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News Feature

Atmospheric science: Cloudy, with a chance of science

When American and Chinese scientists agreed to measure pollution and dust over China, nobody foresaw how difficult it would be. Jane Qiu reports.

Jane Qiu

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The meteorological bureau in the sleepy town of Shouxian in eastern China was buzzing with excitement. It was May 2008, and the spacious courtyard was littered with sophisticated remote-sensing instruments that had just arrived on loan from the United States Department of Energy (DoE). The bureau had been expecting the equipment earlier, but it had been held up by Chinese customs officials for more than two months.

A group of climate researchers and government officials from China and the United States eagerly inspected the new arrivals, which included a cloud radar, a tailor-made lidar (a radar-like instrument that sends out laser beams rather than microwaves) and sensors for studying various features in the atmosphere and the radiation from the Sun. "We can do great things with these here," said Zhanqing Li, an atmospheric scientist at the University of Maryland at College Park, who was leading the Sino-American collaboration.

Over the next few months, these instruments would be pointed up into the Chinese sky to monitor and study aerosols — tiny airborne particles such as dust and soot. The researchers were particularly interested in tracing how aerosols alter the personality of clouds by influencing whether clouds produce rain, how high they extend, how much sunlight they reflect and how long they persist. At present, atmospheric researchers have only a rudimentary understanding of how aerosols affect clouds and that ignorance is one of the major sources of uncertainty in forecasts of future climate.

For aerosol experts, China's sky is close to heaven. The country has high concentrations of particles arising from pollution as well as natural dust blowing in from surrounding deserts. Researchers expected that data from such a particle-rich atmosphere would help to resolve major questions about aerosols and climate. At the same time, it was hoped that the project, staged at four sites across China (see map) would reap political rewards. The joint collaboration, conducted under the umbrella of the DoE's Atmospheric Radiation Measurements (ARM) programme, was viewed as a sign of China's movement towards openness. "This kind of collaboration would have been inconceivable ten years ago," says Thomas Ackerman, an atmospheric scientist at the University of Washington in Seattle.

The political winds did not, however, always blow favourably. With much frustration, the DoE had to alter its usual mode of operation and settle for lower-quality data and a smaller range of measurements than expected. "Between the heights of hope and the depths of despair, it was the most up-and-down deployment we have ever had," says Warren Wiscombe, ARM's chief scientist and an atmospheric scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

The stakes are high because the data collected by the ARM programme will be used to improve the way that climate models simulate clouds and aerosols. When the programme was created in 1989, it collected measurements only at fixed sites within the United States. "But it soon dawned on us that we need as much information as possible from diverse climate systems around the world to build up a complete picture o global climate change," says Wiscombe.

This resulted in a mobile facility, built in 2004, that contains most of the remote-sensing instruments present at the fixed sites. Each year, it visits a different region around the world, where it is run by an on-site technician. A team of scientists in the United States monitors each instrument remotely; they review the data for quality and then upload them in real time into the ARM data archive for use by the worldwide scientific community.

In 2007, Li and Chen Hongbin, deputy director of the Beijing-based Institute of Atmospheric Physics of the Chinese Academy of Sciences, won the bid to bring the mobile facility to China the following year. The project came under the umbrella of a climate-science agreement signed in 1987 between the DoE and China's science ministry. Under that compact, the two countries are committed to sharing data and collaborating on joint field campaigns, climate modelling and strategies for adapting to climate change.

Cloud puzzle

One aim of deploying the ARM mobile facility in China was to investigate an observation that had puzzled atmospheric scientists for some time. Microwave-sensing instruments on the joint US–Japanese Tropical Rainfall Measuring Mission satellite detect large amounts of liquic water in clouds over the coastal region of eastern China, yet the satellite's radar shows that there is very little rainfall.

"The two satellite instruments disagree with one another, which is very unusual," says Chris Kummerow, an atmospheric scientist at Colorado State University in Fort Collins, who discovered the discrepancy with his colleagues (**W. Berg *et al. J. Appl. Meteorol. Climatol.* 45, 434–454; 2006**). Some researchers suspect that the high level of aerosols in the Chinese atmosphere might be the culprit. The standard thinking about aerosols is that the particles often suppress rainfall by providing a nucleation site on which water can condense; they increase the number of cloud droplets and reduce their average size, thus making it harder for small droplets to grow big enough to drop out of the cloud as rain.

