Hindcasting the Last Glacial Maximum: Model Capabilities and Limitations in Ice Sheet-Climate Feedbacks

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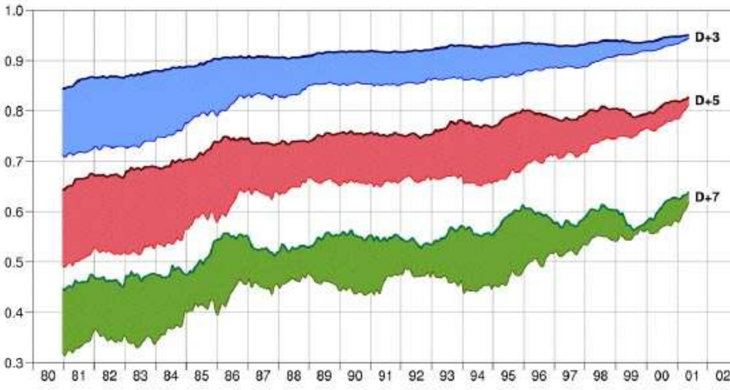
Jan. 18, 2013, Dept. of Earth and Planetary Sciences, Northwestern University

Pressing Questions

- What do global scale climate simulations tell us about the fate of ice sheets?
- Are models parameterized realistically, and if not can we suggest ways to improve?

Given all their complexity why bother with models?

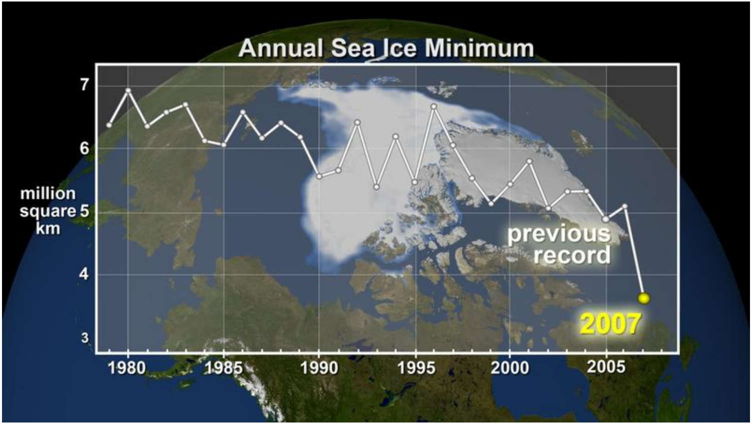
Improvement



Credit: Simmons and Hollingsworth, 2002, Q.J.R. Meteorol. Soc.

Given all their complexity why bother with models?

Unanticipated climate impacts

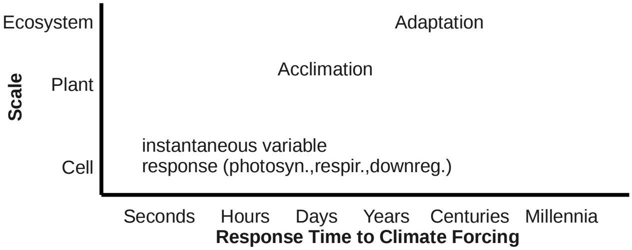


Credit: NASA

Dietze Ecological Forecasting Lab
Ecologists, Geologists, Remote Sensing

Dan Wang, Shawn Serbin, David LeBauer

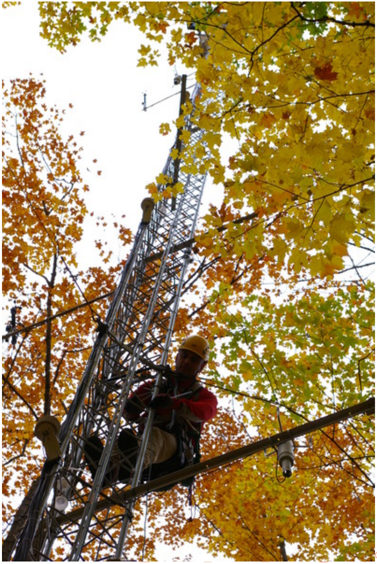
Modeling Activities: Ecological Forecasting



