Inception of the Laurentide Ice Sheet. The North Pacific Ocean connection

Francis O. Otieno, David H. Bromwich and Robert Oglesby

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Background

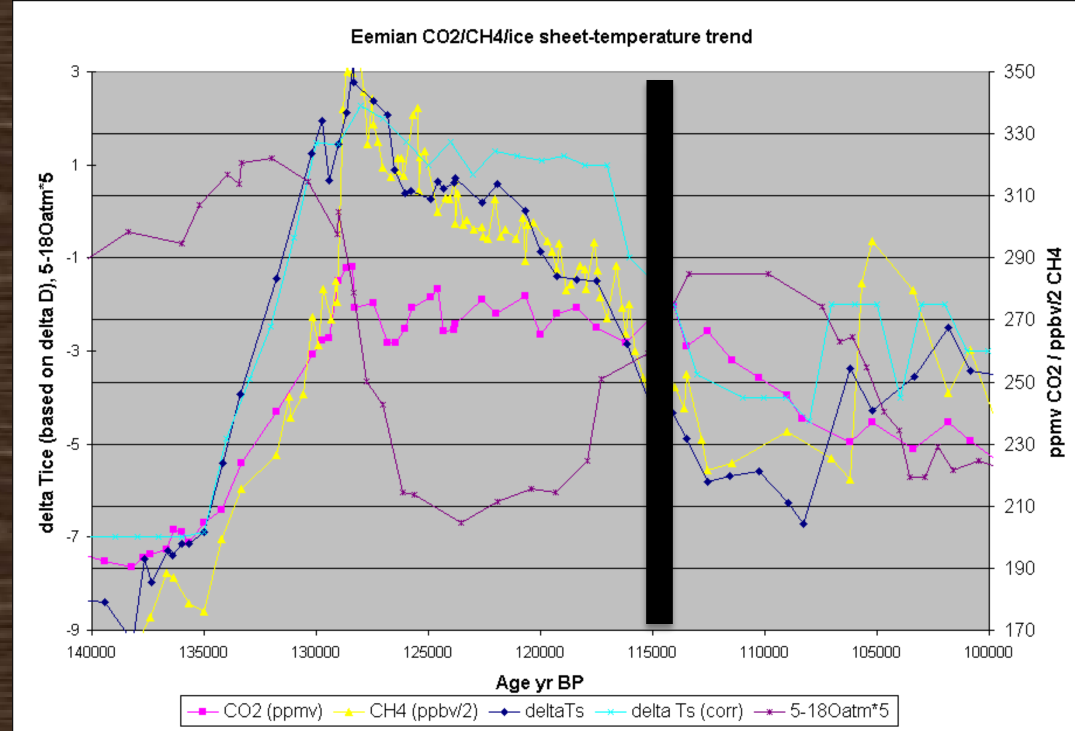
At the peak of the Eemian (~125 kyr BP) surface temperatures were about as warm as at present

Cooled very rapidly by up to 4°C by ~100kyr BP and another 2 °C at the LGM

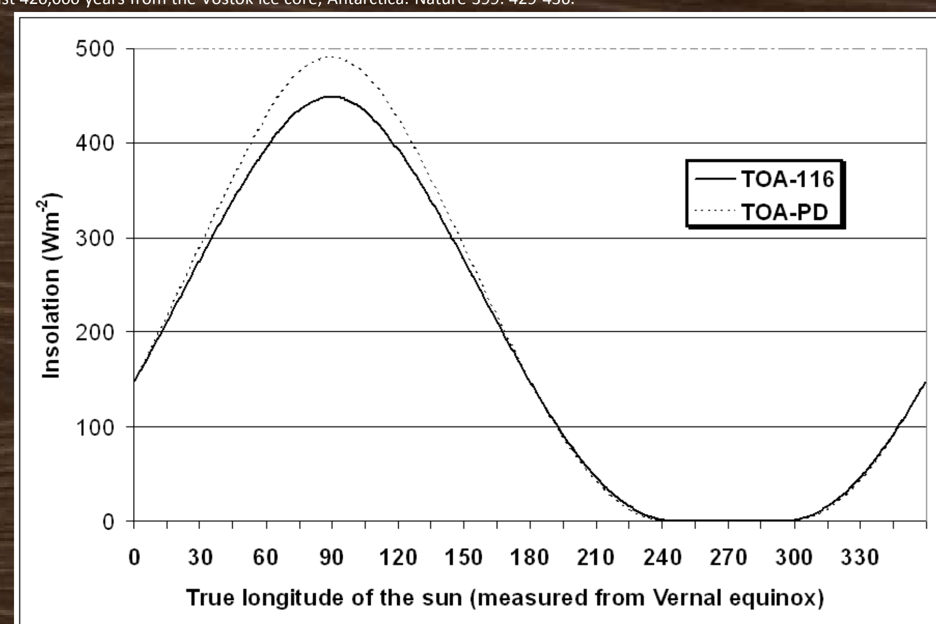
CO_2 started decreasing earlier but then remained about the same time until 115 kyr BP

CH_4 was continuously decreasing before and after 125 kyr BP

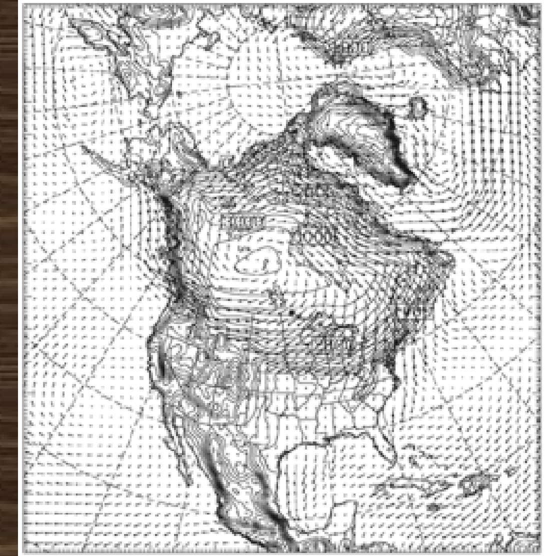
Can CCSM3 accurately simulate what happened as the massive ice sheet was developing



Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.-M. Barnola, I. Basile, M. Benders, J. Chappellaz, M. Davis, G. Delayque, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. Pépin, C. Ritz, E. Saltzman, and M. Stievenard. 1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature 399: 429-436.



The Laurentide Ice Sheet developed about 115 kyr BP and expanded to cover much of Canada and the Great Lakes Area



Changed the Circulation around the ice sheet as the anticyclonic flow developed

The flow in the nucleation region is generally westerly throughout much of the troposphere, making it difficult to advect moisture from the

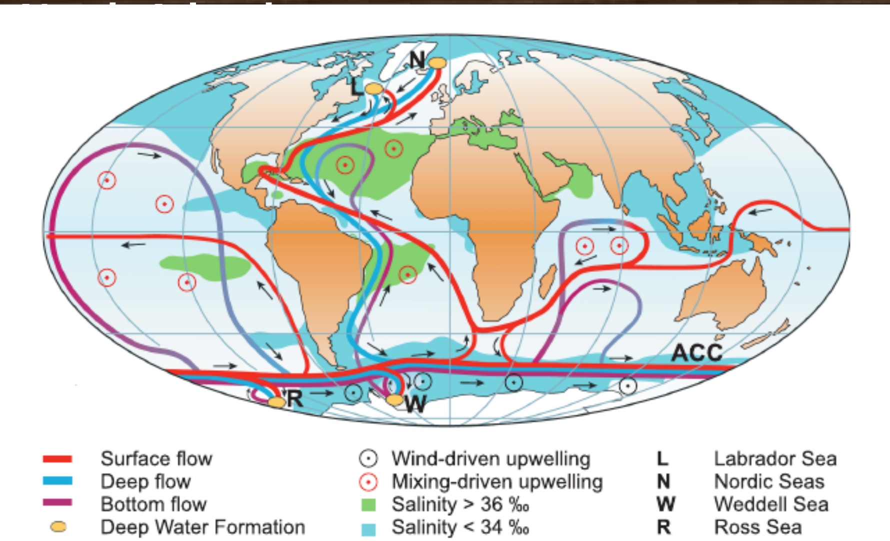


Plate 1. Schematic of the global overturning circulation. See text for explanation. From *Kuhlbrodt et al.* (2007).

Changes in the Atlantic Overturning Meridional Circulation influence heat advection to the Polar Regions.

