Material heterogeneity in suture zones of the Larsen C Ice Shelf, Antarctica

Daniel McGrath\textsuperscript{1}, Konrad Steffen\textsuperscript{1,2}, Paul Holland\textsuperscript{3}, Ted Scambos\textsuperscript{4}, Hari Rajaram\textsuperscript{5}, Waleed Abdalati\textsuperscript{1} and Eric Rignot\textsuperscript{6}

\textsuperscript{1} CIRES, University of Colorado Boulder, USA
\textsuperscript{2} WSL, CH
\textsuperscript{3} British Antarctic Survey, UK
\textsuperscript{4} NSIDC, University of Colorado Boulder, USA
\textsuperscript{5} Department of Civil Engineering, University of Colorado Boulder, USA
\textsuperscript{6} Dept. Earth Science, University of California Irvine, USA

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Pritchard et al., 2012; Nature
Fracture, rifting and weakening

Glasser and Scambos, 2008; J. Glac.
MacGregor et al., 2012; J. Glac.
Thick meteoric inflows

Thin suture zones

Churchill Peninsula

Adie Inlet

Cabinet Inlet

Cole Peninsula

Mill Inlet

Whirlwind Inlet

Francis Island

Joerg Peninsula

Mobiloil Inlet

Hollick-Kenyon Peninsula

Ice Thickness

1350 [m]
1000
650
300
0

ASTER DEM (10x exag.), Cook et al., 2012
Ice Thickness- Griggs and Bamber, 2009
Rift termination and suture zones

Fig. 5. Motion of ice-shelf rift tips between 1986–90 and 2003 and distance travelled as indicated by arrow directions and lengths (for location see box in Fig. 6).

Glasser et al., 2009; *J. Glaciol.*

Holland et al., 2009; *Geophys. Res. Lett.*
A. 1963
Veier Head
Adie Inlet
Figure 3a
Churchill Peninsula

B. 1986
Surface Rifts
Suture Zone
Basal Crevasses
Ice flow direction

C. 2004
Fracture tip alignment
Mass Conservation Model

\[ \frac{\partial \rho H}{\partial t} + \nabla \cdot (\mathbf{V} \rho H) = \dot{a} - \dot{b}, \]

where \( H \) and \( \rho \) are the thickness and mean density of the ice column, \( \mathbf{V} \) is the surface velocity, \( \nabla \) is the two-dimensional gradient operator, \( \dot{a} \) is the surface net mass accumulation rate and \( \dot{b} \) is the basal mass melting/freezing rate (positive is melting).

**Key Datasets:**
Velocity- Rignot et al., 2012; MEaSUREs
Ice Thickness- Griggs and Bamber, 2009
Density- Holland et al., 2011
SMB- Lenearts et al., 2012; RACMO2.1/Ant
Observed surface lowering is likely due to firn densification rather than increased basal melting.
Steady-state Mass Conservation

\[
\frac{\partial \rho H}{\partial t} + \nabla \cdot (\mathbf{V} \rho H) = \dot{a} - \dot{b},
\]

\[
\dot{b} = \dot{a} - \nabla \cdot (\mathbf{V} \rho H).
\]
Along-flow Structural Evolution

Delineate ice shelf structure into three components: the locally accumulated surface accumulation layer, the interior layer and the basally accreted marine ice layer.

The thickness of the surface and basal layers are calculated by integrating the instantaneous rates of surface accumulation and basal melt/freezing along the length (time) of the flowline.

Account for strain thinning by first calculating the vertical strain rate as:
\[ \dot{\varepsilon}_z = -(\dot{\varepsilon}_x + \varepsilon_y), \]
where \( \dot{\varepsilon}_x \) is the along-flow strain rate and \( \varepsilon_y \) is the transverse strain rate.

The apply the formulation of Craven et al. [2009] to calculate the thickness of each layer at the downstream edge of the node (\( Z_2 \)) compared to its thickness at the upstream edge (\( Z_1 \)) as:
\[ Z_2 = Z_1 * e^{\dot{\varepsilon}_z \cdot t} + \frac{\dot{a}}{\dot{\varepsilon}_z} (e^{\dot{\varepsilon}_z \cdot t} - 1). \]
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\[ \dot{\epsilon} = - (\dot{\epsilon}_l + \dot{\epsilon}_t) \]

where \( \dot{\epsilon}_l \) is the along-flow strain rate and \( \dot{\epsilon}_t \) is the transverse strain rate.

Apply the formulation of Craven et al. [2009] to calculate the thickness of each layer at the downstream edge of the node (\( Z_2 \)) compared to its thickness at the upstream edge (\( Z_1 \)) as:

\[ \Delta h = h_2 \times \phi - h_1 (\phi - 1) \]
B. Cole Peninsula

Radar surveys

Wedge of locally accumulated meteoric ice

Marine ice

Observed surface elevations and ice drafts
Key Findings

-Suture zones, regions of heterogeneity in ice shelves, exhibit strong control over rift extent

-Marine ice accumulates in ice draft minima downstream of promontories, as observed by GPR and mass conservation model

-Growing wedge of locally accumulated meteoric ice accounts for 55-65% of total ice thickness near calving front with likely homogenous mechanical properties

-Two implications: i) remaining heterogeneity is sufficient, even as a minority of ice thickness to arrest rift propagation and ii) this is an important sensitivity of ice shelves, as ocean forcings may erode these features, allowing continued propagation of fractures and likely contribute to increased tabular iceberg calving

-If the larger fractures/rifts present in Larsen C were allowed to propagate towards each other, the eastern half of the ice shelf, unconstrained by sidewalls, would appear unviable
Thanks!