Using CESM and CISM to simulate the long-term evolution of climate and the Greenland Ice Sheet during the Last Interglacial (~129,000 to 116,000 yrs ago)

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Photo by Leo Kampenhout

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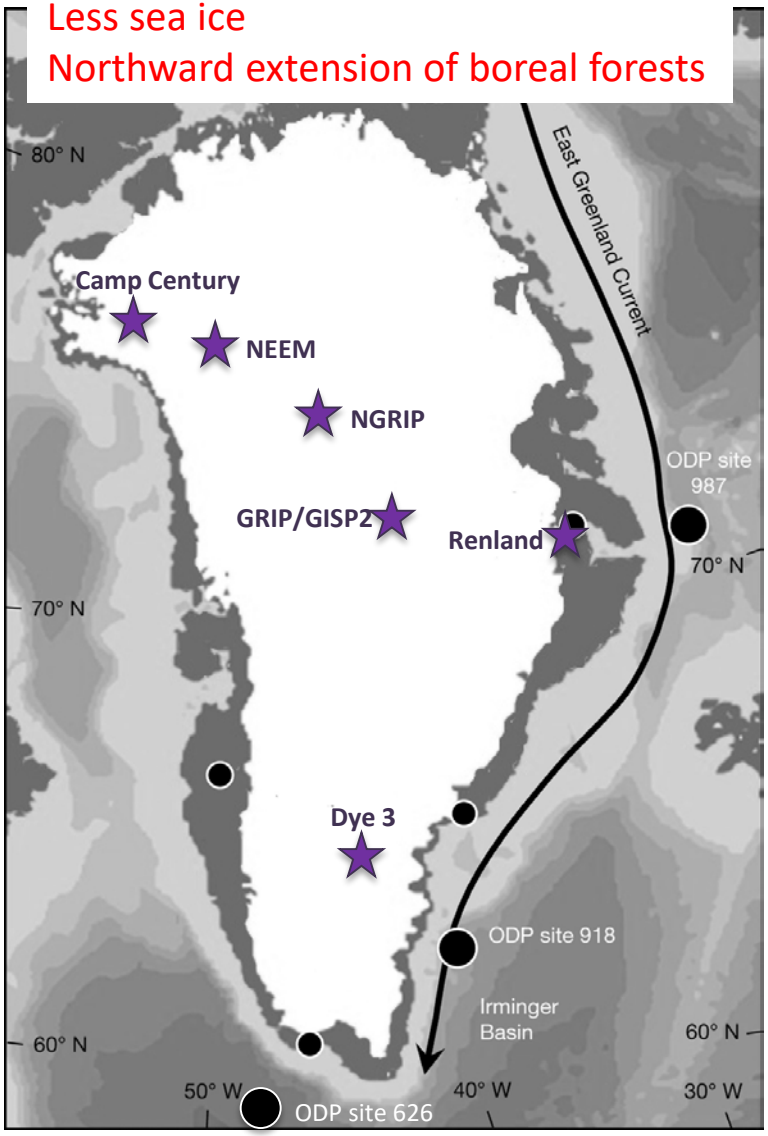
Last Interglacial [129-116 ka] – Some Evidence from Data

Ice cores

- 6 deep ice-coring projects have reached ice layers back to LIG
- ***NEEM: surface elevation estimated 130 ± 300 m below present***
- ***Annual temperatures***
  NEEM: +7 to +11°C
  GISP2: +4 to +8°C
- ***Dye 3: new analysis suggests basal ice predates LIG***

Raynaud et al., 1997; Johnsen et al., 2001; NorthGRIP, 2004; NEEM, 2013; Yau et al., 2016

Less sea ice
Northward extension of boreal forests



Marine cores

- ODP sites offshore contain sediment sourced from Greenland
- ***ODP 626: silt provenance suggests SGrIS present, smaller than in Holocene***
- ***ODP 626: shrub tundra and dense fern vegetation over S. Greenland***
- ODP 918 & 987: stable ice sheet in E. Greenland for most of past million years