Modified from: Smith and Dukes, 2013, GCB

Modeling Activities: Contemporary Period

- Eddy covariance, contemporary carbon balance
- Early, mid, late successional forests
- Instantaneous responses to climate



Jonathan Thom at Willow Creek, WI

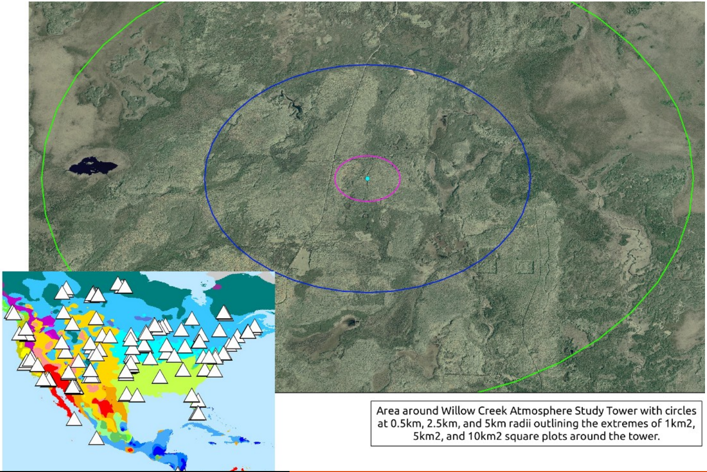
Modeling Activities: Past

- Dendrochronology, past carbon balance

Matthew Bizjack at ChEAS site, WI

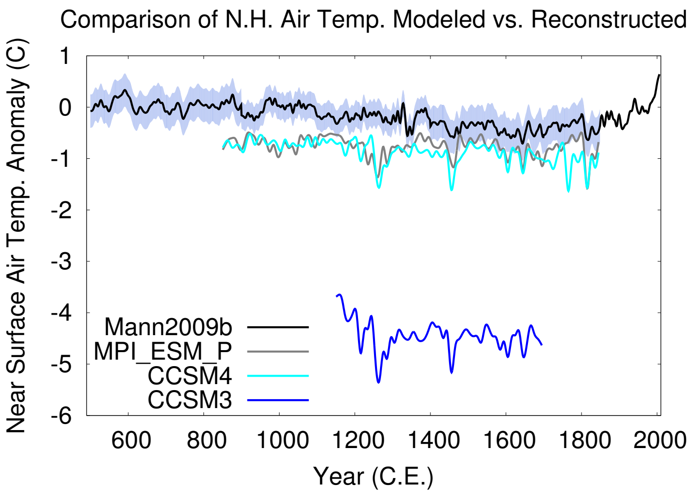
Modeling Activities: Across Space

- Representativeness analysis, inversion modeling, site-tower-airplane-satellite



Area around Willow Creek Atmosphere Study Tower with circles at 0.5km, 2.5km, and 5km radii outlining the extremes of 1km2, 5km2, and 10km2 square plots around the tower.

Confronting Models with Data
Last Millennium

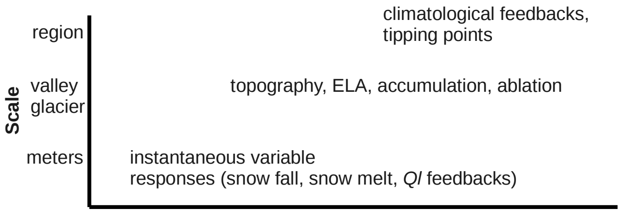


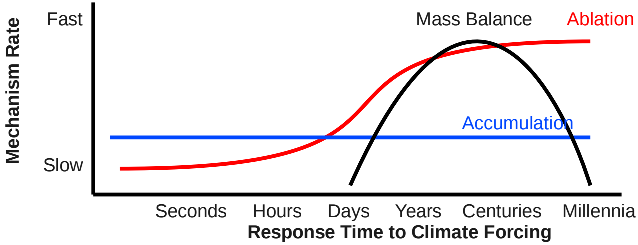
Credit: Mann et al. (2009) Science

Land Surface Models
Capabilities

- Fundamental Earth system processes (biogeophysical: bioenergetics,biogeochemical: photosynthesis, bioenergetics dispersal, mortality
  - biogeophysical: hydrology, orography, radiative responses
  - biogeochemical: photosynthesis, bioenergetics
  - Organismal dispersal, mortality, disturbance, LULC
- Many models and many implementations
- Base models

