2.11 Mean Maximum Snow Cover Water Equivalent

Fig. 1 Stored precipitation in snow cover and hoarfrost

The snow cover water equivalent is the depth of the layer of water that would develop across a level surface when the snow cover has melted, if the melted water were to remain on horizontal ground without any infiltration or evaporation. This parameter is generally measured in mm, with a 1 mm water equivalent being equal to 1kg/m².

The snow cover water equivalent can be described as the precipitation stored over a certain period. As such, the snow cover accumulation can be equated with the formation of a "reserve" of (solid) precipitation whereas the ablation of the stored precipitation can be seen as the reserves being "used up". Thus, the winter snow cover has a sustained impact on the hydrologic balance, sometimes beyond the winter half of the year, primarily due to the delayed effect of the fallen precipitation on the runoff process.

Methodology

In order to determine the snow cover water equivalent for the whole of Germany, a total of 617 Deutscher Wetterdienst (German Meteorological Service) stations were used. 183 of the stations measured the water equivalent (measurements taken three times per week when there was a 5 cm high snow cover) and took daily measurements of the snow cover depth and 434 stations only recorded the daily measurements of the snow cover depth.

At all stations with no measurements for the water equivalent, the latter was calculated with the help of the SNOW-K model on the basis of meteorological data and snow cover depth data (Rachner & Schneider 1992).
The simulation model, which is geared to long-term climatological studies, calculates the complete course of the snow cover's development on the basis of daily meteorological values. The snow cover accumulation is simulated using precipitation measurements with any systematic measurement errors corrected. Equally, the relationships between the type of precipitation and the air temperature are taken into account. The snow cover's metamorphosis and ablation processes are simulated with the aid of the meteorological parameters of air temperature, humidity and global radiation. These data are used to determine the key components of the heat exchange between the snow cover and the atmosphere. The internal processes within the snow cover (change in density and structure, water movement, retention and loss) are taken into account by location-specific parameters.
Any gaps in the water equivalent data series were filled by means of modelling. The reference period for all of the parameters shown is 1961 to 1990 (winter periods 1961/62 to 1990/91).

Map Structures

Map 2.11 "Mean Maximum Snow Cover Water Equivalent" gives an overview of the regional distribution of the mean maximum values, calculated on the basis of the annual maximums in the reference period. The map uses 1 km² grid fields. Different class intervals are used for the grid fields. In the value range < 100 mm the class intervals are 25 mm, in the range from 100 mm to < 300 mm the intervals are 50 mm. The ≥ 300 mm water equivalent values are divided into two classes: 300 mm to < 400 mm and an open-end class from 400 mm onwards.

Most of Germany's territory (approx. 70 %) is comprised of areas with altitudes of < 400 m above mean sea level. Around 20 % of the country's area is taken up by medium-altitude locations (between 400 m and 600 m above mean sea level) and only about 10 % is higher than 600 m above mean sea level (Map 1.1).

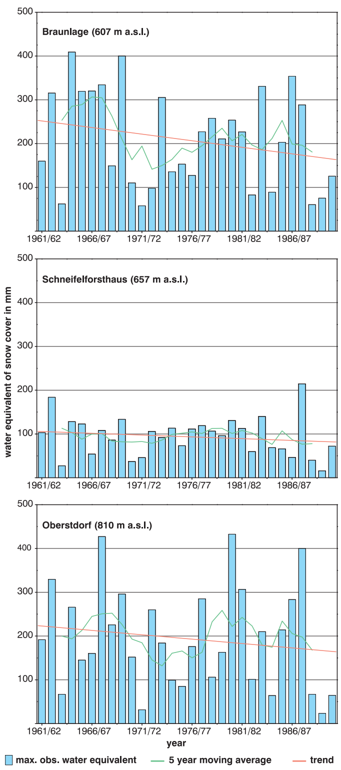

Fig. 2 Time series of the maximum water equivalent of snow cover

As with most meteorological parameters, extreme snow cover water equivalents tend to be related to altitude. However, it should be noted that it is hardly possible to detect these relationships at the lower altitudes nor the regional differences in the lowlands. It is not until the medium altitudes, starting from around 400 m above mean sea level, that we see clear dependencies on altitude and also regional differences. Equally, the extreme values increase specifical stronger with the altitude. This "non-linear" effect reflects different, altitude-dependent snow cover development conditions in the winter period (Map Set 2.10 "Mean Duration of the Snow Cover").

