High latitude changes and feedbacks

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How Do We Know the World Has Warmed?

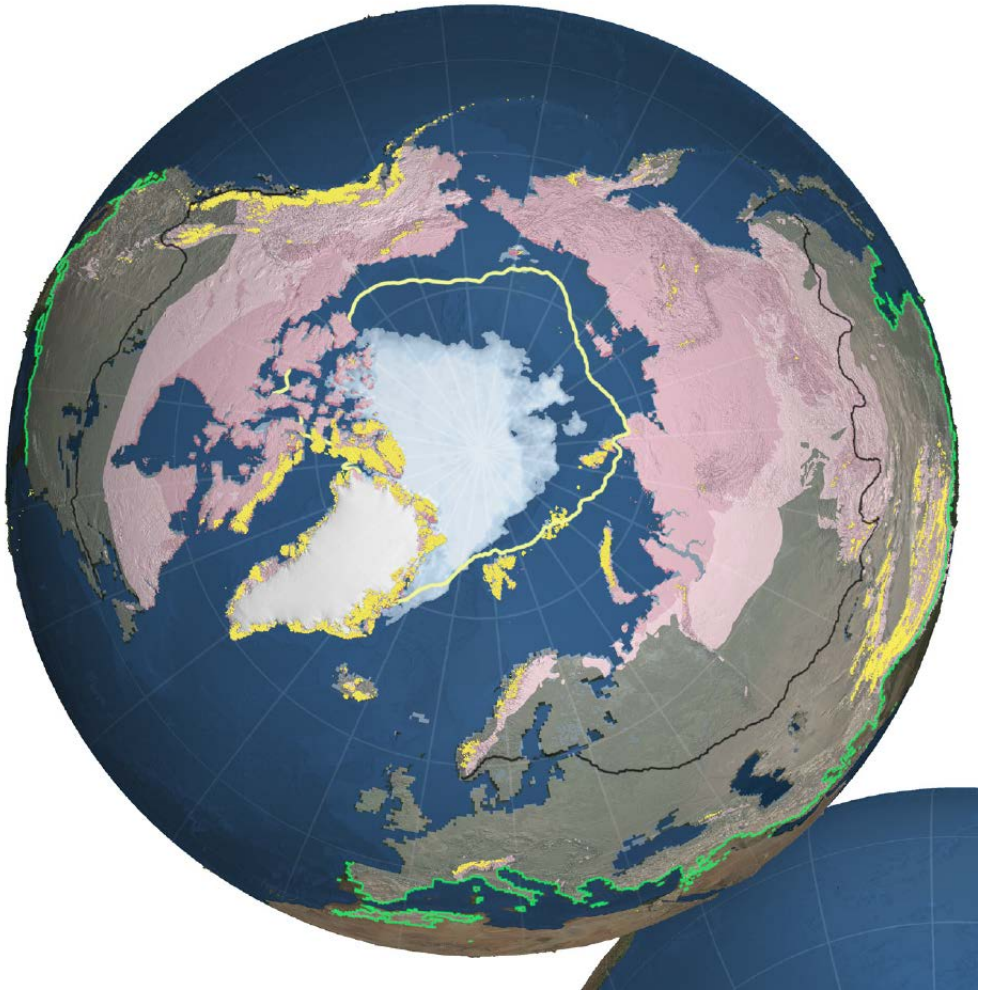

Why is the ice still here?
I was thinking palm trees
and Mai Tais!

McCarty Glacier - Alaska

Mt. Hood, Oregon, courtesy BBC News

globalwarmingart.com; www.nbcnews.com

Cold regions



Observed changes in snow properties

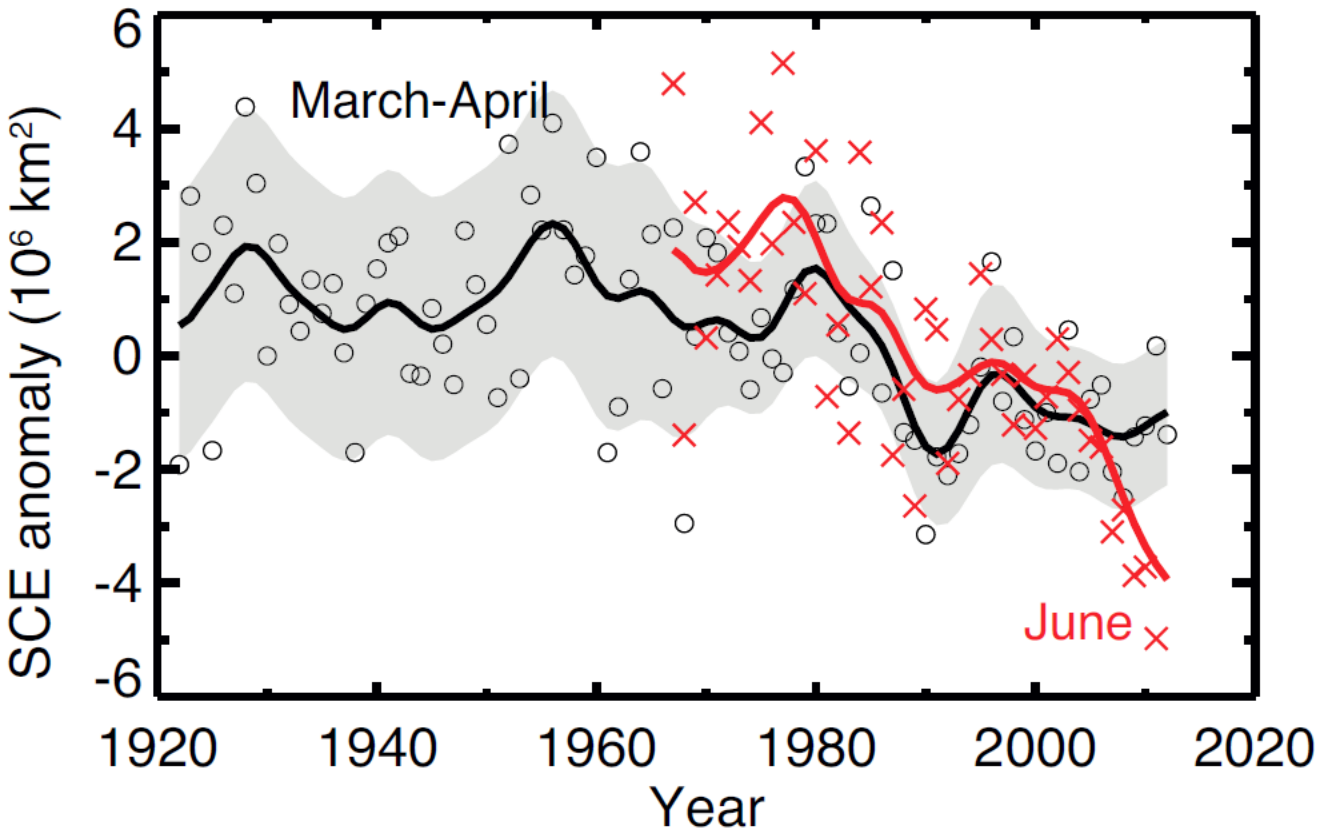
Global warming

Snow depth ?

Snow cover extent ?

Snow phenology ?

