Coherent Doppler lidars

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CITY LIMITS

Observation networks are now using coherent Doppler lidars to monitor and forecast atmospheric hazards over megacities

The number of people living in cities is projected to increase from 54.5% of the world's population today, to 60% by 2030, a United Nations study says. The number of megacities (those with over 10 million inhabitants) is also expected to rise, from 31 to 41 by 2030.

According to the study, 50% of cities are at risk of at least one type of natural disaster, including severe weather, and most megacities are also facing strong air pollution events. Due to the density of the population, the risk of exposure to weather-related and air-quality hazards is high.

WEATHER-RESILIENT CITIES

The World Meteorological Organization (WMO) promotes the development of weather-resilient cities. A WMO study stresses that cities are complex systems that are highly dependent on infrastructures vulnerable to weather-related hazards.

In addition, cities greatly modify the environment, creating unique meteorological and climatological phenomenology. For example, the urban heat-island effect can raise temperatures by 5°C (41°F), exacerbating heatwaves. In cities, dense, congested road traffic and local industries may produce high levels of particles favoring pollution events when associated with stable conditions and low wind.

Many features in cities can influence atmospheric flow, turbulence regime and the microclimate. They can modify the transport, dispersion, and deposition of atmospheric pollutants, within and downstream of urban areas. There is a strong two-way coupling between the forcing effects of the urban areas and the local environment. It has been demonstrated, for example, that urban areas affect thunderstorm intensity and trajectories. In addition, pollution events in megacities are commonly a combination of specific weather conditions (low windspeed, high stability), of local emissions produced by the urban area and their mixing with aerosols of incoming air masses. With cities on the coast, the effects of the diurnal cycle of sea/land breezes on local pollution have also been studied.

A KEY DISCIPLINE

Urban meteorology aims to describe physical and chemical processes on a city scale.

