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14. Validation of Alpine snow in ERA-40

Eric Martin

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Validation of Alpine snow in ERA-40

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Contents

1 Introduction

The interpretation of meteorological models results (including general circulation models (GCM) and operational forecast models) in mountainous region is not easy because of the smoothed orography of this type of model. Few years ago, the Centre d'études de la neige (CEN, Centre for snow research) participated in the validation of the ERA-15 project in the Alpine region. The validation focussed on the period Aug 81 – Aug 91. The purpose of the present work is to conduct a similar validation on the ERA-40 products.

One may say that it is a very local validation for a global run. However, the use of a period covering several years (10 years for this report) allows validations under various conditions (interannual variability). It can be also of some interest as the snow cover validation mixes several variables (temperature, precipitation, surface fluxes).

The snow cover evolution is governed by the surface energy and mass balance. Among all the variables considered, temperature and precipitation are two important factors. It has been chosen to focus on these two variables before snow cover simulations.

The beginning of the report is devoted to classical validations for temperature and precipitation. Reference data for this part come from the operational analysis and surface observations. In a second step, snow cover simulations are used. When available, the results will be compared to ERA-15 results.

2 Data used for this study

It has been chosen to concentrate in this study on the period 1981 /1999 for the following reasons:

- period long enough for interannual comparisons
- availability of the Safran/Crocus climatology (this climatology begins in Aug 81).

2.1 Data from ERA-40 archive

The following data were extracted from the ERA archive since 1 January 1989 on a regular grid 42°/48°N x 3°W/11°E (grid mesh 1°). See Figure 1 representing the spatial domain and the model orography. Although the maximum elevation is of the same order for ERA-15 and ERA-40, the shape is better in the ERA-40 case.

Upper air analyses:	6 hours steps		
	levels: 1000, 925, 850, 775, 700, 600 hPa		
	parameters:	Z	geopotential
		T	air temperature
Surface analyses:	6 hours steps		
	parameters:	10U, 10V	zonal and meridional 10 meter wind
		2T	2 meter air temperature
		2D	2 meter dew point
		SD	snow depth (water equivalent)
		AL	climatological albedo
		SKT	skin temperature

		ST	surface temperature
		SAL	Snow albedo
		SDENS	Snow density

Forecast: based on 00 and 12 UTC forecasts, values cumulated after 12 and 24 hours of forecast.

parameters:	LSP	large scale precipitation
	CP	convective precipitation
	SF	snowfalls
	SSHF	surface sensible heat flux
	SLHF	surface latent heat flux
	SSR	surface net solar radiation
	STR	surface net thermal radiation
	LCC	low cloud cover
	MCC	medium cloud cover
	HCC	high cloud cover
	FAL	albedo

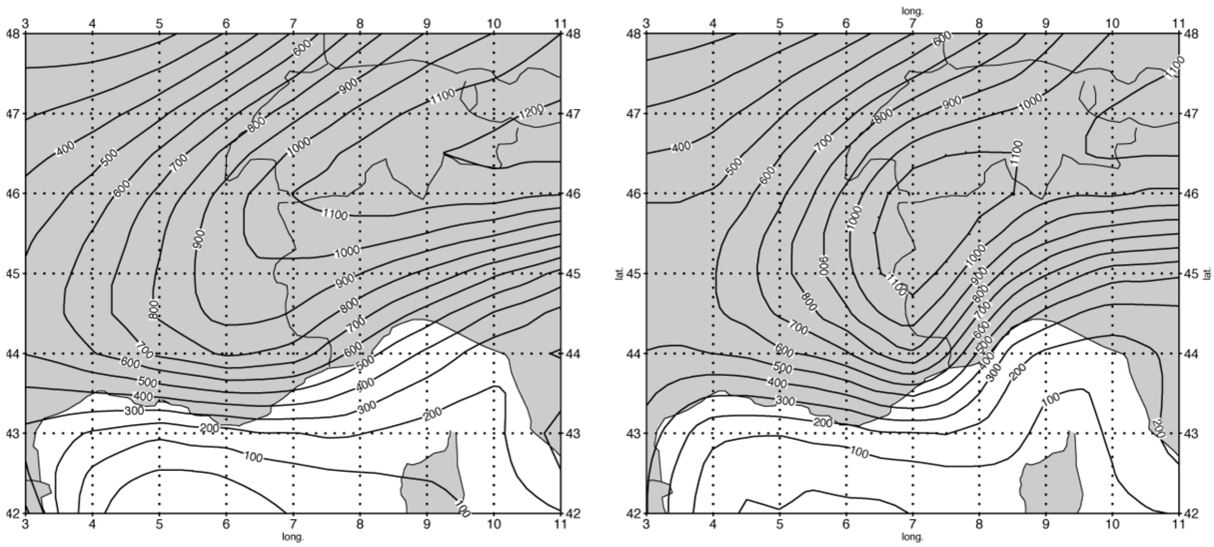

Figure 1: Grid used and orography of the model: left ERA 15, right ERA-40

2.2 Data from operational analyses

The following data were previously extracted from the ERA archive since 1 august 1981 on a regular grid 42°-48°N x 3°W-10.5°E (grid mesh 1.5°).

Upper air analyses: 6 hours steps

levels: 1000, 850, 700, 500, 400, 300 hPa

parameters:	Z	geopotential
	R	relative humidity
	T	air temperature
	U, V	zonal and meridional wind

2.3 Observational data

Météo-France operates a network of automatic weather stations (called Nivôse) situated at high elevations in the French Alps. Temperature from the first of these stations (installed during the 1981 autumn) are used. It is the "Bellecote" station, situated at 3000m a.s.l (Figure 2)

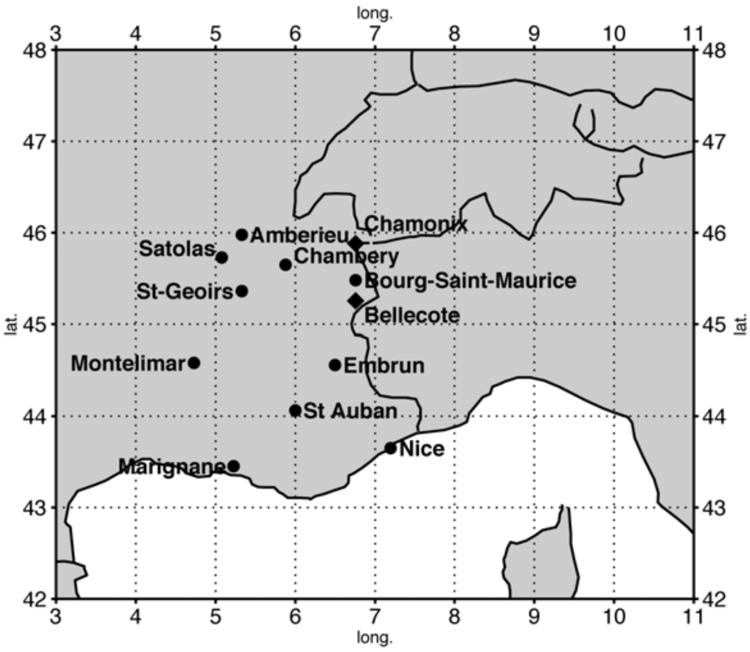

Figure 2: Synoptic stations used for validation

Precipitation from 10 synoptic stations in and around the French Alps are used for forecast controls. These synoptic stations are: Marseille-Marignane, Lyon-Satolas, Nice, Montélimar, Grenoble Saint-Geoirs, Chambéry, Bourg-Saint-Maurice, Embrun, Ambérieu, Saint-Auban.

The CEN has also access to meteorological variables (including snow depth) measured in the snow-network stations, situated generally in ski resorts at elevations between 1000 and 2500m.

2.4 Calculated snow climatology

A snow cover climatology, based on the period august 1981 / July 1991 has been calculated by the CEN with SAFRAN and CROCUS (Martin et al, 1994, Durand et al, 1999). This "climatology" was validated by using snow cover observations at almost 40 sites with elevations ranging from 900 to 3000m. This data are daily values of snow depth, snow water equivalent and bottom runoff in the 23 regions, or massifs of the Alps (Figure 3), with a vertical discretization of 300m.

A short description of SAFRAN and CROCUS can be found in annex.

