Surface mass balance of the Greenland ice sheet simulated with CESM

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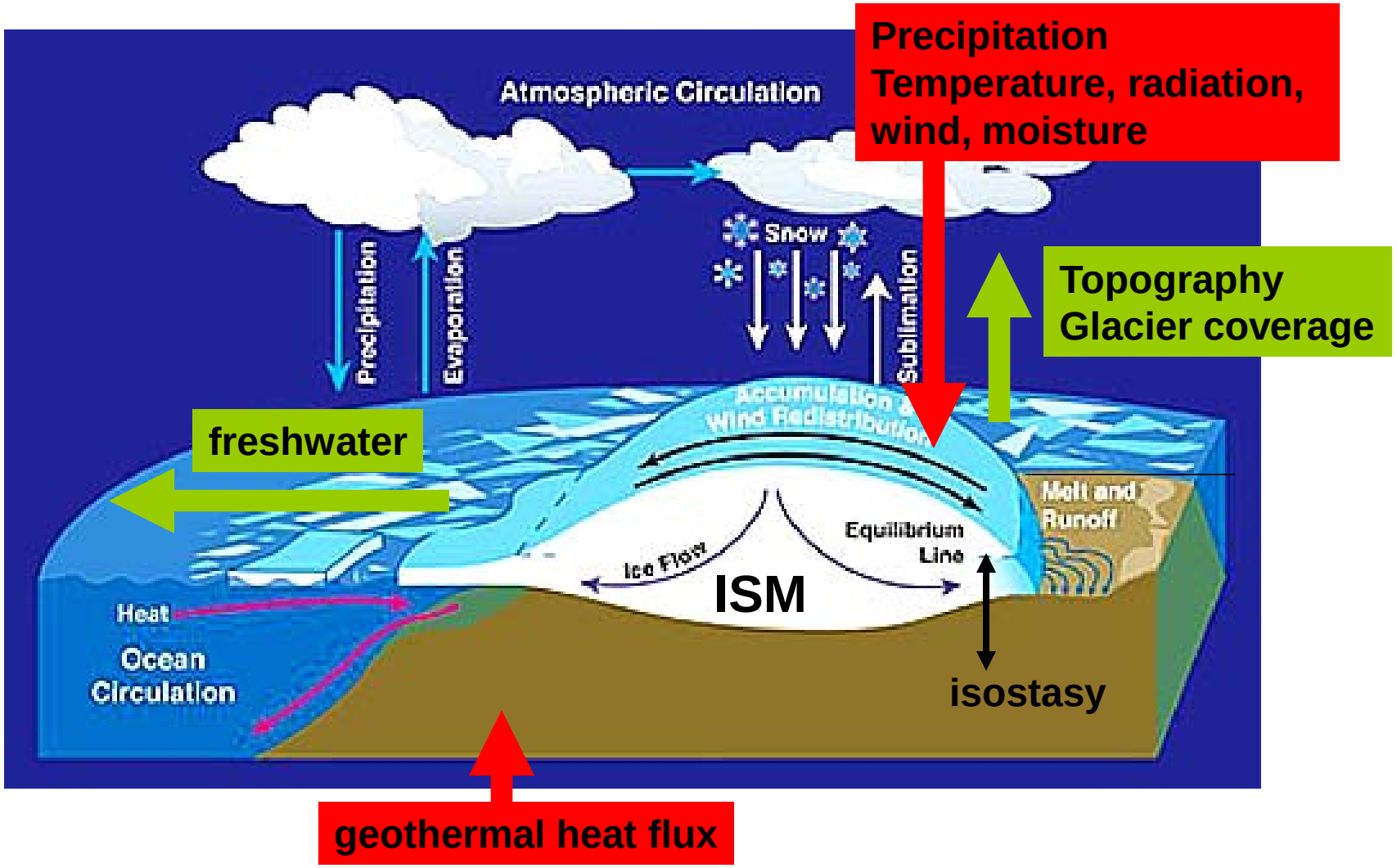
Outline

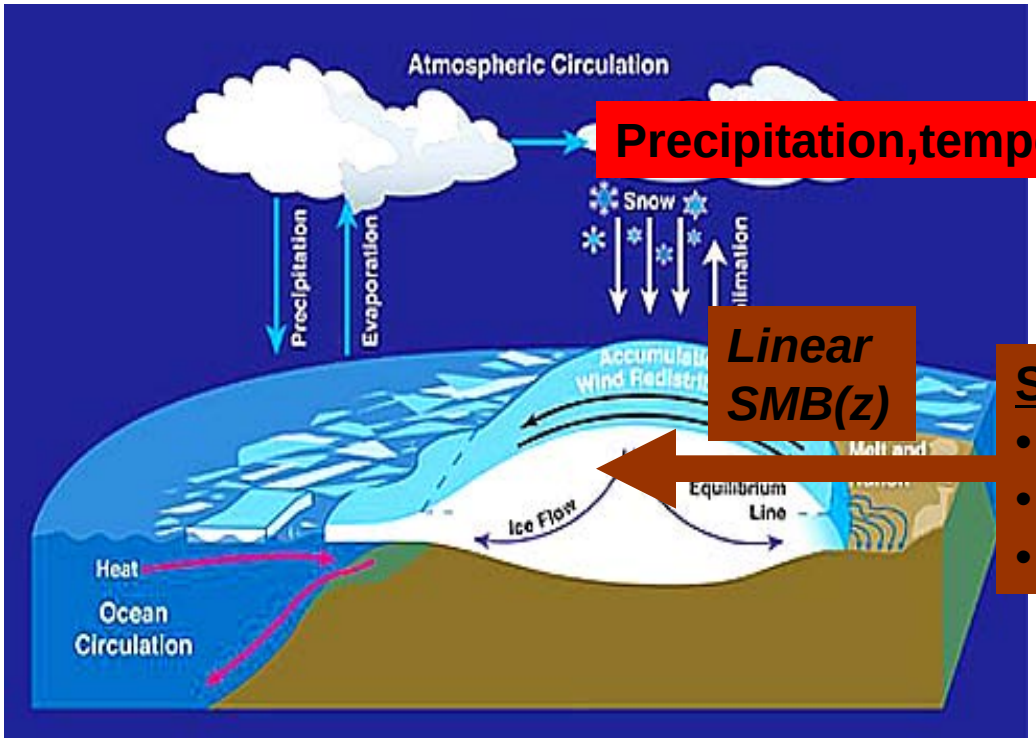
- SMB as simulated with reanalysis forcing
- SMB as simulated with CCSM4.0 offline forcing
- CCSM4.0 Greenland ice sheet pre-industrial climate

New ice sheet component in CESM

Final picture: Ice sheet model bi-directionally coupled to AOGCM



Calculation of SMB



Precipitation,temperature, radiation, wind, humidity

Linear SMB(z)

<u>SMB calculation</u>: (in CLM)

- **at 10 elevation classes**
- **only temp(z) & humidity(z)**
- **snow physics from land model**

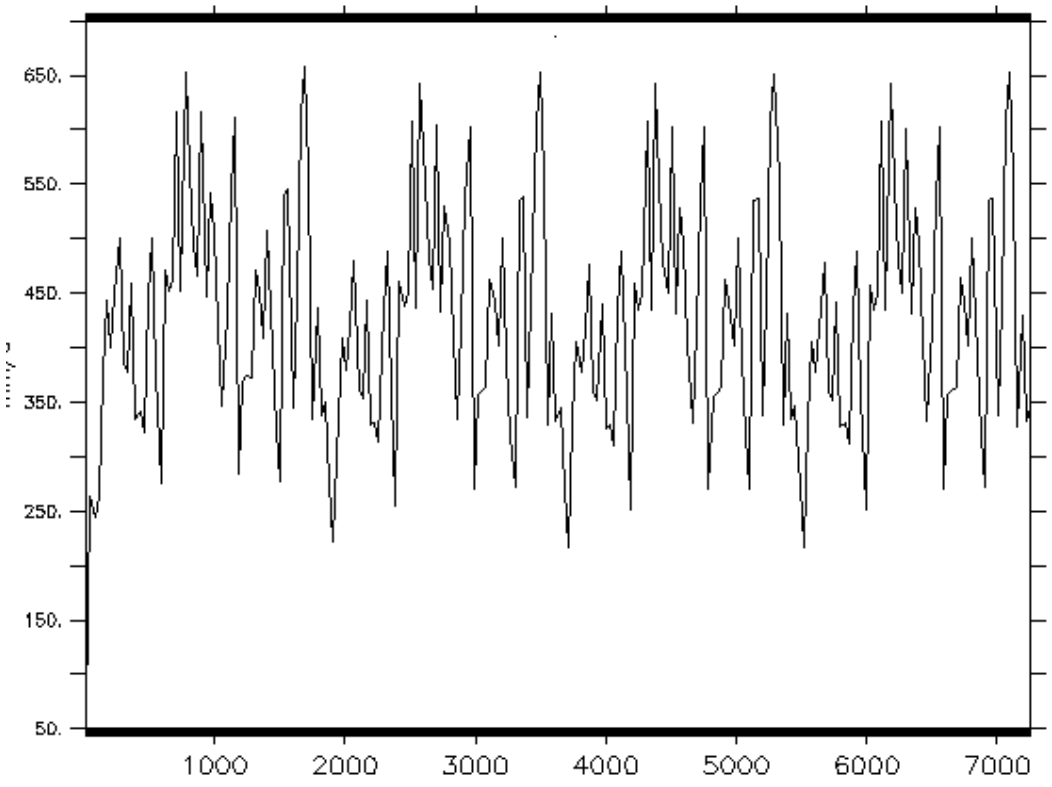
Forcing and validation

- Forcing
  - Reanalysis: bias-corrected NCEP/NCAR (Qian et al. 2006) 1948-2004
    - Precipitation problems 1999-2004
  - CCSM4.0 (offline): FV1, 1850-climate
- Resolutions
  - CLM: FV1, FV2
  - Ice Sheet Model: 10 km, obs. topo
- Validation: RACMO (Ettema et al, GRL, 2008)
  - Resolution 11 km
  - Period 1958-2008
  - Forced by ERA/ECMWF

