Using reanalyses for studying past Eurasian snow cover and its relationship with circulation variability

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Outlines

- Challenging reconstruction of past snow conditions
- Snowpack models : a complementary approach to snow reanalysis and to satellite retrievals
- Reconstruction of Eurasian snow cover based on Crocus simulations driven with Era-interim
- 20CR snow cover over Northern Eurasia in Fall and its relationship with the Arctic Oscillation
- Some weaknesses in the ERA-interim and 20CR snowpack representation over pan-Arctic and Antarctic regions

Snow cover and predictability in polar regions

Multi time scales influence of the snow cover on the atmosphere

- Daily scale : high impacts on the boundary layer (cooling effects, stability ...) $\Longrightarrow$ weather forecast errors
- Seasonal scale : Eurasian snow extent in Fall is a potential source of predictability for the Arctic Oscillation during the following Winter
- Climate scale : an important source of feedbacks (albedo) and high impacts (permafrost thawing, ecosystems, hydrological cycle...)

Poor knowledge of past and present snow conditions

In-situ snow observations

- Only a few long term series of snow depth in the past
- Uneven distribution of observations in space and time

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Satellite snow retrievals

- Daily snow cover and SWE products but ...
- Several shortcomings in the retrieval of snow conditions from satellites :
  - no depth retrievals, only snow cover and snow water equivalent (SWE)
  - no cover observations under cloudy conditions, no SWE observations in melting conditions
- No observations before the 1970's

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⟹ Snow cover reanalyses suffer from time and space inconsistencies
⟹ A complementary approach based on snowpack simulations driven by reanalysed meteorological conditions

1 Introduction

2 Snow models and evaluation data

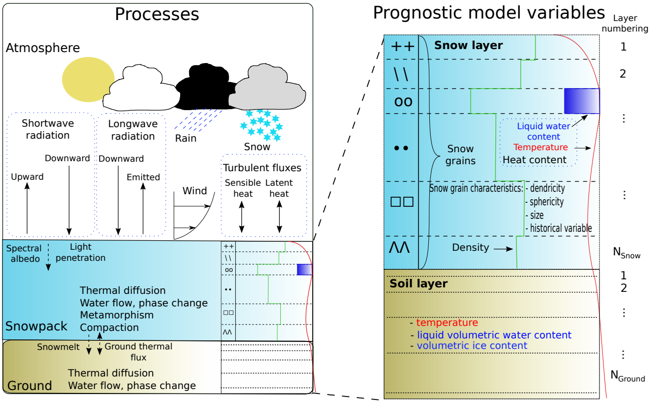
3 ERA-interim / Crocus

4 20CR Snow cover evaluation

5 Persectives

6 Add-ons

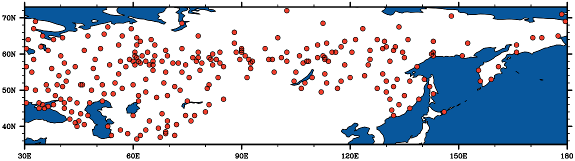
Crocus : a detailed snowpack model coupled with the ISBA-DF soil model



(Brun et al., 1992 ; Vionnet et al., 2012)

Historical data sets for model evaluation

- Historical Soviet Daily Snow Depth (HSDSD) :
  - *daily snow depth at synoptic stations (open fields) / year-round*
  - *263 stations : > 1,100,000 quality-controlled obs. (1979-1993)*
  - *some records start in 1891*
  - *easy access from NSIDC portal*



- + co-located observations of SWE 3 times/month
- + co-located monthly observations of soil temperature

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Simulation configurations

ERA-interim reanalysis ECMWF

- $\sim$ 80 km resolution
- 4D-Var assimilation system
- precipitation from model forecasts
- radiation from model forecasts

(Dee et al., 2011)

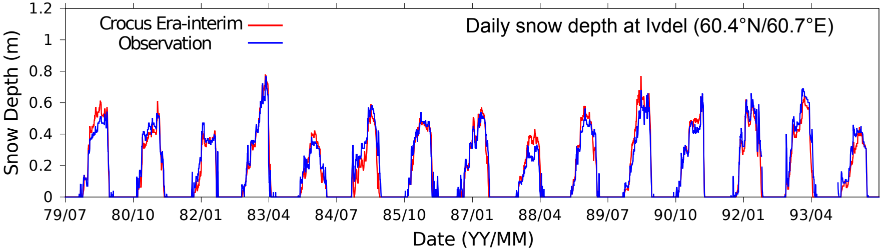
Crocus snow model ISBA-DF soil model

- simulations at each station site (altitudinal correction)
- 2D simulations over Eurasia
- outputs : snow depth, SWE, density, soil and snow internal profiles

+ additional configurations/options :

- forcings from Global Forcing Princeton University data set (PGF) (NCEP-NCAR reanalysis and monthly precipitation scaling from CRU/GPCP)
- ...