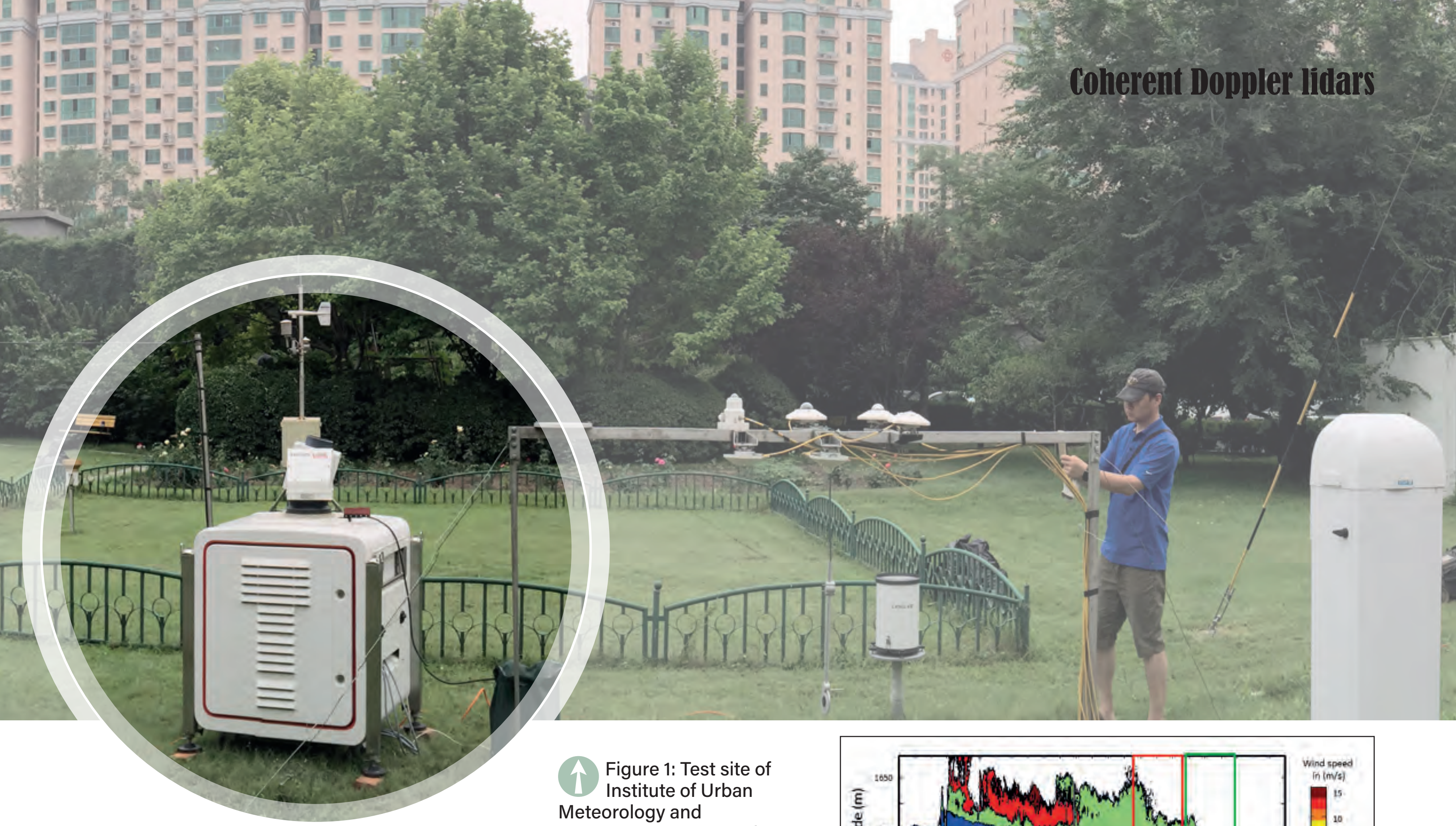


Figure 1: Test site of Institute of Urban Meteorology and WINDCUBE100S Doppler Lidar, central Beijing

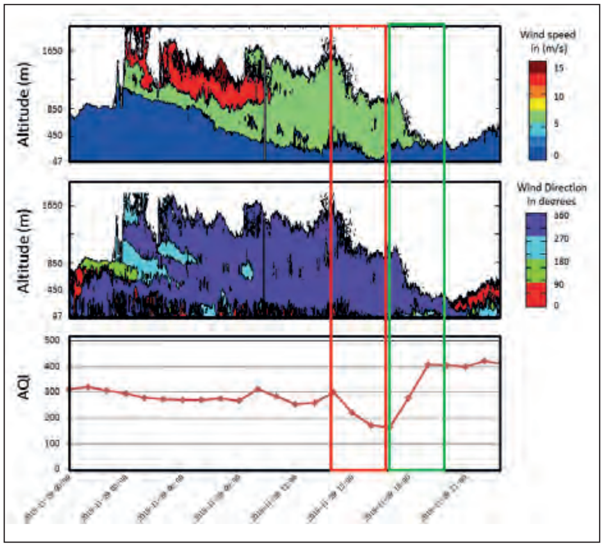


Figure 2: Time series of AQI correlated with horizontal windspeed and direction profiles

Considerable progress has been made in this field over the past 20 years, but many studies are still ongoing and further work is needed to develop more weather-resilient cities.

Numerous research projects and pioneering observation networks are ongoing worldwide in a bid to better understand local specificities of urban areas and their coupling with regional weather and climate conditions, and to better monitor and forecast the different atmospheric hazards that represent the highest risk exposure for human activities and lives. Most of them use advanced observing and modeling technologies. Dedicated observation networks with common surface weather and air-quality stations are enhanced by high-technology remote sensors such as coherent Doppler lidars, combined with very high-resolution numerical prediction weather and air-quality models.

URBAN IMPACTS STUDY IN CHINA

In Beijing, China, the Institute of Urban Meteorology's SURF project (Study of the Urban Impacts of Rain and Fog/Haze) has developed a comprehensive boundary layer meteorological and air quality monitoring network.

It consists of ground-based meteorological and air-quality sensors installed across the Beijing area and a unique urban weather monitoring site (Figure 1) in the city center. The site has a well-equipped 325m (1,066ft) meteorological tower and upper-air remote sensors including a coherent Doppler lidar (Leosphere's WINDCUBE100S) and a microwave radiometer.

