SnowMIP, an intercomparison of snow models: first results.

P. Etchevers♦[1], E. Martin[1], R. Brown[2], C. Fierz[3] ,Y. Lejeune[1]

E. Bazile[4], A. Boone[4], Y.-J. Dai[5], R. Essery[6], A. Fernandez[7] , Y. Gusev[8], R. Jordan[9], V. Koren[10] , E. Kowalczyk[11], R. D. Pyles[12], A. Schlosser[13], A. B.Shmakin[14], T. G. Smirnova[15], U. Strasser[16], D. Verseghy[2], T. Yamazaki[17], Z.-L. Yang[18]

[1]*Centre d'Etudes de la Neige, CNRM Météo-France, Grenoble, France*
[2]*Canadian Meteorological Service, Dorval, Qc, Canada*
[3]*Swiss Federal Institute for Snow and Avalanche Research (SLF), Flüelastrasse 11, CH-7260 Davos Dorf, Switzerland*

[4]*Météo-France, Toulouse, France,* [5]*Institute of Atmospheric Physics; Chinese Academy of Sciences, Beijing, China,* [6]*Hadley Centre, Met. Office, Bracknell, Berks. U.K.,* [7]*Instituto Nacional de Meteorologia, Madrid, Spain,* [8]*Laboratory of Soil Water Physics, Institute of Water Problems, Russian Academy of Sciences, Moscow, Russia,* [9]*CRREL, Cold Regions Research and Engineering Laboratory,Hanover, U.S.A.,* [10]*NOAA/NWS/OH1/HRL, Silver Spring, MD 20910 U.S.A.,* [11]*CSIRO Atmospheric Research, Aspendale, Australia,* [12]*Cooperative Institute for Research in the Environmental Sciences, Boulder, U.S.A.,* [13]*COLA/IGES, Calverton, U.S.A.,* [14]*Laboratory of Climatology, Institute of Geography, Russian Academy of Sciences, Moscow, Russia,* [15]*Forecast Systems Laboratory, Boulder, USA,* [16]*Institute of Hydromechanics and Water Resources Management; ETH-Hönggerberg, Zürich, Switzerland,* [17]*Frontier Observational Research System for Global Change, Tohoku University, Sendai, Japan,* [18]*Dept of Hydrology and Water Resources, The University of Arizona, Tucson, U.S.A.*

Abstract: Many snow models are now used for various applications such as hydrology, global circulation models, snow monitoring, snow physics research and avalanche forecasting. The degree of complexity of these models is highly variable, from simple index methods to multi-layer models simulating the snow cover stratigraphy and texture. The main objective of the intercomparison project SnowMIP (Snow Model Intercomparison Project) is to identify key processes for each application. Four sites have been selected for the representativeness of their snowpack and the quality of the collected data. 26 models have participated in intercomparison by simulating the snowpack with the observed meteorological parameters. The validation of the simulation consists in comparing the results with snow pack observations. In a first step, the analysis focuses on the snow water simulation (compared with weekly snow pits). In particular, the snow water equivalent (SWE) maximum and the snow cover duration are two interesting features to consider, because they allow the estimation of the models abilities in terms of simulating the accumulation and melting periods.

Keywords: snow simulation, model intercomparison, SNOWMIP.

1. Introduction

In the last thirty years, many snow models have been developed and have been used for various applications such as hydrology, global circulation models, snow monitoring, snow physics and avalanche forecasting as well. The degree of complexity of these models is highly variable, from simple index methods to multi-layer models simulating the snow cover stratigraphy and texture. The complexity is determined by multiple

♦ *Corresponding author address*: Pierre Etchevers, Météo-France/CEN, 1441, rue de la Piscine, F-38400 Saint Martin d'Hères, France. E-mail : pierre.etchevers@meteo.fr

constraints: the numeric power of the computer, the availability of complete datasets, the simulated physical processes and the model application. Up to now, snow-cover models have only been subjected to a few comparisons as stand-alone models (e. g. Jin et al., 1999, Essery et al., 1999, Schlosser et al., 2000, Boone and Etchevers, 2001). These comparisons generally concern some models of various complexity which are tested for 1 or 2 sites. These studies established that processes internal to the snow cover are important for improved performance and understanding in most of the cited applications. It also appears that the model performance is very dependent on its final application. In some cases, a very simple model is more relevant than a sophisticated one (for instance, when the input data sets are poor).
Following these studies, it appears that a more general comparison of snow models is needed. Indeed, until now comparisons were limited to a few models and sites. Very few works concern the comparison of models of similar complexity and the results for various sites.
Hence, the main objectives of the intercomparison project SnowMIP (for Snow Model Intercomparison Project) are:

- to define a common method to compare a large variety of models,
- to estimate the impact of the different physical parametrisations,
- to identify the key processes for each application.