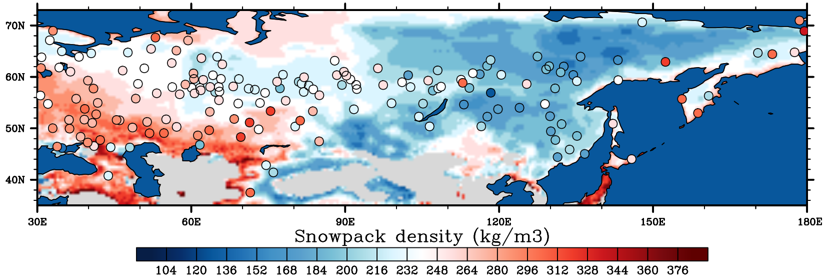
Illustration of Era-interim / Crocus performance



Similar performance to local simulations
driven with observed meteorological observations !

(Brun et al., 2013)

Evaluation of simulated snowpack density



Comparison between observed (circles) and simulated density (2D field) on 10 March (average 1979-1992)

(Brun et al., 2013)

Snow simulations derive characteristics which cannot be directly analysed

Comparison with GlobSnow SWE retrievals

GlobSnow :

- ESA funded snow product developed by FMI
- Gridded daily SWE products based on in-situ snow depth observations and satellite Micro-Wave observations

(Luojus et al., 2011)

All observations	GlobSnow	Crocus/ERA-I
number of obervations	137,379	109,189
bias ($kg\,m^{-2}$)	-4.8	0.9
RMSe($kg\,m^{-2}$)	44.9	44.6

The domain and the period sightly differ.
Snow simulations : ERA-Interim meteorological forcing / blowing snow sublimation

Crocus/ERA-Interim simulations and GlobSnow retrievals perform very similarly for SWE

Evaluation of soil temperature (at 20 cm depth)

soil temperature $\Longleftrightarrow$ snowpack depth and density

For a given SWE, the snowpack thermal resistance $\sim\propto \frac{1}{\rho^3}$
$2\times$ density $\Longrightarrow\sim 8\times$ snow / soil heat flux

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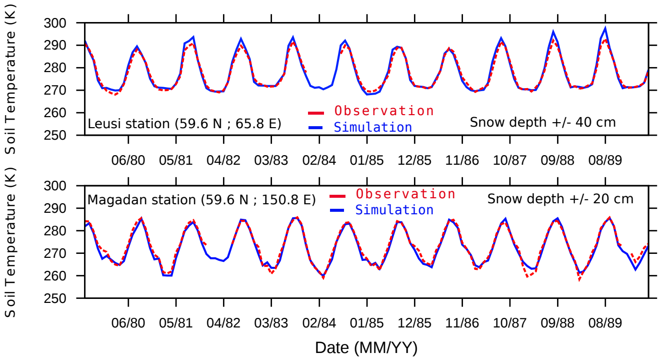

Main results

Present performance of reanalyses and snow models $\Rightarrow$ very performing simulations of local snowpacks

- Small bias in snow depth, onset and melt-out dates, density, SWE and soil temperature (open field and flat)
- A few stations are poorly simulated (unresolved local meteorological conditions : wind, precipitation)
- Much better performance with ERA-Interim than with PGF
- Blowing snow sublimation is a critical process
- Similar performance to satellite snow products which assimilate snow observations $\Longrightarrow$ complementarity still to be exploited !
- Similar performance for snow variables with HTESSEL in ERA-interim/Land (not shown / see Balsamo et al., 2012)

20CR snow cover

1. Introduction
2. Snow models and evaluation data
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4. 20CR Snow cover evaluation
5. Persectives
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20CR snow cover

