

# Satellite View of Particulate Pollution in the Hindu Kush-Himalayas

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**A**tmospheric aerosols are an important factor in climate change in the Hindu Kush-Himalayan region. They alter the Earth's energy budget, primarily by directly scattering and absorbing the incoming solar radiation, indirectly modifying cloud properties. Deposition of light-absorbing

particles such as black carbon decreases snow and ice albedo (reflection coefficient). The growing recognition that atmospheric aerosols affect surface temperature and precipitation patterns has created a demand for science-based information. Spaceborne observations are increasingly being used for this purpose.

Figure 1: MODIS satellite image of large-scale atmospheric brown clouds shrouding the lowlands south of the Himalayas, with a grey veil stretching over the eastern Himalayas, southeastern Nepal, northeastern India, Bangladesh, and the northern Bay of Bengal (1 January 2011)



Source: <http://modis.gsfc.nasa.gov>

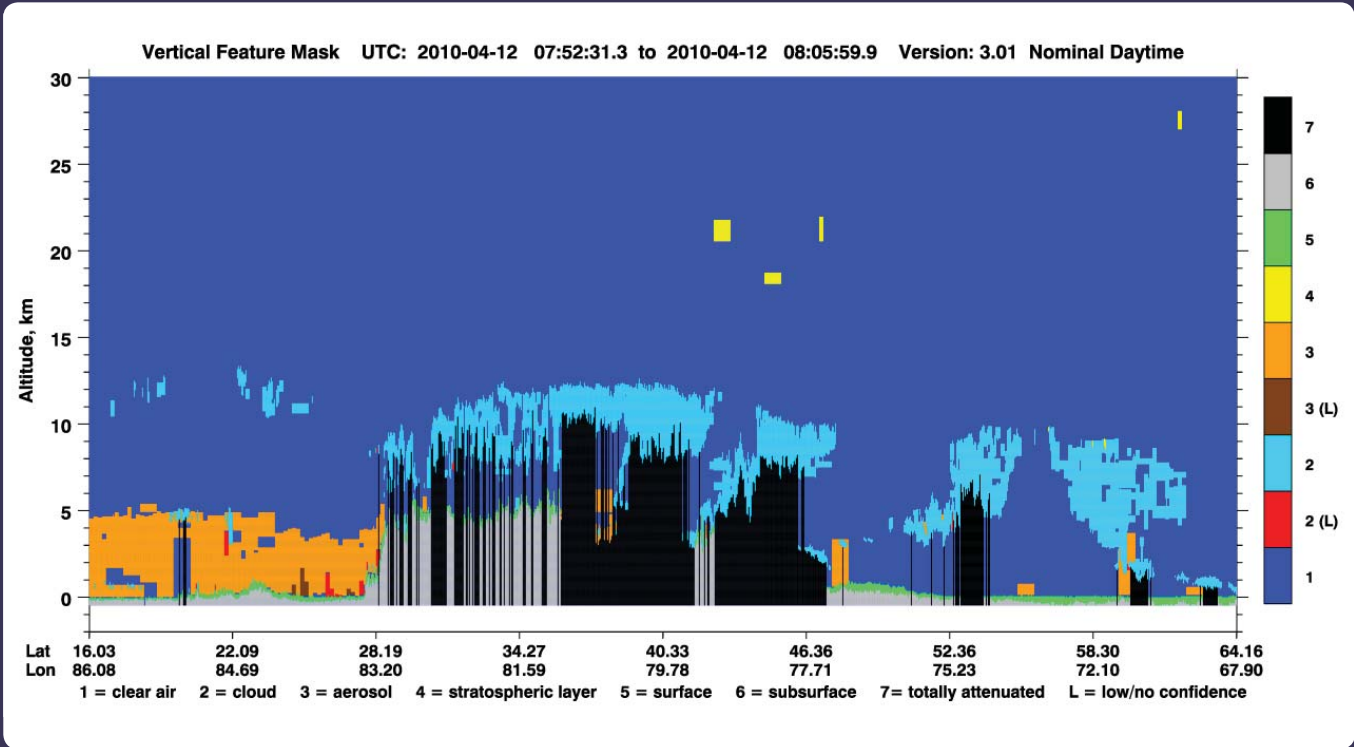
A number of much enhanced satellite systems have been developed over the past few decades, which are enabling quantitative analysis of a variety of atmospheric aerosol related parameters (King et al. 1999). As ground-based measurements in the HKH region are extremely difficult and expensive because of the terrain, satellite observations of particulate pollution provide unmatched opportunities for filling in the data gaps to further understanding of climate change in the region and its impacts.