It is anticipated that the comparison of detailed and simple models will be of great interest for the design of future GCM snow parametrizations and simple snow melt models.

Four sites have been selected and data from these sites have been assembled (section 2). Using the meteorological data, a large number of snow models have been invited to simulate the snowpack for these sites (section 3). Then, the results have been analysed and compared to validation data. A first anaysis is presented , concerning the snow water equivalent (SWE), and the snow cover duration (section 4).

2. The data sets

2.1 The sites

As shown in table 1, four different sites have been chosen for the comparison following two criteria: the site representativeness of a typical seasonal snowpack and the availability of complete data sets for the input data (meteorological parameters) and the validation data (snow pack measurements).

Name	Reference	Lat/lon	Elev. (m)	Season number
Col de Porte (France)	CDP	45.30°N 5.77°E	1340	2
Goose Bay (Canada)	GSB	53.32°N 60.42°W	46	15
Sleepers River (USA)	SLR	44.5°N 72.17°W	552	1
Weissfluhjoch (Switzerland)	WFJ	46.83°N 9.81°E	2540	1

Table 1 *: The four sites used for the snow modes intercomparison.*

The Col de Porte, located in the French Alps, is a middle elevation site. The air temperature is not very cold, even in mid-winter (the monthly average is close to 0°C) and the precipitation amount is high (about 150 kg m^{-2} per month). Rainfall and snow melting can occur during the entire winter and the maximum extent of the snowpack is generally measured in the first days of March. The typical duration of the snow cover is 6 months. Goose Bay is located close to the Labrador river, in eastern Canada. The elevation is very close to the sea level, the air temperature is very low in winter (-16.4°C in January), and the site is very windy and humid (perhumid high boreal climate). The snow cover duration is comparable to Col de Porte : the snowpack reaches a maximum of 1.2 m at the beginning of March. Sleepers River is a mid-mountain site located in the in the north-western part of the Appalachian mountains (Vermont, USA). The monthly averaged temperature is low (<-5°C) during winter and the maximum snow depth is about 1 m. Endly, Weissfluhjoch is the most mountainous site, since it lies at an altitude of 2500 m in the Swiss Alps. Air temperature is comparable to Sleepers River (low during all the winter), but the snow falls are more significant (maximum snow depth generally higher than 2 m). The 4 sites represent quite different climatic and snow characteristics, which allow the testing of the snow models in different configurations : for example, the contrast is high between Weissfluhjoch, where the large snowpack stays cool and dry during the whole winter, and Col de Porte, where the medium snowpack can melt between two snow falls and is often partly or completely wet.

2.2 The input data

The data used as input are standard meteorological parameters collected every hour: incoming short wave and long wave radiation, air temperature and humidity, wind speed and precipitation (amount and phase). The precipitation phase (solid or liquid) is not measured and each data provider has determined it by using other measurements like air temperature, snow depth sensors or different rain gauge types. For SLR and WFJ, only the air temperature was available for calculating the precipitation phase.

2.3 The validation data

Data used for the validation have been collected from the sites by the center or the laboratory managing the sites. The data consist of the surface characteristics, the internal state and the flux exchanges which govern the snowpack (table 2). The snow depth, snow water equivalent and snow bottom runoff allow an estimation of the mass balance of the snow pack. The surface albedo and snow temperature are useful for determining the accuracy of the energy budget simulation. The snow pits are specific measurements of the internal state of the snowpack and they are done following a standard international procedure. They are useful for a precise analysis of the snowpack stratigraphy (vertical profiles of temperature, liquid water content, density, grains,...).

