Representation of snow in NWP

Laura Rontu **HIRLAM-B**

with contributions by
Ali Nadir Arslan FMI, Kalle Eerola FMI, Mariken Homleid, met.no,
Ekaterina Kurzeneva FMI, Roberta Pirazzini FMI, Terhikki Manninen FMI,
Richard Essery U.Edinburgh, Patrick Samuelsson SMHI,
Hrobjartur Thorsteinsson IMO et al.

EWGLAM/SRNWP 2014
Offenbach, 29. 9. – 2. 10. 2014

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COST ES1404

ESSEM COST Action ES1404

A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction

Descriptions are provided by the Actions directly via e-COST.

Snow cover is an essential climate variable directly affecting the Earth energy balance. Snow cover has a number of important physical properties that exert an influence on global and regional energy, water and carbon cycles. Its quantification in a changing climate is thus important for various environmental and economic impact assessments. Proper description and assimilation of snow cover information into hydrological, land surface, meteorological and climate models are critical to address the impact of snow on various phenomena, to predict local snow water resources and to warn about snow-related natural hazards. This induces a challenging problem of bridging information from micro-structural scales of the snowpack up to the grid resolution in models. European research teams have developed different snow measurement practices, instrumentation, algorithms and data assimilation techniques customised to their purposes. However, they lack harmonised approaches, validation and methodologies. The Action will co-ordinate efforts to address these

Earth System Science and Environmental Management COST Action ES1404

- **Description**
- Parties
- Management Committee

General Information*

Proposer of the Action:
Dr. Ali Nadir ARSLAN

Science officer of the Action:
Dr Deniz KARACA

Administrative officer of the Action:
Ms Tania GONZALEZ OVIN

Downloads*

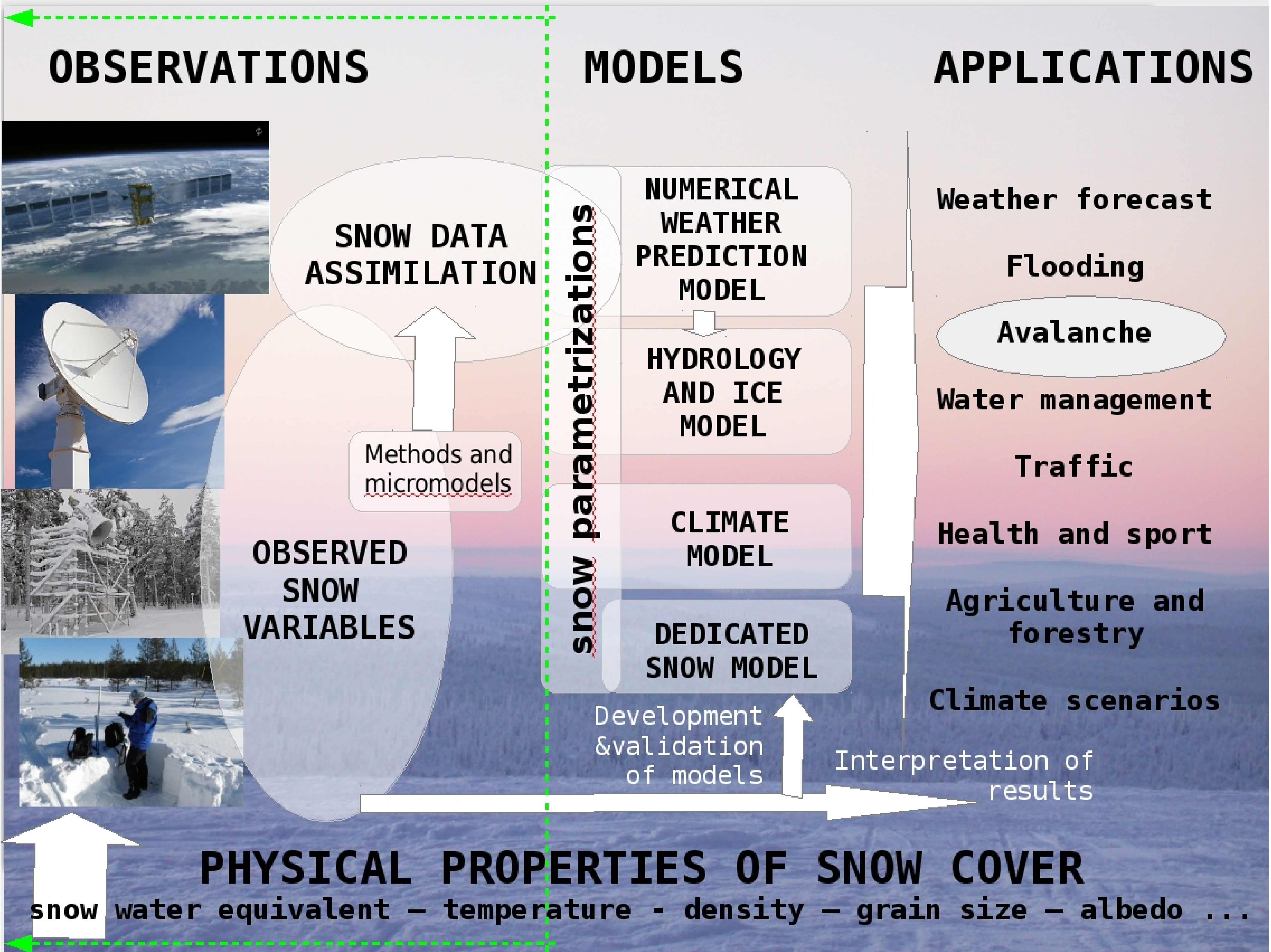
Action Fact Sheet
Download AFS as .RTF

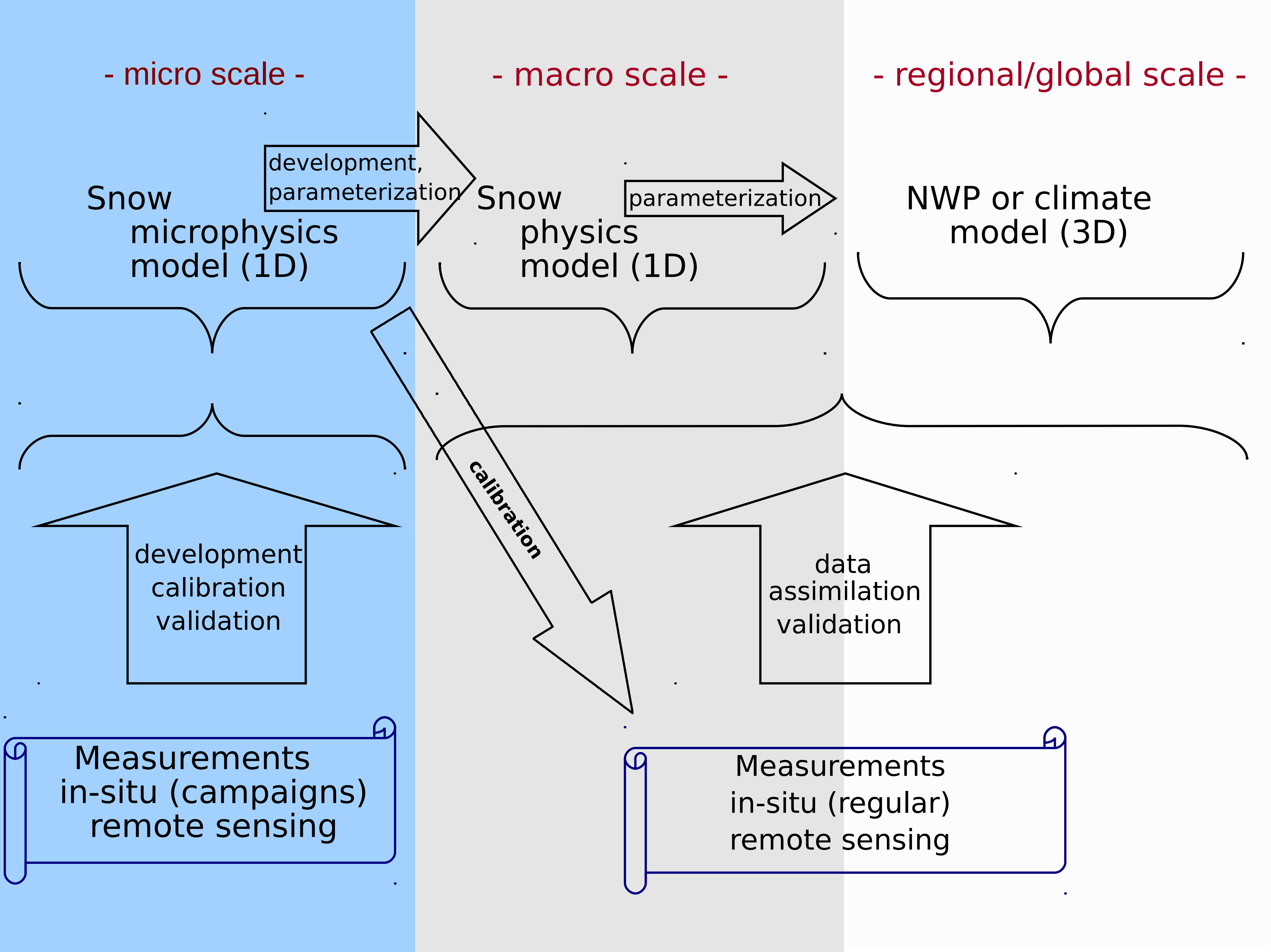
Memorandum of Understanding
Download MoU as PDF

COST Action ES1404 aims at building a better connection between snow measurements and models, between snow observers, researchers and forecasters, for the benefit of various stakeholders and the entire society

Aim of the Action:

To enhance the capability of the research community and operational services to provide and exploit quality-assured and comparable regional and global observation-based data on the variability of the state and extent of snow.


OBSERVATIONS
MODELS
APPLICATIONS
SNOW DATA ASSIMILATION
snow parametrizations
NUMERICAL WEATHER PREDICTION MODEL
HYDROLOGY AND ICE MODEL
CLIMATE MODEL
DEDICATED SNOW MODEL
Methods and micromodels
OBSERVED SNOW VARIABLES
Weather forecast
Flooding
Avalanche
Water management
Traffic
Health and sport
Agriculture and forestry
Climate scenarios
Development &validation of models
Interpretation of results
PHYSICAL PROPERTIES OF SNOW COVER
snow water equivalent – temperature - density – grain size – albedo ...


- micro scale -
- macro scale -
- regional/global scale -
Snow microphysics model (1D)
development, parameterization
Snow physics model (1D)
parameterization
NWP or climate model (3D)
calibration
development
calibration
validation
data assimilation
validation
Measurements
in-situ (campaigns)
remote sensing
Measurements
in-situ (regular)
remote sensing

