Influence of assimilating ground-based microwave radiometer data into the WRF model on precipitation

Wenying HE, Hongbin CHEN & Jun LI

Published online: 07 Jan 2020.

Submit your article to this journal

Article views: 385

View related articles

View Crossmark data

Taylor & Francis
Taylor & Francis Group

Influence of assimilating ground-based microwave radiometer data into the WRF model on precipitation

HE Wenying, CHEN Hongbin and LI Jun

Key Laboratory of Middle Atmosphere and Global Environment Observation (LAGEO), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

ABSTRACT

Ground-based microwave radiometers profilers (MWRPs) have been used in numerical weather prediction (NWP) systems and show different impacts on forecasts. Currently, there are around hundreds of ground-based MWPRs used in weather stations over China; however, the application of MWPRs in NWP systems is rather limited. In this work, two MWRP retrieved profiles were assimilated into the Weather Research and Forecasting(WRF) model for a rainstorm event that occurred in Beijing, China. The quality of temperature and humidity profiles retrieved from the MWRP was evaluated against radiosonde observations and showed the reliability of the two MWRP products. Then, comparisons between the measurements of ground-based rain gauges and the corresponding forecasted precipitation in different periods of the rainstorm were investigated. The results showed that assimilating the two MWRPs affected the distribution and intensity of rainfall, especially in the early stage of the rainstorm. With the development of the rainstorm, adding MWRP data showed only a slight influence on the precipitation during the stable and mature period of the rainstorm, since the two MWRP observations were too limited to affect the large area of heavy rainfall.

WRF模式中同化地基微波辐射计对降水的影响

摘要

地基微波辐射计观测已经用于数值预报中, 并对预报效果产生不同的影响。目前, 中国约有上百台地基微波辐射计, 但是观测数据用到数值预报系统的很有限。本文尝试将两台地基微波辐射计数据同化到WRF数值预报模式, 并针对北京一次暴雨过程, 进行同化试验, 结合地面雨量计测量结果进行比对。试验结果比较表明:同化地基微波辐射计能较明显影响降水初期的降水强度和分布, 与雨量计分布更为接近; 随着暴雨系统发展, 同化两台地基微波辐射计对大面积强降水系统的影响甚微。

1. Introduction

Currently, ground-based microwave radiometers profilers (MWRPs) are widely used in weather stations for providing continuous atmospheric temperature and humidity profiles under all weather conditions (Westwater 1993; Löhnert and Maier 2012). MWRP products have also been applied to many other fields, such as liquid water path retrievals used for weather modification, boundary layer height retrievals used for air-quality monitoring, and forecast indices for operational meteorology (Liu et al. 2015; Cimini et al. 2011, 2015). Attempts have been made to use ground-based MWRP observations in numerical weather prediction (NWP) systems to improve the nowcasting ability of NWP models. Firstly, temperature and humidity profiles retrieved from single ground-based MWRPs were assimilated into MM5

(Fifth-generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model) for a winter fog event (Vandenberghe and Ware 2003), which revealed some positive effects on fog forecasts. Then, in more recent work, the retrieved atmospheric profiles from 13 ground-based MWRPs were assimilated in a convective-scale NWP system (Caumont et al. 2016), demonstrating that the impact was generally neutral except for limited improvements for longer forecast ranges and larger rainfall accumulations. In addition, a network of 140 MWRPs was assimilated into the Weather Research and Forecasting (WRF) model, and the results indicated a positive impact on the forecasted temperature and humidity fields (Hartung et al. 2011).

With the high demand for MWPRs in weather observation systems, there are hundreds of ground-based MWPRs used in weather stations over China nowadays;

however, the application of MWPRs in NWP systems is rather limited. Wang, Lai, and Zhao (2010) implemented a numerical experiment to assimilate the relative humidity profiles retrieved from three ground-based MWRPs for a heavy rain event, and showed that the forecasted rainfall intensity was a clear improvement, but less help for the location of 24-h rainfall accumulation. Due to the complex variation of precipitating clouds, as well as the high level of uncertainty in MWRP retrieval methods, there is a need for more investigations into the potential of MWRP observations in NWP systems.

Therefore, in the study reported in this paper, we attempted to assimilate two sets of ground-based MWRP observations into WRF's data assimilation (WRFDA) system for a rainstorm event that occurred in Beijing, China. We then compared the results with rain gauge measurements to explore the influence of the MWRP observations on the precipitation forecast.