Evaluation of the possibility to drive snow models with 20CR (Compo et al., 2011)

- 20CR targets the highest possible consistency over time
- All variables for driving snow models are available
- 20CR includes an intermediate complexity snow model (NOAH)
- 20CR does not assimilate any snow related observation

$\Longrightarrow$ Detailed evaluation of 20CR snow cover and depth as a first stage

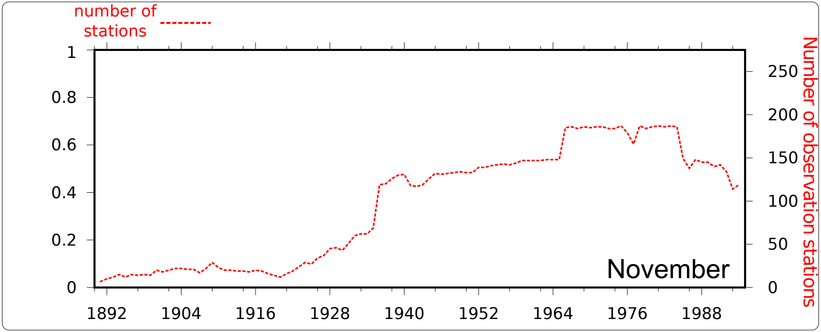
Performance of 20CR snow cover over Northern Eurasia (South 60N)

Evaluation of 20CR snow cover

- Extraction of 20CR daily snow cover gridded field
- Transformation into a binary field (snow / no snow) (threshold 50%) :
  $\Longrightarrow$ SC-20CR
- Same process with Northern Hemisphere weekly snow cover extent :
  $\Longrightarrow$ SC-NOAA
- Transformation of in-situ snow depth observations into "snow / no snow" (threshold 5 cm)
- Creation of a snow detection performance index :
  - rate of daily in-situ observations in agreement with SC-20CR
  - rate of daily in-situ observations in agreement with SC-NOAA

(Peings et al., 2013)

Performance of 20CR snow cover over Northern Eurasia (South 60N)



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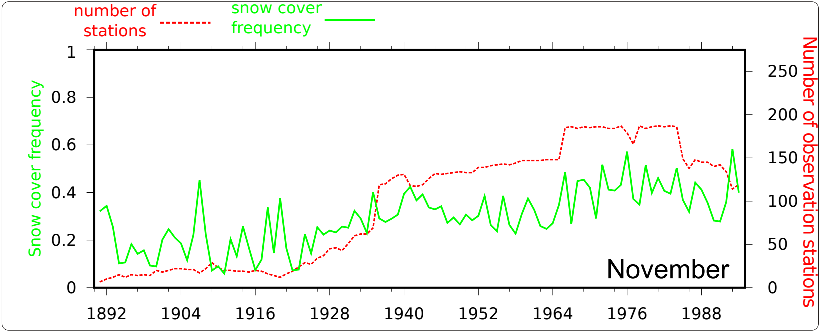

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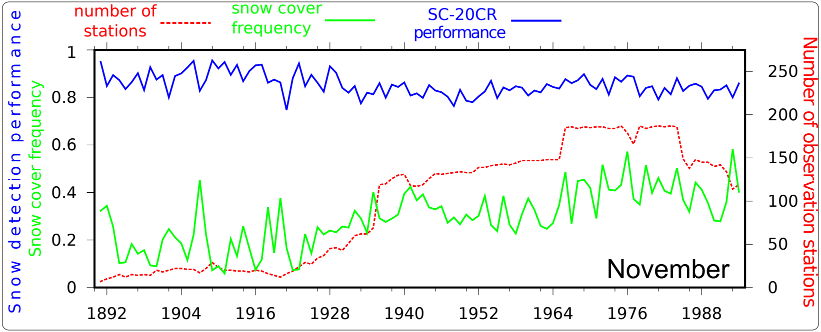

