



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Eidgenössisches Departement des Innern EDI  
Bundesamt für Meteorologie und Klimatologie MeteoSchweiz

Arbeitsbericht MeteoSchweiz Nr. 235

# Weather Type Classification at MeteoSwiss

## Introduction of new automatic classification schemes

*Tanja Weusthoff*





**Arbeitsbericht MeteoSchweiz Nr. 235**

# Weather Type Classification at MeteoSwiss

Introduction of new automatic classification schemes

*Tanja Weusthoff*

## **Bitte zitieren Sie diesen Arbeitsbericht folgendermassen**

Weusthoff, T: 2011, Weather Type Classification at MeteoSwiss – Introduction of new automatic classification schemes, *Arbeitsberichte der MeteoSchweiz*, **235**, 46 pp.

## **Herausgeber**

Bundesamt für Meteorologie und Klimatologie, MeteoSchweiz, © 2011

MeteoSchweiz  
Krähbühlstrasse 58  
CH-8044 Zürich  
T +41 44 256 91 11  
www.meteoschweiz.ch

**Weitere Standorte**  
CH-8058 Zürich-Flughafen  
CH-6605 Locarno Monti  
CH-1211 Genève 2  
CH-1530 Payerne



### **Abstract**

This report gives an overview of the new automatic weather type classifications (WTCs) introduced at MeteoSwiss. Altogether, 10 different classifications based on two different methods are calculated on a daily basis replacing the former manual classifications. These automatic classifications have been re-calculated back to 01/09/1957 providing a long homogeneous time series for climatologic analyses.

The WTCs are evaluated with respect to their ability to explain surface climate variability of precipitation, temperature and sea level pressure. The results for the different meteorological parameters show considerable differences, but for all of them variability is explained better for WTCs with many classes compared to those with fewer classes. The automated classifications explain more variance in winter and autumn compared to spring and summer. A time series analysis shows that for the classification CAP9, there are almost no trends in the frequency of the individual weather classes.

The WTCs introduced at MeteoSwiss are based on single pressure fields. The analysis of WTCs, which are calculated with the same methods, from a new catalogue provided by COST 733 shows that the impact of additional input parameters for the classification procedure is large for temperature but negligible in the case of precipitation.

In addition, some examples of applications using the new WTCs are presented. It is not possible to identify one best WTC that is usable for all possible applications, but for each application the respective “best” WTC has to be chosen. The results presented in this report can help the users finding a suitable WTC for their specific application.



# Table of Content

<b>1</b>	<b><u>INTRODUCTION</u></b>	<b>9</b>
<b>2</b>	<b><u>DATA AND METHODS OF THE NEW CLASSIFICATIONS</u></b>	<b>10</b>
<b>3</b>	<b><u>DATA FOR THE EVALUATION</u></b>	<b>12</b>
<b>4</b>	<b><u>CLIMATOLOGICAL FREQUENCIES OF WEATHER TYPES (CAP9)</u></b>	<b>13</b>
<b>5</b>	<b><u>HOMOGENEITY OF CONVECTIVE / ADVECTIVE WEATHER TYPES</u></b>	<b>17</b>
<b>6</b>	<b><u>QUANTIFYING THE RESOLUTION OF SURFACE CLIMATE BY WEATHER TYPES USING THE EXPLAINED VARIATION</u></b>	<b>19</b>
<b>6.1</b>	<b>METHOD</b>	<b>19</b>
<b>6.2</b>	<b>PRECIPITATION</b>	<b>19</b>
<b>6.3</b>	<b>TEMPERATURE</b>	<b>20</b>
<b>6.4</b>	<b>SEA LEVEL PRESSURE</b>	<b>21</b>
<b>7</b>	<b><u>QUANTIFYING THE RESOLUTION OF SURFACE CLIMATE BY WEATHER TYPES USING THE BRIER SKILL SCORE</u></b>	<b>23</b>
<b>7.1</b>	<b>METHOD</b>	<b>23</b>
<b>7.2</b>	<b>PRECIPITATION</b>	<b>24</b>
<b>7.3</b>	<b>TEMPERATURE</b>	<b>27</b>
<b>7.4</b>	<b>SEA LEVEL PRESSURE</b>	<b>30</b>
<b>8</b>	<b><u>INFLUENCE OF ADDITIONAL INPUT PARAMETERS</u></b>	<b>32</b>
<b>9</b>	<b><u>APPLICATIONS OF WEATHER TYPES @ METEOSWISS</u></b>	<b>35</b>
<b>9.1</b>	<b>EVALUATING THE MODEL SKILL USING WEATHER TYPE CLASSIFICATIONS</b>	<b>35</b>
<b>9.2</b>	<b>WEATHER TYPE DEPENDANT NEIGHBOURHOOD VERIFICATION (T. WEUSTHOFF, MO)</b>	<b>37</b>
<b>9.3</b>	<b>COSMO-MOS (V. STAUCH, MO)</b>	<b>38</b>
<b>9.4</b>	<b>CLIMATOLOGICAL ANALYSES (S. BADER ET AL., 2011, KD)</b>	<b>39</b>
<b>10</b>	<b><u>CONCLUSIONS</u></b>	<b>40</b>



# 1 Introduction

Weather type classifications (WTCs) aim at identifying recurrent dynamical patterns (e.g., of sea level pressure) for a particular region. The resulting weather types can then be used to describe and analyze weather and climate conditions. For more than 60 years the so called Alpenwetterstatistik AWS (SMA, 1985) has been used at MeteoSwiss. The AWS contains 34 different and Alpine region specific parameters, including various weather indices, pressure gradients, details of the air mass and synoptic weather classifications after Schüepp (Schüepp, 1979) and Perret (SMA, 1985). All these parameters have been determined each day by the operational forecasters and were then archived and distributed to the customers once a month. The manual classifications have the disadvantage of being subjective, laborious and likely inhomogeneous in time. Therefore, new objective (automated) WTCs have been introduced at MeteoSwiss with the beginning of 2011, replacing the manual classifications from the AWS. An advantage of the automated classifications is certainly the homogeneity over time as they are calculated in an objective way using (re-)analysis data of the same numerical model (see also Chapter 5).

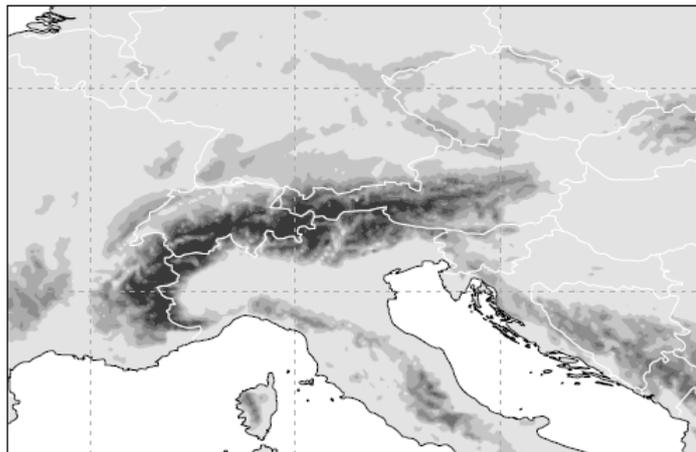
For the operational implementation, two methods (CAP = Cluster Analysis of Principal Components and GWT = GrossWetterTypes), have been identified in a MeteoSwiss wide selection process out of the variety of WTCs collected within the COST Action 733 “Harmonisation and Applications of Weather Type Classifications for European regions” (Philipp et al., 2010). The large catalogue of WTCs for the Alpine 7region provided by COST 733 (cost733cat-1) has been analyzed by Schiemann und Frei (2010) in terms of their capability to predict surface climate variations with a special focus on daily precipitation in the Alpine region. Based on the results of this work and the requirements of (potential) users at MeteoSwiss, the two above mentioned methods have been chosen. Due to different needs of the users (e.g. few classes for verification, many classes for climatological analyses), the methods are calculated with different settings leading to a total of 10 WTCs (see Chapter 2 for details). The WTCs have been re-calculated back until 01/09/1957 using reanalysis data of ERA40 and ERA Interim and thus provide a long time series for climatological analyses. The daily classifications after the reanalysis period (i.e. from 01/01/2011 onwards) are calculated based on the 12 UTC analysis of the numerical weather prediction model IFS of the ECMWF. In addition, the classifications of the forecasts up to 10 days in advance are calculated. If the verification of a numeric forecast model is done separately for each weather type, the forecaster can take into account the weather type dependant model quality using the predicted weather type.

The new automatic WTCs are available to users and shall provide new opportunities for understanding the dynamical causes of past climate variations, for bias-correcting numerical weather prediction models, for developing regional climate change scenarios, and for many other applications.

This report provides an overview over the characteristics of the new WTCs with respect to their ability to explain the variability of the main meteorological parameters. **Chapter 2** briefly describes the new WTCs and their data basis. In **Chapter 3**, the data used in the analysis is introduced. **Chapter 4** gives an overview on the frequencies of the different weather types (shown exemplarily by means of CAP9). Grouping convective and advective cases separately for each WTC, the homogeneity of convective / advective weather types of all WTCs is investigated in **Chapter 5**. In **Chapter 6 and 7**, the results of the two example evaluations (explained variation and Brier skill score) are presented. **Chapter 8** deals with the question of the benefit of additional variables included in the classification process, followed by a short overview of Applications of weather types at MeteoSwiss in **Chapter 9**. Finally, the main results of the report are summarized in **Chapter 10**.

## 2 Data and methods of the new classifications

For the generation of the new automatic weather type classifications, two different methods (CAP and GWT) are applied with different settings leading to a total of 10 classifications for the Alpine region (cf. *Figure 1* for the domain). The operational calculation of the WTCs uses the classification software “cost733class” (cost733class-0.31-07) which has been developed within the COST Action 733 (<http://geo21.geo.uni-augsburg.de/cost733wiki>, still under development). The data basis is the ECMWF ERA40 reanalysis (01/09/1957-08/31/2002), ERA interim reanalysis (01/09/2002-31/12/2010) and the operational IFS (from 01/01/2011). The WTCs are re-calculated from 1957 onwards to provide long statistics for climatologic applications and a large overlap with former manual classifications.



*Figure 1: Classification domain.*

In the following, the two methods GWT and CAP are briefly introduced. For more details the user is referred to the cost733class User Guide available from the COST 733 Wiki page (<http://geo21.geo.uni-augsburg.de/cost733wiki>). The different types of classifications calculated on an operational basis at MeteoSwiss are listed in Table 1. They have been evaluated in terms of the main meteorological parameters (precipitation, temperature, pressure) in order to provide characteristics of the different WTCs to the users.

**CAP** (Cluster Analysis of Principal Components) is a two-stage procedure comprising a principal component analysis to derive the dominant patterns of variability and a subsequent clustering procedure to classify time series of the principal components (Comrie, 1996; Ekstroem et al., 2002). The raw data is filtered before the classification procedure to prevent the influence of seasonal variability in the pressure data. The method can be applied to single pressure fields but also to a combination of different input data like, for example, sea level pressure and vorticity of the 500 hPa level (see Chapter 8). For operational use, the classification has been derived by means of mean sea level pressure using ERA40 as the reference period. The centroids of the so derived weather types have been stored for the assignment of actual dates to the respective weather types. This is done by calculating the distance between the actual pressure field and the centroids of the individual classes. The class number is chosen to be the one with the minimum distance, which is measured by the Euclidean distance metric. The classification is available with 9, 18 and 27 weather types.

The CAP27 weather type classification as provided by COST 733 in the first catalogue (cost733cat-1) has also been used to illustrate typical weather type situations in the Alps with the respective spatial distribution of precipitation, sea level pressure and temperature for HADES (Hydrologischer Atlas der Schweiz, Tafel 2.8; Schiemann and Frei, 2010).

**GWT** (GrossWetterTypes) is a weather type classification with predefined types. The method uses three prototype patterns and calculates the correlation coefficients between each field in the input dataset and the three prototypes (Beck, 2000; Beck et al., 2007). The three prototypes consist of a strict zonal pattern, a strict meridional pattern and a cyclonic pattern with a minimum in the centre. Depending on the three correlation coefficients and their combination each input field is classified to one class. The weather types contain basically the 8 main wind directions (N, NE, E, SE, S, SW, W, NW) and, depending on the num-

ber of types, additionally high and low pressure systems, and wind directions stratified with their cyclonicity. The method can only be used for single pressure fields. GWT is calculated based on sea level pressure and also based on 500 hPa geopotential height, each with 10, 18 and 26 types.

