ATMOSPHERIC SCIENCE

Dirtier air from a weaker monsoon

Aerosol concentrations in China have reached unhealthy levels, at least locally. Model simulations suggest that a significant contribution comes from the weakening monsoon circulation in past decades, trapping more pollutants over land.

Mian Chin

The level of air pollution in China has much increased in the past decades, causing serious health problems. Among the main pollutants are aerosols, also known as particulate matter: tiny, invisible particles that are suspended in the air. These particles contribute substantially to premature mortality associated with cardiopulmonary diseases and lung cancer[1]. The increase of the aerosol level in China has been commonly attributed to the fast rise in pollutant emissions from the rapid economic development in the region. However, writing in *Geophysical Research Letters*, Jianlei Zhu and colleagues[2] tell a different side of the story: using a chemical transport model and observation data, they show that the decadal scale weakening of the East Asian summer monsoon has also contributed to the increase of aerosol concentrations in China.

The life cycle of atmospheric aerosols starts with its emission or formation in the atmosphere. Some aerosol components such as dust, soot and sea salt are emitted directly as particles to the atmosphere, but others are formed there by way of photochemical reactions. For example, sulphate and nitrate aerosols are produced from their respective precursor gases, sulphur dioxide and nitrogen oxides. Aerosol particles can be transported away from their source locations by winds or vertical motion of the air. Eventually, they are removed from the atmosphere by means of dry deposition and wet scavenging by precipitation. Measurements generally show that aerosol concentrations over Asia are lowest during the summer monsoon season[3], because intense rainfall efficiently removes them from the air.

The East Asian summer monsoon extends over subtropics and mid-latitudes. Its rainfall tends to concentrate in rain belts that stretch out for many thousands of kilometres and affect China, Korea, Japan and the surrounding area. Observations suggest that the East Asian summer monsoon circulation and precipitation have been in decline since the 1970s[4]. In particular, a weaker East Asian summer monsoon is characterized by weaker southerly or southwesterly winds, a deficit in rainfall over northern China and larger rainfalls in southern China. By contrast, when the East Asian summer monsoon is strong, the southerly winds and strong rainfalls extend to northern China. The decadal scale decline in the strength of the East Asian summer monsoon since the 1970s would imply an increase in aerosol concentrations in northern China, north of 28° N, and a decrease in southern China if emissions were kept the same. One obvious reason for this direction of aerosol change is that the reduction of monsoon rainfall in northern China would cause less wet scavenging of aerosols by precipitation.

Zhu *et al.*[2] investigated this relationship between aerosol concentrations and the strength of the East Asian summer monsoon and showed that the two parameters have strong negative correlations: the summer aerosol concentrations near the surface over eastern China (110–125° E, 20–45° N) can be 18% higher in the weakest monsoon years than in the strongest years during the investigated period from 1986 to 2006. Yet, they found that it is not wet scavenging by precipitation, but changes in the atmospheric circulation pattern such as wind direction and strength, that exercise the dominant impact. In the weakest monsoon years, the winds block the usual transport pathways of aerosols to prevent the outflow of pollutants from northern China, causing accumulation there during the summer (Fig. 1).

Figure 1 | Smog in Beijing. Aerosol levels have risen substantially over the past decades in some parts of China. Zhu *et al.*[2] show that, although soaring emissions of pollutants are the main source of this increase in aerosol concentrations, the observed weakening of the East Asian summer monsoon has exacerbated the problem by inducing wind and precipitation patterns that trap airborne particles over land.

The possible causes of the weakening trend in the strength of the East Asian summer monsoon remain elusive. Cooling trends in the upper troposphere have been suggested[5], as have rising sea surface temperatures over the central and eastern Pacific[6]. All in all, the evolution of the East Asian summer monsoon may just be part of the atmospheric response to global warming[7]. If so, Zhu and colleagues have presented a compelling case for the effects of climate change on air quality.