From November 27 to December 1, 2015, Beijing was affected by a severe smog event, which covered 530,000km^2 (204,634 square miles). Beijing Environmental Protection Bureau anticipated and forecasted a very high air-quality index (AQI). However, forecasting uncertainty prevented it from issuing a red alert, which is issued when the forecast AQI is over 200 for more than 72 hours.

During the smog event, the AQI was over 200 for four days, with two specific V-turns – a sharp decrease was followed by a sharp increase, on November 29 and 30. Deployed at the IAP tower site since late summer 2015 the WINDCUBE100S continuously monitors the boundary layer, providing windspeed and direction profiles, height and the optical backscatter. AQIs are usually correlated with boundary layer heights, but in this case, there was only one associated increase in the AQI. The V-turns were instead related to different air masses moving from higher altitudes to the ground or from the Beijing region to its urban area (Figure 2).

Firstly, northerly winds brought clean air from 1km (0.6 mile) to the ground, leading to the fall in the AQI during the first V-turn. The AQI suddenly rose due to a cold front arriving from the south at very low altitude (below 200m (656ft)), bringing polluted air to central Beijing. The analysis of the second V-turn revealed that strong vertical motions led to the polluted air near the ground becoming mixed with higher clean air.

This study showed the strong correlation between the pollution observed in cities and the movements of different air masses from the regional to the urban areas. It also demonstrated that well-known effects such as stability and collapse of boundary layer are not always the key factors in pollution events.

Figure 3: Time series of PM concentration measured at three air quality monitoring stations close to Dunkerque port and industrial facilities

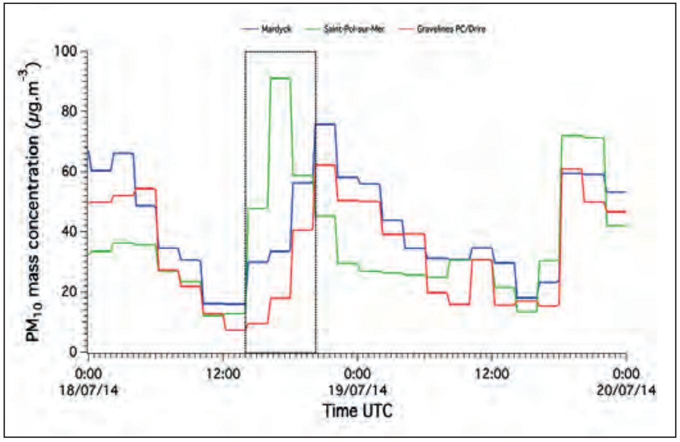
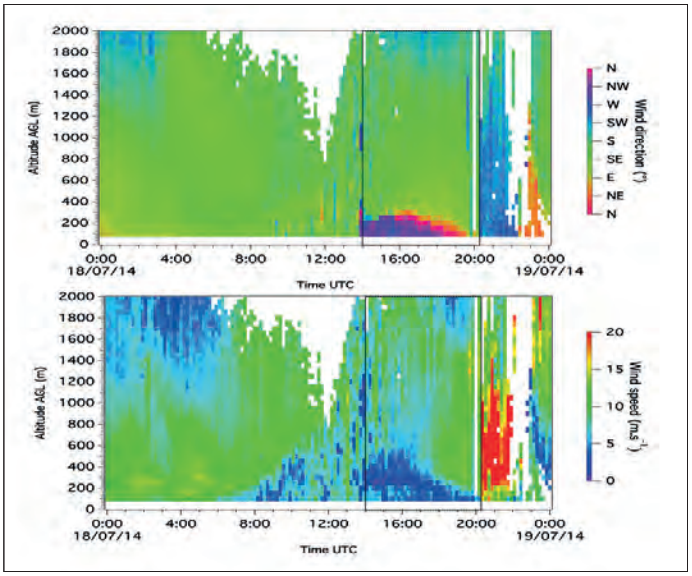


Figure 4: Time height sections of wind direction (top) and windspeed (bottom)



COASTAL CONSIDERATIONS

Many cities are coastal, so the effects of sea and land breezes on AQI are of primary interest. The Laboratory for Physics and Chemistry of the Atmosphere, in Dunkerque, Northern France, is equipped with a unique research infrastructure called IRENE (Innovation and Research in Environmental Sciences). It features a range of technical equipment including a WINDCUBE100S coherent Doppler lidar used for the monitoring and better understanding of local weather events and micrometeorology on air quality.

