Photo Krister Kristensen

Lessons of SNAPS

Snow and avalanche applications
March 2011 - February 2014

Laura Rontu

Thanks to SNAPS and HIRLAM colleagues
from Iceland, Norway, Sweden, Finland, Scotland

Lake 2015 + COST ES 1404 meeting
Evora, 7. – 9. 5. 2015

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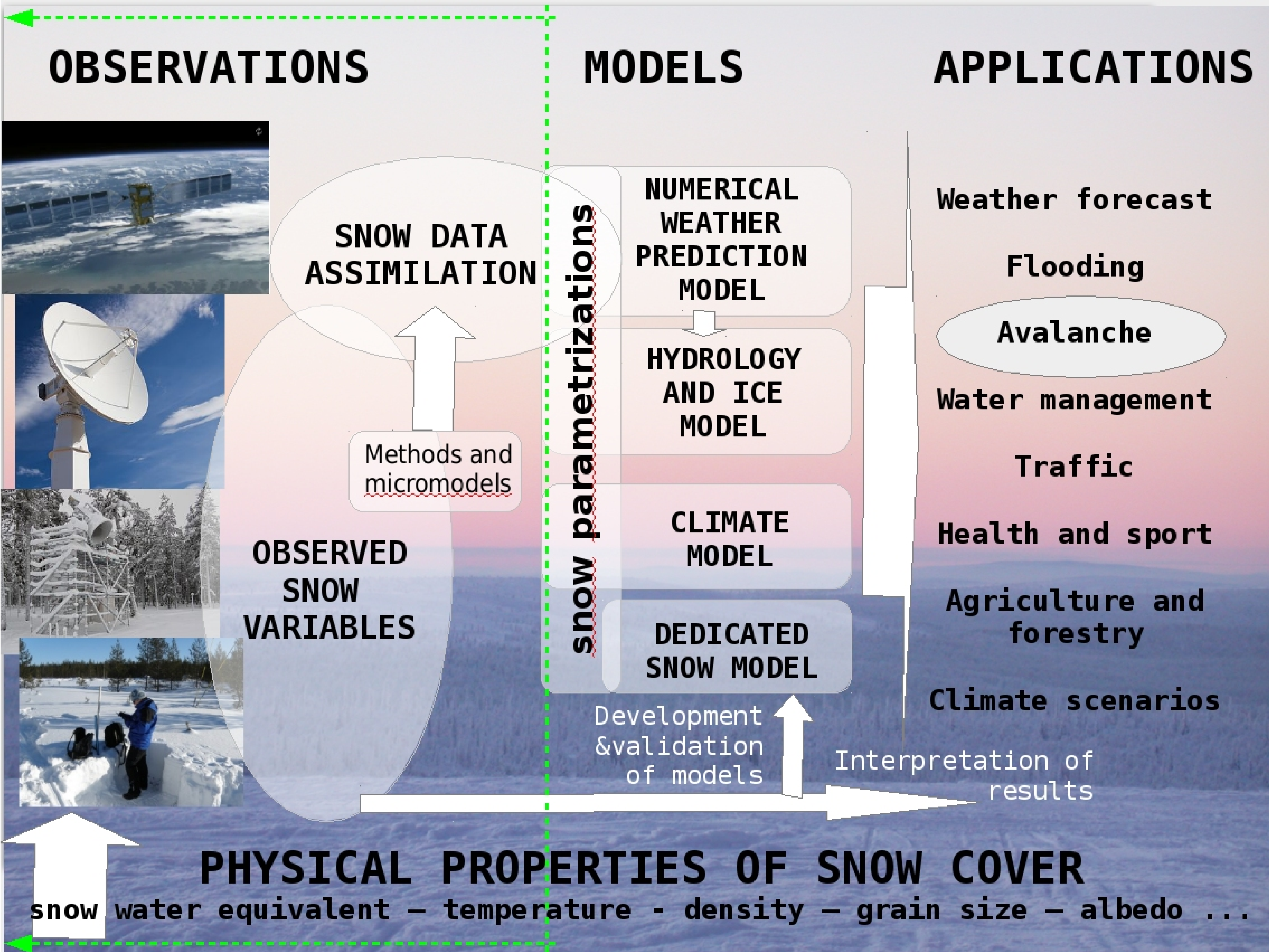
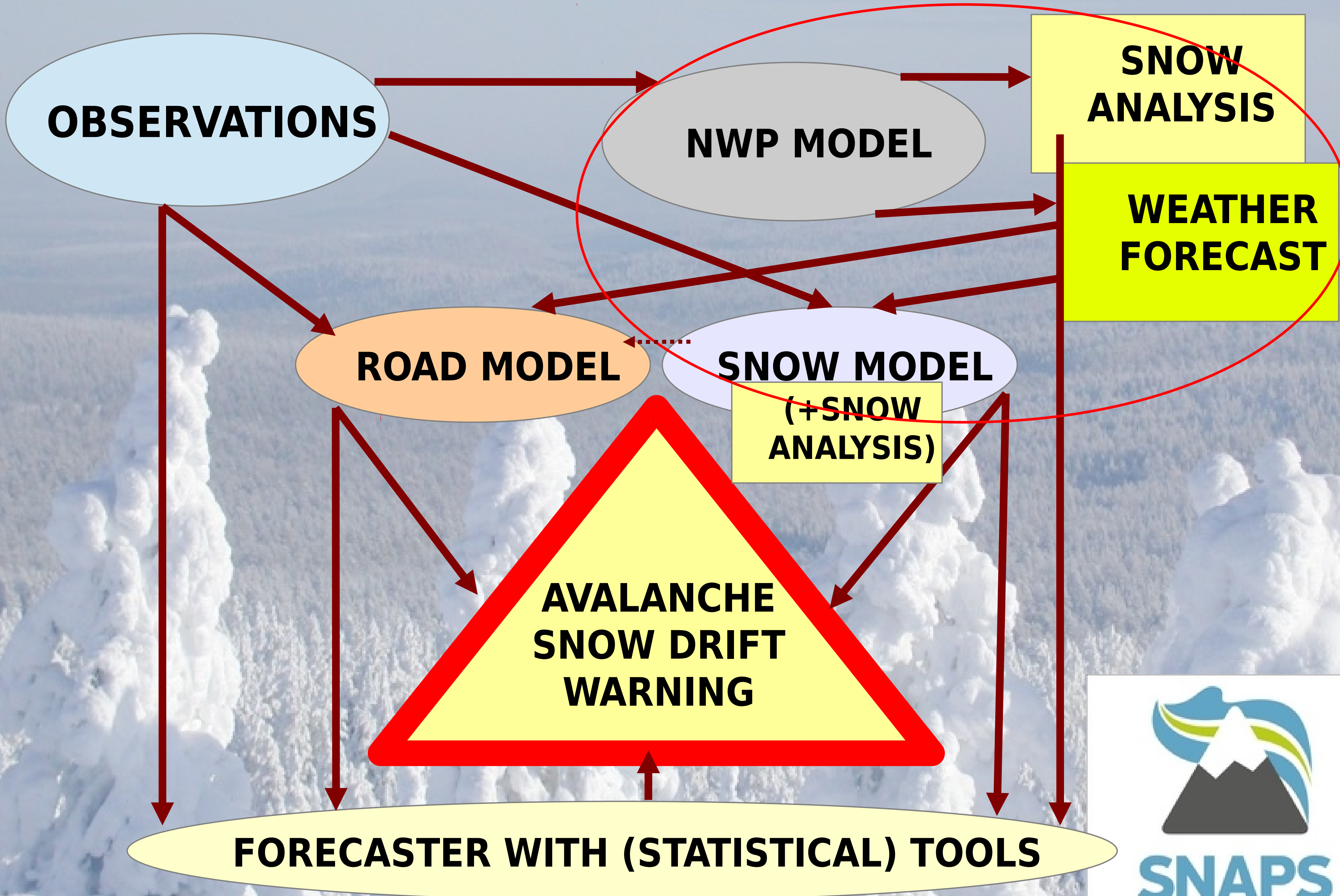


OBSERVATIONS
MODELS
APPLICATIONS
SNOW DATA ASSIMILATION
Methods and micromodels
OBSERVED SNOW VARIABLES
snow parametrizations
NUMERICAL WEATHER PREDICTION MODEL
HYDROLOGY AND ICE MODEL
CLIMATE MODEL
DEDICATED SNOW MODEL
Development &validation of models
Interpretation of results
Weather forecast
Flooding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

Avalanche and snow drift warning chains



SNAPS
Snow, Ice and Avalanche Applications

SNAPS from project application 2011 to the final seminar 2014

Main Application Part 1: Content

SECTION 1: PROJECT INFORMATION

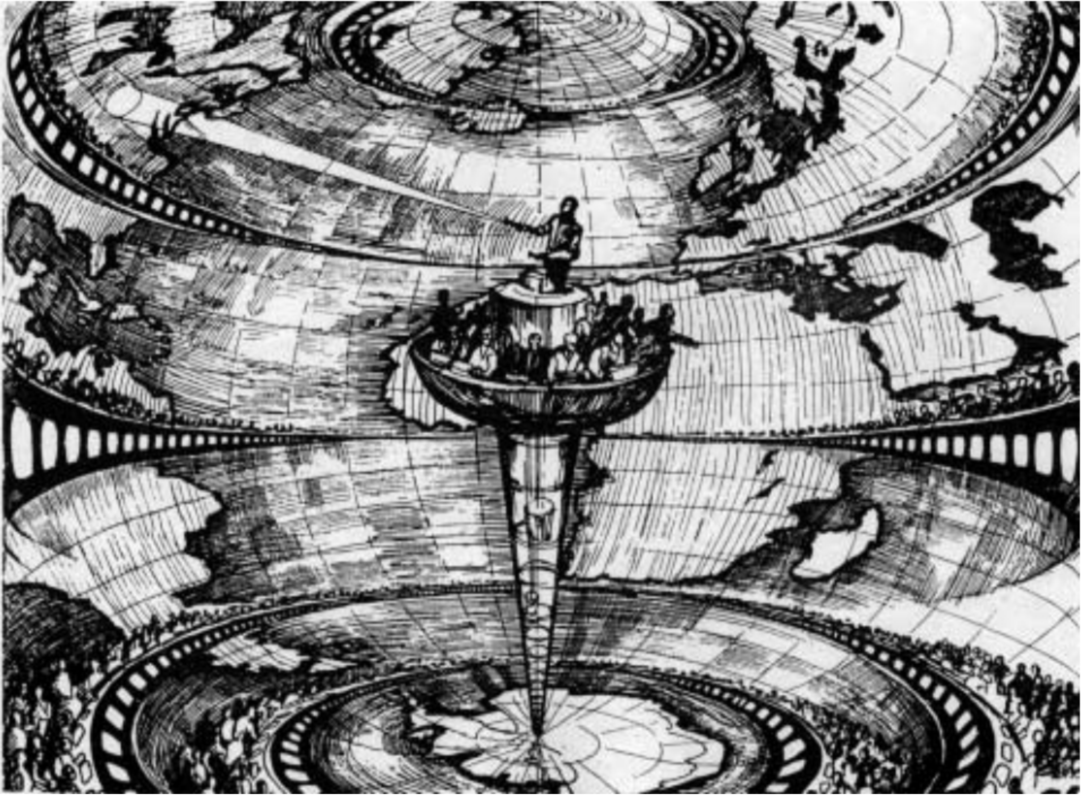
1.1 Project Title: Snow, Ice and Avalanche applications
1.2 Acronym/Abbreviation: SNAPS

