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LIFE+ PROJECT NAME or Acronym

SNOWCARBO

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List of abbreviations

FMI	Finnish Meteorological Institute
MPI-M	Max Planck Institute on Meteorology, Hamburg
JSBACH	Jena Scheme for Biosphere-Atmosphere (model describing biosphere-atmosphere interaction)
ECHAM5	European Centre Hamburg Model (global circulation model, atmosphere)
REMO	Regional climate model

1 Summary

In Snowcarbo the climate models together with their land surface schemes (LSS) are used for estimating present day CO2 balance of Northern areas. The goal of the project is to improve the model predictions facilitating a variety of Earth Observation (EO) and in situ data in constraining and calibrating the models. The core region for which the most extensive set of model simulations and evaluations of model performance will be carried out covers Scandinavia and Baltic countries. However, as the available EO data covers northern Eurasia in whole, the ultimate aim of the project is to provide insight into the quality of the CO2 balance predictions of the Northern Hemisphere. The climate models of Max Planck Institute on meteorology (MPI-M, Hamburg) are used for climate and CO2 exchange simulations in this project. The present version of general circulation model of MPI-M is ECHAM5 whose LSS is called JSBACH. In fact the most up to date version of ECHAM, with JSBACH as fully integrated module, carries a version name ECHAM6. A REgional climate MOdel (REMO) of MPI-M in its present form lacks a LSS capable of simulating CO2 cycle. Thus JSBACH will be used for predicting the terrestrial CO2 exchange with the regional model as well. In this documentation the models and their coupling schemes will be presented. Further, the sequence of evaluation runs together with facilitation of the EO data and the intended approach for the evaluation of the results will be introduced. In this first modeling report the intended simulations are presented for the finest domain that the climate modeling will be applied in the framework of this project. Thus the focus is in REMO and JSBACH models.

2 Models

The COSMOS model family climate models developed at MPI-M are used to simulate past present and future climates over wide range of spatial resolution. Their applications include weather forecasting, analyzing the climate system and projecting climate change. Physical core of these models is Navier-Stokes equation on a rotating sphere with consideration of the relevant energy sources, such as radiation or latent heat, by means of inclusion of appropriate thermodynamic terms. These equations are derived for suitable temporal and spatial resolution using initial and boundary conditions representative for the actual research problem. Atmosphere model ECHAM5 (Roeckner et al. 2003), a regional model REMO (Majewski,1991; Jacob 2001), and a biosphere model JSBACH (Raddatz et al. 2007) - that is the LSS of ECHAM5 - are used in this work.

2.1 ECHAM5

The ECHAM Global Circulation Model (GCM) has its origin in global forecast models developed at European Centre for Medium-Range Weather Forecasts (ECMWF). This model has been modified for climate research, and its development continued to the current cycle ECHAM5. ECHAM is a comprehensive general circulation model of the atmosphere in version that includes land ecosystems. For present day simulations it is typically driven with sea surface temperature (SST) and does not consequently predict actual weather conditions but rather the prevailing climate.

ECHAM requires as input atmospheric concentration of certain greenhouse gases and areal

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fields of orography and land cover type that further determines the surface parameters such as surface albedo, leaf area index and vegetation ratio.

2.2 REMO

REMO is a Regional Climate Model (RCM) that derives from the operational weather forecast model of the Deutscher Wetter Diendst (DWD), thus it has been thoroughly evaluated for its capability to predict the synoptic scale meteorological phenomena. The present version of the model is REMO2008. It can be driven in climate mode and in forecast mode which differ in their boundary data requirements and to some degree in their ability to reproduce actual weather conditions. As the model does not presently consider ecosystem processes implicitly, the LSS JSBACH is used to simulate CO2 exchange in the present work.

Surface characteristics which are constant in time are orography, surface roughness length, land-sea mask and field capacity. Monthly varying parameters are surface background albedo, vegetation fraction and leaf area index (LAI). From version 5.1 on REMO uses a fractional surface coverage i.e. each grid box can contain a land, a water and a sea ice fraction. The large scale forcing fields are prognostic atmospheric variables and prognostic surface variables such as surface temperature, soil temperatures, soil wetness and snow depth

In standard model versions the vegetation cover data is from a global 1km resolution land cover dataset by Hagemann et al. (2002, 1999) according to Olson (1994a, 1994b) dataset constructed by the U.S. Geological Survey (1997, 2002). This is essentially the same data that ECHAM uses for its surface maps. The land cover class data is unambiguously related to following parameters: background surface albedo, fractional vegetation cover, leaf area index (LAI), forest ratio, roughness length, and water holding capacity.

