Evaluation report: Snow observation data in the modeling environment - COST HarmoSnow working group 3

Supplementary Material for "Snow data assimilation methods for hydrological, land surface, meteorological and climate models: Results from a COST HarmoSnow survey"

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1. Executive Summary

It is recognized that proper description and assimilation of snow 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. International 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 COST Action will co-ordinate efforts to address these issues, through establishing harmonized monitoring practices, enhancing the use of observations by promoting new observing strategies, bringing together different communities, facilitating data transfer, upgrading and enlarging knowledge through networking, exchange and training, and linking them to activities in international agencies and global networks.

During the last decades, instrumentation and measurement techniques, especially remote sensing, have advanced fast, providing significant amount of new information about the extent and properties of snow. On the other hand, the description of the varying snow cover has improved in NWP, climate and hydrological models. Furthermore, advanced data assimilation (DA) methods are being developed to combine the improved observations with the improved models. However, in situ measurements from SYNOP ground stations are indispensable for the assimilation of the snow depth at that location. Global NWP models assimilate SYNOP snow measurements from different national ground station networks. which provide measurement data on the GTS.

To provide an overview of the various snow observations used in NWP, hydrology and climate studies for different purposes including validation and data assimilation (e.g. different snow observations are used in different environmental applications), a survey was developed in the framework of the COST Action HarmoSnow ESSEM 1404. The survey was conducted on the web page of COST HarmoSnow from September 2015 to December 2017. The idea of the survey is to assess the current situation of the usage of snow observations in data assimilation, forcing, monitoring, validation, or verification with application in numerical weather prediction, hydrological services, in special models (e.g. road model) and reanalysis runs. Therefore the survey addressed the basic components of numerical models, data assimilation, and snow observations and the results can be used to identify links between different communities of users of snow observations (e.g. numerical weather prediction and hydrology) and to derive future perspectives.

The survey questions were developed in the working group 3 'Snow data assimilation and validation methods for NWP and hydrological models' and consider thematic aspects of numerical models, data assimilation, and snow observations. An accompanying survey on snow measurements in Europe: purpose, practices, and applied instrumentation was developed and conducted by working group 1 'Physical Characterization of Snow Properties' and working group 2 'Instrument and Method Evaluation' of COST HarmoSnow. Both surveys complement each other with the aim to provide a complete picture of snow measurementse and their usage in numerical models.

The survey was published online and participants were invited by mailing lists, during workshops or personal contact to fill out the form. The survey was answered by 51 participants from 31 countries.

The survey results were analysed according to the model environments by user response and their relationship to snow observation data, specifically:

- Numerical weather prediction with data assimilation
- Numerical weather prediction without data assimilation
- Hydrology
- Reanalysis
- Special snow model application
- Multi-Model application
- Miscellaneous models
- No model environment with snow observations

The key findings of the survey include:

1. The survey answers are significant for model environments with snow observation data, as 90% of the responses use such an environment in particular in hydrology, numerical weather prediction with data assimilation, and reanalysis. Survey responses are from Europe, North-America, Asia including centers of operational numerical weather prediction, hydrology, universities, and companies.
2. There are differences in the used snow data assimilation method between numerical weather prediction models and hydrological models as well as in the update frequency of snow observations and the required time interval for consideration of the measurement.
3. The most important snow parameters used in data assimilation are snow depth and snow water equivalent, which are processed by incremental update for NWP or update of absolute values in hydrology and other snow models.
4. Snow observations from SYNOP and additional ground-based measurements are the most important data sources for NWP and hydrology. For the latter, also ground-based remote sensing data are very important. In agreement with NWP preprocessed remote sensing satellite products are often used in hydrology. Satellite radiances are used much less and climatological data are appropriated for hydrological applications.
5. Most user with model environment in hydrology use ground-based remote sensing measurements or products, while this is not the case for NWP or reanalysis. The employed measurement system includes in many cases ultrasonic or laser distance sensors, but also camera, COSMIC ray or radiation sensors.
6. Preprocessed snow products are used in all model environments but have special importance in NWP without DA, reanalysis and other snow models.
7. Quality control of snow observations and products as well as consistency checks are performed manual or automatic in large majority of the model environments used in this survey. For these data processing methods the snow cover field is of particular importance.
8. Depending on the application, the observation data latency becomes important, as responses for NWP with DA and hydrology with responses for latency below 3 h indicate. However, many responses in additional latency comments show that latencies of 1 day, week, or year are acceptable in model environments, e.g. for hindcasts or reanalysis.
9. The exchange of snow data is possible in all model environments, as majority of positive answers show. In most cases, GTS network (NWP, Hydrology) or FTP protocol (Miscellaneous models) is required for data access, but web access or central data hubs are also used.
10. Concrete plans for using new or upcoming data sources of snow observations exist for all model environments, in particular for NWP with DA, hydrology, and reanalysis. These include the use of more satellite data (optical, microwave) but also more ground-based remote sensing data, GPS or COSMIC ray sensors, or additional non-SYNOP networks. Current barriers and limitations for the use of these data are in particular independent of the model environment data availability and ressources to integrate the data in the model environment.

    Considering the results of the accompanying survey on snow measurements in Europe: purpose, practices, and applied instrumentation the main conclusions are that the present-day measurement networks, instruments, and techniques fit to the existing data assimation systems, used in model environments for numerical weather prediction, hydrology, or special snow models. The increasing automatization of the measurments is a task for data management in the DA system (quality control, consistency) but also the demand for snow data in regions with sparse measurement networks, which could remote sensing from satellite solve is a task for DA development (forward operator) and instrument development (e.g. automatic measurement of snow microphysical parameters).

2. Survey Objectives

The aim of the survey, developed in the working group 3 'Snow data assimilation and validation methods for NWP and hydrological models' is to identify and enhance the usage of snow data in numerical models and the survey results contribute to the main objectives of the COST Action HarmoSnow ESSEM 1404 \citep{COST_MoU_2015}:

- Establish a European-wide science network on snow measurements for their optimum use and applications benefitting on interactions across disciplines and expertise.
- Assess and harmonise practices, standards and retrieval algorithms applied to ground, air- and space-borne snow measurements => Foster their acceptance by key snow network operators at the international level.
- Develop a rationale and long term strategy for snow measurements, their dissemination and archiving.
- Advance snow data assimilation in European NWP and hydrological models and show its benefit for relevant applications.
- Establish a validation strategy for climate, NWP and hydrological models against snow observations and foster its implementation within the European modelling communities.
- Training of a new generation of scientists on snow science and measuring techniques with a broader and more holistic perspective linked with the various applications.

The aim is that the outcome from the survey together with the accompanying survey on snow measurements in Europe supports:

- New, innovative and upgraded observing strategies;
- Harmonized snow data processing and handling practices;
- Enhanced usage of snow data for scientific research and applications;
- Broader overview and easier access to existing snow measurements and snow model data for the benefit of different applications, such as NWP models, hydrological, climatology and climate change research as well as monitoring of hydropower, floods and snow avalanches;
- Improved real-time snow measurements for assimilation into operational prediction models leading thus to improved hydrological, meteorological and climate forecasting;integration of the European snow network into global networks (e.g. WMO GCW), thus strengthening WMO and EUMETSAT activities on snow observations;
- New generation of young scientists broader knowledge on snow science and measuring techniques for a variety of applications depending on snow information.

The main scientific impact will emerge from improved snow and weather products via better knowledge of snow properties and their evolution. It will induce a lasting structural improvement of the interaction between participating communities, thus very relevant for the Intergovernmental Panel on Climate Change (IPCC) and Copernicus (Global Monitoring for Environment and Security). Policy and decision makers at all levels from local safety to global environment policy will benefit from improved knowledge on current and future snow cover and climate conditions.

3. Survey Method

3.1 Methodology

The survey consists of 32 questions in 6 sections and 1 text box for additional comments, which are containted in detail in the appendix.

In section 1, personal information (name, position, institute, country) is gathered.

In section 2, general information about the modeling environment and snow observation data is collected with following questions:

1. Do you use snow observation data in your modeling environment?
2. If possible, please give some reasons for no use of snow observation data.
3. In which modeling environment you are using snow observation data?
4. Please give a short description of your modeling environment.
5. Please specify the modeling domain used in your application.
6. Please specify the model horizontal resolution.

Section 3 contains the data assimilation questions:

1. I would like to answer the questions regarding data assimilation
2. Which data assimilation method is used in your system for snow observations?
3. Which update frequency is used for your snow data assimilation?
4. During which time interval (window) snow observations are considered in your snow data assimilation?
5. Which information from SYNOP is used for your snow data assimilation?
6. What model state variable(s) is/are analysed in your snow data assimilation system?
7. How is the key parameter/ How are the analysed variable(s) processed in your snow data assimilation system?
8. Which background field is used in your snow data assimilation?
9. Which estimates of the background error are used in your snow data assimilation?
10. Which estimates of observation errors are used in your snow data assimilation?

In section 4, more detailed information about snow observation data is gathered, including a link to the accompanying survey on snow measurements in Europe from COST working group 1 and 2 :

1. I would like to answer the questions on snow observations from WG1/WG2
2. Please describe the snow observations and products used in the modeling system
3. Do you use ground-based remote sensing measurements or products.
4. Please specify the system you use for ground-based remote sensing snow properties measurements.
5. Do you use preprocessed snow products (e.g. H-SAF or Land-SAF snow products)
6. Please specify the system you use for preprocessed product of snow properties

Section 5 contains questions about data management and data exchange for snow observations:

1. Do you perform a quality control of snow observations or products?
2. What kind of data quality control is performed?

3. Do you perform a consistency check of snow observations or products?
4. Which data consistency checks are performed in your modeling environment?
5. Which observation data latency is acceptable for your modeling environment?
6. Is it possible to exchange the snow data used in your modeling environment with other groups?
7. Which access requirements exist for the snow observation data sets you are using?

In section 6, information about new or upcoming observation sources for snow observation data is gathered:

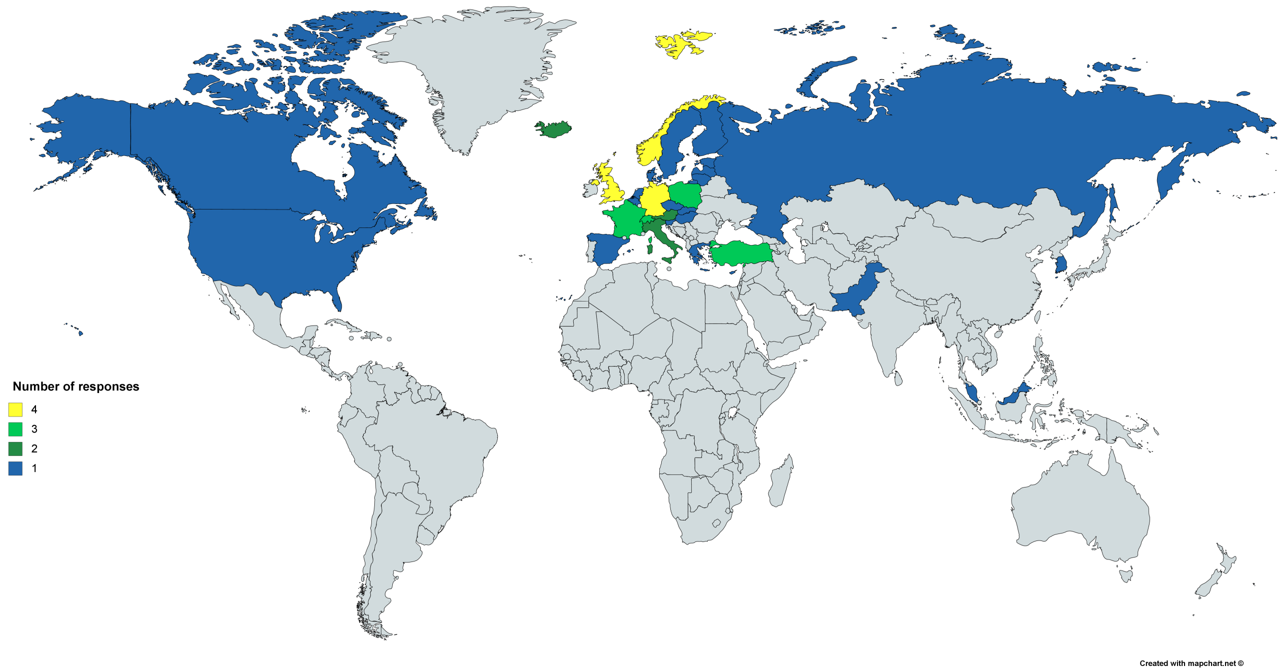
1. Do you have concrete plans to use the new or upcoming observation sources that could be interesting for your modeling environment?
2. Which of the new or upcoming observation sources could be interesting for your modeling environment?
3. What are particular barriers, which prevent you from usage of new observation sources, if you do not use these data?