Spin-up

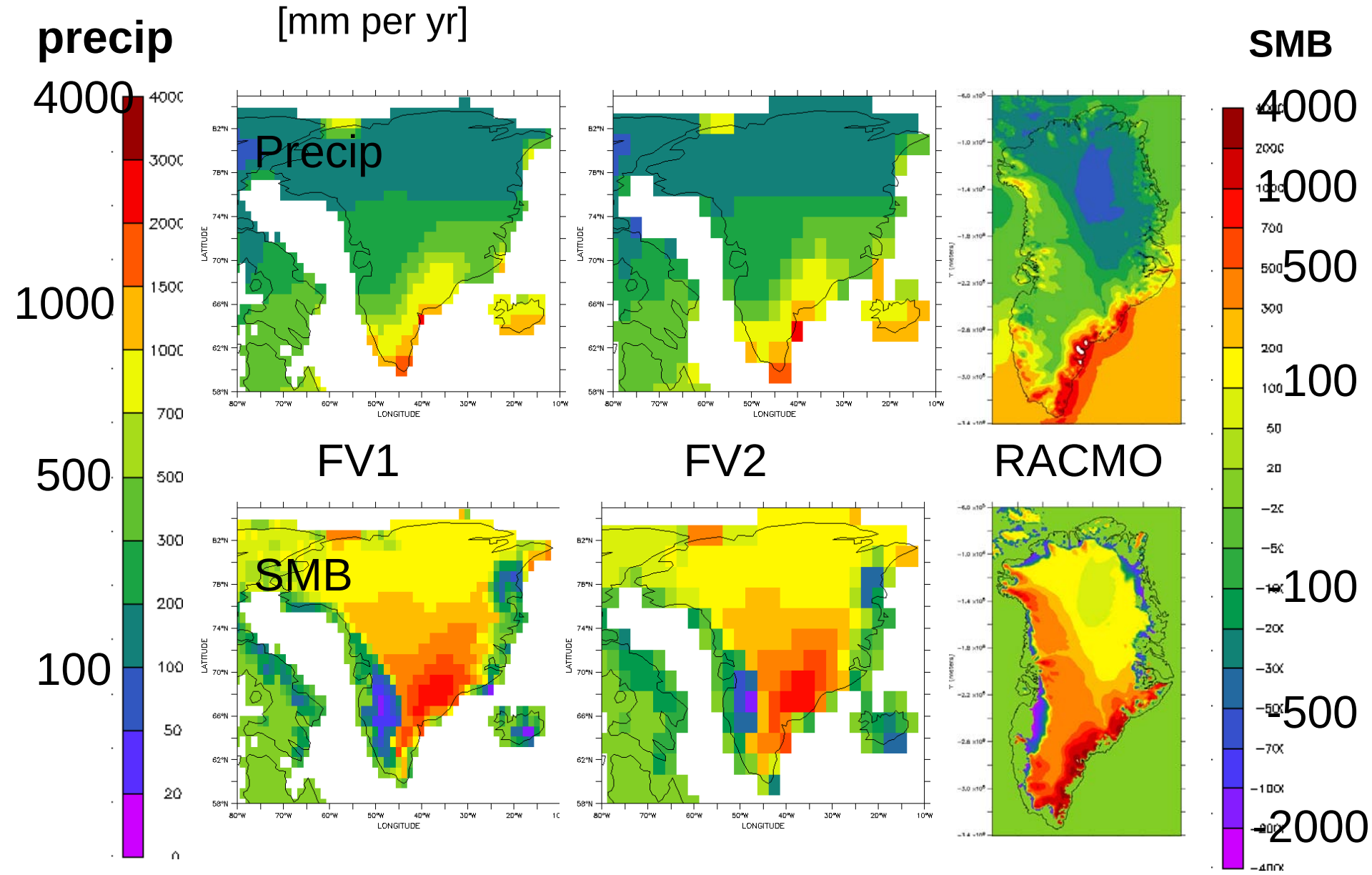
- CLM needs several decades to spin-up the ice smb
  - 1 m criterium
  - Snowpack temperatures

SMB (Gt yr^{-1})



Years 1 to 230, Reanalysis forced run

Reanalysis: SMB and precip

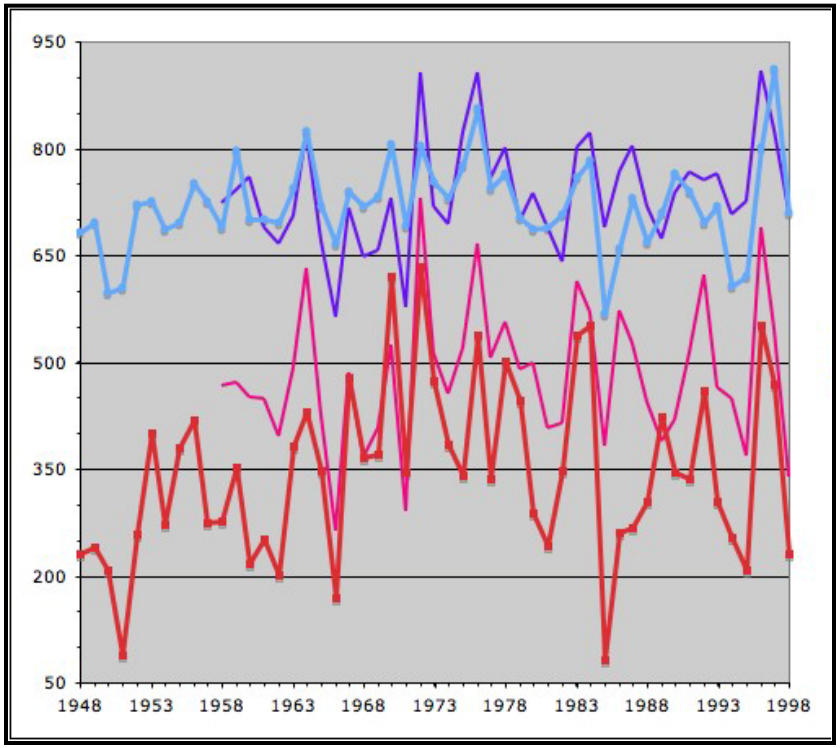


Integrated fields over ice sheet [Gt yr^{-1}]

Variable	FV1	FV2	RACMO	Other reg models (*)
Precip	**721 (61)**	811 (80)	743 (78)	600/696/610
Rain & rain fract	**115 (6)** **0.16**	138 (21) 0.17	46 0.06	22/18/28
Sublim	**-81 (6)**	-77 (6)	26 (3)	5/108/38
SMB	**348 (99)**	416 (98)	469 (107)	288/356/287
Ablation fraction	**0.52**	0.51	0.37	0.52/0.49/0.53
Area ice sheet (10^6 km^2)	2.019	2.131		