2.3 LSS JSBACH

The role of the LSS is to 1) provide the lower boundary condition to the atmosphere for the vertical diffusion scheme (turbulent exchange of heat, moisture, momentum and passive tracers); 2) radiation scheme (short-wave, long-wave radiation fluxes) and 3) hydrological cycle (moisture flux) such that the surface energy and water balance are closed. The model treats the water cycle of vegetated areas by considering the physiological response of vegetation cover to the climatic variables. This requires taking into account the resistance for water vapor exchange due to functioning of water pathways within the plants. The most crucial control of water vapor exchange between the vegetation and the atmosphere – stomatal functioning – constrains the CO2 exchange as well. Thus a LSS, such as JSBACH, that simulates water and energy balances with a high degree of sophistication, is readily able to produce reliable CO2 exchange by vegetation. Additionally, in order to produce a reliable NEE the allocation of carbon into various pools in soil and vegetation and the decomposition of these storages are described.

Vegetation has been divided into 14 classes of plant function types (PFT) who each has its own set of parameters. These parameters include among others PTF specific biochemical parameters, such as maximum carboxylation and electron transport rates and physical parameters such as albedo's in visible and near infrared bands. JSBACH facilitates so called tile approach where four most prominent land cover types are considered in each grid cell. This is necessary in global scale as the grid cells are large and various PFTs play a role through highly nonlinear processes that cannot be fully represented by parameter aggregation.

3 Boundary and initial data

3.1 Land cover data

Both ECHAM5 and REMO use land surface parameter (LSP) dataset (Hagemann et.al., 1999, Hagemann 2002) based on Olson ecosystem classification (Olson 1994a; 1994b) as land cover and use map. Its spatial resolution is about 1 km and it consists of more than 80 classes to whom a set of surface parameters is related. These parameters are background surface albedo α_s, surface roughness length due to vegetation $z_{0,veg}$, fractional vegetation cover c_v and leaf area index LAI for the growing (g) and dormancy season (d), forest ratio c_f, plant-available soil water holding capacity W_{ava}, and volumetric wilting point f_{pwp}. Vegetation model JSBACH has its own set of classes and parameters.

The parameters allocated to each land cover class are further aggregated into surface boundary maps. The method of areal synthesis depends on the nature of the respective parameter. For instance a simple areal weighing cannot be applied to parameters that function through unlinear processes, such as aerodynamic roughness length that controls surface wind shear (see Hagemann et.al., 1999).

Aggregation of certain parameters is revised in Hagemann (2002). In the Nordic areas the standard aggregation of two parameters is modified to account for region specific vegetation and soil features. These two parameters are soil field capacity and fractional vegetation which is related to forest ratio. Soil field capacity is typically high in wide areas of forested wet lands in Finnish and Swedish Lapland, where the land cover is boreal coniferous forest whose allocated soil field capacity is 0.21 that is too low for the soils. Thus the value is overwritten with a constant value of 0.71 according to the distribution of class 15 of the FAO/Unesco soil type dataset (Hagemann 2002).

3.2 Coupling between a LSS and a climate model

Vertical diffusion is the process in accounting for the matter and energy exchange between the atmosphere and the surface. The interaction between the climate model and a LSS can be either implicit or explicit. In an implicit coupling present values of climatic variables that control the surface processes are used and the LSS is called in the vertical diffusion scheme. An explicit coupling approach uses the old values of the controlling climatic variables and the LSS can be called anywhere in the GCM. Because vertical transfer coefficients are calculated in the LSS the surface energy balance stability is improved. The coupling between ECHAM5 and JSBACH is implicit.

In REMO the standard LSS is implicit as well but as it does not account for biophysical processes such as photosynthesis or degradation of carbon in the soils. Thus in order to estimate CO2 balance a standalone version of JSBACH is forced with climate variables produced by REMO. This is called an offline run where neither implicit nor explicit coupling between JSBACH and REMO takes place. Consequently, to evaluate the consistency between the models, it is necessary to estimate the differences in prediction of variables related to surface processes by both models. These variables include for instance sensible heat flux and components of water balance such as surface evaporation and snow depth.