COST ES1404 suggested working groups

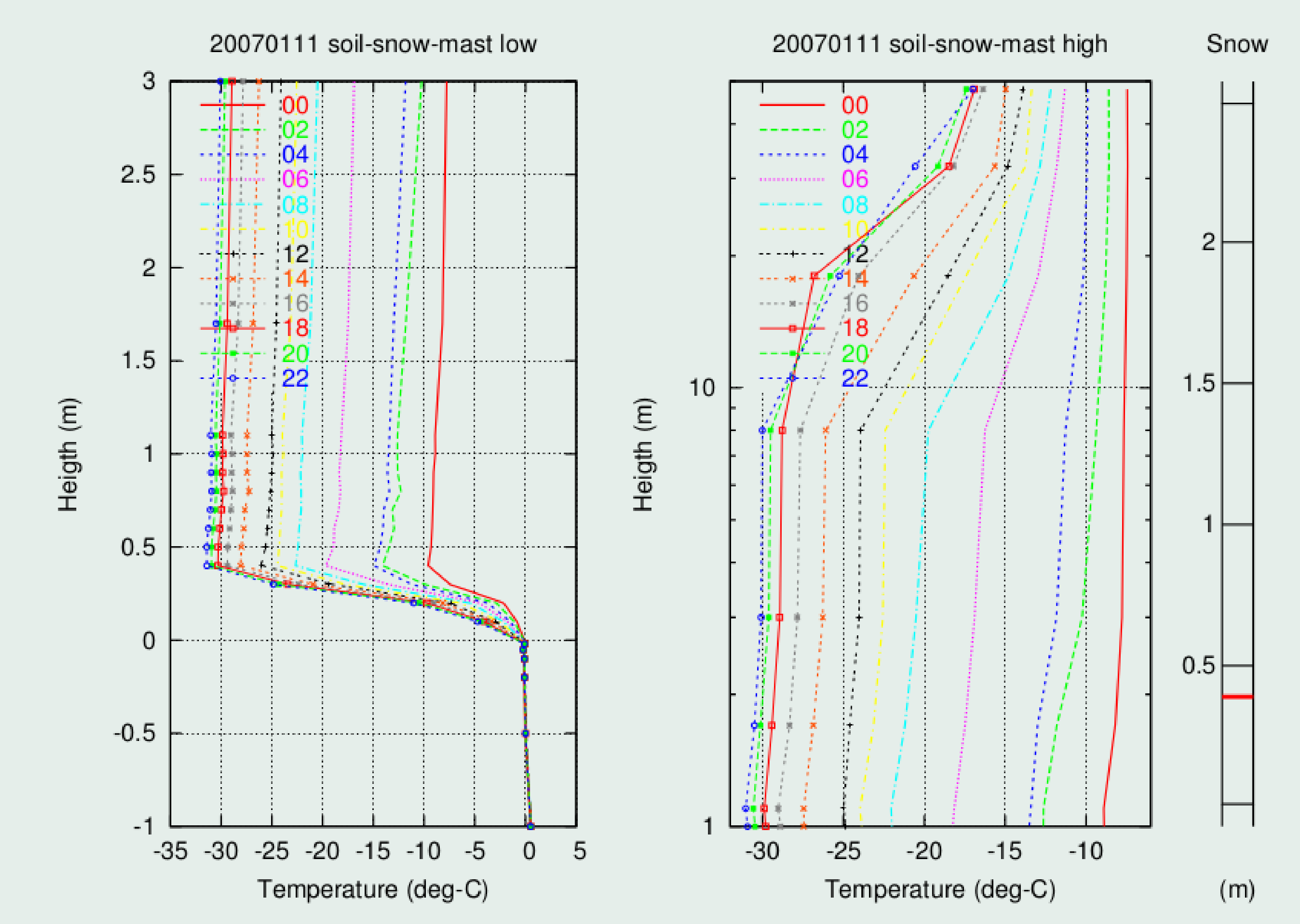
WG1: Physical characterization of snow

WG2: Instrument and method evaluation

WG3: Snow data assimilation and validation methods for NWP and hydrological models

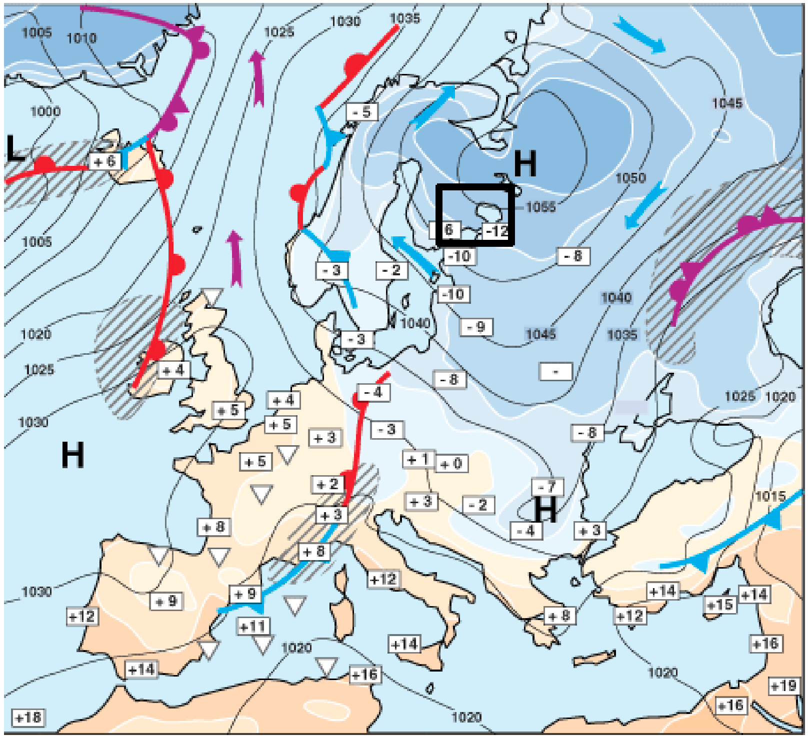
COST ES1404 will not focus on prognostic snow modelling/parametrisations!
And we are talking about snow cover, not snowfall!

What does the snow cover mean for NWP?



Observed temperature profiles from the level of -1m (soil) to 50m (mast) when there was 0.4m snow on ground in Sodankylä and air cooled 20K during 24h

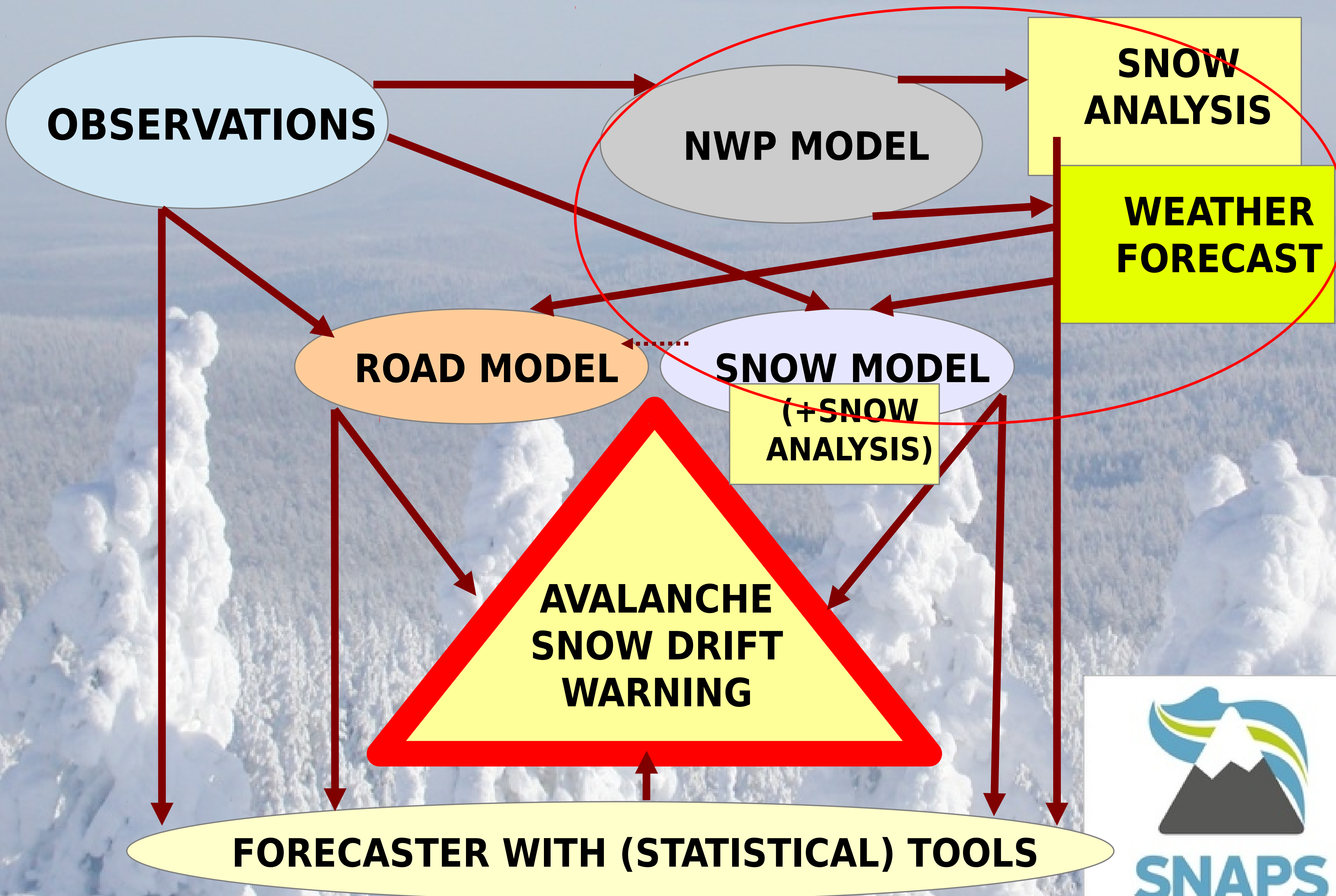
The case of Lake Ladoga, January 2012: role of clouds as predicted by NWP



http://netfam.fmi.fi/Lake12/HIRLAM_Ladoga-anim_hkrp2014.m4v

Kalle Eerola et al., 2014. Impact of partly ice-free Lake Ladoga on temperature and cloudiness in an anticyclonic winter situation – a case study using HIRLAM model. http://tellusa.org .Video prepared by Homa Kheyrollah Pour, 2014

NWP for emergency warnings



SNAPS
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Local and remote sensing snow observations

SYNOP and climate stations:

Ultrasonic or manual snow depth measurements

- Represent local conditions

Satellite instruments:

Passive microwave sensors - e.g SMSI

- Coarse resolution wide area snow water equivalent

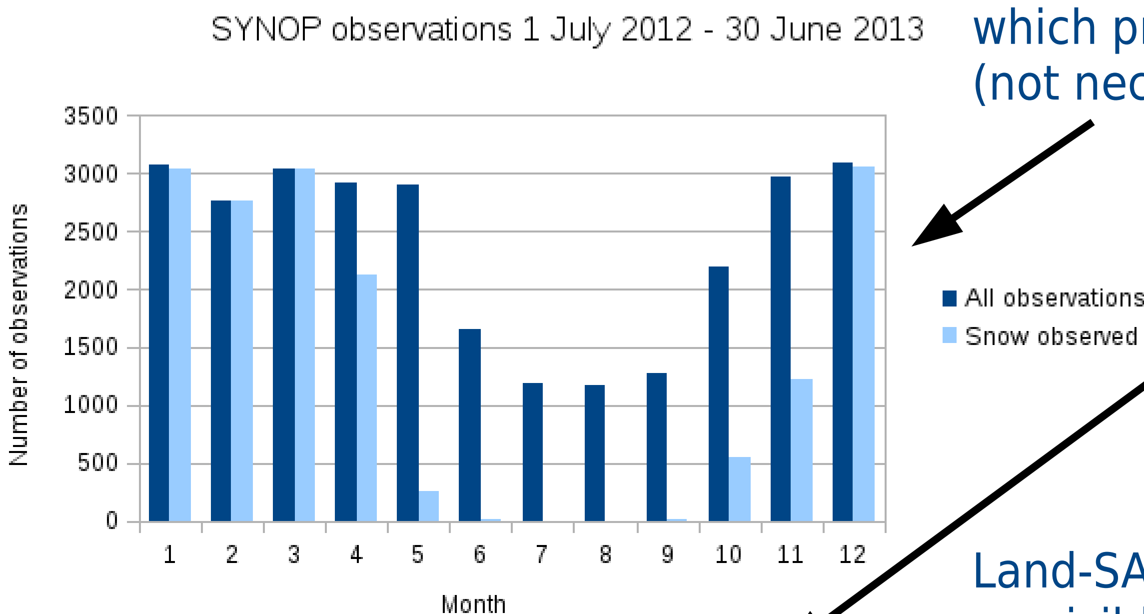
Optical/NIR – e.g.MODIS

- High resolution snow extent
- Limited by cloud and light problems

Active microwave – e.g. SAR from ESA's Sentinel-1

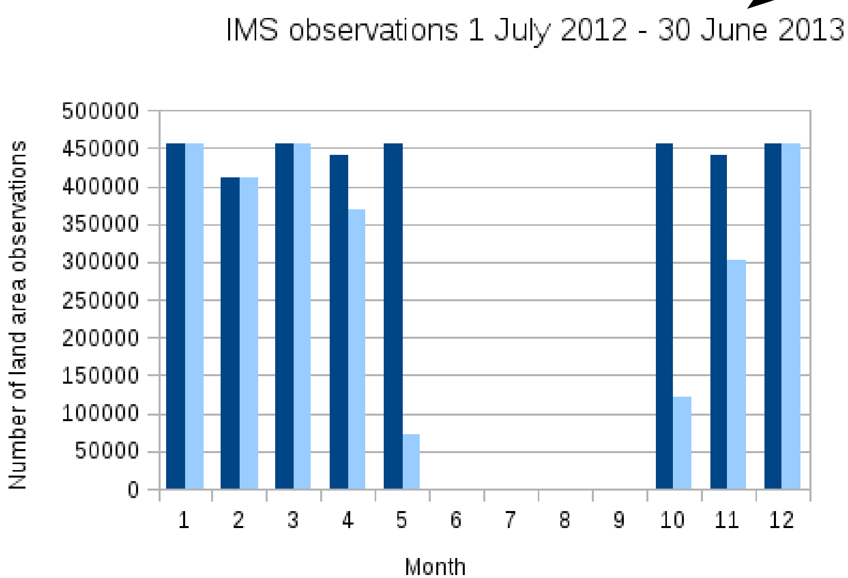
- Very high resolution indication of wet snow
- Narrow swath – infrequent data

