J1.4 REPRESENTATION OF THE ATMOSPHERIC HYDROLOGIC CYCLE OVER THE ARCTIC IN CCSM3

Joel Finnis*
University of Colorado, Boulder

1.0 INTRODUCTION

The freshwater budget of the Arctic Ocean is of critical concern to climate studies, as changes in this budget have the potential to effect climate on a large scale through interactions with global thermohaline circulation (Broecker, 1997). While observational studies have yielded a great deal of information on this subject, a lack of high density Arctic observing networks and long-term observations continue to present significant obstacles. For this reason the use of models continues to be an important part of Arctic hydrologic research. The work presented here has been conducted as part of a larger project aimed at using version three of the Community Climate System Model (CCSM3) to perform an integrated analysis of the Arctic freshwater budget. As a first step towards these goals, the model's representation of the atmospheric hydrologic cycle over northern latitudes has been assessed using available CCSM3 control runs, with a primary focus on specific subwatersheds within the Arctic drainage basin. This includes attempts to identify biases in precipitation and evaporation, as well as atmospheric circulation patterns associated with hydrologic variability. This assessment provides a basis for future modeling work, and a framework in which to examine atmospheric interaction with the larger freshwater budget.

2.0 DATA

Version 3.0 of the Community Climate System Model (CCSM3) is a coupled general circulation model (GCM) with individual atmosphere, ocean, land and sea ice components that exchange information by means of a fifth coupling component. The model can be run in a fully coupled mode, with each model component actively responding to output from the others, or any number of components can be shut off and replaced by with preset values.

Analysis of CCSM3 has been done using output from control runs at both T85 (~1.4^o) and T42 (~2.8^o) resolutions. These runs were intended to simulate current climate conditions, using atmospheric composition present in 1990. Two hundred consecutive years of output from each run were examined, with the selected years occurring late enough into the run for the upper ocean to have reached equilibrium.

Model output has been compared to data from the European Centre For Medium-Range Weather Forecasts (ECMWF) forty year reanalysis project (ERA-40) and precipitation data from the Global Precipitation Climatology Project (GPCP). ERA-40 precipitation forecasts have been shown to be quite accurate over the Arctic (Serreze et al, 2004), although the quality of the evaporation forecasts is uncertain. GPCP data is derived from a combination of satellite and rain gauge measurements, and is included here to give another representation of high latitude precipitation.

3.0 RESULTS & DISCUSSION

3.1 Annual Cycles

Annual cycles of precipitation (P), evaporation (E) and net precipitation (P-E) averaged over some important regions have been examined. When the entire region north of 60^o N is considered, P, E and P-E from both CCSM3 control runs show generally good agreement with observations. The only obvious exception is found over land surfaces during the summer, where ERA-40 gives much higher estimates of

Corresponding author address: Joel Finnis, University of Colorado, PAOS, Boulder, CO, 80309; email: joel.finnis@colorado.edu

evaporation. However, it's possible that some of this discrepancy is at least partially due to overestimates of E in ERA-40. Betts et al (2003) have shown that ERA-40 forecasts of E are too high over northwestern North America, and it's possible that this high bias extends to other land surfaces during the summer.

In addition to considering the entire region north of 60^o, the annual cycles of P, E and P-E over the Ob, Yenisey and Lena River Basins in Eurasia and the Mackenzie River Basin in North America have been examined. These rivers deliver the bulk of freshwater to the Arctic Ocean, and considering their influence on the system, it's important to examine the watersheds of these rivers in close detail. Annual cycles of P and E for each basin are given in figures 1 and 2 respectively.

Consider first the three Eurasian basins. A look at annual cycles of P shows that CCSM3 output falls within the range of observations in the Ob, Lena and Yenisey watersheds. Evaporation within the Eurasian basins (fig. 3.4) is also generally close to ERA-40 forecasts, particularly in the T85 run. The only pronounced problem is in the Lena basin, where E is underestimated by 5-10 mm/month in the T85 run, and by 20-25 mm/month in the T42 run. However, ERA-40 shows much greater summer evaporation within the Lena basin than past estimates (Serreze et al, 2003), and this E difference may be at least partially due to inaccuracies in ERA-40.