3.3 Initial and boundary data use

Climate models and LSSs have to be provided with various gridded data that serve as initial and boundary field for model runs. Especially a regional model requires an extensive set driving data as it has to be frequently constrained from the domain boundaries. Boundary and initial data for climate models consist of 2d surface fields and 3d meteorological fields. Additionally, when REMO2008 is driven in a mode capable of carrying tracers within the domain the model has to be constrained with the initial and boundary fields of the tracer – in this study CO2. The sources of 2d and 3d meteorological and tracer flux and concentration data are given in the "*In situ* data document" (31/12/2009) of Snowcarbo project. In order to predict atmospheric radiative forcing due to absorbers, yearly series of green house gas (GHG) background concentrations are given to the climate model.

4 RCM specific features

4.1 Running modes

REMO can be run in climate and forecast modes. In the climate mode the model is constrained once in ignition of the simulation with initial 3d meteorological and tracer fields and after that it is only forced from domain boundaries while the climate and tracer concentrations within the domain are estimated by the model. In the forecast mode the model is continuously forced with the boundary data with typically daily ignition and a spin up of couple of hours. Because the spin up period is rejected, the daily runs overlap for a duration of the spin up. A run in forecast mode follows closer to the boundary data than a run in climate mode. Thus, as Snowcarbo aims at simulating actual climate, the forecast mode is used for production runs. However, for evaluation of model performance, a climate run is performed as well.

4.2 Restart

The forecast mode is in practice realized through a series of so called restarts. In a restart every variable is initialized with the observed or measured data and no history from the previous time-step is preserved. Consequently, this approach provides us with an easy way to force the climate model with gridded data from other work packages of this project.

4.3 Nesting

Because the gridded boundary and initial data fields for a RCMs have to be typically interpolated from observations or global model simulations, its quality is dependent on difference in resolutions between the regional and the global domain. In order to avoid effects due to distorted boundary data, the RCM runs are often performed in two steps: first the period of interest is simulated for a larger regional domain of intermediate resolution with a subsequent run in the smaller fine resolution domain of interest.

5 Preprocessing of surface and climate data

All the data that REMO and JSBACH use have to be preprocessed from various data sources and data forms into the form applicable by the models. The project personnel possess the preprocessors for creating the REMO surface boundary maps (Fig 1) while the REMO climate data has been produced in MPI. Due to the tile approach applied in JSBACH the preprocessing differs from that of REMO's. However, as many of the parameters of the two models are equal their consistency has to be taken care of.

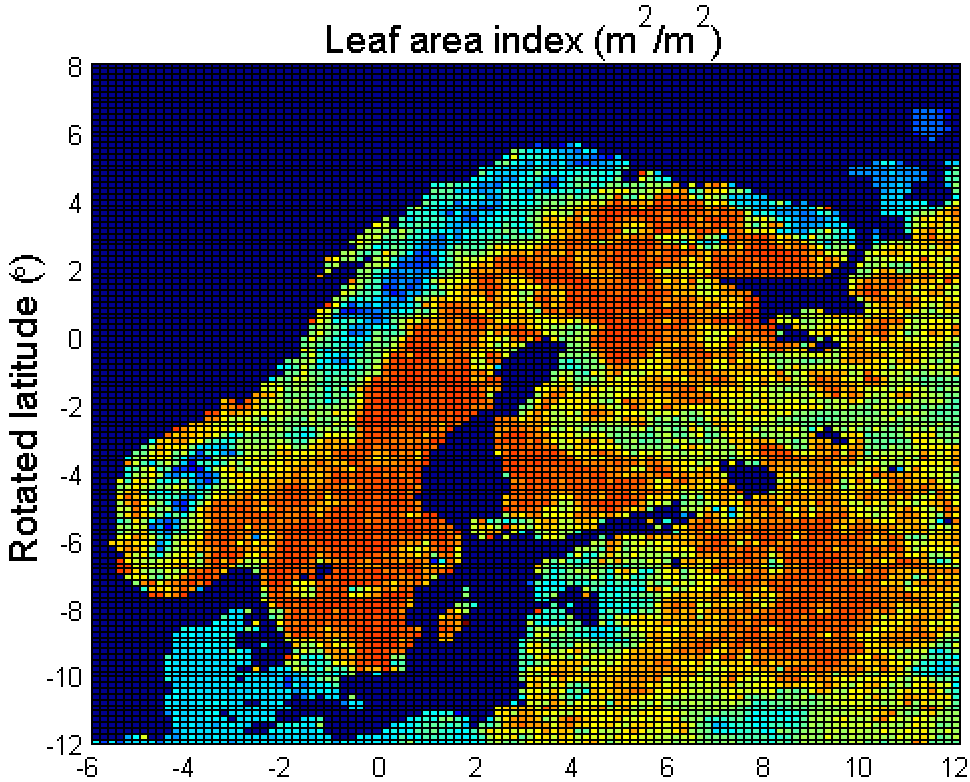

Figure 1. A leaf area index (LAI) map based on the standard land cover data (Olson 1992)