SEA BREEZE STUDY IN FRANCE

A one-year field campaign took place from September 2013 to September 2014 in Dunkerque, near one of the most important industrial and petrochemical areas in Europe. During this experiment, the WINDCUBE100S was configured to continuously monitor vertical profiles of windspeed and direction. This enabled the observation of the fine structure of local meteorological phenomena such as sea breezes. A machine-learning algorithm using meteorological data has been developed to classify the main meteorological phenomena involved in air-pollution events.

Figure 4 illustrates the time-height cross-sections of the wind direction and speed recorded on a summer day with a sea breeze event, while Figure 3 shows PM10 (particulate matter) concentrations recorded on the same day at three air-monitoring stations close to Dunkerque harbor and industrial facilities.

Before the sea breeze onset, the wind profile showed fluctuations due to the development of thermals; PM10 concentrations fell as the boundary layer height increased and the pollutants were diluted in a growing volume. The sea breeze onset was characterized by a rapid shift of wind direction from the land (south) to the sea (northwest), and a fall in windspeed. It coincided with a steep increase of PM10 concentrations, as particles carried out over the sea during the night and fresh emissions were transported within the sea breeze current. The end of the sea breeze was followed by the development of a low-level jet above 200m (656ft) above ground level, parallel to the coastline (west-southwest), that flushed pollutants away from the agglomeration and led to a rapid decrease in PM10 concentrations.

THE HEIGHTS OF PARIS

The WINDCUBE100S also featured in the VEGILOT research project, which studied the effect of the urban heat island on vegetation in Paris. Its 3D scanning capability was used to observe the vertical structure of the boundary layer over the city. Installed on top of the Pierre & Marie Curie University's 70m-high (230ft) building in central Paris, it performed vertical cross-sections of the boundary layer. (Figure 5.)

THE ULTIMATE GOAL

These examples pave the way for routine observations with coherent Doppler lidars of local atmospheric conditions at urban sites. The ultimate goal is not only to describe and understand the physical and chemical processes, but to drive urban development strategies and better forecast air quality and meteorology at large urban sites. Combined improvement of observation networks and high-resolution numerical models is the key to success. Some other projects like the AIRCITY project by ARIA technology demonstrates how a city like Paris can be fully modeled to provide high-fidelity air-quality information, while being initialized by a dense network of upper-air remote sensors such as the WINDCUBE100S. ▮

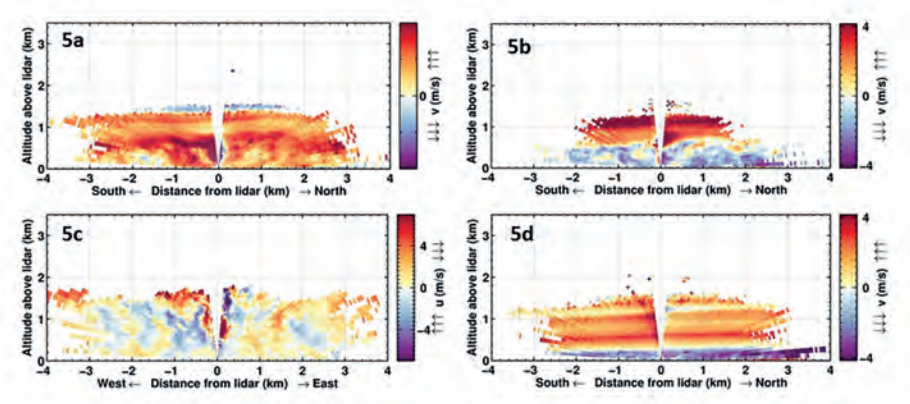


Figure 5a: Convective boundary layer under a diurnal low level jet; 5b: The convective boundary layer with strong directional shear at the boundary layer top; 5c: Turbulent motions in the fully developed convective boundary layer; 5d: Turbulence in the nocturnal boundary layer