Integrated Land EcoSystem Atmosphere Processes Study

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Integrated Land Ecosystem Atmosphere Processes Study

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Editorial

Land Ecosystem-Atmosphere Processes Study in Asia

Climate change and air pollution are different phenomena, but their causes are closely coupled. Rapid economic growth during the past two-three decades in Asia followed by emerging emissions of greenhouse gases (GHGs) and atmospheric pollutants clearly showed the risks of these issues on our society and land ecosystems. Environmental pollutants including GHGs and air pollutants are emitted from megacities and transported long distances away from the local sources. However, sufficient policy mechanisms do not currently exist to mitigate the impacts resulting from such pollution.

Megacities are the centers of economic development of countries, and many challenges remain including the need to improve air quality and, at the same time, mitigate climate change. Enormous progress was made in Asia over the last 2-3 decades, and citizens in cities can now gain benefits from the economic growth. However, significant negative impacts are also expected such as the flood-affected areas particularly in South-Asia and arid area in Central Asia where agriculture is already at the limit of tolerance.

Scientists in Asia have been working hard during the past decade to establish various international joint projects as well as long-term environmental monitoring networks; such as the energy, water, and GHGs flux monitoring network (AsiaFlux, one of regional networks in FLUXNET), International Long-Term Ecological Research (ILTER) and its Asian branch activities, and communication networks under iLEAPS (iLEAPS Asia).

Progress has been made in science and technology based on such observation networks incorporating empirical and process-based models on energy, water, carbon cycles (Ichii et al., in this issue); monitoring and mitigating GHGs emissions from managed ecosystems such as rice paddy, one of the most important crops for agriculture and food security in Asia (Alberto et al., in this issue);

Focuses of science depend on the significance of the existing problems and social needs, while simultaneously, long-term efforts are indispensable for constructing internationally harmonized environmental monitoring systems, which will contribute significantly to detect changes in the atmosphere, water, land ecosystems, and society. Developing human capacity to maintain such environmental monitoring is also required to keep promoting future science.

Thus, there is a need to develop and maintain integrated observation and analysis systems at the Asian scale covering such components as atmospheric GHGs, aerosol, trace gases, air pollutants, land use change, and ecosystem functions and structures, or ecosystem services. Such systems will also contribute to ensure accuracy and consistency of inventory data in each of the countries and regions. There already exists an increasing number of observational platforms such as satellites, aircrafts, ships, and ground stations. However, due to limitations in measurement accuracy and limited spatial temporal coverage in time and space, high uncertainty still remains in emission estimations for environmental pollutants. Integrating reinforced observation data into improved analysis systems using advanced inversion/assimilation models would contribute to reduce the uncertainty in regional source/sink estimations. High-resolution regional analysis systems to detect large point sources could also be put into practical use.

Based on such long-term observation and analysis systems for environmental pollution, we need to estimate impacts of climate change and human activity that may be already appearing in vulnerable regions, such as permafrost, boreal and tropical wetlands including peat swamps, mid-latitude arid zone, and tropical forests where biodiversity is decreasing by severe land-use change. Finally, one of the urgent directions we need to pursue to initiate more meaningful communication with different stakeholders for constructing a more sustainable future through verification of mitigation measures for emission reduction of environmental pollutants, dissemination of scientific knowledge and data to our society.

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Current status of empirical estimates of terrestrial carbon and water cycles using eddy-covariance network and remote sensing data

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Uncertainties in terrestrial carbon cycle

The terrestrial biosphere plays important roles in regional and global carbon cycles through biogeochemical and biophysical processes, in turn affecting the trajectory of climate change. Recent model intercomparison efforts have revealed large and persistent uncertainties in CO_2 fluxes among terrestrial biosphere models [1-3]. These uncertainties propagate into future projections, leading to differences in future climate change scenarios [4]. Evaluations of terrestrial biosphere models using site-level observation, such as that by the eddy-covariance observation network, indicate that current biosphere model simulations tend to deviate among models and observed CO_2 fluxes [2, 3, 5]. These efforts suggest that uncertainties found in site-level consistency would propagate into spatial simulations, leading to large uncertainties in regional and global CO_2 budget estimates.

Reducing uncertainties in carbon cycle simulation is a challenging task because of insufficient observed CO_2 fluxes, which serve as references for refining terrestrial biosphere models at regional and global scales. Recently, the network of eddy-covariance observation has increased, and more data have become physically available. These datasets allow empirical upscaling of terrestrial CO_2 and H_2O fluxes, and their application has shown significant progress. In this article, we introduce an overview of empirical upscaling and the potential applications of the dataset to reduce uncertainties in terrestrial biosphere modelling.

Growth of eddy-covariance measurement network

The network of eddy-covariance observation has been increasing since the 1990s and covers more than 900 sites globally (http://fluxnet.fluxdata.org/about/history/; accessed on February 4, 2018). These sites include more than 100 locations in Asia (http://asiaflux.net/; accessed on February 4, 2018), covering various geographical regions such as southeast Asia, East Asia, and Far East Asia including Siberia. These datasets have been used to assess CO_2 budgets of forests, grasslands, and croplands across various climate regions in Asia. Synthesis studies across Asia [6-9] have deepened our understanding of spatial–temporal patterns of gross primary productivity (GPP), ecosystem respiration (RE), and net ecosystem exchange (NEE) of Asian ecosystems.

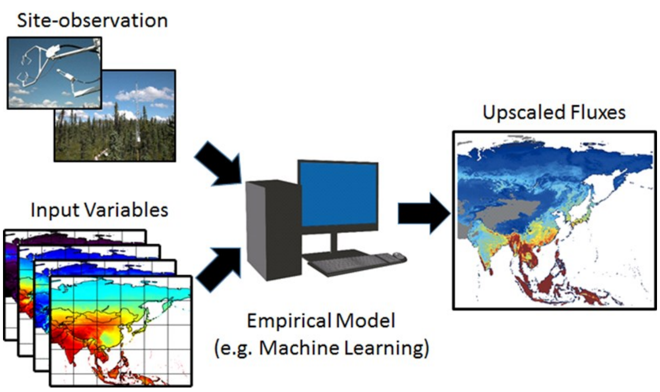

Figure 1. . Scheme diagram for empirical upscaling by the ground-based observation network and remote sensing observation.

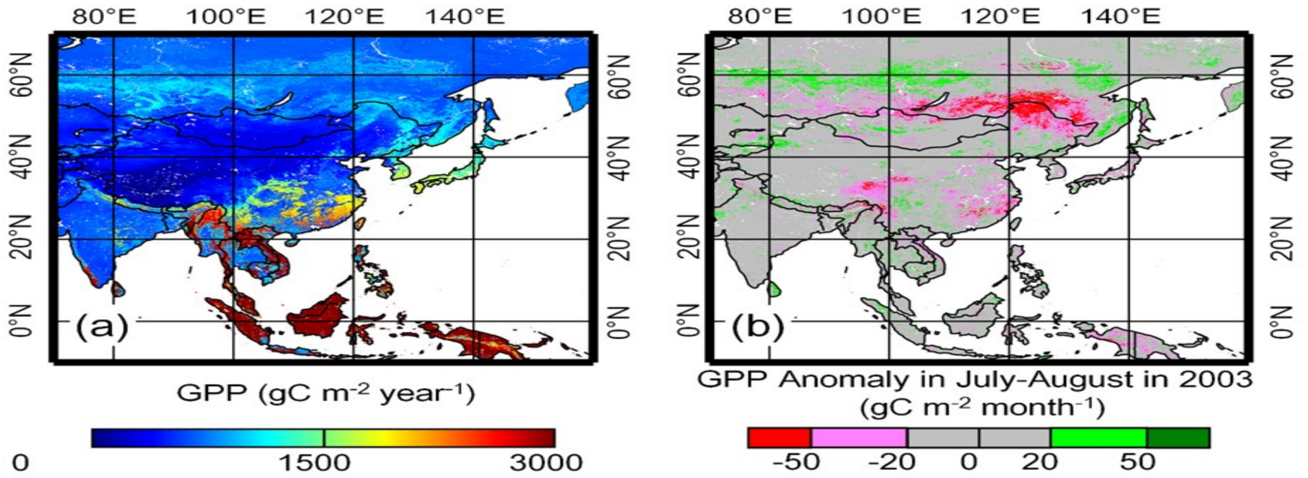

Figure 2. (a) Spatial patterns in annual gross primary productivity (GPP) averaged over 2001–2006. (b) Anomalies in GPP in July–August 2003 compared with those months in 2001–2002 and 2004–2006 [15].

Empirical upscaling of terrestrial CO_2 fluxes using network of ground observation

The increasing network of eddy-covariance observation

shows promise for enhancing the understanding of the terrestrial carbon cycle; however, the observations need to be upscaled for evaluating CO_2 fluxes on a regional to a global scale. Empirical upscaling is used to assess spatio-temporal CO_2 flux based on an empirical relationship between observed fluxes and explanatory variables. This approach first establishes an empirical model at the observation sites, and the model then interpolates and extrapolates the observations by using spatial data from remote sensing observation and meteorological gridded data. Machine-learning algorithms such as neural network, support vector regression (SVR), and model tree ensemble are effective in the construction of an empirical relationship between target and input variables. Models generated by such algorithms are used to assess CO_2 fluxes in global [10-12] and continental scales such as those in Alaska [13, 14], Asia [3, 15, 16], the conterminous United States [17, 18], Europe [19], and North America [20]. An new approach which aims to produce more robust ensemble products based on multiple machine-learning algorithms was initiated in 2011 as FLUXCOM project, and global energy and carbon fluxes products were generated [12, 21].

Application of empirically upscaled fluxes

Monitoring of temporal changes in terrestrial CO_2 fluxes

Empirically upscaled fluxes are determined through direct extrapolation of ground observation and can be used for analyzing changes in terrestrial carbon and water cycles. In such an application, the SVR algorithm was used to analyze interannual variations of CO_2 fluxes in East Asia and Siberia [15]. The SVR-based upscaling over East Asia detected spatially extensive decreases of GPP in summer 2003 in response to anomalously low radiation caused by a stationary rainfront [15]. This result demonstrates the potential use of empirical upscaling in analyses of flux variability under anomalous climate events.

In the case of Alaska, upscaling using 21 eddy-covariance towers [13] has shown CO_2 as a sink over boreal forests in interior Alaska and as a source over tundra in the Arctic during the study period of 2000–2011 (Fig. 3a). For this period, the estimated GPP and RE were 369 ± 22 and 362 ± 12 Tg C yr^{-1}(mean ± interannual variability), respectively, indicating an approximately neutral CO_2 budget. Significant increases in the CO_2 sink were estimated in the boreal forests (green colors in Fig. 3b), where vegetation was recovered for about 20 years after wildfires. In contrast, the CO_2 sink decreased or the source increased as a result of recent wildfires. These results indicate that disturbance information is useful for evaluating long-term changes in CO_2 flux in the upscaling scheme

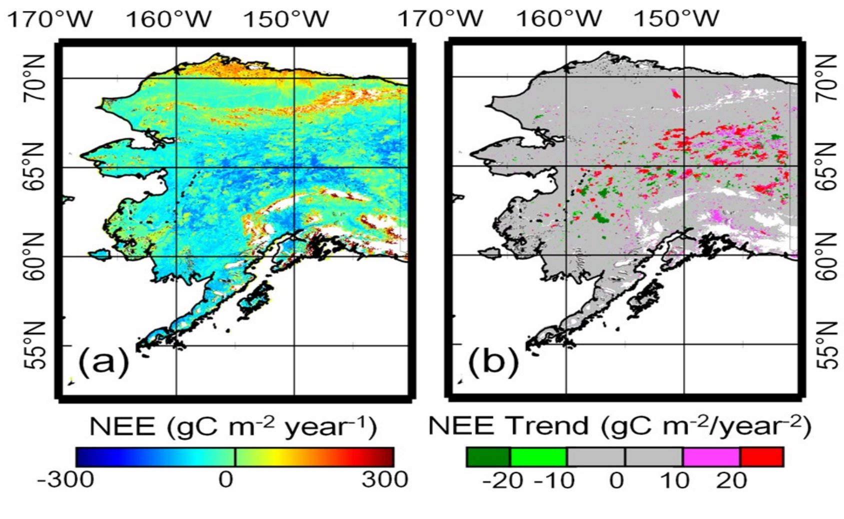

Figure 3. Spatial patterns in (a) net ecosystem exchange (NEE; mean of 2000–2011) and (b) its temporal trend (2000–2011) estimated by the support vector regression algorithm using the network of eddy-covariance measurements in Alaska [13]. Terrestrial carbon uptake is assigned a negative value.