1.3 Project Duration: 3 years	
Start date: 1. March 2011	Finish date: 1. March 2014

1.4 Priority:	
Priority 1: Promoting innovation and competitiveness in remote and peripheral area	X
Priority 2: Sustainable development of natural and community resources	

1.5 Target area / Location of the operation:
Westfjords (Iceland), Sunnmøre and Nordfjord districts (Norway), counties of Norrbotten, Västerbotten and Jämtland (Sweden), Lapland (Finland)

http://www.snaps-project.eu/publication-and-promotion/final-conference/



WEATHER MODELS and SNAPS

Laura Rontu

Finnish Meteorological Institute

International HIRLAM Programme

FMI

Hirlam

ALADIN

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http://www.snaps-project.eu/publication-and-promotion/final-conference/

Starting points: NWP

To provide a three-dimensional weather forecast ,
the NWP model needs

- information about the state of atmosphere and surface in the beginning of every forecast
- knowledge of the surface properties (sea/forest/ice ...) and topography everywhere in the forecast domain
- information about the evolving atmospheric flow beyond the forecast domain

With respect to snow, the NWP model acquires this by

- assimilating conventional and satellite observations about snow
- incorporating a (simple) snow model to forecast snow properties
- utilizing global fine resolution data bases about the surface elevation and properties

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How to combine the efforts of SNAPS and NWP developers?

Would the snow data assimilation of a NWP model provide up-to date observation-based snow maps, sufficient not only for the NWP itself but also for the SNAPS purposes?
- i.e., to replace the satellite snow maps?

Would the forecast of snow properties, made by the NWP model be detailed and reliable enough as direct application for the avalanche and road forecast?
- i.e., to replace the dedicated snowpack model?

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FMI modellers, 2011

We suggest for SNAPS

To provide SNAPS with
kilometer-scale gridded snow depth/water equivalent maps based on HIRLAM/HARMONIE data assimilation

To provide dedicated stand-alone snow data-assimilation system (by the Edinburgh university) with atmospheric forcing data including temperature, humidity, wind, snowfall, downwelling radiation fluxes

From Luleå:

SNAPS meeting, 2012

FMI, IMO and met.no operational

Provide and validate(existing) HIRLAM/HARMONIE prognostic weather and snow variables for SNAPS applications in the target locations

Apply and develop SURFEX-CROCUS(-MEPRA) prognostic model and snow data assimilation for SNAPS forecasts in the target locations

Produce snow maps by applying (existing) HIRLAM/HARMONIE analysis methods to conventional observations

Develop snow analysis in HIRLAM/HARMONIE in order to use better the satellite snow observations

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MODELS used in

Category	Usage	Comments
Operational HIRLAM	Weather, snow maps, atmospheric forcing for Crocus, road weather model	HIRLAM RCR run in FMI
Operational HARMONIE	Weather, snow maps, atmospheric forcing for Crocus, road weather model	Run separately in IMO and FMI
Crocus (Meteo France)	Snowpack structure	Driven by observations or NWP forecasts; research runs and validation in Edinburgh, IMO
Road weather model	Road conditions, including drifting snow	Driven by observations and NWP forecasts, operational in FMI, includes drifting snow algorithm by Skúli Þórðarson
Drifting snow algorithm by Skúli Þórðarson	Drifting snow maps for Iceland	Maps produced in IMO

Photo Krister Kristensen

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OBSERVATIONS used in

Observations	Usage	Comments
Remote sensing optical	Snow extent/fraction maps	Maps in snaps-project.eu
Remote sensing SAR	Wet snow mapping	Maps in snaps-project.eu
Remote sensing passive microwave	Snow Water Equivalent maps	Maps in snaps-project.eu
SYNOP snow depth	Input to NWP model data assimilation, validation	
SYNOP weather observations	Statistical study on weather v.s. avalanches, input to Crocus	
SM4 snow sensor: snow depth and temperature profile	Forecast, validation	Set up during SNAPS in Westfjords and Norway Observations at snowsense.is
Road weather station measurements	Forecast, input to road weather model, validation	
Road weather web cameras	Forecast, validation	

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

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

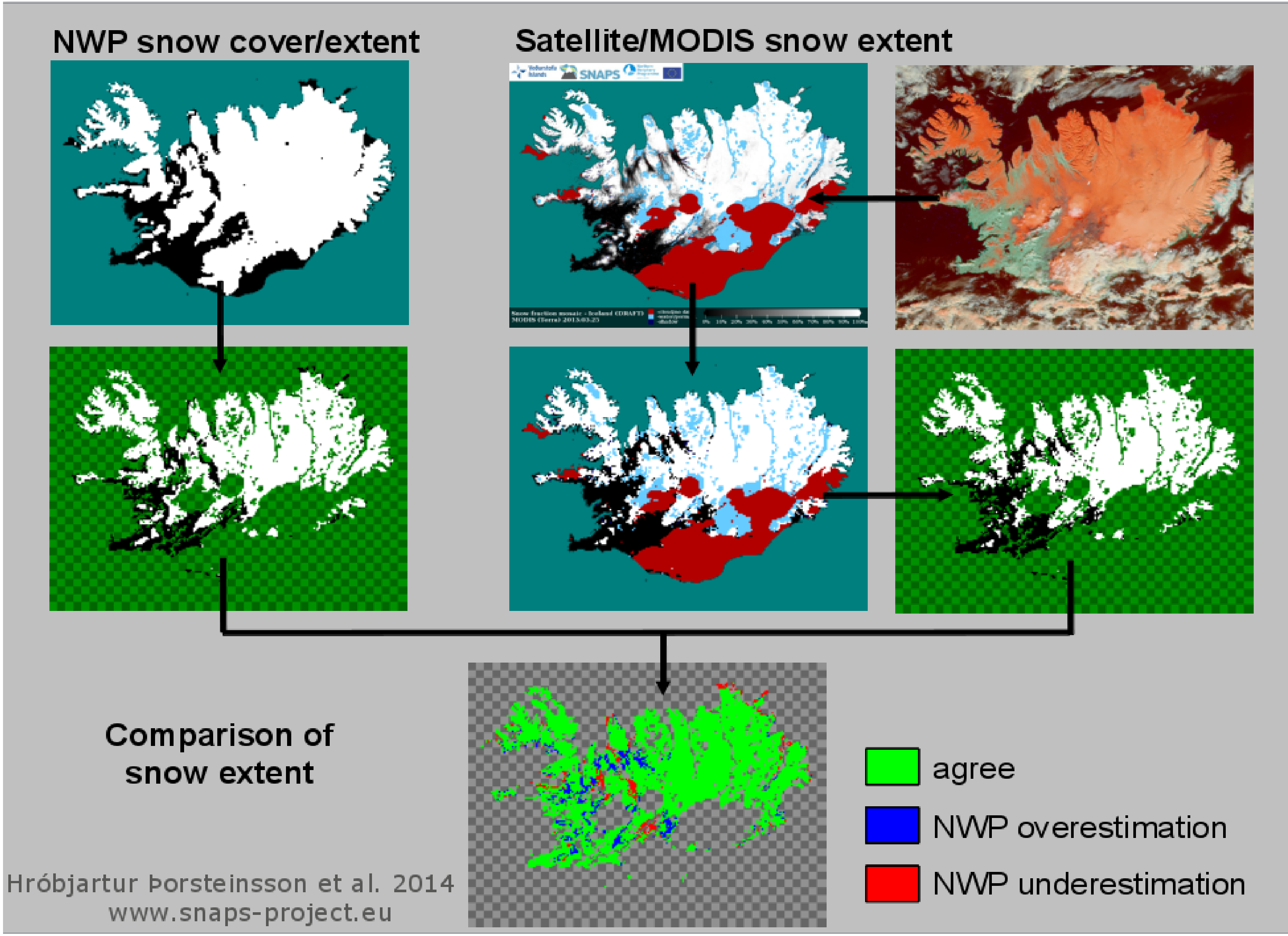
Remote sensing observations

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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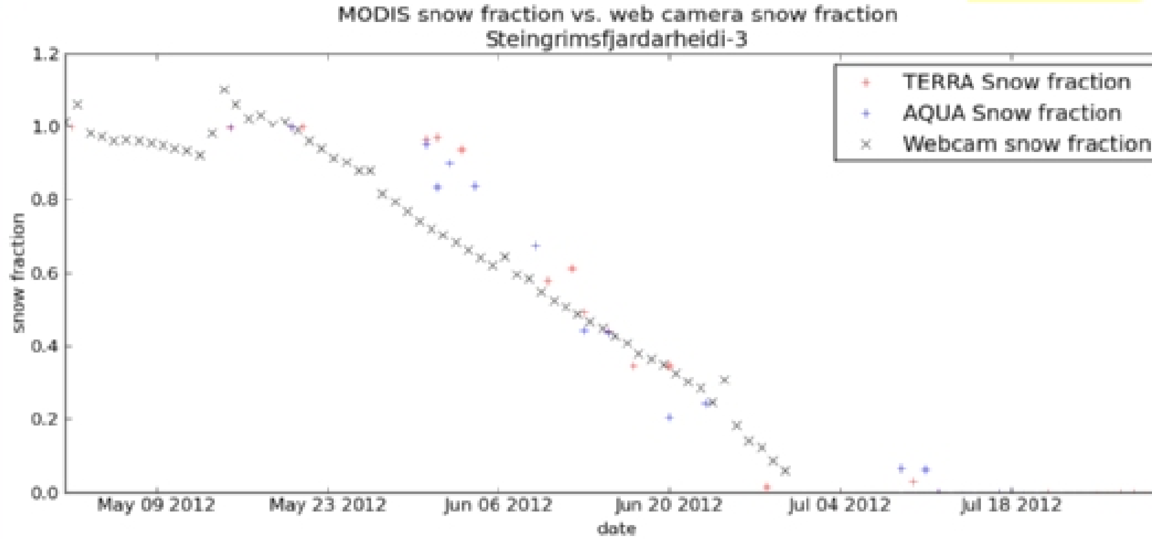
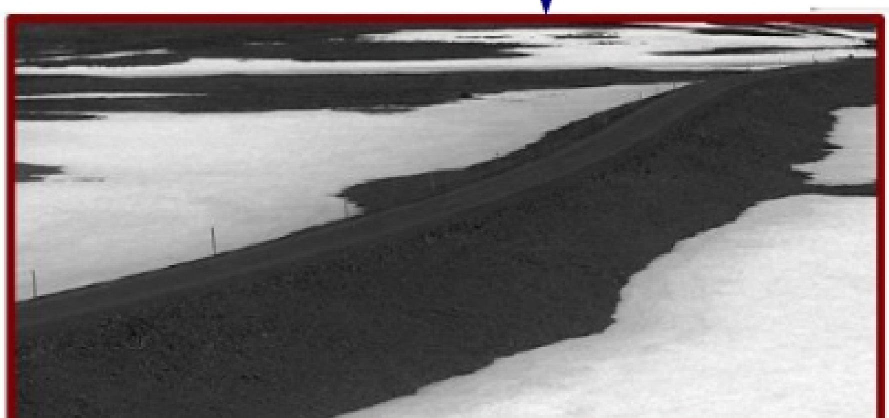
Verification of MODIS snow cover maps with web cameras