In addition to the pure GWT method, the adapted **GWTWS** is calculated based on the GWT classification with 8 types using 500 hPa geopotential heights as input data. Additionally, the mean wind speed in 500 hPa is used to differentiate convective and advective situations (threshold = 7 m/s). In case of advective situations (wind speed  $\geq$  threshold) the weather type derived by the 8 types GWT classification is taken, while in case of convective situations (wind speed  $<$  threshold), the mean sea level pressure (MSL) averaged over the classification domain serves as indicator for low (MSL  $\leq$  1010 hPa), high (MSL  $\geq$  1015 hPa) and flat (1010 hPa  $<$  MSL  $<$  1015 hPa or wind speed  $<$  3 m/s) pressure situations.

A compact description of the weather type classifications can be found on the MeteoSwiss websites ([http://www.meteoschweiz.admin.ch/web/en/services/data\\_portal/standard\\_products/Weather\\_type\\_class.html](http://www.meteoschweiz.admin.ch/web/en/services/data_portal/standard_products/Weather_type_class.html)). For each of the classifications, the characteristics of the different weather types are provided including frequency distributions and composite plots of precipitation, temperature anomalies and mean sea level pressure (MSL) or 500 hPa geopotential height (Z500) for the domains Europe and Alps.

**Table 1:** The new (automatic) weather type classifications introduced at MeteoSwiss.

<b>Classification</b>	<b>Short Description</b>
<b>GWT10_MSL</b>	classification with 8 wind directions and low / high pressure based on <b>mean sea level pressure</b>
<b>GWT10_Z500</b>	classification with 8 wind directions and low / high pressure based on <b>geopotential height at 500 hPa</b>
<b>GWT18_MSL</b>	classification with 2x8 wind directions (cyclonic and anticyclonic) and low / high pressure based on <b>mean sea level pressure</b>
<b>GWT18_Z500</b>	classification with 2x8 wind directions (cyclonic and anticyclonic) and low / high pressure based on <b>geopotential height in 500 hPa</b>
<b>GWT26_MSL</b>	classification with 3x8 wind directions (cyclonic, anticyclonic and indifferent) and low / high pressure based on <b>mean sea level pressure</b>
<b>GWT26_Z500</b>	classification with 3x8 wind directions (cyclonic, anticyclonic and indifferent) and low / high pressure based on <b>geopotential height in 500 hPa</b>
<b>GWTWS (11 types)</b>	classification with 8 wind directions and low / high / flat pressure based on <b>geopotential height in 500 hPa, mean wind in 500 hPa and mean sea level pressure</b>
<b>CAP9</b>	classification with 9 types derived by a principal component analysis and subsequent clustering for the reference period of ERA40 reanalysis, based on <b>mean sea level pressure</b>
<b>CAP18</b>	classification with 18 types derived by a principal component analysis and subsequent clustering for the reference period of ERA40 reanalysis, based on <b>mean sea level pressure</b>
<b>CAP27</b>	classification with 27 types derived by a principal component analysis and subsequent clustering for the reference period of ERA40 reanalysis, based on <b>mean sea level pressure</b>

### 3 Data for the evaluation

The 10 new automatic weather type classifications (WTCs) as well as the two former manual classifications Schüepp (Schüepp, 1979) and Perret (SMA, 1985) are evaluated with respect to precipitation, temperature, and mean sea level pressure. All WTCs are available on a daily basis and classes can be identified by numbers as given in Appendix A.

The reference data for **precipitation** is a gridded dataset of daily precipitation over the Alps with a grid spacing of 25 km covering the period from 1971 to 1999 (Frei and Schär, 1998; Frei and Schmidli, 2006). The gridded **temperature** data has been provided by the ENSEMBLES project (Haylock et al. 2008) in a spatial resolution of 0.5°. **Sea level pressure** has been taken from ERA40 reanalysis (Uppala et al. 2007) with a spatial resolution of 1°. Please note, that the ERA40 reanalysis data has also been used for the classification procedure. To be consistent, these three parameters are evaluated for the same time period, 1971 – 1999, which was also the period, Schiemann and Frei (2010) used in their analysis, and on the same grid, the 25 km regular grid of the precipitation data. Temperature and sea level pressure have been interpolated to that grid using the standard linear interpolation method of the data analysis tool Ferret (<http://ferret.pmel.noaa.gov/Ferret/>). It has to be mentioned that these interpolated fields can only poorly reproduce small-scale structures of temperature and pressure in the Alpine region. The evaluation results of Chapters 6 and 7 would probably show more spatial details if an interpolation were used that includes the small scale topography.

## 4 Climatological frequencies of weather types (CAP9)

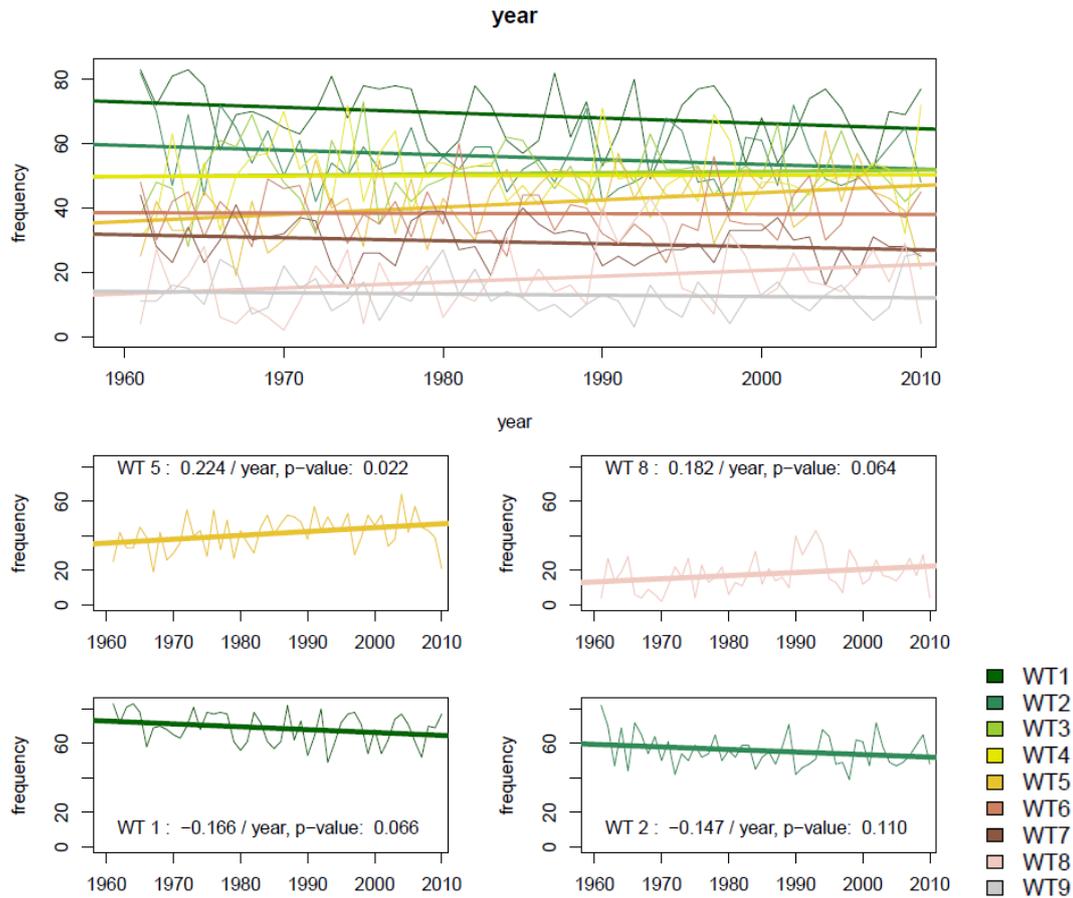
The frequencies of the individual weather types within each WTC vary for different seasons and individual years. This is shown exemplarily by means of the CAP9 weather type classification – the respective weather types are listed in Table 2. The yearly frequencies are displayed in *Figure 2* for the period from 1960 to 2009. The frequencies show considerable variations from year to year. The thick coloured lines represent the linear trends derived from the frequencies. Most weather type classes only show weak and insignificant trends over the considered 50 years. The weather types with the four largest trends are displayed in separate figures together with the slope of the trend line and the p-value of the t-test for a linear model with time as predictor as a measure for the significance. A slight decrease can be seen for WT1 (NorthEast, indifferent) and WT2 (West-SouthWest, cyclonic, flat pressure), while WT5 (High Pressure over the Alps) and WT8 (High Pressure over Central Europe) show an increase. However, only the increasing trend of WT5, which represents high pressure over the Alps, is significant on a 5% level (p-value less than 0.05). The respective composite plots for these four weather types are given in *Figure 3*, displaying the mean sea level pressure, temperature anomalies and precipitation. The two types with decreasing trends are relatively warm and wet advective situations, while the two weather types showing an increase are cold and dry high pressure situations.

Looking into the individual seasons, it becomes obvious, where the increase in the frequency of high pressure situations comes from. In *Figure 4* to *Figure 7*, the yearly frequencies of the weather types are displayed for the four seasons. Again, the weather types with the largest trends are plotted separately. In summer and fall, no significant trend could be detected over the considered 50 years. Especially in summer, the frequencies of the CAP9 weather types stayed almost constant. Significant trends are found in winter and spring. In spring, WT1, which is an indifferent north-easterly flow, shows a decrease of 0.1 days per year. The same decrease in WT1 is observed in winter. Furthermore, the two high pressure weather types (WT5 and WT8) show an increase of 0.15 and 0.17 days per year, respectively. The observed increase in the yearly frequencies is apparently due to an increase of high pressure situations in winter.

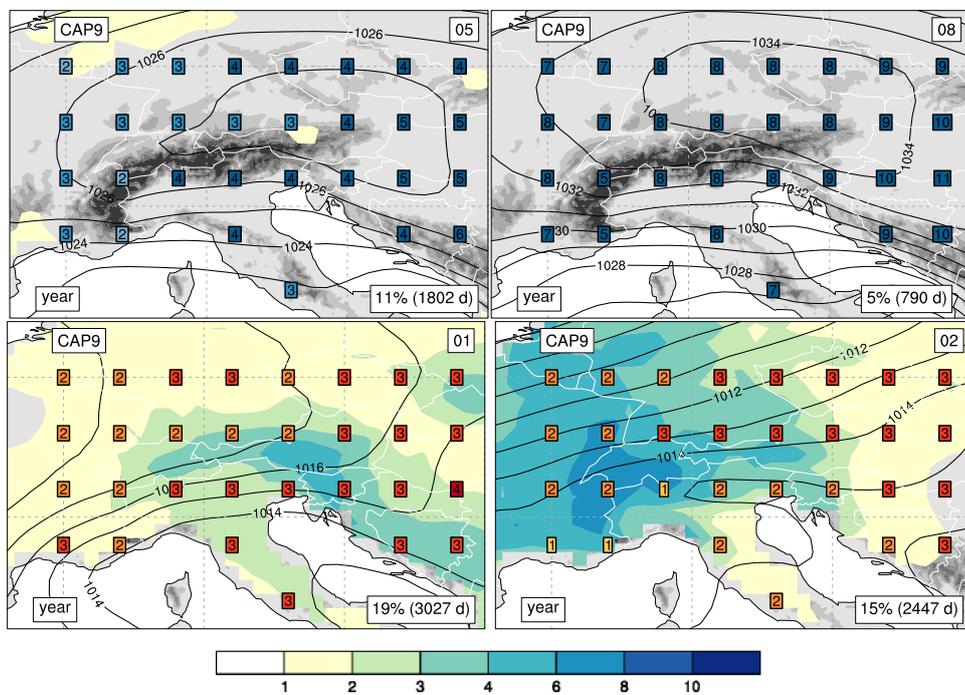
Not only show the trends large variations between the seasons, but also the frequency itself. WT1 is the most frequent weather type in summer with up to 40 % occurrence, while WT8 and WT9 (westerly flow over Southern Europe, cyclonic) rarely occur. The latter are more often observed in the other three seasons, which generally show a more balanced frequency distribution. In winter, the high pressure situation over Central Europe (WT8) occurs more often than in any other season. Also the high pressure over the Alps (WT5) occurs mainly in winter and fall, while spring and summer are dominated by advective weather types.