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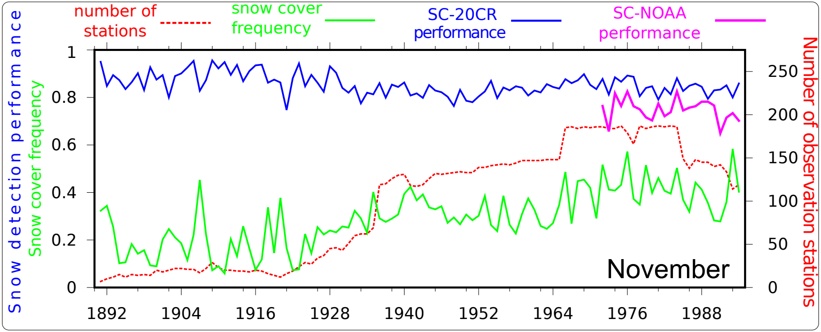
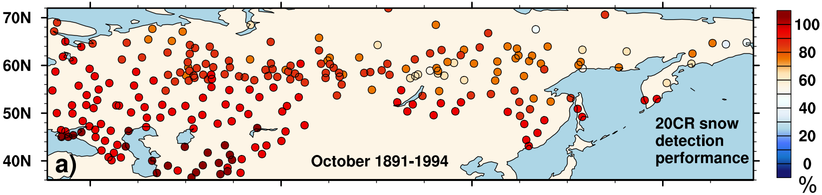


(Peings et al., 2013)

Homogeneous performance of 20CR snow cover in Fall

(Peings et al., 2013)



Homogeneous performance of 20CR snow cover in Fall

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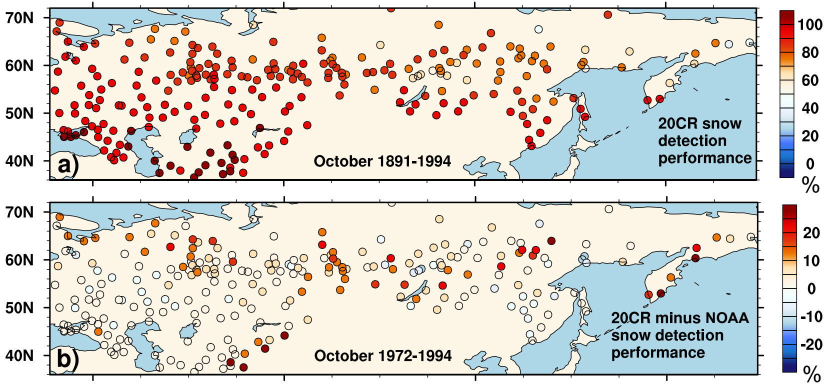

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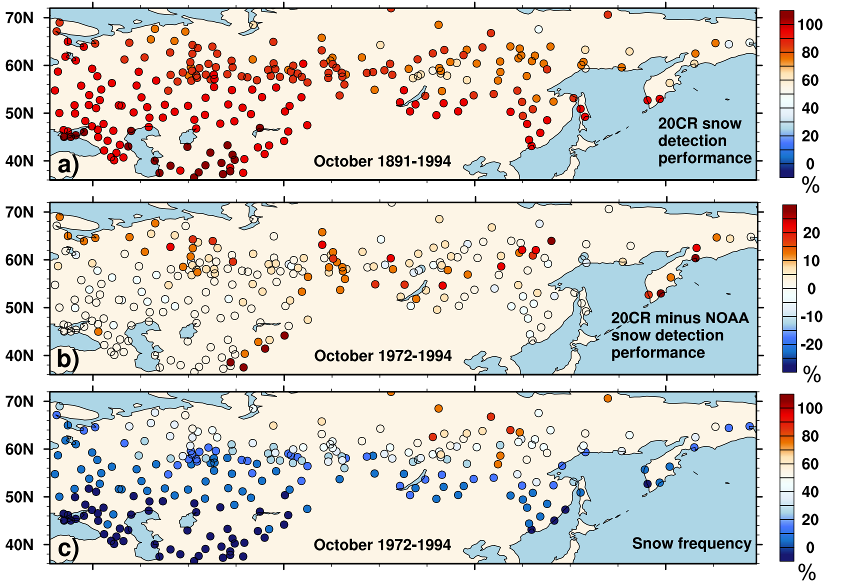
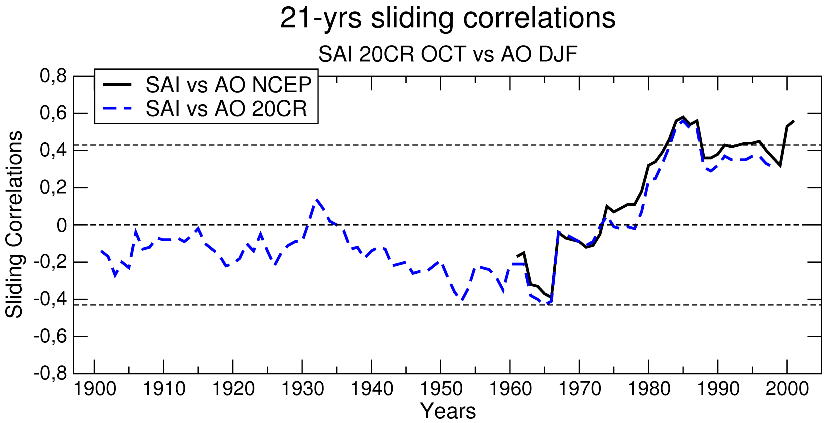