And China's air is chock-full of aerosols, at concentrations three times the global average. The density of aerosols, particularly in the populous eastern part of the country, has been rising rapidly. In eastern central China, Li and his colleagues have found that the number of clean air days — defined as having at least 75% of the maximum visibility — has declined continuously over the past three decades, from 26 in 1976 to 14% in 2007.

The arrival of the equipment in Shouxian was a cause for celebration.

J. QIU; Z. LI; J. QIU

The full effect of all those aerosols is hard to discern. Many other variables, such as the types of aerosol, the nature of the land surface and atmospheric circulation patterns, could influence how aerosols alter clouds. "We need a large data set from as many climate regions as possible," says Mark Miller, an atmospheric scientist at Rutgers University in New Brunswick, New Jersey. "The ARM deployment in China is an important part of that effort."

The plan was to take the monitoring facility to four locations in China with different climates and aerosol types. The two eastern sites were rural Shouxian, 500 kilometres northwest of Shanghai, and Taihu (Lake Tai), in the industrial heartland of the Yangtze River delta region, about 100 kilometres west of Shanghai. These two locations have a similar climate but very different atmospheric aerosols: those over Taihu come mainly from industrial pollution, whereas those in Shouxian come from windblown soil and smoke from burning crop residues.

Taihu is also the site of the largest aerosol paradox: nowhere else is there a greater discrepancy between the amount of liquid water in cloud and the amount of rainfall. "The Taihu site is ideally situated for studying the effects of aerosols on precipitation," says Li.

Another set of instruments was deployed at Zhangye in northwestern China and then the equipment was moved to Xianghe near Beijing. These two sites are much drier and less cloudy than the southeastern locations, allowing researchers to compare aerosol data taken under different climate and environmental conditions. At Zhangye, which is downwind of the Taklimakan and Gobi deserts, the researchers set out to measure dust aerosols and their effect on the amount of solar radiation that reaches the land surface.

At the end of the dust-storm season in July 2008, the instruments were moved to Xianghe to study how government actions to reduce pollution during the Beijing Olympics affected solar radiation reaching the surface. "You rarely have the opportunity to do something like that in a major metropolis," says Miller.

Stops and starts

Despite the high hopes, however, the work in China was an uphill struggle at each step, says operational manager Kim Nitschke. "Originally, our expectations were very high as we thought it would be an exciting time to get into China during the Olympics," says Wiscombe. Then, th

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spate of problems crushed their hopes. "At some points we thought we wouldn't be able to get anything out of it," he says.

The difficulties began right at the start, when the instruments became stuck in Chinese customs because of tightened regulations due to the Olympics. "We were not aware of some of the changes in customs regulations and did not have all the paperwork necessary for getting the instruments through," says Chen. On top of that, some of the sophisticated, upward-pointing instruments, such as the cloud radar, raised much suspicion among customs officials and this helped hold up their release. The delay severely curtailed the field campaign, especially at Zhangye where many of the spring dust storms were missed.

When the instruments were finally up and running in China, the support team in the United States found that the Chinese government would not allow them to access the instruments through the Internet. They could not check the quality of the measurements or fix problems remotely, nor could they upload data to the public database. The on-site technician was able to solve most of the technical issues that emerged, but some subtle problems remained for much of the deployment in China.

To the DoE's further dismay, officials from the Chinese Meteorological Administration (CMA) shut down photometers at the Shouxian and Xianghe sites that were measuring particles of black carbon, a major component of soot. Interestingly, the CMA did not interfere with measurements at other observing sites, possibly because these were being jointly operated with Chinese universities.

At one point in July last year, the DoE threatened to terminate the ARM project in China, but it decided to stay on, in consideration of the effort already invested. Eventually, after lengthy negotiations, the American researchers were granted a two-week window in October 2008, during which they could connect with the instruments remotely from the United States for about four hours each day. Only then were they able to fix the broken cloud radar, enabling it to collect data during the last two months of the project.

