Snowpack modelling: a promising approach for future products merging model outputs with satellite products

Éric Brun

CNRM-GAME, Toulouse, France

Marie Dumont, Fatima Karbou

CNRM-GAME, CEN, Grenoble, France

EARSeL Workshop Remote Sensing of Land Ice and Snow
University of Bern , Switzerland, 3-6 February 2014

METEO FRANCE

cnrs

Monitoring snow conditions : a difficult challenge

In-situ snow observations

- Unique way to measure snow depth in all-weather conditions
- Uneven distribution of observations in space and time

Monitoring snow conditions : a difficult challenge

In-situ snow observations

- Unique way to measure snow depth in all-weather conditions
- Uneven distribution of observations in space and time

Satellite-based snow retrievals

- Daily real-time snow cover and SWE products
- No products before the 1970's

Monitoring snow conditions : a difficult challenge

In-situ snow observations

- Unique way to measure snow depth in all-weather conditions
- Uneven distribution of observations in space and time

Satellite-based snow retrievals

- Daily real-time snow cover and SWE products
- No products before the 1970's

Snowpack model outputs

- Off-line simulations driven with external meteorological forcings
- On-line simulations within an atmospheric model
- Critically dependant on meteorological forcing conditions

Outlines

- Off-line and on-line snowpack modelling from meteorological (re)analyses
- Snowpack modelling versus satellite products : Snow Water Equivalent, snow cover, melting events, surface temperature
- Pro and cons of snowpack modelling and satellite products
- Towards products merging model outputs and satellite retrievals

Targetted scale in this talk : from 15 to 100 km

1 Introduction

2 Snowpack modelling

3 Eurasia

4 Greenland and Antarctica Ice-Sheets

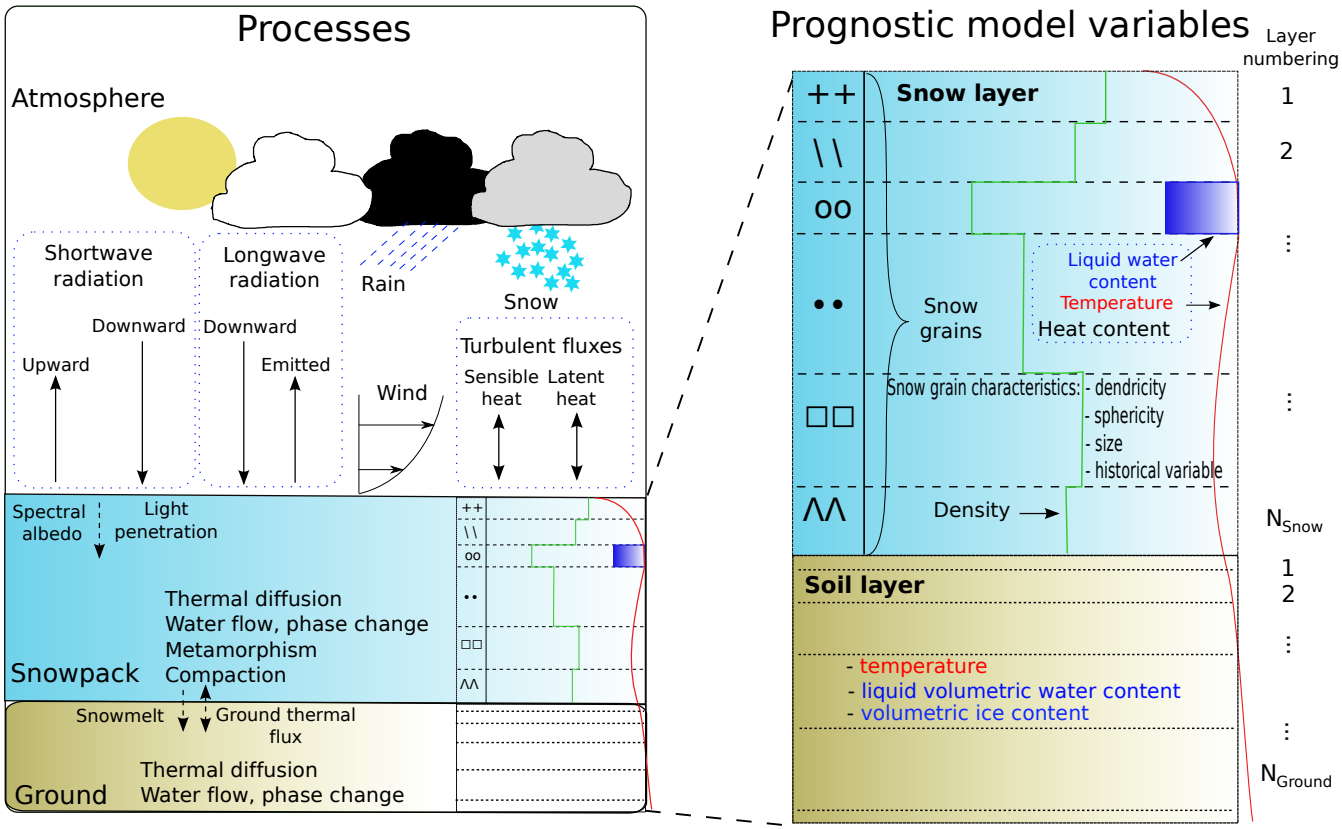
5 Satellite products versus snow models

6 Perspectives

A large diversity in numerical snow models

- Detailed snowpack models for avalanches and snow research : Anderson, Crocus, SNOWTHERM, SNOWPACK, SMAP
- Simple uni-layer snow models for weather forecast and climate models : a lot !
- Intermediate complexity snow models within weather prediction and climate models :
  ISBA-ES, JULES, SNICAR, HTESSEL ...
- Detailed snow models in regional climate models simulating ice-sheets surface mass balance :
  RACMO, MAR
- Intermediate complexity snow models embedded in hydrological models : VIC, ...

