Space applications for management of air pollution in Asia and the Pacific

Photo credit: Kelly Hayden

*The shaded areas of the map indicate ESCAP members and associate members.**

The Economic and Social Commission for Asia and the Pacific (ESCAP) serves as the United Nations' regional hub, promoting cooperation among countries to achieve inclusive and sustainable development. The largest regional intergovernmental platform with 53 member States and 9 associate members, ESCAP has emerged as a strong regional think-tank offering countries sound analytical products that shed insight into the evolving economic, social and environmental dynamics of the region. The Commission's strategic focus is to deliver on the 2030 Agenda for Sustainable Development, which it does by reinforcing and deepening regional cooperation and integration to advance connectivity, financial cooperation and market integration. The research and analysis undertaken by ESCAP, coupled with its policy advisory services, capacity building and technical assistance to governments aims to support countries' sustainable and inclusive development ambitions.

**The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.*

Acknowledgements

The technical paper on Space Applications for Air Pollution Management was prepared by Hana Lee (Ph.D), consultant, Space Applications Section, Information and Communications Technology and Disaster Risk Reduction Division (IDD), under the guidance of Kelly Hayden, Economic Officer Affairs Officer, Space Applications Section and Keran Wang, Chief, Space Applications Section, IDD. Technical inputs were also provided by Matthew Perkins, Economic Affairs Officer, Sustainable Urban Development Section, Environment and Development Division, ESCAP, and Gene Rankey, Professor of Geology, The University of Kansas, United Nations Volunteer. The paper was prepared under the general guidance of Tiziana Bonapace, Director, Information and Communications Technology and Disaster Risk Reduction Division of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP).

The manuscript was edited by Anoushka Ali, consultant, IDD. Layout and graphic design were completed by Xiao Dong consultant, IDD and Qi Yin. Patricia Budiyanto and Amporn Jaturasatienchai of the Space Applications Section, IDD, provided administrative support.

United Nations publication

ST/ESCAP/2987

Acronyms and Abbreviations

air mass factor	AMF
air quality	AQ
Glyoxa	CHOCHO
Dobson unit	DU
fine particulate matter	PM
Formaldehyde	HCHO
Geostationary Environment Monitoring Spectrometer	GEMS
nitrogen dioxide	NO_2
parts per billion by volume	ppbv
slant column density	SCD
solar zenith angles	SZAs
sulphur dioxide	SO_2
tropospheric ozone	O_3
United Nations Environment Programme	UNEP
United Nations Economic and Social Commission for Asia and the Pacific	ESCAP
vertical column density	VCD
volatile organic compounds	VOCs
World Health Organization	WHO

1 Air pollution in the Asia-Pacific region

According to a study by the United Nations Environment Programme (UNEP), air pollution is the fifth leading risk factor for mortality and was estimated to be responsible for around 3.4 million deaths in the Asia-Pacific region, in 2017 (Health Effects Institute, 2019) . Though countries and cities have implemented various air pollution management policies, these only offset the additional pollution produced by a growing population and increasing urbanization (UNEP, 2018). Between 1990 and 2015, the population-weighted annual mean concentration of fine particulate matter (PM 2.5)[1] grew by 19 per cent in Asia and the Pacific (Health Effects Institute, 2018), exceeding the global increase of 10 per cent. In 2018, the Asia-Pacific region was home to 96 of the 100 cities most polluted with PM 2.5 (IQ Air, 2020). Exposure to particulate matter pollution tends to be greater in least developed countries, whereas tropospheric ozone (O_3) concentrations grew faster in more developed or rapidly developing countries and regions, such as in South Asia, where O_3 pollution grew at a much faster rate than the global growth rate (Health Effects Institute, 2019).

Air pollution is increasingly understood as a global issue, requiring an understanding of pollution sources, transport, and transformation from local to regional to global scales (IPCC, 2013). Polluting gases, such as ozone (O_3) and aerosols, particularly PM 2.5, are known to be major risk factors for public health (Cohen and others, 2017; Brauer and others, 2016). Fine particulate matter, such as PM 2.5 and PM 10, have diameters that are smaller than 2.5 μm and 10 μm, respectively, and penetrate deep into the lungs and cardiovascular system, causing diseases including stroke, heart disease, lung cancer, chronic obstructive pulmonary diseases, and respiratory infections. Tropospheric ozone, nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) can irritate and damage the respiratory system, causing problems particularly to people with existing lung problems, such as asthma. Nitrogen dioxide and volatile organic compounds (VOCs), such as formaldehyde, also react to create ozone, or photochemical smog, while SO_2 and NO_2 can contribute to forming particulate matter. According to a World Health Organization report (2014), air pollution in 2012 caused the premature deaths of around 7 million people worldwide. It was estimated that if the aerosol level could be reduced to the safety level, about 300,000 to 700,000 persons could be prevented from premature death in developing countries. Industry, transportation, coal power plants, and household solid fuel usage contribute significantly to air pollution. Air pollution continues to rise at an alarming rate and affects economies and quality of life.

