Physically based and stochastic models for Greenland moulin Formation, longevity, and spatial distribution

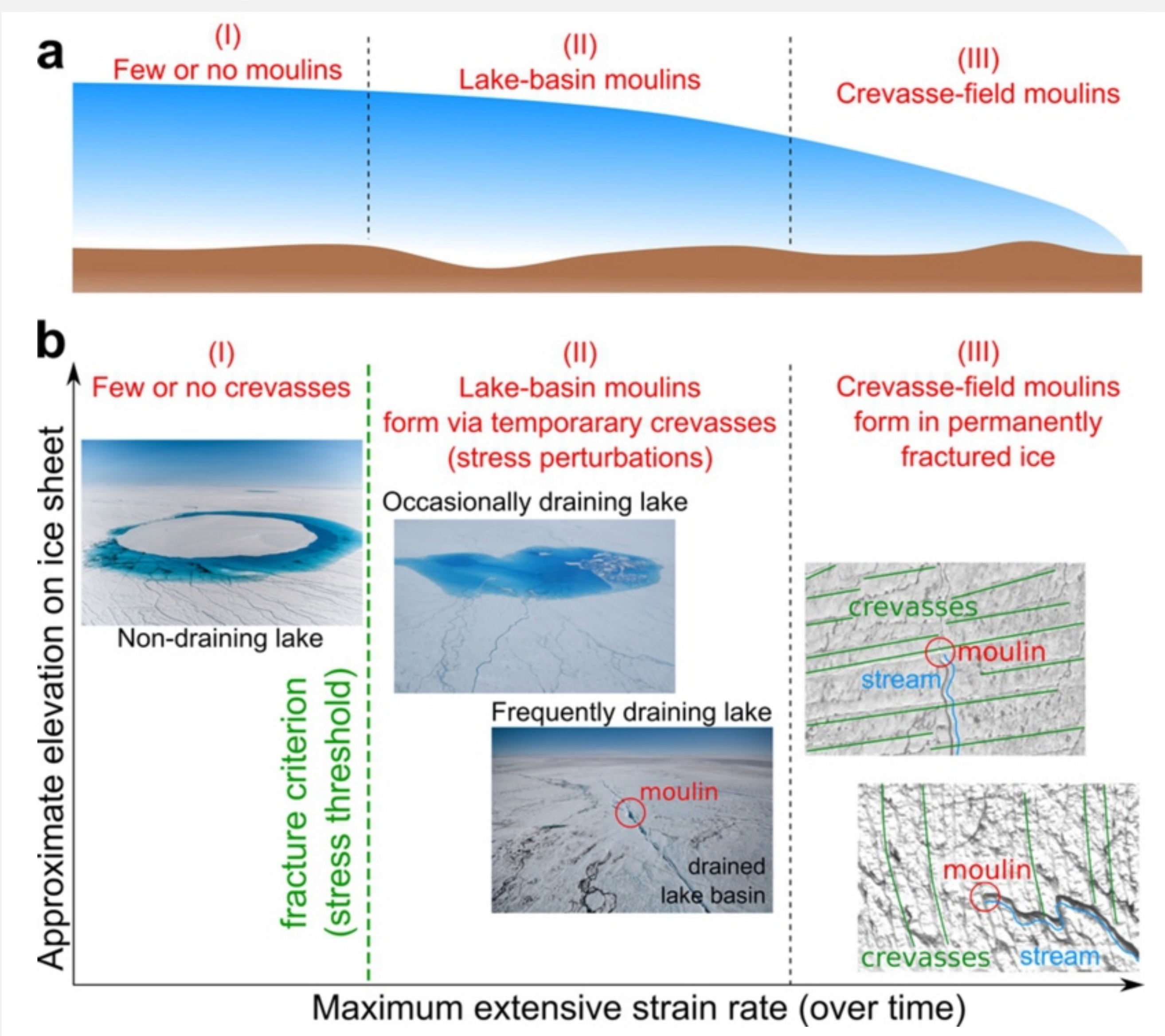
Lauren C. Andrews* & Kristin Poinar~

University at Buffalo | GMAO Global Modeling & Assimilation Office

~kpoinar@buffalo.edu *lauren.c.andrews@nasa.gov

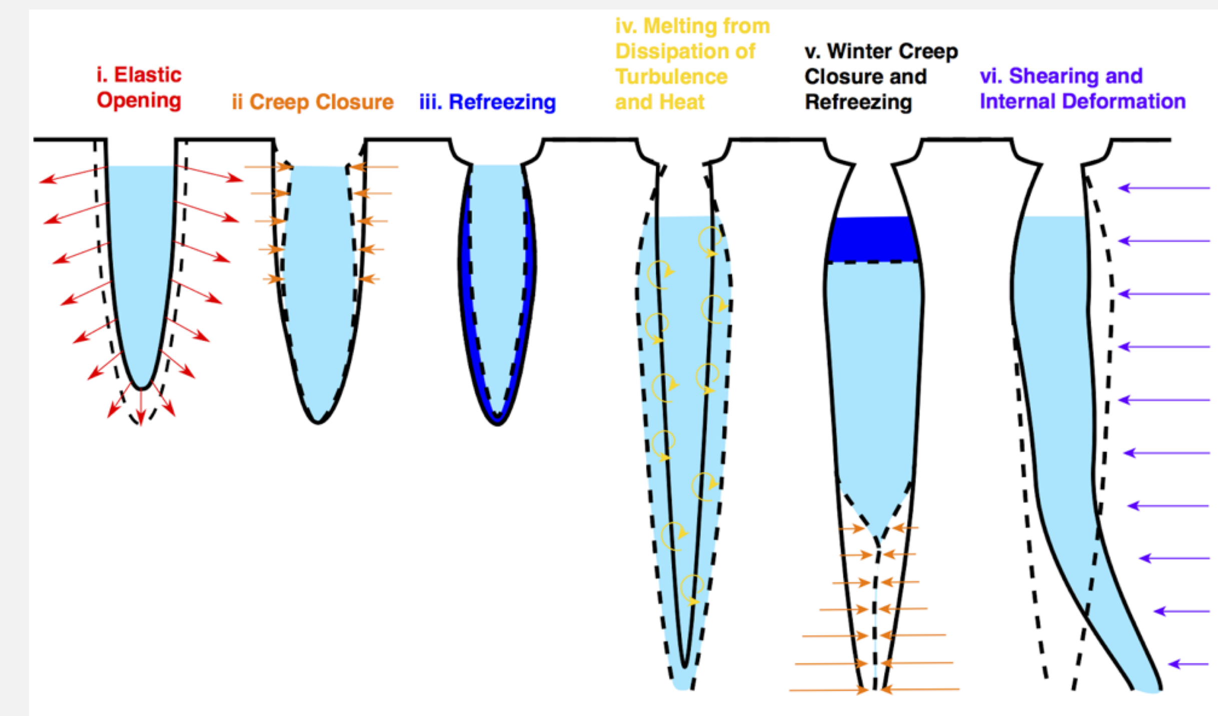
1. Moulin formation and persistence

- Nearly all proglacial water discharge from the Greenland Ice Sheet is routed englacially via moulins.
- Crevasse and moulin formation is dependent on persistent (crevasses) or transient (moulin initiation) stresses which result in surface-to-bed hydrofracture (e.g. Hoffman et al., 2018; Christoffersen et al., 2018).
- Understanding the conditions, including both the transient stress state and the surface runoff flux, needed to form and maintain a moulin are an important component to developing a stochastic model for englacial connections.



