quality of atmospheric data and to strengthen data sharing.

WIGOS embraces many observational networks. On the ground, weather stations measure wind speed and direction, air temperature, precipitation and humidity. Each of the meteorological factors plays an important role in air quality. In general,

for example, the faster the wind speed, the lower is the concentration of a pollutant. When the wind blows stronger, it essentially dilutes the pollutant, allowing it to disperse and dissipate more quickly.

Wind data are also collected by upper-air observational platforms, including balloon radiosondes and aircraft. The resulting wind profiles give scientists a picture of the atmosphere’s structure. Aiding the observations at the surface and aloft are ocean- and space-based sensors. Ships and buoys provide important information about sea temperature, wave height and wave period.

Meanwhile, high above the air we breathe at the Earth’s surface, satellites are increasingly being used for observing both meteorological and air-pollution phenomena. Space-borne instruments can capture the formation of a sandstorm, identify plumes from wildfires, detect regional haze and measure changes in sea ice. The applications are vast and growing. Various types of satellites—polar-orbiting, geostationary operational meteorological satellites and research and development environmental satellites—together provide a wide range of other parameters such as atmospheric chemistry profiles, visible and infrared cloud images, water-vapour images and wind-structure



Volcanoes and other major emission sources

On 15 June 1991, Mt Pinatubo erupted in the Philippines, launching 20 million tonnes of sulphur dioxide high into the atmosphere, creating a 30-megatonne cloud of sulphuric acid particles, also known as aerosols. Within three weeks, the cloud of aerosols was circling the globe and remained in the upper atmosphere (the stratosphere) for two years—scattering sunlight back to space, preventing it from reaching the ground and causing global cooling. Scientists are still studying the event to advance understanding of the climate and weather impacts that volcanic eruptions leave in their wake.

Volcanic eruptions are natural events but many other sources of chemicals in the air are affected by human activities. Scientists must take all sources of pollution into account in their models to forecast air quality, weather and climate. Some major sources of pollutants with a natural component are given below.

Fires: fires in the continental tropics and boreal regions have wide-ranging effects on human health and climate. Sparked by lightning, wild-fires are a major source of carbon monoxide, volatile organic compounds and particulate matter. Fires can also be of human origin as, for example, in agricultural and charcoal production. Fire frequency is often enhanced by hotter, drier conditions associated with climate change.

Plants and trees: vegetation produces volatile organic compounds and pollen, both of which are triggers for asthma and allergic reactions. Isoprene is a common volatile organic compound released by vegetation; it is highly reactive and can contribute significantly to

severe summertime air-pollution events. Some plants produce more reactive pollutants than others. Forestry practices can alter the natural emissions.

Other biological activity: microbial activity releases carbon dioxide, methane, nitrogen oxides and sulphur gases to the atmosphere. Cows and other ruminant animals release methane through their digestive systems. Increased populations of ruminants needed for a growing global population have contributed to an enhanced greenhouse-gas effect.

Lightning: lightning strikes associated with thunderstorms produce high levels of nitrogen oxides and ignite forest fires. As a result, lightning contributes directly to atmospheric ozone formation. Satellites have been used to observe lightning-induced ozone over the tropical Atlantic Ocean. Climate change can affect the occurrence of severe thunderstorms globally.

Sand- and duststorms: sand- and duststorms produce large amounts of particulate matter that often travels far from its source. They can affect weather, climate, respiratory health, disease outbreaks and, possibly, hurricane formation. They can be influenced by human activities such as land-surface modification and agricultural practices.

Other: indoor pollutants include particulate matter and dust, mould spores and gases from cooking fuels or degassing of building materials. Many people spend more time indoors than outdoors, but the serious risks associated with indoor air quality are not the main focus of this booklet.

indicators. What makes these analyses possible is passive sensing, which, essentially, measures the faint natural electromagnetic radiation emitted by the sun, air molecules and warm objects. Geostationary satellites simultaneously gather data on aerosols, global cloud cover, oceanic and atmospheric temperatures and other important information.

Land, ocean, air and space observations provide the basic source of information needed for weather, climate and air-quality assessments and forecasts. WMO has been coordinating and collecting information about air quality since the 1950s. Most information about the chemical composition of the atmosphere comes from several sources simultaneously: surface-based stations measure the air we breathe or that remotely sense atmospheric composition above the surface using sun-tracking spectrometers, lasers and balloon-borne instruments. These are complemented by aircraft and satellite observations.

WMO, through its Global Atmosphere Watch (GAW) programme, coordinates a global atmospheric composition observing network comprising 24 global stations, including the Alert Observatory in Nunavut, Canada, the Mauna Loa Observatory in Hawaii, Mount Kenya Observatory in Kenya, and Ushuaia Observatory in Argentina. The global stations, as well as regional and contributing stations, collect key air-quality data that yield insight into trends and chemical processes that are changing our air. More than 65 countries host GAW surface-based stations. Five GAW World Data Centres coordinate data sharing among these observatories to promote the study of ozone, ultraviolet and solar radiation, greenhouse gases and particles from biomass burning and duststorms. Comprehensive information about GAW stations is available at <http://www.wmo.int/gaw>.

Together, weather, climate and air-quality observing systems enable a systemic approach to studying our ever-changing skies. WMO aids the NMHSs of its Members by providing international standards

and a system for exchanging observations and information. Coverage of observational networks around the world is not evenly distributed. Further investment in atmospheric composition observational systems can close the existing gaps in coverage and provide an even more accurate picture of the atmosphere.

Forecasting air quality

Early on a fair summer's day, it may be obvious that at least the morning is going to be sunny; knowing what the day will bring in terms of various pollutants is more uncertain, however. In recent years, fortunately, improved global and regional observational data have enhanced the capability to forecast air-quality conditions. In many places around the world, a daily air-quality forecast is available alongside the weather forecast. Such a forecast might be: "Sunny and hot today, with high levels of ozone—stay indoors if possible". To create such a forecast, even one with so simple a message, is no easy task. Meteorologists have been working with scientists in many disciplines for decades to improve local and regional air-quality forecasts and turn the data into useful information for the public.

