An Early Eocene Climate Study: Initializing WRF with CAM Output Utilizing Modified WPS Procedures

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1. Introduction

The Early Eocene (~50Mya) was a time of extreme greenhouse gas warming and is characterized as one of the warmest periods in Earth's history since the Cretaceous. Previous modeling efforts have been unable to accurately recreate the warm, temperate climate in the Arctic, thus the mechanisms that led to this warmth are still poorly understood (Edwards et al., 2007; Giorgi and Mearns, 1991; Sloan and Barron, 1992). The problem is the coarseness of the resolution of global climate models (Giorgi and Mearns, 1991; Kirk-Davidoff et al., 2002; Leung et al., 2003).

One solution towards understanding these warming mechanisms is to utilize a dynamical downscaling approach. This allows for the parameterization of small scale physical processes and interactions not possible in coarse scale global climate models (Leung et al., 2003; Murphy, 1999). This ultimately leads to more accurate and detailed climate simulations, particularly at small scales (Feser, 2006; Leung et al., 2003).

This goal of this project is to outline a methodology for early Eocene downscaling through the use of the Weather Research & Forecasting (WRF) model version 2.2.1. Initial and boundary conditions were supplied by the Community Atmosphere Model (CAM). The following section describes the procedure used to input both CAM meteorological and geographic data into WRF.

2. Methodology

2.1. Regridding Surface Data

Surface data acquired from an existing T31 CAM simulation featured a Gaussian grid with points separated by approximately 3.75º latitude and longitude. At the time this work was completed, the geogrid program did not recognize surface data presented on a Gaussian grid, therefore, the surface data (topography, vegetation, and soil categories) were transformed to a regular lat/lon grid. Although longitudinal points are regularly spaced on the Gaussian grid, latitudinal positions are somewhat stretched. The maximum difference in latitudinal positions between the two grids was found to be less than 1º. Since this is small compared to the grid spacing of 3.75º, the surface data were simply reassigned to a regular lat/lon grid. Efforts to regrid the data using bilinear interpolation proved cumbersome and did not have any noticeable impact on the output from geogrid.

The Eocene continental outline was then generated to specify the land/sea mask. It is also useful for display purposes. CAM features a fractional land coverage (LANDFRAC) variable for each grid cell. However, WRF contains only water or land points, which are integral variables to some physical parameterization schemes and are used to specify masking while ingesting meteorological and surface data. To resolve this mismatch, any grid cell containing a partial land fractional coverage was converted to land or water based on whether the value was greater than or less than 0.5, respectively. A cyclic point was added to the landmask, creating the Eocene continental outline as seen in Figure 1.

2.2. Vegetation / Soil Type

The vegetation categories were processed next. CAM utilizes two variables to calculate vegetation; Plant Functional Type (PFT) and Percent of Plant Functional Type (PCT_PFT). Each grid cell in CAM contains four PFTs, each with a percentage of coverage for that grid cell, so a loop in the NCL script was used to determine which PFT had the highest fractional coverage. A new PFT array (called NEWPFT) was created. If the percentage of coverage for a particular PFT was greater than 70%, then the old PFT was directly copied to NEWPFT. If the dominant PFT category percentage was less than 70%, NEWPFT was assigned a value of 88, which we set as a placeholder for mixed forest. NEWPFT was then written out to an ASCII file. Figure 1 shows CAM vegetation prior to their conversion through the geogrid program of the WPS. It should be noted that the landmask variable has not been applied to this image, confirming that the water category (zero) and the other land-based vegetation categories exactly matches the Eocene continental outline as described above. The Eocene boundary condition data is much coarser than modern due to limitations imposed by sparse geologic proxy data as noted in the topography. The early Eocene Arctic was heavily forested with *Metasequoia* and conifer trees (Greenwood and Basinger, 1994), and this is reflected in the vegetation categories shown in Figure 1b with their corresponding listing in Table 1.