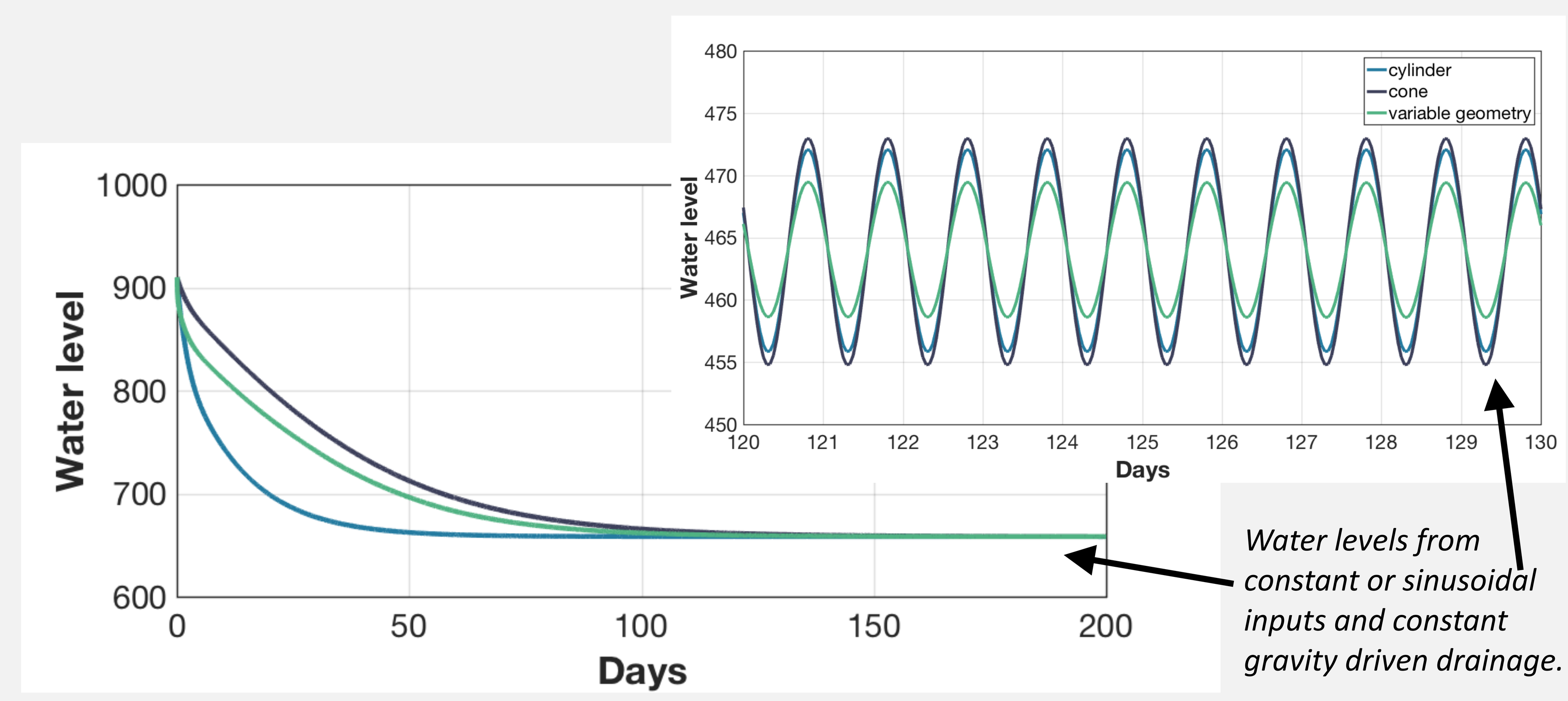
2. Developing moulin geometry

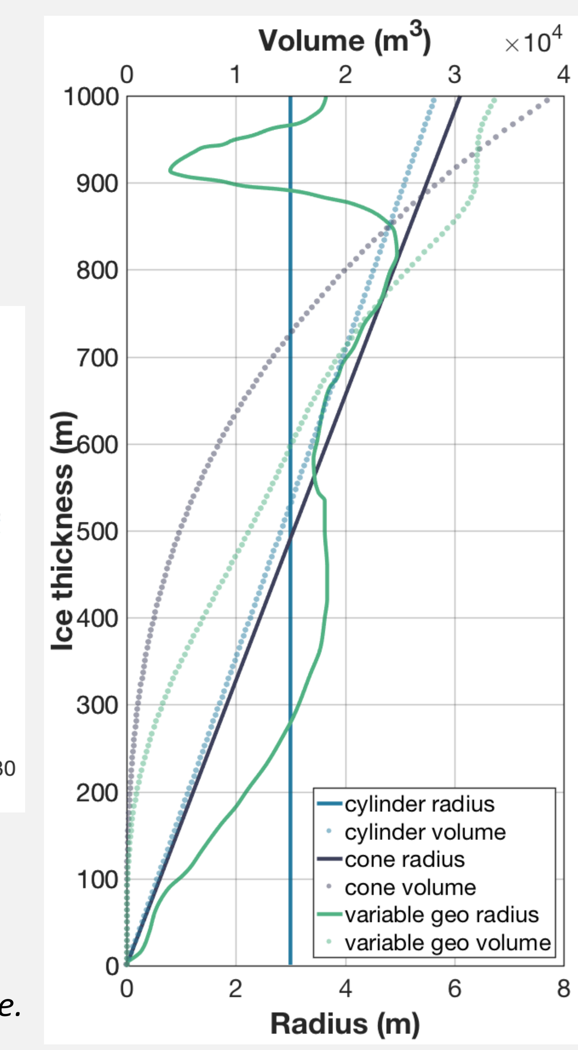
- Moulins persist over months or years when elastic opening and melting due to the dissipation of turbulent and heat energy are equivalent or exceed creep closure and refreezing.
- These geometries become more complex over time as ice deformation and shearing continue to alter moulin shape, potentially impacting the discharge-pressure relationship in individual moulins.