A turning point for air-quality forecasting came in the 1970s, when scientists began intensive study of acid rain. It was the first global recognition of air pollution as a regional issue that needed transboundary cooperation. Rain was carrying sulphur and nitrogen into lakes and onto land, damaging ecosystems. For the first time, scientists were able to firmly establish that the problem was the result of the transport of pollutants hundreds or even thousands of kilometres from their source. This work formed the basis in 1979 of the United Nations Convention on Long-Range Transboundary Air Pollution, which established guidelines for emissions and avenues for cooperation, ultimately reducing the amount of acid rain worldwide. The assessment work also formed the cornerstone of current air-quality forecasts.

With the realization that pollutants could persist in the atmosphere over long periods of time and travel great distances, it became pressing to find improved ways of forecasting air quality. Meteorologists already had methods to forecast the weather and environmental scientists had methods to study pollutants at their point of emission, but no system existed to bring the two sides together. In the wake of the 1979 Convention, the two sides began to collaborate more closely and air-quality forecasting was transformed. Improved numerical modelling capabilities enabled the creation of regional air-quality forecasts, coordinated across entire continents. Since then, scientists have been working to create the best city, regional and global air-quality forecasts.

The challenges to creating accurate and timely forecasts are manifold. First and foremost, scientists need emissions data. They need to know exactly which gases and particles industries are emitting. Early on, providing such information was voluntary, but with the 1979 Convention and additional protocols and regional legislation,

more data became available. Scientists have to combine emissions and other chemical data with meteorological data: pressure, wind, humidity, temperature, cloud cover and precipitation.

In the face of great challenges, NMHSs offer various air-quality forecast products. Many have taken their model and forecasting data and created air-quality indices—a usable, day-to-day air-quality forecast that summarizes the concentrations of various pollutants. The indices will often have a colour code to represent categories of risk from air pollutants, generally calculated from a statistical weighted average of the most prevalent pollutants.

Many countries around the world now issue air-quality indices. How each region issues its indices and forecasts varies: some may use colours, while others use words to convey risk; some may be daily while others are weekly or less frequent; and some look at many particulates and gases, while others may focus on one pollutant only.

The indices can lead to air-quality advisories which are issued in partnership with local environment and health authorities when air-pollution levels exceed national standards. Such advisories contain advice on how to protect human health under the air-quality conditions. Coordinating forecasts and advisories across national borders requires the standardization of measurements and thresholds.

Public air-quality forecasts and indices are important, not only for human health but also for agriculture and forestry management. Ozone exposure can damage the cells of trees and plants, harming their leaves and lowering growth rates. Rising ozone levels, particularly in parts of Asia, are putting food supplies at risk. Some studies have projected lower crop yields in the coming decades as a result of increasing ozone levels. Ozone indices can give farmers advance warning of days when ground-ozone levels could put their crops at jeopardy.



USDA

An example of damage to watermelon leaves by ground-level ozone: many commercial crops are vulnerable to ozone.



Ozone: the good and the bad

The ozone hole over the polar regions is a phenomenon familiar to us all, now. Since the 1980s, scientific assessments, educational campaigns and legislative efforts have imprinted the image in our minds of an ever-expanding tear in the protective stratospheric ozone layer that exposes us to harmful ultraviolet radiation. It was discovered that human activity, namely the use of chlorofluorocarbon (CFC) compounds, was eroding the ozone layer, some 15-35 kilometres up in the atmosphere. After global efforts to ban CFCs and related ozone-depleting substances under the Vienna Convention for the Protection of the Ozone Layer (1985) and the Montreal Protocol on Substances that Deplete the Ozone Layer (1989), the atmospheric concentrations of these gases are now declining slowly. The stratospheric ozone layer is expected to return to normal between 2050 and 2065, thus restoring the ozone layer's protection from harmful ultraviolet radiation.

But that is not the entire ozone story. While the layer of ozone in the stratosphere high above the Earth's surface provides a service to people and the planet, ozone that lies closer to the ground (ground-level ozone) has a more sinister effect. This ozone is formed from both natural and pollution sources—a combination of nitrogen oxides, volatile organic compounds and sunlight—and acts as a greenhouse gas. A result of emissions from vehicles and industries, this “bad” ozone and associated oxidants create the photochemical smog that plagues many urban areas, causing respiratory and cardiovascular health problems. In populous regions, ozone pollution tends to peak in the summertime because of the extra sunlight and heat interacting with industrial and urban emissions. Bad ozone not only poses risks to human health but also is harmful to trees, crops and wildlife. It often occurs at the same time as harmful particulate matter and can have a significant impact on agricultural production.

As scientists worldwide continue to advance their forecasting abilities, so WMO continues to support the efforts of NMHSs to disseminate air-quality information to the public. A major goal is to help people understand the forecasts and indices they receive. These products should effectively communicate the levels of pollutants that put them and the environment at risk and

why the pollutants are dangerous. NMHSs should also work in collaboration with other public services that advise citizens on the actions they can take in response to poor air-quality days. WMO-supported training workshops, standards and guidelines and resource mobilization all contribute to enhancing the air-quality forecasting capabilities of NMHSs.



WEATHER AND CLIMATE: CHANGING THE AIR WE BREATHE

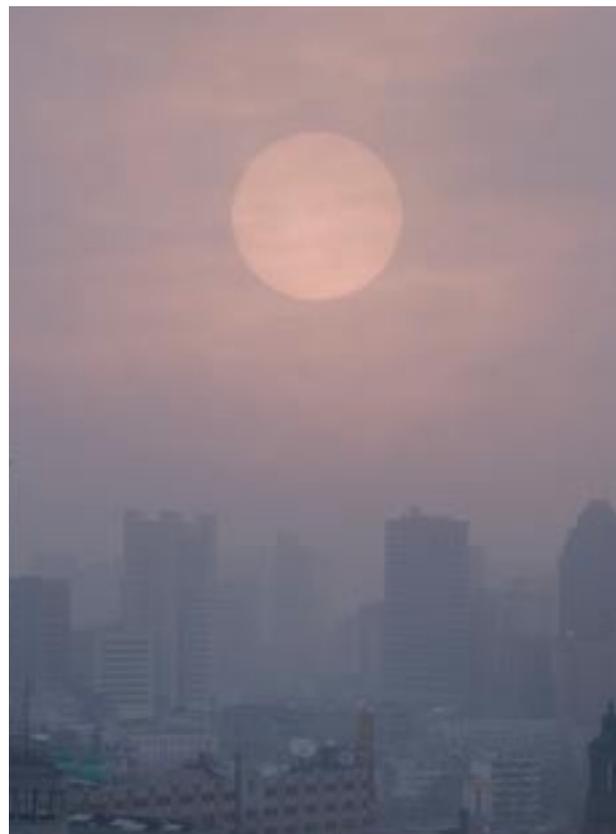
Vast quantities of asphalt, huge numbers of skyscrapers and other buildings, industries, construction sites, millions of people and thousands of cars, trucks and buses: this is the perfect recipe for urban pollution. The asphalt and buildings generate a great deal of heat by absorbing radiation, trapping it within the city during the day and releasing it at night. Cities tend to be 0.5°C-6°C warmer than surrounding suburban and rural areas. This extra heat can strengthen the production of ground-level ozone. The buildings use high levels of air conditioning to cool them down or large amounts of heat to warm them, which releases more heat and air pollution into the city and its surroundings. Electricity usage increases, which, in turn, increases emissions of carbon dioxide, nitrogen oxides and sulphur oxides from power plants nearby. Vehicles, especially in stop-and-go traffic mode, release more carbon dioxide, nitrogen oxides, sulphur dioxide, carbon monoxide and particulate matter.