Reanalysis forced: Variability

Gt per calendar year

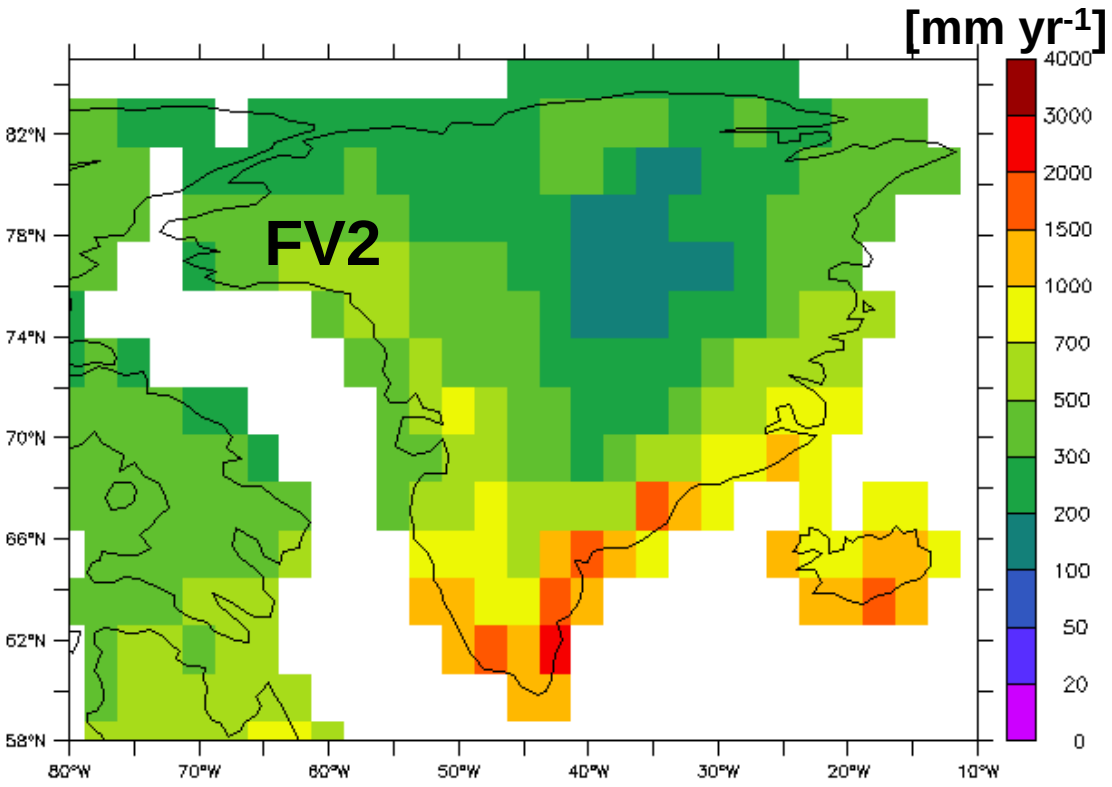


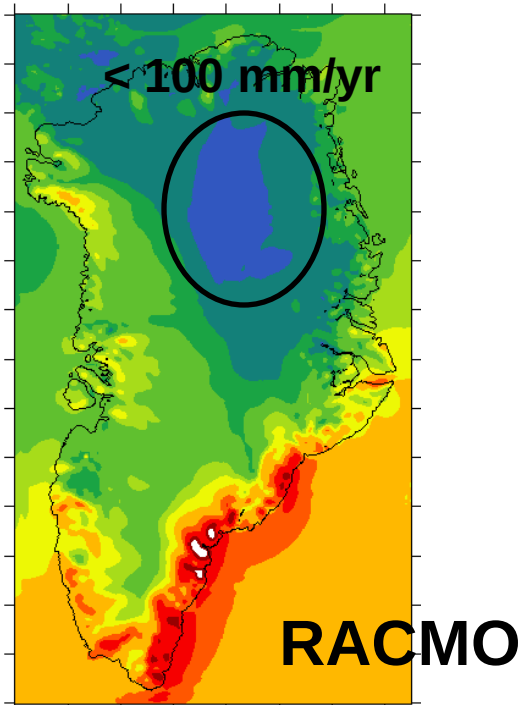
Precip RACMO
Precip CLM ~1deg

SMB RACMO
SMB CLM ~1deg

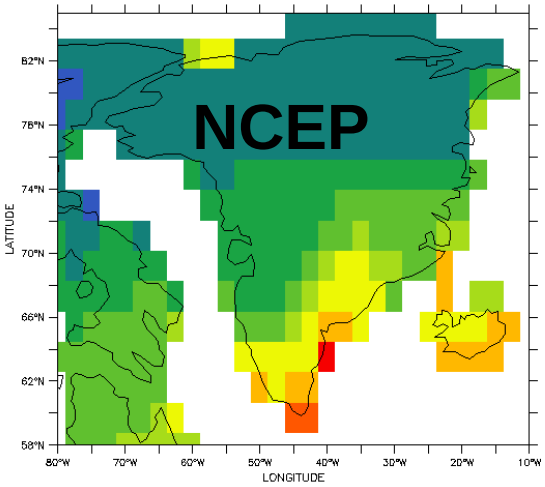
RACMO Data provided by J. Ettema

CCSM4.0: Modelled precipitation

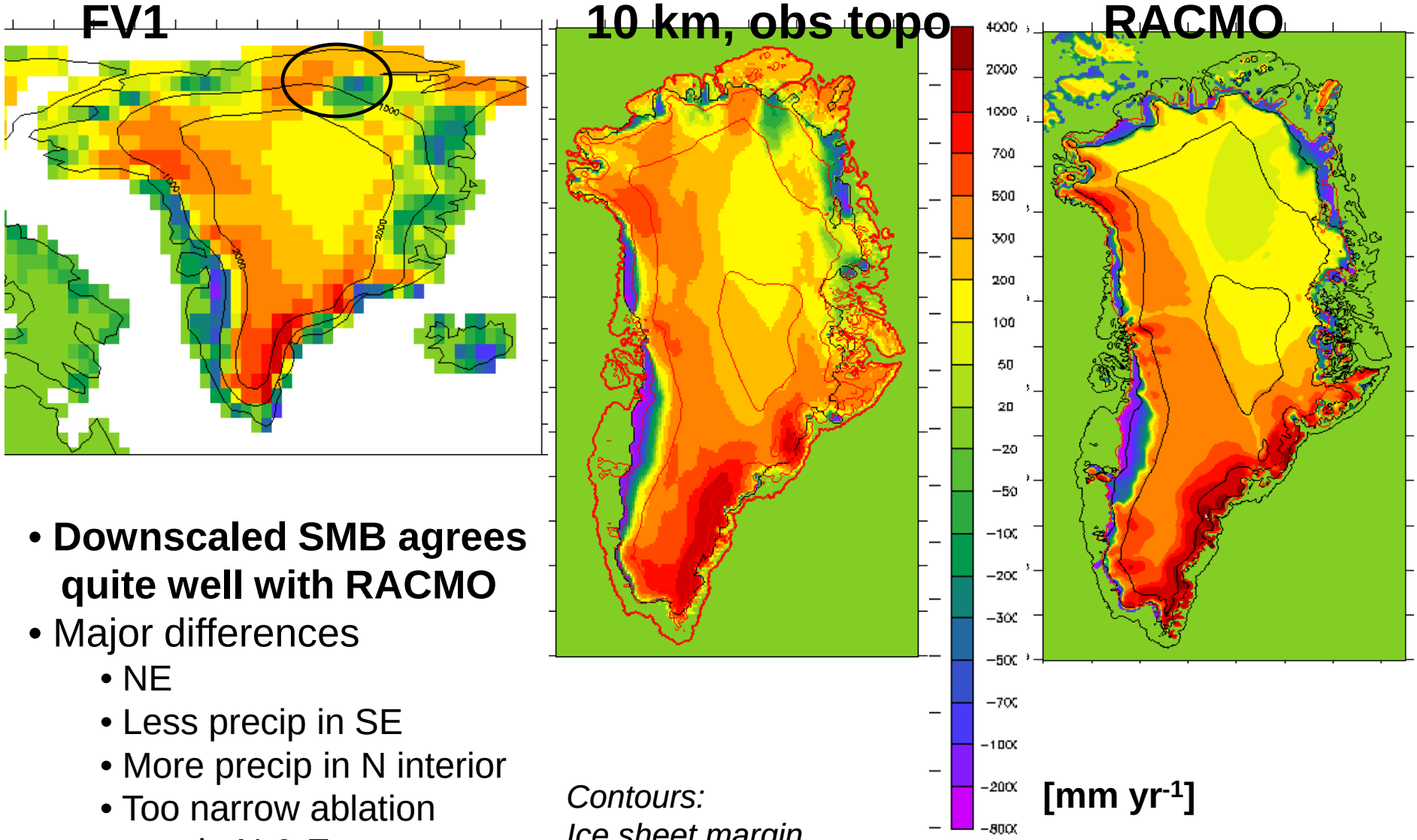




- High precip bands at W & E margins are captured
- Pattern is correct
- Minima (N interior) overestimated
- Maxima (SE & SW) underestimated



Surface mass balance (FV1 - 10 km)