**Table 2:** List of CAP9 weather types.

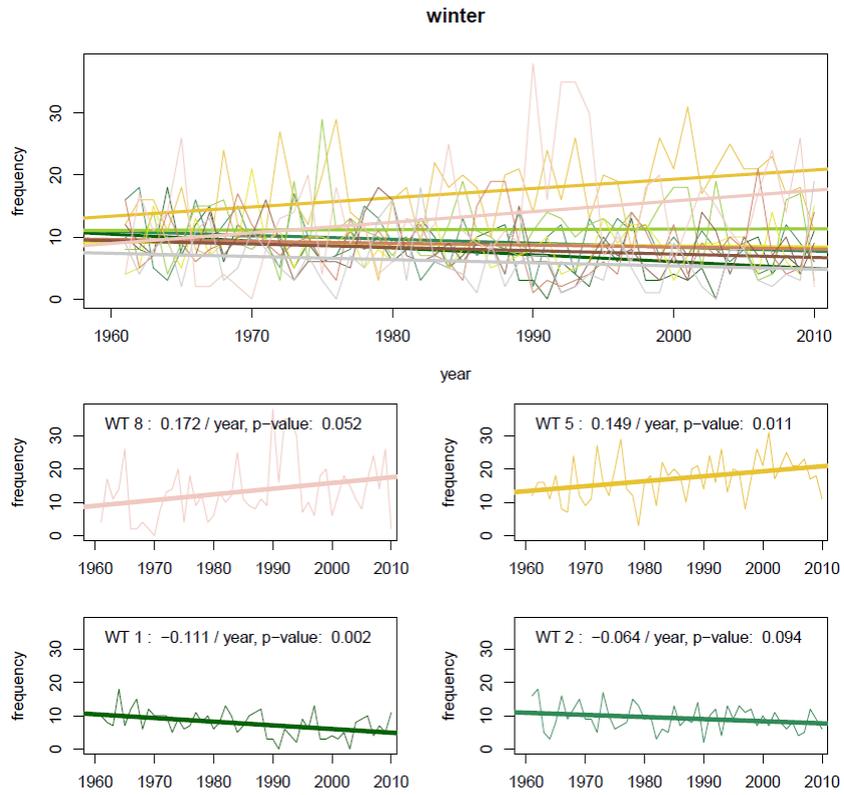
Type	CAP9
1	NorthEast, indifferent
2	West-SouthWest, cyclonic, flat pressure
3	Westerly flow over Northern Europe
4	East, indifferent
5	High Pressure over the Alps
6	North, cyclonic
7	West-SouthWest, cyclonic
8	High Pressure over Central Europe
9	Westerly flow over Southern Europe, cyclonic



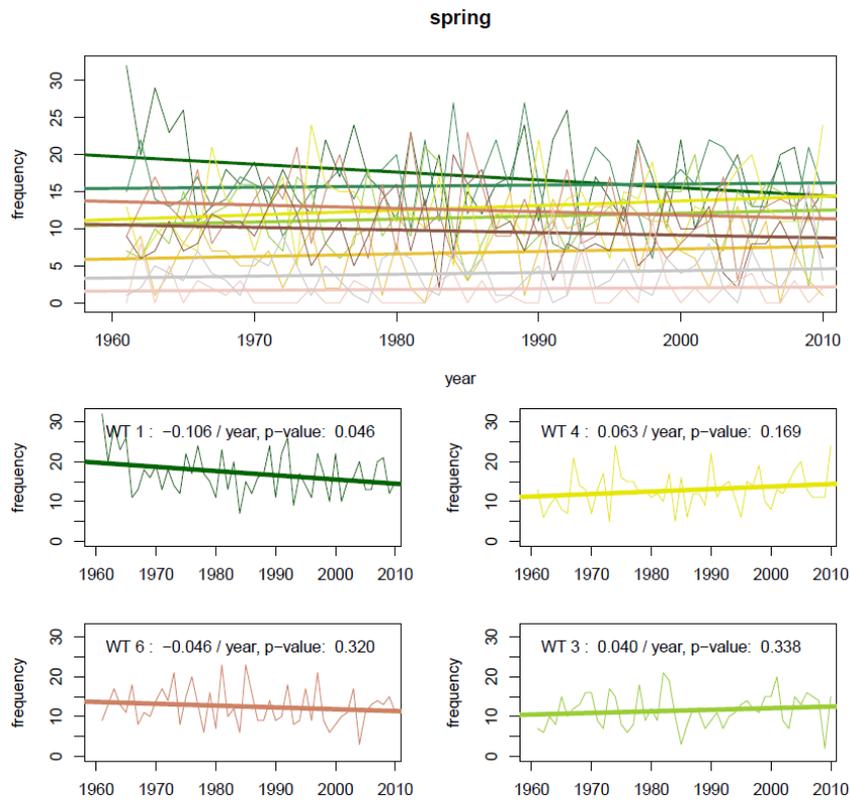
**Figure 2:** Yearly frequencies of CAP9 weather types and linear trends fitted to each weather type for the whole year. The weather types with the four largest trends are also plotted separately. The numbers give the slope of the trend line and the p-value of the t-test, respectively.



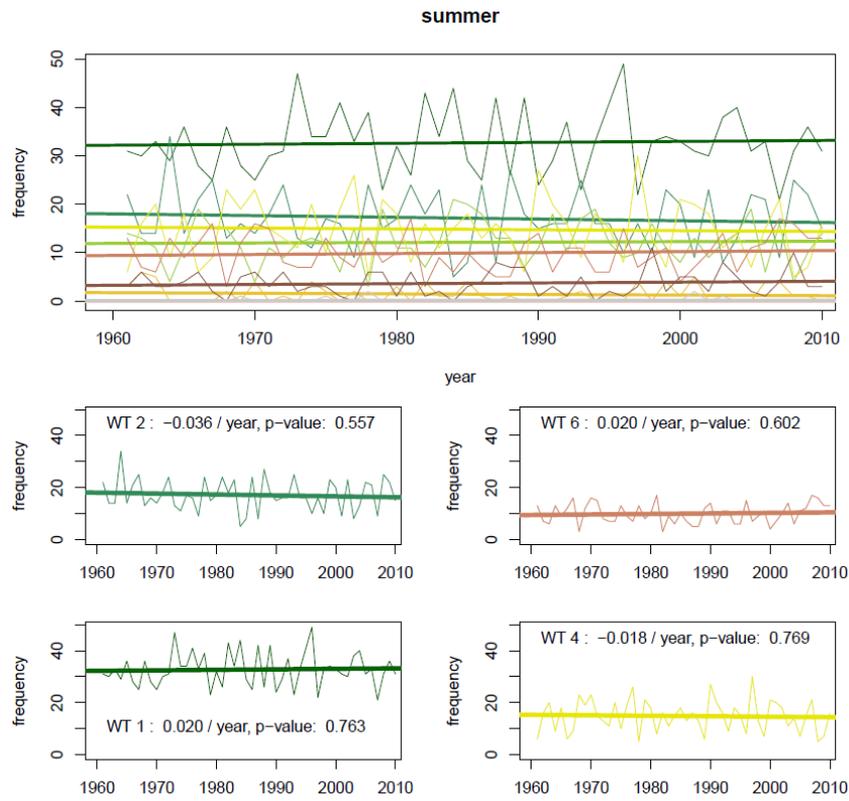
**Figure 3:** Composites of the weather types with the largest yearly trends displaying mean sea level pressure (black contour lines), temperature anomalies (boxes, red=warm, blue=cold) and precipitation (filled contours).



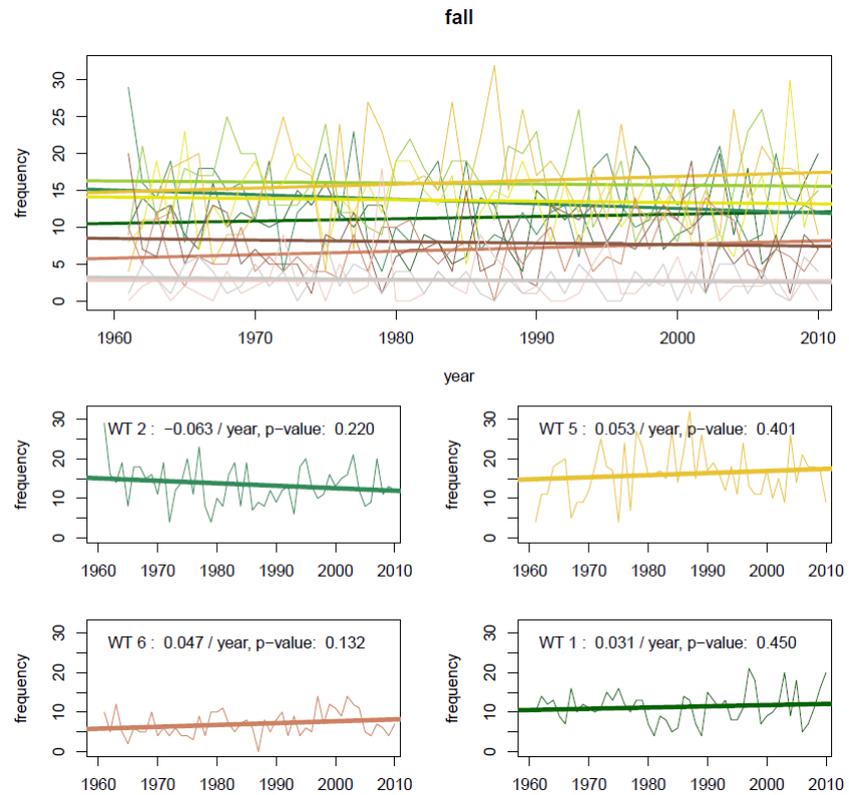
**Figure 4:** As Figure 2, but for winter.



**Figure 5:** As Figure 2, but for spring.



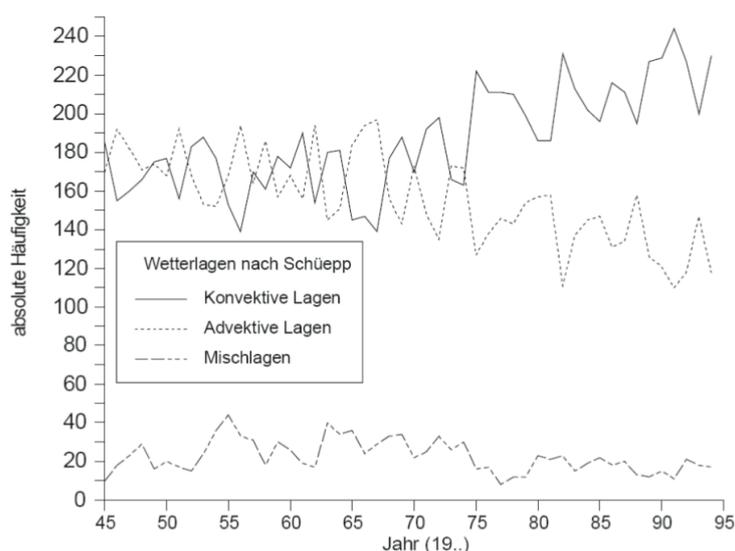
**Figure 6:** As Figure 2, but for summer.



**Figure 7:** As Figure 2, but for fall.

## 5 Homogeneity of convective / advective weather types

One of the advantages of an automatic weather type classification is the objective classification procedure. Classifying the weather by hand may enable a more detailed view of the weather situation but there might also be irregularities due to changes in, for example, the classifying person. Wanner et al. (2000) detected a trend in the number of occurrences of the Schüepp (Schüepp, 1979) main groups from the Alpenwetterstatistik (SMA, 1985). While the number of convective and advective cases stayed relative constant from 1945 to 1975 there has been observed a sudden increase in the number of convective types together with a decrease of the advective cases (see also Salvisberg (1996) and Jetel (2009)). In this chapter, the new automatic classifications are evaluated in order to see whether this trend can also be found. It also needs to be mentioned that the data basis for the manual classification is different from that used for the automatic classifications and the “inhomogeneities” might also be a consequence of the different input data. However, especially for climate related applications, the homogeneity of the classifications is of high importance.

