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Developing A High Performance Computing (HPC) Based Hydrological Modelling Framework To Support Extreme Weather Impact Studies

Dehua Zhu

Yunqing Xuan

Mike Webster

Ian Cluckie

DEVELOPING A HIGH PERFORMANCE COMPUTING (HPC) BASED HYDROLOGICAL MODELLING FRAMEWORK TO SUPPORT EXTREME WEATHER IMPACT STUDIES

DEHUA ZHU, YUNQING XUAN, MIKE WEBSTER, IAN CLUCKIE

College of Engineering, Swansea University, Swansea, SA2 8PP, UK

Abstract

Computer based modelling has long been an established norm in hydrological studies. The demand of computing power in hydrological modelling domain, although keep steadily growing over past decades, it has never been higher as we now look into many impact studies due to climate change. While HPC has long been a major player in the neighbouring field of climate sciences, its role has yet to be defined when the resources become increasingly accessible to hydrological modellers attempting to address the impact of climate change in terms of extreme weather events. In this paper, we present a framework of HPC based hydrological modelling approach that can utilize and maximize the HPC power to support the study on extreme weather impact due to climate change. The framework is intended to achieve 1) seamlessly coupling of the hydrological models with the climate/numerical weather models that are supported by the same HPC platform; 2) supporting large-scale hydrological modelling in greater details; 3) conducting joint ensemble runs of coupled modelling systems so as to account for the modelling uncertainty; 4) supporting multi-model ensembles to identify potential extreme storms with certain climate projections; 5) the ability of processing large volume of data (terabyte level). An example of such system is also discussed with the implementation using Fujitsu's HPC platform, the UK Unified Model (as the climate model backend) and a versatile interface to a number of preferred hydrological models.

Keywords: Extreme Weather Impacts, Hydrological modelling, High Performance Computing, Unified Model, Fujitsu

1. INTRODUCTION

Extreme weather events such as heavy rainfall and flooding are projected to become much more frequent as the impact from climate changes (Yucel and Onen [1]). Prediction of extreme precipitation and flash flooding remains as a critical hydrometeorological challenge that requires improved understanding of the linkages between atmospheric and terrestrial hydrological processes. And quantitative precipitation forecast (QPR) skill is intrinsically important to streamflow prediction skill, which emphasizes the requirement of mesoscale predictions of high resolution in space and time domain. However, in many cases land surface modeling parameters can not only exert significant control on the runoff response to heavy rainfall, but also on the formation or localisation of heavy rainfall as well. Therefore, a comprehensive analysis of the impact of the model configuration of NWP on the simulated hydrological cycle of different scale basins is required.

Although a rising number of regional climate models applications were carried out for different climatic regions worldwide for hydrological purpose, most of which were longer-term regional atmospheric downscaling studies using NWP to analyse the skill of the simulations with respect to near-surface air temperature and precipitation (Gochis [2]). The skill of global and downscaled models is usually evaluated against different gridded observations for precipitation, temperature, evapotranspiration, and against measured discharge time-series on a monthly basis. However, many results show the statistical downscaling has difficulties in reproducing the requirements for hydrological applications, e.g. with long-term mean precipitation biases of 150 mm/month and even higher (Fersch and Kunstmann [3]).

On the other hand, most of the hydrological applications using NWP data are running the atmospheric and terrestrial hydrologic model components separately without two-way interactions, which not only bring out the incapability of characterising the uncertainties of whole modelling system by identifying the source of errors in the streamflows, but also increase the uncertainties in model calibrations and validations.

Therefore, a framework of fully-coupled integrated atmospheric-hydrological modelling systems is required to tackle the challenge of integrated water cycle predictions from the clouds to streamflows. Regional hydrometeorological system model which fully couples the atmosphere with physical and gridded based surface hydrology provide efficient predictions for extreme hydrological events. This modelling system can be used for flood forecasting and warning issues as they provide continuous monitoring of precipitation over large areas at high spatial resolution.

