Dynamic Hydrological Discharge Modelling for Coupled Paleoclimate Runs of the Last Glacial Cycle

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Motivation

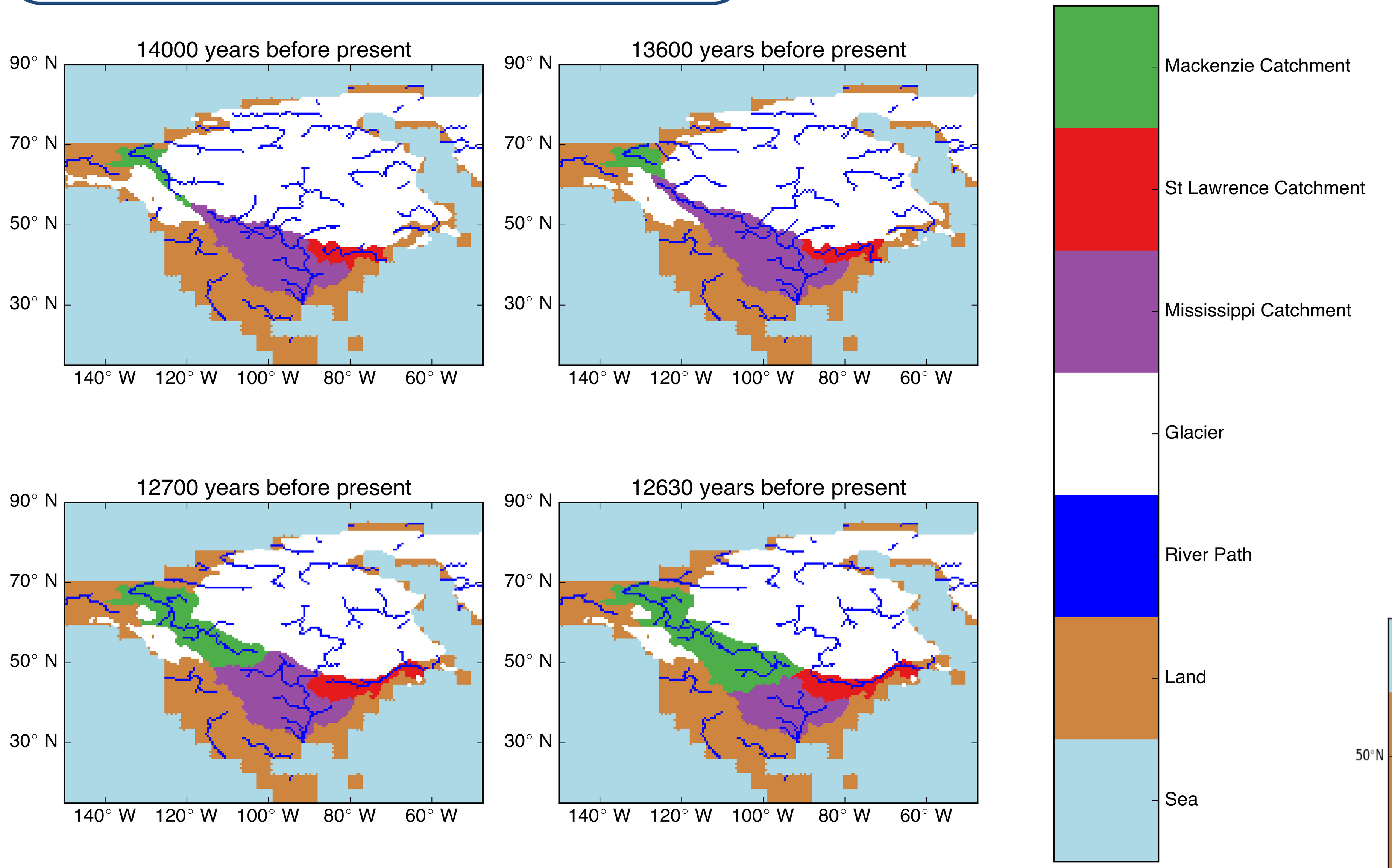
- The continually evolving large ice sheets present in the Northern Hemisphere during the last glacial cycle caused significant changes to river pathways both through directly blocking rivers and through glacial isostatic adjustment. These river pathway changes are believed to have had a significant impact on the evolution of ocean circulation through changing the pattern of fresh water discharge into the oceans.
- A fully coupled ESM simulation of the last glacial cycle thus requires a hydrological discharge model that uses a set of river pathways that evolve with the earth's changing orography.
- Large periglacial lakes formed along the edges of the glaciers. These stored significant quantities of freshwater that was later release in outburst floods as new outlets opened up. Both this storage and such outbursts may have had a significant impact on ocean circulation.