The location of a city can dramatically affect its air quality. At lower latitudes, high temperatures in the summer lead to increased use of air conditioning, which augments pollution. At higher latitudes, the winter can bring haze: a process called heat (or temperature) inversion traps cold air close to the ground, where it stagnates, trapping the pollutants. Topography also has an influence. A city in a valley will experience the effects of heat inversion: pollutants are trapped within the basin, where no wind is strong enough to pass over the mountainous terrain. Near a large lake or the ocean, however, steady breezes may keep pollutants from lingering.

That wind, temperature, precipitation and other meteorological factors play a leading role in air pollution is not new. What is new is the growing awareness of the complexity surrounding these factors and the connection between air pollution and weather. Understanding these relationships has become especially significant in recent years with more urban populations exceeding 10 million people. These megacities

are everywhere: Mumbai, India; Buenos Aires, Argentina; Karachi, Pakistan; Lagos, Nigeria; Mexico City; New York City, USA; Paris, France; and Tokyo, Japan, are just a few. Cities worldwide are growing, with more people than ever choosing urban life, and the trend is expected to continue. United Nations-HABITAT forecasts that, by the year 2030, three out of five people—i.e. 4.9 billion people—will be city dwellers.

This urban population boom is putting more people at risk from pollution. WHO notes that many cities have no air-pollution monitoring, making it difficult to assess air pollution globally. At the same time, WHO estimates that air pollution is especially high in a number of cities that



MIKE KEMP

Air-quality indices are helping to raise awareness about urban air pollution.



Atmospheric particulate matter

Atmospheric particulate matter, or aerosol, is the term for solid or liquid particles suspended in the air. The size of particulate matter is a major factor in its impact on human health. It can affect human health through respiratory infections, asthma and stress on the lungs and heart. As a result, national, regional and international air-quality standards for particulate pollution are based on size.

Total particulate mass in particles smaller in diameter than 10 micrometres (one-seventh the width of a human hair), PM_{10} is a common standard. PM_{10} comes from a variety of sources, including farms, industries, vehicles, biomass burning and power plants. Most PM_{10} is trapped in the nose, throat and upper respiratory tract.

A fraction of PM_{10} , namely, those particles smaller than 2.5 micrometres, whose total

mass is called $PM_{2.5}$, are small enough to penetrate the nose and upper respiratory system and reach deep into the lungs. These finer particles come from gas-to-particle conversion in the atmosphere and are comprised of sulphates, organics and black carbon, as well as toxic organic compounds and heavy metals. They are of concern because, unlike the larger particles that generally dominate PM_{10} , they reach the lung and are beyond the body's natural clearance mechanisms of cilia and mucous and are therefore more likely to be retained.

Not only do the particles differ in size, source, composition and effects but also in how they travel in the air. The larger particles stay in the air for minutes to days, while the finer $PM_{2.5}$ can remain aloft for days to several weeks or even months, depending on how much rain or snow they encounter.

are rapidly expanding in developing countries. Of the two million people who die every year from the effects of air pollution, about half are in developing countries. In these countries, mobilizing resources and developing policies to monitor and address air pollution are especially challenging. Even in developed countries, with substantially lower levels of pollutants, a significant health risk remains from particulate matter and ozone.

Children, the elderly, and people with existing heart and lung conditions are most affected by particulate matter and ozone. In 2006, WHO guidelines said that reducing inhalable particulate matter in heavily affected cities could lower the number of air-pollution-related deaths by 15 per cent. Even as industries in many cities have successfully reduced their emissions over the

years, vehicles in growing cities continue to emit high levels of particulate matter, along with the chemical precursors to ozone. Indeed, a recent study by the European Environment Agency says that road transportation is the single main source of nitrogen oxides, carbon monoxide and some volatile organic compounds and the second-largest source of particulate matter in much of Europe.

Air-quality indices, produced by NMHSs with their partners, are helping to raise awareness about urban air pollution. By alerting people to days with dangerously high levels of pollutants, the indices can enable people to plan their time outdoors, thereby protecting their health. Some studies have attributed lowered admissions to paediatric hospitals to air-quality advisories.

To boost the capabilities of NMHSs to study and predict the meteorological aspects of urban pollution, WMO established the GAW Urban Research Meteorology and Environment (GURME) project. Together with the World Weather Research Programme, this project aims to help NMHSs provide urban pollution forecasting services to the public, as well as to define meteorological and air-quality measurements. The project is carried out in collaboration with other WMO programmes, WHO and environmental agencies and currently has several pilot projects to demonstrate various urban pollution tools.

The first pilot project is studying the causes of pollution formation in the atmosphere in Beijing, China. Coordinated by the China Meteorological Administration, it will help meteorologists design improved systems for monitoring, forecasting and preventing air-pollution events. Also in China, the GURME Shanghai project has implemented an ozone warning system and is working to advance understanding of atmospheric chemistry.

