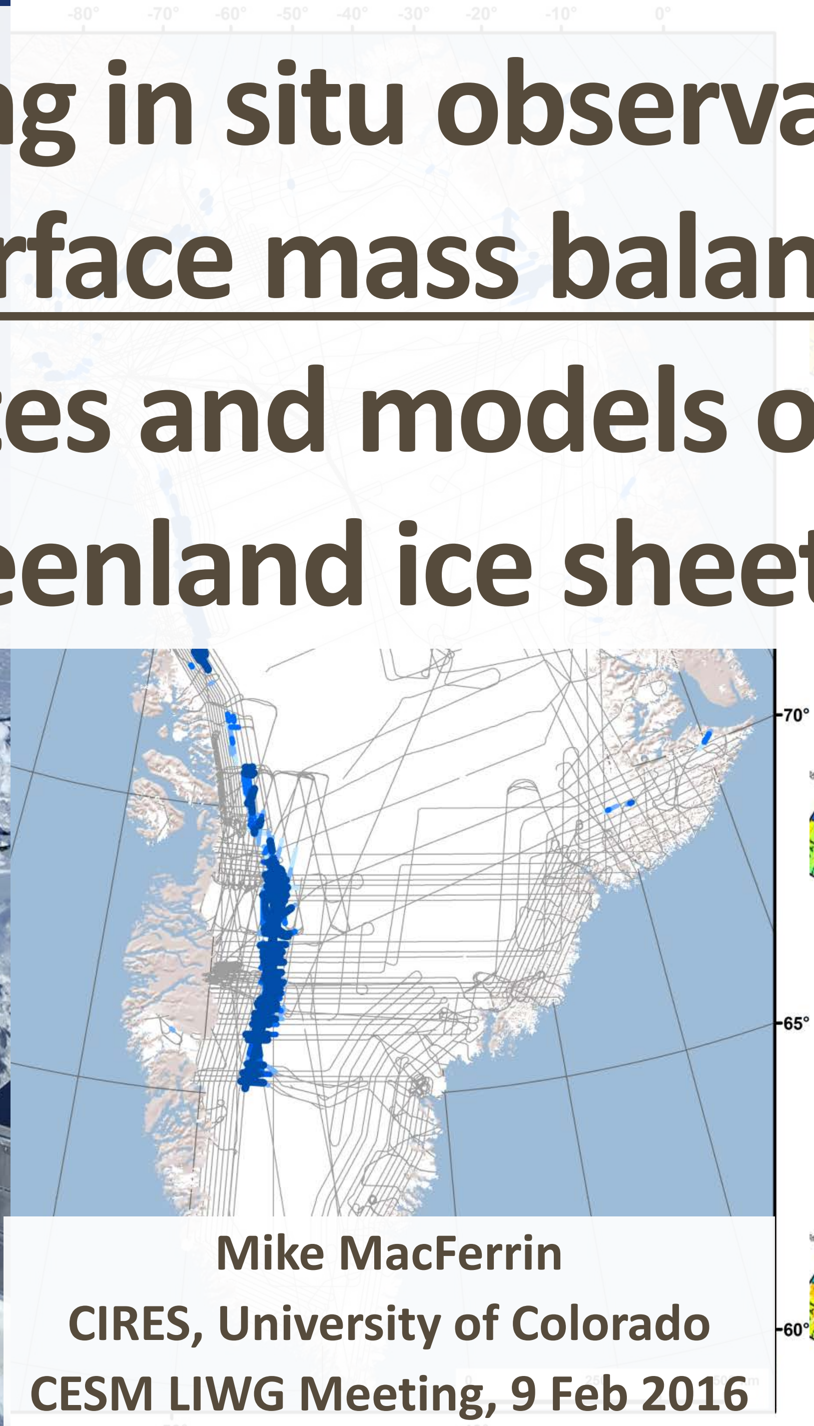
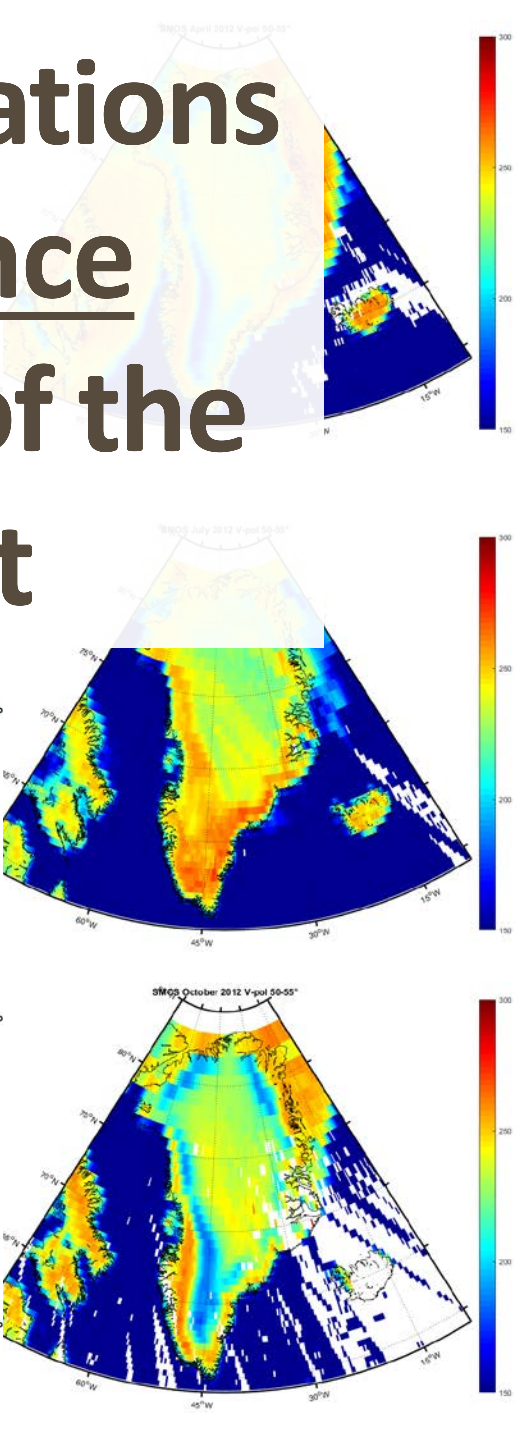
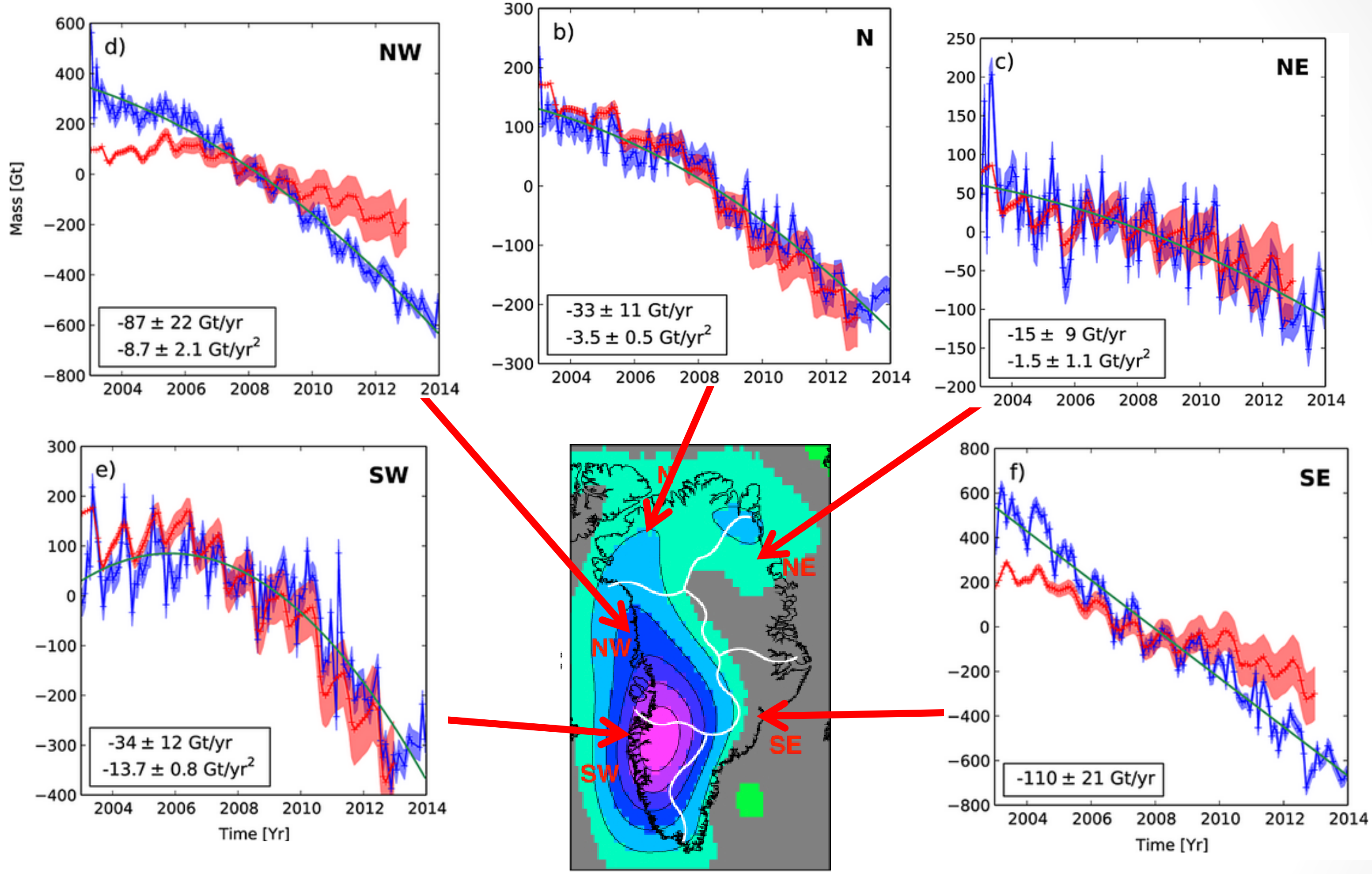
Upscaling in situ observations to <u>surface mass balance</u> estimates and models of the Greenland ice sheet