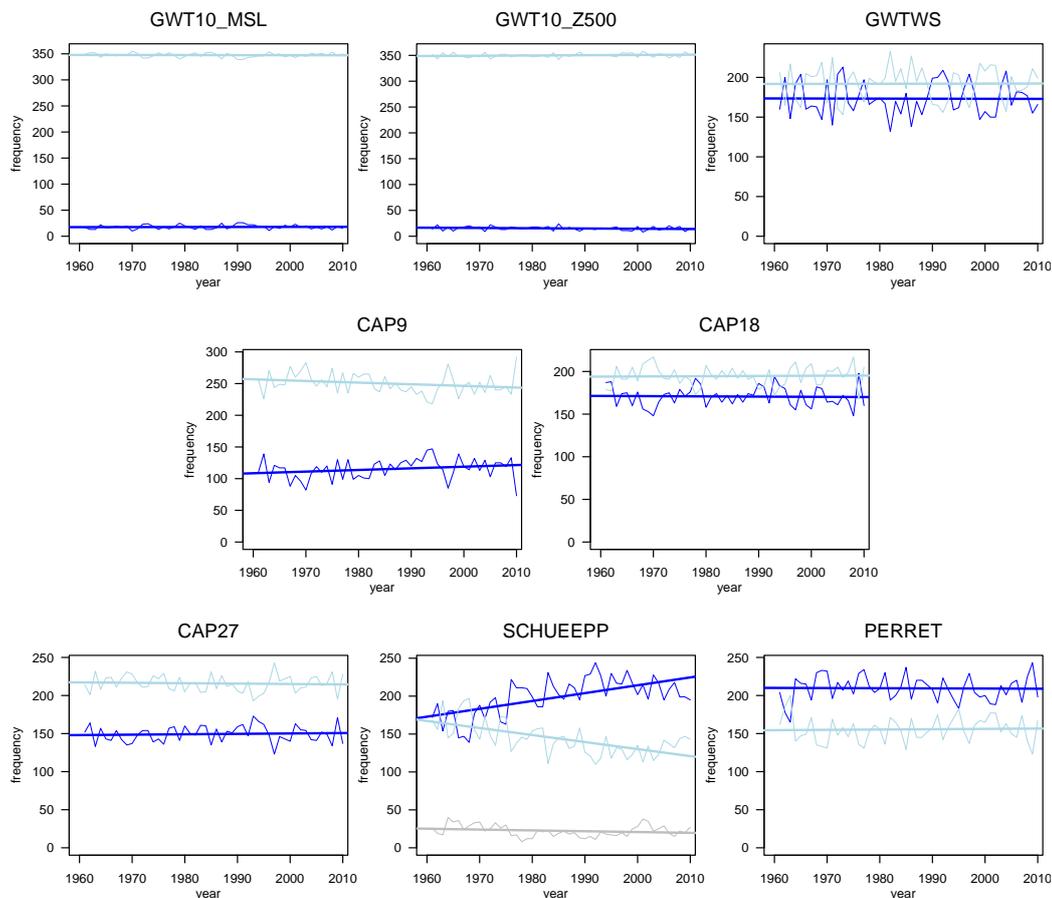


**Figure 8:** Number of occurrences of Schüepp main groups from 1945 till 1994. The main groups consist of convective types (solid), advective types (short dashed) and mixed types (long-short dashed), from Wanner et al. (2000).

The differentiation between convective and advective weather types is not straightforward in the case of the new automatic weather type classifications. In the case of GWT type classifications one may simply attribute the wind directions as advective and all the rest as convective cases leaving out mixed cases. This leads for the pure GWT methods to a very small number of convective cases due to an extremely rare classification of high and low pressure situations. This seems to be better in the adapted GWTWS method, where the total numbers of convective and advective cases are comparable to those of Schüepp. The Hanssen-Kuipers skill score calculated as an indicator for the agreement between GWTWS and Schüepp in differentiating advective and convective cases has a value of  $KSS = 0.37$ . No other separation into advective and convective GWTWS classes yielded a similarly high correspondence (in terms of Hanssen-Kuipers) with Schüepp. The CAP classifications similarly differentiate convective from advective cases, when the cases that were identified as advective but under flat pressure conditions are also attributed to the convective group. See Appendix A for the complete assignment of weather types to the two groups.

Figure 9 shows the numbers of occurrences for the new automatic weather types together with Schüepp and Perret, the trends derived from a linear regression are given in number of occurrences per year in Table 3. From the GWT classifications only one for each classification basis (MSL, Z500) is shown as the different type numbers do not differ in the differentiation of convective and advective situations. All automatic classifications identify more advective than convective cases, while Schüepp shows during the first years a comparable number of advective and convective cases and beginning with the 1970s clearly more convective cases. The larger scale weather type classification Perret identifies also more convective than advective cases, but does not show any considerable trend. Moreover, none of the new automatic

weather type classifications shows the clear trend observed for the Schüepp convective and advective cases. There is a slight trend observable in the case of CAP9, but the only significant trend is the one found for the Schüepp classification.



**Figure 9:** Number of occurrences of convective (dark blue) and advective (light blue) weather types for the years 1958 to 2009 (thin lines) and linear regression (thick lines).

**Table 3:** Trends in the number of occurrence of advective and convective weather types for the different weather type classifications. Given are the slope of the linear trend in occurrences per year and the p-value of the t-test for a linear model with time as predictor.

	advective		convective	
	slope [occ./year]	p-value	slope [occ./year]	p-value
CAP9	-0.259	0.109	0.258	0.108
CAP18	0.025	0.830	-0.026	0.827
CAP27	-0.053	0.622	0.052	0.626
GWT10_MSL	-0.012	0.764	0.011	0.777
GWT10_Z500	0.049	0.198	-0.050	0.181
GWT18_MSL	-0.012	0.764	0.011	0.777
GWT18_Z500	0.049	0.198	-0.050	0.181
GWT26_MSL	-0.012	0.764	0.011	0.777
GWT26_Z500	0.049	0.198	-0.050	0.181
GWTWS	0.010	0.962	-0.011	0.960
SCHUEEPP	<b>-0.927</b>	<b>0.000</b>	<b>1.036</b>	<b>0.000</b>
PERRET	0.042	0.798	-0.021	0.900

## 6 Quantifying the resolution of surface climate by weather types using the Explained Variation

### 6.1 Method

An adequate method to quantify the ability of the WTCs to explain daily variations of meteorological parameters is the evaluation of explained variation. The explained variation (EV) measures the proportion to which a mathematical model accounts for the variation of a given data set. The EV presented in this chapter has been calculated using the procedure implemented in the cost733class software. According to Beck and Philipp (2010), the EV is hereby determined on the basis of the ratio of the sum of squares within weather types (WSS) and the total sum of squares (TSS):

$$EV = 1 - \frac{WSS}{TSS}$$

The sum of squares is calculated as the sum of the squared distances from any point in the data set to the mean of the data:

$$WSS = \sum_{j=1}^l \sum_{i=1}^n (y_{ij} - \bar{y}_j)^2 \quad \text{and} \quad TSS = \sum_{j=1}^l \sum_{i=1}^n (y_{ij} - \bar{y})^2$$

Here,  $y_{ij}$  is the respective data point (time step  $i=1\dots n$ ; weather type  $j=1\dots l$ ),  $\bar{y}_j$  is the estimate of the mean for weather type  $j$  and  $\bar{y}$  is the estimate of the total mean. As we consider areal parameters, the deviation at each pixel is added to the total sums.

It needs to be mentioned that the EV is very sensitive to extreme events and the respective errors, due to the fact that it is based on squared differences. This is especially important in the case of daily precipitation accumulations, which usually have a skewed distribution. Furthermore, the score shows a distinct sensitivity to the number of weather types in the sense that it increases with increasing number of types, which has also been shown by Beck and Philipp (2010). Therefore, WTCs with different type numbers should not be compared.

The EV is evaluated on a monthly, seasonal and yearly basis using the data introduced in Chapter 3 and for the meteorological parameters precipitation, temperature and sea level pressure.

### 6.2 Precipitation

*Figure 10* displays the yearly cycle of the explained variation for daily precipitation in the Alpine region. All WTCs show a minimum in summer and a maximum in winter. The values of the EV range between 0.1 and 0.25. This means that for single months less than 1/4<sup>th</sup> of the precipitation variability can be explained by the WTCs. Interestingly, the EV shows a continuous decrease between January and May, but a quite abrupt rise in September. This asymmetry is observable for all WTCs except for Schüepf and GWTWS.

*Figure 11* shows the seasonal results of the EV (given as symbols according to the legend) as well as the values for the whole year (black circles). The EV for the whole year is small compared to that for individual seasons; only the values for summer are lower for most WTCs. As mentioned above, the EV is sensitive to the number of types and only WTCs with the same number of types should be compared. Generally, CAP shows higher values than GWT with the same number of types, but also larger variations between the seasons. Only in summer, some GWT classifications perform slightly better than the respective CAP classification. GWT with 10 types ranks worst for each period. Out of the WTCs with few weather types, GWTWS gives best results with respect to precipitation in the Alps, followed by CAP9.

In order to test the robustness of these results, two shorter periods (1971-1985 and 1986-1999) have been additionally evaluated separately. Despite some differences in the individual EV results, the general conclusions are also valid for the shorter time periods.

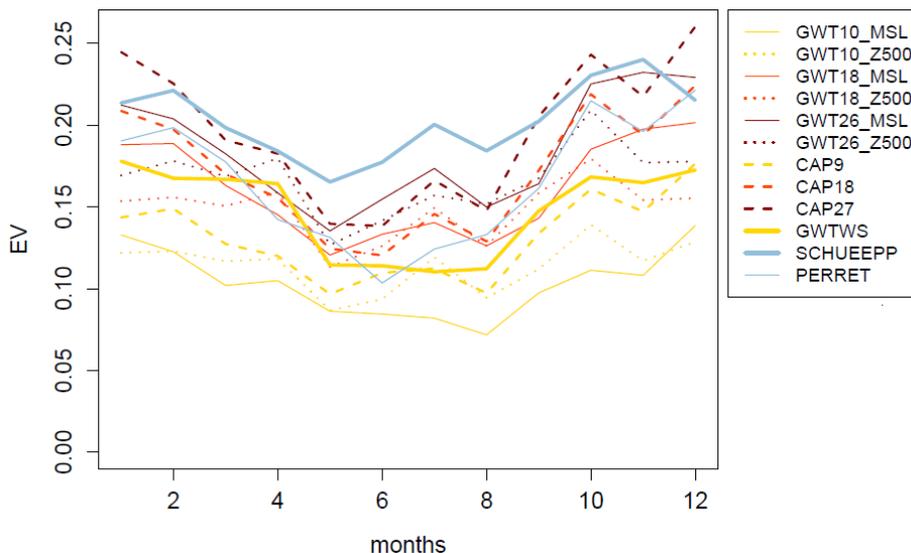


Figure 10: Yearly cycle of the explained variation of precipitation for all classifications.

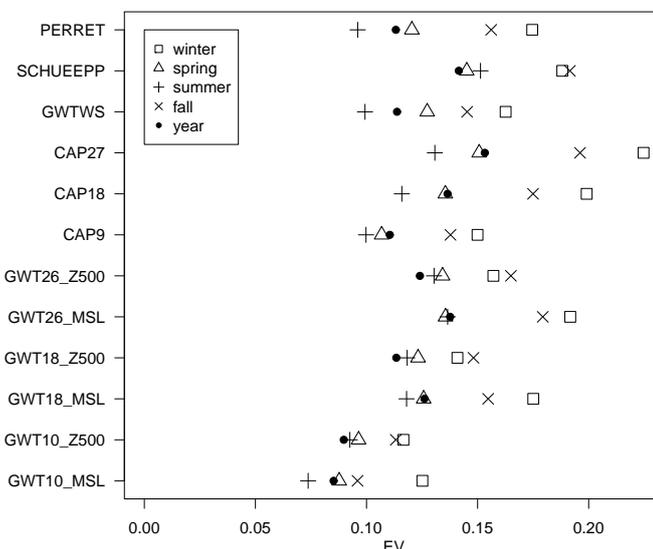


Figure 11: Inter-seasons-variability of the explained variation of precipitation for the different classifications.

### 6.3 Temperature

Temperature variability is apparently better explained by weather types than precipitation with an EV ranging from 0.1 to more than 0.5. The best result in terms of explained variation has been found for the two manual classifications, as long as short time scales (i.e. months) are considered (Figure 12). The yearly cycle shows a maximum of EV for Schüepp in summer with values of more than 0.5. This cannot only be explained by the higher number of weather types, but most probably the good results of Schüepp are due to the fact that the Schüepp classification uses several input parameters like, for example, sea level pressure and geopotential height in 500 hPa. The results presented in Chapter 8 concerning the impact of additional variables as input for the classification support this assumption.

GWT based on 500 hPa geopotential height shows a shape similar to that of Schüepp with a maximum in June. GWT classifications based on mean sea level pressure, in contrast, reveal the maximum values in winter and CAP and GWTWS show only small variations of EV over the year. Almost all WTCs have a lower EV for the whole year than for the individual seasons, which can be seen in Figure 13. Only the CAP classifications show considerable higher values for the longer period. On a yearly basis, the three CAP classifications explain the variation in temperature best of all WTCs with values of up to 30%. Out of

the WTCs with few types, GWTWS and CAP9 give overall best results. Only in winter, GWT10\_MSL outperforms those two revealing results comparable to those of the GWT classifications with more weather types.

Evaluating the first and the second period separately, the main results could be confirmed. The second period (1986-1999) generally revealed higher EV values than the first period (1971-1985).