In Moscow, Russian Federation, a pilot project, coordinated by the Federal Service for Hydrometeorology and Environmental Monitoring, is measuring and modelling the links between weather, air quality and climate. Another pilot project, in collaboration with the US National Oceanic and Atmospheric Administration (NOAA), aims to extend the capability of monitoring background pollutants. These pollutants are not the direct result of specific pollution sources; rather they are in the “background” and monitoring such pollutants often occurs in areas located far from urban development. The GURME pilot project in Latin America focuses on cities, such as Santiago in Chile and São Paulo in Brazil, to build capacity in the region for air-quality services. GURME-supported regional workshops, surveys and guidelines are increasing awareness of air pollution issues and building the capacity for NMHSs to address them.

Urban pollution is a serious threat facing all nations in the 21st century. Working together, meteorologists, hydrologists, atmospheric



CHINA DAILY

The Beijing 2008 Olympics Project of WMO's World Weather Research Programme was initiated to support the 29th Olympic Games and 13th Paralympics in Beijing, China.

chemists and environmental scientists, increase understanding of how urban pollution forms and boost our ability to react appropriately. The work in many cases can extend to studying air pollution anywhere, not solely in urban locations. Most of the meteorological processes at work in urban pollution hold true for any air-pollution event. Additionally, urban pollution can often spread to rural areas and vice versa, creating the need for good regional modelling and cooperation across research disciplines. WMO is committed to helping these efforts in Member countries to improve air quality globally.



NOAA

Arctic haze over the Brooks Range, Alaska, USA

Travelling far and wide

Every winter and spring, the Arctic becomes the centre of a swirling mass of pollutants. A thick reddish-brown haze encircles the region and much of northern Eurasia, bathing the northern-latitude habitats in a mixture of toxic substances. Powerful winds carry pollutants from Europe and Asia to the north in a stable airmass in which the pollutants will reside throughout the winter as they slowly tour the landmasses of the Arctic.

The resulting Arctic haze is more than a mere nuisance. It reduces visibility, affects weather, deposits harmful contaminants into the oceans and onto land and contributes to warming in the region. It is a powerful example of how atmospheric long-range transport can create global air pollution from industrial and urban emissions. The dry, cold Arctic air has little snowfall and enables the pollutants to persist in the region throughout the winter. In lower latitudes, rain will often wash pollutants out of the atmosphere. In the Arctic winter, on the other hand, the pollutants persist until the arrival of the late spring rain.

These types of events are not limited to the Arctic. Many meteorological factors can contribute to the long-range transport of pollutants around the globe. One of the biggest environmental issues of the 1970s and 1980s was the deposition of acid

into our freshwater systems. Acid rain became the flagship issue in the study of long-range transport of pollutants. Human emissions of sulphur and nitrogen oxides through the burning of fossil fuels provide the chemical precursors necessary to acidify rain. Precipitation then carries the highly acidic water far and wide. Deposited in lakes, it can kill fish populations; on land, it can damage crops and trees and erode buildings and infrastructure.

With the help of WMO and other international organizations, the 1979 Convention on Long-Range Transboundary Air Pollution dramatically increased public awareness of acid rain and related phenomena. The Convention, which has 51 Parties, also led to marked decreases in emissions of sulphur dioxide and spawned a series of partnerships and protocols to curb long-range transport of air pollution. The protocols address not only acid rain but also ground-level ozone, persistent organic pollutants, heavy metals (such as mercury) and particulate matter.

In Europe alone, since 1980, sulphur dioxide emissions have decreased more than 70 per cent and nitrogen oxide emissions by more than 35 per cent. In the USA, even as population, energy consumption and vehicle usage all increased, emissions of nitrogen oxides have decreased more than 25 per cent since 1970 and volatile



Blazing a trail: tracking wildfires

In 1997, wildfires blazed throughout extensive parts of South-East Asia. Exacerbated by drought, they covered an area of more than 45 000 square kilometres and led to more than 20 million cases of smog-related health problems. In Malaysia alone, outpatient visits for respiratory disease during the fires increased two- to three-fold. The same year, fires in the Alta Foresta in Brazil increased outpatient visits for respiratory disease 20-fold. In the summer of 2003, the Heyman fire in Colorado, USA, led to a rise in respiratory illness that persisted into autumn.

These examples present a mere snapshot of the serious health risks posed by fires. Controlled by wind, humidity, precipitation and temperature, fires can be considered meteorological events in themselves. They are caused, however, by a number of factors that take them out of the meteorological realm: people often burn vegetation to clear land for agriculture and other land-use changes; they also burn wood for domestic fuel use. Sometimes, their causes are more climatic in nature, such as fires exacerbated by drought.

Collectively called biomass burning, fires from any of these sources can happen anywhere. Scientists estimate that people are responsible for 90 per cent of biomass burning, with the remaining percentage being the result of natural fires. When fires occur, meteorologists provide policy-makers and the public with meteorological data on their likely movements.

Following the 1997 South-East Asia fires, the efforts of members of the Association of South-East Asian Nations led to the establishment of a Regional Specialized Meteorological Centre in Singapore, dedicated to the forecasting of wildfires and related events, supported by WMO. The centre provides satellite imagery and information to the public that give immediate access to the location and size of major fires and smoke plumes and identify the pollutants being released. WMO, in cooperation with WHO and the United Nations Environment Programme, has developed guidelines for policy-makers on actions that can be taken in response to fires. NMHSs and partners elsewhere similarly use satellite imagery and other data to support emergency response to wildfires.

organic compounds have dropped by more than 50 per cent. Central Asia is a relative newcomer to the Convention, with Kazakhstan and Kyrgyzstan recently joining and other countries showing interest. Central Asia is now facing acid rain and nitrification problems at a scale similar to those of North America and Scandinavia in the 1960s and 1970s. Much work still lies ahead to mitigate emissions of these pollutants, especially in the face of substantial population growth worldwide. Effects of long-range transport of air pollution are still visible in our lakes, seas and oceans, for

example the Black Sea in eastern Europe, whose biodiversity and general health have been greatly affected by air pollution since the 1960s.

Enhanced modelling capabilities, aided by the collaboration between meteorologists and atmospheric chemists and physicists, are improving our understanding of the myriad processes that control the long-range transport of pollutants. Because long-range transport issues cross not only disciplines but also borders, they require international collaboration at the highest levels.



A dryland wildfire on an island in the Columbia River, Washington State, USA: dark smoke and dust interact with white water droplets in the cloud above.

The pollution emitted by one country will often deposit in another. It is important for such countries to have agreements and standards in place to disseminate information, including air-quality indices and advisories, to their populations. WMO facilitates such cooperation among its Members' NMHSs, working within global protocols and partnerships.