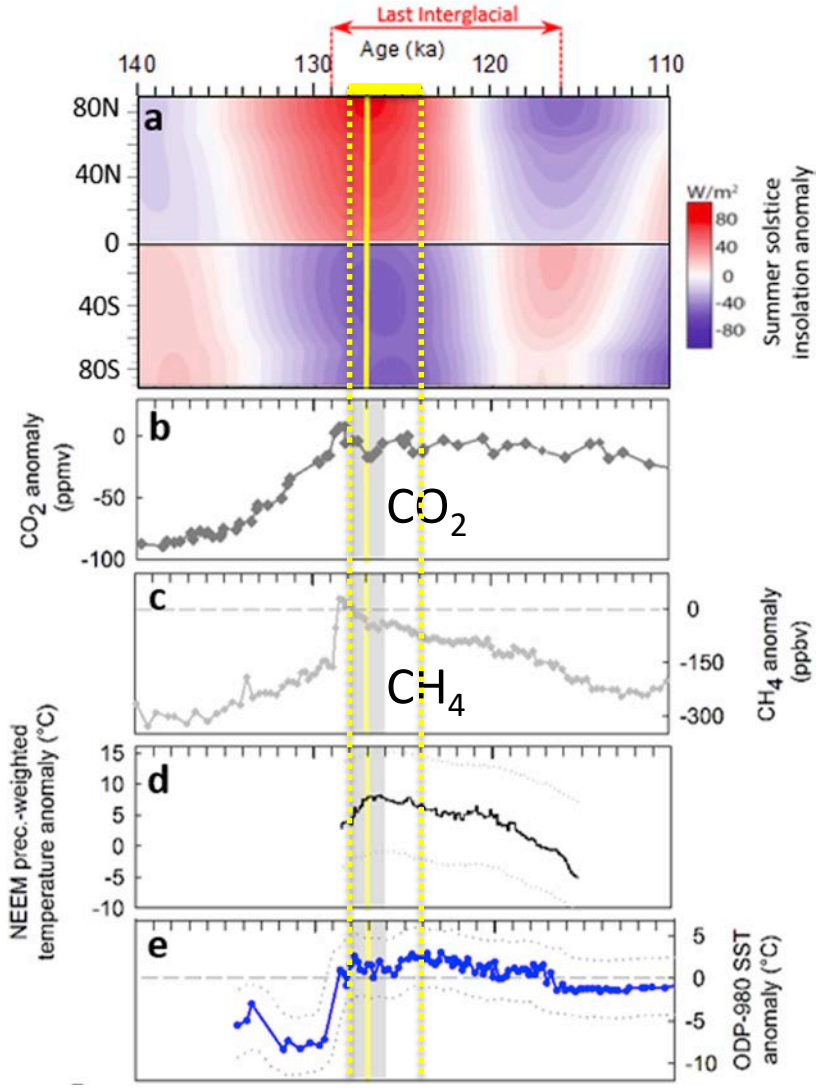
De Vernal et al, 2008; Colville et al., 2011; Hatfield et al., 2016; Bierman et al., 2016

Past Modeling of Greenland Ice Sheet during the Last Interglacial

Global sea level highstand 6-9 meters

Study	SMB method	GIS melting (m of sea level equivalent)
Cuffey and Marshall (2000)	Index	4–5.5
Huybrechts (2002)	Index	5.5
Tarasov and Peltier (2003)	Index	2.7–4.5
Lhomme et al. (2005)	Index	3.5–4.5
Born and Nisancioglu (2012)	GCM snapshots	4.2–5.9
→ Otto-Bliesner et al. (2006)	One-way GCM coupling	2.2–3.4
Stone et al. (2012)	One-way GCM coupling	0.6–3.5
Robinson et al. (2011)	Energy-moisture coupling	0.4–4.4
Quiquet et al. (2013)	Index method	0.7–1.5
Helsen et al. (2013)	Asynch, 2-way coupling reg model	1.2-3.5
Calov et al. (2015)	Asynch, 2-way coupling reg model	0.6-2.5
Yau et al. (2017)	Asynch, 2-way coupling reg model	4.1-6.2
Goezler et al. (2016)	Synch, 2-way coupling global model	1.4

Early Last Interglacial (128 – 124 ka)



Capron et al., QSR, 2017

- Large boreal summer insolation anomalies (128-124ka) resulting from orbital forcing ⟶ assume 127ka insolation anomalies representative.
- Stable GHG concentrations similar to late Holocene
- Continental and oceanic configurations almost identical to modern

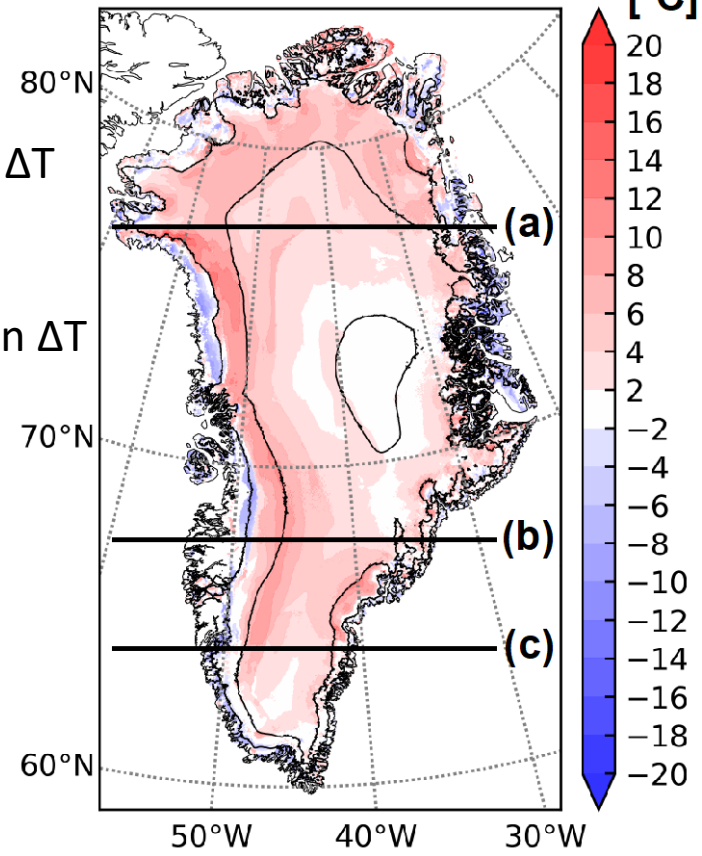
CESM1.5 (FV1x1) coupled to CISM1 (4km)

