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Editorial

Significance of the China Meteorological Assimilation Driving Datasets for the SWAT Model (CMADS) of East Asia

Xianyong Meng *,† and **Hao Wang** *,†

State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin & China Institute of Water Resources and Hydropower Research, Beijing 100038, China

* Correspondence: mxy@iwhr.com (X.M.); wanghao@iwhr.com (H.W.); Tel.: +86-10-68410178 (X.M. & H.W.)

† These authors contributed equally to this work.

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Abstract: The high degree of spatial variability in climate conditions, and a lack of meteorological data for East Asia, present challenges to conducting surface water research in the context of the hydrological cycle. In addition, East Asia is facing pressure from both water resource scarcity and water pollution. The consequences of water pollution have attracted public concern in recent years. The low frequency and difficulty of monitoring water quality present challenges to understanding the continuous spatial distributions of non-point source pollution mechanisms in East Asia. The China Meteorological Assimilation Driving Datasets for the Soil and Water Assessment Tool (SWAT) model (CMADS) was developed to provide high-resolution, high-quality meteorological data for use by the scientific community. Applying CMADS can significantly reduce the meteorological input uncertainty and improve the performance of non-point source pollution models, since water resources and non-point source pollution can be more accurately localised. In addition, researchers can make use of high-resolution time series data from CMADS to conduct spatial- and temporal-scale analyses of meteorological data. This Special Issue, "Application of the China Meteorological Assimilation Driving Datasets for the SWAT Model (CMADS) in East Asia", provides a platform to introduce recent advances in the modelling of water quality and quantity in watersheds using CMADS and hydrological models, and underscores its application to a wide range of topics.

Keywords: East Asia; CMADS; meteorological input uncertainty; hydrological modelling; SWAT; non-point source pollution models

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China and the surrounding region in East Asia are considered to be the birthplace of human civilisation. East Asia experiences the most typical and pronounced monsoon climate in the world, and detailed analyses of the atmospheric hydrological cycle in East Asia can offer a substantial regional contribution to global climate change research.

Travelling back to the 19th century, natural science research in East Asia, and even globally, still followed the paradigm of dividing the whole into smaller components (e.g., dividing systems into elements), and then studying each isolated part individually. In this context, there was no interdisciplinary approach for researching various types of scientific issues simultaneously. By the second half of the 20th century, a highly detailed and complex classification of numerous natural science disciplines had been developed, and scientists were accustomed to dividing scientific fields into a number of sub-fields. This promoted a more professional approach to research and led to the evolution of various cross-disciplines and interdisciplinary disciplines. However, in recent decades, scientists have recognised many problems associated with the single-disciplinary approach of the 19th century. More researchers reconsidered methods for systematically considering and analysing different system elements of multiple disciplines at a more comprehensive level; in particular, they conducted comprehensive integrations based on a high degree of differentiation (i.e., categorising disciplines by specialisations and integrating multiple disciplines). Using research on atmospheric hydrology as an example, in 1962, a number of scientists attempted to use climate data and mathematical models to establish or supplement missing hydrological runoff sequences [1–4]. These studies made pioneering contributions to the field of atmospheric hydrology at a time when there was a lack of hydrological runoff data and meteorology sites were scarce.