Responding to environmental emergencies

Scenario: a train filled with 80 000 litres of ammonia derails. Instantly, the cold, liquefied gas spills out and vaporizes. An immense cloud of heavy gas forms; it hugs the ground and slowly begins to roll downhill towards a town. Direct exposure to ammonia can cause frostbite and serious burns on the skin, as well as irritation of the mouth, throat, lungs and eyes. The authorities immediately make an important call: to the Meteorological Service, whose scientists have the expertise needed to help prevent a larger disaster.

From the moment of the accident, meteorology was controlling every aspect of the hazardous cloud: from how quickly it formed to where it moved. Wind speed and direction, turbulence, humidity, clouds, precipitation and other atmospheric conditions all influence the spread, dispersion and dilution of a contaminant. Meteorologists' experience in understanding air movement and chemistry gives them invaluable understanding of the atmospheric conditions at work. The output from their numerical models of the atmosphere, in collaboration with the expertise of public health experts and emergency response services, help the authorities manage the situation and protect the people.

The scenario described above could happen anywhere in the world. Every year, NMHSs respond to such environmental emergencies. Whenever contaminants unexpectedly enter the atmosphere—whether a chemical spill, an industrial explosion or a nuclear plant accident—meteorologists can monitor and predict the movement, dispersal and concentrations of the toxins. The same principles that guide day-to-day models for weather and air-quality forecasting apply to these events.

WMO's Emergency Response Activities programme facilitates NMHSs' use of numerical models to track and predict the dispersion of airborne contaminants in the event of an environmental

emergency. The collaborative programme was formed in the aftermath of a tragic disaster: the Chernobyl nuclear power plant accident in 1986, which led to a surge in cancer cases in the region. The initial focus of the emergency response programme was thus mitigation of nuclear accidents, but the programme also includes emergency response services for smoke and fire events, volcanic eruptions and chemical releases from industrial accidents.

For nuclear accidents, WMO, in collaboration with the International Atomic Energy Agency (IAEA), maintains eight numerical modelling centres called Regional Specialized Meteorological Centres (RSMCs), which run atmospheric simulations to predict the long-range movement of radioactive substances. The RSMCs, in Australia, Canada, China, France, Japan, the Russian Federation, the United Kingdom and the USA, provide global, non-stop coverage. Within three hours, they can provide real-time emergency response information to IAEA and WMO.

For non-nuclear emergencies, such as the ammonia-spill scenario, the extent of emergency response services depends on available numerical weather prediction and operational support. WMO has been working to expand the scope of this support, encouraging cooperation between NMHSs, their partners and regional operational services. Meteorological data, information and forecasts not only inform emergency response but can also reduce the risk of incidents through preventive action; for example, knowing where best to construct a nuclear plant. Among the information NMHSs provide in the wake of an emergency are trajectories of the paths the substances are taking through the air. Like hurricane trajectory maps, they map both where the substances came from and where they are heading, outlining a likely path of movement. Coordination between WMO, its network of NMHSs and other international organizations ensures the highest level of protection for global populations during and after an environmental emergency.



HIGH ALTITUDE RESEARCH STATION JUNGFRAUJOCH
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THE AIR WE BREATHE: CHANGING OUR WEATHER AND CLIMATE

From the late 1960s to the early 1980s, a drought in the Sahel region of Africa led to a devastating famine that killed one million people and affected many millions more. Rainfall dropped to levels 20-49 per cent lower than in the first half of the 20th century. Thousands of kilometres to the east, rainfall was increasing across large parts of Australia. Some researchers think the two events are linked—by air pollution.

The semi-arid Sahel region, which borders the Sahara on the north, the more fertile regions of Africa on the south, the Atlantic Ocean on the west and the Red Sea on the east, has historically been prone to drought for a number of reasons, including land use and natural climate variability. Some scientists, however, have suggested that sulphate and other small particles also played a role. Emitted in great quantities over Asia by urban pollution and fires, the pollutants change the composition of clouds, making them longer-lasting and brighter. The clouds then reflect more sunlight and cool the ground. This effect, some scientists say, may have weakened the tropical rainbelt in the northern hemisphere and shifted it south, depriving the Sahel of its much needed rainfall but inundating Australia and other regions in the southern hemisphere.



NASA

Biomass burning releases large amounts of particulate matter and greenhouse gases.

Although there is still some uncertainty as to the exact contribution of air pollutants to the Sahel drought and increased Australian rainfall in the second half of the 20th century, recent research, confirmed in the Fourth Assessment Report (2007) of the Intergovernmental Panel on Climate Change (IPCC), has made it clear that air pollution is a major player in global weather patterns and climate. The primary culprits in these events are greenhouse gases, ozone and aerosols—tiny particles suspended in the air, also known as particulate matter.

Most aerosols in the air are in the form of haze. Before they are washed out by rain, they can affect weather. In the upper parts of the atmosphere, aerosols can persist for long periods of time, altering long-term climate as well. The most direct effect of aerosols on weather and climate is that they tend to alter the amount of sunlight reaching the ground. Aerosols also change the properties of clouds and precipitation.

The myriad ways aerosols can affect clouds and precipitation are still under study, but it is clear that aerosols can, and do, change clouds and, as a result, can alter the precipitation cycle for a given area. A WMO co-sponsored scientific assessment of the effects of aerosol pollution on precipitation reaching the ground, *Aerosol Pollution Impact on Precipitation: A Scientific Review* (2009), discusses the many and varied effects of aerosols on precipitation and confirms that aerosols are essential climate variables, together with meteorological variables such as wind speed, pressure, temperature and humidity.

Smoking out inputs to climate change

In the summer of 2004, a record 25 000 square kilometres of Alaska's interior and another 30 000 square kilometres of western Canada burned in numerous wildfires, which reduced visibility and released huge amounts of carbon monoxide. The fires also increased ground-level

Preparing for extreme heat

Bacterial infection, dehydration, headaches, cramps, heat stroke and heat oedema can all follow from a single event—a heatwave. In Denmark, a heatwave is underway if the temperature exceeds 28°C for at least three consecutive days. In South Africa, a few extra degrees would be needed before dangerous conditions set in. The climate in which we grow up and now live is one of the most important factors behind these deadly events: what someone accustomed to a temperate climate feels as oppressive heat might be comfortable to someone acclimatized to a tropical climate. With temperatures rising globally, however, many scientists predict that people will have increasingly fewer places to avoid dangerously high levels of heat.

