PROSNOW – PROVISION OF A PREDICTION SYSTEM ALLOWING FOR MANAGEMENT AND OPTIMIZATION OF SNOW IN ALPINE SKI RESORTS

Samuel Morin[1], Ghislain Dubois[2], The PROSNOW Consortium[3]

[1]Univ. Grenoble Alpes, Université de Toulouse, Météo-France, CNRS, CNRM, CEN, Grenoble, France
[2]TEC Conseil, Marseille, France
[3]Composed of the following partners: Météo-France, TEC Conseil, WSL SLF Davos, University of Innsbruck, BOKU, Joanneum Research, EURAC, Irstea, Alpsolut, Dianeige, Technoalpin, SNOWSAT, CGX Aero in Sys

ABSTRACT: The level of activity, employment, turnover and profit of hundreds of ski resorts in the European Alps primarily depends on meteorological conditions, in particular natural snowfall but also increasingly conditions favorable for technical snowmaking (production of artificial snow). Ski resorts highly depend on appropriate conditions for technical snowmaking (mainly the availability of cold water, as well as sub-freezing temperature with sufficiently low humidity conditions). However, beyond the time scale of weather forecasts (a few days), managers of ski resorts have to rely on various and scattered sources of information, hampering their ability to cope with highly variable meteorological conditions. Improved anticipation capabilities at all time scales, spanning from "weather forecast" (up to 5 days typically) to "climate prediction" at the seasonal scale (up to several months), holds significant potential to increase the resilience of socio-economic stakeholders and support their real-time adaptation potential. This can benefit from the fact the predictability of snow conditions does not depend only on upcoming meteorological conditions but also on the current snow conditions, which govern the short- to mid-term range of snow depth and snow mass on ski slopes. The project PROSNOW, funded from 2017 to 2020 by the European Commission through the Horizon 2020 programme, is building a demonstrator of a meteorological and climate prediction and snow management system from one week to several months ahead, with a seamless approach specifically tailored to the needs of the ski industry. PROSNOW applies state-of-the-art knowledge relevant to the predictability of atmospheric and snow conditions, and investigates and documents the added value of such services. The project proposes an Alpine-wide system (including ski resorts located in France, Switzerland, Germany, Austria and Italy). It joins and links providers of weather forecasts and climate predictions at the seasonal scale, research institutions specializing in snowpack modelling, a relevant ensemble of 8 representative resorts in the Alps, technical bodies representing ski resorts managers, and a group of private technology companies providers proposing high tech services for snow management (on-tracks snow depth monitoring, snowmaking systems, prediction systems, …). This contribution provides a general introduction to the goals, concepts and preliminary results of the PROSNOW project, one year after its inception. It introduces, in particular, the combination of scientific methods used to address current and upcoming snow conditions, together with in-situ monitoring methods, and their application for real-time decision making at the scale of ski slopes in a given ski resort. PROSNOW outcomes are not meant to provide another software or tool for snow managers, but to be streamlined and integrated within existing or emerging snow management tools in ski resorts.

KEYWORDS: Snow management, ski resorts, meteorological forecast, seasonal forecast, climate services, remote sensing

1. CONCEPT

Weather forecast is currently applied to predict snow conditions and snow making potential several days in advance. The predictability of the future snow conditions beyond a few weeks mainly depends on the current snow conditions at the time of the forecast, because of the gradual build-up of the snowpack over the course of the season and the bounded rate of snow ablation processes such as snowmelt. A seamless snow prediction system allowing for improved ski resort management and optimization, covering time scales from one week to several months ahead, can be developed based on appropriate monitoring of current snow conditions, and the use of state-of-the-art climate predictions at the seasonal scale, which is the purpose of PROSNOW. PROSNOW therefore has the capacity to

* *Corresponding author address:*
Samuel Morin, CEN, Météo-France, 1441 rue de la piscine, 38400 St Martin d'Hères, France
(email: samuel.morin@meteo.fr)

develop better anticipation capabilities of ski resort and winter tourism managers. Various forecasting methods will be considered depending on the desired level of accuracy, prior climate knowledge about the considered ski resorts, and the ability to account for the current conditions at the time of the forecast. Seasonal forecasts supporting a sound decision-making tool can only be based on a probabilistic approach, based on ensemble predictions and an appropriate statistical post-processing. Appropriately visualized and communicated, such forecasts can help ski resort managers in anticipating important decisions: inhibition of snow production under conditions where the produced snow is at risk of melting or if it corresponds to anticipated overproduction, identification of the trade-off between water resources for snow making and concurrent uses and of periods with production halt, maintenance decisions to ensure reliable conditions on the slopes etc.