Mike MacFerrin
CIRES, University of Colorado
CESM LIWG Meeting, 9 Feb 2016

Greenland Surface Mass Balance, (2002-2014)

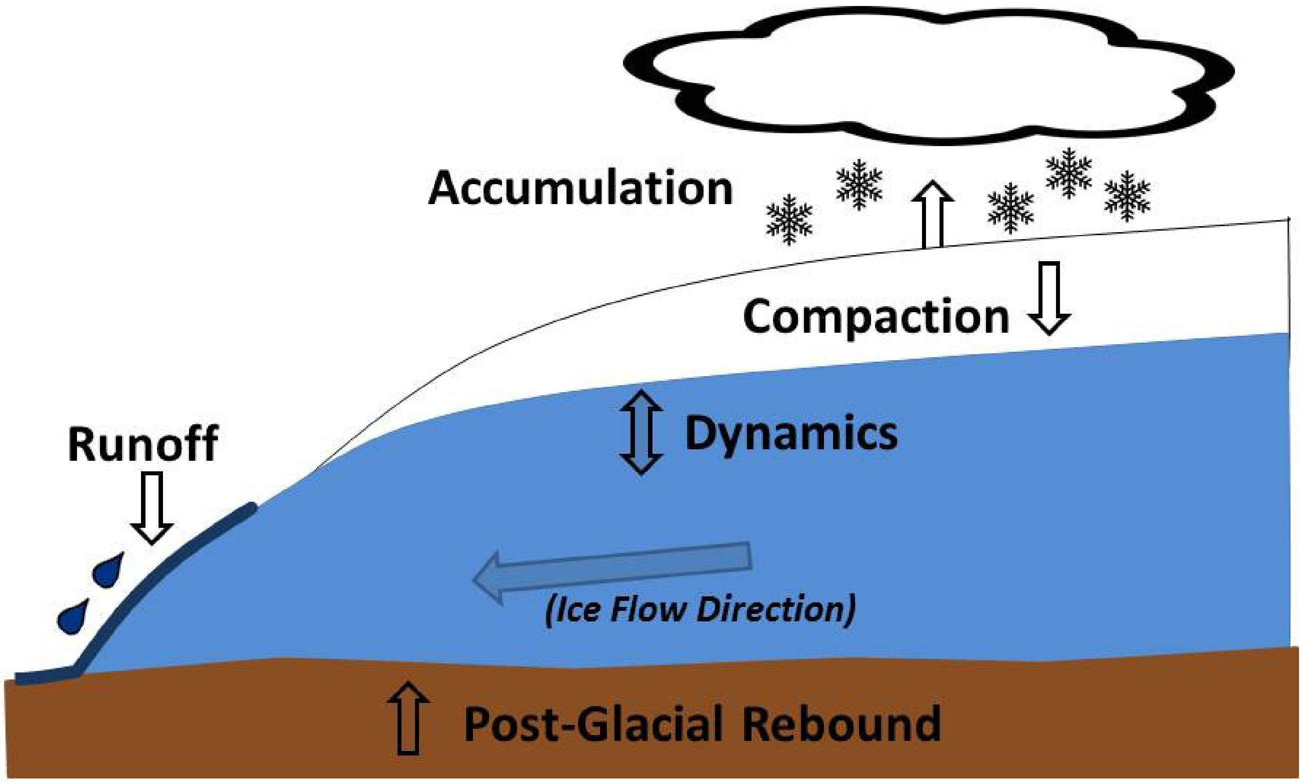


- **Surface Mass Balance (SMB)** accounts for **68% of mass loss** and **79% of acceleration** in Greenland, 2002-2014
- SMB is currently the **dominant mechanism** of mass loss

Velicogna, et al. (2014), GRL

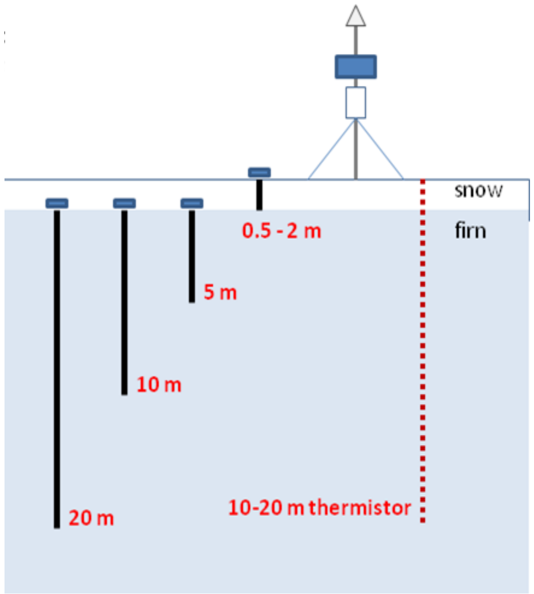
Firn Densification

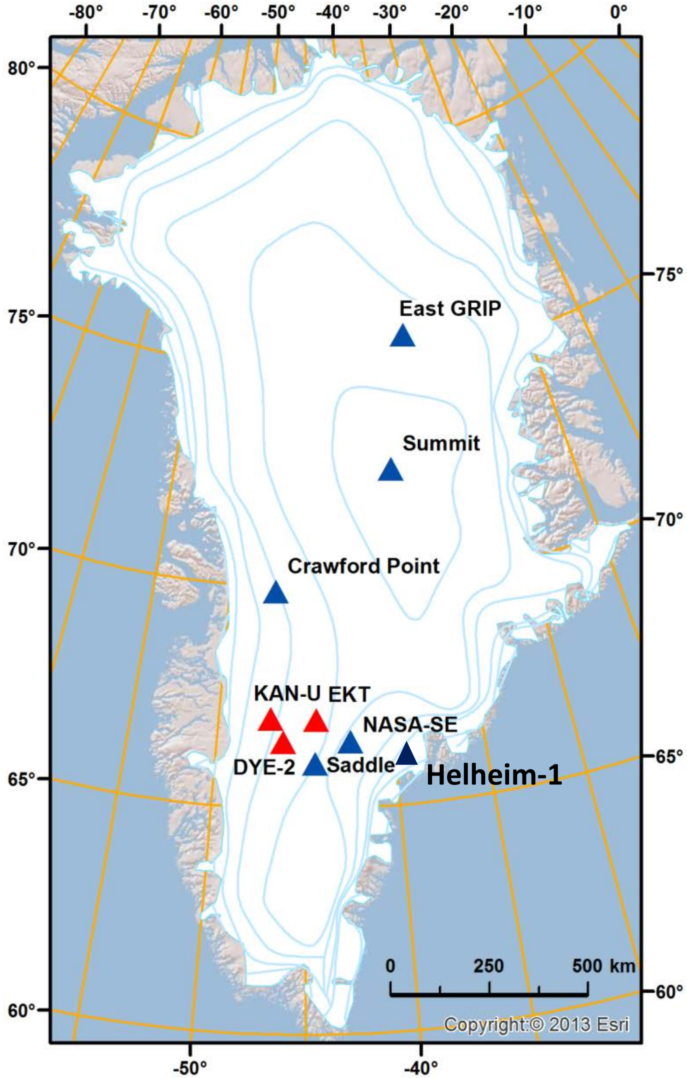
- A primary uncertainty in ice sheet altimetry