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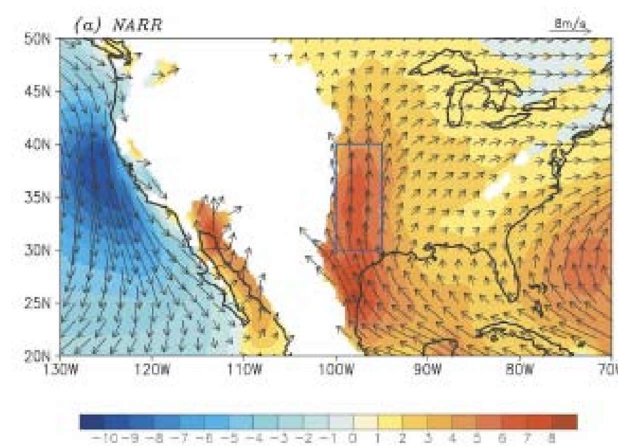


FIG. 1. Summer mean wind vectors (arrows; see scale at upper rhs) at 925 mb for (a) NARR, (b) AGCM control run, and (c) AGCM with global orography removed. The colors indicate the meridional wind component [scale bar at bottom (m s^{-1})]. The rectangular box in (a) and (b) indicates the LLJ region.

Was the moisture that built the LIS drawn in from the North Atlantic, Gulf of Mexico or the North Pacific

Objectives

1. Can variations in present day circulation alone drive glacial inception; used the community land model in offline simulations in idealized simulations

2. Is glacial inception driven by local forcing alone; Solar radiation, CO_2 , extreme circulation

3. What is the role of the feedbacks; use the fully coupled CCSM3

Community Land Model Experiments

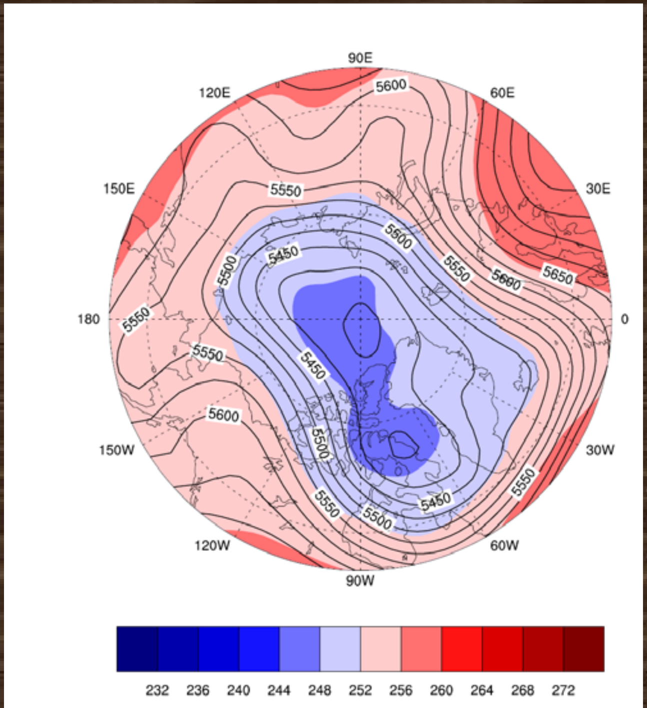
Defining inception : Occurrence of perennial snow
Forced CLM3 with idealized ERA-40

Create a year with extremely wet winter followed by an extremely cold summer season

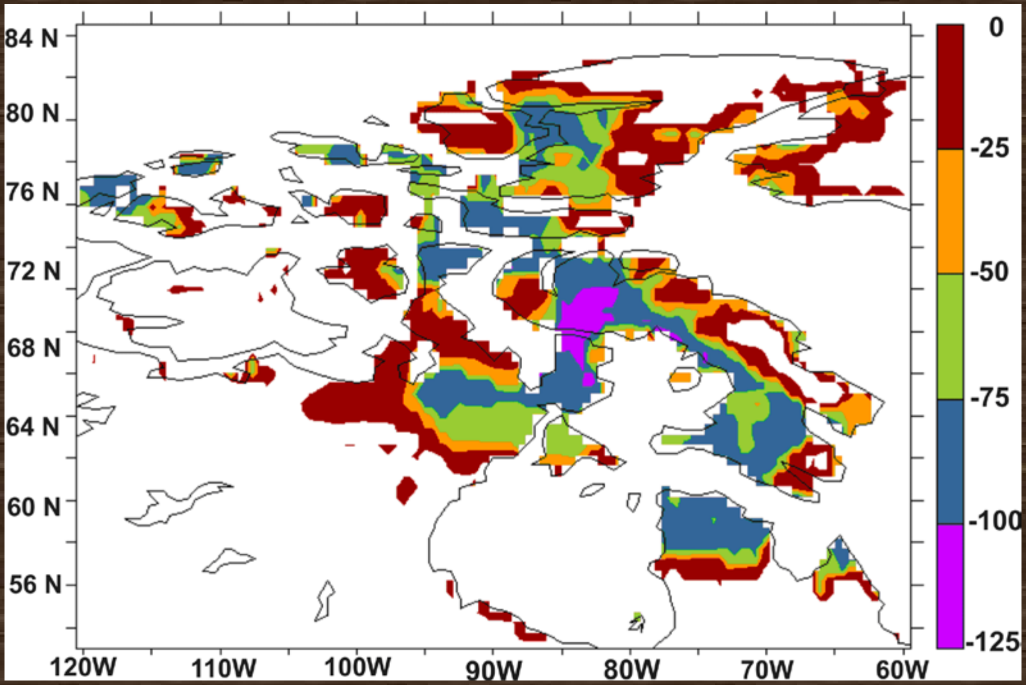
Use this atmospheric forcing in a perpetual simulation
Increased frequency of these extremes together with Eemian conditions.

Starting from warm present-day atmosphere decrease summer insolation until perennial snow develops

Community Land Model Experiments

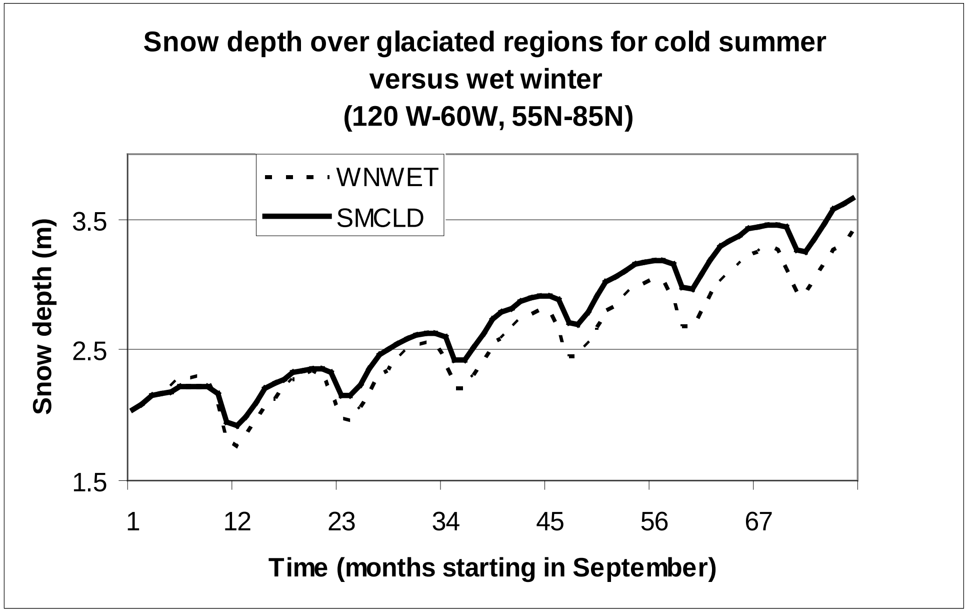


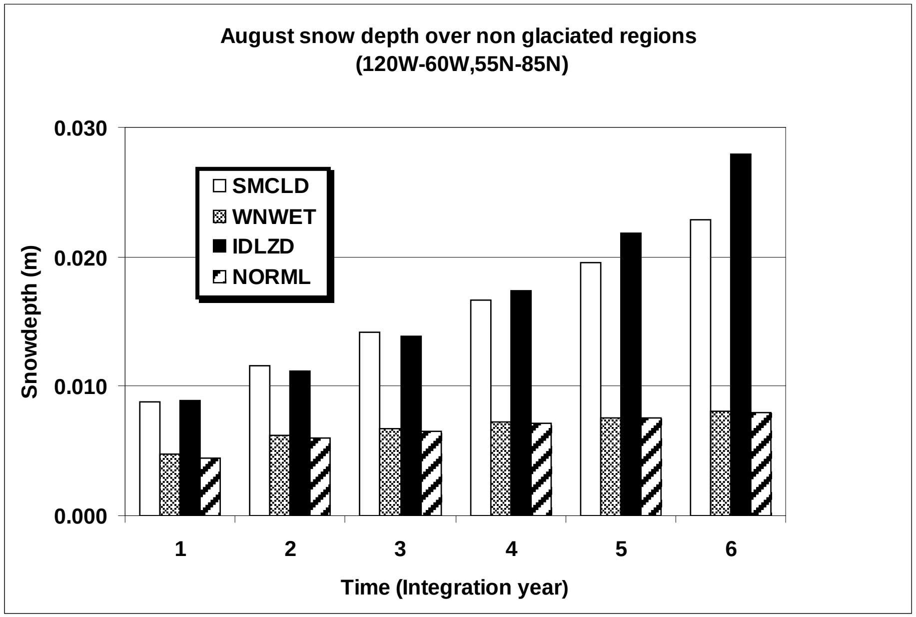
Height of 500mb geopotential (m) and air temperature (K) in June-July-August (JJA) 1972 that is used for the summer of the idealized year



Difference (BP116 minus IDLZD) in August surface solar radiation (W m^{-2}) absorbed in year 20 of integration.