PROSNOW will cover seasonal forecast lead times not addressed by operational weather forecast information already widely used by mountain professionals. PROSNOW will provide information about the future meteorological conditions and snow conditions on ski slopes (accounting for snow management techniques such as grooming and snowmaking).

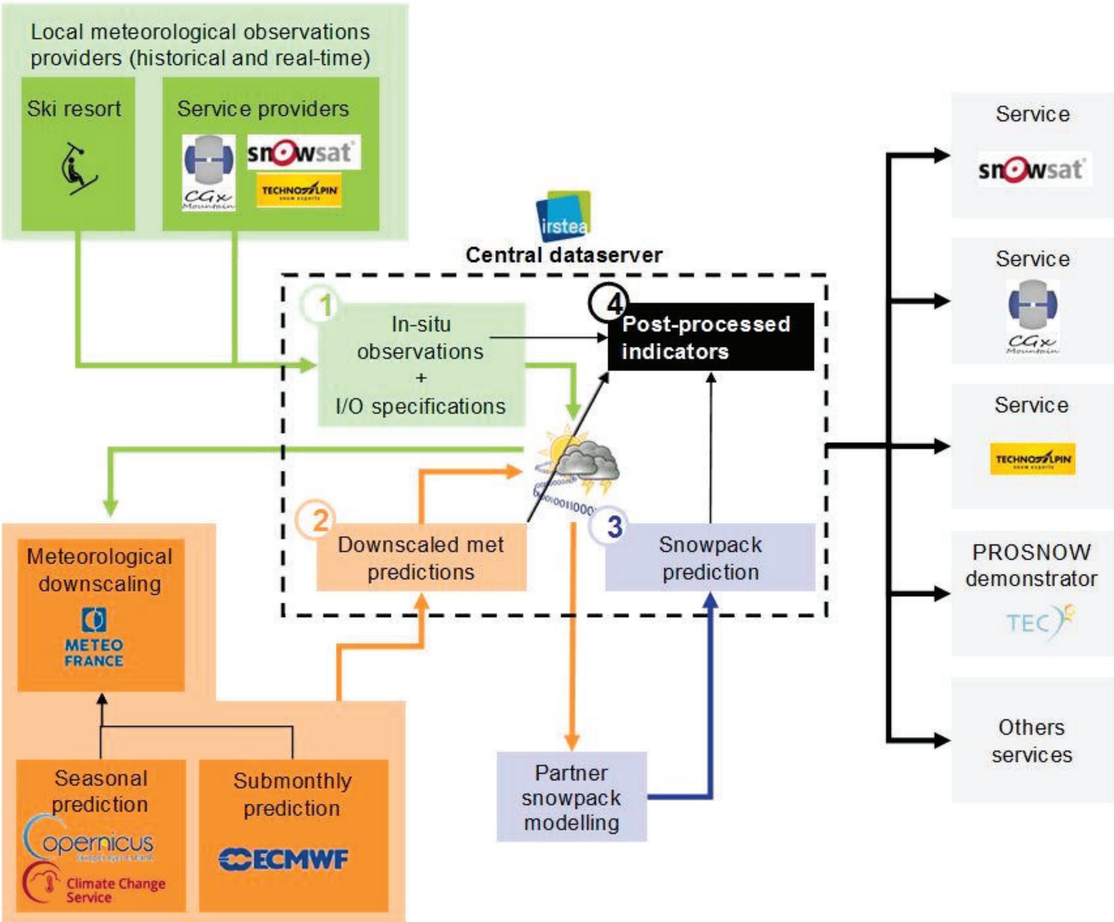

Figure 1: Technical dataflow envisioned for PROSNOW product generation

Beyond the overall scientific concept forming the basis of the PROSNOW products, the main technical concept overarching the generation of the PROSNOW products will consist of a series of interoperable services, through the specification and development of well-defined Application Programming Interfaces (APIs) and webservices making it possible to interface existing and upcoming data streams necessary to generate and distribute the PROSNOW products. The main elements of the data flow supporting the delivery of information is outlined in Figure 1.