2. Data and methods

We have been recorded observations of two ground-based MWRPs since 2014. In this study, to understand the influence of those observations on weather forecasts, temperature and relative humidity profiles (from the surface up to an altitude of 10 km) retrieved from the two ground-based MWRPs were assimilated into the WRFDA system using the three-dimensional variational method.

The MWRPs we used were produced by a company in Germany (Radiometer Physics GmbH), whose specifications included seven channels with frequencies at 22–31 GHz for humidity retrieval, seven channels with frequencies at 50–60 GHz for temperature retrieval, an infrared sensor for detecting cloud base height, a rain sensor for providing rain flags, and other small parts, as shown in Figure 1(a). Different to the limited twice-daily observations of atmospheric sounding profiles from regular and operational radiosondes, ground-based MWRPs can provide high-temporal-resolution temperature and humidity

profiles (~ 1 min) in the troposphere under all weather conditions, although with greater uncertainties for the retrieved profiles under precipitating conditions.

To understand the vertical distribution of temperature and water vapor between big cities, such as Beijing, and its suburban areas, one of the MWRPs was located at the Institute of Atmospheric Physics (IAP; 39.97°N, 116.37°E), Chinese Academy of Sciences, in Beijing, and the other at Xianghe observation station (XH; 39.79°N, 116.95°E) in Heibei, with a distance between them of about 70 km. Before using the MWRP products, we checked the quality of the retrieved temperature and humidity profiles by comparing them with radiosonde observations at the Beijing site. It was found that both temperatures profiles were highly consistent, especially at 0.5–4 km, with root-mean-square errors (RMSEs) of less than 2 K. The RMSEs of the absolute humidity profile were less than 1.0 g m^{-3} at the surface and reduced with altitude. These differences are close to previous comparisons, e.g.,Liljegren et al. (2005), thus indicating the quality of the MWRP products to be reliable.

To simulate the rainstorm event that occurred on 19 July 2016 in Beijing, China, a three-layer nested domain was used in the WRF model; and the third nested domain, with 1-km grid spacing, covered the domain (37°–42°N, 112°–120°E), centered on Beijing city. The model top was 10 hPa, with 57 vertical levels. Since this rainstorm event moved from Southwest to Northeast China, the MWRP at the XH site firstly observed the rainfall to have begun at about 1800 UTC 18 July and lasted for a few hours, while the observations from the MWRP at the IAP site showed less rainfall in Beijing in the corresponding period, as seen from the blue color in the rain flag status bar in Figure 1(b,c).

Based on the detailed rainfall information reflected in the MWRP observations, the corresponding temperature and humidity profile retrievals from 0000 UTC 18 July to 1800 UTC 22 July 2016, with 6-h intervals, were used in the WRFDA system. Firstly, we adjusted the MWRP retrieved profiles into the required data format for
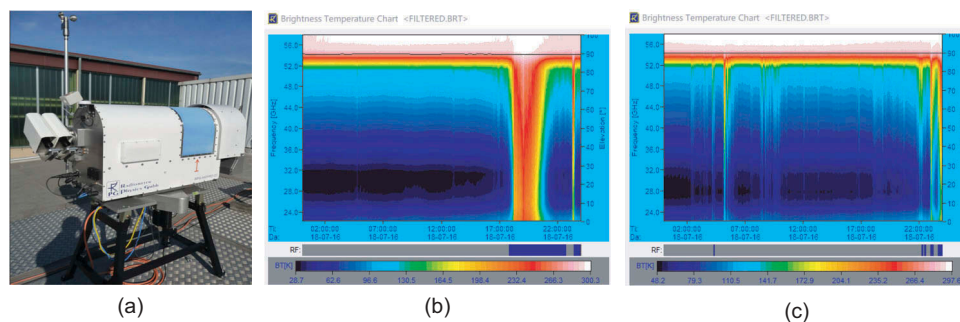

(a)   (b)   (c)

Figure 1. (a) The ground-based MWRP used in this study, and (b, c) the MWRP brightness temperature at (b) XH and (c) IAP on 18 July 2016.

Table 1. Change in the available sounding observations after adding the data of the two MWRPs.

