DFG Schwerpunktprogramm Antarktisforschung

Ice-water interactions in the subglacial Lake Vostok, Antarctica: numerical simulations

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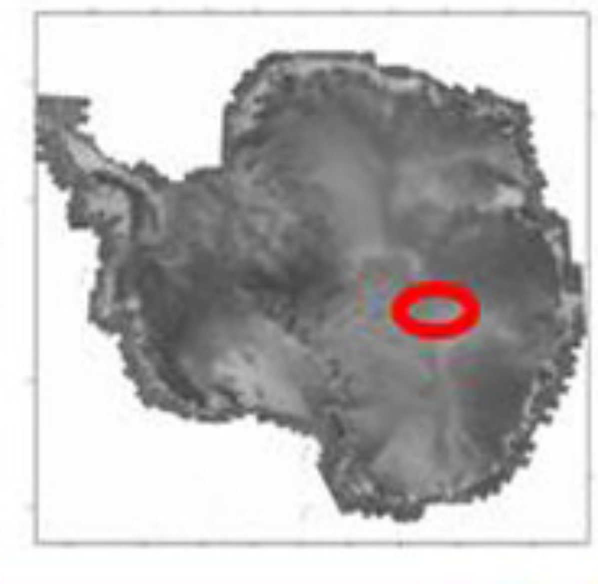
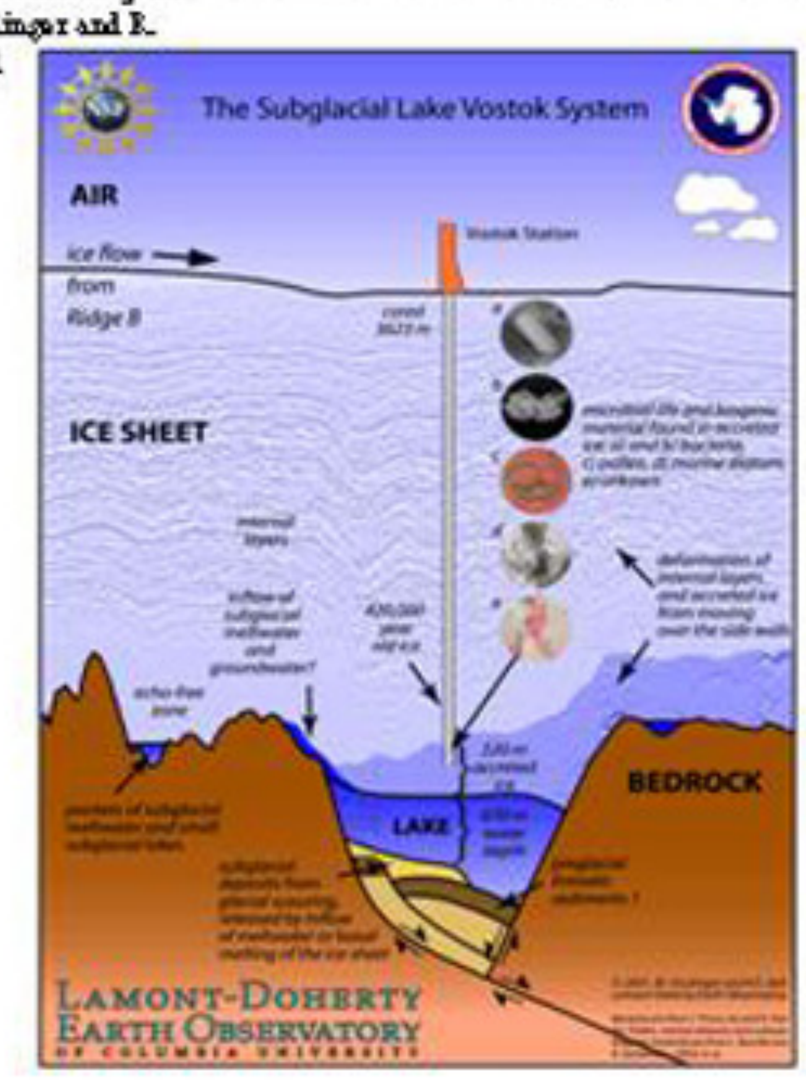
Abstract: During the last few years a wealth of information about the physiography and the physical conditions of the subglacial Lake Vostok has been gathered. The availability of updated data sets of ice thickness and bedrock topography for the subglacial Lake Vostok, based on recent results from airborne geophysical measurements, allowed a new series of model runs, investigating the physical lake conditions. New ideas about governing processes and the lake composition also require a series of new experiments. A 3-dimensional fluid dynamics model is thereby used to investigate the circulation regime within the lake. This model was already used before to successfully determine melt and freeze regimes with simpler lake geometry. First results in a number of new simulations are now available.