The concept behind heatwaves is relatively straightforward: a period of high heat, often coupled with high humidity, sets in a region for days or weeks. The specifics are slightly more complicated, however. Again, where a person lives dictates at what temperature hot becomes too hot. WMO defines a heatwave as when the daily maximum temperature for more than five consecutive days exceeds the average maximum temperature by five degrees Celsius. Such heat extremes can happen anywhere, controlled by a number of meteorological conditions. High-pressure systems, wind direction, cloud cover, humidity and, of course, sunlight and radiation, directly impact the occurrence and frequency of heatwaves. When they strike, they can lead rapidly to increased death rates from heart and respiratory disease. The most vulnerable sections of society are the elderly,

the very young, the ailing and those engaged in outdoor activities.

Over the past 50 years, the number of heatwaves has increased, as noted by the IPCC. That trend is expected to continue in the 21st century, threatening the lives of millions of people. The risk is greatest to those in climates that are generally less prone to extreme heat events, as the inhabitants have less ability to adapt.

To address this emerging threat, WMO and WHO have joined together to prepare Guidance on Implementation of Heat Health Early Warning Systems. The goal is to bring together leaders in climate, health, emergency response and policy-making to manage heat as a health hazard. Planning is underway for several demonstration projects which will help provide regionally applicable, practical advice for the implementation of early warning systems.

WMO is currently studying existing systems that provide early warning of heatwaves, for example, the French Heat-Health Watch Warning System. Established in 2004, the system was a direct response to the deadly heatwave of 2003, which resulted in some 70 000 deaths across Europe. France generally enjoys a moderate climate and was therefore unprepared for extreme heat in the summer of 2003. Immediate action was needed. The French Heat-Health Watch Warning System now activates a national action plan as soon as the heat index rises. The National Institute for Health Watch and Météo-France work jointly



to provide real-time weather and health data that can guide the public to safety during heatwaves. WMO hopes to enhance similar joint efforts elsewhere in the world.

In the future, it could be possible to pair such heat hazard early warning systems with air pollution indices and advisories. Excess heat tends to favour bad ozone days, for example, within urban environments. The combined effects of heatwaves and air pollutants, especially ozone and particulate matter, increase mortality. A high-heat warning issued jointly with a high air-pollution advisory would protect the people of a region, as well as raise awareness of heat as a multifaceted hazard.

Heatwaves also can pose a health risk in the form of wildfires. The Bulgarian heatwave in 2007 exacerbated drought conditions already in place and sparked widespread wildfires. More than 1 500 fires raged in just four days. Such fires not only put people and property in immediate danger but also send into the air potentially harmful particles that affect both human health and regional climate.

Heatwaves are perhaps one of the most unrecognized yet most dangerous atmospheric hazards. Understanding their causes and effects in the context of air quality, weather and climate will strengthen our collective ability to adapt to warmer conditions. Local and regional communities, working cooperatively with meteorological and health services, need to prepare for these events as our climate continues to warm.

ozone amounts across much of the northern hemisphere. Perhaps even more remarkable, however, are studies that suggest the fires cooled the surface for several weeks to months at a time. Smoke particles in the atmosphere temporarily reduce the amount of radiation from the sun reaching the ground. This cooling effect, some scientists say, could be enough to slow global warming in the Arctic should the annual boreal forest fire season intensify.

Studies that examine the effects of smoke particles and other aerosols on climate and climate change are increasingly relevant. Scientists are realizing they need to account for aerosols in their modelling of the atmosphere in order to properly project future climate scenarios. Although aerosols have a generally cooling effect on the surface below them, exactly how much solar energy they block depends on the thickness of the particles, the brightness of the planet's surface and the intensity of the sun, as well as how long the aerosols stay in the atmosphere.

Ground-based sensors and satellites that measure how much sunlight the particles are scattering or absorbing can directly capture the initial event and its movement. This improves scientists' ability to include aerosols in weather and climate models. Models which include aerosols produce results that match the atmosphere more closely. These improvements could also strengthen local and regional weather forecasts. The better scientists are able to capture what is happening in the atmosphere, the more accurate their forecasts will become.

Many of the pollution sources that produce aerosols also produce greenhouse gases, providing another important link to climate studies. Biomass burning, for example, releases not only large amounts of particulate matter but also large amounts of the greenhouse gas, carbon dioxide. Some studies suggest that biomass-burning events have increased globally over the past 100 years, making their inclusion in climate models extremely important.



Integrating climate information in our lives: World Climate Conference-3

Geneva, Switzerland, February 1979: the First World Climate Conference led to the establishment by WMO and UNEP of the Nobel-Peace-Prize-winning IPCC and the WMO co-sponsored World Climate Research Programme, launching new global efforts to understand climate change.

Geneva, Switzerland, November 1990: the momentum continued with the Second World Climate Conference leading to the establishment of the Global Climate Observing System and the United Nations Framework Convention on Climate Change.

Geneva, Switzerland, September 2009: World Climate Conference-3 promises to enhance the tools of climate services so that they can better predict future climate change and inform policy-makers. Organized by WMO in cooperation with other UN agencies, governments and the private sector, the meeting will address the need to integrate climate information into everyday decision-making.

The stakes are high. Our climate affects virtually every element of our daily lives. The food we eat, the water we drink, the weather in which we live and work and the quality of the air we breathe, all depend in part on the climate. Extreme climate events, including floods and drought, are very likely to increase in the future, making communities worldwide more vulnerable to disaster. To best plan for our future, decision-makers and the public need the most accurate, highest-quality climate information available.

World Climate Conference-3, to be held from 31 August to 4 September 2009, will build on the successes of its predecessor meetings and address scientific advances in seasonal, inter-annual and multidecadal climate predictions. This information offers a host of opportunities for decision-makers: services to improve water and agricultural management, disaster mitigation and response, urban planning and energy production, among many other applications. By enabling such outcomes, World Climate Conference-3 will strengthen regional and national capabilities to prepare for, and adapt to, climate variability and change at all levels.



The greenhouse gases emitted by biomass-burning and other aerosol-producing events have a warming effect. Since the Industrial Revolution, human activities have enhanced this greenhouse effect. The combined effect of greenhouse gases and aerosols is under study. Most scientists, however, working to incorporate both effects in their climate models, conclude that an overall global warming trend is occurring.