Pre-existing JSBACH surface boundary fields are for global context and a pre-processor for creating the corresponding fields for the regional domain will be developed in the framework of this project.

6 Model implementation

REMO is written mostly in FORTRAN 77, and JSBACH model is mostly coded in Fortran 90. Both models are being actively developed at Max Planck Institute Hamburg. They extensively utilize the Message Passing Interface parallel programming infrastructure, and are hence able to utilize the power of modern parallelized supercomputers well.

The REMO and JSBACH models are run on Finland's fastest supercomputer, the Cray-XT5m at the Finnish Meteorological Institute. Running the REMO climate model requires lots of computing resources – both in terms of CPU power and disk space. Due to scalability limitations of the code and the limited grid size, the model is run with (only) 120 processor elements. Running one year's simulations and postprocessing the results takes approximately two days, producing over 500 gigabytes of data. The data comes out initially in "IEG" file format ("Max Planck Institute internal file format"), and it is then automatically post-processed to the more widely used NetCDF file format. After this, the JSBACH model reads these NetCDF files as input.

The standalone JSBACH model is quite lightweight as there is no interaction between the grid points, and running it requires no significant computing resources. The data for one year can be generated in less than one hour, and the JSBACH model produces the data directly in NetCDF format. Not all of REMO's output data is needed for input to JSBACH, and the amount of data that JSBACH standalone outputs is significantly more manageable than that which comes out of REMO.

7 Model evaluation

While the principle product of the modeling framework is the estimated CO2 balance, a few other predicted variables can be assessed against the wide observation data set available for the project. Assessment of the variables that can be considered as by-products, from the CO2 balance point of view, is important in order to find out the strengths and weaknesses of the overall modeling framework.
The predicted variables that will be evaluated include the central climatic variables such as temperature and precipitation together with closely related snow cover. In general the variables related to the surface energy balance reveal fundamental features of model performance. In addition to comparison with the observation data, the differences in the predictions of both models have to be explored. In evaluation the areas of good and bad performance are first visually recognized and differences in driving variables are further explored. In order to evaluate the influence of improved land cover data sets both REMO and JSBACH predictions with different surface data will be compared. All in all, the model evaluation consists of model intra-comparison, model inter-comparison and comparison to the observations. In the following the intended evaluations of some central variables are discussed with outline of the methods.
Because at northern areas snow-cover plays a crucial role in controlling the CO2 exchange rates due to its effects on air and soil temperatures and on the soil water content, the snow cover extent and snow depth predicted by both models will be compared to the observations (see WP2). In models the snow depth is given in terms of water content and thus conversion factors have to be used to translate that into relevant units. In offline (or one-way) coupling of REMO and JSBACH, both models predict snow-cover independently. Thus, an inter-comparison of their predictions has to be carried out.
Regionally the performance of the vegetation model can be evaluated against phenological data, such as NDVI from satellites WP3 or in situ data set for phenology WP5. In the case of for instance bud burst or NDVI there is no identical variable predicted by the model but variables closely related, such as LAI (leaf area index) or GPP (gross primary production)

will be used instead. Some variables, such as soil moisture, are both among the in situ phenological data and predicted by the model. In such a case, however, it is crucial to make sure that the definitions of the two variables do match. Often, in order to avoid offsets due to specifications, the phase of the data series rather than the absolute magnitudes of the variables should be observed.
Finally the direct evaluation of the CO2 exchange measures – fluxes and concentrations – will be carried out against *in situ* data (WP4). In this case there is one to one correspondence between the definitions of the measured variables and their modeled counterparts. However, there are certain conditions which have to be fulfilled (WP8). Especially flux signal is of so local nature that its representativeness for the model results has to be carefully considered and the most suitable grid cell for comparison has to be selected before evaluation of model performance against flux data. Concentration data represents a large area horizontally but the most representative vertical model level has to be determined. In both cases the complications due to special meteorological situations have to be carefully considered.
In addition to the CO2 flux data, from the eddy covariance (EC) sites there is local data available on the counterparts of surface energy balance who can be separately evaluated against the model. Furthermore the other flux variables can be utilized in finding the grid cell of best representativeness.