On the Norddeutsches Tiefland (North German Lowlands), the mean maximum water equivalent values reach between 20 mm and 30 mm. With the individual values varying considerably, the mean maximum values measured in the northwest are almost always approx. 20 mm whereas the threshold value of 25 mm is exceeded slightly in many areas in the northeast. Beside the regions on the North German Lowlands, large parts of Southern Germany, such as the Oberrheinisches Tiefland (Upper Rhine Plain) including Kraichgau and Wetterau, as well as parts of the Main region, also record mean water equivalent maximums of only around 25 mm. In the lower locations in the uplands of Sachsen (Saxony) and Thüringen (Thuringia), in many parts of the Alp foothills and the Schwäbisch-Fränkisches Stufenland (Swabian-Franconian scarpland) too, values of 50 mm are rare.

However, significant regional differences are obvious above 400 m above mean sea level, at the medium and high altitudes in the upland ranges. The Harz, Northern Germany's highest elevation, stands out considerably with its water equivalent values being higher than in all of the other upland ranges. The mean maximum water equivalent values in the uplands of Saxony and Thuringia (Erzgebirge and Thüringer Wald) and the Bayerische Waldgebirge (Bavarian wooded mountains: Bayerischer Wald, Oberpfälzer Wald) are also higher than the values recorded at similar altitudes in the West German uplands (Eifel, Westerwald, Hunsrück and Taunus) and in the Schwarzwald (Black Forest) and the Schwäbische Alb (Swabian Alps). This phenomenon cannot be explained by the regional distribution of the winter precipitation. Obviously, however, the snow cover's maintenance or permanence plays a role. This factor increases as the climate becomes more continental from the west/northwest to the east/southeast. This increase in maintenance is reinforced as the altitude of the terrain rises.

Table 1 Maintenance of snow cover (mean 1961/62 to 1990/91)

station	height in m a. s. l.	maintenance
Bremen	4	0,36
Schleswig	43	0,36
Aachen	202	0,29
Kassel	231	0,39
Berus	363	0,30
Schneifelforsthaus	657	0,57
Kl. Feldberg/Taunus	805	0,63
Kahler Asten	839	0,77
Angermünde	54	0,45
Görlitz	238	0,42
Chemnitz	418	0,45
Braunlage	607	0,69
Zinnwald-Georgenfeld	877	0,76
Schmücke	937	0,83
Brocken	1142	0,83
Fichtelberg	1213	0,82
Nürnberg-Kraftshof	310	0,37
Stuttgart-Echterdingen	397	0,37
Passau-Oberhaus	409	0,58
Weiden/Oberpfalz	438	0,49
München-Riem	527	0,46
Zwieselberg	615	0,70
Freudenstadt	797	0,67
Oberstdorf	810	0,73
Hohenpeißenberg	977	0,70

The snow cover's maintenance is best described using the quotients resulting from snow cover duration and snow cover time (Conrad 1935). In this regard, Map Set 2.10 (maps A, B and D) should also be consulted. The snow cover time is the period between the first day of the snow cover and the last day. Direct comparisons of the maintenance values for the Black Forest and the Bavarian wooded mountains showed that the values for the wooded mountains were considerably higher than the others. At the medium altitudes (approx. 500 m above mean sea level) the difference is around 15 %, on the ridges and summits the differences rise to about 20 %. A comparison of Aachen (202 m) and Görlitz (238 m) shows that the snow cover's maintenance is around 30 % higher in Görlitz (Table 1).

Temporal Variability of the Snow Cover Water Equivalent

The annual maximum values of the snow cover water equivalent recorded at selected stations (Fig. 2) exhibit a decreasing trend in the reference period. On the basis of the mean values presented in Map 2.11, the decreases in the medium-altitude and high locations of the mountains are between 30 % and 40 %. It should be added that the fact that these decreases are considerable in some cases is due to the rising number of light-snow winters. The fact that the absolute maximum water equivalent values are at the end of the reference period (Schneifelforsthaus 1987/88; Oberstdorf 1980/81) does not influence the multi-year trend, instead it reflects the increasing variability. The high overall variability of the values from year to year and the shortness of the reference period do not permit a clear statement to be made regarding the trend. When the mean is taken from all the annual maximums, characteristic features in the fluctuations in the time series become much more apparent. Thus, the time periods (consecutive years) which are lower than the mean and those which are higher then become visible (short-term persistence).

Figures 3a to 3c document the very varied development in the different winter periods during the reference period. Due to the need for fixed dates as a guide and the fact that the measuring dates do not usually fall on those fixed dates, simulated water equivalent values were used for the diagram. This also has the advantage that winter periods with only insignificant water equivalent volumes are also taken into account.

At some points in the reference period there is a clearly visible drop in the water equivalents. The graphs give an impression of the size of the "reserves" carried over from one month to the next due to solid precipitation being stored in the snow cover. Those reserves must be considered when assessing precipitation as a parameter of the hydrologic balance in the winter period.