While CCSM3 does a satisfactory job of reproducing the hydrology of the major Eurasian basins, the model does a much poorer job of capturing the hydrology of the Mackenzie River basin (MRB). While the model shows reasonable agreement with observations during summer, it greatly overestimates MRB precipitation throughout the autumn, winter and spring. During these seasons the model produces up to 20 mm/month of excess P over this basin, presenting the largest persistent problem in CCSM3's large-scale Arctic hydrology identified in this study. Potential causes of this problem are discussed in the next section.

3.2 Variability & Relation to Atmospheric Circulation

Composite analysis has been used to identify atmospheric circulation patterns associated with hydrologic variability within the Ob, Yenisey, Lena and Mackenzie Basins, using monthly timeseries of winter (December, January, February) and summer (June, July, August) P-E for each of the four basins. Years in the upper and lower quartiles of these six timeseries have been used to construct high and low composites of 500 mb geopotential height and sea level pressure (SLP). These monthly composites have been combined into seasonal averages (DJF and JJA), allowing large-scale circulation patterns associated with seasonal basin-scale variability to be identified. The P-E timeseries is preferred, as it correlates well with the P time series and provides a rough estimate of eventual river runoff. Results from the model are compared with similar composites constructed by Serreze et al (2003) using NCEP reanalyses.

Winter and summer composites for the Ob, (Fig. 3), Yenisey (Fig. 4) and Lena (Fig.5) Basins from both the T42 and T85 CCSM3 control runs show patterns remarkably similar to those found by Serreze et al (2003). High and low composites constructed for each of these basins showed opposing patterns; rather than displaying each separately, the difference between the high and low composites are presented here. Hydrologic variability over the Ob basin is associated with the position and strength of the Urals trough, a weak 500 mb feature that typically lies immediately east of the Ural Mountains. A slight eastwards shift and deepening of this feature is associated with lower SLP in the Ob basin, suggesting the Urals perturbation is responsible for increased cyclone activity in this region. The Urals trough also appears to influence precipitation over the Yenisey and Lena Basins during the summer, though cyclone activity in these basins is most strongly related to the strength of zonal flow at 500 mb across central Eurasia.

In contrast to the Eurasian basins, winter composites for the MRB show very different patterns from those derived from observations. These differences are illustrated in Fig.6, which shows anomalies from high composites constructed using both the T85 run of CCSM3 and the ERA-40. Composites from both datasets show patterns suggestive of lee-side cyclogenesis near the MRB, with increased 500 mb flow across the Rockies associated with passage of a cyclone through the southern MRB. It seems that such events are important drivers of cold season precipitation within both CCSM3 and the real environment. However, there are important differences between the ERA-40 and CCSM3 composites that suggest CCSM3 is misrepresenting these events. Features around the MRB are more pronounced in the CCSM3 composites, suggesting modeled MRB cyclones are too intense, too persistent, or occur too frequently. Furthermore, the structure of SLP and 500 mb features differ in some important ways, with the CCSM3 composites showing lower SLP over the Gulf of Alaska and 500mb flow across the Rockies from a southwesterly rather than northwesterly direction. These patterns closely resemble those observed during a specific type of lee-side cyclogenesis known as Gulf Redevelopment (GR) events, which are associated with particularly heavy MRB precipitation during the autumn, winter and spring. These events occur when a strong surface cyclone over the Gulf of Alaska interacts with upper level flow from the southwest. The upper level flow encourages the surface cyclone to extend eastwards, eventually spawning a new cyclone on the lee-side of the Rocky Mountains (Lackmann & Gyakum, 1996). Observed GR events are too short and infrequent to leave an obvious signal in the monthly averaged reanalysis data used here, and the fact that such a clear GR-like signal is present in the CCSM3 composites suggests the cold season precipitation biases in the MRB are the result of excessive production of GR-like events. This may not, however, be the case, and an examination of daily model output is required to identify the intensity and frequency of these events.

4. CONCLUSIONS

The work presented here provides a measure of confidence that CCSM3 is capable of realistically reproducing the Arctic atmospheric hydrologic cycle. Although problems have been identified in the model's representation of the Mackenzie River Basin, it performs very well over the Eurasian portion of the Arctic drainage basin. An identified high precipitation bias in the Mackenzie River Basin has been associated with atmospheric circulation patterns that closely resemble those found during Gulf Redevelopment events, and it's possible that an excess of these events is causing this bias.