Clockwise, a balloon used to measure dust; collaboration participants; and a collection of radiometers.

Q. JI.; Z. LI; ARM CLIMATE RES. FACILITY

Political problems caused headaches up to the final days of the year-long stay in China. "Even at the end of the deployment, we were not sure whether we would be able to get anything out of it," says Nitschke. "I had all the data with me on a portable hard drive, but wasn't sure whether I would manage to get them out of China or if the Chinese government would let us make them publicly available."

The CMA did give the green light, and the original data from Shouxian and Zhangye are now available from ARM's archive. Many researchers are philosophical about the difficulties encountered by ARM's China deployment. "China is going through a transitional phase," says Daniel Rosenfeld, an atmospheric scientist at the Hebrew University in Jerusalem, Israel. Although the country is still not as open as people would like it to be, the collaboration clearly signals a move away from the old ways, he says. "The process is not complete yet, but I hope the issue of openness will be a thing of the past soon." Wei-Chyung Wang, a climate scientist at the State University of New York at Albany, and the United States' chief scientist managing the climate-science agreement, says that the project is "one of the most successful collaborations under the agreement". He adds that "this unique experience has really opened up the dialogue and will stimulate more interest in similar collaborations".

Data feast

Participants in the project say they are happy with what they were able to collect. "We now have cloud data from China nobody has ever had before," says Miller. Since the data collected at Shouxian and Zhangye were made publicly available in March and April 2009, respectively, researchers have been busy analysing them. Connor Flynn, an atmospheric scientist at the DoE's Pacific Northwest National Laboratory in Richland, Washington, is excited by the data. "Some of the lidar images are just tragically breathtaking," he says of the pollution measurements.

“We now have cloud data from China nobody has ever had before.”

Mark Miller

He has plotted the lidar data to reveal the concentration and composition of aerosols at various altitudes. "You can see atmospheric layers swirling together, ice crystals falling from a high cloud and their properties changing as they go through other layers," says Flynn. The data also show air masses with distinct aerosol compositions coming together from dust, urban, industrial and agricultural regions and mixing at different altitudes. "You don' always have those diverse sources of aerosols at high concentrations in other parts of the world," he says. The information will be enormously valuable for climate modellers trying to simulate those processes, Flynn adds.

Using data from radiometers, lidar, cloud radar and weather balloon, Li and his colleagues have made some headway in understanding the water–rainfall paradox of the clouds over eastern China. At a meeting jointly convened in Beijing last month by the DoE and China's science ministry, Li showed that the effect of aerosols on rainfall depends on the amount of liquid water in the clouds. When clouds are relatively dry, adding aerosols can suppress precipitation. In wetter clouds, however, aerosols make rain more likely. This is consistent with the observation that the number of days of light rainfall has decreased by 23% in the past 50 years in eastern China; cloud modelling studies show that this can be explained by the increased aerosol concentrations in the region (**Y. Qian *et al.* *J. Geophys. Res.* 114, D00K02; 2009**). What's more, data collected at Shouxian and Taihu show that aerosols apparently affect the thickness of clouds and the altitudes at which they form. "If this proves to be the case, the implications of aerosols for climate change will be tremendous," he says.

But the Chinese data have not solved all the cloud conundrums. Using a computer simulation, Kummerow and his colleagues have pinpointed "a very complicated pattern" in how aerosols affect clouds. "They seem to increase precipitation in some places and decrease rainfall in others," he says. For example, the cloud radar and radiometer data from Shouxian indicate that, on days with comparable aerosol amounts and cloud liquid water, sometimes it rained and sometimes it didn't.

These preliminary passes through the ARM data collected in China show how much remains to be learned there. And the scientific results are not the only dividends the project has yielded. To Chinese researchers such as Huang Jianping, an atmospheric scientist at Lanzhou University in Gansu province, the ARM collaboration helped strengthen China's capability to run long-term field campaigns. Since 2005, Huang has been building up an observational site 40 kilometres east of Zhangye, focusing on climate research of semi-arid regions. "The ARM deployment in Zhangye has allowed us to work alongside the best people in the field," says Huang. And that experience has helped spur Chinese scientists to set their sights far higher.

Jane Qiu writes for Nature from Beijing.

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