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



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Hróbjartur Þorsteinsson et al. 2014

Icelandic Met Office

Photo Krister Kristensen

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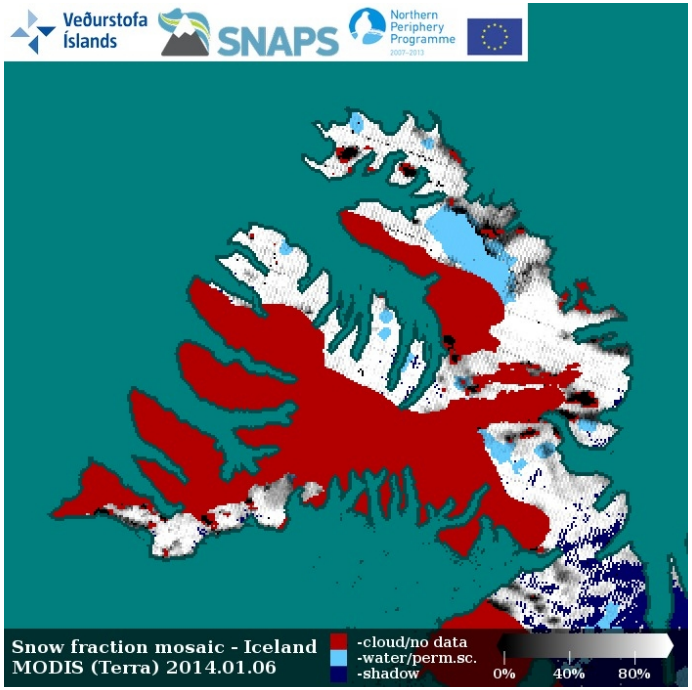
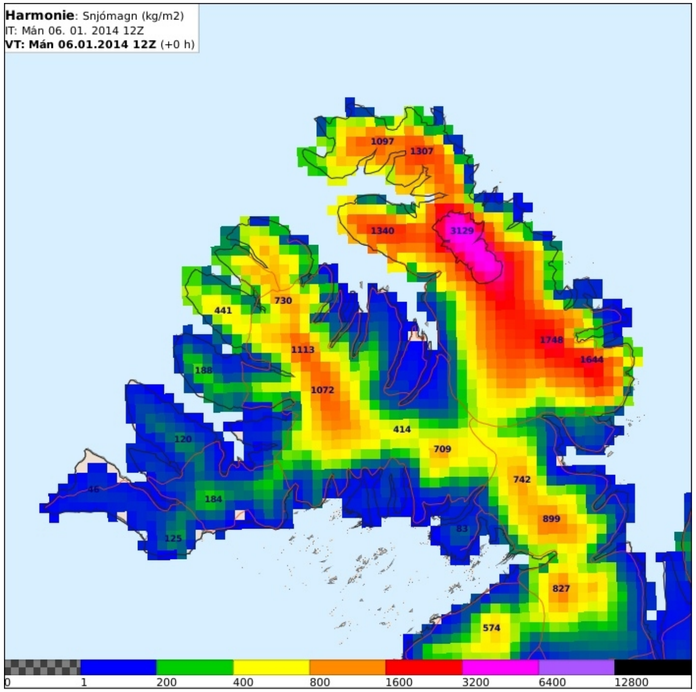
Snow in Westfjords 6 Jan 2014



MODIS satellite
snow cover



HARMONIE Vedurstofa forecast
snow water equivalent

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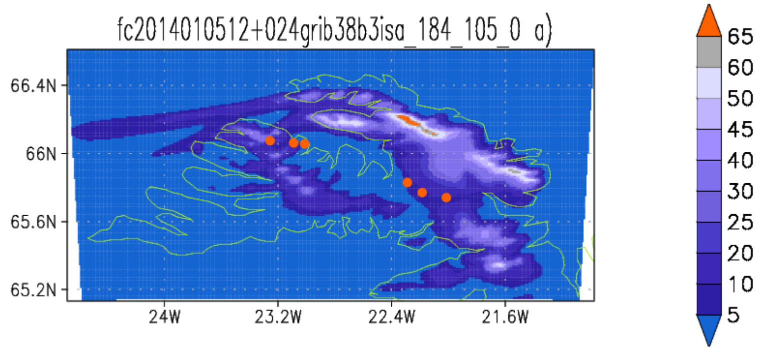
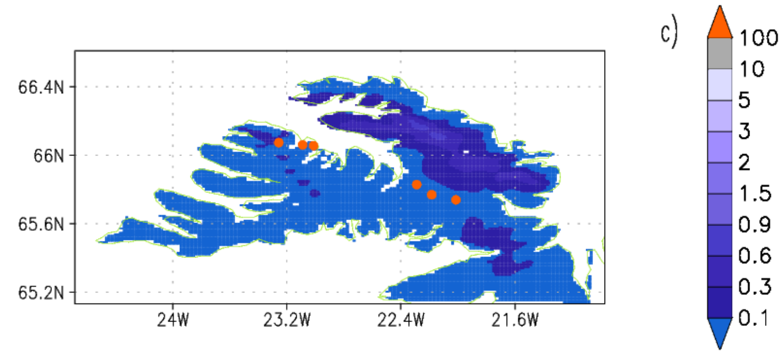
Snow in Westfjords 6 Jan 2014

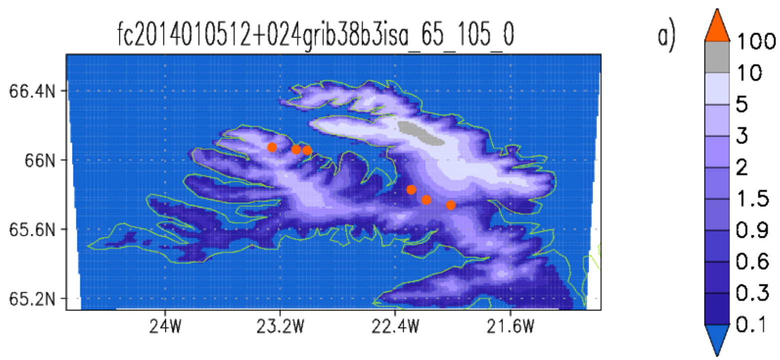
HARMONIE experiment



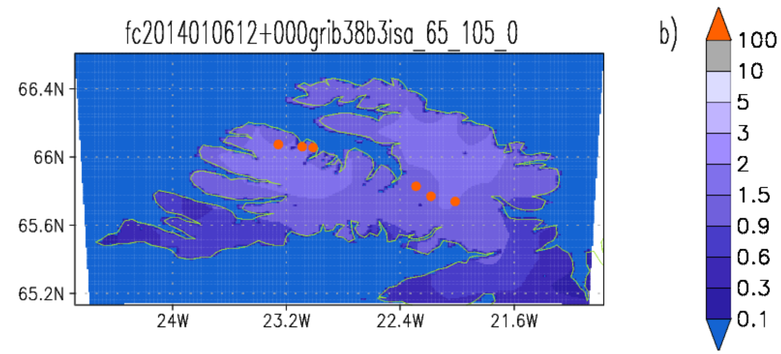
predicted snowfall (mm SWE)



predicted increase of snow depth (m*)



predicted snow depth (m*)



analysed snow depth (m*)
based on observations?

