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ANALYSIS OF FLOODS AND DROUGHTS FOR PAST AND FUTURE CLIMATES IN THE BAGO RIVER BASIN, MYANMAR

Представлені результати оцінки ризику повеней і засух з метою оцінки змін клімату в басейні річки Пегу, М'янми. Модель *опадів-стоків-затоплення (RRI)* була використана для моделювання повені в 2011 та 2014 роках *і* імітаційна модель *RRI* затоплення 2011 р. схожа на ступінь повені за супутниковими даними. *Прошлі* повені та засухи були визначені кількісно, використовуючи *стандартизований індекс опадів* (SPI) та *стандартизований індекс опадів евапотранспірації* (SPEI), а порівняльний SPI (cSPI) був використаний для оцінки зміни опадів між кліматичними показниками 2075-2099 та 1979-2003 років.

Ключові слова: *небезпека повені, посуха, модель опадів-стоків-повеней (RRI), зміна клімату, зміна клімата, атмосферна модель загальної циркуляції (MRI-AGCM3.2S)*

Представлены результаты оценки риска наводнений и засух с целью оценки изменений климата в бассейне реки Пегу, Мьянмы. Модель осадков-стоков-затопления (RRI) была использована для моделирования наводнения в 2011 и 2014 годах и имитационная модель RRI затопления 2011 похожа на степень наводнения по спутниковым данным. Прошлые наводнения и засухи были определены количественно, используя стандартизированный индекс осадков (SPI) и стандартизированный индекс осадков эвапотранспирации (SPEI), а сравнительный SPI (cSPI) был использован для оценки изменения осадков между климатическими показателями 2075-2099 и 1979-2003 годов.

Ключевые слова: *опасность наводнения, засухи, изменение климата, атмосферная модель общей циркуляции (MRI-AGCM3.2S)*

Floods and droughts are analysed under climate change in the Bago River Basin, Myanmar. The Rainfall-Runoff-Inundation (RRI) model was used to simulate 2011 and 2014 floods and the RRI simulated inundation of 2011 flood is similar to flood extent estimated from satellite data. Past floods and droughts were quantified by using the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) and the comparative SPI (cSPI) was used to evaluate the change in precipitation between 2075-2099 and 1979-2003 climates.

Keywords: *flood inundation, drought, climate change, atmospheric model of general circulation (MRI-AGCM3.2S)*

Introduction. The Bago River Basin plays an important role for agricultural production of paddy rice in Myanmar and its socio-economic development is impacted flood and drought disasters [1-3]. Frequent flood events have caused major economic losses to paddy rice agriculture in the Bago River basin and these flood inundation hazards may intensify in the future climates [4-8]. Therefore, this study investigates changes of floods and droughts between past and future climates in the Bago River basin.

Study area. The Bago River basin with a catchment area of 5,348 km^2 is located in south Myanmar at the tropical monsoon climate zone (Figure 1). The Bago River with length of 331 kilometers flows from the hills of Bago Yoma at about 760 m above sea level (masl) to Yangon through the city of Bago, where it confluences with the Myitmaka River at Yangon City and becomes the Yangon River (Figure 1A). The Bago basin has average temperature of 33 ^{o}C in April (hottest month) and of 21 ^{o}C in January (coldest month) with annual average rainfall of about 3185 mm. The coastal flood plain area is the main source of the Bago region economy from wet and dry season agricultural activities, see Figure 1B. For the dam infrastructure, Zaungtu Dam with 0.41 km^3 storage capacity was constructed for electricity generation in 1996 and Kodukwe, Salu and Shwelaung Dams constructed in 2012 to provide irrigation water supply for downstream paddies during wet and dry season cropping (Figure 1A). All four dams do not have flood control capacity for reducing flood peak discharges during rainy season making the coastal flood plain area vulnerable to flood inundation (Figure 1C). In Myanmar, the threat of flooding usually occurs in three waves each year in June, August and late September to October while the highest danger level is anticipated in August due to heavy monsoon rains [1]. During the monsoon season, flood inundation depth affects planted paddy rice in the early growing stage in the Bago River basin.

