Grand Challenge "Cryosphere in a Changing Climate"

ESM-Snow model intercomparison

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Motivation

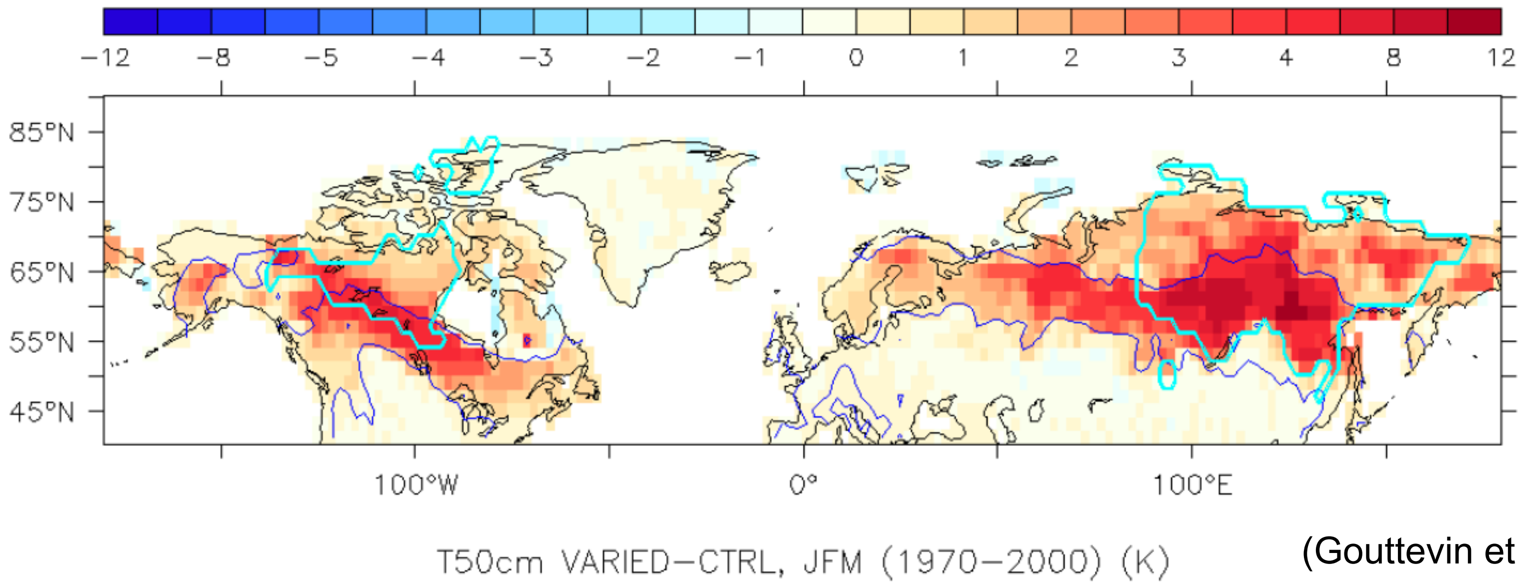
- Rapid snow extent changes in NH
- Climate change indicator & climate model verification parameter
- Snow potentially important for climate prediction on seasonal scale
- Snow feedbacks are key for longer time scales
- RS: Recent progress (SnowPEX)
- Possibility to build on progress in dedicated snow modelling (SnowMIP)

The current strengths and weaknesses of snow models used in ESMs must be assessed in order to provide guidelines for their improvement

Bring together site and large scale modeling community, site and large-scale observations

Issues with snow in ESMs

- Representation of vertical snow variability and fluxes: Number of layers, vertical discretization, …
- Snow fraction parameterisation: depends on the season and vegetation
- Albedo parameterisation: prognostic vs. diagnostic, black carbon
- Snow-vegetation interaction: including multi-energy balance?
- Snow density and its impact on heat conductivity
- Blowing snow and associated impact on sublimation
- Heat conductivity: major impact on underlying soil