Land Surface Models
Capabilities and Limitations



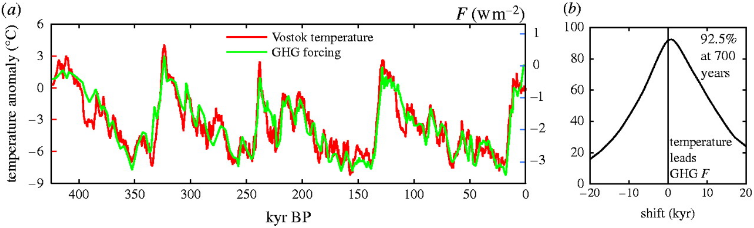


Global Ice System

- Global surface area that is glaciated: one-tenth (one-third during LGM)
- Percent of freshwater total from glaciers: seven-tenths
- Glaciers as climate barometers
- Glacierization potential as a function of effective precipitation, altitude, latitude, *energy*, topography
- Climate effects, melt season, ablation energy, MAT, *ablation and PDD*

Drivers of Global Climate Change

- How influential have ice sheets been in the past?
- Ice sheets as barometers

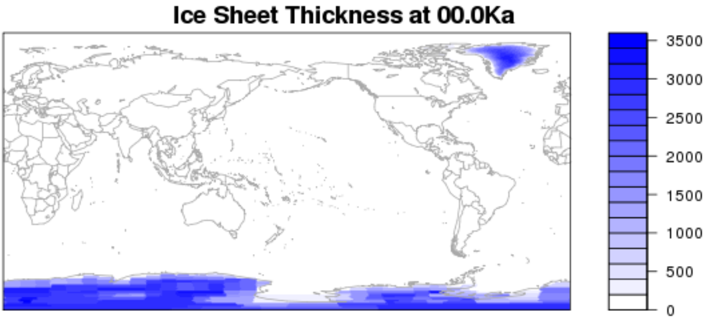


Credit: Hansen et al. (2007) PTRSoc.A.

Contemporary Distribution of Ice Sheets

- one-tenth of Earth's surface

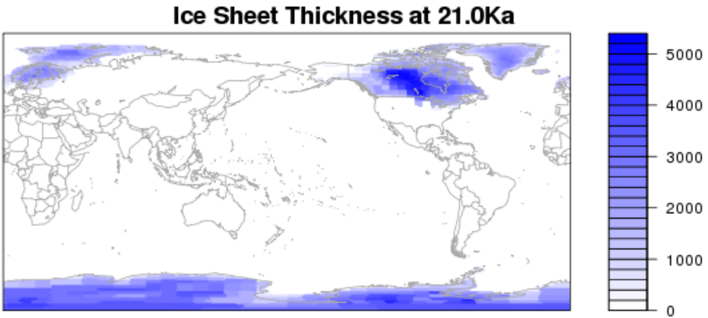
Data from ICE-5G, see Peltier, 2004, Ann.Rev.E.Pl.Sci.



Past Distribution of Ice Sheets

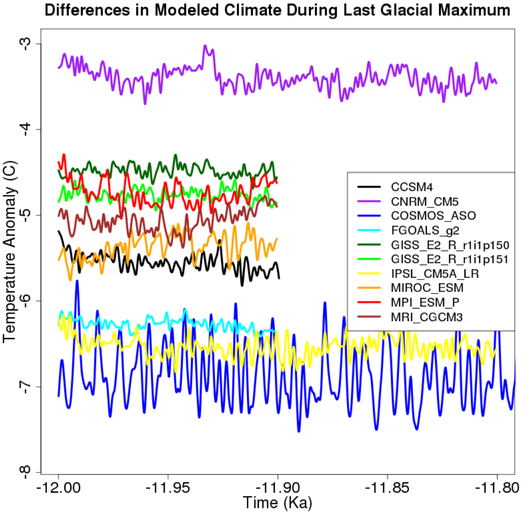
- $>$ one-quarter of Earth's surface
- How to get from A to B and do global scale models parameterize glacierization/degradation thresholds?