3. Does moulin geometry matter?

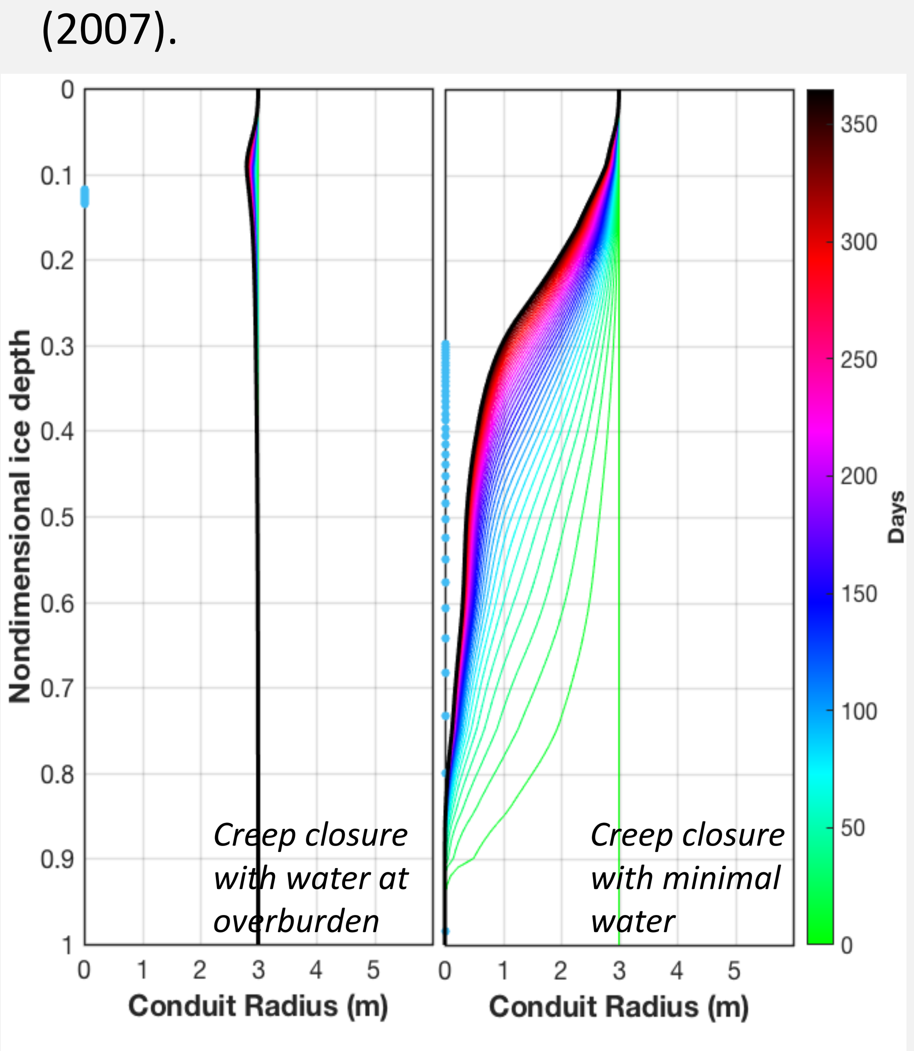
- Moulin may reasonably compose ~10% of the englacial-subglacial hydrologic system and are likely larger than subglacial conduits.
- Moulin shape can alter the equilibrium response time and modify the magnitude of diurnal variability even when the mean radius is the same.