2. THE HPC-BASED INTEGRATED ATMOSPHERIC-HYDROLOGICAL MODELLING FRAMEWORK

The demand of computing power in hydrological modelling domain, although keep steadily growing over past decades, it has never been higher in many impact studies due to climate change. While HPC has long been a major player in the neighbouring field of climate sciences, its role has yet to be defined when the resources become increasingly accessible to hydrological modellers attempting to address the impact of climate change in terms of extreme weather events.

Hydrological applications often employ one modelling at a time on a single desktop computer. In cases of smaller models, such circumstances may provide sufficient computing power in a reasonable time frame, in terms of model domains and simulation periods. However, on the other hand, some hydrological applications are composed of multiple modellings and larger model domains, which definitely demand more computing power than the average desktop computer alone can provide. Nevertheless, the limited access to high performance computing (HPC) and the cost associated may prohibit hydrological community from using HPC in ongoing and computationally intensive modelling project, such as climate impact study, which requires HPC to provide access to large amounts of computing resources that can manage multiple jobs at the same time.

In this paper, a framework of HPC based hydrological modelling approach is presented to utilise and maximise the HPC power to support the study on extreme weather impact due to climate change. The framework is implemented using Fujitsu's HPC platform, the UK Unified Model and a versatile interface to a number of preferred hydrological models, intending to achieve:

1) Seamlessly coupling of the hydrological models with the climate/numerical weather models that are supported by the same HPC platform;

2) Supporting large-scale hydrological modelling in greater details;

3) Conducting joint ensemble runs of coupled modelling systems so as to account for the modelling uncertainty;

4) Supporting multi-model ensembles to identify potential extreme storms with certain climate projections;

5) Ability of processing large volume of data (terabyte level).

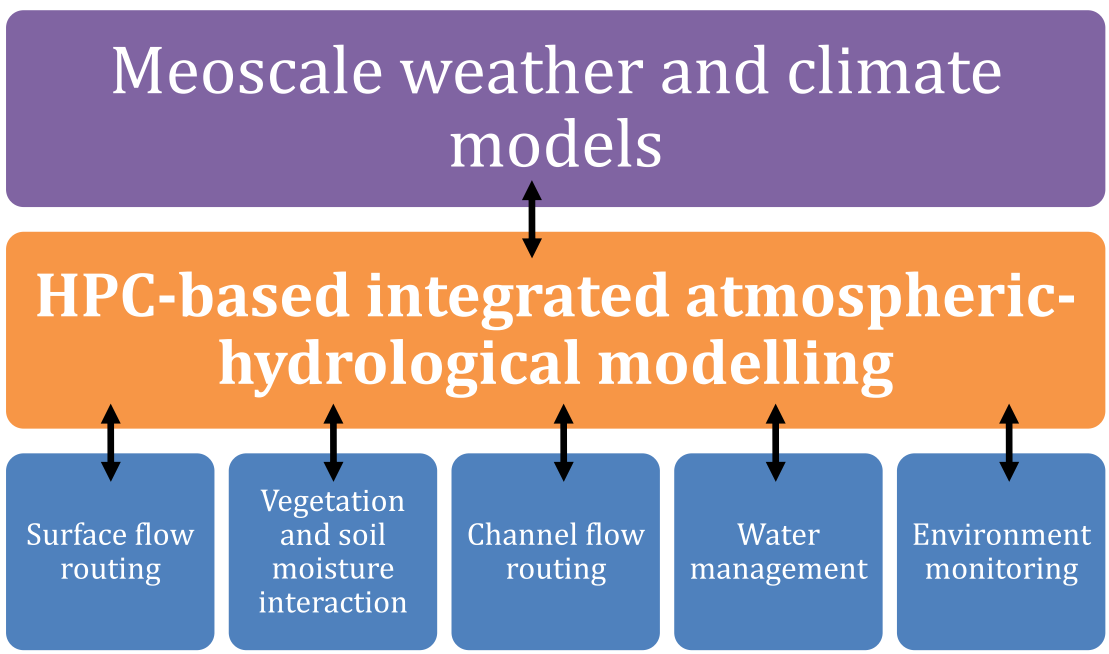

Figure 1. Generalized conceptual schematic of the proposed framework architecture