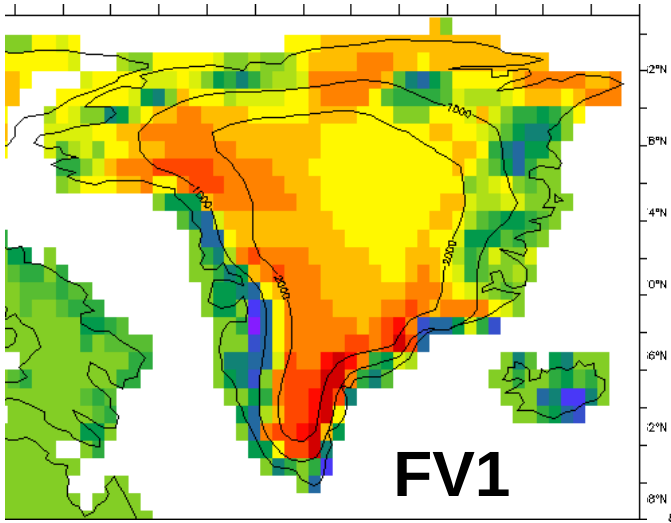


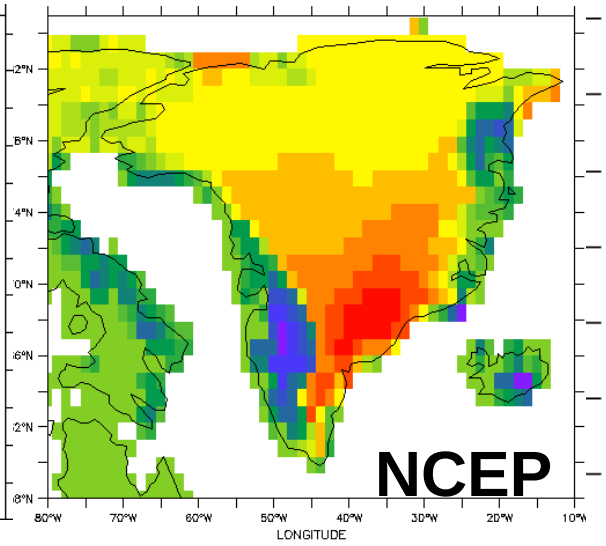
- **Downscaled SMB agrees quite well with RACMO**
- Major differences
  - NE
  - Less precip in SE
  - More precip in N interior
  - Too narrow ablation zone in N & E

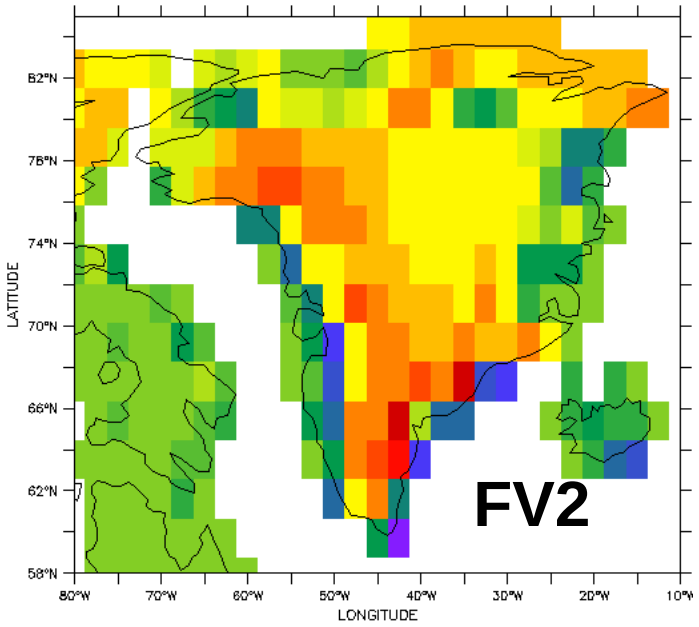
Contours:
Ice sheet margin,
1000, 2000, 3000 m topo

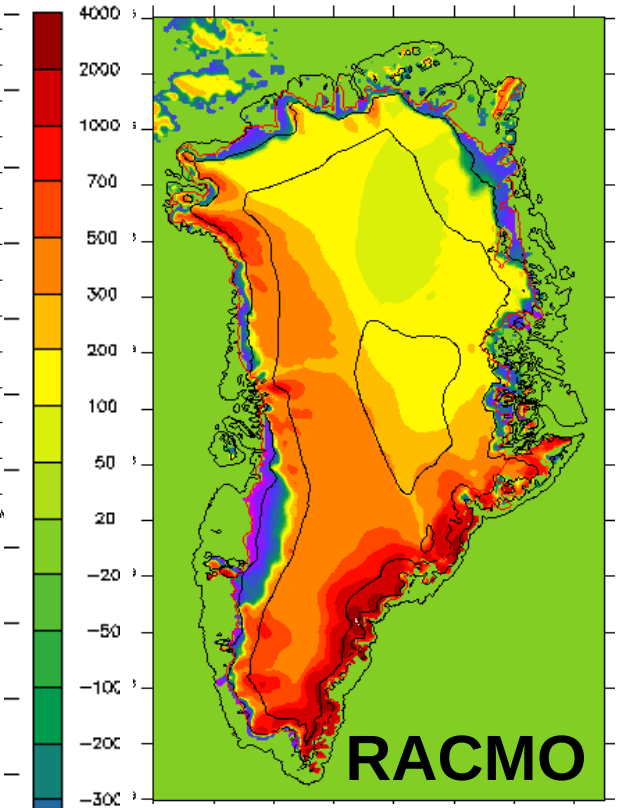
[mm yr^{-1}]

SMB: CCSM4.0 vs NCEP



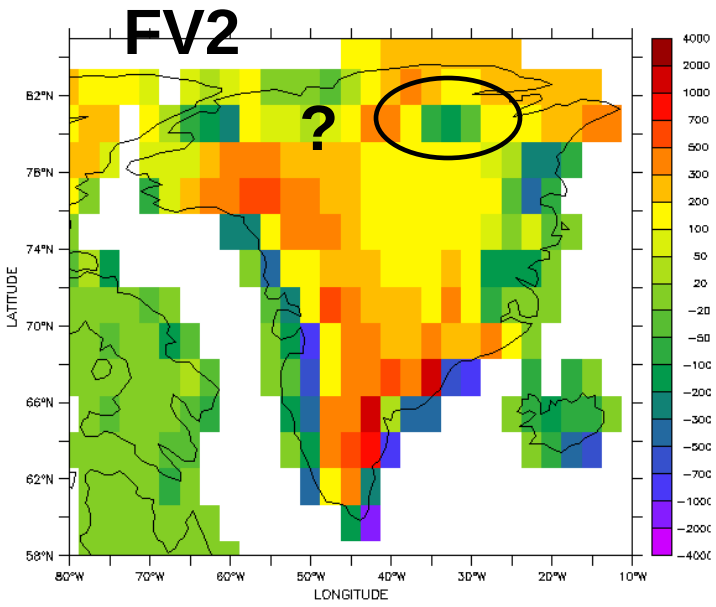




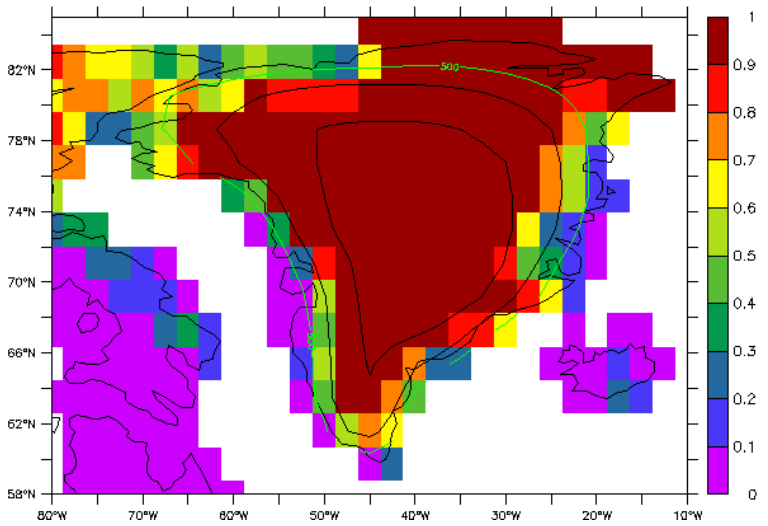


[mm yr^{-1}]

Glacier coverage and SMB



[mm yr^{-1}]



Glacier fraction

- Ablation area in NE not captured: mask problem?
- Ablation area in SE absent in RACMO