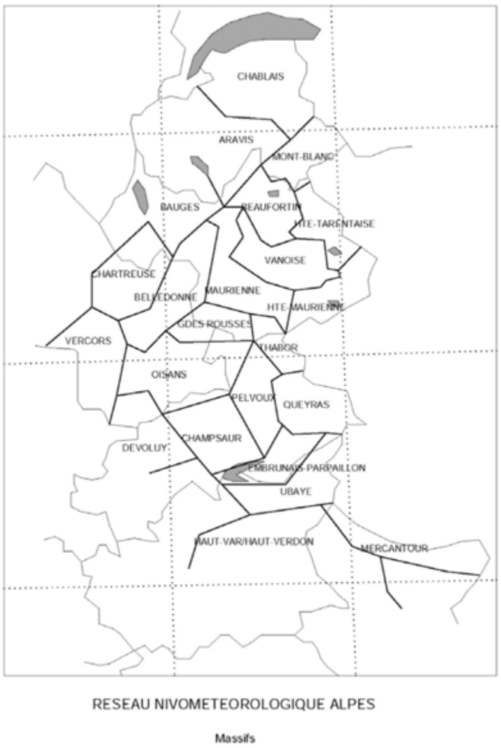

Figure 3: Map of the 23 massifs used by SAFRAN and CROCUS for the calculation of the snow climatology.

3 Temperature validations at Nivôse Bellecôte

In this section, the temperature of the ERA-40 production is compared to operational analyses, ERA-15 (two winters) and observations. In mountains formed by isolated peaks, like the Alps, the air over the summit is generally well mixed with free air (this not the case for high plateaux). Therefore, it is generally admitted that surface air temperature near the top of the mountains can be compared directly to model outputs. It is particularly true in winter, when snow cover reduces the diurnal cycle.

The automatic weather station "Nivôse Bellecôte" (the oldest of the automatic weather stations operated by the CEN) was chosen for such validation. It is situated in the Vanoise massif, at 3000 m a.s.l, near a glacier (lat: 45.48, long: 6.77E). Data from this station are independent of the model outputs, as they are not used in the analysis. As can be seen in Figure 4, the daily mean temperature is very close to the ERA-40 temperature interpolated at the same point.

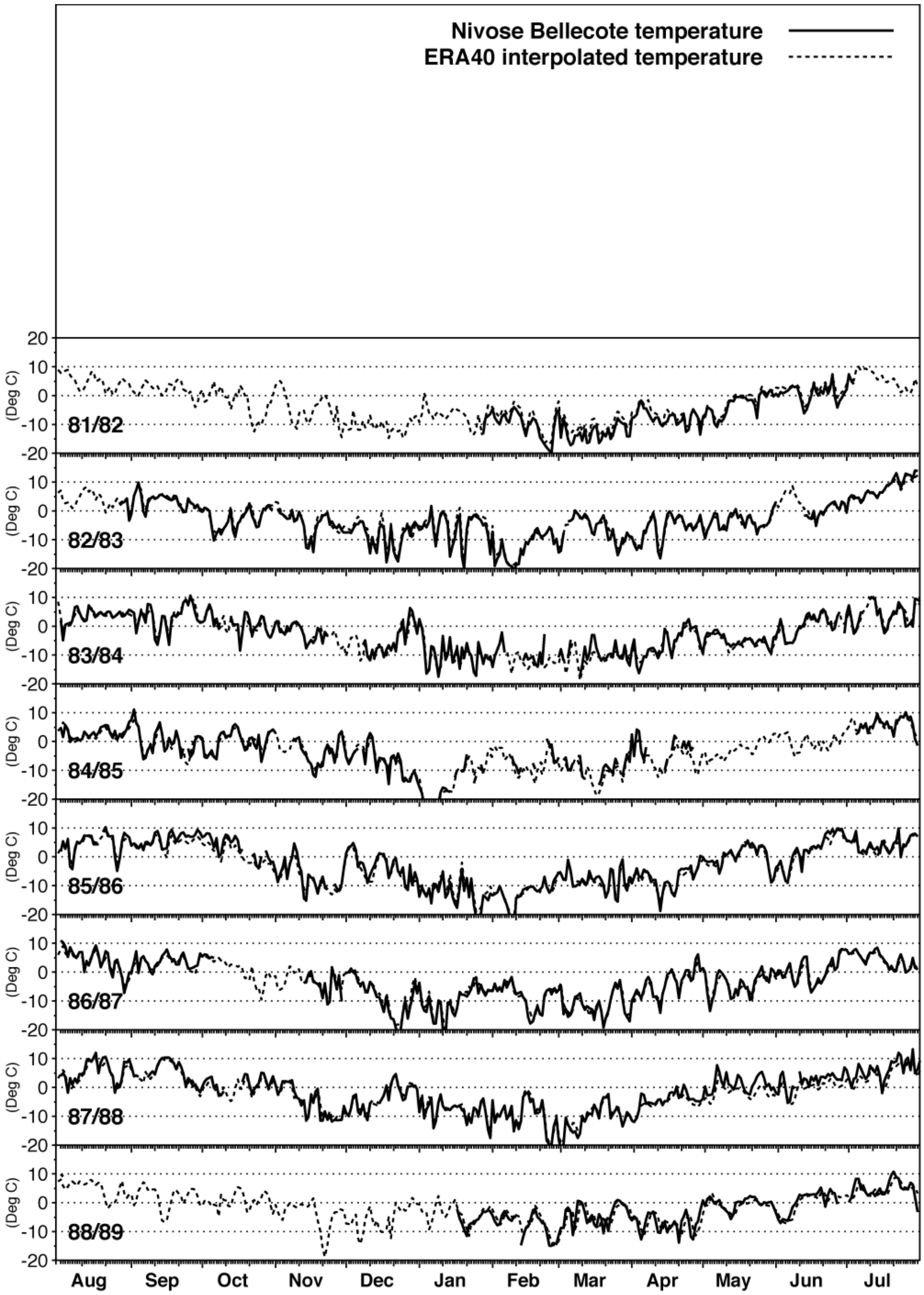

Figure 4: Daily mean temperature at Nivôse Bellecote: observation and interpolated ERA-40 temperature at the same altitude.

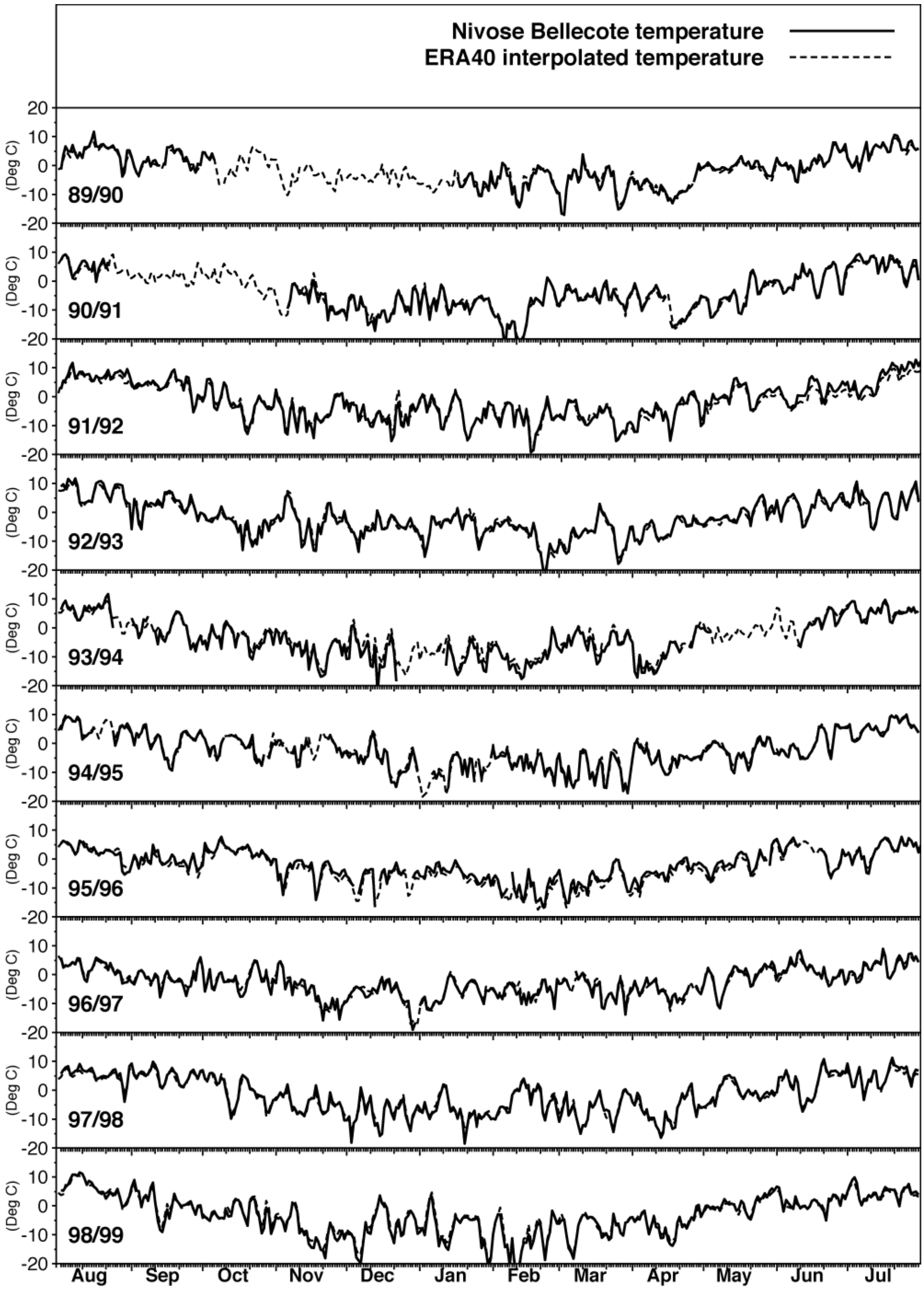

Figure 5: Daily mean temperature at Nivôse Bellecote: observation and interpolated ERA-40 temperature at the same altitude (continued).