Introduction: Lake Vostok, located in central East Antarctica (Fig. 1), constitutes a potential extreme habitat for microbial life (Karl et al., 1999). In the absence of direct measurements, knowledge can only be gained from numerical modelling efforts. Recent investigations have proposed distinct zones of subglacial melting and freezing (Mayer and Siegert, 2000; Siegert et al., 2000). A 220 m thick layer of refrozen 'lake ice' beneath Vostok Station has been discovered (Jouzel et al., 1999). Wüest and Carmack (2000) described the principal physical environment within the lake. Williams (2001) and Mayer et al. (2003) applied a 3D ocean circulation model to understand water flow within the lake. Here, we continue the investigations of Mayer et al. (2003) using recent measurements of the lake geometry (Studinger et al., 2004).

Figure 1: Position of Lake Vostok, Antarctica (indicated by a red ellipsoid) shown on a RADARSAT composite image of 1997 (Jezek et al., 2002, image editing by T. Krumpen, AWI, 2006)



Below: Sketch of Lake Vostok environment by M. Studinger and R. Bell



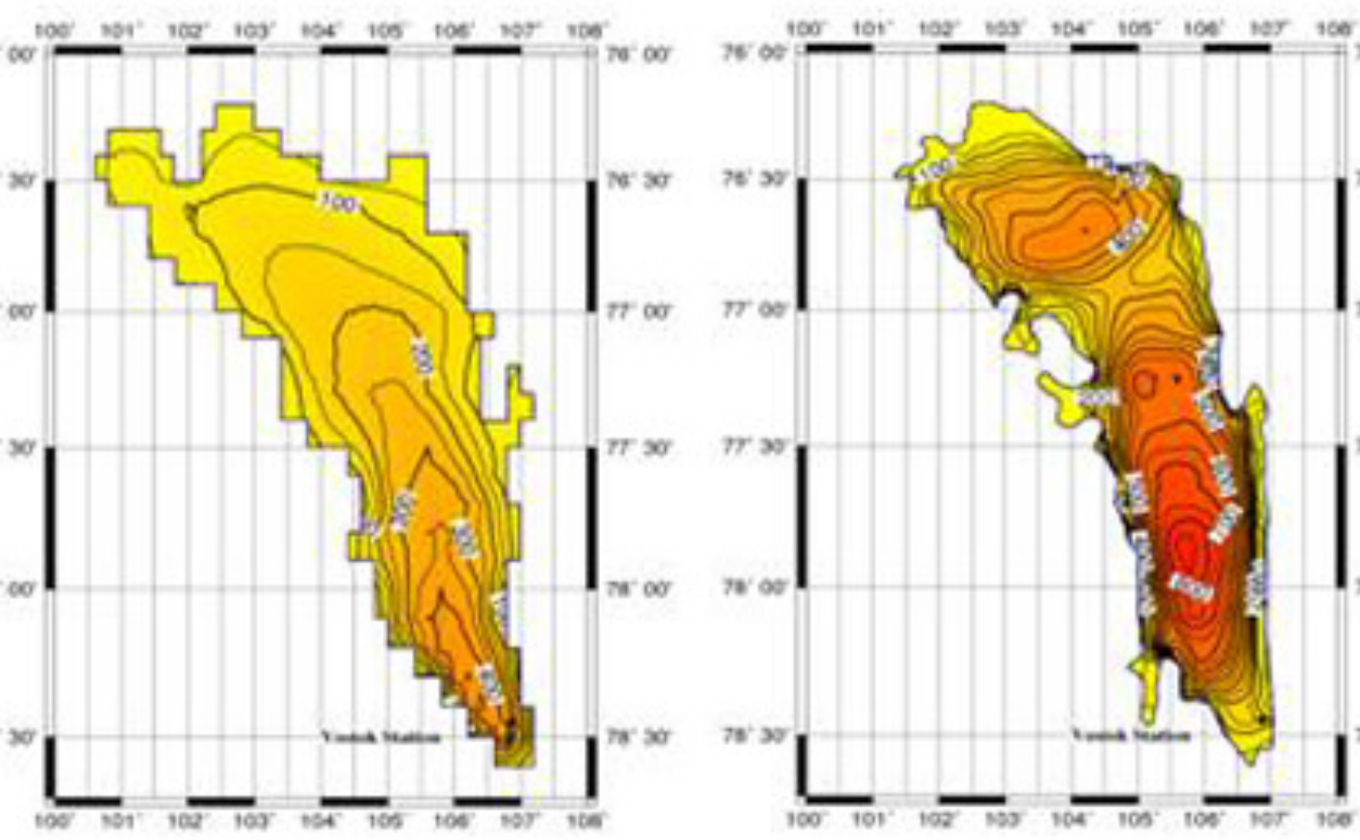
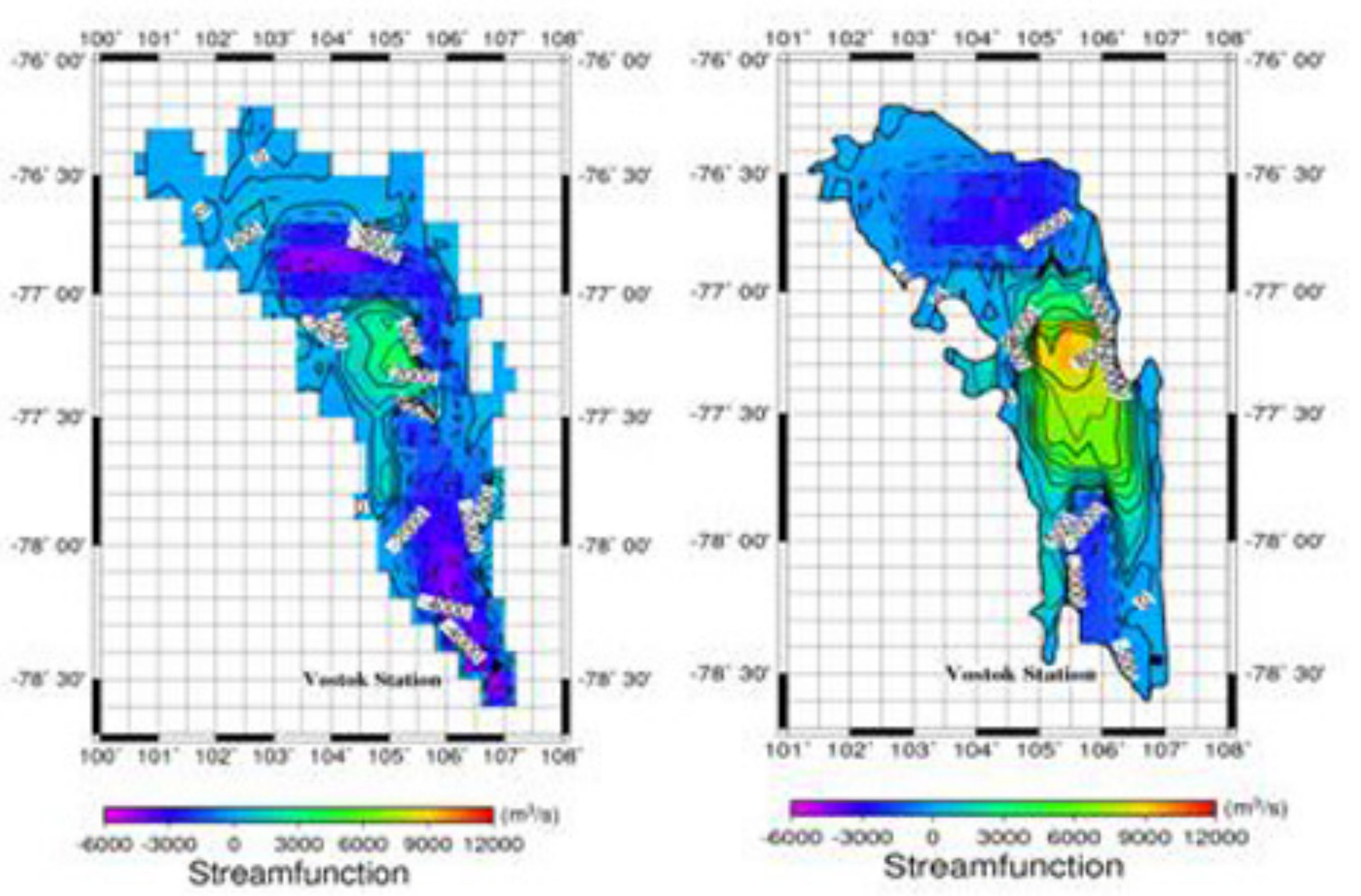


