Progress towards a Calibrated Deglaciation Chronology for the Eurasian Ice Complex

Lot's of poorly constrained components in the glacial system
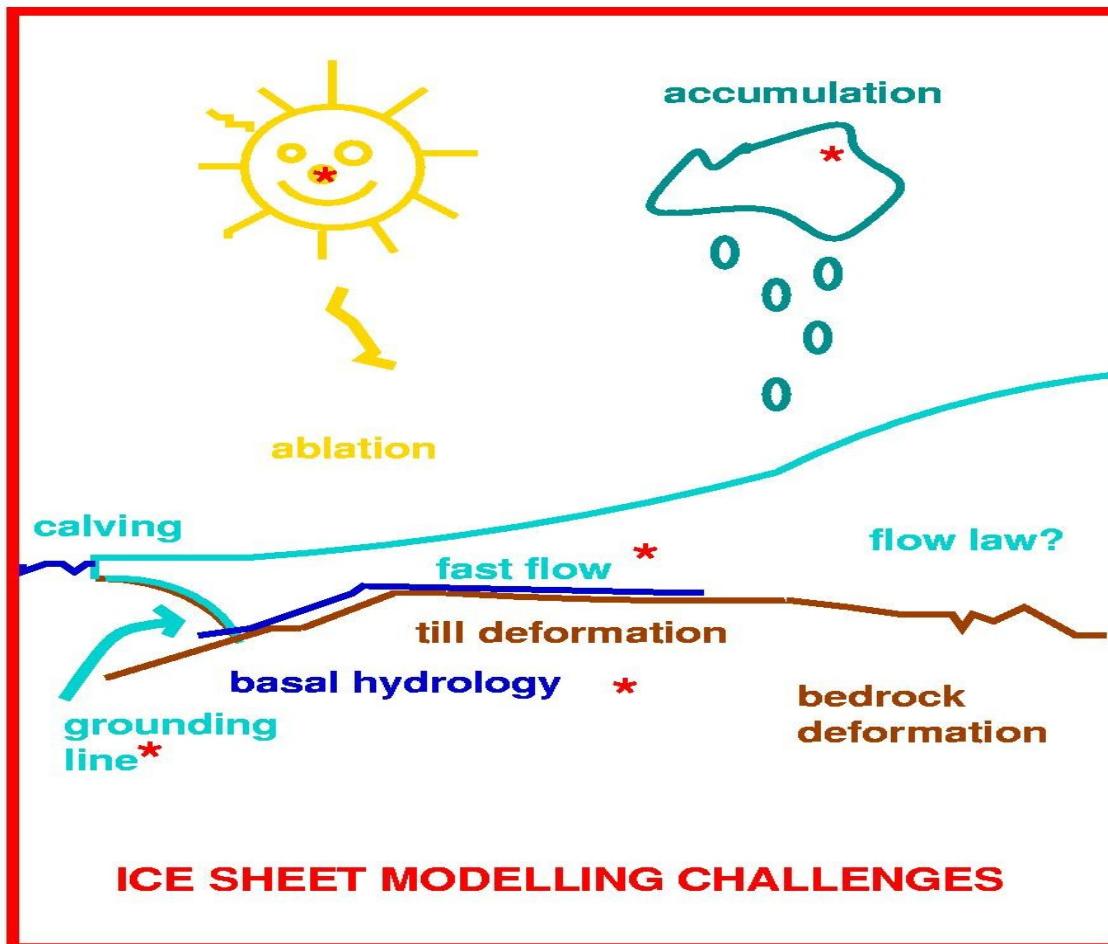
*Poorly constrained system;*
model pre(retro)dictions have generally
lacked meaningful error bars => no
meaningful interpretation.
Solution: 3 components:

#1: Glacial Systems Model (GSM)
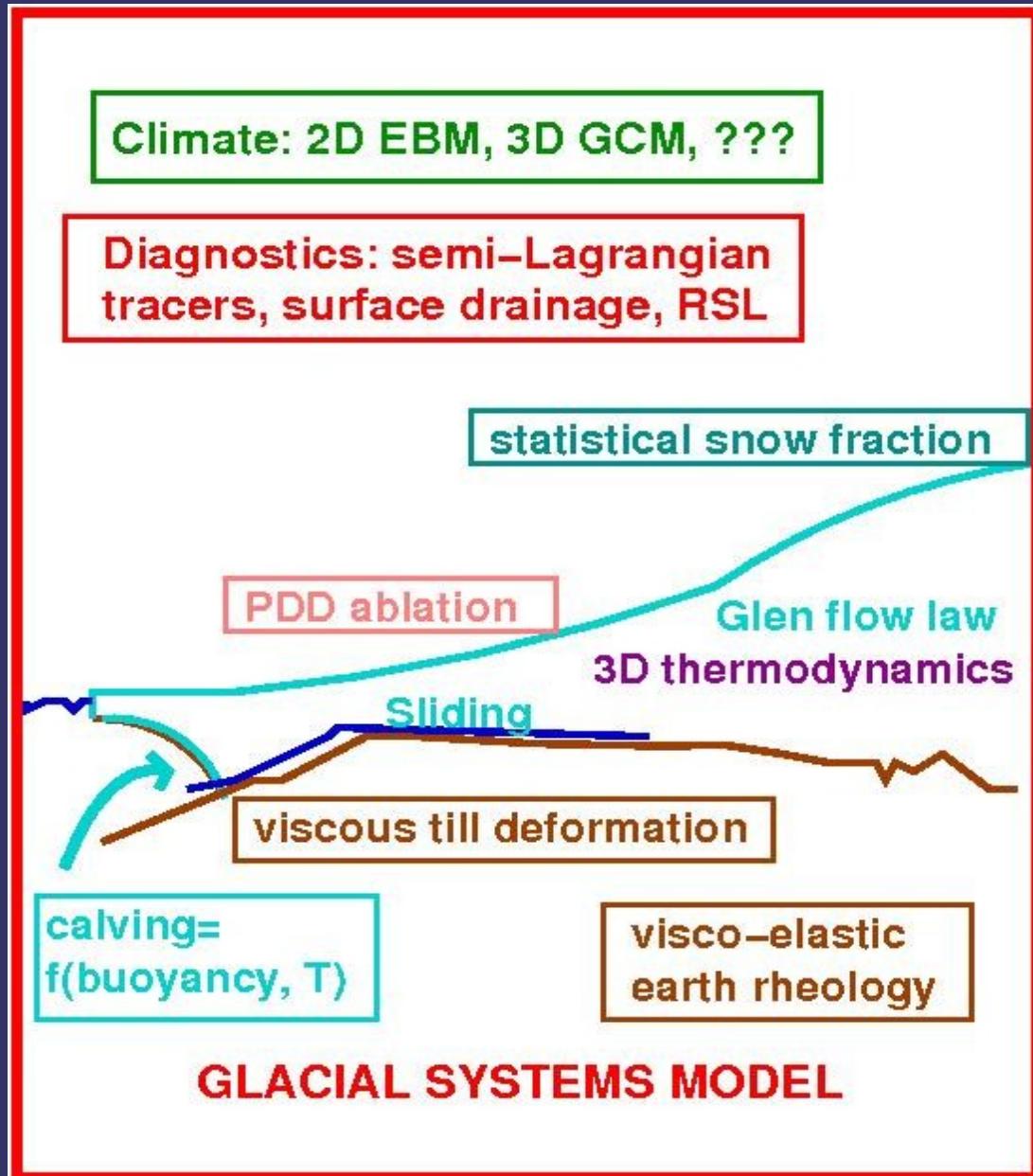
- 3D thermo-mechanically coupled ice-sheet model, 0.5 * 1.0 (lat/long) model resolution
- VM2 viscosity model
- detailed surface mass-balance and ice-calving modules
- global gravitationally self-consistent RSL solver
- fully coupled surface drainage solver

Climate forcing

P.D. July SeaLevel Temperature

LGM July SeaLevel Temperature
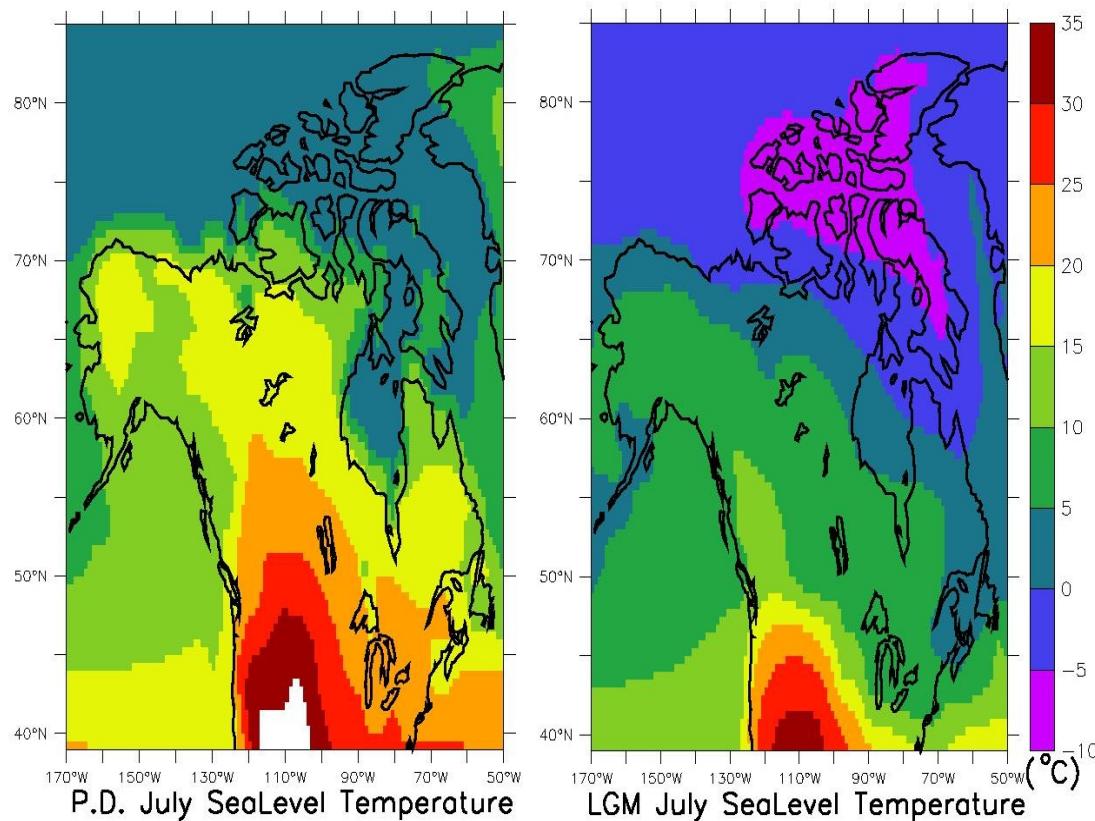
- Last Glacial Maximum (LGM) precipitation and temperature from 4 (6 for N. A.) highest resolution Paleo Model Intercomparison Project GCM runs
  - Mean and EOF fields
- Present day observed fields

120 kyr climate forcing
## (based ss09 chronology)

glacial index (GRIP chronology)
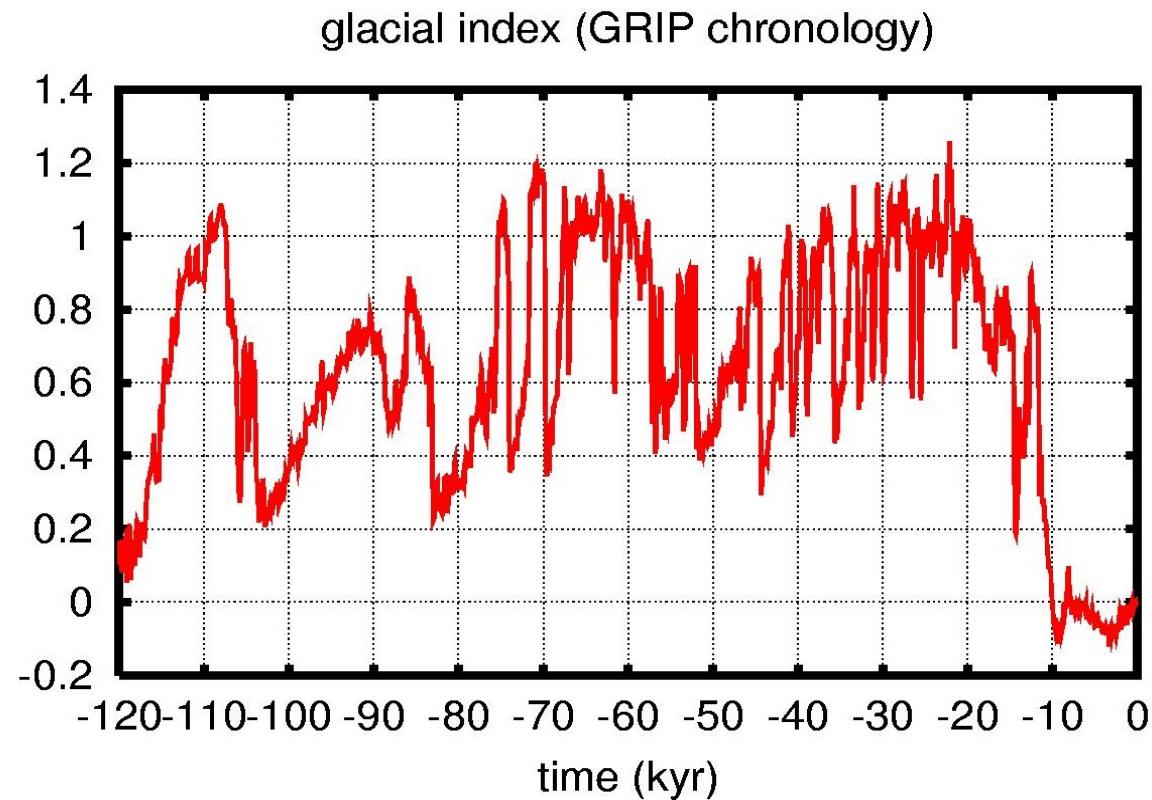
Embrace uncertainty: Lots of ensemble parameters

