Mass balance and dynamics of calving glaciers from high resolution SAR data

Name: Erling Johnson
E-Mail: erling.johnson@dlr.de
Supervisor: Hon.-Prof. Dr. rer. nat. Michael Eineder
Chair of Remote Sensing Technology
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Introduction
Recent global low-resolution mass estimates from glaciers and ice caps show a significant deficit for many ice-covered regions over the world. The uncertainty on the mass balance is still very high, in particular for calving glaciers, which are the main contributors to ice loss in certain climatic sensitive areas. Therefore, in order to estimate the total net mass balance through the mass budget method its components have to be known. Within these the calving flux and calving rate are needed for the ice export determination. This doctoral work develops a complete tool for estimating the ice discharge of a glacier into a lake or fjord based on remote sensing techniques.

Study area
The main areas to be investigated are the 2 largest Patagonia Icefields from South America: North and South Patagonia Icefields (Figure 1), composed mainly on temperate glaciers calving in freshwater (proglacial lakes) and tidal water (fjords).

Fig. 1: The North and South Patagonia Icefields (NPI and SPI) located in South America.
Calving flux and calving rate
The calving flux \( Q_c \) represents the volume of ice that a glacier is losing at his terminus in a determined period of time. Assuming a continuous ice flow through a flux gate \( FG \) the calving flux can be calculated as (Rott et al., 1998):

\[
Q_c = \int_{FG} h \cdot u_c \, dFG \approx \sum_{i=0}^{n} w_i \cdot h_i \cdot u_{ci}
\]

where \( h_i \) is the glacier thickness, \( w_i \) is the gate length and \( u_{ci} \) is the calving rate of the segment \( i \) of glacier front (Figure 2).

![Fig. 2: Map of terminus velocity of a calving glacier (\( u_T \)) with flux gate segments \( FG_i \) delineated between flow lines \( FL_i \).](image)

The calving rate is defined as the volume of ice that breaks off per unit of time and per unit of vertical area from glacier terminus. The calving rate is determined as the difference between the ice velocity at the terminus, \( u_T \) and the rate of change of the terminus position \( L \), along a series of flow lines \( FL_i \) as given by (Cuffey & Paterson, 2010):

\[
u_c = u_T - \frac{dL}{dt}
\]

One important step when calculating the calving rate and flux is the delineation of the front position of the glacier terminus, e.g. from SAR amplitude data during the considered time period. The front position is further needed for the frontal width determination as well as for the displacement of the calving front, \( dL/dt \). The ice surface velocity, \( u_T \), is obtained by means of amplitude correlation applied to high resolution repeat pass SAR acquisitions and its direction determines also the flow lines, \( FL_i \). The ice thickness at the glacier front is inferred from bathymetry measurements at the pro-glacier lake or fjord where available and complemented with the frontal height derived from TanDEM-X.

Total mass balance
The geodetic mass balance is a method based on measurements of the surface elevation dynamics of a glacier determined during a time period. The elevation change rates \( (\Delta h/\Delta t) \) are obtained subtracting two digital elevation models; by integrating this result over the glacier area \( (A) \) the volume change rate is obtained. Finally, this volume multiplied with the ice density \( (\rho) \) leads to the mass change rate (Cuffey & Paterson, 2010).

\[
b_n = \rho \int_A \Delta h \, dA
\]

The total mass balance will be combined with the calving flux for validation of modelled surface mass balance of major outlet glaciers of SPI and NPI.

References