Nevertheless, the climate effects on air pollution trends in China need to be examined together with the trends of pollutant emissions: the amount of sulphur dioxide and soot emitted from power plants, industries, transportation and other human activities has roughly doubled between 1980 and 2006[8]. Such a dramatic increase in pollutant emissions is expected to be the main cause of air-quality degradation in China. The model simulation by Zhu and colleagues, with unchanged emissions throughout the study period (1986 to 2006), clearly reveals the contribution of a weakened East Asian summer monsoon to the worsening of air quality. But they also acknowledge that with the rise in pollutant emissions, the simulated aerosol concentration at the surface would have increased by more than 80% during the same period.

There is another aspect to the relationship between atmospheric aerosol concentrations and monsoon, that is, aerosols themselves could affect monsoon strength and onset. Some aerosols, such as soot and dust, absorb solar radiation and can thereby reduce surface evaporation. This in turn diminishes the land–sea temperature contrast, leading to a weakening of the summer monsoon strength[9]. However, the absorbing aerosols may also be able to strengthen the monsoon circulation through heating of the atmosphere, which leads to a positive feedback in the water cycle[10]. These studies have illustrated the complexity of aerosol–monsoon interactions. The overall effect then depends on the balance between the various influences and can thus vary with location and timing. Still, the connections between air pollution and monsoon need to be considered in the context of forcings from sea surface temperature and land surface processes, in a coupled Earth system.

The findings by Zhu and colleagues[2] indicate that the upward trend of pollutant emissions remains the most important factor influencing the decadal scale change in aerosol concentrations in China. Then, on top of the effect of rising emissions, the weakening of the East Asian summer monsoon has trapped more pollutants over land and reduced the removal of aerosols, thus making air pollution problems worse. ❐

Mian Chin is at the NASA Goddard Space Flight Center, Code 614, Greenbelt, Maryland 20771, USA.
e-mail: mian.chin@nasa.gov

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PALAEOCLIMATE

Analogue complexity

The last deglaciation was punctuated by several millennial-scale climate changes. In the Gulf of California, the cold stages were marked by decreased upwelling, opposite to the changes expected if these shifts were analogous to modern seasonal variability.

Dorothy Pak

The warming of the Earth between the Last Glacial Maximum and the Holocene interglacial was not a steady transition. In the high latitudes, rising temperatures were punctuated by large, millennial-scale fluctuations in temperature that were accompanied by periodic discharges of icebergs in the North Atlantic Ocean[1,2]. These high-latitude variations were also rapidly transmitted through the mid and low latitudes[3,4], but the exact nature of the associated reorganization of ocean and atmospheric circulation is poorly constrained. Analogues to modern seasonal and interannual variations in atmospheric circulation, such as the El Niño–Southern Oscillation (ENSO), are often invoked, particularly when reconstructing conditions in the glacial Pacific Ocean. Writing in *Paleoceanography*, McClymont and co-workers[5] identify dynamic glacial to interglacial changes in temperature and upwelling in the tropical Pacific Ocean and show that they cannot be readily explained by present-day analogues of ocean–atmospheric circulation.

Seasonal changes in the tropical Pacific are linked to the high latitudes through variations in the position of atmospheric high- and low-pressure systems. Seasonal changes also control the location of the band of precipitation associated with the intertropical convergence zone (ITCZ), which migrates north during the boreal summer and closer to the Equator as the Northern Hemisphere cools (Fig. 1). On an interannual (three- to seven-year) basis, the tropical Pacific is also affected by the ENSO phenomenon. During La Niña events — the cool part of the oscillation — the easterly trade winds are strong. The winds drive intense upwelling and hence cooling in the Pacific cold tongue, which extends from the northwestern coast of South America. The strong winds also enhance warmth and precipitation in the western tropical Pacific. Conversely, during El Niño, weakened trade winds allow warm water to spread towards the South American coast.

The seasonal and interannual variations both result in characteristic shifts in sea surface temperature (SST) and salinity. Similar patterns have been identified in the palaeoclimate record. The short-lived seasonal and interannual events have therefore been used as analogues for longer-term changes over millennial-scale shifts from cooler (stadial) to warmer (interstadial) conditions and glacial–interglacial cycles. For instance, high salinity in the eastern tropical Pacific during stadials suggests that the presence