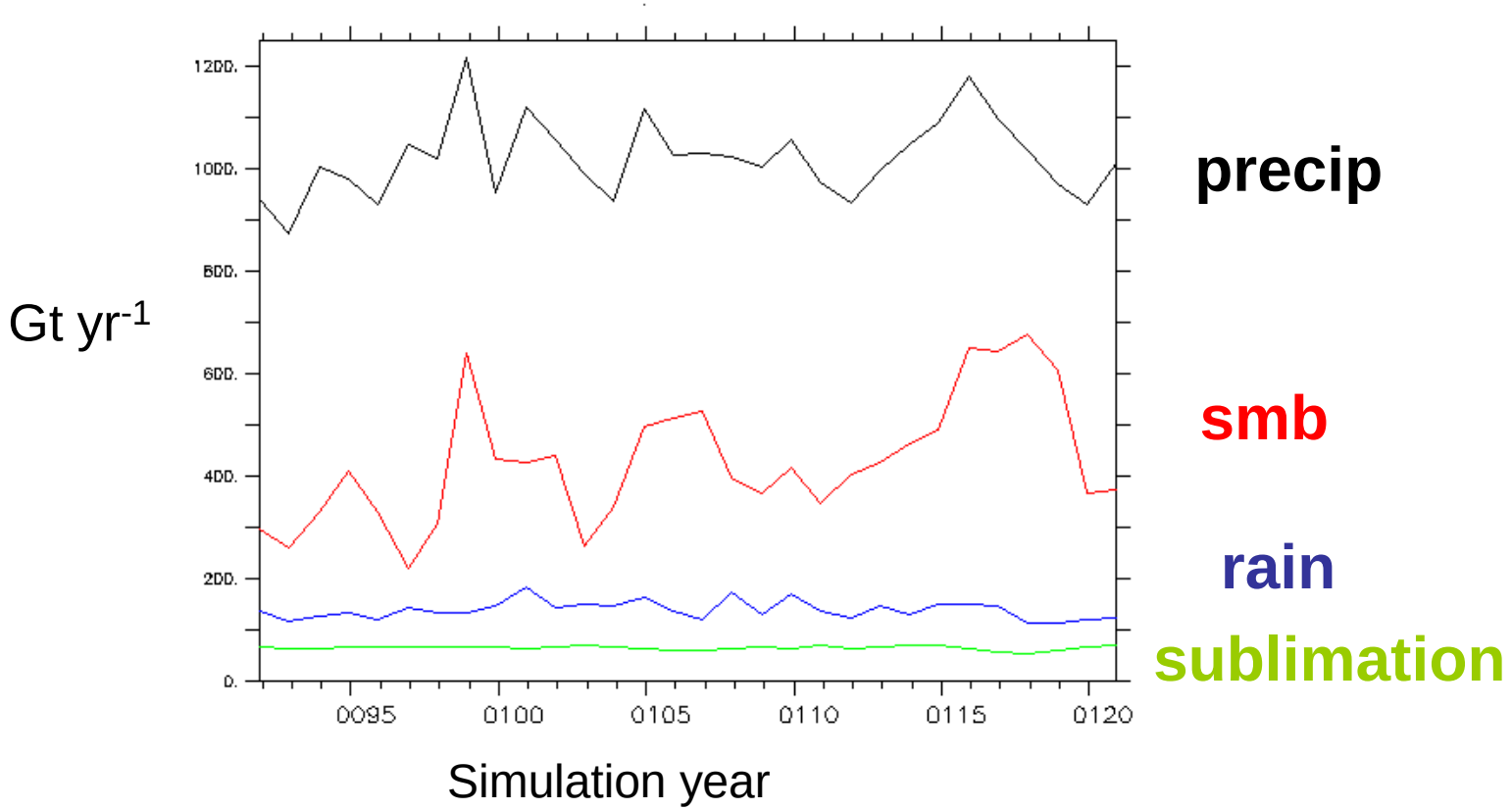
Integrated SMB over ice sheet [Gt yr^{-1}]

Variable	**CCSM4 FV1**	CCSM4 FV2	NCEP FV1	RACMO	Other reg models (*)
Precip	**1019 (75)**	1097 (80)	721 (61)	743 (78)	600/696/610
Rain & rain frac	**139 (17)**	179 (20) 0.16	115 (6) 0.16	46 0.06	22/18/28
Sublim	**66 (4)**	83 (5)	-81 (6)	26 (3)	5/108/38
SMB	**429 (121)**	315 (132)	348 (99)	469 (107)	288/356/287
Abl/precip	**0.58**	0.71	0.52	0.37	0.52/0.49/0.53
Area	**2.019**	2.131	2.019		

(*) MAR (*Fettweis, 2007*)/PMM5 (*Box et al., 2006*) /ERA-40 based (*Hanna et al., 2008*).

- Overestimation precip, in part due to bigger area
- High rain percentage, in the range of reanalysis
- High sublimation, as in Box et al.
- SMB in the range of regional models, but ablation Fraction is very high (~70%)

SMB variability



- High SMB variability, with changes up to 350 Gt yr-1 from one year to next
- Similar variability to RACMO

Downscaled SMB

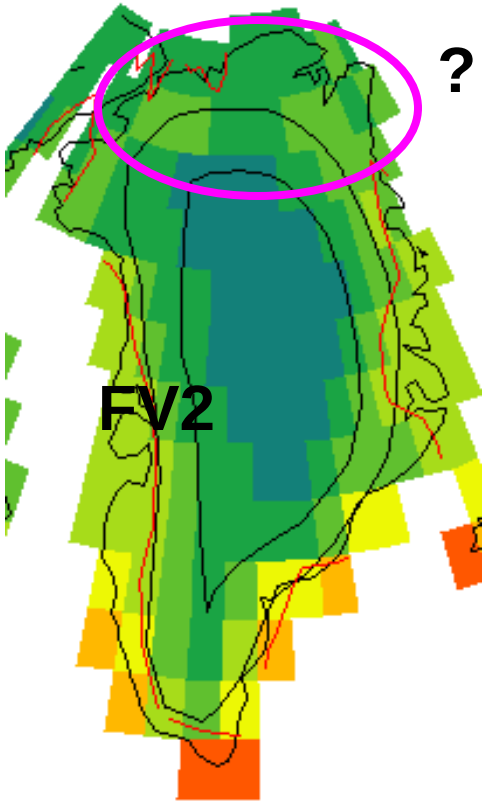
Variable	10 km	CCSM4 FV1	CCSM4 FV2	RACMO	Other reg models (*)
SMB	**438 (97)**	429 (121)	315 (132)	469 (107)	288/356/287
Area (10^6 km^2)	**1.685**	2.019	2.131		

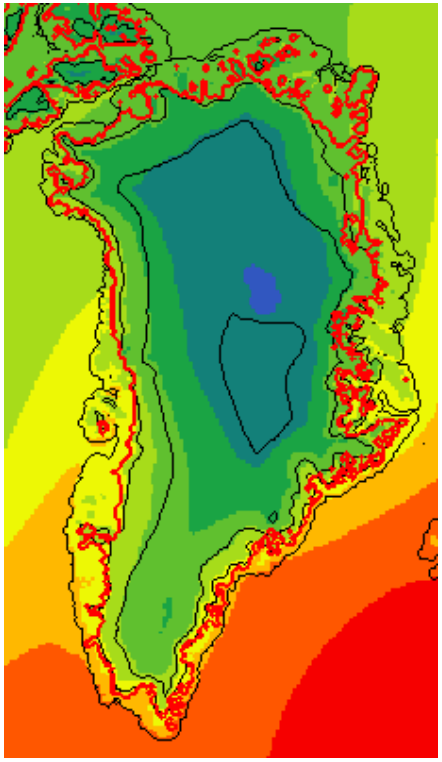
- Slightly higher mass balance after downscaling
- Range: 253-653 Gt per year

Simulated Greenland climate

- Validation with RACMO data 1958-2008 (Ettema et al., TCD)
  - Caveat: pre-industrial vs 20th century!
  - Known bias RACMO
    - Underestimates LW
    - Overestimates turbulent fluxes (too active mixing scheme)
    - They compensate each other, given very good agreement of temp with obs

Near-surface temperature (annual)