Data from ICE-5G, see Peltier, 2004, Ann.Rev.E.Pl.Sci.



Last Glacial Maximum as a Case Study

- Why?
- Temp. bias among models
- Equilibrium climate state, peak ice sheet extent, lower solar radiation inputs



Ice Sheet Gains and Losses

- Mass balance, snow, ice, water, vapor, ELA
- Accumulation, snowfall, effective precipitation
- Ablation, melting, debris, wind removal, calving
- Ablation energy: $Q_m = Q_s + Q_l + Q_h + Q_e$
  - Radiative fluxes: short– and longwave radiation
  - Turbulent fluxes: sensible and latent heat
- Many global climate models use PDD warming to melt snow and ice

Earth System Models of Climate
PMIP-3 Models

PMIP-3 http://pmip3.lsce.ipsl.fr

List of PMIP3/CMIP5 participants
Information as of May 4th 2012

Up to date info: https://pmip3.lsce.ipsl.fr/wiki/doku.php/pmip3:database:status

	Institute	Country	0k *piControl*	6k *midHolocene*	21k *lgm*	LM *past1000 (1000 years)*	1 % CO_2 *1pctCO2 (140 years)*	CMIP5	PlioMIP	Last Interglacial	Holocene	Carbon cycle	Atm	Ocn	Model id	Term of Use	Data Node	Publish to
1	AWI	Germany	Completed	Completed	Completed			No	Yes	Yes	No	Yes	96×48 x L19	120×101 x L40	*COSMOS-aso ?*		*DKRZ ?*	*ESG-WDCC ?*
2	BCC	China	CMIP5 (500)	CMIP5 (100)		CMIP5	CMIP5			No	No	Yes	128×64 x L26	360x232 x L40	bcc-csm1-1	Unrestricted	BCC	ESG-PCMDI
3	BCCR	Norway	Running Summer 2012	Running Summer 2012	Running Summer 2012	Running Summer 2012	Start April 2012 May 2012	No	Yes	Yes	No	Yes	96x48 x L26	100×116 x L32	NorESM1-L	Unrestricted	*DKRZ ?*	*ESG-WDCC ?*
4	CAU-GEOMAR	Germany	Completed	Completed			Running	No	Yes	Yes		No	96x48 x L19	182x149 x L31	KCM1-2-2	Non-commercial only	*DKRZ ?*	*ESG-WDCC ?*
5	CNRM-CERFACS	France	CMIP5 (850)	CMIP5 (200)	Running April 2012		CMIP5			No	No	No	256x128 x L31	362x292 x L42	CNRM-CM5	Non-commercial only	CNRM	ESG-PCMDI
6	FUB	Germany	PMIP3 (400)		PMIP3 (600)			No		No	No	Yes	96×48 x L19	120×101 x L40	COSMOS-ASO	Unrestricted	*IPSL (DKRZ later?)*	ESG-BADC
7	NOAA-GFDL	USA	CMIP5 (470)		Start Spring 2012		CMIP5			No	No	Yes/No	144x90 x L24	360x200 x L50	GFDL-CM3	Unrestricted	GFDL	ESG-PCMDI
8	NASA-GISS	USA	CMIP5 (1163)	Completed	Completed	CMIP5			Yes		Yes	No	144x90 x L40	288x180 x L32	GISS-E2-R	Unrestricted	NCCS	ESG-PCMDI
9	IPSL	France	CMIP5 (1000)	CMIP5 (500)	CMIP5 (200)	Running April 2012	CMIP5		Yes			Yes	96x95 x L39	182x149 x L31	IPSL-CM5A-LR	Unrestricted	IPSL	ESG-BADC
10	KNMI *or ICHEC ?*	Netherlands	Completed	Completed			?	?	Yes	No	No	No	320×160 x L62	362x292 x L42	EC-Earth-2-2	Unrestricted	BADC *or IPSL ?*	ESG-BADC
11a			CMIP5 (900)	Completed	Completed		CMIP5						128x60 x L26		FGOALS-g2	Unrestricted	LASG	ESG-PCMDI
11b	LASG-IAP LASG-CESS	China	CMIP5 (501)	Completed ?	Started ? End ?				Yes			No	x L26	360x180 x L30	FGOALS-s2	Unrestricted	LASG	ESG-PCMDI
11c			Completed			Completed							72x45 x L26		FGOALS-gl	Unrestricted	LASG	ESG-PCMDI
12	LOVECLIM	Belgium France Netherlands	Completed	Completed	Completed	Completed		No		Yes	Yes	No	32x64 x L3	122x65 x L20	LOVECLIM1-2	Unrestricted	IPSL	ESG-BADC
13	MIROC	Japan	CMIP5 (531)	CMIP5 (100)	CMIP5 (100)	CMIP5	CMIP5		Yes			Yes	128x64 x L80	256x192 x L44	MIROC-ESM	Non-commercial only	DIAS	ESG-PCMDI
14	MPI-M	Germany	CMIP5 (1156)	CMIP5 (100)	CMIP5 (100)	CMIP5	CMIP5					No	196x98 x L47	256x220 x L40	MPI-ESM-P	Unrestricted	DKRZ	ESG-WDCC
15	MRI	Japan	CMIP5 (500)	CMIP5 (100)	Running April 2012	Not started July 2012?	CMIP5		Yes	No	No	No	320x160 x L48	364x368 x L51	MRI-CGCM3	Non-commercial only	DIAS	ESG-PCMDI
16	NCAR	USA	CMIP5 (501)	CMIP5 (301)	CMIP5 (101)	CMIP5	CMIP5		Yes			No	288x192 x L26	320x384 x L60	CCSM4	Unrestricted	NCAR	ESG-NCAR
17	OSUVic	USA	Completed	Running May 2012	Running May 2012		Not started April 2012	No		No	No	No	128x64 x L10	100 x 100 x L19	OSUVic-0-3	Unrestricted	?	?
18	CSIRO-QCCCE	Australia	CMIP5 (500)	CMIP5			CMIP5					No	192x96 x L18	192x192 x L31	CSIRO-Mk3-6-0	Non-commercial only	NCI	ESG-NCI
19	UK Groups (UBRIS/LEEDS/EDINBURGH - Hadley)	UK	CMIP5 (497)	CMIP5 (-ES: 102 -CC: 35)	Not started Spring 2012	Running Summer 2012	CMIP5		Yes	Yes	Yes	Yes	192x145 x L38	360x216 x L40	HadGEM2-ES HadGEM2-CC	Unrestricted	BADC	ESG-BADC
20	UNSW	Australia	PMIP3 (1000)	PMIP3 (500)	Running June 2012	PMIP3	PMIP3	No	Yes	Yes	Yes	No	64x56 x L18	128x112 x L21	CSIRO-Mk3L-1-2	Non-commercial only	IPSL *(NCI later?)*	ESG-BADC
21	UofT	Canada	Running June 2012		Running June 2012			No		No	No	No	256x128 x L26	320x386 x L40	UofT-CCSM3	Unrestricted	?	?