Evaluation of terrestrial carbon cycle models

Because empirical upscaling provides an explicit data-driven estimate of CO_2 flux, its estimate is a good candidate for independent data in evaluating terrestrial biosphere models. For example, monthly variation in terrestrial GPP estimated by an empirical upscaling (SVR) is better than those by process-based models at eddy-covariance observation sites in Asia [16]. Furthermore, a comparative study showed that GPP by empirical upscaling tends to have smaller interannual variations than that of process-based model outputs [22].

Consistency of estimated fluxes with top-down estimates

The estimated CO_2 fluxes from empirical upscaling require further evaluation using other data-driven estimations. One such candidate is estimation from atmospheric inversion. Atmospheric inversion estimates the CO_2 budget of land–atmosphere and ocean–atmosphere by using atmospheric transport model and atmospheric CO_2 observations.

Launched in 2009 by Japan, the Greenhouse Gases Observing Satellite (GOSAT) is the first operational satellite that observes the atmospheric CO_2 column concentration globally and is expected to provide better constrained land-atmosphere CO_2 fluxes [23]. Thus, GOSAT-derived land-atmosphere CO_2 flux is an ideal product for evaluating empirically upscaled CO_2 flux at the global or continental scale [11, 16].

The estimated terrestrial CO_2 exchange products of SVR and GOSAT show highly consistent seasonal variations in the high-mid latitudinal regions of the Northern Hemisphere (Fig. 4). For the period of June 2009 to August 2011, the seasonal pattern and amplitude of the two CO_2 exchanges were highly similar in Alaska, Northern

Europe, and East Asia, as shown by IDs 3, 41, and 32 in Fig. 4, respectively. To the contrary, agreement in seasonal variations between the two CO_2 exchanges was not found in the tropical regions of the Southern Hemisphere. Common to the tropical regions, SVR shows larger carbon uptake than GOSAT in the Amazon (IDs 9 and 10), Africa (ID 23), and Southeast Asia (ID 33). This inconsistency is attributed to the observation data used for the construction of the SVR model; among the 144 eddy-covariance site data points, only 4 were available for the tropical regions. Thus, the SVR model constructed with insufficient observation coverage induced biased estimates of CO_2 exchange for the tropical regions. This result implies that although machine-learning models are powerful tools, they can largely misrepresent a target variable if sufficient learning materials are not provided.

Constraining terrestrial biosphere models

Because empirical upscaling provides data-driven products of CO_2 flux and is independent from process-based terrestrial biosphere models, integration of these data into terrestrial biosphere models is an interesting and important potential application. Thus far, only a few studies have applied the estimated fluxes to improvement of terrestrial biosphere modeling. One study demonstrated that the use of empirically upscaled fluxes greatly improved the satellite-based estimation of GPP through improved estimation of maximum light use efficiency (LUEmax) in the MODIS GPP algorithm [17]. The values of the estimated LUEmax were consistent with known results, showing the highest values for cropland and higher values in broadleaf forests than those in needleleaf forests. Empirically upscaled evapotranspiration seasonality has been used to inversely estimate the rooting

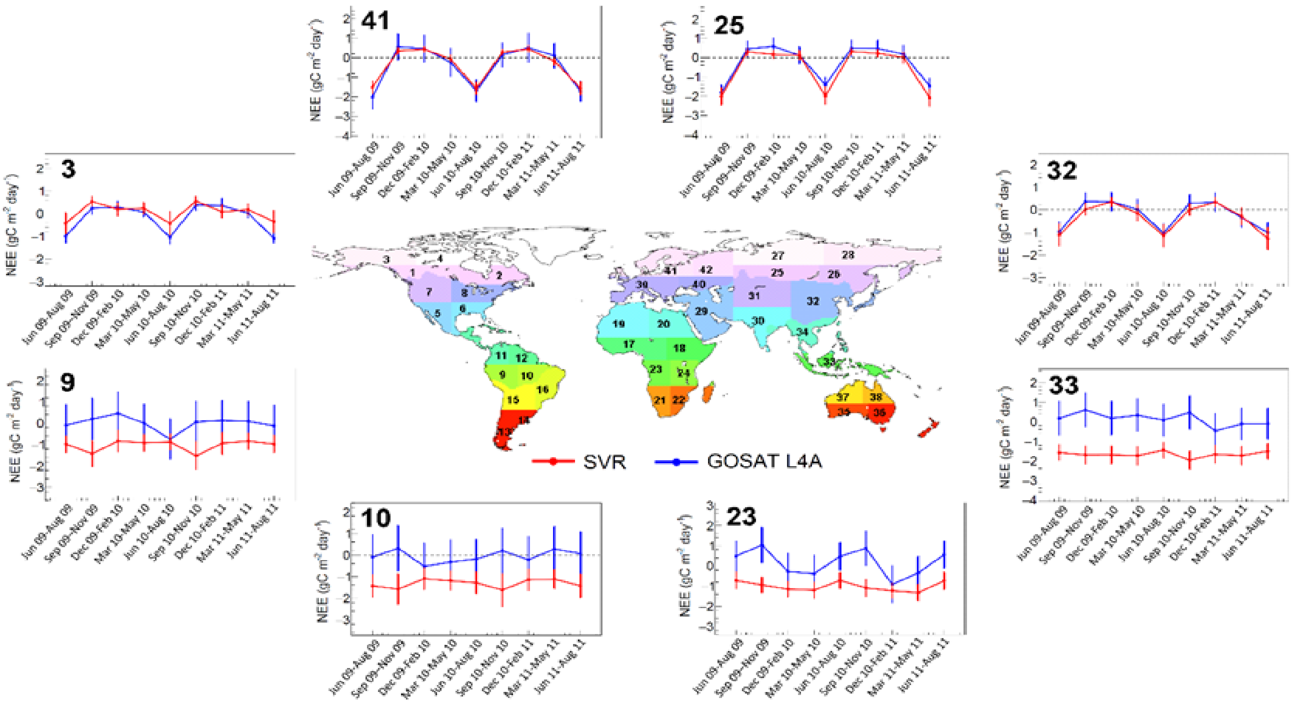

Figure 4. Seasonal variations of CO_2 exchange by the ground-based observation network and the Greenhouse Gases Observing Satellite (GOSAT) [11]. The results of the two methods are highly consistent at middle and high latitudinal regions in the Northern Hemisphere, particularly in boreal and temperate regions. Inconsistent seasonal variations are indicated near the equatorial regions and tropical zones in the Southern Hemisphere.

depth in an ecosystem model in California [24] (Fig. 5).

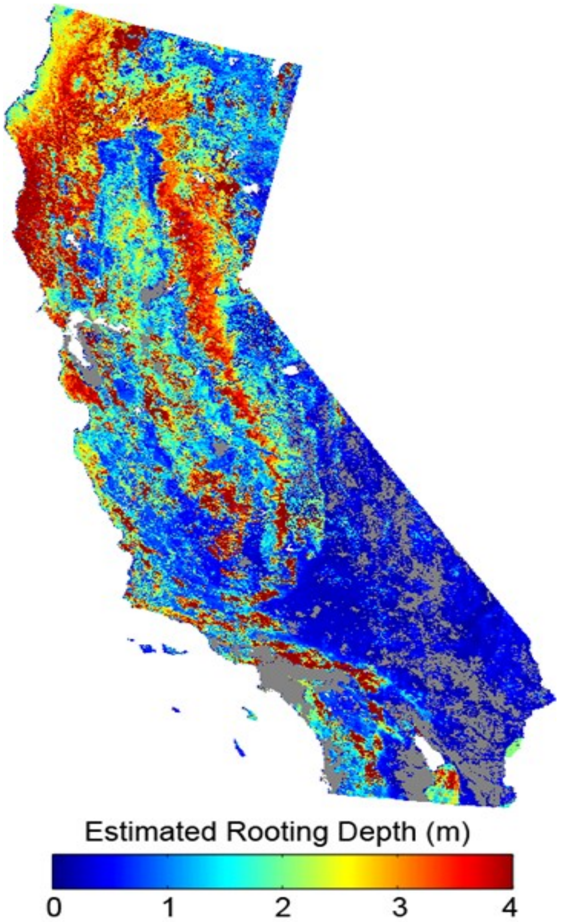

Figure 5. Estimated rooting depths of terrestrial vegetation in California [24]. Evapotranspiration seasonality estimated by support vector regression using Ameriflux observation and remote sensing data was used as the model constraint.

Although the rooting depth is an important parameter for determining soil water content, the estimation of this value is extremely difficult. The ecosystem rooting depth map created in the study successfully improved the simulation of evapotranspiration. The rooting depth setting significantly affected the carbon cycle results; differences of up to 50% in annual total GPP were estimated in the refined simulations.

Summary

Upscaling efforts are widely applied to estimate terrestrial carbon, heat, and water fluxes due to the successful expansion of terrestrial carbon cycle observations. Flux estimation is an appropriate alternative method for determining terrestrial carbon and water cycles. Moreover, this method is a good constraint of ecosystem modelling and can be used for independent evaluation of such models.

As future efforts, improve is needed in the methods themselves, particularly in the estimation of the carbon budget and respiration component. These estimations are difficult because most of the currently available explanatory variables are related to surface vegetation status (e.g., leaf) and climate variables rather than vegetation biomass, and soil carbon content. One study attempted to include information of nitrogen deposition, biomass, soil carbon content, and disturbance history to further improve the model performance, particularly in net carbon balances [18]. However, such information is extremely limited, and it is still difficult to apply the methods on the global scale. Therefore, such data collection is an additional challenge in improving the models. Moreover, the sparseness of eddy-covariance regions in some specific ecosystem types are also problematic; thus, evaluation of the spatial representativeness of the eddy-covariance observation network [25] is another challenge.

Acknowledgement

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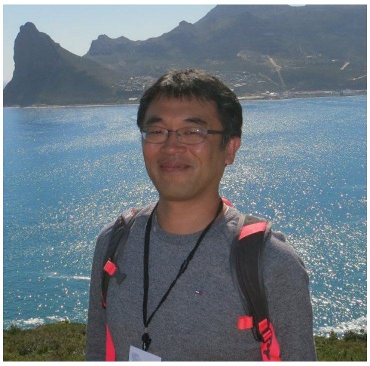

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Masayuki Kondo is an assistant professor at the Center for Environmental Remote Sensing (CEReS), Chiba University since 2017. His research interest is to assess reliable carbon budgets in regional and global scales using terrestrial ecosystem models, atmospheric inversions including GOSAT CO_2/CH_4 inversions, and empirical upscaling of CO_2 fluxes from eddy flux observations, and to provide insight into future prospects of biogeochemical cycles of Earth. Currently, his research focuses on filling a gap between carbon budgets from 'top-down' and 'bottom-up' approaches, particularly in tropical regions.

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Monitoring GHG emissions (water, CO_2, CH_4) and energy exchange from rice-based cropping systems

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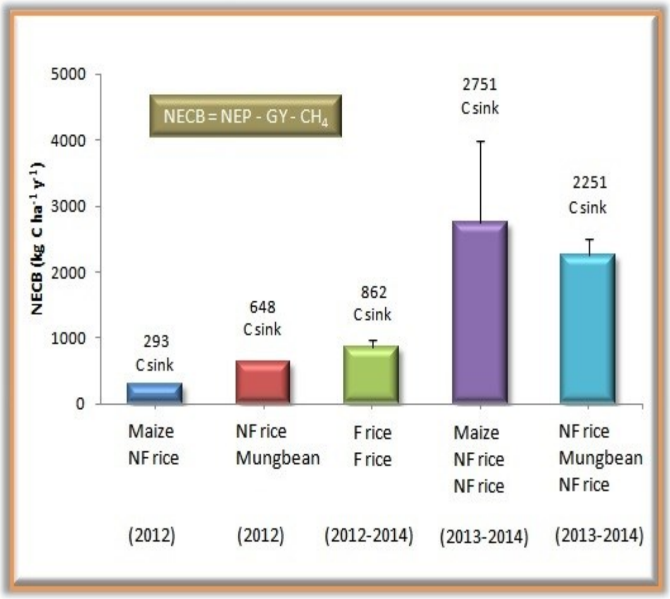
Rice is the staple food and most widely planted crop in much of Asia, where almost 90% of the world's rice is grown and consumed (Dawe, 2007). Rice plays a central role in feeding more than 3 billion people, including most of the world's 1 billion poor. Global rice consumption remains strong and it is driven by both population and economic growth in many Asian and African countries. Therefore, farmers need to produce at least 8-10 million units more paddy rice each year, equivalent to an average yield increase of 0.6 t ha^{-1} to meet the needs for sufficient food (GRISP, 2013).

Rice grows in a wide range of environments and is productive in many situations where other crops would fail. Worldwide, about 93 million ha of irrigated lowland rice provide 75% of the world's rice production. Irrigated lowland rice is grown mostly with supplementary irrigation in the wet season and is reliant entirely on irrigation in the dry season. However, irrigated rice is a profligate user of water which requires 3,000 to 5,000 litres of water for each kg of rice produced. Irrigated lowland rice receives 34-43% of the world's irrigation water (GRISP, 2013).