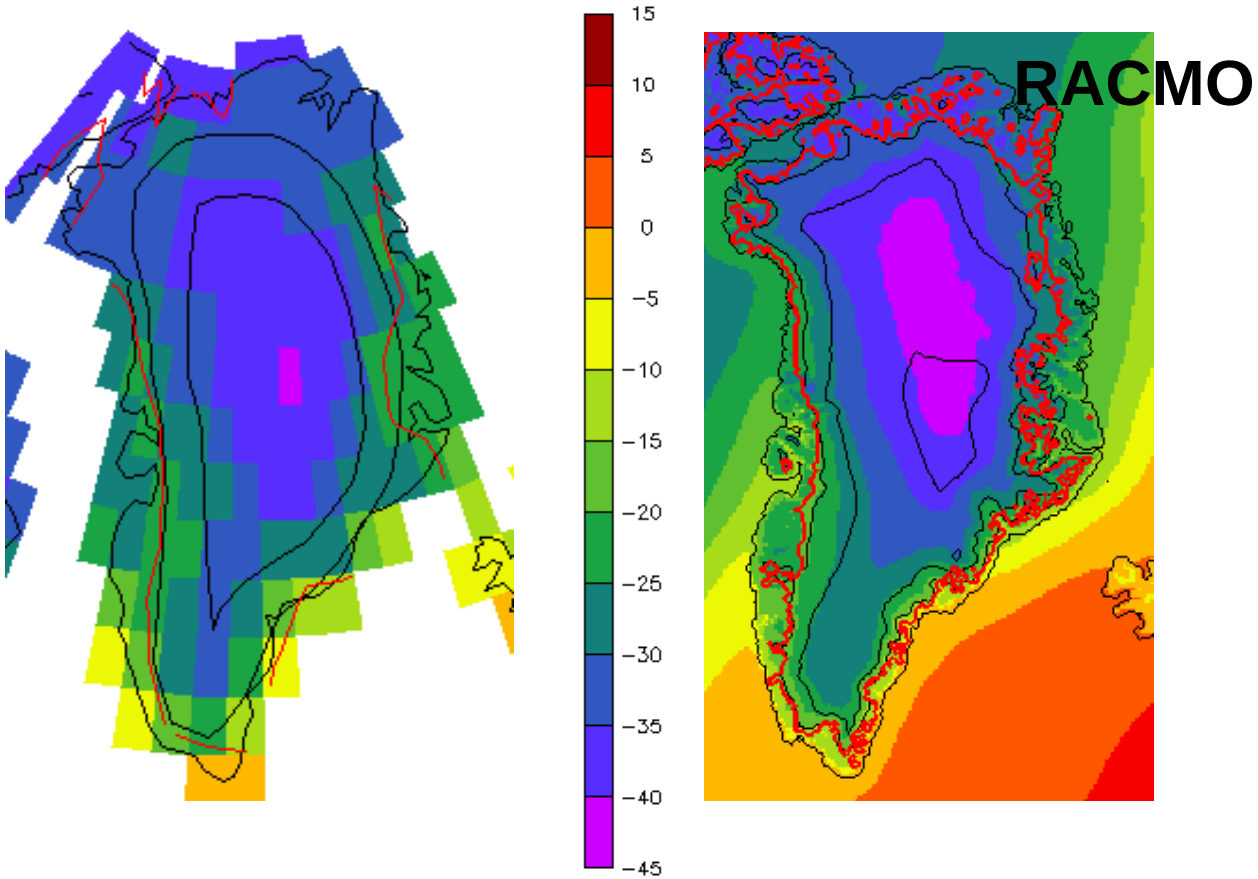
RACMO

Contours
- Ice sheet margin
- 1000,2000, 3000 m topo

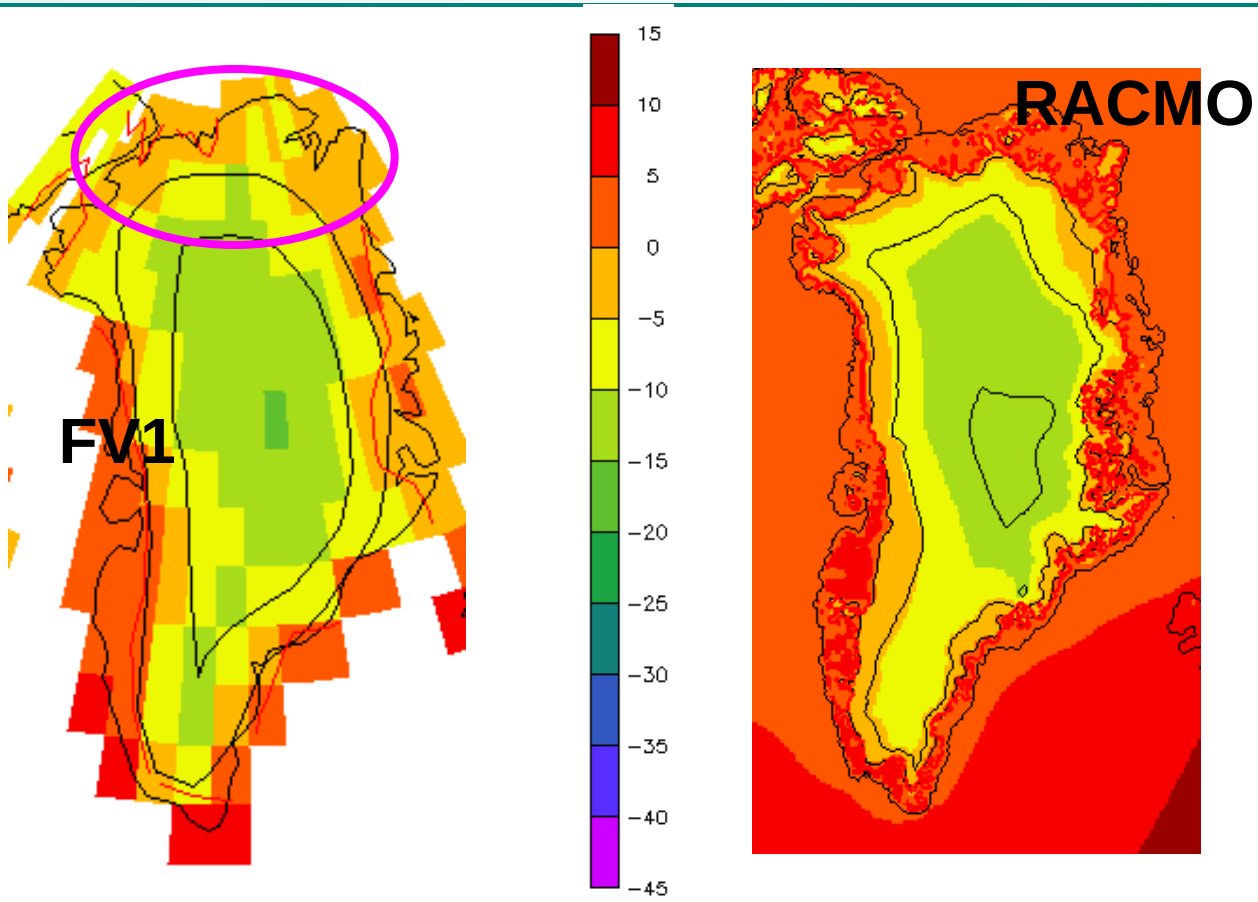
- Warmer interior probably due to lower topo
  - Except at N, h> 1000 m
- N & E Margins: colder than in RACMO
  - Resolution issue in E
  - Mask bias in N?

Near-surface temperature (winter)

FV2



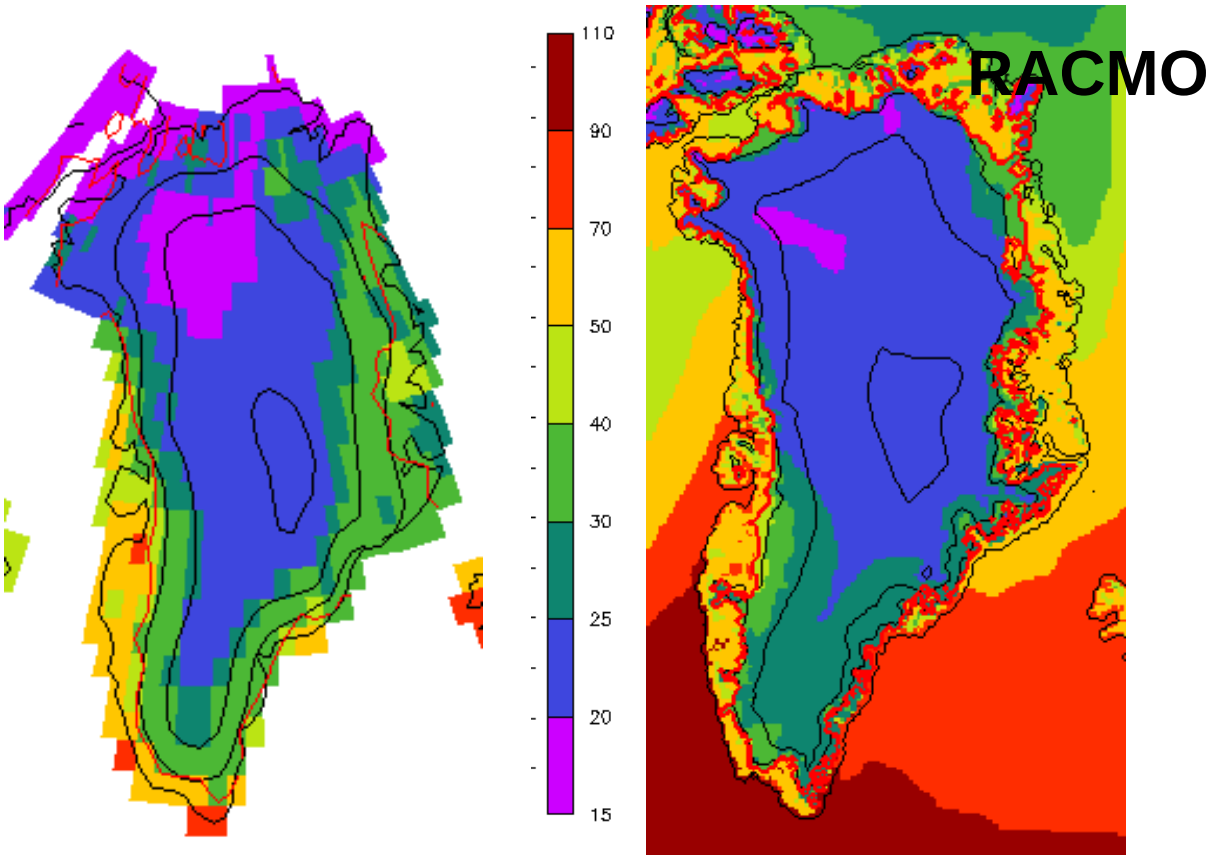
Near-surface temperature (summer)



- Good agreement
- Major differences in the N (cold bias): mask bias?