1) LIG 127ka orbital forcing [LIG]
   - 2000 CISM yrs, 155 CESM yrs
2) LIG 127ka orbital forcing + (idealized) boreal forests to Arctic Ocean in North America and Eurasia [LIGveg]
   - + 2000 CISM yrs, 80 CESM yrs

Evolution of Greenland annual surface temperatures

LIG simulation
(Seasonal insolation anomalies)

YR 2000



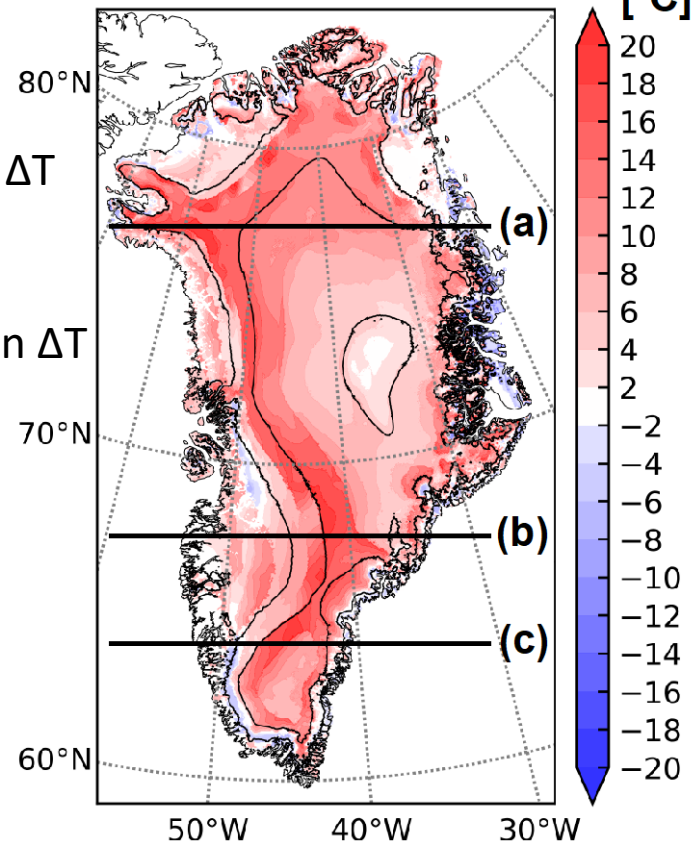
NEEM Ann ΔT
+4ºC

Summit Ann ΔT
~0ºC

Global Mean Ann ΔT: 0ºC

LIGveg simulation
(+Boreal forests extended northward)

YR 4000



NEEM Ann ΔT
+12ºC

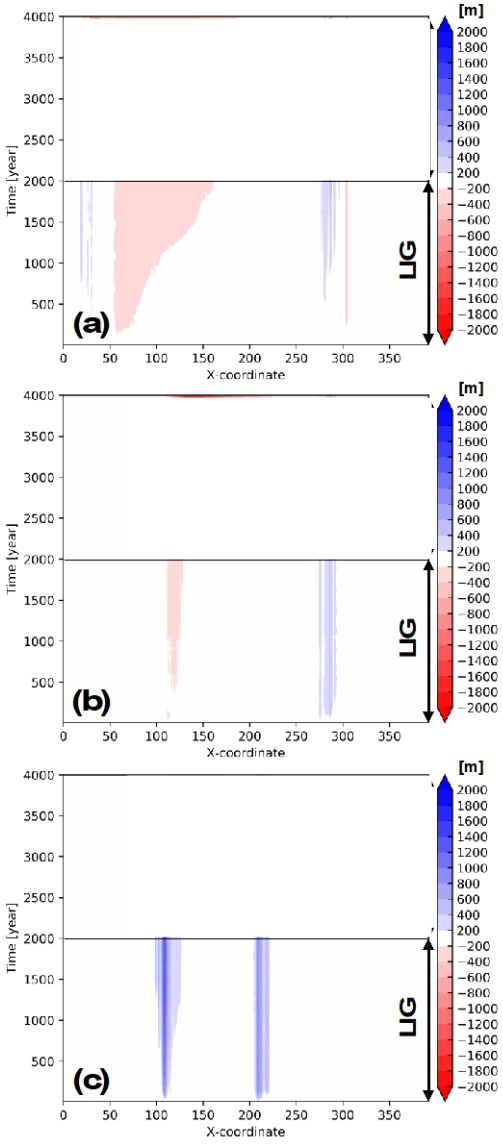
Summit Ann ΔT
~2ºC

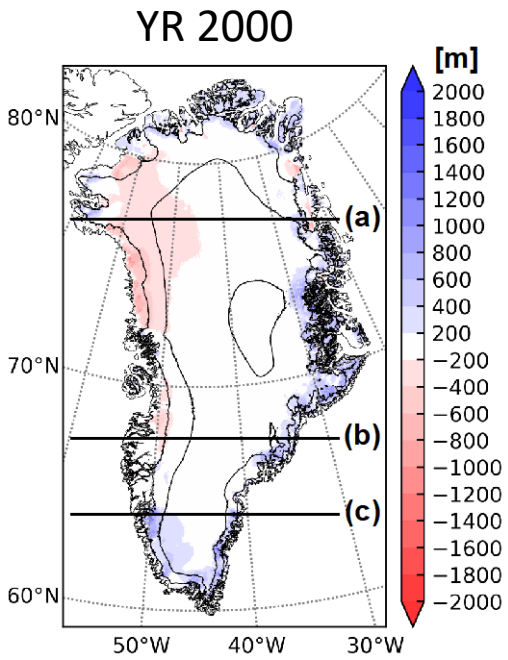
Global Mean Ann ΔT: 0.7ºC !

