EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 95 NUMBER 37
16 SEPTEMBER 2014
PAGES 333–340

Crop Residue Burning: A Threat to South Asian Air Quality

PAGES 333–334

For more than 2 decades, crop residues in Punjab, a region spanning northwestern India and eastern Pakistan, have been burned during October and November to ready fields for the next year's planting. This practice poses a serious threat to air quality in South Asia.

Each year, this extensive agricultural burning lasts for more than 3 weeks. Seasonal meteorological conditions (calm to weak winds and relatively low boundary layer height and insufficient dilution, all following intense monsoons in the months prior) cause smoke from these fires to blanket nearly the whole Indo-Gangetic plain (IGP) from west to east [*Badarinath et al.,* 2009; *Mishra and Shibata,* 2012]. In certain circumstances, these plumes can even get transported over the Himalayan foothills [*Bonasoni et al.,* 2010].

Punjab's air quality has severely deteriorated as a result of these fires. Smoke from these fires exacerbates and may even trigger several respiratory diseases, with infants and the elderly facing the greatest health risks [*Goss et al.,* 2014].

More health risks stem from the transport of the smoke over the IGP's dense urban areas, where it mixes with industrial pollutants such as diesel fumes, power plant emissions, and soot to form air highly concentrated with particulate matter. This air is breathed by close to 900 million people—one eighth of the world's population.

Agricultural burning in Punjab over the past decade has increased sharply [*Vadrevu et al.,* 2011], and with the practice becoming more commonplace, hazards and risks associated with these fires are not expected to abate soon. Therefore, furthering knowledge about aerosol optical and physical-chemical properties, smoke plume characteristics, and the areas where weather patterns concentrate aerosols from biomass burning is essential to climate studies of South Asia.

Punjab: A Burning Food Basket

Punjab, the "food basket" of India and Pakistan, is one of both countries' most agriculturally productive regions. Rice crops are harvested in October and November, and wheat crops are harvested in April and May. The dates of harvesting may vary by a few days to a few weeks, depending upon the status of the crops, which is influenced by the monsoon and accompanying meteorological conditions.

Prior to 1986, farmers manually harvested and plowed fields. After harvests, they left crop residues for 4–6 weeks so that residues mixed with soil and enhanced nutrients for the next crop.

In 1986, farmers began mechanized harvesting, reducing the amount of time spent in the fields and allowing farmers to work more land—both of which increase profits. Combines cut the harvest, leaving behind fields upon fields of stalks still root-bound, rising about a foot off the ground [*Gadde et al.,* 2009]. To get rid of these stalks before the next planting, farmers took to burning them.

When burning occurs in April or May, weather factors serve to dissipate smoke diffusely. In October and November, however, regional weather patterns typically funnel this smoke to the IGP.

A Snapshot of Pollution

Figure 1a shows a Moderate Resolution Imaging Spectroradiometer (MODIS) true-color image taken from the satellite Terra on 30 October 2013, when an extended smoke plume from crop residue burning in Punjab was clearly seen over the IGP. Similar conditions continued until about 20 November, forming haze and smog, especially over the densely populated, agriculturally productive, groundwater-rich industrialized centers of the IGP, such as Lahore in Pakistan and Delhi and Kanpur in India.

Figure 1 is but one example; over the past decade, similar conditions in October–November have been seen and traced by satellite to crop residue burning in Punjab. Although the image shows that the bulk of the plume is clearly sourced from fires in Punjab, the pollution over the IGP in the image is likely some combination of biomass burning, vehicular pollution, and emissions from coal-based power plants [*Prasad et al.,* 2006, 2012]. The degree to which different pollutants are at play, however, needs further study.

How Pollution Spreads

With the onset of the winter months, the decrease in temperature results in lower boundary layer height, favoring the accumulation of pollutants near Earth's surface. In combination with the high relative humidity and other meteorological parameters (e.g., calm winds typical of post-monsoon months), weather promotes the formation of smog [*Gautam et al.,* 2007] (see also Figure 1b). Analysis of MODIS aerosol optical depth (AOD) and data from NASA's Atmospheric Infrared Sounding satellite have shown higher AODs and carbon monoxide volume mixing ratios over the western IGP, with significant gradients toward the east during the peak of the burning period. Nitrogen dioxide concentrations also spike during the fires.