Snow cover extent



IPCC AR5, Fig 4.19

Snow cover extent

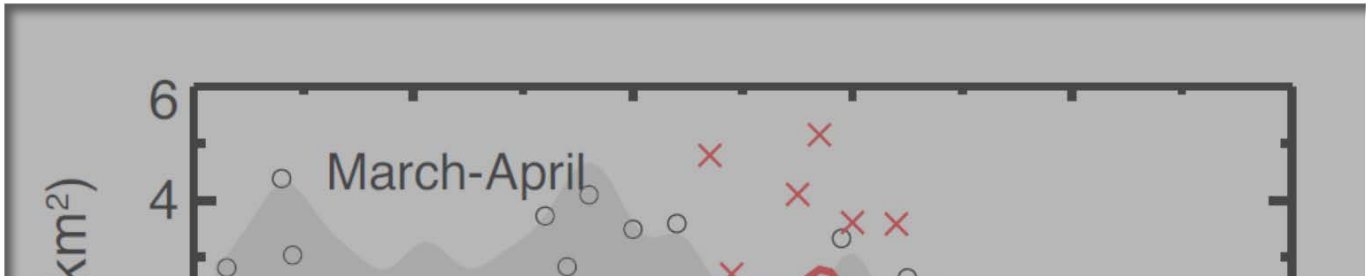
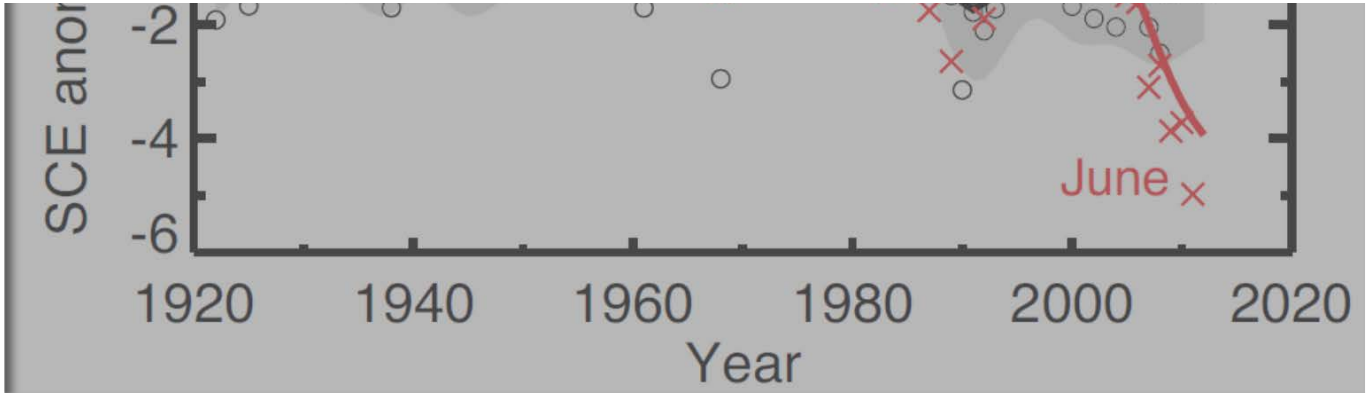


Table 4.7 | Least-squares linear trend in Northern Hemisphere snow cover extent (SCE) in 10^6 km² per decade for 1967–2012. The equivalent trends for 1922–2012 (available only for March and April) are –0.19* March and –0.40* April.

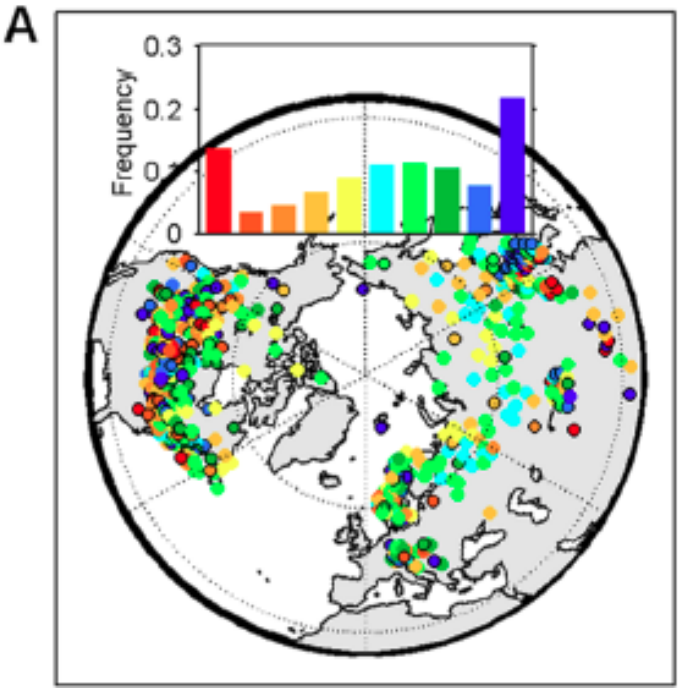
Annual	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
–0.40*	0.03	–0.13	–0.50*	–0.63*	–0.90*	–1.31*	n/a	n/a	n/a	n/a	0.17	0.34