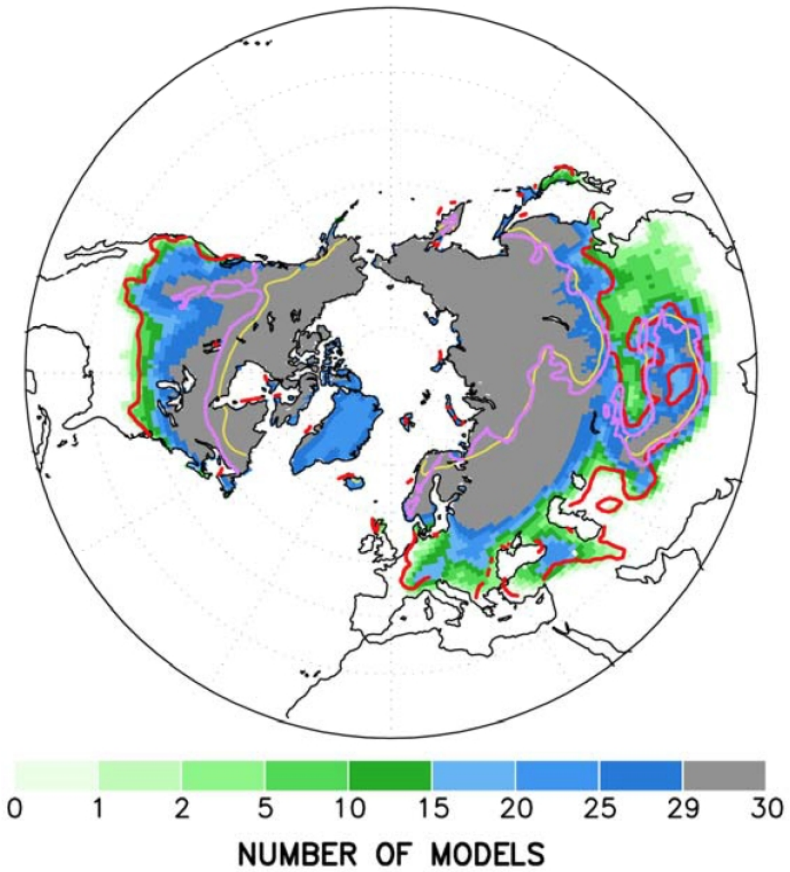
(Gouttevin et al., 2012)