1. Aims

- Develop a sufficiently accurate method for periodically updating the river directions and flow parameters.
- Develop a model for both periglacial lakes and also African paleolakes during the African Humid Period.

2. Challenges

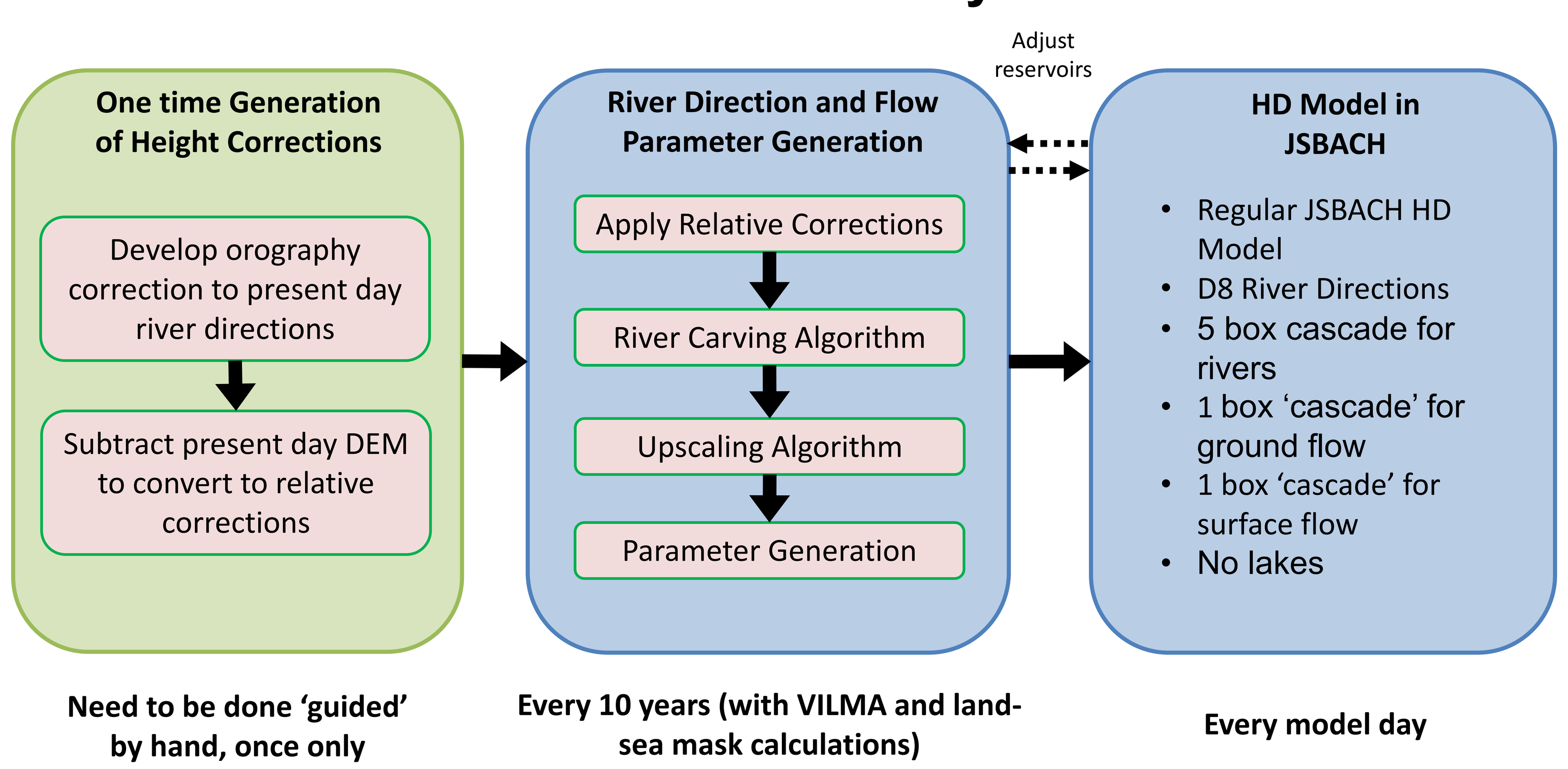
- The natural scale determining the path of rivers and lake basins is far smaller than the scale of simulated paleo-orographies.
- Narrow valleys are not resolved in coarse orographies and thus false inland sink points can be produced.
- Need to use an existing hydrological discharge model embedded in JSBACH that runs on a half degree scale.
- New model must fit within a wider coupled earth system modelling framework for transient paleoclimate runs. Must be fully automatic and computational costs must be kept to a minimum.