Availability of various snow observations over Finland

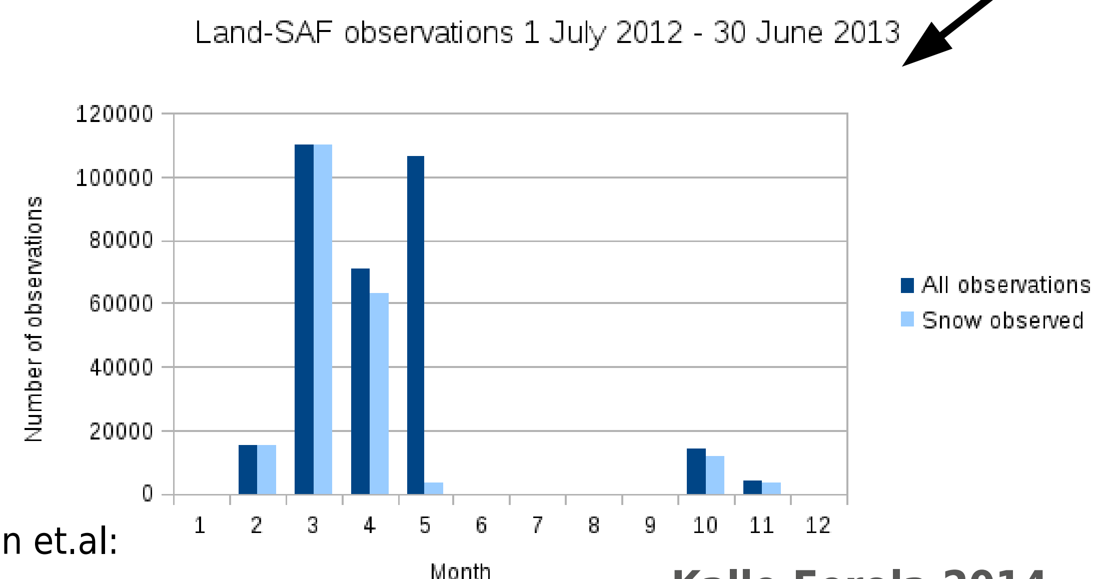


Finnish SYNOP snow depth observations which provide also no-snow information (not necessarily all transmitted via GTS)

Snow extent from the Interactive Multisensor Snow and Ice Mapping System (IMS*): multi-sourced datasets such as passive microwave, visible imagery, operational ice charts and other ancillary data



Land-SAF snow extent from EUMETSAT is based on visible imagery from geostationary Meteosat second generation satellites (MSG)



*National Snow and Ice Data Center (NSIDC), see Brown et.al: Remote Sensing of Environment 147 (2014) 65–78l,

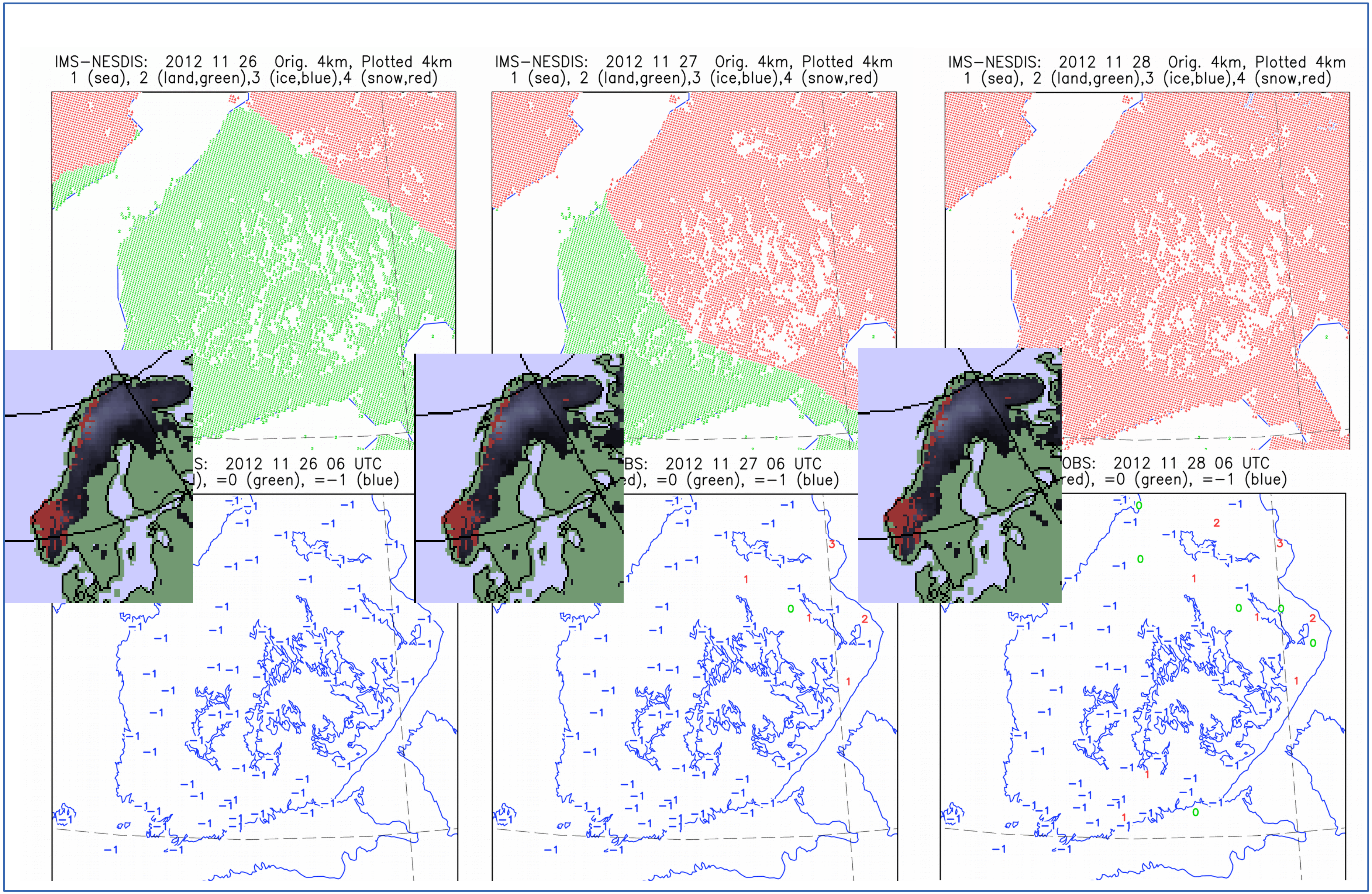
Kalle Eerola 2014

Example of the first snowfall in November 26-28 2012

IMS

Glob-snow SWE

SYNOP



(Land-SAF was not available those days)

What are the most valuable snow observations for NWP?

SYNOP + climate station snow observations, which provide also no-snow information

- Should be more widely available via GTS
- Should include the national group with no-snow information
- NWP models should read correctly the extended SYNOP code

Remote sensing observations

1) Snow water equivalent by passive microwave sensors
2) Snow extent seen by visible and derived from passive and active microwave signals
3) Snow wetness indicated by SAR instruments

Dilemma of using satellite data: ready-made products or spatialization + assimilation of the signals within the surface DA of NWP models?

- Satellites with varying instrument specifications come and go – building long-lasting operational systems is difficult
- Products contain assumptions and rely on additional data sources different from those applied in NWP framework
- NWP model may provide up-to date background based on prognostic snow parametrizations – for quality control, for assimilation

e.g. IMS and Globsnow SWE are products, while SAR backscattering from the just launched Sentinel-1 would represent a raw signal

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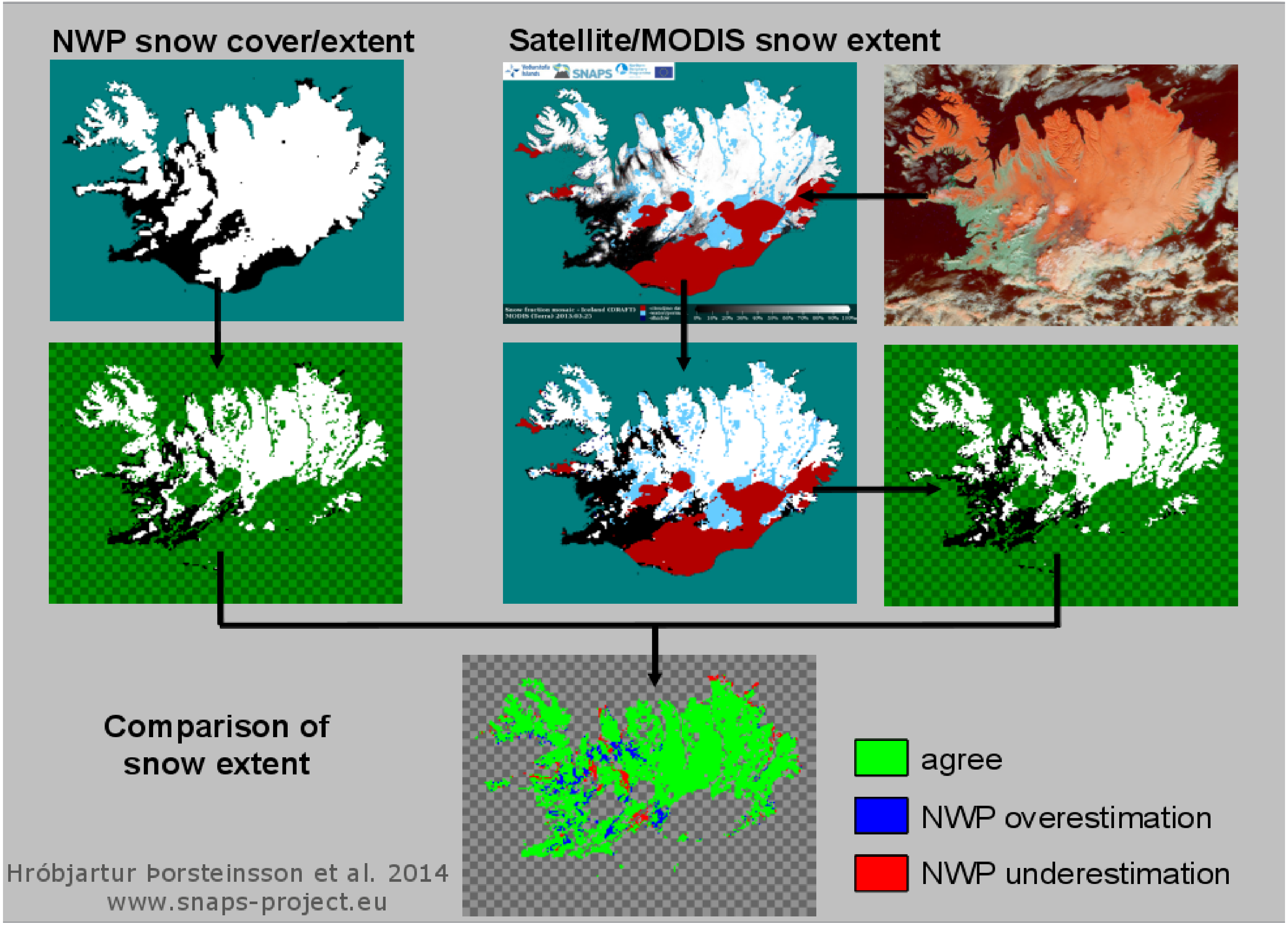

Northern Periphery Programme 2007–2013

Innovatively investing in Europe's Northern Periphery for a sustainable and prosperous future

