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Shanghai's Urban Integrated Meteorological Observation Network (SUIMON): case studies of applications

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1. Introduction

Observations of atmospheric conditions and processes in urban areas are fundamental to understanding the interactions between the underlying surface and the weather/climate, and improving the performance of urban weather, air quality and climate models. Such observations also provide key information for end-users (e.g. decision-makers, stakeholders, public) for a myriad of applications. Shanghai, a coastal city located at the middle of China's coastline (Fig. 1a), had a population greater than 23 million in 2010, with more than 2.6 million automobiles, more than 32,000 tall buildings(>30 m tall) and over 1200 skyscrapers(>100 m tall) in 2012. Shanghai is one of a small group of cities with urban stations with long (>100 years) continuous records (Gherzi, 1950) (in Shanghai dating back to 1872). Today in Shanghai, there are a series of networks of different instrument types (e.g. automatic weather stations , weather radar, Met-towers, wind profilers, lightning mapping systems, remote sensing systems) that provide dense observations through a network of networks, referred to here as SUIMON (Shanghai's Urban Integrated Meteorological Observation Network). The objective of the presentation is to introduce the characteristics, functions, and current state of SUIMON, and to provide examples of intended applications and future plans for its development.

2. Features of SUIMON

Shanghai's urban observations extend over an area (6340 km^2) that is roughly 120km by 120km (Fig. 1). SUIMON, a network of networks, has been established from different systems and instrumentation deployment types. The initial foci for SUIMON relate to high impact weather; urban environmental and micro-meteorological conditions; special needs for end-users.The ultimate goal of SUIMON is to provide measurements of all the processes that influence Shanghai's regional environment and the city itself, including both physical and chemical characteristics of the boundary layer and the free atmosphere, so linkages can be better understood.

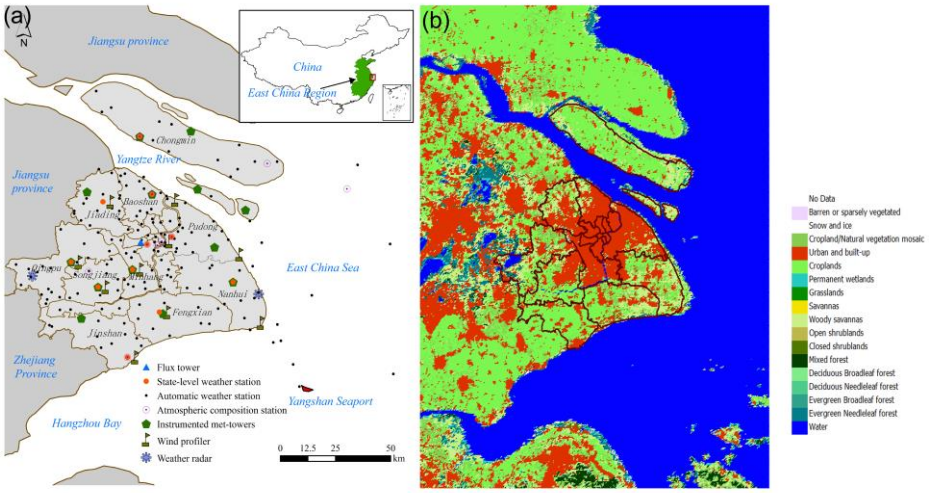

Fig. 1:Shanghai's location within China(inset), observation sites within the Shanghai urban integrated meteorological observation network (SUIMON) in 2013. The 10 counties that make up the province of Shanghai andthe land cover derived from Landsat Thermal Mapper imagery

SUIMON is designed to satisfy the following features:

- Multi-purpose: forecasts, research, service
- Multi-function: high impact weather, urban environment, special end user needs

- Multi-scale: macro/mesoscale, urban scale, neighborhood scale, street canyons, buildings
- Multi-variable: thermal, dynamic, chemical, bio-meteorological, ecological
- Multi-platform: radar, wind profiler, ground-based, airborne, satellite based, in-situ observation, sampling
- Multi-linked: linkages between all platforms

With:

- Management to facilitate exchange of data and information
- Ability to improve coordination of strategies and instruments and to identify gaps in observations based on science and user driven requirements
- Capability to intelligently combine observations from a variety of platforms using a data assimilation system that is tuned to produce the best estimate of the current state of the urban atmosphere.