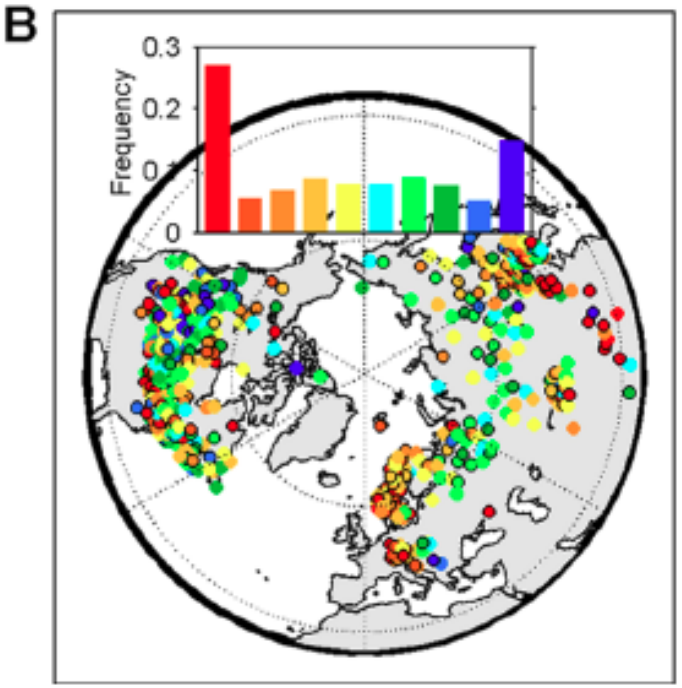
IPCC AR5, Table 4.7

Snow phenology

Trend of snow onset date



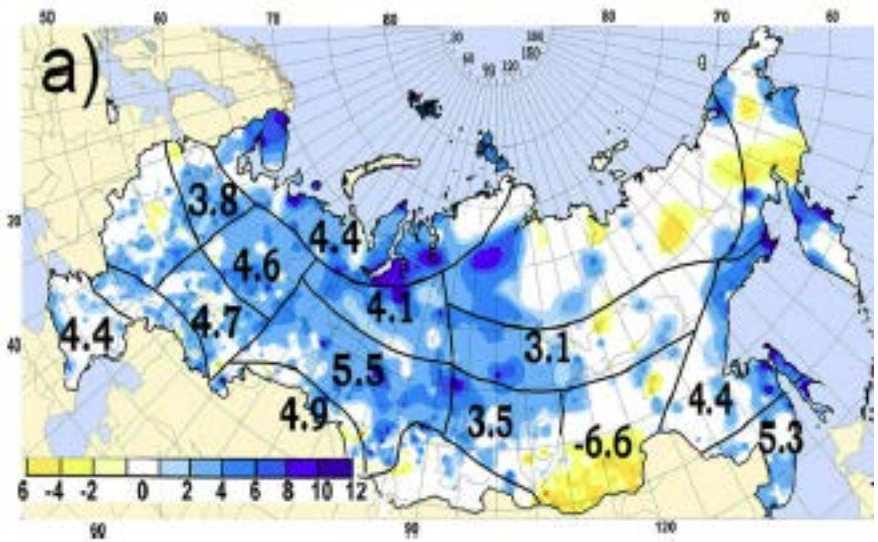
Trend of snow end date



Peng et al., 2013, ERL

Snow depth

Trend of maximum snow depth
1966-2008



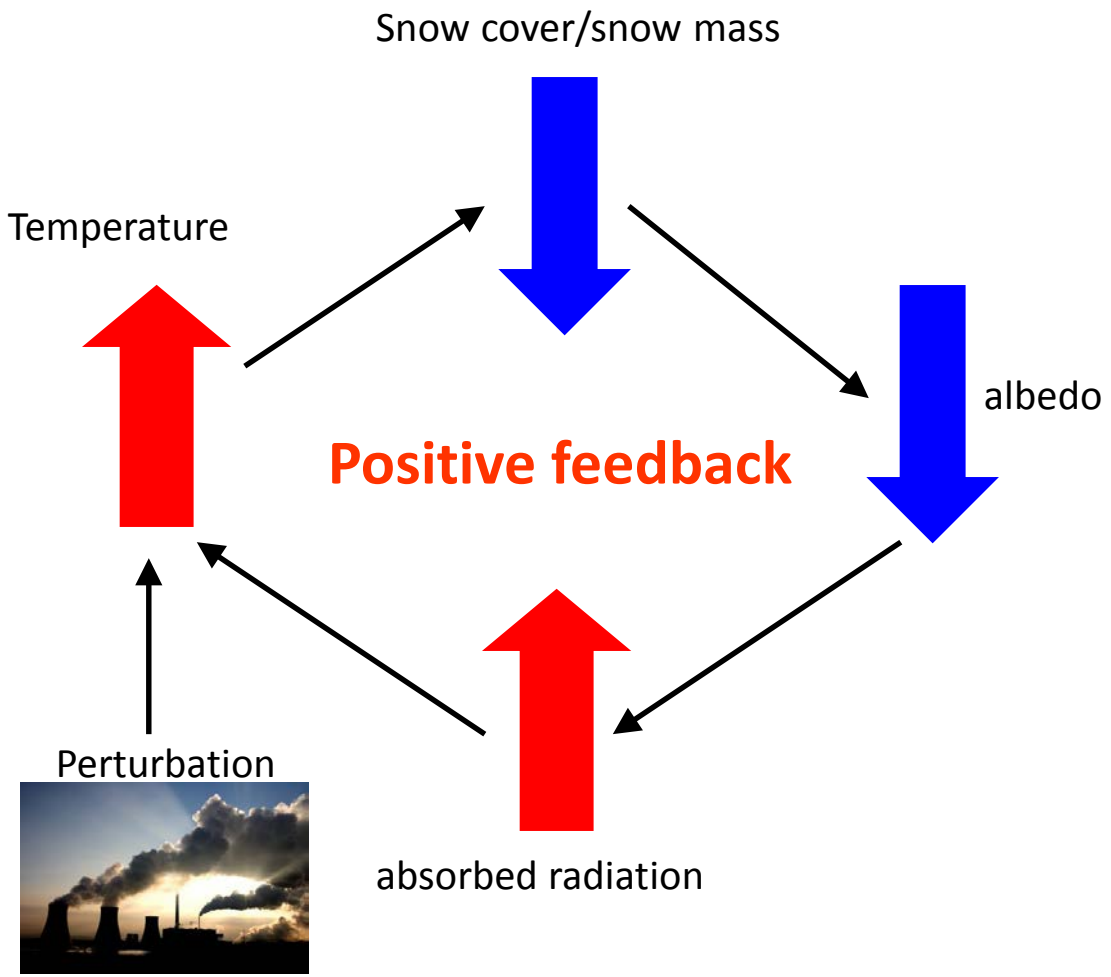
Bulygina et al., 2011, ERL

Changes

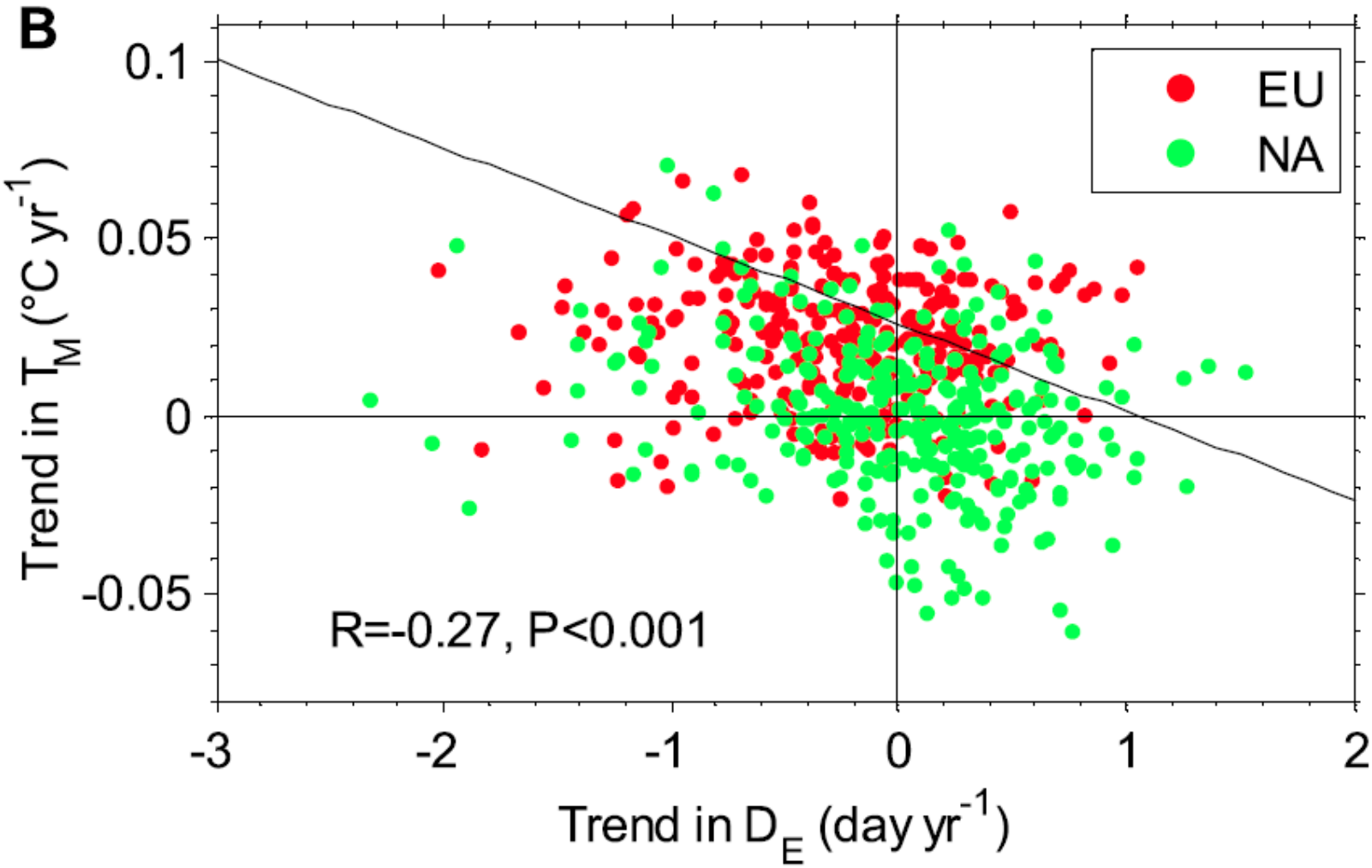
Feedbacks

Snow albedo - climate

Background

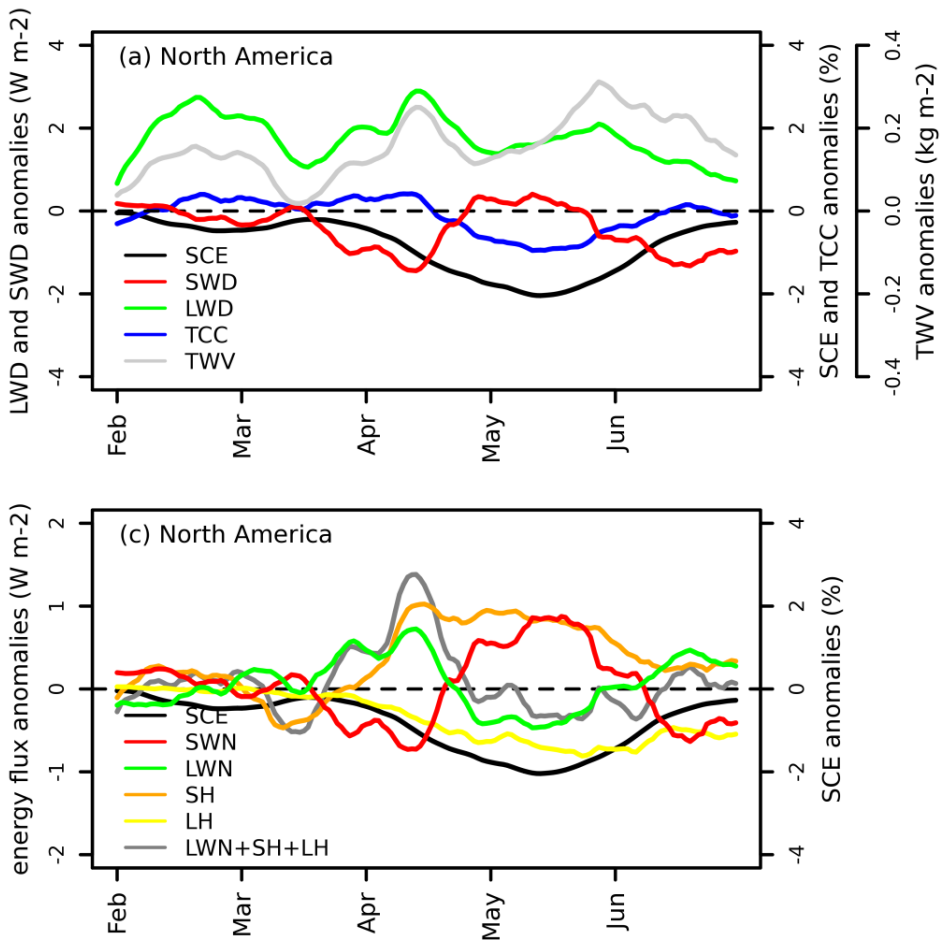