European Union
European Regional Development Fund

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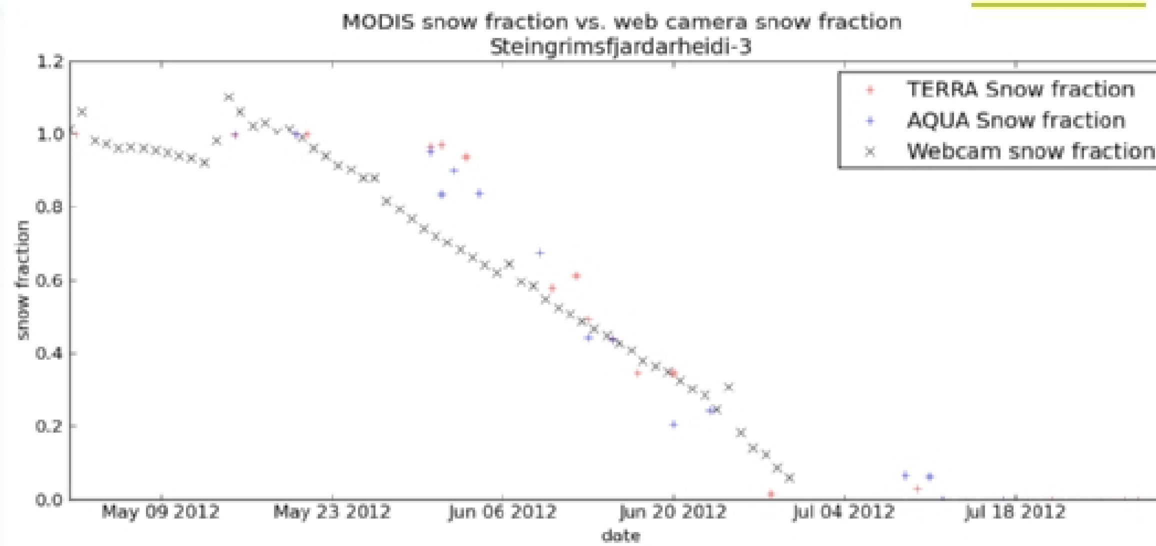
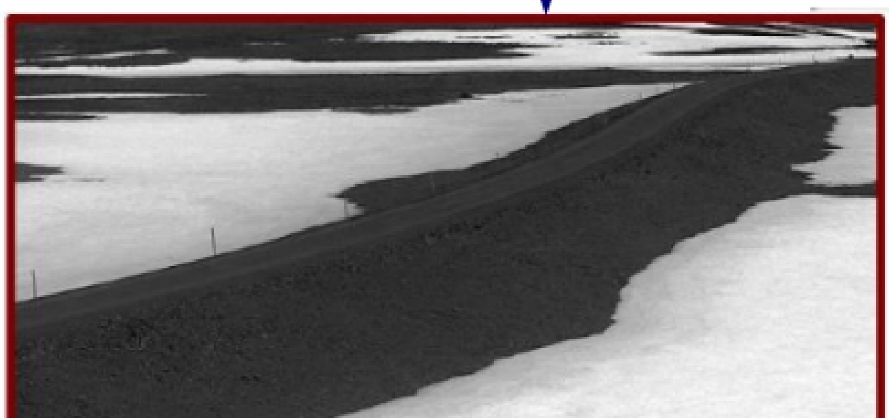
Verification of MODIS snow cover maps with web cameras

SNAPS



Road authority web camera was used to evaluate remote-sensing fractional snow cover



Northern Periphery Programme 2007–2013

Hróbjartur Þorsteinsson et al. 2014

Icelandic Met Office

Prognostic snow schemes available in SURFEX

Single-layer	D95	Douville *et al.* (1995a,1995b)
Multi-layer	Explicit-Snow (ES)	Boone (2000); Boone and Etchevers (2001)
Multi-layer	Crocus	Brun *et al.* (1989,1992); Vionnet *et al.* (2012)

Table 4.1: Summary of the snowpack schemes available in ISBA*

ISBA + D95
Operational in HARMONIE-SURFEX

Layers in snowpack: One
Prognostic variables: SWE, snow density, snow albedo
but no separate snow temperature/liquid water content
Data assimilation: SWE updated with optimally interpolated snow depth

* SURFEX SciDoc v.2

Prognostic snow schemes available in SURFEX

Single-layer	D95	Douville *et al.* (1995a,1995b)
Multi-layer	Explicit-Snow (ES)	Boone (2000); Boone and Etchevers (2001)
Multi-layer	Crocus	Brun *et al.* (1989,1992); Vionnet *et al.* (2012)

Table 4.1: Summary of the snowpack schemes available in ISBA*

ISBA + ES

Next operational in HARMONIE-SURFEX?

Layers in snowpack: ca. 3

Prognostic variables: heat content > temperature and liquid water, layer thicknesses and densities

Data assimilation: None yet

Other features: Possibly to couple MEB

* SURFEX SciDoc v.2

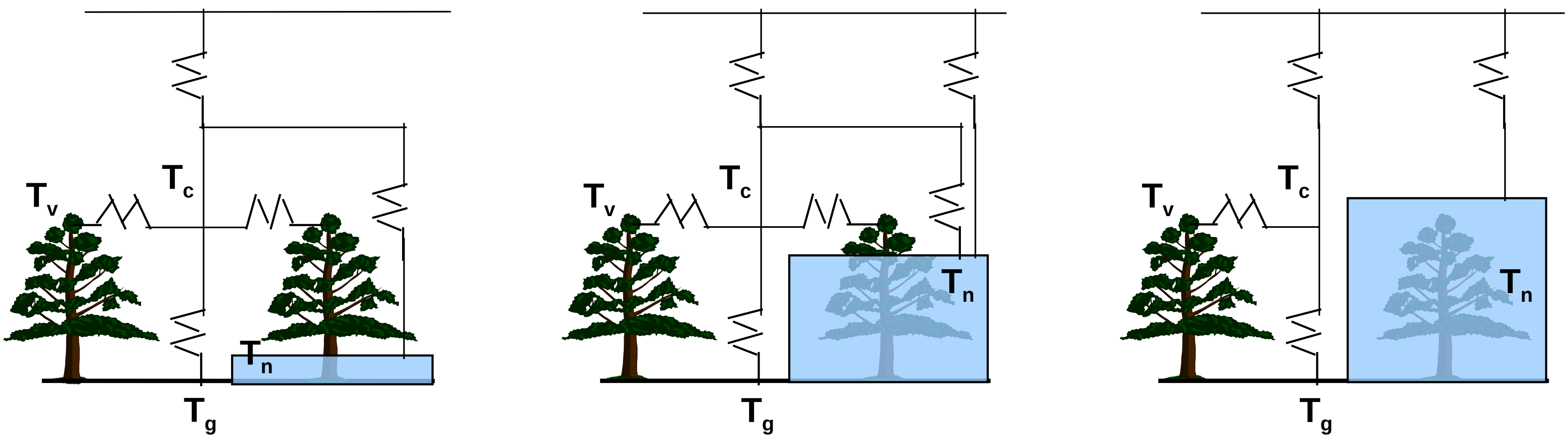
Multi-Energy Balance (MEB)

SMHI

Snow well below the canopy

Snow partly buries the canopy

Snow buries the canopy



MEB is designed to work with

- snow schemes ES (3-L) and CRO (requires separate snow energy balance)
- soil scheme ISBA-DIF (diffusion) with patches (separate forest/grass/bare land)

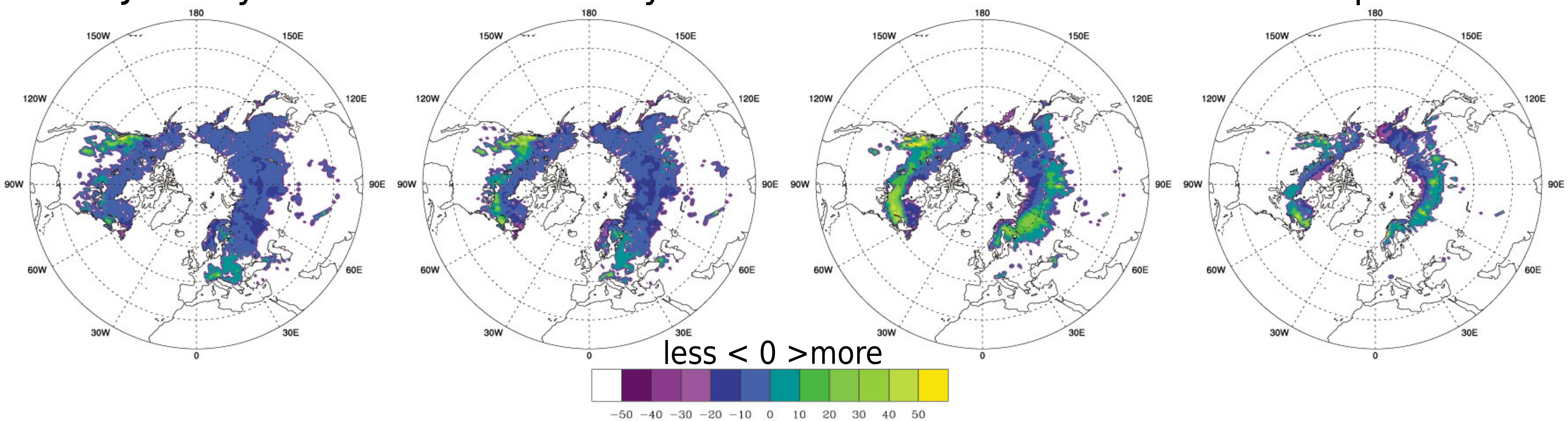
Patrick Samuelsson, 2014

2D offline experiment – Snow Water Equivalent

With MEB:

- Less snow in forested areas in mid winter (10-20 kg m^{-2}) due to snow interception
- More snow in forested areas late in winter (20-50 kg m^{-2}) due to a combination of radiation and turbulence effects
- The melting is delayed