Time	Number of sounding observations	
	Conventional observations in the GTS	After inclusion of MWRP data
1200 UTC 18 July 2016	3	5
1800 UTC 18 July 2016	0	2

radiosondes in the WRFDA system (e.g., LITTLE_R format), such that the MWRP data could be safely assimilated into the WFFDA system in the same way as radiosonde data. Then, the statistics of all available observations at 1200 UTC and 1800 UTC 18 July 2016 were determined, as shown in Table 1. It can be clearly seen from Table 1 that the number of sounding observations increased by two at both times, and with the result at 1800 UTC being particularly positive because there were no soundings at all with the conventional observations of the Global Telecommunications System (GTS) in the WRFDA system. Thus, the indication was that the two sets of MWRP data were successfully assimilated into the WRFDA system.
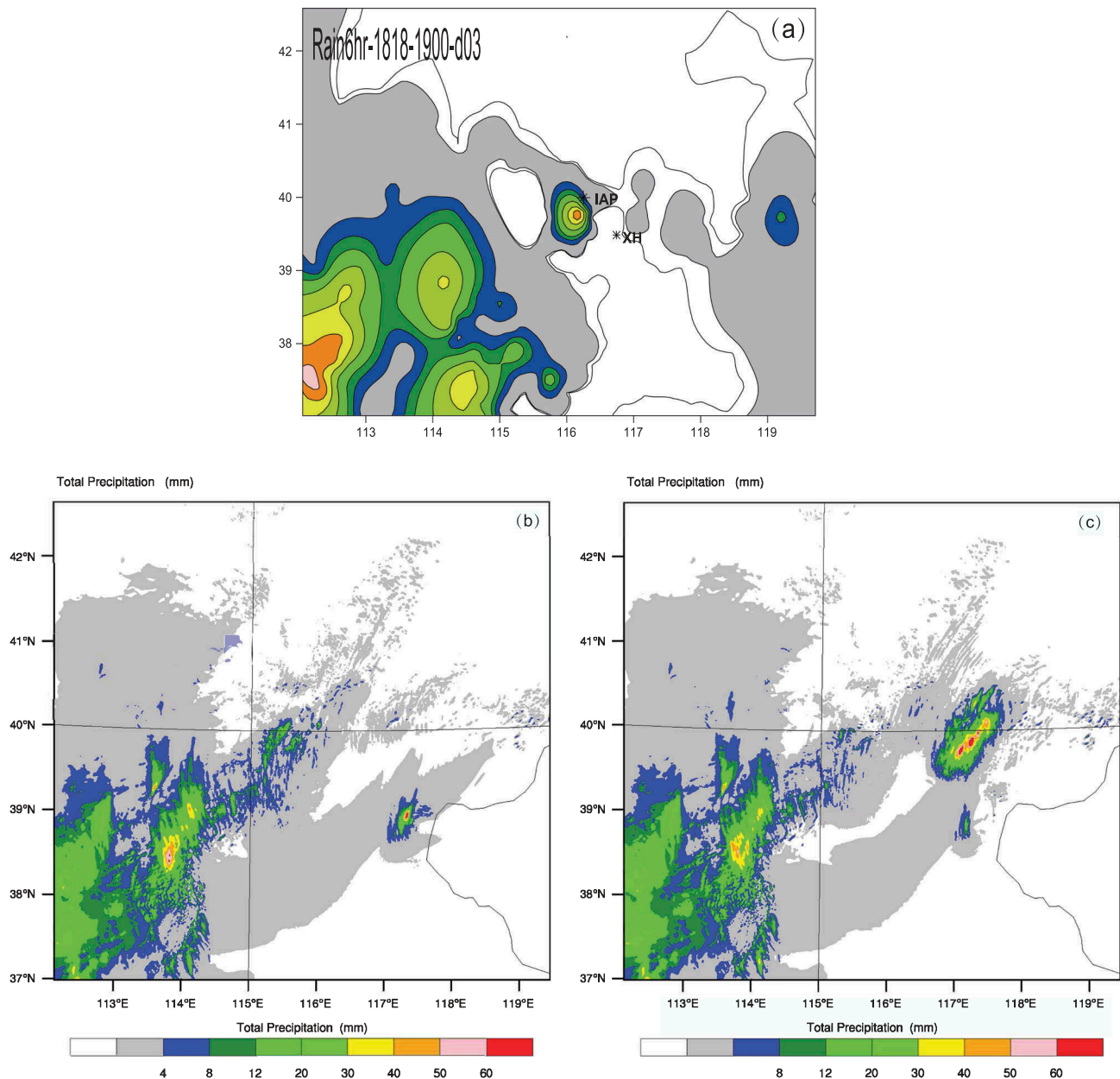

