Using CCSM3 to Understand the Global Hydrological Cycle at Last Glacial Maximum in Comparison to Present Day

Melissa A. Burt[1], David A. Randall[1], and Bette Otto-Bliesner[2]

[1]Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

[2] National Center for Atmospheric Research, Boulder, CO

INTRODUCTION

The global hydrological cycle, the circulation of water in the climate system, is an integral part of the earth's climate system. Therefore, it plays a role in determining the large-scale circulation and precipitation patterns (Hack et al. 2006). There has been little to no research on the hydrological cycle in CCSM3 paleo-climate simulations and this research will bring forth a better understanding of the topic.

The Last Glacial Maximum occurred 21 ka (21000 yrs before present) and was the cold extreme of the glacial period with maximum extent of ice in the Northern Hemisphere. During this period external forcings (i.e. solar variations, greenhouse gases, sea level, etc.) were significantly different in comparison to present, which has an effect on the earth's climate system (Otto-Bliesner et al. 2006).

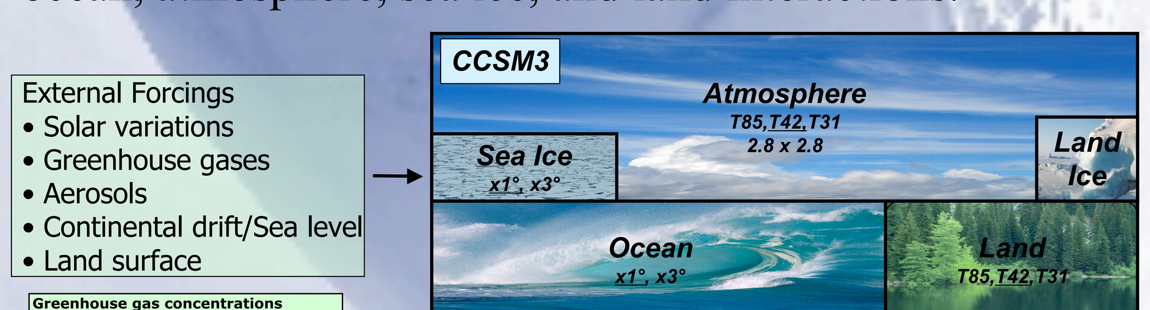
Present day in this study uses forcing appropriate for conditions before industrialization (Pre-industrial 1800 A.D.) .

DATA

Community Climate System Model 3

(Collins et al. 2006)

CCSM3 is a global, coupled model that simulates the ocean, atmosphere, sea ice, and land interactions.



Greenhouse gas concentrations

	LGM	PI
CO_2	185 ppm	280 ppm
CH_4	350 ppb	760 ppb
N_2O	200 ppb	270 ppb

CCSM3 Simulations

Two simulations of CCSM3 ran for a 100-year period for Last Glacial Maximum (LGM) and Pre-industrial (PI).

Forcings and boundary conditions were set to estimates for the particular time period and results are interpreted as the mean conditions for LGM and PI.

SELECTED RESULTS*

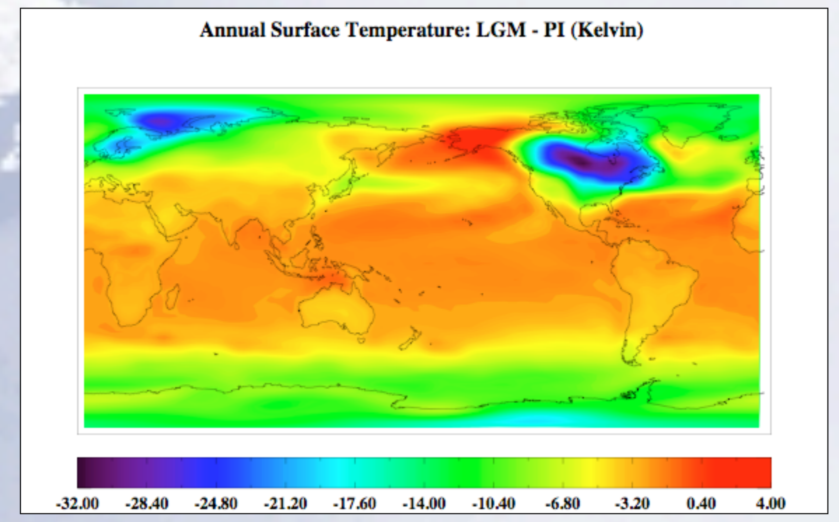


Figure 1. CCSM3 annual surface temperature change (K) for LGM minus Pre-industrial.

