



**SIGMA**

Simulations  
of Geophysical  
Multi-phAse flows

Multiphase instabilities and extreme  
events in different natural systems

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Engineering, & Environmental Engineering



ICE



FIRE

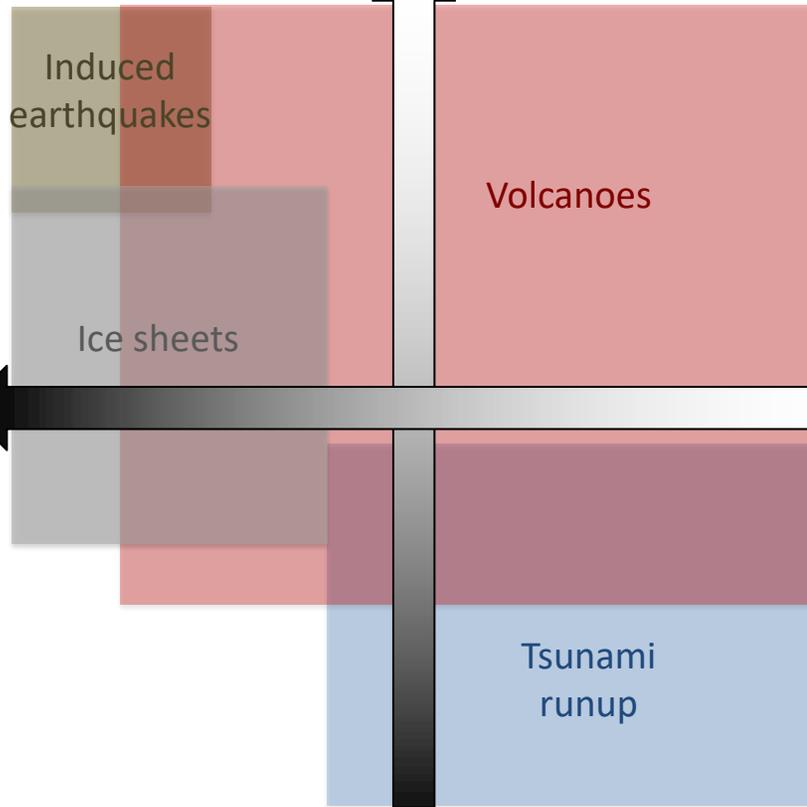


ROCK



WATER

laminar flow



Induced earthquakes

Ice sheets

Volcanoes

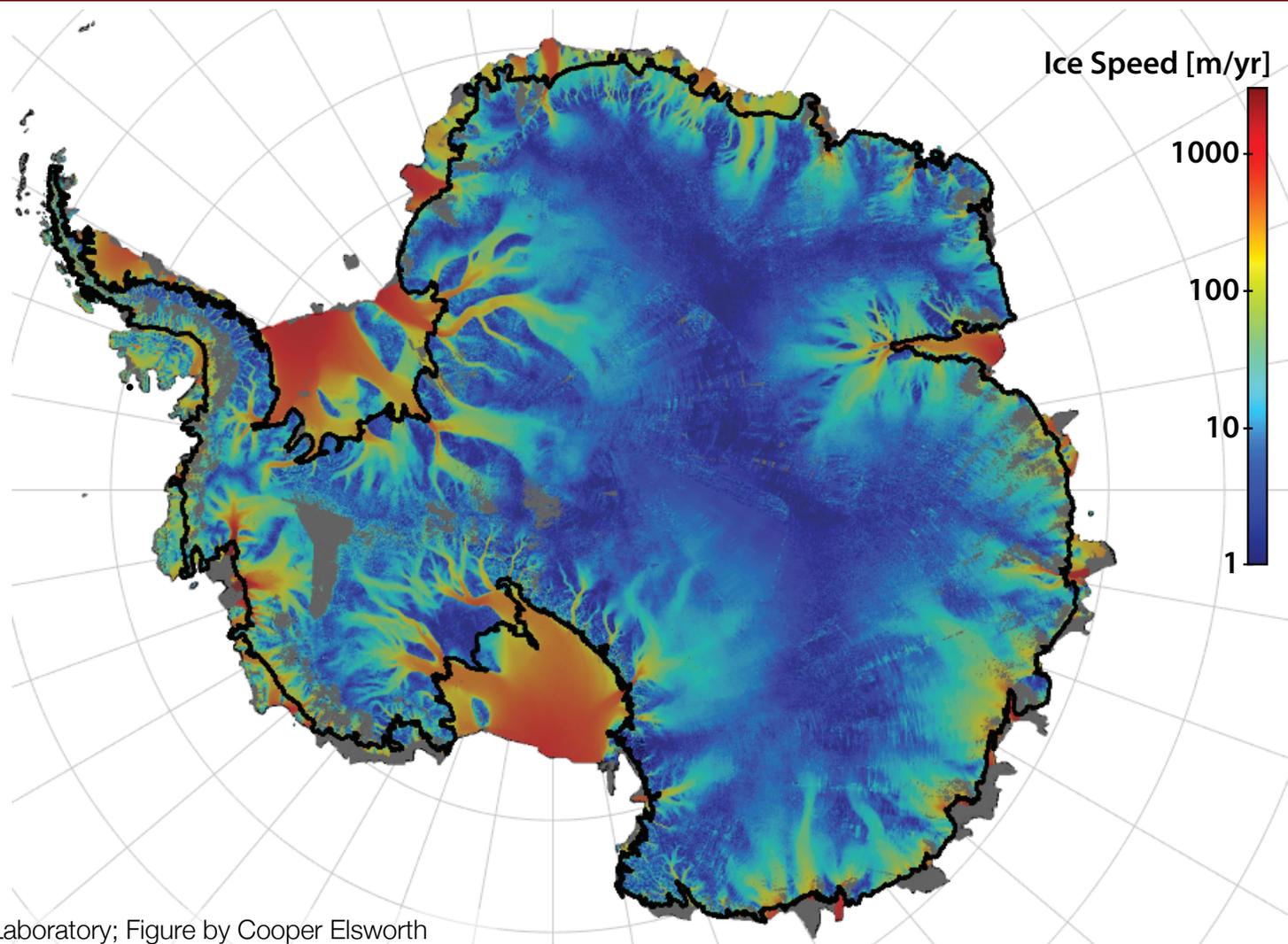
Tsunami runup

more solid

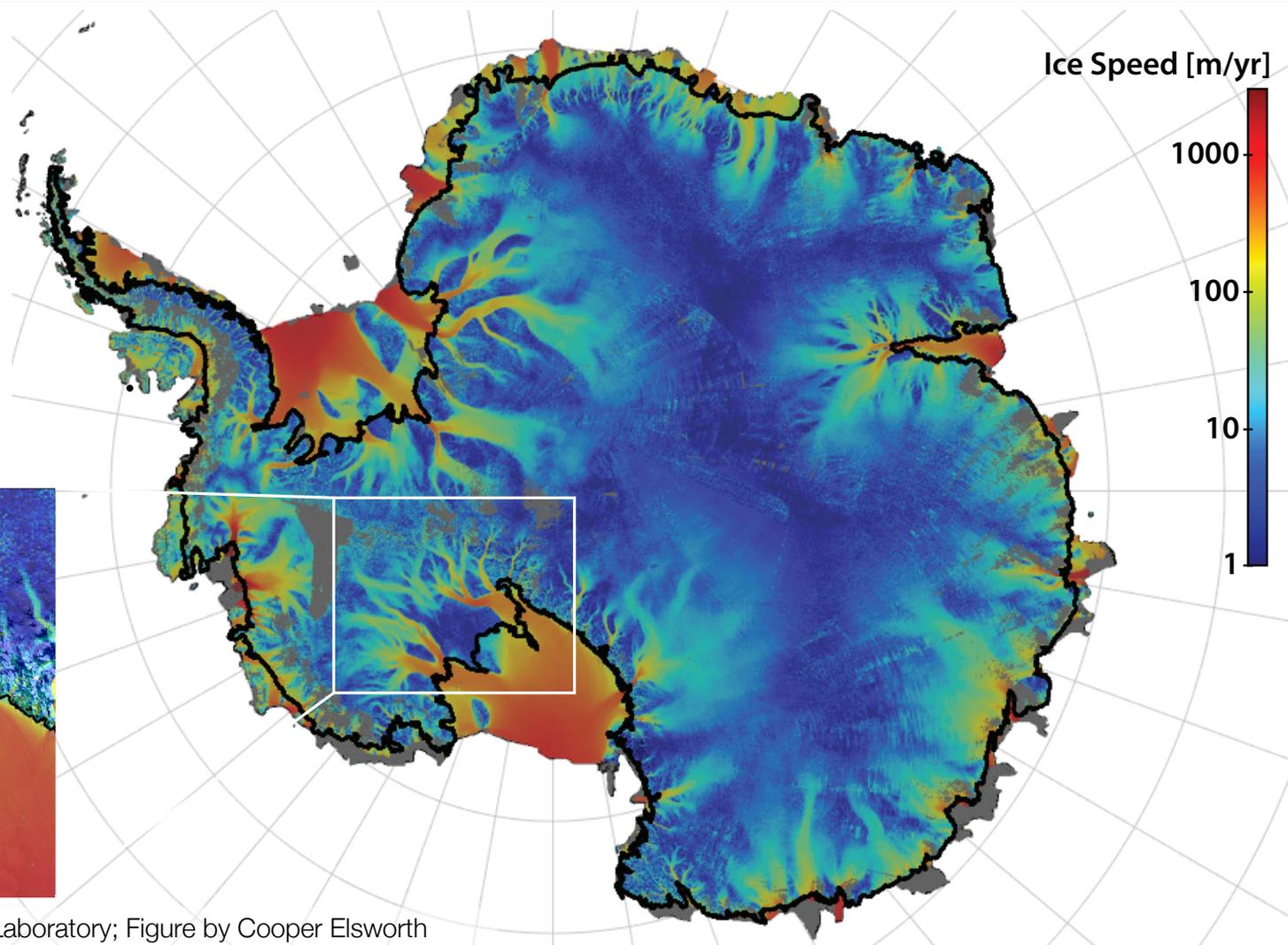
less solid

turbulent flow

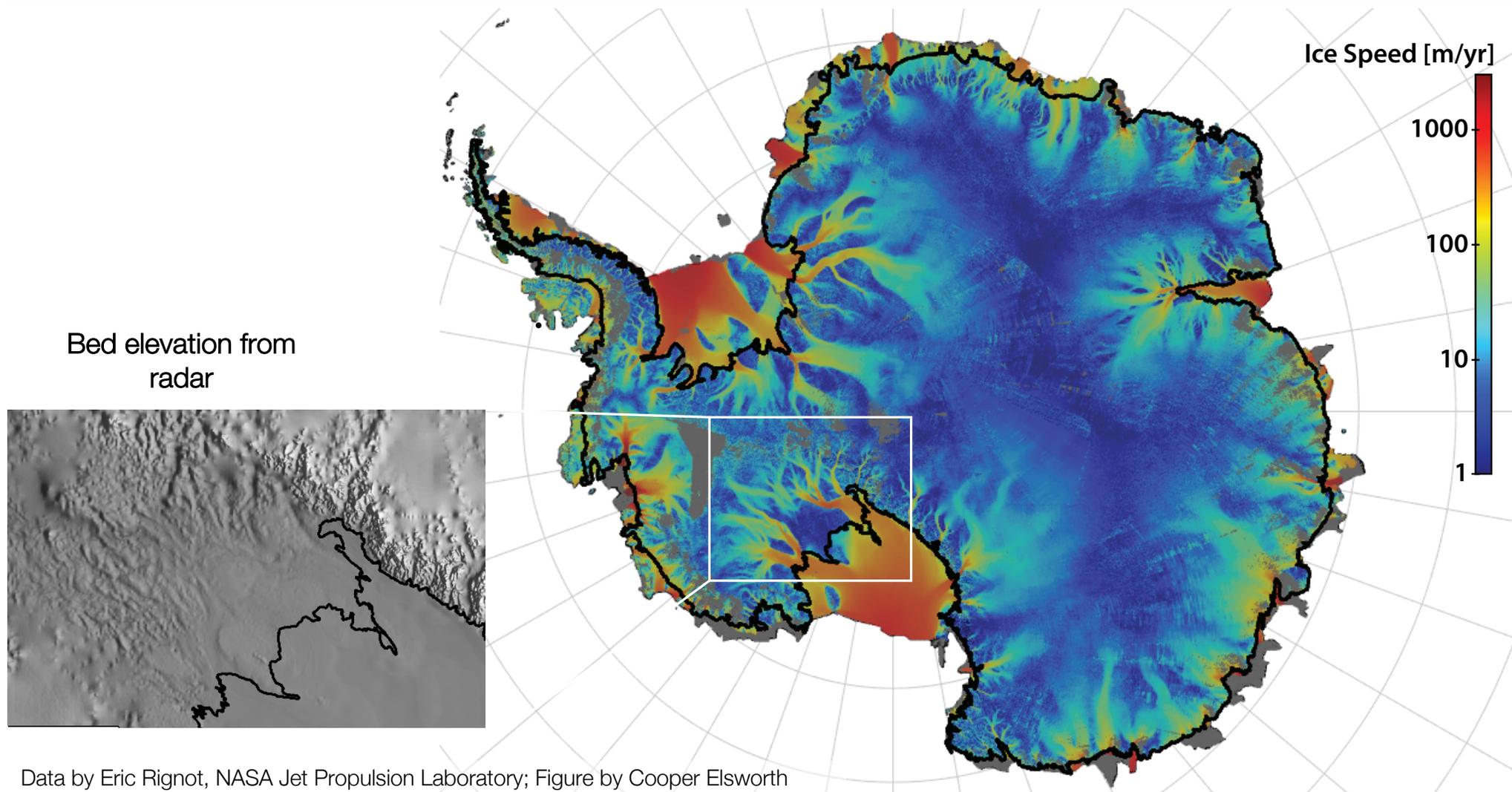
**Extreme event:**  
System behavior changes abruptly over multiple orders of magnitude