3. Application Case Studies

3.1 Heat island, sea breeze and convective weather

The interaction between the sea breeze and the lake breeze is the main factor for the formation and maintenance of the surface shear line which related to the short-term convective weather. Based on the dense meteorological observation network in SUIMON, the distribution of occurrence of the severe convective precipitation events (daily rainfall > 50mm) derived from the dense surface AWS monitoring records shows a high frequency over the urban area and the mouth of the Yangtze river, that matches well with the spatial distribution of cloud-to-ground flash density. This may be due to the presence of the urban heat island and the sea breeze circulation. SUIMON has, and is being, used to investigate UHI effects on thermodynamic instability; UHI convergence in association with intensification and/or initiation of electrically active thunderstorms in the metropolitan area; and UHI enhancement of convective updraft strength in relation to the frequency of lightning, to characterize and evaluate thermodynamic and kinematic structures of thunderstorms, in the context of a better knowledge of the physical process of rain formation maintenance, and evolution

3.2 Photochemical and Urban aerosol pollution

Cities are a major source of air pollution emissions due to the burning of fossil fuels for heating and cooling, industrial processing, and transport of people and goods. Cities also modify their ambient weather (especially winds, turbulence, radiation, mixing height and temperature) in ways that often negatively affect the dispersion, transformation and concentration of those pollutants. Air quality forecasts and warnings are needed at multiple scales of the region, city, and street. Information about the atmospheric circulation are combined with the higher temporal, vertical, and horizontal spatial resolution data (e.g. urban boundary layer structure and mixing layer heights, vertical profiles of winds, turbulence, temperature inversion).The city, with its characteristic roughness height and temperature evolution, has a strong impact on the structure of the urban boundary layer and hence on the pollutant dispersion near the surface.

Within SUIMON O3 concentration and photochemical precursors have been systemically measured and their relations investigated. For example, the ozone “weekend effect” and the impacts of the precursors on ozone formation have been revealed. Ground-based remote sensing (e.g. sun photometer, MPL 4 Lidar, ceilometer) have been used to investigate urban aerosol and fog/haze events.The observations have been used to evaluate the performance of the WRF-Chem model. This is now used routinely as a chemical weather forecast for the Yangtze River Delta Region. Furthermore, SUIMON is being used to improve the chemical weather forecast by providing improved data for a reaction scheme of photo-oxidants and particle interactions. This has been taken further to investigate the relation between air pollution and human health.

3.3 End User applications supported by SUIMON

In Shanghai, urban weather-sensitive applications supported by SUIMON include:

- Urban Flood control: Flood control agencies need data on precipitation (rain, snow) distribution and runoff, as well as the water storage capability of urban pervious surfaces, drainage systems, and water-logged ground.
- Electric power: Power plants, grid operators, and local utilities need high-resolution air temperature for assessing energy demand and resulting loads on the electric grid. Wind and solar radiation are also needed for renewable energy assessments.
- Urban Design: Urban planners and design departments need information on the UHI, vegetation stress index, urban air quality, wind
- Public Health: Pollutant emissions and concentration, solar radiation, wind, humidity and air temperature are needed at appropriate scales for street level, air quality, pollen, predictions of heat stress.
- Transport management: Transport agencies need data on strong winds (especially channeling wind), precipitation and its forms (i.e. rain, freezing rain, sheet or snow), surface state (dry, wet, ice covered), and high-resolution spatial forecasts (e.g. roadway scale) for metros, highways, and seaports.

• Security & Emergency response: Urban emergency response agencies need timely and accurate information on extreme weather, such as detailed street-level flood information, and high spatial and temporal resolution wind, temperature, and moisture data in and above the urban canopy.

For example, given the high frequency of intense storms, the design of billboards that are permitted in the city has become one area of focus given the damage caused when intense gusts cause them to become unattached. Combining Fluent CFD modelling, with the extensive wind data available across the area, has resulted in new designs to reduce damage

4. Future considerations

To meet emerging science-and-user driven needs and requirements, the Shanghai Meteorological Service (SMS)expects to enhance the multi-functions of SUIMON. The emphasis will be on the acquisition of information associated with physical processes of the urban boundary layer and the effects of the underlying surface：

• Meso-and micro-scale processes over urban surfaces (such as cloud microphysics, precipitation processes)

• Height (and structure) of the PBL and vertical profiles of wind, temperature, water vapor and atmospheric composition

• Field studies to validate satellite observations and modeling simulations of urban precipitation processes and to extend basic understanding of the processes involved

• Enhancing existing observing systems to focus on city-atmosphere interactions, especially to monitor and track land-cover/land-use changes, atmospheric composition, cloud microphysics, and precipitation processes

• Modeling systems that explicitly resolve multi-scale (e.g. urban canopy, street, building) processes, aerosols and cloud microphysics, complex land surfaces, to enable a more complete understanding of the feedbacks and interactions

It is expected that SUIMON will continue to evolve because of new user requests and new technologies, as it repeatedly has done over the last 140 years. Many of the developments in the near future are expected to involve better use of the combined database. One key challenge is how to monitor the spaces between buildings given the rapid increase in tall buildings (Table 2) in Shanghai and the many other rapidly growing cities of Asia and South America. Applications from response to fires to management of energy use to near-surface air quality would benefit from improved understanding of this very large urban canopy layer. SUIMON, with measurements to end-user support provides a prototype for Integrated Urban Weather, Environment and Climate Services (Grimmond and WMO Secretariat 2014)

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