Consequences of these issues

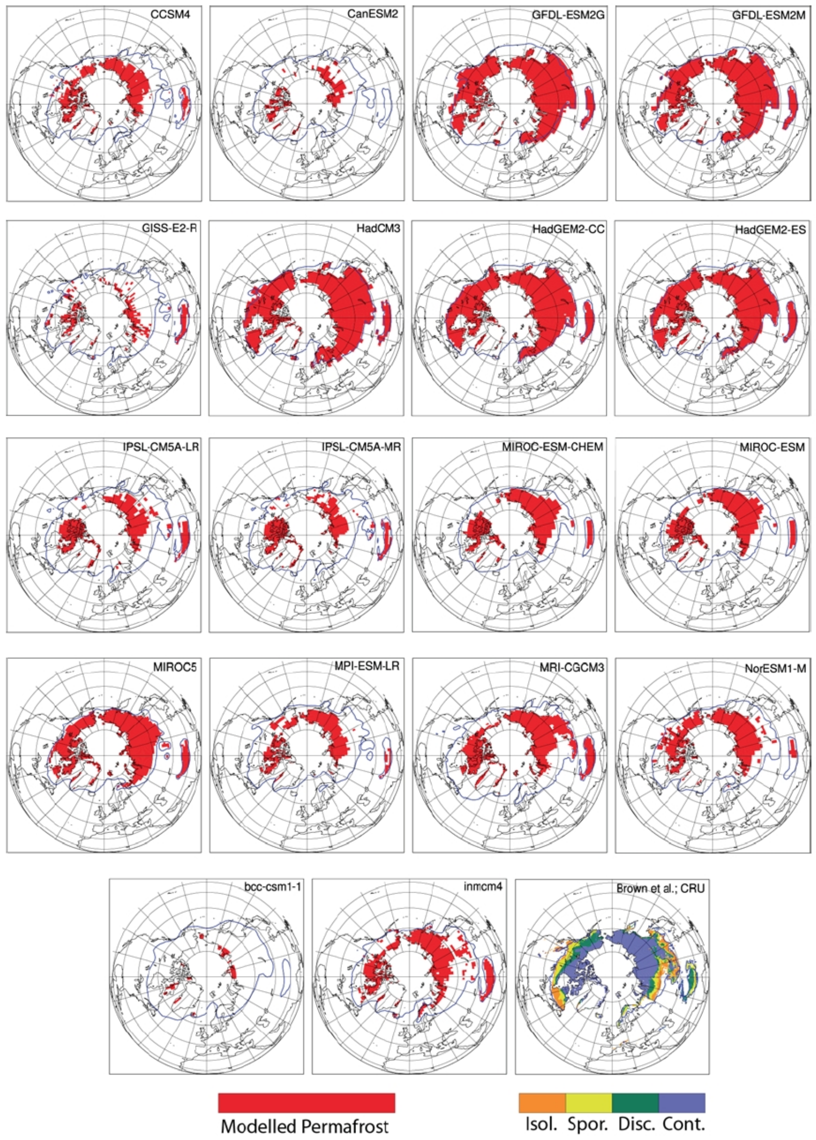
Example: Permafrost extent

Snow extent not that bad, but underlying soil temperatures vary widely.

Reason for misfits: soil + snow physics



(Flato et al., 2013 [IPCC AR5 Ch. 9])

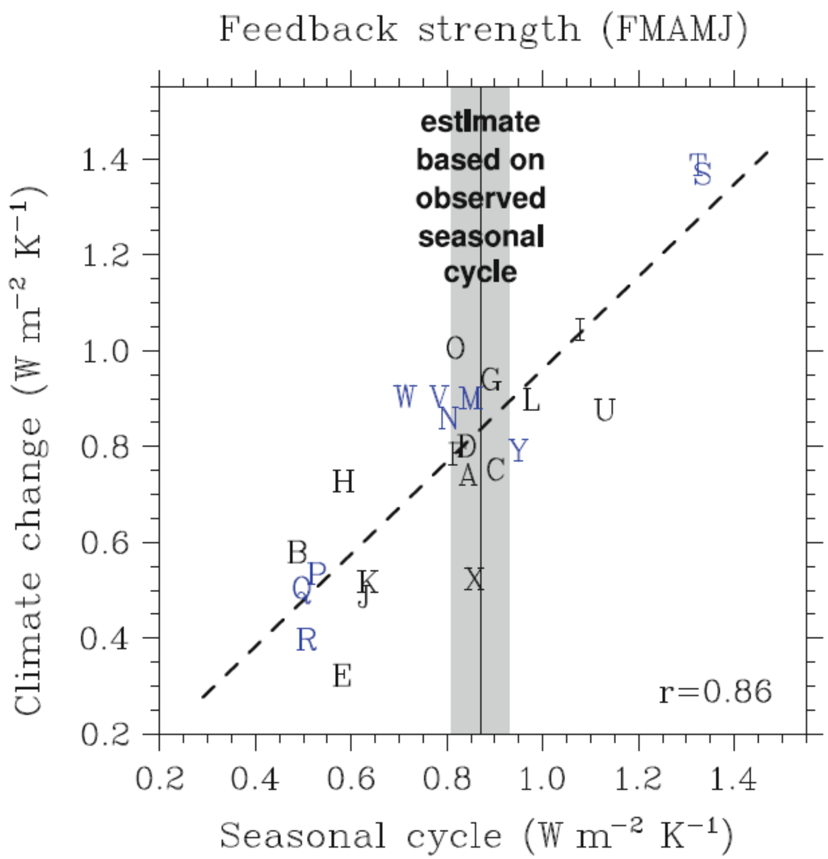


(Koven et al., 2013)

Example: Simulated snow feedback

"*The spread in snow albedo feedback is very similar to that found in CMIP3 models, and it accounts for much of the spread in the 21st century warming of Northern Hemisphere land masses in the CMIP5 ensemble, especially in spring and early summer.*"