Flood hazard assessment. The flood discharge and inundation depth were simulated with the 15-arcsec (about 0.5-km) grid Rainfall-Runoff-Inundation (RRI) model [9], which has been applied for flood hazard assessment in large and small river basins [10-12]. In the Bago River basin, the RRI model was constructed using global datasets and simulated with local data of Zaungtu and Bago stations (Figure 1A). The 15-arcsec resolution Digital Elevation Model (DEM), flow accumulation and flow direction data were obtained from HydroSHEDS [13] and global land cover data were used to identify the paddy field, cropland and others land cover types [14] (Figure 1B). For the Zaungtu and Bago stations, daily precipitation, river water level and river discharge data were collected from the Department of Meteorology and Hydrology, Myanmar, for the 2011 and 2014 floods with 9.6 and 9.4 masl flood water level, respectively. The RRI model simulated discharge of both floods was evaluated using the Nash-Sutcliffe

Efficiency (NSE) [15]. The 2011 flood inundation extent on 13-20 August 2011 compared with Normalized Difference Vegetation Index (NDVI) estimated at 0.5-km grid from red and near-infrared spectral reflectance measurements of the MODIS Terra Level-3 8-day composite products (MOD09A1) [16] (Figure 1C). The NDVI threshold was selected as 0.2 for the Bago River basin and resulted in the flood inundation area of 566 km^2 for Thanatpin and Kawa townships. Severity of 2011 flood was compared with the Standardized Precipitation Index (SPI) [17] estimated from observed long-term daily precipitation data for analysis meteorological droughts and floods. The Standardized Precipitation Evapotranspiration Index (SPEI) was also used to indicate agricultural droughts obtained from available database of global coverage at about 55-km grid [18, 19]. Both indices have the same wet and dry scale due to standardization: extreme dry (SPI and SPEI $\leq$-2), severe dry (-2.0<SPI and SPEI$\leq$-1.5), moderately dry (-1.5< SPI and SPEI$\leq$-1.0), near normal (-1.0<SPI and SPEI<1.0), moderately wet (1.0$\leq$SPI and SPEI<1.5), severe wet (1.5$\leq$SPI and SPEI<2.0) and extreme wet (2.0$\leq$SPI and SPEI).

Climate change assessment. The climate change assessment of flood and drought hazards was conducted between past (01/1979-12/2003) and future 01/2075-12/2099) climates using the calibrated RRI model and comparative SPI (cSPI) approach [20], which has been applied on the river basin as well as regional scales for several standardized indices [20-22]. The cSPI was designed to investigate climate change impacts on the basis of past climates and preserves the same scale of wet and dry climate conditions as described for SPI and SPEI in previous section. For the Bago River Basin, the cSPI approach was applied to daily precipitation between past and future Representative Concentration Pathway (RCP) 8.5 climates obtained from the 20-km grid precipitation of Atmospheric General Circulation Model (AGCM)3.2S developed by the Japanese Meteorological Research Institute (MRI) [23] and bias-corrected with APHRODITE reference dataset [24].