	Frequency	CDP	GSB	SLR	WFJ
Snow water equivalent	W	x	x	x	x
Snow depth	H (except GSB: D)	x	x	x	x
Snow bottom run-off	H	x		x	x
Surface albedo	H	x			x
Surface temperature	H	x			x
SWE	W	x	x	x	x
Snow pits	W	x			x

Table 2 *: The validation data available for the four sites. The frequency is hourly (H) for automatic measurements and daily (D) or weekly (W) for manual measurements.*

3. The experiments

The simulations are "stand-alone" simulation, meaning that the meteorological parameters are prescribed every hour and the models calculate the snowpack evolution. The validation data have not been diffused and no calibration was possible.

Four experiments have been proposed in order to test the sensitivity of the models. The reference experiment (REF) consists in the standard simulation of the snowpack. In the albedo (ALB) experiment, the models use a prescribed constant albedo equal to 0.7. This experiment focuses on the albedo role, which is critical during the melting period. Albedo is a complex property of the snowpack depending on the micro-properties of snow, which are generally not calculated by the snow models. It is generally estimated by empirical formulae linking the snow albedo with the snow age, the grain type, melting and/or density. The ALB experiment should permit a better understanding of the albedo role and bring into light the possible feedbacks in the models. The long wave radiation (LWR) experiment deals with the impact of the measurement uncertainties on the simulation quality. As the surface energy budget is very sensitive to the incoming long wave radiation, an arbitrary error of 20 W m^{-2} is added to the prescribed incoming flux (corresponding to the order of the measurement error magnitude of the LW radiation). The third sensitivity experiment concerns the new snow density (NSD). This parameter may have an important role, as it affects the surface energy budget (through the fresh snow thermal conductivity). As it is never automatically measured, all the models estimate it from other meteorological parameters. By using a constant density of 100 kg m^{3} for the fresh snow, one can estimate the models sensitivity to the fresh snow density. Lastly, the models have the possibility to test their sensitivity to the heat flux from the soil. This flux is generally constant during the winter, except at the beginning of the season (when it is stronger , because the soil has accumulated a large heat content during summer) and at the end (when is it very low, because the melt water penetrates in the soil). Thus, the models can be run using a constant prescribed soil flux during the whole season (between 0 and 7 W m^{2}, depending on the site), or they can explicitly simulate the heat exchanges between snow and ground.

As the vegetation does not exist (as in WFJ) or is only short grass (other sites), the interactions between snow and vegetation are not simulated by the participant models for these experiments. In the same way, the sites are not submitted to significant snow drift (low wind and/or dense snow) and no simulation of this process is done.

4. The results

26 snow models have provided results from all or a part of the experiments, depending on the relevance of the sensitivity studies for themselves. These models included a more or less sophisticated description of physical snow processes (an overview of the general characteristics of the participating models can be found in Essery and Yang, 2001). Three of them are running in two modes: with or without an explicit resolution of the soil/snow heat exchange. The results presented within this paper only correspond to the reference experiment (REF).

4.1 Snow water equivalent

As the majority of the models try to estimate a particular aspect of the snowpack (snow water equivalent, snow surface temperature,...), the snow density is generally roughly derived from other characteristics (age, snow melt) and the simulated snow depth is not always accurate. Thus, it seems to be more relevant to compare the model results to the snow water equivalent (SWE), even if the observational (snow pits) frequency is lower (weekly) and if each snow pit is not done exactly in the same place as the previous one. For each model for each site, figure 1 shows the root mean square error RMS, calculated using the snow pits of each site (19 and 22 for the CDP seasons, 20 for SLR, 22 for WFJ). For GSB, the results are not shown because the snow pits are not done at the same place as the snow gauge. Thus, as the precipitation amount and the observed snow water equivalent are not consistent, the model results do not fit well with the observation. In order to compare the performance for each site, the RMS is normalized by SWE_{max}, the maximum SWE observed during the season (390 and 402 kg m^{-2} for the both seasons in CDP, 238 kg m^{-2} in SLR, 834 kg m^{-2} in WFJ):

$$RMS_{norm} = \frac{RMS}{SWE_{\max}}$$

Two sites (CDP9697 and WFJ) seem to be well simulated by a large majority of models: for 90% of them the RMS_{norm} is lower than 0,26 and for 50% of them the RMS_{norm} is even lower than 0,14. The two seasons are characterized by two distinct phases (accumulation, then melting), and no melt occurs during the winter. The models well simulate the accumulation phase and differences appear during the melting period (meting rate, beginning of melting, end of snow cover). Comparatively, CDP9798 seems to be more difficult to simulate because melting occurs as early as February, the 20^{th}. 60% of the models well simulate the snowpack evolution (RMS_{norm} <0,16), whereas the other models simulate snowmelt which is too fast. SLR is the least well simulated site (RMS_{norm} <0.2 for only 26% of the models). The majority of the models overestimate the observed snowpack during the whole accumulation period, when the air temperature is very low (no melting). The simulated snowpack increases faster than the snow pits, which could be due to the uncertainty on the precipitation phase (calculated by only using air temperature).