Snow albedo feedback from stations



Relative importance of different surface energy fluxes

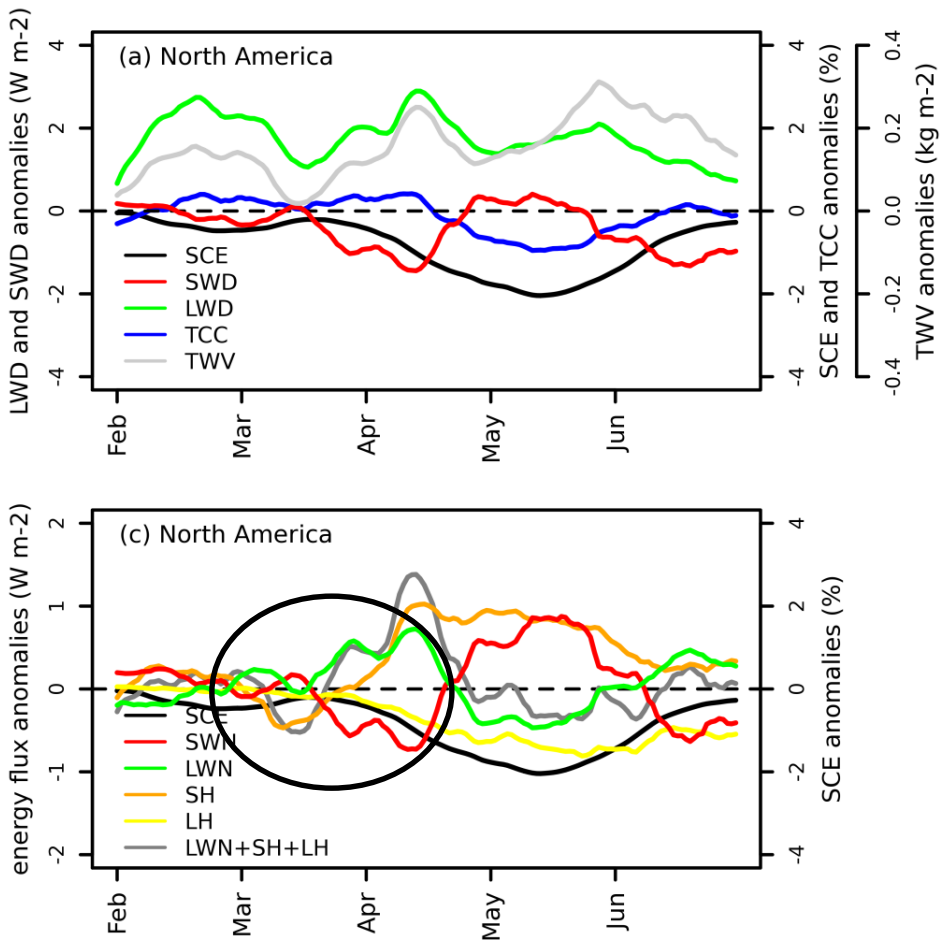
Low SCE years



(Wang et al., 2015)

Relative importance of different surface energy fluxes

LWNET Initialize the anomaly of spring snowmelt

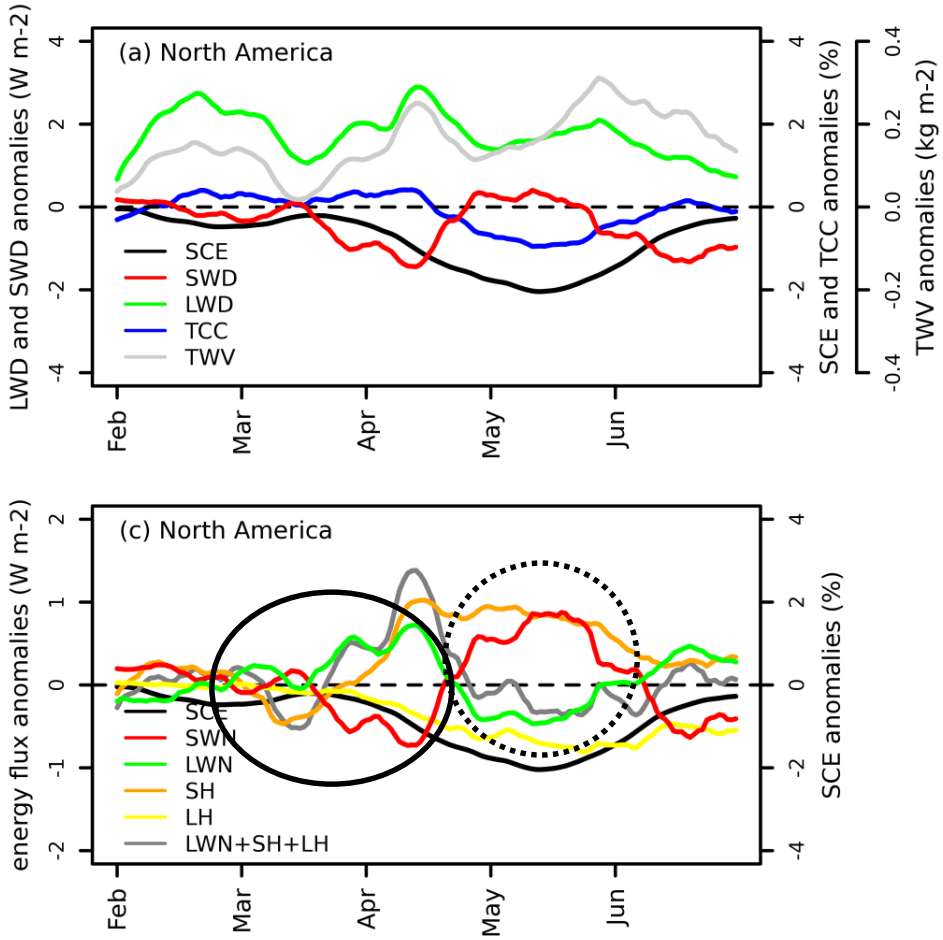


(Wang et al., 2015)

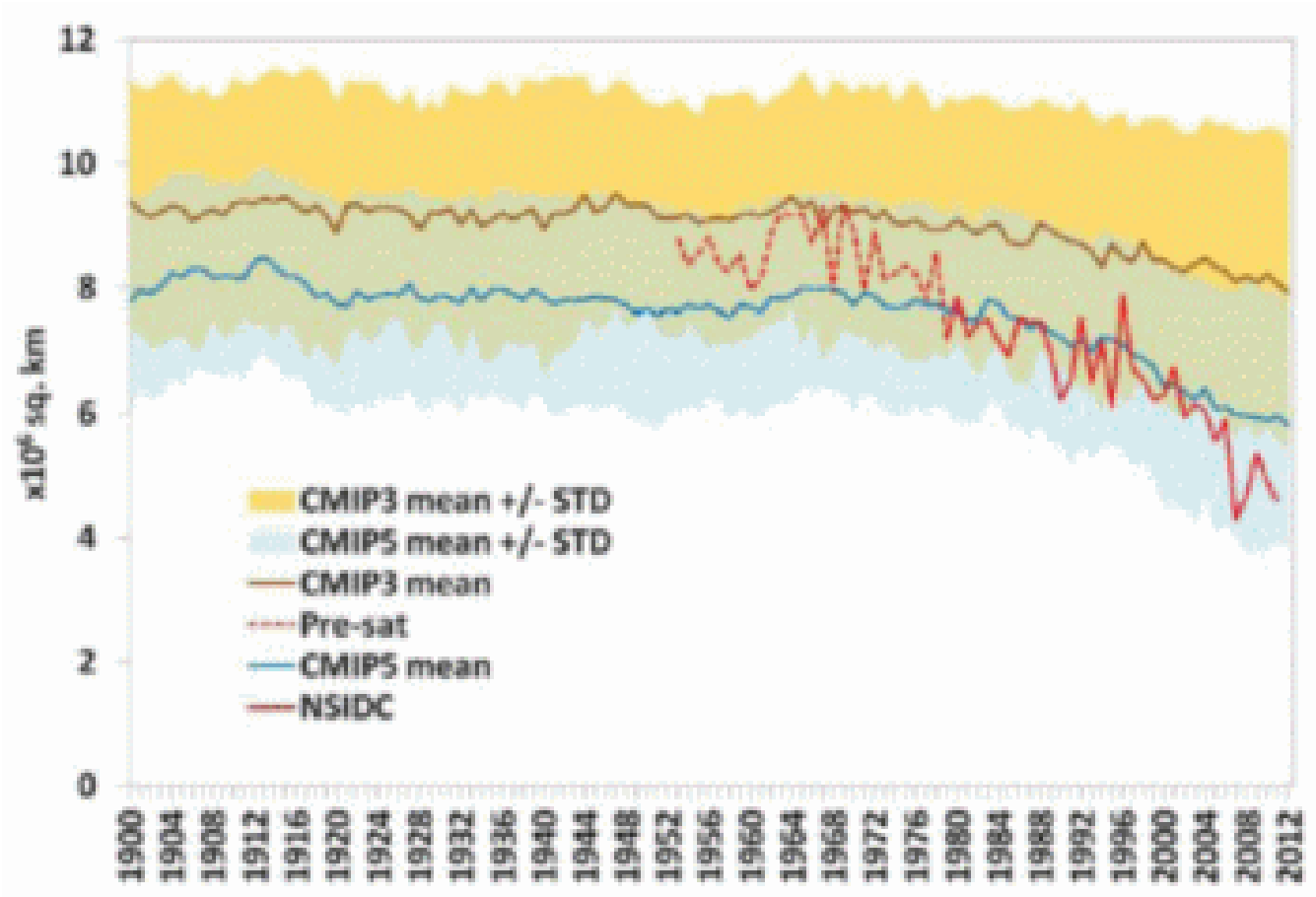
Relative importance of different surface energy fluxes

