MIS 7 and MIS 5 glacial inceptions: investigating the asynchronous build-up of Laurentide and Eurasian ice sheets

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Centro Euro-Mediterraneo per i Cambiamenti Climatici

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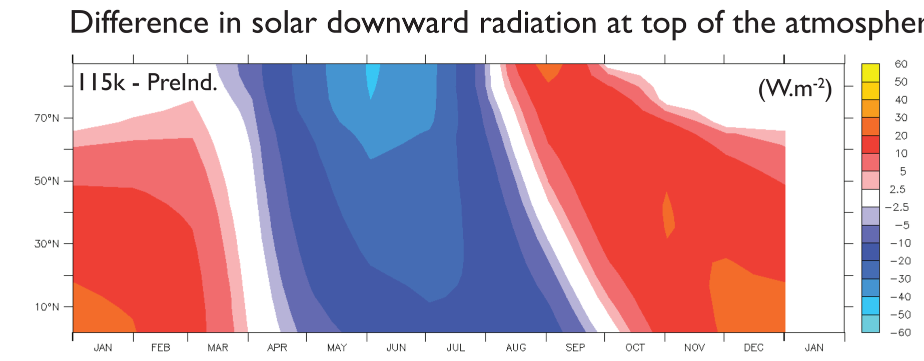
Abstract

During the last glacial cycle, the Laurentide ice sheet was larger than the Eurasian ice sheet. According to ICE-5G multi-proxy and methods reconstruction (Peltier, 2004), the Laurentide was ~ 5 times larger than its Eurasian counterpart (~ 74 m and ~ 17 m Sea Level Equivalent, SLE, respectively. Eustatic sea level was ~ -130 m) while a more recent study based on marine δ18O isotope suggests a smaller difference (Bintanja, 2008). On the contrary, during the penultimate glacial cycle (~245 - 126 kiloyears BP, kyrs BP), the Eurasian ice sheet reached its maximum Quaternary extent (Svendsen et al. 2004). Its volume is estimated to be ~ 60 m SLE based on numerical reconstructions (Lambeck, 2006; Peyaud 2006, Colleoni et al., 2009) implying a smaller ice volume over North America to be consistent with the eustatic sea level (~ -128 m, Waelbroeck et al. 2002). The notion of asynchronous build-ups over North America and Eurasia is supported by recent model estimates of North American and Eurasian ice volume evolution over the last three million years (Bintanja, 2008) which clearly shows a shift in ice volume distribution between the two ice sheets during the penultimate glacial cycle. Before 250 kyrs BP, it seems that the Laurentide ice sheet was always smaller than the Eurasian component. Indeed, the absence of glacial landscape traces from older glacial cycles in North America suggests that the Laurentide ice sheet reached its largest Quaternary extent during LGM, destroying the previous traces of ice dynamics.

What could have caused this change in ice distribution over the Northern Hemisphere? A recent study modelling the last glacial inception (~115 kyrs) suggests that the growth of the Eurasian ice sheet was delayed by high oceanic heat transport into the high latitudes regions (Born et al., 2010). This implies an asynchronous building between the Laurentide and the Eurasian ice sheets. To investigate the mechanisms that could have led to a different ice distribution, we focus here on the glacial inceptions of MIS 5 (~ 115 kyrs BP) and MIS 7 (~ 229 kyrs BP). We use the CESM earth climate model at T31 horizontal resolution to model these two inceptions and forced the Glimmer-CISM ice sheet model at 100km horizontal resolution. Results suggest that the vegetation feedback could help to realistically simulate these two periods since the modelled ice volume does not reached the observed sea level drops. The use of the a dynamics ice shelf module is also necessary to fully understand the inceptions of the Eurasian ice sheet for both period.