* assumed snow density 250 kg/m3

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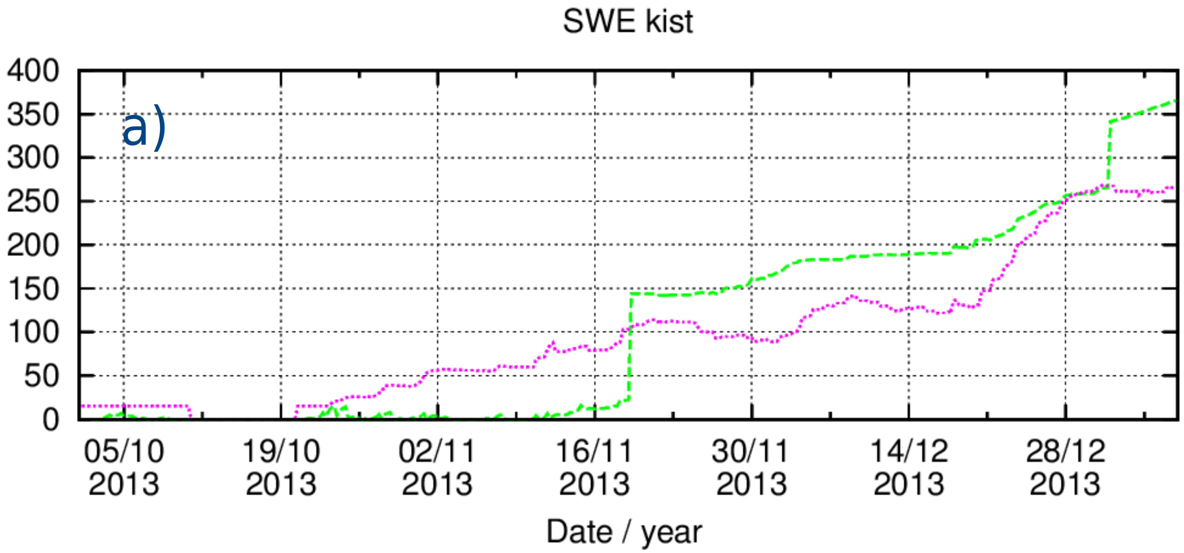
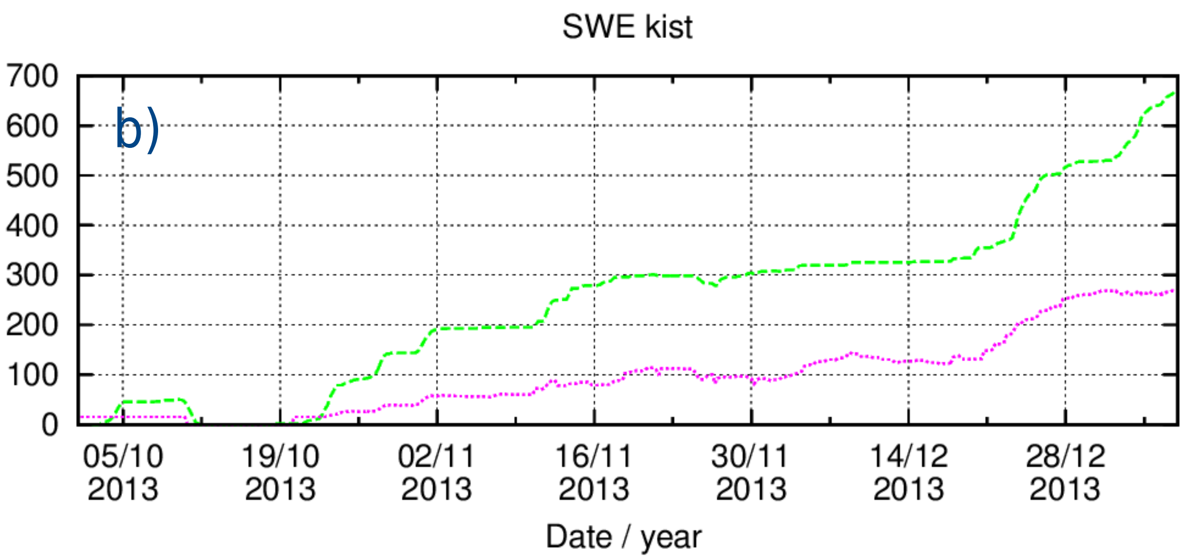


Analysed (a) and predicted (b) snow water equivalent at Kistufell till 6th Jan 2014.

HARmonie 1km,
HIRlam 7km
fc0=analysis,
fc6=6h forecast



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Snow in Westfjords – first conclusions?

Would the snow data assimilation of a NWP model provide up-to date observation-based snow maps sufficient not only for the NWP itself but also for the SNAPS purposes?
- i.e., to replace the satellite snow maps?

Problems:

- Satellite snow maps by optical sensors suffer from cloudiness
- HARMONIE snow forecast looks qualitatively good as snow map but needs more validation
- HARMONIE snow data assimilation may not work properly (due to the lack of observations?)

→ No, we are not yet there:
both NWP forecast and satellite maps are needed for the snow map

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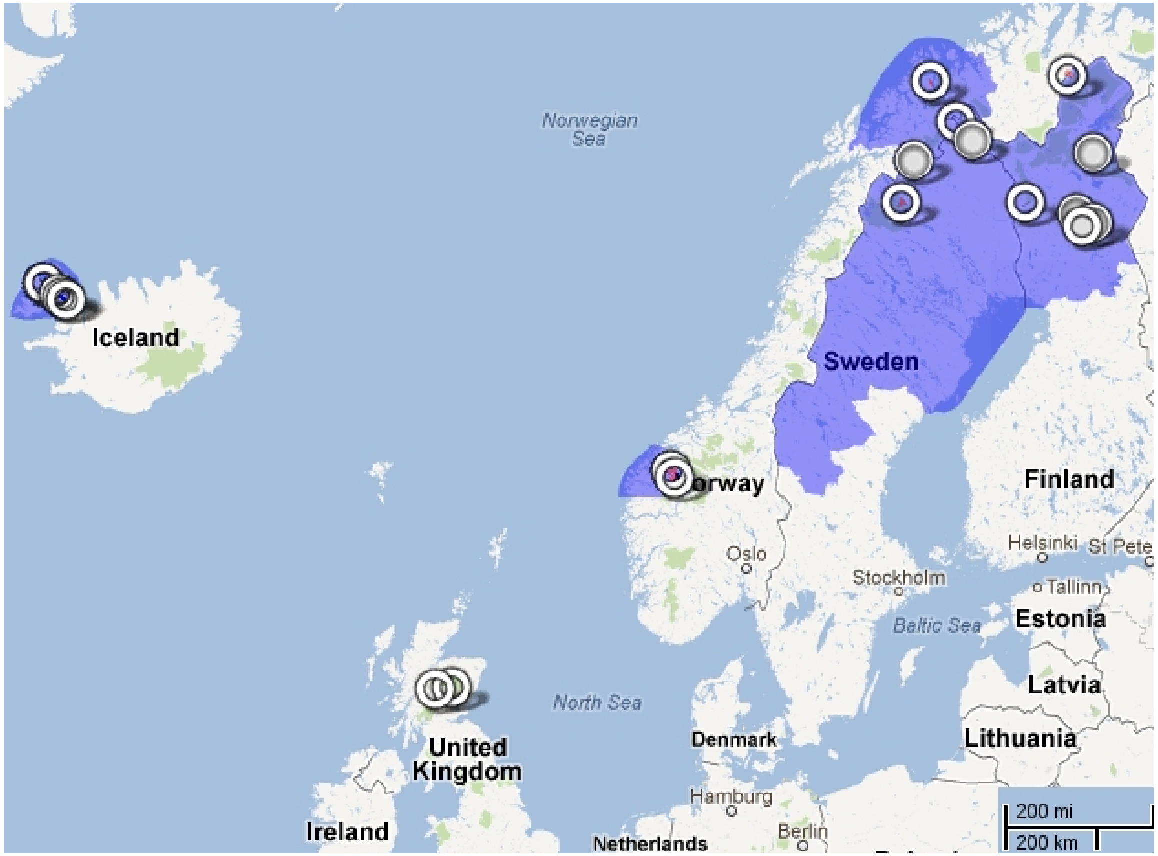
NWP output can be used to drive stand-alone Crocus



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

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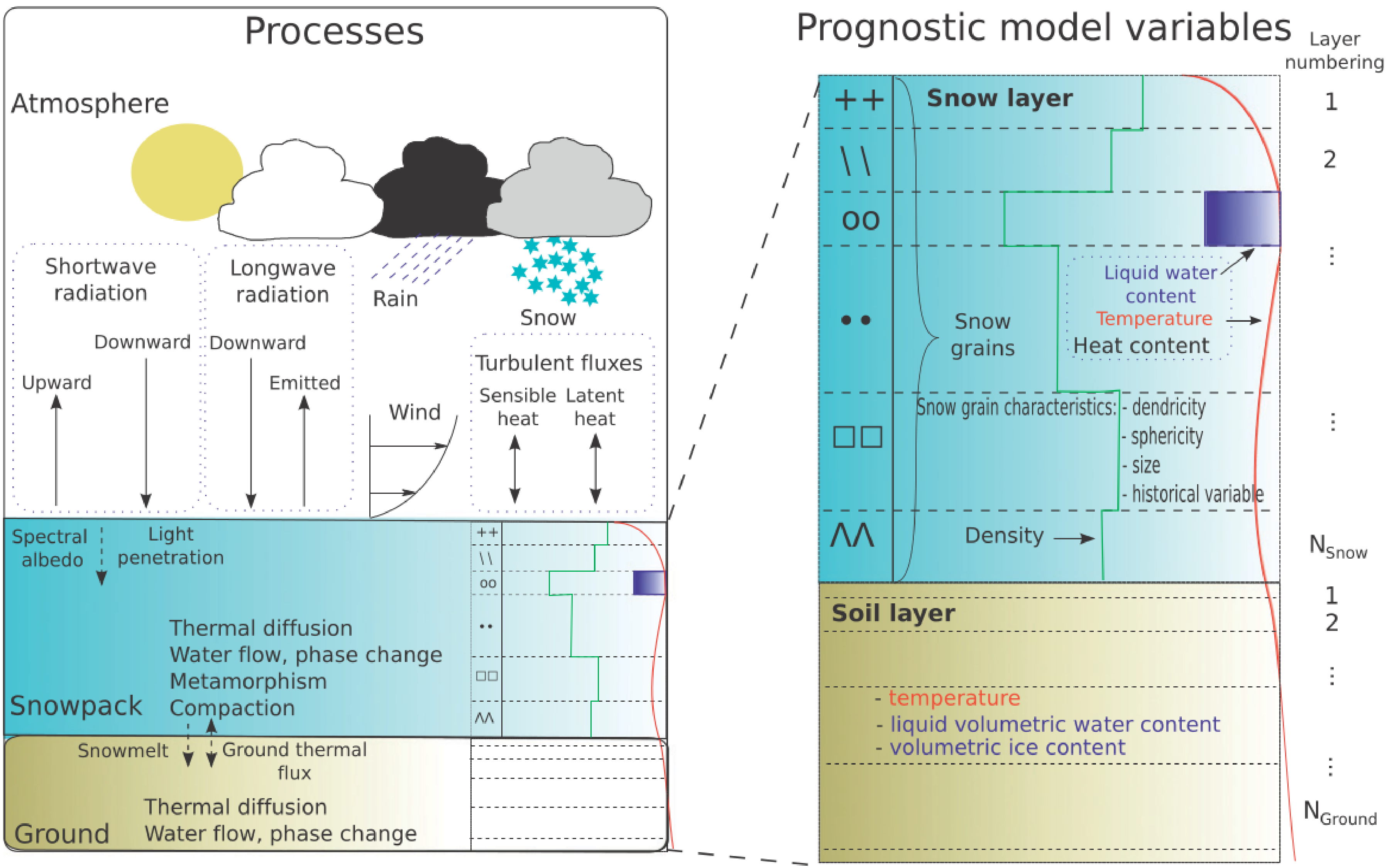
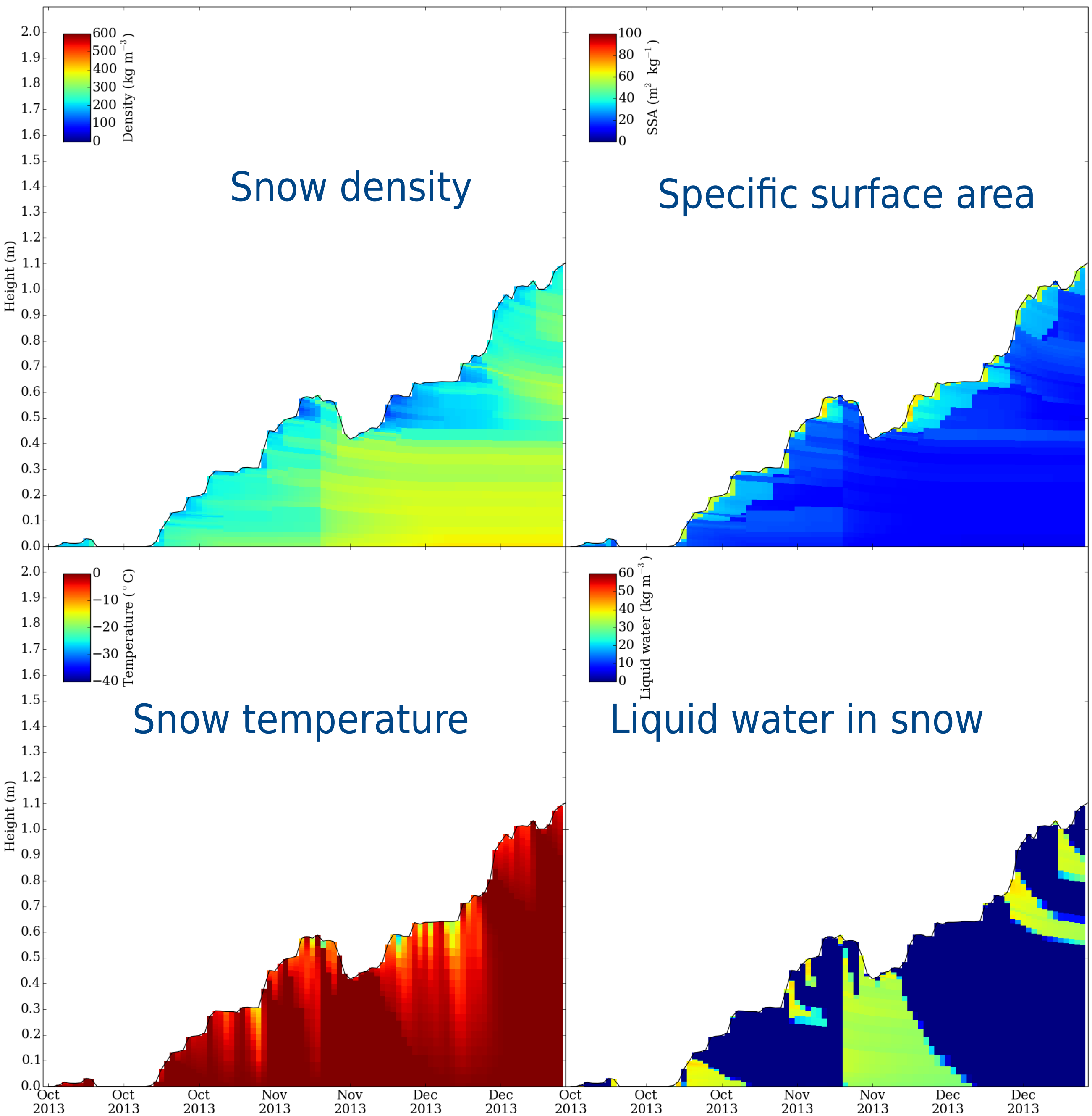
Explicit snow and Crocus snowpack model



