Interannual Variability and Continental Runoff in the CCSM2 Control Simulation

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INTRODUCTION

The delivery of freshwater to the ocean via continental runoff is a critical factor in the global climate system. Carton (1991) found a sea surface temperature (SST) anomaly of up to +1.0 ºC off the Congo from July through April and a similar but smaller (+0.25 ºC) SST anomaly off the Amazon from May through October, resulting from the inclusion of a freshwater flux. Nakamura (1996) used a coupled atmosphere-ocean box model to show a stabilizing feedback exists between thermohaline circulation and the freshwater flux in high latitudes. Weatherly and Walsh (1996) found that alteration of precipitation and continental runoff into the Arctic Ocean had a potential impact on the Arctic sea ice regime. Branstetter et al.(2000) showed with a series of POP simulations decreases in sea surface salinity along with corresponding changes in sea surface temperature in the coastal regions when observed runoff was added to the ocean. Branstetter et al. (2001) showed similar oceanic changes and also indicated the presence of a continental runoff feedback in some of the larger tropical watersheds when RTM was coupled to the Parallel Climate Model PCM which was the precursor to CCSM2. It is clear that the inclusion of riverine freshwater fluxes into computed ocean circulation is an essential component of fully couple Earth climate simulation.

Here we describe and evaluate the riverine fluxes of freshwater to the ocean from rivers in the Community Climate System Model, Version 2 (CCSM2). Both the monthly hydrographs of river discharge from a control simulation using this model were investigated as well as the interannual variability of the discharge. These results were compared to climatological averages of observed streamgage data and to simulations using the atmosphere-land model CCM3. We consider the comparisons of CCSM2 with the CCM3 to be a metric of model advancement and improvement. We seek to quantify the magnitude of freshwater fluxes to the ocean with an eye toward examing ocean climate response. This work provides estimates of the uncertainties associated with climate prediction using CCSM2, and will provide a baseline for future work including the full hydrologic cycle in Earth system modeling.

COMPONENT MODELS

The Community Climate Sytem Model 2 (CCSM2) is a fully coupled climate model that includes atmosphere, ocean, sea ice, land surface, and river transport component models (Blackmon et al., 2001). The Community Climate Model 3 (CCM3.2) is an atmosphere model component that includes LSM as the land surface component model.

CAM	Community Atmosphere Model	
CLM	Community Land Model	Bonan et al., 2002
CSIM	Community Sea Ice Model	Brieglieb et al., 2002
POP	Parallel Ocean Program	Dukowicz and Smith, 1994
RTM	River Transport Model	Branstetter and Famiglietti, 1999; Branstetter, 2001
CCM3	Community Climate Model	Kiehl et al., 1996
LSM	Land Surface Model	Bonan, 1996

More complete documentation of the CCSM2 model is available at www.ucar.ncar.cgd.ccsm2 Observed monthly hydrographs for rivers were obtained from Vörösmarty (1998), compiled from river discharge data at the Global Runoff Data Center in Koblenz, Germany. More information on this database is available at www.rivdis.sr.unh.edu.

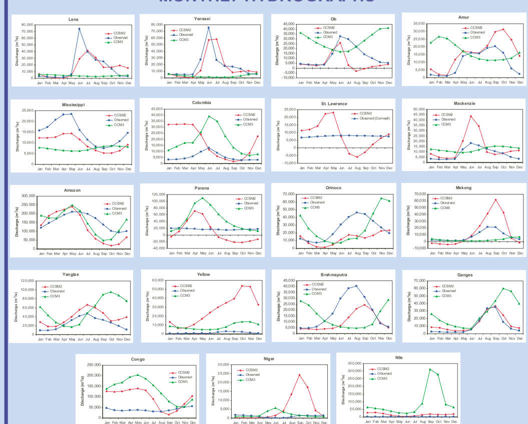
METHODS

A control simulation of CCSM2 was conducted for approximately 1000 years. The results presented here consider a fifty year time period within that 1000 year simulation. Monthly hydrographs of river discharge into the ocean are compared to previous simulations using the CCM3 climate model and also compared to observed streamgage data. The interannual variability is also examined by considering a 50-year time series of the the June discharge for the CCSM2 control simulation. This is also compared to time series of observed June river discharge for as many years as are available. We opted to examine the June time frame since many of the rivers we considered for this study have maximum flow rates in June.