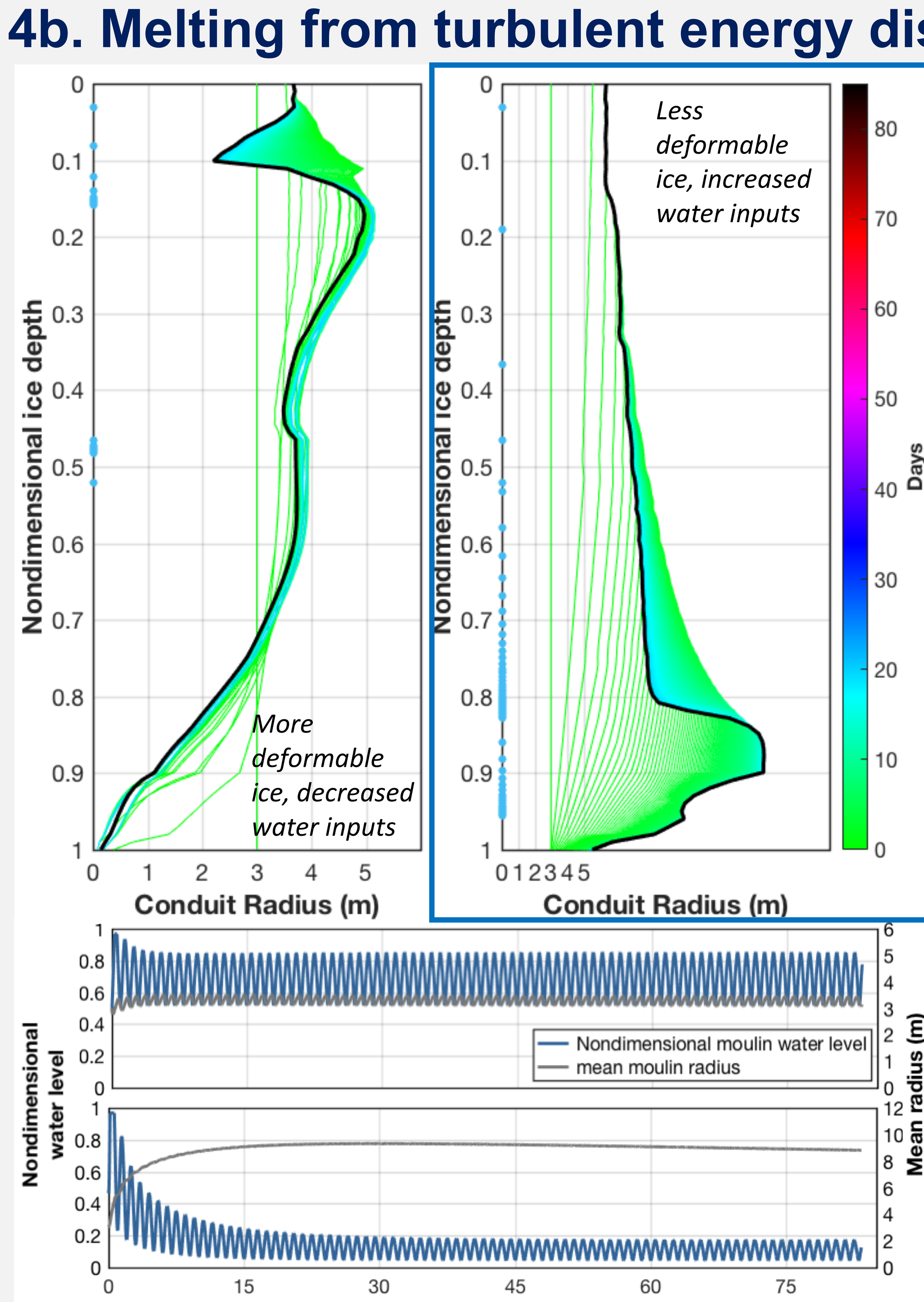


4a. Viscous deformation

- Creep closure equations are modified from borehole observations from Blinov and Dmitriev (1987) and Salamatin et al (1998) with modifications from Talalay and Hooke (2007).



