SnowPEx – Satellite Snow Product Intercomparison and Evaluation Experiment (6/2014 – 5/2016)

Contribution of SnowPEx to CMIP6 (and new satellite mission concept studies)

C. Derksen
ESM-SnowMIP Steering Committee
Various CSA, ESA, and JPL affiliated working groups

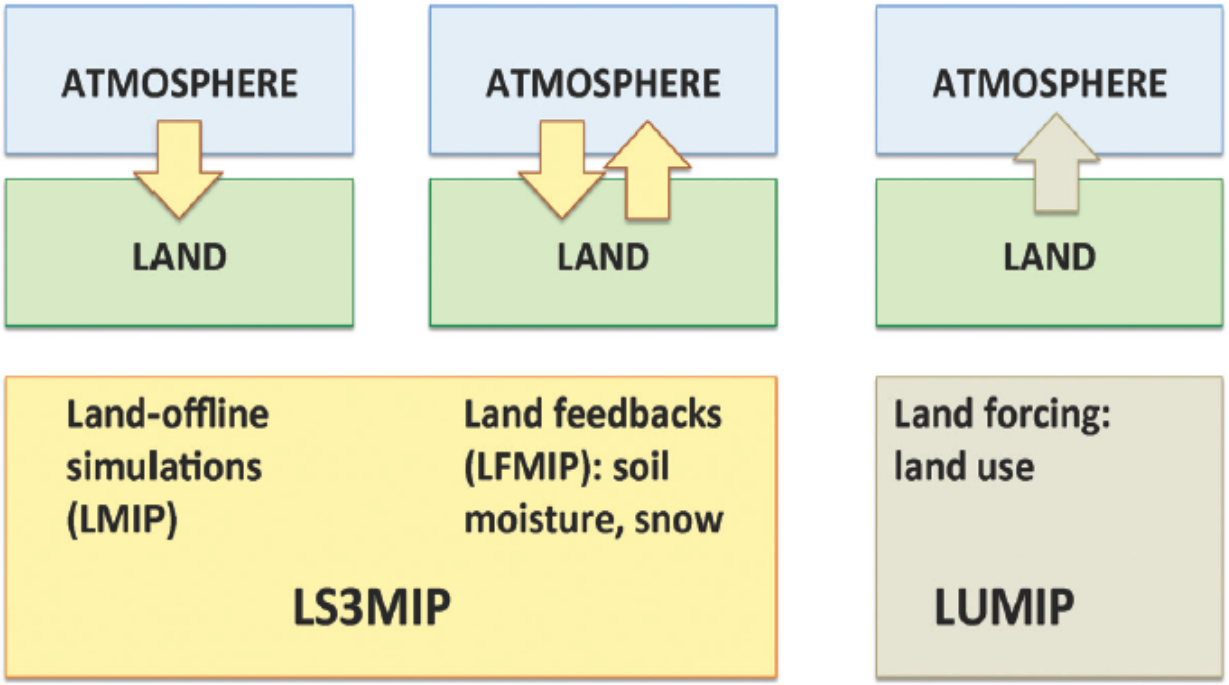
Overview

Part 1: SnowPEx will make a fundamental contribution to the two activities associated with CMIP6:

1. The Land Surface, Snow, and Soil Moisture Inter-Comparison Project (LS3MIP)
   - formally endorsed, CMIP6 MIP
2. Earth System Model Snow Model Inter-comparison Project (ESM-SnowMIP)
   - WCRP CliC endorsed Grand Challenge

Part 2: By illustrating the performance characteristics of current snow products, SnowPEx provides an important foundation to new snow mass mission concept studies emerging at CSA, ESA, and JPL

CMIP6 LandMIPs



3 elements:

- Offline experiments "LMIP" (building upon Global Soil Wetness Project Phase 3) ➔ *Investigating systematic biases*
- Coupled sensitivity experiments (building upon GLACE-CMIP5 and ESM-SnowMIP ➔ *Investigating feedbacks*
- Coupled simulations with prescribed land use ➔ *Investigating land forcing*

LS3MIP
Land Surface, Soil moisture and Snow Model Intercomparison Project

Grand Challenge "Cryosphere in a Changing Climate"

ESM-Snow model inter-comparison project

G. Krinner, C. Derksen, R. Essery,
S. Hagemann, A. Hall, H. Rott, A. Slater

Proposed Experiments:

- Evaluation of snow cover simulations in CMIP5 historical runs to describe the current state of snow representation in ESMs
- ESM simulations with prescribed (observed SWE; observed albedo) versus freely evolving snow conditions to identify snow feedbacks on the atmosphere
- Local simulations over a few selected supersites (i.e. representative of polar, alpine, continental, maritime conditions) to allow evaluation with comprehensive observations