Though the irrigated lowland rice cropping system is sustainable, it is faced with several challenges in terms of increasing population to feed, shrinking resources, water scarcity, labor shortage, and its contribution to global warming through the emissions of greenhouse gases. Productive lands are continuously being converted to commercial and residential areas. Worldwide, water for agriculture is becoming increasingly scarce as competition between industrial, municipal, and environmental users of water grows and due to decreasing resources as climate variability increases (Rijsberman, 2006). By 2025, 15-20 million ha of irrigated rice in Asia may suffer from water scarcity (Tuong and Bouman, 2003).



Interventions to respond to water scarcity imply a reduced use of irrigation water or a diversification to other more water-efficient crops. At the same time, urbanization and economic development in rural areas caused a severe labor shortage during farm operations. Therefore, the traditional rice cultivation practices cannot continue in many parts of Asia where water and labor scarcity are becoming the major drivers of change. The required increase in rice production must be achieved with less water, less labor, and less land in more resource-efficient, environment-friendly production systems that are resilient to climate change and contribute less to greenhouse gas emissions.

In an effort to develop innovative, resilient, and sustainable rice farming technologies with increased resource-use efficiency, the International Rice Research Institute (IRRI) established the Ecological Intensification (EI) platform in 2011. A major goal of this research platform is to develop scientifically sound principles that will guide agronomic decisions to achieve productivity gains through the intensification of cropping systems while meeting acceptable environmental standards. The innovation research platform is conducted on three 4-ha study sites (a total of 12-ha fields) at the IRRI Experiment Station. The three sites are designed as production-scale experimental systems in which modern technologies are dynamically explored and adapted to the needs for different intensification and diversification options. One 4-ha study site (Block UY) is devoted to improving rice monoculture with traditional tillage of flooded soil. The other two 4-ha study sites (Block UE and Block UJ) are devoted to developing and adapting diversified rice-based systems. In 2012, the three double cropping patterns studied are (i) flooded rice – flooded rice in Block UY, (ii) non-flooded rice – mungbean in Block UE, and (iii) maize – non-flooded rice in Block UJ. Whereas in 2013-2014, the cropping systems were intensified from double to triple in Block UE (non-flooded rice – mungbean – non-flooded rice) and in Block UJ (maize – non-flooded rice – non-flooded rice), while Block UY (flooded rice – flooded rice) remained unchanged. A range of agronomic and environmental parameters are being closely monitored in these rice-based cropping systems in an effort to assess their ecological footprints. Eddy covariance (EC) systems were installed at the center of each of the three study sites to closely monitor energy, water, and carbon balances of the systems. These EC systems play an integral role to quantify the net ecosystem C budget and water productivities of each cropping system. Additionally the daily evapotranspiration is used to inform irrigation scheduling to optimize water productivity.

Preliminary results show that flooded rice monoculture can sequester more C (on a mass basis) than the diversified rice-based double cropping systems. Intensification (shift from double to triple cropping) enhances the net ecosystem C budget of the different rice-based cropping systems. The mean water productivities (WPET) for maize, flooded rice, non-flooded rice, and mungbean are 2.08±0.26, 1.43±0.09, 1.20±0.31, and 0.51±0.15 kg grain per m_3 water evapotranspired, respectively.

The EC measurements at IRRI have yielded 6 publications dealing with different aspects of CO_2, CH_4, water and energy budgets as affected by flooded and non-flooded rice systems (Alberto et al., 2009, 2011, 2012, 2013, 2014a, b). The innovations and component technologies arising from the research platform will contribute to future transformation of existing rice-cropping systems across the humid tropics.

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Vertical and temporal variations of O_3 and aerosol observed at periurban Taehwa Research Forest (TRF) with biogenic emissions being mixed with urban plumes

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Abstract

O_3 and its precursors (NO_x, CO, Volatile Organic Compounds (VOCs)) were measured at six heights of a 41 m tower at Taehwa Research Forest (TRF) near Seoul Metropolitan Areas during 2011~2014. VOCs were measured using PTR–QMS (proton transfer reaction –quadrupole mass spectrometry). The concentrations of O_3 and NO_x reached the maximum at 15:00 and at 8:00 and 20:00, respectively, which was similar in diurnal variations observed in urban air quality monitoring sites in Korea. Trace gas gradient measurements (O_3, CO, NO_x, and VOCs) show that the levels of O_3 and SO_2 were higher over the canopy (> 20 m) than below the canopy (< 20 m). In contrast, isoprene and monoterpenes – biogenic VOCs (BVOCs) showed higher concentrations below the canopy. In addition, O_3 concentrations were observed in the annual highest in June, which coincides with both the maximum BOVC levels and the maximum net primary production (NPP). These four year interdisciplinary observations including ecology and atmospheric chemistry parameters highlight the roles of suburban forests as emitters for ozone precursors and ozone removers from dry deposition. Particularly, the urban emissions were well represented by a distinct maximum of EC (elemental carbon) in the morning.

1. Introduction

In South Korea (referred in this paper as Korea), photochemical air pollution became has become a public concern since the 1990s. To abate ozone and air pollution, new legislation was enacted and regulation was reinforced. As a result, the air quality has been much improved for PM_{10} as well as CO and SO_2. The average concentrations of O_3 have also decreased until the early 2000s but a increasing trend has been observed since then. The previous studies suggest ozone formation was close to VOCs-limited condition in Seoul metropolitan areas (Han et al., 2013, references hereinafter). In most cities including Seoul, however, concentrations of O_3 have increased again since 2005. In addition, NO_2 concentrations remained unchanged, while NO_x emission was reduced (e.g., An et al., 2015). Furthermore, a national target of $PM_{2.5}$ level (25 mg m^{-3} for annual average and 50 mg m^{-3} for 24h average) was established in 2015, as public health concerns regarding fine aerosols are growing. These societal needs emphasize improved scientific understandings in the photochemical reaction system governing the production of O_3 and secondary aerosols.

Lately, BVOCs (biogenic volatile organic compounds) have drawn much attention in their roles as contributing regional and global radiative forcing. In the global scale, BVOCs emissions are estimated to be 1000 TgC yr^{-1} (Guenther et al., 2012), while the emission rate of VOCs from anthropogenic sources is approximately 100 TgC yr^{-1} (Kansal, 2009). Went first highlighted the roles of BVOCs in tropospheric photochemistry as the precursors for "blue haze" in mountain regions (Went, 1960). Later, Chameides et al. (1988) demonstrated that isoprene, the most abundant species of BVOC, was intimately involved in ozone formation in the Southeastern U.S. It is only recently in East Asia, that the role of BVOCs has been highlighted in the most megacities including Beijing (Ran et al., 2011), Kyoto (Bao et al., 2010), and Shanghai (Geng et al., 2011). In comparison, the study of BVOCs has been very limited in Korea (e.g., H. Kim et al. 2015; S. Kim et al., 2015, S.-Y. Kim et al., 2013a, b).

In South Korea, the forest area comprises 65 % of the whole territory with coniferous and deciduous trees in the fractions of 42 % and 26 %, respectively and it is even higher (72 %) in cities (Korea Forest Service, 2008). As the Seoul Metropolitan Area (SMA), a home of 23.5 million is surrounded by forest, it is situated in a complicated mixture of anthropogenic and biogenic photochemical precursors. Therefore, the understanding of photochemical processes leading to ozone and secondary aerosol formation requires process level understanding of BVOC photo-oxidation in various anthropogenic influences.

In this context, the National Institute of Environmental Research (NIER) took the initiative in research on BVOCs and their effect on air quality and established an atmospheric observatory at Taehwa Research Forest (TRF). The objective of this article is to introduce a recent study conducted at TRF in Korea and briefly report the main results of reactive gases including ozone and BVOCs and aerosols observed at TRF.

2. Experiment

Taehwa Research Forest is located in 35 km southeast of The center of Seoul (Fig.1). There is about 800 ha of afforested area used for education and research pf the College of Agriculture & Life Sciences in Seoul National

Figure 1. Map showing the Taehwa Research Forest

University. The observation facility including a 41-m walkup tower and laboratory was built by NIER at 165 m above the sea level (37.18°N, 127.19°E) in a planted forest (300 ha) with Korean Pine (Pinus koraiensis Siebold et Zucc.). The rest is natural forest with deciduous trees of Murray (Quercus serrata Murray) and Blume (Quercus aliena Blume). The tower is equipped with sampling inlets at six heights (4.1, 9.5, 15, 20, 31, 39 m), among which meteorological sensors were installed at 4.1, 20, and 40 m and 3d anemometers at 20 and 39 m.

Gaseous species including O_3, NO_x, CO, and SO_2 were continuously monitored using trace-level gas analyzers (49i, 42i-TL, 48i-TLE, 43i-TLE, Thermo Scientific, Inc., Franklin MA, U.S.A) and VOCs were determined by Proton transfer reaction-quadrupole-mass spectrometry (PTR-QMS, IONICON Analytik GmbH, Innsbruck, Austria) during the intensive experiment periods. The air was pulled through a PFA tubing (OD 6.35 mm, ID 3.96 mm) at 10 L min-1 for 10 minutes every six heights, of which 50 sccm was introduced to PTR-QMS and the rest was to manifold. PTR-MS utilizes the high affinity of H3O+ ion toward the majority of VOCs (soft chemical ionization) and quadrupole mass filter (Gouw and Warneke, 2007). The PTR-MS was set to measure isoprene, methylvinylketone (MVK) + methacrolein (MACR), monoterpenes, sesquiterpenes, toluene, and benzene, and some oxygenated species such as methanol, acetone, and acetaldehyde. Detection limits were determined from a catalyst system with zero air. Detailed methods can be found elsewhere (e.g., de Gouw and Warneke, 2007).

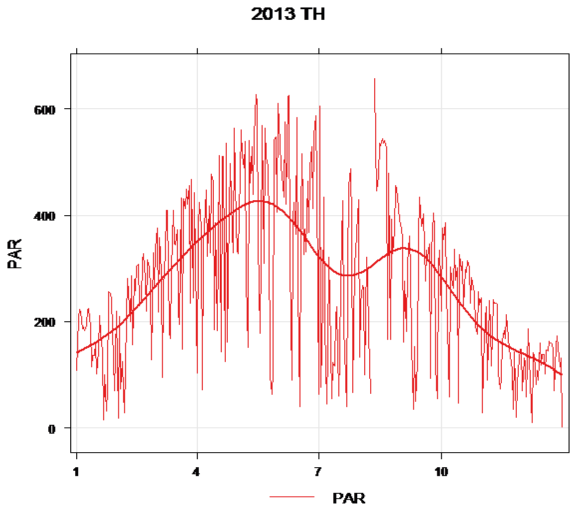
In addition to gaseous species, aerosol properties were measured in the other two-story container, from which the roof air was sampled to determine $PM_{2.5}$ OC (organic carbon) and EC (elemental carbon) concentrations and size-resolved number concentrations of aerosols in diameter between 10~500 nm. The former was measured by OC EC analyzer (Model-5 Semi-continuous OC/EC Field Analyzer, Sunset Laboratory Inc., USA) with NIOSH 5040 protocol and the latter by SMPS (scanning mobility particle sizer, Model 3034, TSI Inc., USA).

3. Temporal and vertical characteristics of Taehwa Research Forest

PAR (photosynthetically active radiation) and NPP (net primary production) were observed at an ecology tower ten meters apart from the atmospheric observatory. The daily variations of these two parameters are presented for 2013 in Figure 2. PAR reached the maximum in June and showed the second peak in September with a dip during July ~ August. The temperature used to be the maximum in August in the study region. The northeast Asia is under influence of the Asian monsoon system, which brings cold and dry air with strong northerly winds in winter and moist and warm air from the Pacific Ocean with heavy rainfall in summer. In July, the heavy rain and overcast led to decrease in PAR. Accordingly, the NPP of deciduous trees was the maximum in June while that of coniferous trees remained nearly constant from April to October.

VOCs were measured during 15~23 May and 31 May ~4 June in 2012, 13-16 May, 30 May~6 June, and 7~9 August in 2013. Among these, hourly concentrations of isoprene and monoterpenes are presented against heights (Fig. 3). Their concentrations were higher below canopy (< 20 m) than above canopy and the highest in June followed by May and August. During the measurement period, the hourly maximum concentrations of isoprene and monoterpenes were 4 ppbv and 0.8 ppbv observed in the late afternoon and early morning, respectively.