5. BIBLIOGRAPHY

Betts, A.K., J.H. Ball and P. Viterbo, 2003: Evaluation of the ERA-40 surface water budget and surface temperature for the Mackenzie River Basin. *Journal of Hydrometeorology*, **4**. . 1194-1211.

Broecker, Wallace. S., 1997: Thermohaline circulation, the Achilles Heel of our climate system: Will man-made CO_2 upset the current balance?. *Science,* vol. **278**, 1582-1588.

Lackmann, Gary M., and J. R. Gyakum, 1996: The Synoptic- and planetary-scale signatures of precipitating systems over the Mackenzie River Basin. *Atmosphere-Ocean*, vol. **34**, 647-674.

Serreze, M.C., D.H. Bromwich, M.P. Clark, A.J. Etringer et al, 2003: Large-scale hydro-climatology of the terrestrial Arctic drainage system. *Journal of Geophysical Research*, vol. **108**, 8160, doi:10.1029/2001JD000919.

Serreze, M.C., A. Barrett and F. Lo, 2004. Northern High Latitude Precipitation as Depicted by Atmospheric Reanalyses and Satellite Retrievals. In Press.

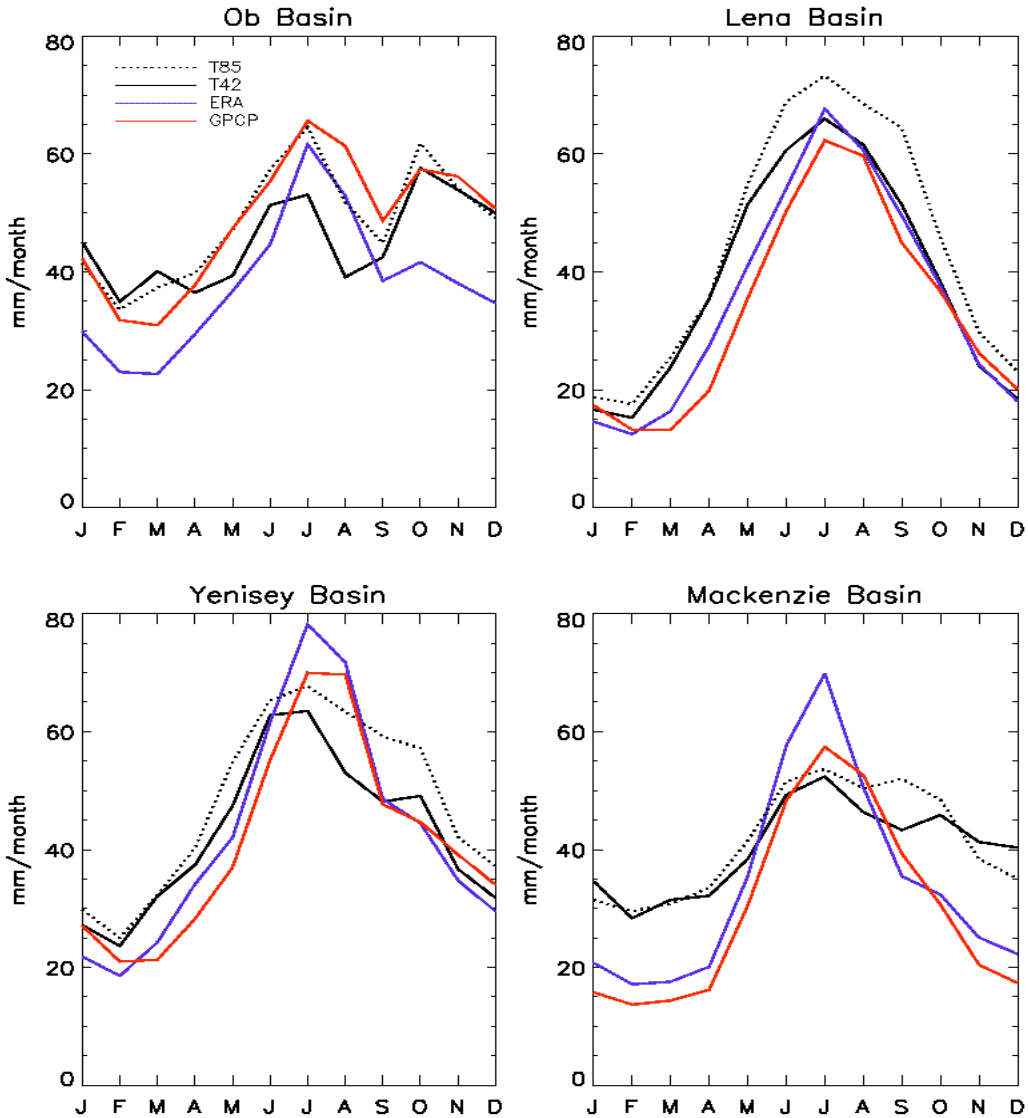

Figure 1: Annual cycles of precipitation averaged over key Arctic watersheds from T42 (solid black) and T85 (dashed black) control runs of CCSM3, ERA-40 (blue), and GPCP (red).