With the gradual deepening of scientific research and continuous development of disciplinary theory, atmosphere and hydrology researchers began to conduct in-depth studies of atmospheric or water cycle mechanisms based on their own expertise. Differences in these two fields led to the rise of several subtle distinctions in the research directions of topics such as atmospheric circulation and water cycle research by atmospheric scientists and hydrologists (e.g., in terms of methods, techniques, etc.). For instance, researchers with a background in atmospheric sciences are more likely to focus on macro land-to-air interactions and their macroscopic effects on larger regions and the globe; they generally prefer studying the balance of various fluxes at the surface. For example, when studying atmospheric processes, atmospheric scientists have developed various land–air coupling models to simulate land-to-air interaction processes. From the Bucket model [5] in the mid-1990s to the Community Land Model (CLM) in the 21st century [6], land–air models have undergone a series of complex evolution processes. During this period, meteorologists developed various land models, including BATS [7], Simplified Simple Biosphere (SSIB) [8], A Revised Land Surface Parameterization (SiB2) [9,10], and the Common Land Model (CoLM) [11], etc. Based on the atmosphere-based Bucket model, the above-mentioned models gradually evolved into the more complex and generalised CLM model, by integrating components such as land surface, ocean and sea ice, sulphate aerosols, non-sulphate aerosols, carbon cycle, dynamic vegetation, and atmospheric chemistry [12]. When developing land models, atmospheric researchers are more concerned with improving the accuracy of various elements of the atmospheric forcing field, to reduce its uncertainty as an input in land models. In this process, various assimilation techniques and multi-source data (e.g., observation stations, radar stations, satellite remote sensing data, aerial data, and model data) have been widely used to establish atmospheric reanalysis datasets at various scales. Examples include the National Centers for Environmental Prediction/National Center for Atmospheric Research NCEP/NCAR-(R1) reanalysis dataset and National Centers for Environmental Prediction-Department of Energy (NCEP-DOE)-(R2) reanalysis dataset [13,14], Climate Forecast System Reanalysis (CFSR) by NCEP [15], European Centre for Medium-Range Weather Forecasts (ECMWF) 15-year Re-Analysis (ERA-15) [16], ECMWF Re-Analysis from September 1957 to August 2002 (ERA-40) [17], ECMWF Reanalysis-Interim (ERA-Interim) [18], Japanese 25-year Reanalysis project (JRA-25) [19], and the CMA Land Data Assimilation System (CLDAS) [20]. These reanalysis data sets provide important basic data for global researchers to analyse climate–water cycles. However, in focusing on macro-energy balances, meteorologists do not have sufficient resources to consider the microscale water balance processes of hydrological cycles, which is the main interest of hydrologists. When atmospheric scientists consider the hydrological confluence process, they mostly use simple conceptual methods for calculations (e.g., a vector-based river routing scheme [RAPID]) [21], and such simple conceptual models are not applicable under many conditions (e.g., where there is artificial intervention in a river area or in areas experiencing extreme climate change).

As noted above, hydrologists are primarily concerned with the micro-scale water balance processes of hydrological cycles. In 1959, the development of the Stanford Watershed Model (SWM) [22] set a precedent for the development of hydrological conceptual statistical models. However, it was not until 1979, after the advent of the distributed hydrological model topography-based hydrological model (TOPMODEL) [23], that fully distributed hydrological models for small- and medium-sized watersheds began to be accepted by the scientific community. Representative examples of such models include the Soil and Water Assessment Tool (SWAT) [24] and the Soil and Water Integrated Model (SWIM) [25]. As the development of these hydrological models continued to mature, more physical processes were gradually integrated into the models' calculations, leading to more complete expressions of the physical processes involved therein.

Atmospheric scientists are more inclined to use complex, more accurate atmospheric-driven land models coupled with simple hydrological models (i.e., conceptual models). In contrast, most hydrological scientists use simple atmosphere-driven (e.g., meteorological observatory) conceptual or distributed (complex) hydrological models. This presents two problems. First, the simple hydrological conceptual models currently used by meteorologists cannot reproduce real runoff processes and their related components (e.g., sediment erosion, non-point source pollution, floods, etc.) in areas with complex geological structures and significant artificial influences (or extreme changes in climate). Second, hydrologists, especially researchers in East Asia, cannot easily use the limited number of available meteorological sites to rationally and effectively determine the model parameters of complex distributed hydrological models. Consequently, researchers can only use low-quality meteorological data that are more akin to simulation games than research tools, which are unlikely to yield accurate conclusions.