(a)



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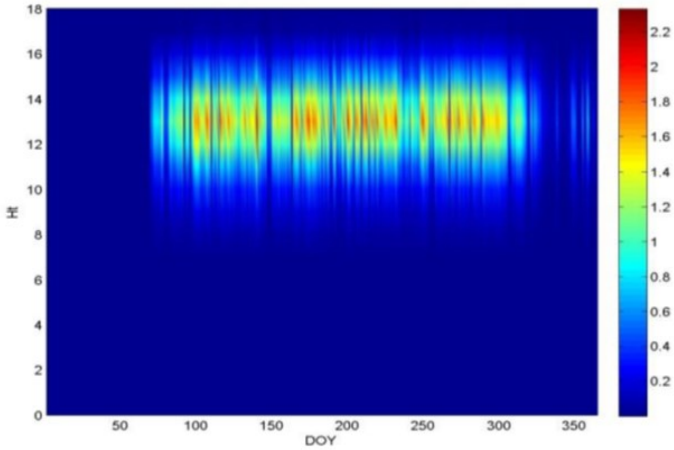

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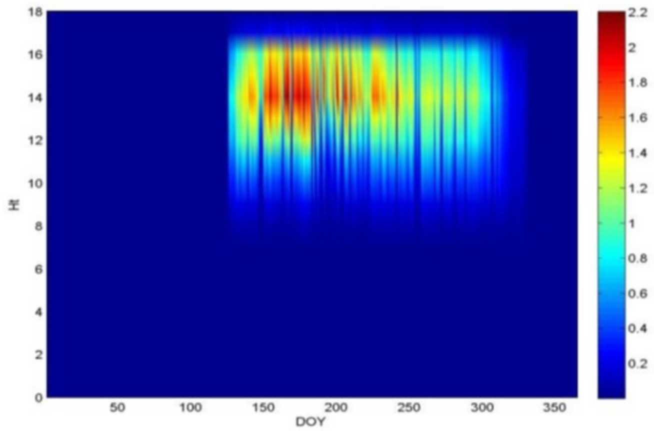
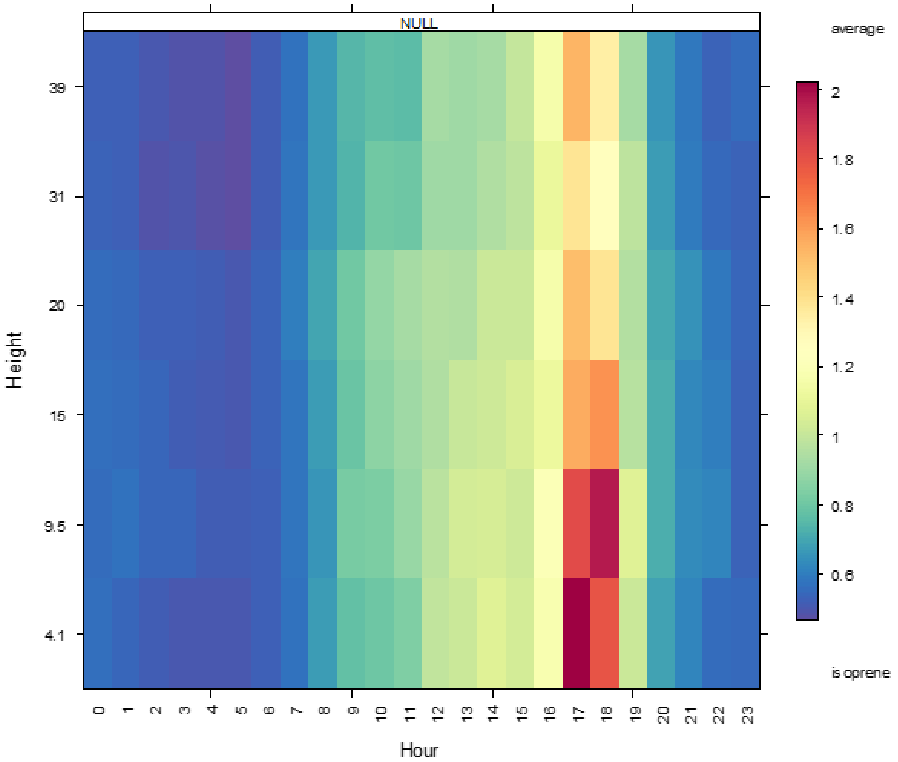


Figure 2. Daily distributions of (a) PAR (photosynthetic active radiation in Wm^{-2}), (b) NPP (net primary production in $gC\ m^{-2}\ day^{-1}$) against height (m) for coniferous and (c) deciduous trees observed at TRF in 2013.



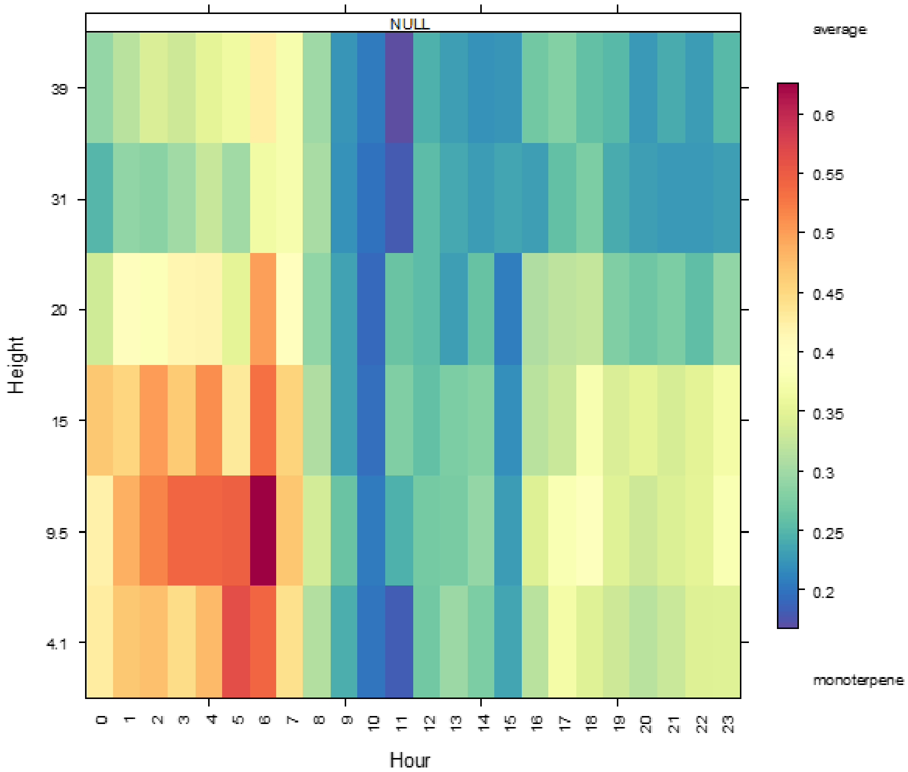


Figure 3. Vertical-diurnal variation of a) isoprene and b) monoterpenes that were measured at TRF during early June in 2012 and late May ~ early June and early August in 2013

These are similar in concentration to what was observed at Mt. Tai Mo Shan in Hong Kong (Gouet al., 2012) and higher that those from Mt. Gongga (Zhang et al., 2014) and Mt. Mang in China (Suthawaree et al., 2012), and Hyytiala forest in Finland (Lappalainen et al., 2009).

During the measurement period, concentrations of both isoprene and monoterpenes were higher before summer monsoon (May~June) than after monsoon (August), of which difference was greater for isoprene than monoterpenes. At TRF, the average temperature was 19.8 ± 4.7 (℃) and 27.3 ± 2.2 (℃) before and after summer monsoon season, respectively. It is well know that the emissions of BVOCs are controlled by temperature and light (Lappalainen et al., 2013; Guenther, 1997).

As shown in Figure 3, PAR was the maximum in May~June. Accordingly, NPP was greater in June, which was apparent for deciduous trees. This tendency turned out to be regional characteristics of vegetations in Northeast Asia (Shim et al, 2014).

In diurnal variation, the maximum concentration of Isoprene was found around 17 h (local time) with an enhancement from 2pm. Monoterpenes concentrations began to increase from 16 h and remained high through the night

4. Temporal and vertical distributions of O_3 and other reactive gases

The measurement of reactive gases of O_3 and its precursors such as CO, NO_x and SO_2 began 2011 and continued through 2015 except the occasions of maintenance. For 2011~2014, ozone measurements were compiled to examine its vertical and temporal variations at TRF. The O_3 concentrations were the highest about 3pm and remained high until 5pm (Fig.4), which was similar to isoprene in diurnal variation.

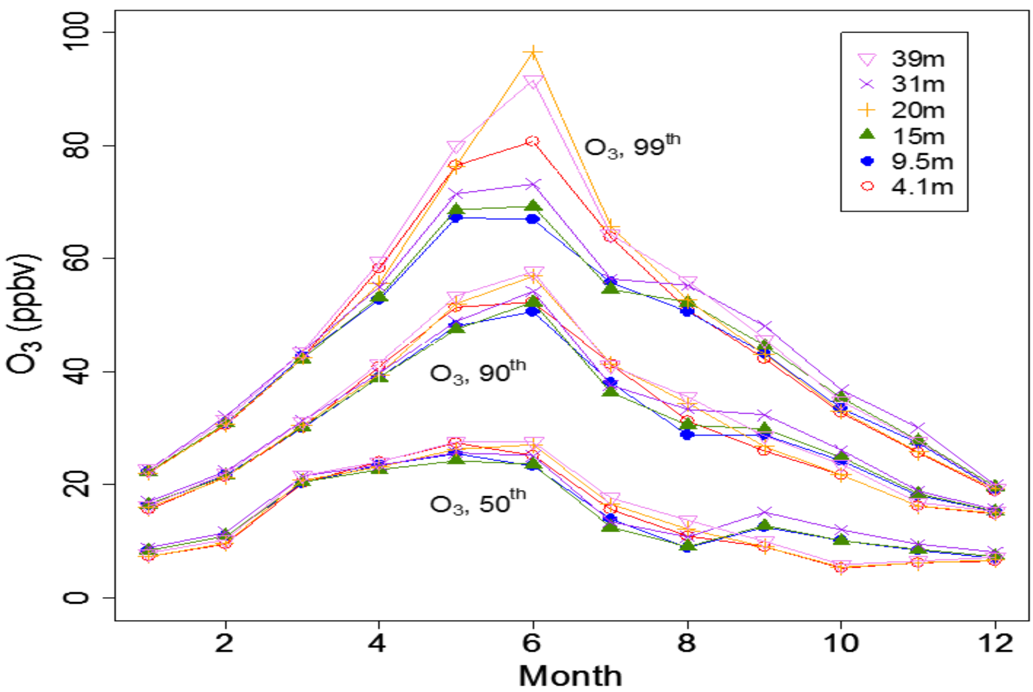


Figure 4. Monthly distributions of the 50th, 90th, and 99th percentiles of O_3 concentrations at six heights measure during 2011~2014.

The 99th percentiles of O_3 variation show a clear maximum in May~June and its concentration was noticeably decreased during July-August, even though the temperature was high. There was an evident change in O_3 concentration before and after the summer monsoon season, which is a typical pattern observed at background sites as well as at urban sites in Korea including Seoul (e.g., Han et al., 2013; An et al., 2015). If the vertical profiles were compared for each month (Fig. 5), there was no variation in winter. In contrast, O_3 concentrations varied significantly with heights in warm seasons, of which magnitude was the greatest in June.

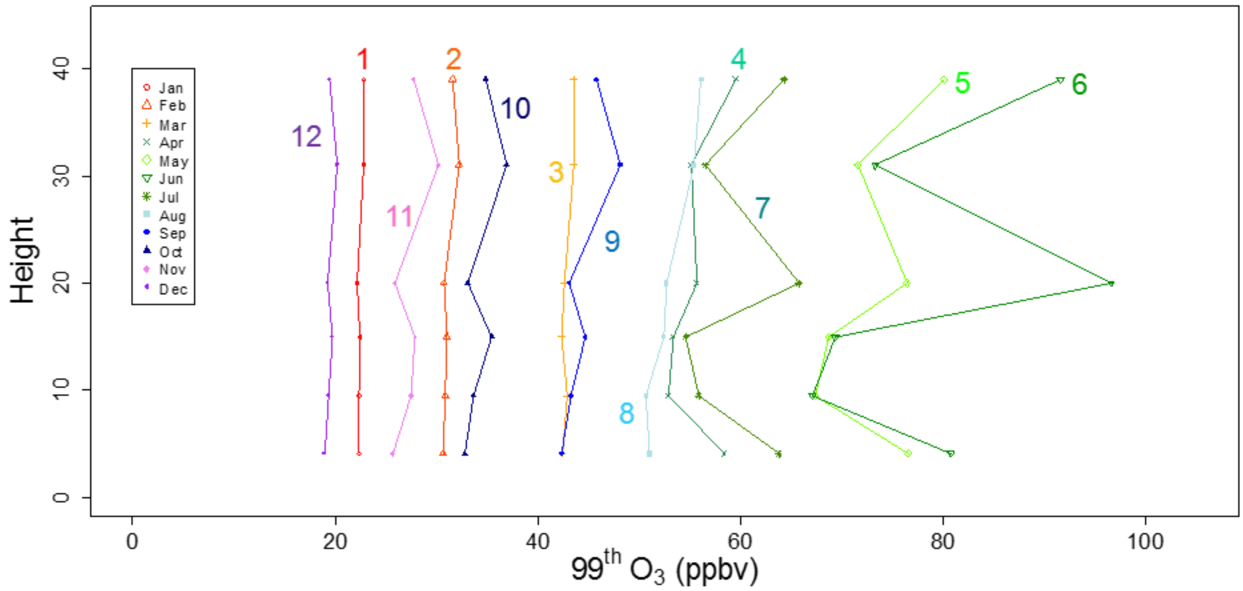


Figure 5. Vertical distributions of the 99th percentiles O_3 concentrations averaged each month for 2011~2014.