Crocus / ISBA-DF : a coupled snowpack / soil model



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

Optional blowing snow processes : compaction and sublimation

Vegetation effects not yet simulated

Configuration of off-line Crocus simulations

ERA-interim reanalysis ECMWF (Dee et al., 2011)

- $\sim$ 80 km resolution
- precipitation from model forecasts :
  no use of any observed precipitation !
- radiation from model

Crocus snow model ISBA-DF soil model

- Northern Hemisphere :
  1˚x 1˚/ 1979-2013
  27˚N / 90˚N
- Greenland :
  15 km / 1979-2013
- Antarctica :
  25 km / 2000-2011

+ results form on-line snow modelling in 20CR reanalysis

1 Introduction

2 Snowpack modelling

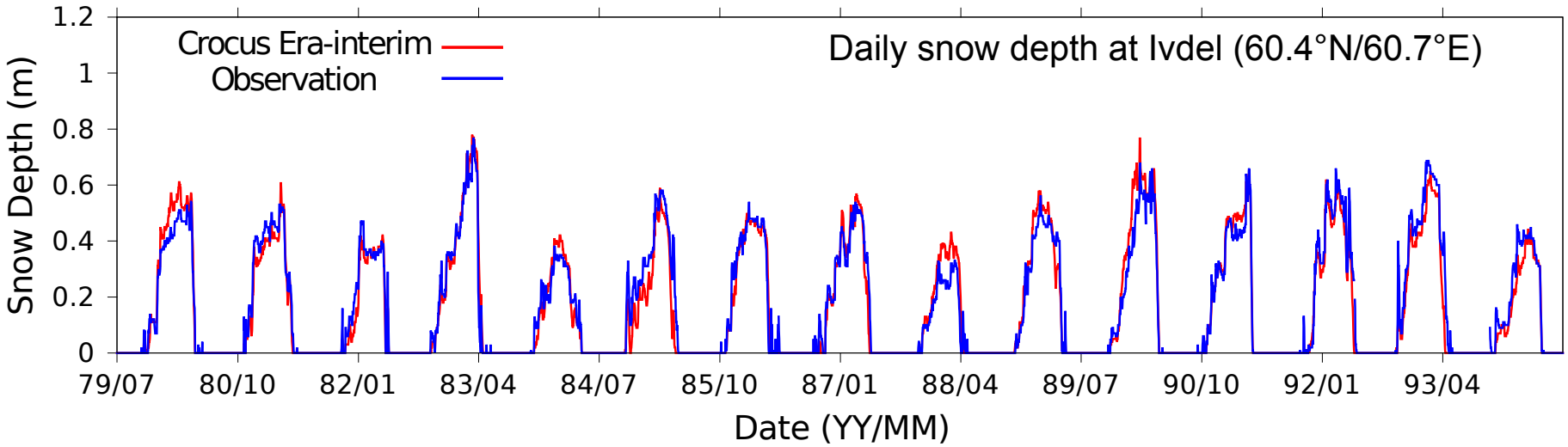
3 Eurasia

4 Greenland and Antarctica Ice-Sheets

5 Satellite products versus snow models

6 Perspectives

Illustration of Era-interim / Crocus performance

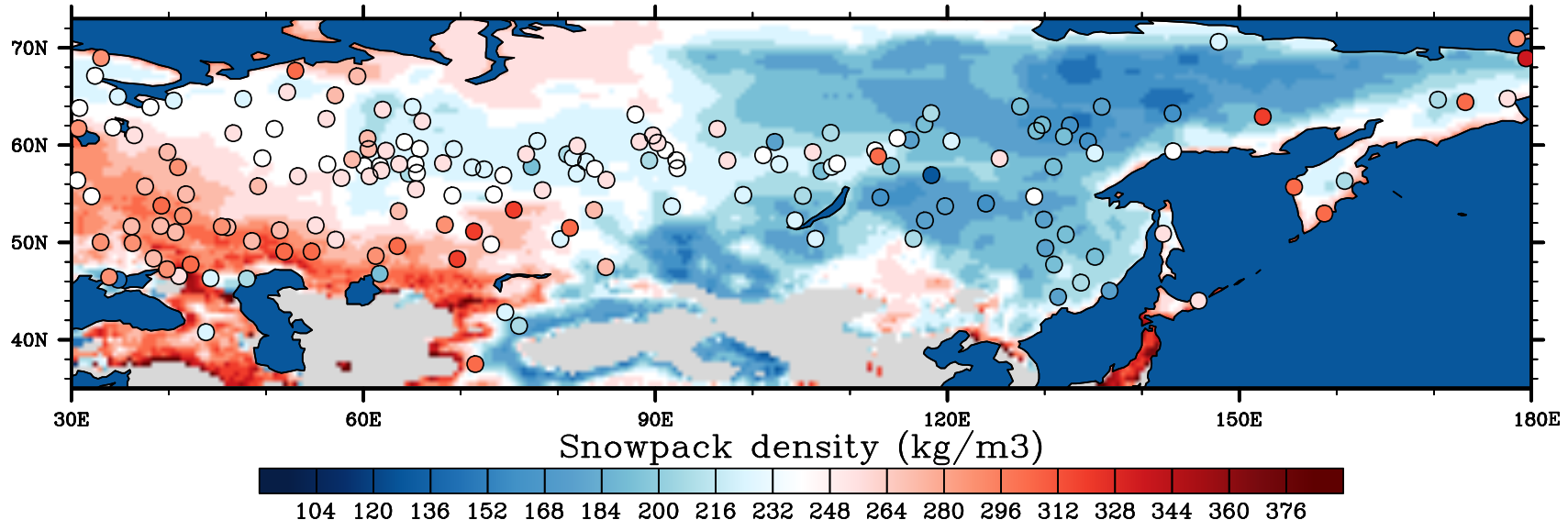


Performance over 250 stations 1979-1993

- Very small bias and high correlations :
  - snow depth, date of maximum snow depth
  - onset and melt-out dates
- A few stations are poorly simulated
  (unresolved local meteorological conditions : wind, precipitation)

(Brun et al., 2013)

Evaluation of simulated snowpack density



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

Snow models derive vertical profiles of characteristics which are rarely measured :

- density, grain size, temperature, liquid water, soil temperature

Comparison with GlobSnow SWE retrievals (1979-1993)

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 V1	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