When looking at statistical parameters such as mean error or rms error in winter (DJF: December-February), one may note that the mean error is in the same order of magnitude in operational analysis, ERA-15 and in EA40. The operational analysis is slightly better with the exception of the beginning of the period (first two winters especially) (Table 1 and Table 2). ERA-40 is colder than the operational analysis at the beginning of the period (especially first three winters). After, ERA-40 is warmer. ERA-15 is very close to ERA-40.

DJF		81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	all
nbdays		34	90	72	70	90	90	90	41	43	90	
obs - op. ana	mean error	-2.31	-1.48	0.60	0.38	-0.05	-0.65	0.10	0.39	-0.46	-0.41	-.47
	rms	2.53	2.28	2.38	1.81	1.65	1.53	1.05	1.10	1.13	0.92	1.70
obs – ERA-40	mean error	-1.97	-1.00	0.80	0.29	-0.16	-0.61	-0.39	-.38	-0.46	-0.37	-.43
	rms	2.23	1.80	2.27	1.97	1.77	1.48	1.24	1.04	1.12	1.18	1.65
obs – ERA-15	mean error	-1.73	-1.04	0.84	0.26	-0.17	-0.61	-0.37	-.80	-0.54	-0.71	-.41
	rms	2.05	1.80	2.25	1.96	1.94	1.60	1.22	1.30	1.24	1.35	1.65

DJF		91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99	all
nbdays		91	90	73	82	86	89	90	90	
obs - op.ana	mean error	0.43	0.62	-1.25	0.02	1.57	-0.11	-0.31	-0.81	0.16
	rms	1.20	1.14	2.13	1.12	1.30	1.09	1.05	1.17	1.28
obs - ERA-40	mean error	-0.32	-0.29	-1.89	-0.44	1.38	-0.24	-0.33	-0.98	-.38
	rms	1.41	1.20	2.12	1.11	1.32	1.26	1.25	1.23	1.36
obs - ERA-15	mean error									
	rms									

Table 1: Comparison between Bellecote observations, operational analyses and ERA in winter (DJF). All values in °C. nbdays: number of days with valid observations.

DJF		81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	all
ERA-40-op ana	mean diff.	-0.39	-0.47	-0.07	0.06	0.11	-0.03	0.50	0.70	0.22	-0.03	-0.01
	rms	0.96	1.13	0.910	0.94	0.95	0.77	0.92	0.85	0.78	0.86	0.91
ERA-15-op ana	mean diff.	-0.61	-0.47	-0.02	0.06	0.05	-0.05	0.39	1.09	0.26	0.37	-0.03
	rms	1.11	0.98	0.90	0.91	0.93	0.80	0.76	1.41	0.78	0.91	0.90

DJF		91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99	all
ERA-40-op ana	mean diff.	0.75	0.92	0.61	0.56	0.17	0.13	0.03	0.18	0.41
	rms	1.01	1.06	0.75	0.87	0.73	0.72	0.72	0.75	0.82
ERA-15-op ana	mean diff.									
	rms									

Table 2: Comparison between ERA and operational analyses at Bellecote (°C).

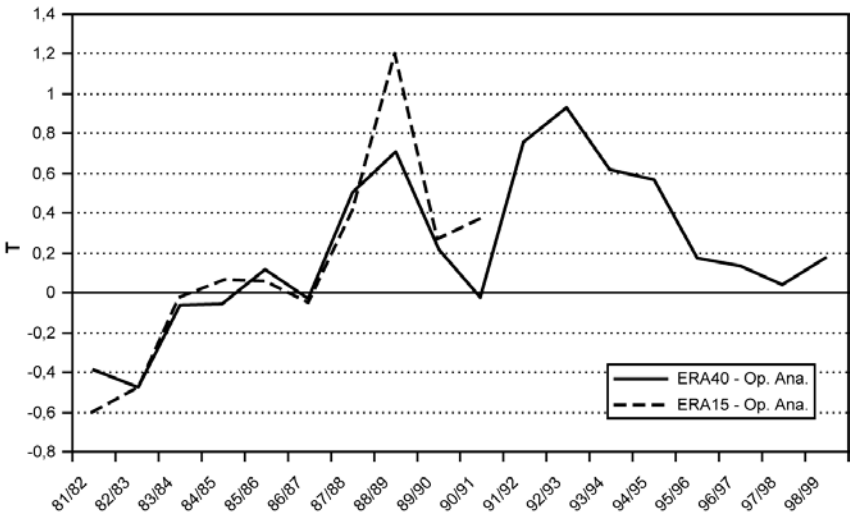

Figure 6: Evolution of the difference between ERA-40 and Op. Ana and ERA-15 and Op. Ana at Bellecôte. (Data from Table 2)

4 Total precipitation

4.1 Spin up for precipitation: comparison of precipitation based on 0/12 and 12/24 H forecasts.

The purpose of this section is to determine the effect of the model spin up on precipitation. Several possibilities are offered by ERA products to determine precipitation amount. It has been chosen to use the forecasts based on 00:00 H and 12:00 H and to compare precipitation simulated between the forecast steps 0/12H and 12/24H.

Figure 7.shows the mean precipitation for the period January 81, December 99, based on 12/24H forecasts (in mm/year) . It is well known that the Mediterranean sea area is dryer than the region situated in the North, but orography modifies this simple distribution: precipitation is maximum in the north-west slope of the Alps, on the contrary, there is a very dry region in the lee of the mountain (south-east slope).

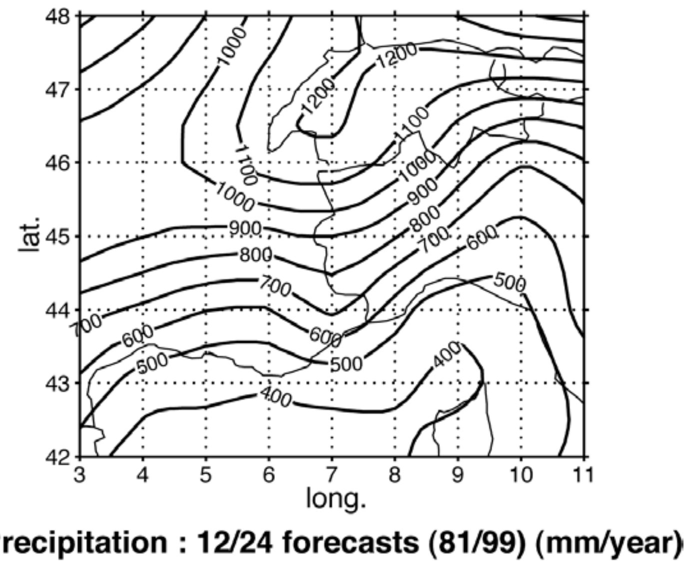

Figure 7: ERA-40 total precipitation

The comparison on the period Aug 81 – Jul 91 between ERA-15 and ERA-40 shows that the precipitation patterns are better in ERA-40 than in ERA-15 (Figure 8). This is mainly due to better shape of the orography in ERA-40. On the average, ERA-15 precipitation are lower than ERA-40 ones.

The spin up effect can be seen on Figure 9: precipitation is higher when considering the period 12/24H. In the North of the French Alps <46°,7°>, where precipitation is higher, the precipitation is increased by 30% (12/24 forecasts – 00/12 forecasts) in ERA-40 results. Near the Mediterranean sea <44°, 8°> the increase is only +10%. In ERA-15, the percentage is equivalent, but the absolute values are lower.