Figure 1 is the CCSM3 annual surface temperature change between Last Glacial Maximum and Pre-industrial. The coldest temperatures between LGM and PI were over North America, where the Laurentide Ice Sheet was located. Temperatures were about 32 K lower at LGM in this region. Over Northern Europe, colder temperatures existed where the Fennoscandian ice sheet was located. Sea surface temperatures (SSTs) at LGM were a few degrees colder in the tropics compared to PI. Globally averaged, annual temperature at LGM was about 4.6 K colder than Pre-industrial, with greatest cooling at high latitudes of both hemispheres and over the continental ice sheets of North American and Europe.

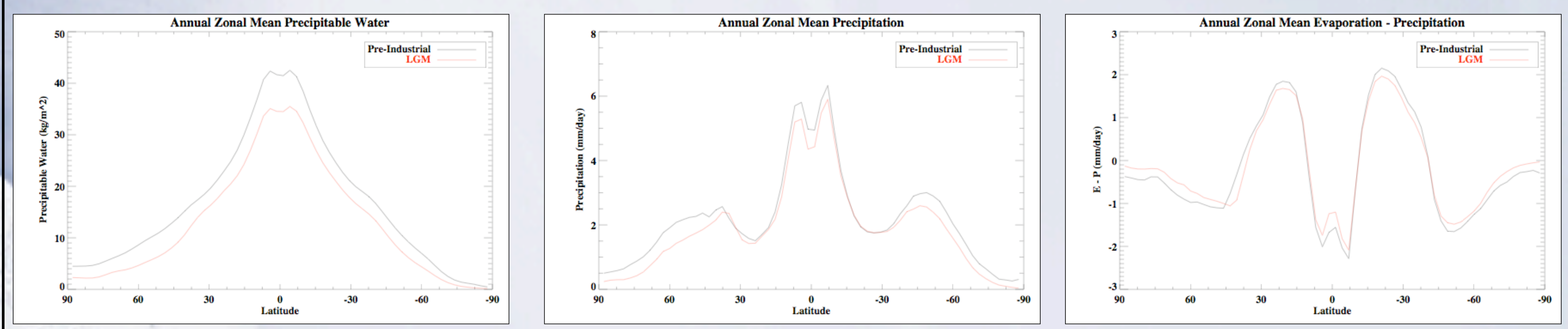


Figure 2. Zonally averaged annual precipitable water (left), precipitation (middle) and Evaporation minus Precipitation (right), in mm day^{-1} for Pre-industrial (black) and LGM (red).

The zonally averaged annual precipitable water indicates the amount of moisture (or water vapor) in the atmosphere. The change in precipitable water follows (to first order) the temperature change; if there is colder air it can hold less water vapor, so the atmosphere will be drier. At LGM, precipitable water is roughly 10kg m^{-2} less than the PI value. Figure 2 (middle panel) is the zonally averaged annual precipitation rate and greatest precipitation is located near the Equator. This region is known as the ITCZ (Intertropical Convergence Zone), an area where the winds converge, forcing moist air upward. Water vapor condenses out as the air cools and rises, resulting in a band of heavy precipitation in this region. At LGM, precipitation is a few mm per day less than at PI. The far right panel of Figure 2, is the zonally averaged Evaporation minus Precipitation. E-P is negative in the deep tropics and therefore a sink of moisture, while it is positive in the subtropics, and a source of moisture. During LGM, near the tropics there is less precipitation than at PI, and in the subtropics there is less evaporation, indicating that LGM had a drier climate. Figure 3 shows the zonally averaged annual mean meridional moisture transport for each period. The transport of moisture from the subtropics into the deep tropics is confined to the lower 1500m of the atmosphere for LGM and PI. The major difference is that this moisture transport is weaker at LGM.