Unsteady relationship between Eurasian SC and the AO



(Peings et al., 2013)

Conclusions and Perspectives

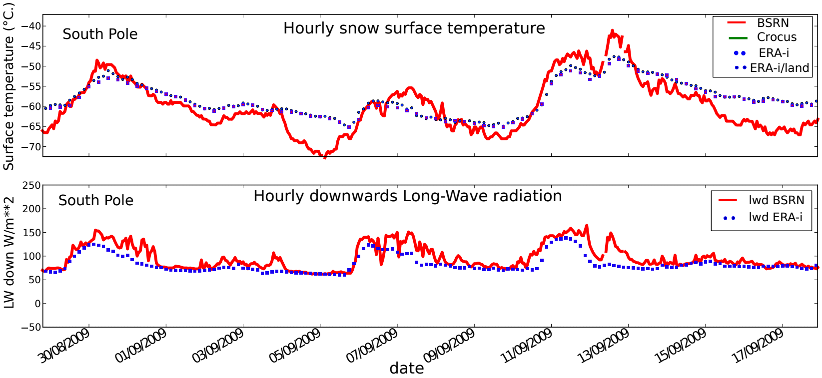
ERA-interim : excellent forcings for driving snow models

- a very reliable source of meteorological variables
- better than PGF data set which uses observed monthly precipitation

$\Longrightarrow$ realistic and unbiased simulations of snow depth, SWE, density
$\Longrightarrow$ realistic and unbiased simulations of snow covered periods
$\Longrightarrow$ snow reconstruction as reliable as in-situ/satellite gridded products

... but some weaknesses in ERA-interim snow scheme probably hidden by the analysis process

Weaknesses in surface temperature (South Pole)



courtesy (Tatarinova and Fréville)

$\Longrightarrow$ warm bias in annual snow surface temperature ∼3˚C.

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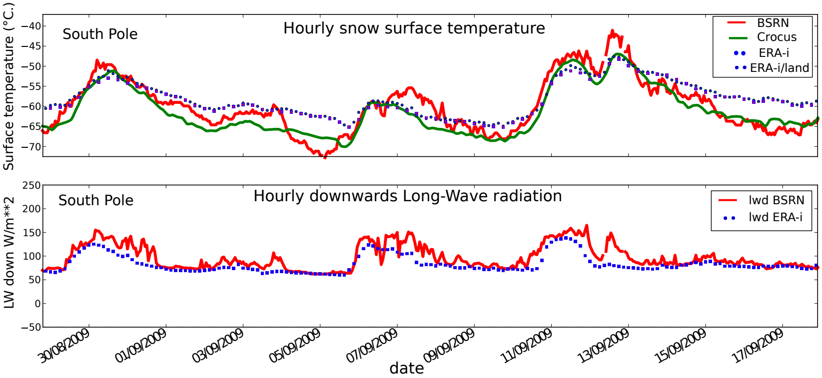


courtesy (Tatarinova and Fréville)

$\Longrightarrow$ warm bias in annual snow surface temperature $\sim$3˚C.