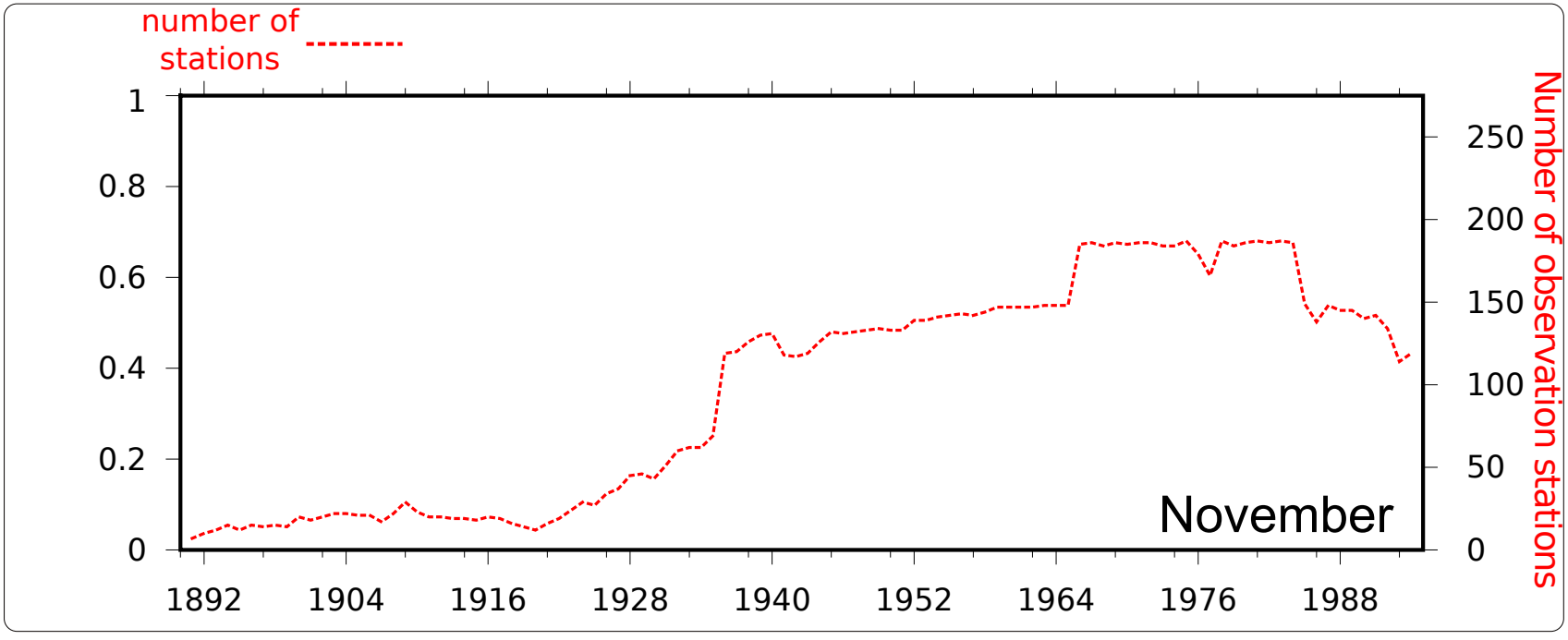
Crocus/ERA-Interim simulations and GlobSnow retrievals perform very similarly for SWE

20CR on-line simulation of snow cover

Evaluation of 20CR snow cover

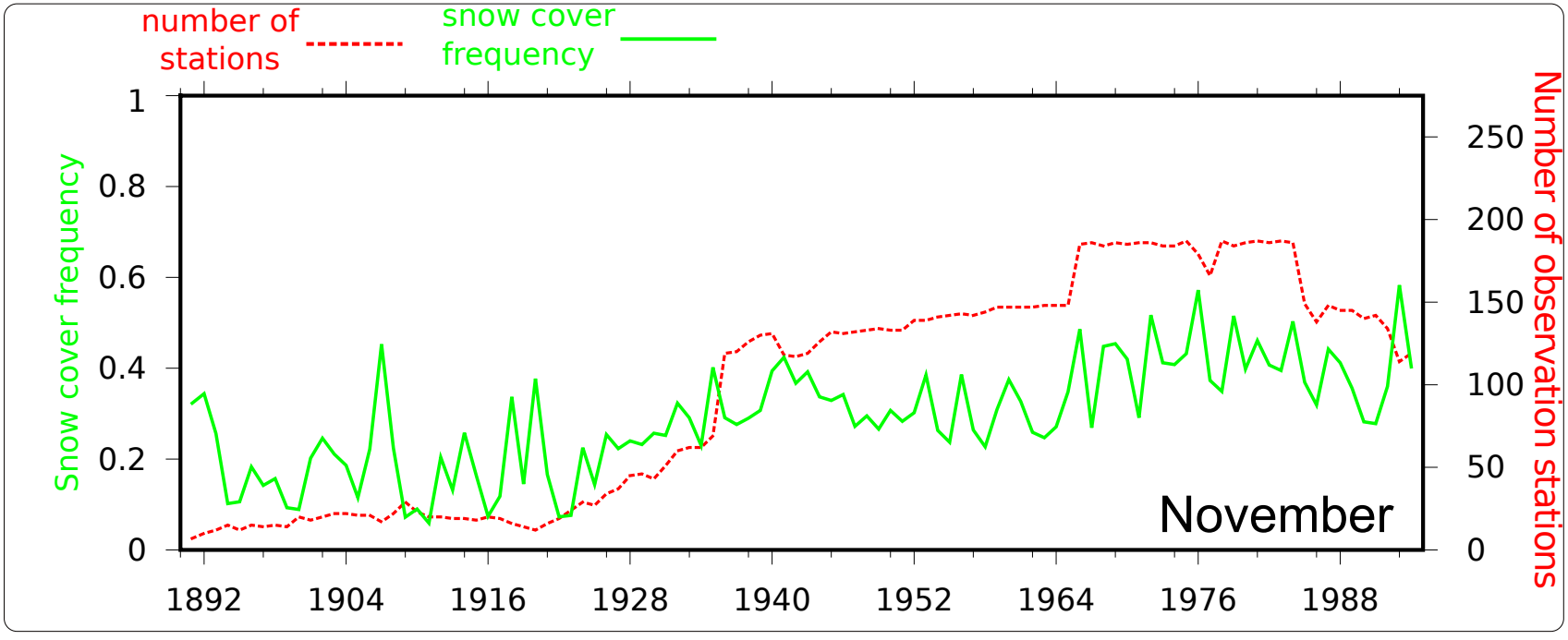
- 20CR is a 1870-2010 reanalysis assimilating only surface pressure
- 20CR simulates snow with an intermediate complexity snow model (NOAH)
- 20CR does not assimilate any snow related observation
  $\Longrightarrow$ targets the highest possible consistency over time
  (Compo et al., 2011)

Steady amazing performance of 20CR snow cover during Fall over Northern Eurasia (South 60N)