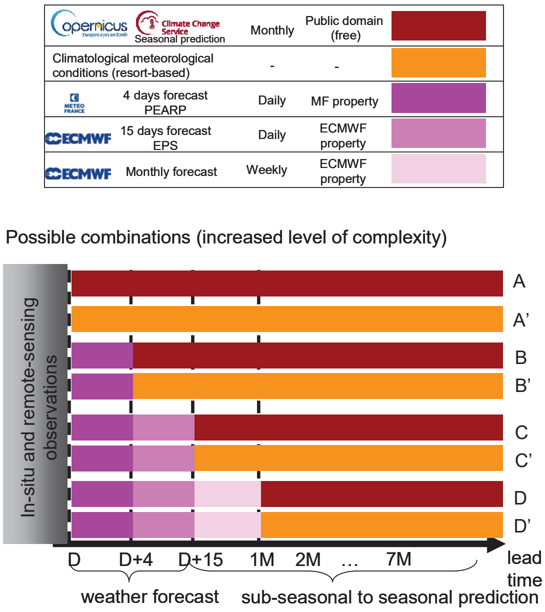

Figure 2: Possible combinations of forecast products for the seasonal prediction.

2. MONITORING AND FORECASTING METHODS

As shown on Figure 1, the PROSNOW product needs to combine various data sources using a series of state-of-the-art observation and modeling tools.

Seasonal prediction and downscaling: Multi-model evaluation of seasonal skill of Seasonal Forecasts (month 2 to 4), have shown that northern mid-latitudes (30°N-70°N) show a maximum predictability in winter (Shi et al., 2015, Batté and Doblas-Reyes, 2015), which is particularly favorable for the PROSNOW project. This is explained by the presence of warm/cold events in the tropical Pacific and of enhanced teleconnection patterns during this season. On average, the time correlation is 0.30-0.40 for averages in January-February-March, which does not permit a successful deterministic predictability of temperature and precipitation on a particular location, but offers probabilistic forecasts showing an added value with respect to the prediction based on climatological conditions only. Teleconnection indices like NAO (North Atlantic Oscillation) show time correlations of about 0.50. This allows expanding seasonal predictions beyond the limit of deterministic predictability of the atmosphere (10-15 days). Using meteorological observation data from the ski resort concerned, appropriate downscaling/correction methods will be employed (quantile mapping, statistical adaptation methods), in order to extract relevant information from large-scale atmospheric models to local scale mountainous regions. Such approaches have been implemented for various socio-economic applications (e.g. hydrology, Singla et al., 2012) but not specifically for mountain meteorological and snow conditions hitherto. It remains to be demonstrated whether this source of information will specifically add value to the forecast produced within PROSNOW. Carmagnola et al. (2018) are currently developing the background framework for this assessment. Seasonal prediction data provided by Météo-France after appropriate downscaling will cover a broad range of already available or upcoming state-of-the-art prediction systems operating over the European domain (including research-grade seasonal forecasts and the Copernicus Climate Change Service - Seasonal Prediction forecasts). Furthermore, the project will also use shorter-term forecast from either from national meteorological services and the ECMWF, in order to provide predictions covering all the time scales from a few days to a few months in a seamless manner, even accounting for the fact that Seasonal Predictions are refreshed on a monthly basis at most.

Snowpack modeling: Several physically based models have been developed during the last few decades, which represent processes at play in the natural snowpack (e.g. Crocus - Brun et al., 1992, SNOWPACK-Alpine3D - Lehning et al., 2006, AMUNDSEN - Strasser, 2008). Recently, Hanzer et al. (2014) and Spandre et al. (2016) have presented modeling approaches which also account for snow management practices. Such models are already operating in the respective mountain areas concerned by the PROSNOW project. PROSNOW aims to apply the above-mentioned snow cover models AMUNDSEN, Crocus and SNOWPACK-Alpine3D both for past and future snow conditions in forecast mode (Hanzer et al., 2018). The models will be driven by meteorological and climate predictions at different time scales and will be used to translate the expected meteorological and climate situations to snow cover conditions, their seasonal evolution and the related implications for snow management. The fact that several models are employed in the project guarantees a smooth implementation of the models in the mountain areas covered by the project, in terms of observation data availability and operating environment.