- 3(5 for North America) ice dynamical
- 13(16) regional precipitation
  - LGM precipitation EOFs most significant for North America
- 4(4) temperature
- 4(4) ice calving
- 4(2) ice margins
- 1 model version
- = 29 (32)

Need constraints -> #2: DATA

# *Initial European deglacial margin chronology (Saarnisto and Lunkka, 2003)*

Margin chronology

- −10kyr
- −11kyr
- −12kyr
- −13kyr
- −14kyr
- −15kyr
- −16kyr
- −20kyr
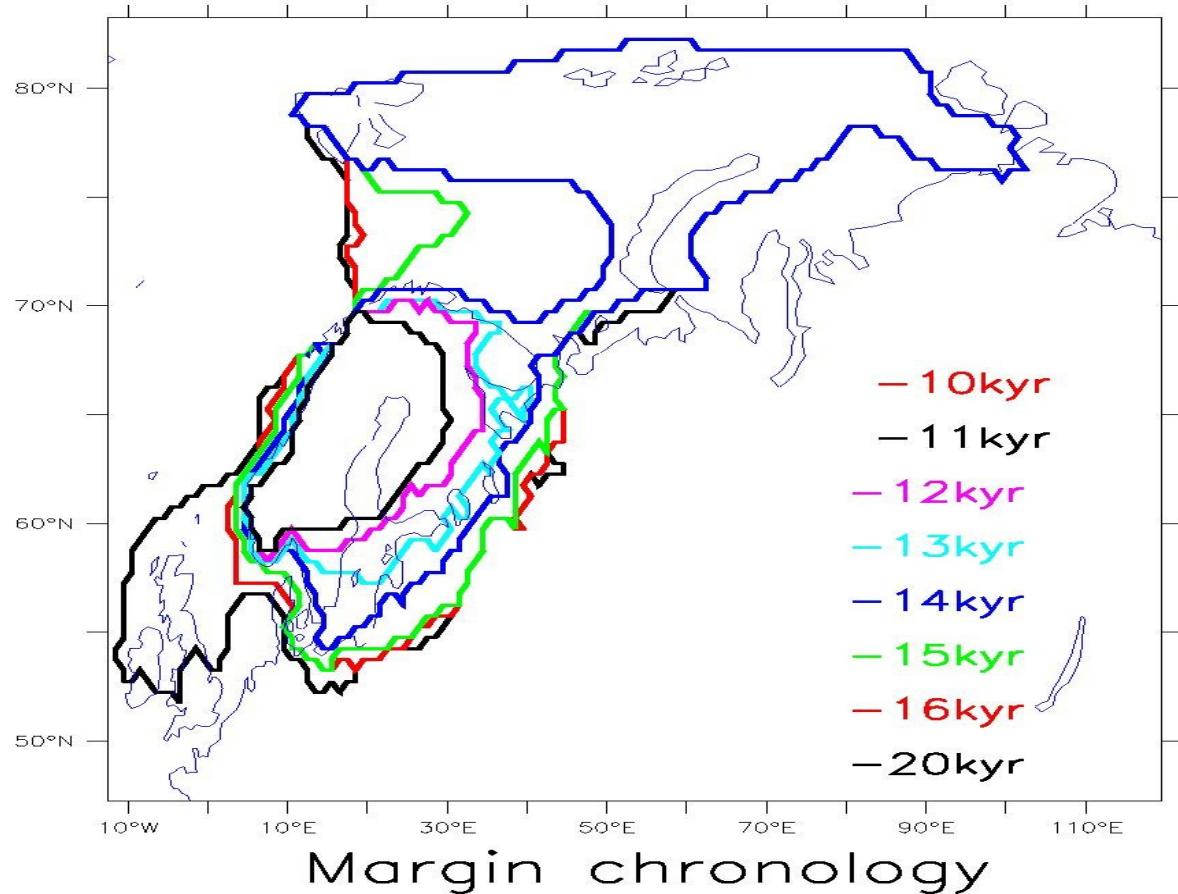
- ◆ margin forcing: surface mass-balance near ice margin adjusted to fit chronology
 - ◆ applied up to +- @100 km buffer zone

New margin chronology *(Oct/06)*

Oct/06 Margin chronology
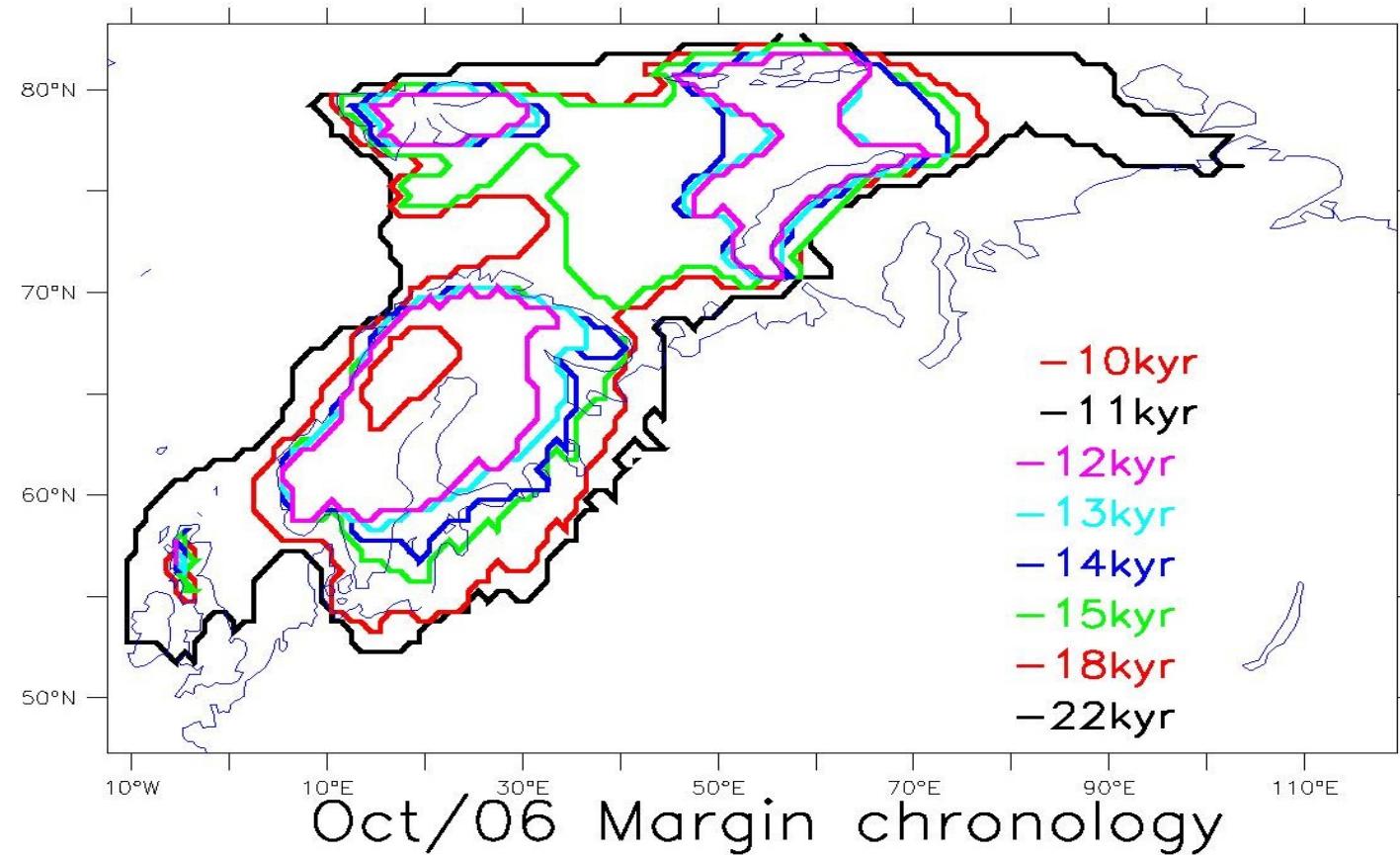
RSL data; site weighting (U. of Toronto RSL database)

RSL site weight map
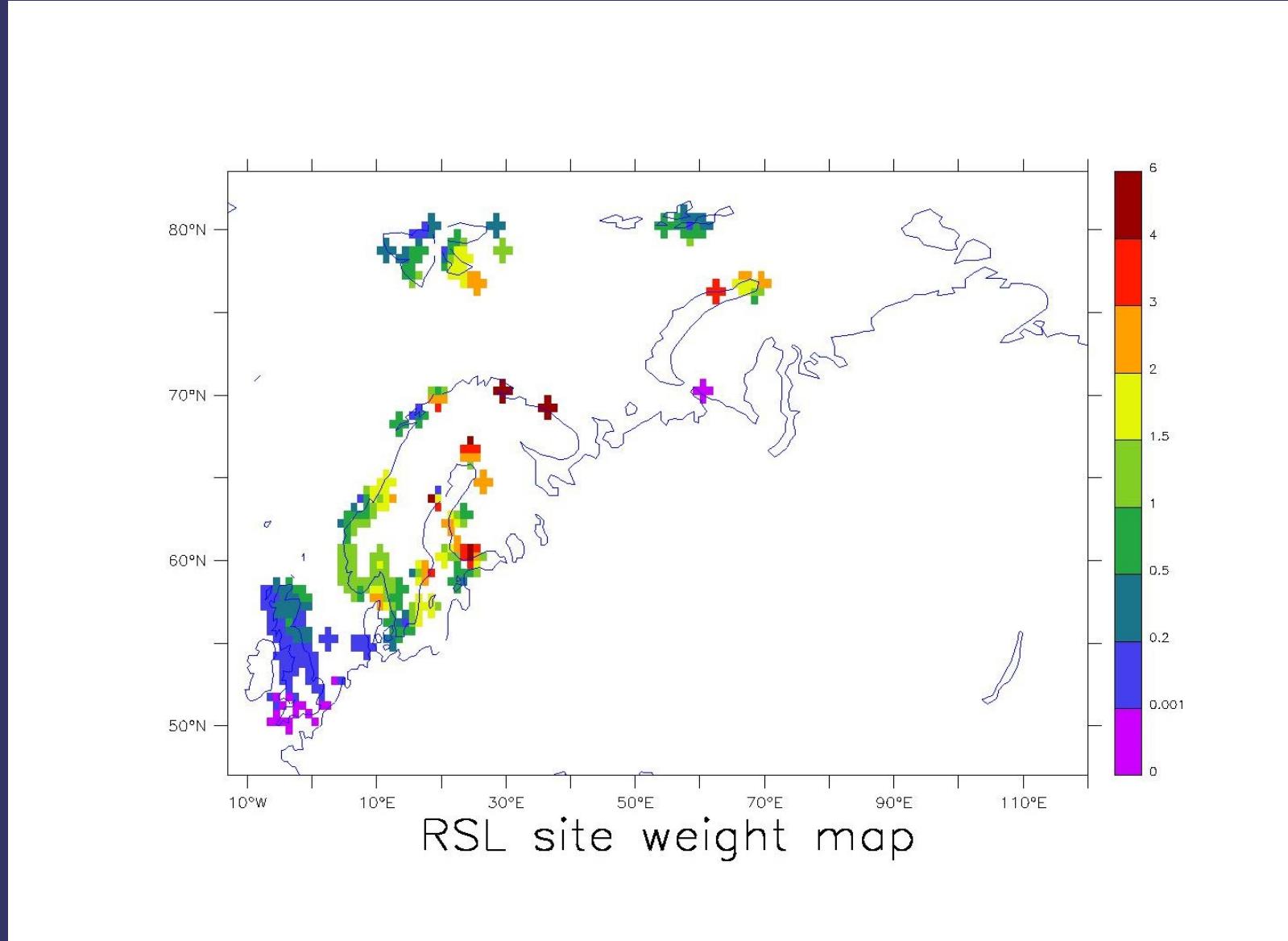
*Noisy data and non-linear system =>
need #3: calibration and error bars*

Bayesian calibration

SYSTEMS MODEL

3D thermo-mech.
coupled dynamical
ice-sheet model
RSL calculator

INPUT PARAMETERS

climate forcing
ice calving
ice dynamics

??