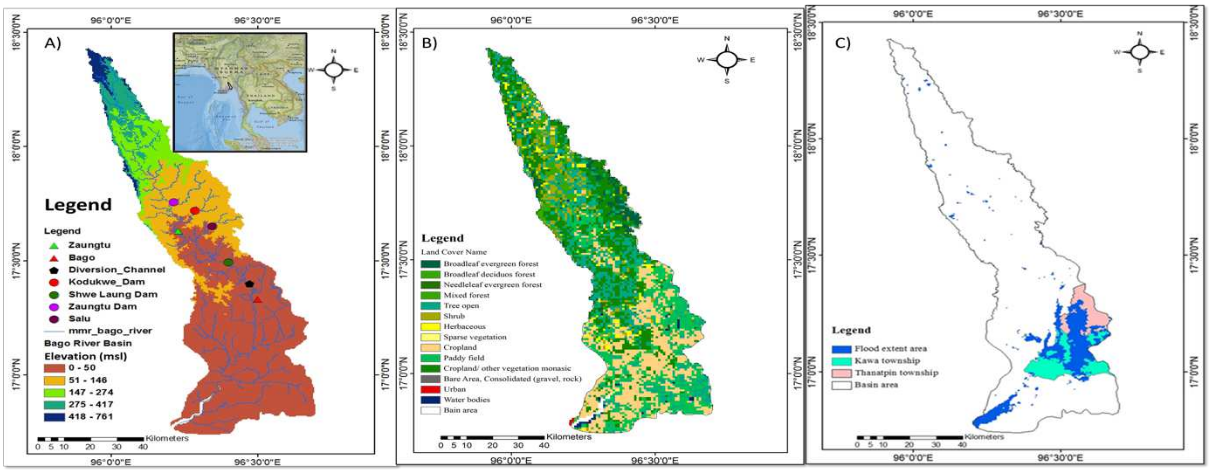

Figure 1. **The Bago River basin elevation[13] A), land cover[14] B), and the 2011 flood water extent estimated from MODIS images [16] C). Locations of Zaungtu and Bago gauging stations shown by triangles and four dams by circles A) and Kawa and Thanatpin townships are colored by pink and green C).**

Results and discussion. Figure 2 demonstrates river discharge at the Bago gauging station during the 2011 and 2014 flood events. For the 2011 flood, the RRI model simulation

with Zaungtu river discharge as a boundary matched observed discharge, see Figure 2A. In Figure 2B, the 2014 flood simulation has NSE of 0.81 and correlation coefficient of 0.9 while the peak discharge was underestimated in the RRI model, which may the influence of upstream dam operation. In Figure 3, the simulated 2011 flood inundation depth (Figure 3A) and duration (Figure 3B) from the RRI model is 612 km^2, which is similar to the 2011 flood inundation extent of 566 km^2 estimated with NDVI from MODIS images (Figure 3C). From the RRI simulated flood inundation depth above 0.5 m, 12.5% of basin area is prone to flooding and the 2011 flood caused about 15 million Kyats of damages for rice paddies during vegetative state.

Figure 4 demonstrates 6-month SPI and SPEI values to demonstrated meteorological and agricultural droughts in the Bago River basin. In Figure 4, the 6-month SPEI values indicate agricultural drought duration of several seasons during 1980s-90s compared with the meteorological droughts from 6-month SPI values such as 1982, 1987, 1988, 1991 and 1998. In some cases, 6-month SPI values are lower than 6-month SPEI values such extreme 1979 and 2013 droughts indicating the coarse grid of global dataset [19]. The 1-, 3-, and 12-month SPI and SPEI values have similar pattern and are not shown. For the flood hazard, 6-month SPI indicates extreme wet climates in 2005 and 2006 and severe wet climates in 2010, 2011 and 2014. In recent years, the Bago River basin flooding has been reported in 2011, 2012 and 2014 making 6-month SPI values consistent with past floods. In addition, the 1-month SPI values have similar results indicating sharp wet climate peaks and are not shown. These results indicate the usefulness of SPI for meteorological drought and flood monitoring.

For the analysis of climate change, median values of 3-, 6-, 12- and 24-month cSPI for past and future climates were compared and indicated an increase in median values under the RCP8.5 future climate scenario. This increase of median values indicates increasing wet conditions in the Bago River basin and indicates an increase in flood severity. In addition, the MRI-AGCM3.2S daily precipitation of past (1979-2003) and RCP8.5 future (2075-2099) climates was used in the calibrated RRI model resulting in 27% of river flow leading to potential increase in flood inundation areas in the Bago River Basin. and 12.6% of precipitation increases in the future between present and future climates.