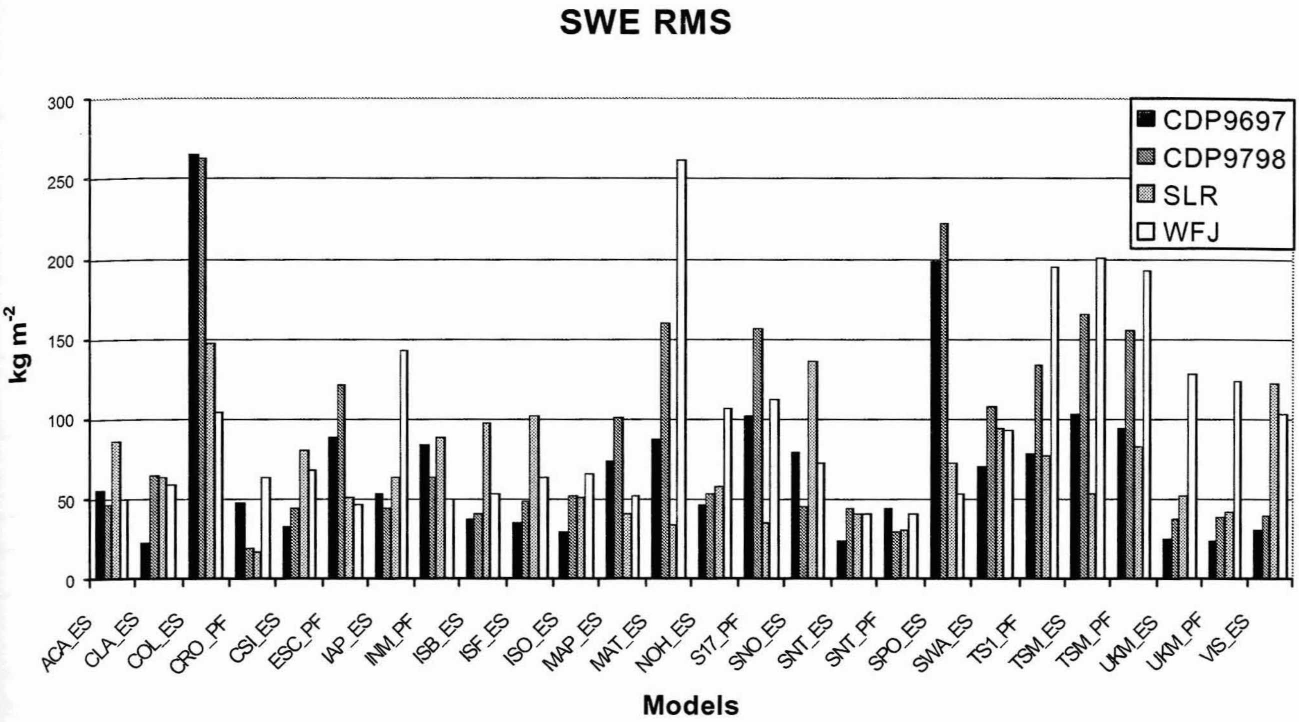

Figure 1 *: RMS of the simulated SWE for each model on the different sites*

4.2 Maximum snow water equivalent

The maximum snow water equivalent (value and date) indicates if the snow accumulation period is well simulated and if the snow melt occurs at the right time. The table 3 indicates the standartd deviations of the maximum snow water equivalent (SWE_{max}) and the date of the SWE_{max} calculated by the models. The observed values have been estimated from the weekly snow pits for each site. Thus, the accuracy of the estimated SWE_{max} date is limited by the measurement frequency (weekly) and by the spatial variability of the snow cover between two snow pits.