2.3. Topography

Topography was the other surface variable to be culled from CAM before running geogrid. CAM uses the standard deviation of topography height (SGH) instead of topography height directly. This was easily rectified by dividing SGH by 0.13 when reading in the variable to convert to topography height (Shellito 2008, personal communication).

It should be noted here that the SGH and PFT variables from CAM reside in separate NetCDF files, each with its own landmask variable. This posed problematic with topography in wetland areas near the coast. This inconsistency was resolved by comparing the two landmask variables. If the PFT landmask showed a grid cell to be water, and the SGH landmask indicated land, then that cell was assigned a water point. If the PFT landmask showed land, and SGH landmask equaled water, then that cell was designated land. For all assigned land points in this manner, or with topography height less than 10 meters, the topography was set to 10 meters. This creates a terrain drop everywhere along the coast. This will be handled by Geogrid. Topography at all the assigned water points was set to 0. The topography was then written to the ASCII file.

The geographic data now resides in an ASCII file, but in order to attain the required binary format, a FORTRAN script was used. FORTRAN scripts were written for topography, vegetation, and a new variable, soil type. These were placed in separate folders as the Geogrid portion of WPS requires that the binary files for each variable are placed in separate folders. Topography was read in directly, while the vegetation and soil type variables required conversion for use in WRF. "Where" statements were used to convert CAM vegetation categories to WRF's 24 category USGS landuse categories (see Table 1 for conversions). Shellito et al. (2007) used a constant soil type in the CAM run, thus based on the CAM soil composition; all land points were assigned a loam soil type in WRF. It was discovered that errors were incurred around 180º longitude in the interpolation caused by the way in which the data was written in a wraparound fashion, thus an extra longitude point was written in at this point. The binary files were written out and index files were created for each binary file.

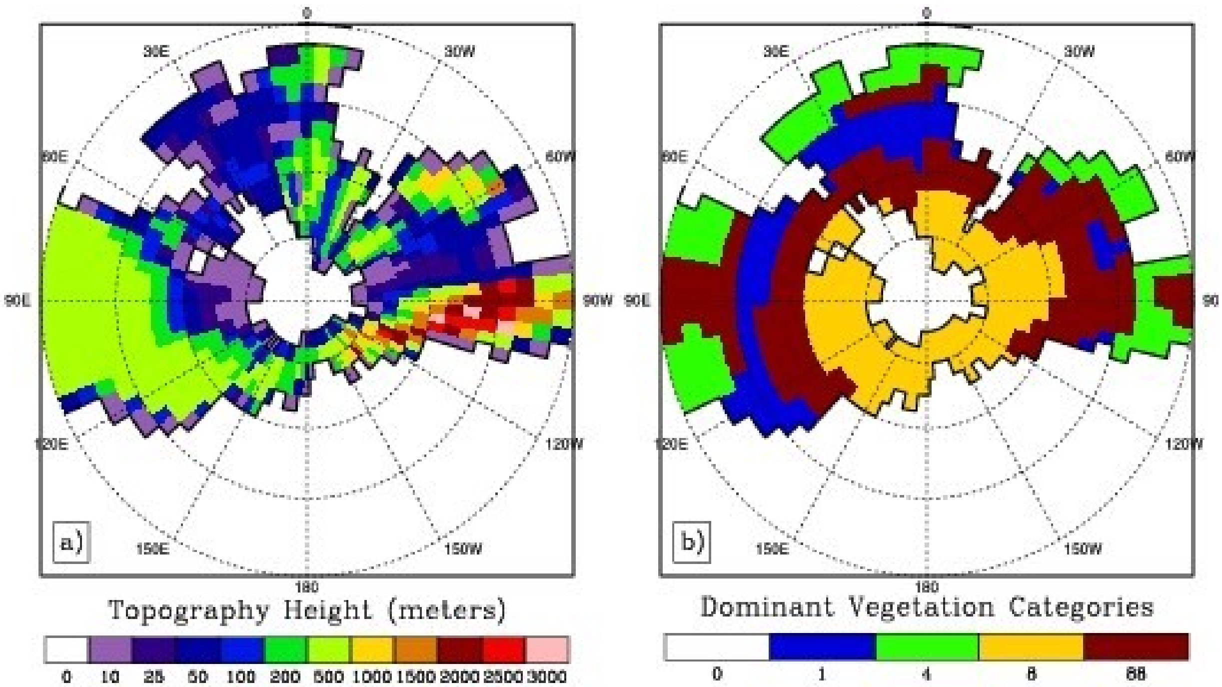

Figure 1: Geographic data from CAM prior to conversion showing a) topography height and b) vegetation categories.