Firn Densification

- Firn Compaction Verification and Reconnaissance (FirnCover)





Community Firn Model

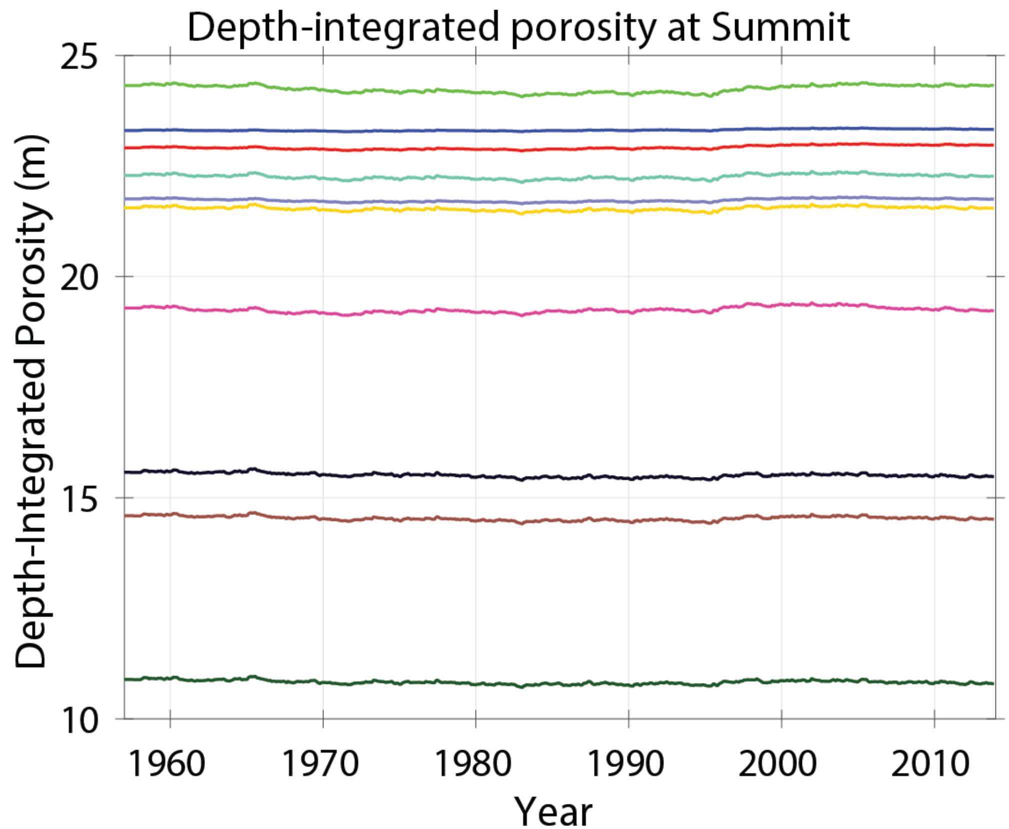
- Vertical compaction models from published literature

Herron & Langway, 1980	J. Glaciology, stress-based solution	**Goujon et al., 2003**	JGR Atmospheres
Herron & Langway, 1980	J. Glaciology, analytic solution	**Barnola et al., 1991**	Tellus B
Essery et al., 2013	Advances in Water Resources	**Ligtenberg et al., 2011**	The Cryosphere
Cummings et al., 2013	U. Montana Snow, Ice & Climate	**Simonsen et al., 2013**	J. Glaciology
Arthern et al., 2010	J. Geophysical Research	**Li & Zwally, 2011**	Annals Glaciology

- Most make steady-state climate assumptions

CFM Results at Summit, Greenland

- Forced with 1958 – 2013 temperature and accumulation (RACMO)
- Total porosity differs up to 220%



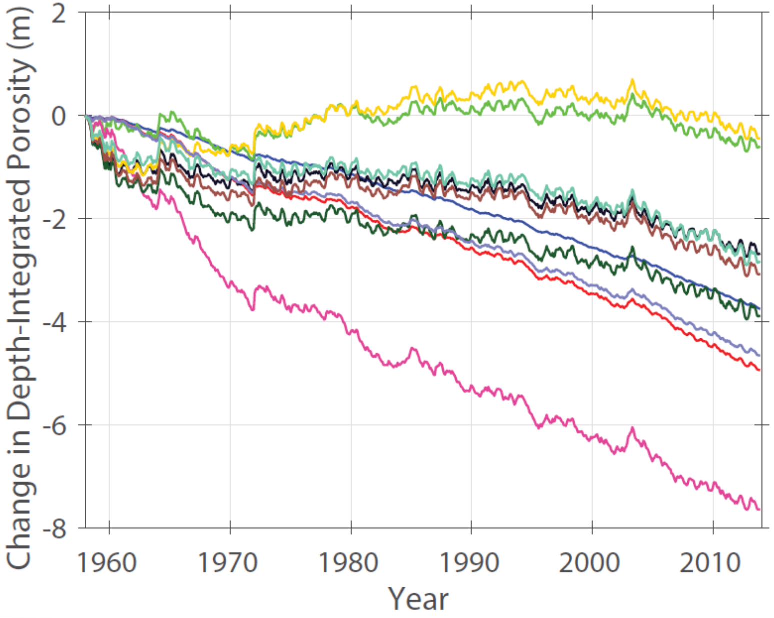
Max Stevens, University of Washington

Firn Model Initialization

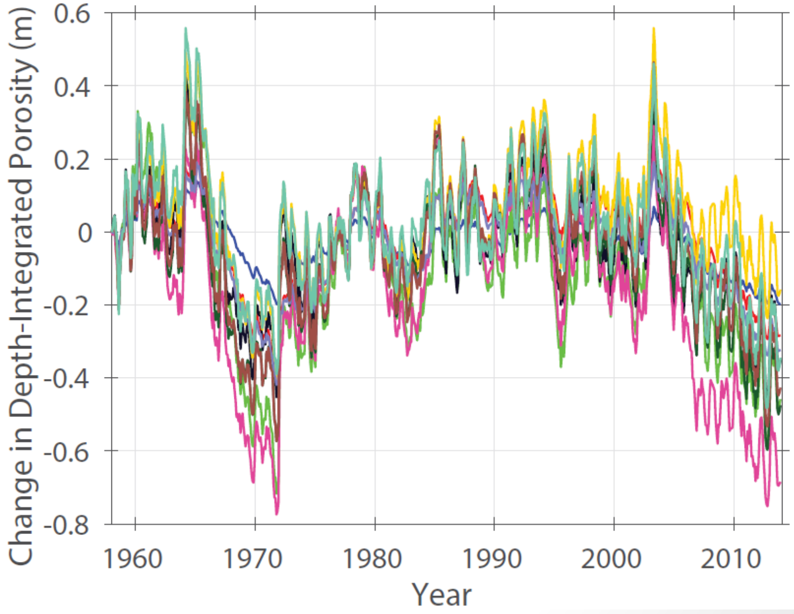
- Compare firn models forced by identical current climate
- Extremely sensitive to initialization