The survey closes with an text box for additional comments and suggestions or important points, which are missed in the questionnaire or which were not explicitly asked. In some questions, participants are asked to provide more details or reasons, if they answered "yes" (questions 3 and 5 in section 4, questions 1, 3, and 6 in section 5, question 1 in section 6) or "no" (question 1 in section 1). Furthermore, for question 1 in section 2, an answer "no" leads to skipping of all questions in this section and the survey continues with section 3. Similar, "no" for question 1 in section 3 skipped all remaining questions for data assimilation and the next question is question 1 in section 4. For question 1 in section 5, "no" skipped questions 2-4 in this section.

Google Forms was used as platform for the survey. A link from the web page of COST HarmoSnow to the survey was created. Within the survey a link to the accompanying survey on snow measurements in Europe from COST working group 1 and 2 exist. Google Forms collected the answers in a spread sheet during the conductance of the survey and provided a brief evaluation with charts.

3.2 Participating countries

The survey was answered by 51 participants from 31 countries. As shown in the distribution of the number of answers among the countries in Fig. 1, all answers are from countries from the northern hemisphere and most from central Europe (27). With the Nordic countries, Russian Federation, USA and Canada, most countries in the boreal forest belt answered the survey. These countries contain regions, which always have seasonal snow in north-hemispheric winter, while for countries in central and southern Europe the number of days with snow cover depends on on the altitude. For reporting countries closer to the equator, snow in climatological mean is limited to the mountains, however is an important factor for meteorological and hydrological applications.



Geographical distribution of answers in the survey. Figure prepared with "mapchart.net".

4. Survey Results

The assessment results are grouped corresponding to the objectives of the survey by the main users of snow observations in models, i.e. numerical weather prediction with and without data assimilation, hydrology, reanalysis, special snow model applications. Furthermore, users running multi models, Miscellaneous models and with no model application are considered. These different groups are used in the sections of the survey: 1. Institutions; 2. modeling environment and snow observation data; 3. data assimilation; 4. detailed information about snow observation data; 5. data management and data exchange for snow observations; 6. new or upcoming observation sources for snow observations.

4.1. Institutions

Table 1 gives details of the participating institutes in each country. According to this table, in connection with snow observation data 16 institutes use numerical weather prediction models with data assimilation (**WDA**), 6 without data assimilation (**W**), 23 institutes use hydrological models (**H**), 10 institutes use reanalysis (**RA**) and 4 institutes employ special snow models (**S**). 8 institutes use other (miscellaneous) models with snow observations (**O**). 11 universities participated in the survey and 2 companies gave response to the questions. If application of multi models in one institute are stated by respondents during the survey, e.g. at ZAMG, numerical weather prediction models are used together with operational snow cover model (SNOWGRID) coupled to INCA Nowcasting system and reanalysis data for climate applications exist back to 2006, "**M**" for multi models is used in these cases. There are operational weather services in some countries running several NWP models, which could differ in their usage of snow observation data. Therefore "**W**" or "**WDA**" could occur for one institute together.

If no particular model environment for snow observation data was stated, "**X**" was used for these 5 cases. As indicated in one such a response, an appreciation of the COST HarmoSnow was given since this project aims to improve also global NWP models. From this improvement downstream limited-area models could benefit, even if they don't use a modeling environment with snow observation data.

Country	Total number of answers	Model environment	Number of answers per institution
United Kingdom	4	WDA	1, Met Office
		M (WDA, RA)	1, Met Office
		WDA	1, ECMWF
		H	1, University of Edinburgh
Austria	2	M (WDA, H, S, O)	1, ZAMG - Institute for Meteorology and Geodynamics, Vienna
		W	1, ZAMG - Institute for Meteorology and Geodynamics, Vienna
Iceland	2	X	1, National Power Company Iceland
		H	1, Reykjavik University
Germany	4	WDA	1, Deutscher Wetterdienst (DWD)
		WDA	1, Deutscher Wetterdienst (DWD)
		O	1, Deutscher Wetterdienst (DWD)
		H	1, Federal Institute of Hydrology
Finland	1	WDA	1, Finnish Meteorological Institute (FMI)
Turkey	3	M (WDA, H)	1, Cukurova university
		RA	1, Middle East Technical University (METU)
		M (H, O)	1, Anadolu University
France	3	O	1, Météo-France/CNRS
		M (H, RA)	1, Météo-France
		H	1, IRSTEA
Norway	4	WDA	1, Norwegian Meteorological Institute
		WDA	1, Norwegian Meteorological Institute
		M (H, S)	1, University of Oslo
		RA	1, Norwegian Water Resources and Energy Directorate
Switzerland	3	WDA	1, MeteoSwiss
		M (H, RA, O)	1, Institute for Snow and Avalanche Research, WSL
		H	1, Institute for Snow and Avalanche Research, WSL
Italy	2	M (H, RA)	1, Politecnico Milano
		H	1, CIMA Research Foundation

Poland	3	W X M (W, RA)	1, Institute of Meteorology and Water Management 1, Institute of Meteorology and Water Management 1, Institute of Meteorology and Water Management
Denmark	1	M (WDA, S)	1, Danish Meteorological Institute (DMI)
Sweden	1	H	1, Vattenregleringsföretagen
Hungary	1	W	1, Hungarian Meteorological Service
Czech Republic	1	O	1, Czech University of Life Sciences Prague
Slovakia	1	H	1, Institute of Hydrology SAS
Slovenia	1	H	1, Slovenian meteorological service/ARSO
Estonia	1	M (W, S)	1, Estonian Environment Agency
Latvia	1	H	1, Latvian Environment, Geology and Meteorology Centre
Lithuania	1	X	1, Lithuanian Hydrometeorological Service under the Ministry of Environment
The Netherlands	1	M (H, RA, O)	1, Deltares / WUR
Spain	1	WDA	1, Agencia Estatal de Meteorología (AEMET)
Greece	1	H	1, University of Thessaly
Cyprus	1	X	1, Cyprus Department of Meteorology
Canada	1	O	1, Environment and Climate Change Canada
Malaysia	1	X	1, Malaysian Meteorological Department
Pakistan	1	H	1, Pakistan Meteorological Department
Republic of Korea	1	WDA	1, National Institute of Meteorological Sciences
USA	1	M (WDA, H)	1, National Center for Atmospheric Research (NCAR)
Belgium	1	M (H, RA)	1, KU Leuven
Russian Federation	1	M (WDA, W, H, RA)	1, Hydrometcentre of Russia/ Lomonosov MSU

4.2 Modeling environment

4.2.1 Do you use snow observation data in your modeling environment?

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	16	0
Numerical weather prediction without data assimilation (6)	6	0
Hydrology (23)	23	0
Reanalysis (10)	10	0
Special snow model application (4)	4	0
Multi-model application (15)	15	0
Miscellaneous models (8)	8	0
No model environment with snow observations	0	5
Total response from participants (51)	**46**	**5**

4.2.2 If possible, please give some reasons for no use of snow observation data

Reason for no use of snow observation data
Not enough information in real time, density of the network, no proper scheme applied for snow assimilation so far.

Not enough information in real time, single snow observation point, difficulties in incorporating snow data into modeling environment (mostly computational)
Not enough data to use, both field data and remote sensing data. A extensive program has been initiated to gather snow information. Hopefully within the next 2-3 years it will be included in modelling for our water resources models
Organisation of modeling system that be use don't use snow observation data, modeling system calculates it.
Run only limited area NWP model over tropical region.

4.2.3 In which modeling environment you are using snow observation data?

Model environment	Survey responses
Numerical weather prediction with data assimilation	16
Numerical weather prediction without data assimilation	6
Hydrology	23
Reanalysis	10
Special snow model application	4
Multi-model application	15
Other models (Miscellaneous models*)	8
No model environment with snow observations	5
Total response from participants (51)	**46**

*Miscellaneous models
Operational snow cover model
Snowpack modelling research mode
Snow Cover/Precipitation Supply Analysis and Prediction
Snowmelt Prediction with snow data assimilation
Evaluation of climate models
Agroclimatology/agrometeorology (forcing using snow data)
Hydrology discharge & snow DA
Hydrology (to validate snow states), DA

4.2.4 Please give a short description of your modeling environment

Model environment	Survey responses

Numerical weather prediction with data assimilation	1. Full NWP system with snow data assimilation 2. Operational snow cover model (SNOWGRID) coupled to INCA Nowcasting system operated in near realtime (15 min time, 100 m spatial resolution) and to ALARO for a 72-H forecast, reanalysis possible back to 2006. Output are gridded snow depth and SWE fields that are used for diverse customer products (avalanche warning services, hydropower and electrical companies, road maintenance services, local municipalities, winter tourism,...) and to initialize/correct the initial snow cover for the NWP model AROME operated at ZAMG. At that time, in-situ snow observations and remote sensing data (e.g. MODIS fractional snow cover) data are only used to validate the model or to improve specific processes. Currently we are investigating the added-value of an operational data assimilation using those data. 3. Process-oriented modelling system with snow data usage for the validation. 4. Full NWP system with data assimilation (global, limited area mode) 5. HIRLAM - HARMONIE full high-resolution limited area NWP models with data assimilation. This reply concerns the FMI operational system in its present form. 6. Full NWP system with data assimilation. Snow depths observations assimilated by Optimum Interpolation. 7. Full NWP system with data assimilation 8. Full LAM NWP system with data assimilation (COSMO-7, COSMO-2, COSMO-1, COSMO-E) 9. Fully coupled (land and atmosphere) NWP system, with data assimilation. 10. Full NWP system with data assimilation - fully coupled land-atmosphere 11. Full NWP systems with data assimilation (HIRLAM and HARMONIE) 12. Full NWP system with data assimilation, in AROME-MetCoOp and AROME-Arctic 13. Limited Area NWP model with snow data assimilation, with OI. 14. Global NWP System with snow data assimilation 15. Streamflow model with SWE assimilation; forcing land-surface models with observed meteorology and SWE 16. Limited area NWP system, snow analysis data are provided from global NWP system ICON
Numerical weather prediction without data assimilation	1. Full NWP system with data assimilation (AROME at 2.5 km and ALARO at 8 km); Snow is not assimilated in the NWP models. It is cycled from one model run to the other through the first guess in the data assimilation system. Snow data are used for the validation of the snow in the models. Snow data assimilation is planned to be used operationally somewhen in future, when it will be available in the ALADIN/AROME code. 2. Limited area NWP models AROME 2.5km and ALARO 4.8km both running with ISBA surface scheme (Noilhan and Planton 1989) and Optimal Interpolation "CANARI" for soil temperature and soil moisture initialisation Mahfouf 1991/Bazile 2000. AROME is also running with 3D-Var for atmospheric initialisation and 3 soil layers SURFEX scheme (ALARO 2 layer online ISBA). For snow we use a daily 1km MODIS product from ENVEO company for yes/no decision satellite no snow->snow is removed from the model if any, satellite snow but model not -> snow is set to constant value. In AROME, snow initial values over Austria are replaced by the a data of an external snow model "SNOWGRID" developed at ZAMG by Olefs et al. Furthermore a additional snow melting is done in the OI-system if 2m temperature exceeds 0°C. So, there is no real snow assimilation considering observation and model errors of snow, but just some replacement of initial data. Prognostic snow variables are SWE, snow albedo and snow density. Only the first is initialised, while the other start with a constant value for fresh snow and then develop according to the prognostic functions of the ISBA scheme. 3. Verification of NWP models AROME and ALARO.Verification of CROCUS snow model." 4. A limited area NWP system with data assimilation, road condition modelling in development. 5. Crocus Snow Model 6. Limited area NWP system, snow analysis data are provided from global NWP system ICON