As driving data and physical parameterisations can significantly impact the performance of regional dynamical atmospheric models in reproducing hydrometeorologically relevant variables (Del Genio, et al. [4]), one of core themes of this framework is to develop an efficient integration of coupled modeling system with distributed infrastructure for collecting and sharing hydrometeorological observations, including how data assimilation employed in different regions, how data sharing technologies developed according to international standards for data discovery and exchange, such as standards developed by the Open Geospatial

Consortium and adopted by GEOSS (Parodi, et al. [5]). The proposed data system will not only contribute to the management of data flows for coupled prediction modelling system, but also enable flexible configuration of model inputs and manage provenance for selected model outputs.

3. CONCLUDING COMMENTS AND FUTURE WORKS

The demand for improvement of assessments and predictions of key hydrological modelling variables is driving a multitude of model development efforts in the hydro-sciences. The proliferation of weather and climate impacts research is driving a host of new environmental prediction model development efforts as society seeks to understand how climate does and will impact key societal activities and resources and, in turn, how human activities influence climate and the environment (Rios-Entenza and Miguez-Macho [6]). This trend of hydrometrological model development has highlighted the role of model coupling as a fundamental activity itself and, at times, a significant bottleneck in weather and climate impacts research in the future.

In the further study, analyses will focus on the strengths and weaknesses of conducting coupled modelling system predictions versus experiments where atmospheric and terrestrial hydrologic model components are run separately without two-way interactions.

More importantly, the capability of the coupled modelling system with different options will be evaluated, e.g. different data assimilation, various hydrological modellings. Moreover, rainfall event structures and associated flood responses will be fully analysed with gauge and satellite-derived precipitation against measured streamflow values. The modelling system is expecting to show skills in capturing the spatial and temporal structure of extreme rainfall events and resulted flood hydrographs in high spatial and temporal resolutions.

The framework is also offering a discussion on the opportunities for fostering open, standards-based approaches for code development, model interoperability and data and metadata structures as well as the need for multi-scale and multi-physics model structures.

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REFERENCE

[1] Yucel, I. and Onen, A., "Analysis of extreme rain and flood events using a regional hydrologically enhanced hydrometeorological system", In *EGU General Assembly Conference Abstracts*, Vol. 15, (2013). pp. 4057.

[2] Gochis, D., "Integrated hydrometeorological system predicttions with the fully-coupled WRF-HYDRO modelling system", In *Geological Society of America Abstracts with Programs*, Vol. 45, No. 7, (2013).

[3] Fersch, B. and Kunstmann, H., "Atmospheric and terrestrial water budgets: sensitivity and performance of configurations and global driving data for long term continental scale WRF simulations Climate Dynamics", *Climate Dynamics*, (2013), pp 1-30.

[4] Del Genio, A. D., Wu, J. and Chen, Y., "Characteristics of Mesoscale Organization in WRF Simulations of Convection during TWP-ICE", *Journal of Climate*, Vol. 25, No. 17, (2012), pp 5666-5688.

[5] Parodi, A., Hooper, R., Jha, S. and Zaslavsky, I., "Advancing hydrometeorological prediction capabilities through standards-based cyberinfrastructure development: The community WRF-Hydro modeling system", In *EGU General Assembly Conference Abstracts*, Vol. 15, (2013), pp. 6011.

[6] Rios-Entenza, A. and Miguez-Macho, G., "Regional Climate Simulations of the Hydrological Cycle in the Iberian Peninsula with a Coupled WRF-HYDRO Model", In *AGU Fall Meeting Abstracts*,Vol. 1, (2008), pp. 04.