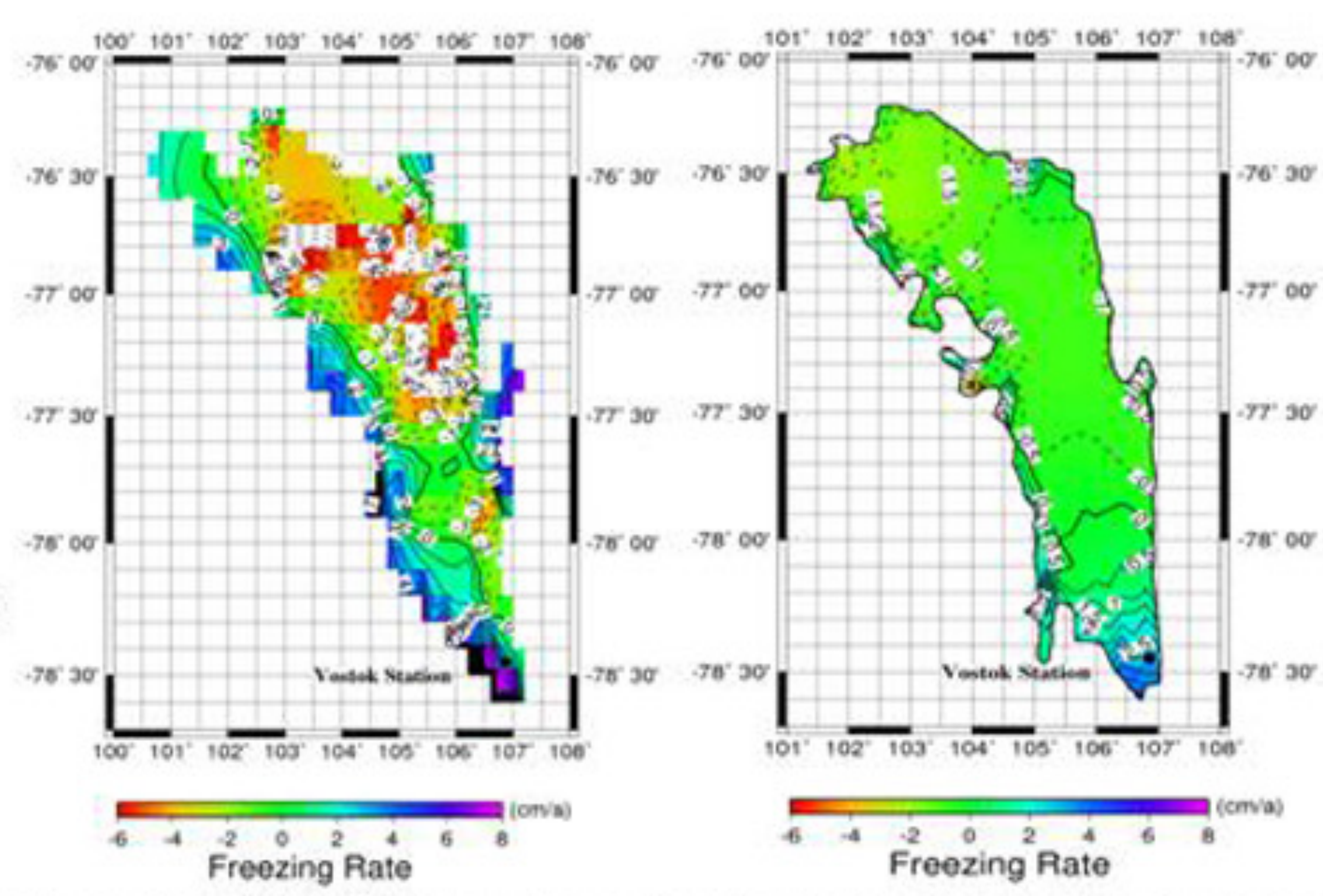
Figure 2: Comparison of the old (left Mayer et al., 2003; 0.2 x0.1) and new (right Studinger et al., 2004; 0.1 x0.05) bathymetry used for modelling the conditions in Lake Vostok.

