TOKYO METROPOLITAN AREA CONVECTION STUDY FOR EXTREME WEATHER RESILIENT CITIES

BY TSUYOSHI NAKATANI, RYOHEI MISUMI, YOSHINORI SHOJI, KAZUO SAITO, HIROMU SEKO, NAOKO SEINO, SHIN-ICHI SUZUKI, YUKARI SHUSSE, TAKESHI MAESAKA, AND HIROFUMI SUGAWARA

Large cities with populations of several million people are inherently vulnerable to severe weather, such as torrential rainfall, lightning, and tornadoes. An increase in the occurrence of torrential rainfall and strong typhoons, in our changing climate, can cause extensive damage to large cities. The number of days with thunderstorms has been increasing in Tokyo, Japan, in recent years, and the need for an advanced monitoring and forecasting system for extreme weather is becoming greater. In response, the Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS), which consists of an unprecedentedly dense observation network and relevant modeling and societal studies, has been conducted since April 2010 by the National Research Institute for Earth Science and Disaster Prevention (NIED), the Meteorological Research Institute (MRI), and more than 25 national institutions and universities in Japan that research local high-impact weather (LHIW) in the Tokyo metropolitan area (Maki et al. 2012). The objectives of TOMACS include 1) elucidation of the mechanism of LHIW in urban areas (e.g., torrential rain, flash floods, strong winds, and lightning), 2) improvement in nowcasting and forecasting techniques of LHIW, and 3) the implementation of high-resolution weather information to end users through social experiments.

Since 2013, TOMACS has been expanded to an international test bed study for LHIW in urban areas. The international partners include the Bureau of Meteorology (BOM, Australia), Sao Paulo University (Brazil), Environment Canada (Canada), University of Hohenheim (Germany), Pukyong National University (Korea), University Paris-Est (France), the National

THE FIRST INTERNATIONAL WORKSHOP ON TOKYO METROPOLITAN AREA CONVECTION STUDY FOR EXTREME WEATHER RESILIENT CITIES

WHAT: Nearly a hundred scientists from around the world discussed early findings from an international research project in the Tokyo metropolitan area that targets local high-impact weather in urban areas.
WHEN: 4–5 December 2013
WHERE: Tsukuba, Japan

AFFILIATIONS: NAKATANI, MISUMI, SUZUKI, SHUSSE, AND MAESAKA—National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Ibaraki, Japan; SHOJI, SAITO, SEKO, AND SEINO—Meteorological Research Institute, Tsukuba, Ibaraki, Japan; SUGAWARA—National Defense Academy, Yokosuka, Kanagawa, Japan
CORRESPONDING AUTHOR: Dr. Ryohei Misumi, National Research Institute for Earth Science and Disaster Prevention, 3-1 Tennodai, Tsukuba 305-0006, Japan
E-mail: misumi@bosai.go.jp

DOI:10.1175/BAMS-D-14-00209.1

In final form 19 December 2014

Center for Atmospheric Research (NCAR, United States), and Colorado State University (United States). TOMACS was approved as the Research and Development Project (RDP) of the World Meteorological Organization (WMO)'s World Weather Research Programme (WWRP) at a meeting of the Joint Scientific Committee of WWRP from 18 to 19 July 2013 (Nakatani et al. 2013). TOMACS ends in June 2016.

The first international workshop on TOMACS was held at MRI late in 2013 with an attendance of approximately 90 scientists, which included scientists from overseas. After the opening addresses by Akihide Segami (director general, MRI) and Tsuyoshi Nakatani (TOMACS principal investigator, NIED), 31 scientific presentations were conducted. Keynote speeches were given by Paul Joe (Environment Canada), who reviewed the nowcasting research conducted by WWRP, and by Stephane Belair (Environment Canada), who discussed the recent development of a modeling study of severe weather on an urban scale. Details of the program are available online (at http://mizu.bosai.go.jp/c/c.cgi?key=TOMACS).

OBSERVATION AND MODELING STUDIES. As a part of TOMACS, a dense observation network has been deployed over the Tokyo metropolitan area, including X-band and C-band polarimetric radars, a Ku-band fast-scanning radar, three-dimensional scanning coherent Doppler lidars, microwave radiometers, global positioning systems (GPS), radiosondes, and unmanned aerial vehicles, in addition to the operational observations made by the Japan Meteorological Agency (JMA) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan (Fig. 1). A list of observation instruments and their targets is shown in Table A1 of Nakatani et al. (2013). In the workshop, several observational results obtained by using these instruments were presented. Eiichi Sato (MRI) showed the detailed structure and time evolution of a cumulonimbus, which developed a tornado in Tokyo on 23 July 2013 and was observed with a fast-scan Ku-band radar capable of obtaining volume scan data at 1-min intervals. He showed a descending radar echo just before the touchdown of the tornado. Another tornado, which caused F3 damage in Tsukuba City on 6 May 2012, was analyzed by Hiroshi Yamauchi (MRI) with data from a C-band polarimetric radar. Debris that was dispersed by the tornado was clearly identified by the correlation coefficient between the horizontal and vertical polarization signals (r_{hv}) in his analysis. Characteristics of the GPS slant delay (an indicator of water vapor in the atmosphere) for the tornado event was presented by Yoshinori Shoji (MRI). Sadao Saito (MRI) presented a case study of an interaction between two misocyclones that developed over Tokyo and caused strong wind (Saito et al. 2013).