**INFERENTIAL
CALCULATOR
MCMC**

OBSERVATIONS

strandline elevation
basal uplift
Relative Sea Level

**BAYESIAN CALIBRATION OF A
WISCONSIN DEGLACIATION MODEL**
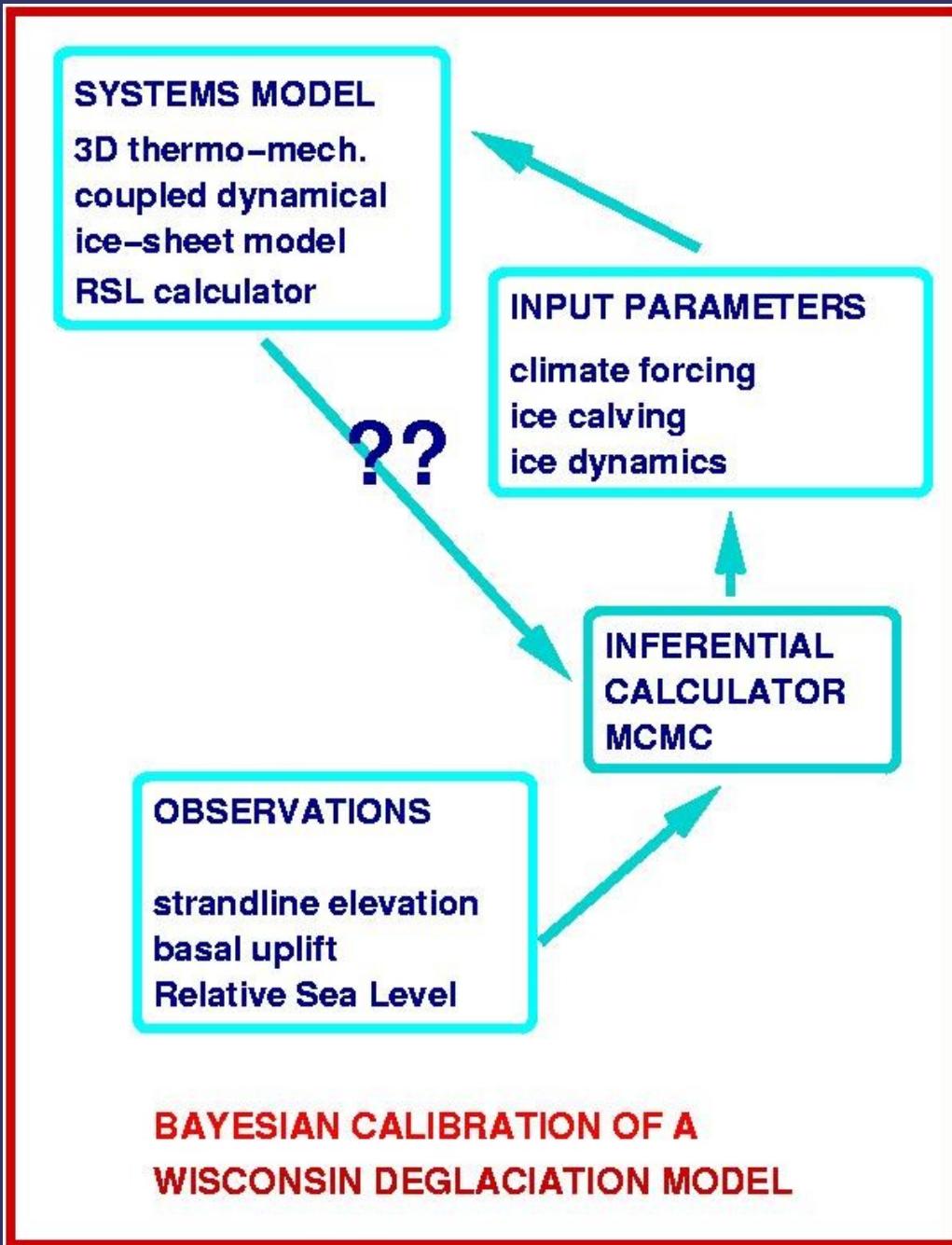
- Sample over posterior probability distribution for the ensemble parameters given fits to observational data using Markov Chain Monte Carlo (MCMC) methods
- Other constraint:
  - Minimize margin forcing

Large ensemble Bayesian calibration

**SYSTEMS MODEL**

3D thermo-mech.
coupled dynamical
ice-sheet model
RSL calculator

INPUT PARAMETERS

climate forcing
ice calving
ice dynamics

STATISTICAL EMULATOR
Bayesian
neural networks

INFERENTIAL CALCULATOR
MCMC

OBSERVATIONS

strandline elevation
basal uplift
Relative Sea Level

BAYESIAN CALIBRATION OF A WISCONSIN DEGLACIATION MODEL
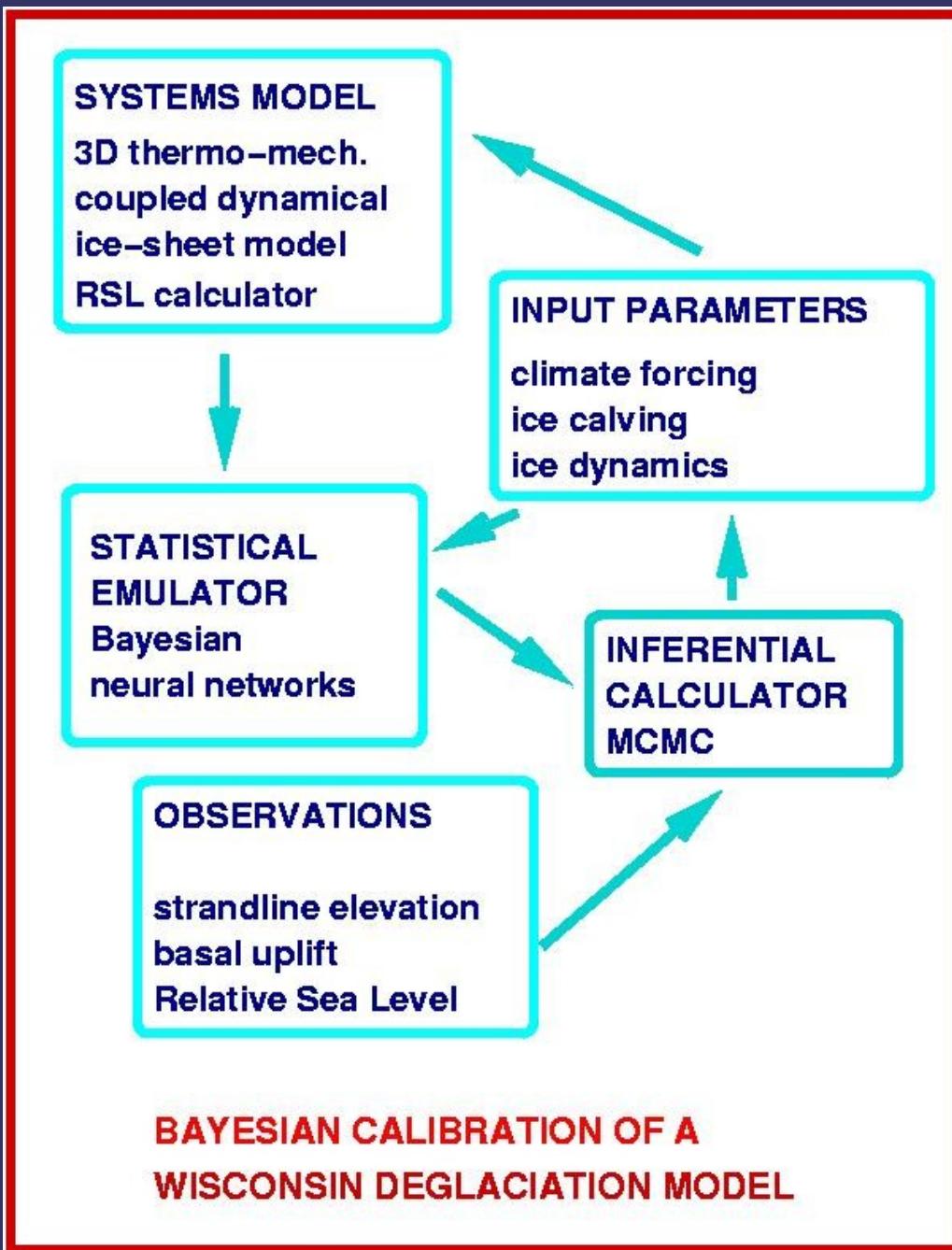
- Bayesian neural network integrates over weight space
  - Can handle local minima
- O(1 million) model sampling

Results

- from 1 calibration iteration with new margin
- 923 model runs
- @ 2 million MCMC samplings

Overall best RSL fitting models

- Key:
  - Black and red: new margin, 2 best runs
  - Green: old (Saarnisto and Lunkka) margin
- most sites have data only back to no more than -12 to -14 kyr
- Generally good fits except for Scotland and Norway
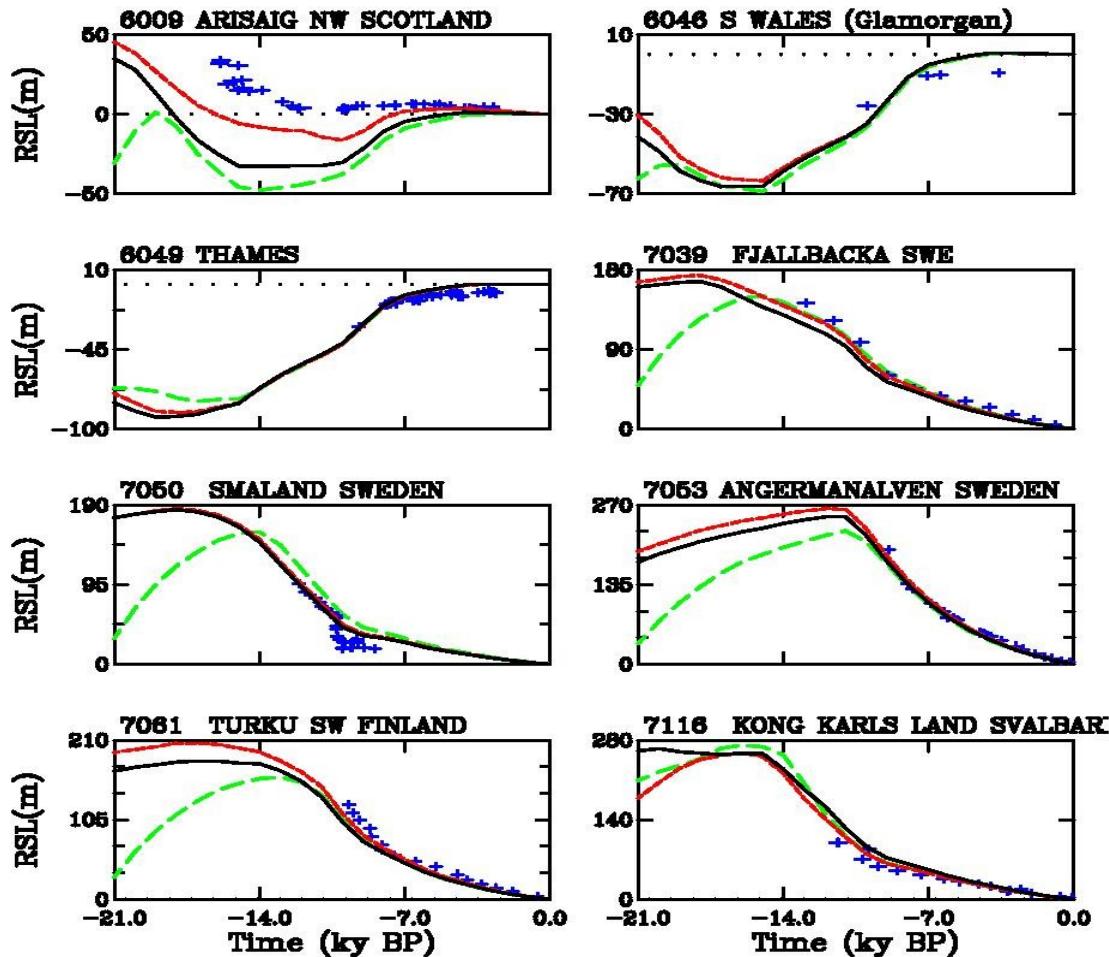
Problem with Norwegian coast
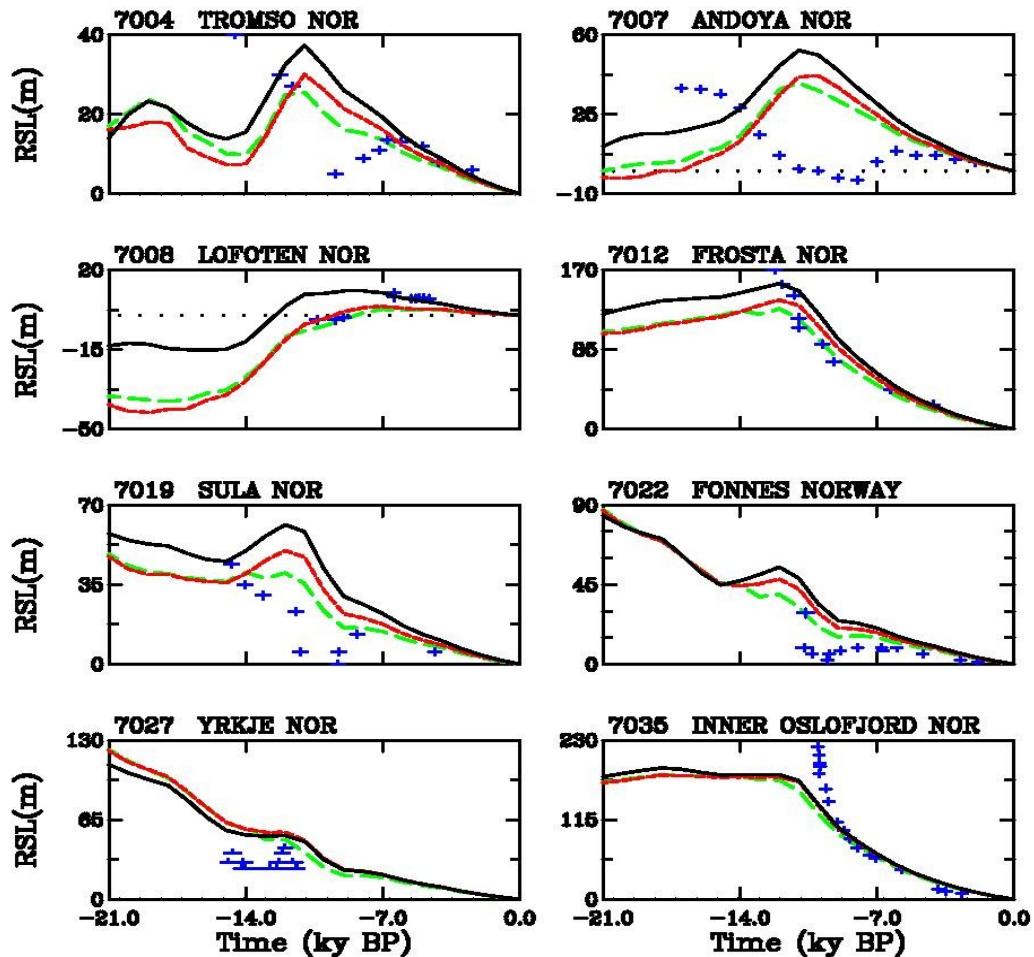
- Key:
  - Black and red: as before
  - Green: red run with further modifications to the margin chronology: -11 kyr -> -13 kyr, 12/11/10 -> 11.8/11.4/10.7 kyr
- margin chronology and/or fjord resolution and/or lithospheric thickness?