Remotely-sensed and in-situ observations: Remotely sensed data can provide twofold key information to the models. On one side, they can be used to correctly initialize the state variables of the models. On the other side, they can be used to cross-compare the results of the forecast and evaluate them (e.g. Notarnicola et al., 2013a, 2013b). In this case, remotely sensed snow maps will be considered as reference data. Remote sensing data can be provided on two scales: on a scale of 250m resolution a time series of 14 years snow cover based on MODIS data developed by EURAC will be used. On the scale of 10m – 20m the latest Copernicus Sentinel 1 and 2 data (radar and optical) with 5 to 10 days repetition time will be employed. Several types of in-situ observations will be used from ski resorts and used to further refine PROSNOW output. In-situ meteorological observations acquired in ski resorts, when available, will be used to characterize local climate and perform the statistical adaptation of large scale seasonal predictions. In-situ, long-term monitoring of snow conditions (in particular snow depth) will be used to assess snow model output performance. When available PROSNOW will harvest and use snow depth measurements increasingly carried out by grooming machines during their daily operations, allowing real time assessment of snow condition on ski slopes and allowing to take them into account to forecast their time evolution into the future. Real time snow production data will also be used to better initialize the forecast system.

Statistical post-processing: Seasonal prediction systems rely heavily on ensemble forecasting methods, because deterministic forecasts cannot be used beyond a few days. Even at short lead-times, probabilistic frameworks make it possible to incorporate several components including cost assessments and thresholds, to provide a decision-making framework accounting for the various elements to consider and acknowledging the uncertainty held by some of its key constituents, in particular the meteorological/climate prediction part. PROSNOW will thus build on cutting edge statistical approaches to develop the decision making framework, and will package their results in visualization toolboxes adapted to be used by non-experts and adjusted to fit their operational decision-making processes.

Once the data is produced and post-processed, it will be channelized through an information system allowing direct integration (through webservices) in the graphical user interface of the end-users. The stand-alone PROSNOW demonstrator (internet-based for desktops and mobile apps) will be built upon this architecture, along with the possibility for existing snow management software commercialized by solutions provides associated (TECHNOALPIN, SNOWSAT, CGX AERO) or not to the project PROSNOW to integrate this novel source of data into their own software. This focus on the development of standardized web services, associating from the design stage key players of the snow management industry, will foster the inclusion of PROSNOW information into existing resort management platforms and significantly enhance market uptake of the PROSNOW concept, rather than developing and independent, stand-alone tools which would add to already existing tools.

Figure 2 shows the possible combinations of forecast products considered in the project. Seamless combination of the existing body of information at all relevant time scales will provide unprecedented information in support of snow management decision making. Not only seasonal prediction systems, but also short-term forecasting systems will be considered.

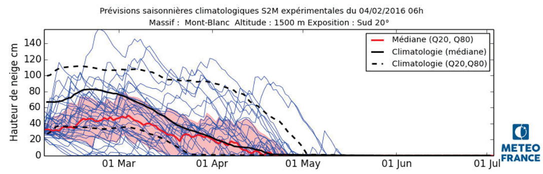

Figure 3: Example of a seasonal prediction corresponding to configuration B’ of Figure 2.

Figure 3 illustrates an example of a seasonal prediction of snow depth for a location in the Mont-Blanc area (1500 m altitude, 20° south-facing slope), simulated with the snowpack model Crocus and initialized on 4 February 2016. In this case, the first 4 days of the forecast of snow conditions are provided by an ensemble system of numerical weather predictions (Vernay et al., 2015), and the prediction is extended into the season using a climatology of meteorological conditions (Morin et al., 2013) (configuration B’ of Figure 2). The plot clearly shows how the 2015-2016 snow season natural snow deficit is likely to continue well into the months of February and March 2016. Predictions would be greatly improved moving towards C/C’ or D/D’ configurations (see Figure 2), considering in-situ or remotely-sensed observations to improve the initialization, and accounting for grooming and snowmaking in the generation of prediction of future snow conditions. This figure also highlights the fact that the predictability of snow conditions depends not only on future weather conditions, but also the starting state of the snowpack (because of its cumulative nature) and, in the future, the management options used (e.g. with/without snowmaking).