Issues with snow in ESMs

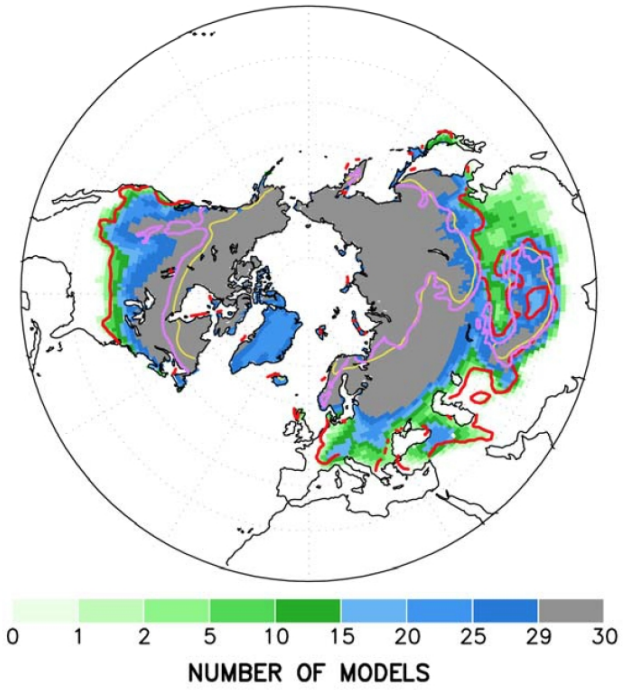
- Representation of vertical snow variability and fluxes: Number of layers, vertical discretization, …
- Snow fraction parameterisation: depends on the season and vegetation
- Albedo parameterisation: prognostic vs. diagnostic, black carbon
- Snow-vegetation interaction: including multi-energy balance?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