Figure 2. Distribution of 6-h rainfall (a–c) from 1800 UTC 18 July to 0000 UTC 19 July 2016 and (d–f) from 0000 UTC to 0006 UTC 20 July 2016, in the third nested domain: (a, d) precipitation from rain gauge measurements; (b, e) forecasted results from assimilating conventional observations; and (c, f) forecasted results from assimilating conventional observations and the data of the two MWRPs. The locations of the two MWRP sites (IAP and XH) are labeled in (a).
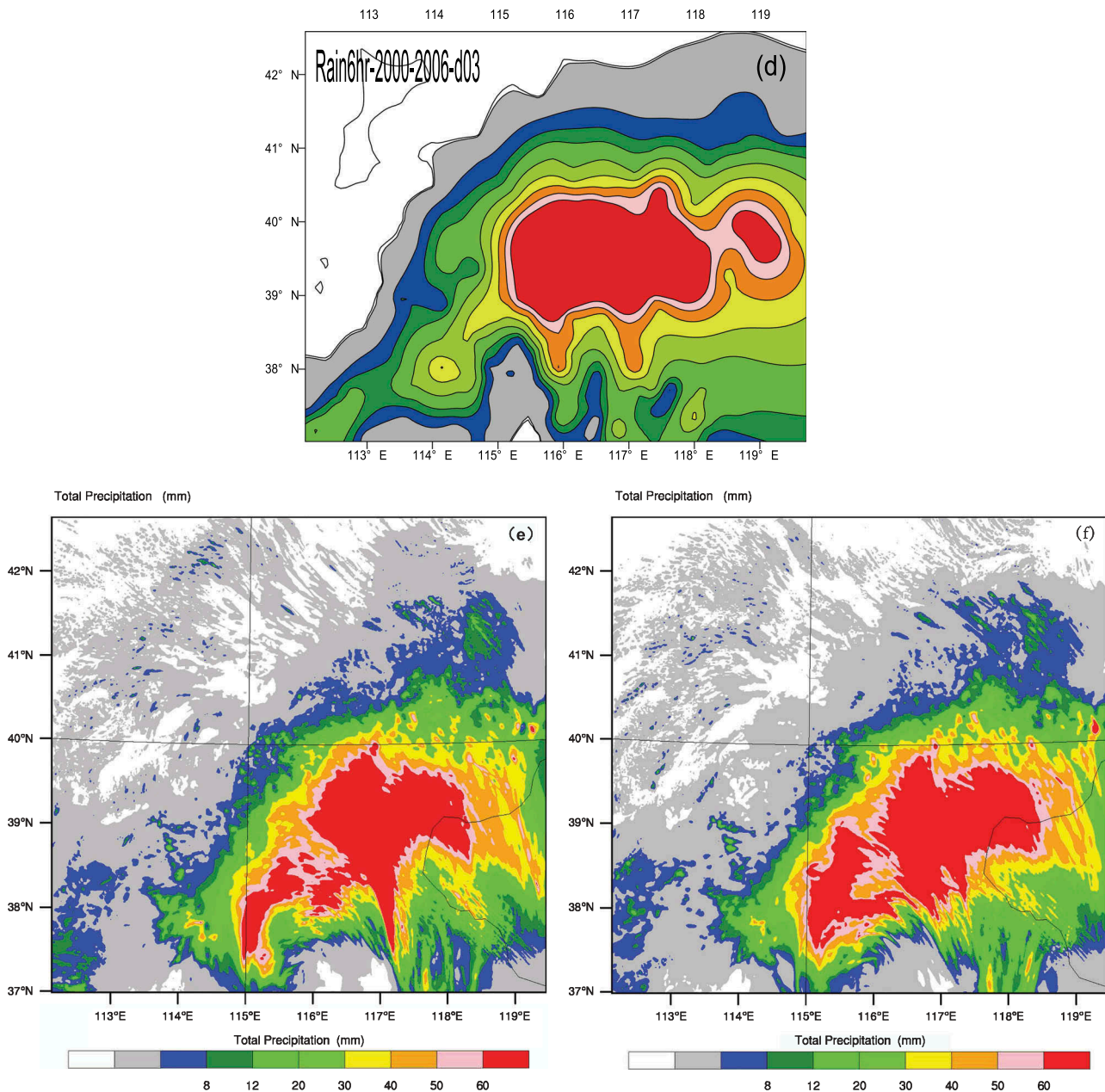
Figure 2. Continued.