Polarimetric radars are useful tools for making quantitative precipitation estimations (QPEs). Alexander Ryzhkov [University of Oklahoma–National Oceanic and Atmospheric Administration (NOAA)] presented simultaneous observation data of heavy rainfall that were observed with C-band and S-band polarimetric radars. Takeshi Maesaka (NIED) explained a method of obtaining the QPEs used in analyses of the X-band polarimetric radar network (X-NET) operated by various universities and institutes and the X-band polarimetric radar information network (XRAIN) operated by MLIT. Tetsuya Sano (Yamanashi University) analyzed strong radar echoes initiated in a basin surrounded by high mountains. An X-band phased array radar, which was recently developed, was introduced by Tomoo Ushio (Osaka University). The radar can observe the three-dimensional structure of convective echoes in several tens of seconds with high spatial resolution. The data indicated a quick evolution of the convective echoes.

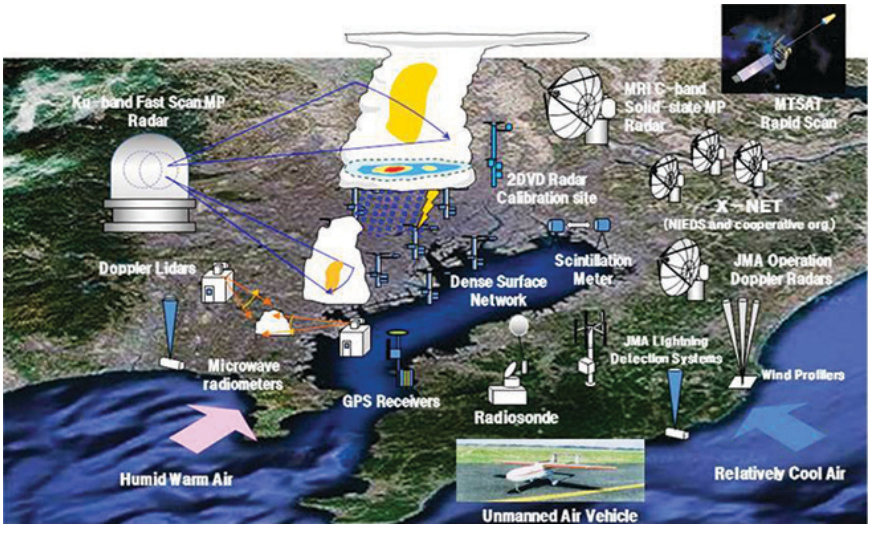

Fig. 1. Observation instruments in the TOMACS field campaign (after Nakatani et al. 2013).

The study of boundary layers is also an important subject for TOMACS. Yasushi Fujiyoshi (Hokkaido University) classified the wind structures in the boundary layer in Tokyo based on the Doppler velocity patterns observed with a 3D-scanning coherent Doppler lidar. Naoko Seino (MRI) showed the results of radiosonde observations carried out during TOMACS. Hirofumi Sugawara (National Defense Academy) estimated the effects of the sensible heat flux over an urban area on the atmospheric stability based on the flux observations. His results indicated that the urban effect increases the convective available potential energy by 15%. Stephane Belair (Environment Canada) presented results obtained by using the Canadian external urban and land surface modeling system [Global Environmental Multiscale Surface (GEM-SURF)] and suggested applying the system to the Tokyo metropolitan area.

NOWCASTING AND DATA ASSIMILATION STUDIES. The use of X-NET and XRAIN has a great impact on nowcasting studies. Kohin Hirano (NIED) applied a nowcasting model based on vertically integrated liquid water content (VIL) to the Tokyo metropolitan area. She showed that VIL is more correctly estimated by the specific differential phase K_{DP} derived from polarimetric radars than by the radar reflectivity factor Z and that VIL-based nowcasting has advantages for forecasting within a 10-min period. Yukari Shusse (NIED) developed a detection system for precipitation cores, which is defined by the maxima of Z in the volume scan data. The system is expected to be used for the detection of high differential reflectivity Z_{DR}, which is an indicator of large raindrops. Alan Seed (BOM) presented the spatial distribution of errors in the short-term ensemble prediction system (STEPS) caused by orographic enhancement and rain shadows. He considered that the errors could be corrected by an intelligent method. Shakti P. C. (NIED) applied STEPS to the TOMACS region and compared the results with that of JMA nowcasting.