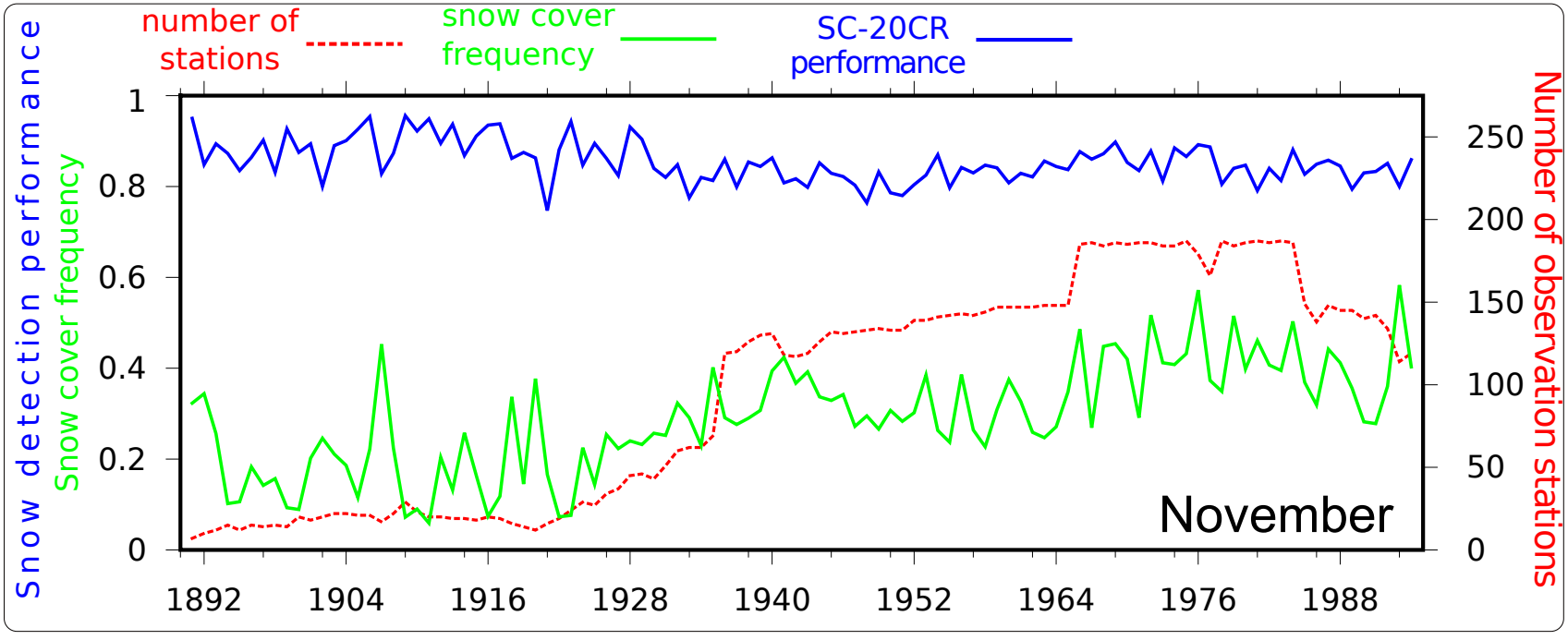
(Peings et al., 2013)

Steady amazing performance of 20CR snow cover during Fall over Northern Eurasia (South 60N)



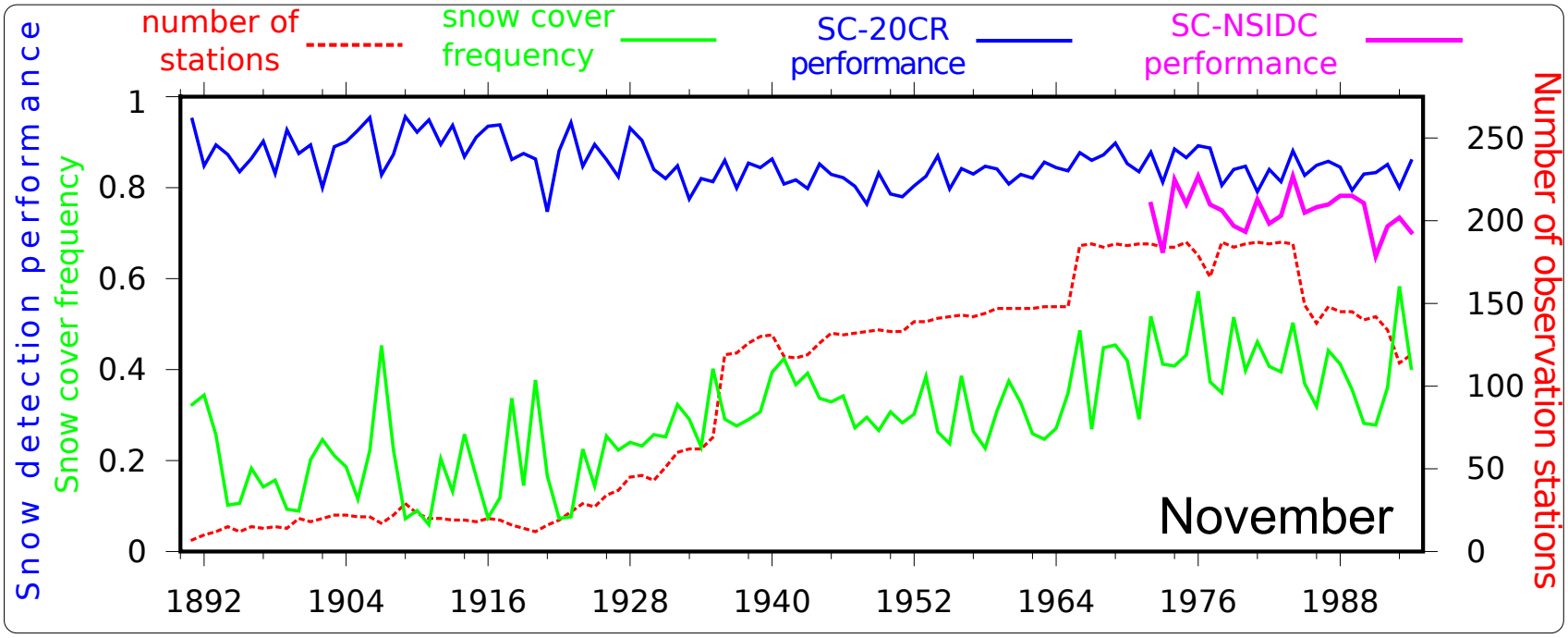
(Peings et al., 2013)