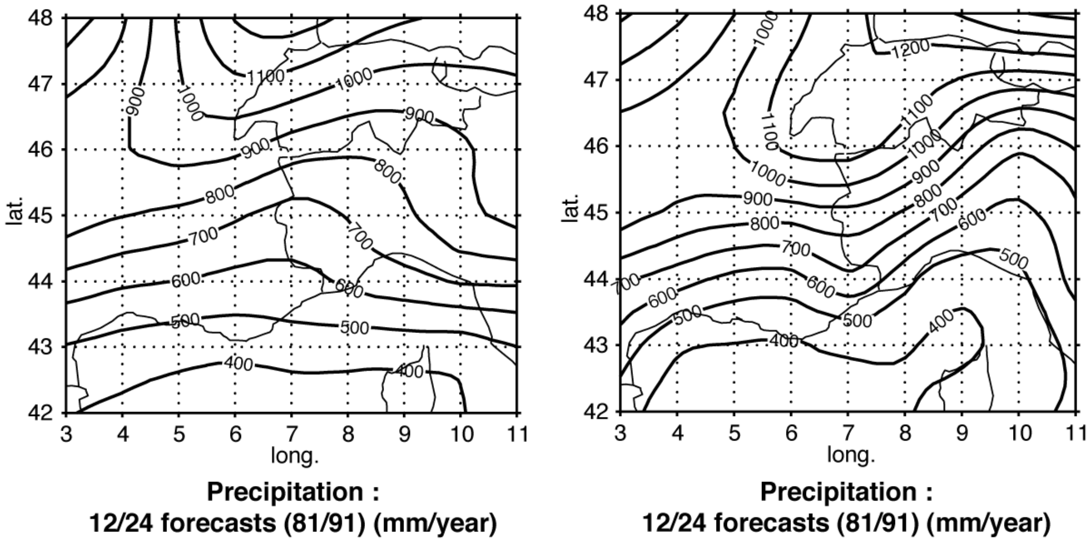

Figure 8: Total annual precipitation Left ERA-15, right ERA-40

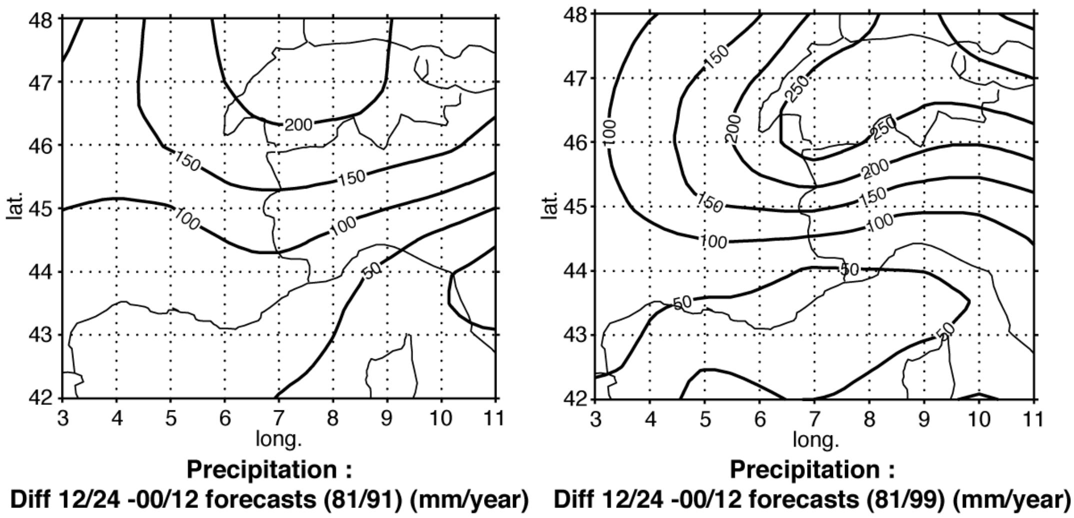

Figure 9: Spin up: difference between precipitation based 12-24 forecast and 00-12 forecast. Left ERA-15, right ERA-40

4.2 Validation against observations

Data from the 10 selected synoptic stations (Figure 2) were used to control ERA precipitation (all data cover the period January 1989/December 1999). Table 3 compares for these stations observations and the nearest ERA grid point. On all stations (except Embrun, in a very dry valley in the centre of the massif), the 12/24H forecast is a better estimate of observed precipitation.

Station	OBS	Nearest ERA point (00/12H)	Nearest ERA point (12/24H)	Grid point number
Ambérieu	1127	789	979	21
Lyon-Satolas	855	789	979	21
Chambery	1185	852	1092	22
Bourg-Saint-Maurice	955	841	1121	31
Grenoble Saint Geoirs	846	677	841	30
Montelimar	790	677	841	30
Embrun	714	719	868	32
Saint Auban	644	515	581	40
Marignane	465	360	415	48
Nice	783	581	677	41
mean	**836**	**690**	**829**	

Station (Aug81/Jul91)	OBS	ERA-15	Nearest ERA point (12/24H)	Grid point number
Ambérieu	1242	890	999	21
Lyon-Satolas	866	890	999	21
Chambery	1244	930	1134	22
Bourg-Saint-Maurice	977	712	1156	31
Grenoble Saint Geoirs	939	770	853	30
Montelimar	836	770	853	30
Embrun	709	675	874	32
Saint Auban	666	580	561	40
Marignane	465	450	396	48
Nice	636	570	679	41
mean	**858**	**723**	**850**	

Table 3: Top: Comparison between mean annual total precipitation at 10 stations situated in the French Alps and the nearest grid point (numbers from the top left corner)
Bottom: Comparison between mean annual total precipitation at 10 stations situated in the French Alps and the ERA-40 and ERA-15 results .

On the average, ERA-40 reproduces in a quite good manner the monthly variability of precipitation (Figure 10), even if there are some strong underestimations in some of the wettest months: Sept 94, Nov 96, Oct 89.

For Nice, the ERA-40 precipitation is lower than the observed one (Figure 11). On the contrary, for Lyon and Bourg-Saint-Maurice, ERA-40 precipitation are higher. This is due to the orographical effect in the model. For instance, Lyon is situated in the Rhône Valley, 100 km away from the Alps, but in the model it is situated in the mountain slope and precipitation are enhanced. Bourg-Saint-Maurice (as Embrun) is situated in the heart of the Alps, in a relatively dry valley: this very local phenomenon cannot be represented by the model.

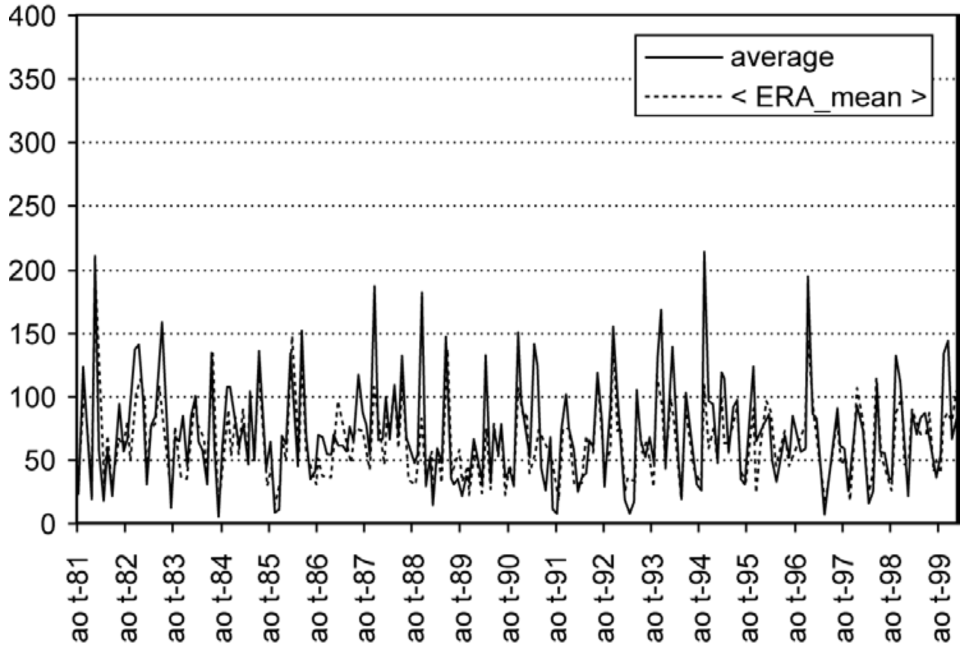

Figure 10: Monthly precipitation (mm) from Aug.81 to Dec 99. continued line: mean precipitation of the ten stations, dashed line: ERA mean precipitation (12/24H forecasts).