NASA-SE

Initialized 800 years, **mean** temp & accum 1958-2013 from RACMO

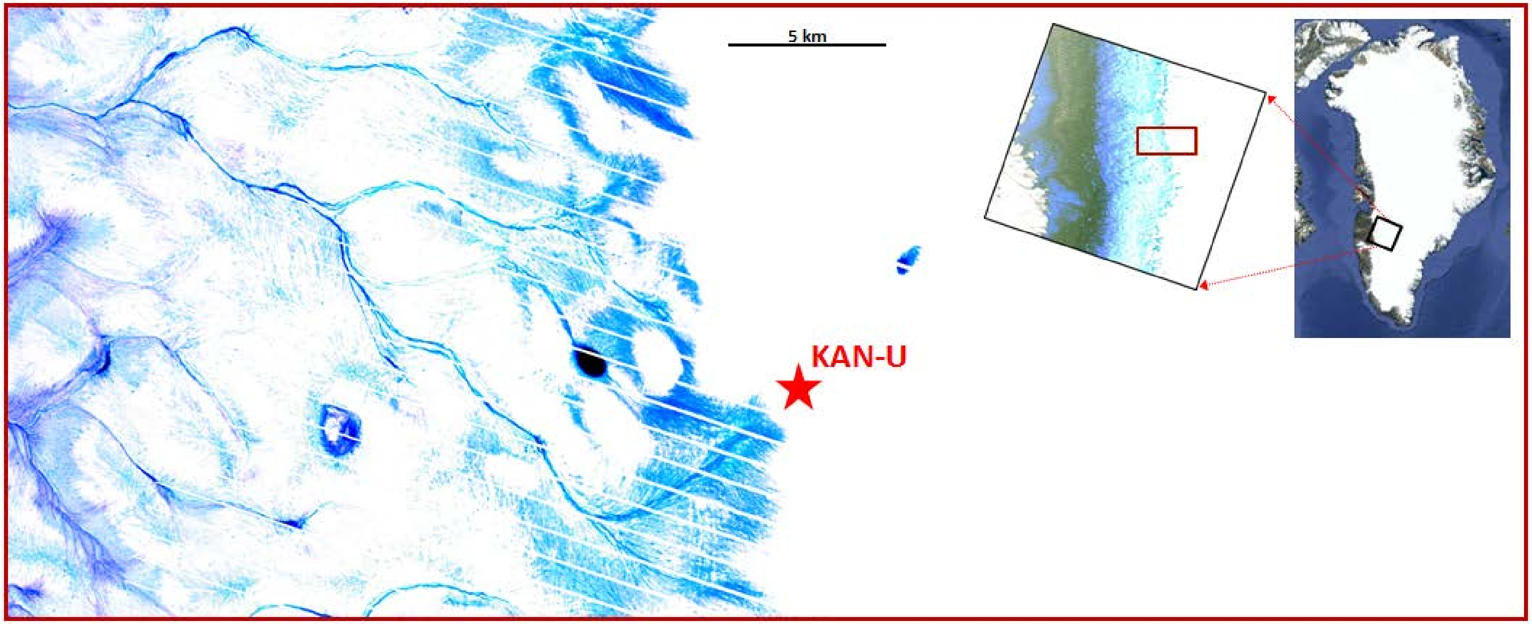


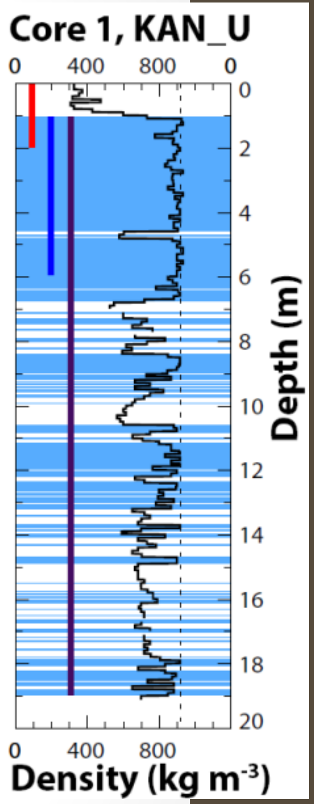
Initialized 800 years, **looped** temp & accum 1958-1978 from RACMO



Max Stevens, University of Washington

Shallow Firn Saturation

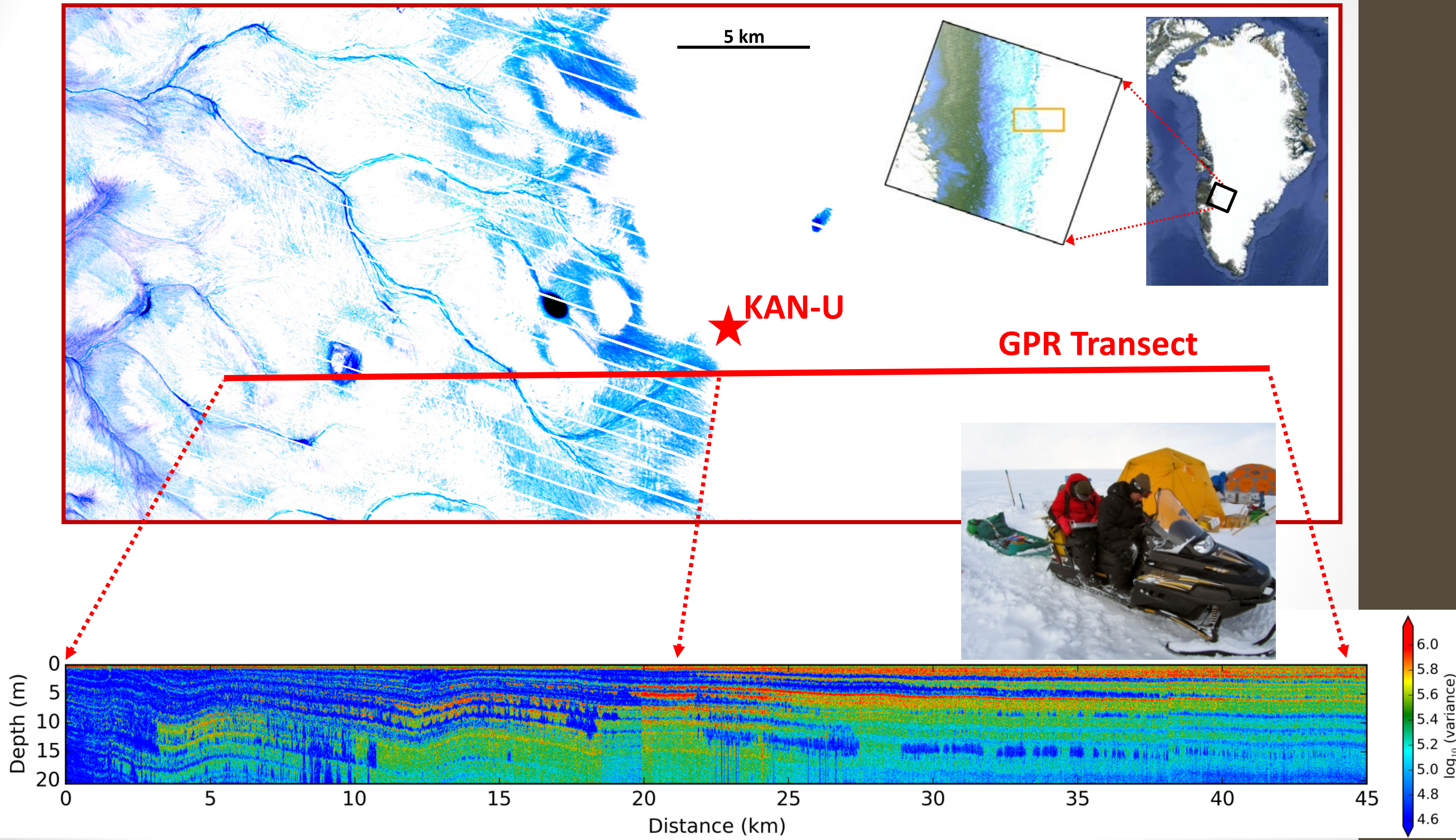




- Runoff line jumped 25 km uphill in 2012
- Shallow firn was saturating in successive "big" melt years (2002, 2005, 2007, 2010), which "primed" the firn for runoff