SW radiation, annual

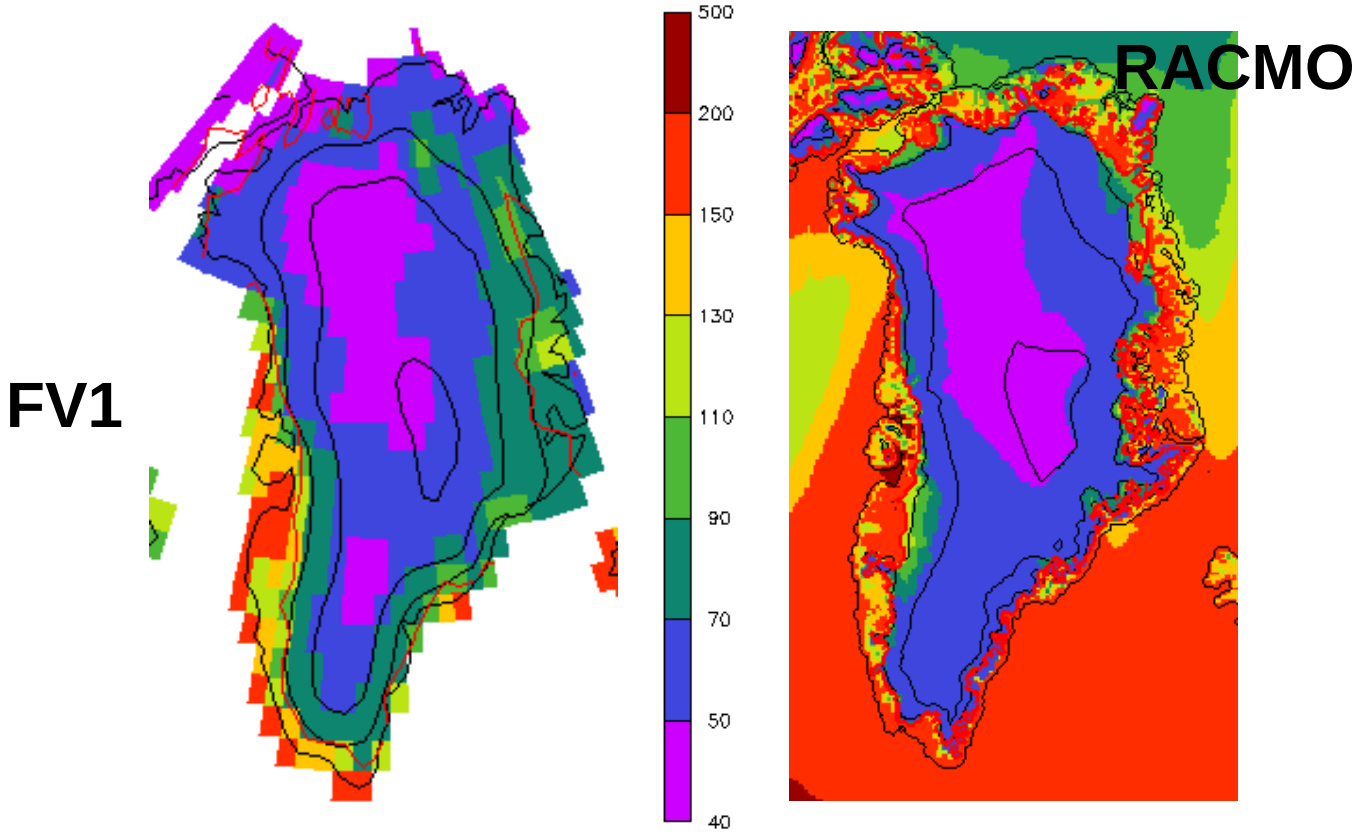
FV1



RACMO

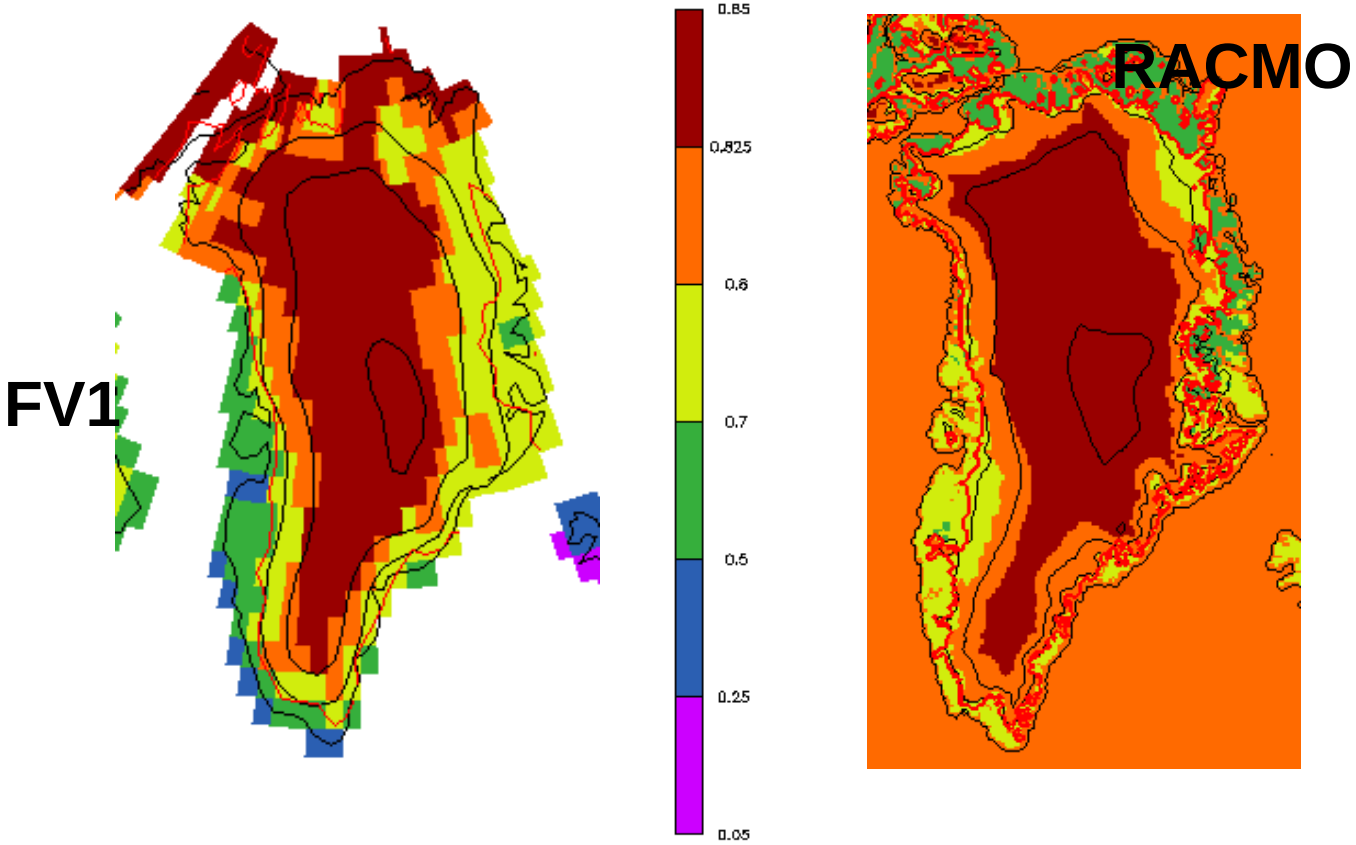
- Overestimation at E & SE margins
- Underestimation at N margin