Qu and Hall (2013), doi:10.1007/s00382-013-1774-0



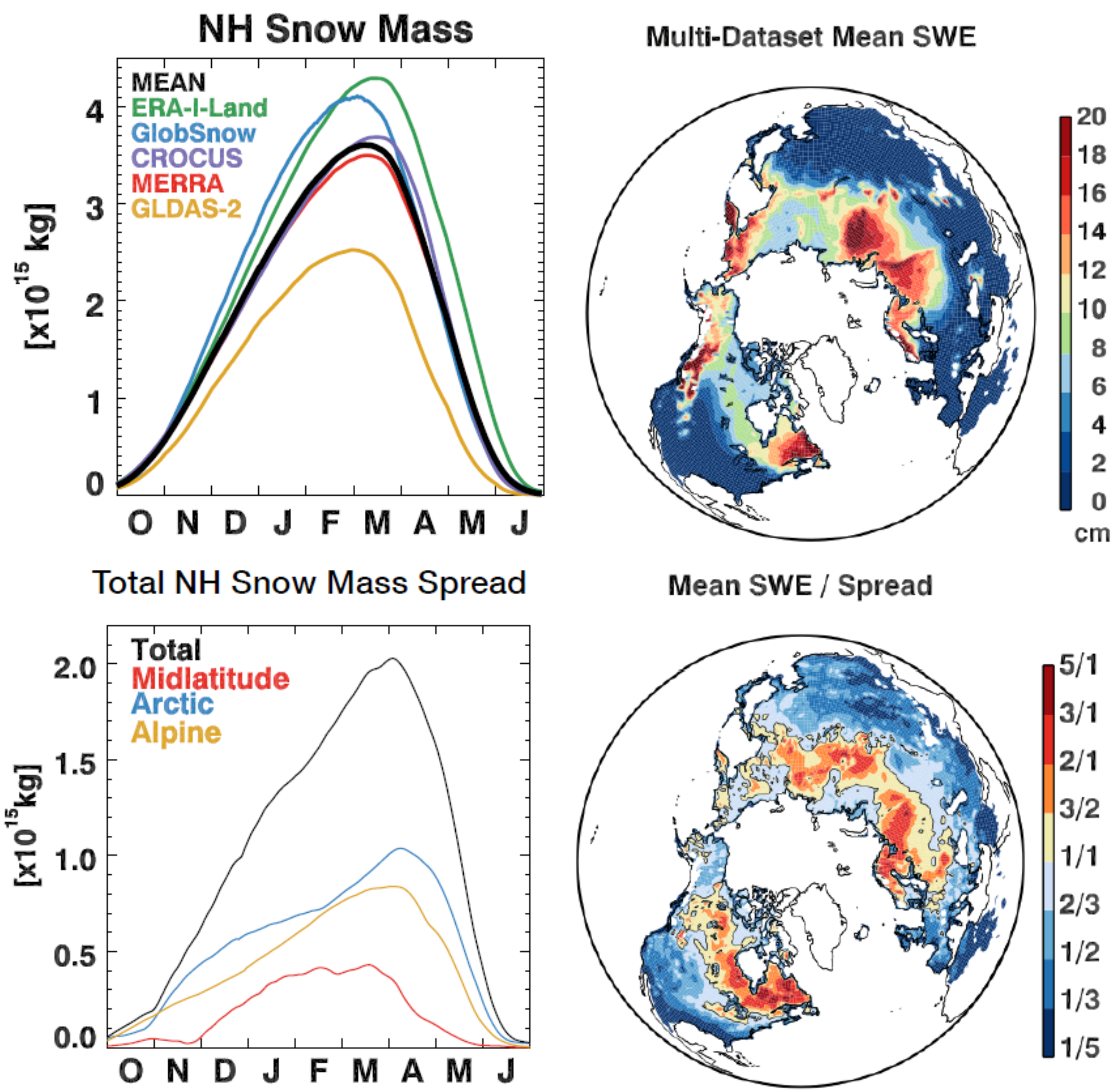
What we learned from previous snow model intercomparisons

- Site-level, with dedicated models
- Models capture broad features of snow accumulation and ablation
- Broad spread between models, particularly in warmer conditions
- There is no « best » model
- Model performance is not clearly related to model complexity
- Driving and evaluation data errors are hard to separate from model errors
- Interpretation of results complicated by different interpretation of instructions and different degrees of calibration
- But much of the spread can be reproduced in multi-physics ensembles, with more physically-based parameterizations performing better

A word on (global) snow climatologies

- There is considerable inter-dataset spread in Northern Hemisphere snow mass and snow cover extent derived from available terrestrial snow products

- Efforts are underway (through ESA SnowPEx) to derive an optimal ensemble of observed products in order to provide an observational foundation for CMIP6 land MIPs (i.e. LS3MIP)



