Clim. Past Discuss., 5, C828–C833, 2009
www.clim-past-discuss.net/5/C828/2009/

Climate of the Past Discussions

Interactive comment on "Paleometeorology: visualizing mid-latitude dynamics at the synoptic level during the Last Glacial Maximum" *by* M. B. Unterman et al.

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Received and published: 16 October 2009

General Comments:

The authors would first like to thank all three referees for their constructive and in-depth comments. This study is an explorative first-step look into synoptic scale LGM simulations and this paper is its first report. As we are diving into more process studies within the hourly data, as well as another longer hourly integration based at ORNL, we didn't want to report on everything just yet, and more or less focus simply on northern hemisphere LGM storminess. Other finds, including the second integration will be reported on in detail in future submissions.

Specific Response to Paul Valdes:

The fact that a more in-depth study of the storm tracks and their behaviour during the LGM has not been carried out is in part due to the limited period of the integration, less than a year. The limited nature of the synoptic scale simulation is off-set by the multi-year in-tandem climatological run – a simulation using the same boundary conditions but saved at different temporal resolution (cf. Kim et al. 2008). This provides a first-look analysis of synoptic scale features using the LGM boundary conditions allowing us to highlight the benefits of higher resolution in simulating storm tracks and cyclones in a paleoclimate simulation with a view to encourage longer runs at such resolutions, including our own future work. It would be nice to include a synoptic T42 comparison with equivalent animations and cyclone properties. However, a rather in-depth comparison of the same simulation at lower temporal scales was done in our partner study of Kim et al. (2008) to show the usefulness of the T170 resolution used here. One example is the correlation between surface temperatures and groundwater data. Another comes in the form of precipitation along the Indian monsoon region where at T42 a band of precipitation runs orthogonal to the Tibetan Plateau while regional precipitation along the Eastern Ghats is non-existent (cf. Figures 2 through 9, Kim et al. 2008). We could also reference the recent paper on extra-tropical cyclones (Bengtsson et al., 2009) in high-resolution models where great lengths were taken to show that at resolution T213 extra-tropical cyclones were simulated with great realism, including their intensities, structure and lifecycles – as compared to similar systems at T63. The does point out however the need to restructure the introduction of this paper to make these points more clear. Consequently, Paul is correct in that the introduction should be more developed and we should have contrasted with a few other studies such as Kageyama and as suggested by Huber the paper by Donahoe and Battisti. We will do this in the revised version following the interactive discussion.

Paul also asks if the 1 hourly saves are really necessary. Well, for the animations it certainly is as otherwise it would not highlight important scientific results such as all the characteristics in LGM storm lifetimes, starting simply from storm development (cf. Bengtsson et al. 2009 as well). Three hour resolution would be sufficient for fast moving storms, and mesocylones if the integration is at sufficient spatial resolution such as T170 here. However, the hourly saves were deemed necessary as a future work may be aimed at in-depth process studies such as wave-wave interactions and a potential no-analogue scenario below the ice margin. The high frequency data is also very useful for looking at the mechanisms that are active in cyclone formation and development that can occur on relatively fast time scales, for example the occlusion process where the storm changes from baroclinic to barotropic can occur over a period of 12-18 hours.

Specific Response to Matt Huber:

Huber is right in that qualitatively the storm track would be quite similar between T42 and T170 at least in terms of the number of synoptic scale storms that could be identified. However, what the higher resolution gives us is a better simulation of the storms (see Bengtsson et al., 2009) and hence a more realistic interaction with their environment – an example of this comes in the in-tandem partner study of Kim et al. (2008) where we ran the same boundary conditions for a longer integration. Here we compared in depth the T170 results to a T42 comparison. One example of this comes in the Andes where LGM and modern P-E values are compared and a more accurate distribution is found in the T170 without introducing new physics. Another example, which would influence local storm tracking (and mentioned in the Valdes response), comes in the Indian monsoon region where at T42 a band of precipitation runs orthogonal to the Tibetan Plateau and regional precipitation along the Eastern Ghats is non-existent in the lower resolution version. In terms of the synoptic scale simulation, the resolution in fact would make a big difference as described in detail in Bengtsson et al. (2009). The shear number of storms tracked would be relatively similar to that at T42, but the distribution of storm intensities would be different as well as the loss of features in storm development.