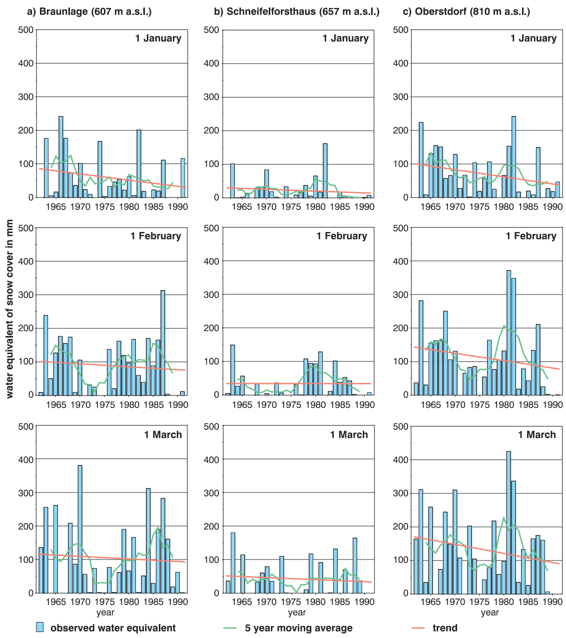

Fig. 3 Time series of the water equivalent of snow cover at 1. January, 1. February, 1. March at the stations (a) Braunlage, (b) Schneifelforsthaus and (c) Oberstdorf

The mean snow cover development process applicable for the reference period can be seen in Figure 4 (which shows mean measurements of the snow cover depth and mean simulated water equivalent values). In each case, mean daily values are used. The hydrograph curves provide clear evidence of characteristic features in the winter meteorological conditions in Central Europe. Even when the mean values are based on a 30-year period, the recurring meteorological phenomena, as thoroughly examined and described by Flohn (1954), still stand out. By comparing the charts for Schneifelforsthaus and Braunlage, one can also clearly see the strong maritime influence on snow cover development (shorter maintenance) in the Eifel region.

2.11 Mean Maximum Snow Cover Water Equivalent – Continuation

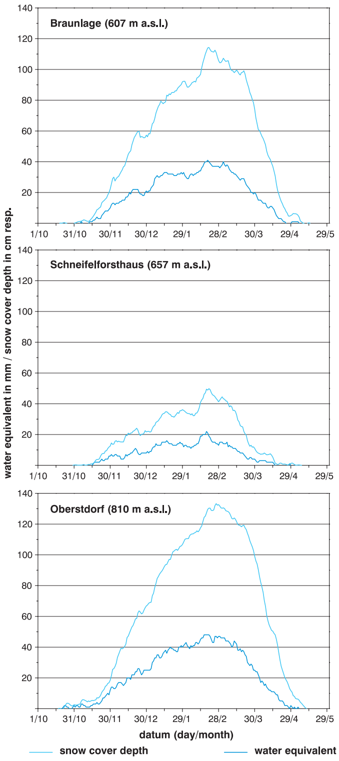

Fig. 4 **Mean course of snow cover development: snow cover depth and water equivalent**

▣ Regional Variability of the Snow Cover Water Equivalent

Figures 5a to 5c show the regional differences in the development of the mean maximum water equivalent values and the highest observed water equivalent values beyond the winter months for the months of September/October and May/June, too. These diagrams add essential information to that provided in Map 2.11 on the mean (annual) behaviour of the maximum snow cover water equivalent since they break that data down into detailed information for the winter months. The stations were chosen so as to ensure an even distribution which, however, also takes into account regional characteristics (particularly different altitudes). The stations are divided into the following regions:

- Fig. 5a: Northwestern and Western Germany
- Fig. 5b: Northeastern Germany
- Fig. 5c: Southern Germany

Even though the mountain ridges and summits only account for a very small proportion of the overall area examined and the values shown only apply to the region covered in that particular place, this data can be used to obtain an impression of the maximum possible snow cover in the region concerned. Regional differences in the distributions cannot be statistically validated due to the high variability of the data.