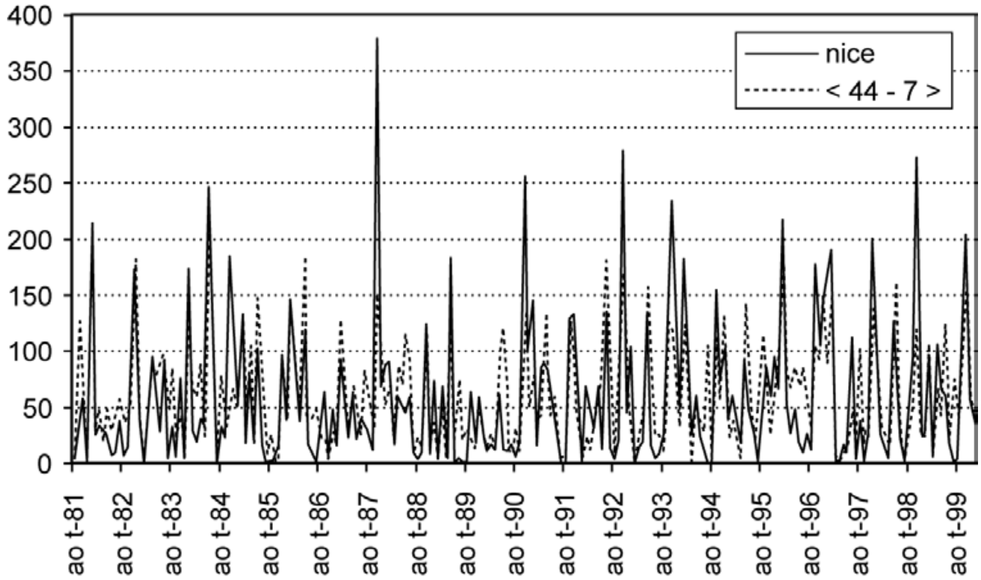

*Figure 11: Monthly precipitation (mm) from Aug.81 to Dec 99. continued line: mean precipitation of **Nice**, dashed line: ERA mean precipitation (12/24H forecasts).*

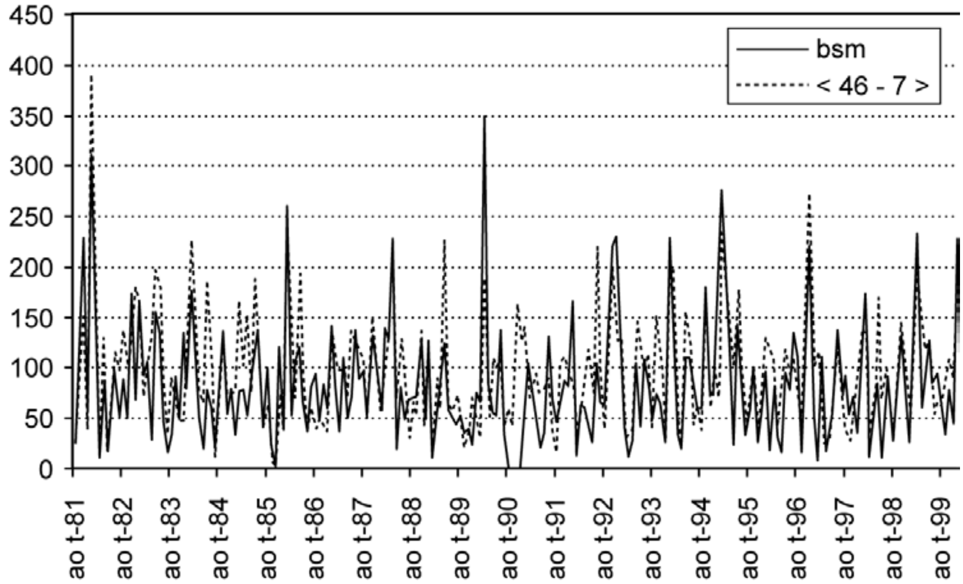

Figure 12: Monthly precipitation (mm) from Aug.81 to Dec 99. continued line: mean precipitation of ***Bourg-Saint-Maurice****, dashed line: ERA mean precipitation (12/24H forecasts).*

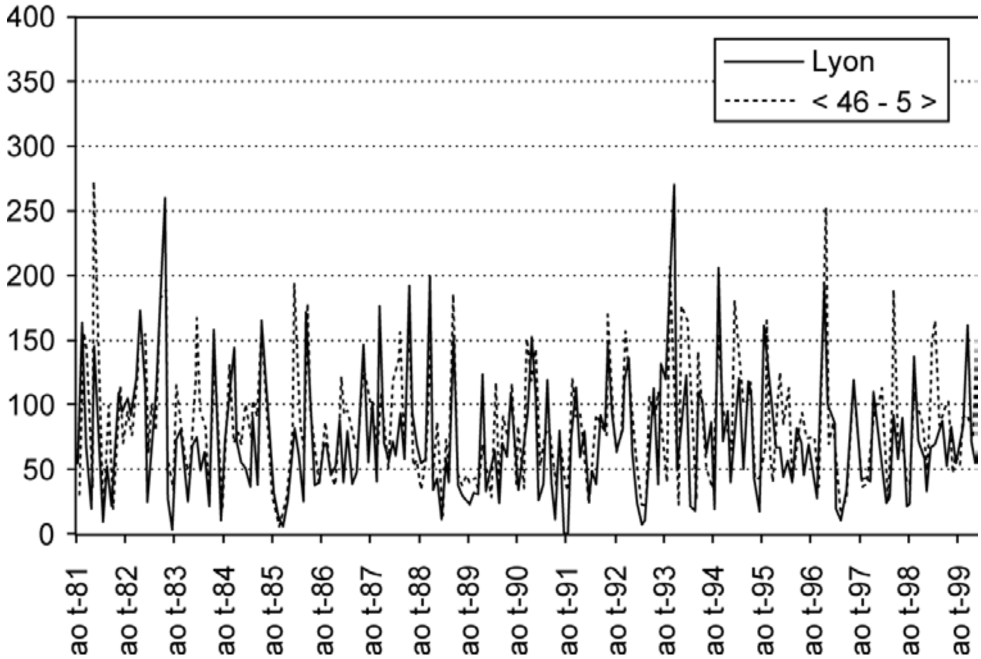

Figure 13: Monthly precipitation (mm) from Aug.81 to Dec 99. continued line: mean precipitation of ***Lyon (St Exupéry),*** *dashed line: ERA mean precipitation (12/24H forecasts).*

4.3 Conclusion

The comparison of ERA-40 data and observations shows that precipitation based on 12/24H forecasts are more reliable than precipitation based on 0/12H forecasts. The 19 year average at the 10 selected stations is 836 mm year^{-1} the mean of the selected grid point is 829 mm year^{-1}.

The ERA-15 precipitation where slightly underestimated: during the period Aug 81 – Aug 91 the ERA-15 precipitation (based also on 12/24H) was 570 mm year^{-1}, against 640 mm year^{-1} for the mean of the 10 stations. The ERA-40 results appear better than those of the previous reanalysis.

5 Snowfall

5.1 Spin up for snowfall

Concerning snowfall only, the mean snowfall are highly correlated to the orography, and the spin up is usually small (increase of 10% or less), Figure 14 and Figure 15.