Impact of new mx/mn
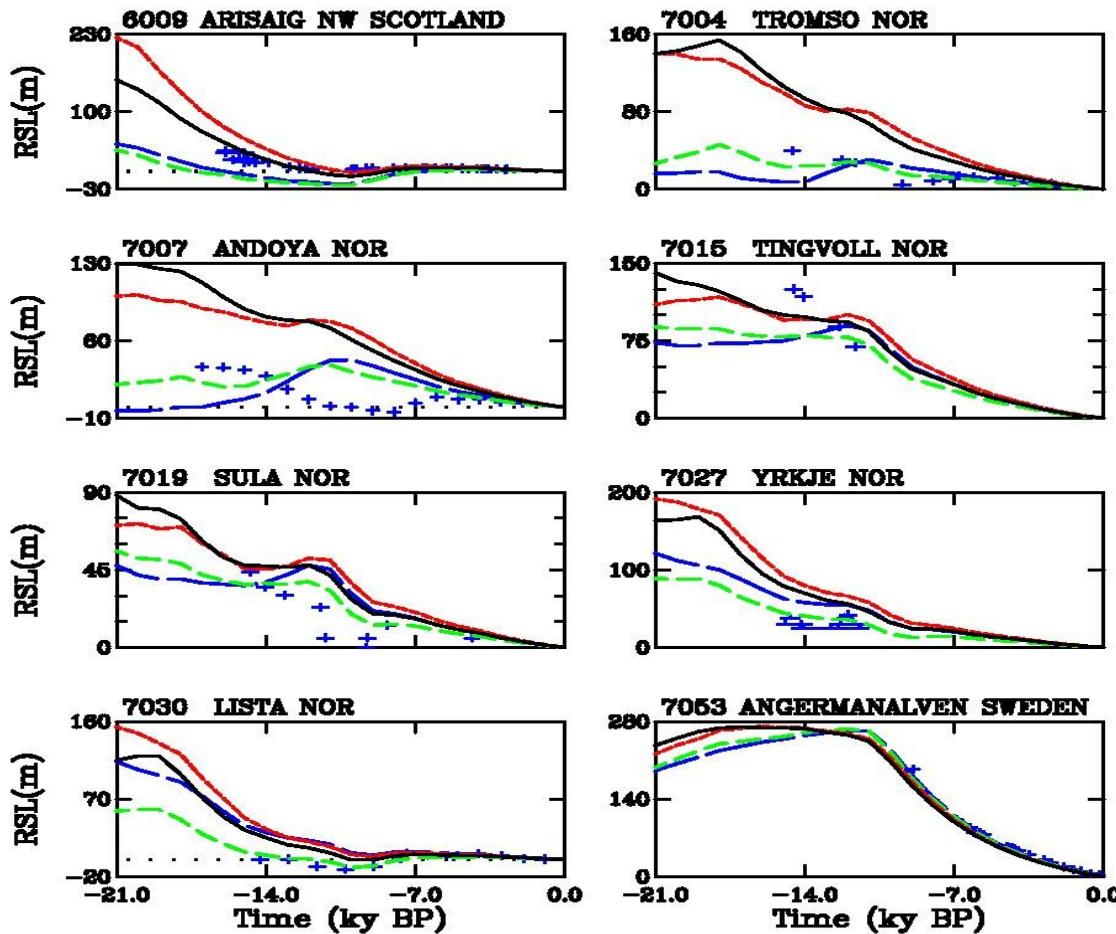
Key:
- Black : nn4717 : one of best with mx/mn
- Red: nn4717 without mx/mn
- Blue: nn4599 one of best from pre-mxmn calibration
- Green: mx/mn pair of nn4599

Mean ensemble -20 kyr ice velocity and surface elevation

New margin −20kyr ice velocity (m/yr)

Mean ensemble -20 kyr ice velocity and surface elevation

New BGmxmn margin −20kyr ice velocity (m/yr)
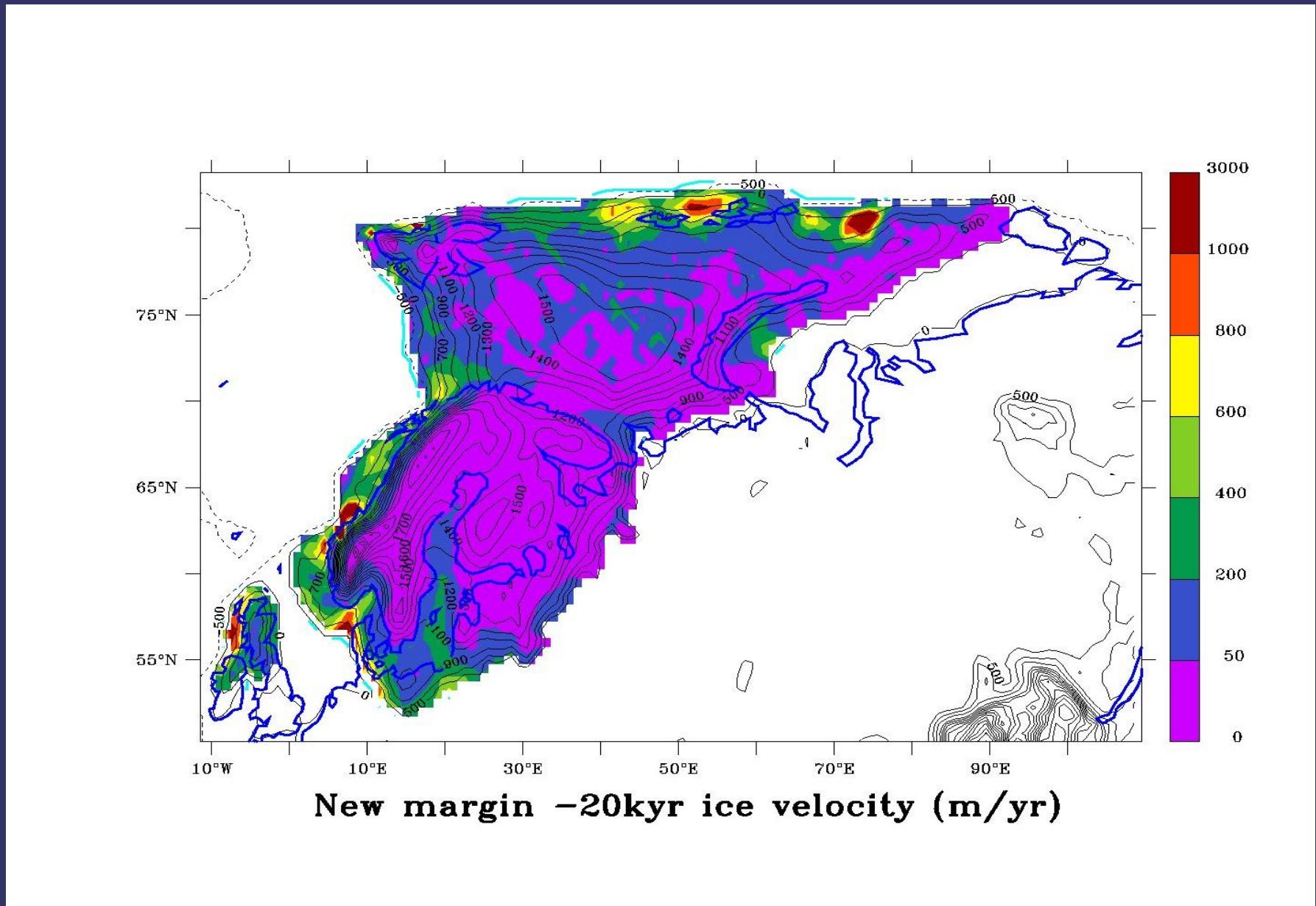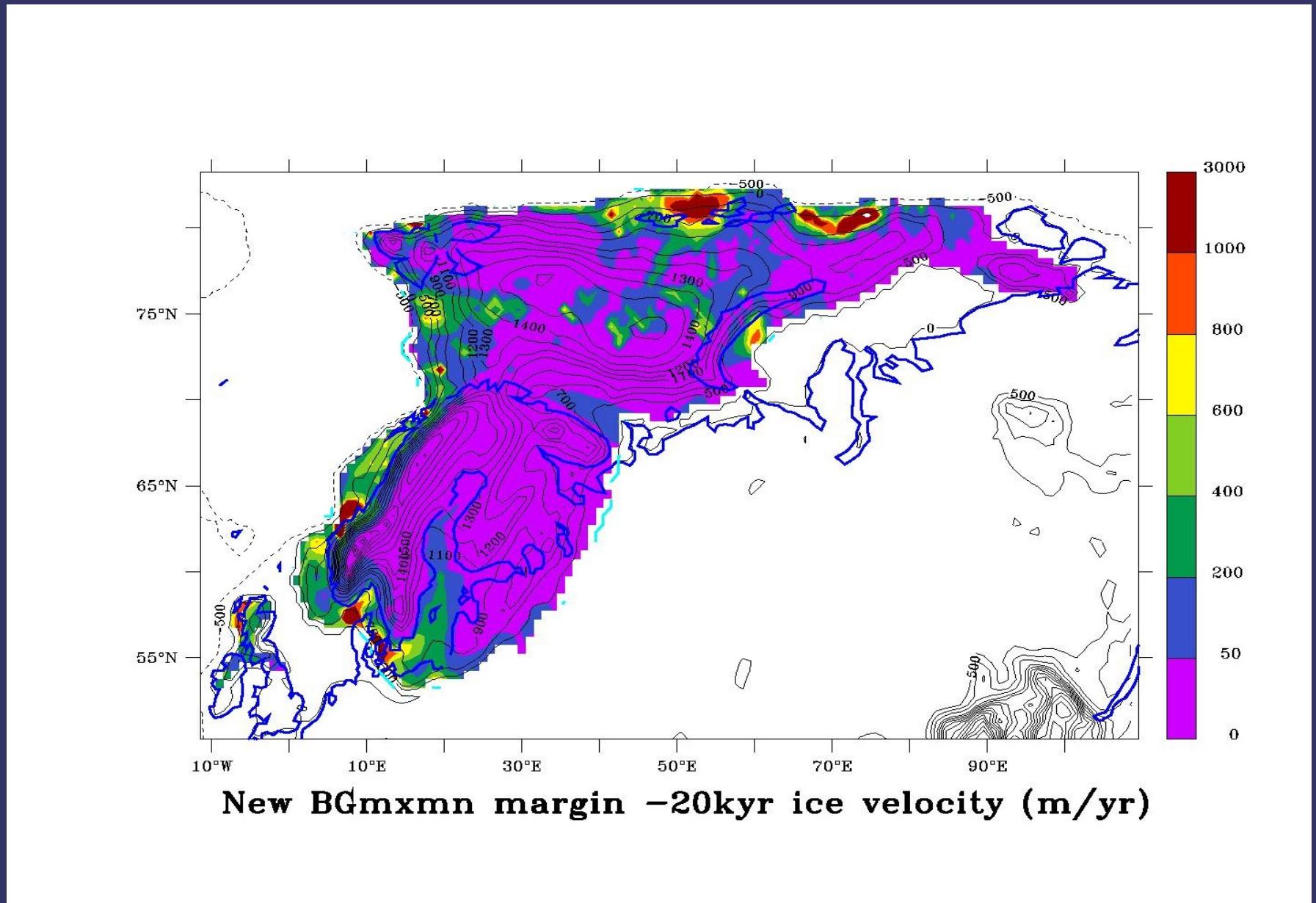
# ICE-5G -20 kyr ice surface elevation