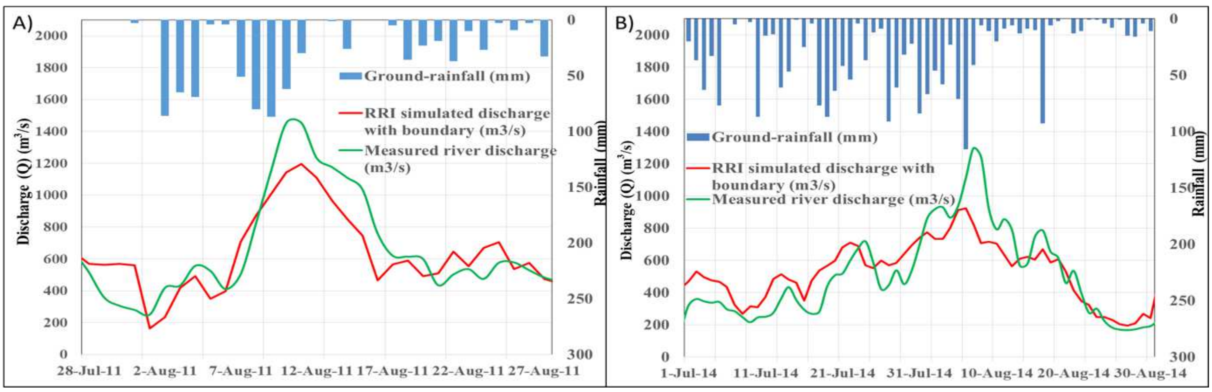

Figure 2. **RRI model simulated river discharge at the Bago gauging station for 2011 flood A) and B) 2014 flood B). The Zauntu river discharge was used as a boundary condition in the RRI model.**

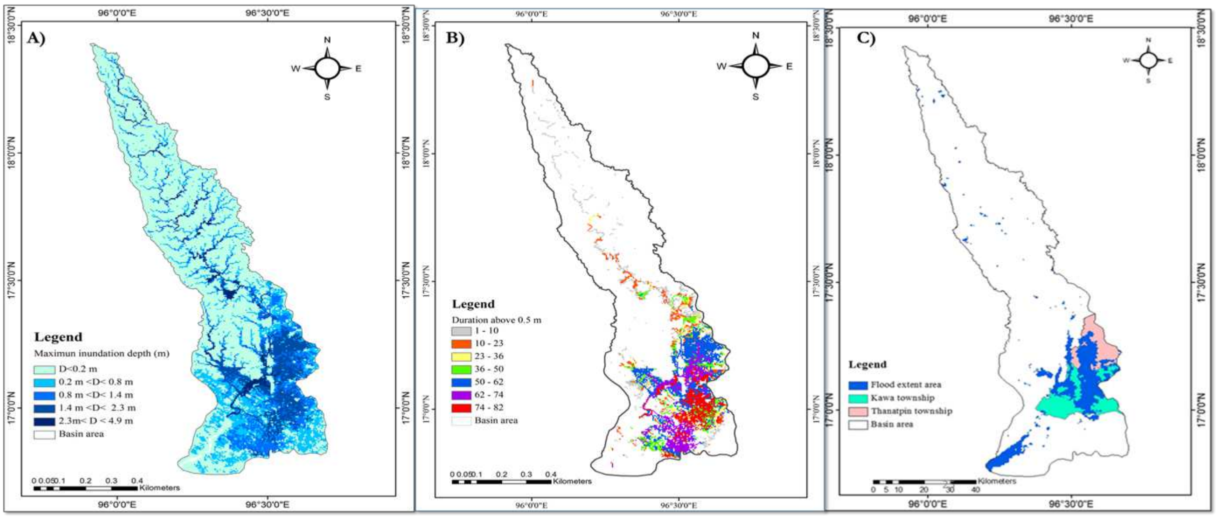

Figure 3. **The flood inundation extent and depth of 2011 flood simulated with the RRI model A) and duration of flood inundation B). The 2011 Flood inundated extent of two townships from the MODIS remote sensing images C).**