CAM Category	CAM Category Desciption	WRF Category	WRF Category Description
0	Water	16	Water
1	Needleleaf Evergreen Temperate Tree	14	Evergreen Needleleaf
2	Needleleaf Evergreen Boreal Tree	14	Evergreen Needleleaf
4	Broadleaf Evergreen Tropical Tree	13	Evergreen Broadleaf
6	Broadleaf Deciduous Tropical Tree	11	Deciduous Broadleaf Forest
7	Broadleaf Deciduous Temperate Tree	11	Deciduous Broadleaf Forest
8	Broadleaf Deciduous Boreal Tree	11	Deciduous Broadleaf Forest
14	C4 Grass	7	Grassland
15	Corn	7	Grassland
88	Mixed Forest	15	Mixed Forest

Table 1: Vegetation categories input from CAM into WRF. The CAM categories were converted into the WRF categories using the NCAR Command Language.

2.4. Running Geogrid

The GEOGRID.TBL file was modified to include only terrain height, landuse categories (and to calculate a landmask from this field), and soil type. All links to modern geographic data were removed. The categorical variables (landuse and soil type) were given a purely “nearest neighbor” interpolation option, while topography used a “weighted four point” interpolation only. All variables used no smoothing. WPS was set to a polar stereographic projection with 45km resolution on a 200 X 200 grid centered over the North Pole. Geogrid was run and the results compared favorably with that from CAM output (Figure 2). Note that Geogrid smoothed out and lowered the terrain near the coast where the terrain had been set to 10 meters. Also, note that these images do not use a landmask, so the processed data are shown to exactly match the desired Eocene continental outline.

2.5. Running Metgrid

Now that Eocene boundary conditions have been processed through Geogrid, the meteorological data must be input. Ten years of CAM output at six hour intervals were provided by Shellito et al. (2007). The CAM model was run at T31 resolution (3.75º X 3.75º) with 2240ppm CO_2 using early Eocene boundary conditions. Meteorological data for the Arctic was read in and average for all points along and north of 60ºN. The data was then time filtered using Fourier and spectral analysis to identify regime transitions at high latitudes on synoptic timescales for input into WRF.

Once such an event was identified, the data was prepared for input through the WRF Preprocessing System (WPS) version 2. WPS requires the use of unformatted binary format for input data; however, the output from CAM is in NetCDF format. The conversion to binary format was accomplished through the use of the NCAR Command Language (NCL) and FORTRAN.

Since CAM meteorological data are also in NetCDF format, the Ungrib program is replaced by another NCL script. The meteorological data is ingested and interpolated to isobaric levels (CAM uses a hybrid vertical level system that transitions from terrain following at low levels, to isobaric at upper levels), and written out to binary format. Again, WPS requires unformatted binary writes, so a FORTRAN subroutine was utilized within NCL to open a file and write out the data using NCL’s WRAPIT function. The files were named with the “FILE:” naming system as required and sent directly to Metgrid. As long as all three dimensional variables contain the same number of vertical levels, Metgrid runs without issue. This may require some adding or removing of “fill level” lines in METGRID.TBL depending on which variables are read in. This produces the required input files for WRF. WRF can then be run without modification.