Legend

Status expected completion date	Available in CMIP5 DB (nb years in CMIP5 DB)
No	Available in PMIP3 DB (nb years in PMIP3 DB)
Yes	

PMIP3 + PlioMIP groups: Note that the models used for PlioMIP are often not (exactly) the same as the ones used for PMIP3/CMIP5

PlioMIP-only (not in the table): LPAP, UoM

Earth System Models of Climate
CMIP5 Models that Generated Output

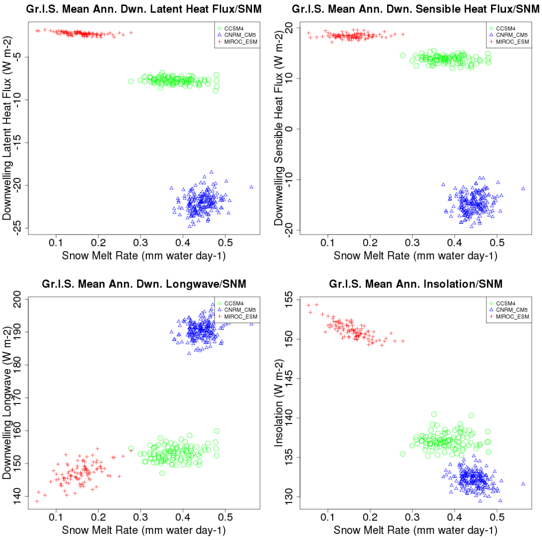
CMIP5 multi-model ensemble (Taylor et al. 2012, BAMS)