	CDP9697	CDP9798	SLR	WFJ
σ_{SWEmax} (SWE_{max} standard deviation , in mm)	36.5	36.5	77.3	43.9
σ_{date_SWEmax} ,(Date standard deviation , in days)	38.2	13.6	14.1	5.8
Excluded models	2	2	2	1

Table *3 : Standard deviation of the SWE_{max} and of date where SWE_{max} is reached (calculated for all of the models together by comparison with observations). Some models have been excluded because their results are too far from the observations.*

The values of σ_{SWEmax}, the standard deviation of the maximum SWE, correspond to the analysis of the whole season: compared to the maximum SWE itself, σ_{SWEmax} is low for WFJ, moderate for CDP and high for SLR. σ_{date_SWEmax}, the standard deviation of the date where SWE is maximum, is a minimum at WFJ (5.8 days), where the accumulation and melting periods are distinct. For SLR and CDP9798, it is higher (about two weeks), because melting and accumulation can occur simultaneously. The highest value of σ_{date_SWEmax} is reached on the site CDP9697 (38.2 days), where two SWE peaks are observed (at the beginning of December and of February). All of the models well reproduce the first one, which is due to large snow fall events. At the end of December, the atmospheric conditions allow a limited melting, which is overestimated by several models (group 1 of the figure 2). For these models, the maximum SWE corresponds to the first peak. The models of the group 2 well calculate the melting and the maximum SWE is correctly determinated, if one considers the uncertainty on the observed date due to spatial variability between two snowpits. The group 3 simulates a maximum SWE at the end March, with a value a bit overestimated compared to the observation.