ICE-5G −20kyr ice surface elevation (m)
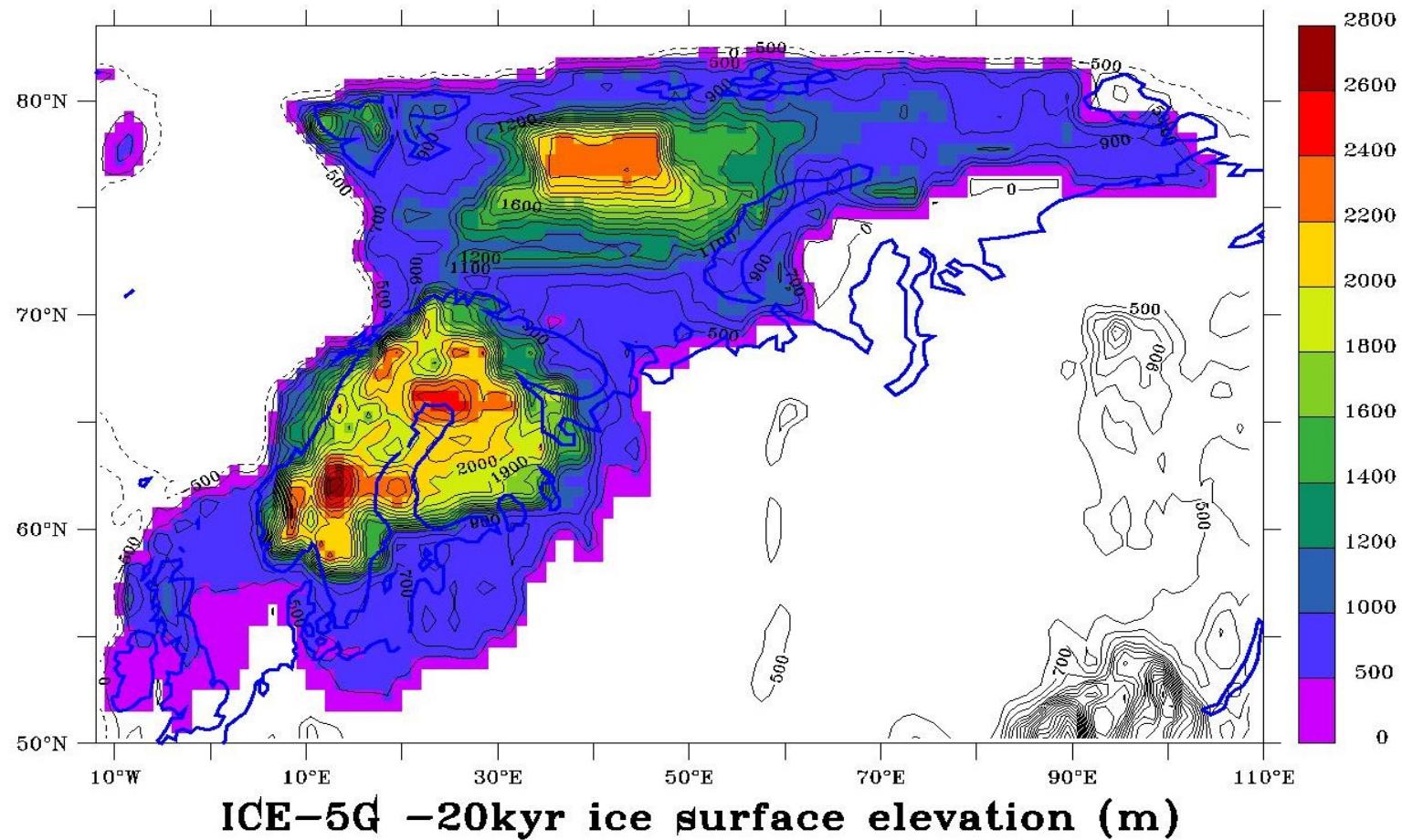
-20kyr: Ensemble mean - ICE-5G
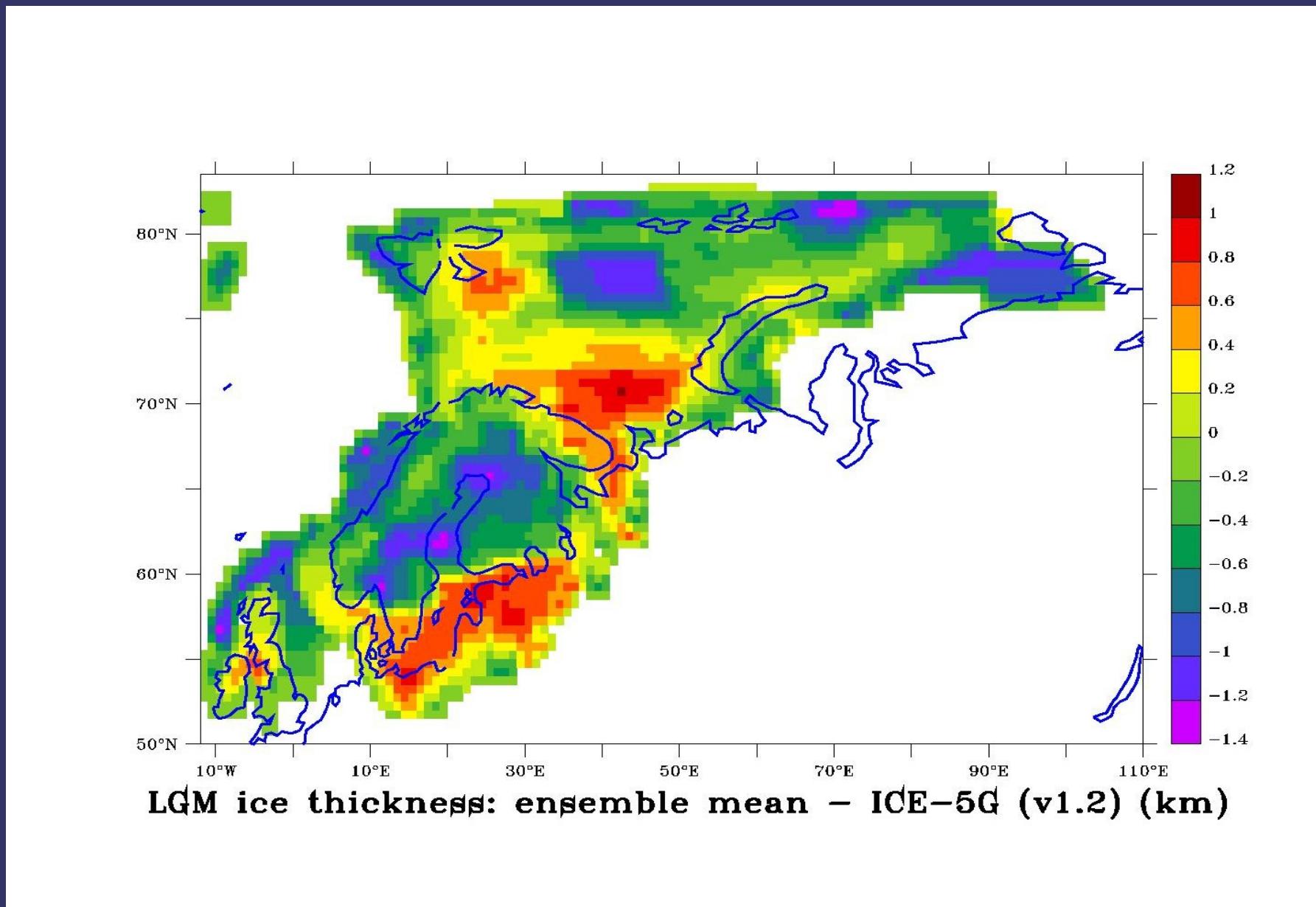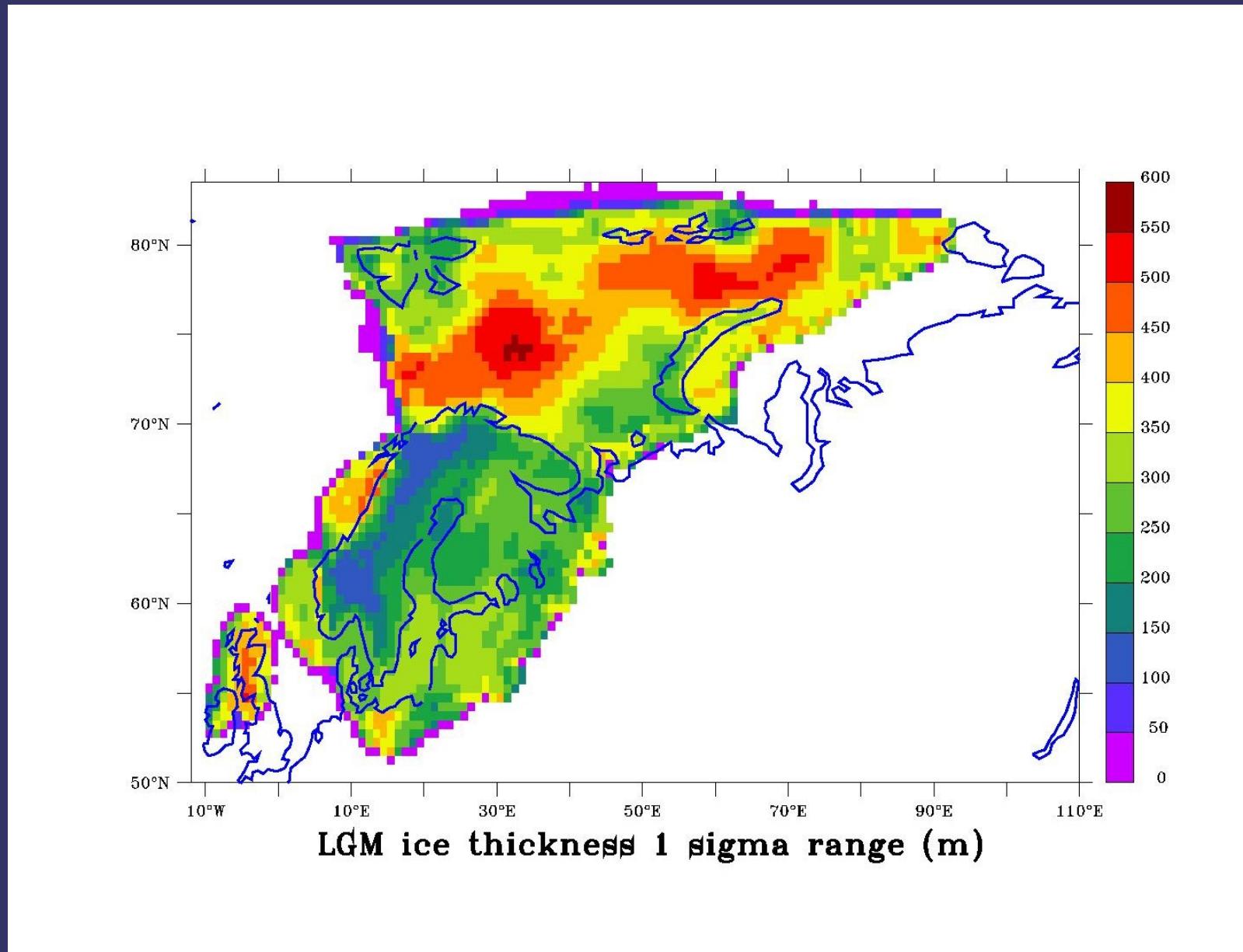
LGM ice thickness: ensemble mean − ICE-5G (v1.2) (km)

1 sigma range for LGM ice thickness!

LGM ice thickness 1 sigma range (m)

mx/mn: 1 sigma range for LGM ice thickness

LGM BGmxmn ice thickness 1 sigma range (m)
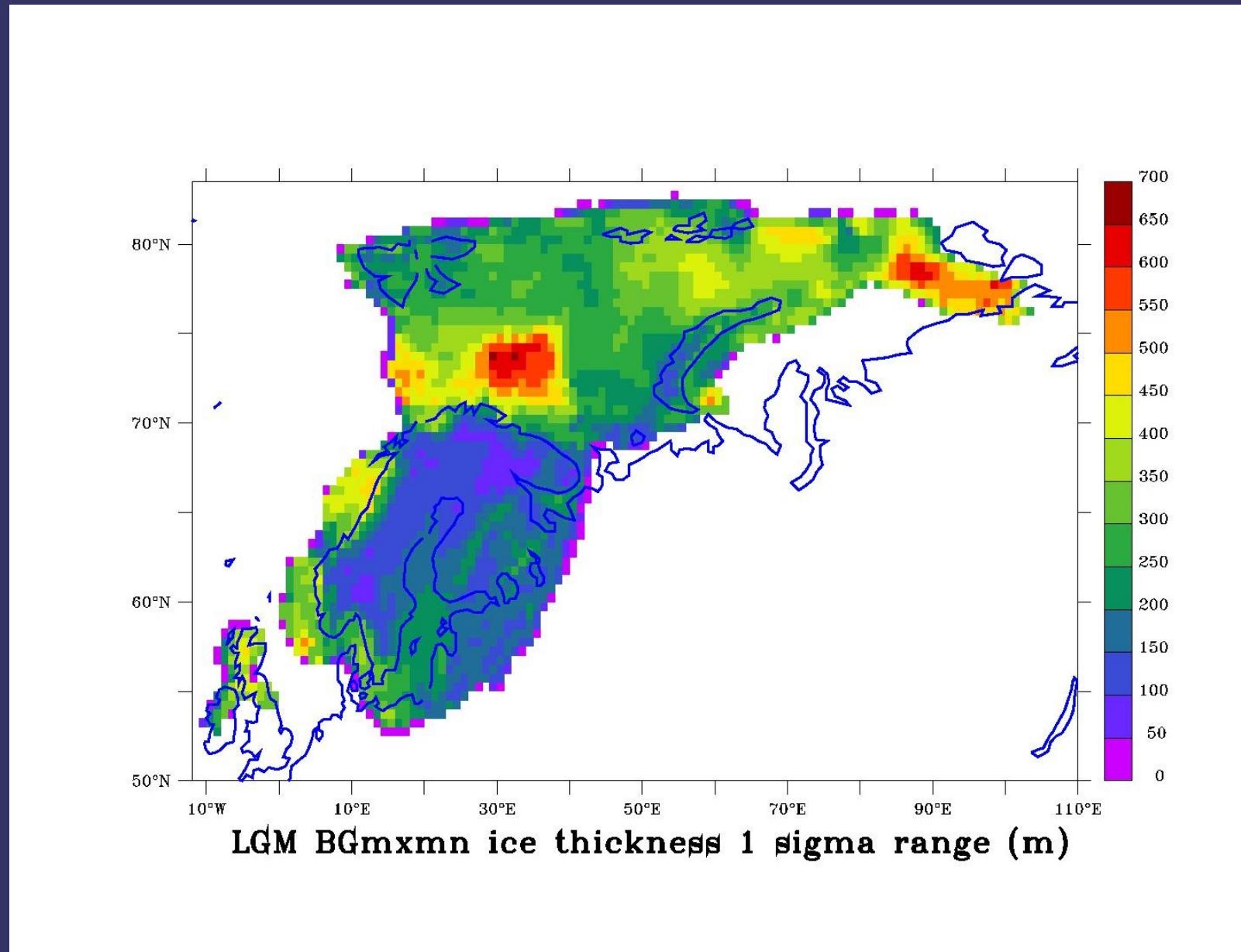
Ensemble mean present-day rate of uplift