Mudryk et al (2015) J. Climate

Continental and Hemispheric Satellite Snow Extent Products

Name	Product type	Pixel Spacing	Frequency	Period	Main Sensor	Organisation
NOAA IMS	Binary	4 km	daily	2004 -	OPT, PMW,	NOAA (Helfrich et al.)
NOAA IMS	Binary	24 km	daily	1997 -2004	OPT, PMW	NOAA
GlobSnow	Fractional FSC	1 km	daily - monthly	1996-20 12	ATSR2 AATSR	SYKE, ENVEO et al. – ESA support
MOD10	Fractional FSC	0.5 km	Daily	2000 -	MODIS	NASA / NSIDC (Hall et al.)
AVHRR Pathfinder	Binary	5 km	daily	1992 -2004	AVHRR	CCRS (Zhao, et al)
CryoLand	Fractional (Europe)	0.5 km	daily	2000 -	MODIS	ENVEO / SYKE et al.- EC -FP7

Main questions

- How bad are current snow models (specific ones & those used in climate modeling)?
- What processes do they have to represent in a climate model?
- How strong are, and will be, snow-related climate feedbacks (real & model world)?

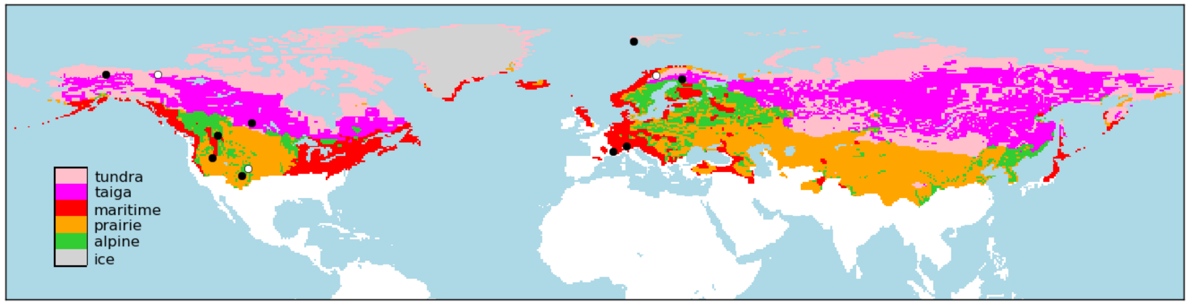
Axes

- Evaluation of snow models against new, diverse and longer site observations: Extend SnowMIP 1&2
- Evaluate snow in CMIP6 models (coupled and LMIP) – link to LS3MIP
- Quantify snow feedbacks in CMIP6 simulations – link to LS3MIP

Site simulations

- Tier 1:
  - Reference site simulations
- Tier 2:
  - Shallow soil
  - Large-scale forcing
  - Fixed albedo
  - High thermal conductivity

Site	Snow Class	Forcing and Evaluation	Global Offline Diagnostic	Time Period
Reynolds Creek, USA	Alpine	X	X	1984-2008
Col de Porte, France	Alpine	X	X	1993-2011
Senator Beck, USA	Alpine	X	X	2006-2012
Weissfluhjoch, Switzerland	Alpine	X	X	1996-2010
Sodankyla, Finland	Taiga	X	X	2007-2014
BERMS, Canada	Taiga	X	X	1997-2014
Imnavait Creek, USA	Tundra	X	X	2007-2013
Bayelva, Svalbard	Tundra	X	X	
Marmot Basin, Canada	Alpine	X	X	2007-2014
Fraser, USA	Alpine		X	
Trail Valley Creek, Canada	Tundra		X	
Abisko, Sweden	Taiga		X	



