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Interactive comment on "Mapping technique of climate fields between GCM's and ice models" *by* T. J. Reerink et al.

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Response to the comments by D. Roche and an anonymous referee:

This manuscript documents in detail the technical issues of projecting and interpolating climate fields between geographical and equidistant based coordinate systems. Combined with the OBLIMAP code, in which the equations from this manuscript are literally used, we intend to provide the ice and climate community a software package which is easy to understand, to implement, and to extend.

Concerning the first important remark of Referee #1:

Although we indeed independently derived the oblique stereographic projection and its inverse, we agree Snyders work should be cited and discussed. The oblique equations

in Snyder (1987) are obtained by taking the polar projection with an additional translation to the oblique case, while in our case we directly derive the oblique case by finding the points of intersection of several surface equations and parameter representations. In his chapter 5 Snyder discusses partly the oblique translation with its exceptions and their alternatives, intermediate derivations are omitted. It is hard to abstract his final oblique stereographic equations, but we have not found a better hint to derive his equations so far. Rutt (2009), a nice example of model documentation, discusses in section 6 the mapping in Glimmer, however it does not give the details as we do and in the latest Glimmer manual we could not find more than a reference to Snyder.

For our purpose the data should be projected on well defined and well oriented grid planes (of any size and at any location); this requires an accurate and clear derivation. In case of OBLIMAP any grid has the Cartesian orientation relative to the normal vector on the spherical surface, which implies that a continuous collection of projected grid planes over the globe can be obtained including the polar cases. With our derivation we obtained a single set of projection equations which were successful in all eight octants (and borders) of the spherical surface, and at the oblique poles. We think the derivation in our appendices are clear, complete, and relatively easy to follow, and we feel supported by the comment of D. Roche (Referee).

With the expertise of our projections, we implemented finally successfully for all eight octants the Snyder equations in OBLIMAP. Both methods give the same results for our applications, in case we adopt our α into the Snyder projection instead of k_0. Working with α is more intuitive, and an α for an optimal projection is estimated by OBLIMAP in advance, so a least squared method (see Snyder p. 157) can be avoided.

We recommend our method including the derivation because it is well documented, it concerns a direct oblique approach, it guarantees a continuous collection of well defined Cartesian orientated projection planes over the globe, it uses an intuitive angle α to define an optimal projection plane, and because the OBLIMAP inverse projection is two times faster in computation avoiding the use of both arcsin and arccos which are vertical-asymptotic functions.

Furthermore, our direct oblique methodology might be of interest in future applications of high accuracy: to derive an oblique stereographic projection and its inverse in case the earth surface is represented by a geoid, or by a function even closer to the earth topography. In that case S should be replaced, but T remains a sphere through M'.

We will improve the manuscript by discussing these Snyder related issues in the introduction. Besides we decided to include the inverse oblique stereographic projection of Snyder in OBLIMAP, so one has the possibility to use the Snyder equations. This allows comparison of both methods, but also serves as an illustrative example for including in OBLIMAP one of the many other (azimuthal) projections which are available in Snyder.

Concerning the second important remark of Referee #1 and the first remark of D. Roche (Referee):

With OBLIMAP we developed a general mapping package. In most work in which climate fields are projected to an ice model the polar stereographic projection is used, so by changing to an oblique projection, the oblique stereographic projection was a logical choice. However, with the name OBLIMAP we anticipated, the OBLIMAP routines were designed in a way that adding other oblique projections is really easy. We think that it is a good suggestion of Referee #1 to consider the oblique Lambert azimuthal equal-area projection. We believe the oblique stereographic and the oblique Lambert azimuthal equal-area are the two projections which are of most interest. Therefore we decided to include the oblique Lambert azimuthal equal-area (Snyder p. 182-187) in the OBLIMAP code.

The stereographic projection is conformal and azimuthal (i.e. perspective, see Snyder p. 154), and by choosing an optimal projection plane in a parallel manner relative to the tangent plane (in our case with α) it can be close to equal-area. Conformal means that the relative local directions are true at any given point (Snyder p. 4), which might

be important from ice modeling perspective to keep a match with the ice flow directions. The Lambert azimuthal equal-area projection is equal-area and azimuthal (see Snyder p. 182) but non conformal. Its equal-area property is interesting for mapping of conserved quantities. However, citing Snyder at pages 3 and 5: "It cannot be said that there is one 'best' projection for mapping. It is even risky to claim that one has found the 'best' projection for a given application" and for areas as large as the US: "a trained eye cannot often distinguish whether the map is equal-area or conformal". In our applications both projection methods give very similar results indeed. For small areas one could argue that the distortions are that small that an equal-area method is convenient because of surface conservation (but be aware this doesn't imply exact volume conservation).

The reason to use an oblique approach instead of a polar approach is that only with an oblique projection one can choose an optimal projection for any area on Earth. Projecting a local area at low latitude with a polar projection will unnecessary lead to larger distortions (because the projection plane cannot be centralized). Furthermore, it is inconvenient because such an area will be far off the grid centre, and one has to determine a shift. To and fro mapping of such 'oblique' areas will still yield good results with a polar projection, because the inverse is exactly inverse, but the mapped fields in the ice model will be more and more distorted for areas at lower latitude. We compared (after shifting) oblique and polar projected fields, but that is awkward because the difference in projection causes a different 'stretching' of the area, so the large differences are at ice model grid points laying in areas with large gradients because actually not the same points are compared: immediately causing large differences. Once again: in OBLIMAP the optimal projection is chosen for any given centre, which is of large practical convenience.