New margin: mean rate of uplift (mm/yr)
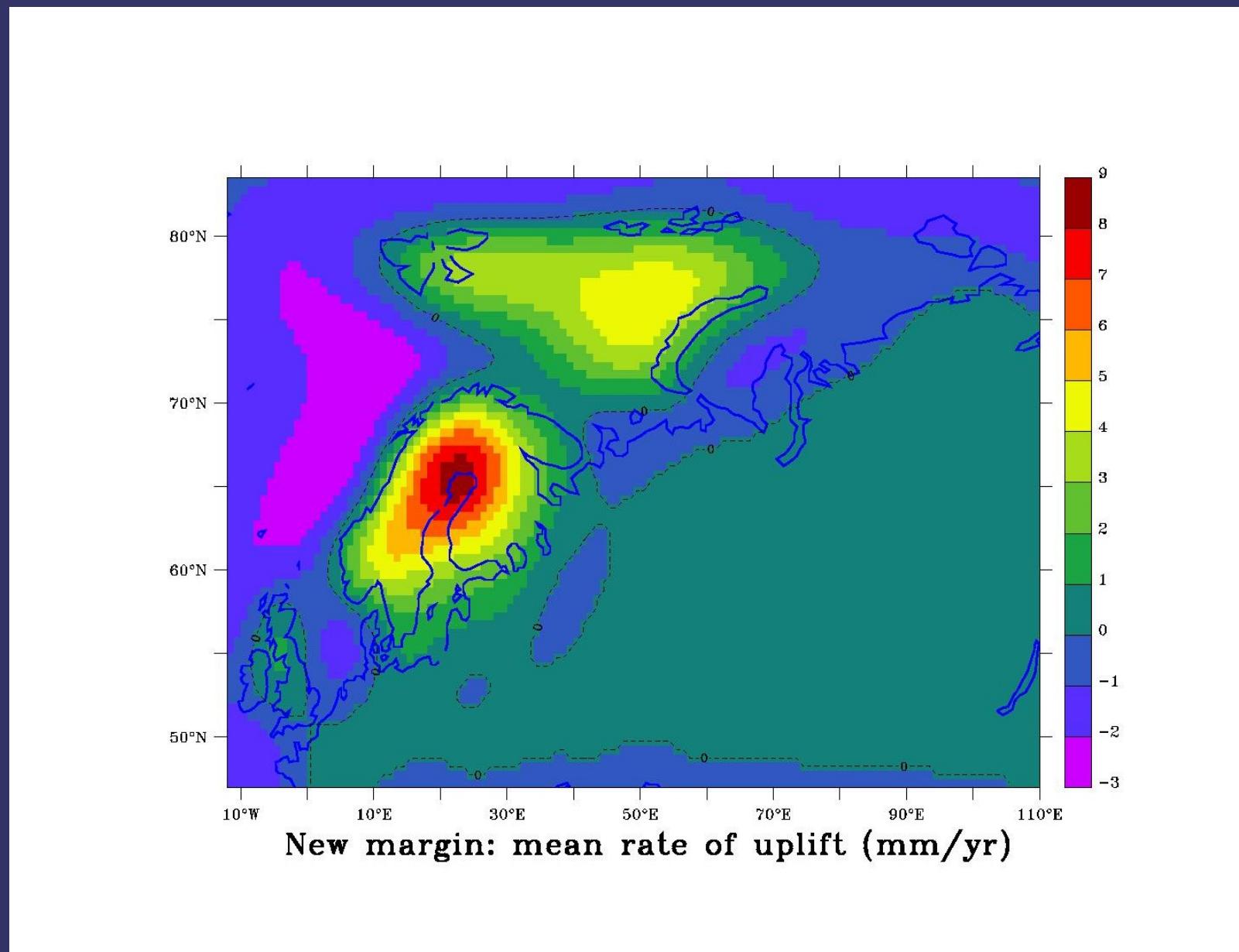
1 sigma range of ensemble rate of uplift

1 sigma range for rate of uplift (mm/yr)

Deglacial eustatic sea-level chronology

Eurasian eustatic contribution (m)

Legend:
- New (winter 2007) margin
- New margin (with max/min)
- old margin
- ICE-5G (VM2) Version 1.2

Time (kyr)
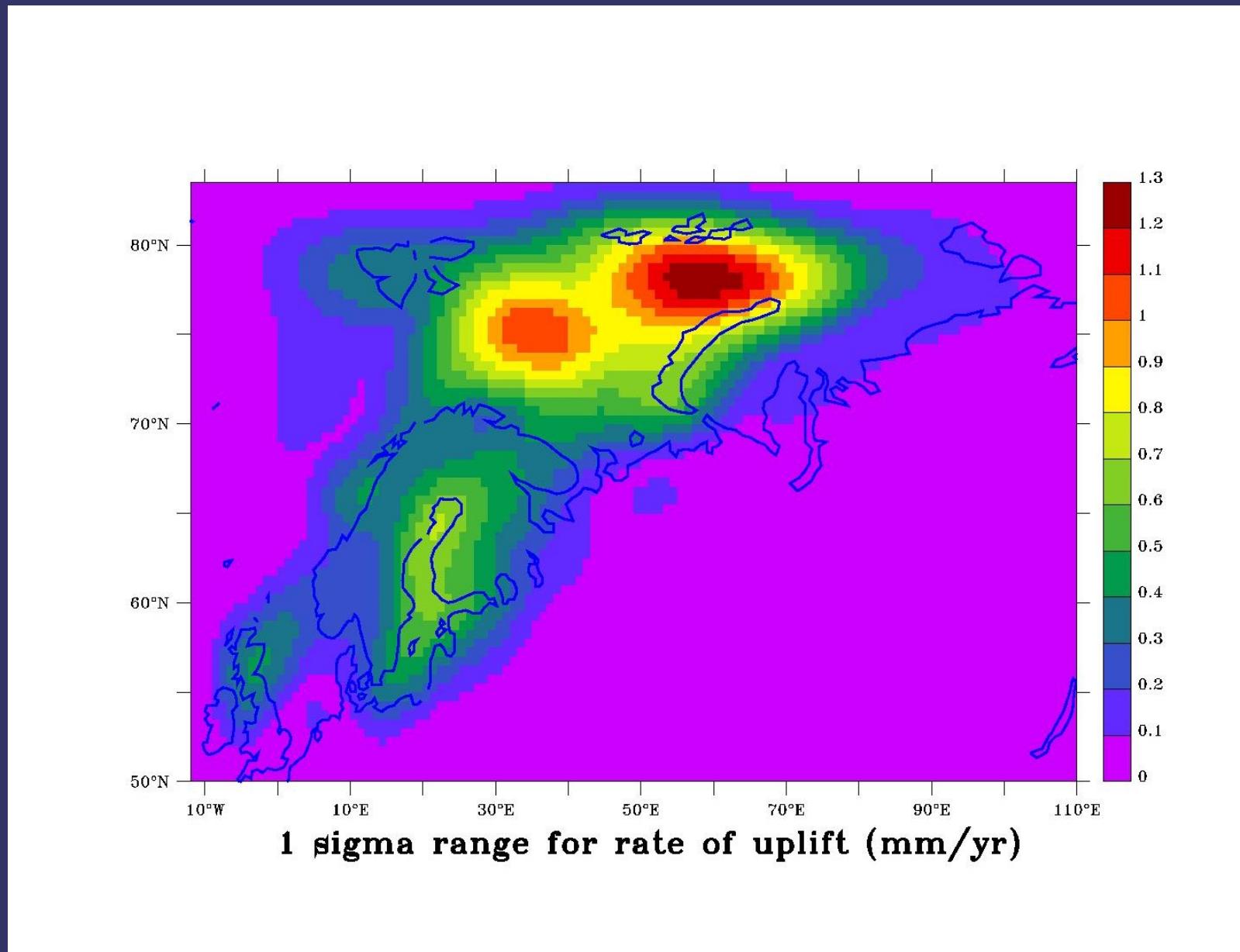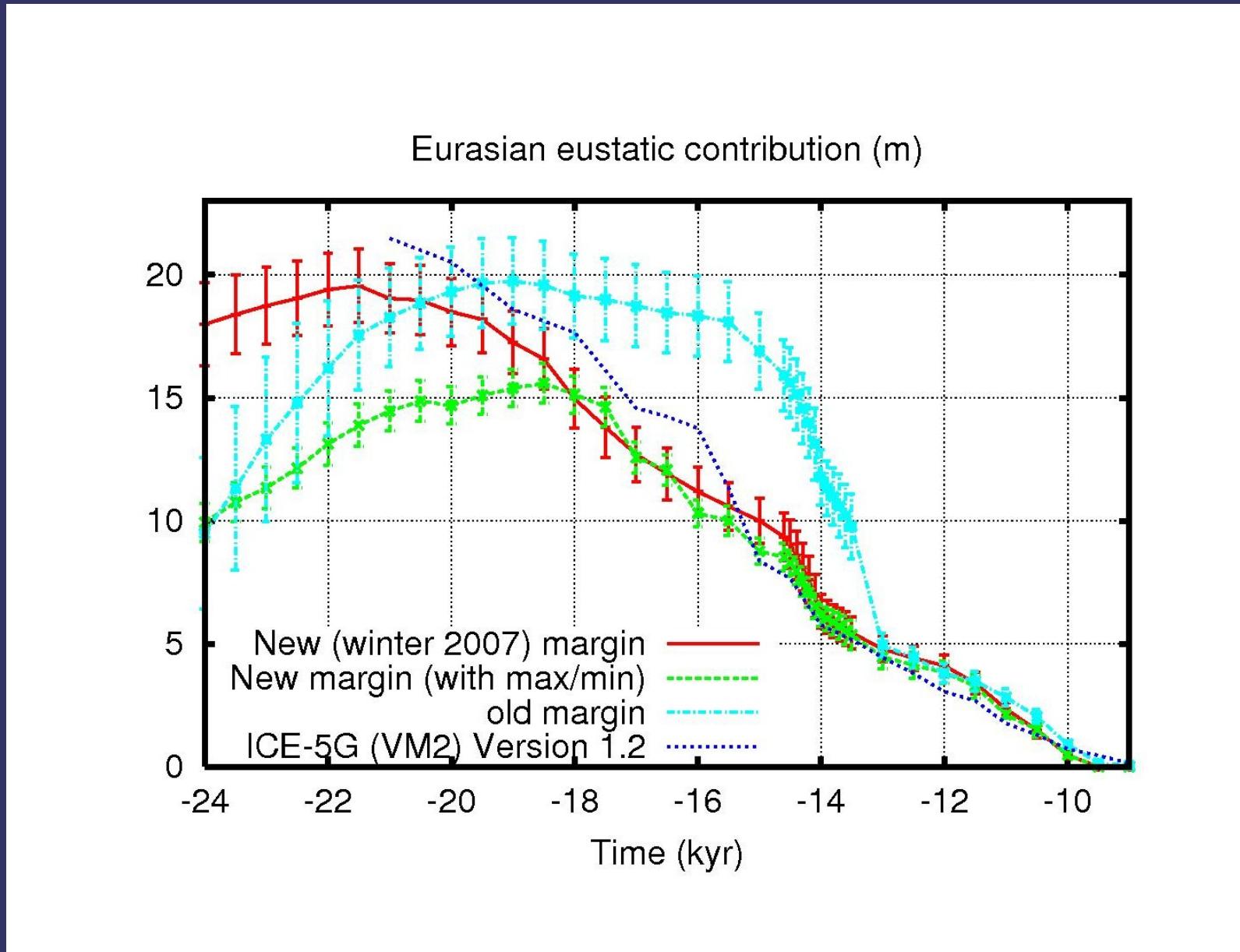
Northern Hemispheric contribution to eustatic sea-level