Consequences of these issues

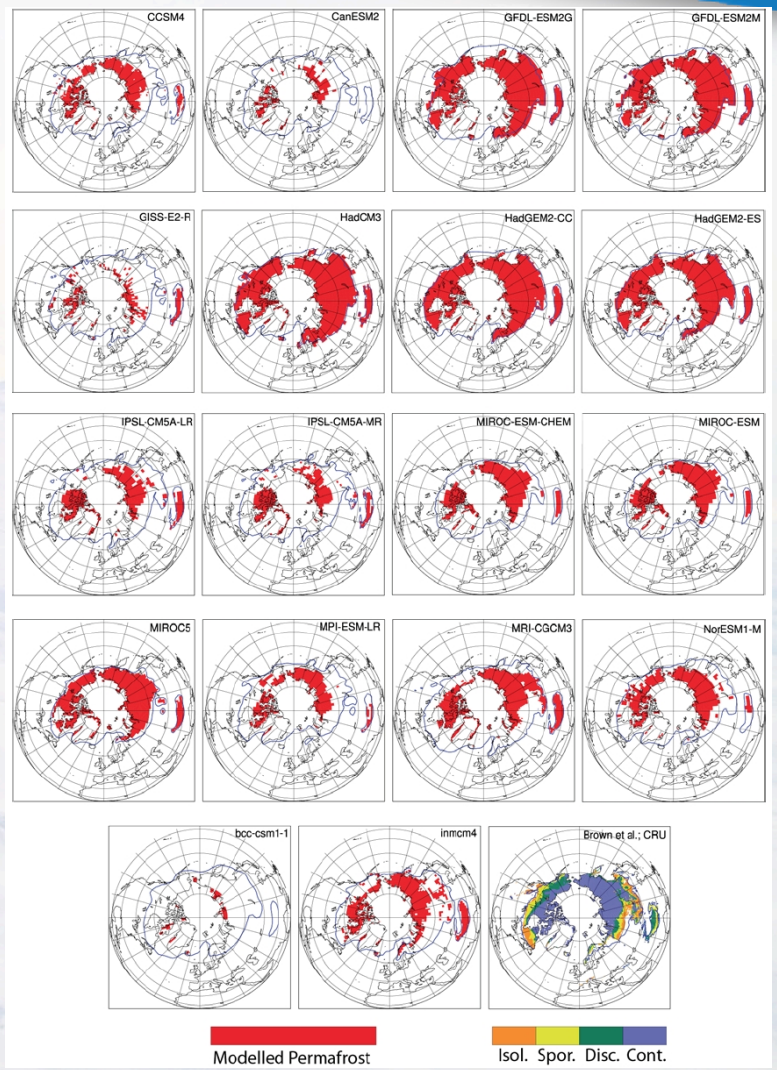
Permafrost extent

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

Reason for misfits: soil + snow physics



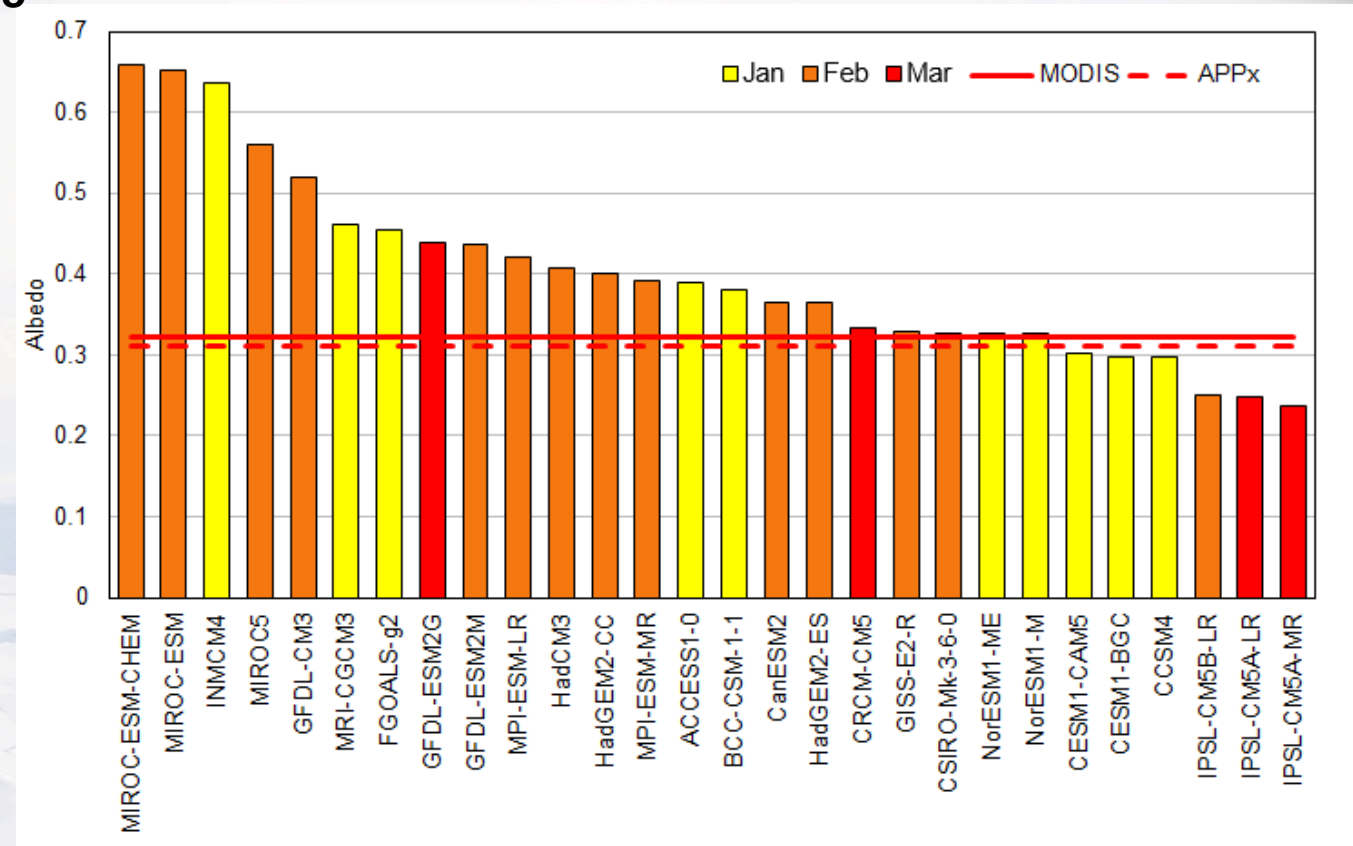
(Flato et al., 2013 [IPCC AR5 Ch. 9])



(Koven et al., 2013)