Evolution of Greenland ice sheet thickness

1) LIG simulation

- Overall SMB > 0
- Ice sheet area: ~96% modern
- SLE: 0.6 meters





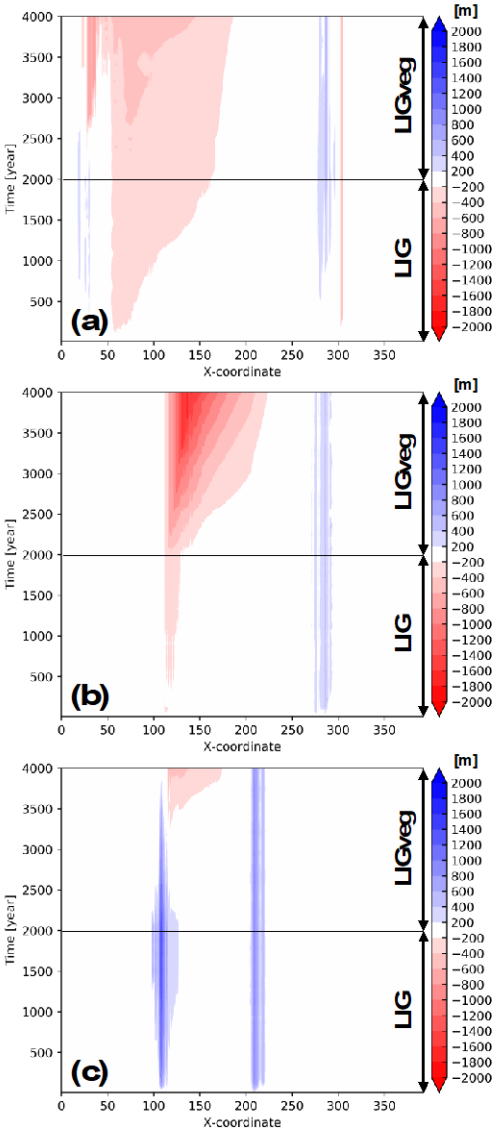
Evolution of Greenland ice sheet thickness