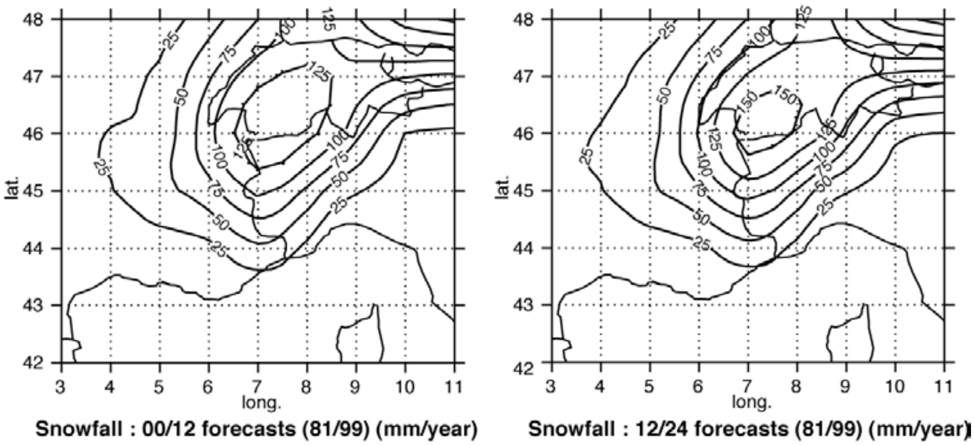

Figure 14: same as Figure 7, but for snowfall only

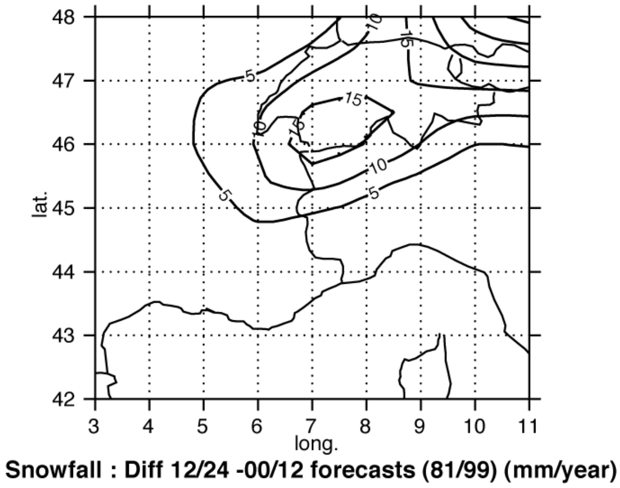

Figure 15: Same Figure 8, but for snowfall only

5.2 Comparison with snowfall analysed by SAFRAN

Figure 16 compares the monthly snowfall at the point 46°N, 7°E (1100m) to the snowfall analysed by SAFRAN for the massif Beaufortain at 900 and 1200 m. Although the general shape is captured, the snowfall is strongly underestimated. This can be clearly seen in Figure 17 where the annual snowfall is plotted. The ERA-40 snowfall is below the 900 m a.s.l SAFRAN analysis. This underestimation is linked to the underestimation aof snowfall as the surface temperature seems correct: averaged 2meter temperature 7.51°C, 8.390C at 900m and 6.85°C at 1200m for Safran

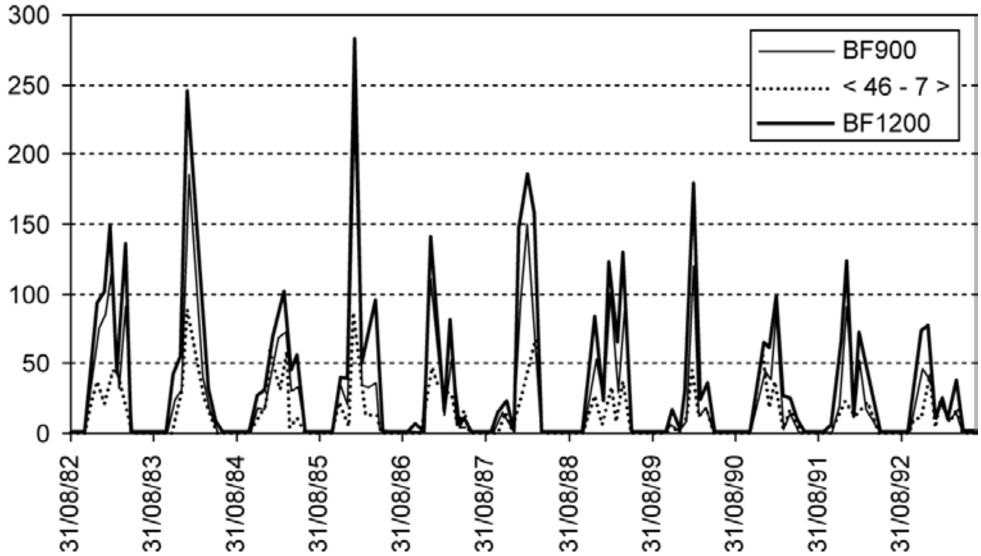

Figure 16: Comparison of the ERA-40 monthly snowfall (point 46°N, 7°E, 1100 m a.s.l) and analysis by Safran for the massif Beaufortain at 900 and 1200m.

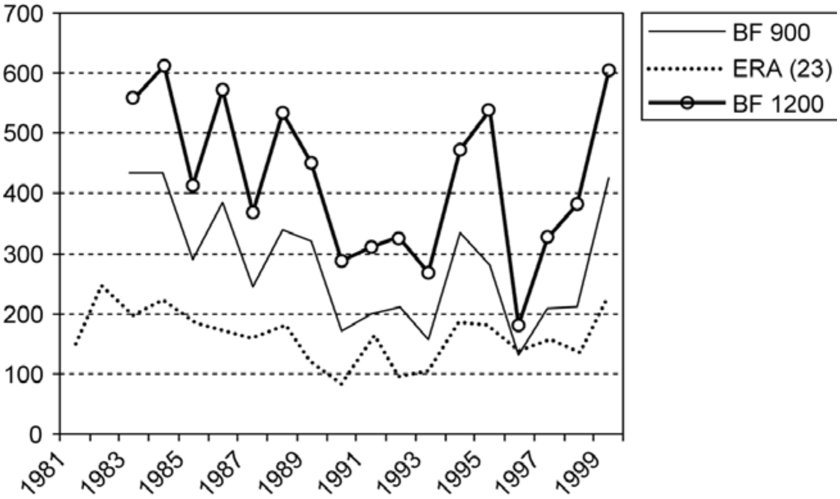

Figure 17: Comparison of the ERA-40 winter snowfall (point 46°N, 7°E, 1100 m a.s.l) and analysis by Safran for the massif Beaufortain at 900 and 1200m. 1990 = winter 1989/1990.

6 Snow cover simulations

The snow water equivalent (SWE) produced by ERA-40 has been compared to the snow water equivalent analysed by Safran/Crocus. Concerning ERA-40 the point 46°N, 7°E, 1100 m a.s.l (called also point 23) has been selected. The Safran/Crocus SWE used was calculated for the massif Beaufortain (in the immediate vicinity of the grid point 23) and for the elevation 900 m and 1200m.

The comparison are presented in Figure 18 (900 m) and Figure 19(1200 m). It is not easy to compare the two SWE because of the difference in elevation. However, it must be noted that ERA-40 captures a significant part of the interannual variability. The years with a poor snow cover from 89/90 to 92/93 are reasonably well simulated. The underestimation of snowfall (winter 94/95, winter 98/99 especially) is visible.

When looking at the snow cover within the winter, the snow cover evolution is realistic, and the daily evolution is in most case in agreement between ERA-40 and Safran/Crocus. These results are better than those found for ERA-15 (changes in the snow model occurred between the two reanalyses).