ABSTRACT

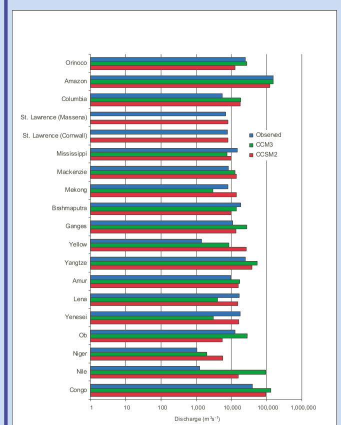
A 1000-year control simulation of the NCAR CCSM2 climate model was analyzed with regard to continental runoff effects. The results were compared to observational data and previous simulations using CCM3. The interannual variability of the river discharge in the control simulation was comparable to stream-gage data in some cases. At times the variability of the simulation exceeded that of observations. In a statistical analysis using the coefficient of variation, the Mississippi River showed the greatest similarity in interannual variability between the control simulation and the observed data. The variability of the Nile and St. Lawrence Rivers, however, was much higher than the observations indicated. River discharge into the Arctic Ocean improved significantly over the earlier CCM3 simulations, based on monthly hydrograph averages from the CCSM2 control simulation. The Niger, St. Lawrence, and Congo Rivers were among those that still did not show the appropriate discharge into the oceans. The stability of the CCSM2 control simulation will allow examination of the variability of the water cycle on a multi-century scale.

MONTHLY HYDROGRAPHS



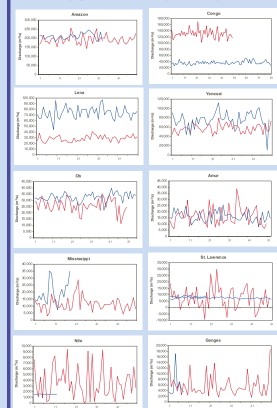
The figures above show the monthly river discharge into the ocean for nineteen representative rivers. The observed lines are average climatology values from streamgage data. The CCSM2 lines are fifty-year averages from the NCAR CCSM2 control simulation. The CCM3 lines are from an earlier simulation using CCM3.2 which included LSM as the land surface component.

MEAN ANNUAL HYDROGRAPHS



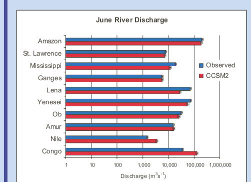
The bar chart above shows the mean annual discharges for eighteen rivers. Bars are included for CCSM2, CCM3, and observed data. A log scale is used to make comparison easier for both large and small discharge rivers.

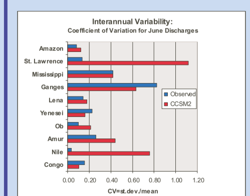
JUNE TIME SERIES



The figures above show time series of June river discharges for ten rivers. The red lines are from fifty years of the CCSM2 control simulation and the blue lines are from observed streamgage data. Note: for the St. Lawrence River, two blue lines are shown; the longer series is streamgage data taken at Massena, New York, and the short at Cornwall, Ontario. Cornwall is farther downstream, but the series is longer at Massena.

INTERANNUAL VARIABILITY





The bar charts above give the means and coefficients of variation for the fifty year time series of June river discharges (both for the CCSM2 control results and the observed streamflow). In most cases, the model simulation showed more variability between years than the observations indicated.

CONCLUSION

In an analysis of the CCSM2 control simulation with respect to the freshwater discharge into the ocean, in most cases the CCSM2 showed a significant improvement over CCM3 when compared to observations. The Arctic rivers (Ob, Yenesei, and Lena) all showed a marked improvement in timing of discharge into the ocean, although they still underestimate discharge compared to observations. Since the fully coupled CCSM2 requires interdependence between the land surface hydrology and atmospheric transport and precipitation and oceanic moisture sources, any shortcoming in any of these components will have an impact on the overall computed climate. An additional source of error in the river discharge simulations stems from errors or bias in the precipitation patterns over the continents. In the case of the Congo River basin region, for example, CLM2 produced more precipitation than observations indicate, which correspond with the river discharge differences. Comparison of the time series June discharges and corresponding coefficients of variation for these showed that some rivers such as the Mississippi show comparable interannual variability between the CCSM2 control simulation and observations. Others such as the St. Lawrence and Nile do not compare well. In these cases, the lack of control mechanisms in the river transport component model, whether natural or artificial, could account for the variation. A clear result of this analysis is the criticality of the hydrologic cycle in climate simulations and that freshwater fluxes are central to future climate prediction.

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