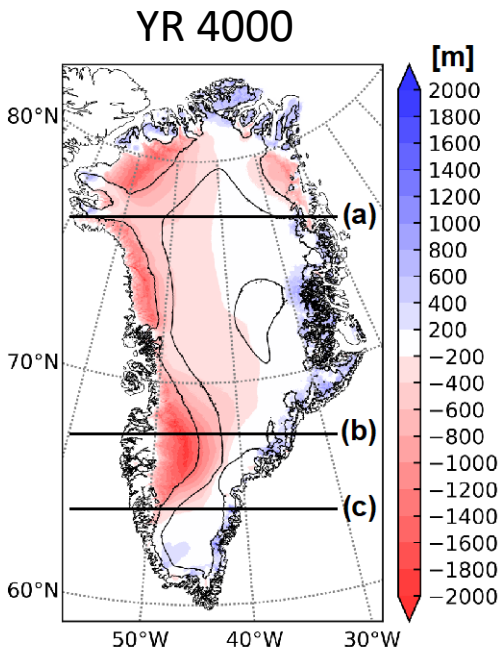
2) LIGveg simulation

- Overall SMB < 0
- Ice sheet area: ~85% modern
- SLE: 1.8 meters

1) LIG simulation

- Overall SMB > 0
- Ice sheet area: ~96% modern
- SLE: 0.6 meters





Evolution of Greenland ice sheet

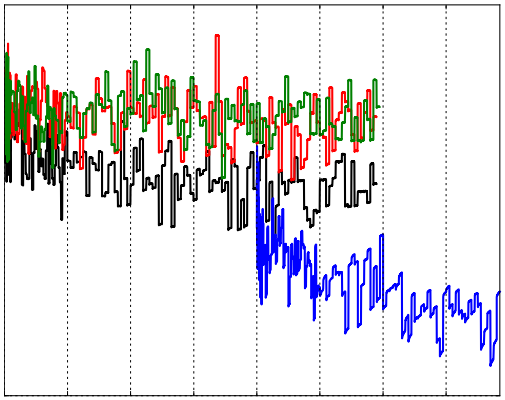
rea

Sea-level equivalent

LIG: SLR: 0.1 m/kyr

LIGveg: SLR: 0.7 m/kyr

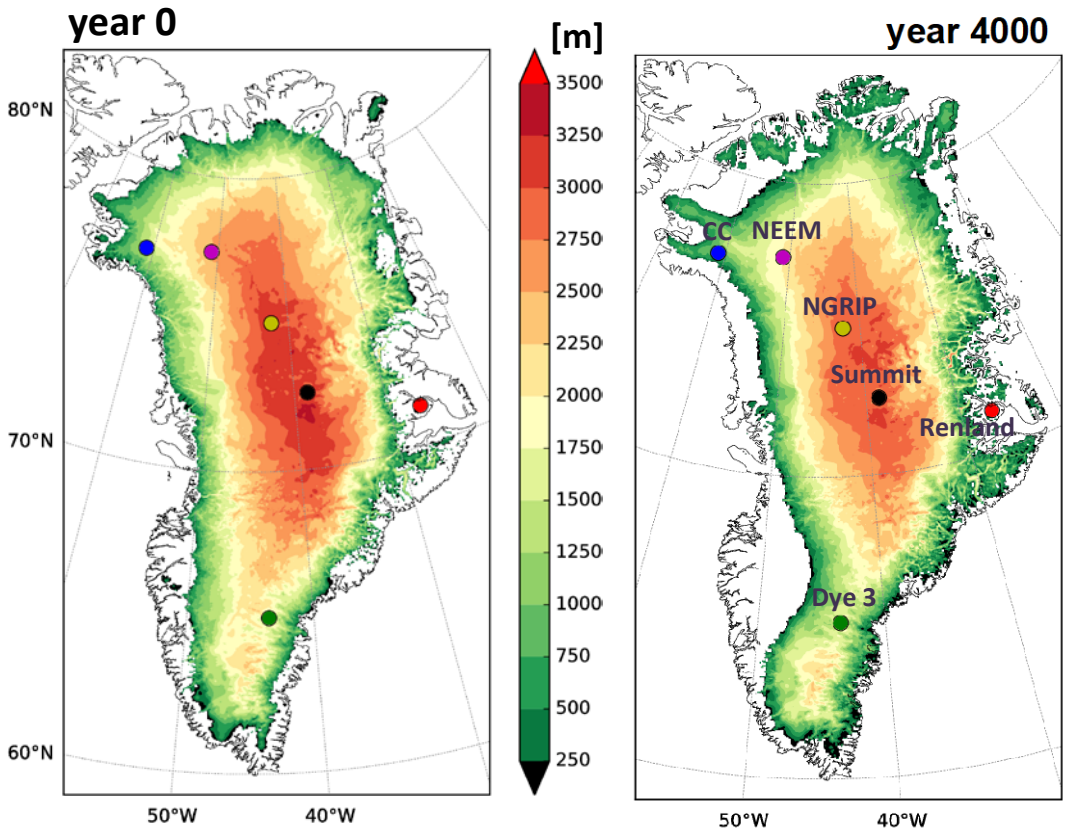
SMB



Calving

Summary

- ~ Thickness change at ice cores
  - CampCentury -450m
  - NEEM -400m
  - NGRIP -200m
  - Summit -40m
  - Renland +20m
  - Dye 3 -200m