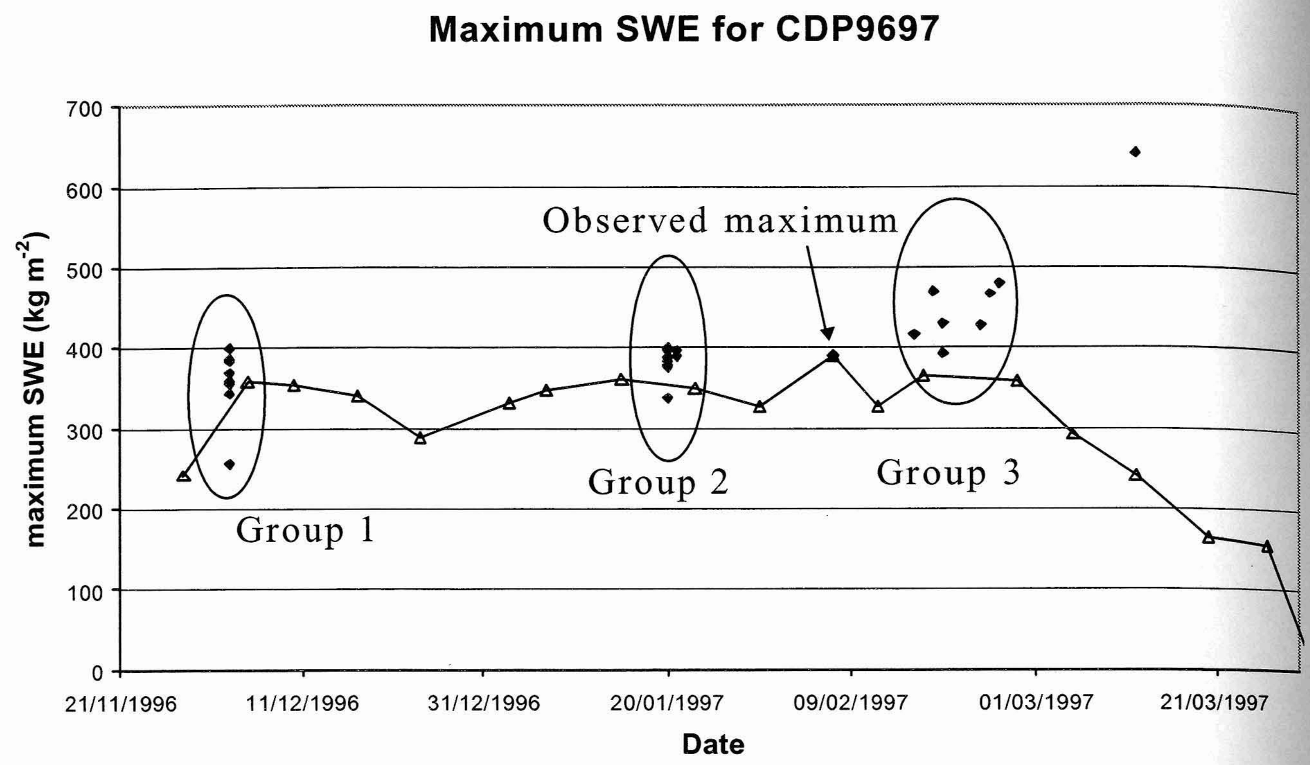

Figure 2 *: Maximum SWE simulated by the models (horizontal coordinate : date, vertical coordinate : value). Each diamond corresponds to a model, the triangle to the SWE observations.*

4.3 Snow cover duration

The snow cover duration is a particularly important feature of the snowpack because it has a major impact on the surface energy budgets. For instance, the surface energy fluxes are strongly governed by the surface temperature, which is limited to 273.16 K if snow is present. Moreover, the snow cover limits evaporation from ground. Thus, the presence of snow influences at the same time the local atmospheric circulation and the watershed water resources.

On average, the snow cover duration is underestimated at CDP9798 (-10.5 days) and overestimated at SLR (17.3 days). The RMS of the snow cover duration is roughly the same for all sites (16 to 23 days), which indicates that this parameter does not allow to the classification of the model ability to simulate the local snow cover (table 4).

	CDP9697	CDP9798	GSB	SLR	WFJ
Averaged snow cover duration error (SCDE, days)	1.8	-10.5	-2.5	17.3	-7.3
Snow cover duration error RMS (days)	16	18.5	17.2	22.9	16
% of accurate models (SCDE<1 week)	35	64	15	8	36
Excluded models	0	1	0	0	0

Table 4 *: Snow cover duration error (SCDE, in days, calculated by using the snow depth observations) : average for all models, RMS, fraction of accurate models (SCDE<1 week) and number of excluded models for the calculation.*

If one considers the fraction of the most precise models, the best simulated site is CDP9798, where the snow cover duration error is lower than 1 week for 65% of the models. About one third of the models reach an equivalent score for CDP9697 and WFJ9293, due to different melting rates in spring. Only 8% of the models calculate a correct snow cover duration in SLR, which is coherent with the overestimation of the snowpack mass balance already mentioned above. 15 % of the models calculate a correct snow cover duration in GSB, on average for 15 seasons.

For the 5 sites, the RMS on the snow cover duration is 17.4 days in average for all models (figure 3). It is lower than 2 weeks for 35% of the models (9,6 days for the best one). If one excludes the SLR site (where the snowpack is overestimated by a great majority of models), the fraction of models with a RMS lower than 2 weeks reaches 54% (5.8 days the for the best one).