Huber's comment on using animations is also correct in that their use needs to be focused on enhancing scientific understanding rather than just showing 'gee-wiz' material. I think that their use in the paper achieves this by showing the greater realism of the simulation of storms, surface temperature fluctuations, and convective precipitation all the while not forgoing normal dynamical approaches. Comparing with T42 here might have been useful but not critical to the message. A more in-detailed comparison of our results at different resolutions can be found in Kim et al. (2008) Figures 2 through 9. However, the question of the appropriateness of the variables used in the animation is interesting and of course more variables could be displayed as well – we will include upper level U,V, to demonstrate properties of the jet, and geopotential height (zg) as suggested by Huber in our final revised version.

In terms of the software packages used in this study, Huber makes some good points in terms of the efficiency of using CDO and others. In fact, although we focused on the Matlab scripting in the methods section of this first submission, we have created animations using a combination of NCL and their visualization package and even worked with GRADS, CDO and the like – the geopotential height animation we are including in the final revised version is an example of our use of NCL, and we will revise the methods section to reflect this. Overall we have also found that the internal methods used in NCL are very efficient like CDO and do come in handy for certain calculations. However, we still feel as though the Matlab package created is specifically more flexible for animation frame generation and maintains a high resolution colour output (256 colours) for our high resolution model output. Nonetheless we will modify our methods section to reflect our work with CDO and NCL and not solely focus on our Matlab script.

Specific Response to Anonymous:

The aim of this paper was indeed to introduce this kind of exploratory simulation at this resolution, during a climate extreme such as the LGM, and to use high resolution visualizations to demonstrate the synoptic scale. The referee is indeed correct in that we should have better explained the scientific importance of using such forms of visualizations and the benefits of doing so. We also feel that, along the lines of Huber's comments, we should include more animations that are also more scientifically interesting than just the single surface animation provided on the initial paper. We will do both in the final revised paper as this is an important point. Specifically we will be including upper level winds, geopotential height and geopotential height anomaly animations to highlight key points that were not sufficiently described in the results section of the initial submission.

Bengtsson et al. (2009) demonstrated that you do not necessarily get that much difference in the physical number of synoptic scale storms when comparing high and low spatial resolution integrations but what you do get is better representation of the properties of the storms such as development and growth rates, as well as the varying amounts of different storm intensities - the later of which being of key importance to a study of this kind. Generally it would be nice to have done a third in-tandem simulation at a lower resolution but with synoptic scale outputs, but the resolution comparisons in the climatological run explain most of the referee's concerns outside of those already expressed in Bengtsson et al. (2009). It should be noted that for mesoscale processes an even higher resolution would probably be needed. Nonetheless, in our climatological run of Kim et al. (2008) T170 outputs are compared in detail to outputs of the same parameters at T42 (cf. figures 2 through 9). At first glace it is easy to see differences that would play a key role in features within the synoptic scale outputs such as the intricacies of surface temperature around and within the rocky mountains – something simply attributed to the better resolution of topography in the T170's case. Another key feature to point out is within the precipitation field where at T42 a band of precipitation actually runs orthogonal to the Tibetan plateau while at T170 it is more realistic. Within the same field, the south eastern Indian mountain range of the Eastern Ghats is visible at T170 while the precipitation response is removed at T42. These comparisons of resolution on important climatological, as well as synoptic scale parameters should be brought up again in the introduction of this paper – something that could also help introduce the comparisons of the climatological run.

Though we didn't degrade the data to determine the bounds of temporal resolution, we would argue that going below a 3-hourly save would start to blur features we highlight here – 6-hourly might be fine by way of tracking but visualizing storm development from beginning to end would be impossible. As we mentioned in Paul's response, the high frequency data is also very useful for looking at the mechanisms that are active in cyclone formation and development that can occur on relatively fast time scales, for example the occlusion process where the storm changes from baroclinic to barotropic can occur over a period of 12-18 hours. The high temporal resolution is also beneficial for looking at storm structure and energetics and the lifetimes of short-lived polar lows which sometimes only last on the order of 24 hours. We will point out examples of this in the revised introduction. For future analyses we plan on looking into certain process studies such as a potential low variability standing eddy below the ice margin and wave-wave interactions - using hourly saves for these for instance would seem best. We could highlight the finds of Bengtsson et al. (2009) to highlight some of these points.

To compare the synoptic storm tracking with Eulerian statistics would simply require more data. This however is something we do not have yet given the exploratory nature of this study (cf. Hoskins and Hodges, 2002) – it would be something of value to look at after another integration is done at the same resolution.

Interactive comment on Clim. Past Discuss., 5, 1883, 2009.