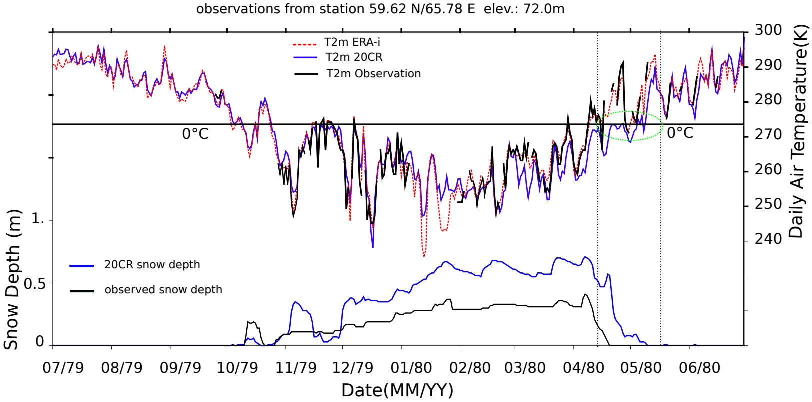
Impressive performance of 20CR snow cover in Fall

- steady performance since 1891
- homogeneous performance over Northern Eurasia
- not as good as ERA-i/Crocus but better than satellite products !

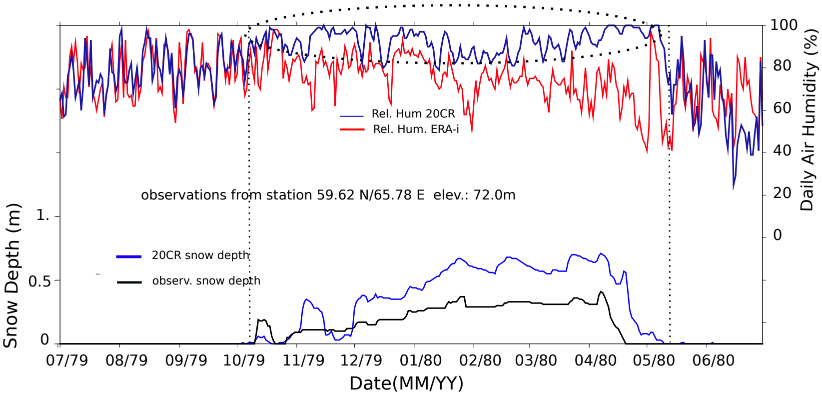
Some weaknesses :

- overestimation of snowfalls in mid-winter
- overestimation of humidity in presence of snow
- too cold air temperatures during the melting season

Weaknesses over snow covered regions



Weaknesses over snow covered regions



Acknowledgements

Thanks for your attention !

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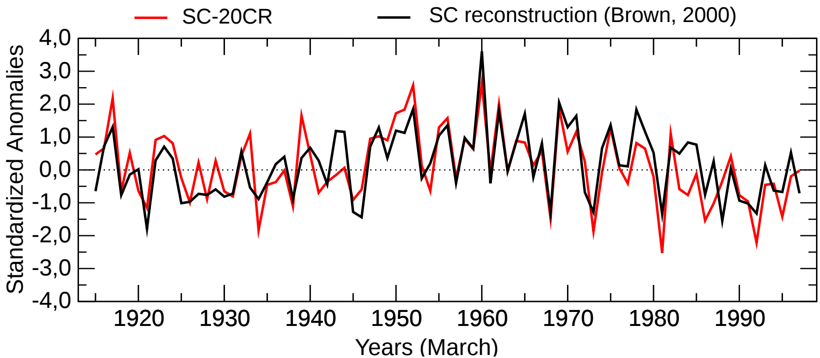
- ANR project CLASSIQUE
- EU project COMBINE
- CONCORDIASI

20CR snow cover extent over North America versus Brown reconstruction

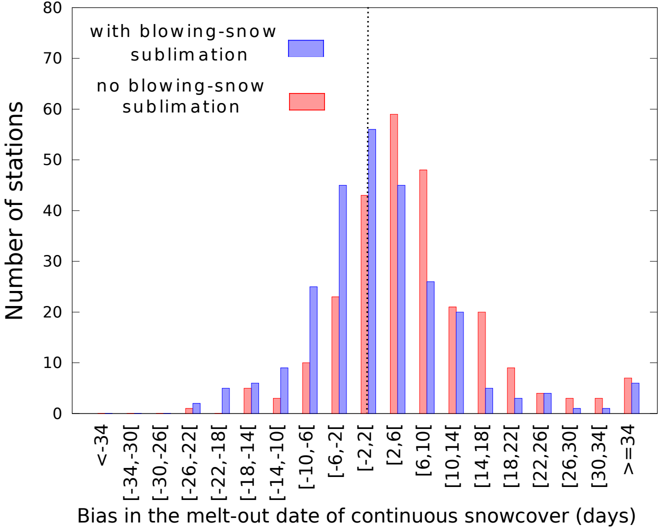


(Peings et al., in press)