N. Hem. eustatic contribution (m)

inferred global
ensemble mean
old EU margin
ICE-5G

Time (kyr)
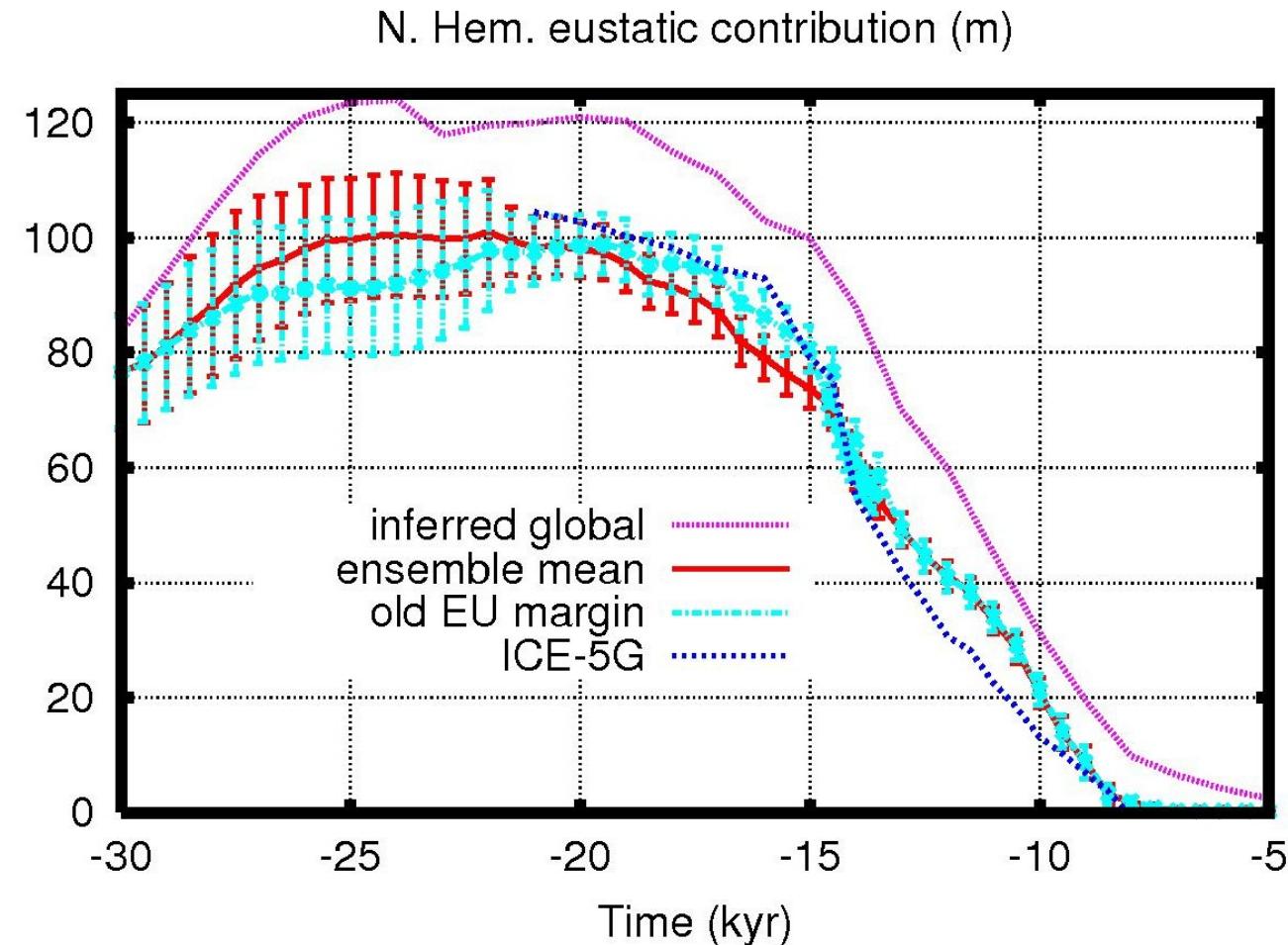
Far-field RSL
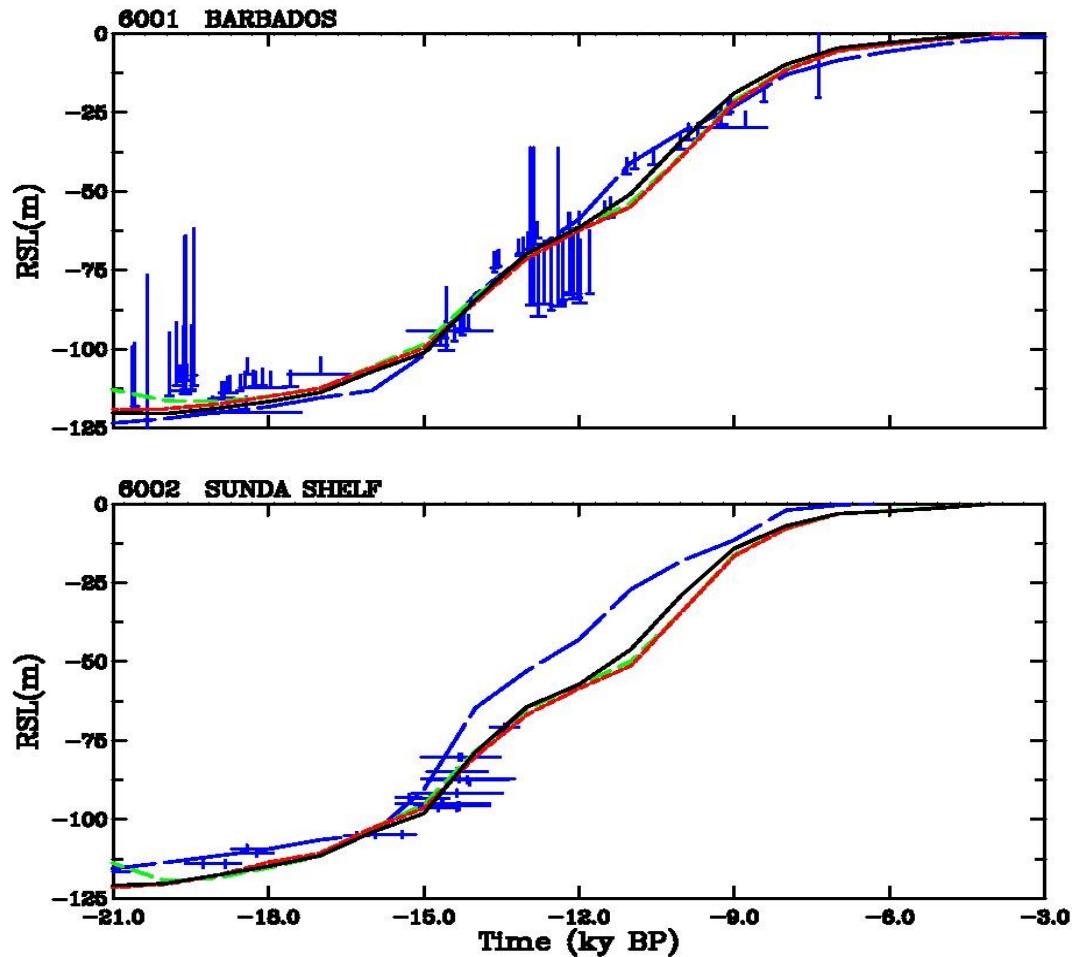
- Key (as before)
  - red and green from calibration
  - black is hybrid
  - blue is ICE-5

Deglacial eustatic sea-level chronology
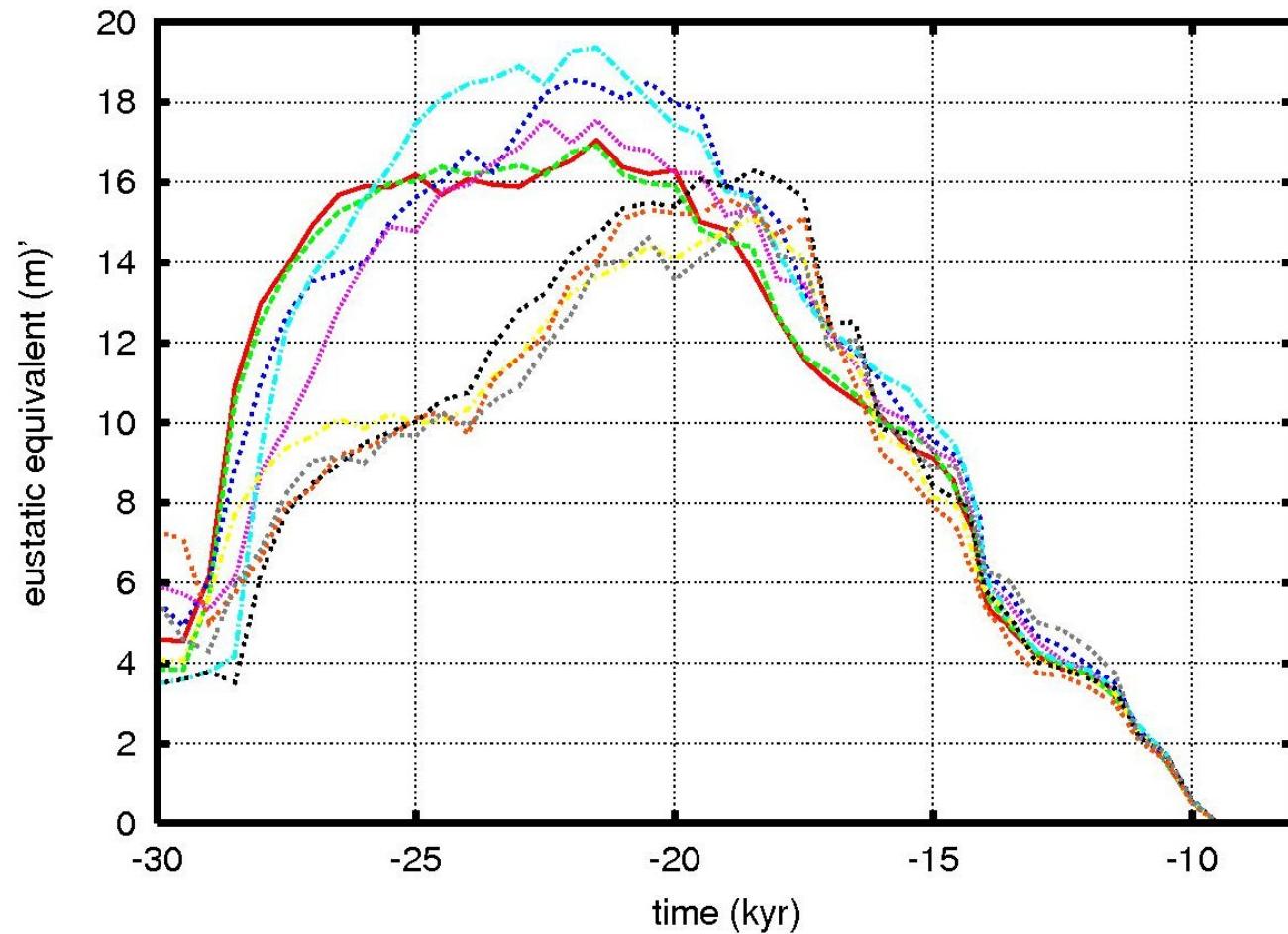
Deglacial eustatic sea-level chronology
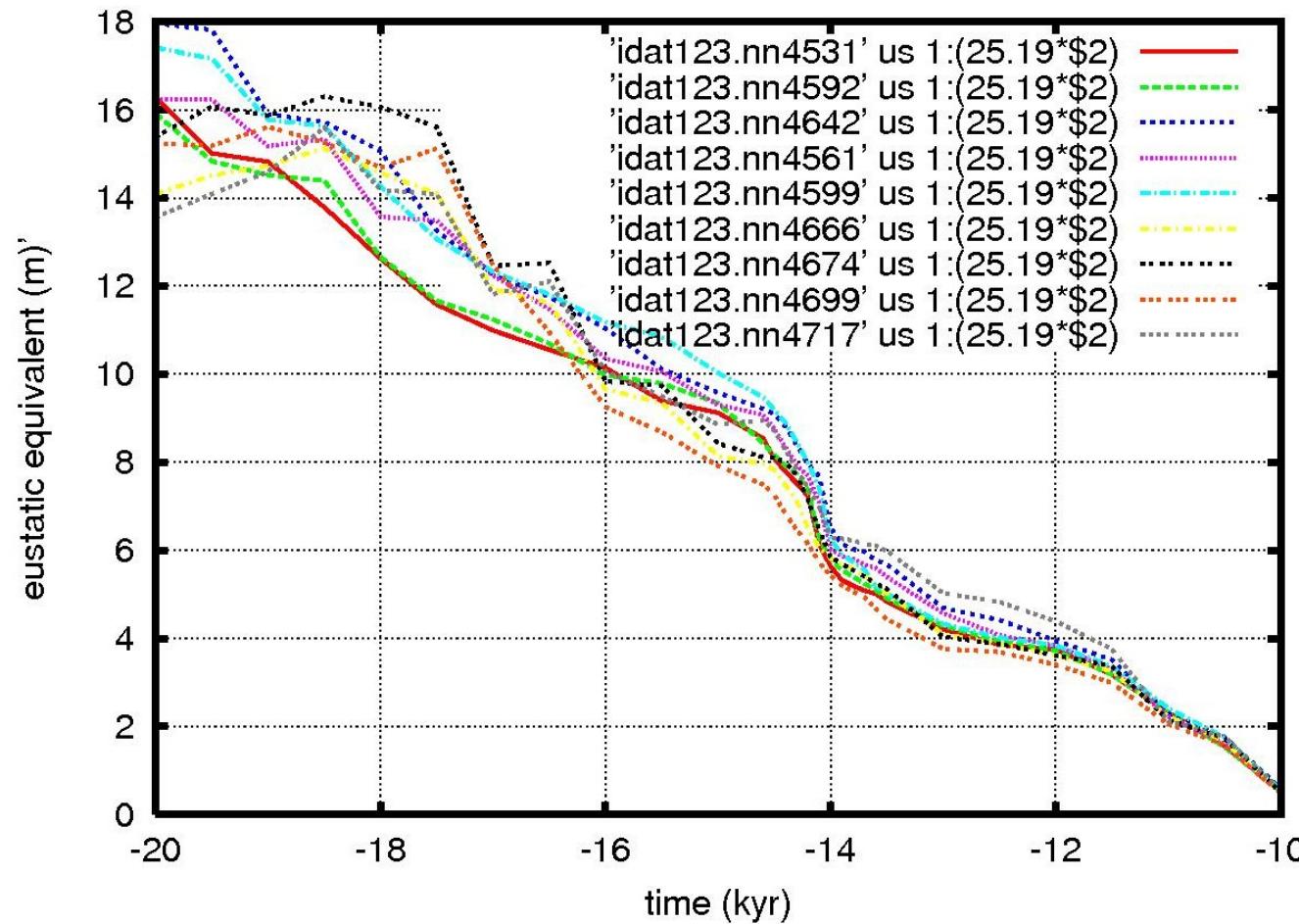
Summary