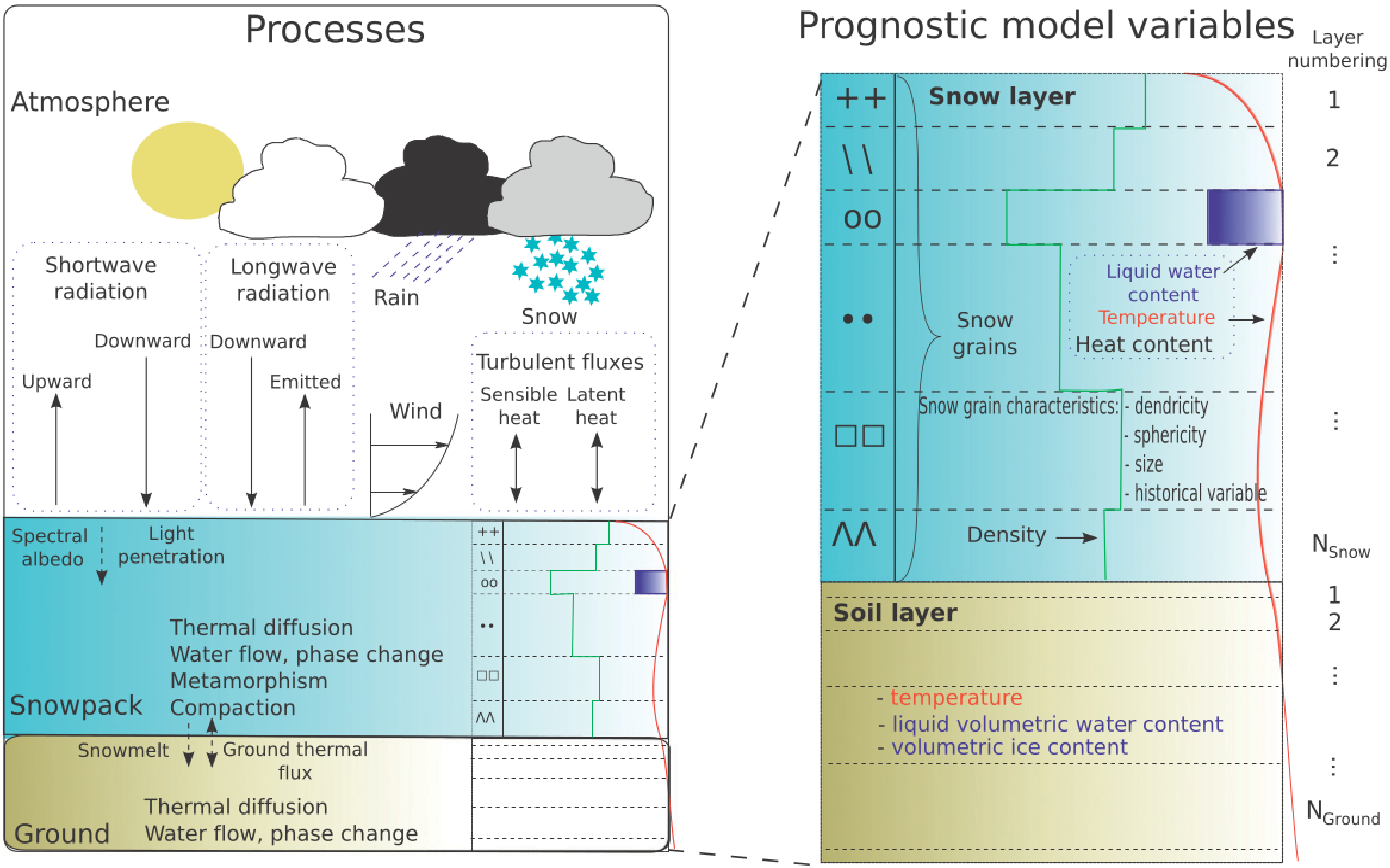
January February March April



Difference SWE ISBA-MEB – ISBA
Average over 1978-2008 in kg m^{-2}

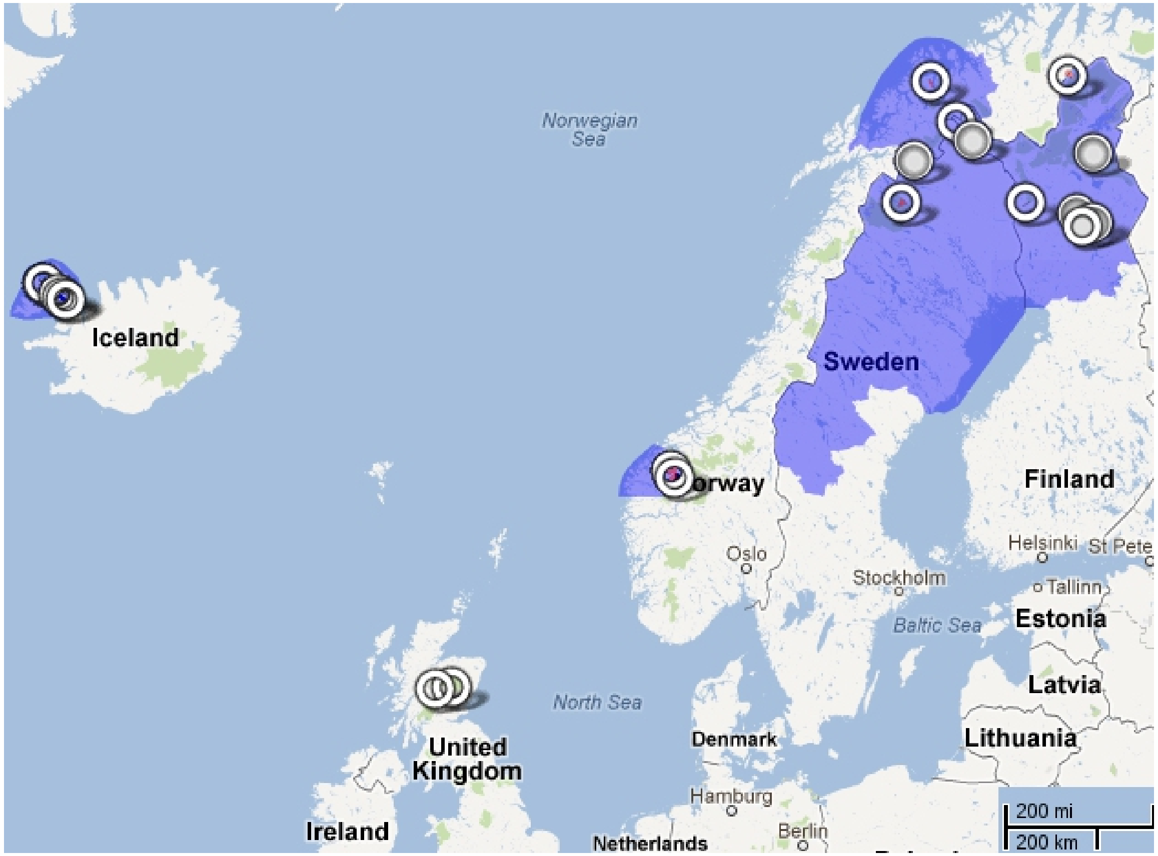
Patrick Samuelsson, 2014

Explicit snow and Crocus snowpack model



Brun, E., V. Vionnet, A. Boone, B. Decharme, Y. Peings, R. Valette, F. Karbou and S. Morin, Simulation of northern Eurasian local snow depth, mass and density using a detailed snowpack model and meteorological reanalyses, J. Hydrometeor., 14, 203–219, doi: 10.1175/JHM-D-12-012.1, 2013.

NWP output can be used to drive stand-alone Crocus



Data picked from HIRLAM and HARMONIE

Lowest model level variables to be used as atmospheric forcing for SURFEX/CROCUS, wind drift

Snow-related variables for comparison/validation against observations

Northern Periphery Programme 2007–2013

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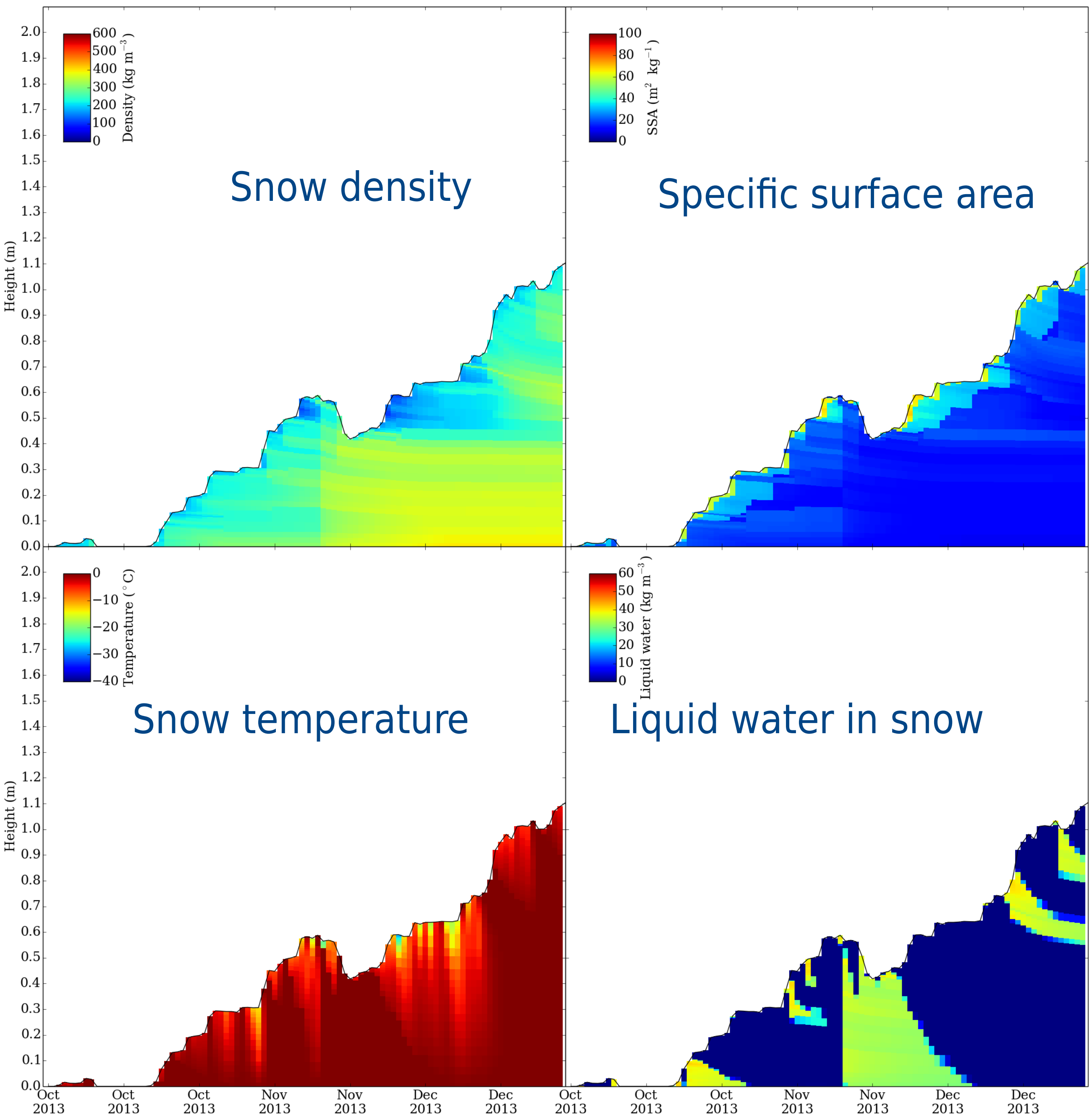
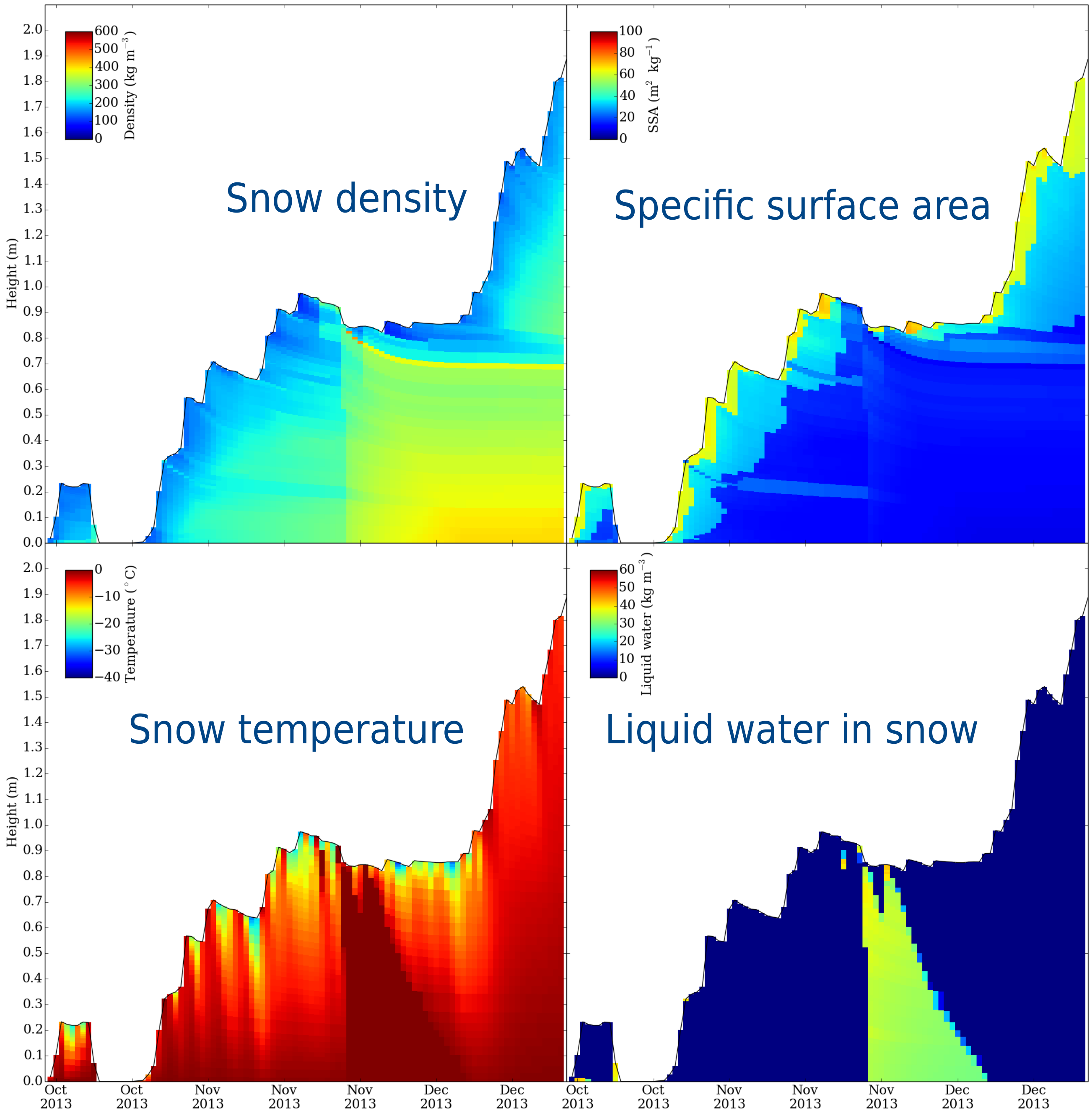
CROCUS on Kistufell (23.257W 66.074N)