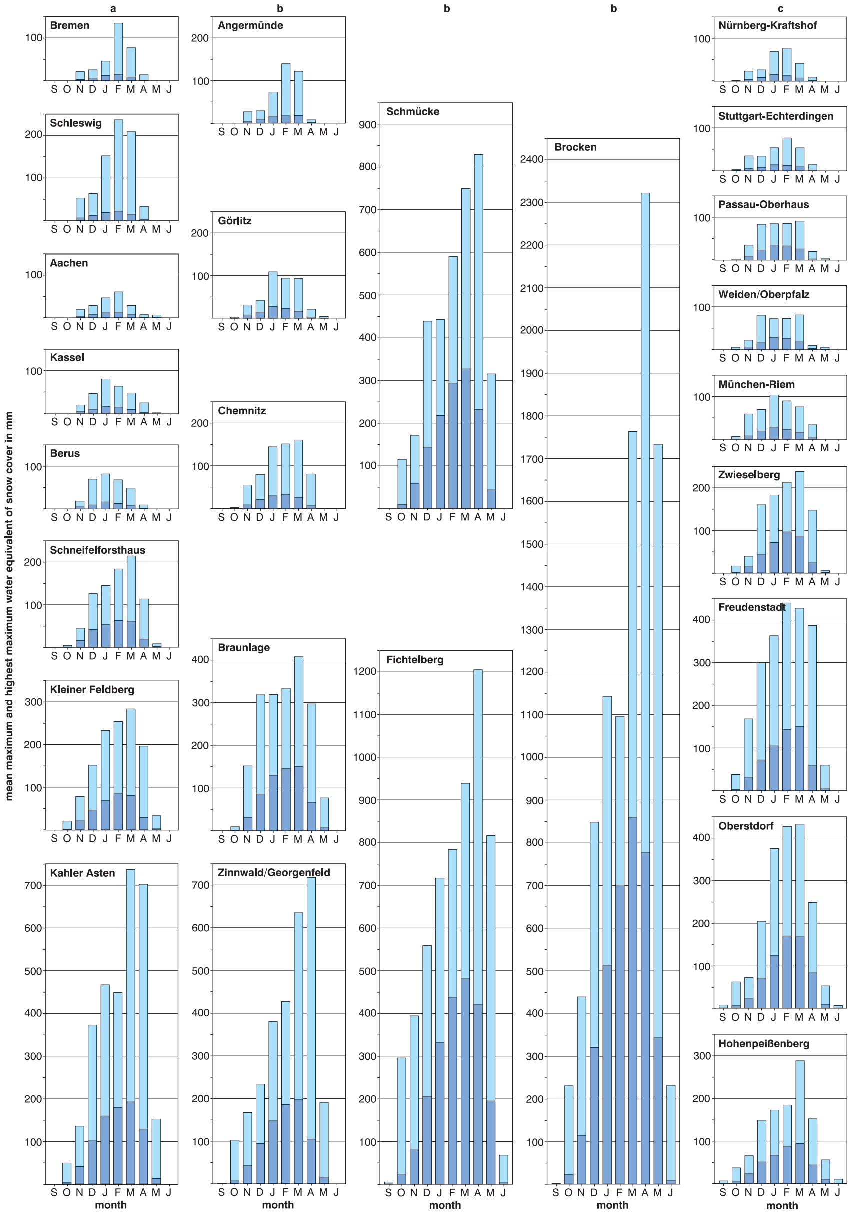

Fig. 5 **Mean maximum (▪) and highest maximum (▫) water equivalent of snow cover at selected sites in the winter months** (stations as given in Map 2.11)

(a) Northwestern and Western Germany
(b) Northeastern Germany
(c) Southern Germany

The highest values observed on the North German Lowlands, particularly in the coastal regions, are so high that they even exceed the maximum values recorded at stations at considerably higher inland locations. This phenomenon is caused by the extreme meteorological conditions in the winter of 1978/79. The ratio of the absolute highest values to the mean maximum water equivalent values reaches 10:1 and more in these cases. On the lowlands, these ratios usually only range from 5:1 to 7:1. As the height of the terrain increases, the ratio of these two parameters decreases, i. e. the extreme values start to vary less. At locations higher than 600 m above mean sea level, the factors are primarily only between 2 and 3, with 4 being achieved in isolated cases. As one would expect, the variability is most significant at the beginning and the end of the winter period.

The diagrams also show that the (mean) date on which annual maximum water equivalent values are registered moves towards spring as the terrain becomes higher. On the lowland and the low-altitude locations of the uplands, the extremes are already reached in January and February for the most part. In the medium-altitude and high locations, there is a shift to March and April (Map Set 2.10, Map C).

Practical Information

The individual annual maximum water equivalent values during the reference period can differ considerably from the mean values shown in Map 2.11 due to the extreme variability of the snow cover parameters. Figures 2 to 5 provide additional information on this aspect. The stations selected for the map (excluding ridges and summits) represent not only their location but also extreme snow cover-water-equivalent characteristics typical for their specific region.

Strictly speaking, any statement made concerning extreme snow cover water equivalent values only applies to conditions on open land. It is not possible to make general statements about the influence of forests on snow cover development and the generation of extreme water equivalent values. However, it can be taken as certain that the snow which accumulates on the forest ground is likely to be less than on adjacent open land because of the fallen precipitation being intercepted by the crown canopy. Furthermore, it can be assumed that a number of factors influence the snow cover's development, particularly forest parameters such as type, age and density (BRECHTEL 1984).