Data by Eric Rignot, NASA Jet Propulsion Laboratory; Figure by Cooper Elsworth



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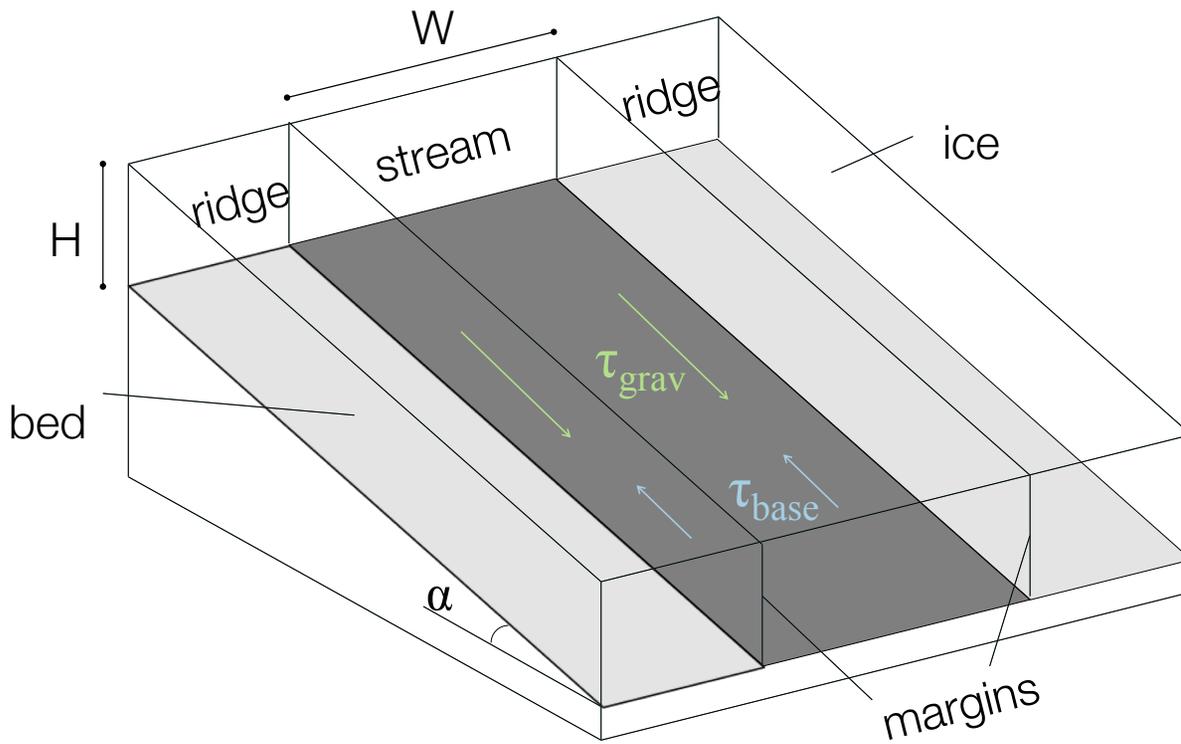
Data by Eric Rignot, NASA Jet Propulsion Laboratory; Figure by Cooper Elsworth