Hydrology	1. Operational snow cover model (SNOWGRID) coupled to INCA Nowcasting system operated in near realtime (15 min time, 100 m spatial resolution) and to ALARO for a 72-H forecast, reanalysis possible back to 2006. Output are gridded snow depth and SWE fields that are used for diverse customer products (avalanche warning services, hydropower and electrical companies, road maintenance services, local municipalities, winter tourism,...) and to initialize/correct the initial snow cover for the NWP model AROME operated at ZAMG. At that time, in-situ snow observations and remote sensing data (e.g. MODIS fractional snow cover) data are only used to validate the model or to improve specific processes. Currently we are investigating the added-value of an operational data assimilation using those data. 2. Process-oriented modelling system with snow data usage for the validation. 3. "Surface re-analysis on european scale (UERRA project) and snow model to provide snow cover and characteristics at 5km;" 4. Off-line land surface models with and without data assimilation 5. Hydrological modeling 6. Operational snow melt modelling framework with data assimiliation of available snow monitoring data @ Switzerland / 1km grid resolution 7. "We are using snow data as input information in hydrological model (HBV) and forecasting system to have information about snow depth and water storage in snow cover." 8. Snow accumulation and melt models, spatially distributed rainfall-runoff models 9. "We use Snow Melt Runoff Model (SRM) to estimate the expected discharge in IRS (Indus River System) for Flood forecasting during Summer Season as a result of Snow Melt coupled with Monsoon Rains.SRM is conceptually based upon temperature index model designed to simulate snowmelt in mountainous areas . SRM is run in a semi-distributed manner. Model Input variables are distributed among several elevation zones (each with approximately 500m of relief), and include daily estimates of air temperature, precipitation, and snow-covered area . SRM also operates on a daily time step which eliminates the need to simulate snow pack processes that operate on sub-daily timescales. Following mathematical equation is used in SRM to simulate daily streamflow discharge Q (m3 s-1): Qn+1= Qn kn+1 + (1-kn+1) f [(cSi,n * ai,n (Ti,n + Ti,n) Si,n + cRi,n * Pi,n)Ai] (1)" 10. stream flow model, Crocus model for snowpack 11. Rainfall - Runoff Model 12. "Snow cover data significantly improves runoff simulations regardless of the model complexity. We have demonstrated this for physically based, distributed models and for conceptual models.The key reference for this is:Finger D., Vis M., Huss M. and J. Seibert (2015). The value of multiple data set calibration versus model complexity for improving the performance of hydrological models in mountain catchments. Water Resour. Res., 51, doi:10.1002/2014WR015712." 13. The Shyft modeling framework (github.com/statkraft/shyft) is used to calculate catchment discharge. Several different snow model parameterizations are available. 14. Distributed hydrological model including snow module and assimilation of streamflow, SWE, etc 15. Meteo hydrological forecasting chain for flood forecasting with data assimilation. 16. SYKE HBV-model, SMHI HBV-model 17. Operational snowmelt models with data assimilation 18. Conceptual hydrological models 19. Streamflow model with SWE assimilation; forcing land-surface models with observed meteorology and SWE 20. Full land surface modeling system with data assimilation 21. Hydrological Modeling with data assimilation and calibration (low water and flood forecasting, climate impact studies, monitoring of extreme events) 22. Limited area NWP system, snow analysis data are provided from global NWP system ICON 23. Rainfall-runoff hydrological model and snowmelt and accumulation model
Reanalysis	1. "Surface re-analysis on european scale (UERRA project) and snow model to provide snow cover and characteristics at 5km;" 2. Fully coupled (land and atmosphere) NWP system, with data assimilation. 3. Hydrological modeling 4. Operational snow melt modelling framework with data assimiliation of available snow monitoring data @ Switzerland / 1km grid resolution 5. Calibration and validation of the seNorge-snow modell (energy-Balance ande HBV-snow routine) 6. Crocus Snow Model 7. Distributed hydrological model including snow module and assimilation of streamflow, SWE, etc 8. Uncertainty modelling of the model parameters and inputs to snowmelt models. Runoff is simulated and results are compared with physical model ourputs and remote sensing snow products. 9. Full land surface modeling system with data assimilation 10. Limited area NWP system, snow analysis data are provided from global NWP system ICON
Special snow model application	1. Operational snow cover model (SNOWGRID) coupled to INCA Nowcasting system operated in near realtime (15 min time, 100 m spatial resolution) and to ALARO for a 72-H forecast, reanalysis possible back to 2006. Output are gridded snow depth and SWE fields that are used for diverse customer products (avalanche warning services, hydropower and electrical companies, road maintenance services, local municipalities, winter tourism,...) and to initialize/correct the initial snow cover for the NWP model AROME operated at ZAMG. At that time, in-situ snow observations and remote sensing data (e.g. MODIS fractional snow cover) data are only used to validate the model or to improve specific processes. Currently we are investigating the added-value of an operational data assimilation using those data. 2. Full NWP systems with data assimilation (HIRLAM and HARMONIE) 3. A limited area NWP system with data assimilation, road condition modelling in development. 4. The Shyft modeling framework (github.com/statkraft/shyft) is used to calculate catchment discharge. Several different snow model parameterizations are available.

Multi-model application	1. Operational snow cover model (SNOWGRID) coupled to INCA Nowcasting system operated in near realtime (15 min time, 100 m spatial resolution) and to ALARO for a 72-H forecast, reanalysis possible back to 2006. Output are gridded snow depth and SWE fields that are used for diverse customer products (avalanche warning services, hydropower and electrical companies, road maintenance services, local municipalities, winter tourism,...) and to initialize/correct the initial snow cover for the NWP model AROME operated at ZAMG. At that time, in-situ snow observations and remote sensing data (e.g. MODIS fractional snow cover) data are only used to validate the model or to improve specific processes. Currently we are investigating the added-value of an operational data assimilation using those data. 2. Process-oriented modelling system with snow data usage for the validation. 3. "Surface re-analysis on european scale (UERRA project) and snow model to provide snow cover and characteristics at 5km;" 4. Fully coupled (land and atmosphere) NWP system, with data assimilation. 5. Hydrological modeling 6. Operational snow melt modelling framework with data assimiliation of available snow monitoring data @ Switzerland / 1km grid resolution 7. Full NWP systems with data assimilation (HIRLAM and HARMONIE) 8. A limited area NWP system with data assimilation, road condition modelling in development. 9. Crocus Snow Model 10. The Shyft modeling framework (github.com/statkraft/shyft) is used to calculate catchment discharge. Several different snow model parameterizations are available. 11. Distributed hydrological model including snow module and assimilation of streamflow, SWE, etc 12. Conceptual hydrological models 13. Streamflow model with SWE assimilation; forcing land-surface models with observed meteorology and SWE 14. Full land surface modeling system with data assimilation 15. Limited area NWP system, snow analysis data are provided from global NWP system ICON
Miscellaneous models	1. Operational snow cover model (SNOWGRID) coupled to INCA Nowcasting system operated in near realtime (15 min time, 100 m spatial resolution) and to ALARO for a 72-H forecast, reanalysis possible back to 2006. Output are gridded snow depth and SWE fields that are used for diverse customer products (avalanche warning services, hydropower and electrical companies, road maintenance services, local municipalities, winter tourism,...) and to initialize/correct the initial snow cover for the NWP model AROME operated at ZAMG. At that time, in-situ snow observations and remote sensing data (e.g. MODIS fractional snow cover) data are only used to validate the model or to improve specific processes. Currently we are investigating the added-value of an operational data assimilation using those data. 2. We use the surfex model in research mode to model the evolution of the snow cover. 3. Grid-based physical snow model with focus on the formation of precipitation supply (being the total runoff formed by snow melt and rain falling into the snow layer and not being retained). Analysis of the past 30 hours and forecast of the next 72 hours, 4 times a day (00, 06, 12 and 18 UTC). Use of observations (synoptic data, precipitation, snow depth, snow water equivalent) during the analysis phase and of NWP data during the forecast phase. Snow data serve as reference for the model state during analysis. If differences between model and observations surpass a certain threshold, model is adjusted to the observations (weighted adjustment, not entirely). 4. Operational snow melt modelling framework with data assimiliation of available snow monitoring data @ Switzerland / 1km grid resolution 5. Snow models within land surface schemes - may not be entirely relevant to this questionnaire but I will proceed anyway! 6. A snow cover-modelling technique to simulate snow cover presence/absence and sow depth within the cold season of the year for agrometeorological applications and snow cover climatology. 7. Distributed hydrological model including snow module and assimilation of streamflow, SWE, etc 8. Conceptual hydrological models
No model environment with snow observations	-
Total response from participants (51)	**46**

4.2.5 Please specify the modeling domain used in your application

Model environment	Global	Limited area	One-way/two-way nesting of domains	Other modeling domains*	Total responses
Numerical weather prediction with data assimilation (16)	5	9	0	2	**16**
Numerical weather prediction without data assimilation (6)	0	5	0	1	**6**
Hydrology (23)	0	11	0	11	**22**

Reanalysis (10)	1	4	0	4	**9**
Special snow model application (4)	0	3	0	1	**4**
Multi-model application (15)	1	8	0	5	**14**
Miscellaneous models (8)	0	5	0	3	**8**
No model environment with snow observations (5)	0	0	0	0	**0**
Total response from participants (51)	**5**	**28**	**0**	**12**	**45**

***Other modeling domains**
INCA-L domain for SNOWGRID and part of the austrian AROME domain
No snow assimilation
Switzerland and surrounding areas at 1km resolution
Offline simulations
Local Water Simulation Forecast System
No snow data assimilation in NWP
Semi-distributed
Catchments applications
Both Global and Limited area applications
River basins
The calculation system of one/two or three nested domains for 8 different areas
Catchment (which can be divided into altitude bands)

4.2.6 Please specify the model horizontal resolution

Model environment resolution	**Below 1km**	**Between 1km and 5 km**	**Between 5km and 10 km**	**Between 10 km and 20 km**	**Between 20km and 50 km**	**Larger than 50 km**	**Other model resolutions***	**Total responses**
Numerical weather prediction with data assimilation (16)	2	5	0	4	0	0	5	**16**
Numerical weather prediction without data assimilation (6)	0	4	0	1	0	0	1	**6**
Hydrology (23)	7	3	0	0	1	1	10	**22**
Reanalysis (10)	0	4	0	1	0	1	3	**9**
Special snow model application (4)	2	0	0	1	0	0	1	**4**
Multi-model application (15)	3	3	0	2	0	0	6	**14**
Miscellaneous models (8)	2	2		1	1		2	**8**
No model environment with snow observations (5)	0	0	0	0	0	0	0	**0**
Total response from participants (51)	**8**	**14**	**0**	**6**	**2**	**2**	**13**	**45**

***Other model resolutions**
Catchment scale
Catchment scale
Different model resolutions 2.5-15km
10-80km

Model is calibrated on hydrological observation points
5 km & 16 km
nil
Semi-Distributed application
Catchment scale
Both fine (1-5 km) and coarse scale (20-50 km) applications
Elevation zones (~100 m altitudes)
13.2 km, 7 km, 2.2 km, 1.1 km
Catchment

4.3 Data assimilation

4.3.1 I would like to answer the questions regarding data assimilation

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	12	4
Numerical weather prediction without data assimilation (6)	1	5
Hydrology (23)	13	10
Reanalysis (10)	5	5
Special snow model application (4)	2	2
Multi-model application (15)	9	6
Miscellaneous models (8)	4	4
No model environment with snow observations (5)	1	4
Total response from participants (51)	**27**	**24**

4.3.2 Which data assimilation method is used in your system for snow observations?

Model environment	Optimum Interpolation	Cressman analysis method	Kalman Filter	Ensemble Kalman Filter	Other methods*
Numerical weather prediction with data assimilation (16)	8	3	0	1	3
Numerical weather prediction without data assimilation (6)	0	0	0	0	1
Hydrology (23)	4	0	4	9	9
Reanalysis (10)	2	0	2	4	3
Special snow model application (4)	1	0	1	0	1
Multi-model application (15)	3	0	3	6	5
Miscellaneous models (8)	1	0	0	3	3
No model environment with snow observations (5)	0	0	0	0	1
Total response from participants (51)	**12**	**3**	**4**	**9**	**14**

*Other data assimilation methods
Particle filter
Simple update method
Simple exchange of init values
EKF in the future
I'm not sure
Asynchronous EnKF
Nudging assimilation
HBV snow routine
Bias Detecting Ensemble (new)
Moving Horizon Estimation
Particle filter
Particle filter
Moving Horizon Estimation (MHE)
Particle filter

4.3.3 Which update frequency is used for your snow data assimilation?

Model environment	1 hour	6 hours	12 hours	1 day	Other frequency*	Total responses
Numerical weather prediction with data assimilation (16)	0	3	1	6	2	**12**
Numerical weather prediction without data assimilation (6)	0	0	0	0	1	**1**
Hydrology (23)	0	0	0	9	3	**12**
Reanalysis (10)	0	0	0	3	1	**4**
Special snow model application (4)	0	0	0	1	1	**2**
Multi-model application (15)	0	0	0	6	2	**8**
Miscellaneous models (8)	0	0	0	4	0	**4**
No model environment with snow observations (5)	0	0	1	0	0	**1**
Total response from participants (51)	**0**	**3**	**2**	**15**	**6**	**25**

*Other frequency
3 hours, but snow depths are only analysed at 06 and 18 UTC
3 hours
ALARO 6h AROME 3h
3 hourly
whenever the data come in, checked every 3 hours
Can be diverse: from 1h to 1day

4.3.4 During which time interval (window) snow observations are considered in your snow data assimilation?

Model environment	1 hour	3 hours	6 hours	12 hours	Other time interval*	Total responses
Numerical weather prediction with data assimilation (16)	1	2	3	1	5	**12**
Numerical weather prediction without data assimilation (6)	0	0	0	0	1	**1**
Hydrology (23)	2	2	0	1	7	**12**
Reanalysis (10)	0	1	0	0	3	**4**
Special snow model application (4)	1	1	0	0	0	**2**
Multi-model application (15)	1	2	0	0	5	**8**
Miscellaneous models (8)	1	0	0	0	3	**4**
No model environment with snow observations (5)	0	0	0	1	0	**1**
Total response from participants (51)	**4**	**4**	**3**	**3**	**12**	**26**

*Other time interval
Synoptic observations at 06 and 18 UTC
24 hours
Under development - satellite obs will contain info from the previous 24 hours. In situ obs will probably be within 1 or 3 hours
Updated snow data is available once a day (morning readings from manual observations + data from automatic stations)
Satellite daily snowgrid uses 15min precipitation data
5 hours
day
?
1 day
Daily
up to one year
From 1h to 1day

4.3.5 Which information from SYNOP is used for your snow data assimilation?

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. Snow depth 2. Snow height. To my understanding there is no SWE in SYNOP! 3. Snow height 4. Snow height, Precipitation in combination with T2M-temperature. If missing information from ww reports is used to retrieve snow height increments 5. snow height, 6-hourly precipitation, T2m, weather type (ww) 6. None 7. Snow depth, state of ground where available (for diagnosing snow-free). Probably also T2m for quality control." 8. snow height 9. SWE 10. Snow height 11. not yet used synop data in snow data assimilation 12. SWE
Numerical weather prediction without data assimilation (6)	1. In Snowgrid precipitation and T2m is used in combination from SYNOP and non SYNOP but also RADAR.