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.

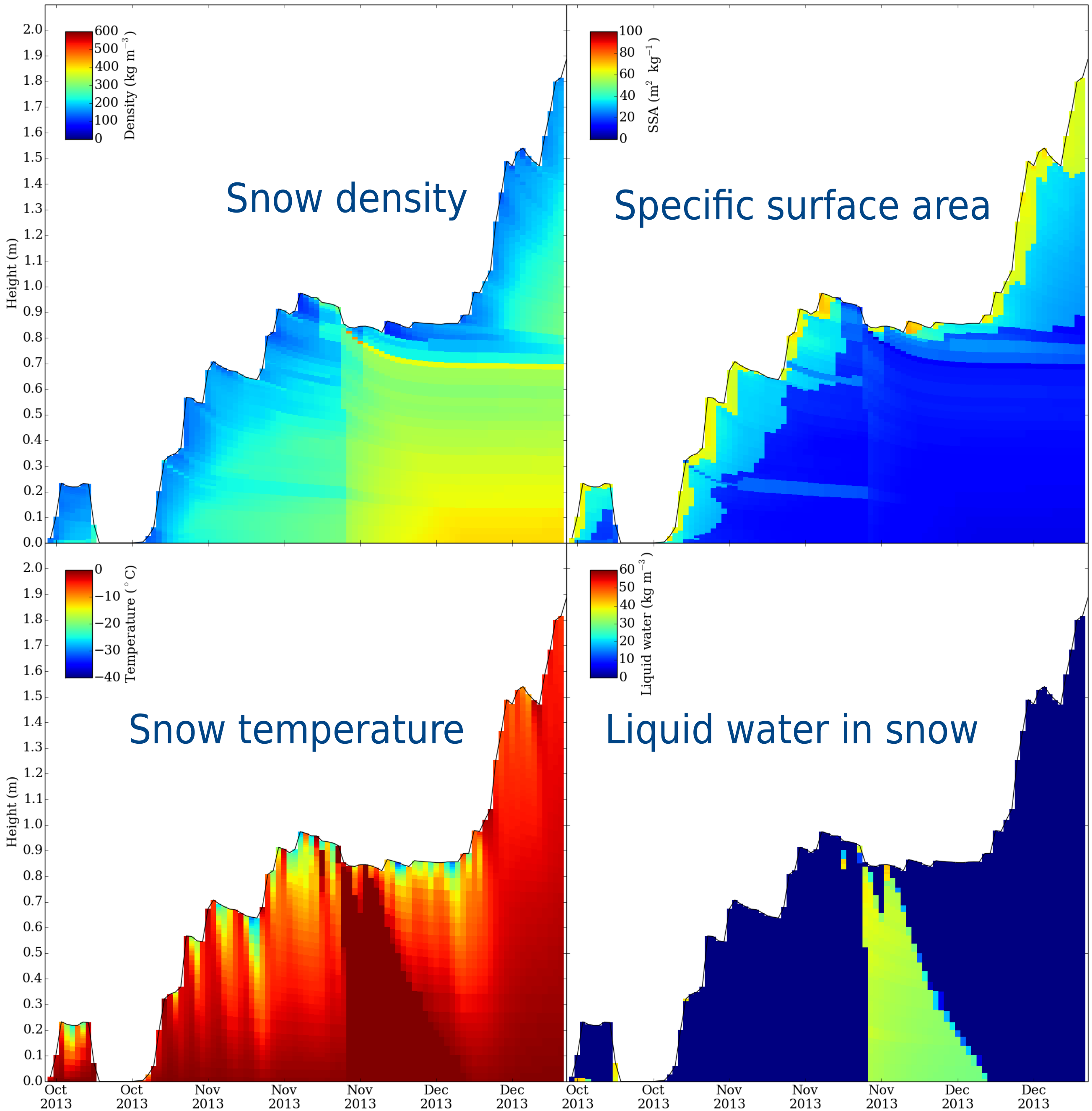
CROCUS on Kistufell (23.257W 66.074N)



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

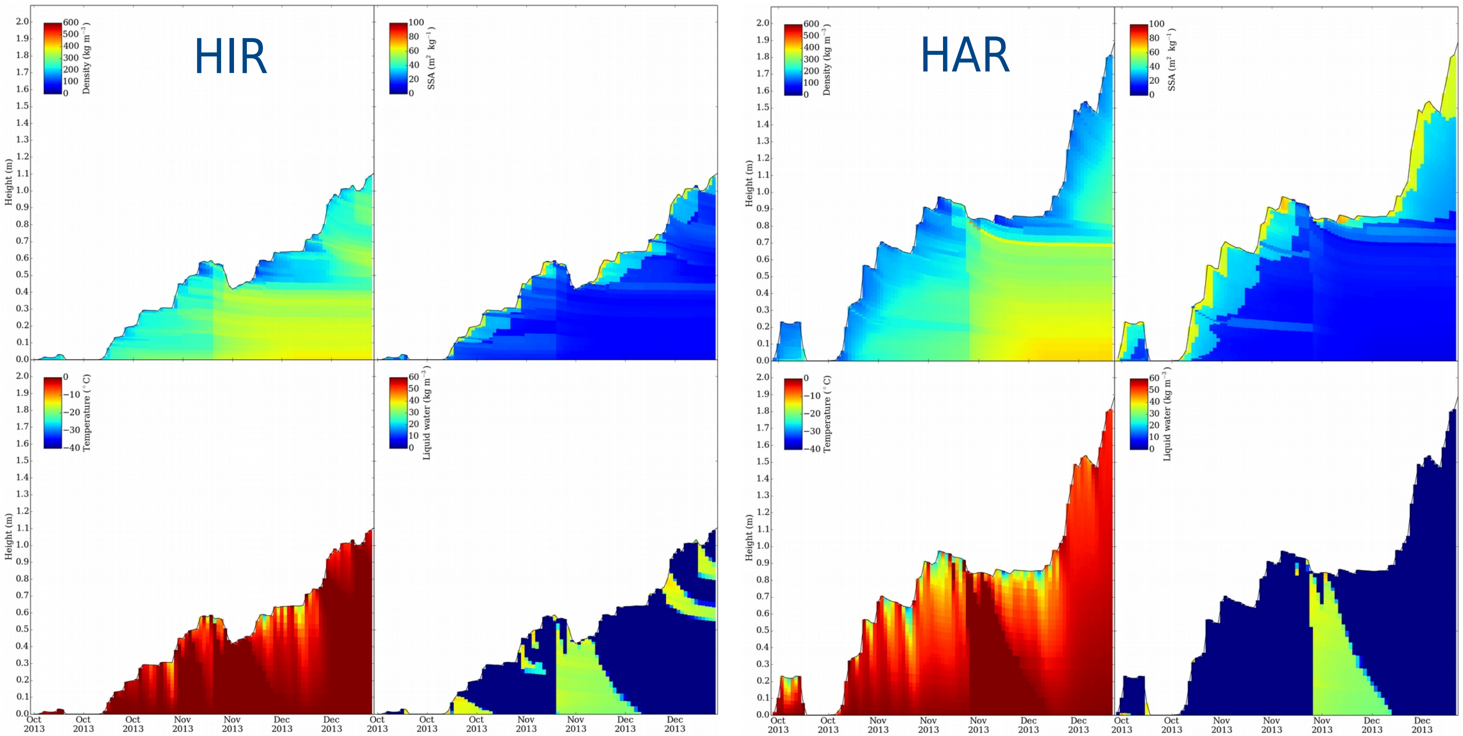
CROCUS on Kistufell (23.257W 66.074N)