Tracking atmospheric aerosol pollution

The TOMS (Total Ozone Mapping Spectrometer), available since 1978, was not primarily designed to look at aerosols, but it provides excellent observations of elevated smoke or dust layers above the scattering atmosphere. In 1995, satellite-based observations entered an exciting new phase with the launch of GOME (Global Monitoring of Atmospheric Ozone), the first satellite instrument designed specifically to retrieve the composition of trace gases and pollutants in the troposphere. After the pioneering study by weather satellite imager Advanced Very High Resolution

Radiometer (AVHRR) (Nakajima and Higurashi 1998), the United States National Aeronautics and Space Administration (NASA) launched POLDER (Polarization and Directionality of the Earth's Reflectances), the first instrument designed for aerosol measurement, in 2000, adding a new dimension to atmospheric aerosol research. Two new instruments, MODIS (Moderate-resolution Imaging Spectroradiometer) and MISR (Multi-angle Imaging Spectroradiometer), which have been in orbit since 2000 as part of the NASA Science Mission Directorate Earth Observing System (EOS), have been providing imagery on large-scale atmospheric aerosol pollution as well as quantitatively monitoring aerosol properties globally, notably aerosol optical depth (AOD). These instruments can even distinguish small pollution particles from coarse sea-salt and dust particles (King et al. 1999; Kaufman et al. 2002). More recently, CALIPSO (Cloud-Aerosol LiDAR and Infrared Pathfinder Satellite Observation) was launched in April 2006 with LiDAR (active sensors) on board. This has made it possible to measure aerosol vertical distributions, providing new insights into the role of clouds and atmospheric aerosols in regulating the Earth's weather, climate, and air quality.

Figure 2: Aerosol vertical distributions observed by CALIPSO satellite in the Indo-Gangetic plains and HKH mountains; the higher loading of aerosols to the south of the Himalayas is clearly visible (bottom left) (12 April 2010)



These recently developed advanced spaceborne sensors enable the quantitative analysis of atmospheric aerosol optical thickness, aerosol size distribution, and single scattering albedo (how reflective or absorbent the atmosphere is due to the presence of aerosol). They are also providing information on the global distribution of, and seasonal and interannual variation in:

- sources of aerosols (e.g., forest fires, wind-blown dust, industrial pollution);
- aerosol loading and optical properties;
- direct radiative forcing (i.e., the change in radiative flux at the top of the atmosphere);
- indirect radiative forcing through the measurement of cloud albedo.

The global distribution of aerosols observed by MODIS led to the discovery of regional plumes of air pollution, known as atmospheric brown clouds (ABCs). As a result of satellite-based observations, the transport of fine particulate pollution is now viewed differently; pollution is now seen as a global, rather than local, phenomenon.

Information from a number of satellites provides crucial data which has enhanced our ability to monitor the state of the atmosphere, led to improved models of pollution dynamics, and helped scientists to predict changes in atmospheric composition with greater confidence. The recent impact of volcanic ash on European aviation is a compelling reminder of the utility of satellite observations in monitoring and understanding the tropospheric constituents of the atmosphere. Satellite observation is also radically changing the field of atmospheric physics and chemistry. The remote observation of the physical and optical properties of aerosols, combined with ground-based measurements, make it possible to study the impacts of aerosols on the climate system. These and other satellite observations have advanced our understanding of the climate system and dramatically improved climate models and climate change projections.