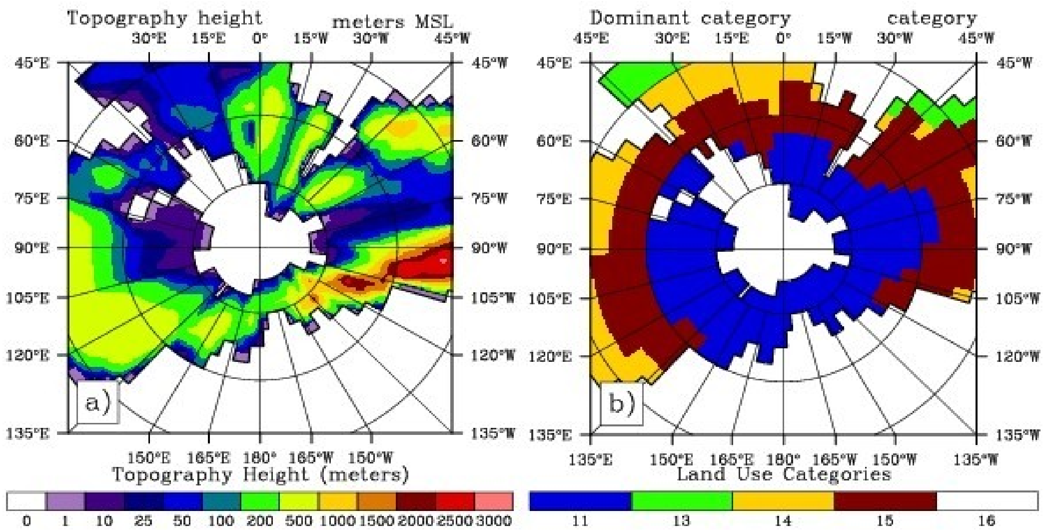

Figure 2: Output from Metgrid showing a) topography height and b) vegetation categories.

III. Discussion

This study is important to regional paleoclimate modeling in a number of ways. Rather than viewing the Eocene from a purely climatological approach, this study allows us to determine what weather events or patterns led to the observed climate indicators. We can now look at variability on short time scales and in higher spatial resolution. This project will allow for the use of WRF in other paleoclimate work by demonstrating how to use boundary conditions other than modern. The use of WRF's physics packages could prove to be extremely useful.

IV. References

Edwards, T. L., M. Crucifix, and S. P. Harrison, 2007: Using the past to constrain the future: how the palaeorecord can improve estimates of global warming. Progress in Physical Geography, 31, 481-500.

Feser, F., 2006: Enhanced Detectability of Added Value in Limited-Area Model Results Separated into Different Spatial Scales. Monthly Weather Review, 134, 2180 – 2190.

Giorgi, F., and L. O. Mearns, 1991: Approaches to the simulation of regional climate change - A review. Reviews of Geophysics, 29, 191 - 216.

Greenwood, D. R., and J. F. Basinger, 1994: The paleoecology of high-latitude Eocene swamp forests from Axel Heiberg Island, Canadian High Arctic. Review of Palaeobotany and Palynology, 81, 83 – 97.

Kirk-Davidoff, D. B., D. P. Schrag, and J. G. Anderson, 2002: On the feedback of stratospheric clouds on polar climate. Geophysical Research Letters, 29.

Leung, L. R., L. O. Mearns, F. Giorgi, and R. L. Wilby, 2003: Regional Climate Research. Bulletin of the American Meteorological Society, 84, 89 - 95.

Murphy, J., 1999: An Evaluation of Statistical and Dynamical Techniques for Downscaling Local Climate. Journal of Climate, 12, 2256 - 2284.

Shellito, C., Kiehl, J., Lamarque, J., and Sloan, L., 2007, A New Look at the Early Eocene Arctic Climate in CCSM3: Sensitivity to pCO2 and Basin Geography, *Eos Trans. AGU*, 88(52), Fall Meet. Suppl., Abstract PP33A-1010

Sloan, L. C., and E. J. Barron, 1992: A comparison of Eocene climate model results to quantified paleoclimatic interpretation. Palaeogeography, Palaeoclimatology, Palaeoecology, 93, 183 – 202.