Photos courtesy Kurt Cuffey

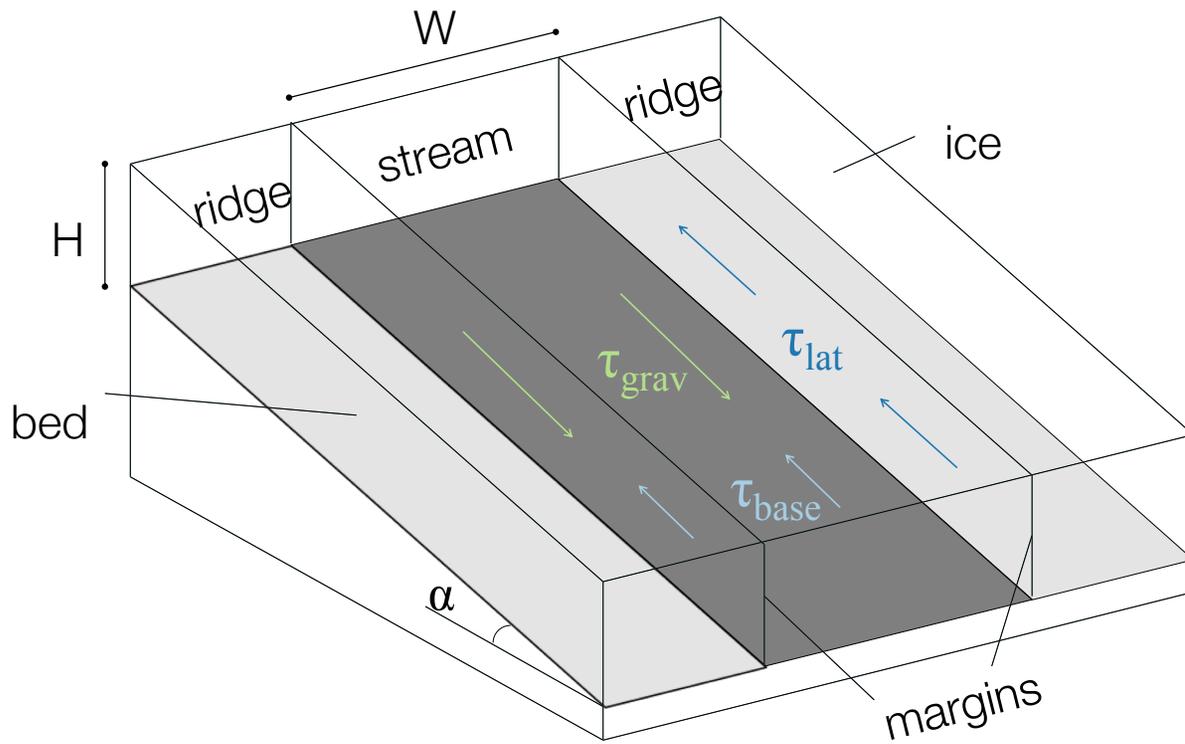


Photo courtesy of Mike Hambrey, Taylor Glacier, Antarctica,



$$\tau_{grav} = \rho g H \sin(\alpha) \approx 11kPa$$

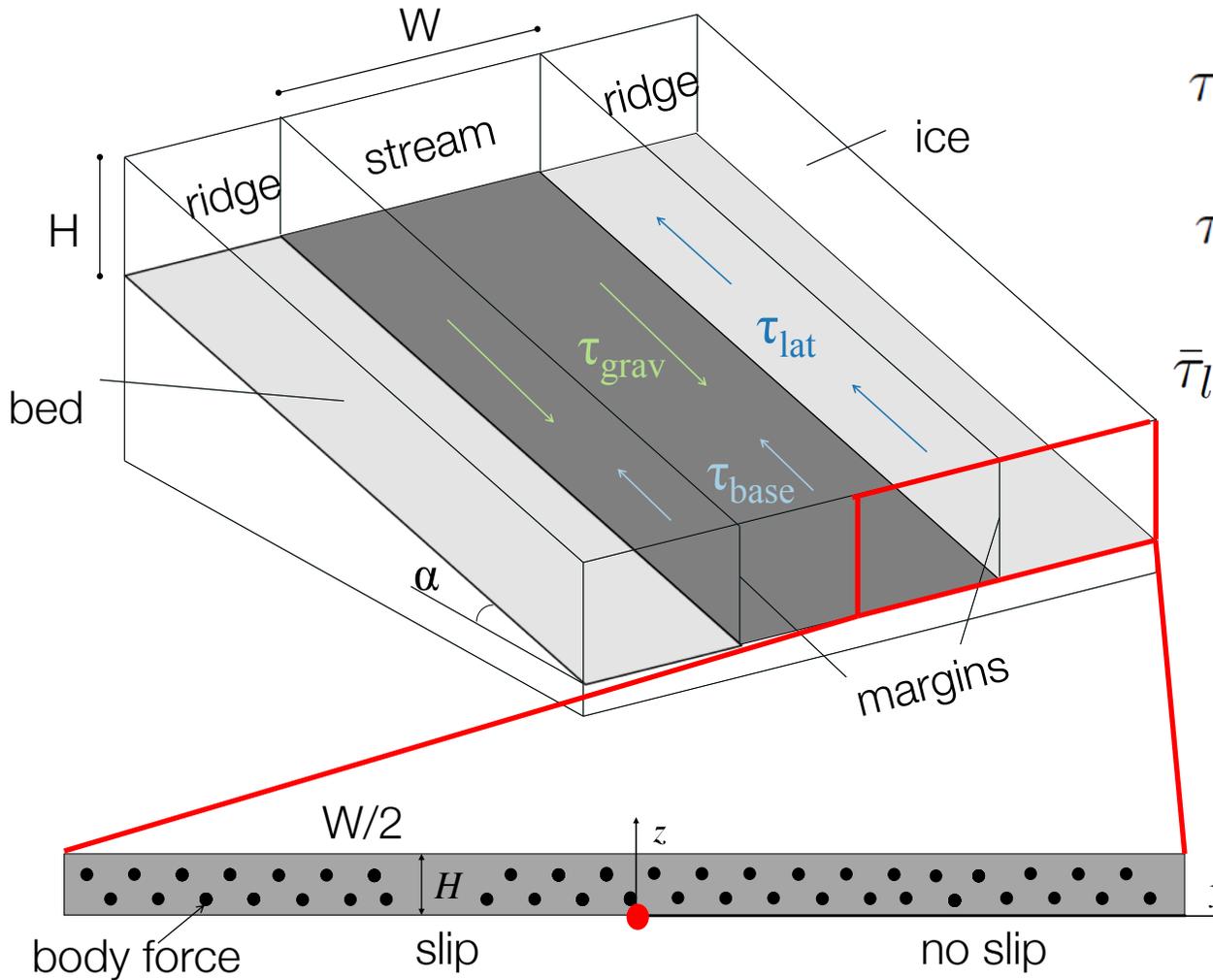
$$\tau_{base} = 3 - 5kPa$$



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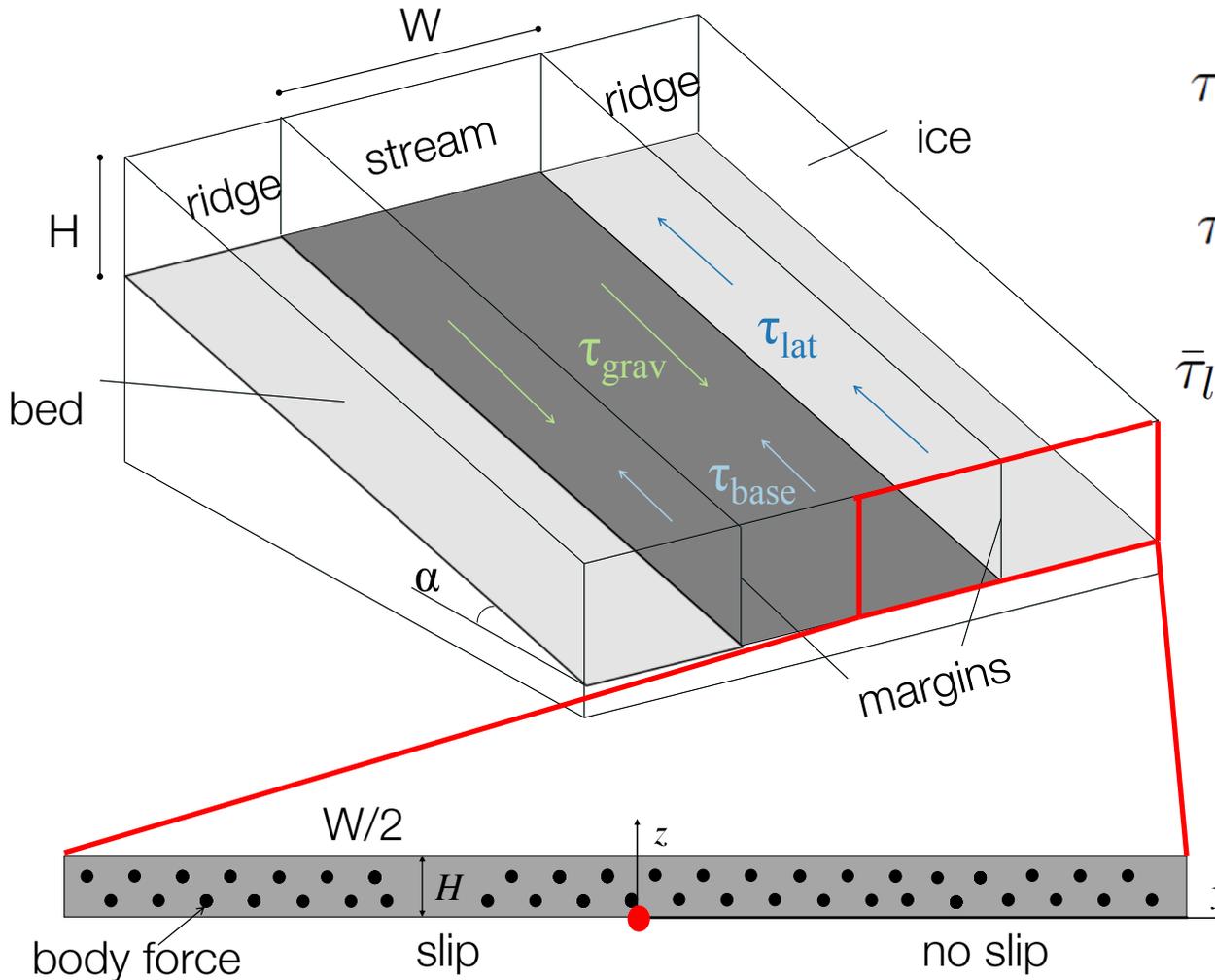
$$\bar{\tau}_{lat} H = \overline{(\tau_{grav} - \tau_{base})} \frac{W}{2}$$



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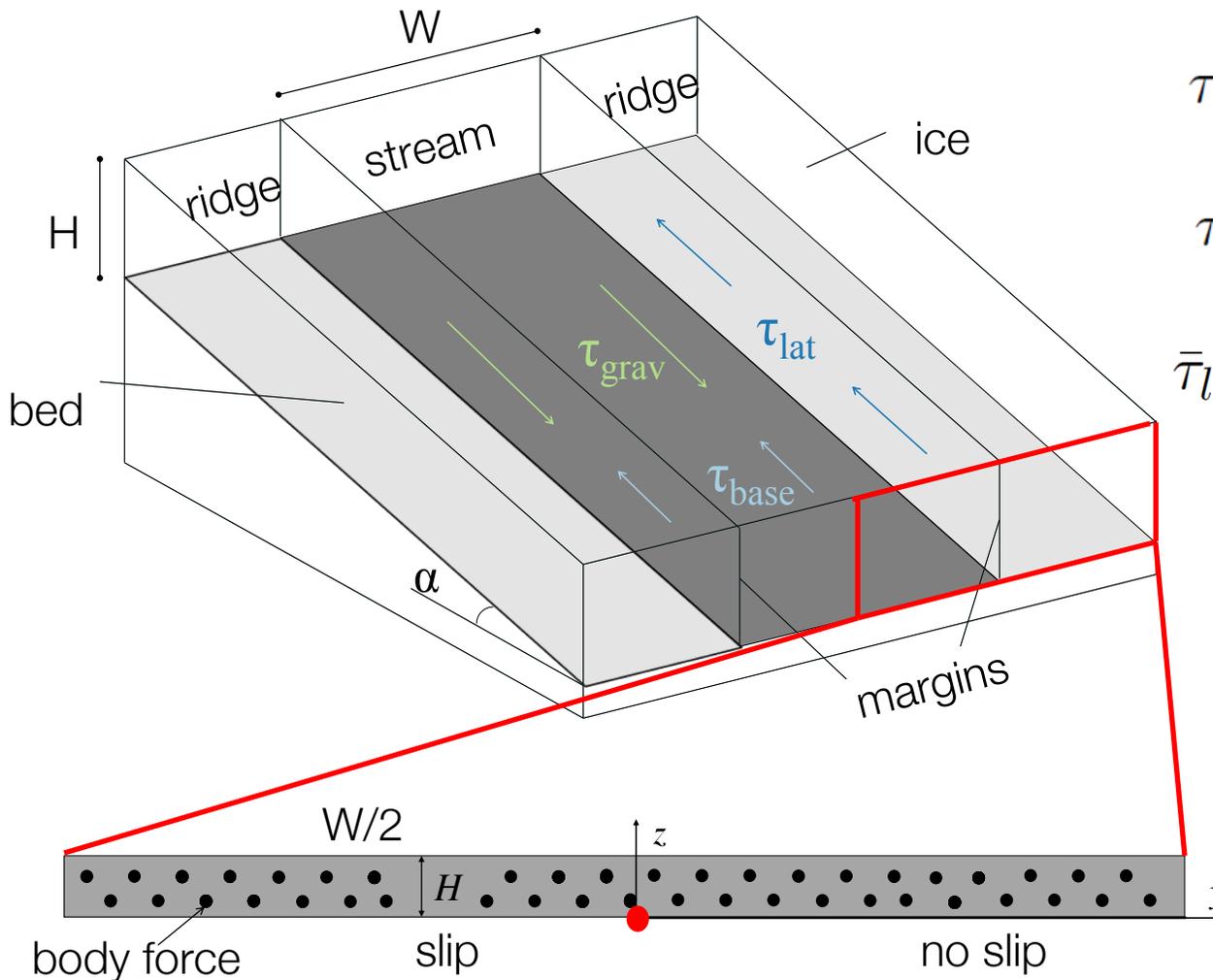
$$\tau_{grav} = \rho g H \sin(\alpha) \approx 11kPa$$

$$\tau_{base} = 3 - 5kPa$$

$$\bar{\tau}_{lat} H = \frac{(\tau_{grav} - \tau_{base}) W}{2}$$

$$\tau \dot{\epsilon} = \frac{J_{tip}}{4\pi r} \left[ \sqrt{4 - \sin^2(\theta)} + \cos(\theta) \right]$$

$$J_{tip} \approx H \bar{\tau}_{lat} \dot{\epsilon}(\bar{\tau}_{lat})$$



$$\tau_{grav} = \rho g H \sin(\alpha) \approx 11kPa$$

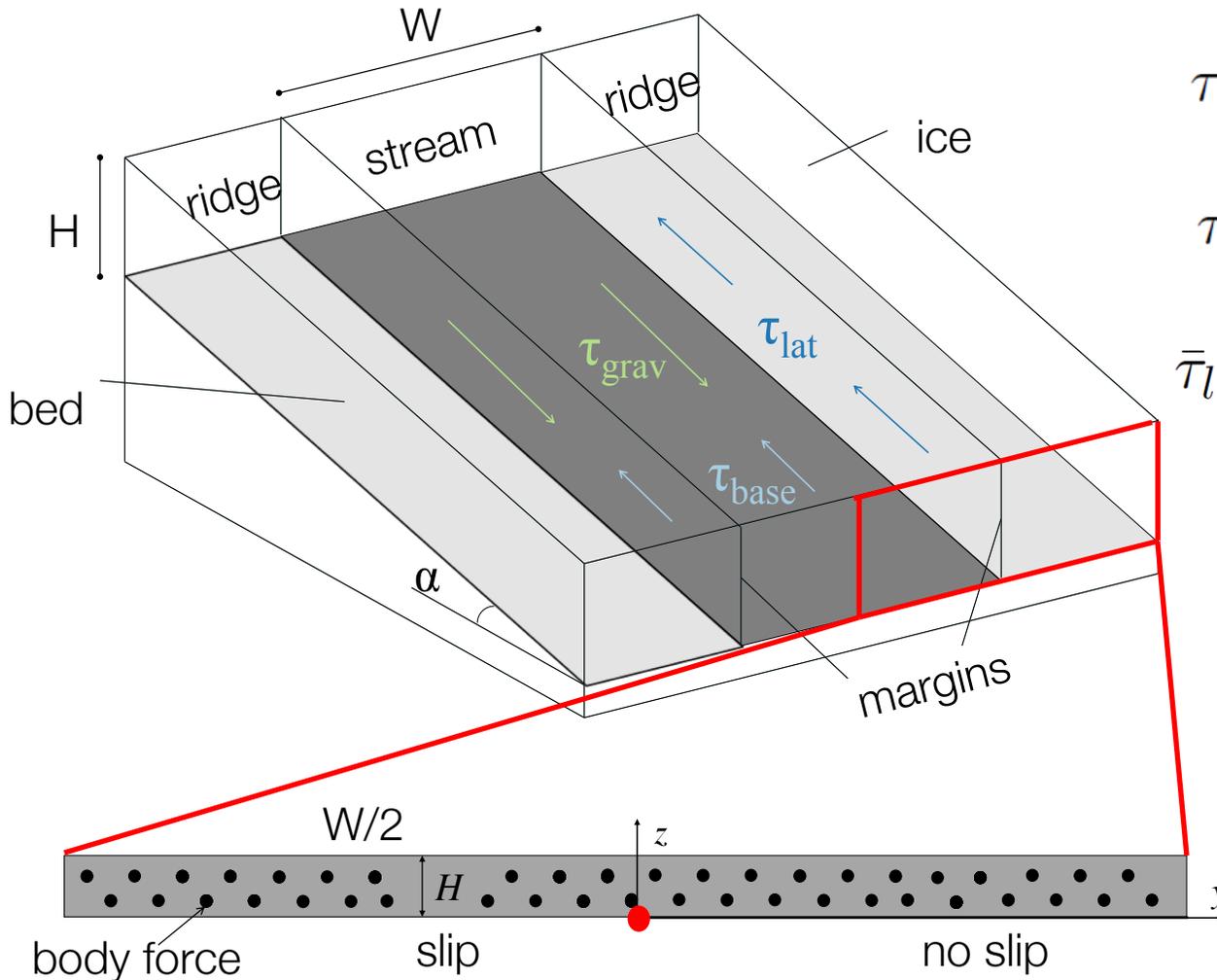
$$\tau_{base} = 3 - 5kPa$$

$$\bar{\tau}_{lat} H = \frac{(\tau_{grav} - \tau_{base}) W}{2}$$

$$\tau \dot{\epsilon} \sim \left( \frac{W}{H} \right)^4$$

$$\tau \dot{\epsilon} = \frac{J_{tip}}{4\pi r} \left[ \sqrt{4 - \sin^2(\theta)} + \cos(\theta) \right]$$