LWNET Initialize the anomaly of spring snowmelt

SWNET amplify this anomaly



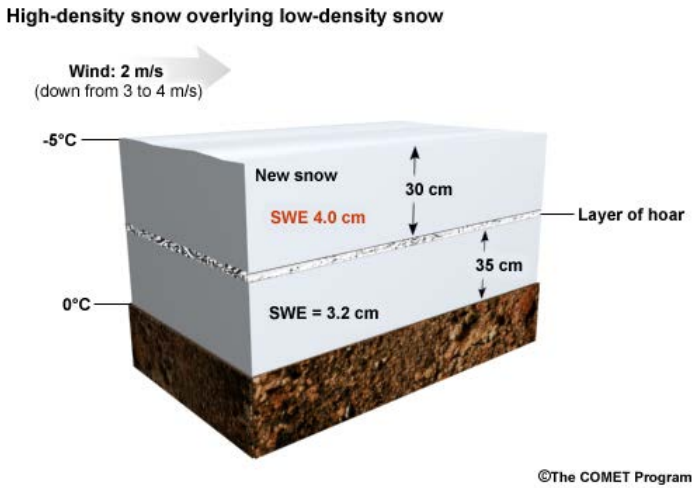
(Wang et al., 2015)

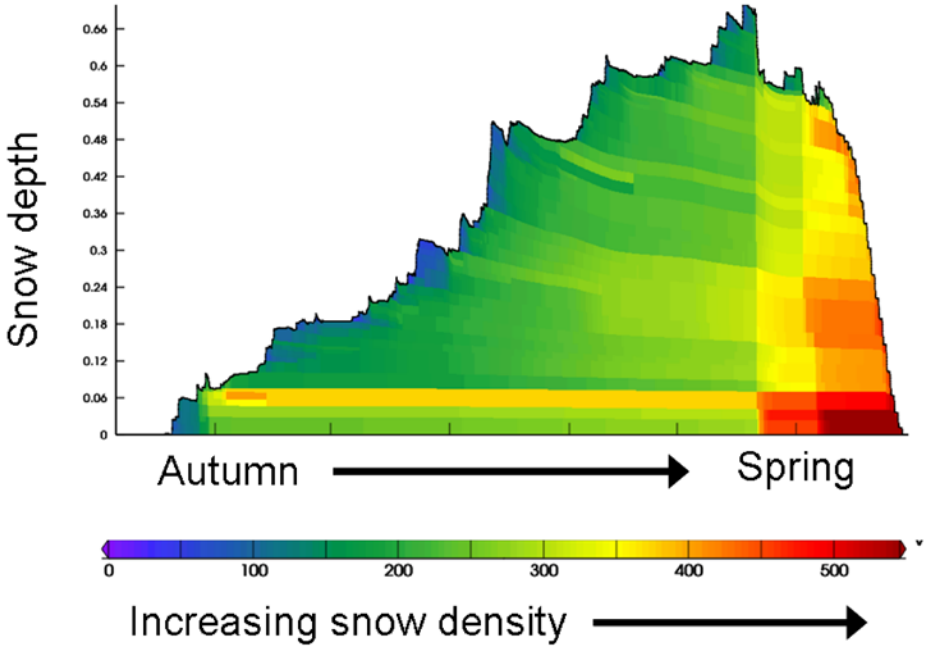


Stroeve et al. (2012)

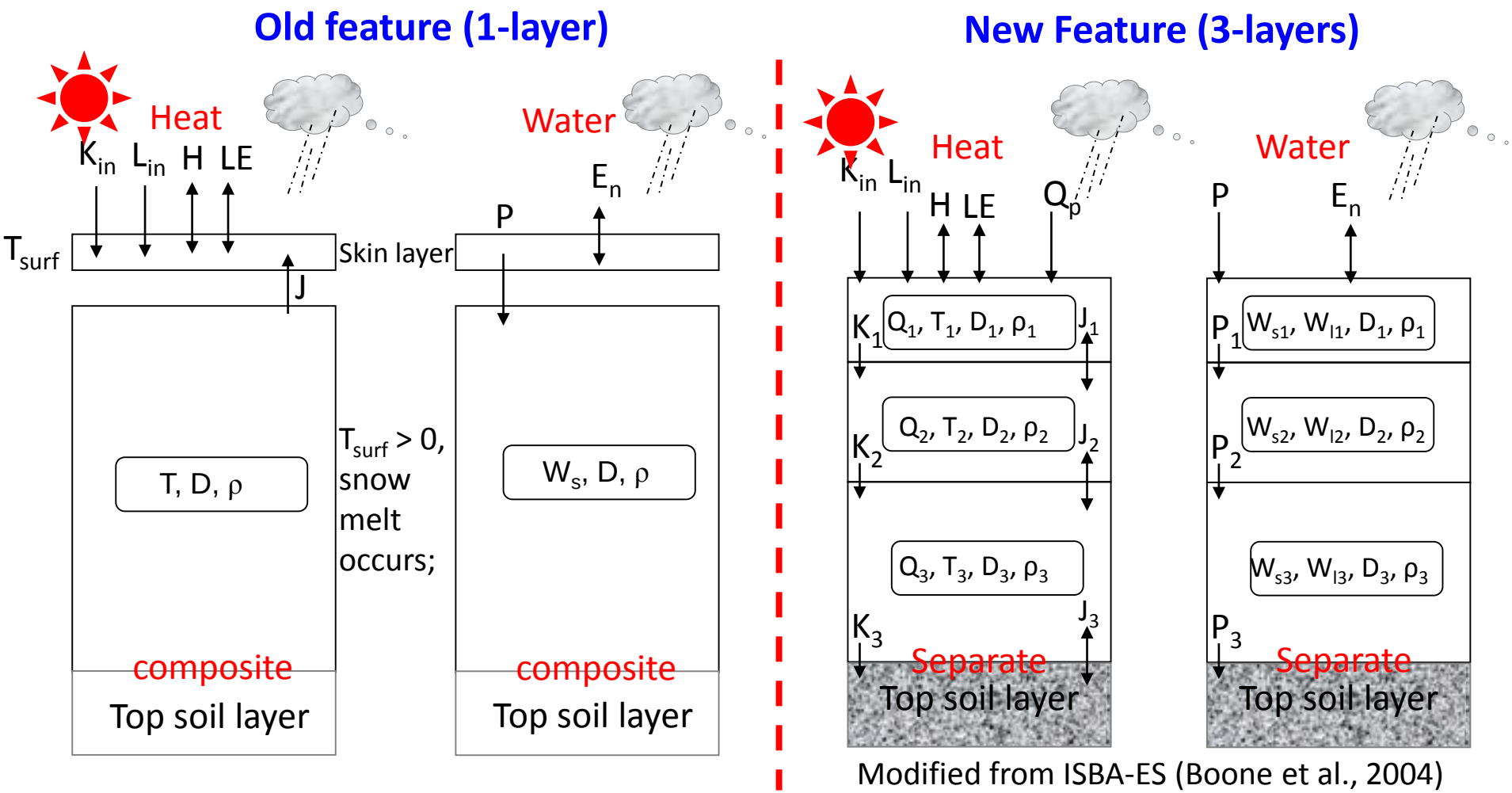
Snow simulations


Day 1 - 10 AM
Day 1 - 3 PM
Day 2 - 10 AM
Day 2 - 4 PM


High-density snow overlying low-density snow
Wind: 2 m/s
(down from 3 to 4 m/s)
-5°C
New snow
30 cm
SWE 4.0 cm
Layer of hoar
35 cm
0°C
SWE = 3.2 cm
©The COMET Program