4b. Melting from turbulent energy dissipation



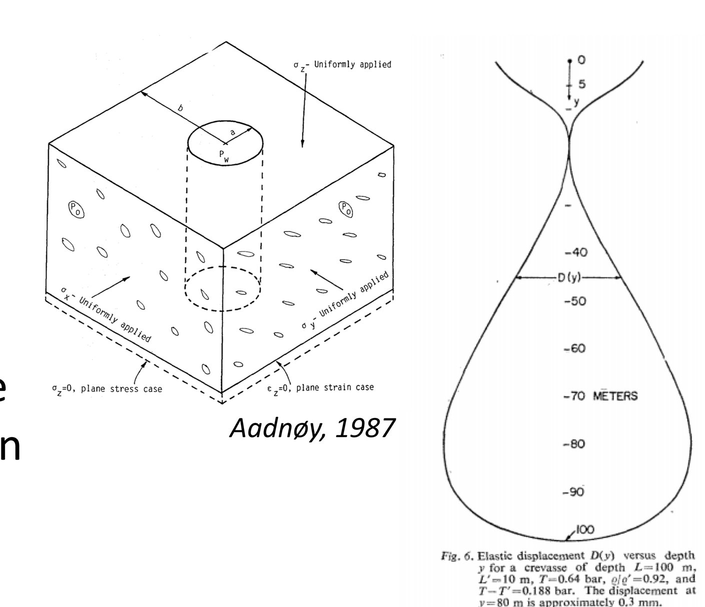
Issue: **realistic ice and meltwater discharge characteristics, but potentially unrealistic geometries and water levels**

Solution: **improved representation of turbulent energy production and dissipation**

- In subglacial models, all turbulent energy is immediately directed to melting the surrounding ice.
- This assumption is not appropriate for a moulin, where ice temperatures are variable throughout the column and cryohydrologic warming occurs.
- Use a k-Ɛ model to simulate the mean characteristics of turbulent flow and calculate turbulent kinetic energy and rate of turbulent dissipation energy.

Solution: **include elastic ice deformation**

- Water levels in moulins vary substantially over short (diurnal and multiple days), suggesting that elastic deformation may be an important part of moulin geometry, particularly in stiff ice.



5. Beyond moulin geometry: predicting crevasse and moulin extent

- The analytic model (right) will be combined with the englacial hydrology model (above) to create a stochastic model of moulin and crevasse locations with increasing surface melt.
- The stochastic model will be a predictive, computationally efficient representation of the englacial hydrologic system, which is currently not represented in GCMs or most ISMs.