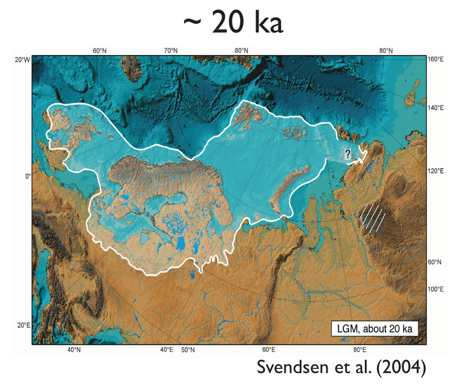
Experiment set-up: 115 kyrs BP

Difference in solar downward radiation at top of the atmosphere



From inception to Last Glacial Maximum

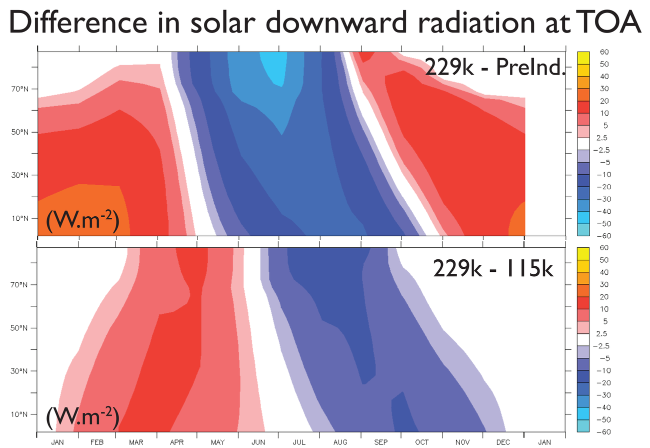
Eurasian ice sheet extent ~ 20 ka



	Orbitals	Perihelion	CO2	CH4	NO2	Topo.	Vegetation	Numerical simulations Type	Resol.	Length
PreInd.	1990	Jan. 4th	284	791	275	Present	Preind.	AOGCM	T31	400 yrs
115k	115k	Jan. 13th	262	472	251					

Experiment set-up: 229 kyrs BP

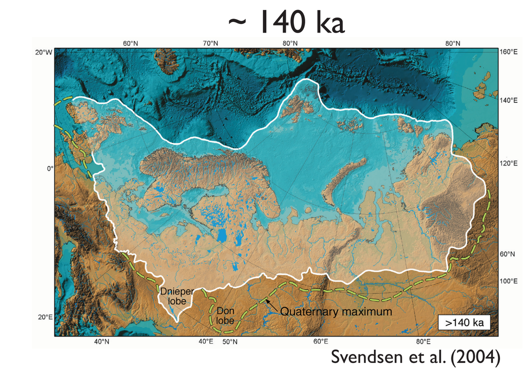
Difference in solar downward radiation at TOA



From inception to glacial maximum

North American ice sheet dimensions: smaller than during LGM?

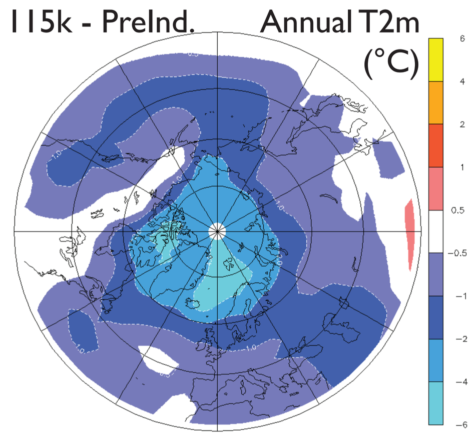
Eurasian ice sheet extent ~ 140 ka

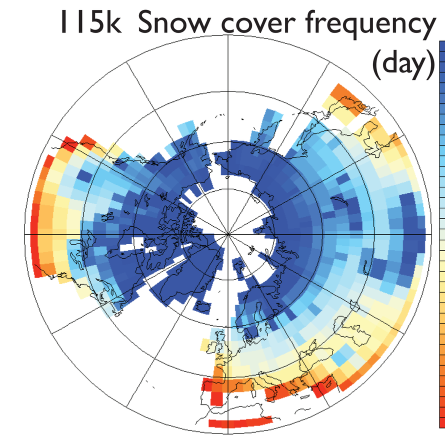


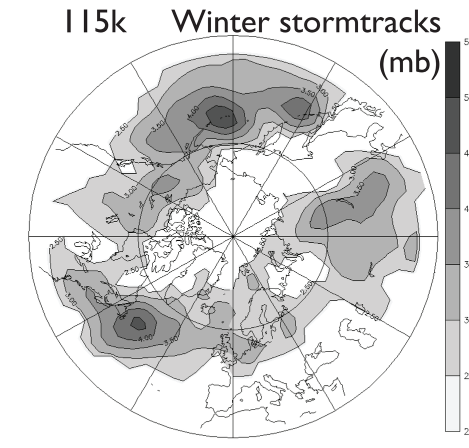
	Orbitals	Perihelion	CO2	CH4	NO2	Topo.	Vegetation	Numerical simulations Type	Resol.	Length
229k	229k	Feb. 1st	224	493	256	Present	Preind.	AOGCM	T31	400 yrs