Problems of air pollution in Asia and the Pacific have led to an increased interest in regional air quality (AQ). Anthropogenic air pollutants are emitted from industries and power plants,

1 Percentage of people living in cities with various PM2.5 levels in μg/m3.

automobiles, agricultural waste burning, and other sources, as gaseous pollutants (NO_2, SO_2, ammonia (NH_3), VOCs, carbon monoxide (CO), etc.), and in particulate form (particularly, as black carbon (BC) and organic carbon (OC) that are primary components in PM 2.5. Dust and sea salt are emitted from natural sources, partly as PM 2.5 but mostly as PM 10. The gaseous pollutants are oxidized in the atmosphere to form secondary pollutants, such as ozone and other oxidants (e.g., hydrogen peroxide (H_2O_2) and peroxyacetyl nitrate (PAN)), nitric and sulfuric acid, and oxygenated organic compounds. Some of these species turn to secondary aerosols (particulate matters) by the physical transformation in sulfuric acid, ammonium sulphate, ammonium nitrate, and organic aerosols. These secondary aerosols are the most important components of PM 2.5, together with the primary fine particles directly emitted from combustion. The total of these primary and secondary, and gaseous and particulate, air-born species combine to define air quality (AQ). Thus, systematic observations of ozone, aerosols, and their precursors; NO_2, SO_2, VOCs, etc., over wide areas, together with meteorological observations, are critical to public health and environmental policy in this region.

Aerosol is closely related to the quality of human life and the degradation of the environment. The climatic and environmental issues related to atmospheric aerosols are wide-ranging, with concerns about land use and increasing desertification, dust storms, acid rain, air pollution, etc. Aerosol directly influences radiative forcing through the scattering and absorption of solar radiation. It can also serve as cloud condensation nuclei to change the microphysics and lifetime of clouds, thereby indirectly changing radiative forcing and hydrological circulation. In recent decades, dramatic human activities caused by fast industrialization, urbanization, and motorization have severely destroyed the global bio-geo-chemical balance at an unprecedented scale. The study of climate change and the impact of human activities on the environment has become increasingly critical, and aerosol research has become a key field in atmospheric science.

Haze is a weather phenomenon that not only affects cloud processes, but also public health, agricultural production and global climate change, attracting the attention of scientists all over the world (Anderson and others, 2003; Molina and Molina, 2004; Yadav and others, 2003, pp. 265-277). With haze, visibility is severely reduced due to enhanced aerosol concentrations in the presence of high humidity. In a clean, unpolluted atmosphere, atmospheric visibility can reach about 200 km, however, with haze, visibility can be significantly reduced, often to just a few kilometres or less.

2 Supporting space applications for decision-making and management of air pollution

Ground monitoring and remote sensing: differences and complementarities

Ground monitoring and satellite-based remote sensing are two essential ways of monitoring air quality. As compared to ground monitoring, satellite-based remote sensing uses an analysis of electromagnetic radiation to provide a wider spatial and temporal (e.g., long-term transboundary and transport) coverage of air quality, from a regional to a global scale. Nonetheless, the resolution of measurements is rather poor for local observations. Thus, remote sensing does not provide adequate information for a specific site.

In contrast, ground monitoring measurements of air quality gauge the physical and chemical concentrations on a finer spatial scale, but are limited in the ability to provide information about these processes on a regional scale. Therefore, both ground and satellite-based remote sensing measurements are necessary to understand better air quality and its impact on the environment, weather, and climate.

Monitoring air pollution using remote sensing

The use of space applications, for various purposes, has advanced rapidly in recent years. Such advances in technology have resulted in better sensors and techniques for extracting data, while the costs of utilizing remote sensing information are constantly reducing. Remote sensing is a process of detecting physical characteristics of an area based on measuring electromagnetic radiation from a distance, such as via a satellite. The sensor mounted on the satellite (or drone, plane, etc.,) measures the loss of radiation across and within specific bandwidths, or frequencies, which reflect what radiation has been absorbed by various physical characteristics. Different objects absorb different frequencies, or combinations of frequencies, allowing, through analysis, some differentiation of objects such as vegetation, water, clouds, soil, etc. Remote sensing has considerable practical applications for supporting development, though it also has limitations, such as climatic and physical conditions that lead to uncertainties in measurement and difficulties in interpretation. Nevertheless, the use of remote sensing has expanded substantially, and can be used for managing crops, monitoring disasters, providing early warnings, mapping surface features, monitoring changes in pollution or land use, among many other applications.

For air pollution, it is also possible to monitor specific pollutants and model their movement, allowing for decision-makers to determine the impact of policy actions. One of the primary methods of detecting air pollution through remote sensing is the Differential Optical Absorption Spectroscopy (DOAS) method.

The DOAS method consists of two steps to retrieve trace gases (NO_2, SO_2, VOC, etc.,) for space-borne applications. To obtain the slant column density (SCD), the DOAS method is used to fit the differential absorption crosssections to the measured sun-normalized Earth radiance spectrum. The slant column density is translated into the vertical column density using the air mass factor (AMF).

The first step in the DOAS algorithm is to determine the SCD, which is defined as the amount of trace gas moving along an average path taken by photons within a fit window as they travel from the sun through the atmosphere to the satellite sensor. This path is represented in Figure 1 by the blue lines. The SCD is determined by fitting a function to the ratio of the measured Earth radiance to the solar irradiance data. This fit is applied to data taken in a specific wavelength range, called the fit window, which needs to be optimized for each trace gas separately. A polynomial function, which serves as a high-pass filter, is applied to account for scattering and absorption that vary gradually with the wavelength, e.g., reflection by the surface and scattering by molecules, aerosols, and clouds. Also, the high-pass filter takes out gradually varying radiometric calibration errors and other instrumental multiplicative effects.

Figure 1. Sketch of satellite radiation measurement and geometry in a plane parallel atmosphere.