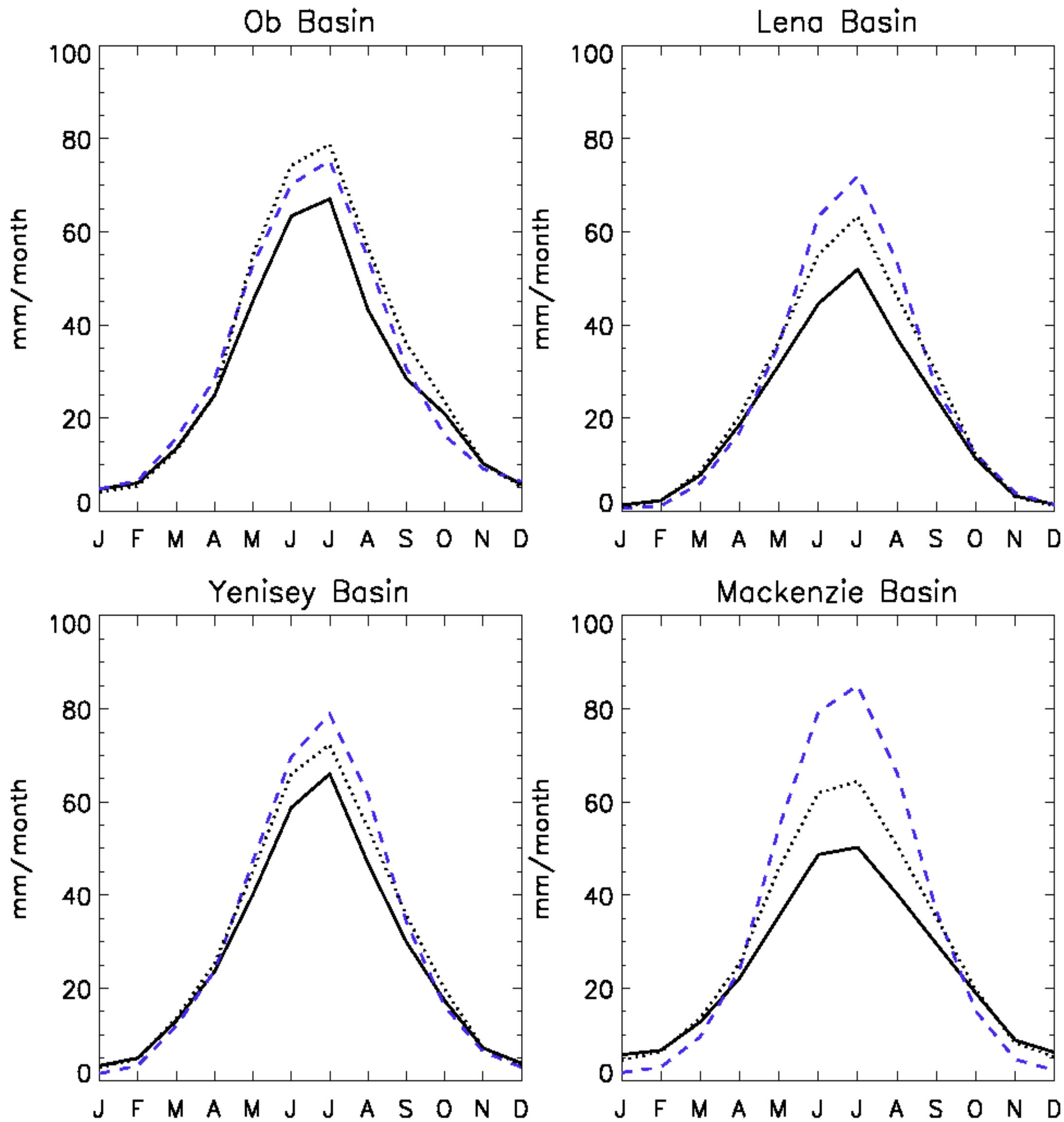

Figure 2: Annual cycles of evaporation averaged over key Arctic watersheds from T42 (solid black) and T85 (dashed black) control runs of CCSM3, as well as ERA-40 (dashed blue).