3. ASSESSMENT OF THE DEMAND AND CO-DESIGN

3.1 Co-design

The shared technical knowledge on ski and snow management across the Alps, the good level of engineering skills of snow management professionals (in ski resorts and in private companies supplying services and equipment), the presence of public and private resort operators, and long-term meteorological and climate expertise for mountain regions, originally developed in the field of avalanches forecast and hydrology, makes the ski industry a valuable case for co-design of a dedicated product. The sector has the capacity not only to demonstrate the value of climate services, but also to illustrate a beneficial co-design of services. Moreover ski resorts are under direct threat of the ongoing climate change and encounter significant pressure to adapt to changing environmental conditions, exemplified by the recent series of challenging early winter situations with poor natural snow conditions and too high temperature for snowmaking (in particular the beginning of the snow seasons 2014/2015, 2015/2016 and 2016/2017 throughout the entire Alpine regions).

The development of the PROSNOW products will be coordinated and primarily carried out by the scientific partners of PROSNOW. Two types of socio-economic stakeholders directly concerned by snow in ski resorts will be involved in the co-design of PROSNOW products, namely ski resorts themselves but also representative private companies operating in the field of snow management.

PROSNOW associates as formal partners a blend of world leading private companies operating in the field of snow management. They are in charge of developing and supplying ski resorts with snow management equipment (snowmaking units, grooming machines) and services (desktop or embedded management software, consulting for slope preparation etc.). From their commercial and advisory position they possess a unique overview of snow management practices in various ski resorts which will be a critical resource to develop PROSNOW products which will fit market expectations at the European scale and beyond. They will also contribute to the project through the exemplification on how PROSNOW products could be inserted into existing snow management platforms, thereby increasing the potential for market replication and the penetration of the PROSNOW products in the ski industry market.

PROSNOW associates 8 Alpine ski resorts in order to improve the content of the products and their capacity to match the demand, and to test the developed PROSNOW products under operational conditions. The choice of these partner resorts allows representing the diversity of geographical, climate and technical characteristics, infrastructure and snowmaking equipment, as well as governance setting and economic dynamics, which often depend on national framing conditions. The variety of cases will allow assessing the real interest for climate services for different types of constraints.

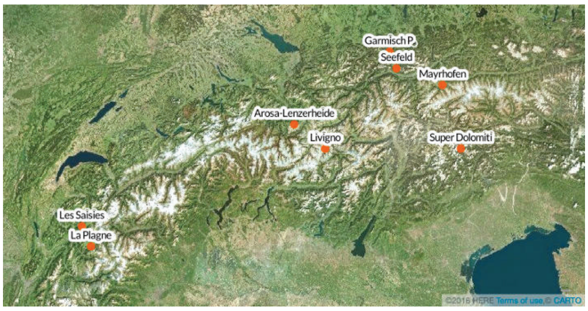

Figure 4: Location of the pilot ski resorts associated to the project.

3.2 Market analysis and exploitation

The ultimate goal of PROSNOW is to develop an operational service deployed in a potentially large number of ski resorts. Work is underway, primarily associating the pilot ski resorts but also other stakeholders involved in the ski tourism business, in order to assess as precisely as possible what is the extent of the market for a potential PROSNOW commercial service and what could be its business model.

4. NEXT STEPS

The PROSNOW project has started in September 2017 for a total duration of 3 years. At the time of writing this article, it is thus one year into the project lifetime. Most basic technical elements are currently being developed and refined (see Hanzer et al., 2018, Carmagnola et al., 2018), in order to develop the functional and technical specifications of the forecasting system, and in particular the way ski resorts are geographically represented, and the way tactical and strategic snow management options are accounted for. This is required on order to use the PROSNOW system in a decision making context. Simultaneously, work is currently underway to refine the post-processing and visualization options, making it possible to ski resort managers to make use of the future service. In parallel, work already addresses the various facets of the future exploitation of the PROSNOW service (intellectual property rights, enabling conditions for running the service, market analysis and business model). It is remarkable that, although still in a early stage, PROSNOW is generating a lot of attention from the ski tourism industry in Europe. This demonstrates critical expectations from this field, and is best illustrated by the fact that PROSNOW was awarded the Jury's Prize of the Digital Mountain Award during the 2018 edition of the bi-annual "Mountain Planet" fair in Grenoble, France, in April 2018.

5. ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730203.