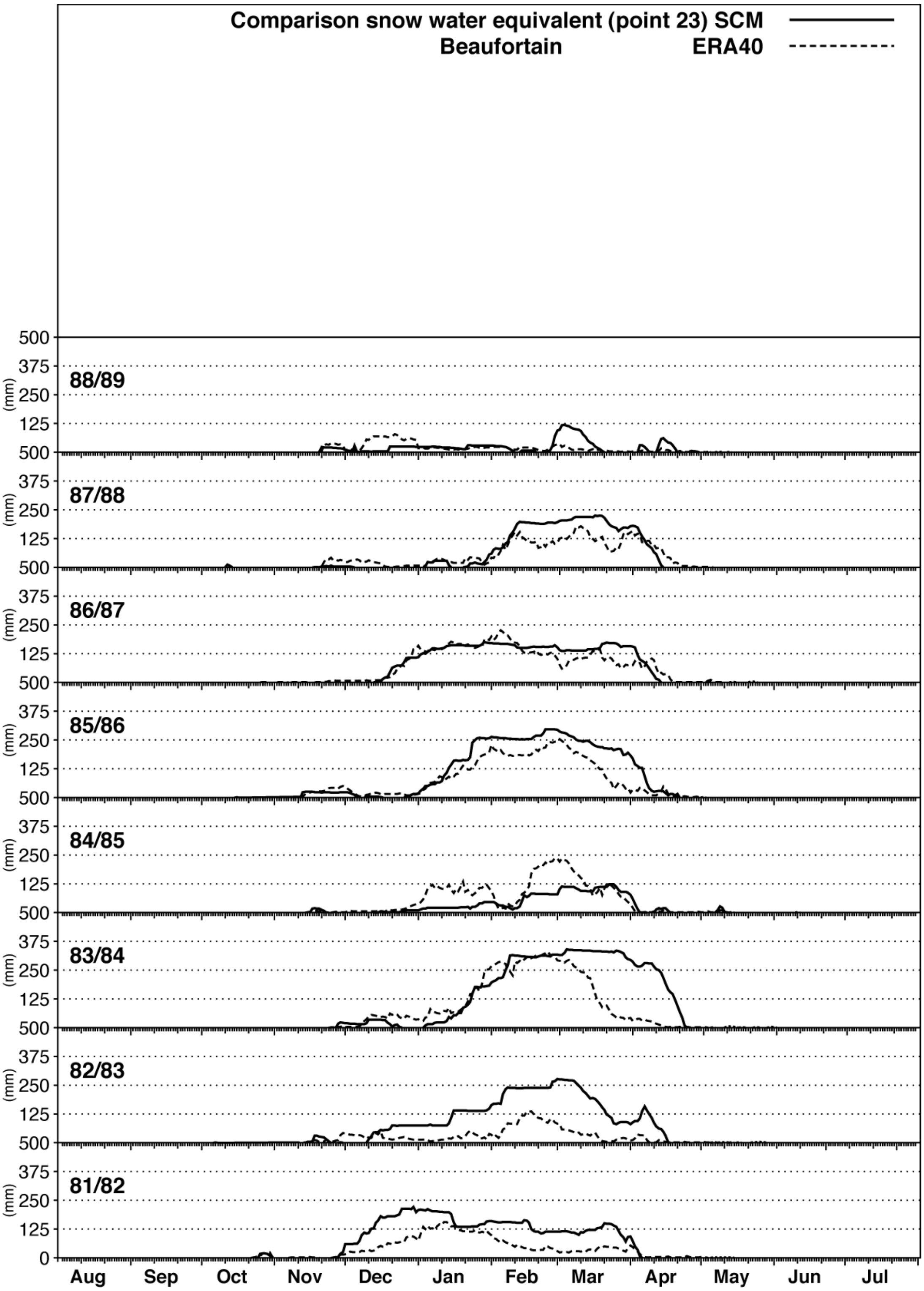

Figure 18: Comparison between the snow water equivalent produced by ERA-40 (point 46°N, 7°E, 1100 m a.s.l) and the Safran/Crocus analysis for the massif Beaufortain at 900 m a.s.l.

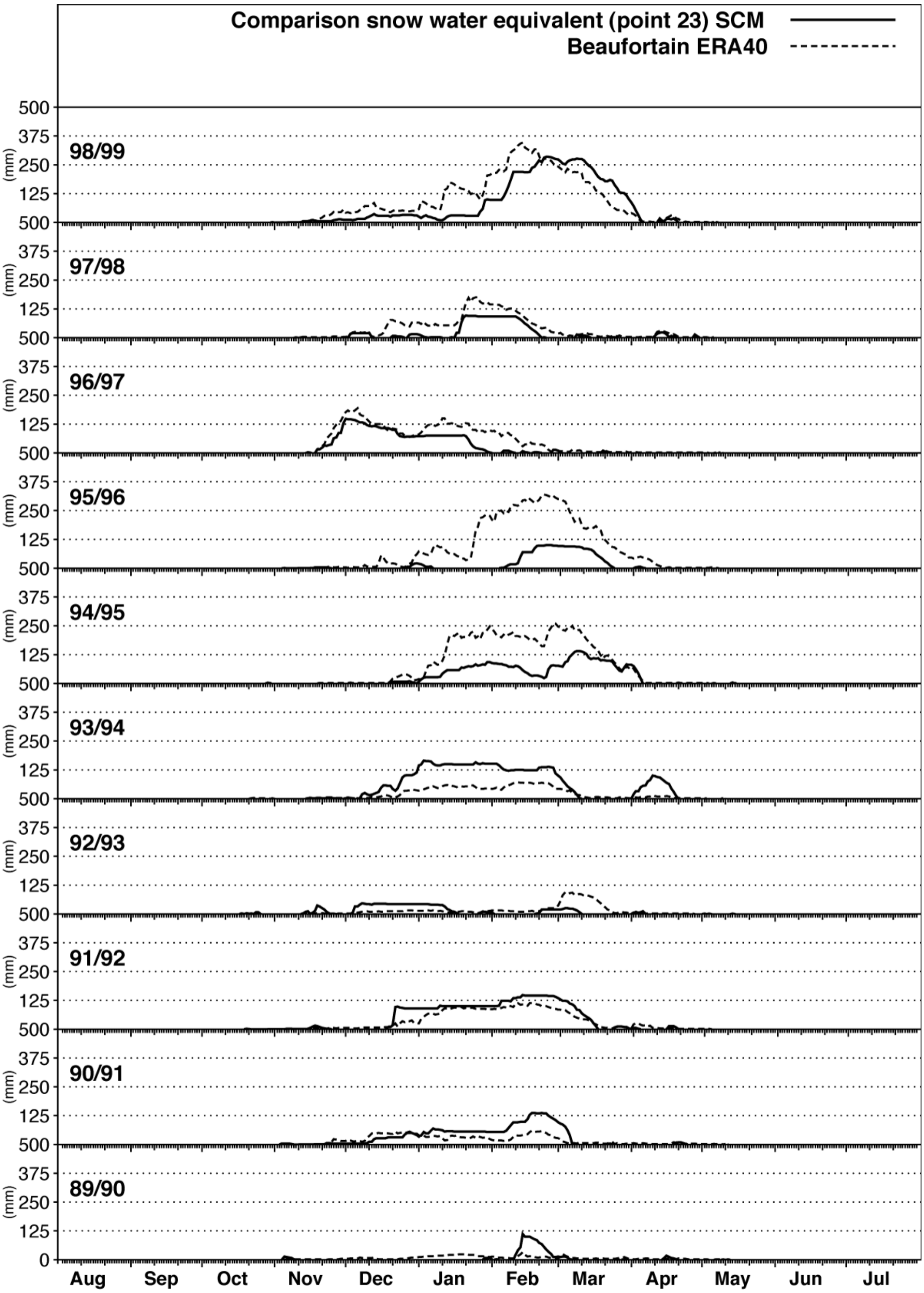

Figure 18(Continued): Comparison between the snow water equivalent produced by ERA-40 (point 46°N, 7°E, 1100 m a.s.l) and the Safran/Crocus analysis for the massif Beaufortain at 900 m a.s.l.