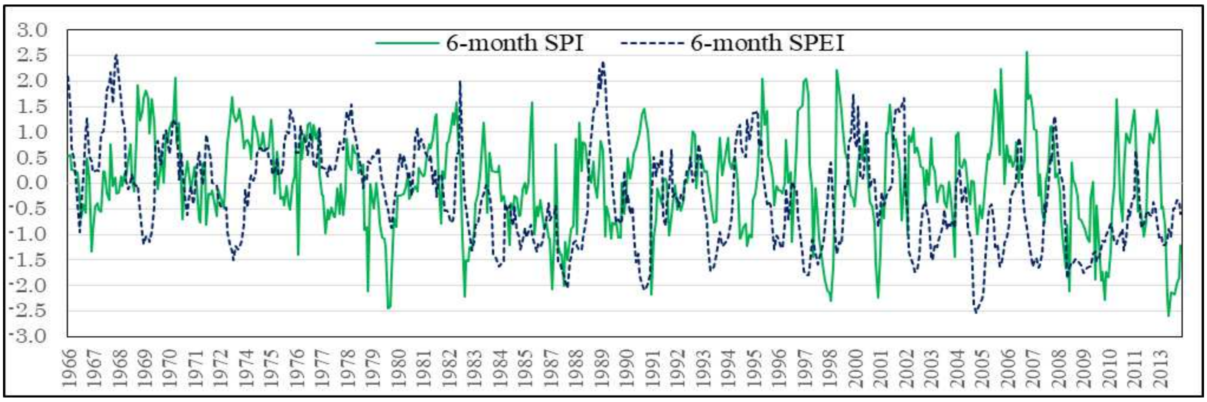

Figure 4. **6-month Standardized Precipitation Index (SPI) from local precipitation and Standardized Precipitation Evapotranspiration Index (SPEI) obtained from [19].**

Conclusions. We conducted flood and drought hazard assessment under climate change using a rainfall-runoff-inundation (RRI) model and standardized indices. The RRI model was applied to analyze flood discharge and inundation depth of the 2011 and 2014 flood events and compared with the 2011 flood extent estimated from satellite images. These flood inundation maps can be utilized for mitigation measures of future disaster prevention activities and conducting flood risk assessment in terms of agricultural damages to paddies in the Bago basin. For historical floods and droughts, severity and frequency analysis of wet and dry climates was conducted with Standardized Precipitation Index (SPI) estimated with local precipitation and Standardized Precipitation Evapotranspiration Index (SPEI) obtained from global precipitation and evapotranspiration datasets.

Considering the effects of climate change, the comparative SPI (cSPI) approach and RRI model with the daily precipitation data to assess the future floods and droughts in the Bago River basin using MRI-AGCM3.2S, which was bias corrected for past (1979-2003) and future Representative Concentration Pathway (RCP)8.5 scenario(2075-2099) climates. The cSPI values show the increasing dry condition in the summer while the amount of precipitation also

increases in the future climate conditions. For the assessing the river flow for the future climate condition, the MRI-AGCM3.2S precipitation data under current and future climate condition was used in the calibrated RRI model. As a result, 12.6% of precipitation and 27% of river flow increases in the future wet season suggesting an increase of flood inundation areas in the Bago River Basin.

REFERENCES

1. Asian Disaster Preparedness Center (ADPC) (2009). Myanmar Action Plan on Disaster Risk Reduction. Ministry of Social Welfare, Relief and Resettlement, Myanmar, 89 p.
2. Department of Agricultural Planning (DAP) (2013). Myanmar Agriculture at a Glance. Nay Pyi Taw: Ministry of Agriculture and Irrigation.
3. United Nations Environment Programme (UNEP) (2012). National Adaptation Programme of Action (NAPA) to Climate Change. Myanmar's National Action Adaptation Programme, Ministry of Transport, Myanmar, 127 p.
4. Zin, W., Kawasaki, A., Takeuchi, W., San, Z., Htun, K., Hnin, A. T., and Win, S. (2018). Flood Hazard Assessment of Bago River Basin, Myanmar. *J. of Disaster Research* 13: 14-21.
5. Zin, W., Kawasaki, A., and Win, S. (2015). River flood inundation mapping in the Bago River Basin, Myanmar, *Hydrological Research Letters* 9(4): 97–102.
6. Win, S., Zin, W., Kawasaki, A., and San, Z. (2018). Establishment of flood damage function models: A case study in the Bago River Basin, Myanmar, *International Journal of Disaster Risk Reduction*: *in press,* https://doi.org/10.1016/j.ijdrr.2018.01.030
7. Kawasaki, A., Ichihara, N., Ochii, Y., Acierto, R.A., Kodaka, A., and Zin, W. (2017). Disaster response and river infrastructure management during the 2015 Myanmar floods: a case in the Bago River Basin, *International Journal of Disaster Risk Reduction* 24: 151-159.
8. Htut, A.Y., Sangam, S., Vilas, N., and Kawasaki, A. (2014). Forecasting Climate Change Scenarios in the Bago River Basin, Myanmar*, J. Earth Sci Clim Change* 5: 228
9. Sayama, T. (2015). Rainfall Runoff Model (Manual) ver. 1.4.2. International Centre for Water Hazard Management (ICHARM), Public Works Research Institute (PWRI), Tsukuba, Japan.
10. Sayama, T., Ozawa, G., Kawakami, T., Nabesaka, S. and Fukami, K. (2012). Rainfall–runoff–inundation analysis of the 2010 Pakistan flood in the Kabul River basin, *Hydrological Sciences Journal* 57(2): 298-312, DOI: 10.1080/02626667.2011.644245
11. Nawai, J., Gusyev, M., Hasegawa, A., and Takeuchi, K. (2015). Flood and drought assessment with flood control infrastructure: A case study of the Ba River basin, Fiji. In Weber, T., McPhee, M.J. and Anderssen, R.S. (eds) MODSIM2015, 21st International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2015: 1607-1613 pp. ISBN: 978-0-9872143-5-5.
12. Okazumi, T., Miyamaoto, M., Shrestha, B., and Gusyev, M. (2014). Uncertainty estimation during the process of flood risk assessment in developing countries: Case study in the Pampanga River basin, *J. of Disaster Research 9(1): 69-77.*