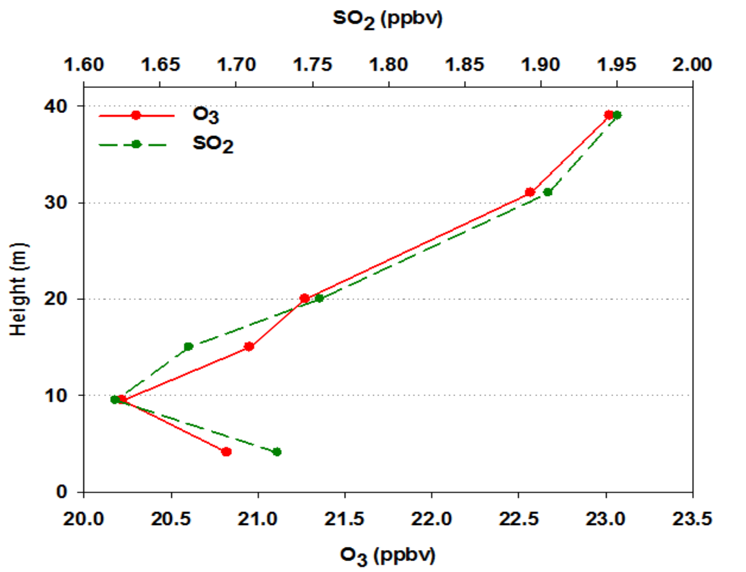


Figure 6. Average vertical profiles of the O_3 and SO_2 concentrations measured during 2012~2013.

In vertical profile, the enhancement of O_3 was the most noticeable at 20 m in June, of which the tendency was consistently observed from April to July. There was a good correlation between hourly average concentrations of O_3 and isoprene. In addition, the box-model analysis showed that isoprene contributed about 15% to the afternoon O_3 concentration in June (H. Kim, 2015). Therefore, the vertical profile of 99^{th} O_3 concentrations likely indicates the role of isoprene in O_3 formation under the maximum biological activity .

In June, O_3 concentrations were high (Figure 5 and 6) and its average concentration was 34 ± 20 ppbv, which was similar to that of Seoul (35 ppbv) and comparable to those from previous studies in which biogenic emissions were mixed with urban plumes (Guo et al., 2013; Suthawaree et al., 2010). NOx and PAN levels were lower than megacities of the East Asia (such as Seoul in Korea or Beijing and Guangzhou in China) but higher than those of rural forest sites (Shim et al., 2015a). It was noteworthy that PAN concentration was enhanced after the typical afternoon peak in June, which was concurrent with the maximum of isoprene and its oxidation products. Because BVOCs are intimately involved in NO-NO_2 cycle and PAN formation, it will have to be thoroughly examined the effect of urban and biogenic influence on O_3 formation through further research and photochemical modeling.

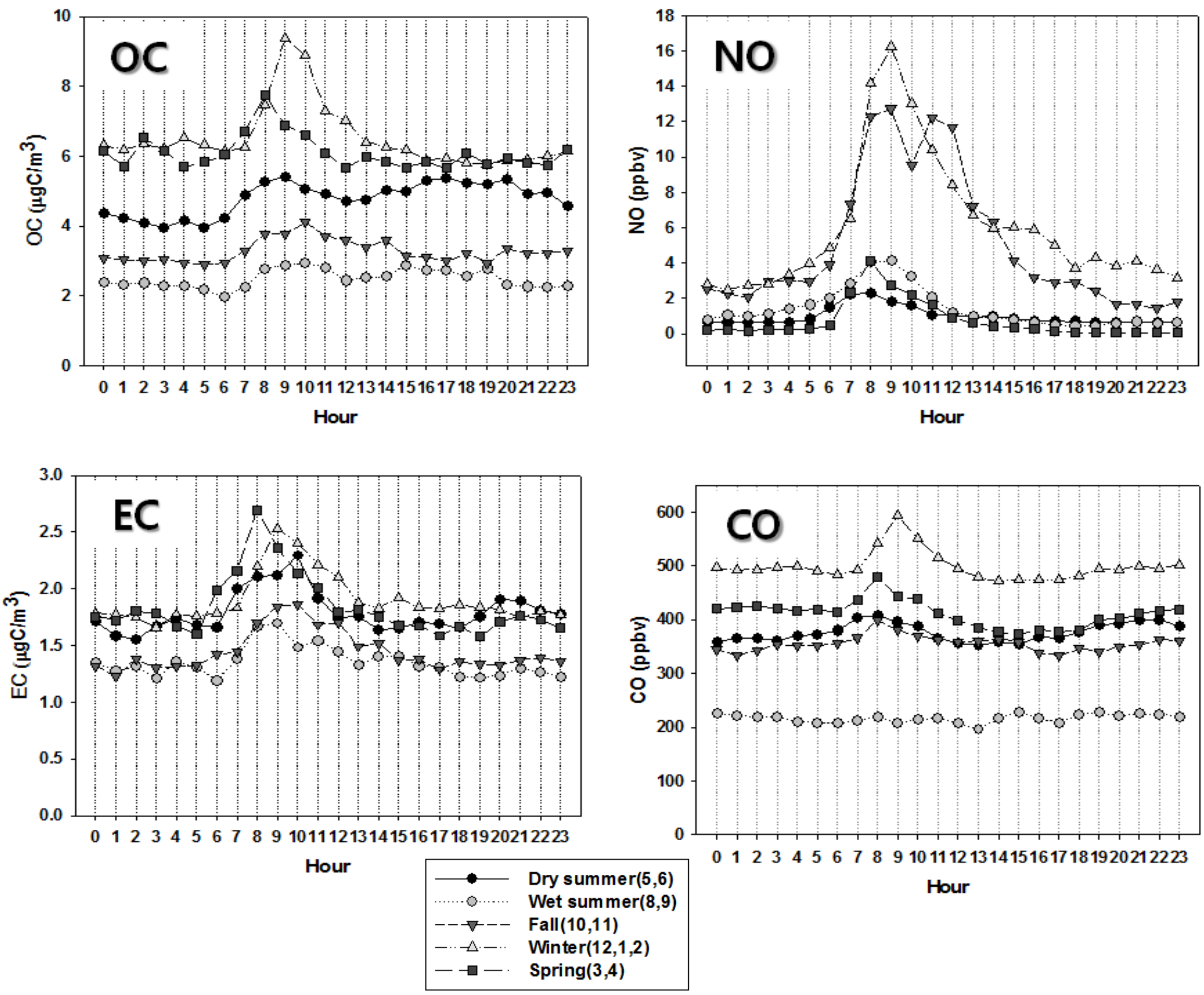


Figure 7. Diurnal variations of seasonal mean OC and EC of PM2.5 with NO and CO during May 2013 ~ April 2014. Data were divided into the five seasons shown in the legend box.

SO_2 is well known to be removed by leaves through stomatal and non-stomatal uptake. At TRF, the vertical profile of SO_2 concentrations indicate active uptake by trees at nighttime (Fig. 7). Likewise, the concentrations of O_3 were decreased with altitude of which tendency was in agreement with that of SO_2. The concentrations of monoterpenes were observed in the highest level below the canopy (< 20 m) during the night to the early morning. Considering high reactivity of monotperpenes towards O_3, chemistry driven dry deposition of O_3 would be significant (Shim et al., 2015b).

5. $PM_{2.5}$ OC and EC and number-size distributions of nano-particles

Organic carbon (OC) and elemental carbon (EC) of $PM_{2.5}$ were continuously measured at TRF during May 2013-April 2014. The average concentrations of the entire measurements were 5.0 ± 3.2 μgC m^{-3} for OC and 1.7 ± 1.0 μgC m^{-3} for EC. Unlike BOVCs and O_3, the levels of both OC and EC was remarkably enhanced in winter (6.5 μgC m^{-3} for OC and 1.9 μgC m^{-3} for EC) and decreased after summer monsoon season

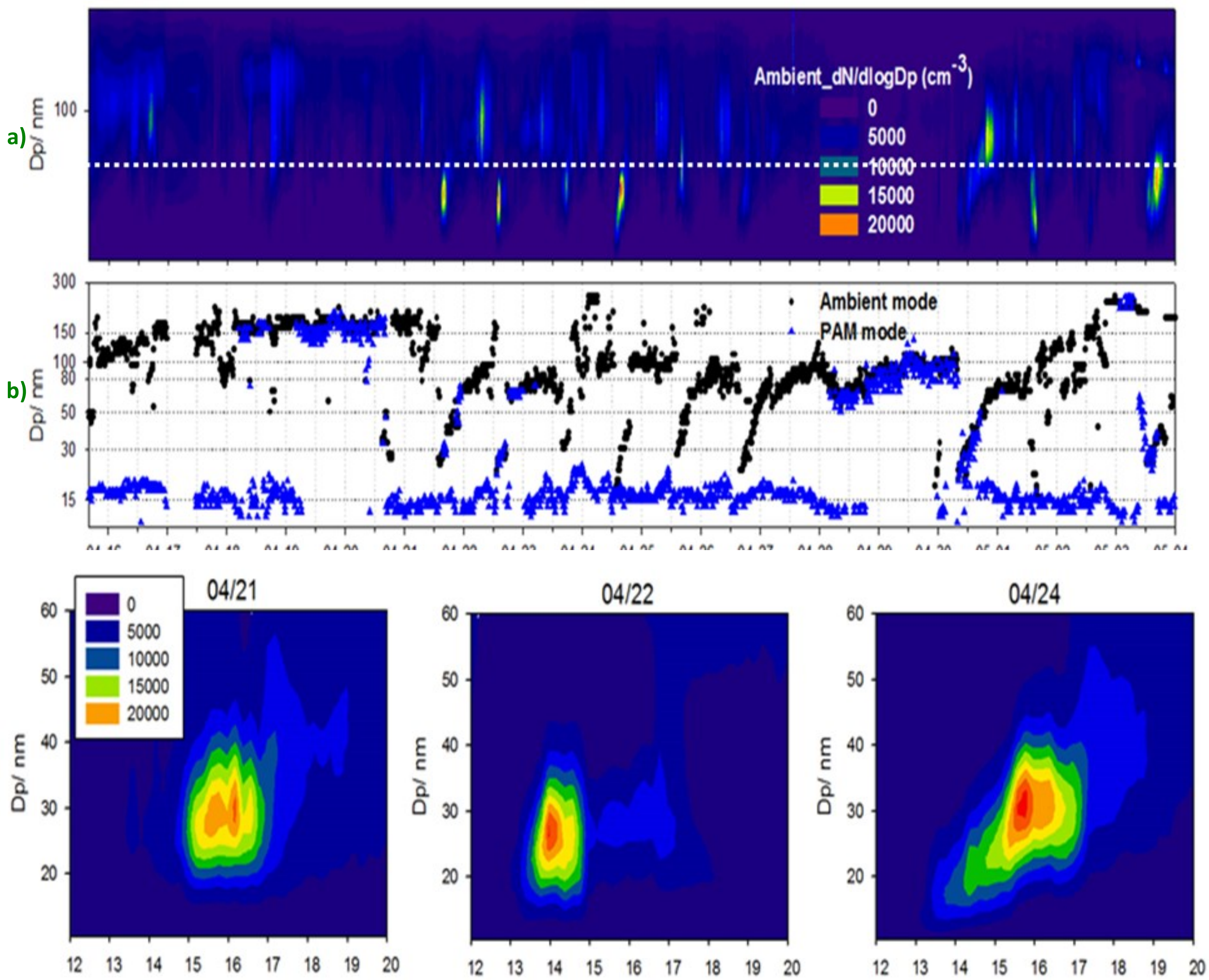


Figure 8. Size resolved number of aerosols between 10~500 nm measured at TRF during April ~ May 2014. a) number concentrations, b) mode diameters, and number concentrations for several days when particle growth were observed on 21, 22, and 24 April.

(2.5 μgC m^{-3} for OC and 1.4 μgC m^{-3} for EC), leading to the highest OC/EC ratio in winter. The diurnal variation of EC showed a clear maximum in the morning through the year, which reveals the influence of vehicle emissions. While the primary peak of OC appeared in the morning along with EC, there was a broad second peak in the afternoon only during May~June (Fig. 7). It was consistent with enhanced concentrations of both O_3 and BVOCs, particularly isoprene. The measurements results of the carbonaceous composition indicate that the TRF is under the constant urban influence from local and long range transported sources. Thus, the biogenic influence was tangible in the afternoon during May~June, which was well presented in SMPS measurement results.