Snow depth
0.66
0.6
0.54
0.48
0.42
0.36
0.3
0.24
0.18
0.12
0.06
0
Autumn
Spring
0
100
200
300
400
500
Increasing snow density

Snow module

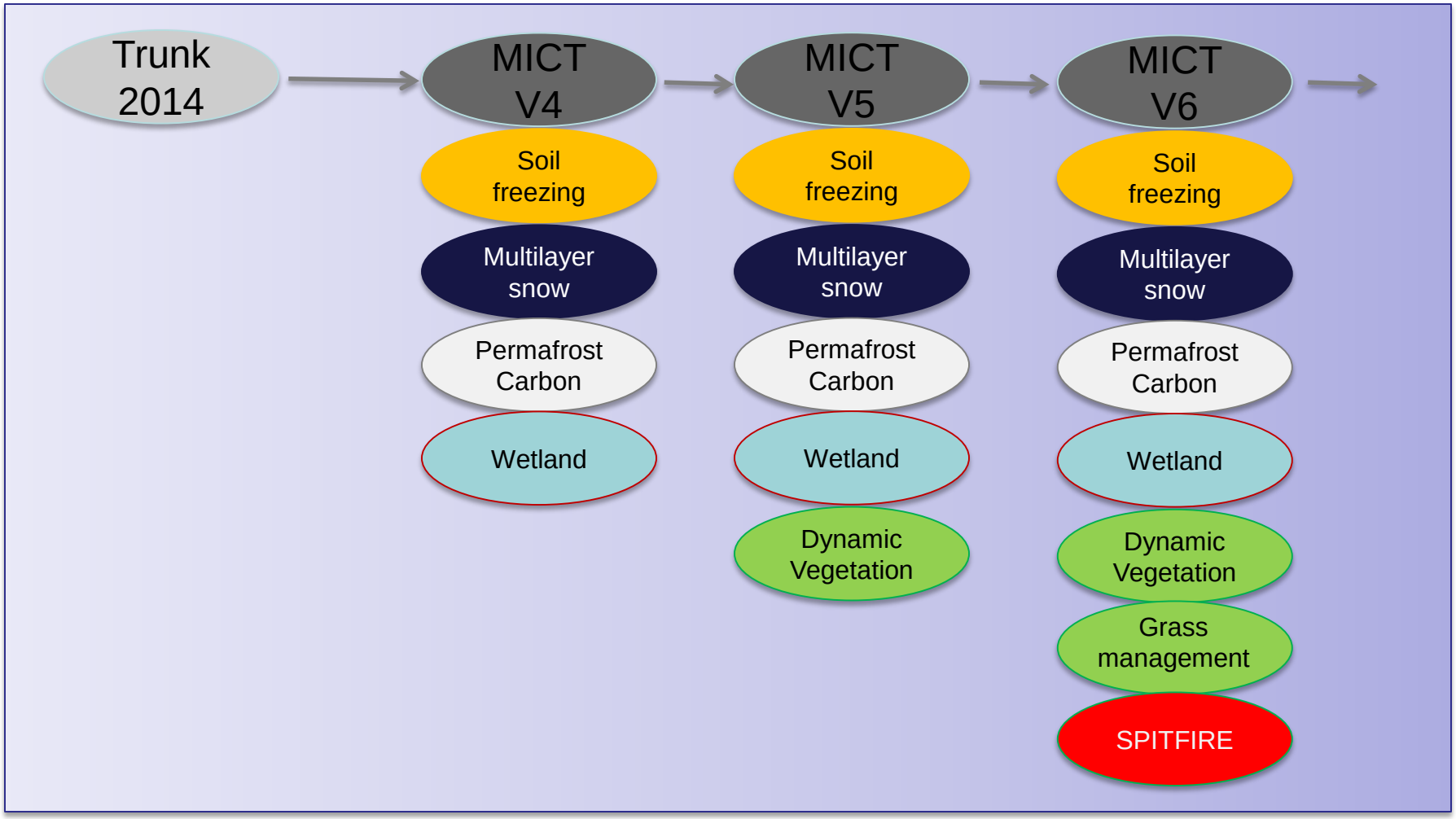


Modified from ISBA-ES (Boone et al., 2004)

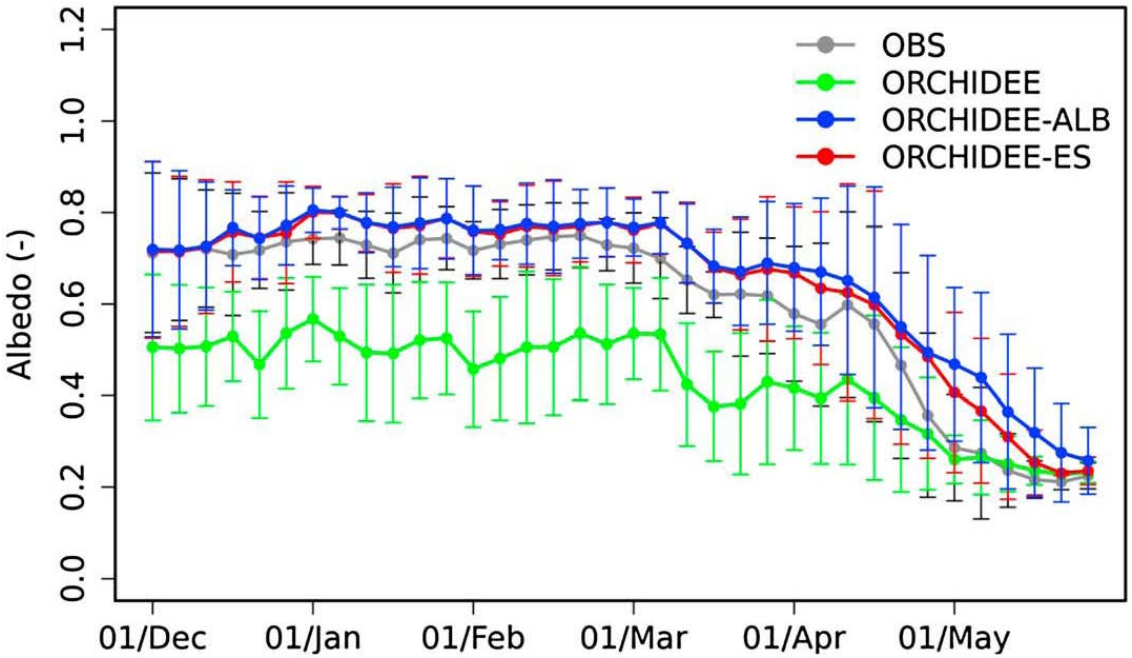
K_{in} (short wave radiation), **L_{in}** (longwave radiation), **H** (sensible heat flux), **LE**(latent heat flux), **J** (conduction heat flux), **W_s** (Snow layer water equivalent), **W_l** (Snow layer liquid water content), **D** (snow depth), **ρ** (snow density, constant in ORC-O) , **P** (precipitation), **E_n** (evaporation), **T**(snow temperature), **Tsurf** (skin layer temperature), **Q** (snow layer heat content), **Q_p**(advective heat from rain and snow)