Results from Idealized CLM3





- Area averaged snow depths (m) for initially glaciated grids for the wet winter (WNWET) and cold summer (SMCLD) experiments.
- CLM3 in CCSM3 had snow depths fixed at 1000 kg/m3 snow water equivalent. Not good for inception everything extra is turned into run off
- Lifting the cap causes the snow depths to increase unrealistically. Was aimed at accurately represent present day seasonal snow cover.

- Small growth occurs for non glaciated areas
- Comparable to the normal scenario (limited growth)
- The idealized case and cold summer experiments

Results from Idealized CLM3

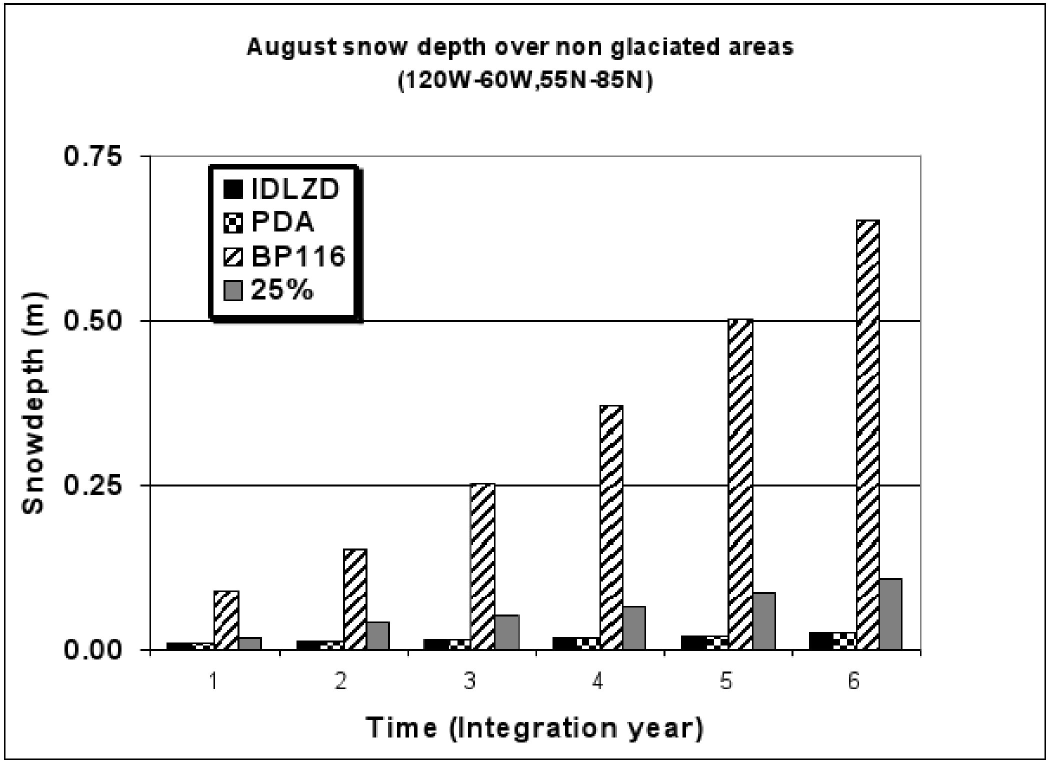


Fig. 9: Area (120 °W-60 °W, 55 °N-85 °N) averaged snow depths (m) for areas that are initially not glaciated from four experiments (i) IDLZD –idealized atmospheric forcing comprising wet winters and cold summers and contemporary orbital configuration in CLM3 (ii) PDA-same as IDLZD but with 116 kyr orbital configuration in CLM3 (iii) BP116-same as PDA but with an additional 4°C cooling of the atmosphere (iv) 25%- same as IDLZD but with 25% reduction (about twice the estimated reduction at the end of the Eemian) in ERA-40 incident shortwave radiation. The plot shows that snow depths from a cooler atmosphere are much larger than even those from a two-fold reduction in insolation.

CCSM3 Experiments

Determine if the Milankovitch forcing trigger a feedback responses that amplifies the impact of the modest insolation reductions

Run the fully coupled (ocean-atmosphere-land-sea-ice) CCSM3 model at T42 for the inception period ~115 kyr BP.

Minimize the effects of model spin up by using combinations of initial/restart files from a previous 1870 CCSM3 control runs in a branch configuration.

Use the model to test individual contribution of CO_2, CH_4, and orbital forcing

changes in circulations, heat and moisture transports that may have contributed to the rapid growth of LIS

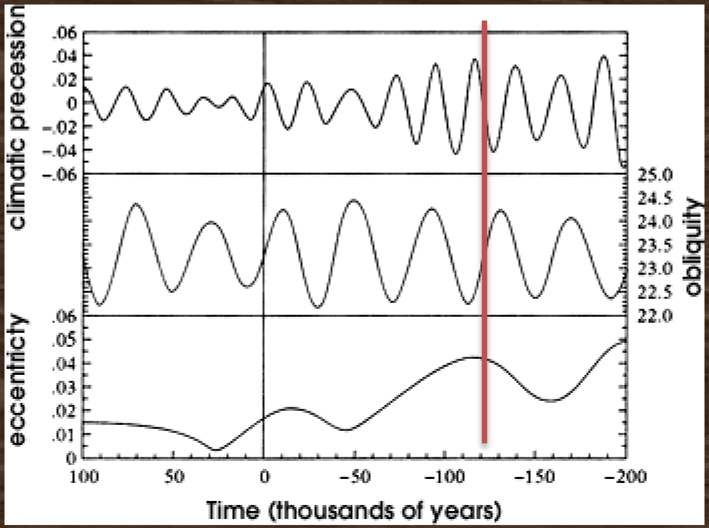
	115 kyr BP (BP115K)	Pre Industrial (PREIND)
Obliquity	22.58 Degrees	23.45 Degrees
Eccentricity	0.0414	0.0167
Longitude of Perihelion	290.9	282.7
CO_2	250 ppm	289 ppm
CH_4	500 ppbv	901 ppbv
N_20	281 ppbv	281 ppbv
CFC11	0	0
CFC12	0	0
Vegetation	PD	PD
Elevation	PD	PD
SST	POP	POP
Duration	200 yrs	200 yrs

CCSM3 Results

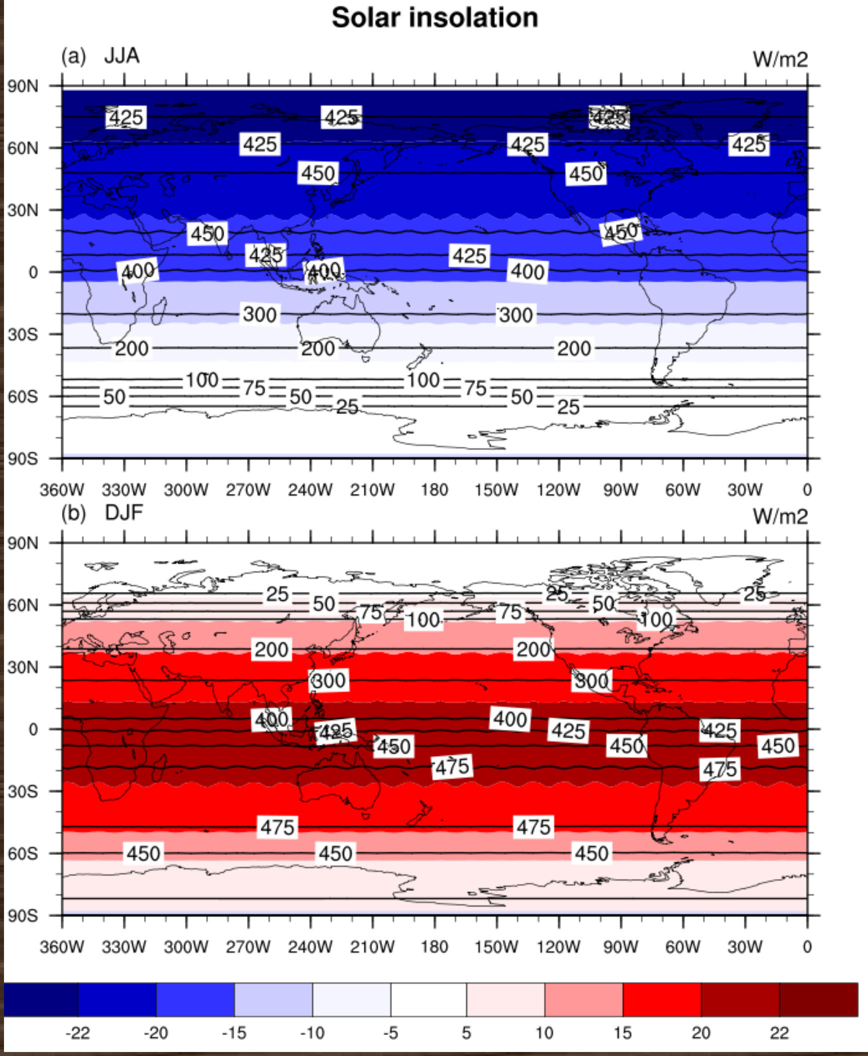
In JJA nearly the entire NH shows cooling. Cooling is greatest north of 65oN