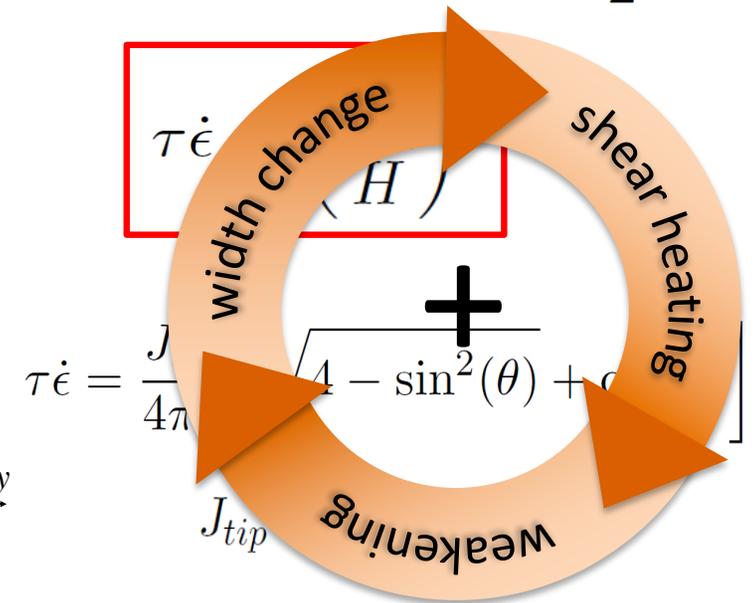
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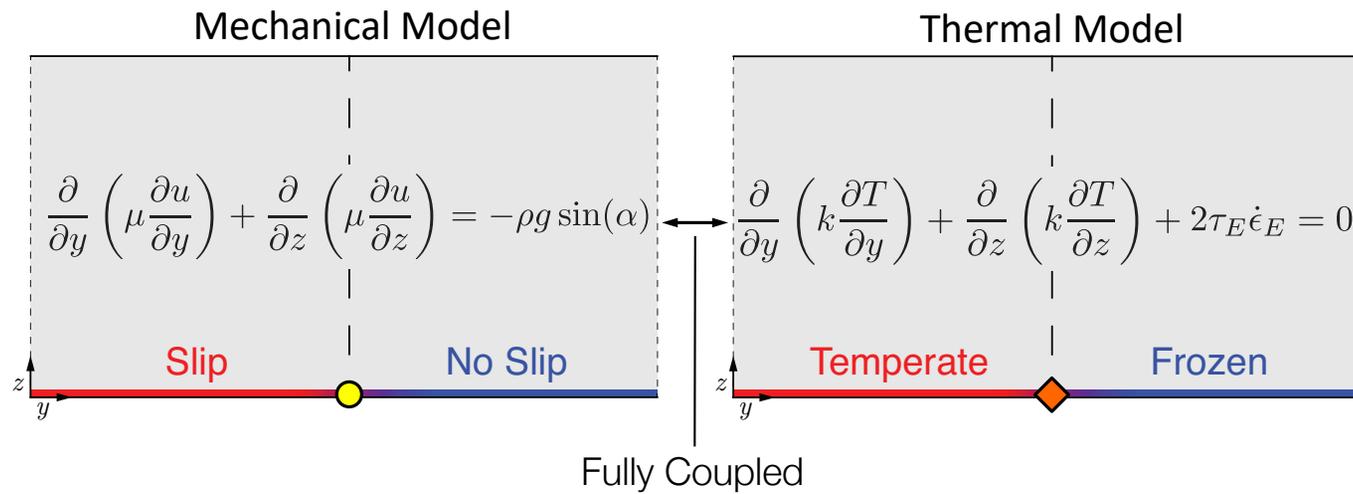
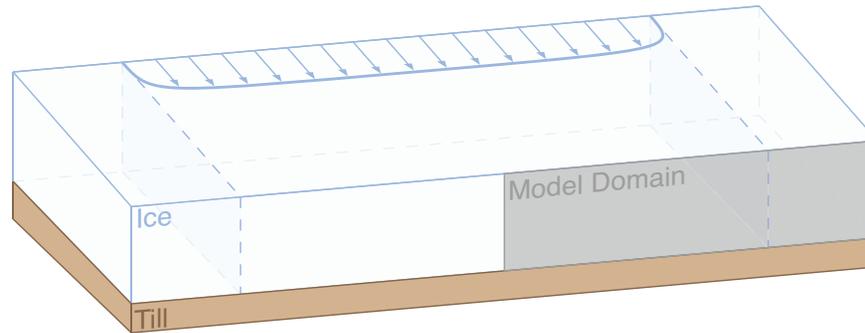


$$\tau_{grav} = \rho g H \sin(\alpha) \approx 11kPa$$

$$\tau_{base} = 3 - 5kPa$$

$$\bar{\tau}_{lat} H = \frac{(\tau_{grav} - \tau_{base})}{2} \frac{W}{2}$$





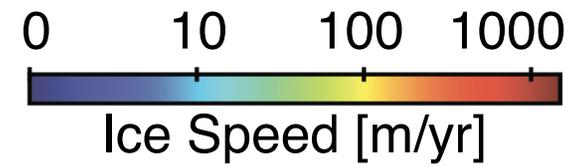
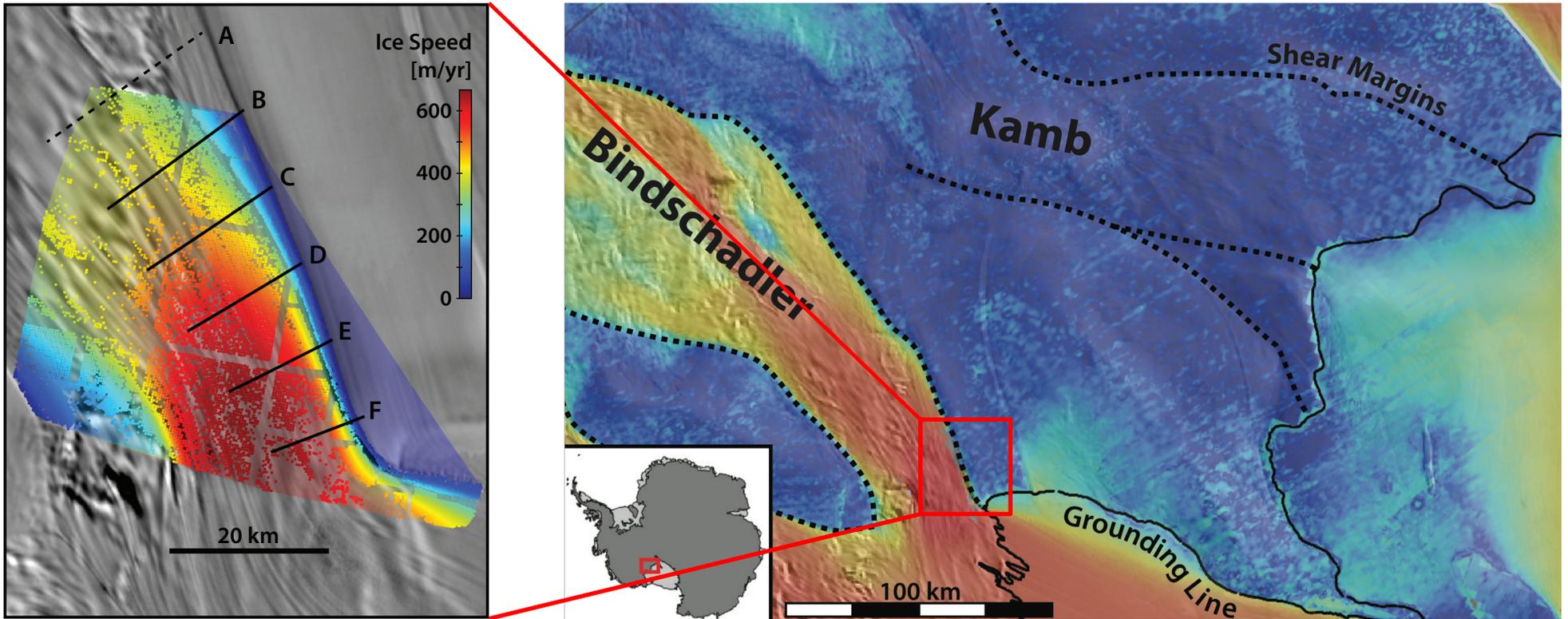
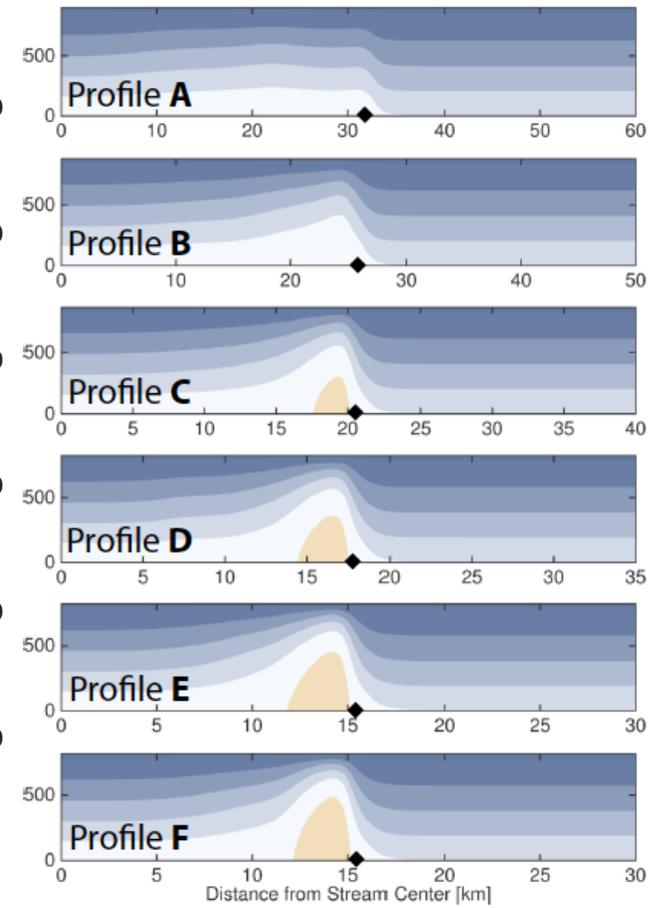
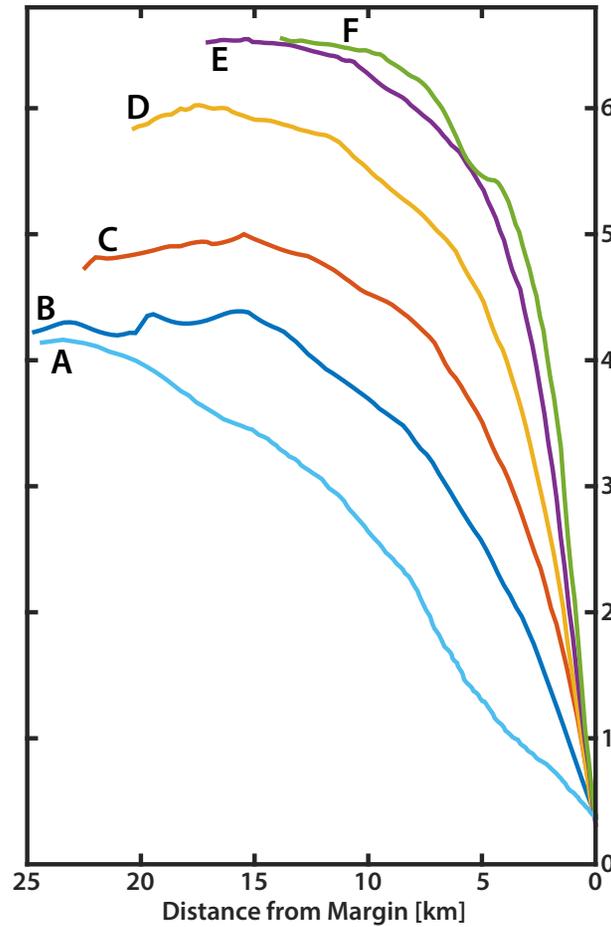
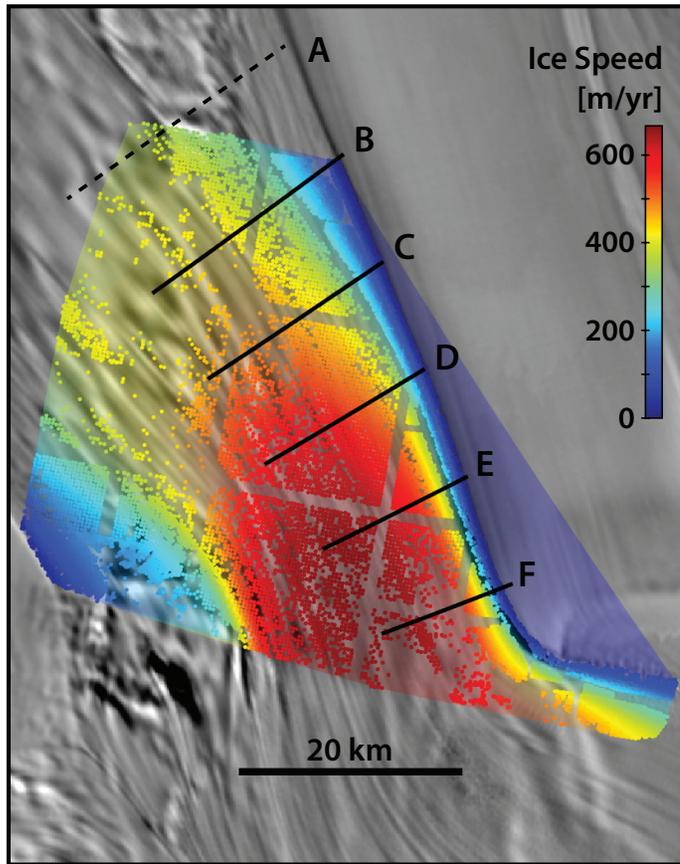
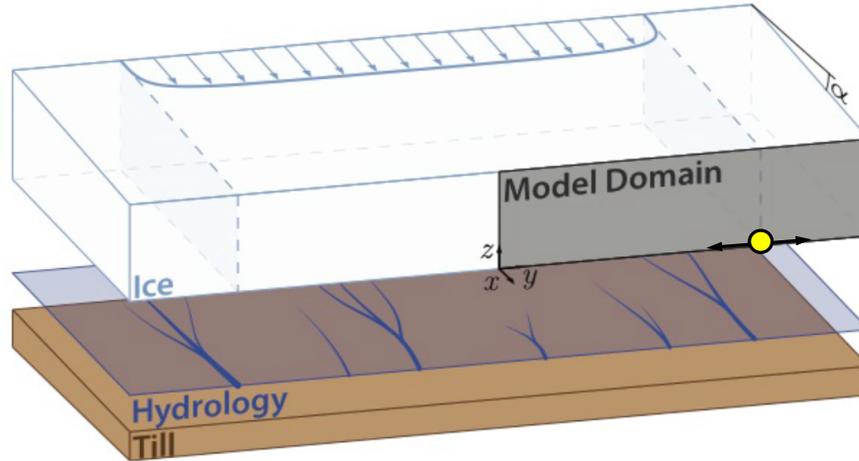
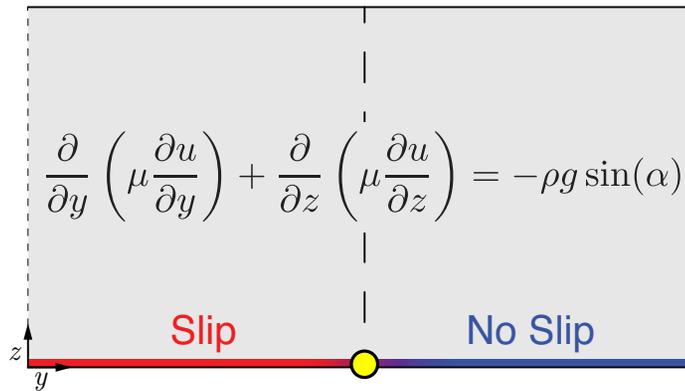