Hydrology (23)	1. No use of Synop 2. SWE 3. Snow height, SWE, precipitation and air temperature 4. 1) snow cover area, 2) SWE 5. real time precip, wind, temperature, where available. 6. Snow height, SWE, precipitation/temperature 7. Snow height 8. Presipitation, Temperature 9. snow height 10. SWE, Precipitation, Temperature 11. SWE 12. Snow height, SWE 13. Snow height, SWE, snow temperature, albedo, radiation: depends on the case (I'm not doing operational stuff, only research)
Reanalysis (10)	1. None 2. No use of Synop 3. SWE 4. Snow height, SWE, precipitation and air temperature 5. Snow height, SWE, precipitation/temperature
Special snow model application (4)	1. snow height 2. real time precip, wind, temperature, where available.
Multi-model application (15)	1. None 2. No use of Synop 3. snow height 4. SWE 5. Snow height, SWE, precipitation and air temperature 6. real time precip, wind, temperature, where available. 7. Snow height, SWE, precipitation/temperature 8. SWE, Precipitation, Temperature 9. SWE
Miscellaneous models (8)	1. none 2. Snow height, SWE, precipitation and air temperature 3. Snow height, SWE, precipitation/temperature 4. SWE, Precipitation, Temperature
No model environment with snow observations (5)	1. Precipitation and Temperature
Total response from participants (51)	**27**

4.3.6 What model state variable(s) is/are analysed in your snow data assimilation system?

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. Snow Water Equivalent and snow density 2. SWE 3. Snow water equivalent 4. Snow depth 5. snow water equivalent, snow density, snow pack temeprature, interception water storage 6. snow amount (kgm-2) - areal density 7. Snow amount (areal density, kgm-2) 8. snow water equivalent 9. snow water equivalent 10. Snow depth 11. snow amount (kg/m2) 12. SWE
Numerical weather prediction without data assimilation (6)	1. SWE

Hydrology (23)	1. Depth, SWE 2. SWE, heat content 3. SWE, accumulation and melt rates 4. 1) SWE, 2) Snow cover area 5. snow water equivalence 6. SWE 7. SWE 8. SWE 9. All! SWE, density, HS, energy content, etc. 10. SWE 11. SWE 12. Snow water equivalent 13. Snow depth, snow water equivalent, snow density, snow temperature: depends on the case
Reanalysis (10)	1. snow amount (kgm-2) - areal density 2. Depth, SWE 3. SWE, heat content 4. SWE, accumulation and melt rates 5. SWE
Special snow model application (4)	1. snow water equivalent 2. snow water equivalence
Multi-model application (15)	1. snow amount (kgm-2) - areal density 2. Depth, SWE 3. snow water equivalent 4. SWE, heat content 5. SWE, accumulation and melt rates 6. snow water equivalence 7. SWE 8. SWE 9. SWE
Miscellaneous models (8)	1. all the snow variables 2. SWE, accumulation and melt rates 3. SWE 4. SWE
No model environment with snow observations (5)	1. snow depth
Total response from participants (51)	**27**

4.3.7 How is the key parameter/ How are the analysed variable(s) processed in your snow data assimilation system?

Model environment	Update of absolute values	Incremental update of first guess from model forecast	Other method*	Total responses
Numerical weather prediction with data assimilation (16)	1	9	2	**12**
Numerical weather prediction without data assimilation (6)	1	0	0	**1**
Hydrology (23)	7	3	2	**12**
Reanalysis (10)	1	1	2	**4**
Special snow model application (4)	1	1	0	**2**
Multi-model application (15)	3	3	2	**8**
Miscellaneous models (8)	3	0	1	**4**
No model environment with snow observations (5)	0	1	0	**1**
Total response from participants (51)	**10**	**12**	**4**	**26**

*Other method
Analysis of absolute values + use of incremental updates of model first guess

update of first guess from model forecast
assimilation of fluxes (SWE changes)
optimal forcing perturbations

4.3.8 Which background field is used in your snow data assimilation?

Model environment	Model forecast	Pre-Analysis	External analysis	Climatology	Other*
Numerical weather prediction with data assimilation (16)	10	2	1	0	0
Numerical weather prediction without data assimilation (6)	1	0	0	0	1
Hydrology (23)	9	2	1	1	0
Reanalysis (10)	4	0	0	1	0
Special snow model application (4)	2	0	1	0	0
Multi-model application (15)	8	0	1	1	0
Miscellaneous models (8)	4	0	0	0	0
No model environment with snow observations (5)	1	0	0	0	0
Total response from participants (51)	**21**	**4**	**2**	**1**	**1**

*Other
SNOWGRID analysis over Austria

4.3.9 Which estimates of the background error are used in your snow data assimilation?

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. A fixed value of background error is used. Horizontal and vertical weighted functions are accounted for in the OI. 2. prescribed constant value (I think) 3. distance weighted (horizontal and vertical) 4. distance weighted (horizontal/vertical) 5. Errors are not considered 6. Background error not accounted for 7. Background error covariances specified as product of background error variance and horizontal and vertical structure functions Horizontal structure function: 2nd order autoregressive function of horizontal separation (of obs and grid point, and of pairs of obs) Vertical structure function: Gaussian function of vertical separation (of obs and grid point, and of pairs of obs) Background error variance: estimate based on other Centres' experience Assimilation scheme still under development, so parameter values not yet finalised 8. distance weighted 9. distance weighted (horizontal/vertical) 10. The BG error for snow depth is 3.1. I don't know the method used for the calculation of this value 11. compare to previous day 12. Variance of ensemble of model simulations
Numerical weather prediction without data assimilation (6)	1. none

Hydrology (23)	1. none 2. model ensemble 3. We have separate data assimilation approaches for snow accumulation and melt within our model framework using optimal interpolation as well as EKF. For details please see: J. Magnusson, D. Gustafsson, F. Hüsler, T. Jonas; Assimilation of point SWE data into a distributed snowcover model comparing two contrasting methods; 2014; Water Resources Research, 50, 7816–7835, doi:10.1002/2014WR015302 4. don't know, i use the MODIS snow cover product 5. gridpp algorithm from Met Norway 6. - 7. Distance weighted 8. Absolute distributed measurements Estimation of the present value according to a normal value. 9. distance weighted 10. None 11. Variance of ensemble of model simulations 12. stochastic noise 13. Rough estimate
Reanalysis (10)	1. Background error not accounted for 2. none 3. model ensemble 4. We have separate data assimilation approaches for snow accumulation and melt within our model framework using optimal interpolation as well as EKF. For details please see: J. Magnusson, D. Gustafsson, F. Hüsler, T. Jonas; Assimilation of point SWE data into a distributed snowcover model comparing two contrasting methods; 2014; Water Resources Research, 50, 7816–7835, doi:10.1002/2014WR015302 5. -
Special snow model application (4)	1. distance weighted 2. gridpp algorithm from Met Norway
Multi-model application (15)	1. Background error not accounted for 2. none 3. distance weighted 4. model ensemble 5. We have separate data assimilation approaches for snow accumulation and melt within our model framework using optimal interpolation as well as EKF. For details please see: J. Magnusson, D. Gustafsson, F. Hüsler, T. Jonas; Assimilation of point SWE data into a distributed snowcover model comparing two contrasting methods; 2014; Water Resources Research, 50, 7816–7835, doi:10.1002/2014WR015302 6. gridpp algorithm from Met Norway 7. - 8. None 9. Variance of ensemble of model simulations
Miscellaneous models (8)	1. not applicable 2. "We have separate data assimilation approaches for snow accumulation and melt within our model framework using optimal interpolation as well as EKF. For details please see: J. Magnusson, D. Gustafsson, F. Hüsler, T. Jonas; Assimilation of point SWE data into a distributed snowcover model comparing two contrasting methods; 2014; Water Resources Research, 50, 7816–7835, doi:10.1002/2014WR015302" 3. - 4. None
No model environment with snow observations (5)	0
Total response from participants (51)	**27**

4.3.10 Which estimates of observation errors are used in your snow data assimilation?

Model environment	Survey responses

Numerical weather prediction with data assimilation (16)	1. A fixed observation error is used. 2. Prescribed constant value (in principle different for different observation types, but only SYNOP snow thickness is used) 3. Observations are suposed to have uncorrelated errors. Standard deviations of observation and background errors are both 5 kg/m2. 4. None 5. Errors are not considered 6. Observation errors not accounted for. However, some anomalous observations are identified and rejected from the assimilation by quality control procedures. 7. Assumed to be uncorrelated. Observation errors for SYNOP snow depth and snow depth diagnosed from satellite snow cover will be estimated, based on experience of ECMWF. 8. varies for different models 9. Standard deviation of error is given in namelist 10. 3,3 11. compare to background snow information 12. Use the method of Slater and Clark (2006, JHM)
Numerical weather prediction without data assimilation (6)	1. none
Hydrology (23)	1. multiplicative 2. depends on the instrument, data type and observation operator; error covariance matrix 3. Please see answer to previous question 4. SWE: standard deviation from the mean Snow cover: % of cloud cover area in the observational dataset 5. assumed, weighted function with wind speed. 6. based on literature 7. Measurement error 8. Confidence intervals 9. standard published error bounds 10. None 11. Use the method of Slater and Clark (2006, JHM) 12. stochastic noise 13. Rough estimate
Reanalysis (10)	1. Observation errors not accounted for. However, some anomalous observations are identified and rejected from the assimilation by quality control procedures. 2. multiplicative 3. depends on the instrument, data type and observation operator; error covariance matrix 4. Please see answer to previous question 5. based on literature
Special snow model application (4)	1. varies for different models 2. assumed, weighted function with wind speed.
Multi-model application (15)	1. Observation errors not accounted for. However, some anomalous observations are identified and rejected from the assimilation by quality control procedures. 2. multiplicative 3. varies for different models 4. depends on the instrument, data type and observation operator; error covariance matrix 5. Please see answer to previous question 6. assumed, weighted function with wind speed. 7. based on literature 8. None 9. Use the method of Slater and Clark (2006, JHM)
Miscellaneous models (8)	1. MODIS surface reflectance errors 2. Please see answer to previous question 3. based on literature 4. None
No model environment with snow observations (5)	0
Total response from participants (51)	**27**

4.4 Snow observation data

4.4.1 I would like to answer the questions on snow observations from WG1/WG2

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	3	13
Numerical weather prediction without data assimilation (6)	1	5
Hydrology (23)	7	16
Reanalysis (10)	4	6
Special snow model application (4)	2	2
Multi-model application (15)	5	10
Miscellaneous models (8)	4	4
No model environment with snow observations (5)	2	3
Total response from participants (51)	**16**	**35**

4.4.2 Please describe the snow observations and products used in the modeling system

Model environment	SYNOP	non-SYNOP ground based	remote sensing ground based (ultrasonic, laser)	remote sensing satellite (radiances)	remote sensing satellite (preprocessed product - SAF)	Climatological data sets	Other
Numerical weather prediction with data assimilation (16)	12	6	2	4	5	2	2
Numerical weather prediction without data assimilation (6)	5	3	1	2	3	2	1
Hydrology (23)	13	15	9	6	10	8	2
Reanalysis (10)	6	5	5	4	7	2	2
Special snow model application (4)	2	2	2	1	1	1	0
Multi-model application (15)	8	8	6	6	7	4	2
Miscellaneous models (8)	5	5	4	3	4	3	2
No model environment with snow observations (5)	1	1	1	1	1	1	3
Total response from participants (51)	**32**	**24**	**15**	**12**	**19**	**14**	**9**

*Other
Multisensor product
External NCEP snow analysis
Satellite snow mask
We use a snow bulk density model to convert snow height into SWE if SWe data is not directly available
Part of boundary and initial conditions from global modelling system ICON
None
LBC frm global model
No
GPR