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

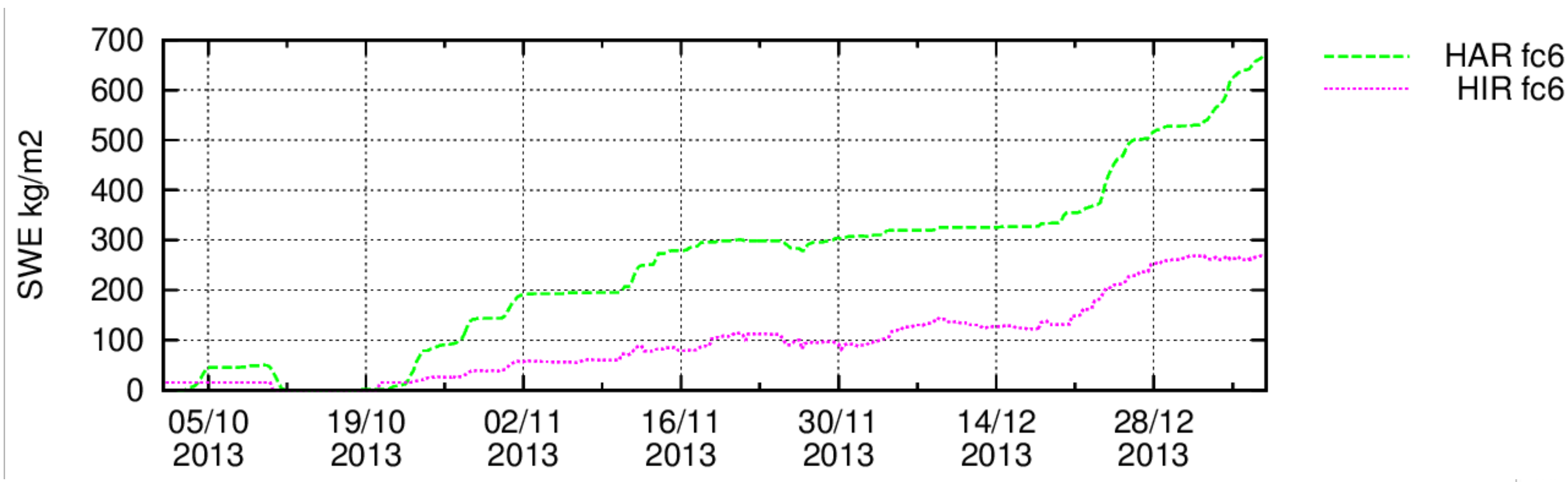
SNAPS
Snow, Ice and Avalanche Applications

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



Snow in Westfjords
– next conclusions?

Would the forecast of snow properties, made by the NWP model be detailed and reliable enough as direct application for the avalanche and road forecast?
- i.e., to replace the dedicated snowpack model?

Problems:

- The present snow schemes in NWP HARMONIE or HIRLAM do not provide enough information about snowpack properties and are not really combined with (satellite) observations via data assimilation
- NWP models seem to provide good enough input for stand-alone snow models like CROCUS but sensitivity of results to the input shoud be studied systematically

→ No, we are not yet there:
both NWP forecast and decicated models are needed for the avalanche and snow drift forecasts

Future NWP model for dedicated applications?

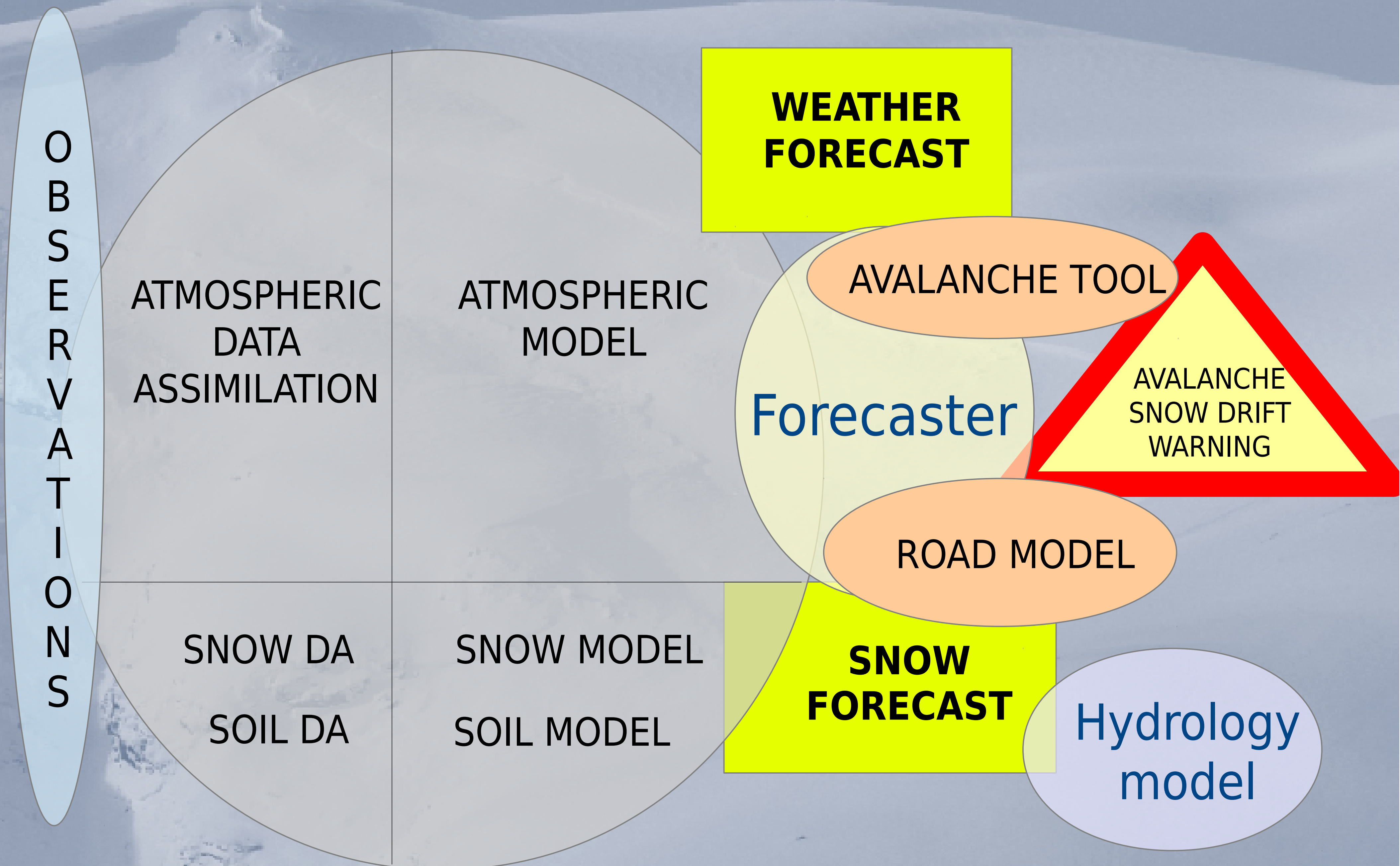


Photo Krister Kristensen

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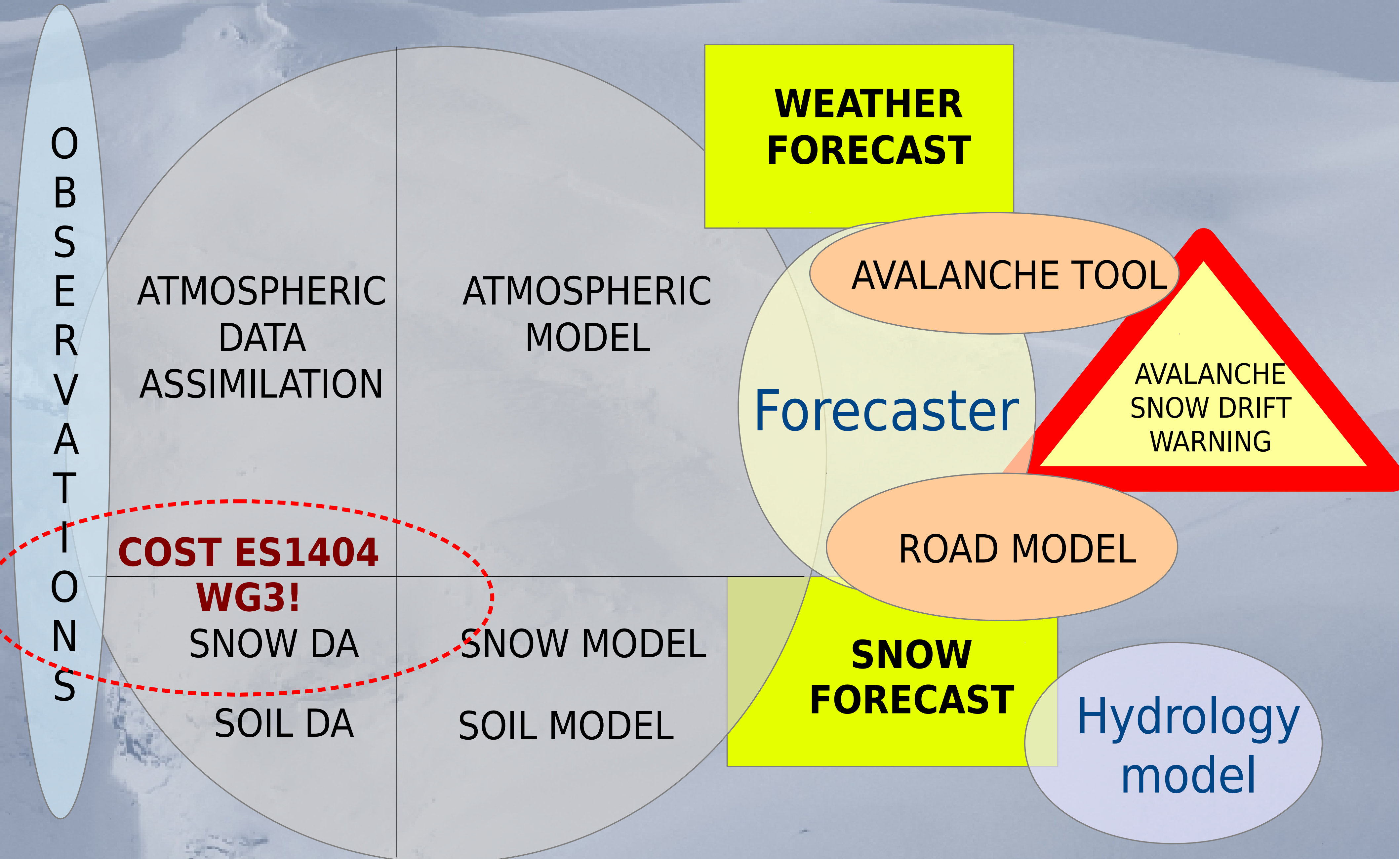
Future NWP model for dedicated applications?