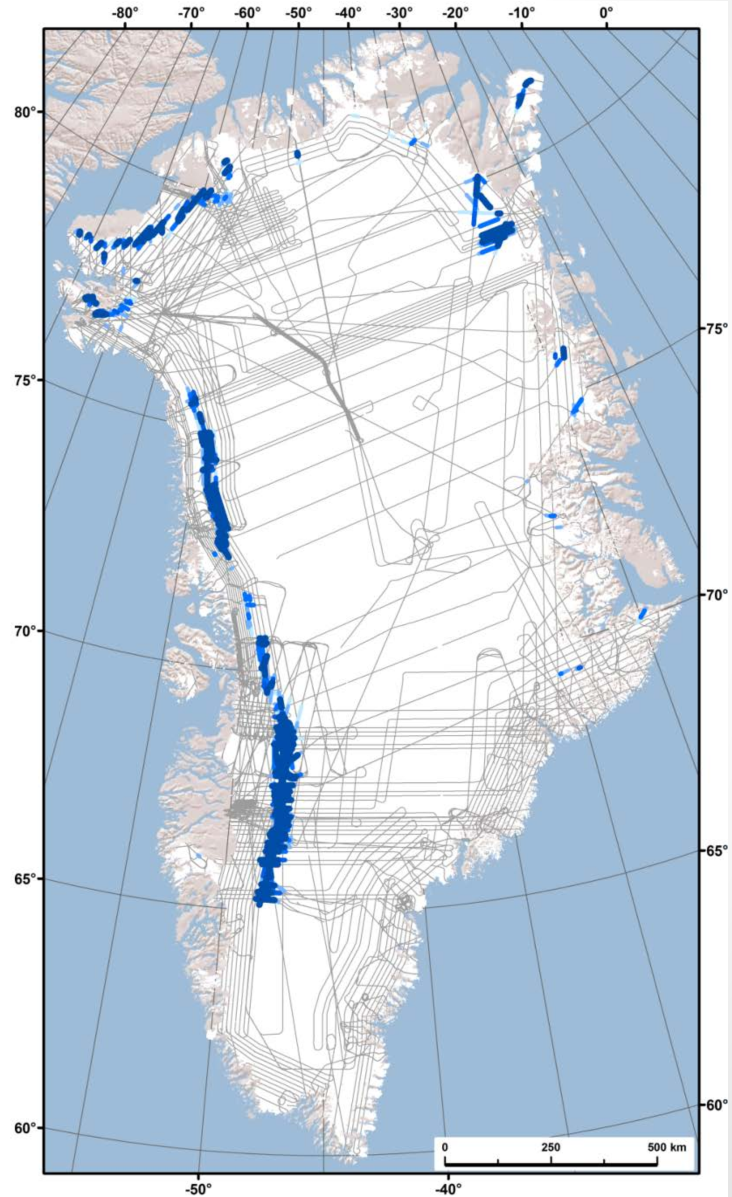
Machguth et al. (2016), Nature Climate Change

Mapping ice lids with GPR



Mapping Ice Lids with IceBridge

- Perched lids (>1 m thickness) span 60,000 km^2
- Firn can saturate <u>rapidly</u>
- Runoff can migrate rapidly uphill
- **In 2012**, Ice lids in SW Greenland added 11±4% to regional runoff



Early saturation modeling

Solving for the ratio (M/C), we obtain

$$\frac{M}{C} \geq \left[\frac{c}{L}T_f + \left(\frac{\rho_{pc}-\rho_c}{\rho_c}\right)\right]\left[1 + \left(\frac{\rho_{pc}-\rho_c}{\rho_c}\right)\right]^{-1} \qquad \text{(A2)}$$

Substituting typical numbers for density and temperature for Arctic surface snow at the start of the melt season (e.g., $T_f = -15°C$ and $\rho_c = 0.3\ \mathrm{g\,cm^{-3}}$), M/C takes the value 0.697. This number turns out to be quite insensitive to reasonable variations in T_f and ρ_c, and for a wide variety of firn conditions, the necessary condition for runoff can be stated simply as

$$\frac{M}{C} \approx 0.7$$

Pfeffer , Meier & Illangasekare *(1991), JGR*

Pfeffer, Meier & Illangasekare (1991), GRL

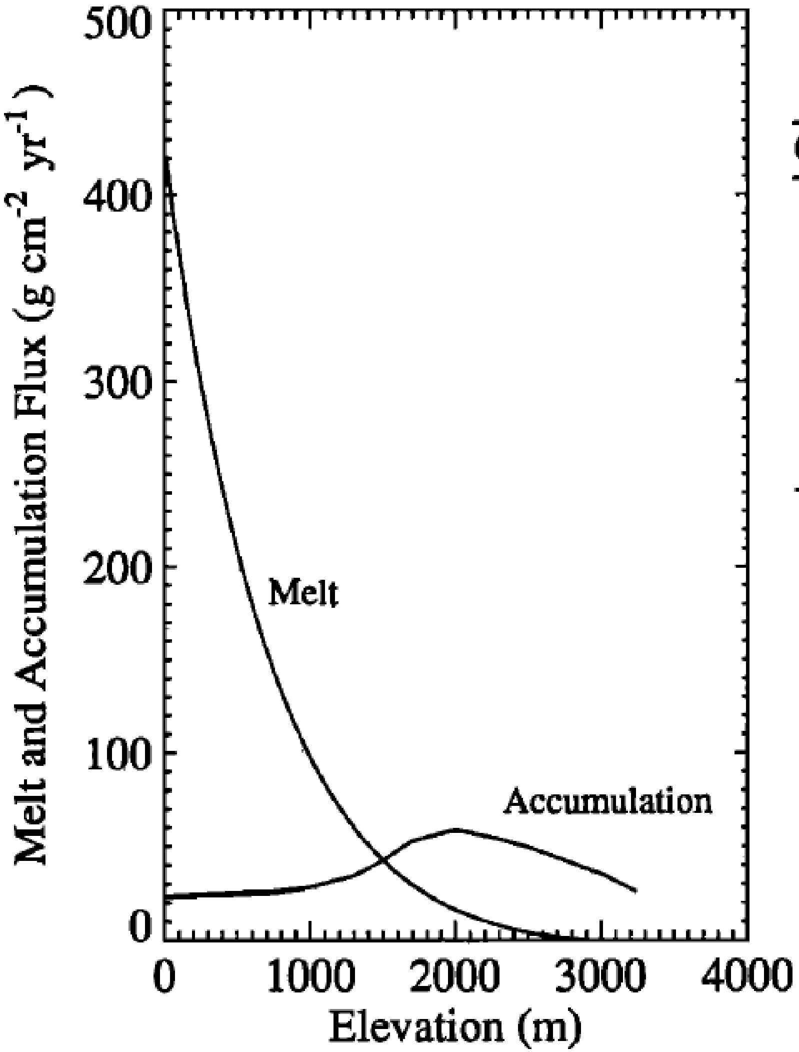
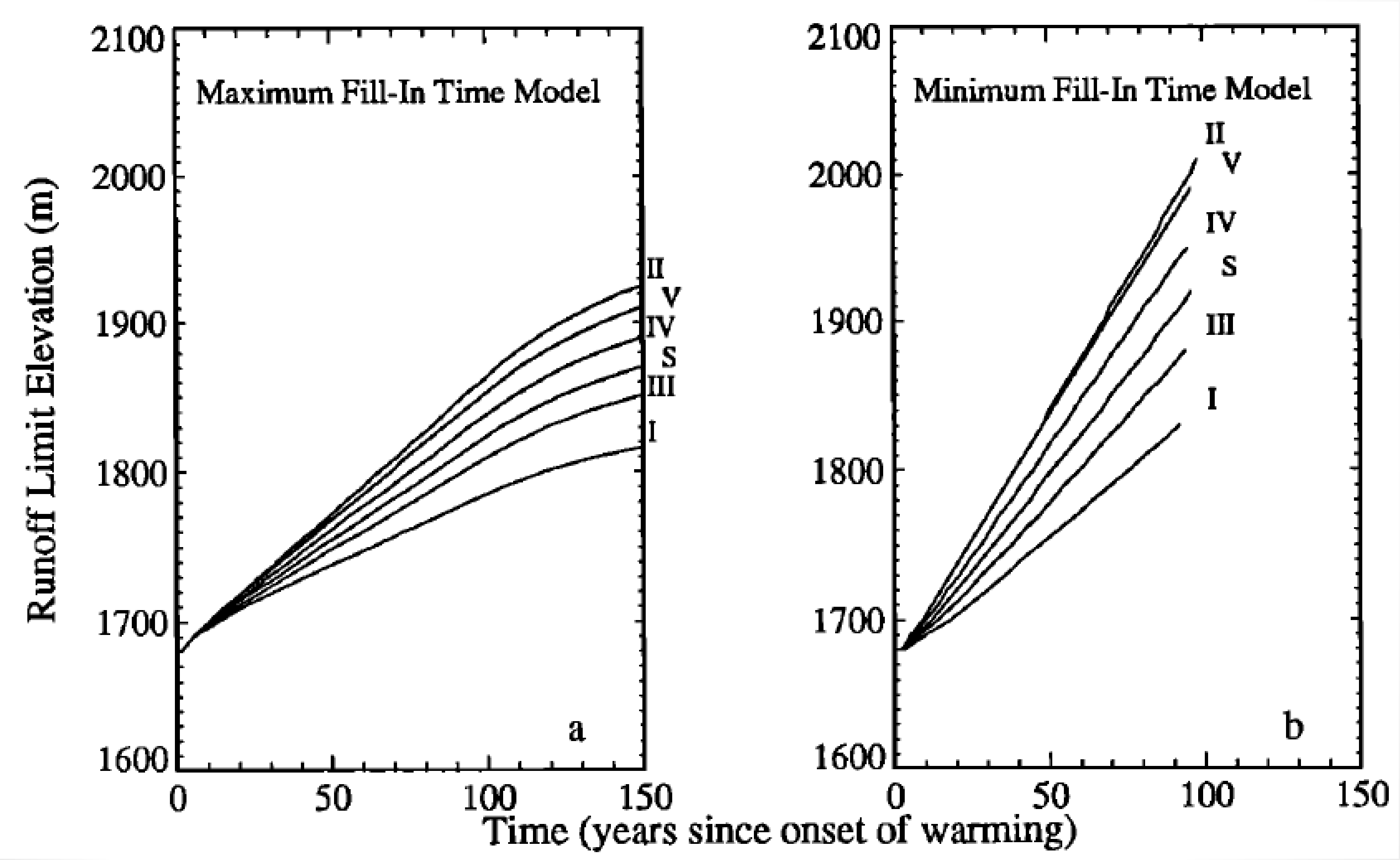