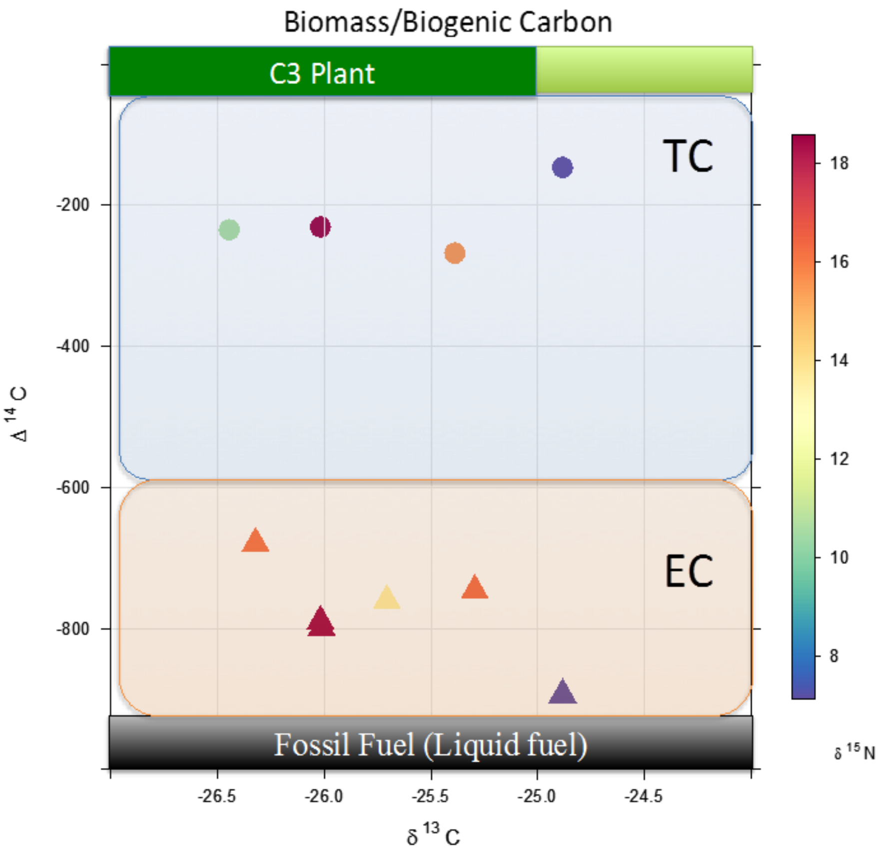


Figure 9. Carbon and nitrogen isotope values of ^{13}C and ^{14}C and ^{15}N for $PM_{2.5}$ collected daily at TRF in August 2014. Carbon analysis were done for TC (total carbon) and EC (elemental carbon). Nitrogen values are presented as colors.

The size-resolved aerosol number concentration was measured with SMPS in May~June 2014 (Fig. 8). In the experiment, SMPS was alternatively run with PAM (potential aerosol mass) reactor accelerating oxidation of aerosols, but the following discussion is limited to ambient aerosols. There were two types of particle burst events observed during the experiment. One was regularly observed in the morning with less number of aerosols than those of the other. In particular, the morning burst was associated with EC enhancement. In contrast, there was more remarkable enhancement of aerosol numbers in the afternoon for only several days, during which the mode diameter of aerosol increased between 13 h and 15 h (Fig. 8b). The afternoon burst took place in accordance with isoprene maximum in terms of season and time, which is a plausible evidence for isoprene to take a part in aerosol growth.

To assess the contribution of fossil and biomass to carbonaceous aerosols, isotope analysis was conducted for EC and TC (total carbon). PM2.5 samples were collected using a high- volume sampler in August 2014. EC was isolated with SWISS_4S protocol by Zhang et al. (2012) and 14C/12C ratio was determined using AMS (Accelerated Mass Spectrometer) facility in UC Irvine. For the same sample, stable isotopes including 13C and 15N were analyzed using CF-IRMS (Continuous Flow Isotope Ratio Mass Spectrometry). The preliminary results indicate EC was mostly from fossil possibly in liquid phase (Fig. 9). TC contains more OC than EC and implies greater biogenic contribution. However, caution needs to be exerted because results were obtained from few samples only in summer.

Isotope analysis is a powerful tool to apportion the sources and will be further employed to understand the exchanges between atmosphere and land ecosystem.

6. Summary and outlook

BVOCs (biogenic volatile organic compounds) were measured using a PTR-QMS (proton transfer reaction - quadrupole mass spectrometer) at a 41 m tower at Taehwa Research Forest near Seoul metropolitan areas (SMA) in May, June, and August 2012. Their concentrations were highest in June, when PA photosynthetically active radiation) and NPP (net primary production) were the highest. In contrast, the levels of BVOCs were the lowest in August among the three months, even though the temperature was the highest. It was mostly likely due to heavy rains during the summer monsoon season. In vertical profile, the concentrations of isoprene and monoterpenes were evidently higher below canopy (< 20 m) than above canopy (> 20 m). While isoprene concentration was enhanced in the afternoon and reached the maximum around 17 h (local time), monoterpenes began to increase around 16 h and remained high through the night.

In conjunction with BVOCs, O_3 and its precursors were measured. Of these, PAN appeared the best indicator for the TRF site to assess anthropogenic influences such as emissions from nearby highway and from Seoul metropolitan areas. The O_3 concentrations were the highest at the top level and reached the maximum around 3 PM. The seasonal variation of O_3 was clear with the maximum in June, which was in accordance with maximum PAR and BVOCs concentrations. It is well known that isoprene is highly reactive, producing O_3 in the afternoon, which was also observed at TRF. In addition, the night-time build-up of monoterpenes coincides with a strong negative gradient towards the ground. This observations strongly suggests a roles of chemistry in ozone dry-deposition in forest environments.

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Atmospheric observatory and flux tower at TRF with graduate students who participated in measurements and produced the results discussed in the present study.

ileaps

Integrated Land EcoSystem Atmosphere Processes Study

Special Issue - Asia

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A new Atmospheric Chemistry facility for Integrated Land Ecosystem -Atmosphere Processes Study (iLEAPS) in the North West Indo-Gangetic Plain (NW-IGP)

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A new state of the art of atmospheric chemistry facility was set up at the Indian Institute of Science Education and Research Mohali, a suburban site (30.667 N, 76.729 E, 310 m a.s.l.) in the state of Punjab, north west India in August 2011. The objectives are to undertake process based and real time atmospheric chemistry investigations using advanced experimental mass spectrometric and spectroscopic instrumentation, satellite data and atmospheric models. The facility houses India's first proton transfer reaction mass spectrometer (PTR-MS) and is one of only eight laboratories worldwide capable of measuring the total OH Reactivity of ambient air and currently the only one in India (Kumar and Sinha 2014). This facility has also made pioneering efforts to make the published datasets from this understudied region available to the research community in electronic format (Sinha et al. 2015; Pawar et al. 2015; Schultz et al. 2017). It will serve multiple purposes, namely 1) help address uncertainties in atmospheric chemistry, air quality and climate science from an important understudied region of the world through quality assured high time resolution research data and its analysis 2) enthusing graduate and undergraduate students to take up research in a high priority research area through world class training on sophisticated analytical instrumentation 3) serving the community and policy makers by providing information about the daily regional air quality and exceedances of criteria air pollutants.

Volatile organic compounds, key air pollutants such as carbon monoxide, ozone, nitrogen oxides, fine and coarse mode particulate matter, sulphur dioxide, ammonia and greenhouse gases including carbon dioxide, nitrous oxide, methane and water vapour and all important meteorological parameters are continuously measured at this facility and a six year plus dataset (2011 till date) has been acquired till date.

By virtue of being the first research group in India to deploy such a facility for ambient air measurements quantification of ambient VOCs such as acetonitrile, methanol, acetaldehyde and isoprene was accomplished for the first time at an Indian site (Sinha et al. 2014). Using the continuous in-situ ozone measurements from this facility made over two years and regional measurements relative yield loss relationships for Indian paddy and wheat cultivars have been obtained, which show that they are much more sensitive to ozone damage compared to cultivars used in western countries. A first order assessment of ozone related crop yield losses in the agricultural states of Punjab and Haryana has been undertaken which demonstrated that previous modelling based studies underestimated the magnitude of the loss substantially (Sinha

Another study (Garg et al. 2015) the first to use high-time- resolution observations of biomass burning tracers to identify biomass burning events by combining real time measurements of gas- phase VOC combustion tracers with Black Carbon (BC) measurements for identification of ambient combustion plumes.

The results demonstrated the limitation of using the two- component aethalometer model for source- apportionment of BC in complex emission environments like north India, thus warning about the erroneous conclusions that may be reached by incorrect application of the model which have been typically applied to elucidate the contribution of fossil fuel and biomass burning to ambient black carbon mass concentrations.

Using the facility, considerable research efforts over the past five years have focused on detailed atmospheric chemistry investigations of agricultural stubble burning, which occurs in the north west Indo-Gangetic Plain every year in April/May and October/November for wheat and rice straw respectively. By capturing the emission activity in real time through multi-year measurements, it has been shown that this activity is a large source of reactive volatile organic compounds and carcinogenic benzenoids and perturbs the atmospheric composition on a regional scale with widespread air quality and atmospheric chemistry implications (Sarkar et al. 2013, Sinha et al. 2014). In particular, emissions of reactive gases such as benzenoids, isoprene and acetaldehyde from agricultural fires fuel regional scale enhancements in both surface ozone and secondary organic aerosol (e.g. Kumar et al., 2016; Chandra and Sinha, 2016; Kumar et al., 2016; Kumar et al., 2018). A key finding is toxic nitrogenous gases such as isocyanic acid and amides have both photochemical and pyrogenic sources in the Indian environment.

While it is known that biomass fires can be a significant emission source of reactive atmospheric carbon, the speciation and quantification of such emissions and their impacts through secondary reactivity of photochemically formed compounds are still poorly constrained in atmospheric environments. By applying direct OH reactivity and VOC speciation measurements made using the facility, several new reactive compounds (e.g. amine and amides) were identified which are currently missed by state of the art atmospheric chemistry models and a large ambient missing OH reactivity of about 40% in periods affected by the biomass burning show that much of the reactive compounds and hence chemical composition is still poorly understood. Such new insights will yield improved understanding of atmospheric chemistry-air quality climate feedbacks in biomass-fire impacted atmospheric environments.

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Climate Change Research in India: Retrospect and Prospect

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1. History of Global CC research

Responding to the need for an independent scientific assessment in the wake of growing concerns for human induced climate change, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) jointly set up the Intergovernmental Panel on Climate Change (IPCC) in the year 1988 with the aim of preparing science based assessment on all aspects of climate change and its impacts and developing realistic response strategies.

The scientific evidence brought up by the first IPCC Assessment Report of 1990 underlined the importance of climate change as a challenge requiring international cooperation to tackle its consequences. Since then the IPCC has delivered on a regular basis the most comprehensive scientific reports about climate change produced worldwide, the Assessment Reports. So far IPCC has brought out 5 assessment reports. The Sixth Assessment Report is expected to be finalized by 2022.

2. History of India's CC research

India too responded to the global concerns for the systematic research in climate change areas soon after the first assessment report of IPCC was published in 1990. Fortunately by this time India had already initiated some research initiatives. The country has had the fortune of having over 100 years of systematic meteorological observations. Recognising the importance of climate research in the country the Department of Science & Technology initiated an extra-mural funding programme called Indian Climate Research Programme (ICRP) in 1997 immediately after the 2nd Assessment report of IPCC was released in the year 1995. The ICRP focused on the research priorities in understanding climate variability at different time scales and its impact and consists of analysis of observational data from ground-based, ship-based and satellite-based measurements; modelling studies with coupled ocean-atmospheric general circulation models and identification of the climate component of agricultural productivity, impact of climate on environment, global warming and climate change etc. There were several Multi-disciplinary and multi-institutional field observational programmes also conducted in the Indian sub-continent region during this period. These included Monsoon Trough Boundary Layer Experiment (MONTBLEX) ; Land Surface Process Experiment (LASPEX); Bay of Bengal Monsoon Experiment (BOBMEX), ARMEX (Arabian sea Monsoon EXperiment) and Indian Ocean Experiment (INDOEX).