Model	Modeling Group	Ice Sheet	Atmosphere	Land	Ocean	Sea Ice
CCSM4	USA	prescr.	CAM4.0 (Neale et al. 2010,NCAR)	CLM3.5 (Olesen et al. 2008,JGR)	POP2 (Smith et al. 2010,NCAR)	CICE (Hunke et al. 2010,LANL)
CNRM-CM5	France	prescr.	ARPEGE (CNRM)	SURFEX (CNRM)	NEMO (CNRM)	GELATO (Salas-Mélia, 2002,OcnMod)
MIROC (Watanabe et al.,2011, Geos.Mod.D.)	Japan	prescr.	AGCM	MATSIRO	COCO	COCO

Last Glacial Maximum Experimental Design

- Orbital Parameters, eccentricity, obliquity, perihelion
- Solar constant
- Atm. Trace gasses (CO_2, CH_4, N_2O, O_3, CFC)
- Atm. Aerosols, Atm. pressure
- Vegetation
- Ocean bathymetry, salinity
- Wathershed basin flow
- Ice sheet extent, topography
- Ice sheet mass balance

Annual Fluxes and Melt Rates (look at the priority among models)



Annual Fluxes and Melt Rates

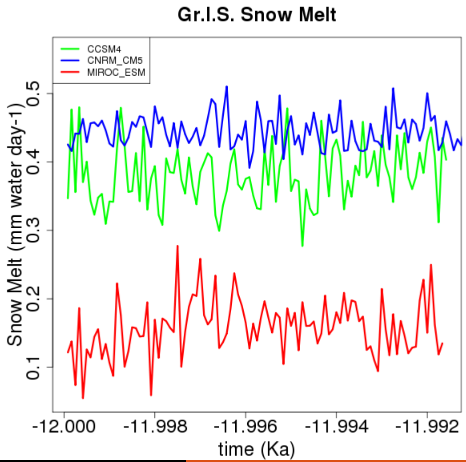
Priority of models for component Q-fluxes

DHFLS	**DHFSS**	**RLDS**	**RSDS**
MIROC	MIROC	CNRM	MIROC
CCSM4	CCSM4	CCSM4	CCSM4
CNRM	CNRM	MIROC	CNRM

DHFLS: downward latent heat flux
DHFSS: downward sensible heat flux
RLDS: downwelling longwave radiation
RSDS: downwelling shortwave radiation

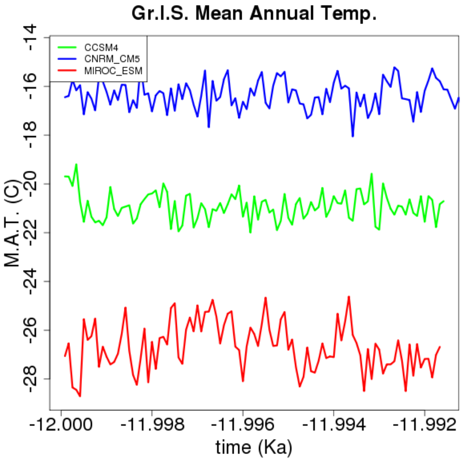
Snow Melt Surprise

- Model with the most energy available to melt snow has the *least* snow melt. Why?