TABLE 1. Parameters for Future Climate Scenarios

Climate Model	ΔT, °C	$\Delta c / c$	Variation From Standard Model
S	4	0.10	
I	3	0.10	1°C cooler
II	5	0.10	1°C warmer
III	4	0.15	50% wetter
IV	4	0.5	50% drier
V	4	0.0	no change in accumulation from present

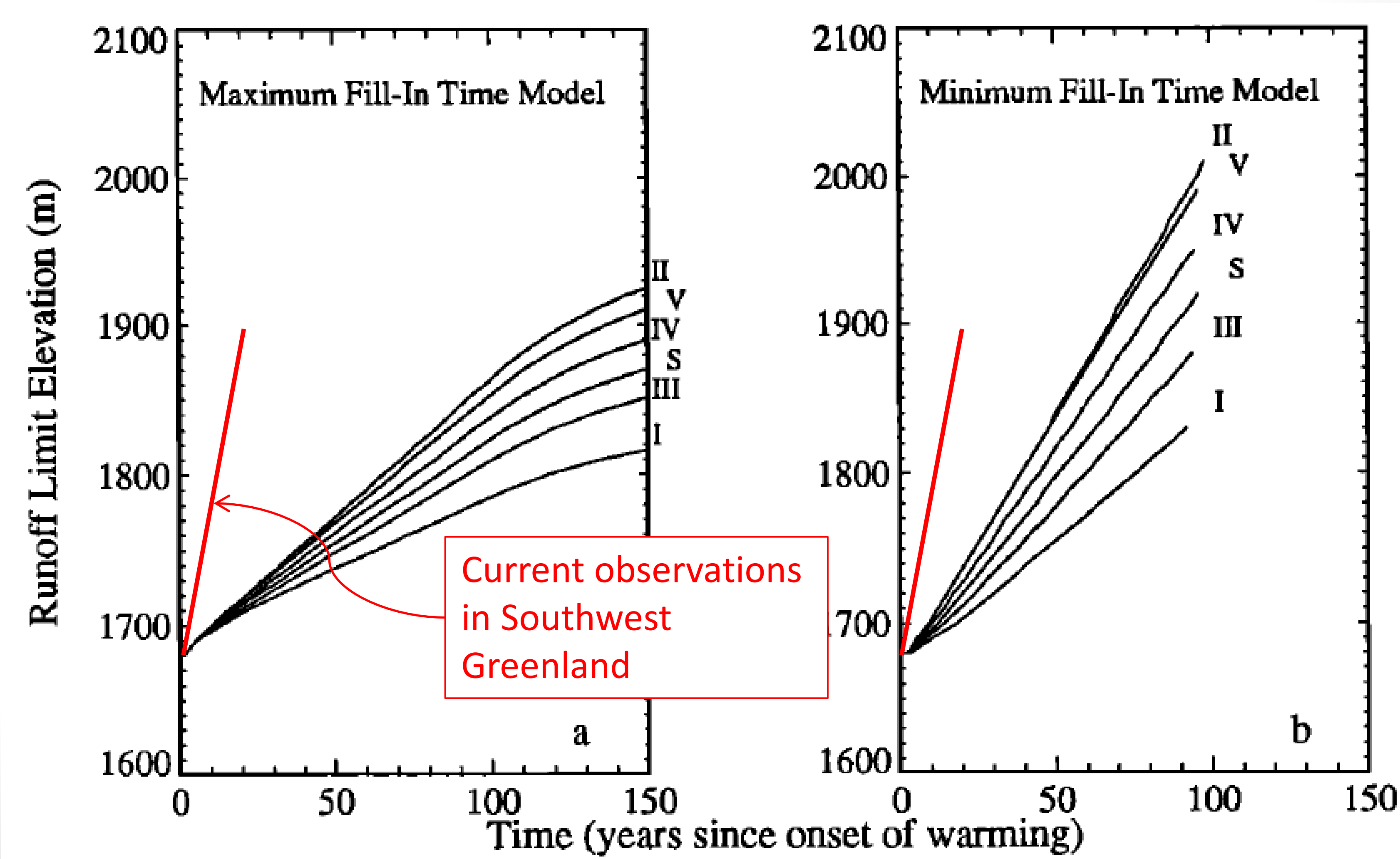
Pfeffer , Meier & Illangasekare *(1991), JGR*

Early Saturation Modeling (cont'd)



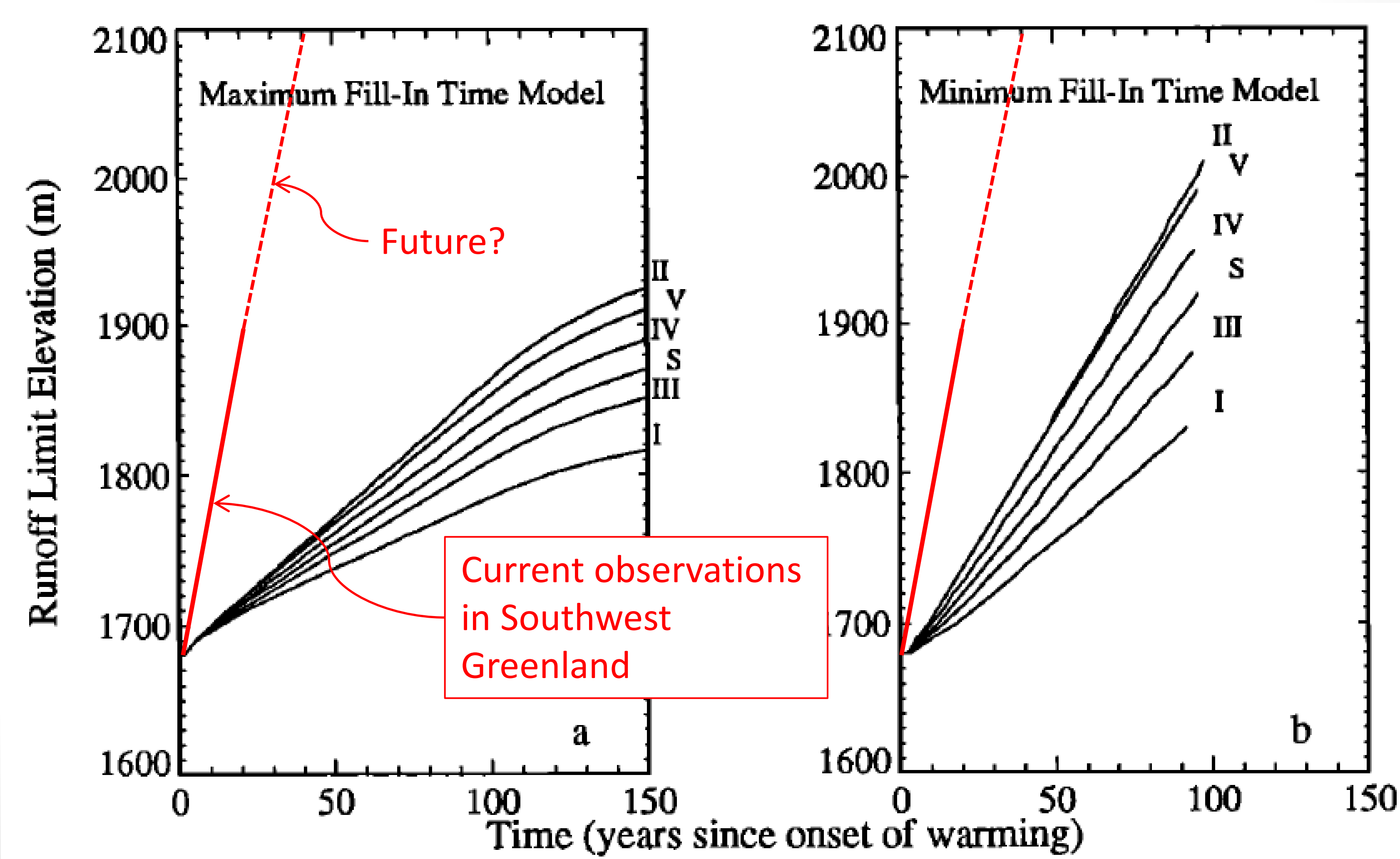
Pfeffer , Meier & Illangasekare *(1991), JGR*