4.4.3 Do you use ground-based remote sensing measurements or products?

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	2	14

Numerical weather prediction without data assimilation (6)	1	5
Hydrology (23)	12	11
Reanalysis (10)	4	6
Special snow model application (4)	2	2
Multi-model application (15)	6	9
Miscellaneous models (8)	4	4
No model environment with snow observations (5)	2	3
Total response from participants (51)	**18**	**33**

4.4.4 Please specify the system you use for ground-based remote sensing snow properties measurements

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. Lufft (Jenoptik) distance measurement with laser. Ground network of 50+ stations across all regions and altitudes in Austria. 2. ultra-sonic
Numerical weather prediction without data assimilation (6)	1. USH-8
Hydrology (23)	1. Lufft (Jenoptik) distance measurement with laser. Ground network of 50+ stations across all regions and altitudes in Austria. 2. ultrasonic depth gauges microwave radiometers 3. MODIS 4. ultrasonic depth sensors 5. SnowEx field data will be used starting in 2018 6. Ultrasonic with laser 7. Campbell SR50 sensors are mounted to stations of the Swiss automatic snow monitoring network IMIS 8. web cameras and potentially UAS 9. camera systems to provide snow cover area. 10. sonar depth sensors 11. Snow depth measurements 12. NRC (from EDF)
Reanalysis (10)	1. MODIS 2. SnowEx field data will be used starting in 2018 3. Campbell SR50 sensors are mounted to stations of the Swiss automatic snow monitoring network IMIS 4. Snow depth measurements, COSMIC ray sensors
Special snow model application (4)	1. Lufft (Jenoptik) distance measurement with laser. Ground network of 50+ stations across all regions and altitudes in Austria. 2. camera systems to provide snow cover area.
Multi-model application (15)	1. Lufft (Jenoptik) distance measurement with laser. Ground network of 50+ stations across all regions and altitudes in Austria. 2. MODIS 3. SnowEx field data will be used starting in 2018 4. Campbell SR50 sensors are mounted to stations of the Swiss automatic snow monitoring network IMIS 5. camera systems to provide snow cover area. 6. Snow depth measurements
Miscellaneous models (8)	1. Lufft (Jenoptik) distance measurement with laser. Ground network of 50+ stations across all regions and altitudes in Austria. 2. Campbell SR50 the main utrasonic snow depth sensor in use in Canada 3. Campbell SR50 sensors are mounted to stations of the Swiss automatic snow monitoring network IMIS 4. Snow depth measurements
No model environment with snow observations (5)	1. Jenoptik SHM 30 Snow Depth Sensor 2. ultarsonic show height elevations sensors. CS725 non contact SWE measurements. Long wave and short wave radiation measurements. Temperature profiles of snow and soil

Total response from participants (51)	**18**

4.4.5 Do you use preprocessed snow products?

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	6	10
Numerical weather prediction without data assimilation (6)	3	3
Hydrology (23)	7	16
Reanalysis (10)	5	5
Special snow model application (4)	1	3
Multi-model application (15)	6	9
Miscellaneous models (8)	5	3
No model environment with snow observations (5)	0	5
Total response from participants (51)	**16**	**35**

4.4.6 Please specify the system you use for preprocessed product of snow properties

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. IMS snow cover product 2. MODIS fractional snow cover 250 m resolution 3. Snow depth from IMS snow analysis 4. NOAA NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS) 5. Snow analysis fields from ICON system 6. H-SAF daily snow cover product (H31)
Numerical weather prediction without data assimilation (6)	1. Snow analysis fields from ICON system 2. ENVEO daily MODIS 1km product of snow cover percentage 3. Verification of CROCUS results with satellite measurements
Hydrology (23)	1. MODIS fractional snow cover 250 m resolution 2. Snow analysis fields from ICON system 3. SWE retrievals, SCF retrievals (mostly provided by NSIDC) 4. Land-SAF 5. H-SAF snow products 6. H-SAF Snow products H10, H11, H12 and H13 7. MODIS
Reanalysis (10)	1. NOAA NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS) 2. Snow analysis fields from ICON system 3. SWE retrievals, SCF retrievals (mostly provided by NSIDC) 4. Land-SAF 5. H-SAF products
Special snow model application (4)	1. MODIS fractional snow cover 250 m resolution
Multi-model application (15)	1. MODIS fractional snow cover 250 m resolution 2. NOAA NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS) 3. Snow analysis fields from ICON system 4. SWE retrievals, SCF retrievals (mostly provided by NSIDC) 5. Land-SAF 6. H-SAF snow products

Miscellaneous models (8)	1. MODIS fractional snow cover 250 m resolution 2. Snow extent from Meteosat (SEVIRI) and from NOAA (AVHRR). 3. MERRA, MERRA-land, ERAinterim-land, GlobSnow, MODIS, IMS-24km, IMS-4km, NOAA-CDR, CMC snow depth analysis 4. Land-SAF 5. H-SAF snow products
No model environment with snow observations (5)	0.
Total response from participants (51)	**16**

4.5 Data management and data exchange

4.5.1 Do you perform a quality control of snow observations or products

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	12	4
Numerical weather prediction without data assimilation (6)	1	5
Hydrology (23)	17	6
Reanalysis (10)	8	2
Special snow model application (4)	3	1
Multi-model application (15)	10	5
Miscellaneous models (8)	8	0
No model environment with snow observations (5)	1	4
Total response from participants (51)	**34**	**17**

4.5.2 What kind of data quality control is performed?

Model environment	Survey responses

Numerical weather prediction with data assimilation (16)	1. Temperature check, redundancy (in time and space) check, first guess departure check, blacklist. 2. outlier, physical possible range 3. Handling of missing data 4. check against background, OI check 5. Observations are compared to first guess 6. "h_snow < 1.5[m] x (1+zob/800[m]), with h_snow=snow depth, zob=stationheight, fg-check: dsn_inc(t-1,t) <= 0.8[m] x (1+zob/2000[m]) x max(0,min(1,(287.16[K]-T2m)/10[K])) dsn_inc(t-1,t)=Snow height increment between previous and present analysis." 7. "At first, observed snow depth is subject to a plausibility check. It is rejected if it exceeds an acceptance limit which depends on station height. Then, a first guess quality control check is performed. Here, the previous snow depth analysis is considered. (see http://www.cosmo-model.org/content/model/documentation/core/cosmoAssim.pdf)" 8. "1. A check is made against the model land/sea mask to exclude any obs that fall outside the model land area. 2. Binary snow/no snow obs are resampled onto the model grid to give a fractional cover. Minimum fractional cover and maximum surface temperature thresholds are then applied together to identify incorrectly specified snow cover. 3. Extreme time delays in IMS obs (resulting in missing a new snow event) are controlled by using a day-old model forecast alongside the current day's. The model evolution of the snow event can then be compared with IMS obs and the obs excluded if the event is not represented in the obs." 9. " Handling of missing data, data management (likelihood control, data consistency)" 10. "Still in development. Plan to include the following: Checks for gross error, based on max O-B values, max surf T with snow Consistency between state of ground and snow depth Use of quality flags in H-SAF product Land/sea checks Max values set for analysis increment (T-dependent)" 11. includes manual screening 12. Handling of missing data
Numerical weather prediction without data assimilation (6)	1. Handling of missing data, data management (likelihood control, data consistency)
Hydrology (23)	1. outlier, physical possible range 2. " Handling of missing data, data management (likelihood control, data consistency)" 3. Working with relatively small data volumes, so can perform quality control by visual inspection 4. Manual processing 5. Manual quality control 6. validation of automatic measurements (snow depth, water equivalent, density) by manual measurements 7. Lots and lots... flags, comparison to model forecasts, specific conditions 8. for every single data point: plausibility checks, filling gaps or replacing unplausible data where possible + useful 9. - currently non, but this is work in planning/progress 10. inidividual evaluation. Tedious and non-automated. 11. "Handeling of missing data Validation rules" 12. evaluation of physical range of measurements 13. Check of HBV calculated sprinflood against observed sprongflood 14. manual 15. Handling of missing data, validation analysis 16. Validation between satellite derived products and Station data as well as with simulated snow estimates (hydro-validation) 17. Missing data, combination of MODIS satellites
Reanalysis (10)	1. "1. A check is made against the model land/sea mask to exclude any obs that fall outside the model land area. 2. Binary snow/no snow obs are resampled onto the model grid to give a fractional cover. Minimum fractional cover and maximum surface temperature thresholds are then applied together to identify incorrectly specified snow cover. 3. Extreme time delays in IMS obs (resulting in missing a new snow event) are controlled by using a day-old model forecast alongside the current day's. The model evolution of the snow event can then be compared with IMS obs and the obs excluded if the event is not represented in the obs." 2. " Handling of missing data, data management (likelihood control, data consistency)" 3. Manual processing 4. Lots and lots... flags, comparison to model forecasts, specific conditions 5. for every single data point: plausibility checks, filling gaps or replacing unplausible data where possible + useful 6. "Handeling of missing data Validation rules" 7. Missing data- and quality controll 8. Some statistical analysis to observe the consistency of the data and some filtering techniques for the post-processing of the data.
Special snow model application (4)	1. outlier, physical possible range 2. includes manual screening 3. inidividual evaluation. Tedious and non-automated.

Multi-model application (15)	1. outlier, physical possible range 2. "1. A check is made against the model land/sea mask to exclude any obs that fall outside the model land area. 2. Binary snow/no snow obs are resampled onto the model grid to give a fractional cover. Minimum fractional cover and maximum surface temperature thresholds are then applied together to identify incorrectly specified snow cover. 3. Extreme time delays in IMS obs (resulting in missing a new snow event) are controlled by using a day-old model forecast alongside the current day's. The model evolution of the snow event can then be compared with IMS obs and the obs excluded if the event is not represented in the obs." 3. " Handling of missing data, data management (likelihood control, data consistency)" 4. Manual processing 5. includes manual screening 6. Lots and lots... flags, comparison to model forecasts, specific conditions 7. for every single data point: plausibility checks, filling gaps or replacing unplausible data where possible + useful 8. inidividual evaluation. Tedious and non-automated. 9. "Handeling of missing data Validation rules" 10. Handling of missing data, validation analysis
Miscellaneous models (8)	1. outlier, physical possible range 2. satellite viewing angle filtering 3. Check for implausible data (e.g. too warm for snow cover formation depending on elevation and season), outliers (Dixon test). 4. QC of surface snow depth observations for climate monitoring. Check the internal consistency of snow depth changes (change from one day to the next) against observed precip and air temperature. 5. Data managment 6. for every single data point: plausibility checks, filling gaps or replacing unplausible data where possible + useful 7. "Handeling of missing data Validation rules" 8. Handling of missing data, validation analysis
No model environment with snow observations (5)	1. Manual comparison of recorded data with visual observations provided from web camera.
Total response from participants (51)	**34**

4.5.3 Do you perform a consistency check of snow observations or products

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	5	7
Numerical weather prediction without data assimilation (6)	1	0
Hydrology (23)	11	6
Reanalysis (10)	6	2
Special snow model application (4)	1	2
Multi-model application (15)	8	2
Miscellaneous models (8)	6	2
No model environment with snow observations (5)	0	1
Total response from participants (51)	**19**	**15**

4.5.4 Which data consistency checks are performed in your modeling environment?

Model environment	Survey responses

Numerical weather prediction with data assimilation (16)	1. limit snow depth depending on air temperature 2. "Calculation of sum of weights for snow depth (1) and snow depth increments calculated from precip and t2m (2) Use snow height only when weight from contributing obs (1) exceeds min value, use snow depth increment (2) else when average weight of (1) and (2) exceeds min value." 3. snow height only when snow cover is larger than zero, incresing of snow height only when precititation is larger than zero 4. "Analysis increments will only be added if surface T is below a threshold. Snow-free state of ground reports will only be used if snow depth is absent" 5. manual checking based on observations changing in time.
Numerical weather prediction without data assimilation (6)	1. snow height only when snow cover is larger than zero, incresing of snow height only when precititation is larger than zero
Hydrology (23)	1. snow height only when snow cover is larger than zero, incresing of snow height only when precititation is larger than zero 2. consistency of accumulated snow mass and snowfall 3. Manual check 4. Manual consistency checks 5. large deviations from model prediction are flagged; buddy check in case of spatial aggregation 6. apart from the obvious checks we use statistical and visual intercomparision tools between data from similar stations, where similar = same region and same elevation 7. Modis snow cover maps have been compared with post-processing by the Icelandic Met Office 8. - 9. manual analysis 10. Snow cover only when there is SWE in a pixel 11. outlier test (using climatological data), consitency between observed (station data) and remote sensing estimates as well as simulation results by taking changes from day to day into account
Reanalysis (10)	1. snow height only when snow cover is larger than zero, incresing of snow height only when precititation is larger than zero 2. Manual check 3. large deviations from model prediction are flagged; buddy check in case of spatial aggregation 4. apart from the obvious checks we use statistical and visual intercomparision tools between data from similar stations, where similar = same region and same elevation 5. - 6. When snow cover >2cm check the snow height
Special snow model application (4)	1. manual checking based on observations changing in time.
Multi-model application (15)	1. snow height only when snow cover is larger than zero, incresing of snow height only when precititation is larger than zero 2. Manual check 3. manual checking based on observations changing in time. 4. large deviations from model prediction are flagged; buddy check in case of spatial aggregation 5. apart from the obvious checks we use statistical and visual intercomparision tools between data from similar stations, where similar = same region and same elevation 6. - 7. Snow cover only when there is SWE in a pixel
Miscellaneous models (8)	1. snow water equivalent only greather than zero when snow depth is greather than zero. 2. Compare regionally-average time series over regions with relativley dense surface observations. 3. "The first day with snow cover was considered the first day at the beginning of the cold season in which the snow cover was equal or higher than 1 cm. The last day of snow cover was the last day at the end of the cold season when the snow cover was equal or higher than 1 cm." 4. apart from the obvious checks we use statistical and visual intercomparision tools between data from similar stations, where similar = same region and same elevation 5. - 6. Snow cover only when there is SWE in a pixel
No model environment with snow observations (5)	0.
Total response from participants (51)	**19**