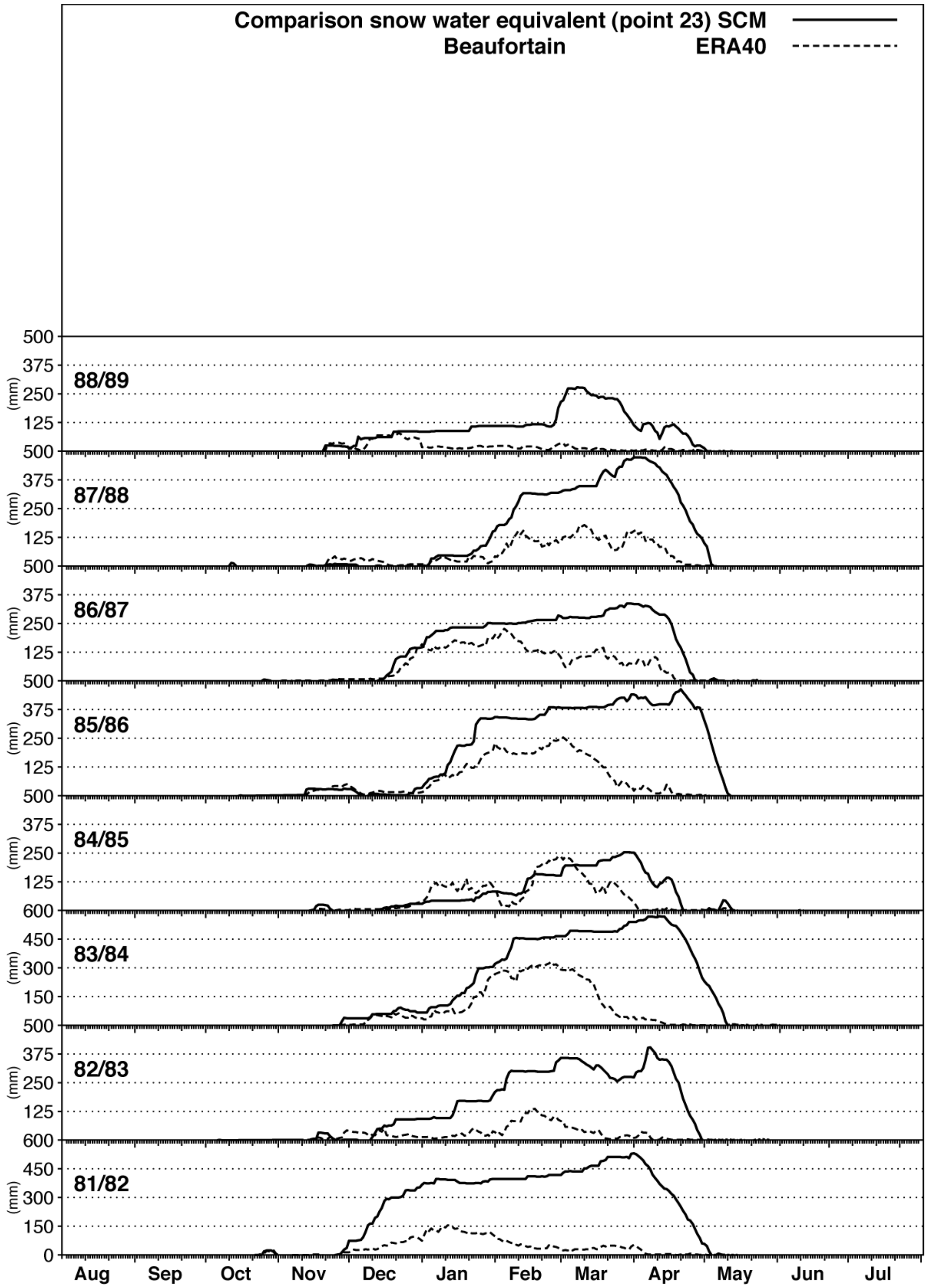

Figure 19: Comparison between the snow water equivalent produced by ERA-40 (point 46°N, 7°E, 1100 m a.s.l) and the Safran/Crocus analysis for the massif Beaufortain at 1200 m a.s.l.

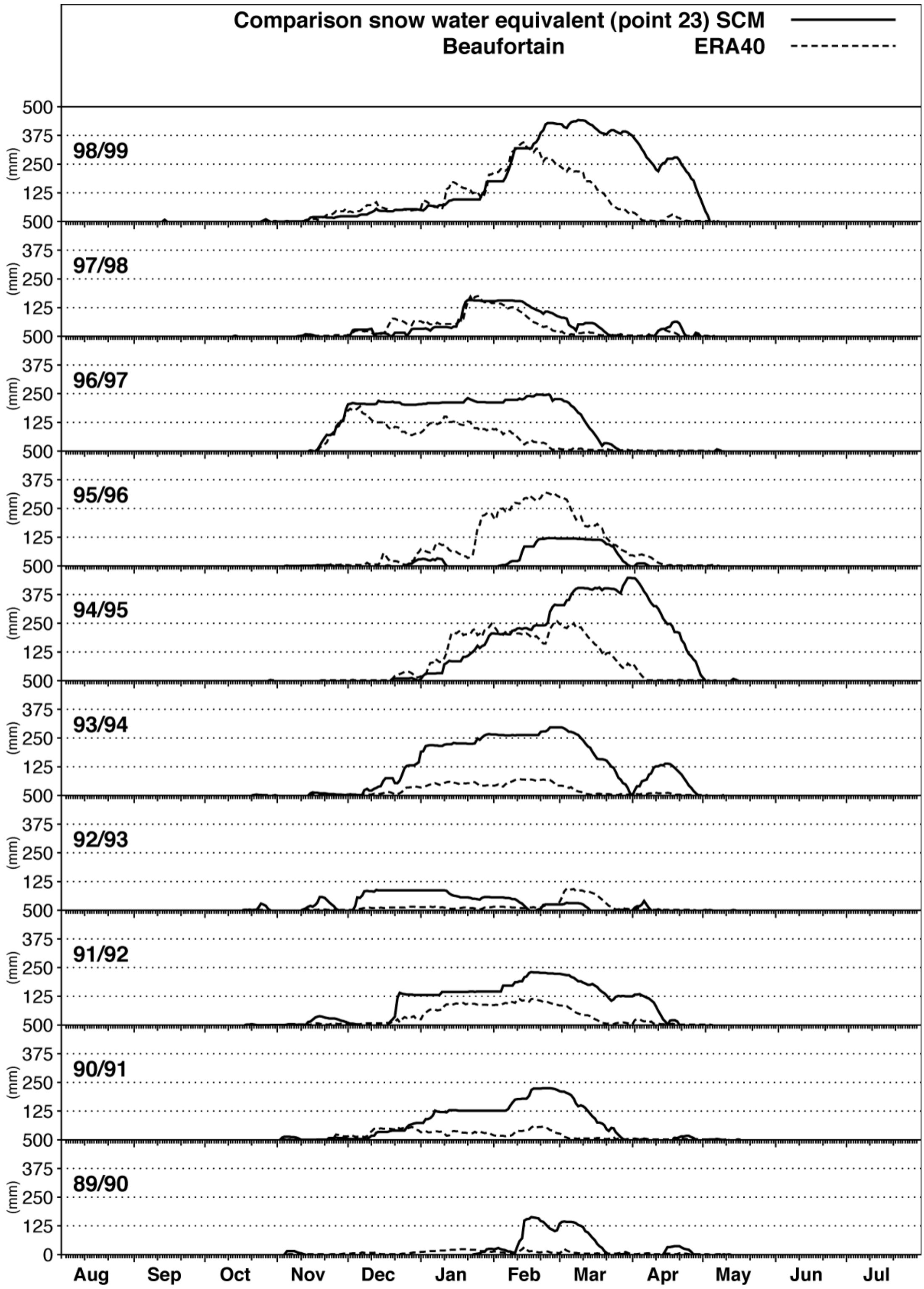

Figure 19(Continued): Comparison between the snow water equivalent produced by ERA-40 (point 46°N, 7°E, 1100 m a.s.l) and the Safran/Crocus analysis for the massif Beaufortain at 1200 m a.s.l.

7 Conclusion

This reports presents various validations of ERA-40, all focused on the French Alps region. The data used for validation are the ECMWF operational analyses, temperature observations at remote automatic weather stations in mountain, precipitation from synoptic stations and a snow climatology calculated by the analysis system SAFRAN coupled with the snow model CROCUS.

Concerning temperature, the ERA-40. results are very good at high elevation (very close to the Nivôse Bellecôte observations and operational analyses despite a slight warm bias).

Precipitation are quite well simulated when looking at the average on the region and on a monthly basis. However, the comparison results are less good when looking at individual stations (discrepancy between real orography and model orography). However snowfall are strongly underestimated and the interannual variability seems also underestimated. The spin up has been quantified on total precipitation and on snowfall.

ERA-40 snow cover simulations compare reasonably well with the Safran/Crocus climatology, despite the underestimation of Snowfall.

ERA-40 results are better than ERA-15 in some points

- precipitation amounts (based on 12/24H forecasts) seems more realistic
- snow cover (SWE) is better simulated.

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ANNEX

A1 SAFRAN

SAFRAN (a French acronym for Système d'analyse fournissant des renseignements à la neige) is an objective meteorological analysis system (Durand et al, 1993). Its specifications are to provide the input data of the snow model with 300m vertical increments on various aspects. For this purpose, the French Alps were divided into 23 regions considered as homogeneous from a meteorological point of view.

The analyses is completed in three steps:

- analysis of the temperature wind, humidity at 00, 06, 12, 18 H
- analysis of daily precipitation amounts
- hourly interpolations and calculation of radiation terms.

The data sources are meteorological mesoscale model outputs, radio-soundings, standard and automatic observation networks. The system uses an optimal interpolation scheme to derive the main variables (temperature, wind velocity, humidity, cloudiness). Precipitation amounts are derived from climatologically analysed fields (Bénichou and Le Breton, 1987) and observations by using an optimal interpolation method. Incoming short-wave and long-wave radiation are derived with an atmospheric radiative model (Ritter and Geleyn, 1992).

A2. CROCUS

CROCUS is a one-dimensional snow model that simulate the evolution of the snowpack characteristics as a function of weather conditions (Brun et al, 1989, 1992). The input data of the model are: air temperature, humidity, wind velocity, short-wave and long-wave incoming radiation, amount and phase of the precipitation at an hourly time step.

The model derives the internal state of the snowpack: temperature, liquid water content, density and snow types. To calculate the different variables, the snowpack is divided into layers parallel to the slope. Energy transfers are projected perpendicular to the slope. The thickness of the different layers is variable versus depth and time. Since the variations of the greatest amplitude occur near the surface, the thicknesses of the upper layers are smaller than the thicknesses of the bottom layers.

The phenomena taken into account are: energy exchanges inside the snowpack and at the snow-soil and snow-atmosphere interfaces, absorption of solar radiation with depth, phase changes between solid and liquid water, water transmission through snowpack, mass exchanges due to precipitation and water runoff, settlement, metamorphism of snow.

The evolution of temperature is calculated by using an implicit scheme centred in time, the evolution of the other variables is calculated with explicit methods. The albedo of the snow cover is calculated by the model itself and depends on the snow types near the surface.