Early Saturation Modeling (cont'd)



Pfeffer , Meier & Illangasekare *(1991), JGR*

Early Saturation Modeling (cont'd)

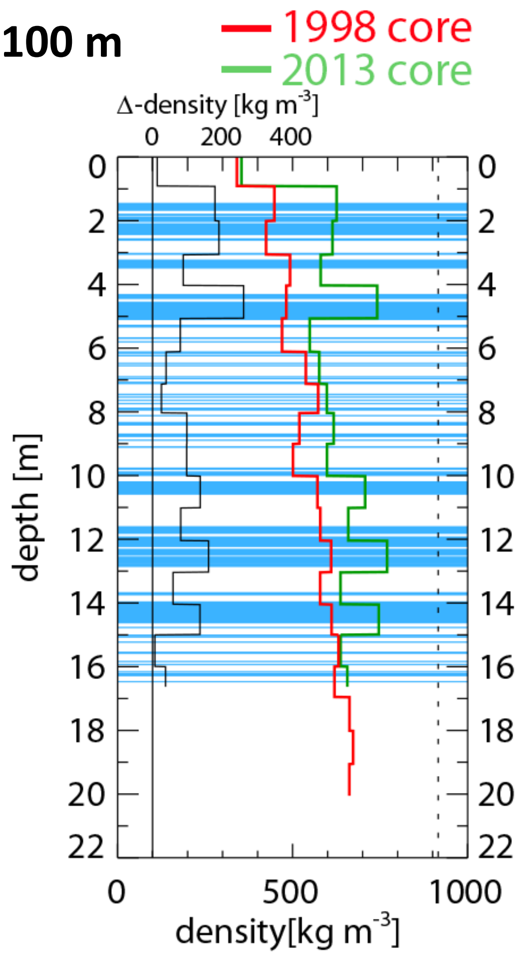


Pfeffer , Meier & Illangasekare *(1991), JGR*

Dye-2 Firn Cores, 2100 m.a.s.l.

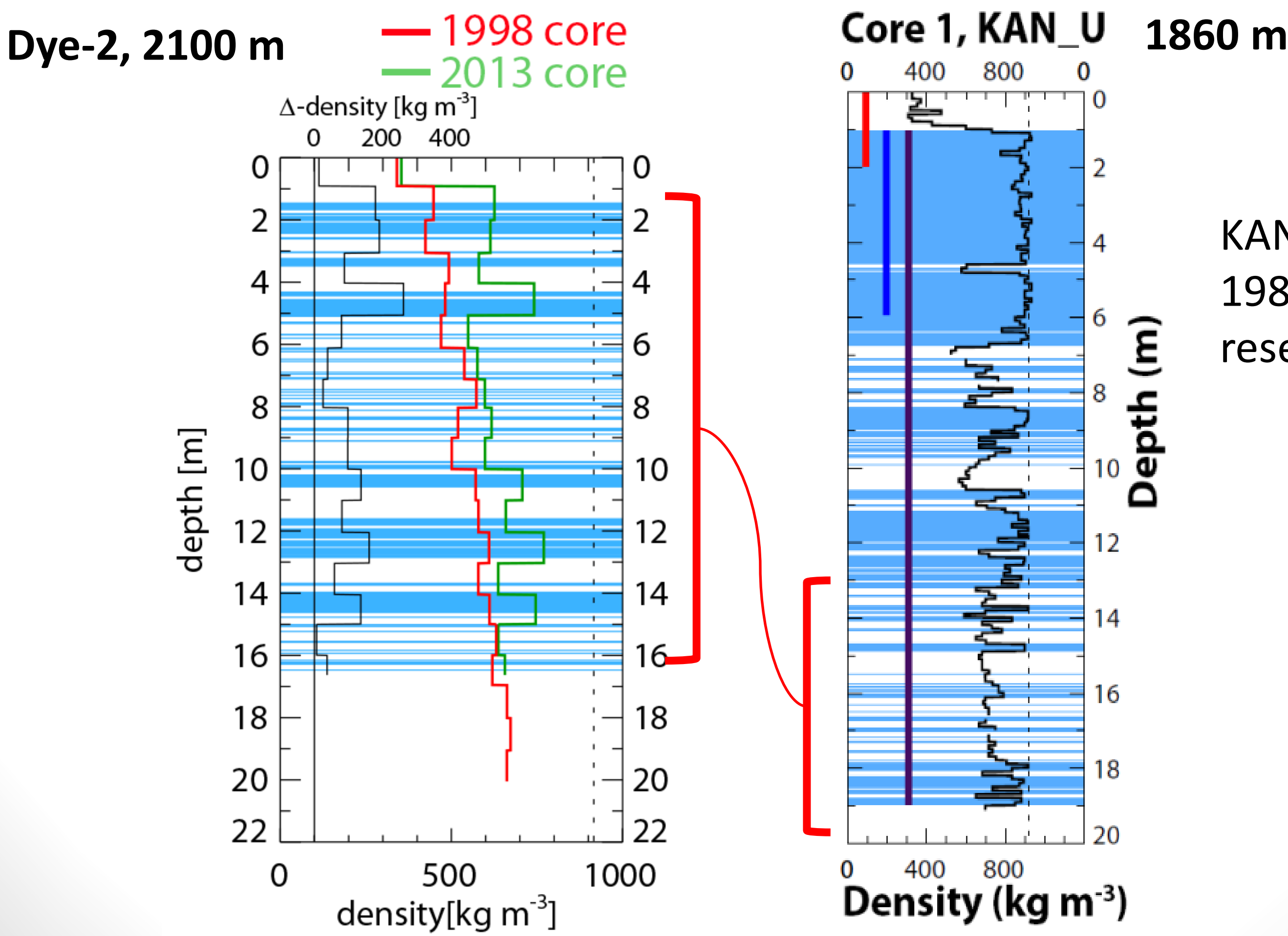
- 1998 – less than 5% ice content
- 2013 – greater than 25% ice content in top 16 m