Steady amazing performance of 20CR snow cover during Fall over Northern Eurasia (South 60N)



(Peings et al., 2013)

Steady amazing performance of 20CR snow cover during Fall over Northern Eurasia (South 60N)



(Peings et al., 2013)

1 Introduction

2 Snowpack modelling

3 Eurasia

4 Greenland and Antarctica Ice-Sheets

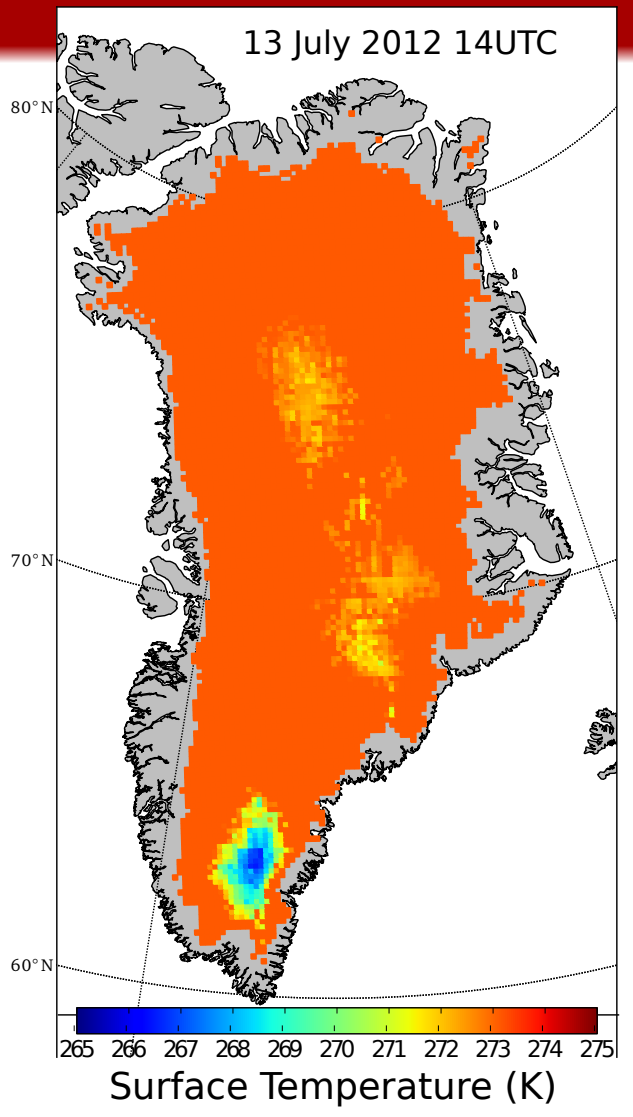
5 Satellite products versus snow models

6 Perspectives

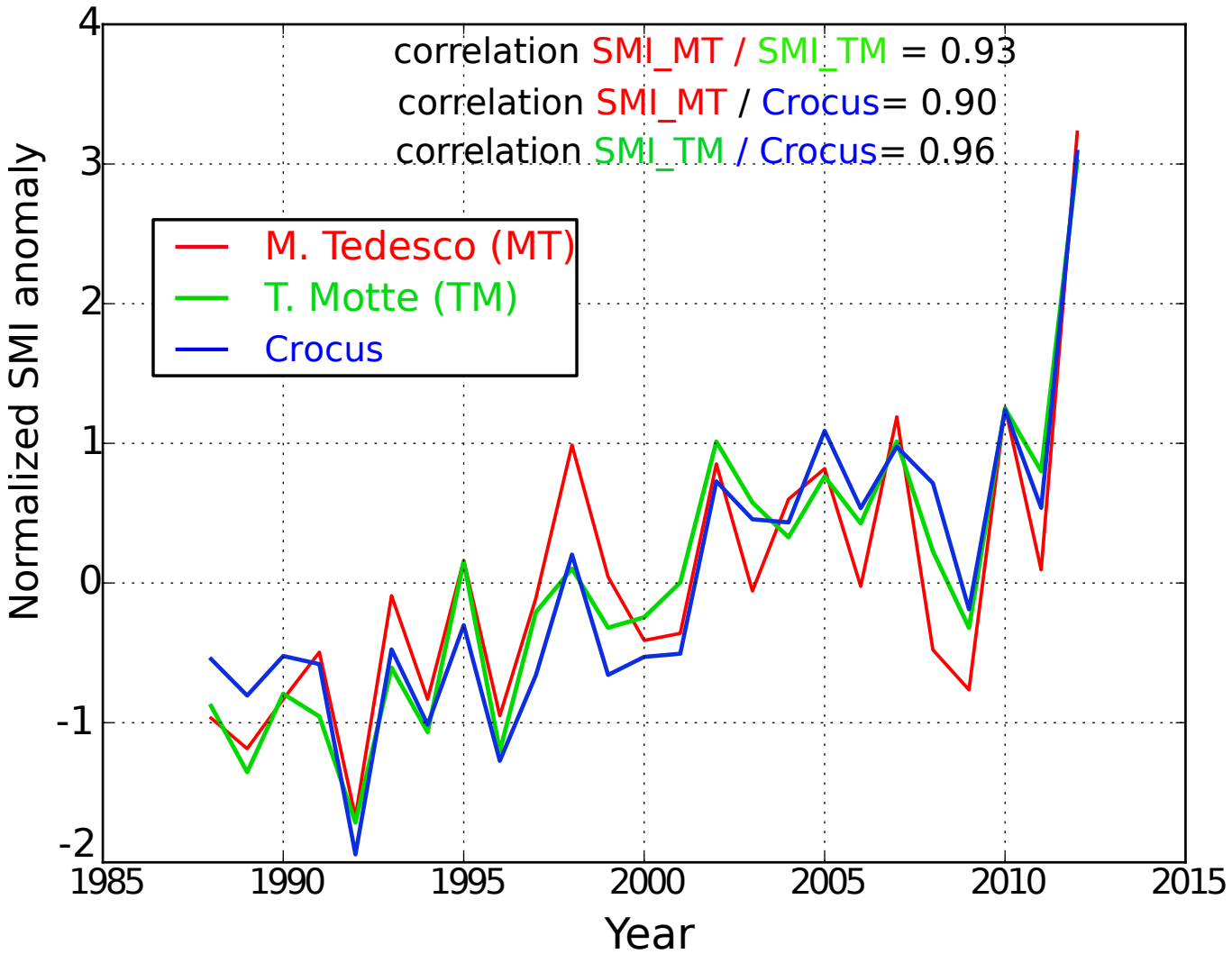
Snow modelling to simulate the GrIS surface mass balance

Reconstruction of melting events

- Observation :
  - melting events from space-borne micro-wave radiometers
  - 2 different Snow Melt Index algorithms :
  * Mott and Anderson (1995)
  * Tedesco (2009)
- Snow model :
  - Surface temperature $\geq$ -0.1 ˚C.