In the SH 115 kyr BP orbit results in higher (positive anomalies) radiation

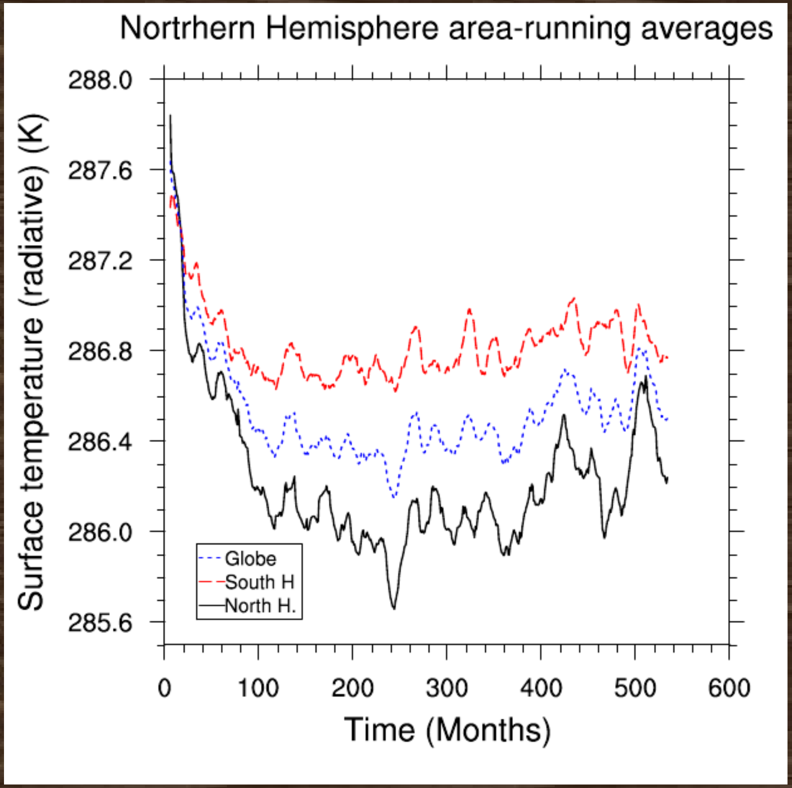
TOA solar forcing is nearly uniform along the latitudes