Under Intensive Research in High Priority Areas (IRHPA) programme of DST a Global Climate Modelling Project was supported at Indian Institute of Tropical Meteorology (IITM), Pune to develop a general circulation model (GCM) to predict the Climate at seasonal scale. Also under IRHPA, a Centre on Global Change was positioned at National Physical Laboratory (NPL), New Delhi to study the Green House Gas emissions and related activities. The IPCC adopted this Centre's Methane budget estimates for India. In order to understand the role of Ocean in Climate variability, in particular relating to the monsoon phenomena, DST supported monitoring of Oceanic region surrounding India using Ships of Opportunity as Indian contribution to the international Tropical Ocean Global Atmosphere (TOGA-I) Program.

However, unlike western world, India remained short of resources to position a sophisticated infrastructure for climate change research until the end of 20th century. The number of climate change researchers and analysts in India was relatively small - the number of researchers involved on a continuing basis on all climate-change-related activities was less than a hundred in those days. There was also a relatively clear institutional division between those working in the realm of the physical and natural sciences and those working on policy related issues. If we classify the institutions that are involved in the climate change issues, we see that the largest single disciplinary groups of climate change researchers in India were climatologists and meteorologists.

The number of institutions working on climate change research could be counted on fingers. Many of the scientists or groups work at these institutions in a relatively independent fashion, though there are occasions when they have successfully collaborated towards common goals, like the Indian Methane campaign (1991) that demonstrated a lower level of emission from Indian paddy cultivation.

3.CC Research initiatives in early 21st century

Soon after 3rd Assessment Report of the IPCC was released in 2001, DST took the initiative to build an International Centre for S&T Capacity in Climate Change and organized several workshops that included a side event at the 8th Conference of Parties (CoP-8) in New Delhi in the year 2002. A Centre for Climate Change Research (CCCR) was eventually established as part of Indian Institute of Tropical Meteorology (IITM), Pune in 2009. In the mean time responding to the 4th Assessment Report of IPCC (AR4) brought out in 2007, India released its National Action Plan on Climate Change (NAPCC) on 30th June 2008. The NAPCC contained some major initiatives that included launch of 8 national missions on climate change.

These are-

- National Solar Mission (NSM)
- National Mission for Enhanced Energy Efficiency (NMEEE)
- National Mission on Sustainable Habitat (NMSH)
- National Water Mission (NWM)
- National Mission for Sustaining the Himalayan Eco-system (NMSHE)
- National Mission for a Green India (NMGI)
- National Mission for Sustainable Agriculture (NMSA)
- National Mission on Strategic Knowledge for Climate Change (NMSKCC)

Out of these 8 missions, 4 of them viz, NSM, NMEEE, NMSH and NMGI focused on mitigation; 3 of them viz., NMW, NMSHE and NMSA relate to adaptation initiatives and 8th Mission (NMSKCC) exclusively dealt with carrying out dedicated research in climate change areas to develop strategic knowledge.

4. Climate Change Research Initiatives by DST under NAPCC

The Department of Science & Technology, Ministry of Science & Technology was entrusted with the responsibility of coordinating two out of these eight national missions on climate change. These are: (a) National Mission for Sustaining Himalayan Ecosystem (NMSHE) and (b) National Mission on Strategic Knowledge for Climate Change (NMSKCC). Both these missions were launched with broad objectives of building S&T Capacity for sustenance of Himalayan Ecosystem and for developing strategic knowledge system

Both NMSHE and NMSKCC were initiated during 2011-13. There has been a good progress achieved under both the missions since then. Some of the major achievements under the two missions are summarized in the table overleaf:

National CC Mission	Institutional mechanism established
NMSHE	1. A Centre of Himalayan Glaciology at Wadia Institute of Himalayan Geology, Dehradun; 2. 6 Thematic Task Forces anchored around 6 lead institutions viz., Wadia Institute of Himalayan Geology (WIHG), Dehradun; National Institute of Hydrology (NIH), Roorkee; GB Pant National Institute of Himalayan Environment and Sustainable Development (GBNIHESD), 3. Almora; Wildlife Institute of India (WII), Dehradun; Jawaharlal Nehru University (JNU) and Institutions of Indian Council of Agriculture Research (ICAR); 4. State CC Centres in 11 out of 12 Himalayan States viz., J&K, Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Meghalaya, Sikkim, Tripura and West Bengal, 5. An Inter-University Consortium of 4 universities viz., Kashmir University, Srinagar; Jammu University, Sikkim University and Jawaharlal Nehru University, Delhi and 6. An Indo-Swiss Capacity Building Programme in glaciology and related areas.
NMSKCC	1. 8 Centres of Excellence one each at IISc, Bangalore; IIT Bombay; IGCS, IIT Madras; ICRISAT, Hyderabad; IIT Delhi; IIT Kharagpur; BHU, Varanasi and National Institute of Malaria Research, Delhi; 2. 20 Major R&D Programmes at NIO, Goa (2); NBRI, Lucknow (2); IARI, Delhi; Delhi University; TNAU, Coimbatore; IIT, Delhi (2); BSIP, Lucknow; IRMA, Anand; Allahabad University; IISER, Pune ; CUSAT, Cochin; Andhra University ; IIT Guwahati ; IIT Bhubaneshwar ; IISER Mohali; IRADe, Delhi; 3. 11 State Climate Change Centres in Madhya Pradesh, Punjab, Chattisgarh, Karanataka, Kerala, Puducherry, Tamail Nadu, Telangana, Maharashtra, Orissa and Haryana; 4. 2 National Network Programmes in the first phase (CC & Human Health and Climate Modelling) and 4 Network programmes in the second phase (CC & Human Health, Climate Modelling, CC & Coastal Vulnerability and CC & aerosols); 5. 7 Human Capacity Building Programmes one each at Administrative Staff College of India (ASCI), Hyderabad; Indian Institute of Public Administration (IIPA), New Delhi; Tata Institute of Social Sciences (TISS), Mumbai; Indian Institute of Forest Management (IIFM), Bhopal; Ashoka Trust for Research in Ecology and the Environment (ATREE) Bangalore and Visvesvarya National Institute of Technology (VNIT), Nagpur; 6. 8 Global Technology Watch Groups (GTWGs) led by National Institute of Advanced Studies (NIAS), Bangalore; IIT Madras and TIFAC, Delhi; 7. Indo-US Fulbright-Kalam Doctoral and Post-Doctoral Fellowships in Climate Change (annually 6 fellowships)

5. Prospect of climate change research in India

India is witnessing expansion of climate change research initiatives launched by various government ministries/ departments as part of implementation of national missions on climate change under the National Action Plan on Climate Change. These research initiatives cover programmes in all the three areas of CC viz., science, adaptation and mitigation. The ministries/departments which spearhead these programmes include; Department of Science & Technology; Ministry of Earth Sciences; Ministry of Environment, Forests and Climate Change; Ministry of Agriculture; Ministry of Water Resources, River Development & Ganga Rejuvenation; Ministry of New and Renewable Energy; Ministry of Power; Ministry of Urban development; etc. A large number of institutions and scientists are part of this multi-ministerial research network.

During past 5 years the DST-sponsored programmes have made a significant impact and resulted in a large number of useful publications in national and international journals. Over 600 research publications have come out of these programmes so far, out of which a large numbers are in international journals of high impact factors. About 60 new techniques have been developed as part of programmes under two missions. Nearly 1000 scientists, experts and students and 200 institutions in the country have been associated with climate change programme of DST. Nearly 150 PhD and PG students have been enrolled as part of two missions in different projects. More than 200 Workshops were organized wherein over 5500 personnel were trained. State CC Centres conducted 150 training programmes wherein 20000 personnel were trained. In addition, missions supported 40 national level events wherein over 2000 participants benefited. Overall 35000 people were trained in climate change related disciplines and skills under various programmes.

6. The Way Forward

India has over the years built a strong climate change research base in terms of number of quality researchers, long term data and infrastructure. The Climate Change Programme of DST has achieved considerable progress during past 5 years. Plans are afoot to strengthen the programme by building human and institutional capacities, developing greater linkages among the institutions and widening the network of researchers.

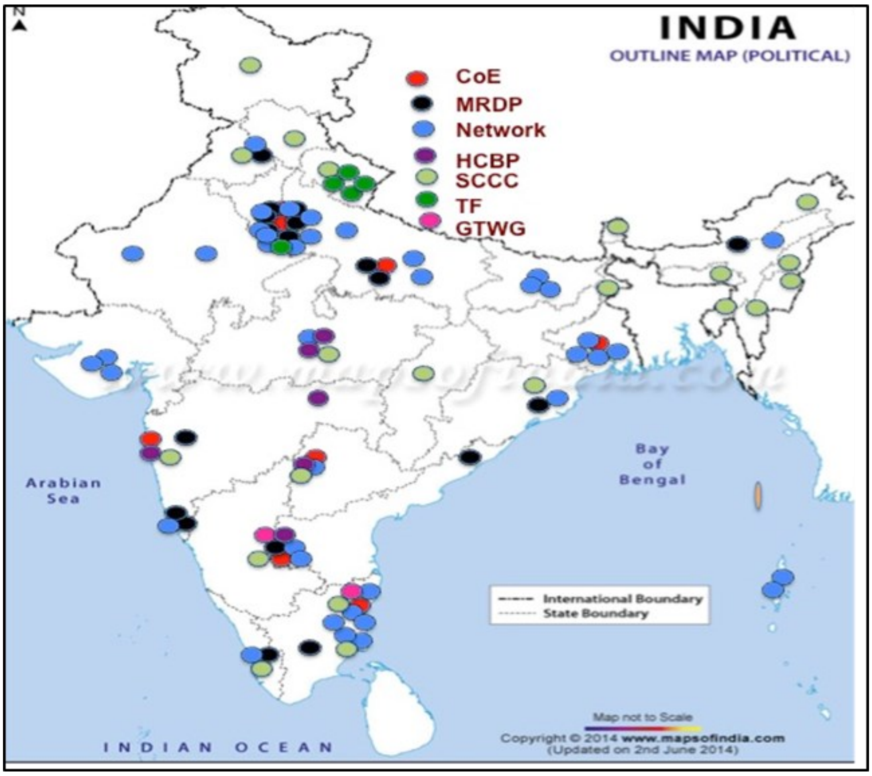

Figure 1. locations of various programmes/projects initiated under two missions.

Dr Akhilesh Gupta obtained his M.Sc. degree in Physics from Lucknow University and Doctorate degree in Atmospheric Sciences from Indian Institute of Technology, Delhi. He is a weather forecaster by training. Dr Gupta is presently heading the Climate Change Programme of the Department of Science & Technology, Government of India and is implementing two National Missions on Climate Change under National Action Plan on Climate Change launched by Govt. of India. These missions focus on building research capacity in the climate change areas in India. Dr Gupta has published over 110 research papers in various National and International journals. He is co-editor of 3 books, author of over 200 articles and nearly 300 reports. Dr Gupta was a member of National Coordination Team which drafted India's National Action Plan on Climate Change in 2008. He is a Fellow of Indian National Academy of Engineering (INAE) and Indian Meteorological Society. He was awarded D.Lit(Honoris Causa) by JRH University in 2013 and Honorary Professorship by Amity University Rajasthan

Key Atmospheric Processes Affecting Emission-Deposition Relation (APED) in China

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Mission

Quantify precisely the emission-deposition relation, identify the key emission and deposition areas, and assess the potential ecological risks in China; with the above results, assist the government for national air pollution control based on ecological risks caused by atmospheric pollution.

Timeline 2017/07-2020/12

Estimated Cost: 26.69 billion RMB

Grant number: 2017YFC0210100

Number of Partners: 10 partners, including Jinan University; Tianjin University; Peking University; Institute of Atmospheric Physics, CAS; Nanjing University; China Agriculture University; Nanjing University of Information Engineering; Guangzhou Institute of Geochemistry, CAS; Sun Yat-sen University; and Center for Ecological Environment Research, CAS.

1. Obstacles and Objectives of APED

The haze and photochemical smog in China, especially in East China, is one of the major environmental problems around the world. The unclear mechanisms of weather –climate reaction, particulate matters explosion and growths, reactive organic matter degradation as well as atmospheric deposition processes are the current major obstacles to hinder interpreting precisely the regional atmospheric emission-deposition relation in China. The Program of Key Atmospheric Processes Affecting Emission-Deposition Relation (APED), together with the aforementioned 3 topics and the other 4 fields (monitoring, emission inventory, human health and air quality control) constitute the China National key R & D Programs—Atmosphere Special, which are which are funded by the **Ministry of Science and Technology of the People's Republic of China**. The other programs related to the 3 topics mentioned at the beginning provide part of the basics for ***APED***.

Research on relation between emission and deposition of atmospheric constituents has provided **a crucial link to understand** biogeochemical cycling of elements through the Earth System. The trace elements emitted from sources could experience complicated atmospheric processes, including emissions, transport (e.g., thermodynamic process in boundary layer and turbulence), chemical transformation, and dry/wet deposition which may eventually lead to profound ecological effect. Specific to the atmospheric deposition processes, the bottleneck that needs to urgently break through, includes ① the unclear microscopic mechanisms of cloud physics and chemistry embedded in the wet deposition schemes; ② accuracy of parameterization schemes for dry deposition on typical land surfaces (e.g. forest, urban, cropland and grassland); and ③ lack of regional high resolution observation data of deposition fluxes for model validation.