Carbon monoxide and nitrogen dioxide are among the main elements of smog. Both also work to seed smog with ground-level ozone, a potent greenhouse gas.

The smog formed over Punjab, however, does not stay in the west. The smoke plumes from the crop residue burning are mostly concentrated between the surface and roughly 800–900 meters in altitude, as profiles from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) instruments have shown. Results of a recent study [*Kaskaoutis et al.,* 2014] revealed that smoke plumes are transported below 2.5 kilometers over the IGP and are mostly well homogenized along the transport (see Figure S2 in the supporting information in the online version of this article). Depending upon certain meteorological conditions, especially wind speed and direction at lower atmospheric levels (below 700 hectopascals), the smoke plumes need about 3–4 days to move from northwest to southeast over the IGP.

During this transportation, smog strongly modifies the aerosol optical and physical properties over the region by mixing with anthropogenic pollution background, emissions from power plants, and natural aerosols. In fact, nitrogen dioxide concentrations are higher during the peak burning period over the whole IGP.

The aerosols from agricultural crop residue burning in Punjab were least present over the marine environment of the Bay of Bengal,

By R. P. Singh and D. G. Kaskaoutis

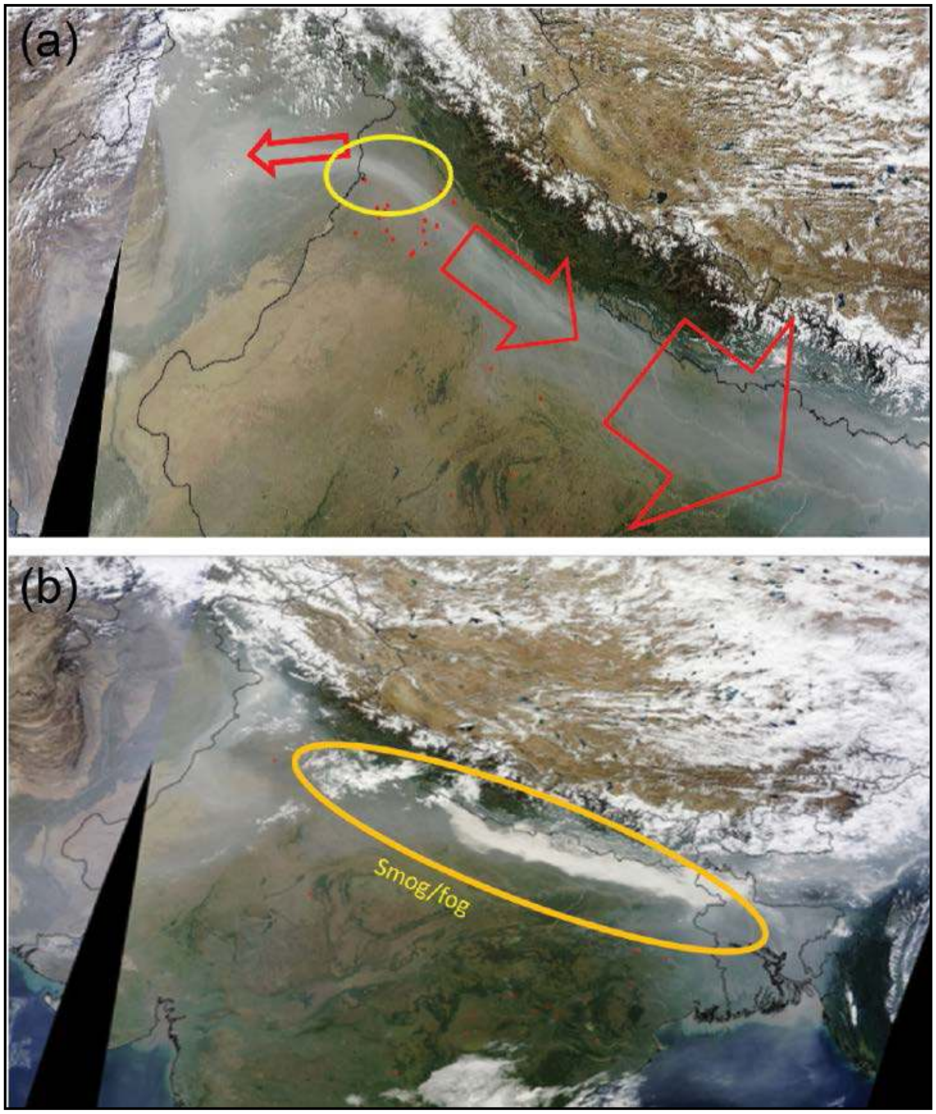

Fig. 1. (a) The Terra satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) image from 30 October 2013, showing transport of plumes from crop residue burning in Punjab (yellow circle shows crop residue burning areas) toward the east of the Indo-Gangetic plain (IGP) and also toward border areas of Pakistan. (b) MODIS image from 1 November 2013, showing the same plume form intense smog and fog over the IGP.