HIRLAM forecast (resolution 7 km/65L) temperature, humidity, wind, downward SW and LW radiation and (snow) precipitation were applied to drive CROCUS for the autumn 2013 at Kistufell target point

SNAPS
Snow, Ice and Avalanche Applications

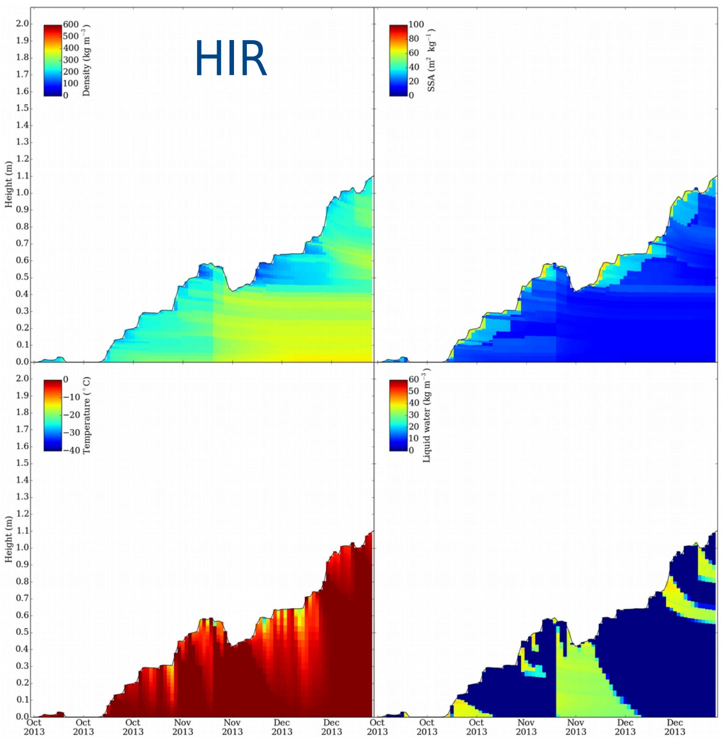
CROCUS on Kistufell (23.257W 66.074N)

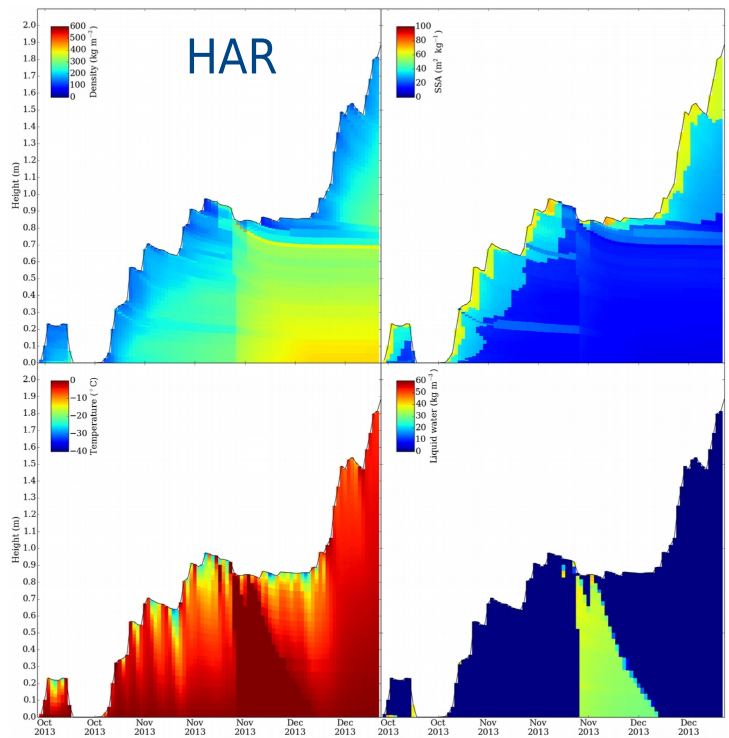


HARMONIE/AROME forecast (1km/65L) temperature, humidity, wind, downward SW and LW radiation and (snow) precipitation were applied to drive CROCUS for the autumn 2013 at Kistufell target point

SNAPS
Snow, Ice and Avalanche Applications

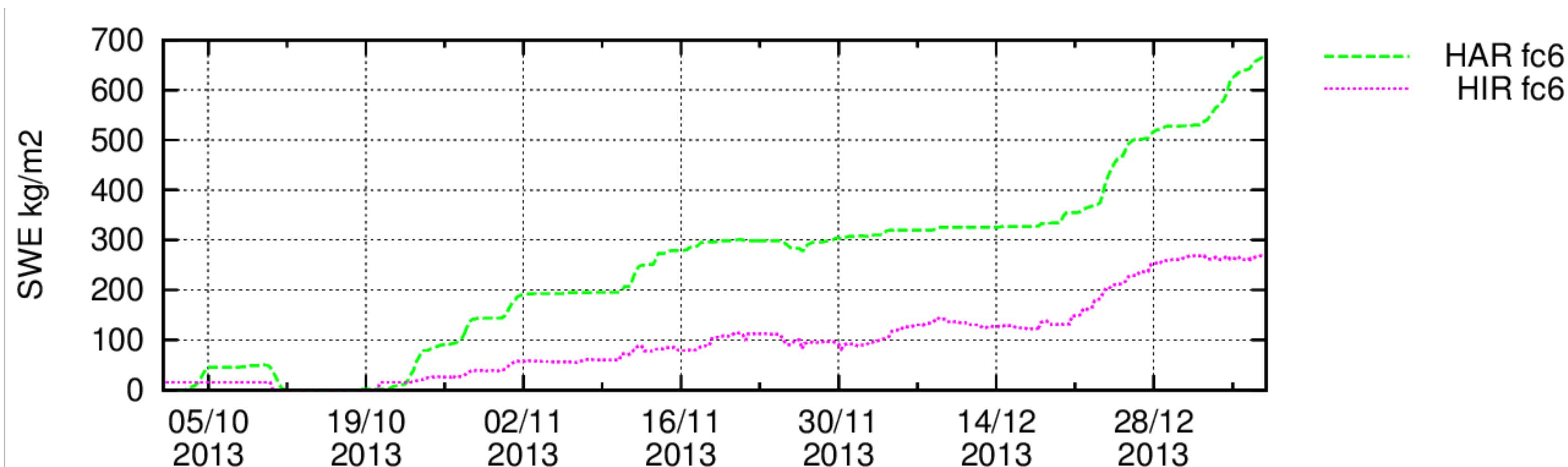
CROCUS on Kistufell (23.257W 66.074N)





The result is different because of the different atmospheric forcing by two weather models

CROCUS could also be driven by observations, but they are seldom sufficiently available



How to use advanced snow schemes in NWP?

Our aim:

Multilayer prognostic soil + Soil data assimilation +

Multilayer prognostic snow - vegetation + Snow data assimilation

The problem:

Multilayer soil and snow schemes and MEB have been developed

for climate models without any data assimilation

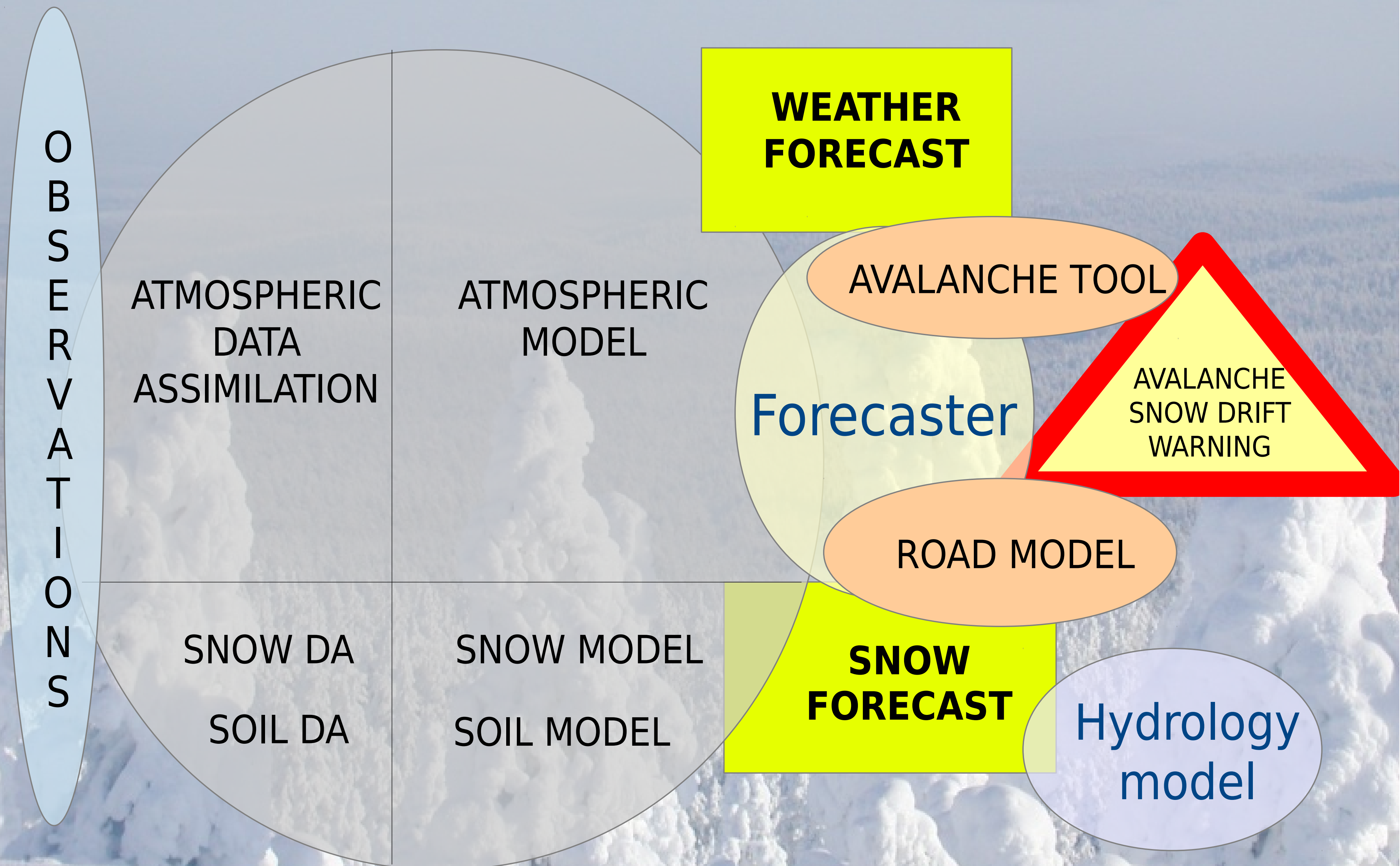
Solution would require some work:

Soil Scheme	Soil DA	Snow scheme	Snow-veg scheme	Snow DA	Application
Force-restore	OI/EKF +OI (Canari)	D95	none	snowOI (Canari)	NWP
		ES	MEB	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
			none	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
		CRO	MEB	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
			none	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
	none	D95	none	none	climate
		ES	MEB	none	climate
			none	none	climate
		CRO	MEB	none	climate
			none	none	climate
Multi-layer	{OI/VAR/EKF} +OI(Canari)	D95	none	snowOI(Canari)	NWP
		ES	MEB	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
			none	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
		CRO	MEB	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
			none	[{snowOI/VAR/EKF}] +snowOI(Canari)	NWP
	none	D95	none	none	climate
		ES	MEB	none	climate/ NWP?
			none	none	climate
		CRO	MEB	none	climate
September 2014 / EK			none	none	climate

BLUE: exists RED: does not exist { }: not started yet [ ]: not absolutely necessary

Table by Ekaterina Kurzeneva, 2014

Future NWP model for dedicated applications?