Consequences of these issues

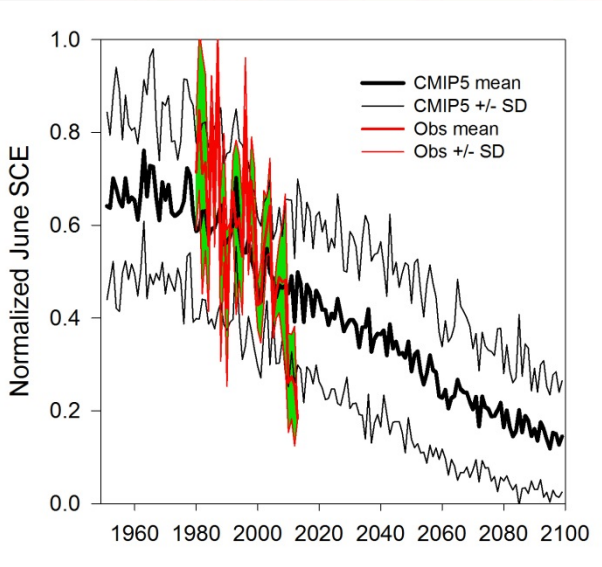
Snow albedo

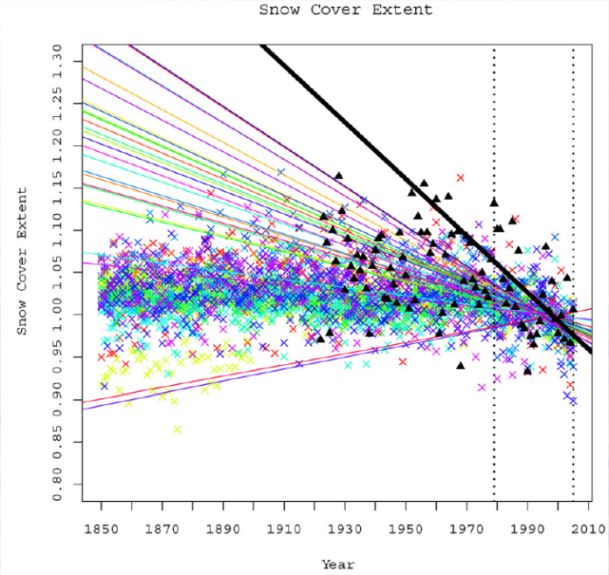


Maximum monthly albedo of CMIP5 models over the ***Northern Hemisphere boreal region***. Colors show month of peak albedo timing (observations = March). Thackeray et al., JGR

Consequences of these issues

Ability of climate models to capture observed rates of spring snow cover reduction

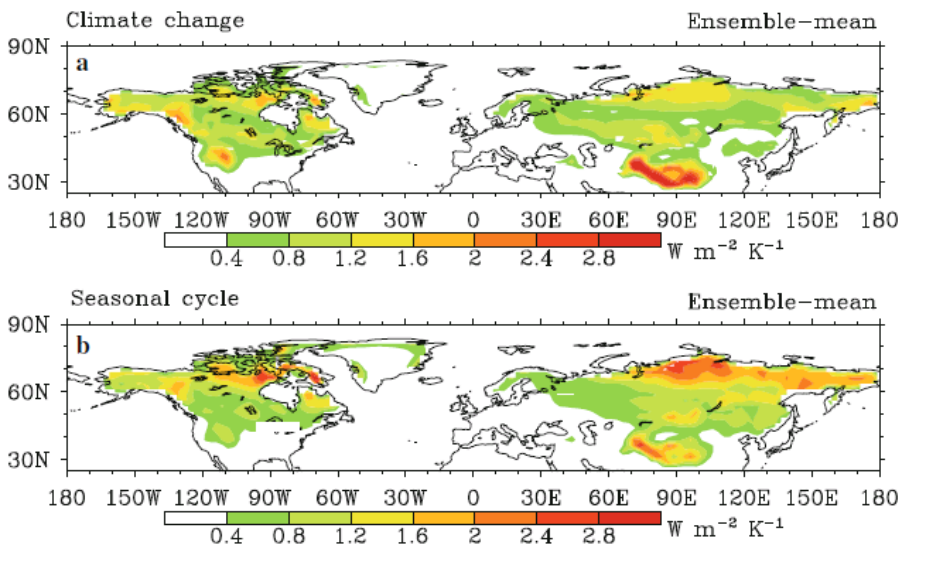


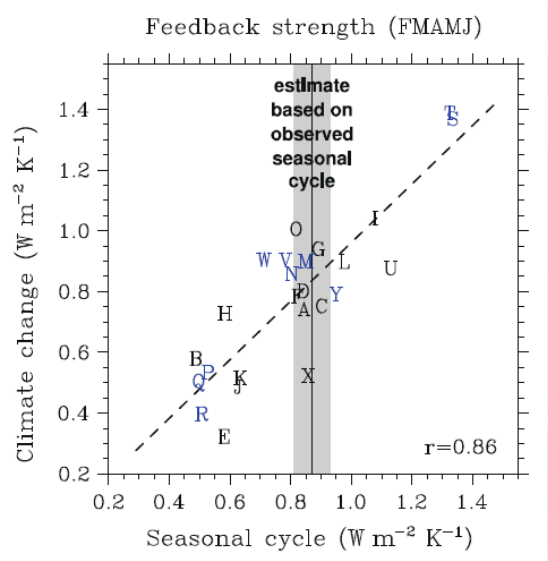


Brutel-Vuilmet et al. (2012); Derksen and Brown (2012): CMIP5 models underestimate the significant reductions in spring snow cover extent observed during the satellite era

Consequences of these issues

Linkage between snow-albedo feedback and 21st century warming





Qu and Hall (2013): The spread in snow albedo feedback accounts for much of the CMIP5 spread in the 21st century warming of Northern Hemisphere land masses