located about 900 kilometers southeast of Punjab. In contrast, aerosol loading and pollutants were highly concentrated over the western and central IGP [*Kaskaoutis et al.,* 2014]. Sometimes the smoke plumes also disperse over Pakistan's Indus Basin because of circulation of air masses, contributing to pollution outflow over northeastern parts of the Arabian Sea as well as over central India at higher altitudes (2.5–3.5 kilometers) [*Badarinath et al.,* 2009].

Health Hazards Spur Monitoring Efforts

The intense smog and fog caused by crop burning and exacerbated by weather and climate factors are believed to affect the health and well-being of millions of people living along the IGP. Smog pollutants are known to irritate respiratory tracts, and increased levels of smog over urban environments have been shown to cause serious health effects [*Goss et al.,* 2014] such as impeded breathing for those working outdoors, chronic asthma, and even lung cancer (see http://bit.ly/AirQualityParticles).

However, the degree to which smog is caused by these fires has not been fully quantified.

In light of this, the Indian Meteorological Department has deployed several Sun photometers to monitor atmospheric aerosols all over India. The large enhancement in aerosol loading and the modification in optical, physical, and chemical properties that have been recorded along the IGP during the post-monsoon season (October–November) revealed a need for deployment of such Sun photometers in every state to track the long-range transport of smoke plumes and pollutants.

High-quality data are required to understand the dynamics of atmospheric aerosols and formation of fog and smog over the IGP during the winter season (the end of October to February). The Kanpur station of the international Aerosol Robotic Network (AERONET; see http://bit.ly/AERONET) has provided such long-term data since January 2001.

Using data from the Kanpur AERONET station, scientists have shown that atmospheric emissions, pollution, and accumulation of aerosols have continuously increased over the IGP during the past decade, especially from October to February [*Kaskaoutis et al.,* 2011; *Kishcha et al.,* 2014]. This increase, researchers say, can be attributed mostly to biomass burning and anthropogenic emissions, and scientists are working to quantify the exact degree to which fires contribute to smog formation over the IGP.

Pollution's Broad Reach

Previous short-lived campaigns over South and Southeast Asia, for example, as part of the internationally funded Indian Ocean Experiment (INDOEX) [*Ramanathan et al.,* 2001] and NASA's Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC4RS) [*Hyer et al.,* 2013], have highlighted the strong role that biomass burning in tropical regions has in regional climate. These campaigns also show that Asian pollution outflow can modify atmospheric chemistry and climate dynamics more globally.

For example, thick smoke aerosol plumes may significantly affect atmospheric circulation, monsoon and El Niño–Southern Oscillation systems, precipitation patterns, glaciology, and atmospheric heating over the Tibetan Plateau. This creates a climatic imbalance likely centered over Punjab.

What Can Be Done?

Curbing the widespread burning of crop residues in Punjab may prove difficult. For example, scientists will need to get hard numbers on how much the burning of crop residues in Punjab contributes to smog over the IGP. Medical professionals will need to organize broad studies to more firmly tie chronic lung problems in South Asia to smog. These are not just research challenges—closed attitudes toward sharing data may hinder broad coordinated focus on air quality over South Asia.

Once more data come in to firmly quantify crop residue burning as a large contributor to air pollution over the IGP, what happens next? A scenario that could reduce pollution involves the Indian and Pakistani scientific communities motivating their governments to encourage manual harvesting in Punjab. However, even if officials acknowledge the pollution problems, requiring that farmers take a financial hit by changing the way they make their living may be politically unpopular. It may also be functionally impractical: Both India and Pakistan rely on farms in Punjab—farms quickly harvested by combines—to feed their burgeoning populations, and manual harvesting may not offer the same yields. Further, for any change in practice to manifest into a change in pollution levels, both countries would need work to solve the problem because air cannot be confined within national borders.