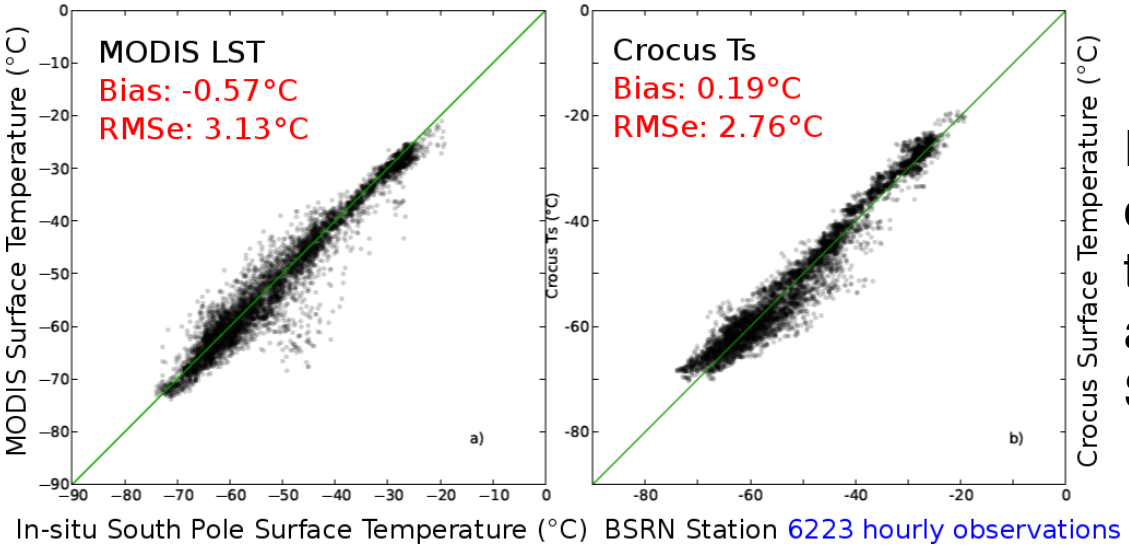


Performance in the reproduction of melting events



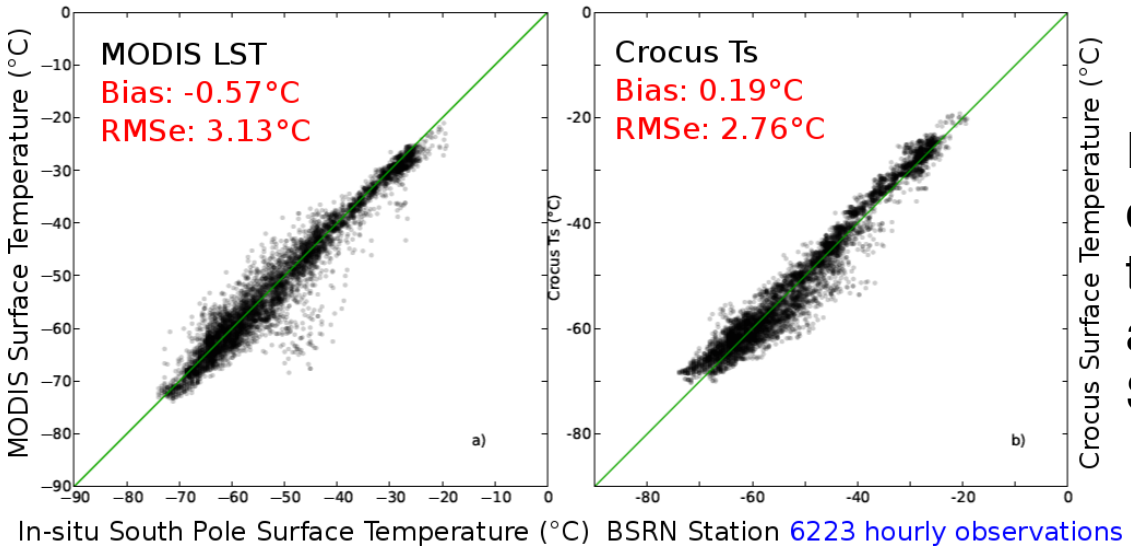
Better correlation between the model and TM algorithm
between TM and MT algorithm (SMI extracted from Tedesco et al., 2013)

Performance in the simulation of surface temperature in Antarctica (more details in H. Freville's talk)



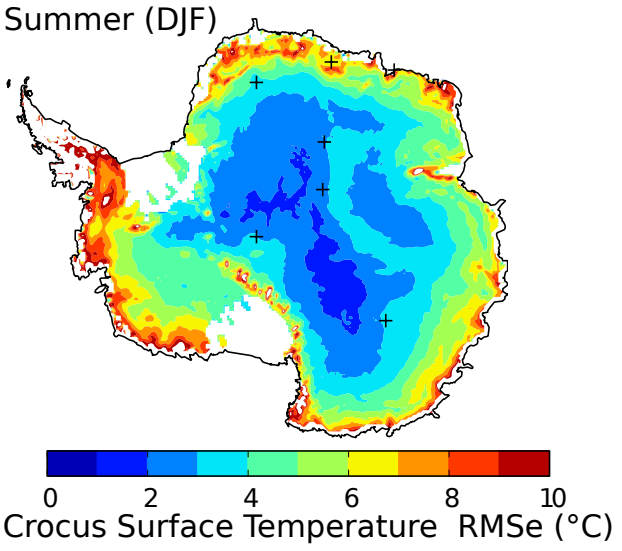
Evalution against in-situ observations hourly surface temperature of MODIS (left) and Crocus/ERA Interim (left) South Pole 2009

Performance in the simulation of surface temperature in Antarctica (more details in H. Freville's talk)



Evalution against in-situ observations hourly surface temperature of MODIS (left) and Crocus/ERA Interim (left) South Pole 2009