LS3MIP experiments

Experiment name	Tier	Experiment description / design	Configu-ration	Start End	# Yrs per simu-lation	Ens. size	# Yrs total	Science question and/or gap addressed with this experiment	Possible synergies with other MIPs	Run schedule
LMIP-H	1	Land only simulations	LND	1850-2014	165	2	330	Land reanalysis	LUMIP, C4MIP, CMIP6 historical	Jan-Jun, 2016
LMIP-F	2			2015-2100	86	4	344	Climate trend analysis		
LFMIP-CAO1	1	Prescribed land conditions 1980-2014 climate	LND-ATM-OC	1980-2100	121	1	121	Diagnose land-climate feedback including ocean response	Scenario-MIP	After DECK (2017?)
LFMIP-CAO4	2					4	484			
LFMIP-CA5	2	Prescribed land conditions 1980-2014 climate; SSTs prescribed	LND-ATM			5	605	Diagnose land-climate feedback over land		
LFMIP-RAO1	1	Prescribed land conditions 30yr running mean	LND-ATM-OC			1	121	Diagnose land-climate feedback including ocean response		
LFMIP-RAO4	2					4	484			
LFMIP-RA5	2	Prescribed land conditions 30yr running mean; SSTs prescribed	LND-ATM			5	605	Diagnose land-climate feedback over land		
LFMIP-HP10	2	Initialized pseudo-observations land	LND-ATM-OC	1980-2014	35	10	350	Land-related seasonal predictability	CMIP6 historical	

ESM-SnowMIP experiments

Coupled and global offline experiments:

- Transparent snow
- Fixed albedo
- Prescribed SWE
- No snow insulation of soil

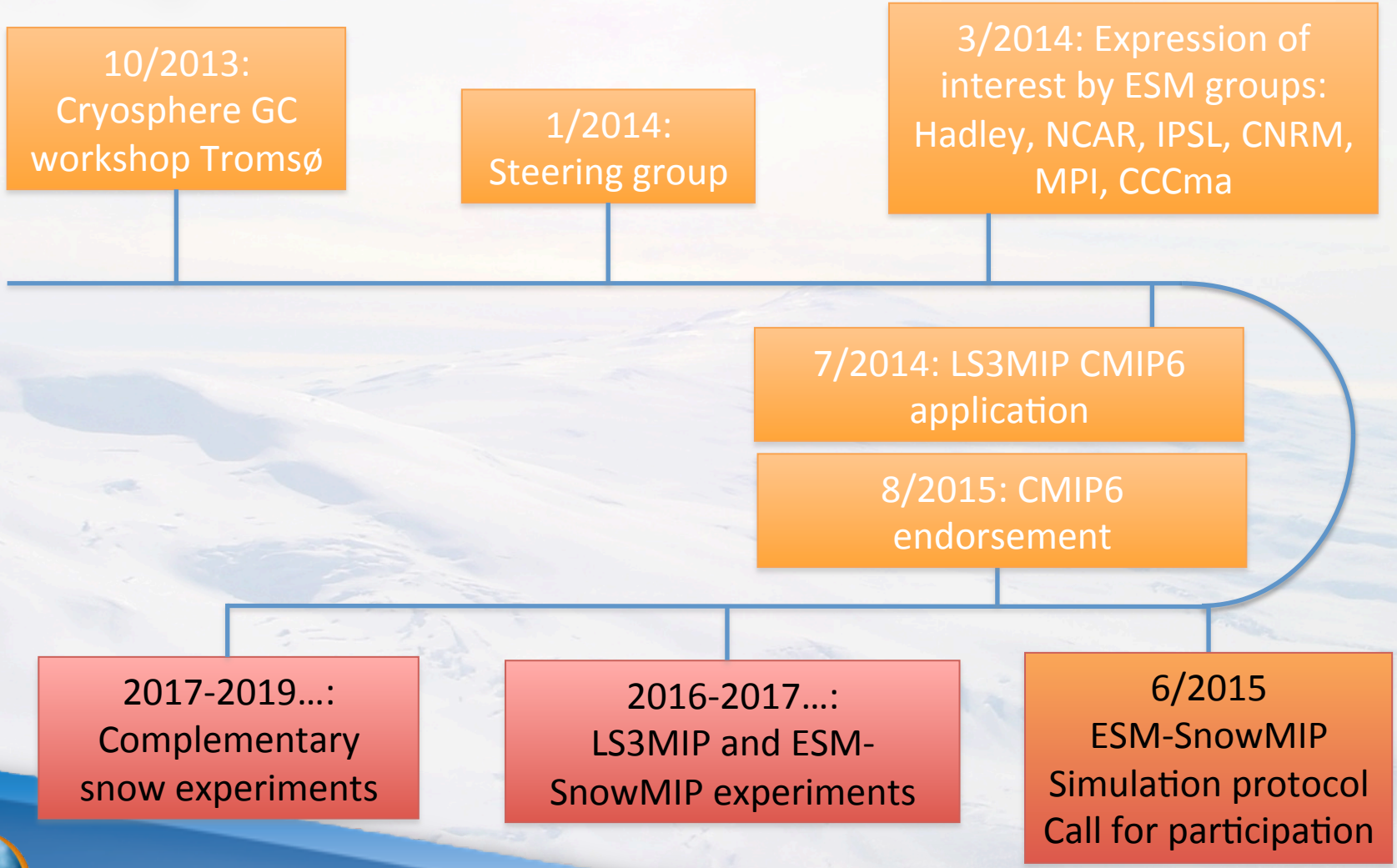
Site simulations:

- Point versus gridded versus downscaled forcing
- Global offline experiments at the site scale

Site simulations

Site	Geographic location	Snow Class	Forcing and Evaluation	Diagnostic only
Reynolds Creek	117°W / 43°N	Alpine	X	
Col de Porte	6°E / 45°N	Alpine	X	
Senator Beck	108°W / 38°N	Alpine	X	
Weissfluhjoch	10°E / 47°N	Alpine	X	
Sodankylä	27°E / 67°N	Taiga	X	
BERMS	106°W / 54°N	Taiga	X	
Imnavait Creek	150°W / 59°N	Tundra	X	
Dome C, Antarctica	123°E / 75°S	Polar desert	X	
Bayelva, Svalbard	12°E / 79°N	Tundra	X	
Marmot Creek	115°W / 51°N	Alpine	X	
Samoylov	126°E / 72°N	Tundra		X
Fraser	106°W / 40°N	Alpine		X
Trail Valley Creek	133°W / 69°N	Tundra		X
Abisko	19°E / 68°N	Taiga		X

Timeline


10/2013: Cryosphere GC workshop Tromsø
1/2014: Steering group
3/2014: Expression of interest by ESM groups: Hadley, NCAR, IPSL, CNRM, MPI, CCCma
7/2014: LS3MIP CMIP6 application
8/2015: CMIP6 endorsement
2017-2019…: Complementary snow experiments
2016-2017…: LS3MIP and ESM-SnowMIP experiments
6/2015 ESM-SnowMIP Simulation protocol Call for participation

Contributions from SnowPEx to CMIP6

1. Prescribed snow conditions (LS3MIP)

2. Prescribed observed snow water equivalent experiment (ESM-SnowMIP)

3. Evaluation of simulated snow mass and snow extent (all coupled and offline experiments)

4. Evaluation of site simulations

New Snow Mass Mission Concept Studies

- A Canadian Space Agency snow mass mission concept study is underway, to address a fundamental observational gap which limits the development of enhanced operational environmental monitoring, services, and prediction at Environment Canada
- The mission is driven by snow mass as the primary requirement and recognizes the potential contribution from spaceborne radar measurements, but is not starting from any pre-determined technological concept
- Studies have not yet shown the comprehensive validation of radar derived SWE retrievals, nor the successful application of these retrievals to modeling (hydrology; NWP; climate) applications
- Secondary measurement objectives (sea ice; land ice; ocean vector winds) have been defined but do not drive the payload analysis
- Identifying international partnership opportunities will be an important component of the study

Snow Mass Mission Concept Justification

Snow plays a critical role in climatological, hydrological, and ecological processes across a significant portion of the Northern Hemisphere, represents an essential freshwater resource for human use, and influences a number of hazards (i.e. spring flooding; drought propagation).

How much snow is there? Where, in what ways, and why are snowpacks changing?

Specific scientific objectives for moderate resolution (~1 km) terrestrial snow products:

1. Quantify the spatially and temporally dynamic amount of freshwater stored in seasonal snow **(monitoring and process studies)**
2. Provide observational support for high resolution prediction (via data assimilation) of the land surface for NWP and hydrological modeling **(predictions)**
3. Diagnose systematic snow mass biases in the land modules of current Earth System Models **(projections)**