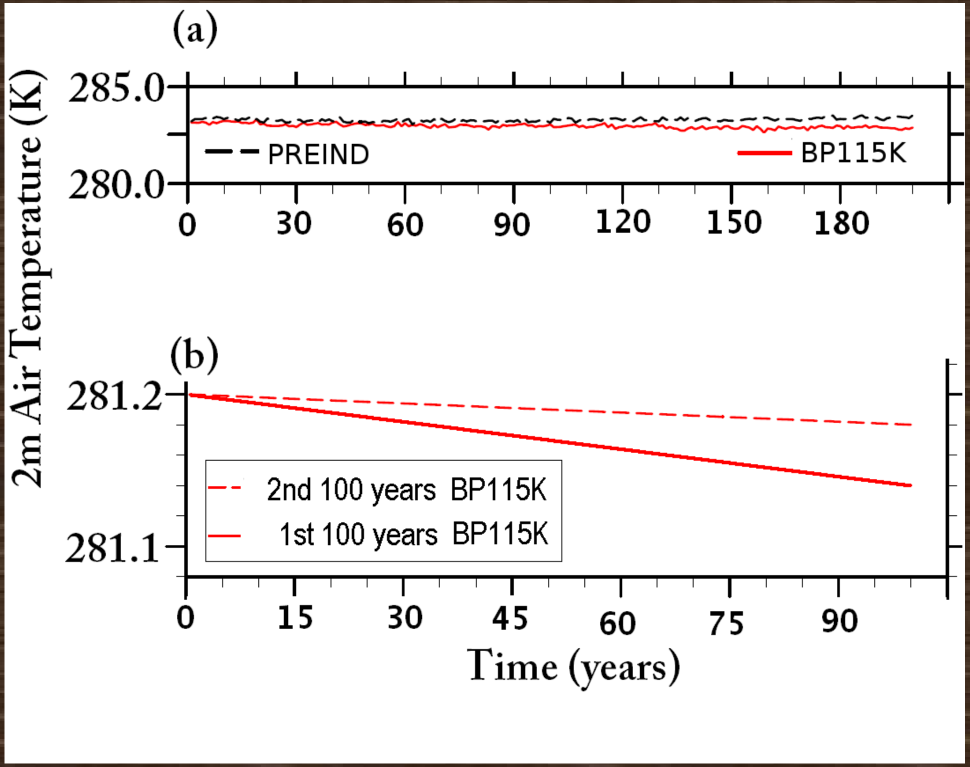


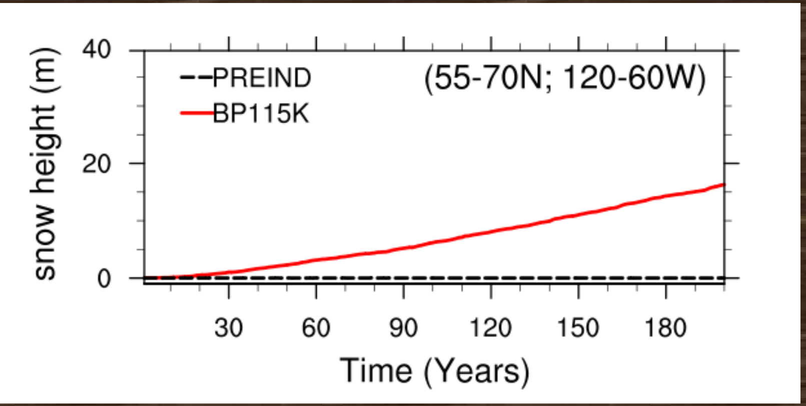
Berger and Loutre, 1991



CCSM3 Results



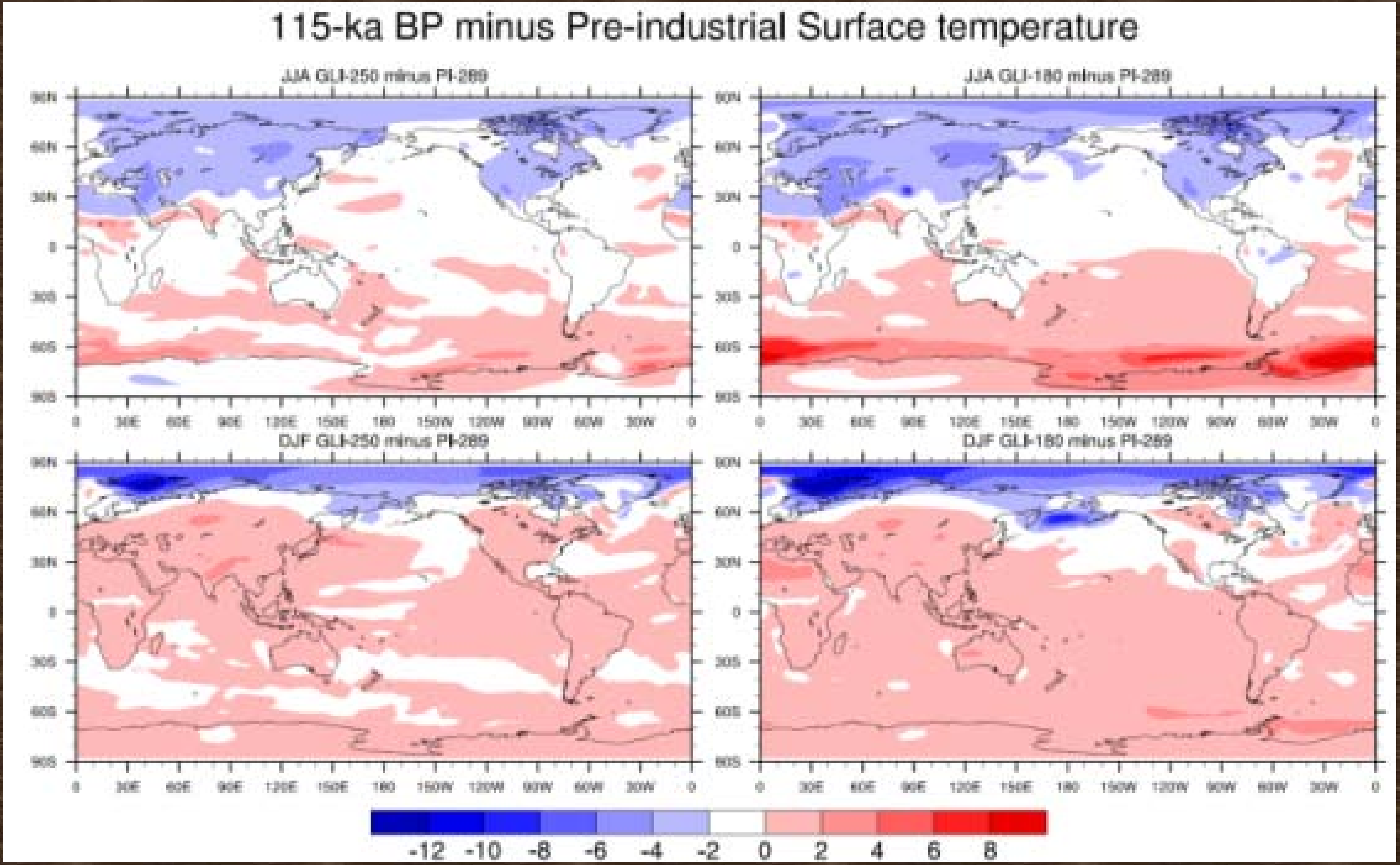




Globally averaged temperature trends lower in the last 100 years

Snow depths over non glaciated grid points

No change in control experiment (PREIND)



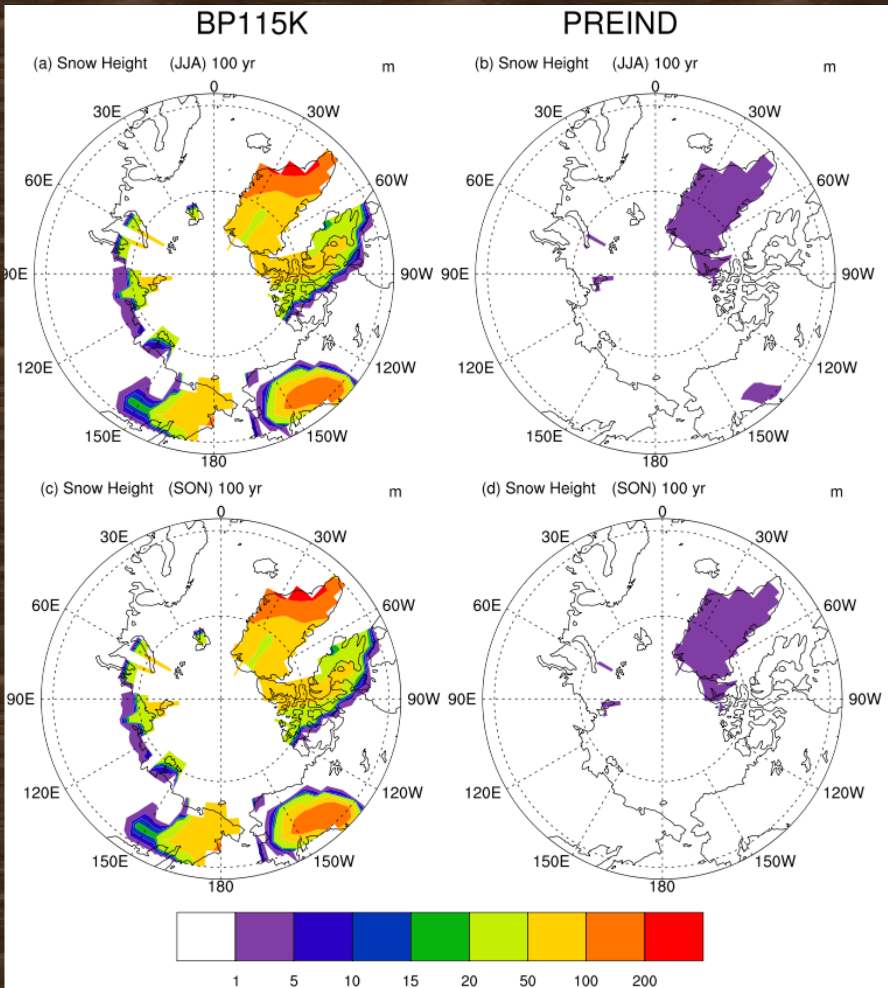
Lower CO2 only magnifies the anomalies

CCSM3 Results

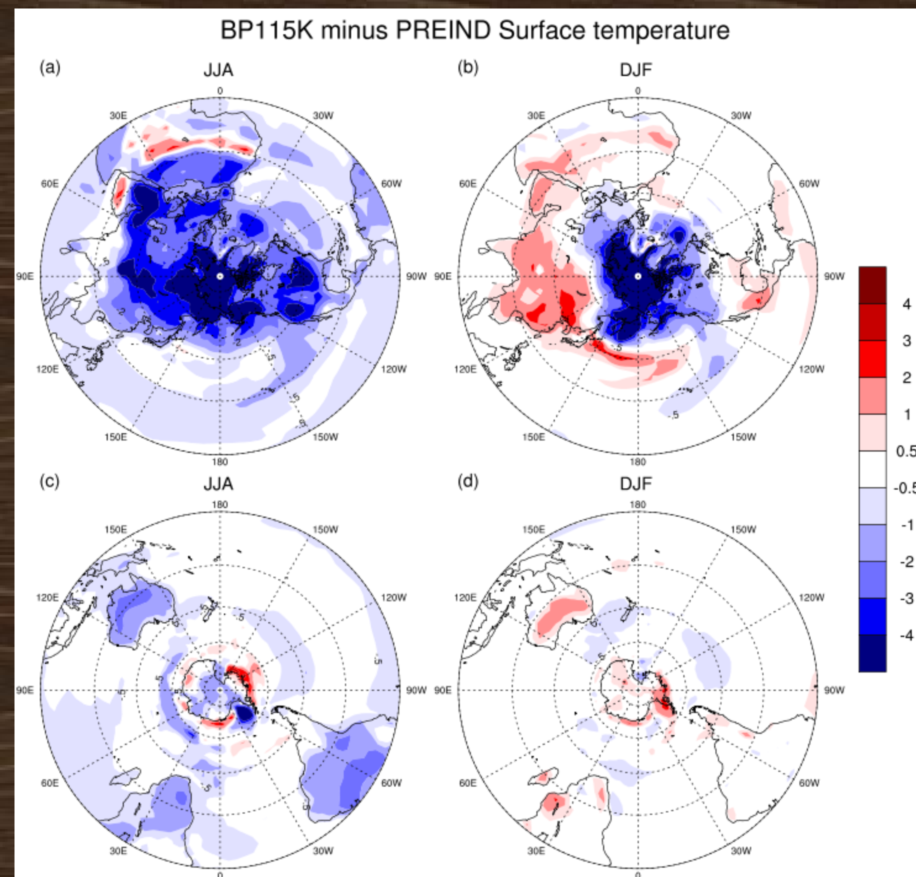
115 Forcing results in colder NH summers