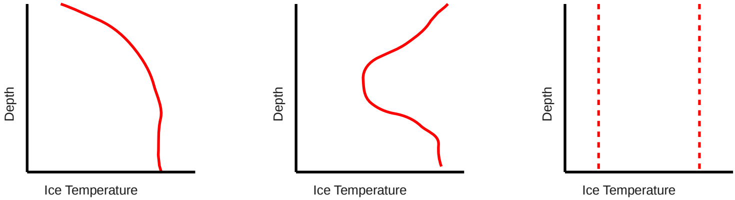
Reasons for Snow Melt Surprise

- Temperature drives snowmelt
- Spatial, climatic differences



Issues with Snow Melt–Energy Flux Disconnect

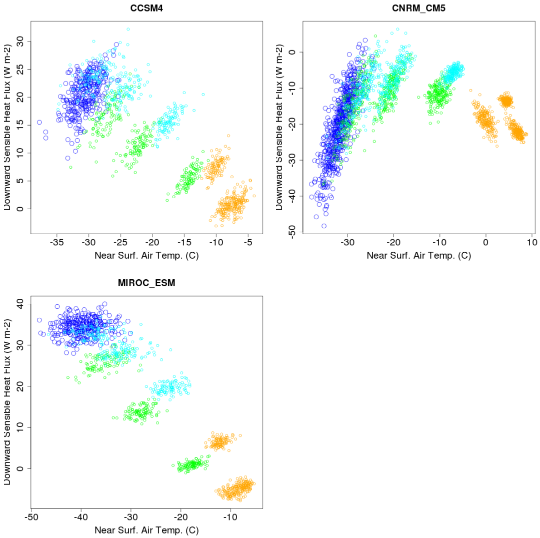
- Seasonal changes in atmospheric temperature give rise to differing dT/dz profiles, which in turn affect turbulent heat fluxes
- Seasonal changes in BL height and TKE



Conceptual temperatures through ice in different seasons (winter, summer, no gradient)

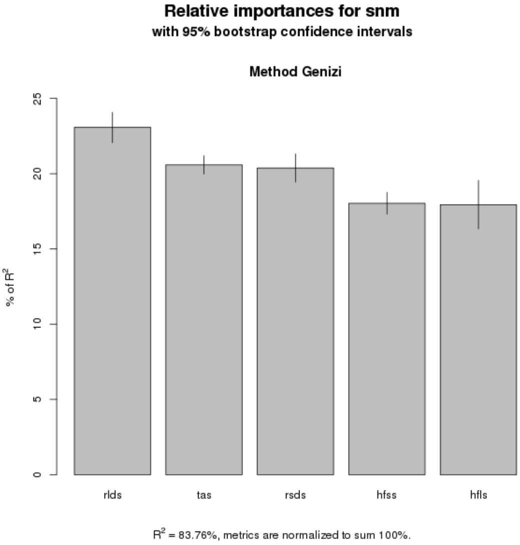
Digging Deeper into Model Mechanisms

- How do models compare in terms of downward sensible heat flux and temperature
- Seasonal changes in turbulent flux and BL height



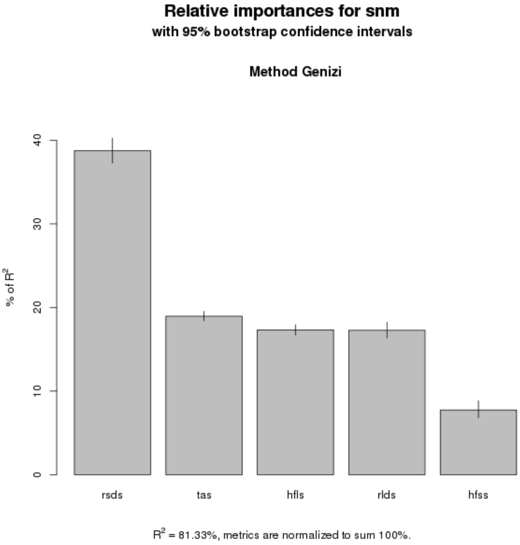
CCSM4

- CCSM4 uses PDD approach
- RSDS



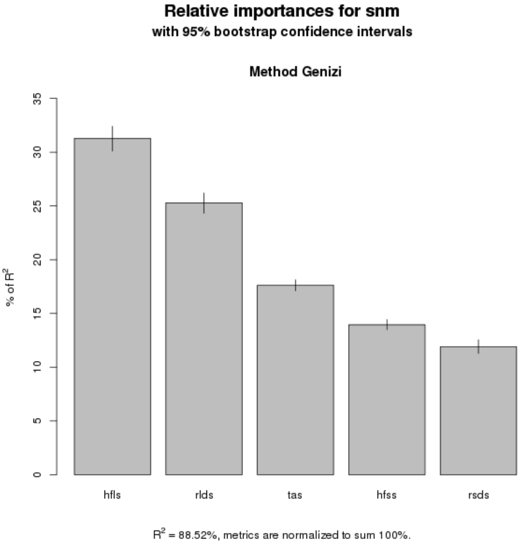
CNRM-CM5

- CNRM-CM5 (SURFEX's ISBA LSM) uses an energy balance approach to melting snow across a multi-layer snowpack
- RSDS