13. Lehner, B., Verdin, K., and Jarvis, A. (2008). New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94, http://hydrosheds.cr.usgs.gov.

14. Tateishi, R., Thanh Hoan, N., Kobayashi, T., Alsaaideh, B., Tana, G., and Xuan Phong, D. (2014). Production of Global Land Cover Data - GLCNMO2008, *J. of Geography and Geology*, Vol. 6, No. 3, 99-122, 2014, http://dx.doi.org/10.5539/jgg.v6n3p99.

15. Nash, J. E. and Sutcliffe, J. V. (1970). "River flow forecasting through conceptual models part I - A discussion of principles". *J. of Hydrology*. 10 (3): 282–290. doi:10.1016/0022-1694(70)90255-6.

16. Vermote, E. (2015). MYD09A1 MODIS/Aqua Surface Reflectance 8-Day L3 Global 500m SIN Grid V006 [Data set]. NASA EOSDIS LP DAAC. doi: 10.5067/MODIS/MYD09A1.006

17. McKee, T.B., Doesken, N.J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology, American Meteorological Society Boston, MA, USA, 179-183.

18. Vicente-Serrano, S.M., Begueria, S., and Lopez-Moreno, J.I. (2010). A multi-scalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index. *J. Climate* 23, 1696–1718.

19. Global SPEI database (2018), Accessed on http://spei.csic.es/database.html

20. Hasegawa, A., Gusyev, M.A., Ushiyama, T. and Iwami, Y. (2015). Drought assessment in the Pampanga River basin, the Philippines - Part 2: A comparative SPI approach for quantifying climate change hazards. In Weber, T., McPhee, M.J. and Anderssen, R.S. (eds) MODSIM2015, 21st International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2015: 2388-2394 pp. ISBN: 978-0-9872143-5-5.

21. Hasegawa, A., Gusyev, M.A., and Iwami, Y. (2016). Meteorological Drought and Flood Assessment using the Comparative SPI Approach in Asia under Climate Change. *J. of Disaster Research* 11(6): 1082-1090, doi: 10.20965/jdr.2016.p1082

22. Gusyev, M.A., Hasegawa, A., Magome, J., Sanchez, P., Sugiura, A., Umino, H., Sawano, H. and Tokunaga, Y. (2016). Evaluation of water cycle components with standardized indices under climate change in the Pampanga, Solo and Chao Phraya basins. *J. of Disaster Research* 11(6): 1091-1102, doi: 10.20965/jdr.2016.p1091

23. Kitoh, A. and Endo, H. (2015). Changes in precipitation extremes projected by a 20-km mesh global atmospheric model, *Weather and Climate Extremes* 11: 41-52, ISSN 2212-0947, http://dx.doi.org/10.1016/j.wace.2015.09.001.

24. Yatagai, A., Kamiguchi, K., Arakawa, O., Hamada, A., Yasutomi, N. and Kitoh, A. (2012). APHRODITE: Constructing a Long-term Daily Gridded Precipitation Dataset for Asia based on a Dense Network of Rain Gauges, *Bulletin of American Meteorological Society*, doi:10.1175/BAMS-D-11-00122.1.