Wang et al. (2013), JGR

Evolution of high-latitude ORCHIDEE version



Snow module validation



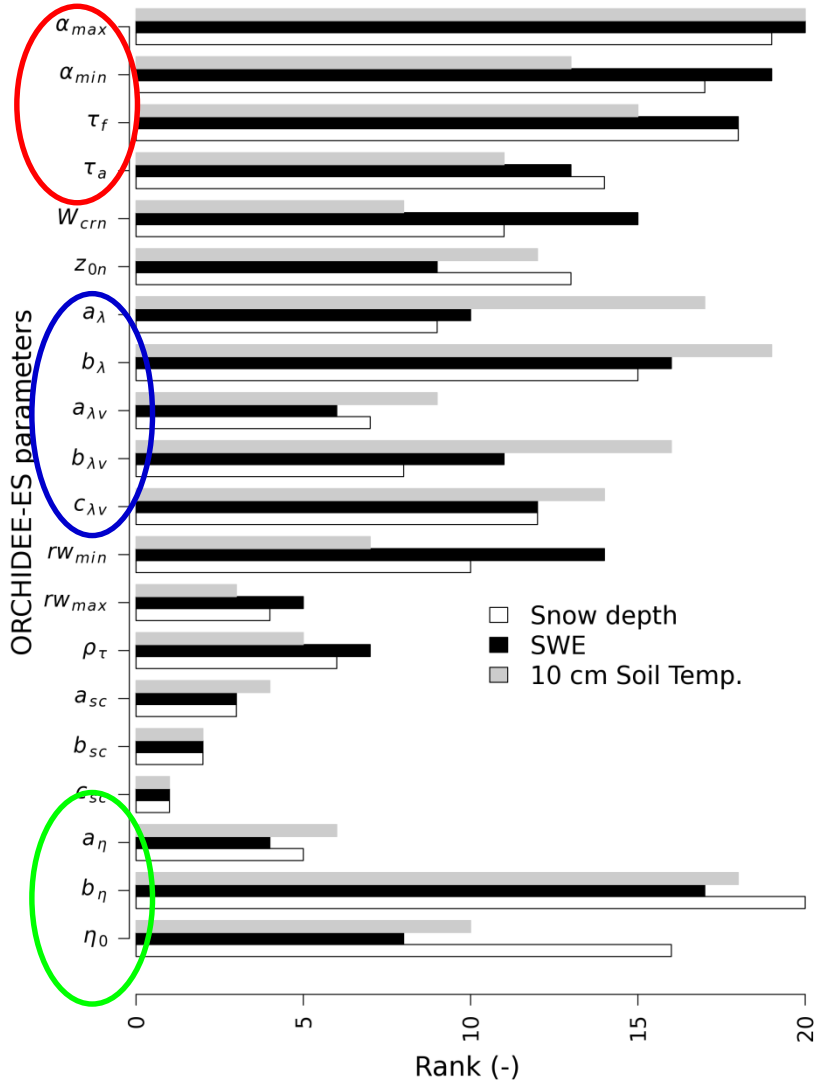
Parameters for snow module

Parameters sensitivity – Morris Analysis

Albedo

Conductivity

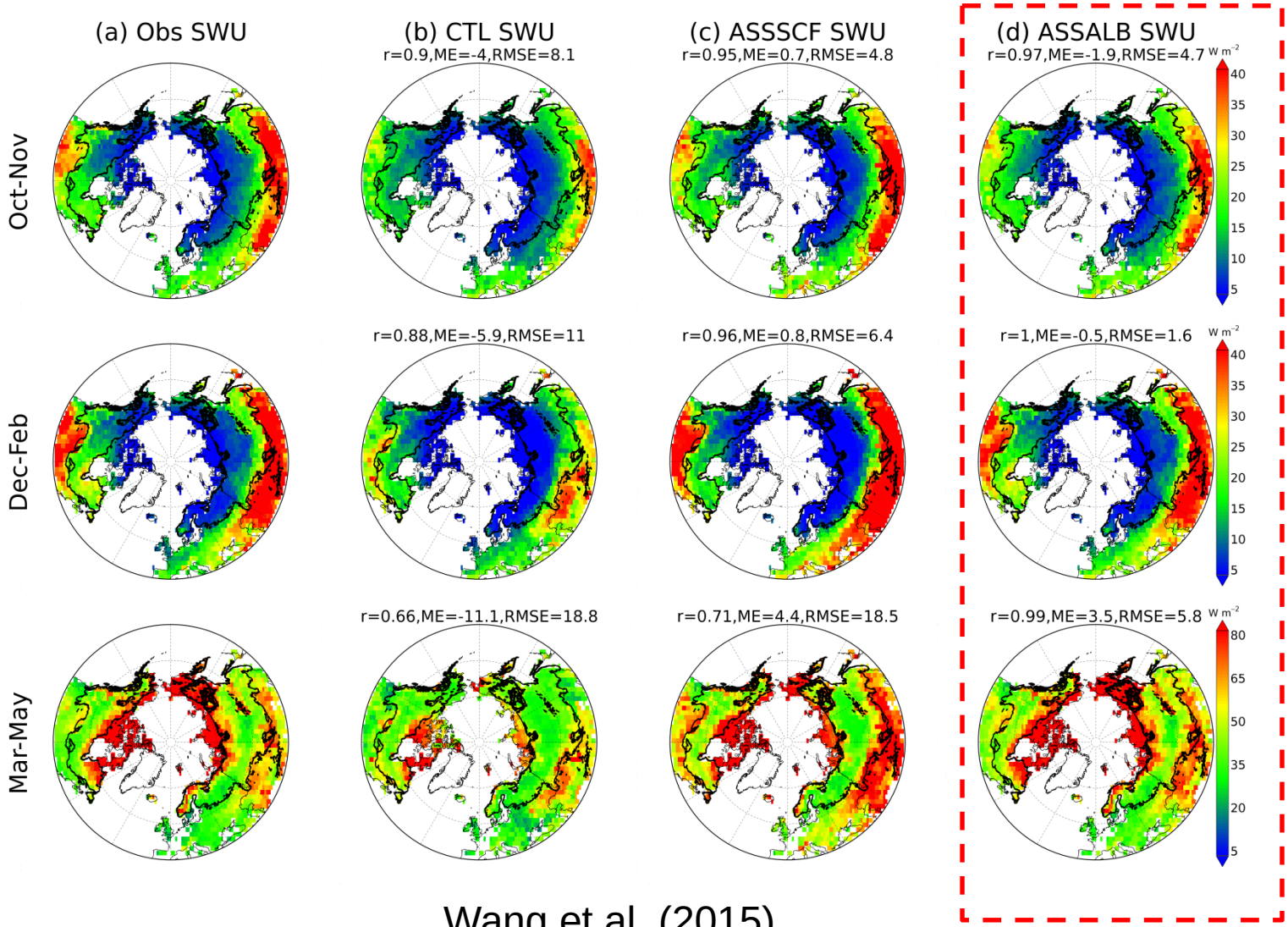
Density



Coupled simulation

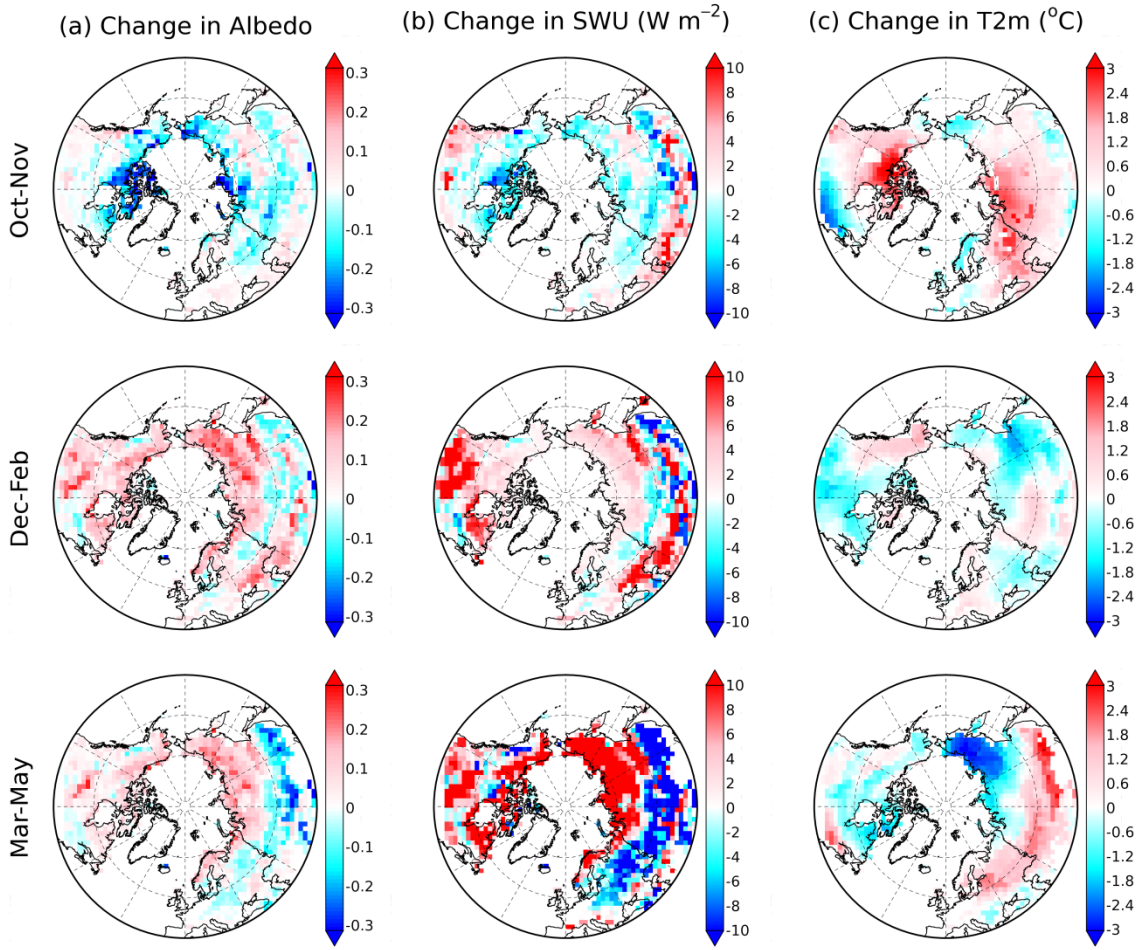
ORCHIDEE + LMDZ

Removing modeled Albedo bias through data assimilation



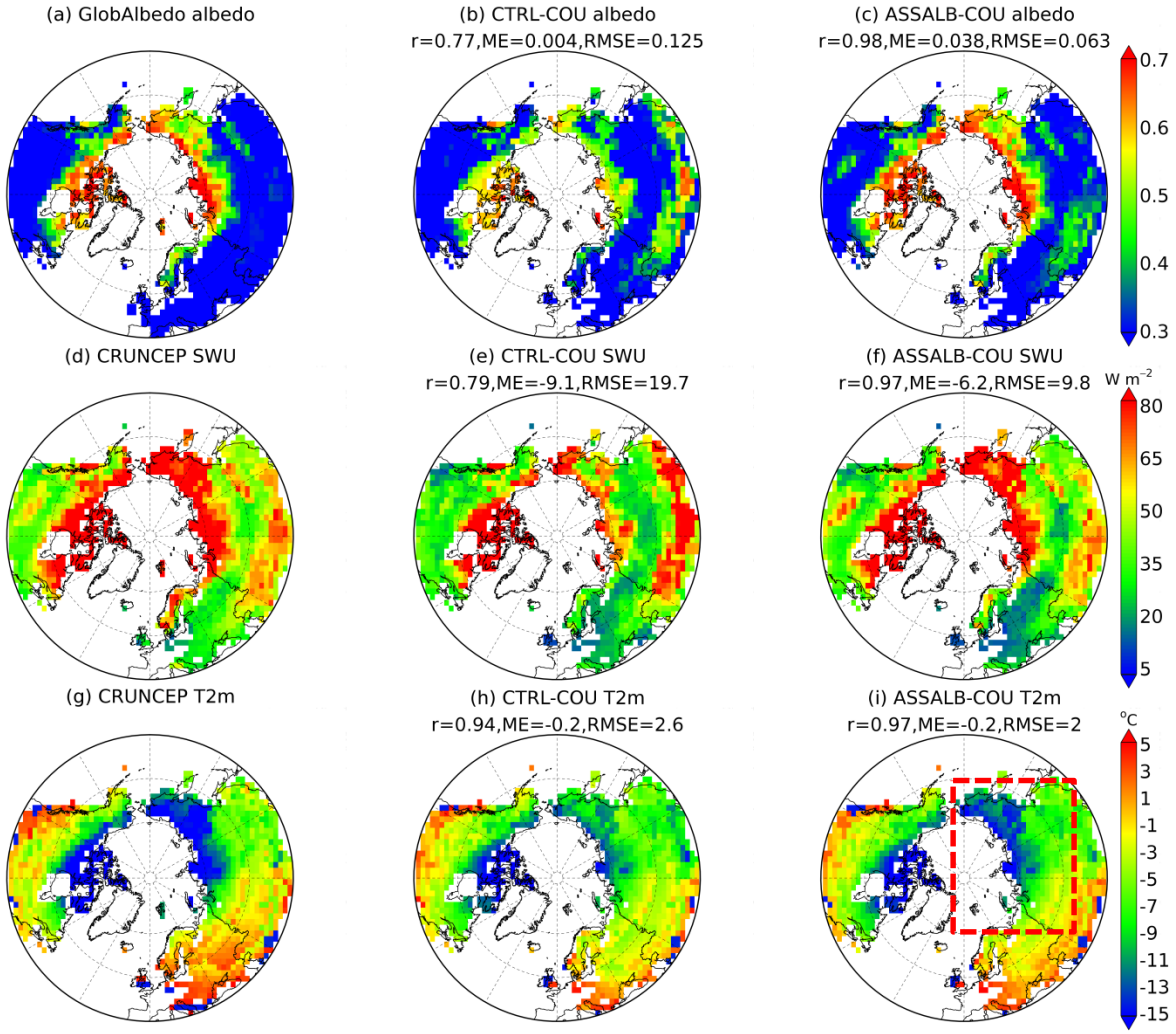
Wang et al. (2015)