REFERENCES

Batté, L. and F.J. Doblas-Reyes, Stochastic atmospheric perturbations in the EC-Earth3 global coupled model: impact of SPPT on seasonal forecast quality. Climate Dynamics, 45, 3419-3439, doi:10.1007/s00382-015-2548-7, 2015.

Bellaire, S. and B. Jamieson, Forecasting the formation of critical snow layers using a coupled snow cover and weather model, Cold Reg. Sci. Technol., 94, 37-44, 2013.

Carmagnola, C. M., S. Morin, M. Lafaysse, M. Vernay, H. François, N. Eckert, L. Batté, J.-M. Soubeyroux and C. Viel, Combination of climatological information and meteorological forecast for seamless prediction of alpine snow conditions, Proceedings ISSW Innsbruck 2018.

François, H., S. Morin, M. Lafaysse and E. George-Marcelpoil, Crossing numerical simulations of snow conditions with a spatially-resolved socio-economic database of ski resorts : a proof of concept in the French Alps, Cold Reg. Sci. Technol., 108, 98–112, doi : 10.1016/j.coldregions.2014.08.005, 2014.

Hanzer, F., Marke, T. and Strasser, U. Distributed, explicit modeling of technical snow production for a ski area in the Schladming region (Austrian Alps). Cold Reg. Sci. Technol., 108, 113-124, 2014.

Hanzer, F., M. Bavay, C. Carmagnola, P. Ebner, M. Lafaysse, M. Lehning, U. Strasser and S. Morin, Simulating snow conditions in ski resorts with the physically based snowpack models AMUNDSEN, Crocus and SNOWPACK/Alpine3D, Proceedings ISSW Innsbruck, 2018.

Lehning, M., Völksch, I., Gustafsson, D., Nguyen, T.A., Stähli, M., and Zappa, M., ALPINE3D: a detailed model of mountain surface processes and its application to snow hydrology. Hydrological Processes, 20, 2111-2128, 2006.

Morin, S., M. Lafaysse, C. Coléou and Y. Lejeune, Will there (still) be snow for the upcoming winter holidays ? On the conditional predictability of snow conditions several weeks to months in advance, Proceedings of the International Snow Science Workshop Grenoble - Chamonix Mont-Blanc - 2013, 7-11 October, Grenoble, France, 1171-1176, 2013.

Notarnicola, C., Duguay, M.; Moelg, N.; Schellenberger, T.; Tetzlaff, A.; Monsorno, R.; Costa, A.; Steurer, C.; Zebisch, M. Snow Cover Maps from MODIS Images at 250 m Resolution, Part 1: Algorithm Description. Remote Sens., 5, 110-126, 2013.

Notarnicola, C., Duguay, M.; Moelg, N.; Schellenberger, T.; Tetzlaff, A.; Monsorno, R.; Costa, A.; Steurer, C.; Zebisch, M. Snow Cover Maps from MODIS Images at 250 m Resolution, Part 2: Validation. Remote Sens., 5, 1568-1587, 2013.

Shi, W., N. Schaller, D. MacLeod, T.N. Palmer, A. Weisheimer. Impact of hindcast length on estimates of seasonal climate predictability. Geophys. Res. Lett., doi: 10.1002/2014GL062829, 2015.

Singla, S., Céron, J.-P., Martin, E., Regimbeau, F., Déqué, M., Habets, F., and Vidal, J.-P.: Predictability of soil moisture and river flows over France for the spring season, Hydrol. Earth Syst. Sci., 16, 201-216, doi:10.5194/hess-16-201-2012, 2012.

Spandre, P., S. Morin, M. Lafaysse, Y. Lejeune, H. François and E. George-Marcelpoil, Integration of snow management processes into a detailed snowpack model, Cold Reg. Sci. Technol., 125, 48-64, doi :10.1016/j.coldregions.2016.01.002, 2016.

Strasser, U. Modelling of the mountain snow cover in the Berchtesgaden National Park. Technical Report No 55. Berchtesgaden National Park, 2008.

Vernay, M., M. Lafaysse, L. Mérindol, G. Giraud and S. Morin, Ensemble forecasting of snowpack conditions and avalanche hazard, Cold Reg. Sci. Technol., 120, 251-262, doi :10.1016/j.coldregions.2015.04.010, 2015.