Owing to the limitations of multiple objective factors, such as economy and geological structure, the overall distribution density of traditional observational meteorological stations (e.g., precipitation, temperature, humidity, wind speed, soil temperature, and soil moisture) in East Asia is low. Atmospheric hydrology studies in various fields over the past few decades in East Asia were not comprehensive, owing to the limited access to meteorological data. Despite the fact that researchers in East Asia can now use existing published reanalysis data (e.g., CFSR, NCEP, etc.) to conduct climate analyses in the region, since the needed assimilation and revision of the above reanalysis products were not conducted by stations in most parts of East Asia [26], the reanalysis results and actual results often differ substantially. For example, the CFSR precipitation data in summer in China are severely overestimated [26]. Recently, scientists in East Asia have started collecting small amounts of meteorological observation data by establishing field monitoring sites, and funding in atmospheric hydrological research in East Asia is being increased in an attempt to reduce the gap between atmospheric hydrology research in East Asia and worldwide. However, distortions of the meteorological input data used in scientific analyses (e.g., acquisition failure, lack of data, presence of outliers, etc.) reduce the reliability of the findings, with differences in input data possibly resulting in entirely different results. A major cause of the emergence of this phenomenon is that meteorological data collection does not follow a standard procedure; data are assimilated from multiple sources, revised based on the large number of stations, and are accessible in the public domain.

East Asia is a part of the largest continent in the world. In addition, it is the world's most densely populated region, with approximately 1.5 billion inhabitants. The underlying geography is complex and highly differentiated, leading to large climate variations. For example, this region contains the Qinghai–Tibet Plateau, the world's highest, which has a unique alpine climate that profoundly influences the climate in East Asian countries and across the globe. Owing to climate change, East Asia's water resources have been facing multiple pressures over recent years, such as uneven distributions of droughts and floods, water pollution, and water shortages. Consistent with the limitations in weather station observations, shortcomings related to economics, terrain, and other objective factors make it difficult to perform large-scale, long-term, high-frequency monitoring studies of water pollution and other related topics (such as floods, droughts, water scarcity, etc.) in East Asia.

To address the many aforementioned difficulties, the China Meteorological Assimilation Driving Datasets for the SWAT model (CMADS) [26,27] was developed by Xianyong Meng using STMAS assimilation techniques [20], as well as big data projection and processing methods (including loop nesting of data, projection of resampling models, and bilinear interpolation). CMADS comprises many variables, including daily average temperature, daily maximum temperature, daily minimum temperature, daily cumulative precipitation (20–20 h), daily average relative humidity, daily average specific humidity, daily average solar radiation, daily average wind, daily average atmospheric pressure, soil temperature, and soil moisture. CMADS was developed to provide high-resolution, high-quality meteorological data for use by the scientific community. Applying CMADS can significantly reduce meteorological input uncertainties and improve the performance of non-point source pollution modelling, since water resources and non-point source pollution can be more accurately localised. In addition, researchers can employ high-resolution time series data from CMADS to perform spatial- and temporal-scale analyses of meteorological data. Over the past few years, the CMADS dataset has received attention from around the world, including researchers in the United States, Germany, Russia, Italy, India, and South Korea, among others. As a developer of CMADS, we have used the CMADS driven SWAT model to simulate the runoff of many watersheds, such as China's Heihe River Basin [26] and Manas River Basin [27], and obtained satisfactory results. We expect researchers around the world to take full advantage of the CMADS owing to its high spatiotemporal resolution, unified procedure (including latitude and longitude, and elevation), and reliable quality. CMADS can be used to carry out studies of various distributed models (e.g., the SWAT and Variable Infiltration Capacity (VIC) models) and high-resolution climate verification and analyses. Given that meteorological data pertaining to East Asia are scarce, the use of CMADS can assist researchers globally to perform more efficient and effective scientific comparisons and in-depth investigations with a standard procedure.