Impacts of albedo assimilation during snow season



Wang et al. (2015)

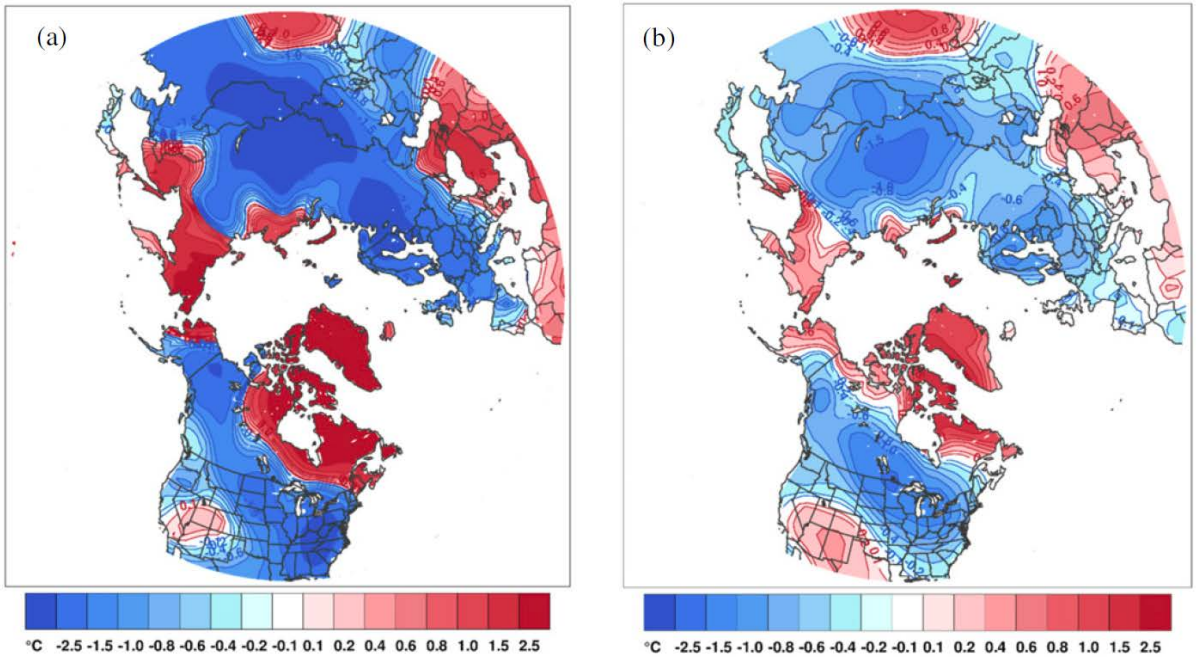
Impacts of albedo assimilation on spring climate



Air temperature simulations are significantly improved during the spring in particular over the eastern Siberia region

Wang et al. (2015)

Global Warming May Trigger Winter Cooling



http://web.mit.edu/jlcohen/www/papers.html

http://news.sciencemag.org/2012/01/global-warming-may-trigger-winter-cooling