Data assimilation of the dense observation data obtained in TOMACS is also an important challenge. Takuya Kawabata (MRI) is developing a fine-mesh (500-m grid) four-dimensional variational data assimilation (4D-Var) system, which is capable of assimilating fine-mesh observation data, such as those from coherent Doppler lidars (Kawabata et al. 2014). Application of a local ensemble transform Kalman filter (LETKF) to the TOMACS data was explained by Hiromu Seko (MRI). Kazuo Saito (MRI) conducted an ensemble forecast with a cloud-resolving model for a severe rainfall event over Tokyo. The variational Doppler radar assimilation system (VDRAS) developed by NCAR was also used for assimilation of the TOMACS X-band radar data by Soichiro Sugimoto (Central Research Institute of Electric Power Industry).

Hydrological use of radar data as well as communication with end users are also subjects of TOMACS. Qian Chaochao (Chuo University) presented the hydraulic characteristics of open drainage channels during heavy rainfall. A Japanese psychologist, Naoya Sekiya (Toyo University), used large screens in downtown areas to show the radar echoes observed by X-band radars to the public. He studied the behavior and responses of the people who observed the screens.

RELATED INTERNATIONAL PROJECTS. LHIW in urban areas is not an issue limited to Tokyo but rather is a common problem throughout the world. Exchange of information with other projects that share similar academic goals is important for TOMACS. The Dallas Fort Worth Water Research Network (DFW-WARN), presented by V. Chandrasekar (Colorado State University), is a research and innovation network that links academic researchers, local stakeholders, and industry to address hydrological issues as they relate to urban sustainability, flood hazard warnings, and mitigation and the management and design of urban water infrastructures. The RainGain project, as described by Daniel Schertzer (University of Paris-Est), is a European project aimed at improving the prediction of pluvial floods in cities. The city of Sao Paulo, Brazil, with a population exceeding 10 million, also faces problems of severe weather and air pollution. Augusto Jose Pereira Filho (University of Sao Paulo) presented a study that used the mobile X-band polarimetric weather radar (MXPOL). Dong-In Lee (Pukyong National University) presented the results of an observation experiment over Jeju Island, an isolated South Korean island inhabited by more than a half million people that employs a dense disdrometer network. He discussed the effects of the island on raindrop size distribution.

FUTURE PLANS. The future plans of TOMACS were discussed after the academic sessions. It was confirmed that a portion of the observation data will be shared with registered participants, including the data of the X-band polarimetric radars, the coherent Dopplar lidar, soundings, and other operational observations and numerical forecasts. A subsequent TOMACS meeting was held in November 2014

in Tokyo. We believe that the observations and forecasting and nowcasting techniques developed with this project will be applicable to many countries where similar disasters occur in urban areas.

ACKNOWLEDGMENTS. We are grateful to Kohin Hirano, Michiko Otsuka, Masaru Kunii, Ayako Nakai, and Natsumi Imai for their contribution to the workshop as members of the local organizing committee. TOMACS is funded by the Japan Science and Technology Agency (JST) as part of the "Social System Reformation Program for Adaption to Climate Change."

REFERENCES

Kawabata, T., K. Ito, and K. Saito, 2014: Recent progress of the NHM-4DVAR towards a super-high resolution data assimilation. *SOLA,* **10,** 145–149, doi:10.2151/sola.2014-030.

Maki, M., and Coauthors, 2012: Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS). *Proc. Seventh European Conf. on Radar in Meteorology and Hydrology,* Toulouse, France, Météo-France. [Available online at www.meteo.fr/cic/meetings/2012/ERAD/extended_abs/NET_236_ext_abs.pdf.]

Nakatani, T., Y. Shoji, R. Misumi, K. Saito, N. Seino, H. Seko, Y. Fujiyoshi, and I. Nakamura, 2013: WWRP RDP science plan: Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS). WWRP JSC Doc. 4.6, 26 pp. [Available online at www.wmo.int/pages/prog/arep/wwrp/new/documents/Doc4_6_TOMACS_RDP_proposal_20130704.pdf.]

Saito, S., K. Kusunoki, and H. Y. Inoue, 2013: A case study of the merging of two misocyclones in the TOMACS field campaign area of Tokyo on 26 August 2011. *SOLA,* **9,** 153–156, doi:10.2151/sola.2013-034.