4.5.5 Which observation data latency is acceptable for your modeling environment?

Model environment	Below 1 hour	Below 3 hours	Below 6 hours	Below 12 hours	Other*
Numerical weather prediction with data assimilation (16)	3	4	0	4	5
Numerical weather prediction without data assimilation (6)	0	1	0	0	4
Hydrology (23)	3	2	2	0	14
Reanalysis (10)	0	0	1	1	7
Special snow model application (4)	1	1	1	0	1
Multi-model application (15)	1	1	2	1	9
Miscellaneous models (8)	1	0	0	1	6
No model environment with snow observations (5)	1	0	1	1	2
Total response from participants (51)	**6**	**7**	**3**	**6**	**27**

*Other
24 hours
24 hours
24 hours
once a day 12 UTC
research applications - not real time
Typically 3 hours for intergration with our operational forecast, however we backtrack every change in the input data until 10 days before NOW
snow data is only used for validation
depends on what is possible satellite for example is limited by number of overpasses and clouds
depends on re-assimilation scheme. If reassimilation based on EMCMW then below 6h, otherwise below 1h-2h
near real-time is sufficient
Not Applicable
daily
LBC from GCM
We use the snow modelling for research purposes, i.e. the moddeling is typically carried out after the end of the snow season
more than 12 h
no
24-hour
1 year
day
day basis
Below 1 week
1 day
1 Day
right now, months is OK. When we send this into operation (not my group, but collaborators), then we need less than a day
~ 24 hours
Below 24 hours
I'm a researcher, so not concerned. For an operational application for hydrological forecasting, 1 or 2 days could still be fine I guess

4.5.6 Is it possible to exchange the snow data used in your modeling environment with other groups

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	13	3
Numerical weather prediction without data assimilation (6)	4	2
Hydrology (23)	17	6
Reanalysis (10)	8	2
Special snow model application (4)	3	1
Multi-model application (15)	10	5
Miscellaneous models (8)	4	4
No model environment with snow observations (5)	3	2
Total response from participants (51)	**38**	**13**

4.5.7 Which access requirements exist for the snow observation data sets you are using?

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. GTS only 2. FTP access, NetCDF, ASCII 3. GTS only, data is already there for everyone to use. 4. GTS 5. FTP access, GTS 6. FTP access, data in GRIB2 format 7. GTS, EUMETCast 8. They are provided to ECMWF. 9. GTS 10. GTS only 11. ftp 12. Its publicly available thru the US NRCS (Snotel data) 13. GTS, FTP access
Numerical weather prediction without data assimilation (6)	1. GTS only 2. ftp 3. Exchange is possible in principle if we start using it. 4. GTS, FTP access
Hydrology (23)	1. GTS only 2. ftp 3. At that point, certain data is available on request. We use data from various sources / providers, so there is no simple answer to this question. 4. FTP access, GTS and other special data formats. 5. We do not have automatic protocols for data exchange. Th eexchange is however possible after the discussion about conrete requirements. 6. Special Data format 7. No special requirements 8. will have to be set up... 9. we are developing a real-time data server for the camera acquired data. 10. FTP 11. FTP access, XML-links 12. internet 13. Its publicly available thru the US NRCS (Snotel data) 14. whatever NASA offers, FTP, HPPS 15. FTP, netcdf Format is in work 16. GTS, FTP access 17. I' not owner of data, I use data that are either opendata or available upon request

Reanalysis (10)	1. GTS only 2. FTP access, data in GRIB2 format 3. At that point, certain data is available on request. We use data from various sources / providers, so there is no simple answer to this question. 4. WMS 5. FTP 6. FTP 7. whatever NASA offers, FTP, HPPS 8. GTS, FTP access
Special snow model application (4)	1. They are provided to ECMWF. 2. Exchange is possible in principle if we start using it. 3. we are developing a real-time data server for the camera acquired data.
Multi-model application (15)	1. GTS only 2. FTP access, data in GRIB2 format 3. At that point, certain data is available on request. We use data from various sources / providers, so there is no simple answer to this question. 4. They are provided to ECMWF. 5. Exchange is possible in principle if we start using it. 6. we are developing a real-time data server for the camera acquired data. 7. FTP 8. Its publicly available thru the US NRCS (Snotel data) 9. whatever NASA offers, FTP, HPPS 10. GTS, FTP access
Miscellaneous models (8)	1. ftp from MODIS web site 2. At that point, certain data is available on request. We use data from various sources / providers, so there is no simple answer to this question. 3. Mainly FTP (NSIDC) 4. FTP
No model environment with snow observations (5)	1. FTP access 2. Web access, SFTP 3. special data format
Total response from participants (51)	**38**

4.6 New or upcoming observation sources for snow observations

4.6.1 Do you have concrete plans to use the new or upcoming observation sources that could be interesting for your modeling environment?

Model environment	Yes	No
Numerical weather prediction with data assimilation (16)	11	5
Numerical weather prediction without data assimilation (6)	1	5
Hydrology (23)	17	6
Reanalysis (10)	8	2
Special snow model application (4)	1	3
Multi-model application (15)	9	6
Miscellaneous models (8)	4	4
No model environment with snow observations (5)	2	3
Total response from participants (51)	**30**	**21**

4.6.2 Which of the new or upcoming observation sources could be interesting for your modeling

environment?

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. "Additional in situ data - Satellite datasets currently in development" 2. Satellite datasets currently in development, new ground-based observation from GPS sensors, wet snow from SAR 3. SWE microwave satellite; snow cover optical and microwave satellite; (snow) albedo optical, microwave - still quite far from operational application but developed hopefully within the COST collaboration 4. AMSR2, SAR 5. wet snow cover from SAR (sentinel-1) 6. Satellite datasets currently in development 7. ground-based obs. 8. Satellite datasets currently in development, new ground-based observation from GPS sensors, wet snow from SAR 9. Plan to use ground-based observations of snow depth from non-SYNOP networks (in addition to SYNOP obs), where available on the GTS. Plan to assess AMSR-2 snow depth and SWE products for potential assimilation. 10. sentinel products, in-situ SWE from GPS, snow liquid water and snow surface ground observations. 11. snow from SAR
Numerical weather prediction without data assimilation (6)	1. Satellite datasets currently in development, new ground-based observation from GPS sensors, wet snow from SAR
Hydrology (23)	1. snow microstructure measures from reflectance 2. - 3. Satellite datasets 4. Satellite datasets in development, new ground-based observation from GPS sensors, wet snow from SAR,. etc- 5. Happy to try any; we are starting to try out all of the NASA SnowEx remote sensing data next. 6. network of ground thermometers, GPS measurements, ground-based photogrammetry 7. Satellite datasets currently in development, new ground-based observation from GPS sensors, wet snow from SAR 8. Satellite datasets 9. "Satellite datasets currently in development SWE" 10. SCA from Sentinel2 11. Any types of snow observation sources 12. any and all, particularly satellite and air-based observations 13. sentinel products, in-situ SWE from GPS, snow liquid water and snow surface ground observations. 14. snow from SAR 15. Snow data of Copernicus Services 16. New satellite datasets, ground observations from new instruments 17. Reliable spatialised SWE data over large areas
Reanalysis (10)	1. - 2. Satellite datasets 3. Satellite datasets in development, new ground-based observation from GPS sensors, wet snow from SAR,. etc- 4. Happy to try any; we are starting to try out all of the NASA SnowEx remote sensing data next. 5. data from Sentinel Satellite 6. Satellite datasets currently in development, new ground-based observation from GPS sensors, wet snow from SAR 7. Plan to use ground-based observations of snow depth from non-SYNOP networks (in addition to SYNOP obs), where available on the GTS. Plan to assess AMSR-2 snow depth and SWE products for potential assimilation. 8. Cosmic ray sensors
Special snow model application (4)	1. sentinel products, in-situ SWE from GPS, snow liquid water and snow surface ground observations.

Multi-model application (15)	1. Satellite datasets 2. Satellite datasets in development, new ground-based observation from GPS sensors, wet snow from SAR,. etc- 3. Happy to try any; we are starting to try out all of the NASA SnowEx remote sensing data next. 4. Satellite datasets currently in development, new ground-based observation from GPS sensors, wet snow from SAR 5. - 6. Plan to use ground-based observations of snow depth from non-SYNOP networks (in addition to SYNOP obs), where available on the GTS. Plan to assess AMSR-2 snow depth and SWE products for potential assimilation. 7. sentinel products, in-situ SWE from GPS, snow liquid water and snow surface ground observations. 8. snow from SAR 9. New satellite datasets, ground observations from new instruments
Miscellaneous models (8)	1. Sentinel2 2. - 3. sentinel products, in-situ SWE from GPS, snow liquid water and snow surface ground observations. 4. New satellite datasets, ground observations from new instruments
No model environment with snow observations (5)	1. remote sensing of sc and swe 2. Satellite datasets, and otehr observations that we couldn't use.
Total response from participants (51)	**30**

4.6.3 What are particular barriers, which prevent you from usage of new observation sources, if you do not use these data?

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. Data availability or Data quality 2. none 3. Lack of manpower to do the development and implementation 4. time to evaluate the potential improvements and introduce the data with operational chain 5. Available limited ressources for implementation into DA system, limited access to special snow measurement networks 6. Data availability on the GTS 7. Not yet an operational product, and temporal resolution not really sufficient until there are 2 platforms in operation. Our limited area snow DA is still in development so not ready to use new obs yet anyway. Anticipate 2 year timeframe. 8. No particular 9. We haven't got enough resources 10. difficulty getting to the data as a research 11. consistency in technology development 12. lack of information on possibilities to have access to other data and lack of information on which data. 13. "Non-SYNOP ground-based network snow depth observations are currently only exchanged on the GTS by a few countries. Obs need to be put on the GTS to be able to use them for data assimilation in operational NWP systems. Active reporting of snow-free conditions (zero snow depth) is infrequent, in both SYNOP and other stations. This needs to change to enable the provision of a huge amount of additional data for use in NWP systems." 14. technology and accuracy for in-situ SWE observations still a big problem. time and financial ressources for snow surface temperature and snow liquid water content. 15. pricing 16. Funding & time
Numerical weather prediction without data assimilation (6)	1. Human resources, lack of know-how. 2. no 3. lack of human resources 4. Lack of people who can work on it. There is for example a snow height Optimal Interpolation already available inside ALARO/AROME, but it needs new formulation of background error, tuning and testing, there is also NCEP free 1km snow product which could easily be used for yes/no decision, but some coding for interpolation and testing would be needed. Right now, there is no time to do that. 5. - 6. consistency in technology development