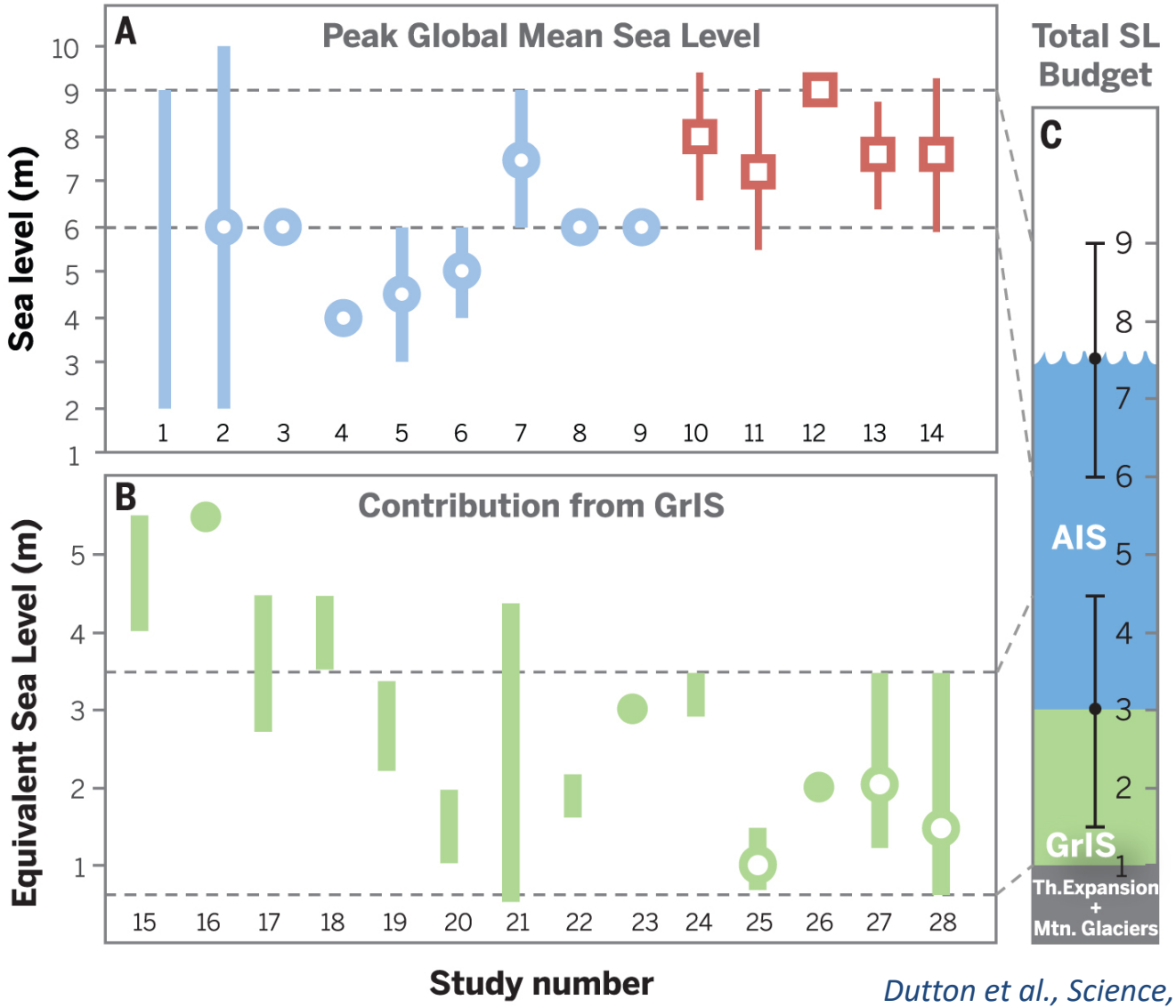
Next steps

✸Transient simulation✸

- Rerun with final CESM2 configurations and spunup GrIS initial state
- Refine vegetation map
- New calving/marine basal melt parameterizations, possibly

Peak Global Mean Sea Level during the Last Interglacial

Last Interglacial [129 – 116 ka]

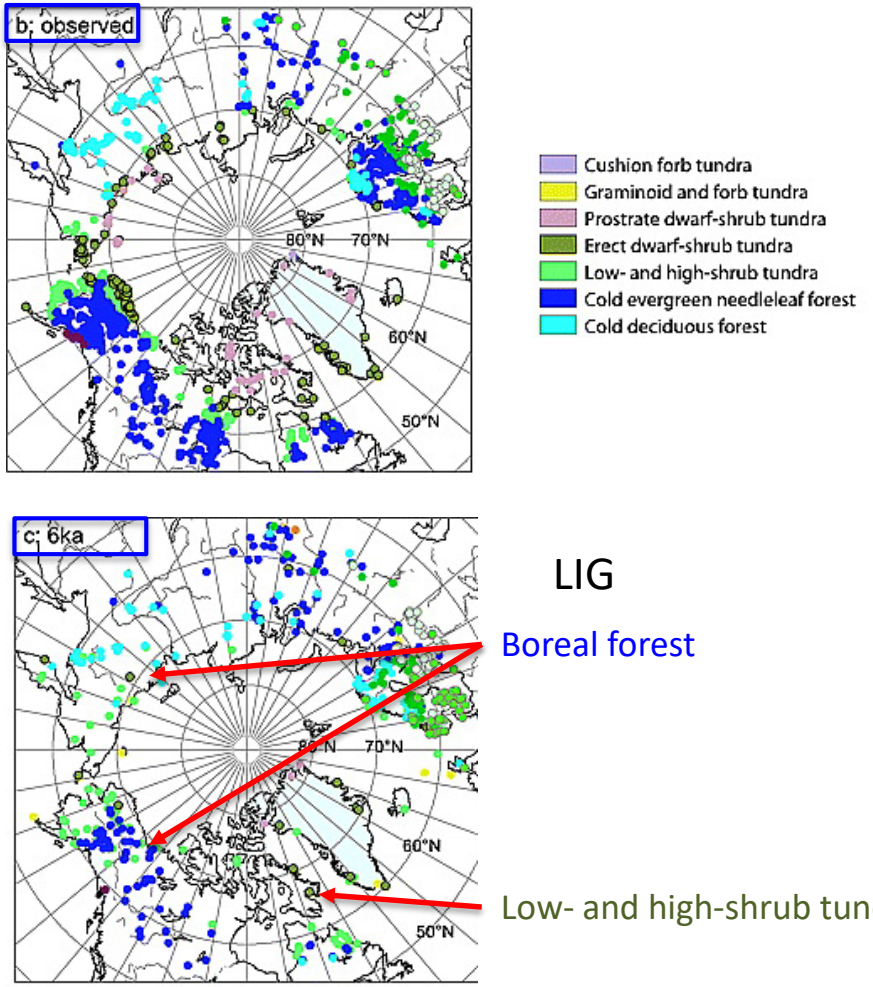


Dutton et al., Science, 2015

Two Exploratory Simulations Last Interglacial (128 – 124 ka)