These obstacles may seem insurmountable. However, any effort to overcome them will start with dedicated scientific effort to examine the scope of the problem. Without this first step, crop residue burning in Punjab will continue its unchecked influence on weather, climate, and health in the IGP.

References

Badarinath, K. V. S., S. K. Kharol, and A. R. Sharma (2009), Long-range transport of aerosols from agriculture crop residue burning in Indo-Gangetic Plains—A study using LIDAR, ground measurements and satellite data, *J. Atmos. Sol. Terr. Phys., 71,* 112–120.

Bonasoni, P., et al. (2010), Atmospheric brown clouds in the Himalayas: First two years of continuous observations at the Nepal Climate Observatory-Pyramid (5079 m), *Atmos. Chem. Phys., 10,* 7515–7531.

Gadde, B., S. Bonnet, C. Menke, and S. Garivait (2009), Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines, *Environ. Pollut., 157,* 1554–1558.

Gautam, R., N. C. Hsu, M. Kafatos, and S.-C. Tsay (2007), Influences of winter haze on fog/low cloud over the Indo-Gangetic plains, *J. Geophys. Res., 112,* D05207, doi:10.1029/2005JD007036.

Goss, P. E., et al. (2014), Challenges to effective cancer control in China, India, and Russia, *Lancet Oncol., 15,* 489–538, doi:10.1016/S1470-2045(14)70029-4.

Hyer, E. J., J. S. Reid, E. M. Prins, J. P. Hoffman, C. C. Schmidt, J. I. Miettinen, and L. Giglio (2013), Patterns of fire activity over Indonesia and Malaysia from polar and geostationary satellite observations, *Atmos. Res., 122,* 504–519.

Kaskaoutis, D. G., S. K. Kharol, P. R. Sinha, R. P. Singh, K. V. S. Badarinath, W. Mehdi, and M. Sharma (2011), Contrasting aerosol trends over South Asia during the last decade based on MODIS observations, *Atmos. Meas. Technol. Discuss., 4,* 5275–5323.

Kaskaoutis, D. G., S. Kumar, D. Sharma, R. P. Singh, S. K. Kharol, M. Sharma, A. K. Singh, S. Singh, A. Singh, and D. Singh (2014), Effects of crop residue burning on aerosol properties, plume characteristics, and long-range transport over northern India, *J. Geophys. Res. Atmos., 119,* 5424–5444, doi:10.1002/2013JD021357.

Kishcha, P., A. M. da Silva, B. Starobinets, and P. Alpert (2014), Air pollution over the Ganges Basin and northwest Bay of Bengal in the early postmonsoon season based on NASA MERRAero data, *J. Geophys. Res. Atmos., 119,* 1555–1570, doi:10.1002/2013JD020328.

Mishra, A. K., and T. Shibata (2012), Synergistic analyses of optical and microphysical properties of agricultural crop residue burning aerosols over the Indo-Gangetic Basin (IGB), *Atmos. Environ., 57,* 205–218.

Prasad, A. K., R. P. Singh, and M. Kafatos (2006), Influence of coal based thermal power plants on aerosol optical properties in the Indo-Gangetic basin, *Geophys. Res. Lett., 33,* L05805, doi:10.1029/2005GL023801.

Prasad, A. K., R. P. Singh, and M. Kafatos (2012), Influence of coal-based thermal power plants on the spatial–temporal variability of tropospheric NO_2 column over India, *Environ. Monit. Assess., 184,* 1891–1907, doi:10.1007/s10661-011-2087-6.

Ramanathan, V., et al. (2001), Indian Ocean Experiment: An integrated analysis of the climate and the great Indo-Asian haze, *J. Geophys. Res., 106,* 28,371–28,398.

Vadrevu, K. P., E. Ellicott, K. V. Badarinath, and E. Vermote (2011), MODIS derived fire characteristics and aerosol optical depth variations during the agricultural residue burning season, north India, *Environ. Pollut., 159,* 1560–1569.

Author Information

—Ramesh P. Singh, School of Earth and Environmental Sciences, Schmid College of Science and Technology, Chapman University, Orange, Calif.; email:rsingh@chapman.edu; and Dimitris G. Kaskaoutis, Department of Physics, School of Natural Sciences, Shiv Nadar University, Tehsil Dadri, India