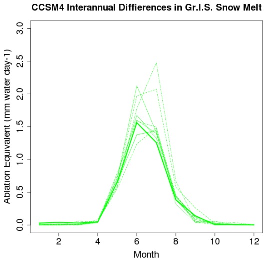
MIROC-ESM

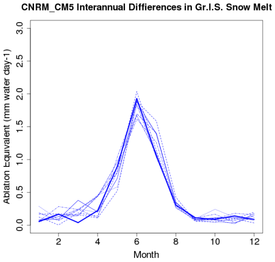
- ?snow melt method?, dust deposition and albedo effects
- HFLS

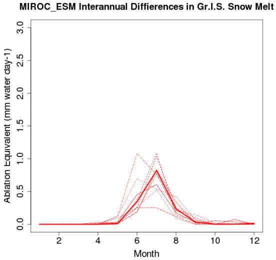


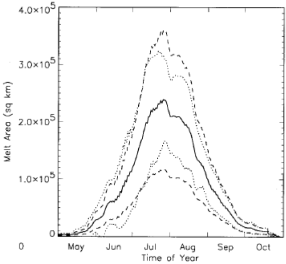
Snow Melt Seasonality
Model vs. Present Day Remote Sensing

- MIROC & CNRM 1-2 months out of phase
- Both have shoulder season melt issues



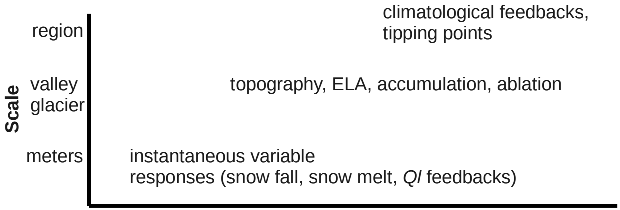


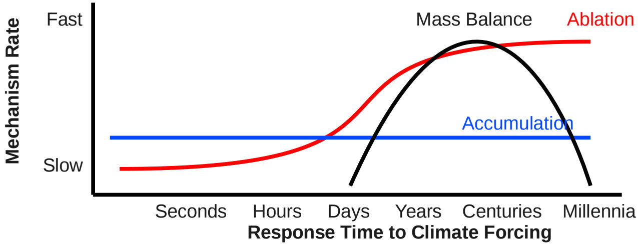




Lower right fig.: Abdalati and Steffen, 1997, JoCl

Open Questions
Take Home Message





Open Questions
Next Steps

- What do global scale climate simulations tell us about the fate of ice sheets?
  - .. how rest of the Earth system responds when glaciers held constant (hydrologic cycle, storminess, carbon balance)
  - ... but not directly about glacierization tipping points, or longer term feedbacks
- Feedbacks from turbulent fluxes and LHF within ice not well represented
- Are models parameterized realistically, and if not can we suggest ways to improve?
  - Radiative and turbulent fluxes that are internally consistent will allow for realistic melt rates and acceleration through changes in TKE
  - Response fxns, multi-layer snowpack/ice gradients will help
- EB snow melt methods dominated by insolation perturb snow melt seasonality (SWdown 40-80% in most cases)

Acknowledgments

- Michael Dietze (Boston U.), Shawn Serbin (UW-Madison), Jason Thomason (ISGS)
- CMIP-5 and PMIP-3 contributors, Earth System Grid participants, Lawrence Livermore Natnl. Lab.
- CCSM4 contributors and the National Center for Atmospheric Research
- CNRM-CM5 modelers and Centre National de Recherches Météorologiques
- MIROC-ESM contributors and Japan Agency for Marine-Earth Science and Technology and the University of Tokyo
- This presentation: www.climatemodeling.org/∼bjorn/talks/