8 Planned run settings

In order for the final production run to produce the most reliable estimates of CO2 balance, the sequence of the run has to be designed with care. This will include evaluation of the models against various data, estimation of the errors, recognition of the reasons for faulty predictions and finding the ways to diminish the problems. In the following the intended runs are listed with a brief explanation on the purpose of the run and a preliminary idea about the evaluation of the attained results.

REMO model is run for the pre-existing climate data series, i.e. for years 2001-2007, in climate and forecast modes. The results by both modes are checked for any distortion due to relatively dense model grid and the need of double nesting is estimated accordingly. Even though the forecast mode with daily ignitions from the observed data is presumably the climate modeling approach to be applied in this project, the comparison with climate mode runs is expected to provide insight in strengths and weaknesses of both approaches.

REMO model is run with three different land use data – the original Olson data set, GlobCover and Corine (CLC)+GlobCover land cover classifications from WP11. The differences in energy balance partitioning due to different surface parameter maps will be assessed. Unfortunately a decisive selection of the most suitable land cover data is handicapped due to the local nature of the energy balance data from the flux sites. Thus, further modeling steps will be carried for both newly implemented land cover classifications.
Furthermore, the distribution of wet lands will be revised and higher field capacities will be allocated according to new maps. Also the allocation of forest ratio and vegetation ratio will be restored because according to the refined maps the increased values are too high. Additionally, the importance of the applied land use will be estimated by repeating the calculations for a purely artificial land cover map consisting solely of a class Boreal coniferous forest.

JSBACH runs subsequent to the REMO simulations will be carried out with the standard version of the stand alone JSBACH who requires the input in daily time step. For this aim the forcing data is extracted from hourly weather data series. Depending on the state of developing a JSBACH standalone version running on instantaneous time steps, the simulations are optionally carried out with hourly mean weather data forcing. Another important preparation for this aim is creation of suitable land cover maps that are consistent with the respective data set from REMO runs. Point-wise evaluation of the produced 2D maps of CO2 fluxes will be carried out against the data from several flux sites located in the domain.

At the stage when a fully coupled REMO-JSBACH model exists and is available for the Snowcarbo project all the runs will be repeated and the benefits gained with the two-way coupling scheme over the one-way coupled set up will be estimated in terms of the degree of energy balance closure. Moreover the basic comparison between modeled and measured fluxes will be carried out.

Design of the runs utilizing observed snow cover characteristics will be started when the results obtained from comparisons between measurements and modeled values exist. A preliminary plan is to substitute the snow water equivalent of the initial and boundary data with the respective EO data. Subsequently the impact of the change to the flux estimates will be assessed.

The final step of each complete model sequence is the second REMO run in a mode that transport the CO2 tracers producing concentration field due to surface sources within the domain. The results of this modeling step are consequently compared with CO2 concentration data obtained from Pallas GAW station (see *In situ* data document 31/12/2009). Even though this variable is expected to be the most uncertain the phase of the yearly cycle will provide a reference for timing of ecosystem functioning.

9 First results

REMO run with the standard land cover data was carried out and the preliminary snow cover data series is currently being used in developing the methodology to compare that against the observations. Comparison will be carried out against the areal maps (Fig 2.) as well as against local data series (Fig 3.).