3. Results

The rainstorm event began at midnight on 19 July, then gradually enhanced on 20 July, weakened on 21 July, and finally moved out of Beijing on 22 July 2016. To see the impact of MWRP assimilation on the precipitation, 24-h forecasts were made at 0000 UTC, 0600 UTC, 1200 UTC, and 1800 UTC from 18 to 22 July 2016, and then comparisons were made between ground-based rain gauge measurements and the corresponding forecasted precipitation in different periods.

Our focus was on the distribution of the forecasted precipitation in the third nested domain, centered on Beijing city. We chose 1800 UTC 18 July 2016 as the beginning period of the rainstorm event, and 0000 UTC 20 2016 as the stable period. As Figure 2 shows, the 6-h rainfall forecasts at 1800 UTC 18 July and 0000 UTC 20 July 2016 were separately compared with the corresponding rain gauge observations.

It can be seen from Figure 2 that both forecasted precipitation areas were similar to that of the rain gauge observations, except for some details with respect to rainfall intensity. For instance, an obvious rainfall intensity center was found in the southwest corner of the domain from the rain gauge data, whereas weak precipitation was found there in both sets of forecasted

results. For the isolated rainfall center in the middle of the domain shown in Figure 2(a), the forecasted precipitation without MWRP data (Figure 2(b)) showed a weaker cell to the south of the observation, while the corresponding precipitation from using MWRP data (Figure 2(c)) showed a stronger rainfall center close to the observation, albeit the rainfall area was wider than that indicated by the rain gauge data. The isolated rainfall center shown in Figure 2(c) was closer to the two MWRP sites, marked in Figure 2(a), and was more consistent with the rain gauge measurements, indicating that adding two MWRP profiles contributed to properly forecasting the isolated rainfall cell.

Similar comparisons, at 0000 UTC 20 July 2016, were made as the rainstorm developed, as presented in Figure 2(d–f). The 6-h rainfall distribution from the rain gauge observations showed a larger area of heavy precipitation over the whole of Beijing city (6-h accumulated rainfall > 150 mm), indicative of the mature and stable period of the rainstorm event. The range and intensity of both sets of forecasted 6-h precipitation were more consistent with the observations, although there were some fine differences in intensity locations in the forecasted precipitation, such as more heavy rainfall in the southwest area of the domain in the forecasted results. Additionally, the patterns of both sets of forecasted precipitation were almost identical in this period, which implies the influence of assimilating two sets of MWRP data on the precipitation was not significant during the stable period of the rainstorm.

To clearly see the differences, both sets of gridded forecasted precipitation from the model were matched with the observations from rain gauges (Figure 3). Here, our focus was on comparing the forecasted 24-h rainfall at 0000 UTC 20 July 2016, because there was a large area of heavy rainfall in Beijing at that time. It can be seen from Figure 3 that both forecasted rain areas, especially

for heavy rainfall with accumulated rainfall greater than 50 mm, were similar to observed, and the locations of strong rain centers also agreed with the observations, such as the eastward center. Compared with the extra-heavy rainfall (such as the accumulated rainfall > 150 mm) from the rain gauge measurements, the intensity of forecasted precipitation seemed obviously weaker, particularly in the center of the domain. Similar to the 6-h rainfall comparisons, the forecasted 24-h precipitation using conventional observations and adding the MWRP data looked almost identical, further demonstrating that assimilating two sets of MWRP data for a larger area of rainfall barely had an effect on the forecasted precipitation.

4. Summary

In this work we assimilated two ground-based MWRPs' retrieved profiles into the WRFDA system for a rainstorm event that occurred in Beijing, China, and compared the results with rain gauge measurements to understand the influence on the forecasted precipitation. The comparison showed that assimilating the two MWRPs' data affected the distribution and intensity of rainfall, especially in the beginning period of the rainstorm. With the development of the rainstorm, adding the two MWRPs' data seemed have a slight impact on the precipitation during the stable and mature period of the rainstorm, since the two sets of MWRP observations were too limited to affect the large area of the heavy rainfall.

