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Grain growth and experimental deformation of fine-grained ice aggregates

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Ice is one of the most abundant materials in our solar system. It is the principal constituent of most of the moons of the outer solar system. Thus, the flow behavior of ice is of great interest when studying geodynamic processes on icy moons. Grain growth is an elementary process that is assumed to be important in the ice sheet layering of planetary moons, where temperatures 100-273 K exist. We concentrate on the questions to what extent grain growth may influence the evolution of strength of deforming ice and if the grain growth process is independent or dependent of deformation. The answers to these questions will help us to quantitatively test the hypothesis that the progressive evolution of the grain (crystal) size distribution of deforming and recrystallizing ice directly affects its rheological behaviour in terms of composite grain-size-sensitive (GSS) and grain-size-insensitive (GSI) creep, and that this might, after time, result in a steady state balance between mechanisms of GSS and GSI creep. We performed static grain growth experiments at different temperatures and a pressure (P) of 1 atm, and deformation experiments at P = 30-100 MPa starting in the GSS-creep field. The starting material ice I_h has a grain size < 2 μm and was generated by a special pressure-release technique described by Stern et al. (1997) resulting in dense ice aggregates. The ice grains of the polycrystalline starting samples were randomly oriented and the material has a porosity of $< 0.5\%$. For the grain growth tests a Hart Scientific temperature bath was filled with d-Limonene as cooling medium. The ice specimens were put into sealed alumina cylinders. For the grain growth tests, temperatures (T) between 213 K and 268 K were chosen. The durations of these tests varied between one day and two weeks. For the deformation experiments, temperatures of > 170 K and strain rates between 10^{-8} s^{-1} and 10^{-4} s^{-1} were chosen. Grain sizes, grain size distributions and grain topologies were measured by cryogenic SEM and image analysis techniques. We found clear evidence of grain growth and a significantly T-dependent variation of grain size distributions. The observations allow us to calibrate values for the grain size exponent n and the activation energy Q as used in conventional grain growth laws. We simulated grain growth of ice based on the microphysical model of Kellermann Slotemaker (2006). This model takes into account full grain size distributions and allows grain boundary migration driven by different acting forces. We will show the importance of these driving forces for grain growth and deformation in polycrystalline ice aggregates.

References

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