By adding the oblique Lambert azimuthal equal-area projection and its inverse to the OBLIMAP code, we got already one step further than initially intended with this paper. Both referees appreciate the clear structure of the paper. We therefore propose to address the possibility of using this oblique Lambert azimuthal equal-area projection and to generally discuss and compare these results in the discussion, but maintain the current structure of the paper which is based on the oblique stereographic projection.

Concerning the third important remark of Referee #1:

Of course we can compare the integrated values of the mapped area of both grids, but the involved GCM points which correspond to the edge points of the IM grid will not represent exactly the same area. We therefore decided to compare the area-integrated values per surface unit. This overcomes a difference in integrated values due to a possible small mismatch of the represented grid edge area. Both these IM and GCM values could be multiplied by e.g. the IM area to obtain a representative estimate for the total mapped area.

At the GCM grid the area per grid point has to be calculated for the spherical surface, which is complicated in case the four corners (situated between the grid points) all have different λ and ϕ coordinates. Using the standard surface integral on a sphere is not appropriate in that case. The RACMO data is defined on a reduced Gaussian grid which causes this complicated situation, but in general this grid is constructed in that way that the grid points represent equal areas. If we assume that all this reduced Gaussian grid points are equal in area, we easily can obtain the area integrated value. The CCSM grid points can be weighted by the spherical surface integral to obtain the area integrated value. Because the high latitude points represent smaller areas, the average values for CCSM in Table 3 will change significantly because these points were equally weighted instead of area weighted.

We consider the results of an optimal oblique stereographic projection and the oblique Lambert equal-area projection and did not find much difference from which we conclude that in those cases the 'stereographic' area distortion probably will be rather small. A possible second order effect arising from a correlation between the local area distortion and e.g. the mass balance is therefore not expected to be important. How-

ever, an area integrated approach is a useful check.

Concerning the minor remarks of Referee #1:

We adapted and corrected almost all minor comments as suggested, a few comments are addressed here:
(2) We think this is mentioned at p. 937 line 12-13.
(4) Wrong (typo) indeed: it should be R cos(α), as in equation (A2).
(6) Snyders equations are not 'spelled out', how to handle the arctan is defined in note 2 at page ix of Snyder. A drawback in his equations are the use of arcsin and arccos. We presented our inverse equations in a computationally beneficial form. (10) We used the standard Mean Absolute Error (MAE). RMSE is preferred above the MAE in case large errors are particularly undesirable (often for measurement comparison). We chose the simplest and intuitive MAE, but this choice is arbitrary. We suggest that we adapt at p. 951 line 6 the text in such a way that it is clear we use absolute errors; a standard MAE method.
(24) and comment (13) of D. Roche:
The figures are most informative and convincing. We included the figures of nine miscellaneous experiments, they represent tests with: two GCM data sets, which differ in resolution, in grid distribution, and in global extent, different IM extents, different amount of involved mapped points, areas with complicated patterns because of the topography (e.g. islands), local areas being part of a larger (glaciated) system, areas at the border of the GCM domain, areas covering data gaps, areas covering the Greenwich longitude, and a spread of oblique locations. We could omit the figures of Iceland because it resembles the Svalbard case. Ellesmere is an area at the border of the RACMO covered area, has a demanding topography, and its amount of involved mapped points is nicely intermediate.

Concerning the (remaining) remarks of D. Roche (Referee):

(2) We can discuss our method for areas as large as an oblique Hemisphere or even

larger in an extra paragraph in the discussion. As an example we added the specific configuration file for the Northern Hemisphere to OBLIMAP. While testing such extended cases we encountered situations in which our optimal alpha estimation is not longer unambiguous, this is improved by giving an advising message. Additionally, we derived the equations for an optimal alpha and the corresponding NX * dx extent for a squared IM grid for a given angle γ being equal to the angle ICM' in Figure 2. This γ = 45 degrees for half the globe. With help of some trigonometric calculus we obtained:

$$\alpha = 2\text{arctan}\left(\sqrt{\frac{1}{2\pi}}\tan(\gamma)\right) \quad (1)$$

$$N_x\,\Delta x = R\,[1+\cos(\alpha)]\tan(\gamma) \quad (2)$$

for $0 \leq \gamma \leq 90$ degrees. With this equations it is easy to project a certain part of the globe, without trial and error. Of course taking a very large projected area will increase the mapping errors.
(3) We can provide a zoom-in panel (some work), but depending on the final figure size we can decide about that. (The N with dot will be removed from the figure.)
(4)-(12): Will be adapted.

We thank the anonymous referee and D. Roche (Referee) for their useful comments, we think the manuscript and the OBLIMAP package have benefited from them.

Interactive comment on Geosci. Model Dev. Discuss., 2, 935, 2009.