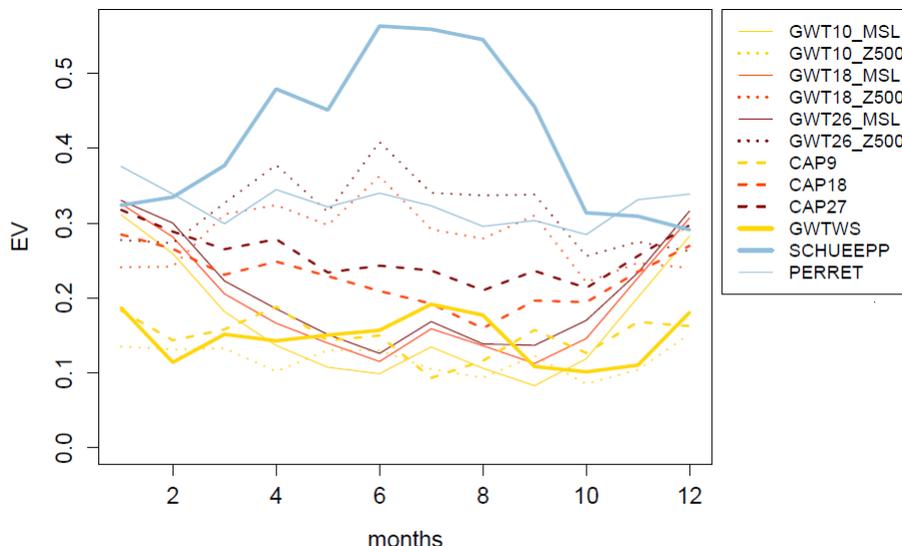


Figure 12: Yearly cycle of the explained variation of temperature for all classifications.

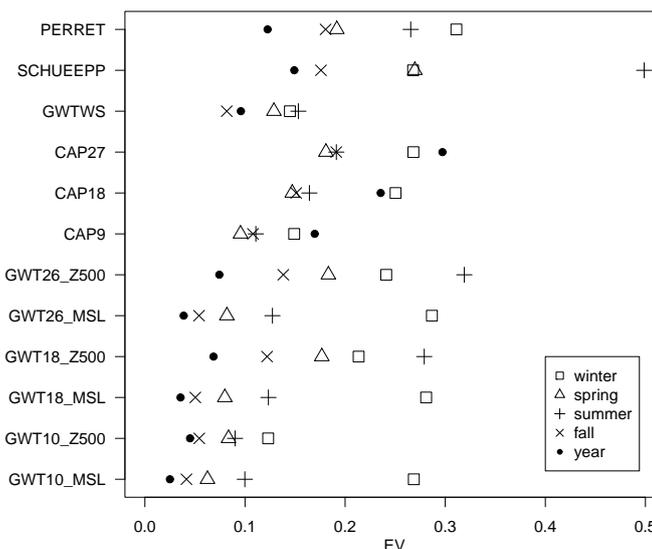


Figure 13: Inter-seasons-variability of the explained variation of temperature for the different classifications.

### 6.4 Sea level pressure

For all time scales (months, seasons and year) CAP classifications explain more than 80% of the daily sea level pressure variation (Figure 14 and Figure 15). This is due to the fact that these weather types are derived from sea level pressure by means of a principal component analysis and subsequent clustering. Some of the other WTCs are also based on sea level pressure, but they are using predefined weather types governed by the main wind directions. The EV is consequently lower for these WTCs. For all WTCs, the variation between months and seasons is much smaller than that found for precipitation and temperature. Apart from the CAP classifications, the two manual classifications give best values on all time scales, followed by the GWT classifications, which show increasing values for increasing weather type numbers. In winter, the GWT classifications based on 500 hPa geopotential give equal or better results than those based on sea level pressure, while they have a considerable lower value of EV in sum-

mer. Also, for all of the other WTCs, the EV in summer is considerably lower than for the other seasons. An additional evaluation of two shorter periods (1971-1985 and 1986-1999) confirmed these results.

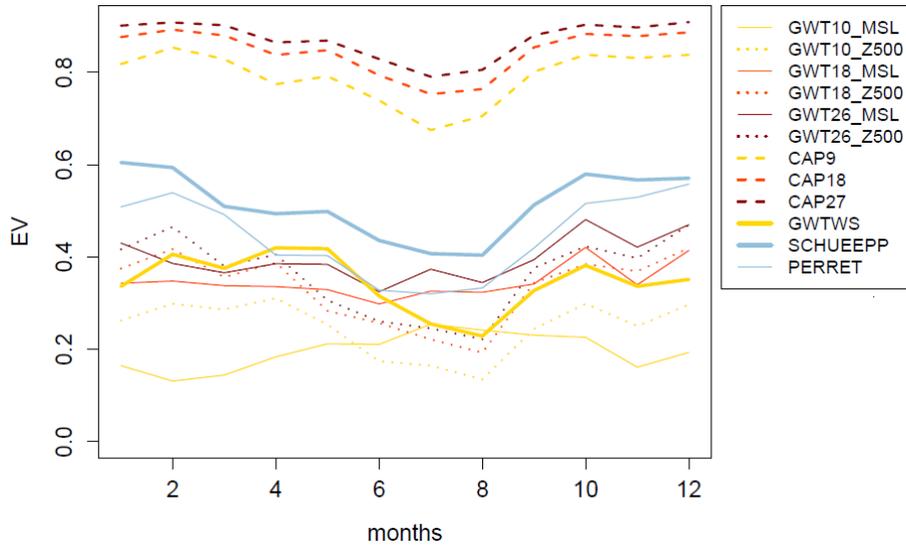


Figure 14: Yearly cycle of the explained variation of sea level pressure for all classifications.

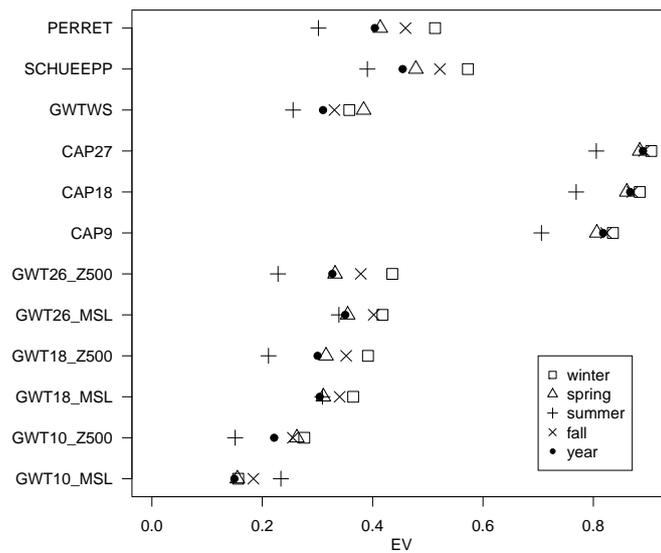


Figure 15: Inter-seasons-variability of the explained variation of sea level pressure by the different classifications.

## 7 Quantifying the resolution of surface climate by weather types using the Brier skill score

### 7.1 Method

In order to quantify the capability of the weather type classifications (WTCs) to describe surface climate variations, the WTCs are evaluated using the approach of Schiemann and Frei (2010) which is based on the Brier skill score (BSS). In addition to precipitation, which was also presented in the cited work, temperature and sea level pressure are looked at. The respective data is described in Chapter 3. The evaluation is done for the time period from 1971 to 1999.

Schiemann and Frei (2010) consider a WTC in an application with a dichotomous variable (e.g. occurrence of error / no-error) as a framework that yields a probabilistic forecast. The empirical frequency  $y_i$  of the event in WT  $i$  ( $i = 1 \dots I$ ) can be estimated by observations available over a reasonably long period of time. When a day  $k$  is attributed to WT  $i$ ,  $y_i$  can be considered as a prediction of the probability of the event to occur on day  $k$ . Such a prediction is consequently available for all days  $k = 1 \dots N$  classified into weather types. A common measure for the skill of binary probabilistic forecasts is the Brier skill score, which compares the actual value of the Brier score to those from a perfect and from a trivial reference prediction.

$$BSS = \frac{BS - BS_{ref}}{BS_{perf} - BS_{ref}}$$

In a perfect forecast, events and non-events would be perfectly separated by weather types and the Brier score would consequently have a value of  $BS_{perf} = 0$ . Using climatologic prediction as reference, with  $y_i$  being the observed frequency of the event independent of the weather type ( $y_i = \bar{o}$ ) yields  $BS_{ref} = \bar{o}(1 - \bar{o})$ . The skill score for WTC evaluation then follows as

$$BSS = \frac{\frac{1}{N} \sum_{i=1}^I N_i (y_i - \bar{o})^2}{\bar{o}(1 - \bar{o})}$$

For the purpose of WTC evaluation, BSS thus simplifies to the resolution term of the classical Brier skill score, because a WTC is a perfectly calibrated probabilistic forecast and hence the reliability term is equal to zero (see Murphy 1973). The BSS ranges between 0 and 1 with larger values indicating more skill. One characteristic of the BSS is that the numerator increases if there are large deviations of the conditional event frequency from the climatologic unconditioned frequency. Thus, WTCs encompassing populated types with large deviations from the climatology are particularly skilful.

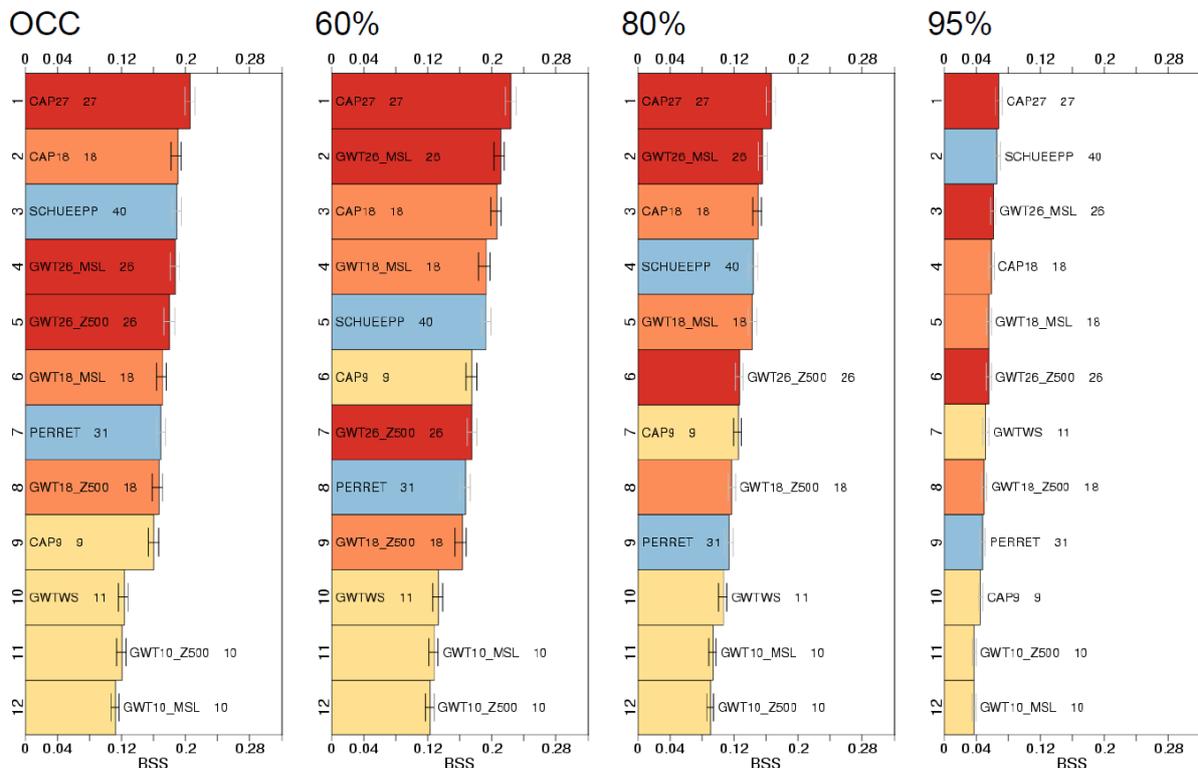
The BSS is calculated for each WTC using different thresholds to define an event. For precipitation, the thresholds are defined by occurrence (OCC) and three different quantiles (60%, 80%, 95%), which are determined for each season and each grid point of the data separately. An event is counted if the precipitation exceeds the value of the respective quantile. For temperature and sea level pressure, slightly different quantiles are used: 10%, 50%, 75% and 90%.

The evaluation is done for the whole year and also for the four individual seasons. The different WTCs are then ranked according to their spatial mean BSS. The sampling uncertainty of the skill has been determined by a non-parametric bootstrap resampling described in Schiemann and Frei (2010). The BSS has also been calculated pixel-wise allowing for a spatial differentiation of the skill.

## 7.2 Precipitation

The values of the BSS calculated for precipitation range between 0.04 and 0.28. The BSS generally increases with increasing number of weather types, which was also found by Schiemann and Frei (2010). Small and moderate precipitation thresholds give a higher BSS than extreme events. For all four thresholds shown in *Figure 16*, CAP27 has the highest BSS, while the two GWT10 classifications show the lowest scores. This is similar in the different seasons (*Figure 17*). Only in summer, the two GWT26 classifications and Schüepp are slightly better. Generally, the two manual classifications Perret and Schüepp (with each containing more than 30 types) range somewhere in between the best and the worst performing classifications with a tendency to better ranks. The BSS reveals higher values in winter and fall for all WTCs, while summer and spring scores are lower. This could also be observed in the results of the explained variation presented in Chapter 6.2.