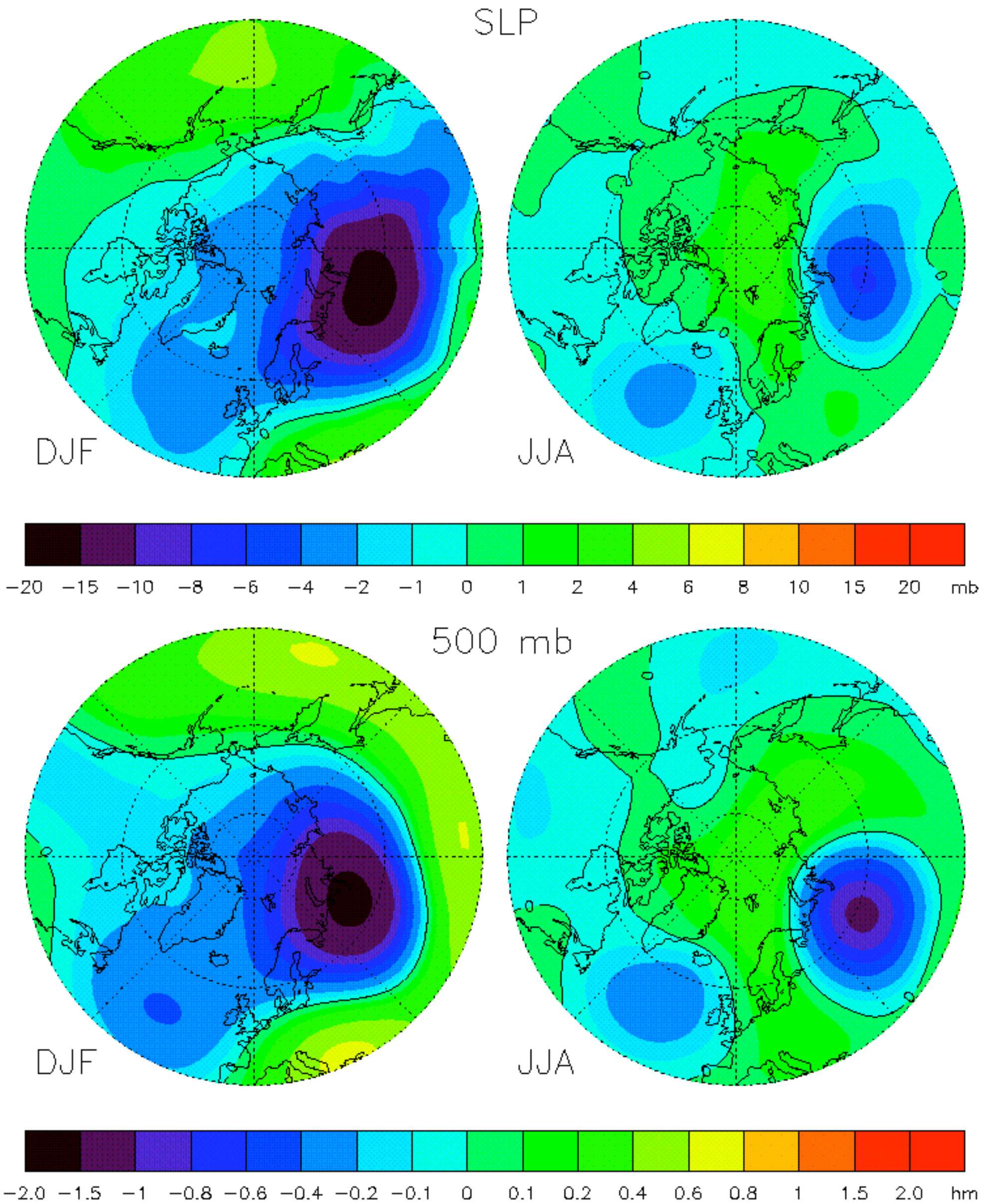

Figure 3: Composite analysis for the Ob basin of winter (left) and summer (right) SLP and 500 mb geopotential. Shown are the differences between high and low composites.