Evaluation of Crocus hourly surface temperature
againts MODIS LST (Summer 2000-2011)



1 Introduction

2 Snowpack modelling

3 Eurasia

4 Greenland and Antarctica Ice-Sheets

5 Satellite products versus snow models

6 Perspectives

Respective advantages

Satellite products (SWE and cover)

- Based on observations
- Active R&D community
- Continuous improvements
- Active and diverse users community
- Space agency support
- Global coverage

Snow models driven with meteorological reanalyses

- Historical coverage (from 1870)
- Global coverage
- Independent on snow observations (if no assimilation)
- Active developing community
- Cheap

Respective disadvantages

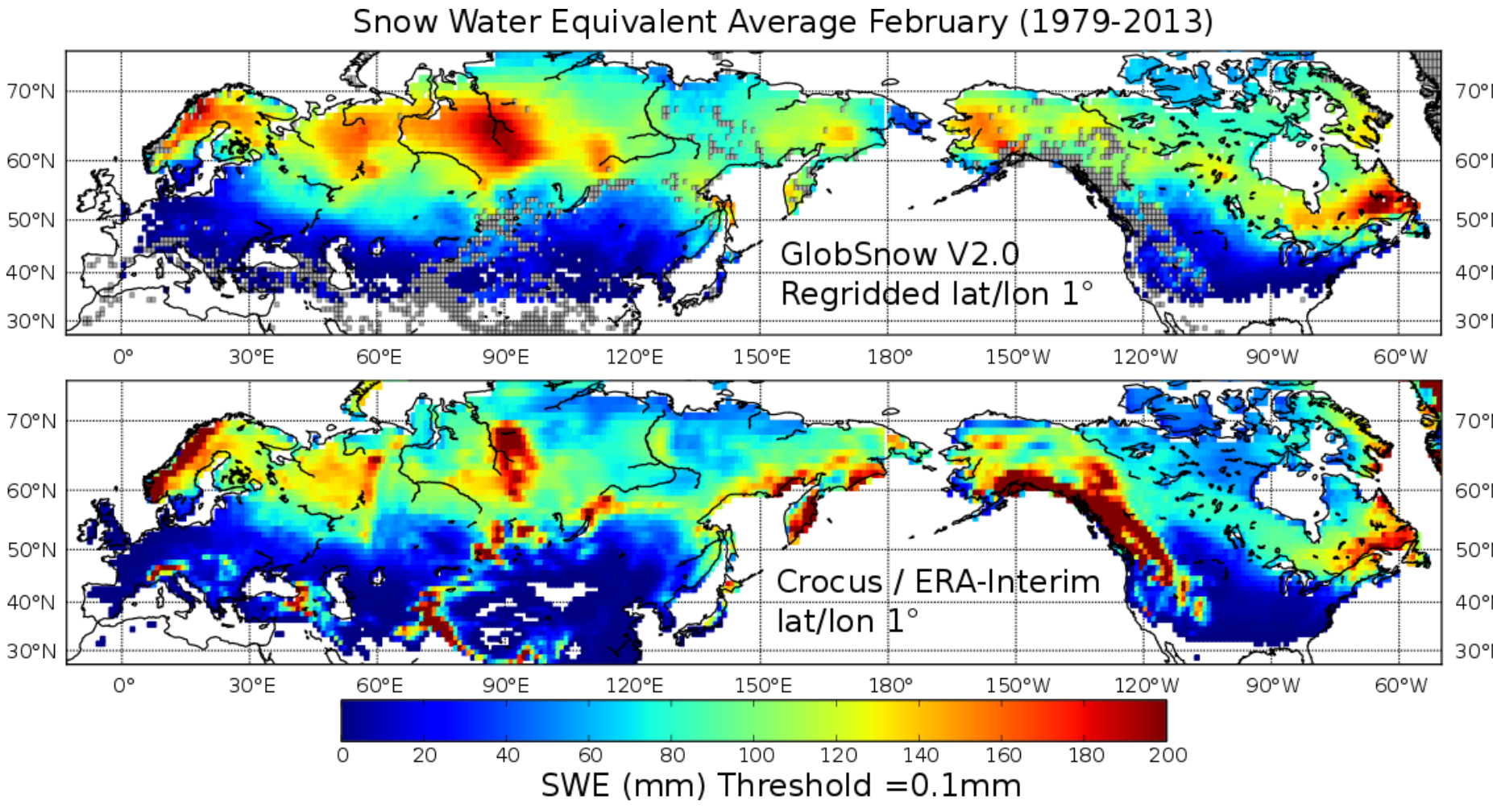
Satellite products (SWE and cover)

- Time inconsistency :
  - evolving sensors
  - evolving in-situ observations (if assimilation)
- intrinsic scientific limitations
- weather dependant (cover)
- snow quality dependant (SWE)