Hydrology (23)	1. time, at the moment. No concrete plans currently. 2. Our current focus is on enhancing our models / data assimiliation methodology; not on integrating more observational data into our system. 3. time and funding 4. access, data formats, latency etc 5. human ressources 6. Cost, complex access 7. Data documentation, data delivery, data access 8. "Problems with data assimilation in existing systems and models. Knowledge about new data sources, formats, restriction etc." 9. We use the data in research/PhD projects, but not on a regular-long-term basis. i.e. many years of monitoring. 10. Calibration/validation of data 11. lack of manpower for control, etc 12. consistency in technology development 13. Lack of scientific personnel 14. Data availability, man power to work on the tasks 15. I have no pre-concepts in using new data but I have to validate them in the Alpine environment and compare their performances to older products 16. There has not yet been anything developed to fit into our model sustem 17. clouds, timeliness 18. technology and accuracy for in-situ SWE observations still a big problem. time and financial ressources for snow surface temperature and snow liquid water content. 19. pricing 20. Funding & time 21. Human ressources 22. Data formats, lack of man power and time 23. Quality and covered area (I need data over catchments, not only point scale)
Reanalysis (10)	1. no 2. Our current focus is on enhancing our models / data assimiliation methodology; not on integrating more observational data into our system. 3. access, data formats, latency etc 4. human ressources 5. Cost, complex access 6. Data documentation, data delivery, data access 7. "." 8. consistency in technology development 9. "Non-SYNOP ground-based network snow depth observations are currently only exchanged on the GTS by a few countries. Obs need to be put on the GTS to be able to use them for data assimilation in operational NWP systems. Active reporting of snow-free conditions (zero snow depth) is infrequent, in both SYNOP and other stations. This needs to change to enable the provision of a huge amount of additional data for use in NWP systems." 10. The quality of the data obtained from the new observation sources
Special snow model application (4)	1. Human resources, lack of know-how. 2. time, at the moment. No concrete plans currently. 3. lack of information on possibilities to have access to other data and lack of information on which data. 4. technology and accuracy for in-situ SWE observations still a big problem. time and financial ressources for snow surface temperature and snow liquid water content.
Multi-model application (15)	1. Human resources, lack of know-how. 2. no 3. time, at the moment. No concrete plans currently. 4. Our current focus is on enhancing our models / data assimiliation methodology; not on integrating more observational data into our system. 5. access, data formats, latency etc 6. human ressources 7. Cost, complex access 8. Data documentation, data delivery, data access 9. consistency in technology development 10. lack of information on possibilities to have access to other data and lack of information on which data. 11. "Non-SYNOP ground-based network snow depth observations are currently only exchanged on the GTS by a few countries. Obs need to be put on the GTS to be able to use them for data assimilation in operational NWP systems. Active reporting of snow-free conditions (zero snow depth) is infrequent, in both SYNOP and other stations. This needs to change to enable the provision of a huge amount of additional data for use in NWP systems." 12. technology and accuracy for in-situ SWE observations still a big problem. time and financial ressources for snow surface temperature and snow liquid water content. 13. pricing 14. Funding & time 15. Data formats, lack of man power and time

Miscellaneous models (8)	1. none 2. The quality of operationally available remote sensing data (snow water equivalent) or the data availability itself (snow depth). 3. Our current focus is on enhancing our models / data assimiliation methodology; not on integrating more observational data into our system. 4. access, data formats, latency etc 5. New sources is not my main issue - my main issue is delays accessing in situ data e.g. Russian online snow survey data are not updated past 2011. 6. - 7. technology and accuracy for in-situ SWE observations still a big problem. time and financial ressources for snow surface temperature and snow liquid water content. 8. Data formats, lack of man power and time
No model environment with snow observations (5)	1. Closed assimilation scheme, restricted to forecasting variables. 2. No particular barriers 3. limited development for Iceland of such products 4. we just got this modeling system, we don't have much of the experience. organisation made the system as it is. But we would like to make it beter. 5. Presently only run limited area NWP model. In future, might run global model.
Total response from participants (51)	**51**

4.7 Additional comments

4.7.1 Please use the following text box to write down important points, which are missed in the questionnaire or which were not explicitly asked.

Model environment	Survey responses
Numerical weather prediction with data assimilation (16)	1. "Collaboration in snow DA community. What kind of new snow observation data exist - information exchange with measurement community about new snow observation data" 2. "See http://www.cosmo-model.org/content/model/documentation/core/cosmoAssim.pdf.Further questions to Jean-Marie Bettems (MeteoSwiss) or Martin Lange (DWD)" 3. Status on snow observations based on satellite is at present not well known to us. 4. I am doing snow data assimilation in an uncoupled land-surface/hydrologic system only. It seems like the questions assume DA activities are done in a coupled atmospheric system based on the global vs LAM and resolution questions.
Numerical weather prediction without data assimilation (6)	1. We are in principle interested to draw more attention on usage of snow observations in our modelling activities. However, the changes and developments are very slow due to lack of resources. 2. we do not any assimilation yet so only first part of the questionnaire is important.
Hydrology (23)	1. Chosing suitable methodology is very much linked to the availability of data, which in the case of snow data hugely differs from country to country. This is why collaboration between partners from different countries can be difficult. 2. - 3. Extent of the different types of snow measurements 4. I am doing snow data assimilation in an uncoupled land-surface/hydrologic system only. It seems like the questions assume DA activities are done in a coupled atmospheric system based on the global vs LAM and resolution questions. 5. Estimating and use of predicting uncertainty within the modeling chain, combination/synthesis of snow estimates of NWP, Hydrological models and observations (Station and remote sensing data), use of hydrological modelling and observed streamflow data for validation of snow information (hydro-validation), Validation issues (statistics etc.), Snow mapping (Interpolation), heterogeniety of snow field in montainous/alpine areas
Reanalysis (10)	1. we do not any assimilation yet so only first part of the questionnaire is important. 2. Chosing suitable methodology is very much linked to the availability of data, which in the case of snow data hugely differs from country to country. This is why collaboration between partners from different countries can be difficult.
Special snow model application (4)	1. We are in principle interested to draw more attention on usage of snow observations in our modelling activities. However, the changes and developments are very slow due to lack of resources. 2. Status on snow observations based on satellite is at present not well known to us.

Multi-model application (15)	1. We are in principle interested to draw more attention on usage of snow observations in our modelling activities. However, the changes and developments are very slow due to lack of resources. 2. we do not any assimilation yet so only first part of the questionnaire is important. 3. Chosing suitable methodology is very much linked to the availability of data, which in the case of snow data hugely differs from country to country. This is why collaboration between partners from different countries can be difficult. 4. - 5. Status on snow observations based on satellite is at present not well known to us. 6. I am doing snow data assimilation in an uncoupled land-surface/hydrologic system only. It seems like the questions assume DA activities are done in a coupled atmospheric system based on the global vs LAM and resolution questions.
Miscellaneous models (8)	1. Chosing suitable methodology is very much linked to the availability of data, which in the case of snow data hugely differs from country to country. This is why collaboration between partners from different countries can be difficult. 2. - 3. - no mechanism exists for real-time exchange of in situ SWE obs
No model environment with snow observations (5)	1. n/a 2. None 3. Modeling system calculates snow depth so we jsut check it and corect if it needs to be corected. 4. Appreciate the HarmoSnow Project. It will improves the NWP GCM and thus other downstream products in general.
Total response from participants (51)	**16**

5. Summary and Conclusions

The pre-defined user groups of numerical models, i.e. (i) numerical weather prediction with and (ii) without data assimilation, (iii) hydrology, (iv) reanalysis, (v) special snow model applications, (vi) Miscellaneous models, (vii) model environment without snow observations are considered for the evaluation of the survey (Tab 4.1). Furthermore the application of several models, i.e. models belonging to (i) - (viii) in one organization is considered in an additional group, i.e. (viii) multi models.

These groups are created according to the response for the question about the modeling environment. Multiple answers were possible.

Snow observations play a important role in the model environment of the 51 survey participants, as 46 answered "yes, snow observations are used in the modeling environment" (Tab 4.2.1). Only 10% are actually not using snow observation data due to technical limitations (e.g. network) or due to the used model (e.g. model domain).

Considering the user groups of snow observation data for numerical models, the dominant modeling environments are hydrology, numerical weather prediction with data assimilation, and reanalysis (Tab 4.2.3). Snow observation play only a minor role in NWP without data assimilation. In "Miscellaneous models", snow observations used e.g. in models for snow cover, snow melt, discharge, forcing in agroclimatology/agrometeorology and for evaluation of climate models and for validation.

More details by a short description about the used modeling environment was given by 46 participants of the survey (Tab. 4.2.4) showing that for numerical weather prediction with data assimilation operational global and limited-area NWP systems with full snow-DA dominate, while in numerical weather prediction without data assimilation limited-area models, stand-alone snow models, and model validation and verification were considered. For hydrology snow melt, run-off, snow water storage, discharge and flood forecasting are important applications.In the "Re analysis" model environment e.g., surface reanalysis, data assimilation in coupled NWP, hydrological modeling are used. Special snow model application considers e.g., operational snow cover model coupled to nowcasting system, road condition modelling or modelling of catchment discharge. The employment of multi models are the case for about 30% of the participating organizations showing that only a few organizations apply 4 different model categories while most participants belonging to this group running less than 3 different model environment classes (e.g., hydrology and reanalysis or numerical weather prediction with data assimilation and special snow model). The group "Miscellaneous models" are created from additional responses of survey participants about their modeling environment and includes physical snow models within land-surface schemes, snow cover models or conceptual or distributed hydrological models.

Numerical weather prediction with snow data assimilation is used for global and limited area domains but global application without snow data assimilation does not exist in the survey (Tab 4.2.5). For hydrology, limited-area domains and other domains (catchments, river basins) are important, similar to special snow models or Miscellaneous models, while reanalysis based applications are performed on global scale and limited-area domains. There was no response for the nesting facility, although additional comments in other domains suggested a nesting of domains.

The horizontal resolution of operational application of numerical weather prediction models with snow data assimilation is between 10 km and 20 km (e.g. for global models) while limited-area models and models without snow data assimilation often use resolutions below 5 km (Tab. 4.2.6). Hydrological models, special snow models or Miscellaneous models operate often with resolutions below 1 km (e.g. for catchment scale).

For the groups numerical weather prediction with data assimilation and hydrology (contained also in multi models) most participants decided to give response for the questions about data assimilation (Tab. 4.3.1). The optimum interpolation method is the most used DA method for snow observation in numerical weather prediction with data assimilation, while Ensemble Kalman Filter dominates in hydrology, reanalysis and Miscellaneous models (Tab. 4.3.2). A large number of additional responses were given for hydrology, e.g. particle filter method. In most cases the update of snow observations once a day is used while in numerical weather prediction with data assimilation are also update frequencies below 12 hours, e.g. 6 hours and 3 hours occur (Tab. 4.3.3). The time interval that is used to take observations into account in data assimilation is in most cases below 12 hours for numerical weather prediction (Tab. 4.3.4). For hydrology, special snow models and Miscellaneous models time intervals below 6 hours are important but there are responses in other intervals suggesting that 24 hours window is used.

Snow parameter snow depth (SD) and snow water equivalent (SWE) are used in most cases for data assimilation in NWP and hydrology although SWE is not measured by standard SYNOP stations and must be derived from other parameters (Tab 4.3.5). In some cases, temperature, precipitation, snow cover area, radiation, wind and weather type is used in the modeling environment for snow data assimilation. Snow depth and SWE are the most important model state variables, which are analysed in the DA system (Tab. 4.3.6). Depending on the model environment group, additional variables are considered, i.e. accumulation and melt rates for hydrology, temperature, density for NWP, heat content for reanalysis. The analysed snow variables are processed by incremental update in most cases of NWP with snow DA, while in hydrology and Miscellaneous models the update of absolute values dominates (Tab. 4.3.7). Other approaches as assimilation of fluxes or optimal forcing perturbations have only a few responses. The background field of the DA is in most cases the model forecast independent of the model environment (Tab. 4.3.8). Only in less than 3 responses pre-analysis, external analysis, climatology or other background fields are used respectively.

For the estimation of the background error in snow DA, a distance weighted approach is used in NWP with snow DA (Tab. 4.3.9). This method is also used in hydrology and special snow models but not in reanalysis. In all model environements in addition to distance weighted approach a number of different methods are also used. For the observation error used in snow DA (Tab. 4.3.10) independent of the model environment no dominant method was found from the reponses since a wide variety of approaches are used.

The most participants agreed to answer questions from the accompanying survey on snow measurements in Europe: purpose, practices, and applied instrumentation was developed and conducted by working group 1 'Physical Characterization of Snow Properties' and working group 2 'Instrument and Method Evaluation' of COST HarmoSnow (Tab. 4.4.1), in particular participants using NWP with and without snow DA, and hydrology.

Snow observations from SYNOP and additional ground-based measurements are the most important data sources for NWP and hydrology (Tab. 4.4.2). For the latter, also ground-based remote sensing data are very important. In agreement with NWP preprocessed remote sensing satellite products are often used in hydrology. Satellite radiances are used much less and climatological data are appropriated for hydrological applications. Additional data, used by survey participants are e.g., external snow analysis or multisensor satellite products.

In agreement with Tab. 4.4.2, most user with model environment in hydrology use ground-based remote sensing measurements or products (Tab. 4.4.3), while this is not the case for NWP or reanalysis. The employed measurement system includes in many cases ultrasonic or laser distance sensors, but also camera, COSMIC ray or radiation sensors (Tab. 4.4.4).

Preprocessed snow products are used in all model environments but have special importance in NWP without DA, reanalysis and Miscellaneous models (Tab. 4.4.5). The used products are e.g. from IMS snow cover, satellite (MODIS, SEVIRI, AVHRR), SAF (H-SAF, Land-SAF), NWP-based snow analysis or reanalysis (Tab. 4.4.6).

Quality control of snow observations and products is performed in large majority of the model environments used in this survey (Tab. 4.5.1) even there is one response of quality control for NWP without snow DA and model environment without snow observations. Filtering of outlier, manual and automatic treatment of missing data or implausible values with different sophistication is used in all model environments (Tab. 4.5.2). Data assimilation in NWP is used for this purpose, as some responses show.