Winters are warmer over Asia and North Pacific Ocean

Not much change in SH particularly over the ocean



Perennial snow develops in 115 kyr but not in the Pre-industrial control



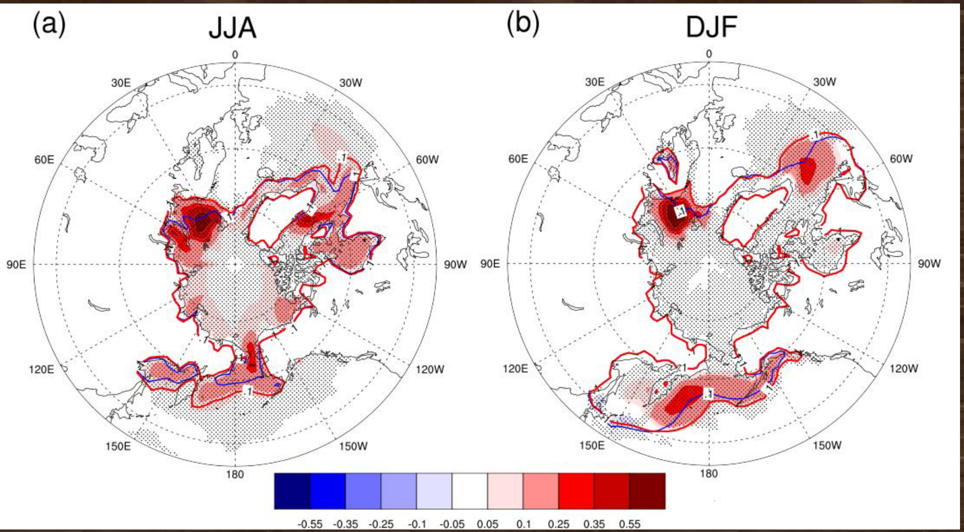
CCSM3 Results

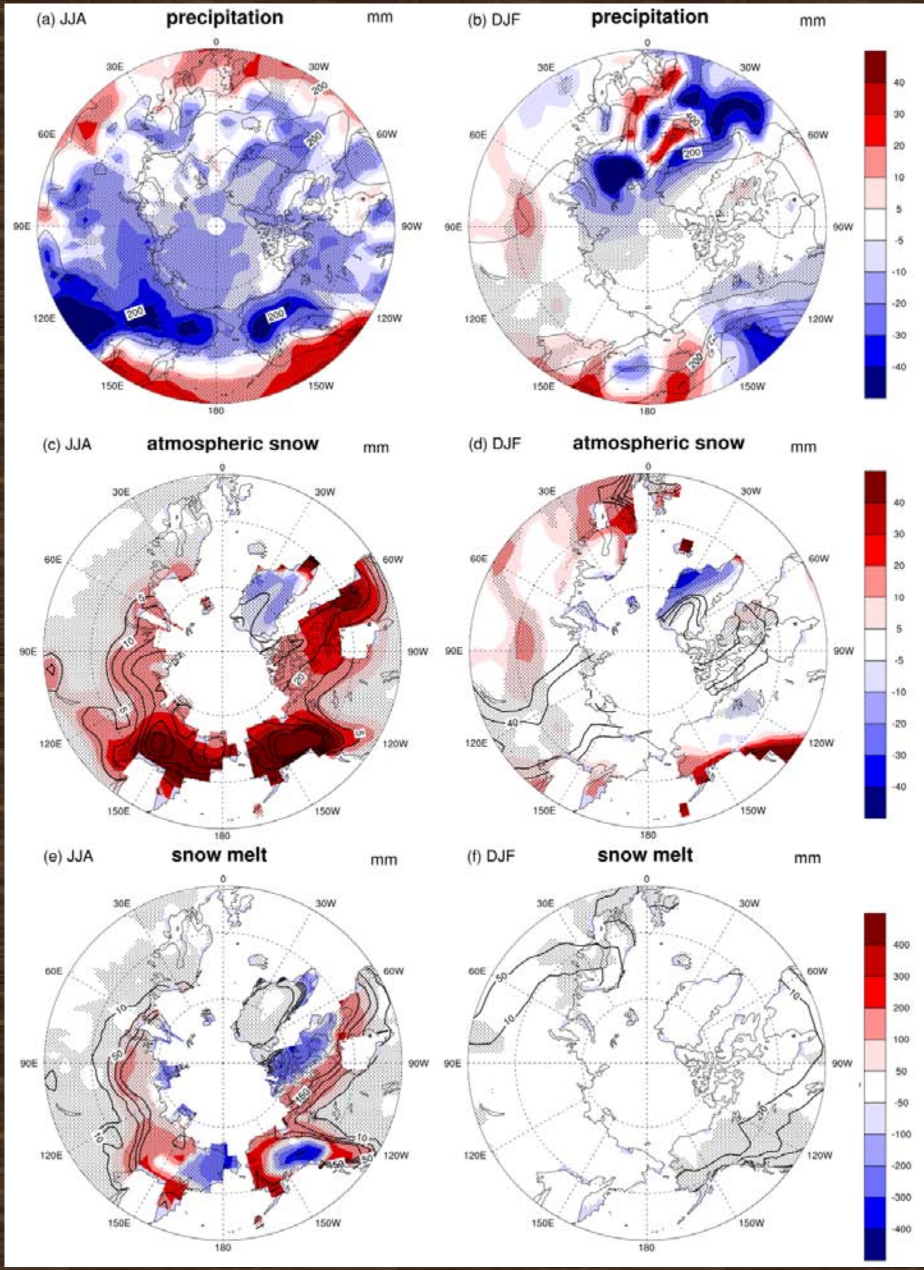
Increased JJA Precipitation over the North Pacific and decreased over Canada

Increased JJA snowfall land areas north of Pacific

Decreased snow melt particularly over Alaska

Sea ice increased over the North Pacific in JJA





CCSM3 Results

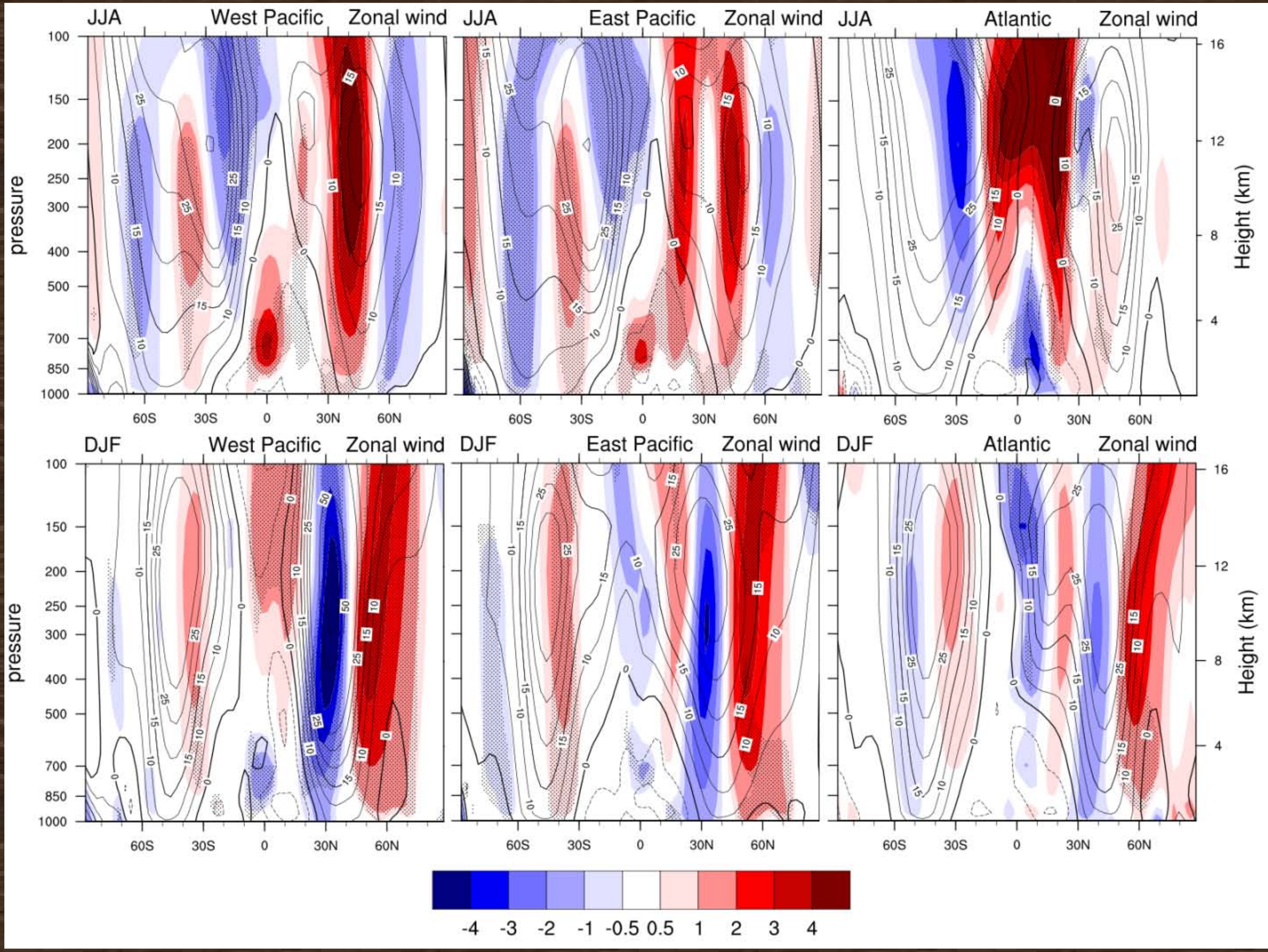
Not much difference in the global zonal average

