Representation of snow in NWP

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Richard Essery U.Edinburgh, Patrick Samuelsson SMHI,
Hrobjartur Thorsteinsson IMO et al.

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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 contribute efforts to address these issues through the establishment of a joint monitoring, operations and services.
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

SNOW DATA ASSIMILATION

Models

Numerical weather prediction model

Hydrology and ice model

Observed snow variables

Snow parametrizations

Methods and micromodels

Dedicated snow model

Climate model

Physical properties of snow cover

Water equivalent - temperature - density - grain size - albedo ...

Applications

Weather forecast

Flooding

Avalanche

Water management

Traffic

Health and sport

Agriculture and forestry

Climate scenarios

Interpretation of results

Development & validation of models
Snow microphysics model (1D)

Snow physics model (1D)

NWP or climate model (3D)

- micro scale -

- macro scale -

- regional/global scale -

Measurements in-situ (campaigns)
remote sensing

Measurements in-situ (regular)
remote sensing

development, parameterization

parameterization
data assimilation validation

development

validation
calibration
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

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Local and remote sensing snow observations

SYNOP and climate stations: O
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)

Example of the first snowfall in November 26-28 2012

(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

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

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

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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Comparison of snow extent

Hróbjartur Þorsteinsson et al. 2014
www.snaps-project.eu
Verification of MODIS snow cover maps with web cameras

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

Hróbjartur Þorsteinsson et al. 2014
Prognostic snow schemes available in SURFEX

<table>
<thead>
<tr>
<th>Single-layer</th>
<th>D95</th>
<th>Douville <em>et al.</em> (1995a, 1995b)</th>
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</table>

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

<table>
<thead>
<tr>
<th>Scheme Type</th>
<th>Model</th>
<th>References</th>
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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)

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

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
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.
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.
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:
<table>
<thead>
<tr>
<th>Soil Scheme</th>
<th>Soil DA</th>
<th>Snow scheme</th>
<th>Snow-veg scheme</th>
<th>Snow DA</th>
<th>Application</th>
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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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<td>Globsnow</td>
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<td>Met Office</td>
<td>IMS</td>
<td>Update</td>
<td>2009</td>
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</table>
Optimal interpolation of snow depth of SYNOP station observations

Snow depth > SWE using assumed snow density

Background error correlations include horizontal and vertical terms*

* 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)
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.

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
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.
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!

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?
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)
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!