1) LIG 127ka orbital forcing [LIG]
   - 2000 CISM yrs, 155 CESM yrs

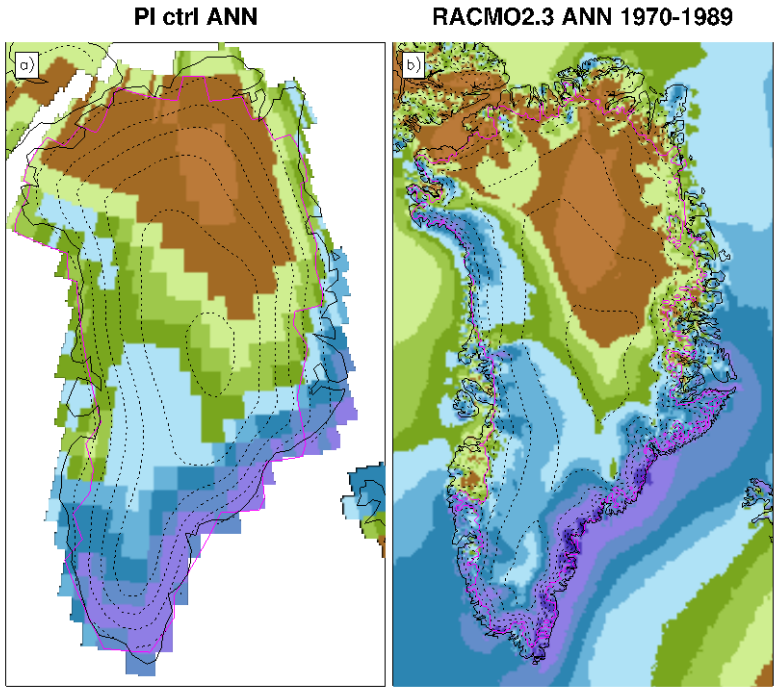
2) LIG 127ka orbital forcing + (idealized) boreal forests to Arctic Ocean [LIGveg]
   - + 2000 CISM yrs, 80 CESM yrs



Surface mass balance - Comparison to RACMO2.3

SMB = Snow + Rain – Runoff - Sublimation

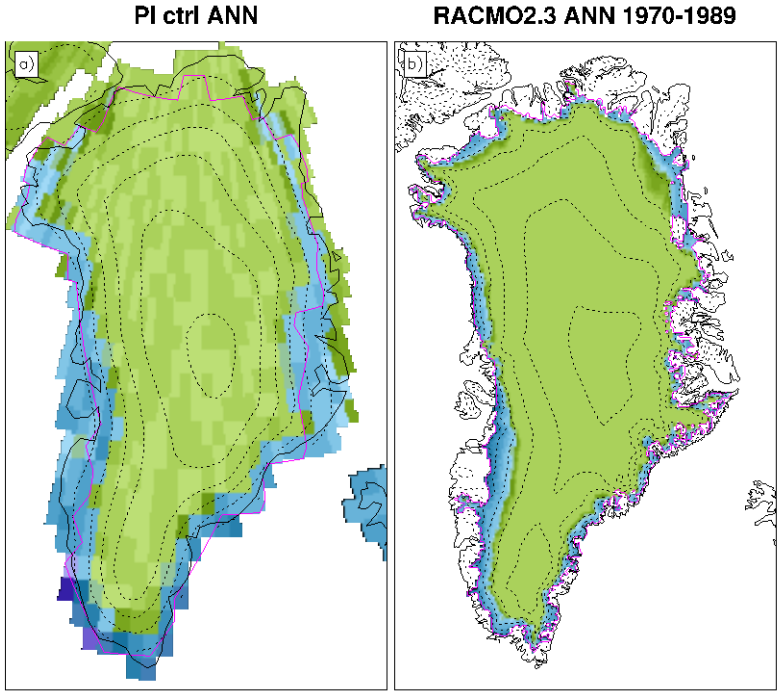
Snow



Solid precipitation (snow) [mmWE / yr]