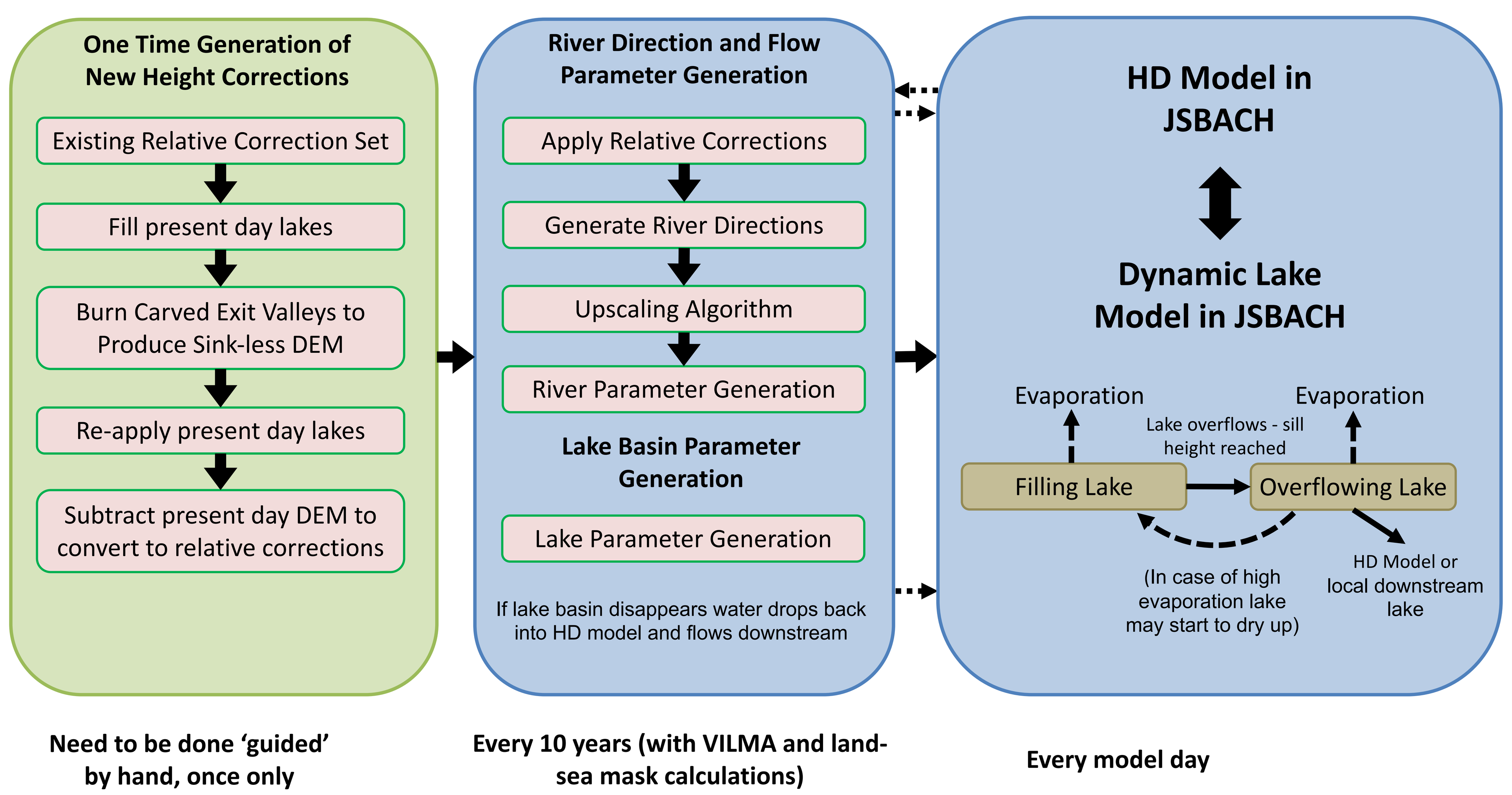
Comparison of rivers generated using the method presented here for four times during the last deglaciation using the ICE-6G_C orography reconstruction. Rivers are shown where the cumulative flow to a given grid cell (on the 0.5 degree grid) is greater than or equal to 75 cells. The catchments for the Mississippi, St. Lawrence and Mackenzie rivers are marked.