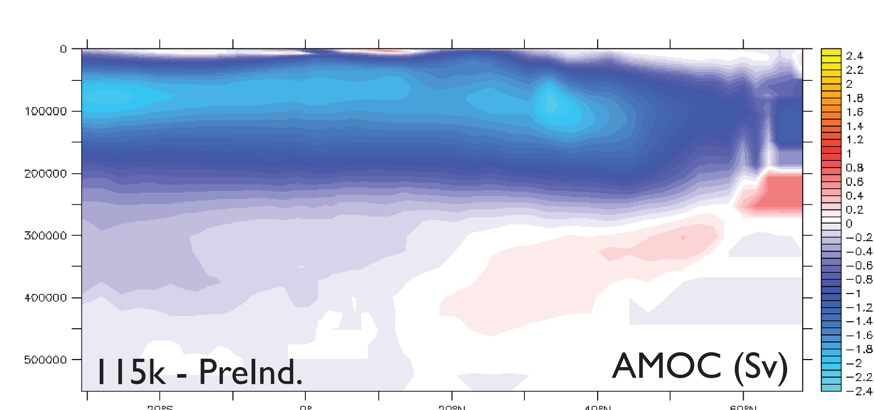
115 kyrs BP vs Preindustrial

Climate Model: CESM1.0 (Community climate model)







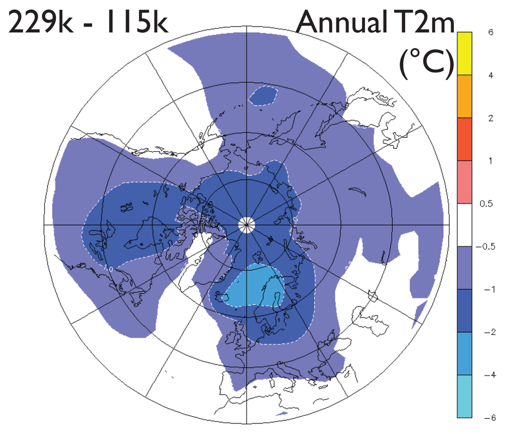


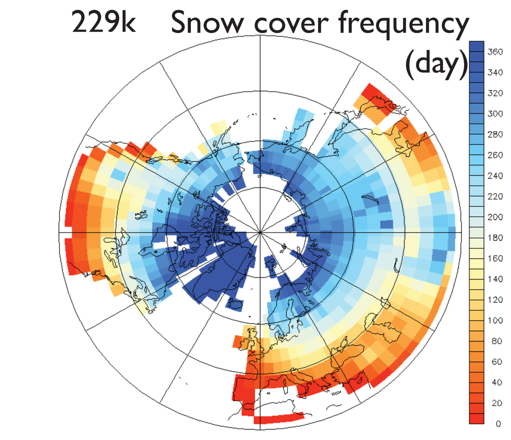
Orbitals and GHG favorable to inception at 115k

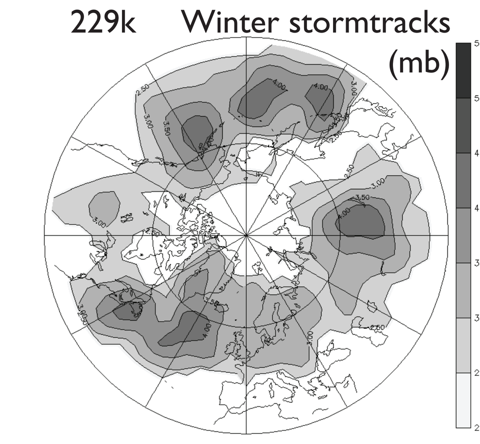
- Atmospheric temperature drops over the inception areas
- Permanent snow cover is highly extended
- Meridional Overturning Circulation is slightly slowed down and slightly deeper compared to the Pre-Industrial period.