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Operational snow analyses

Model	Observations	Assimilation	Operational
CMC	SYNOP	OI	1999
ECMWF	SYNOP	Cressman	1987
	IMS	Cressman	2004
		OI	2010
HARMONIE	SYNOP	OI	2010
HIRLAM	SYNOP	Cressman	1995
	SYNOP	OI	2004
	Globsnow	OI	Experimental
Met Office	IMS	Update	2009

Richard Essery
http://www.ecmwf.int/newsevents/meetings/workshops/2013/Polar_prediction/Presentations/Essery.pdf

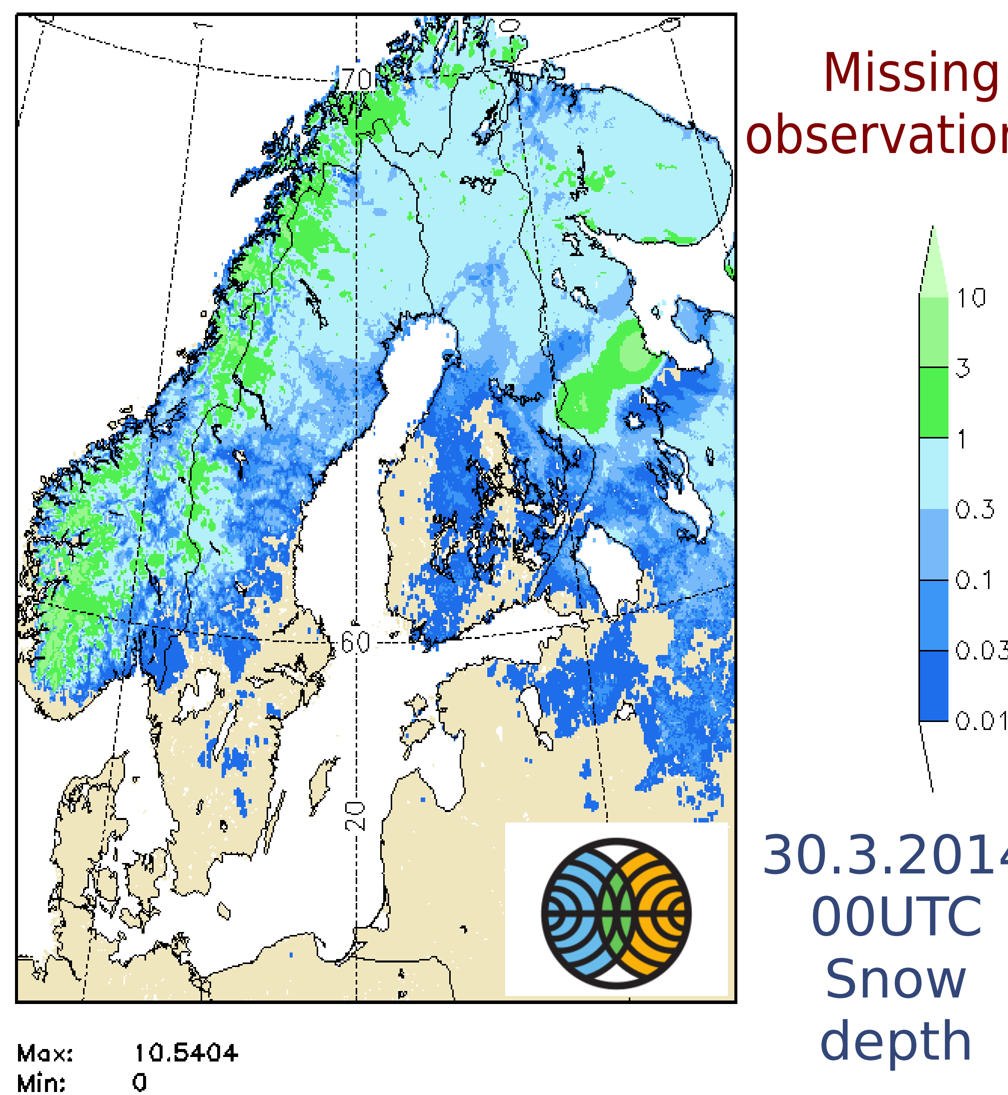
Operational CANARI snow analysis

spreads snow observations to model grid in horizontal

Optimal interpolation of snow depth of SYNOP station observations

Snow depth > SWE using assumed snow density

Background error correlations include horizontal and vertical terms*

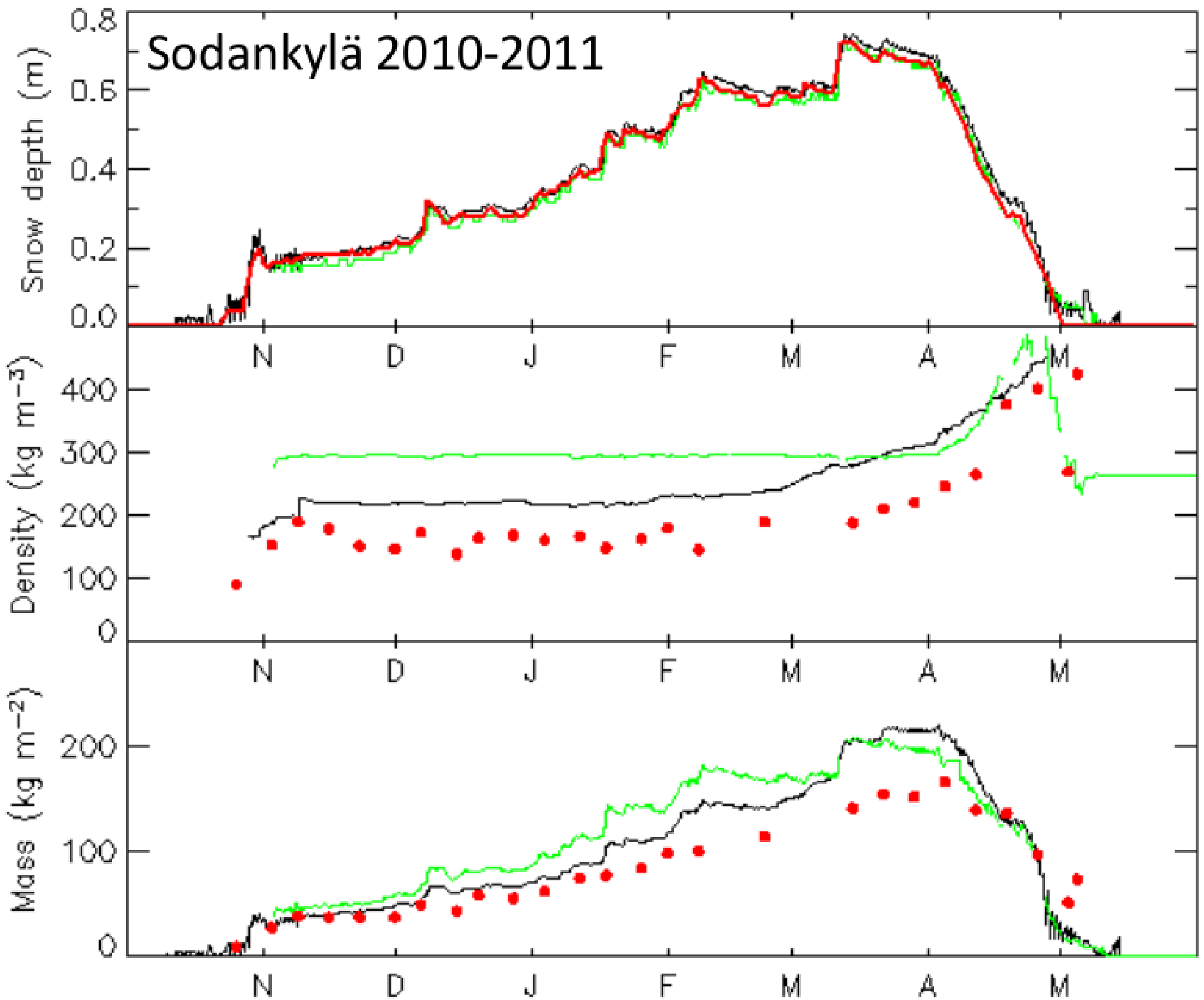


Missing observations?

30.3.2014 00UTC Snow depth

* presentation by Mariken Homleid, ASW13

Operational snow analyses



SYNOP snow depths and FMI snow pits (from Timo Ryyppö)

Hirlam snow analyses (from Laura Rontu)

ECMWF snow analyses (from Patricia de Rosnay)

Richard Essery

http://www.ecmwf.int/newsevents/meetings/workshops/2013/Polar_prediction/Presentations/Essery.pdf

Development of snow data assimilation methods

Assimilation of ground-based snow data requires:

- good background estimate of snow density
- good estimates of observation and model errors (underestimation of model / observation error ratio is worse than overestimation)
- may not require advanced data assimilation techniques

The use of a Kalman Filter will still be beneficial if information can be propagated to unobserved state variables through off-diagonal elements in the gain matrix, either due to correlation between state variables in the model or the use of a complex observation operator such as a microwave emission model or assimilation of radiance data.

Richard Essery
http://www.ecmwf.int/newsevents/meetings/workshops/2013/Polar_prediction/Presentations/Essery.pdf

Concluding remarks

Simple snow schemes are used in present NWP models, with snow mass, density, albedo in one layer
but advanced multilayer prognostic snow schemes exist

Horizontal interpolation via optimal interpolation is applied to conventional snow depth observations
but a lot more remote sensing and local snow cover observations exist

Advanced data assimilation methods will be needed to combine multilayer prognostic snow and soil parametrizations with various types of remote-sensing observations in operational NWP models

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COST ES1404 suggested working groups

WG1: Physical Characterization of Snow

WG2: Instrument and Method Evaluation

WG3: Snow data assimilation and validation methods for NWP and hydrological models

WG1: Physical Characterization of Snow

Challenges for optical remote sensing of snow:

•Pixels contain not only snow
•Definition of 100% snow cover?
•Definition of fractional snow cover
•Definition of snow during melting periods
•Spatial and temporal variation of snow properties

Is this 100% snow coverage? What is the coverage, when the trees are also white?

WG1: Physical Characterization of Snow properties

Task 1.1: Identifying and assessing the essential snow variables (snow grain size, snow depth, snow density, snow covered area, snow temperature, thermal conductivity, albedo, full microstructure, snow impurity concentration)

Task 1.2: Physical characterization of essential snow variables: Relationships between variables; How snow variables are affected by atmospheric thermodynamic and dynamic (wind drift) forcing; Response time scales of different snow variables, …

Task 1.3: Snow network optimization, data quality control and homogenization: How much snow variables vary in space during different seasons and over different environments . User needs; Ground-truth with satellite-based observations; Quality control and homogenisation recommendations.

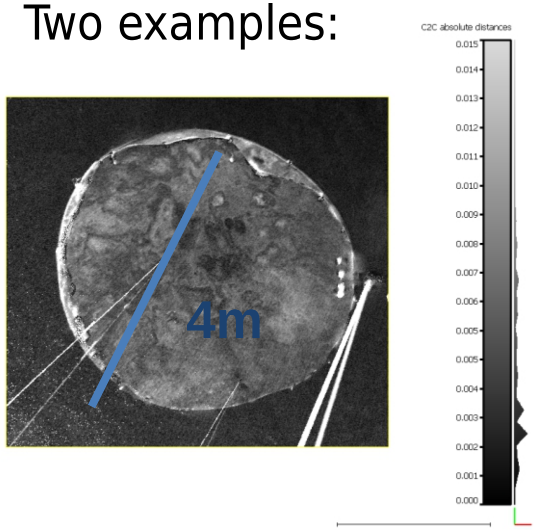
Task 1.4: Harmonization of snow observations in terms of measured variables: Practical and organizational actions needed for harmonization will be assessed. The potential generated from a harmonized network of snow observations for network operators and data users will be assessed.

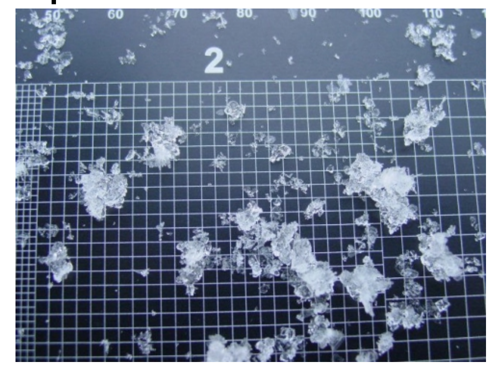
Task 1.5: WG1 interacts with WG2 as to techniques applied for measurement of essential snow variables and to WG3 as to the physical characterization of modelled snow variables.