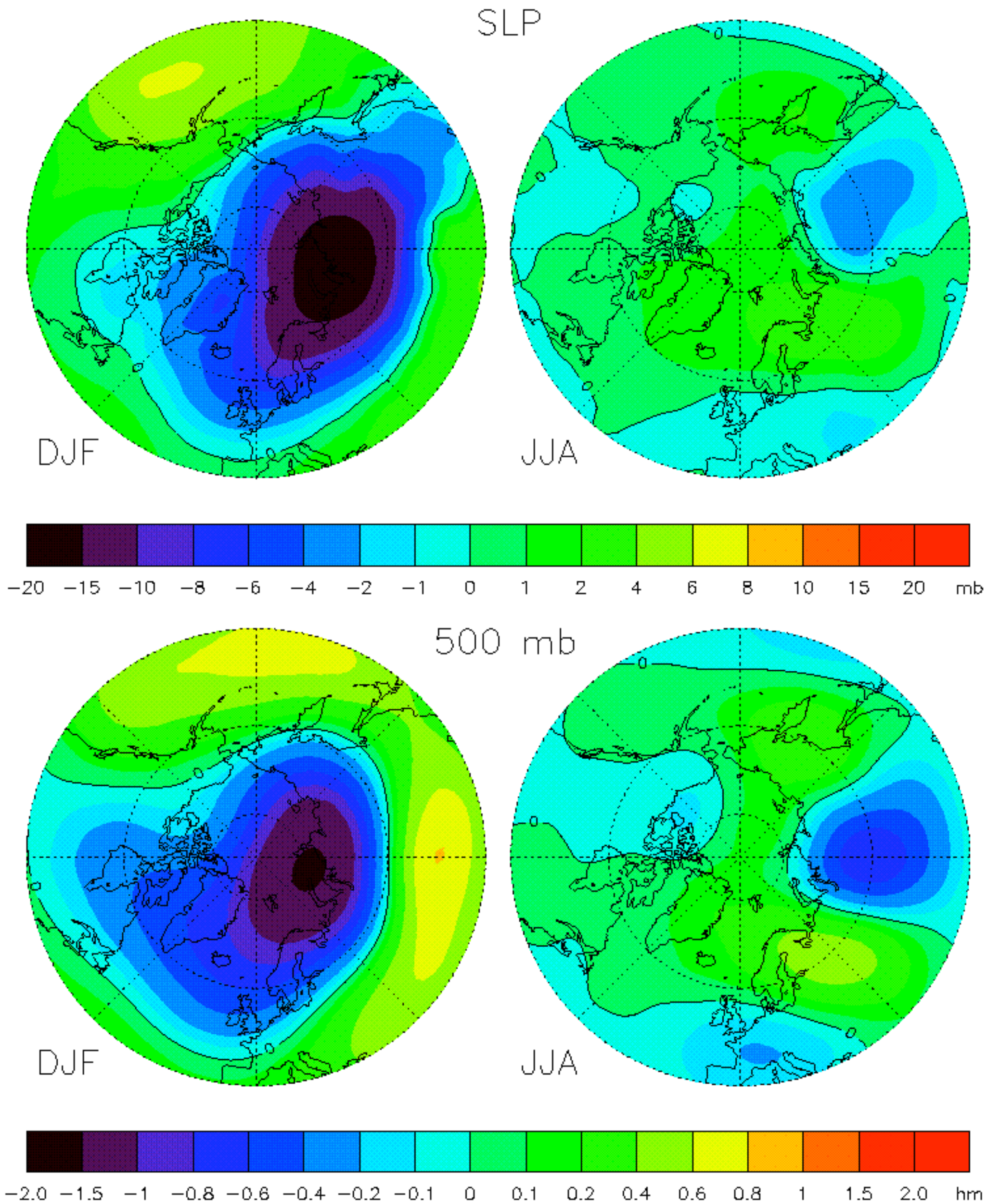

Figure 4: Composite analysis for the Yenisey basin of winter (left) and summer (right) SLP and 500 mb geopotential. Shown are the differences between high and low composites.