SW radiation, JJA



- Overestimation at E & S margins
- Underestimation at N margin

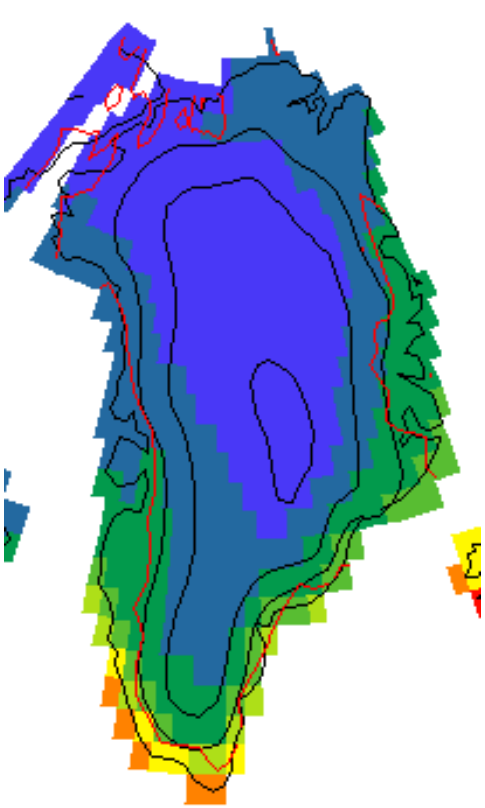
Albedo, annual



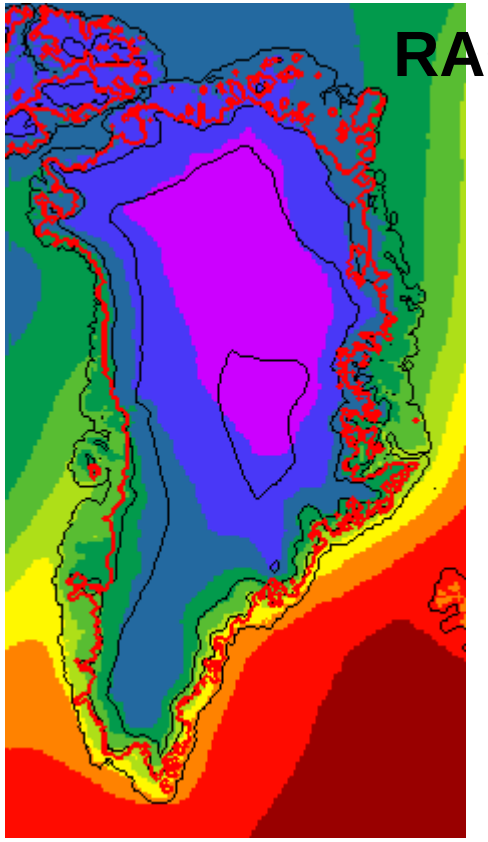
- Too high in the E
- Ice-free areas:
  - W: lower albedo
  - E: higher albedo

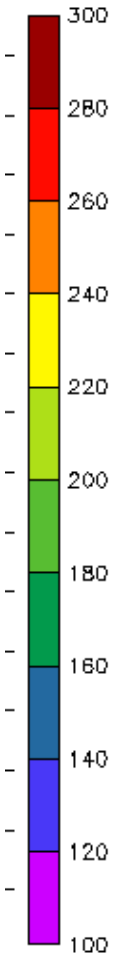
Atmospheric LW radiation, winter

FV1



RACMO





- Higher values in CCSM4.0
- But RACMO underestimates downward LW *(Ettema et al. TCD, 2010)*

Summary

- Good simulation present climate
- Good simulation surface mass balance
- Main problems:
  - N ablation zone
  - Excessive precipitation

Outlook

- Compare Greenland climate and SMB to that of other models (EC-EARTH)
- Ice sheet model on
- Two-way coupling: glacier mask and topography changes are permitted

Extra slides

Existent coupled ice sheet - AOGCM models

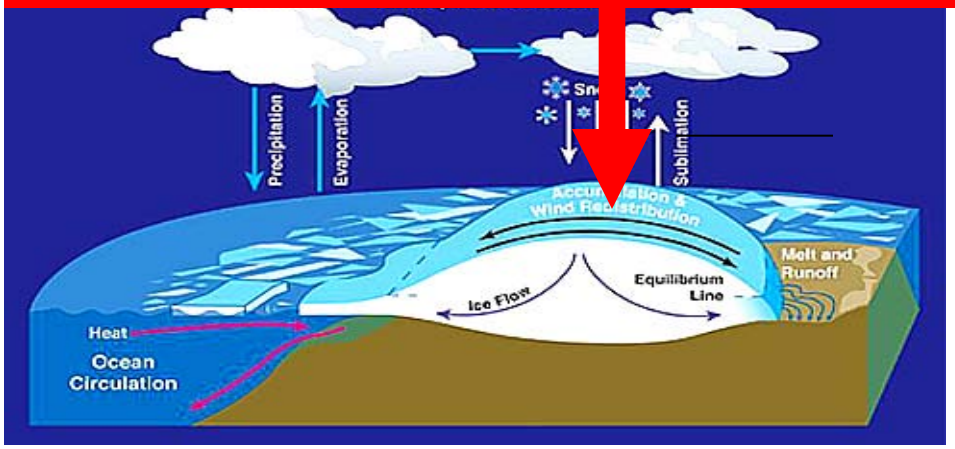
- Huybrechts' model-Hadley Center Model (*Ridley et al. 2005, AR4*)
- SICOPOLIS (R. Greve) - ECHAM (MPI-MET, Hamburg)
  - ECHAM3/LSG (*Vizcaíno et al., Clim Dyn, 2008; Mikolajewicz et al., Clim Dyn, 2007*)
    - Low climate sensitivity
    - Degree-day
  - ECHAM5/MPIOM (*Vizcaíno et al., Clim Dyn, in press; Mikolajewicz et al., GRL, 2007*)
    - Higher climate sensitivity
    - Energy balance
    - Direct forcing of ice sheet model (without anomaly forcing)
- CCSM4.0 for AR5 (in development, NCAR, LANL & myself)

Without ocean model:

- Marshall's model-CAM (*Pritchard et al. 2008*)

Atmospheric forcing to Ice Sheet-Climate Models

Precipitation & temperature (*PDDs*)
+ radiation, wind, moisture (*energy balance calculation*)

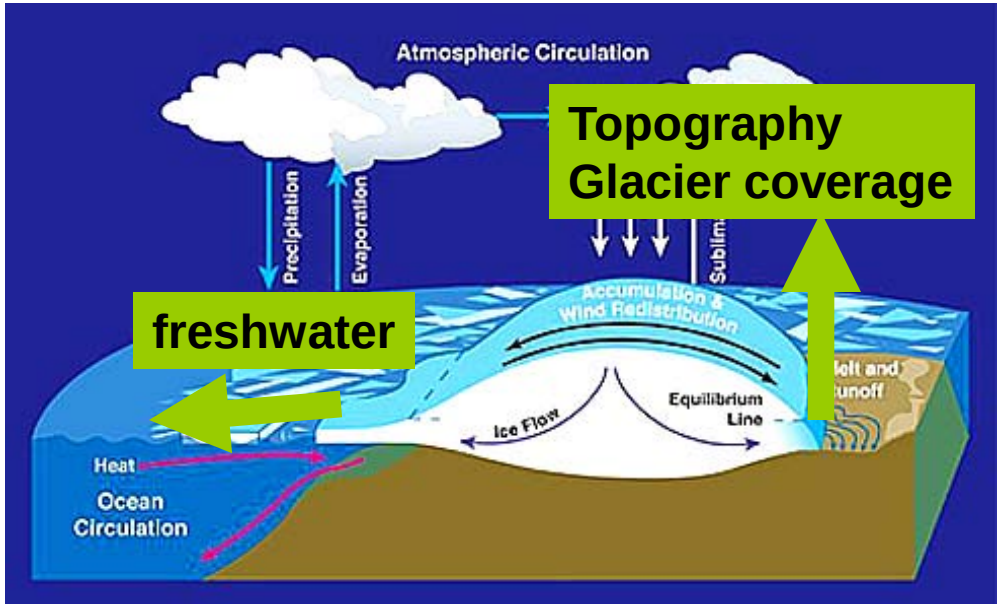


- Input for ice sheet model
  - Surface mass balance
  - Uppermost layer temp
- Issues forcing:
  - Anomaly forcing
- Issues downscaling
  - Energy & mass conservation
  - Choice of lapse rates

<u>Lapse rates</u>

- T-2m
  - fixed, 4-10 deg C
  - Seasonal variation
- Precip:
  - desertification effect
- Radiation:
  - dLW/dz=cte=A; A<0
  - dSW/dz=0
- Moisture:
  - rel_humidity(z)=cte
- Wind
  - dwind(z)/dz=0

Ice sheet forcing to climate system



Topography

- Feedbacks
  - Atm circ
  - Thermodynam.
- only included in long-time studies

Glacier coverage

- Feedback: albedo
- Issues:
  - Fractional mask
  - Vegetation model

Freshwater fluxes

- Feedback: ocean circulation
- Issues:
  - Hydrological model
  - Liquid/solid
  - Sea level change