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.

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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


Bolungarvik, Westfjords,
Iceland. Photo Laura Rontu
THANK YOU!
COST ES1404 support is gratefully acknowledged

Photo Krister Kristensen

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(Snow data assimilation)

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

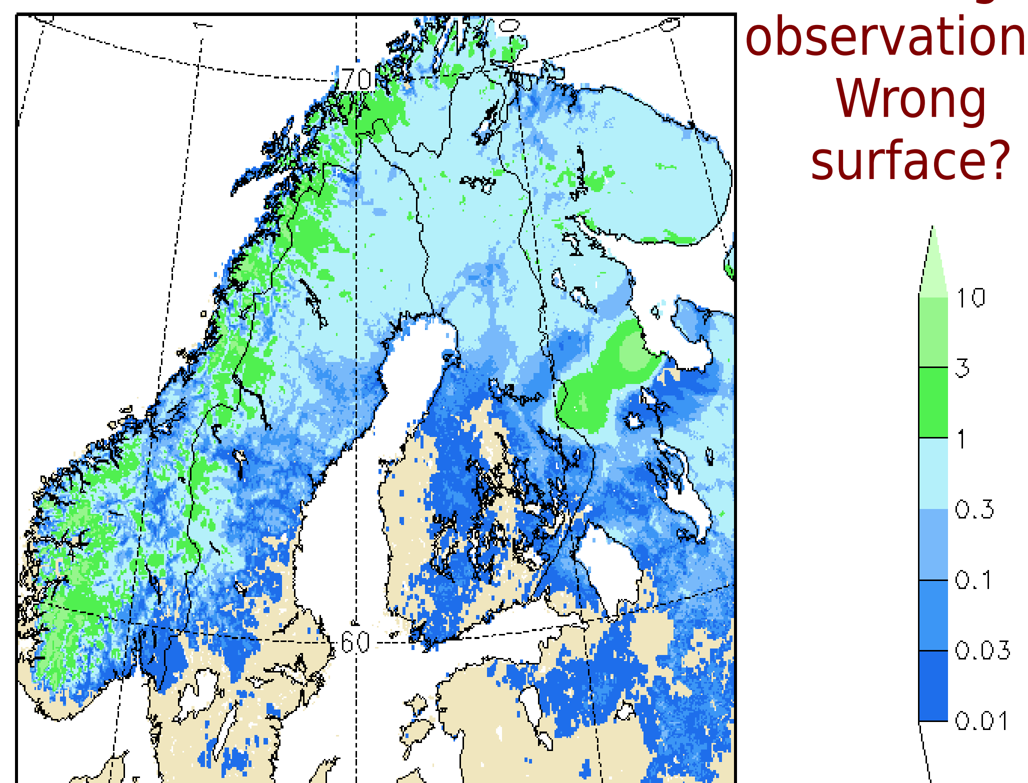
spreads snow observations to model grid in horizontal

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? Wrong surface?



Max: 10.5404
Min: 0

30.3.2014 00UTC Snow depth

* presentation by Mariken Homleid, ASW13

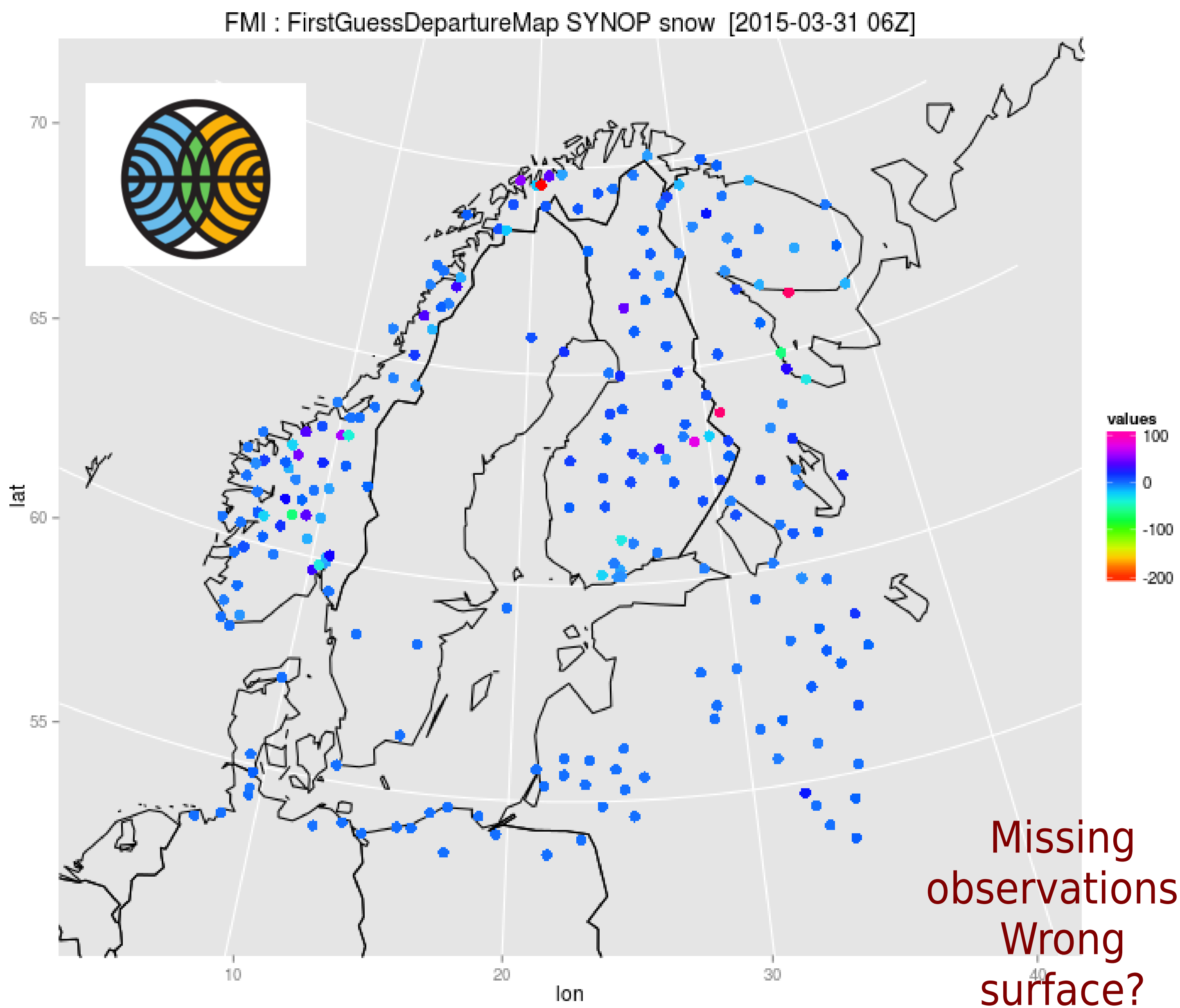
Operational CANARI snow analysis

spreads snow observations to model grid in horizontal

FMI snow analysis 31.3.2015

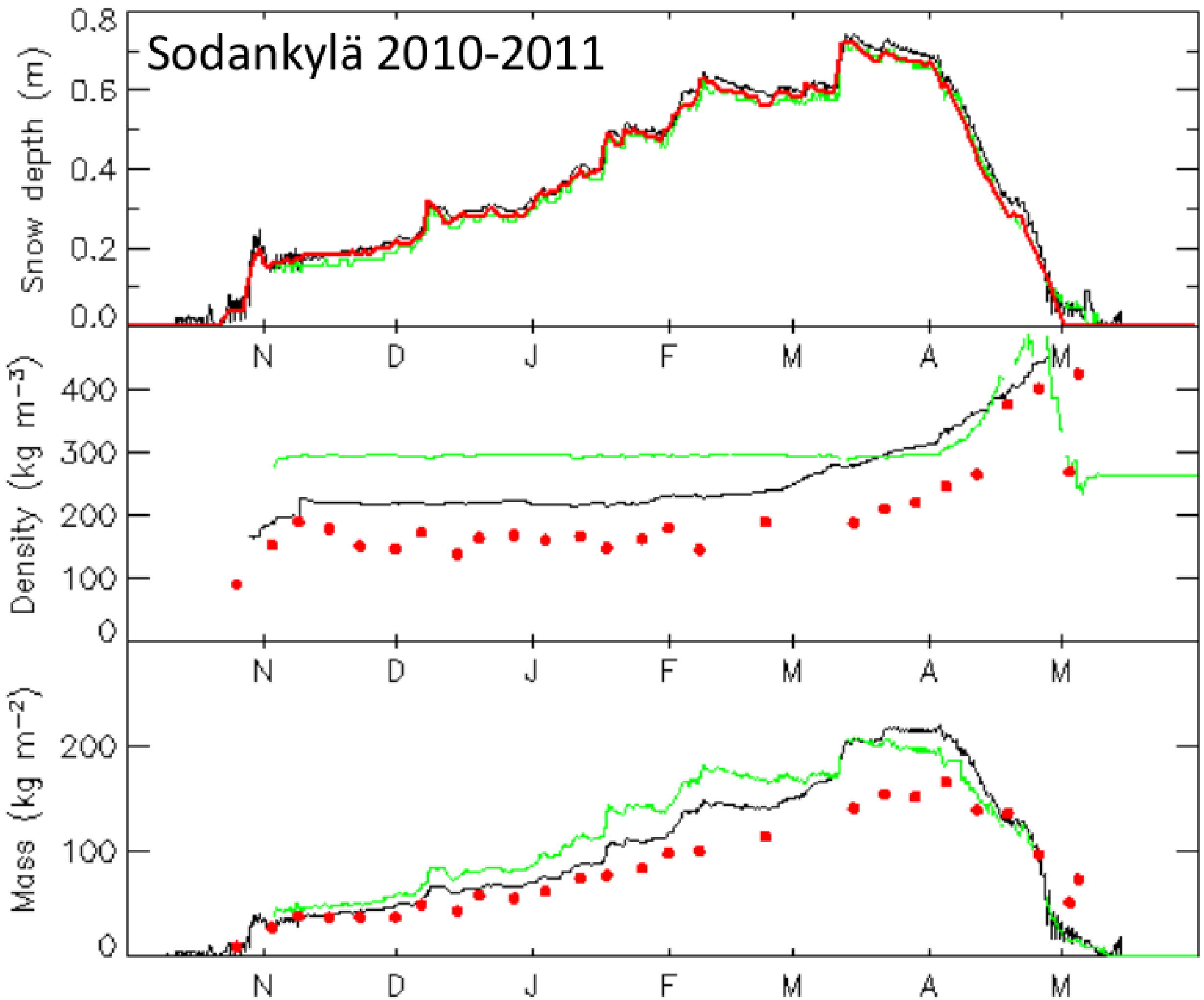
The map: first guess - observation

Problems:
Red dots in the east and NW
Missing obs in Sweden



Missing observations? Wrong surface?