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References

1. Fibbing, M.B. On the use of correlation to augment data. *J. Am. Stat. Assoc.* **1962**, *57*, 20–32. [CrossRef]
2. Benoit, B.M.; James, R.W. Noah, Joseph, and operational hydrology. *Water. Resour. Res.* **1968**, *4*, 909–918.
3. Rodríguez-Iturbe, I. Estimation of statistical parameters for annual river flows. *Water. Resour. Res.* **1969**, *5*, 1418–1421. [CrossRef]
4. Stockton, C.W. The Feasibility of Augmenting Hydrologic Records Using Tree-Ring Data. Ph.D. Thesis, The University of Arizona, Tucson, AZ, USA, 1971.
5. Budyko, M.I. The heat balance of the earth's surface. *Sov. Geogr.* **1961**, *2*, 3–13. [CrossRef]
6. Dai, Y.; Zeng, X.; Dickinson, R.E.; Baker, I.; Bonan, G.B.; Bosilovich, M.G.; Scott Denning, A.; Dirmeyer, P.A.; Houser, P.R.; Niu, G.; et al. The common land model. *Bull. Am. Meteorol. Soc.* **2003**, *84*, 1013–1023. [CrossRef]
7. Dickinson, R.E.; Henderson-Sellers, A.; Kennedy, P.J. *Biosphere-Atmosphere Transfer Scheme (BATS) Version 1e as Coupled to the NCAR Community Climate Model*; NCAR Technical Note NCAR/TN-387+STR; National Center for Atmospheric Research: Boulder, CO, USA, 1993.
8. Xue, Y.; Sellers, P.J.; Kinter, J.L.; Shukla, J. A Simplified Biosphere Model for Global Climate Studies. *J. Clim.* **1991**, *4*, 345–364. [CrossRef]
9. Sellers, P.J.; Randall, D.A.; Collatz, G.J.; Berry, J.A.; Field, C.B.; Dazlich, D.A.; Zhang, C.; Collelo, G.D.; Bounoua, L. A Revised Land Surface Parameterization (SiB2) for Atmospheric GCMS. Part I: Model Formulation. *J. Clim.* **1996**, *9*, 676–705. [CrossRef]
10. Sellers, P.J.; Los, S.O.; Tucker, C.J.; Justice, C.O.; Dazlich, D.A.; James Collatz, G.; Randall, D.A. A Revised Land Surface Parameterization (SiB2) for Atmospheric GCMS. Part II: The Generation of Global Fields of Terrestrial Biophysical Parameters from Satellite Data. *J. Clim.* **1996**, *9*, 706–737. [CrossRef]
11. Dai, Y.J.; Zeng, X.B.; Dickinson, R.E. *Common Land Model, Technical Documentation and User's Guide*; Georgia Institute of Technology: Atlanta, GA, USA, 2001; pp. 1–69.
12. Oleson, K.W.; Dai, Y.J.; Bonan, G.; Bosilovich, M.; Dickinson, R.; Dirmeyer, P.; Hoffman, F.; Houser, P.; Levis, S.; Niu, G.-Y.; et al. *Technical Description of the Community Land Model (CLM)*; NCAR Tech Note NCAR/Tn-461+Str; National Center for Atmopheric Research: Boulder, CO, USA, 2004; p. 173.
13. Trenberth, K.E.; Anthes, R.A.; Belward, A.; Brown, O.B.; Habermann, T.; Karl, T.R.; Running, S.; Ryan, B.; Tanner, M.; Wielicki, B. *Challenges of a Sustained Climate Observing System*; Springer: Berlin, Germany, 2013.