The spatial analysis shown in *Figure 18* gives an impression about the regional characteristics of the WTCs. Most WTCs show the highest BSS values in the northern and western part of the domain (e.g. CAP). The GWT classifications based on 500 hPa geopotential height reveal higher skill in the south of the Alps, while those based on mean sea level pressure have better skill on the alpine ridge and in the north of the Alps. The manual classifications show a more equally distributed skill.



*Figure 16: BSS for precipitation covering the whole year and using different thresholds.*

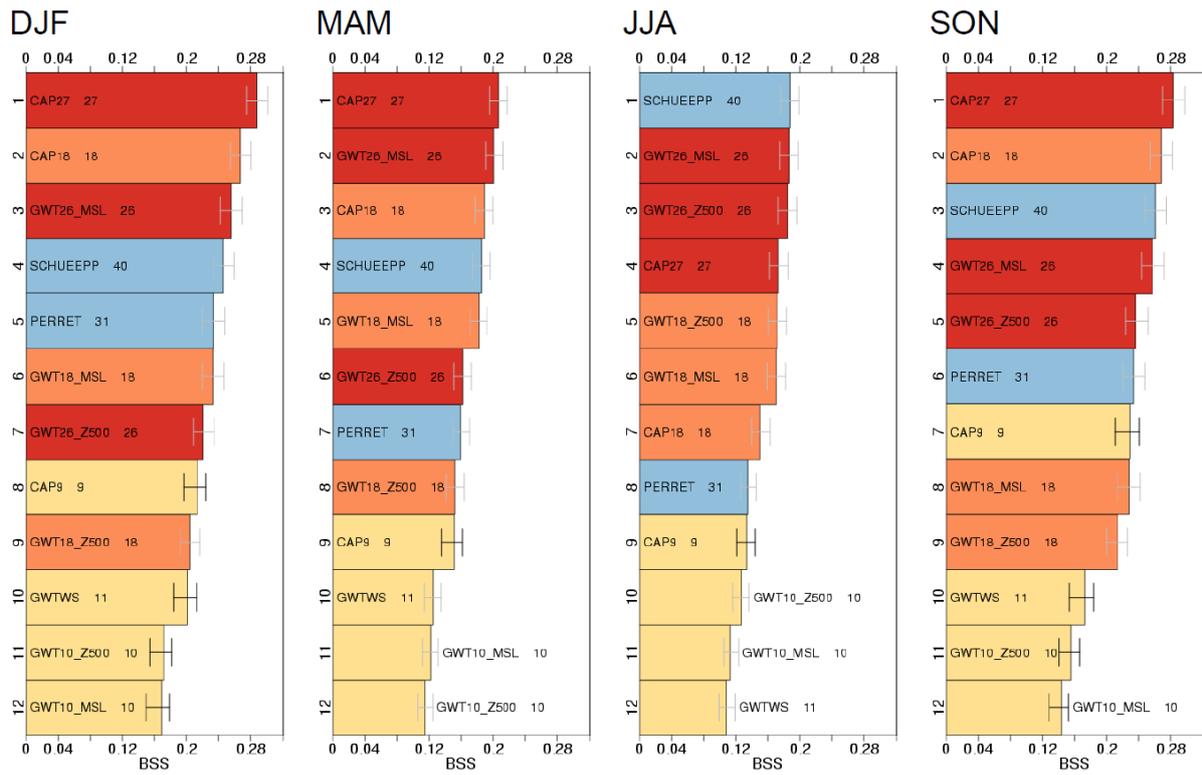


Figure 17: BSS for precipitation in the different seasons and for the 60% quantile.

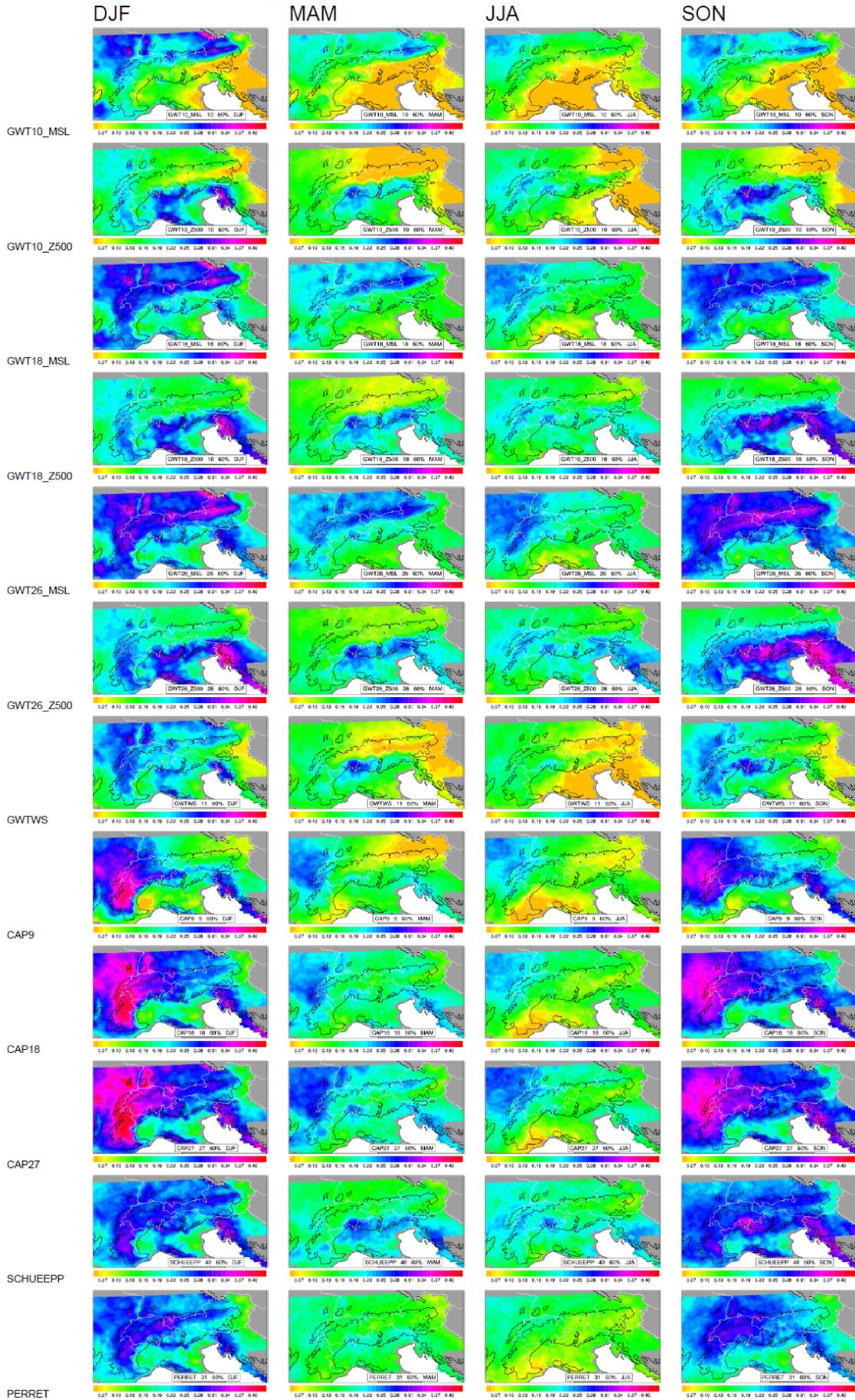


Figure 18: Spatial distribution of BSS for precipitation using the 60% quantile to define an event.

### 7.3 Temperature

The BSS values for temperature range between 0.01 and more than 0.38. The differences in skill between the individual WTCs are large compared to precipitation. For the different thresholds and the whole year, CAP27 reveals the highest BSS (Figure 19). Moreover, all CAP classifications perform better than the GWT based classifications, while the two manual classifications rank in between those two groups. This is different when the individual seasons are considered (Figure 20). Here, Schüepp and Perret clearly dominate the table with BSS values of up to 0.38 found for Schüepp in summer. This can also be seen in the results of the explained variation (Chapter 6.3) and is probably due to the input variables of the manual classifications (see also Chapter 8): WTCs using input variables from at least two pressure levels seem to be superior to those based on single pressure fields as long as temperature is considered. For the automatic classifications there is no clear dominance of any classification type observable in the different seasons. Again, WTCs with different number of types should not be compared as the BSS increases with increasing number of weather types. While in summer and winter some GWT classifications rank higher than the CAP classifications with the same number of types, the opposite is observed in spring and fall. However, the GWT classifications with 10 types always perform worst. In contrast to precipitation, temperature is apparently better explained by weather types in winter and summer, while the skill is lower in the other seasons.

The spatial distribution of the BSS as displayed in Figure 21 clearly shows the superiority of Schüepp in summer with values of up to 40% in the central and north-western domain. In summer and winter, most WTCs show the highest BSS values northwest of the Alps, GWT18\_Z500 and GWT26\_Z500 on the alpine ridge. In spring and fall, the spatial distribution of skill looks more uniform with highest values for CAP18 and CAP27 as well as Schüepp and Perret.

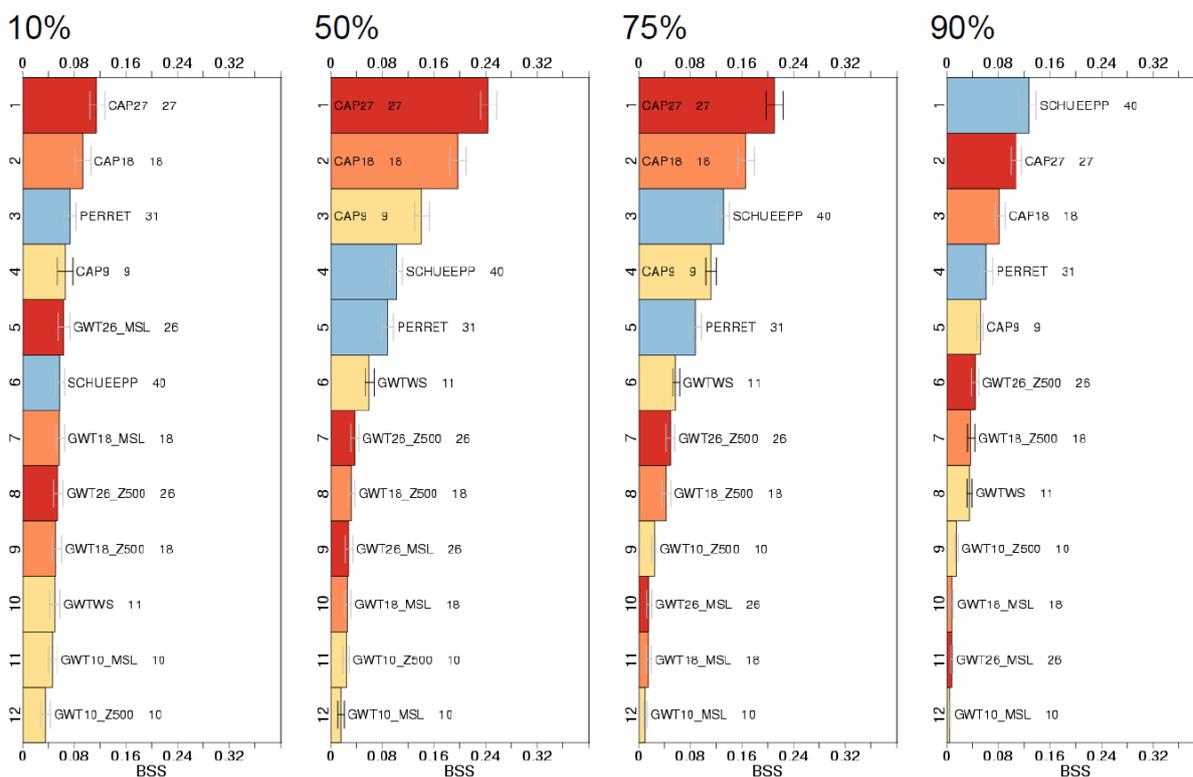


Figure 19: BSS for temperature covering the whole year and using different thresholds.