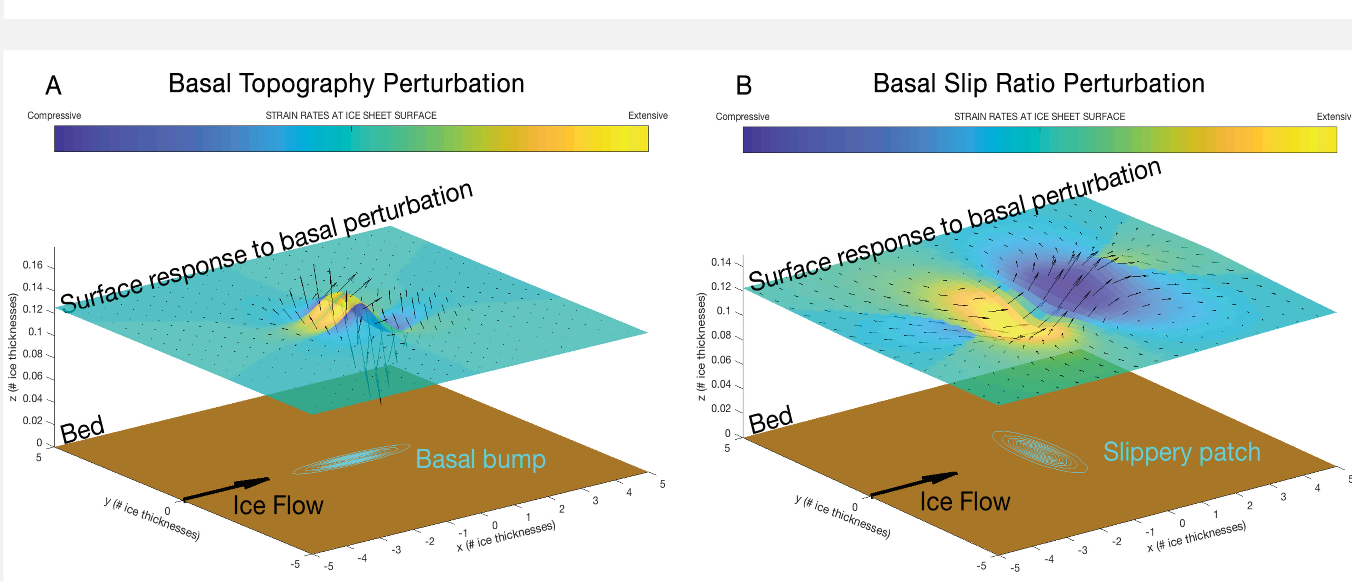
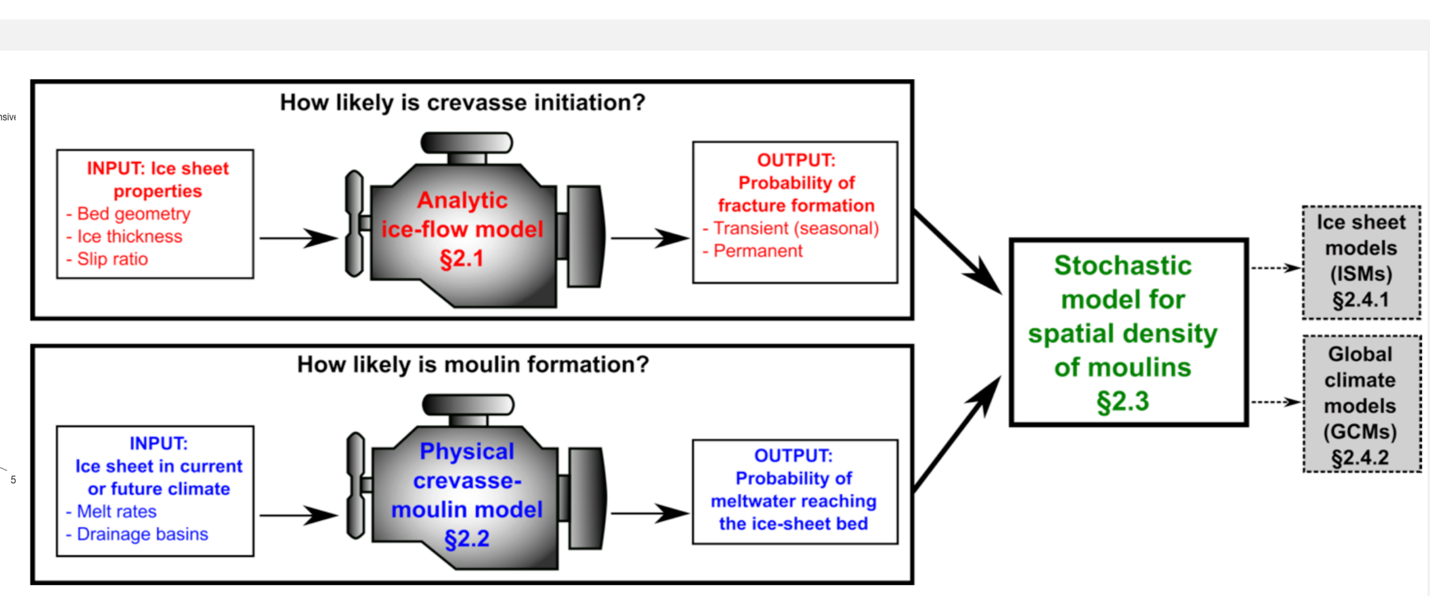


Illustration of the analytic model for the ice-sheet surface response (top surface) to a basal slipperiness perturbation. Ice flow is from left to right. Ice flow is extensive upstream of the slippery patch; this region may seed crevasses.



Conceptual diagram of the components necessary for the development of a stochastic model for moulin density.

E-mail: lauren.c.andrews@nasa.gov | *Web:* gmao.gsfc.nasa.gov

National Aeronautics and Space Administration