Figure by Cooper Elsworth, Data from Ted Scambos, NSIDC

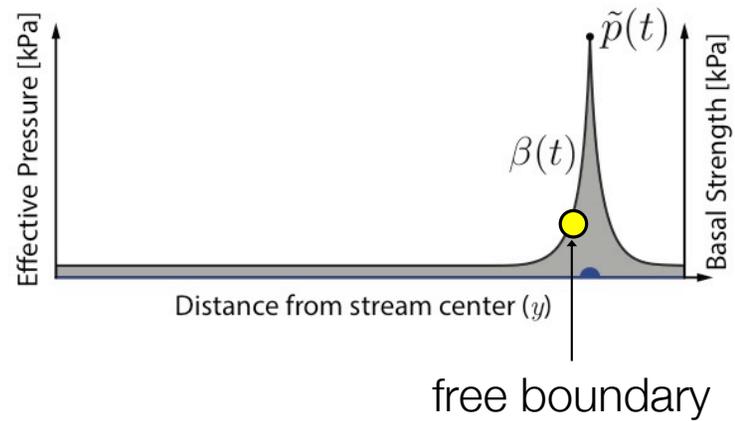


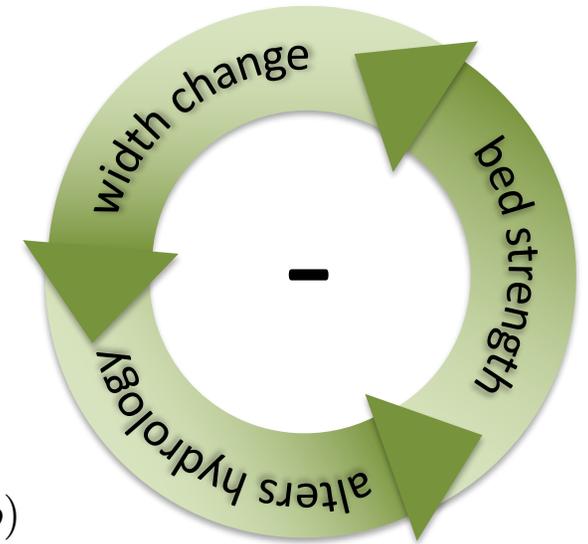
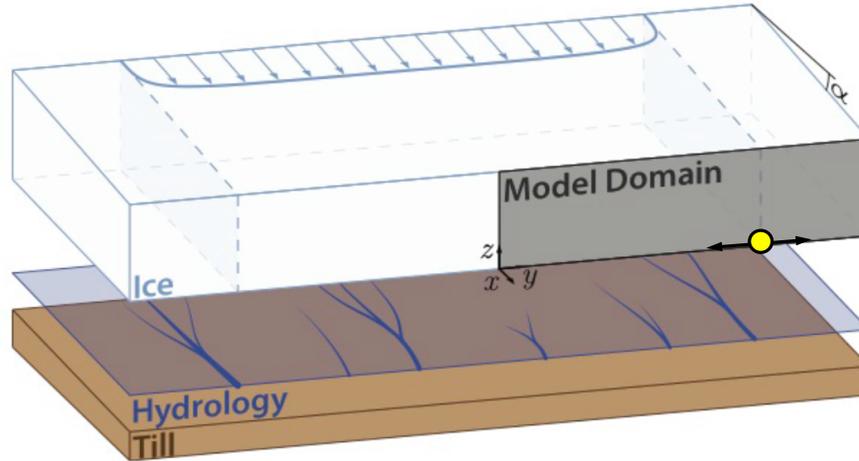


Mechanical Model

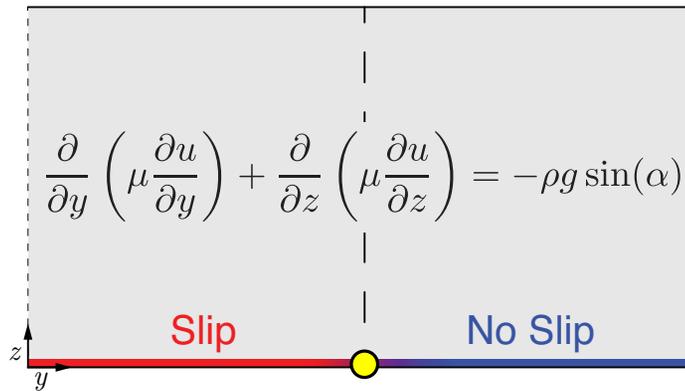


$$\tau_* = f(\sigma_n - p)$$

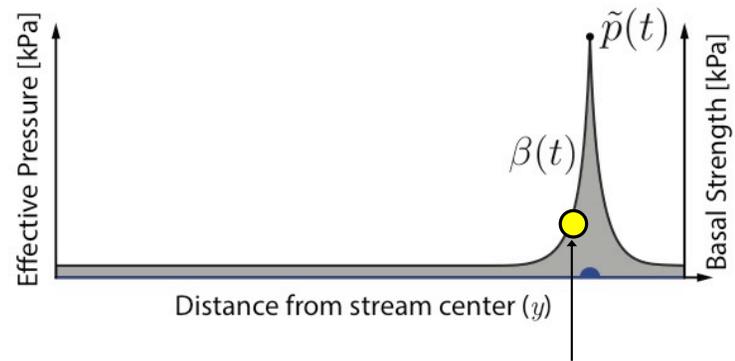




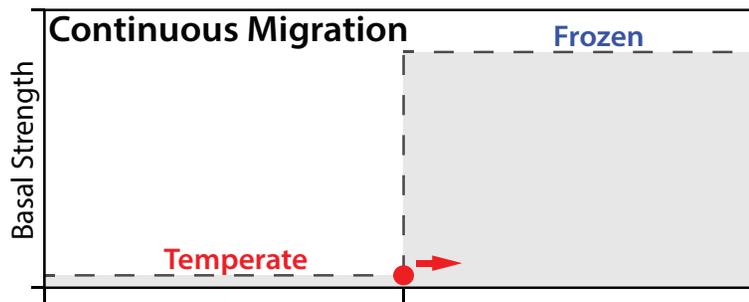
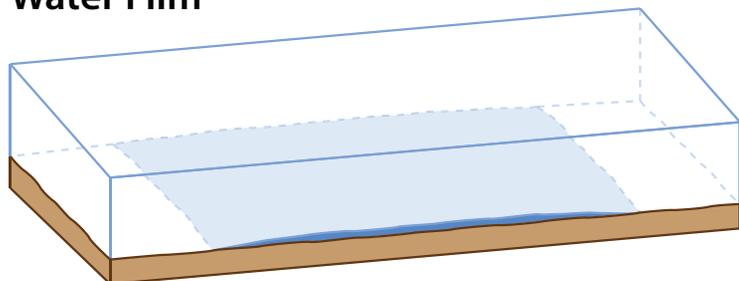
Mechanical Model



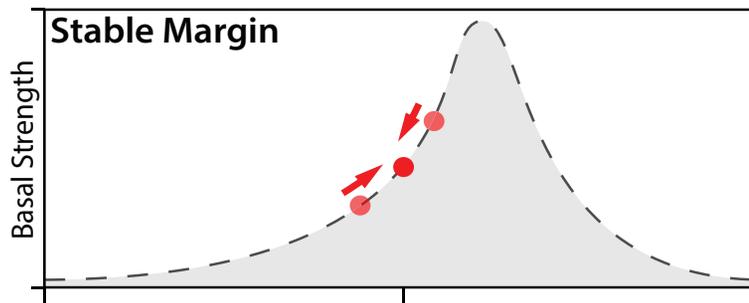
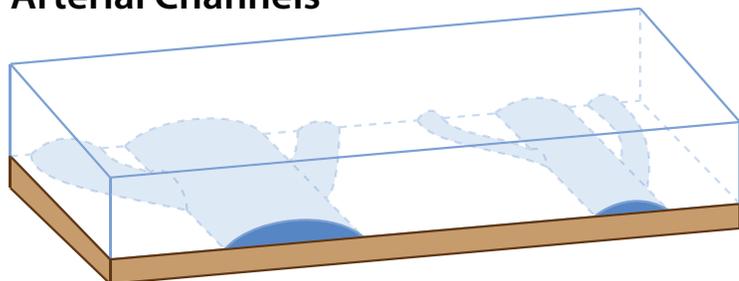
$$\tau_* = f(\sigma_n - p)$$