Overall performance

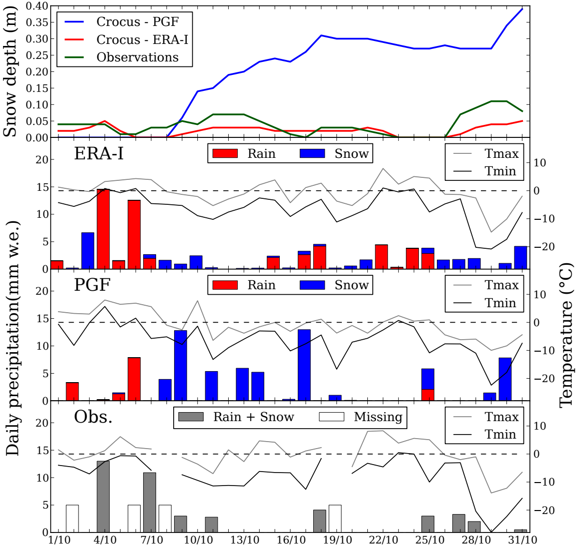
Forcing data set		ERA-I	PGF	ERA-I	PGF	ERA-I	ERA-I
GPCC precipitation scaling		no	no	yes	yes	no	yes
Blowing snow sublimation		no	no	no	no	yes	yes
Variable	Statistics						
Snow depth (m)	Mean	0.150	0.168	0.120	0.165	0.118	0.093
	Bias	0.039	0.056	0.008	0.053	0.006	-0.019
	Corr.	0.887	0.844	0.889	0.862	0.884	0.865
	RMSe	0.117	0.151	0.096	0.143	0.097	0.103
Annual snow duration (days)	Mean	152.0	156.2	145.3	155.6	144.2	134.9
	Bias	6.6	10.8	-0.1	10.2	-1.2	-10.5
	Corr.	0.952	0.946	0.958	0.948	0.950	0.939
	RMSe	21.3	24.0	19.0	23.4	20.8	25.3
Onset of continuous snow cover (days since 1st July)	Mean	134.7	130.2	136.7	130.6	138.4	142.4
	Bias	-5.1	-10.1	-2.9	-9.8	-1.2	3.0
	Corr.	0.893	0.849	0.896	0.854	0.878	0.840
	RMSe	17.1	21.8	16.3	21.5	17.9	21.2
End of continuous snow cover (days since 1st July)	Mean	284.9	284.7	280.7	284.3	280.1	274.9
	Bias	7.2	7.4	2.6	7.1	2.0	-3.6
	Corr.	0.873	0.860	0.879	0.863	0.875	0.858
	RMSe	19.1	20.1	17.2	19.8	17.5	18.7
Snow water equivalent ($kg\,m^{-2}$)	Mean	88.1	87.8	70.2	86.3	68.9	53.1
	Bias	20.1	19.8	2.3	18.3	1.0	-14.8
	Corr.	0.712	0.633	0.736	0.678	0.710	0.712
	RMSe	49.1	56.0	40.5	52.0	41.6	42.8
Density ($kg\,m^{-3}$)	Mean	215.5	195.5	212.6	195.5	211.4	205.7
	Bias	-6.6	-26.7	-9.7	-26.7	-10.3	-15.4
	Corr.	0.669	0.623	0.665	0.626	0.662	0.652
	RMSe	46.2	55.0	47.3	55.0	48.0	50.1

Melt-out date distribution



PGF temperature/soil inconsistency (ex. Pirovskoe)

Pirovskoe (57.6 N / 93.3 E)