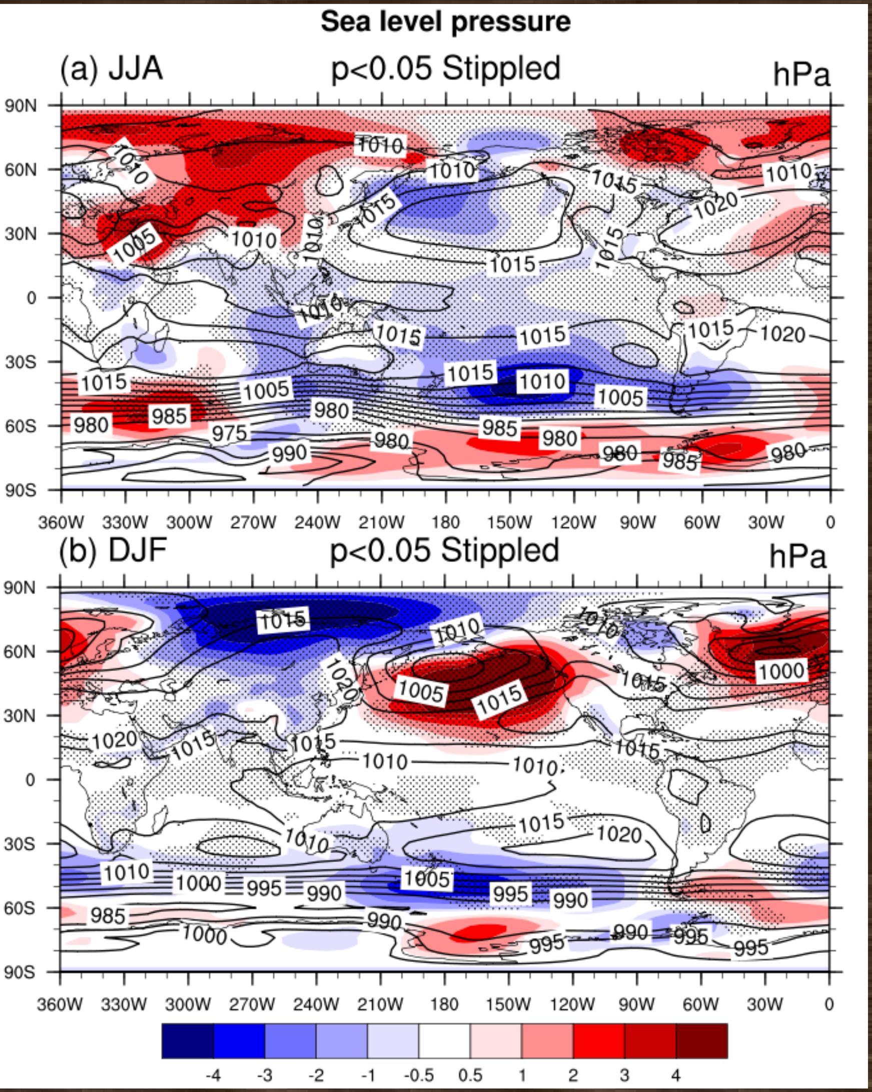
Regional averages show differences

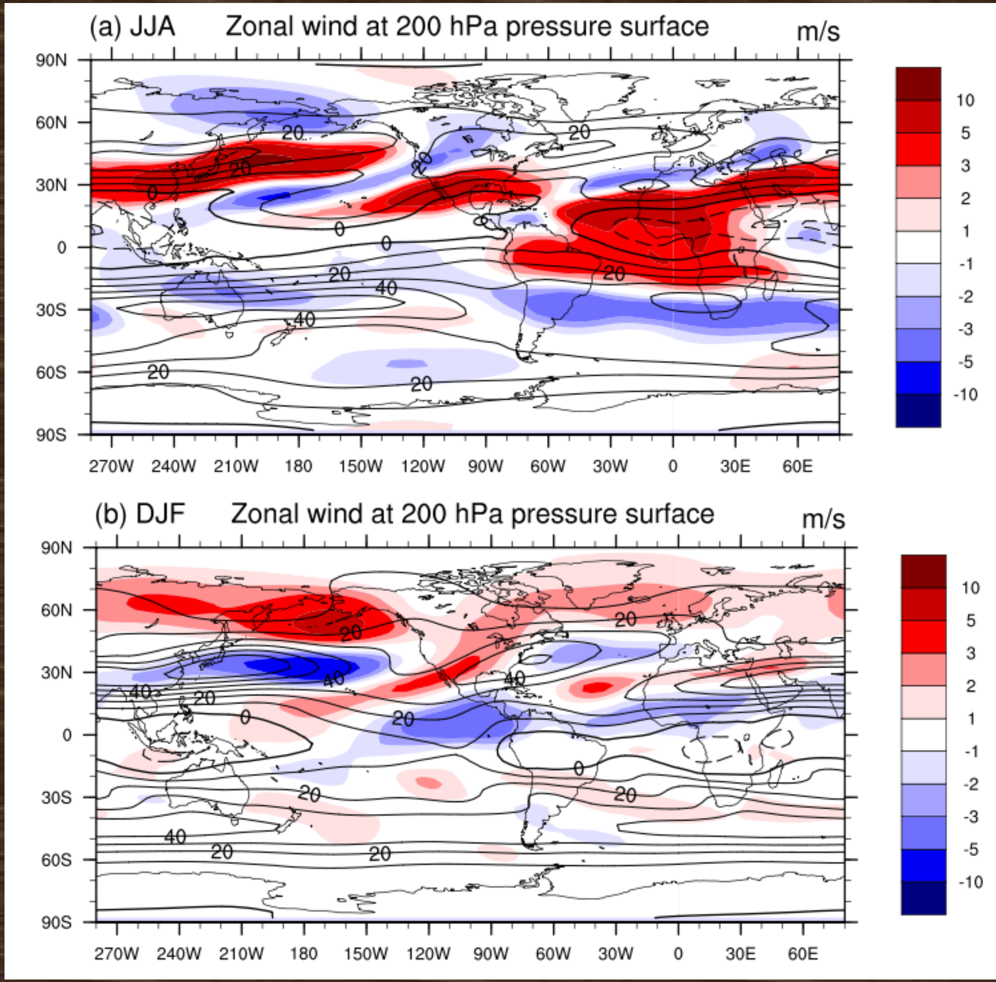
West Pacific JJA zonal flow stronger

DJF shifts in the area of stronger westerly winds

North Atlantic Patterns not very coherent

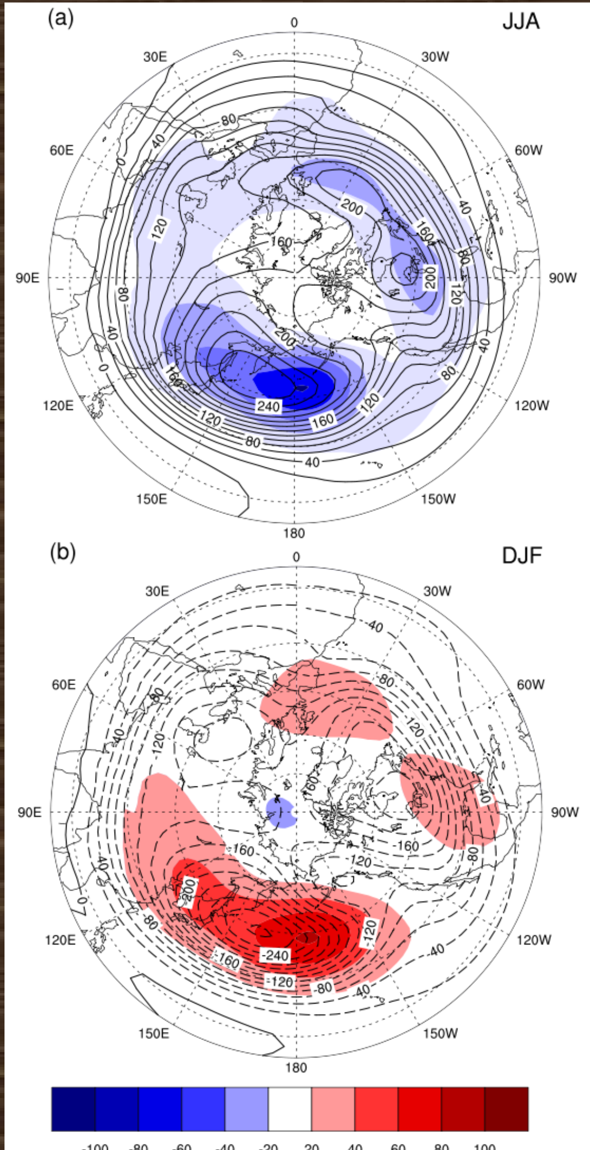




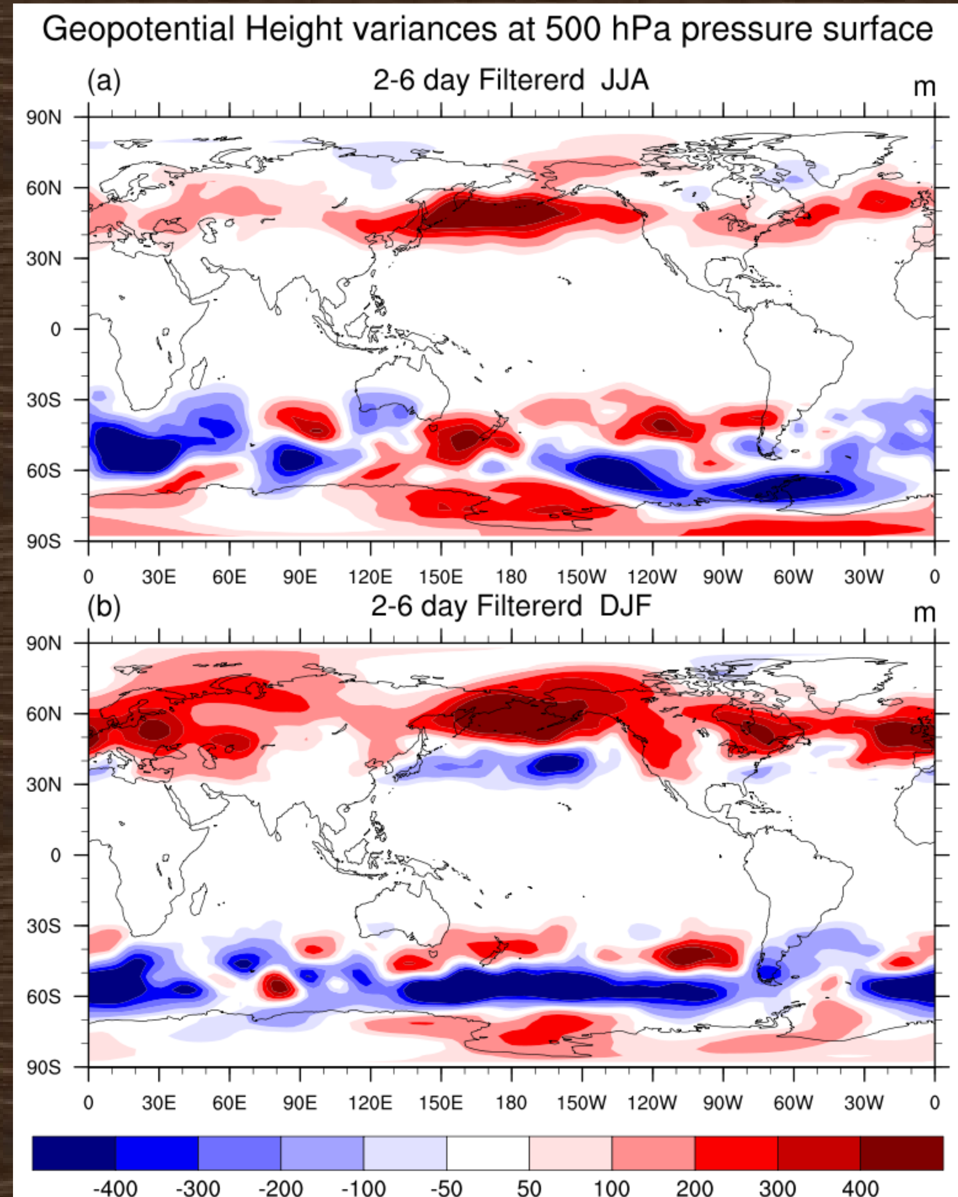


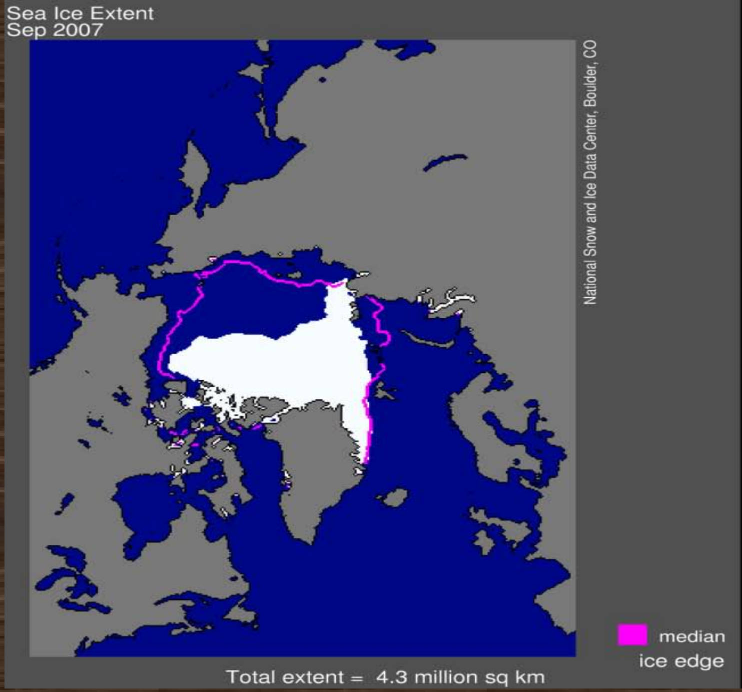
115 kyr BP summer more like present day winter and vice versa

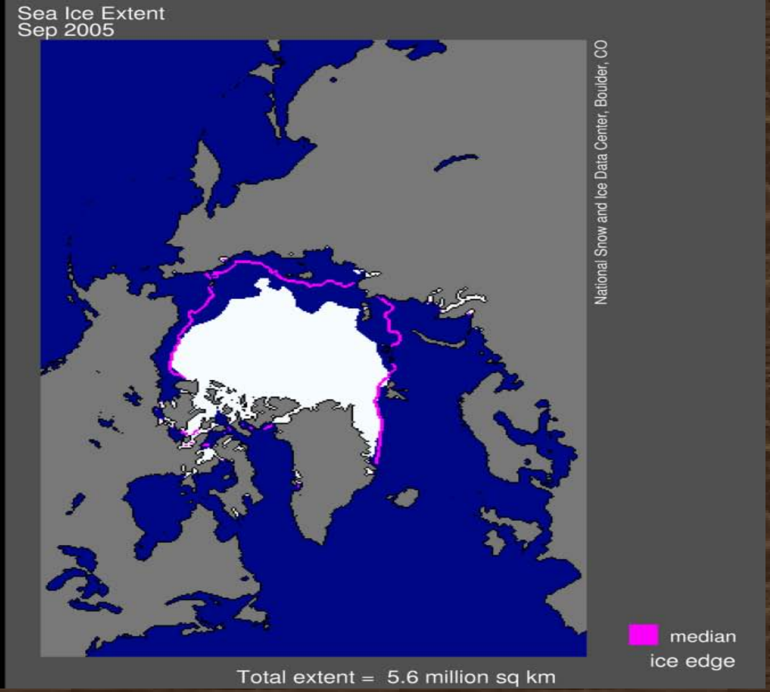
Large differences occur in the North Pacific Ocean



Differences (BP115K minus PREIND; colors) in 500 geopotential height anomalies in (a) JJA and (b) DJF. The contours (gpm) are the PREIND differences from the annual mean. (+ve contours- continuous: -ve dashed)







Sea ice loss in 2007 mostly on the Pacific Ocean side associated with anomalous circulation (L'Heureux et al. 2008)

Yanase and Abe-Ouchi, (2010) found somewhat different pressure anomalies in the North Pacific Ocean at the Last Glacial Maximum, with a strengthened Aleutian low and a weakened Pacific High

Francis and Hunter (2007) found contemporary anomalies in the zonal wind component significantly impact ice-edge in the Bering Sea

Aleutian Low and associated storm tracks appear to intensify (Salathé Jr 2006)

Conclusions

Inception requires positive feedbacks otherwise local forcing must be unrealistically large

The North Pacific Ocean is important to the atmospheric response at 115 kyr BP

The atmospheric response to the Eemian forcing is thermally driven and is largest downstream of the nucleation region of the Laurentide Ice Sheet in the North Pacific Ocean

Contrary to others we find perennial snow in Alaska likely from the previous snow depth parameterization in CCSM3

The reasons for the modest cooling in the Subtropical Pacific merits additional research