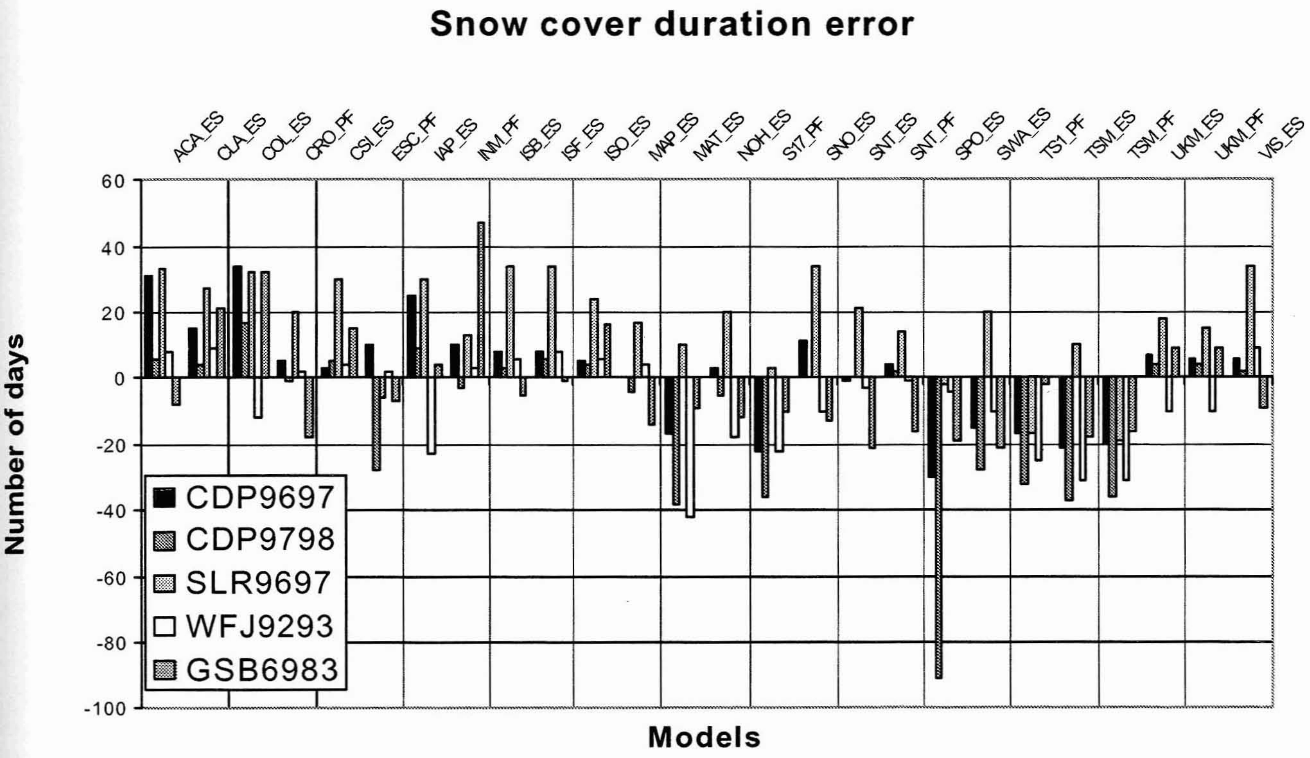

Figure 3 *: Snow cover duration error for each model and for the different sites.*

5. Conclusion

The results of 26 snow models have been compared to validation data for the different experiment sites. Some models show a good ability to correctly simulate the snow pack features for all of the sites, whereas other models are more adapted to particular conditions. The WFJ site is the best simulated site, because the accumulation and melting periods are distinct. SLR is the most difficult site (the snowpack is overestimated by most of the models), which is probably due to vague precipitation phase. Between these two extremes, the two CDP seasons are moderately well simulated because accumulation and melting periods are mixed. The SWE evolution for the season CDP9697 is generally better estimated, but the snow cover duration is better capturated by models for the season CDP9798. The next step of the analysis will focus on the explanation of the model differences. The energy budget will be examined and compared to validation data such as albedo or snow surface temperature. The sensibility experiments will be used to bring into light the complex feedbacks, the role of the parametrisations and the impact of scheme complexity. This more detailed study will then try to classify the models following their characteristics and their applications.

References

Boone, A. and Etchevers P., 2001. An intercomparison of three snow schemes of varying complexity coupled to the same land-surface model: Local scale evaluation at an Alpine site. Journal of Hydrometeorology, 2, 374--394.

Essery R., Martin E., Douville H., Fernadez A., Brun E., 1998. A comparison of four snow models using observations from an alpine site. Climate Dynamics, 15, 583-593.

Essery R. and Yang Z. -L., 2001.An overview of models participating in the snow model intercomparison project (SNOWMIP). Proceedings of the SnowMIP Workshop, 11 July 2001, 8th Scientific Assembly of IAMAS, Innsbruck

Jin, J., Gao X, Yang Z. L., et al., 1999. Comparative analyses of physically based snowmelt models for climate simulations. J. of Climate,12 (8), 2643-2657 part 2.

Schlosser C.A., Slater A.G., Robock A., Pitman A.J., Vinnikov K.Y., Henderson-Sellers A., Speranskaya N.A., Mitchell K., Boone A., Braden H., Chen F., Cox P., de Rosnay P., Desborough C.E., Dickinson R.E., Dai Y.J., Duan Q., Entin J., Etchevers P., Gedney N., Gusev Y., Habets F., Kim J., Koren V., Kowalczyk E., Nasonova O.N., Noilhan J., Schaake J., Schmakin A.B., Smirnova T.G., Verseghy D., Wetzel P., Xue Y. and Yang Z.L., 2000: Simulation of a boreal grassland hydrology at Valdaï, Russia: PILPS Phase 2(d). Monthly Weather Review: Vol. 128, No. 2, pp. 301–321.