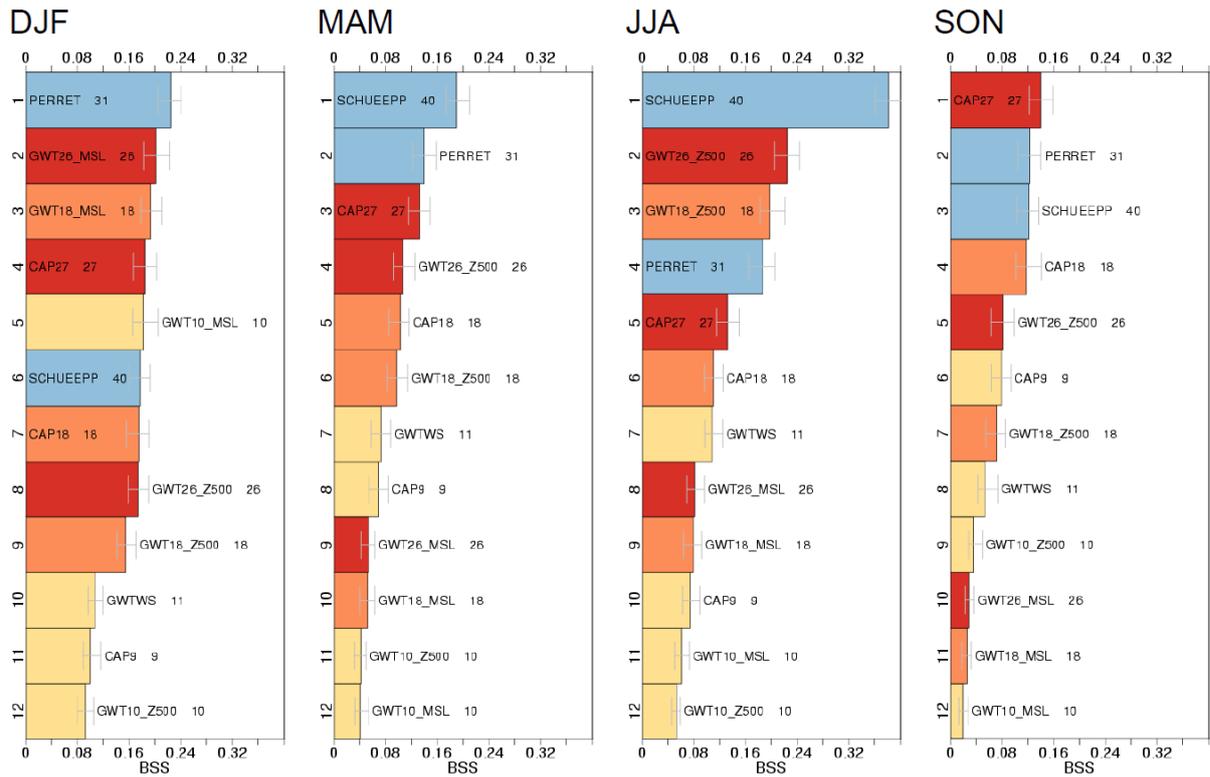


Figure 20: BSS for temperature in the different seasons for the 50% quantile.

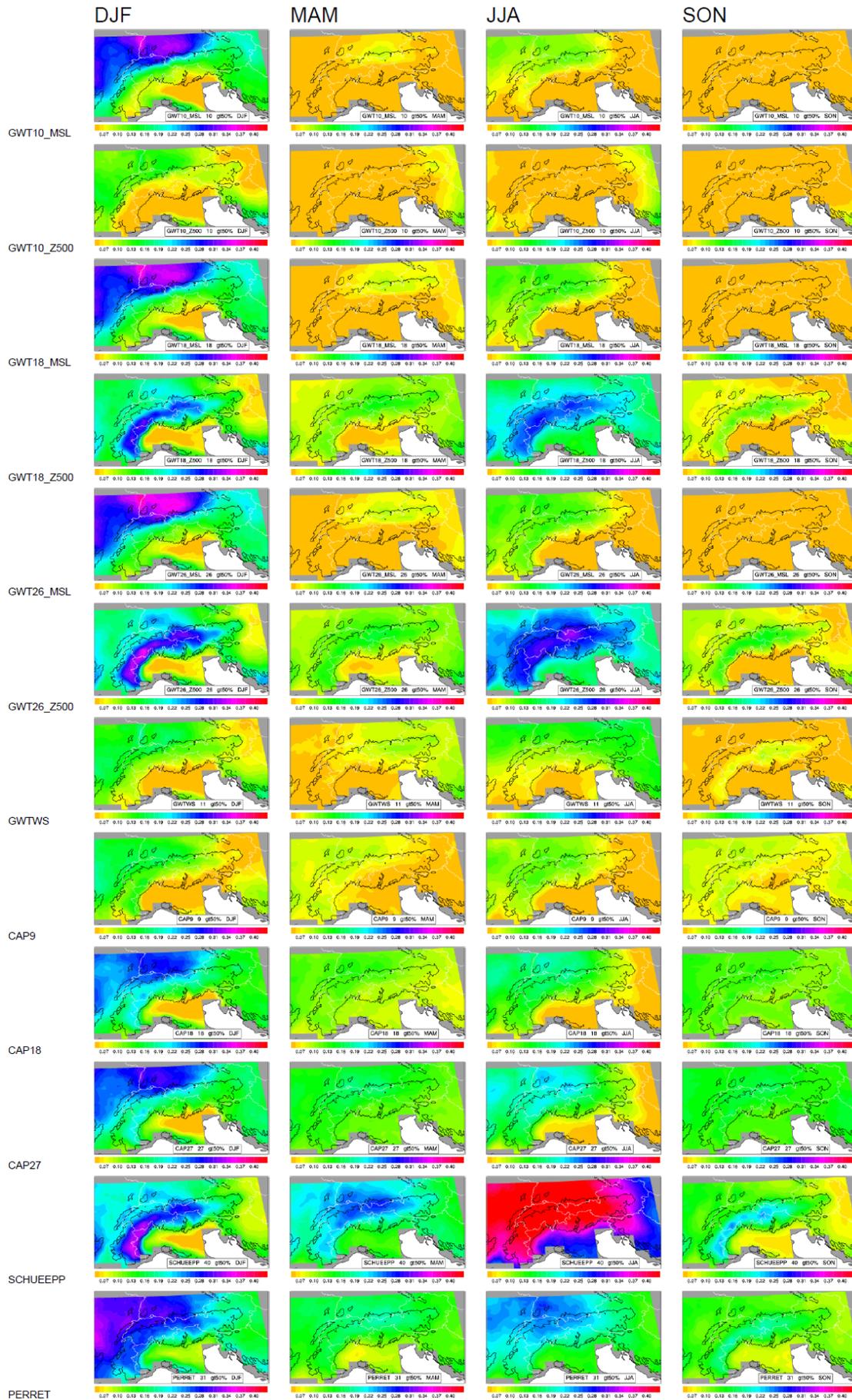


Figure 21: Spatial distribution of BSS for temperature using the 50% quantile to define an event.

## 7.4 Sea Level Pressure

The BSS values for sea level pressure clearly show the differences in the classification methods (compare Chapter 6.4). CAP uses the sea level pressure to identify the dominant pressure patterns and derives the classification types accordingly, while GWT is based on predefined weather types defined by the main wind directions. This explains the high values of 0.7 and more for the CAP classifications, while all other WTCs show values between 0.05 and 0.45 (Figure 22), which is still higher than for the other evaluated parameters. The CAP classifications are followed in rank by the manual Schüepp and Perret, while the GWT classifications fill the lower ranks. As with temperature, the BSS slightly increases with increasing threshold, except for the highest threshold, as well as with increasing number of types.

There is almost no difference between the different seasons (Figure 23). However, summer tends to show slightly lower values. There are also rarely variations in the spatial distribution of BSS due to the relatively low spatial variability of sea level pressure; the spatial BSS results are therefore not presented here.

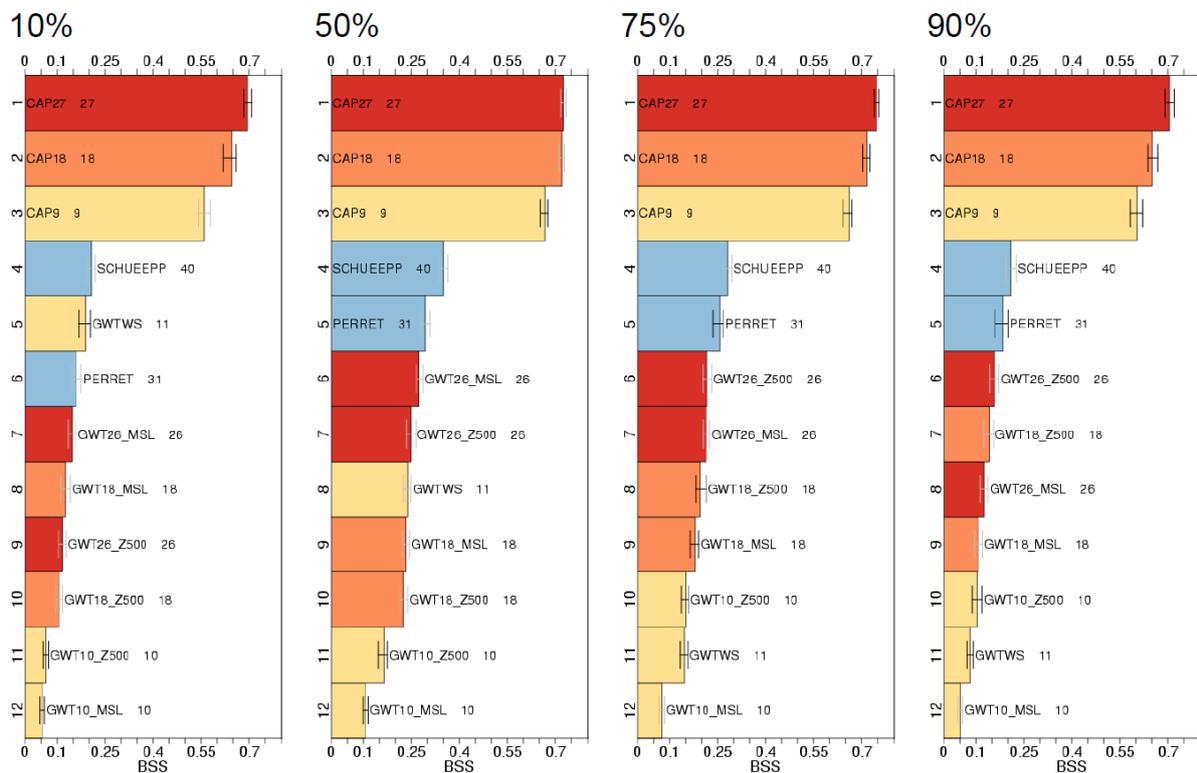


Figure 22: BSS for sea level pressure covering the whole year and using different thresholds.

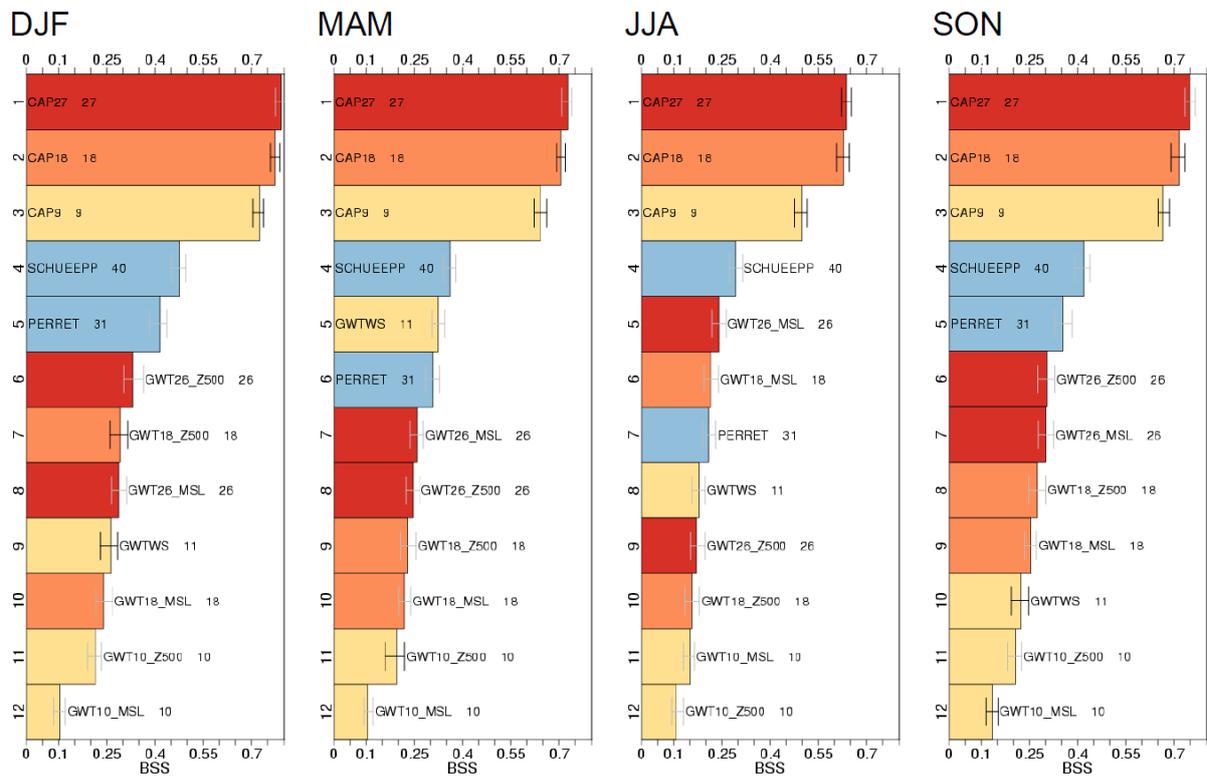


Figure 23: BSS for sea level pressure for the different seasons and the 50% quantile.