### Water Film



### Arterial Channels



### Distributed Cavities

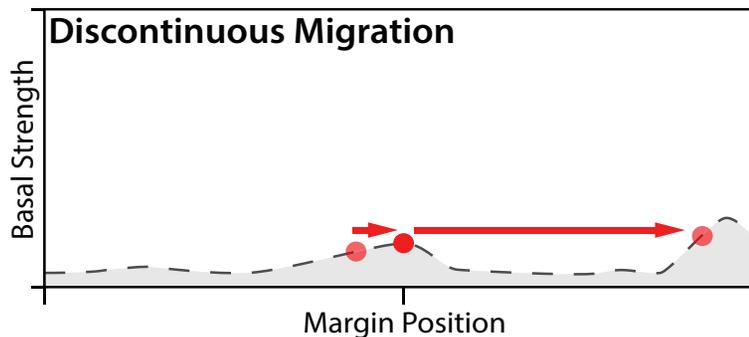
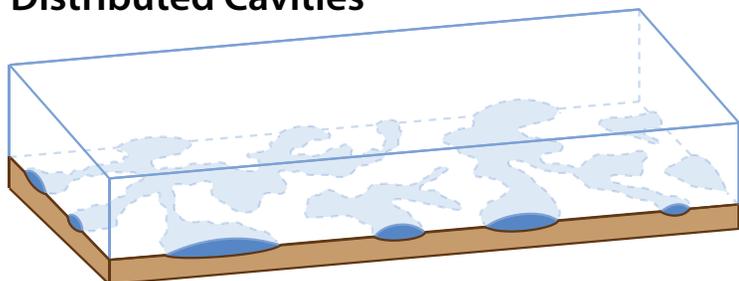
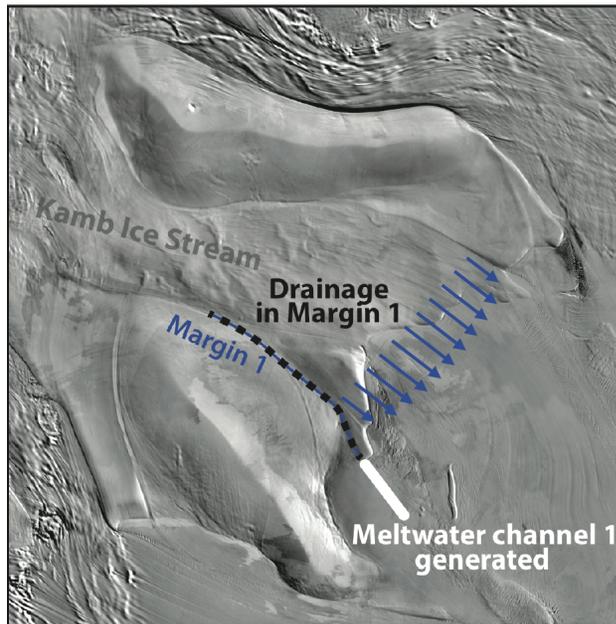
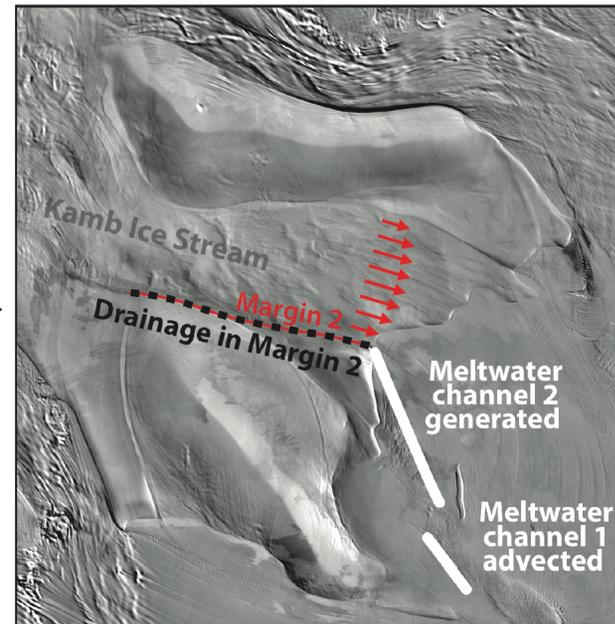
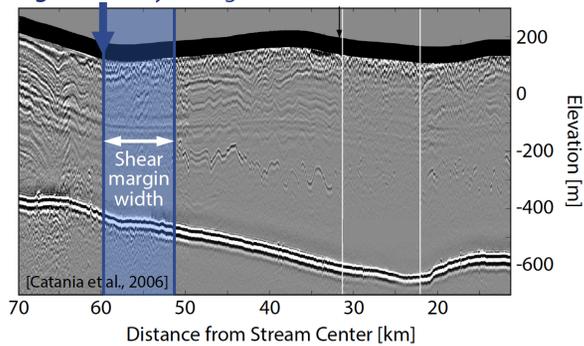


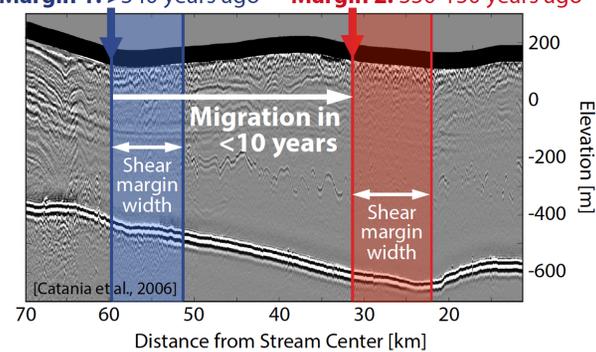
Figure by Cooper Elsworth



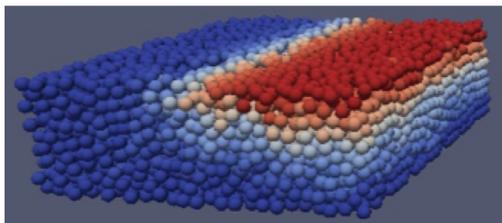
Margin 1: >340 years ago



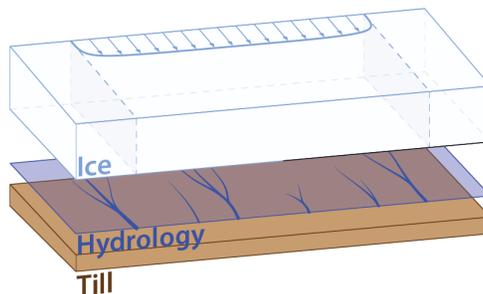
Margin 1: >340 years ago    Margin 2: 330-150 years ago



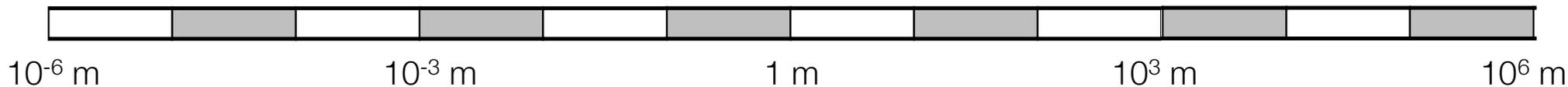
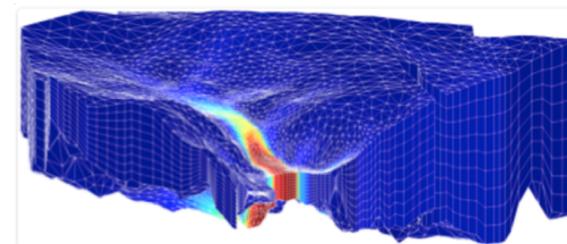
Granular scale



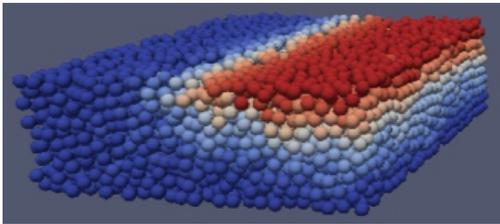
Ice stream scale



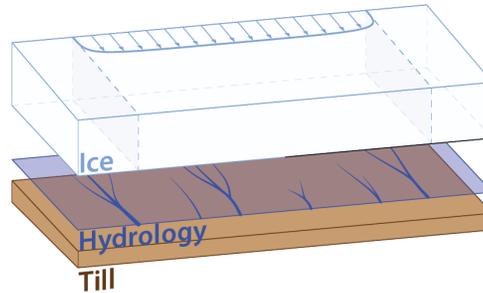
Ice sheet scale



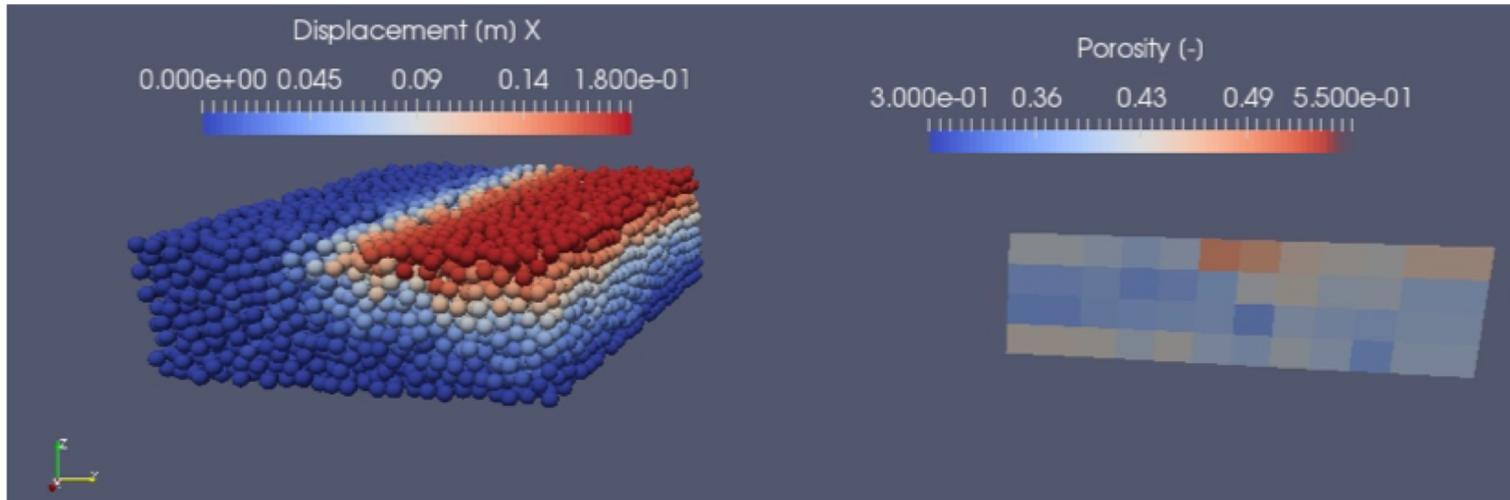
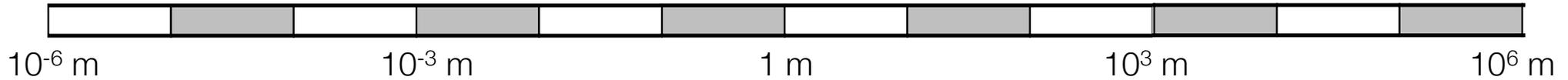
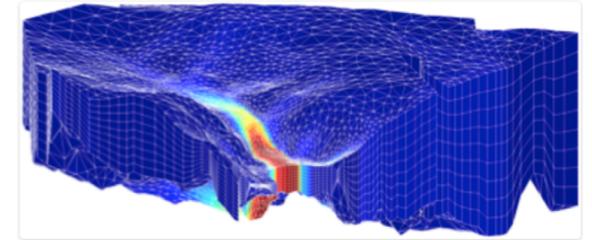
Granular scale



Ice stream scale



Ice sheet scale



Simulations by Alejandro Cabrales and Indraneel Kasmalkar; Collaboration with Anders Damsgaard and Liran Goren

## Conclusions for Modeling

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1. Multiphase interactions at the granular scale can trigger a shift in the system-scale dynamics.
2. Multiphase flows are profoundly nonlinear and are prone to both positive and negative feedback loops.
3. Data plays multiple roles from validation to model testing and shedding light on model limitations.