Currently, more and more ground-based MWRPs are being used in local weather stations throughout China. How to make full use of these MWRP observations in NWP systems is still a challenging issue, and therefore we need to continue to explore the potential of ground-based MWRP data for weather forecasts in the future.
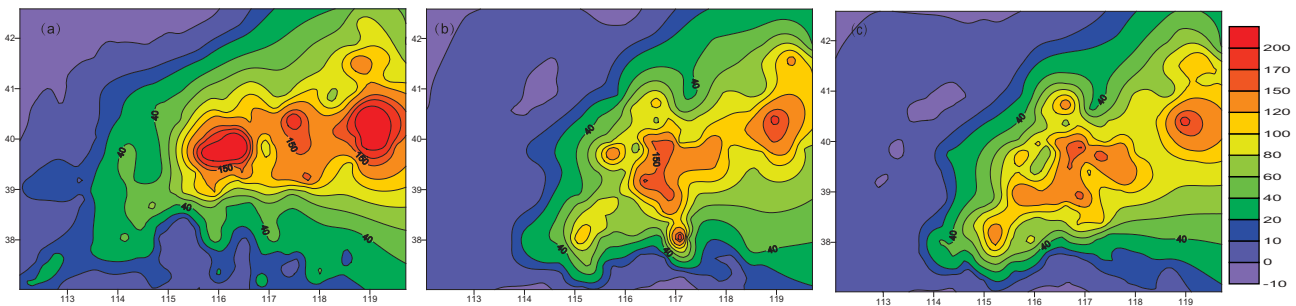

Figure 3. Distribution of matching 24-h rainfall from 0000 UTC 20 July to 0000 UTC 21 July 2016: (a) rain gauge observations; (b) with assimilation of conventional observations; (c) with assimilation of conventional observations and the data of the two MWRPs.

Acknowledgments

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

References

Caumont, O., D. Cimini, U. Löhnert, L. Arboledas, R. Bleisch, F. Buffa, M. Ferrario, et al. 2016. "Assimilation of Humidity and Temperature Observations Retrieved from Ground-based Microwave Radiometers into a Convective-scale NWP Model." *Quarterly Journal of the Royal Meteorological Society* 142: 2692–2704.

Cimini, D., E. Campos, R. Ware, S. Albers, G. Giuliani, J. Oreamuno, P. Joe, et al. 2011. "Thermodynamic Atmospheric Profiling during the 2010 Winter Olympics Using Ground-based Microwave Radiometry." *IEEE Transactions on Geoscience and Remote Sensing* 49: 4959–4969. doi:10.1109/TGRS.2154337,2011.

Cimini, D., M. Nelson, J. Güldner, and R. Ware. 2015. "Forecast Indices from a Ground-based Microwave Radiometer for Operational Meteorology." *Atmospheric Measurement Techniqus* 8: 315–333. doi:10.5194/amt-8-315-2015.

Hartung, D. C., J. A. Otkin, R. A. Petersen, D. D. Turner, and W. F. Feltz. 2011. "Assimilation of Surface-based Boundary-layer Profiler Observations during a Cool Season Weather Event Using an Observing System Simulation Experiment. Part II: Forecast Assessment." *Monthly Weather Review* 139: 2327–2346. doi:10.1175/2011MWR3623.1.

Löhnert, U., and O. Maier. 2012. "Operational Profiling of Temperature Using Ground-based Microwave Radiometry at Payerne: Prospects and Challenges." *Atmospheric Measurement Techniqus* 5: 1121–1134. doi:10.5194/amt-5-1121-2012.

Liljegren, J. C., S. A. Boukabara, K. C. Pereira, and S. A. Clough. 2005. "The Effect of the Half-width of the 22GHz Water Vapor Line on Retrievals of Temperature and Water Vapor Profiles with a 12-Channel Microwave Radiometer." *IEEE Transactions on Geoscience and Remote Sensing* 43: 1102–1108. doi:10.1109/tgrs.2004.839593.2005.

Liu S.B., W.Y. He, H.Y. Liu, and H.B. Chen. 2015. "Retrieval of Atmospheric Boundary Layer Height from the Ground-based Microwave Radiometer Measurements." *Journal of Applied Meteorological Science* 26 (5): 626–635. (In Chinese). doi:10.11898/1001-7373.20150512.

Vandenberghe, F., and R. Ware. 2003. "Four-dimensional variational assimilation of ground-based microwave observations during a winter fog event". International Workshop on GPS Meteorology. International Symposium on Atmospheric Sensing with GPS. Tsukuba, Japan, 14–17 January".

Westwater, E. R. 1993. "Ground-based Microwave Remote Sensing of Meteorological Variables." In *Atmospheric Remote Sensing by Microwave Radiometry*, edited by M. A. Janssen, 145–213. New York, NY: Wiley.

Wang Y. H., A. W. Lai, and Y. C. Zhao. 2010. "Numerical Study of an Excessive Heavy Rain Event by Assimilating Humidity Profiles Retrieved from Ground-based Microwave Radiometers." *Torrential Rain And Disasters* 29 (3): 201–207. (In Chinese).