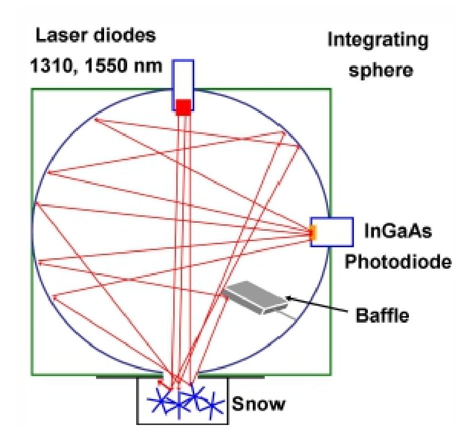
WG2: Instrument and Method Evaluation

There is a strong need to intercompare, standardize and validate the methods in Europe

Two examples:







Laser scanning

Snow height map measured over a 4-metre diameter area versus one snow pit (= point).

Snow grain size in 2D grid versus 3D Snow Specific Area (SSA) measurements

WG2: Instrument and Method Evaluation

Task 2.1: Review of space-borne and ground-based sensors/instrumentation with estimates of their uncertainties

Task 2.2: Guidelines for in-situ snow observations and related training (Accuracy of methods and instruments; Error sources; Representativeness of point values; Recommended length and sampling resolution for line measurements).

Task 2.3: Spectroradiometry for snow studies: Making field spectrometer data consistent; Harmonising data processing (e.g. spectral sampling, geo-rectification in case of airborne measurements, filtering techniques for continuous spectra).

Task 2.4: Methods to measure snow grain size: current worldwide development with varying grain size definition. The wealth of measurement techniques requires a thorough assessment and inter comparison.

Task 2.5: Methods to measure mechanical properties of snow: High relevance for avalanche formation. Field tests for harmonising snow stability assessment across European avalanche services, and for testing snow properties using snow penetrometry (SnowMicroPen).

Task 2.6: WG2 interactions with WG1 as to the definition of measured snow variables and with WG3 in terms of observation uncertainties.

WG3: Snow data assimilation and validation methods for NWP and hydrological models

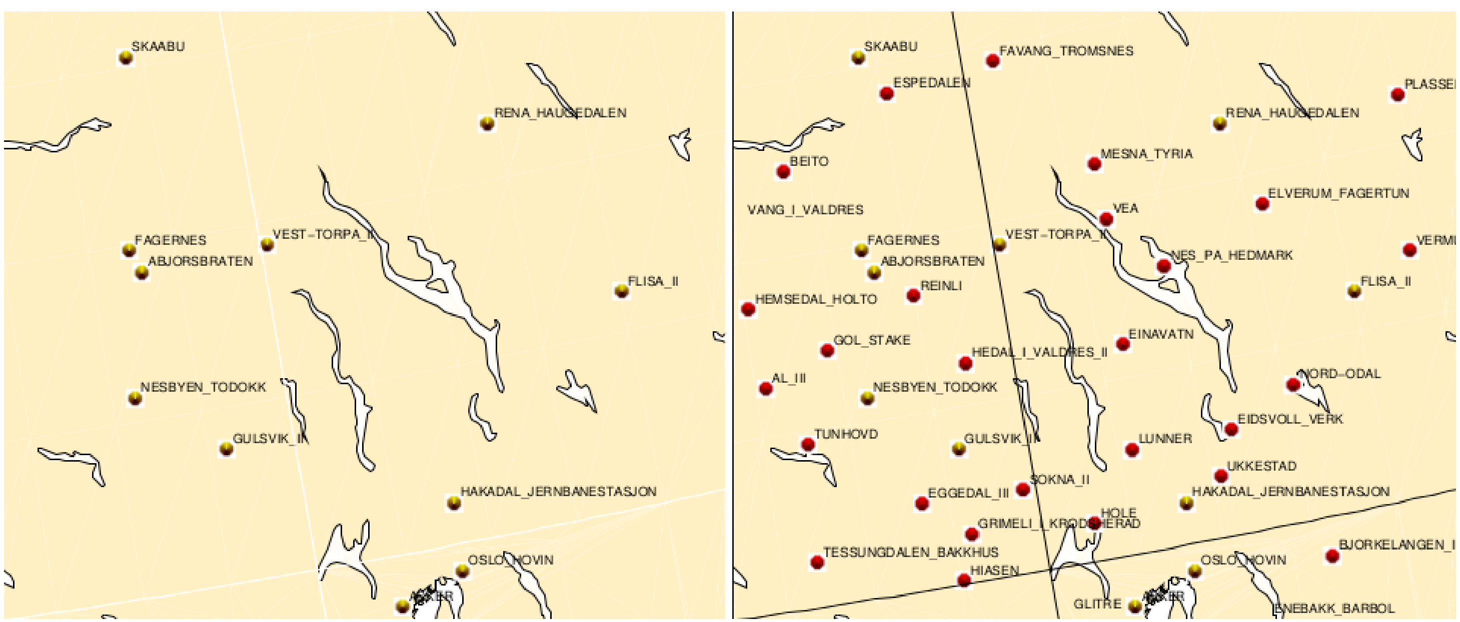
Which snow observations do we assimilate into Numerical Weather Prediction models and how?

PRESENTLY:

- We take from SYNOP stations only snow depth
- We select only snow extent from satellite data
- We convert data to model grid using the method of "Optimal Interpolation"

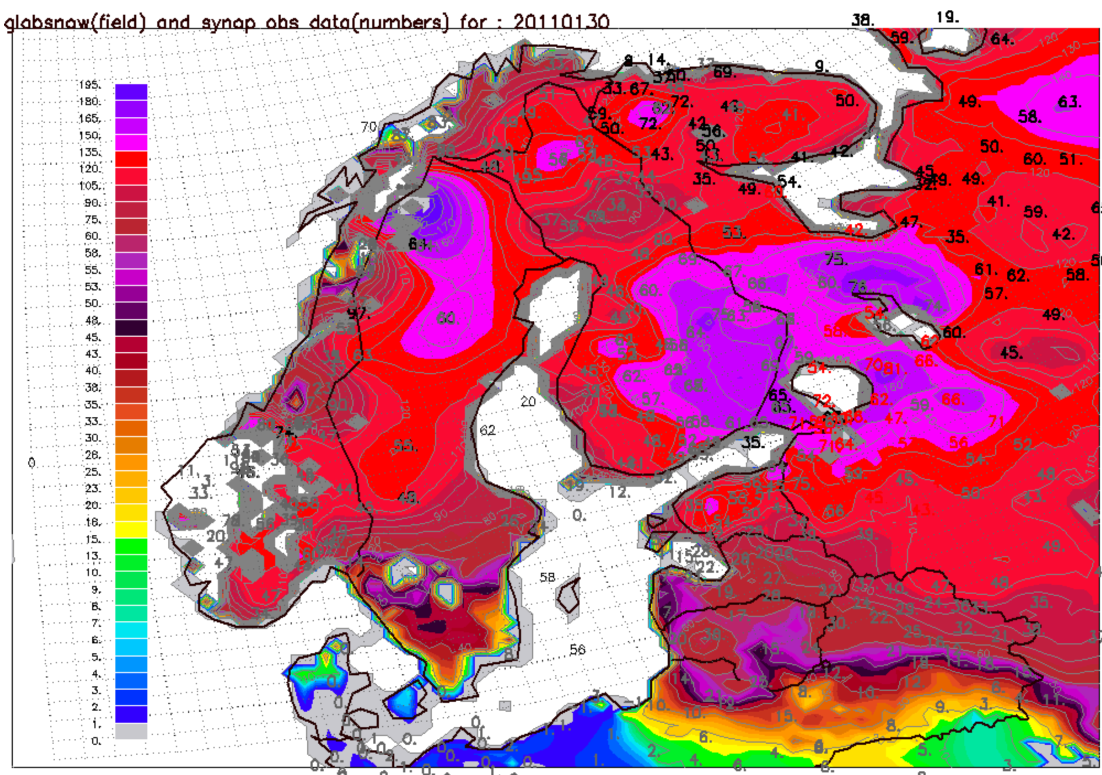
Do we need more data and better methods?

If we also assimilated snow depth observations from local climate stations, the forecast error of two-metre temperature in spring would decrease. However, these data are only available locally in National Weather Services!



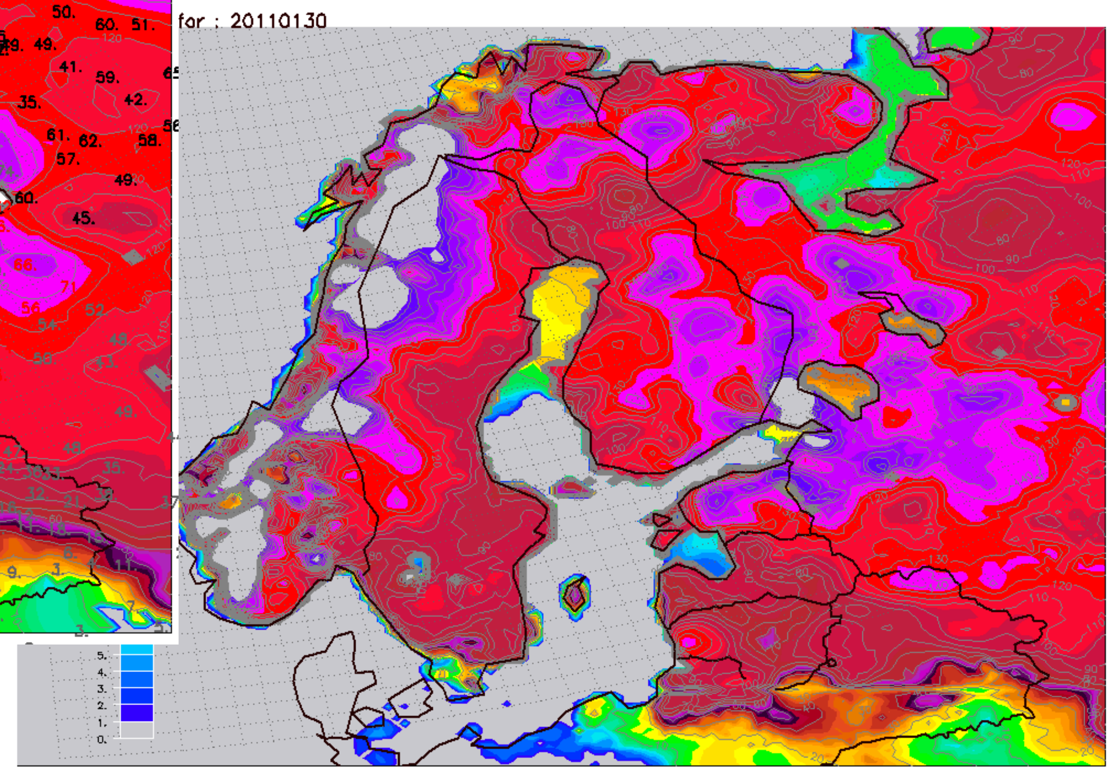
How to assimilate more remote sensing observations?

- Observations: predicted and observed parameters differ!
- Methods: advanced methods to be developed to assimilate satellite retrievals instead of remote sensing snow products!



Snow depth observations as given by
SYNOP (numbers) + Globsnow remote sensing product
(colour)

… assimilated into a NWP model



WG3: Snow data assimilation and validation methods for NWP and hydrological models

Task 3.1: Overview assessment of future perspectives as to snow observations in NWP, hydrology and climate studies for the sake of validation and assimilation.

Task 3.2: **Developing methods to update non-observed forecasted physical snow properties** (e.g. snow temperature, wetness, density profiles, and mechanical properties) based on the observed ones

Task 3.3: Advancing assimilation of new and developing satellite observations of snow properties and their combination with conventional in-situ snow data.

Task 3.4: Improving wider use of conventional snow observations in NWP, hydrological and climate models (i.a. observations from HR national networks).

Task 3.5: Quantifying model and observational errors for data assimilation from results of WG1 and WG2.

Task 3.6: **Remote sensing and in-situ observations fusion techniques** for snow-melt modelling in all weather conditions (esp. under cloudy conditions.

Near future NWP snow tasks related to COST ES1404

Acquire more and ensure full usage of SYNOP/climate station snow depth observations

Introduce passive microwave SWE observations (Globsnow via Hydro-SAF) into the snow analysis

Research task: Develop advanced data assimilation methods to combine multilayer prognostic snow to various types of remote-sensing observations


THANK YOU!