State of research: M. Studinger of Lamont-Doherty University, Columbia, USA, is the responsible scientist for the most up-to-date geometry data of Lake Vostok (Studinger et al., 2004). He kindly provided the new data which have been processed and adapted for the first comparative experiments. In Figure 2, the new discretised water column thickness is shown compared to the old version used in Mayer et al. (2003). The new bathymetry is based on high resolution gravimeter measurements and data inversion, revealing bedrock elevation and ice thickness. Besides the increased horizontal resolution of 0.1° x 0.05 ° (about 2.5 km in longitude and 5.5 km in latitude) and therefore a better representation of the narrow region in the vicinity of Vostok Station, the water column thickness depicts a completely different shape. Lake Vostok is separated into two basins, which are separated by a west-east ridge with a water depth of only 250 m. The water column thickness within the basins is about twice the former estimation, which will influence the flow regime and the lakes environment.



← Figure 3: Vertically integrated mass transport stream-function for old (left) and new (right) model setup after 250 years of integration for fresh water conditions.

Figure 4: → Freezing rate for old (left) and new (right) model setup after 250 years of integration for freshwater conditions. Melting of ice at the bottom of the ice sheet is taken to be negative, freezing is positive.



Flow regime: Figure 3 shows the calculated flow pattern for the different lake geometries is shown. Because the lake is completely covered by the ice sheet, forcing of thew flow occurs only through density differences induced by melting and freezing processes at the ice base, and through geothermal heating. The flow regime for the most recent bathymetric setup shows a main cyclonic (clockwise) gyre in the central basin with transports of about 8500 m^3/s. In the northern basin and in the south-eastern part of the lake anti-cyclonic flow occurs. In this respect the results are similar to the former study, although the bathymetry especially in the northern part was strongly different.

Mass balance: The calculated basal mass balance (Fig. 4) of the lake shows a melt-regime for the most part of the lake. Melt rates up to 2 cm/yr are found in the northern part of the lake where the ice sheet is thickest. In the south, where Vostok Station is located, basal freezing occurs with rates exceeding 5 cm/yr. Underneath Vostok Station about 3.5-4 cm /yr of freezing can be detected. This is in good agreement with earlier estimates of Williams (2001) and by Bell et al. (2002), derived from GPS ice velocity estimates. Along the western margin of the lake, a freezing zone can be detected, which is related to the dynamic thinning of the ice sheet, when becoming afloat from the grounded base to the lake.