14. Kanamitsu, M.; Ebisuzaki, W.; Woollen, J.; Yang, S.-K.; Hnilo, J.J.; Fiorino, M.; Potter, G.L. NCEP-DEO AMIP-II Reanalysis (R-2). *Bull. Am. Meteorol. Soc.* **2002**, *83*, 1631–1643. [CrossRef]
15. Saha, S.; Moorthi, S.; Pan, H.L.; Wu, X.; Wang, J.; Nadiga, S.; Tripp, P.; Kistler, R.; Woollen, J.; Behringer, D.; et al. The NCEP Climate Forecast System Reanalysis. *B. Am. Meteorol. Soc.* **2010**, *91*, 1015–1057. [CrossRef]
16. Gibson, J.K.; Kållberg, P.; Uppala, S.; Nomura, A.; Hernandez, A.; Serrano, E. ERA Description. In *ECMWF ERA-15 Project ReportSeries, No.1*; European Centre for Medium-RangeWeather Forecasts: Shinfield, Reading, UK, 1997; Available online: https://www.ecmwf.int/search/elibrary?authors=Gibson (accessed on 7 October 2017).
17. Uppala, S.M.; KÅllberg, P.W.; Simmons, A.J.; Andrae, U.; Da Costa Bechtold, V.; Fiorino, M.; Gibson, J.K.; Haseler, J.; Hernandez, A.; Kelly, G.A.; et al. The ERA-40 re-analysis. *Q. J. R. Meteorol. Soc.* **2005**, *131*, 2961–3012. [CrossRef]
18. Dee, D.P.; Uppala, S.M.; Simmons, A.J.; Berrisford, P.; Poli, P.; Kobayashi, S.; Andrae, U.; Balmaseda, M.A.; Balsamo, G.; Bauer, P.; et al. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. *Q. J. R. Meteorol. Soc.* **2011**, *137*, 553–597. [CrossRef]
19. Onogi, K.; Tsutsui, J.; Koide, H.; Sakamoto, M.; Kobayashi, S.; Hatsushika, H.; Matsumoto, T.; Yamazaki, N.; Kamahori, H.; Takahashi, K.; et al. The JRA-25 reanalysis. *J. Meteorol. Soc. Jpn.* **2007**, *85*, 369–432. [CrossRef]
20. Meng, X.Y.; Wang, H.; Wu, Y.P.; Long, A.H.; Wang, J.H.; Shi, C.X.; Ji, X.N. Investigating spatiotemporal changes of the land surface processes in Xinjiang using high-resolution CLM3.5 and CLDAS: Soil temperature. *Sci. Rep* **2017**, *7*. [CrossRef]
21. David, C.H.; Habets, F.; Maidment, D.R.; Yang, Z.L. RAPID applied to the SIM-France model. *Hydrol. Process.* **2011**, *25*, 3412–3425. [CrossRef]
22. Crawford, N.H.; Linsley, R.K. *The Synthesis of Continuous Streamflow on a Digital Computer*; Technical Report No. 12; Department of Civil Engineering, Stanford University: Stanford, CA, USA, 1962.
23. Beven, K.J.; Kirkby, M.J. A physically based variable contributing model of basin hydrology. *Hydrol. Sci. Bull.* **1979**, *24*, 43–69. [CrossRef]
24. Neitsch, S.; Arnold, J.; Kiniry, J.; Williams, J. *Soil and Water Assessment Tool Theoretical Documentation Version 2009*; Texas Water Resources Institute Technical Report No. 406: College Station, TX, USA, 2011.
25. Krysanova, V.; Wechsung, F.; Arnold, J.; Srinivasan, R.; Williams, J. *SWIM: Soil and Water Integrated Model*; Potsdam Institute for Climate Impact Research (PIK): Potsdam, Germany, 2000.
26. Meng, X.; Wang, H.; Cai, S.; Zhang, X.; Leng, G.; Lei, X.; Shi, C.; Liu, S.; Shang, Y. The China Meteorological Assimilation Driving Datasets for the SWAT Model (CMADS) Application in China: A Case Study in Heihe River Basin. *Preprints* **2016**. [CrossRef]
27. Meng, X.Y.; Wang, H.; Lei, X.H.; Cai, S.Y.; Wu, H.J.; Ji, X.N.; Wang, J.H. Hydrological Modeling in the Manas River Basin Using Soil and Water Assessment Tool Driven by CMADS. *Teh. Vjesn.* **2017**, *24*, 525–534.