0.01 1 5 20 50 100 150 200 250 300 400 500 700 1000 2000 4000

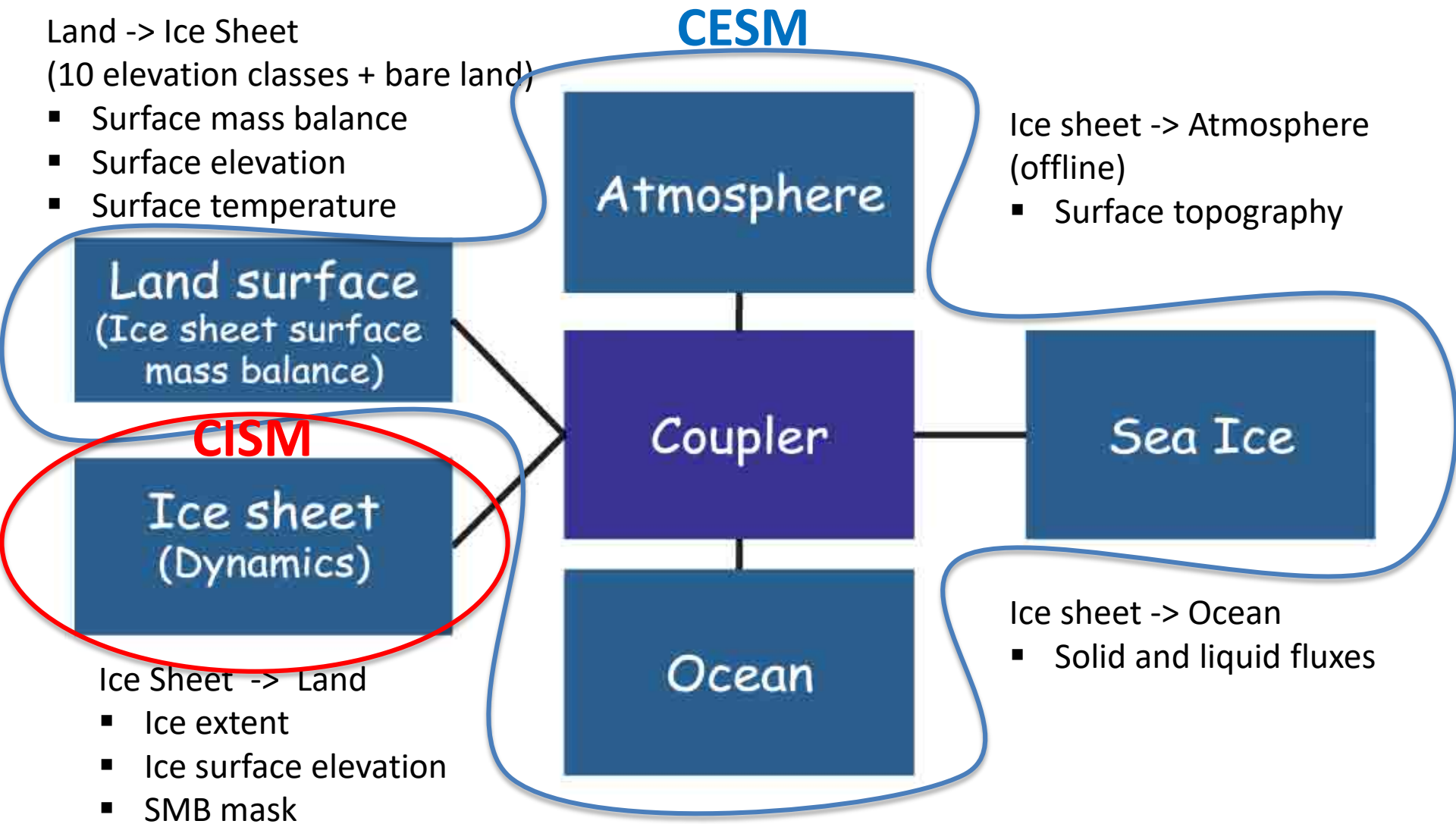
Runoff



Runoff [mmWE / yr]

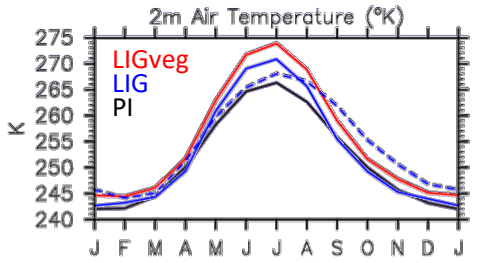
−5500 −4000 −2500 −1000 −200 −50 0 50 200 1000 2500 4000 5500

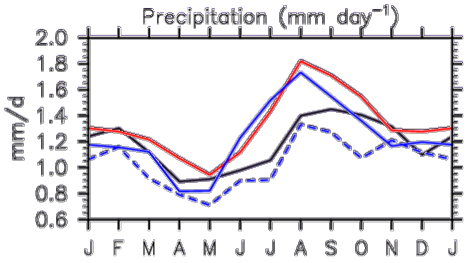
CESM (FV1x1) – CISM (4 km) – two-way coupling

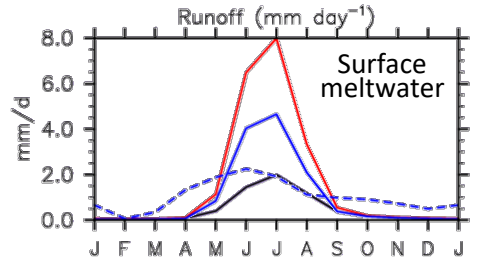


CLIMATE: Greenland & Arctic sea ice

Seasonal cycle over Greenland



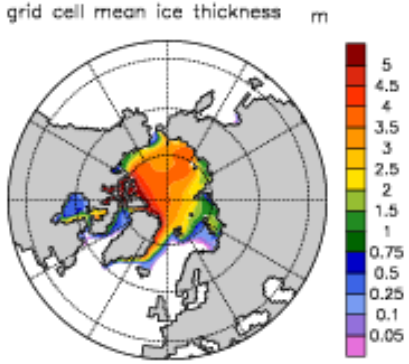




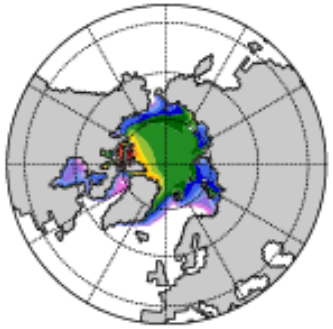
Land: 60-90N, 60-20W

JAS Sea ice thickness

Preindustrial



LIG



LIGveg