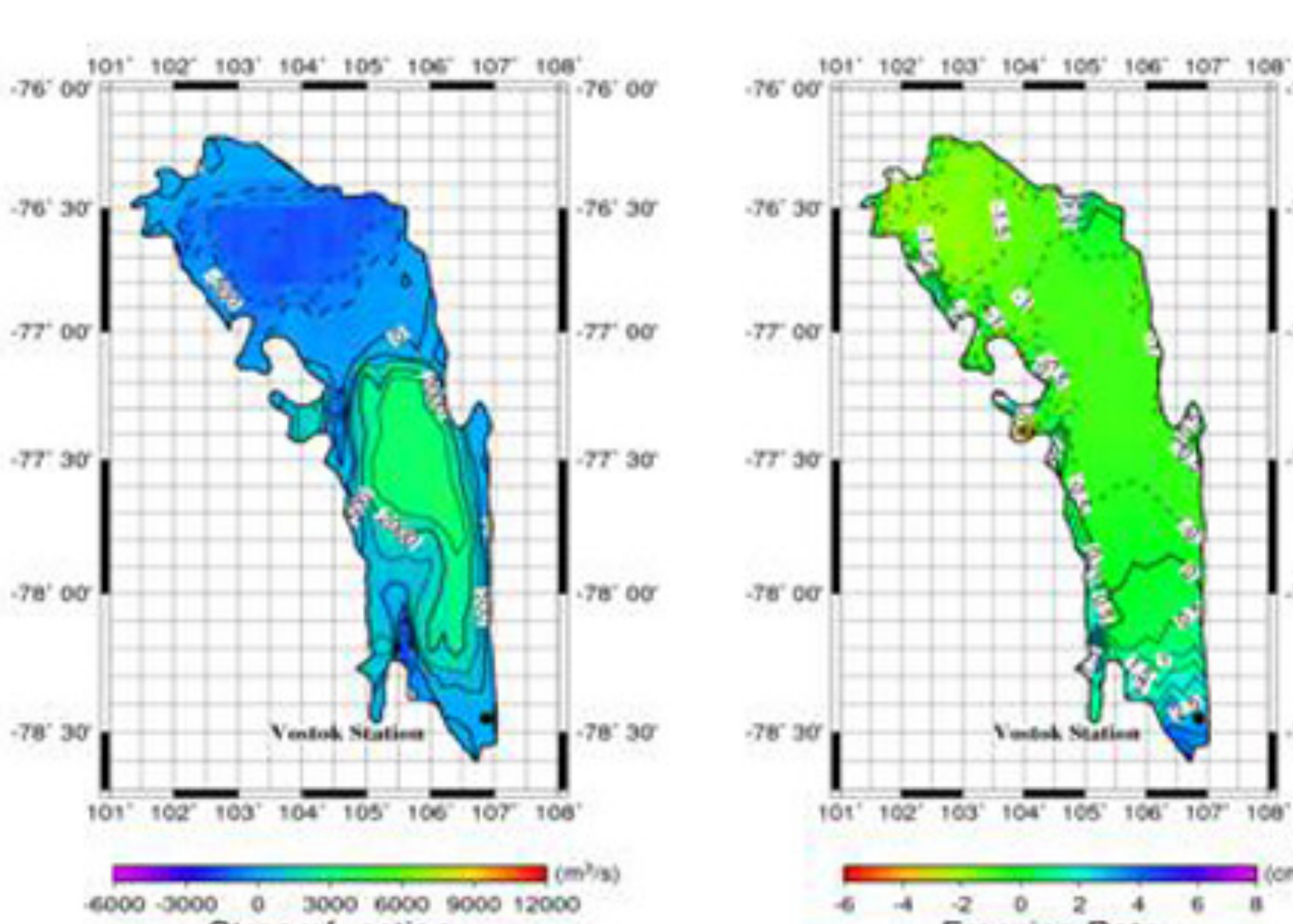


Figure 5: Vertically integrated mass transport stream-function (left) and freezing rate (right) for low salinity model setup after 250 years of integration.

Numerical experiments with low salinity (1.2) water: The flow regime shows a reduced circulation in the northern and southern basins (Fig. 5). Due to salinity, the water column is vertically stratified in the northern part of the lake, where strongest melting occurs (Fig. 6). Salinity dominates the density structure instead of the pure thermal effect in the case of a freshwater lake. The temperature regime depicts much more structure. In the southern freezing area, vertical mixing down to the bottom homogenizes the water column.

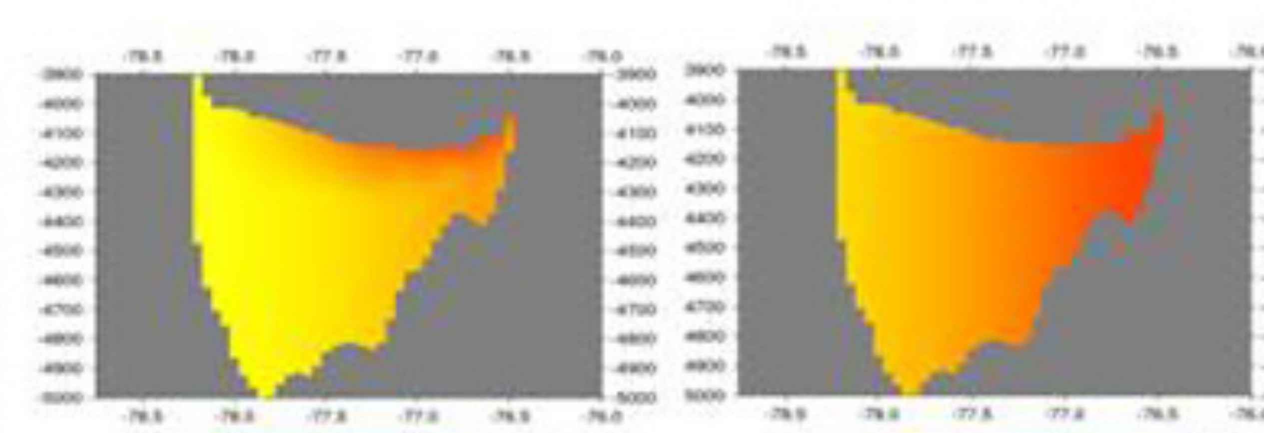


Figure 6: Vertical section of temperature along 105.5 E (left: freshwater, right: low salinity).

The future: The next steps will cover a thorough analysis of the flow regime in respect to the velocity field (barotropic or baroclinic), overturning time scale, the melt and freeze pattern, and possible exchanges between the northern and central basin. Hereafter, additional experiments with different lake salinities will show the sensitivity of the new flow regime to the lake environment. New processes like frazil ice formation and the existence of clathrates in the lake will be considered in the model experiments

References
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