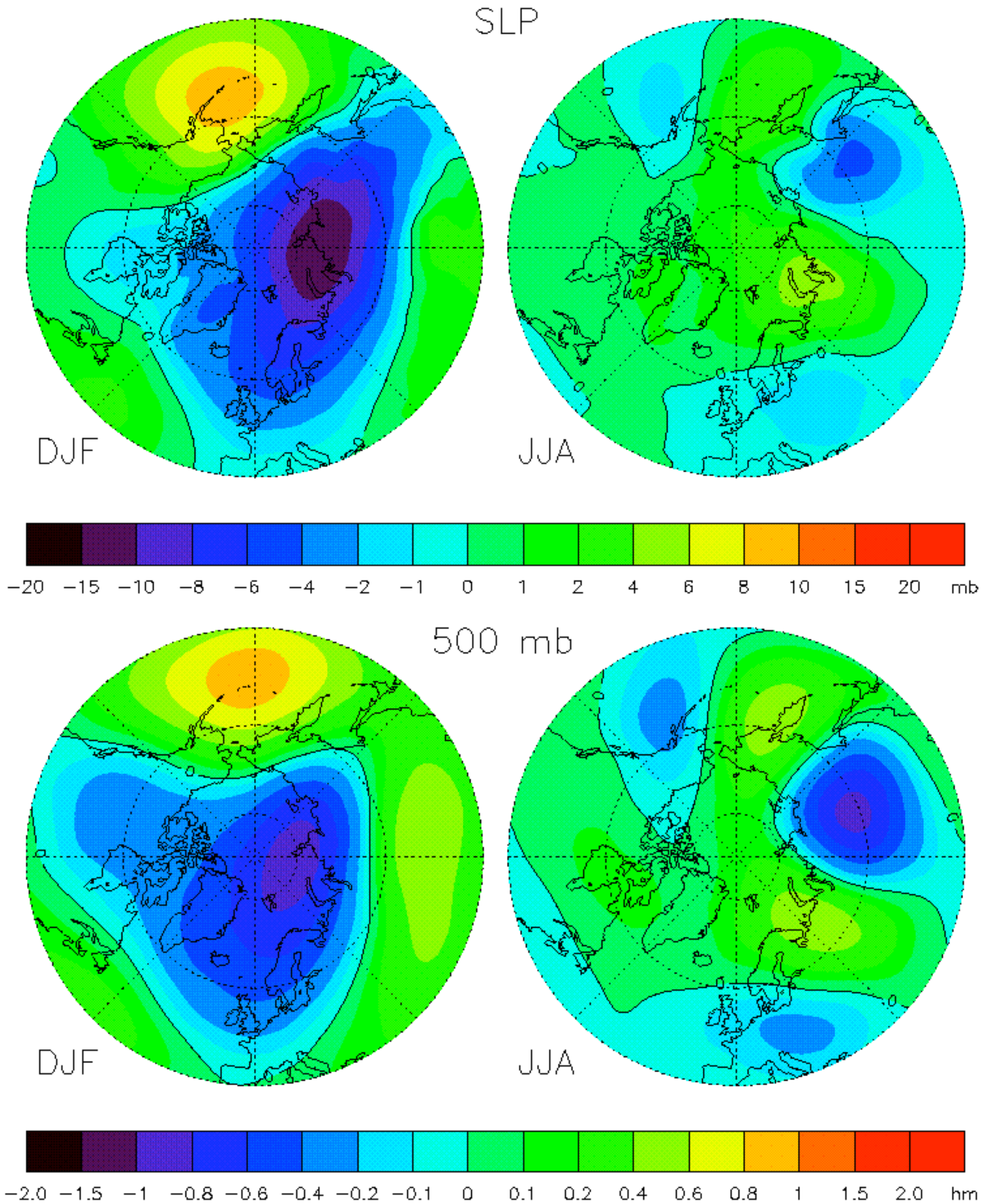

Figure 5: Composite analysis for the Lena basin of winter (left) and summer (right) SLP and 500 mb geopotential. Shown are the differences between high and low composites.