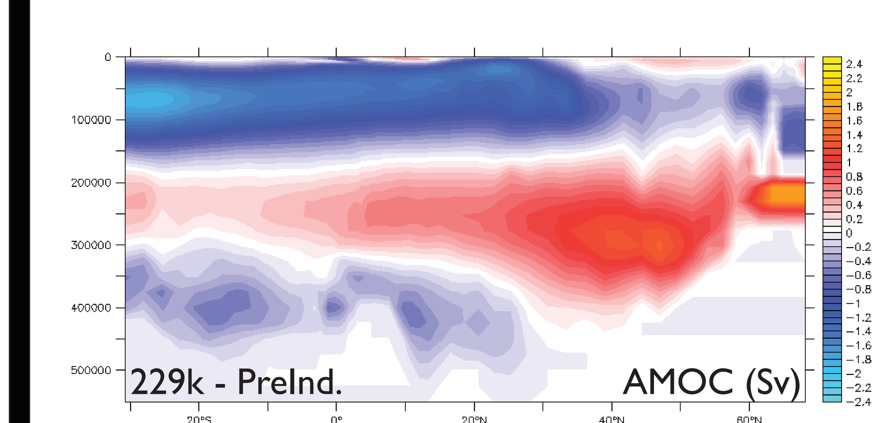
229 kyrs BP vs. 115 kyrs BP

Climate model: CESM1.0 (Community climate model)









Orbitals less favorable to inception at 229k

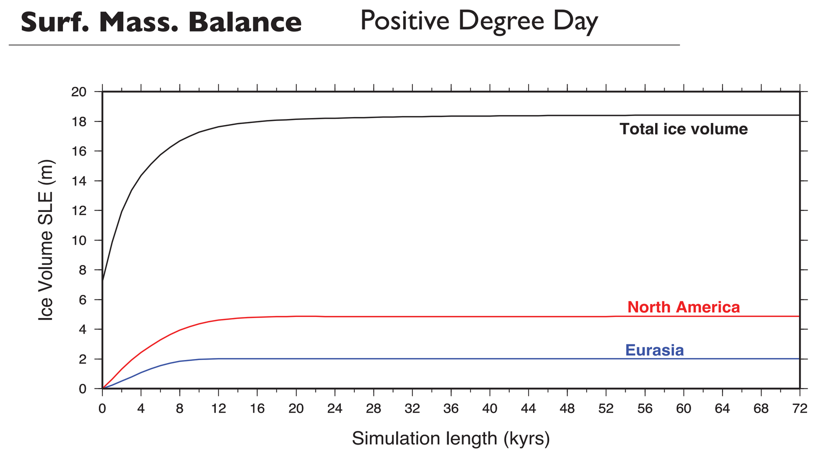
- Atmospheric temperature colder than at 115k
- Stormtracks are more intense (more moisture over Eurasia)
- Permanent snow cover is less extended (warmer springs)
- Meridional Overturning Circulation is more vigorous than at 115k, more deeper
- Antarctic Bottom waters do not reach northern latitudes as high as at 115k.

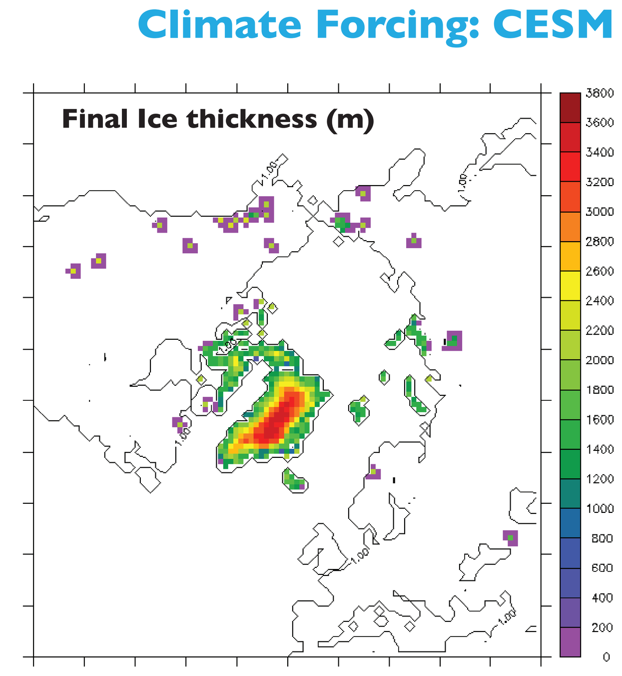
115 kyrs BP: simulated ice sheets

Model: Glimmer-CISM 2.0
Climate Forcing: CESM 1.0

Experiment set-up:

Initial topo:	present-day
Initial ice thickness:	Greenland (~ 7.2 m SLE)
Resolution:	100km x 100 km
Length:	72 000 years
Surf. Mass. Balance	Positive Degree Day





Modelled inception: Sea-level drop ~ 12 m

Observations: 124 k Interglacial → sea-level drop ~ 17 m → 115 k

30% ice volume missing

Under the 115k climate forcing, the grounded ice* reaches equilibrium after 16 kyrs

*this version of Glimmer-CISM does not allow the ice shelves to spread over the Arctic continental shallow shelf

229 kyrs BP: simulated ice sheets

Model: Glimmer-CISM 2.0
Climate Forcing: CESM 1.0

Experiment set-up:

Initial topo:	present-day
Initial ice thickness:	Greenland (~ 7.2 m SLE)
Resolution:	100km x 100 km
Length:	72 000 years
Surf. Mass. Balance	Positive Degree Day

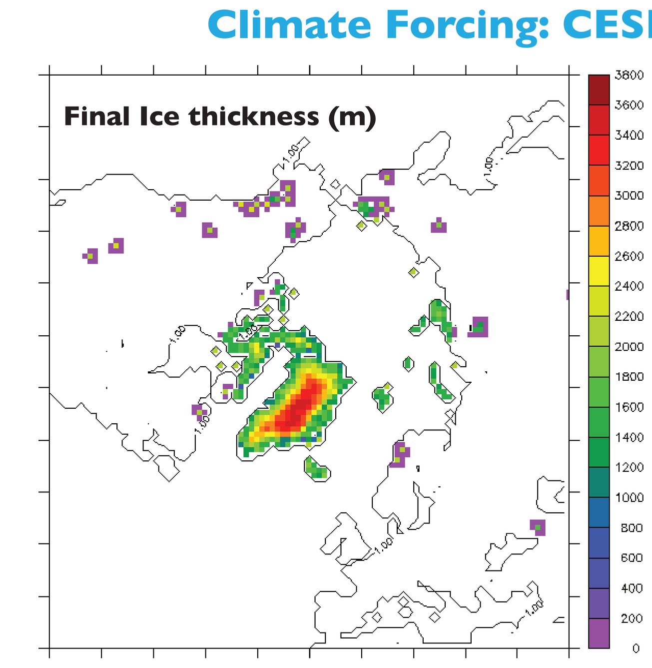
	Total Area (km²)	North America (% tot. area)*	Eurasia (% tot. area)*
115k	352x10⁴ (18.5)	32(5)	7 (2)
229k	365x10⁴ (19)	34(5.3)	9 (1.3)

Ice Volume in m SLE

Modelled inception: Sea-level drop ~ 12 m

Observations: 237 k Intergl. → sea-level drop ~ 40 m → 229 k

70% ice volume missing



Contrary to what suggests the climate forcing, **Glimmer-CISM** is **more favorable** to inception at 229k and especially over North America

*These calculations exclude the Cascade mountain range and the Siberian highs

Conclusions

- According to observations, the inception at 229k seemed to be faster than at 115k but our simulations are not able to reached the observed sea-level drop at 229k: **missing vegetation feedback?**
- These simulations do not allow us to understand whether the North American ice sheet was less developed than in Eurasia at 229k because:
  - the surface mass balance scheme used in Glimmer-CISM does not take into account the **difference in the permanent snow cover**
  - **no ice shelf dynamics** into Glimmer-CISM. Limits the comparison between the more continental North American ice sheet and the more insular Eurasian one.

Perspectives

- Run CESM 1.0 with dynamics vegetation
- Perform ice sheets simulations for 229k and 115k using the Shallow Shelf Approximation
- Use a different mass balance scheme to account for the snow cover discrepancies

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