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 <u>correlation between state variables in the model</u> or the use of a <u>complex observation operator</u> such as a <u>microwave emission model</u> or <u>assimilation of radiance data</u>.

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

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

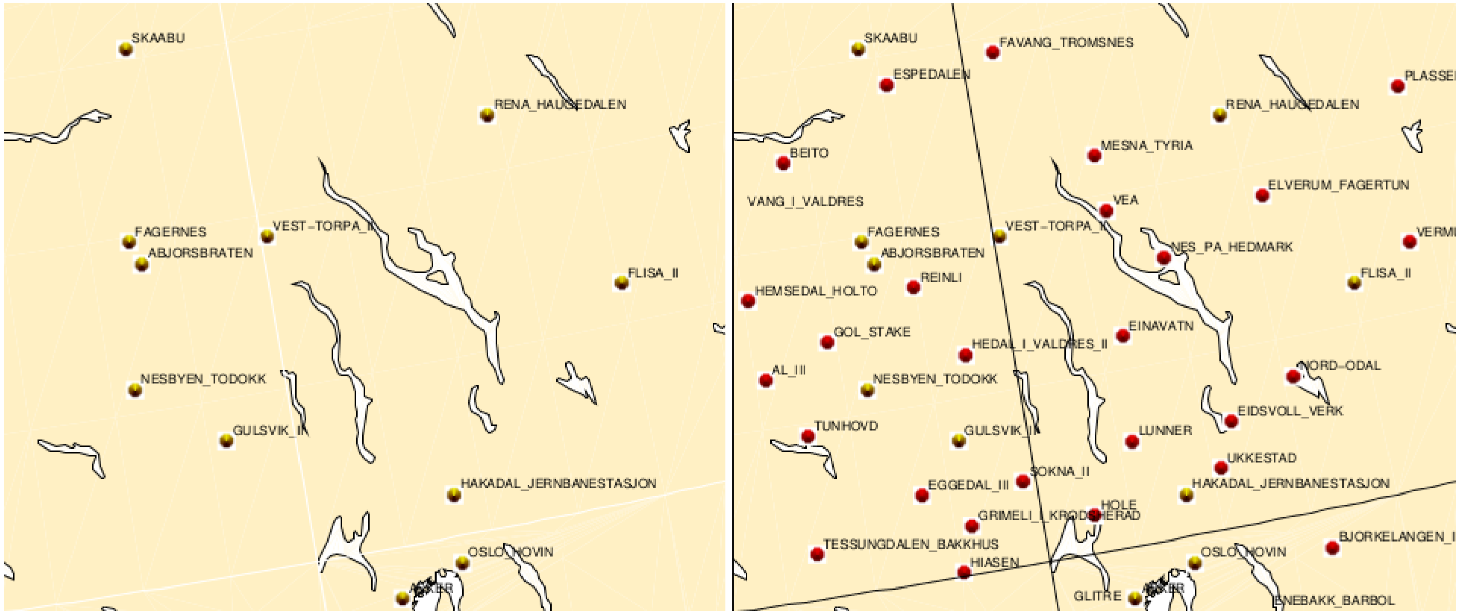
Which snow observations do we assimilate into Numerical Weather Prediction models and how?

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"

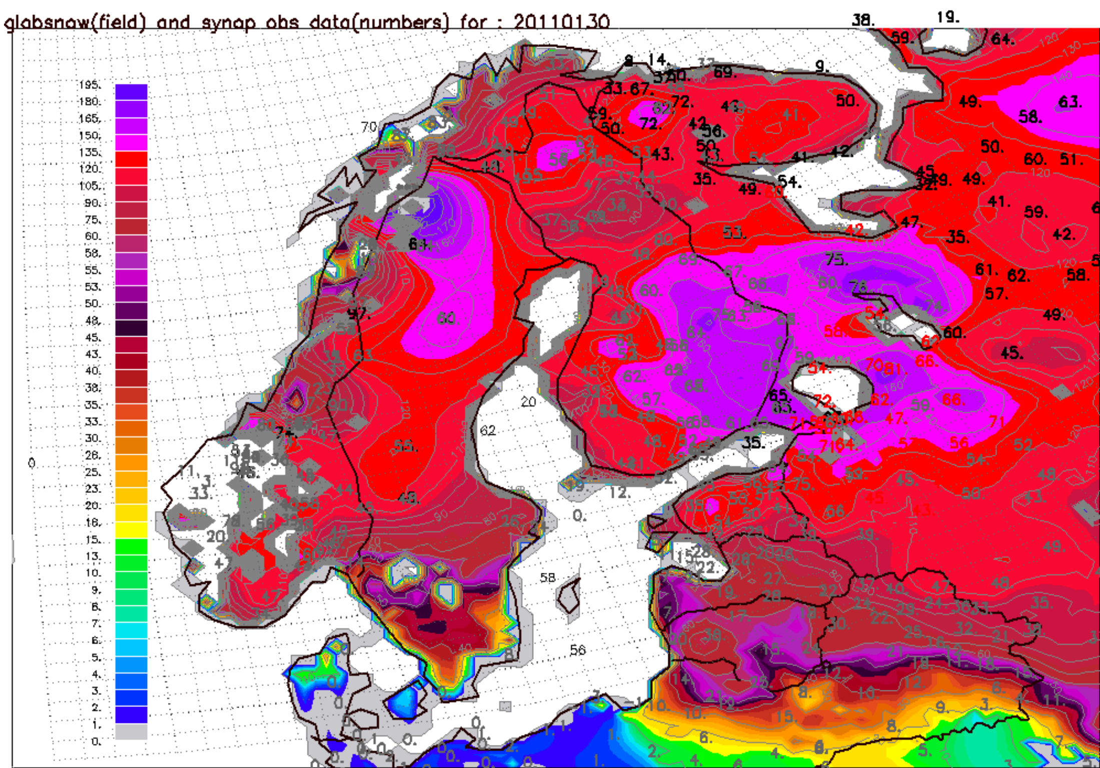
Do we need more data and better methods?

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

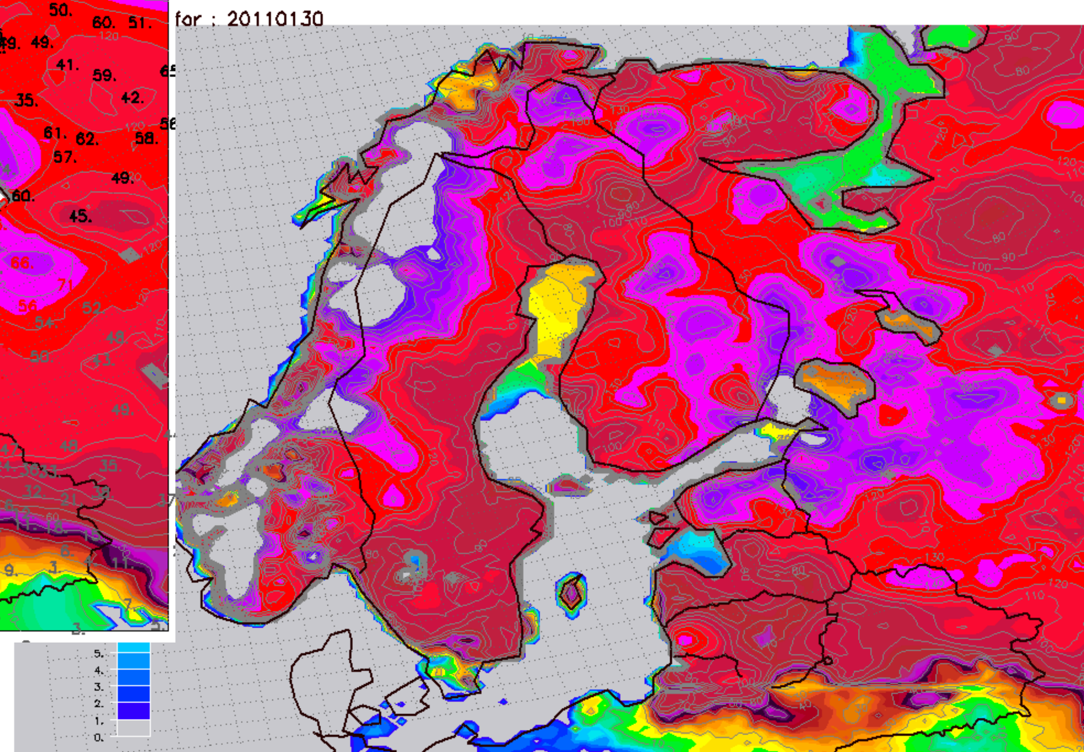



Photo Krister Kristensen

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
			none	none	climate

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

September 2014 / EK

Table by Ekaterina Kurzeneva, 2014

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


Photo Krister Kristensen

How to make HARMONIE + CROCUS operational?

Experience of the Norwegian Meteorological Institute
- setup by Dagrun for operational runs

- Every day, pick data from HARMONIE and/or observations for selected points
- Create atmospheric forcing for every point from the beginning of winter
- Run CROCUS for every point from the beginning every day
- Every day, get new updated CROCUS output, interpret with MEPRA

→ Works, but with a lot of extra efforts

We would need method to update CROCUS results incrementally, based on incrementally updated forcing from the latest HARMONIE forecast

Or could we, after all, in the future do the whole work in the HARMONIE framework?

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Towards integrated snow modelling in NWP?

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Why should we perhaps consider developing such an alternative?

Snowpack details are not necessary for the weather forecast - only fluxes between air and snow are - but NWP framework would be optimal for operational modelling of snow properties

- Practical aspects (c.f. Norwegian experience on CROCUS offline coupling)
- Coupling between atmosphere and surface every time step of the forecast at every grid point
- Possibility to provide a forecast for couple of days, not only snow cover analysis
- Framework for developing snow data assimilation in connection with other surface and atmospheric data assimilation
- Optimised high-performance computig environment around

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Towards integrated snow modelling in NWP?

Requirements and possible limitations

High resolution → limited domain with

- a special HARMONIE setup for the proper use of nonhydrostatic dynamics
- detailed description of the surface properties

CROCUS as the snow parametrization scheme in HARMONIE

- Cycling from day to day with (or for the beginning without?) data assimilation
- Proper connection to other snow-related parametrizations
  (sea ice, lakes, vegetation…)
- Optimisation for the operational use

Tools for postprocessing CROCUS output for avalanches/snow drift

- MEPRA, road weather model …

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