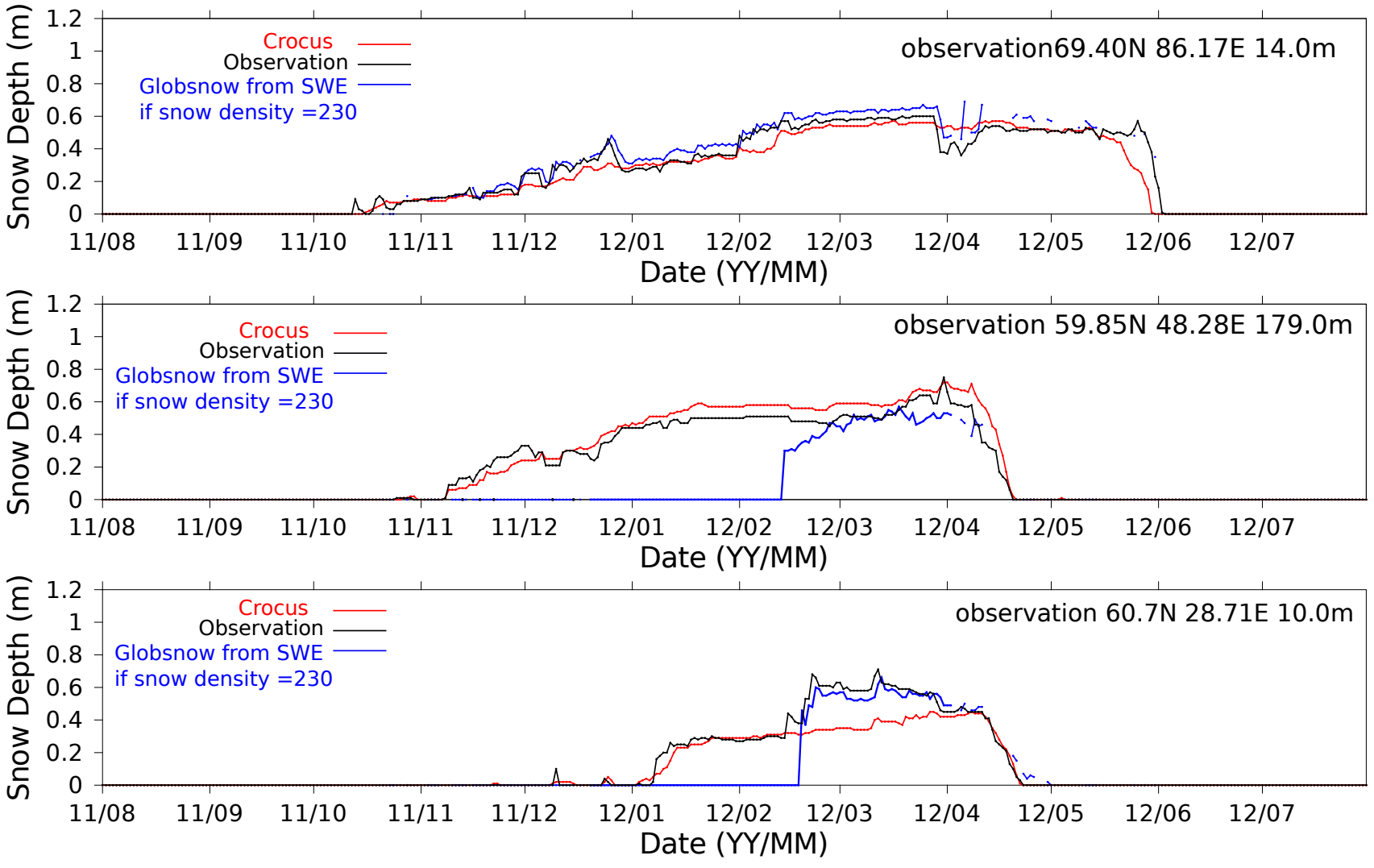
Snow models driven with meteorological reanalyses

- Model biases and errors
- Representation of snow vegetation interactions
- No use of observations (if no assimilation)
- Strongly dependant on forcing conditions

Differences between GlobSnow SWE and Crocus/ERA-Interim SWE



Representative illustration of GlobSnow and Crocus/ERA-Interim weaknesses



1 Introduction

2 Snowpack modelling

3 Eurasia

4 Greenland and Antarctica Ice-Sheets

5 Satellite products versus snow models

6 Perspectives

Towards merging snow satellite and model products

From satellite products side

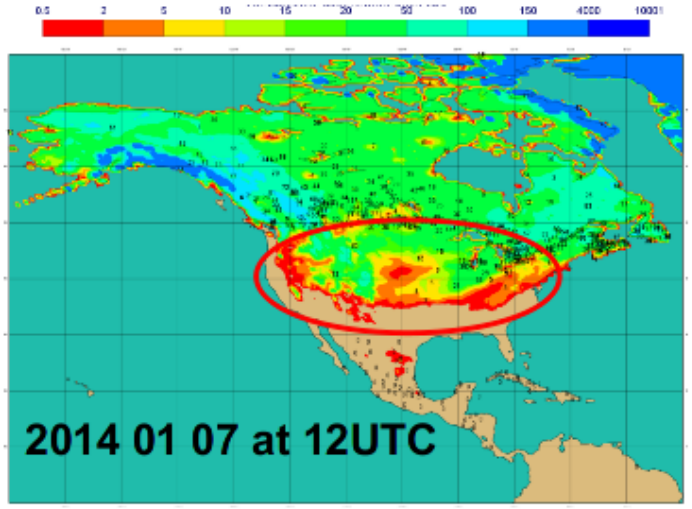
- Use of snow model outputs as a background :
  - simulated profiles of density, temperature and grain size
- Use of snow model outputs as time interpolators :
  $\Longrightarrow$ filling data at onset and melting-out periods
  $\Longrightarrow$ consistency in monthly averaged products
- Use of snow model outputs to improve MW signal processing :
  - ongoing studies (i.e. SNOWPACK model at Sodankila)
- Use of simulated density to turn in-situ snow depth into SWE

From snow models side

- Assimilation of satellite products :
  - routinely done in prediction systems (snow cover mainly)
  - to be generalized (i.e. snow reanalysis in EartH2Observe project)
- Use of satellite products to evaluate snow models
  $\Longrightarrow$ snow models improvement

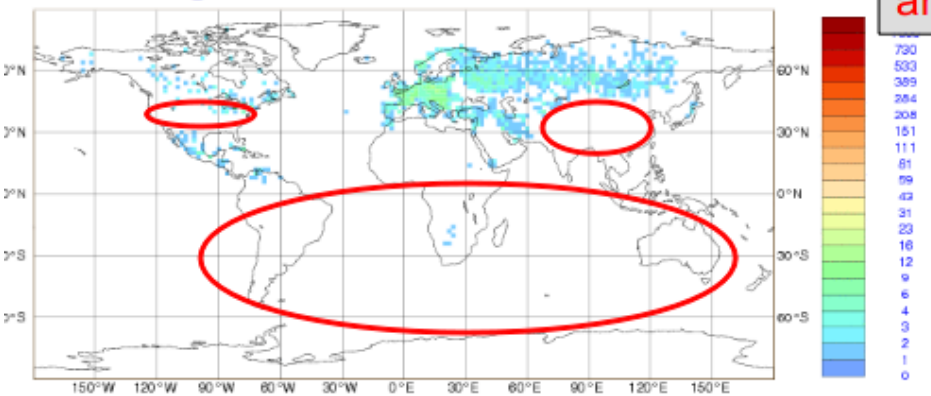
Importance of in-situ snow observations for both satellite and model products

ECMWF Operational monitoring of SYNOP snow depth: number of observations on 2014 01 04 at 00UTC (21-09 UTC):
observations gap in USA, China and southern hemisphere



GCW Snow Watch initiative to improve in situ snow depth data access (NRT and rescue), Brun et al 2013

http://www.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow/



Acknowledgements

Thanks for your attention !

This study was supported by :

- ANR : project CLASSIQUE
- CNES : projects CONCORDIASI and Ts-Antar