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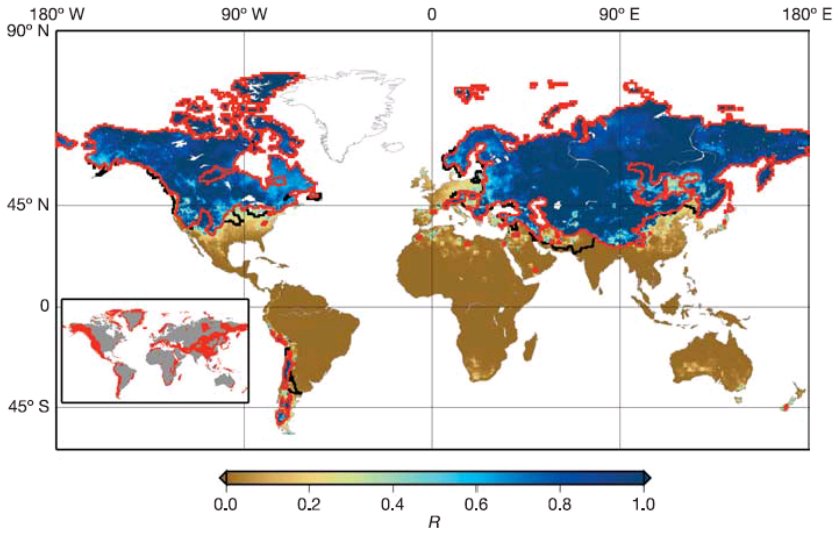
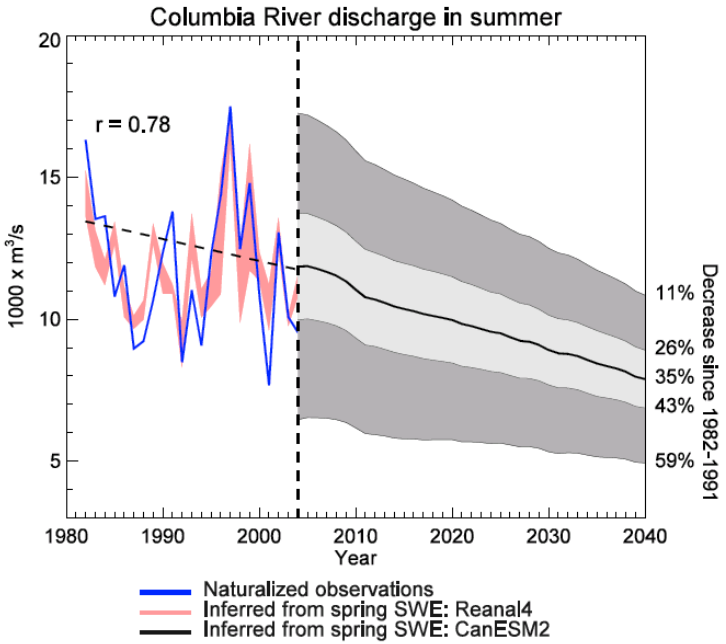


Accumulated annual snowfall divided by annual runoff over global land regions

Barnett et al., Nature, 2005



Observed historical spring SWE and discharge for the Colorado River watershed, and projected streamflow changes from a large ensemble of CanESM2 simulations

Fyfe et al., In prep.

- Snow cover provides a vital freshwater resource over a large fraction of the northern hemisphere
- This resource is under stress from warming temperatures and shifts in precipitation regimes

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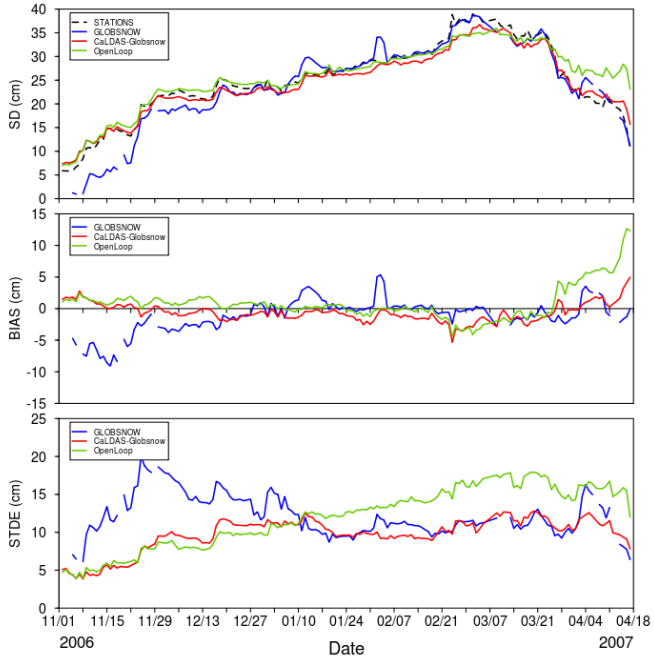
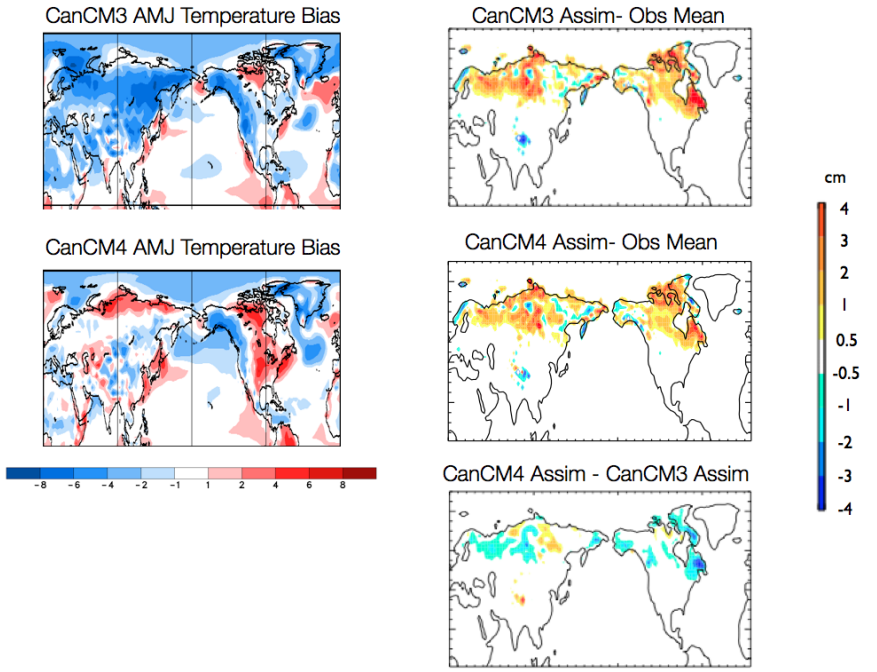