- pre-mx/mn margin European contributions:
  - LGM: 19.5 +- 1.5 m eustatic (@ 15m with mx/mn)
  - mwp1-a: 3.1 +- 0.5 m eustatic (4.9 +- 0.8 m old margin)
    - (@ 2m with mx/mn)
- Eastern challenge:
  - problems with western margin chronology for Fennoscandia and/or sub-grid issues related to lack of resolution of fjords and/or lithospheric thickness and/or climate forcing
- physical model + calibration against data => meaningful error bars/probability distributions

An example -26 and -24kyr
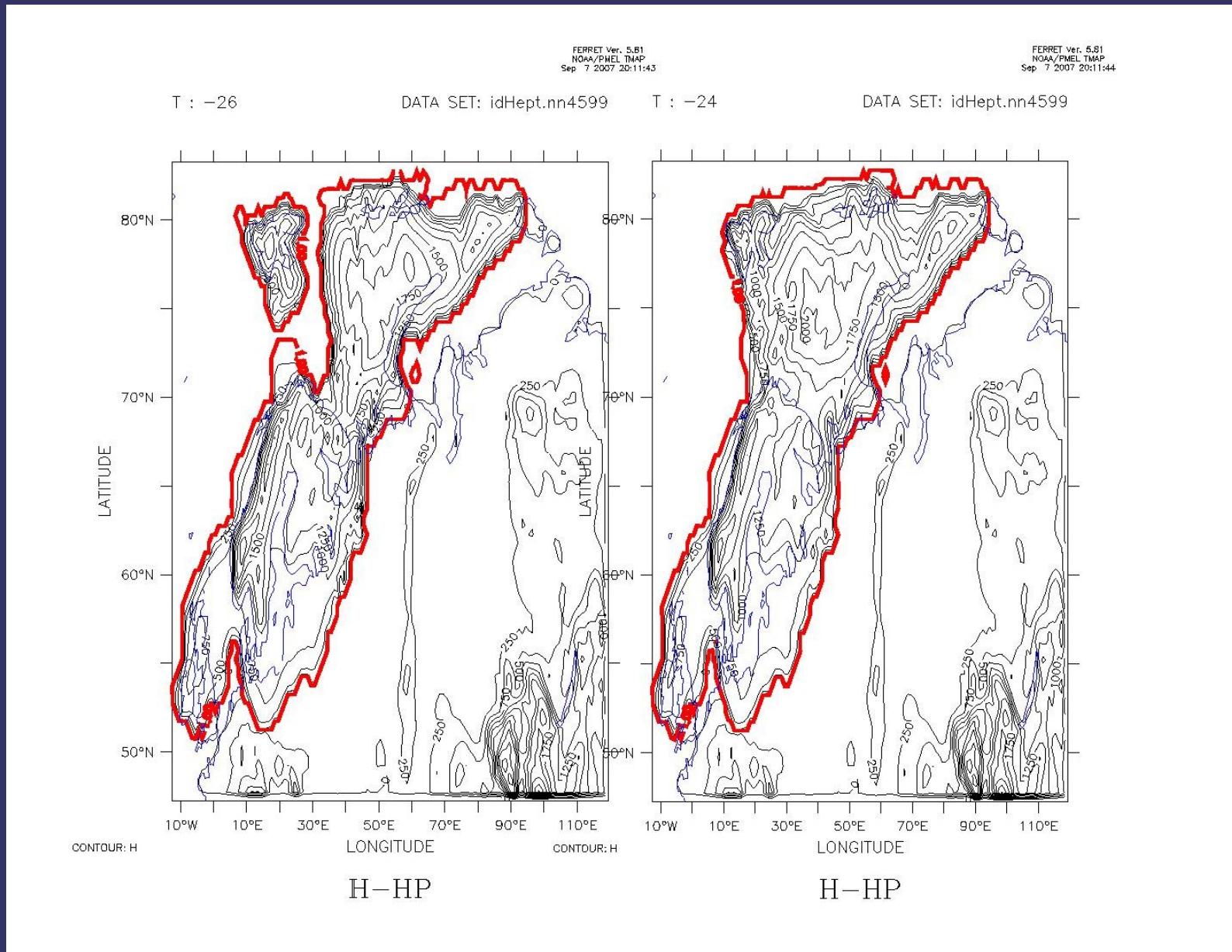
-22 and -20 kyr
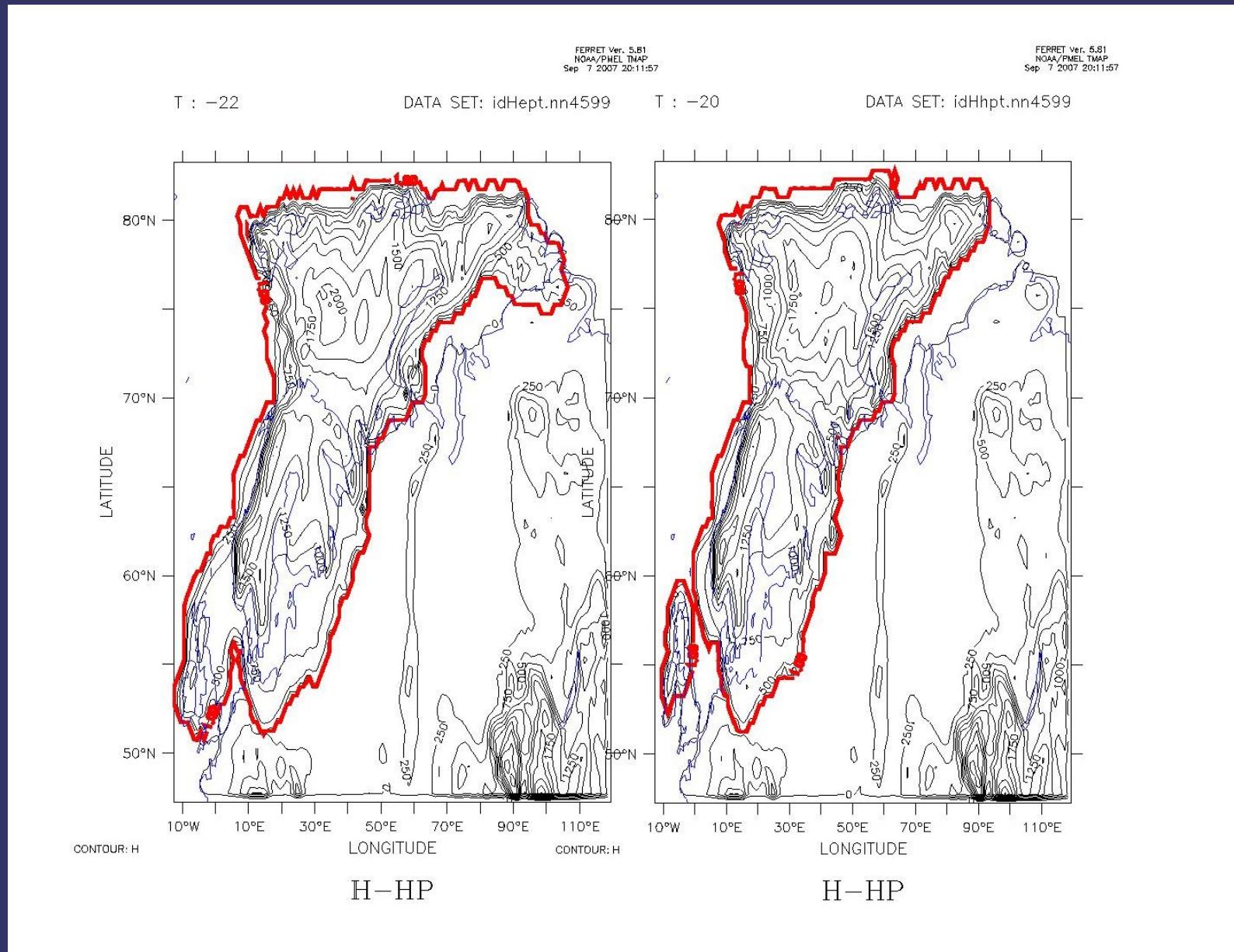
-18 and -16 kyr
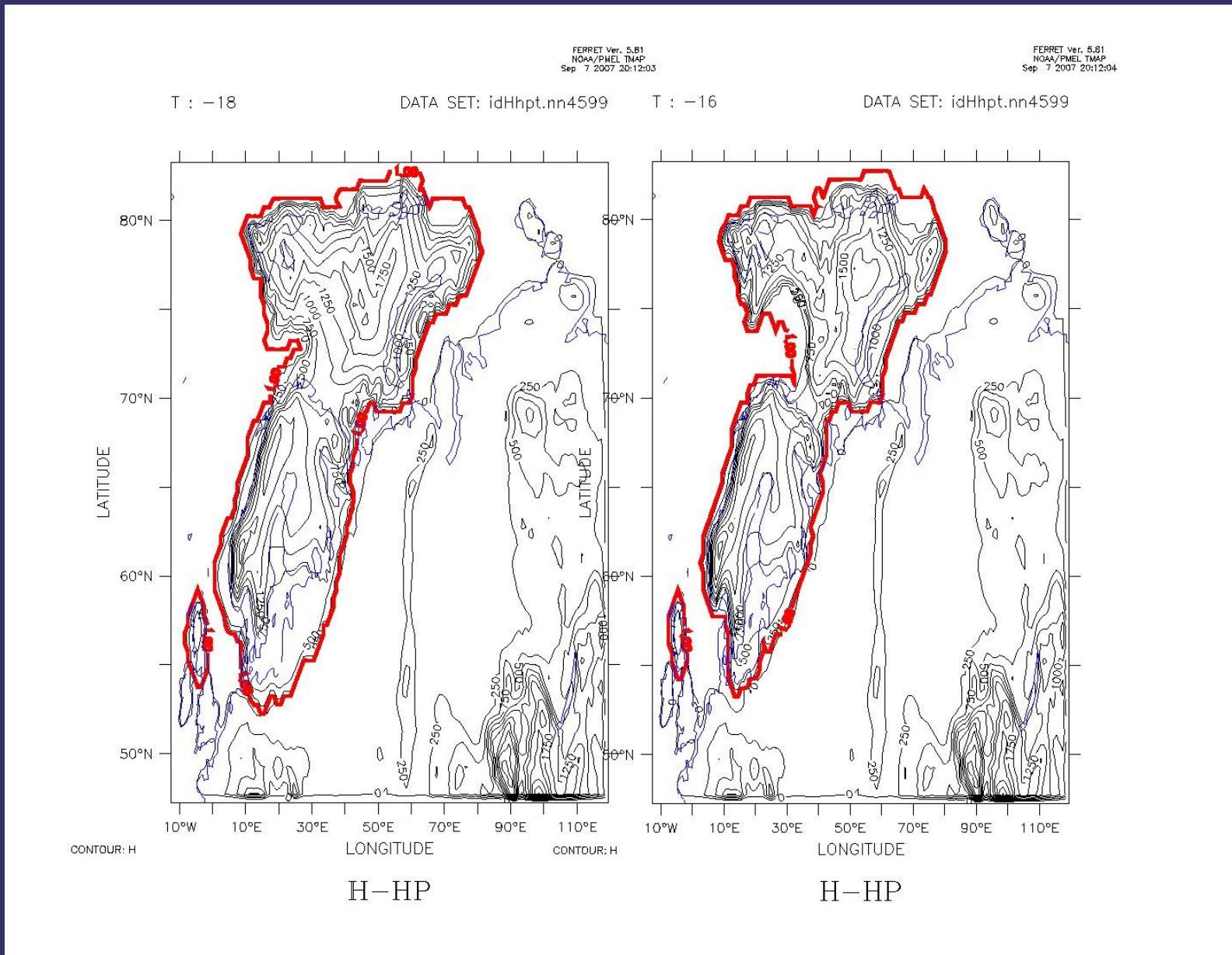
mwp-1a

YD onset

termination