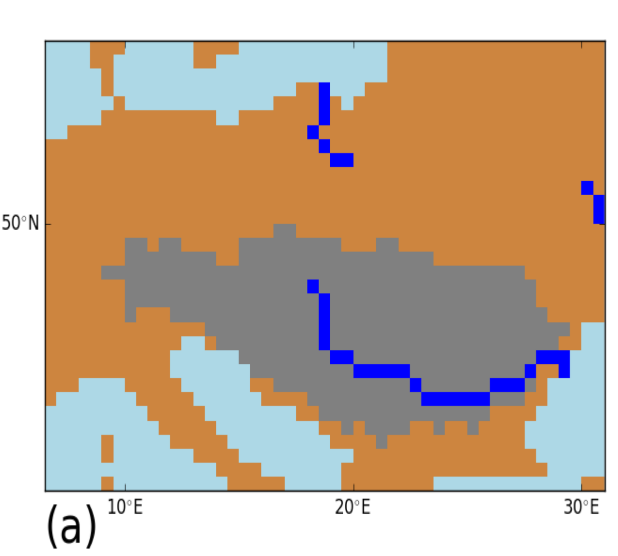
3. Method

I. For Rivers Only

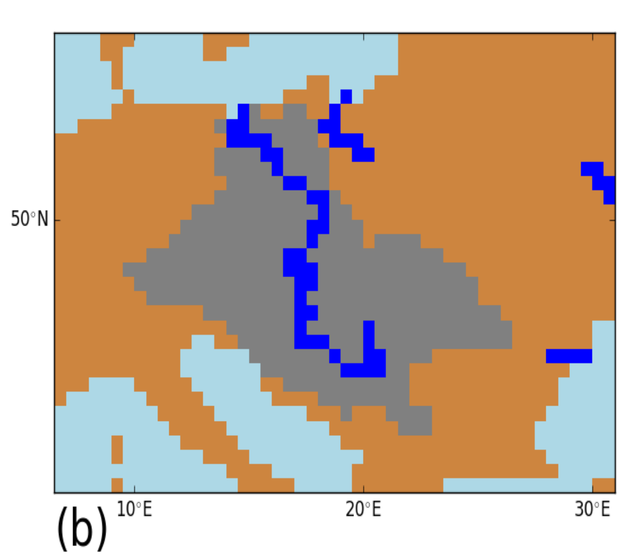


II. For Rivers and Lakes Together (under development)

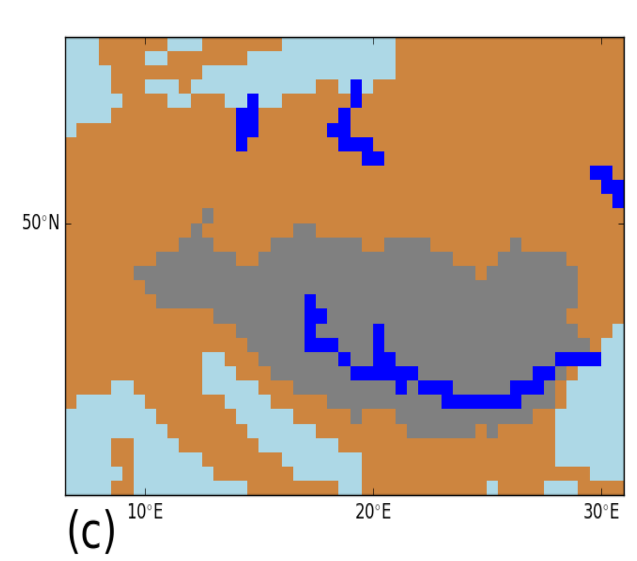




An example of the need for relative corrections to the orography: This shows the Danube as it appears in the current non-dynamic JSBACH HD model setup - close to reality.