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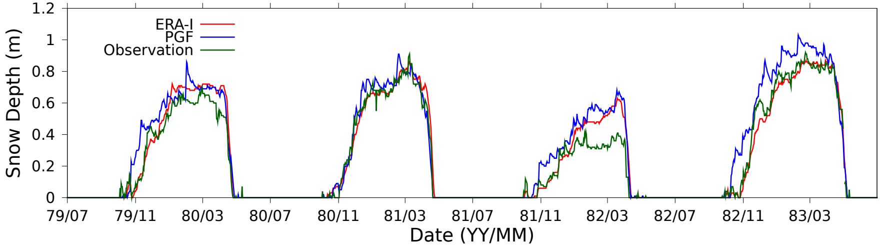
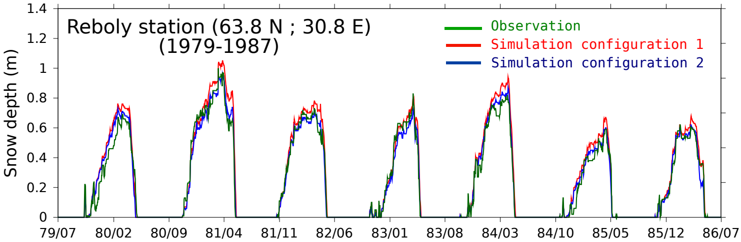
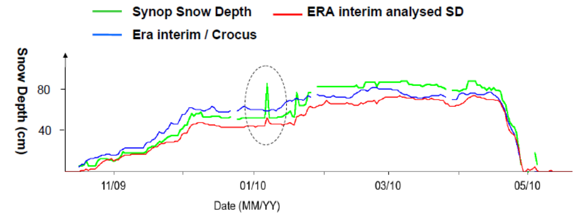


Evaluation of the simulations (no reinitialization, no calibration)

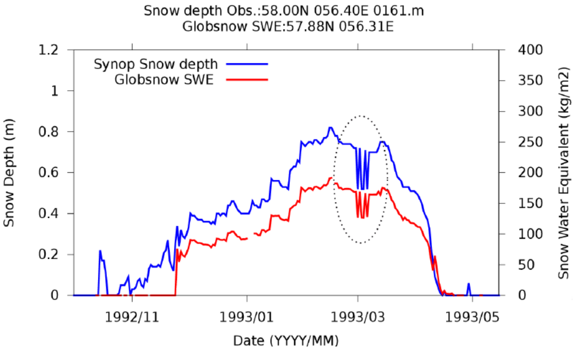


Statistical indices over 263 stations x 14 years simulations bias, RMSe and correlation

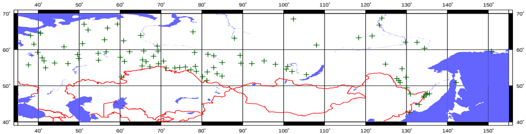
- Daily snow depth
- Annual snow duration (Snow Depth > 1 cm)
- Annual dates of onset and melt-out of continuous snow cover
- Snow Water Equivalent (SWE) and density (3 obs. per month)

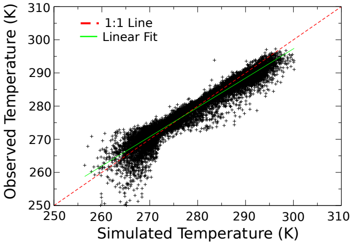


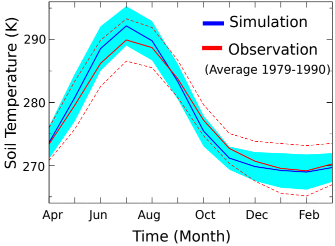
Station 60 N 88 E Winter 2009-2010



Evaluation of soil temperature (at 20 cm depth)







Comparison between observed and simulated soil monthly soil temperature (1979 to 1990)
ERA-Interim meteorological forcing / blowing snow sublimation

Year-round : 11760 monthly obs. ⇒ Bias = 0.1 K / RMSe = 2.5 K

Winter (DJF) : 2900 monthly obs. ⇒ Bias = -0.5 K / RMSe = 2.8 K

- Simple single-layer snow models :
  - NWP and climate models
  - simulation of grid cell snow mass, temperature and albedo
- Intermediate complexity snow models ($\sim$ 5 layers) :
  - climate or hydrological models and regional snow analysis systems
- Snowpack models ($>$ 10 layers, grain size and shape) :
  - avalanche forecast and snow sciences
  - local snowpack simulations

Detailed models perform better only over open fields (SNOWMIP1 / SNOWMIP2)