## Ramifications for sea-level rise adaptation planning

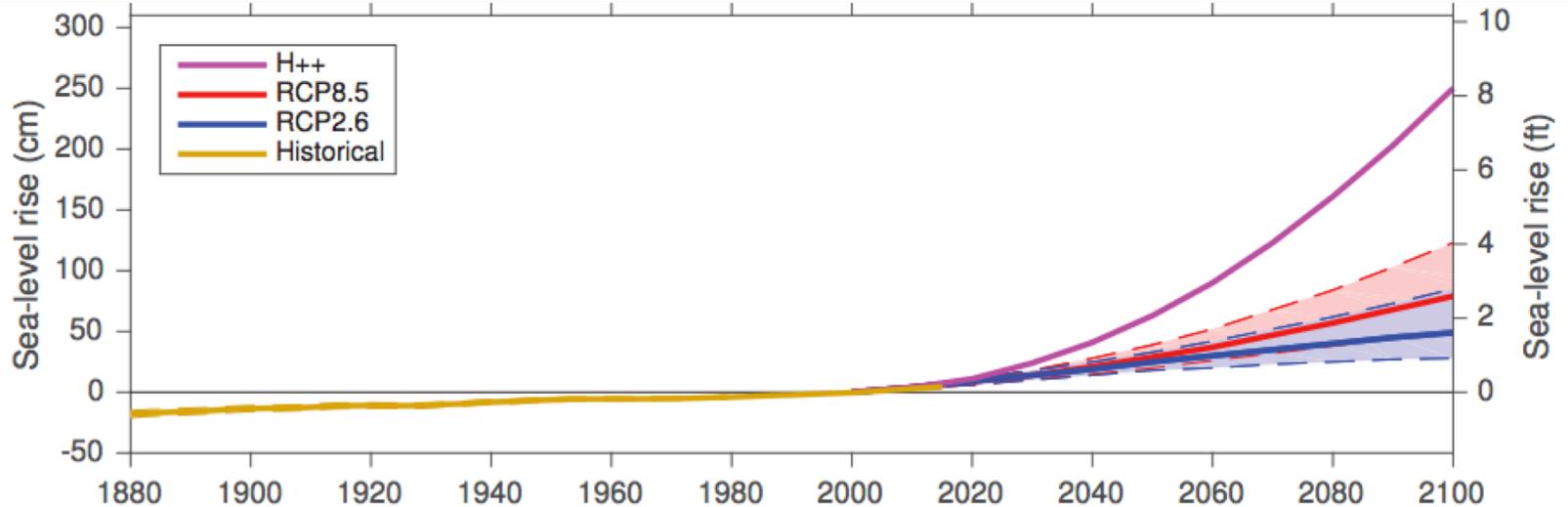
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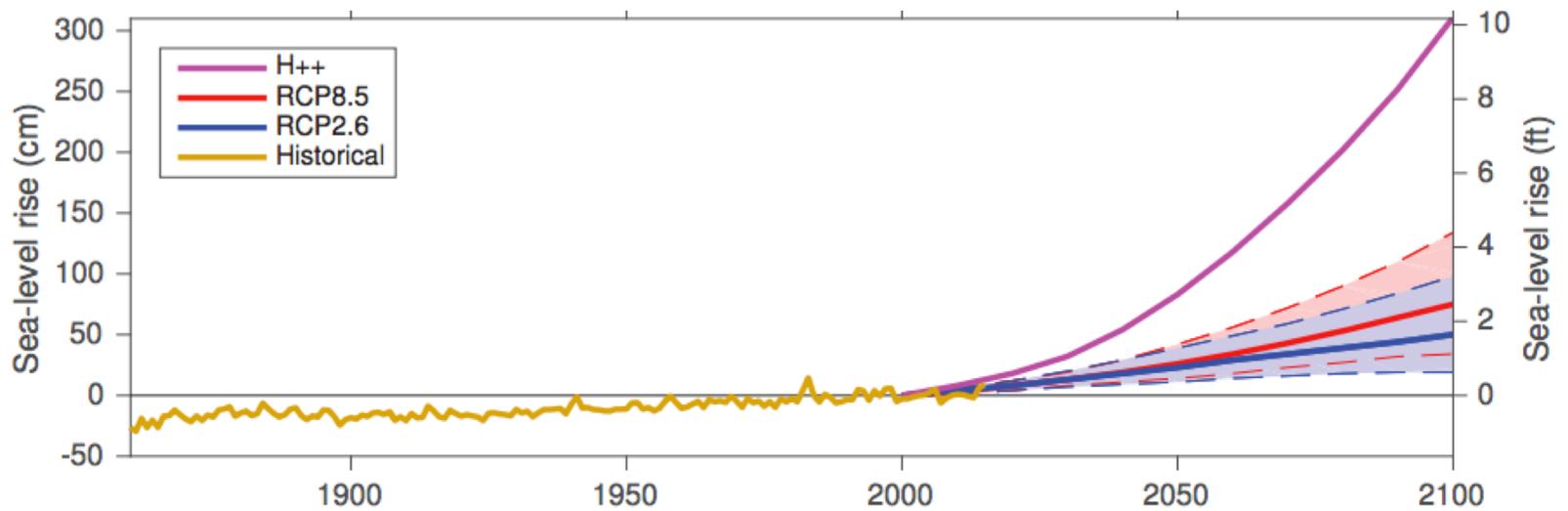
# Ramifications for sea-level rise adaptation planning