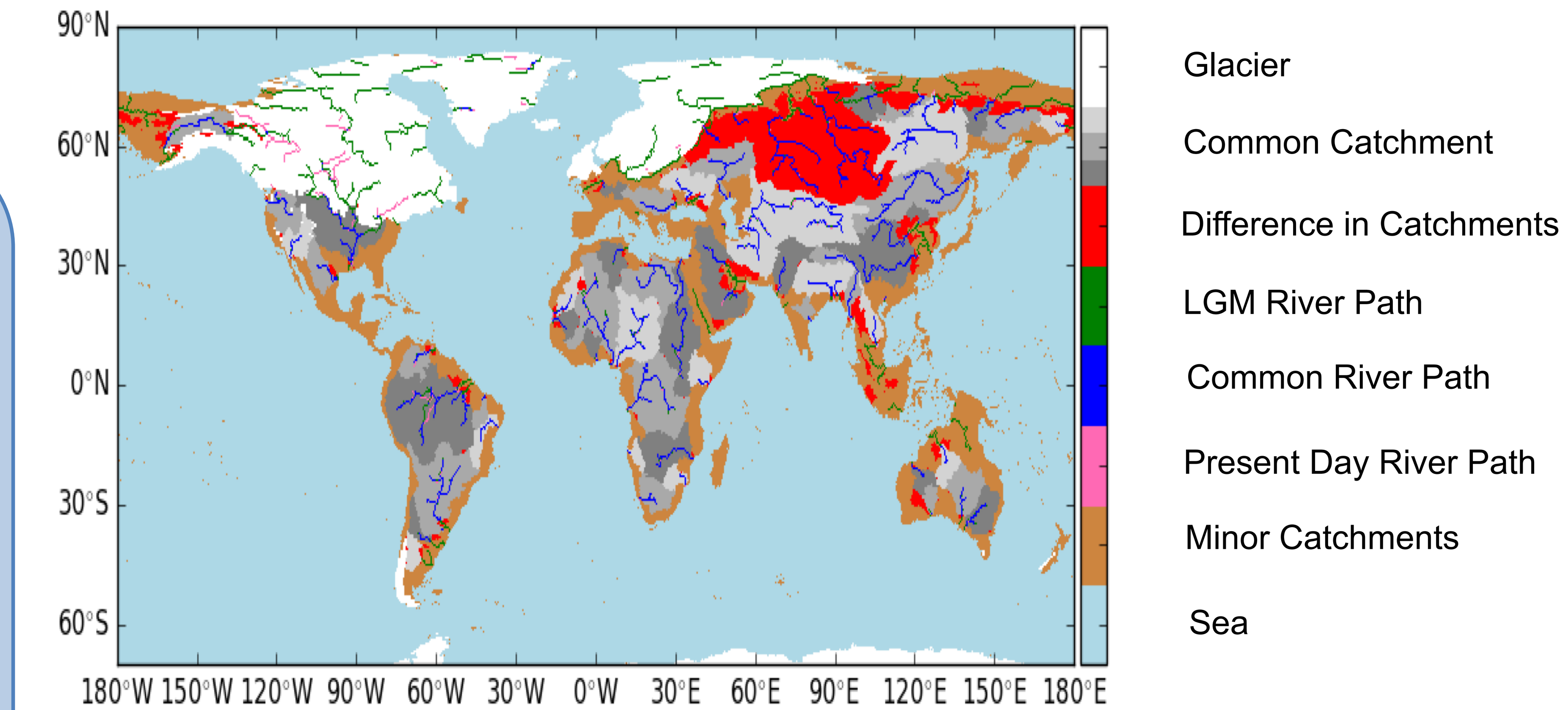
This shows the Danube catchment produced by applying the method presented here to a present day orography without applying any relative corrections. The Danube can't get through the Iron Gates gorge and instead flows into the north sea.



This shows the Danube catchment generated by applying the method described here after a few selected cells in the orography have had height corrections applied. Fairly good match to catchment of non-dynamic setup.

4. Results

- The river catchments derived from a 10 minute present day orography match the manually corrected river directions used in the current non-dynamic JSBACH setup to within 5% in most cases. All significant disagreements are due to minor deficiencies in the current non-dynamic JSBACH setup's manually corrected river directions.
- The upscaling algorithm up-scales catchments to within a accuracy of 1- 2% or less in almost all cases.
- Trial runs with and without this method show it has a significant effect on ocean circulation at the LGM.



The most significant rivers and catchments at the LGM compared to the present day generated using the ICE-6G reconstructed orography. Rivers are shown where the number of other cells flowing to a given cell is greater than 100. The various colours show various rivers that existed only at the LGM (green), only at the present day (pink) or at both (blue). Major river catchments common to both times are shown in three shades of grey. Red shows major differences. True sinks have been removed.

Conclusions

The method presented here provides an effective method for the generation of dynamic river directions and flow parameters for paleoclimate simulations which can be run on the existing modelling framework within JSBACH (the land surface model of MPI-ESM1). This method will be used in fully coupled paleoclimate runs made using MPI-ESM1. Tests show this procedure reproduces the known present-day river network to a sufficient degree of accuracy and also produces flow parameters that give satisfactory response characteristics. Work is ongoing to add the possibility of modelling paleolakes to this setup.

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Reference: Riddick, T., Brovkin, V., Hagemann, S., and Mikolajewicz, U.: Dynamic hydrological discharge modelling for coupled climate model simulations of the last glacial cycle: the MPI-DynamicHD model version 3.0, Geosci. Model Dev., 11, 4291-4316, 2018.

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