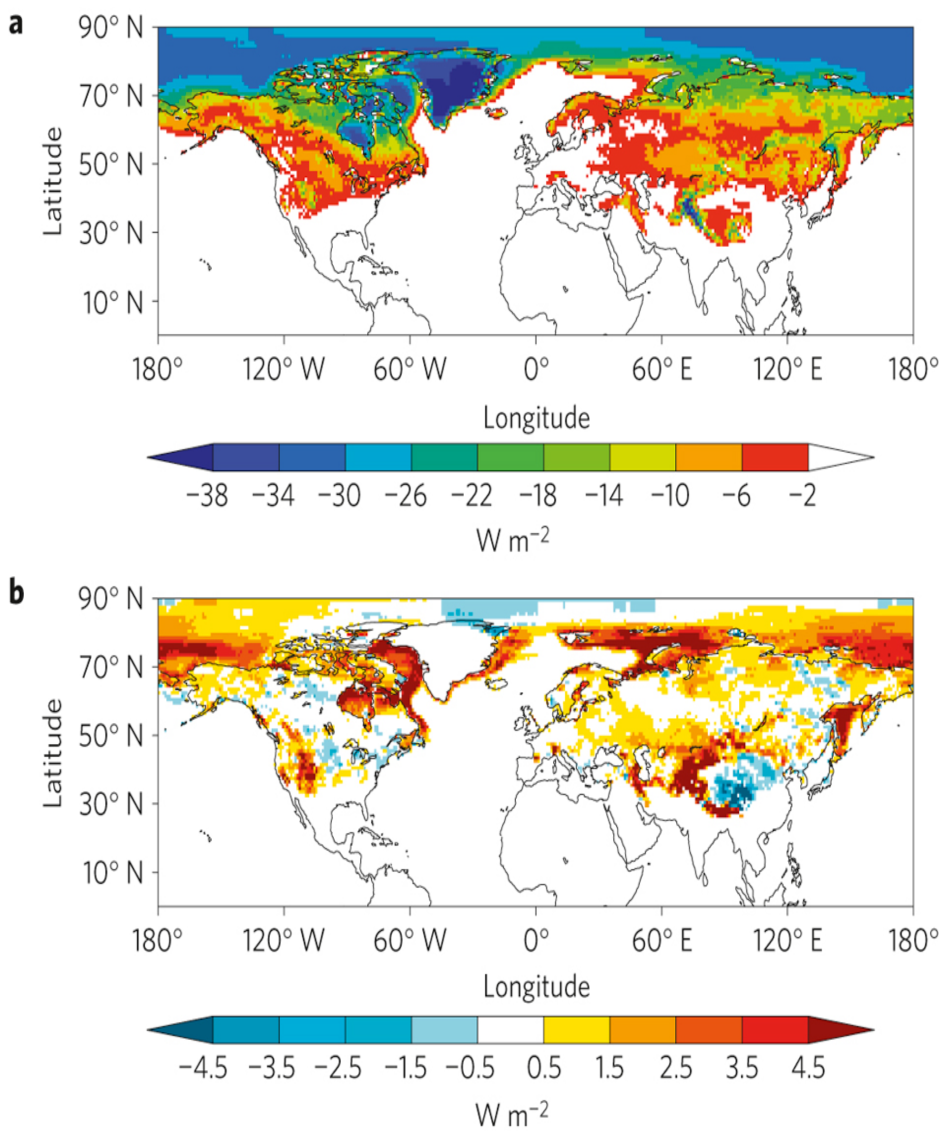
Data provided by NCAR/EOL under sponsorship of the National Science Foundation. http://data.eol.ucar.edu/

Global simulations

Tier 1:

- Forced (uncoupled) global simulations:
  - Fixed snow albedo
  - Prescribed “observed” snow water equivalent
- Coupled: LS3MIP land forcing simulations restricted to snow:
  - total snow effect
  - snow effect on SW radiation only

Snow radiative effect



(Flanner et al., 2011)

- Instantaneous perturbation to Earth's solar energy budget induced by the presence of surface cryospheric components
- Diagnosed through parallel radiation calculations of surface albedo and solar energy fluxes with and without the presence of snow
- Analogous to cloud radiative effect
- Northern Hemisphere (NH) 1979–2008 CrRE derived from a variety of remote sensing data (MODIS, AVHRR, AMSR-E)
- Change in NH CrRE during 1979–2008: +0.45 (0.27–0.72) W m^{-2}, half of which was caused by reduced terrestrial snow
- Include snow radiative effect calculations in ESM-SnowMIP/LS3MIP global simulations

Planning

- Linked to LS3MIP: global ESM-SnowMIP simulations complementary
- Finalize site forcing data (now)
- Kick-off workshop Dec 10, Fort Mason, San Francisco (pre-AGU)
- Start site simulations
- Global off-line and coupled simulations: After CMIP6 (LS3MIP)
- Long term:
  - snow on sea ice
  - snow on ice sheets.