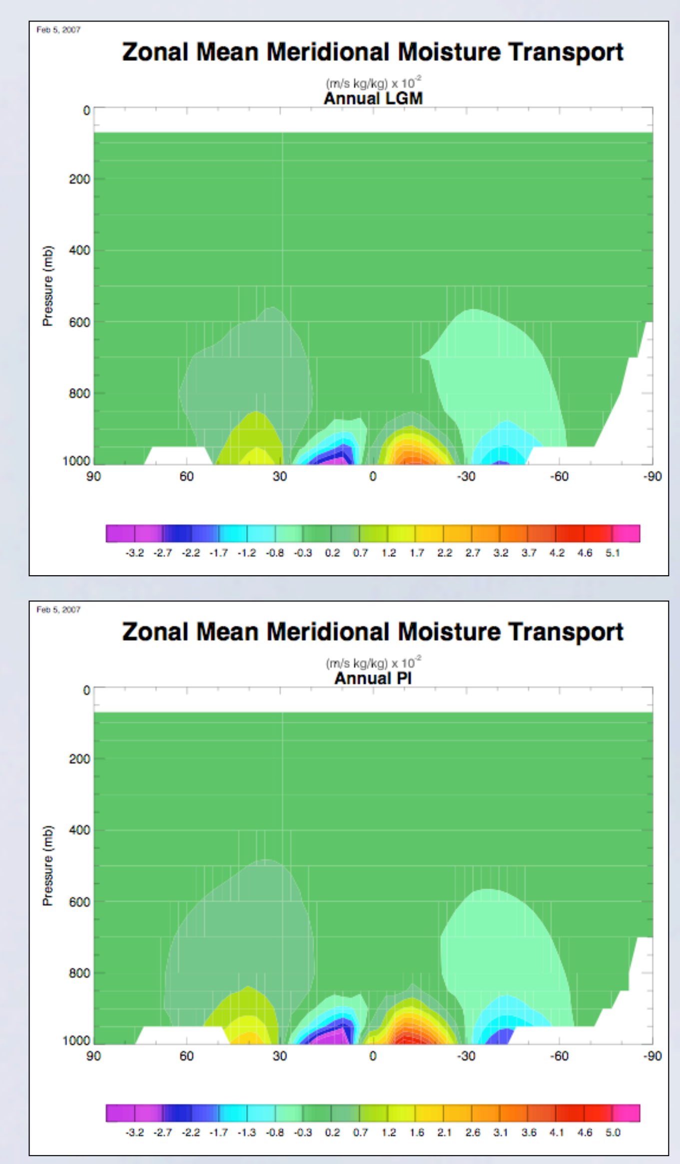


Figure 3. Zonally averaged annual mean meridional moisture transport in (m s^{-1} kg kg^{-1}) x 10^{-2} for LGM (top) and Pre-industrial (bottom).

*The mean climate results shown are for the last 50 years of each CCSM3 simulation.

HYDROLOGIC CYCLE

Results here indicate that conditions at LGM were significantly different than present day. The globally averaged, annual temperature was 4K colder. The amount of moisture at LGM in the atmosphere,when compared to present day was decreased. Precipitable water was down 15% and precipitation was 0.25 mm day^{-1} less than Pre-industrial amounts. These results indicate that Last Glacial Maximum was a colder and more arid climate, indicating a slower hydrologic cycle.

Question: Why is the hydrologic cycle slower in a cooler climate?

The Clausius-Clapeyron equation says that temperature is proportional to the saturation vapor pressure. The higher the saturation vapor pressure, the more water vapor the atmosphere can hold. In a colder climate, the saturation vapor pressure would be less, so therefore the air can hold less water vapor, which will lead to a decrease in precipitation. If the precipitation rate decreases, the evaporation rate will most likely decrease as well. Due to less water in the atmosphere, the processes involved in the hydrologic cycle will be slowed.

REFERENCES

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CONTACT INFO

Melissa A. Burt
Department of Atmospheric Science
Colorado State University
mburt@atmos.colostate.edu
(970) 491-8194