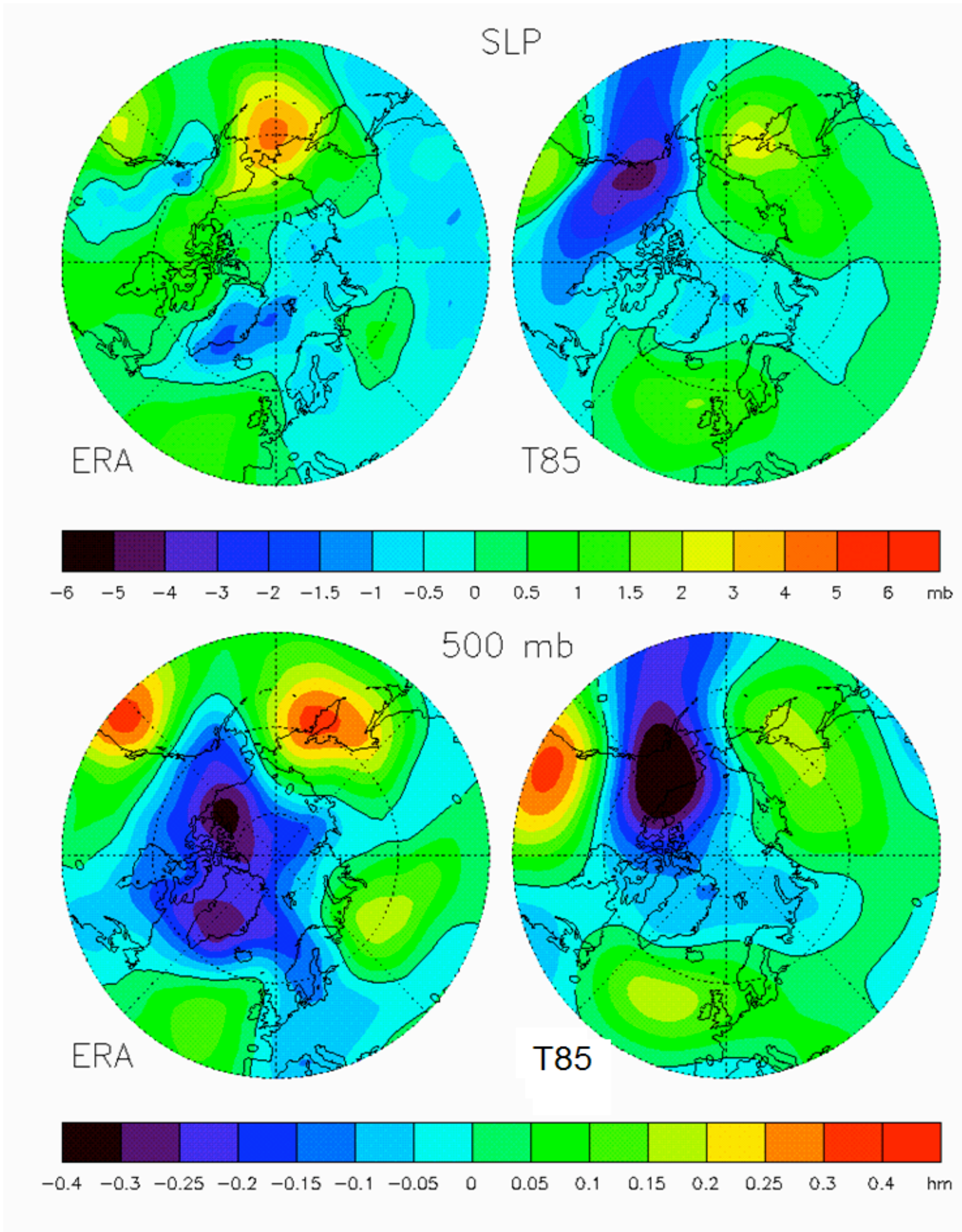

Figure 6: Anomalies in the high composites of SLP and 500 mb composites from ERA-40 (left) and the T85 control run of CCSM3 (right).