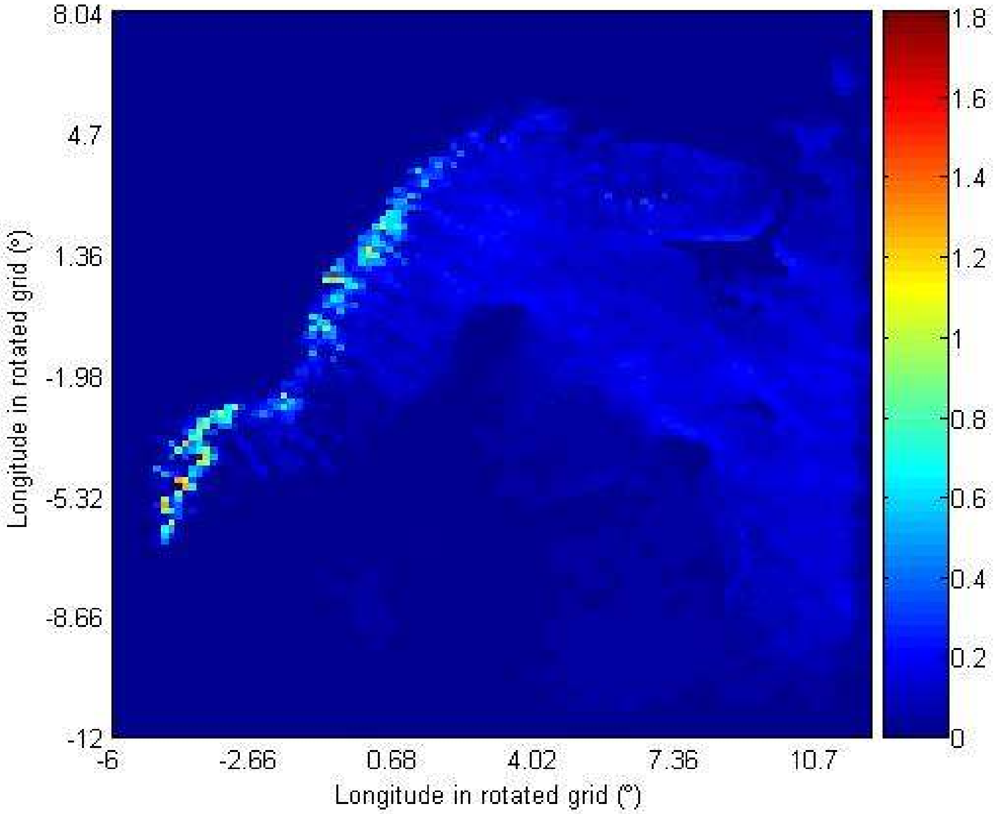

Figure 2. Snow depth in terms of water equivalent (m) within the domain on March 1st 2005.

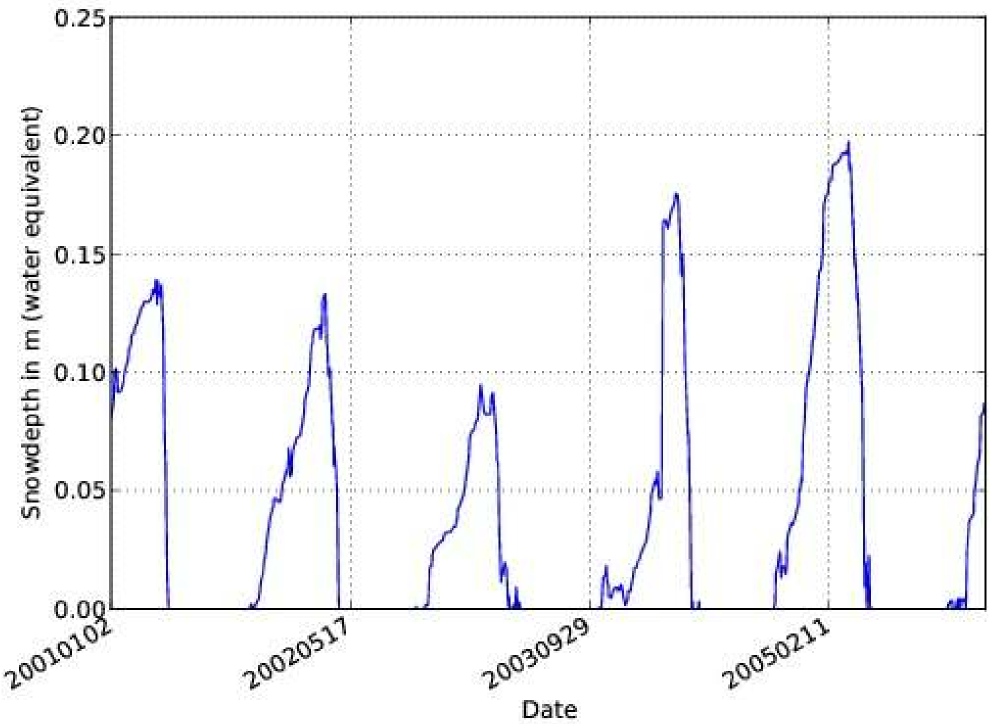

Figure 3. Time series of snow depth in terms of water equivalent at the Finish GAW station, Sammaltunturi, covering years from 2001 until end of 2005.

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