In view of the above bottleneck, APED aims to improve and optimize the quantitative simulation of atmospheric processes in China, by integrating the sophisticated wet and dry parameterization schemes (on typical land surfaces) into the regional atmospheric chemical and transmit model, which will be applied to quantify the atmospheric emission-deposition relation, identify the key emission and deposition areas, as well as assess the potential regional ecological risks, the results of which will provide more scientific support for the government to control the national air pollution based on ecological risks caused by atmospheric pollution. The typical pollutants concerned by APED are O_3, NH_3, SO_2, NO_X and PM2.5, while the typical land surfaces of concern are forest, urban, cropland and grassland.

Research infrastructure

APED is hosted by Jinan University, and involves other 9 organizations, including Tianjin University, Peking University, Institute of Atmospheric Physics, CAS, Nanjing University, China Agriculture University, Nanjing University of Information Engineering, Guangzhou Institute of Geochemistry, CAS, Sun Yat-sen University, and Center for Ecological Environment Research, CAS.

To achieve the missions, the program is divided into 6 sub-projects (Figure 1), respectively to:

integrate and develop the deposition observation network based on the key emission and deposition areas in China, to provide the routine deposition data for model validation (Sub-project 1);

optimize the boundary layer parameterization schemes on the basis of tower gradient observation (Sub-project 2) ;

③ explore and develop high resolution measurement technique for dry deposition fluxes of typical pollutants (e.g., O_3, NH_3, SO_2, NO_2, etc.); by which obtain the high resolution data for evaluation and improvement of dry deposition parametrization schemes (Sub-project 3);

④ investigate the physical and chemical characteristics of cloud and mist solute components and the related processes on the basis of the high resolution online observation system (for physical and chemical properties of cloud droplets), and cloud and mist polyphase chemical reaction experiment platform, which provides validation data for the study on mechanisms of wet deposition and improvement of its parameterization schemes (Sub-project 4);

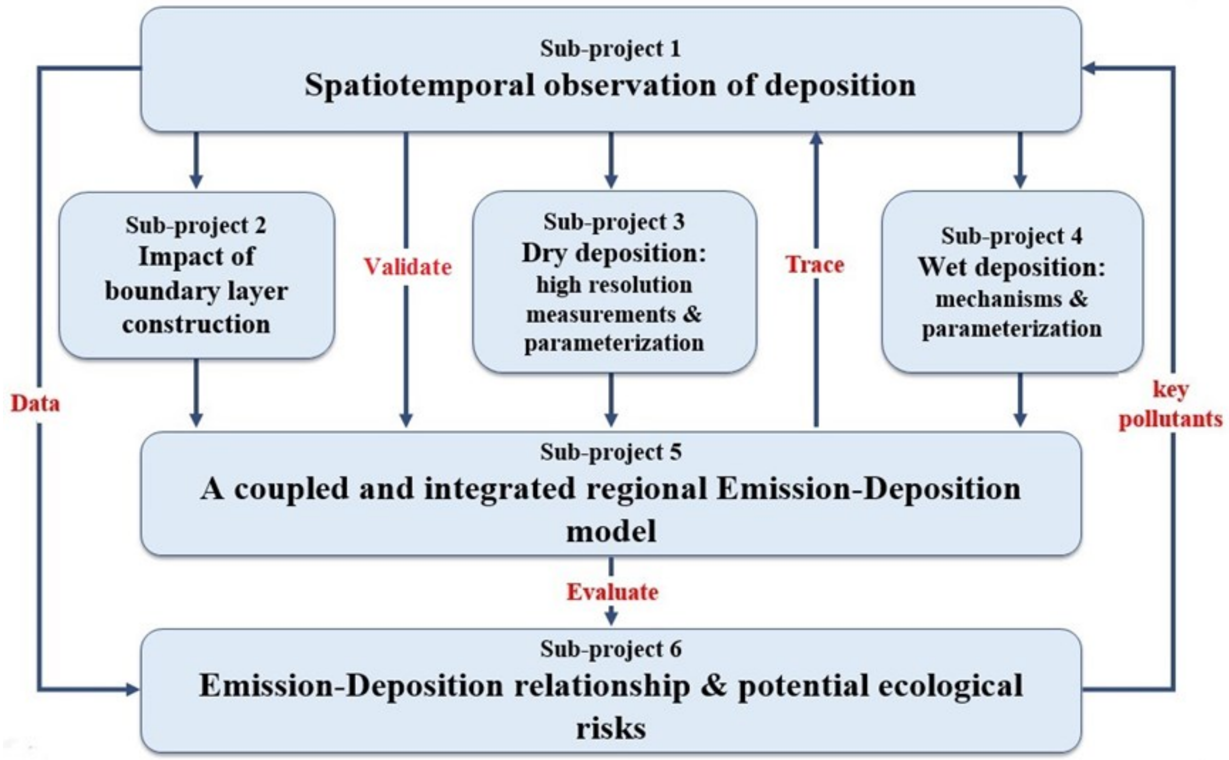

Figure 1. Research infrastructure

⑤ integrate the sophisticated wet and dry parameterization schemes (on typical land surfaces) into the regional atmospheric quality model and validate the simulated results with the network observation data (Sub-project 5)

⑥ quantify the atmospheric emission-deposition relation, identify the key emission and deposition areas, and assess the regional potential ecological risks by applying the integrated regional model (Sub-project 6).

3. The observation networks and field experiment platforms

The observation network integrated from the haze and photochemistry observation network, acid deposition observation network (established by the meteorological department) and nitrogen deposition network (established by China Agriculture University) are providing the basic data of wet and dry deposition fluxes since 1980's for the whole program (Sub-project 1) (Figure 2).

Except the networks, other 6 sites (Figure 3) with typical land surfaces in East China are selected for tower gradient observation of pollutant concentrations and boundary layer parameters related to dry deposition aerodynamic resistance (Sub-project 2), measurement for parameters related to dry deposition surface resistance (e.g. soil characteristics, types and dynamic of vegetation, canopy structure, etc.) (Sub-project 3), high resolution observation of air concentrations and dry deposition fluxes of pollutants (Sub-project 3), cloud droplets high resolution online observation (Sub-project 4), as well as cloud and mist multi-phases chemical reaction experiment platform (Sub-project 4). All of the above observation networks and experimental platforms will provide the data for improvement and optimization of both dry and wet deposition parameterization schemes and validation of the regional atmospheric model. Furthermore, Isotope technology will also be applied to trace the emission sources for N and S to assist the identification of key emission areas (Sub-project 1).

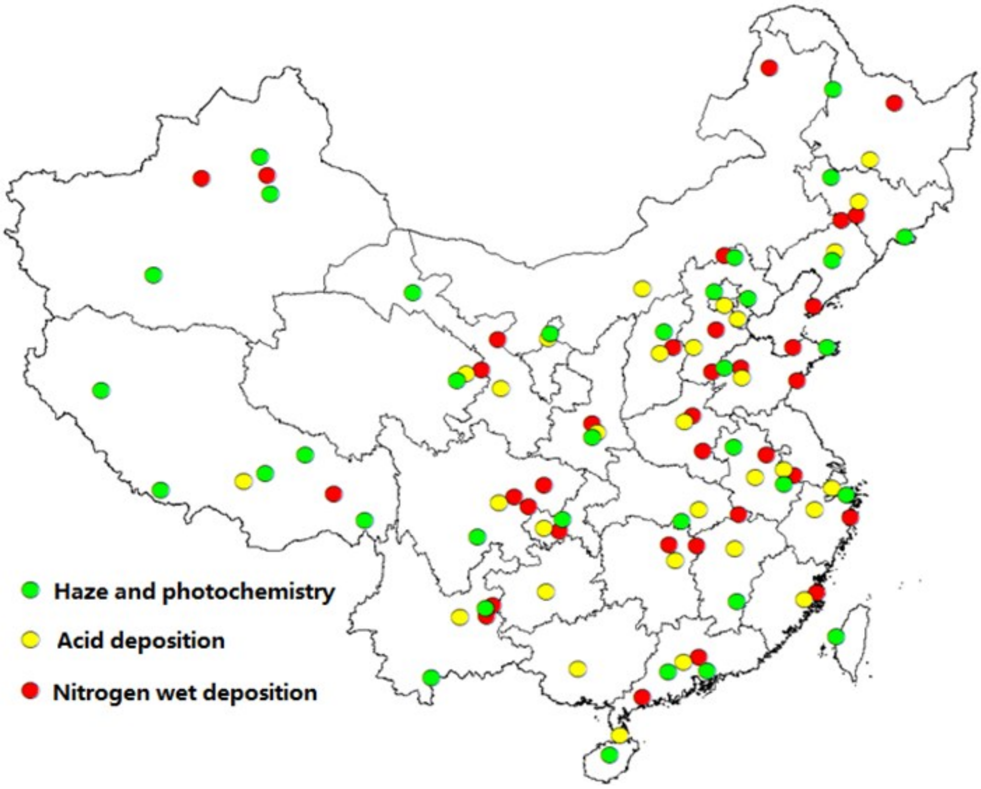

Figure 2. Routine observation networks in China

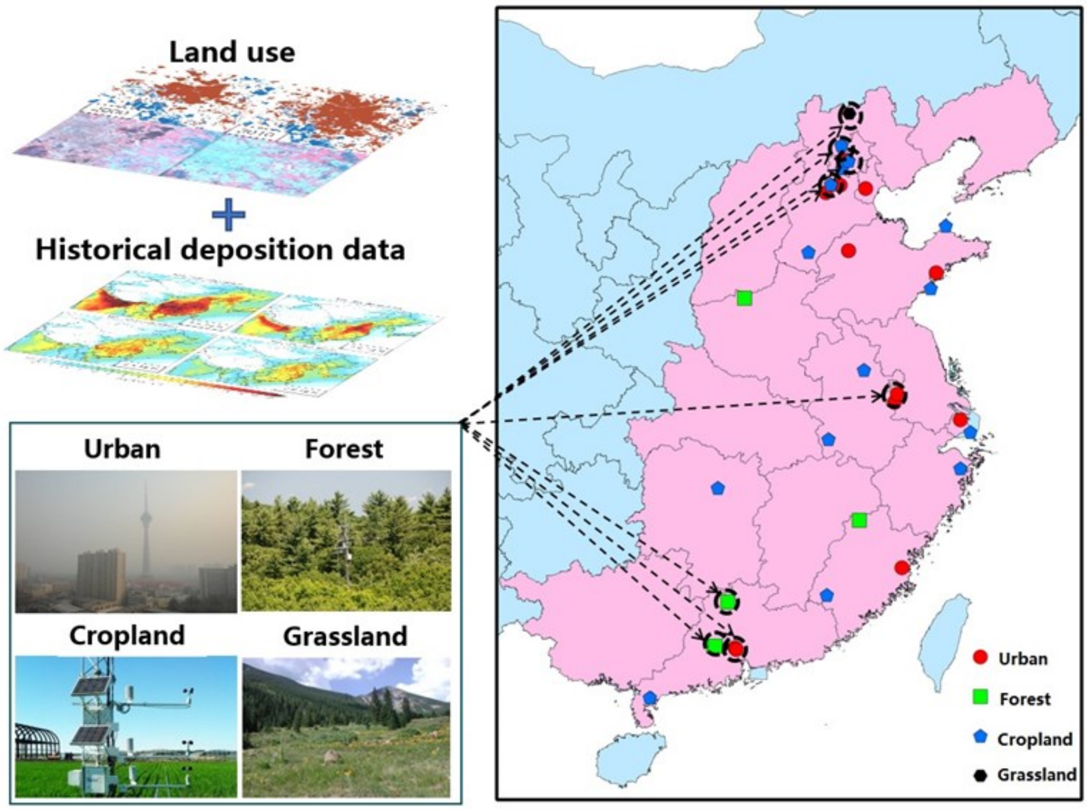

Figure 3. Field measurement sites on typical land surfaces for validation and optimization of wet and dry deposition parameterization schemes

Xuemei Wang is Chair of the APED, and Professor of Institute for Environmental and Climate research at Jinan University, China. Her personal research has focus on interactions between the land-surface and atmospheric environment, combining models and observations. She has published approximately 110 papers since 2000. She is awarded the national "Outstanding Young Scientist awards", and has led more than 5 national and international science projects funded by the NSFC. She is SSC members of iLEAPs and iCACGP.

Our next publication will be focusing on 'Soil water stress' and will be published in May, therefore if you would like to submit a piece specifically for this issue, please send your article of no more than 1,500 words, in English to Victoria Barlow at the iLEAPS IPO — ipo@ileaps.org /ileaps@ceh.ac.uk by Friday 27th April 2018

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