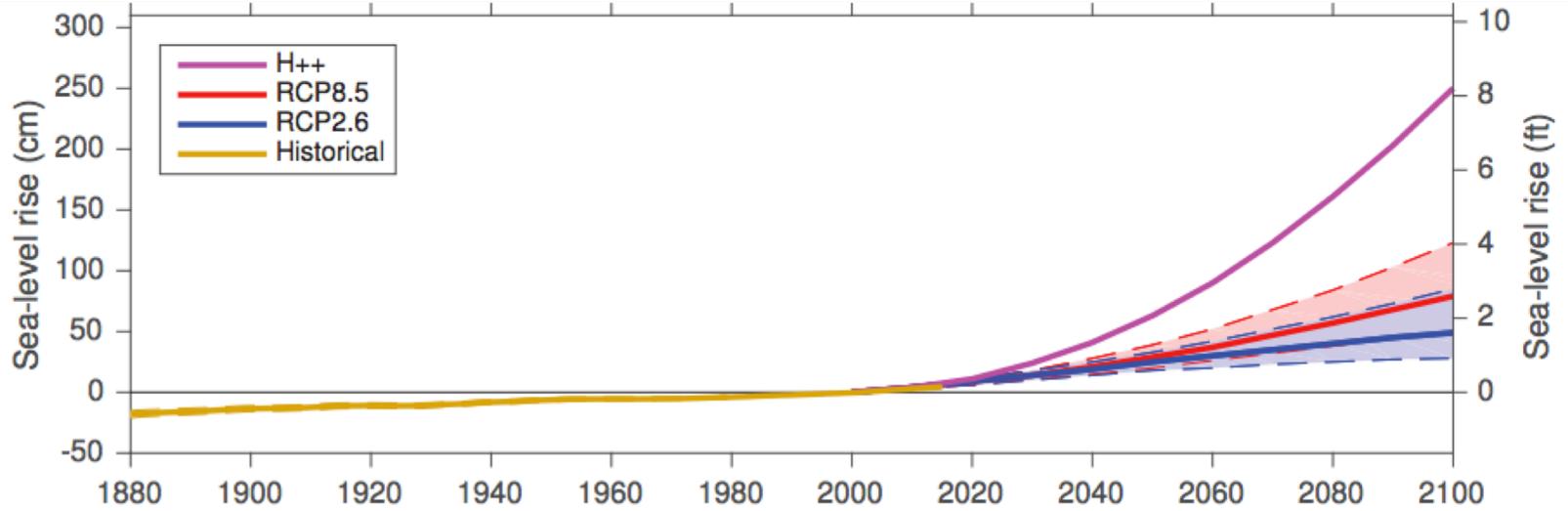
Global mean sea level



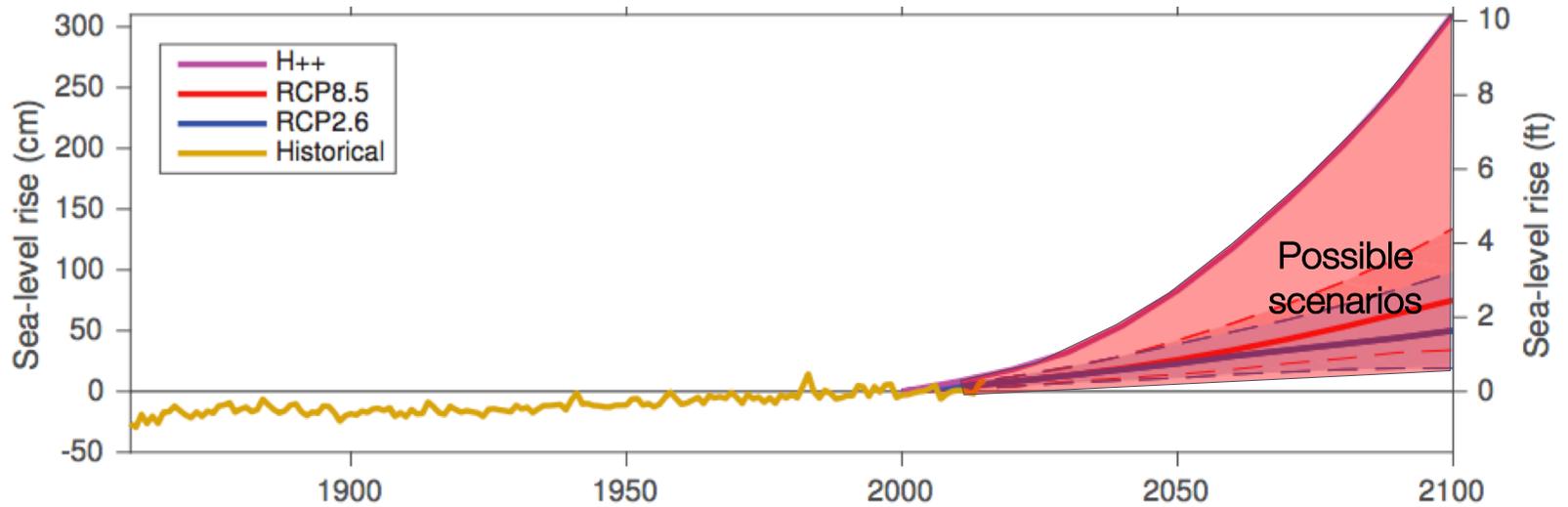
Relative sea level in San Francisco Bay

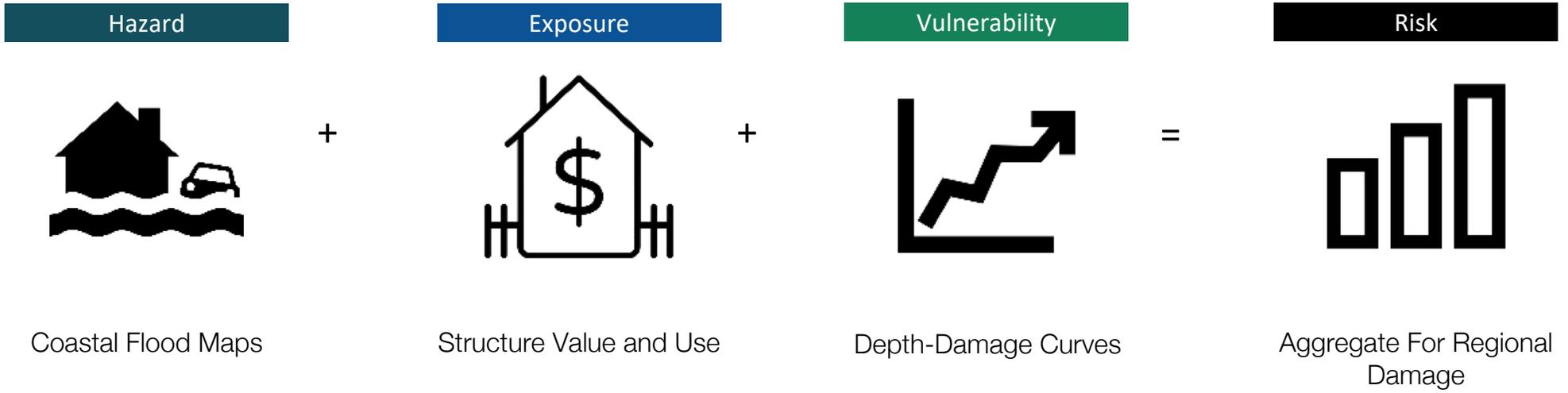


Global mean sea level

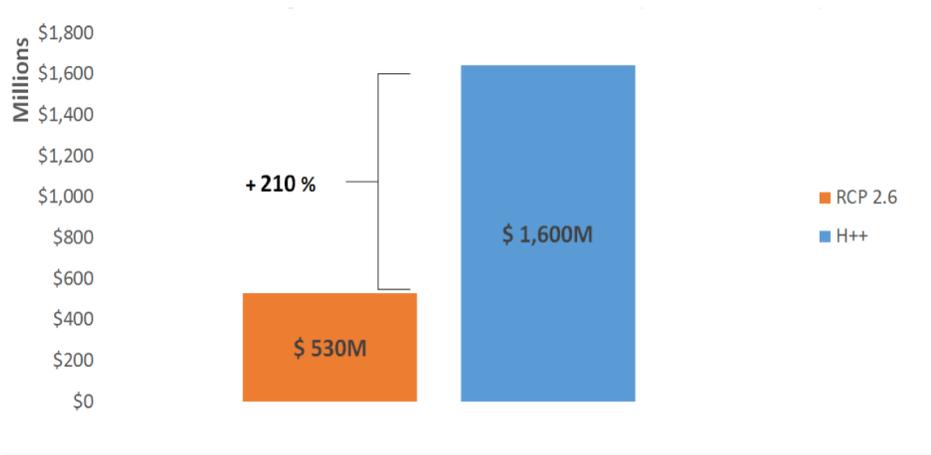


Relative sea level in San Francisco Bay

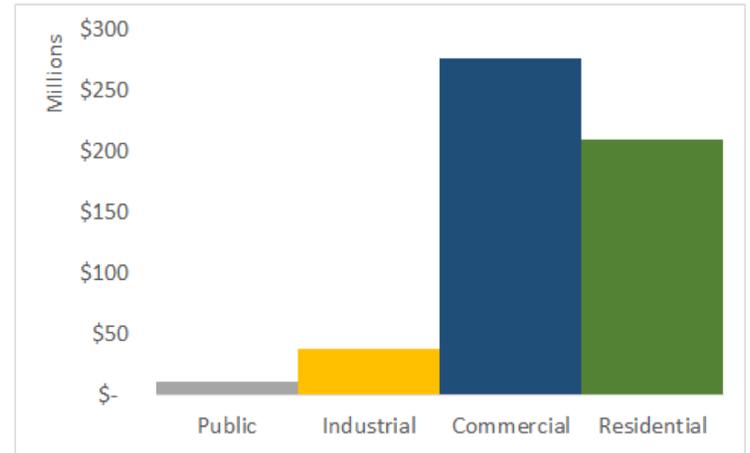




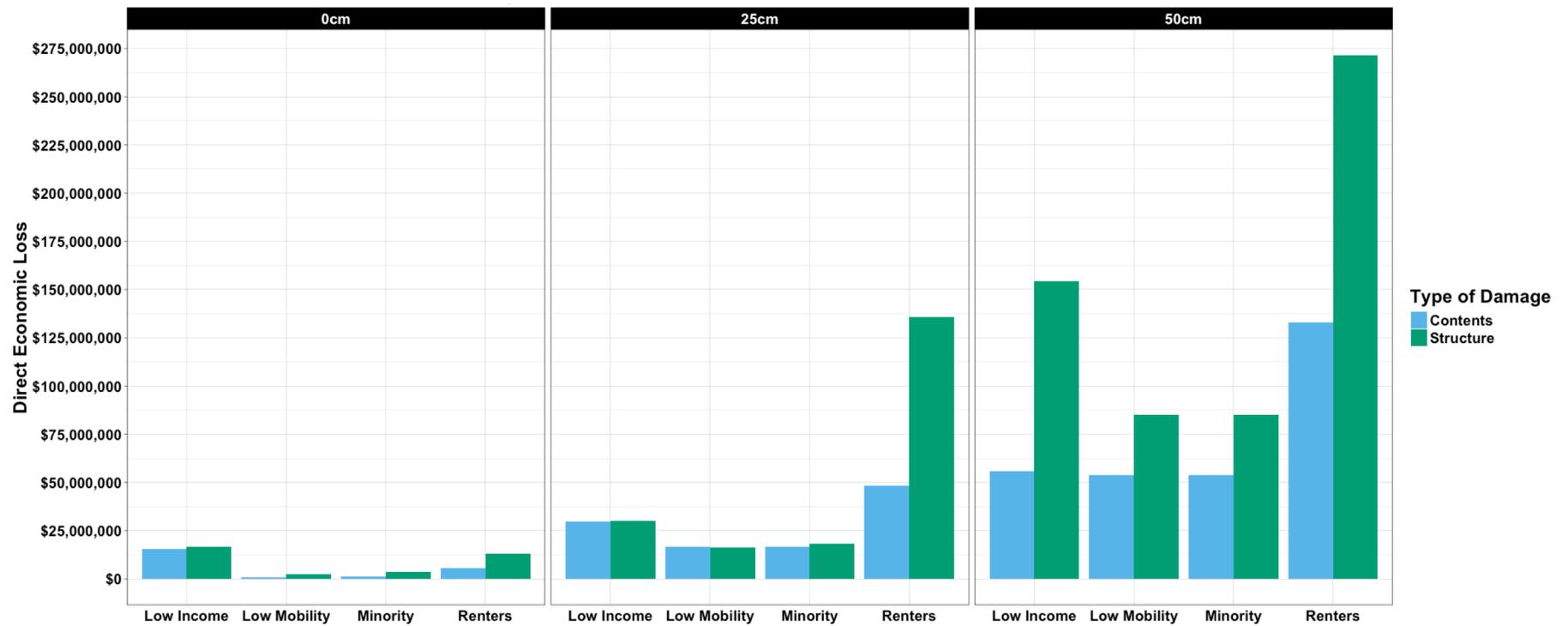
San Mateo County Average Annualized Loss for 2020-2040 (in current \$)



Average Annual Loss by Sector



# Who will be affected disproportionately?

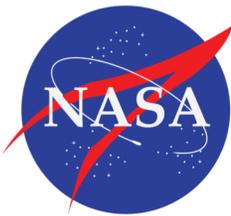


K-means clustering analysis by Ifeoma Anyansi

Thank you

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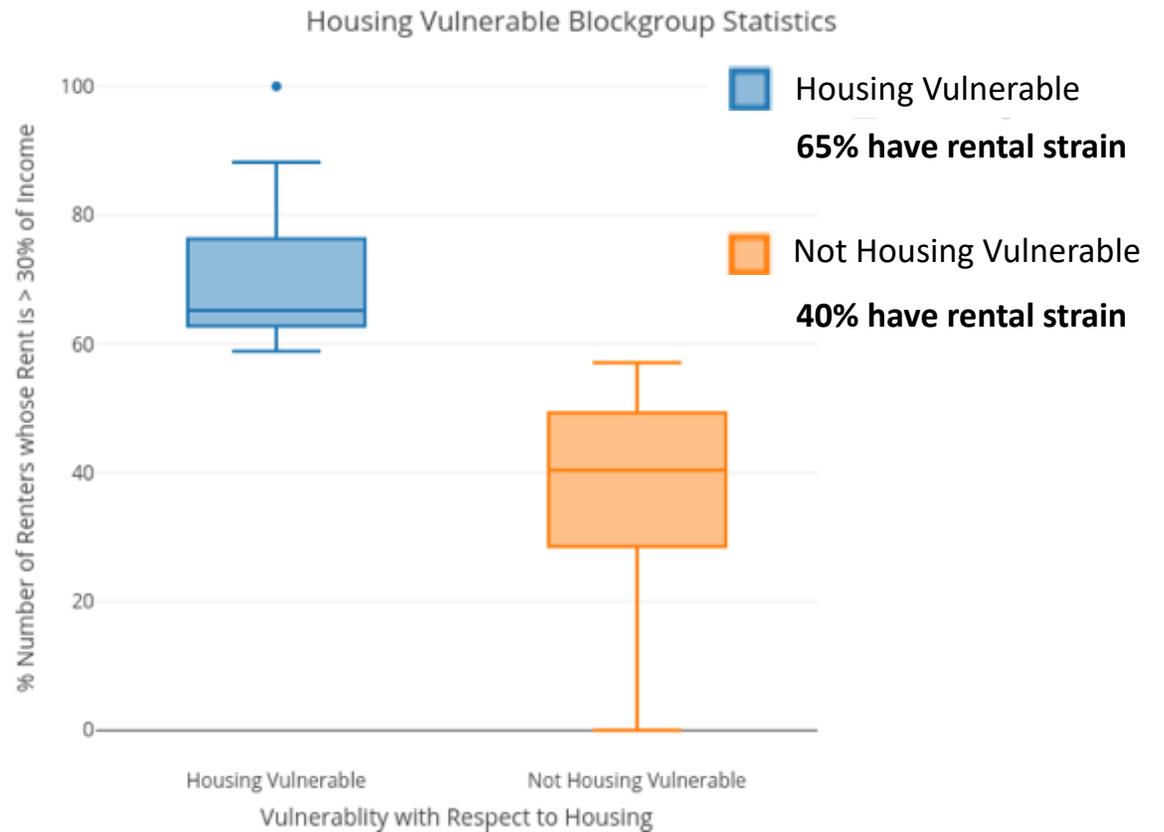
*Uncertainty is an uncomfortable position, but certainty is an absurd one.*  
– Voltaire



# How to describe this population?

*A high % of the population has rent that is greater than 30% of their income*

- 1 Low Income
- 2 Minority
- 3 Renters
- 4 Low Mobility



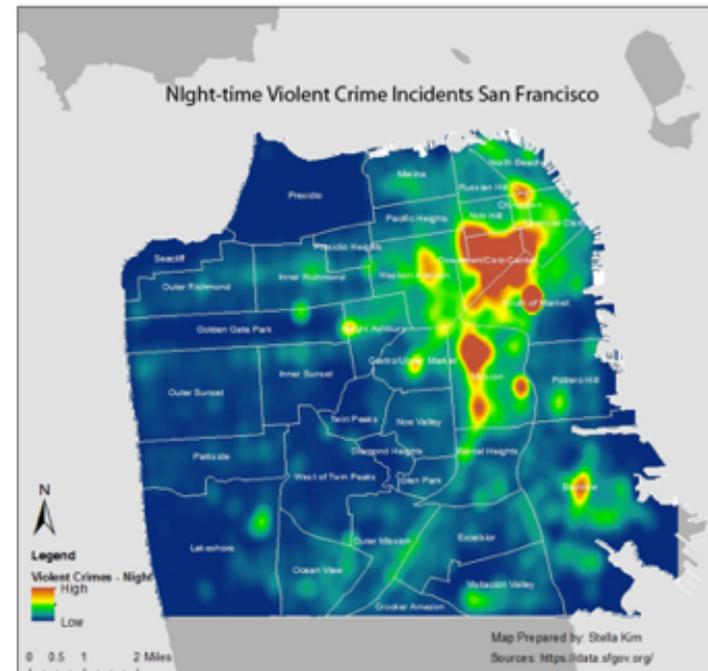
# What is clustering?

- The process of grouping similar data together.
- The goal is that neighborhoods within a cluster are similar to one another.
- Block Group size = ~ 1500 People

## Examples:

**Land Use:** Identifying groups of houses that have similar house values, type, and location

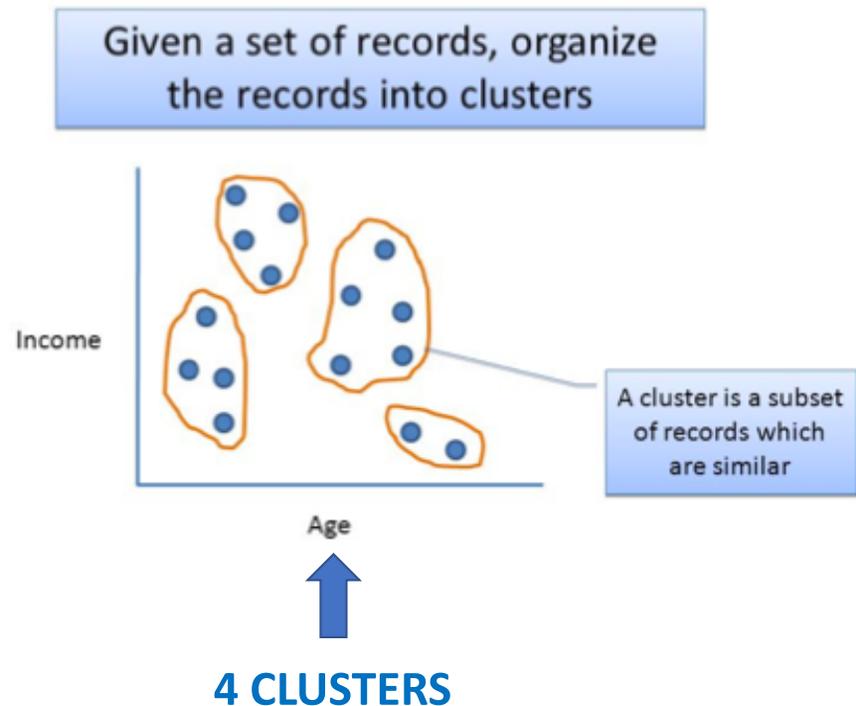
**Vulnerability:** Identifying neighborhoods that have similar vulnerabilities  
ex. Low-income, % disabled



What is the spatial distribution of vulnerability?

# 8 Variables for Clustering Analysis

- **% Unemployment**
- **No Vehicle**
- **Education**
- **Disabled**
- **Rent over 30% income**
- **Per Capita Income**
- **% Black**
- **% Hispanic**



# 4 Different Vulnerability Clusters for Bay Area

## Economically Vulnerable



### Low Income

- Per Capita Income
- % Unemployed

## Socioeconomically Vulnerable



### Minority

- % Black,
- % Hispanic
- % Didn't Graduate Highschool
- %Unemployed

## Housing Vulnerable



### Renters

- % Number of Rental Units With Rent > 30% of Income

## Mobility Vulnerable



### Low Mobility

- % Disabled
- % No Vehicles