Error metrics for snow assimilation experiments using the coarse resolution (25 km) GlobSnow product over western Canada



Temperature and SWE biases in the Canadian Seasonal to Interannual Prediction System (CanSIPS)

- Operational NWP requirements: daily coverage, moderate resolution (~1 km), well characterized retrieval uncertainty
- Operational seasonal prediction requirements: relaxed spatial and temporal resolution requirements

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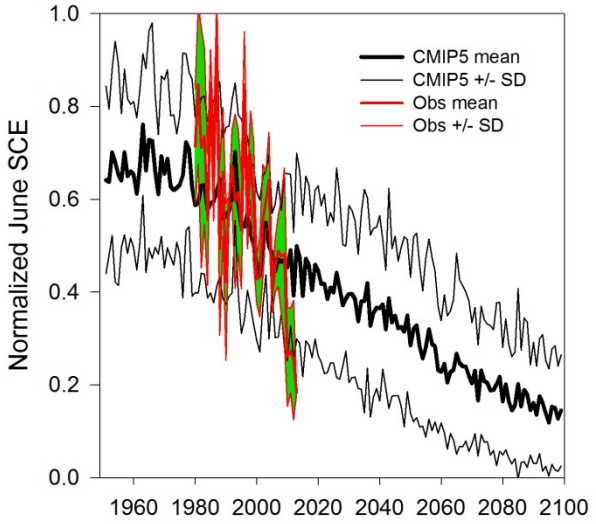
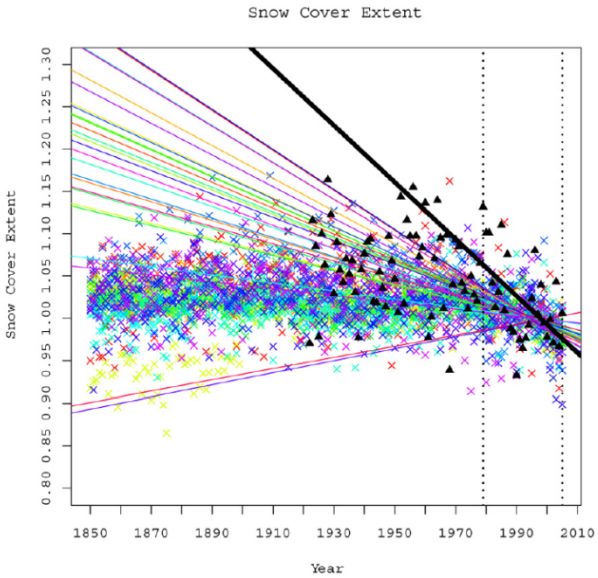


June NH snow cover extent from observational snow analyses and CMIPS models (historical + rcp8.5 scenario)

Derksen and Brown, GRL, 2012



March–April NH snow cover extent for historical CMIP5 simulations (colored crosses) and observations (black triangles)

Brutel-Vuilmet et al., Cryos., 2012

- CMIP5 models do not capture the significant reductions in spring snow cover extent observed during the satellite era
- Enhanced observations required in support of improvements to model physics and diagnostics

Complementary ESA Activities

Scientific evaluation of mission concepts to monitor snow mass and other cryospheric parameters
ITT on ESA emits

SnowSAR campaign data analysis study (SCADAS)
ITT on ESA emits. Release once all campaign data available.

Microstructural origin of electromagnetic signatures in microwave remote sensing of snow
First progress meeting held

SnowLAB campaign, Swiss Alps
Start this winter and extend 3 years

Snow Product Inter-comparison
2014-2016

Complementary NASA Activities

- Ongoing NASA THP projects: snow – radar interactions in tundra environments (PI: Dr. Matthew Sturm, University of Alaska – Fairbanks) and new approaches to backscatter modeling of snow (PI: Dr. Leung Tsang, University of Michigan)
- Snow Mass Mission Concept Study underway at JPL
- Wideband Instrument for Snow Measurements (WISM; NASA Instrument Incubator) Initial test flights in February 2015
- SnowEx: Potential multi-year airborne/ground campaign funded via the NASA Terrestrial Hydrology Program (2017-2019?)

Summary

SnowPEx will make a fundamental contribution to CMIP6 MIPs

- Some thought is needed in how to communicate SnowPEx results to the climate modeling community

By illustrating the performance characteristics of current snow products, ***SnowPEx provides an important foundation to new snow mass mission concept studies emerging at CSA, ESA, and JPL***

- Thought is needed in how to sustain the SnowPEx effort beyond this project