Dye-2, 2100 m



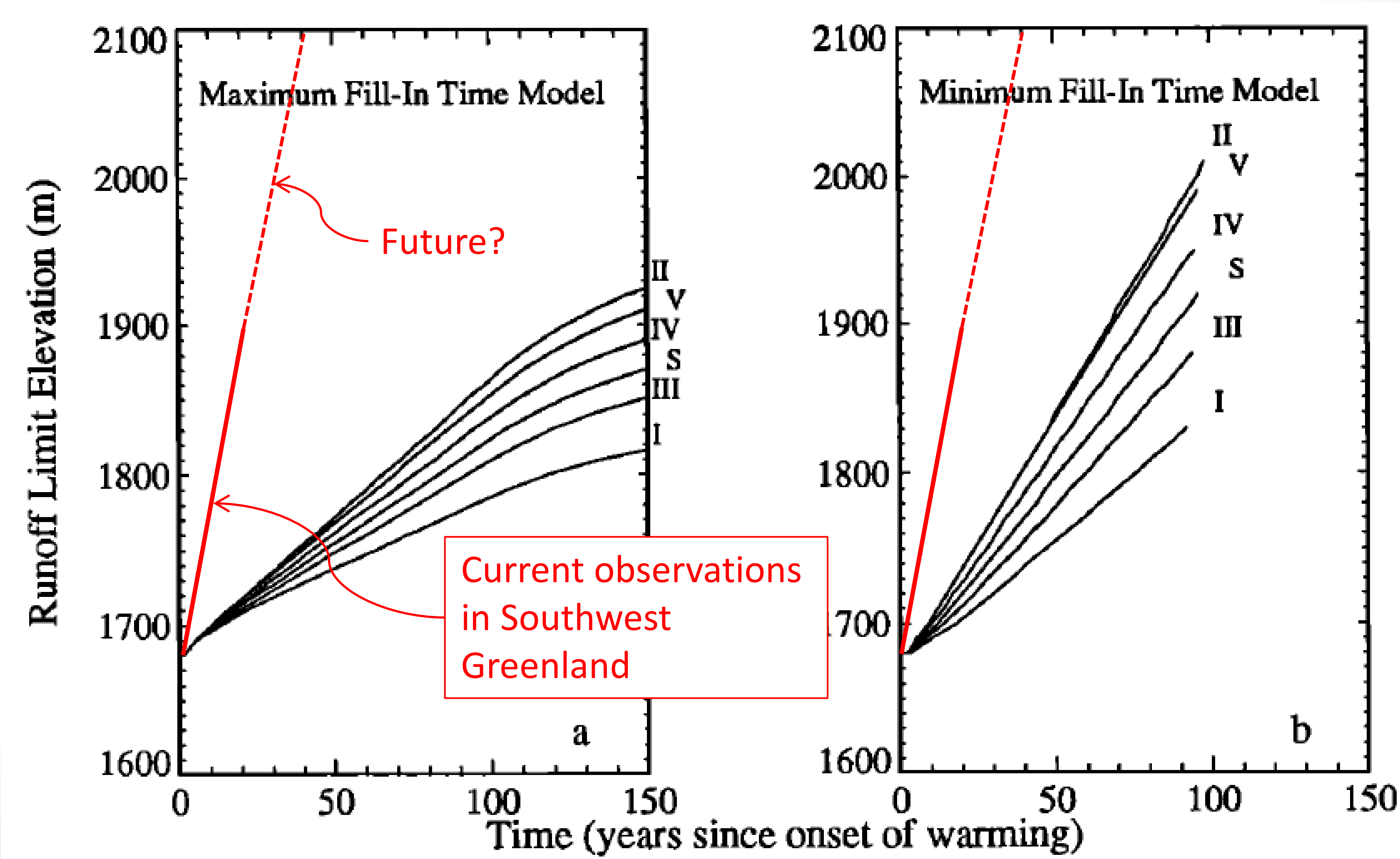
Dye-2 Firn Cores, 2100 m.a.s.l.

- 1998 – less than 5% ice content
- 2013 – greater than 25% ice content in top 16 m



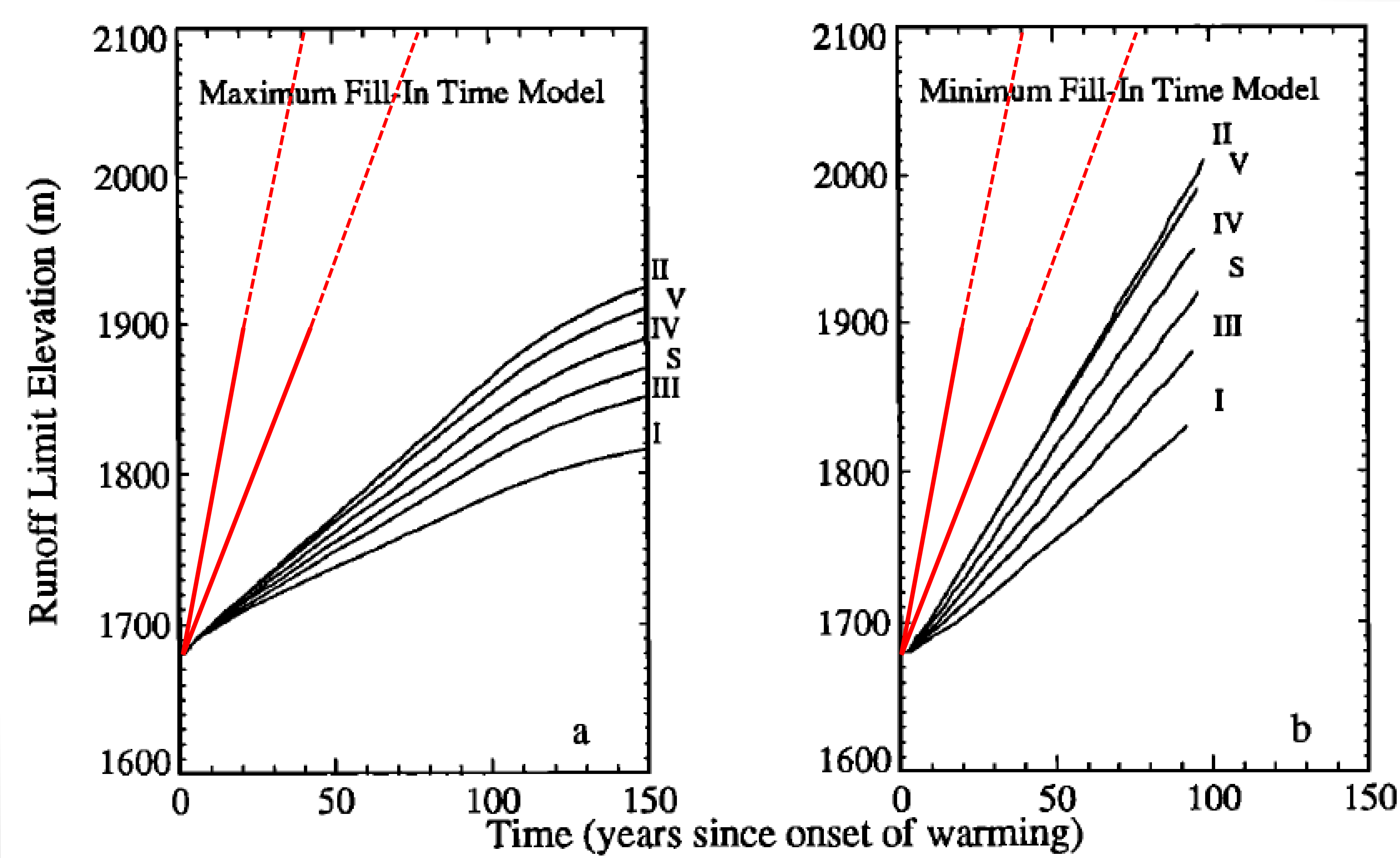
KAN-U firn from 1980-1990s resembles Dye-2 now

Early Saturation Modeling (cont'd)



Pfeffer , Meier & Illangasekare *(1991), JGR*

Early Saturation Modeling (cont'd)



Pfeffer , Meier & Illangasekare *(1991), JGR*

Conclusions

- As temps rise, Surface Mass Balance (SMB) now dominant in Greenland
- Firn has “memory”
  - Initialization and ensemble strategies crucial for short-term simulations
- Community firn model (CFM) density intercomparisons are under way
- SMB exhibits high variability and non-linear “threshold” behaviors
- Spatial resolution is an issue (always is!), thoughtful parameterizations are necessary

Conclusions

- As temps rise, Surface Mass Balance (SMB) now dominant in Greenland
- Firn has “memory”
  - Initialization and ensemble strategies crucial for short-term simulations
- Community firn model (CFM) density intercomparisons are under way
- SMB exhibits high variability and non-linear “threshold” behaviors
- Spatial resolution is an issue (always is!), thoughtful parameterizations are necessary
- I’d like to contribute (a job?)

Questions?

University of Colorado
Boulder

CIRES

NASA

UNIVERSITY OF
WASHINGTON