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The distributed model intercomparison project – Phase 2: Experiment design and summary results of the western basin experiments

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SUMMARY

The Office of Hydrologic Development (OHD) of the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) conducted the two phases of the Distributed Model Intercomparison Project (DMIP) as cost-effective studies to guide the transition to spatially distributed hydrologic modeling for operational forecasting at NWS River Forecast Centers (RFCs). Phase 2 of the Distributed Model Intercomparison Project (DMIP 2) was formulated primarily as a mechanism to help guide the U.S. NWS as it expands its use of spatially distributed watershed models for operational river, flash flood, and water resources forecasting. The overall purpose of DMIP 2 was to test many distributed models forced by high quality operational data with a view towards meeting NWS operational forecasting needs. At the same time, DMIP 2 was formulated as an experiment that could be leveraged by the broader scientific community as a platform for the testing, evaluation, and improvement of distributed models.

DMIP 2 contained experiments in two regions: in the DMIP 1 Oklahoma basins, and second, in two basins in the Sierra Nevada Mountains in the western USA. This paper presents the overview and results of the DMIP 2 experiments conducted for the two Sierra Nevada basins. Simulations from five independent groups from France, Italy, Spain and the USA were analyzed. Experiments included comparison of lumped and distributed model streamflow simulations generated with uncalibrated and calibrated parameters, and simulations of snow water equivalent (SWE) at interior locations. As in other phases of DMIP, the participant simulations were evaluated against observed hourly streamflow and SWE data and compared with simulations provided by the NWS operational lumped model. A wide range of statistical measures are used to evaluate model performance on a run-period and event basis. Differences between uncalibrated and calibrated model simulations are assessed.

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Results indicate that in the two study basins, no single model performed best in all cases. In addition, no distributed model was able to consistently outperform the lumped model benchmark. However, one or more distributed models were able to outperform the lumped model benchmark in many of the analyses. Several calibrated distributed models achieved higher correlation and lower bias than the calibrated lumped benchmark in the calibration, validation, and combined periods. Evaluating a number of specific precipitation-runoff events, one calibrated distributed model was able to perform at a level equal to or better than the calibrated lumped model benchmark in terms of event-averaged peak and runoff volume error. However, three distributed models were able to provide improved peak timing compared to the lumped benchmark. Taken together, calibrated distributed models provided specific improvements over the lumped benchmark in 24% of the model-basin pairs for peak flow, 12% of the model-basin pairs for event runoff volume, and 41% of the model-basin pairs for peak timing. Model calibration improved the performance statistics of nearly all models (lumped and distributed). Analysis of several precipitation/runoff events indicates that distributed models may more accurately model the dynamics of the rain/snow line (and resulting hydrologic conditions) compared to the lumped benchmark model. Analysis of SWE simulations shows that better results were achieved at higher elevation observation sites.

Although the performance of distributed models was mixed compared to the lumped benchmark, all calibrated models performed well compared to results in the DMIP 2 Oklahoma basins in terms of run period correlation and %Bias, and event-averaged peak and runoff error. This finding is noteworthy considering that these Sierra Nevada basins have complications such as orographically-enhanced precipitation, snow accumulation and melt, rain on snow events, and highly variable topography. Looking at these findings and those from the previous DMIP experiments, it is clear that at this point in their evolution, distributed models have the potential to provide valuable information on specific flood events that could complement lumped model simulations.

1. Introduction

1.1. Overview

The Office of Hydrologic Development (OHD) of the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) led two phases of the Distributed Model Intercomparison Project (DMIP) as cost-effective studies to guide the transition into spatially distributed hydrologic modeling for operational forecasting (Smith et al., 2012a; Smith et al., 2004) at NWS River Forecast Centers (RFCs). DMIP 1 focused on distributed and lumped model intercomparisons in basins of the southern Great Plains (Reed et al., 2004; Smith et al., 2004). DMIP 2 contained tests in two geographic regions: continued experiments in the U.S. Southern Great Plains (Smith et al., 2012a,b) and tests in two mountainous basins in the Sierra Nevada Mountains, hereafter called DMIP 2 West. Since the conclusion of DMIP 1, the NWS has used a distributed model for basin outlet forecasts (e.g., Jones et al., 2009) as well as for generating gridded flash flood guidance over large geographic domains (Schmidt et al., 2007). The purpose of this paper is to present the DMIP 2 West experiments and results.

Advances in hydrologic modeling and forecasting are needed in complex regions (e.g., Hartman, 2010; Westrick et al., 2002). Experiments are needed in the western USA and other areas where the hydrology is dominated by complexities such as snow accumulation and melt, orographically-enhanced precipitation, steep and other complex terrain features, and sparse observational networks. The need for advanced models in mountainous regions is coupled with the requirements for more data in these areas. Advanced models cannot be implemented for operational forecasting without commensurate analyses of the data requirements in mountainous regimes.

A major component of the NWS river forecast operations is the national snow model run (NSM) by the NWS National Operational Hydrologic Remote Sensing Center (NOHRSC; Rutter et al., 2008; Carroll et al., 2001). For over a decade, NOHRSC has executed the NSM in real time at an hourly, 1 km scale over the contiguous US (CONUS) to produce a large number of gridded snow-related variables.

1.2. Science questions

DMIP 2 West was originally formulated to address several major science questions (Smith et al., 2006). They are framed for the interest of the broad scientific community with a corollary for the NOAA/NWS. These science questions and issues are highly intertwined but are listed separately here for clarity.

1.2.1. Distributed vs. lumped approaches in mountainous areas

Can distributed hydrologic models provide increased streamflow simulation accuracy compared to lumped models in mountainous areas? If so, under what conditions? Are improvements constrained by forcing data quality? This was one of the dominant questions in DMIP 1 and the DMIP 2 experiments in Oklahoma. Smith et al. (2012a,b) and Reed et al. (2004) showed improvements of deterministic distributed models compared to lumped models in non-snow, generally uncomplicated basins. The specific question for the NOAA/NWS mission is: under what circumstances should NOAA/NWS use distributed hydrologic models in addition to lumped models to provide hydrologic services in mountainous areas? While many distributed models have been developed for mountainous areas (e.g., Garen and Marks, 2005; Westrick et al., 2002; Wigmosta et al., 1994), there remains a gap in our understanding of how much model complexity is warranted given data constraints, heterogeneity of physical characteristics, and modeling goals (e.g., McDonnell et al., 2007). Several major snow model intercomparison efforts have been conducted in recent years such as Phases 1 and 2 of the Snow Model Intercomparison Project (SnowMIP; Rutter et al., 2009; Etchevers et al., 2004) and the Project for Intercomparison of Land Surface Process models (PILPS; Slater et al., 2001). In addition, several comparisons of temperature index and energy budget snow models have been conducted (e.g., Debele et al., 2009; Franz et al., 2008a,b; Lei et al., 2007; Walter et al., 2005; Fierz et al., 2003; Essery et al., 1999; WMO, 1986a,b). Comprehensive studies such as the Cold Land Processes Experiment (CLPX; Liston et al., 2008) have also been performed. However, to the best of our knowledge, there have been few specific tests of lumped and distributed modeling approaches in mountainous basins with a focus on improving river simulation