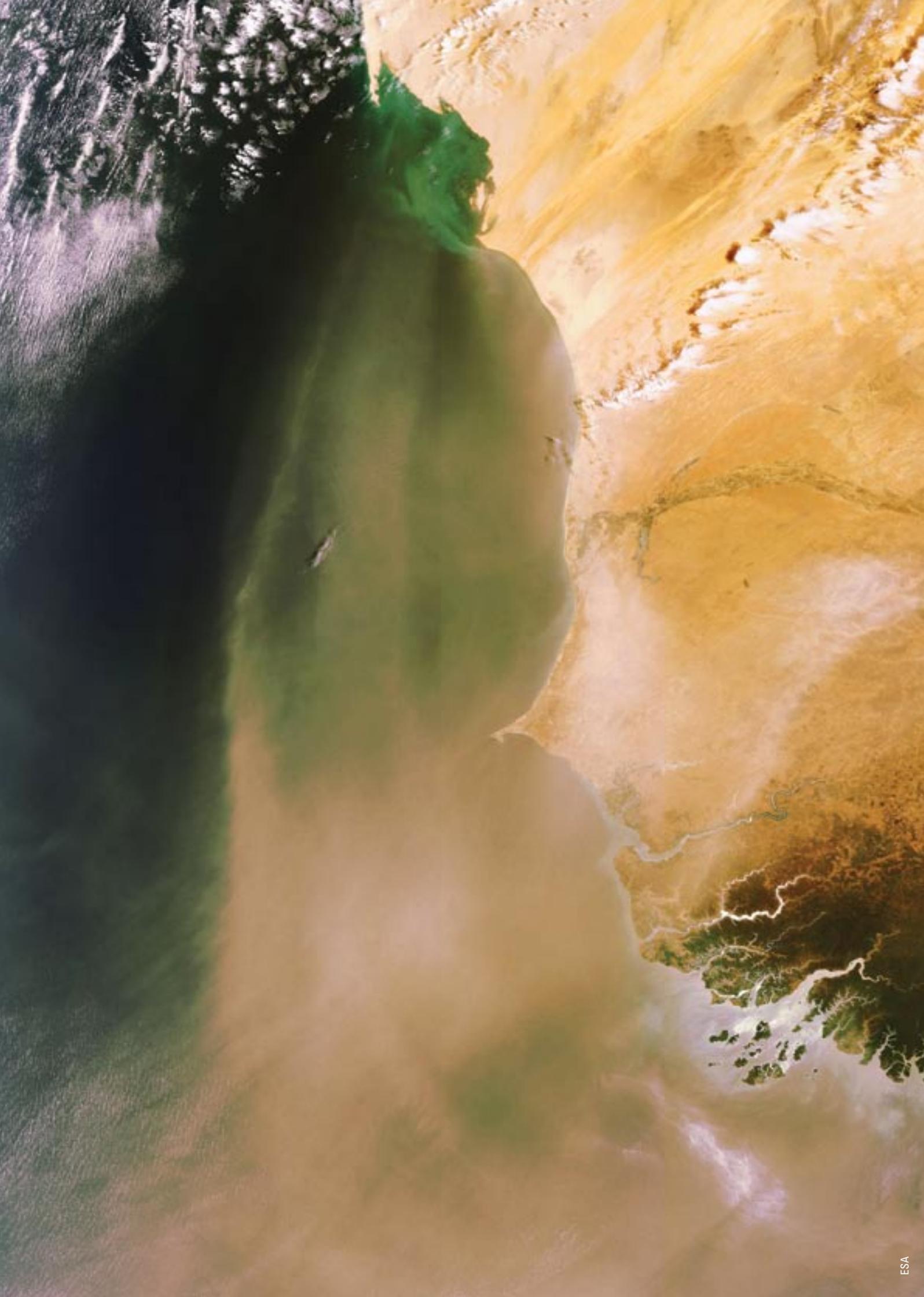
Indeed, despite a small cooling effect from the widespread volcanic aerosols emitted by Mt Pinatubo in the early 1990s, the WMO/UNEP-sponsored IPCC concludes that the average global air surface temperature has increased about 0.74°C from 1905 to 2005. “Most of the observed increase since the mid-20th century,” it says, “is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.” Under current conditions, the IPCC projects that global surface temperature will rise 1.1°-6.4°C during the remainder of century.

A warming climate can exacerbate air pollution in a number of ways. Climate change is expected to increase desertification patterns worldwide, thus increasing the risks posed by sand- and duststorms. It also increases the risk

of drought, which can lead to more fires and, in turn, more aerosols. Climate-change models indicate that fires will continue to increase in both frequency and intensity with rising global temperatures. On a more local level, higher temperatures can strengthen urban heating, trapping more pollutants within cities. More generally, climate change can exacerbate heat-related pollution events.

Because of the tremendous impact they have on the global climate system, greenhouse gases often lead to increased health risks. The IPCC predicts, for example, increased frequency and intensity of flooding, drought and other natural hazards as a result of a warming climate. Our ability to mitigate these risks and adapt as a society depends on the ability of climate scientists to understand the role of greenhouse gases and their emissions in the atmosphere.

Only by fully accounting for the various emissions into the atmosphere—both natural and human-made, aerosol and greenhouse gas alike—can scientists accurately project the future state of our climate. Every day, climate scientists working with NMHSs are improving climate modelling and predictions to help plan for our future.



CROSSCUTTING RESEARCH: SAND- AND DUSTSTORMS

Every now and then, a strong gust of wind passes over the Gobi Desert, loosening sand and dust and lifting the particles high into the atmosphere, sometimes more than one kilometre. Winds can often carry the particles far and wide, making the local storm a global phenomenon. One such sandstorm blanketed one-eighth of China in 2006, depositing some 330 000 tonnes of sand upon Beijing in a single evening. The resulting haze limited visibility in five Chinese cities to less than 100 metres.

Covering more than one million square kilometres in northern China and Mongolia, the Gobi Desert is but one major source of airborne sand and dust in Asia and the world. Sand- and duststorms are also generated in the Sahara Desert and other arid regions of Africa, Asia and North America. As soon as these clouds of sand and dust arrive, they pose a health risk to populations and ecosystems. The particles disable the respiratory system, reduce visibility and damage crops. They also have a

profound impact on the weather-climate system, changing the amount of sunlight that reaches the ground. This range of effects makes sand- and duststorms an important crosscutting research area for meteorology, atmospheric chemistry and environmental science.

The WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) facilitates sand- and duststorm research in a number of areas, notably the forecasting of events. Fourteen operational or research dust-forecasting centres currently produce daily dust and sand forecasts. Such forecasting is possible, as sand- and duststorms are essentially meteorological phenomena, with wind being their primary driver. Other weather factors, such as precipitation, also come into play, for example, if rain has recently fallen in a desert region, a strong wind is less likely to dislodge the particles from the ground. Drought, on the other hand, can exacerbate conditions for sand- and duststorms.



SHUGGIE FISHER

The Gobi Desert is a major source of airborne sand and dust not only in Asia but also beyond.



Sand and dust: feeding the oceans?

Dust and sand often carry with them key ingredients for life in the world's oceans, notably iron, nitrogen and phosphorous. In the presence of these nutrients, algae will bloom, fuelling the larger oceanic food chain. Satellite imagery has shown that sand- and duststorms can carry particles thousands of kilometres from source. Some scientists now

think that large oceanic algal blooms can be linked to sand- and duststorms. Research has suggested that sandstorms off West Africa have fertilized huge plankton blooms in the tropical eastern Atlantic. The effect of these blooms on the exchange of carbon dioxide between the atmosphere and oceans is also an active area of research.

These meteorological and climatic factors enable forecasts that predict when and where plumes of sand and dust will appear and provide governments, businesses and communities with early warnings. The SDS-WAS helps ensure that all populations affected by sand- and duststorms have access to forecast products. The better the

NMHSs are able to forecast sand- and duststorms and provide warnings, the better society can be protected from the harmful effects of the particles they carry. Some studies have suggested that acute respiratory infections among children, to which sand- and duststorms contribute, are one of the major causes of mortality in developing countries.



FINBARR O'REILLY

Children run home as a duststorm arrives in eastern Chad.

Several lines of research are open. For example, scientists are investigating whether such storms might affect the occurrence of tropical cyclones. Recent research has revealed that years with increased sand in the atmosphere off the coast of Africa had less hurricane activity in the western Atlantic. Weather forecasting models that incorporate the effects of sand and dust on the dynamics of the tropical atmosphere and ocean are under development. They will provide greater understanding of the development of tropical cyclones and facilitate planning for, and response to, their potential impacts.

Another open area of research is the connection between sand- and duststorms and airborne diseases such as meningitis. Some medical professionals believe that particles cause infections in the upper respiratory tract system that make people more vulnerable to the bacteria that cause meningitis, but more research is needed.

Enhanced observational data of sand- and duststorms are aiding research in all these fields. A recent addition to the observational arsenal for sand and dust are surface-based and satellite LIDAR (light detection and ranging) systems, which measure the vertical profile of the aerosols according to how they reflect and absorb light. Other observational

tools include surface-based suntracking sunphotometers and satellite instruments. The WMO GAW programme is a key player in the coordination of worldwide observations of sand- and duststorms. The SDS-WAS will continue to use these and other observational networks to further understand their genesis, evolution and effects.



A GOOD INVESTMENT

Weather, climate and the air we breathe are all closely entwined. The more scientists learn about our atmosphere, the more they discover a myriad of complicated feedback cycles that control our air: not only can weather conditions create or control air pollution events, but air pollutants can also change our day-to-day weather and long-term climate. By observing these phenomena, assessing their impacts and creating forecasts and guidelines for use by policy-makers and the

public, NMHSs and their national partners are providing invaluable products to further protect human health and the environment.

The number of air-quality services available around the globe is increasing yearly, due to the collaborative efforts of WMO, its Members and their partners. Continued investment in global air-quality research, observations and forecasting and analysis tools is necessary to ensure



The view from WMO

The interactions of geography, weather and air pollution are striking from the top floor of the WMO headquarters building in Geneva, Switzerland. Lake Geneva lies on one side of the building with the Alps in the distance and the Jura Mountains can be seen on the other side. On a windy day in the winter, when the lake is being strafed by the *bise*—a strong, cold north-east wind that funnels through the mountains into the Lake Geneva valley—it is easy to see how the skies can be clear on so many days. These winds can dilute and carry many pollutants away from the city. On other days, a thin haze settles over the region—a reminder that dust and sand from the Sahara, as well as air pollution from industrial parts of Europe, can travel thousands of kilometres.

Every city, every region has its own air-quality story to tell: the intricate interactions of weather, climate and air pollution. WMO and its Members hope to tell those stories to the world and to strengthen globally

coordinated and shared efforts to improve the quality of the air we all breathe.

WMO is the UN system's authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. WMO has a membership of 188 States and Territories. It originated from the International Meteorological Organization, which was founded in 1873. Established in 1950, WMO became the specialized agency of the United Nations for meteorology (weather and climate), operational hydrology and related geophysical sciences in 1951.

Like weather, climate and the water cycle, air pollution knows no national boundaries. International cooperation at the global scale is essential for the development of predictions and applications. WMO provides the framework and the support for that international cooperation.

the best air-quality services and to improve weather and climate predictions. The NMHSs of some WMO Members still lack comprehensive observational platforms to study aerosols, ozone and greenhouse gases; others lack the modelling and simulation capabilities to support daily, weekly or monthly air-quality indices; yet others may need assistance combining their meteorological data with air-quality data. All, however, benefit from continuing advances in science and technology that are underpinned by research leading to improved observations, predictions and data sharing. Without air-quality products, policy-makers would be ill-equipped to make decisions on how to reduce air pollution in their regions and how generally to contribute to the mitigation of, and adaptation to, climate change.

Alongside efforts to boost forecasting and observational capabilities, a need exists for widespread educational campaigns to boost awareness of air quality as a significant local, national, regional and international issue that affects human health, ecosystems, weather and climate. Meteorologists are but one set of important contributors to this issue. Their work must involve other atmospheric scientists, public health experts, environmental scientists and medical professionals, among others. In that vein, people need to come to rely on all these resources for their air-quality questions. WMO will continue to support collaboration among these groups at all levels. Training, workshops, conferences, standards and guidelines and technology efforts all work toward the goal of international data sharing and cooperation.

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