## Particulate pollution in the HKH region

South Asia's unique meteorological features and its proximity to regions with high emissions make the Hindu Kush-Himalayan region vulnerable to the impacts of atmospheric aerosols. The long and dry winter, which lasts from November to March, is conducive to the accumulation of air pollutants in much of South and Southeast Asia, leading to the formation of atmospheric

brown clouds. Cold, heavy air slides down the southern face of the Himalayas into the lower lands, holding pollution close to the ground. In winter, eastern Pakistan, northern India, much of Nepal, and Bangladesh are regularly plagued by thick air pollution consisting of extremely high levels of particulate matter. Cold air often ends up trapped underneath a layer of warm air, resulting in a temperature inversion and locking pollutants in place. Ambient particulate matter is the most common and significant health hazard in all of the HKH countries. The aerosol vertical distributions in the Indo-Gangetic plains and HKH mountain regions (Figure 2) show a thick layer (up to 5 km from the surface south of the Himalayas) of aerosol pollution in the region.

Recent scientific studies have found that the radiative forcing due to atmospheric aerosols is generally high in many parts of Asia, including the HKH region. The region's contribution to the total emission of air pollutants from HKH countries is minimal, but the aerosol loading in the region is high because of the transport of pollutants from surrounding regions. The high atmospheric concentrations of particulate matter, including black carbon, at high elevations have rapidly increased the amount of black carbon deposition on ice and snow over recent decades, resulting in strong direct and snow-albedo radiative forcing. Because of the high black carbon content in snow and ice and the high level of incident solar radiation, the snow-albedo radiative forcing is estimated to be considerably higher over the Himalayas and Tibetan Plateau than in other snow-covered regions of the world.

Satellite observations of the HKH region are unmatched in providing sufficiently frequent spatial coverage to detect the dynamic nature of the transport of atmospheric pollution across the region. Comprehensive ground-based and airborne measurements are either too expensive or not feasible because of the mountainous terrain. Satellite observation of atmospheric particulate pollution in the region has enabled scientists to fill in previous data gaps, for better understanding of the role of atmospheric circulation, atmospheric aerosol transport, aerosol composition, aerosol deposition on ice and snow, and year-to-year aerosol variability in regional climate change. Daily satellite observations yield continually updated data on atmospheric processes and the state of the atmosphere, which together with ground-based in situ observation enable scientists to predict changes with greater accuracy. This knowledge will support appropriate early warning systems which will ultimately save lives and property in the region.





Haze over the Kathmandu valley, Nepal

## Deriving maximum benefit from satellite observations of pollution in the HKH region

The use of satellite observations in the HKH region, including the observation of atmospheric pollutants, is likely to accelerate in the coming years. This will result in an increased ability to predict atmospheric processes in the region through the cross-disciplinary integration of analysis and interpretation, and, ultimately, through a deeper understanding of the dynamic processes that govern pollutant transport, transformation, and removal in the region. It is important to understand the fundamental observations and research behind satellite observations, and to be able to use the satellite data products, which have many practical applications and societal benefits. However, the countries in the HKH region have limited capacity, in terms of infrastructure and workforce, to use satellite data to its maximum potential. However, some programmes have been initiated, notably in China and India, to launch and maintain satellites to study aerosols. The scientific community in the region, although small, is poised to make great progress towards understanding the complexity of atmospheric processes and predicting the effects of aerosols on climate.

Resources are required to maintain the current momentum. A trained workforce of atmospheric scientists and technicians is needed to develop appropriate tools to analyse and interpret satellite observations in the region. Open access to satellite data for the broad scientific community and international collaboration are crucial in training and maintaining such a workforce. In addition, essential infrastructure, such as atmospheric models, computing facilities, and ground networks with long-term data records, is required to validate and maximise the utility of satellite data. Multiple, synergistic

observations, including satellite observations and in situ measurements, linked with the best atmospheric models available, should be employed and supported. To study the aerosol distribution, composition, and associated impacts accurately to address the scientific and societal challenges of the future, there is a need for continuous satellite observations, ground-based and in situ measurements, and dedicated field experiments. These need to be integrated with atmospheric models, which are likely to reproduce increasingly realistic pictures of aerosol distribution within and outside the HKH region. This requires national and international support.

We live in interesting times for aerosol research. If current emission trends and policies continue, air pollution will remain a major issue in the region – seriously affecting our climate and health. Satellite observations, ground-based observations, and model simulations of atmospheric pollution in the region would provide a foundation for the development of a regional agreement to control the emission of atmospheric pollutants and mitigate climate change and other effects of pollution. Such an agreement is integral to the sustainable development of the region.

## References

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