In comparison with a quality control, a snow data consistency check is performed in all model environemnts but in the majority of the responses for hydrology, reanalysis and Miscellaneous models (Tab. 4.5.3). For this data preprocessing manual and automatic methods exists, based on basic physical principles (Tab. 4.5.4), where the snow cover field is of particular importance.

Depending on the application, the observation data latency becomes important, as responses for NWP with DA and hydrology with responses for latency below 3 h indicate (Tab. 4.5.5). However, many responses in additional latency comments show that latencies of 1 day, week, or year are acceptable in model environments, e.g. for hindcasts or reanalysis.

The exchange of snow data is possible in all model environments, as majority of positive answers show (Tab. 4.5.6). In most cases, GTS network (NWP, Hydrology) or FTP protocol (Miscellaneous models) is required for data access (Tab. 4.5.7), but web access or central data hubs are also used.

Concrete plans for using new or upcoming data sources of snow observations exist for all model environments, in particular for NWP with DA, hydrology, and reanalysis (Tab 4.6.1). In all detailed answers of Tab, 4.6.2 the use of more satellite data (optical, microwave) but also more ground-based remote sensing data, GPS or COSMIC ray sensors, or additional non-SYNOP networks are of interest for particpants of the survey. Current barriers and limitations for the use of these data are in particular independent of the model environment data availability and ressources to integrate the data in the model environment (Tab 4.6.3).

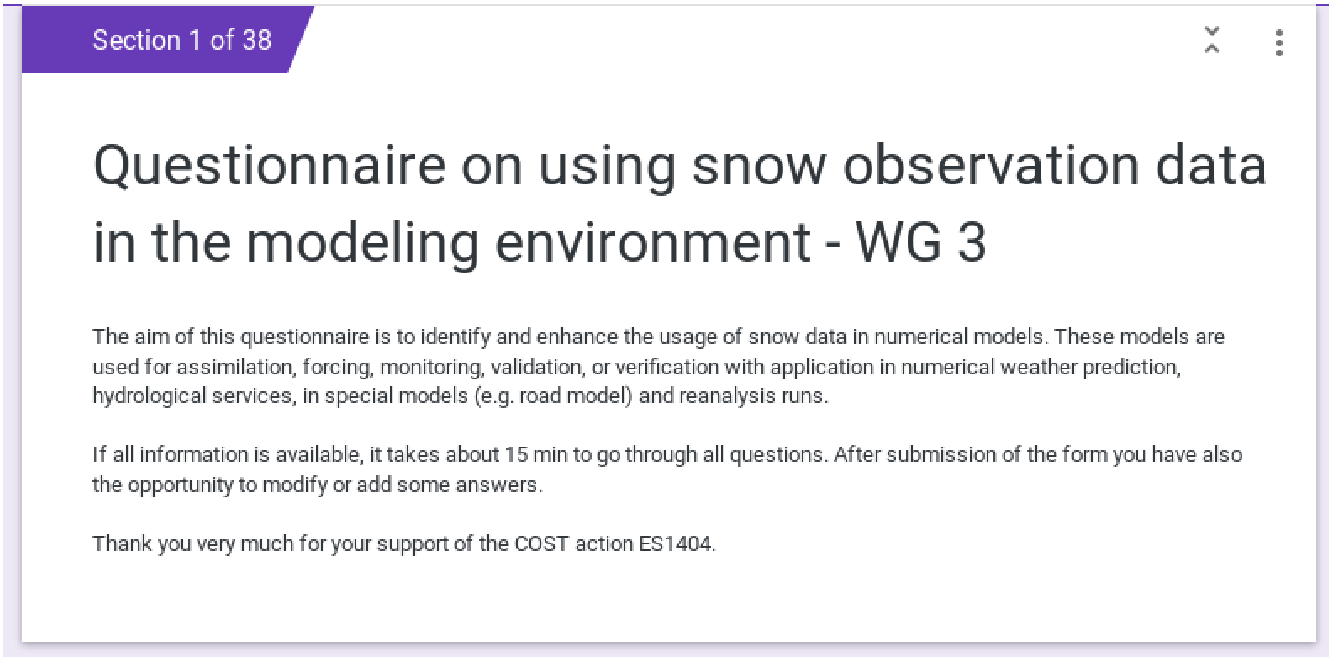
Additional comments on the survey was given by survey participants in Tab 4.7.1. The structure of the survey was addressed as well the collaboration in the modeling community using snow data and additional information about the development of the modeling environment.

For conclusions, the results of the accompanying survey on snow measurements in Europe: purpose, practices, and applied instrumentation are taken into account, which reveal that in Europe there is a fit of the demanded snow macrophysical parameters by data assimilation and the measurement environment, since snow depth, snow presence, snow density and snow water equivalent are the most measured parameters \citep{SurveyWG1WG2}. For the assimilation of these data into models it is an important information that in many cases these m acrophysical parameters are measured with different instruments and techniques, in particular for snow depth and SWE. The degree of automatization is highest for snow depth, where 60% of the considered cases ultrasonic or laser sensors are used. Also for SWE automatic instruments exist. The addressed measurement of snow microphysical and electromagnetic parameters match the concrete plans for model environments to use more remote sensing data ground-based or from satellite which require information about these parameters, even if radiances should be assimilated.

The present-day measurement networks, instruments, and techniques fit to the existing data assimation systems, used in model environments for numerical weather prediction, hydrology, or special snow models. The increasing automatization of the measurments is a task for data management in the DA system (quality control, consistency) but also the demand for snow data in regions with sparse measurement networks, which could remote sensing from satellite solve is a task for DA development and instrument development (e.g. automatic measurement of snow microphysical parameters).

6. Appendix

The appendix contains the question slides from Google Forms used for the questionnaire.



Section 1 of 38

Questionnaire on using snow observation data in the modeling environment - WG 3

The aim of this questionnaire is to identify and enhance the usage of snow data in numerical models. These models are used for assimilation, forcing, monitoring, validation, or verification with application in numerical weather prediction, hydrological services, in special models (e.g. road model) and reanalysis runs.

If all information is available, it takes about 15 min to go through all questions. After submission of the form you have also the opportunity to modify or add some answers.

Thank you very much for your support of the COST action ES1404.

Section 2 of 38

Personal Information

Description (optional)

Name and Surname *

Short-answer text

Position

Short-answer text

Institute *

Short-answer text

Country *

Short-answer text

Section 3 of 38

Modeling environment and snow observation data

Description (optional)

Do you use snow observation data in your modeling environment *

Examples: NWP, Hydrology, Snow models

- ◯ Yes
- ◯ No

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Modeling environment and snow observation data

Description (optional)

If possible, please give some reasons for no use of snow observation data. *

Examples: not enough information in real time, density of the network

Long-answer text

Modeling environment

Description (optional)

In which modeling environment you are using snow observation data? *

- [ ] Numerical Weather Prediction with snow data assimilation
- [ ] Numerical Weather prediction without snow data assimilation
- [ ] Hydrology (forcing using snow data)
- [ ] Special application (e.g. road model with snow data)
- [ ] Reanalysis using snow data
- [ ] Other...

Modeling environment

Description (optional)

Please give a short description of your modeling environment. *

Examples: Full NWP system with data assimilation, stream flow model.

Long-answer text

Modeling domain

Description (optional)

Please specify the modeling domain used in your application. *

If you are running global and limited area/nested models with own snow data assimilation please fill out the form for each of the models.

- ◯ Global
- ◯ Limited area
- ◯ One-way/two-way nesting of domains
- ◯ Other...

Model resolution

Description (optional)

Please specify the model horizontal resolution. *

- Below 1 km
- Between 1km and 5 km
- Between 5km and 10 km
- Between 10 km and 20 km
- Between 20km and 50 km
- Larger than 50 km
- Other...

Data assimilation questions

Description (optional)

I would like to answer the questions regarding data assimilation *

- Yes
- No

Data assimilation method

Description (optional)

Which data assimilation method is used in your system for snow observations? *

If "other" method is used, please give a short description or reference.

- [ ] Optimum Interpolation
- [ ] Cressman analysis method
- [ ] Kalman Filter
- [ ] Ensemble Kalman Filter
- [ ] Other...

Data assimilation update frequency

Description (optional)

Which update frequency is used for your snow data assimilation? *

Example: data assimilation is running hourly or once a day

- 1 hour
- 6 hours
- 12 hours
- 1 day
- Other...

Data assimilation window

Description (optional)

During which time interval (window) snow observations are considered in your snow data assimilation? *

Example: Observations are collected during a prescribed time interval for consideration in the assimilation cycle

- 1 hour
- 3 hours
- 6 hours
- 12 hours
- Other...

SYNOP information

Description (optional)

Which information from SYNOP is used for your snow data assimilation? *

Example: Snow height, SWE, Precipitation in combination with T2M-temperature

Long-answer text

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Model variables

Description (optional)

What model state variable(s) is/are analysed in your snow data assimilation system? *

Example: Snow depth, snow water equivalent, snow density

Long-answer text

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Processing

Description (optional)

How is the key parameter/ How are the analysed variable(s) processed in your snow data assimilation system? *

Please use also "other" to give a description if the processing differs between horizontal and vertical direction

- [ ] Update of absolute values
- [ ] Incremental update of first guess from model forecast
- [ ] Other...

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Background field

Description (optional)

Which background field is used in your snow data assimilation? *

- [ ] Model forecast
- [ ] Pre-Analysis
- [ ] External analysis
- [ ] Climatology
- [ ] Other...

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Background error estimates

Description (optional)

Which estimates of the background error are used in your snow data assimilation? *

Example: distance weighted (horizontal/vertical)

Long-answer text

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Observation error estimates

Description (optional)

Which estimates of observation errors are used in your snow data assimilation? *

Long-answer text

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Observation data

Description (optional)

I would like to answer the questions on snow observations from WG1/WG2 *

Please note: the WG1/WG2 questionnaire is focused on observations and developing of instruments.

- Yes
- No

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Observation data

Please use the questionnaire from WG1/WG2 in an own tab or window using the address: http://costsnow.fmi.fi/index.php?page=Q1

The WG1/WG2 questionnaire is focused on observations and developing of instruments.

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Further questions on snow observation data

Description (optional)

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Snow observations and products used in the modeling system

Please describe the snow data sources used for the model application

Snow observations and products *

- [ ] SYNOP
- [ ] non-SYNOP ground based
- [ ] remote sensing ground based (utrasonic, laser)
- [ ] remote sensing satellite (radiances)
- [ ] remote sensing satellite (preprocessed product - SAF)
- [ ] Climatological data sets
- [ ] Other...

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Remote sensing ground-based

Description (optional)

Do you use ground-based remote sensing measurements or products *

Example: Snow height from ultrasonic or laser scanner

◯ Yes

◯ No

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Remote sensing ground-based

Description (optional)

Please specify the system you use for ground-based remote sensing snow properties measurements *

Long-answer text

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Preprocessed product

Description (optional)

Do you use preprocessed snow products *

Example: H-SAF or Land-SAF snow products

- ○ Yes
- ○ No

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Preprocessed product

Description (optional)

Please specify the system you use for preprocessed product of snow properties *

Example: H-SAF or Land-SAF products

Long-answer text

Processing - Quality control

Description (optional)

Do you perform a quality control of snow observations or products *

- Yes
- No

Processing - Quality control

Description (optional)

What kind of data quality control is performed? *

Please describe the quality checks applied on observation data: Handling of missing data, data management, preprocessing (which?)

Long-answer text

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Data consistency

Description (optional)

Do you perform a consistency check of snow observations or products *

Example: In order to find inconsistent data which passed the quality control

- Yes
- No

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Data consistency

Description (optional)

Which data consistency checks are performed in your modeling environment? *

Connecting data: example: snow height only when snow cover is larger than zero

Long-answer text

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Observation data latency

Description (optional)

Which observation data latency is acceptable for your modeling environment? *

Example: The acceptable time needed from measurement, data transmission, storage in a data base until using in a data assimilation code

- Below 1 hour
- Below 3 hours
- Below 6 hours
- Below 12 hours
- Other...

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Access requirements

Description (optional)

Is it possible to exchange the snow data used in your modeling environment with other groups *

- Yes
- No

Access requirements

Description (optional)

Which access requirements exist for the snow observation data sets you are using? *

Examples: FTP access, GTS only, special data format

Long-answer text

Additional observation sources

Description (optional)

Do you have concrete plans to use the new or upcoming observation sources that could be interesting for your modeling environment? *

- Yes
- No

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Additional observation sources

Description (optional)

Which of the new or upcoming observation sources could be interesting for your modeling environment? *

Example: Satellite datasets currently in development, new ground-based observation from GPS sensors, wet snow from SAR, ...

Long-answer text

Section 36 of 38

Additional observation sources

Description (optional)

What are particular barriers, which prevent you from usage of new observation sources, if you do not use these data? *

Long-answer text

Section 37 of 38

Additional comments and suggestions

Description (optional)

Please use the following text box to write down important points, which are missed in the questionnaire or which were not explicitly asked.

Long-answer text

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Thank you very much, once again, for your support.

Description (optional)