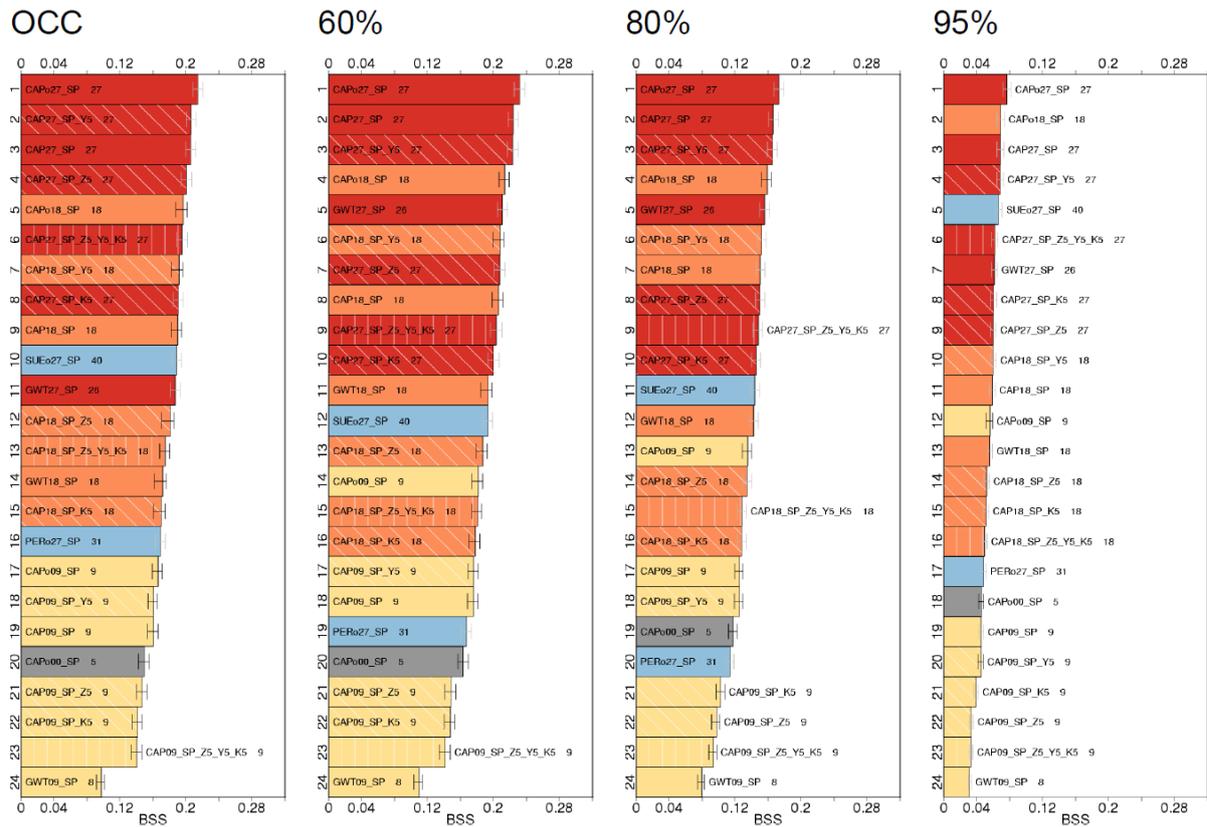
## 8 Influence of additional input parameters

While the first classification catalogue of COST 733 (cost733cat-1) contained only automatic classifications based on sea level pressure, the new classification catalogue (cost733cat-2.0) provides some classifications, which are additionally calculated for different input parameters. From the two WTCs introduced at MeteoSwiss, only CAP is available with different settings with up to four input parameters for the classification procedure, while GWT is only calculated for sea level pressure. In this chapter, all CAP classifications available in cost733cat-2.0 are evaluated in order to assess the additional value gained by using more input parameters. GWT and the two manual classifications are included to complete the picture.

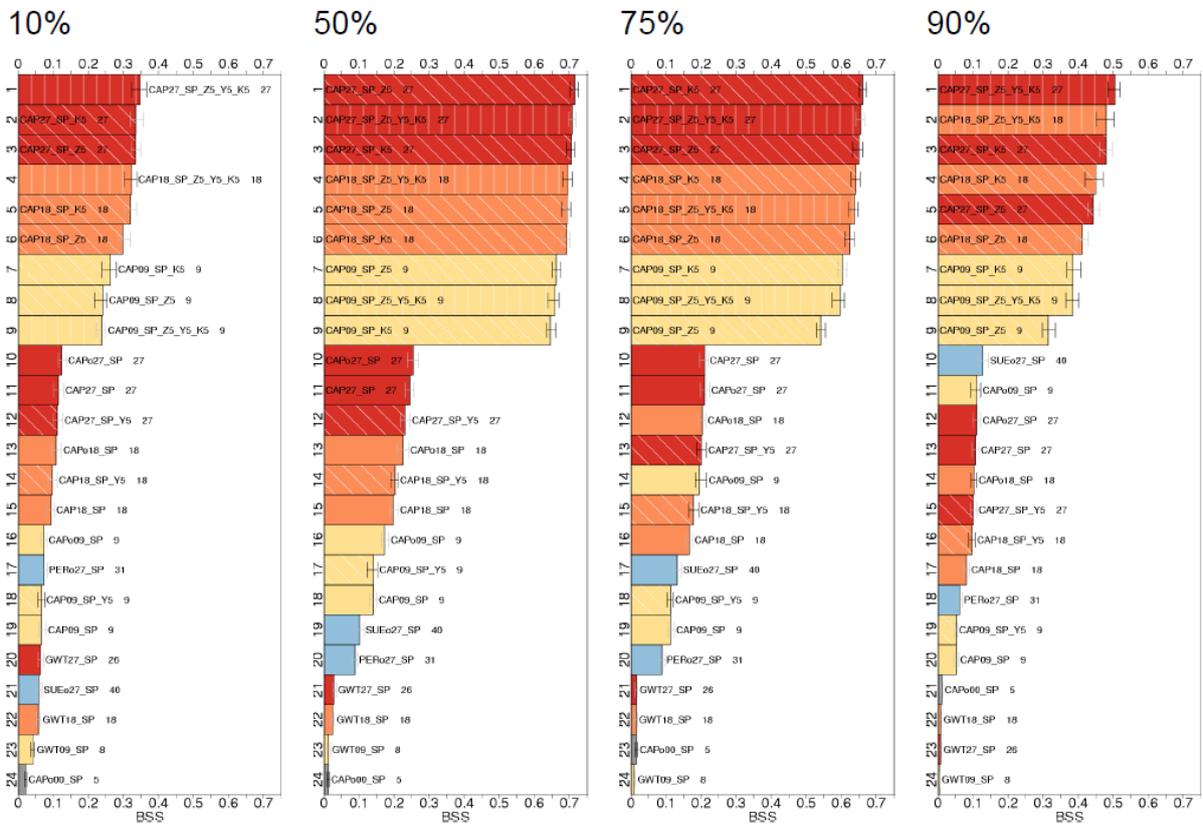
The results for precipitation are shown in *Figure 24*. For CAP, the following classifications are listed: the original classifications provided by the respective author for catalogue cost733cat-1 (marked with a small "o", e.g. CAPo27\_SP) and the recalculated classifications using the cost733class software (e.g. CAP27\_SP), which have been produced for different input data. The input data are mean sea level pressure (SP), 500 hPa geopotential height (Z5), vorticity of the 500 hPa level (Y5), and thickness between 500 hPa and 850 hPa geopotential height (K5).

The results for precipitation show rarely an impact of additional variables. The original CAPo27 based on sea level pressure, which was identified as best classification with respect to the stratification of precipitation in the Alps by Schiemann and Frei (2010) still performs best in the ranking, followed by all other combinations of CAP27. In conclusion, CAP classifications which are based on more than one input variable are not superior to those only based on sea level pressure when precipitation is considered.

This is completely different for temperature (see *Figure 25*). The WTCs based on more than one variable perform considerably better than those only based on a single pressure level. The addition of only vorticity in 500 hPa (Y5) has rarely an effect, but adding geopotential height (Z5), or thickness (K5), or all tested variables results in a strong increase of the BSS. The BSS for WTCs using 2 or more input variables reaches values of more than 0.7. Even CAP9 classifications with more than one input variable reach higher BSS values than the CAP27 classifications based on single pressure fields and the manual classifications. These multi-variable classifications also outperform the manual classifications, even when only summer months are considered (see *Figure 26*). For temperature, it would, therefore be advisable to use more than one input variable to create a WTC that is able to explain the climatologic temperature variations in the Alpine region.



**Figure 24:** BSS for precipitation and four different thresholds. Classifications based on one variable are uniformly coloured, while those based on two or more variables are shaded (angular lines: 2 variables, vertical lines: 4 variables).



**Figure 25:** As Figure 24 but for temperature.

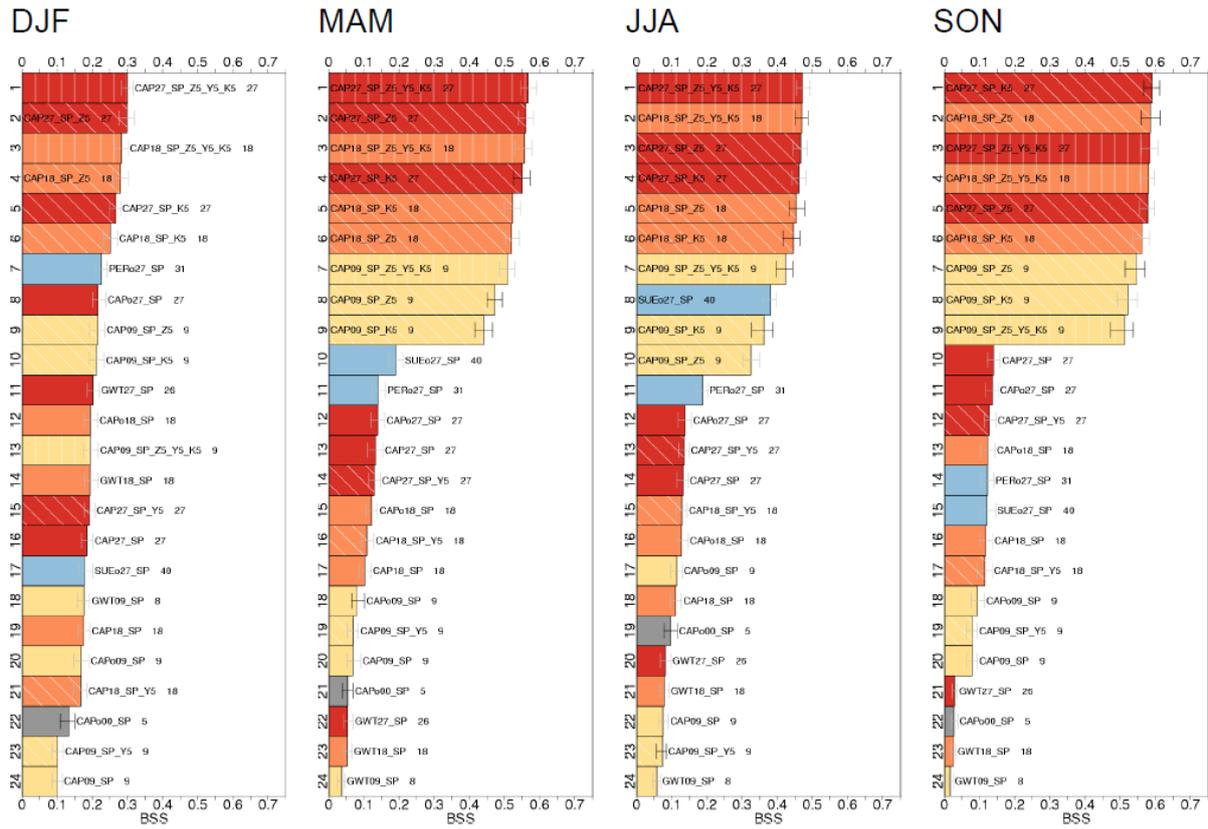


Figure 26: As Figure 24 but for temperature and different seasons (threshold = 50 % quantile).

## 9 Applications of weather types @ MeteoSwiss

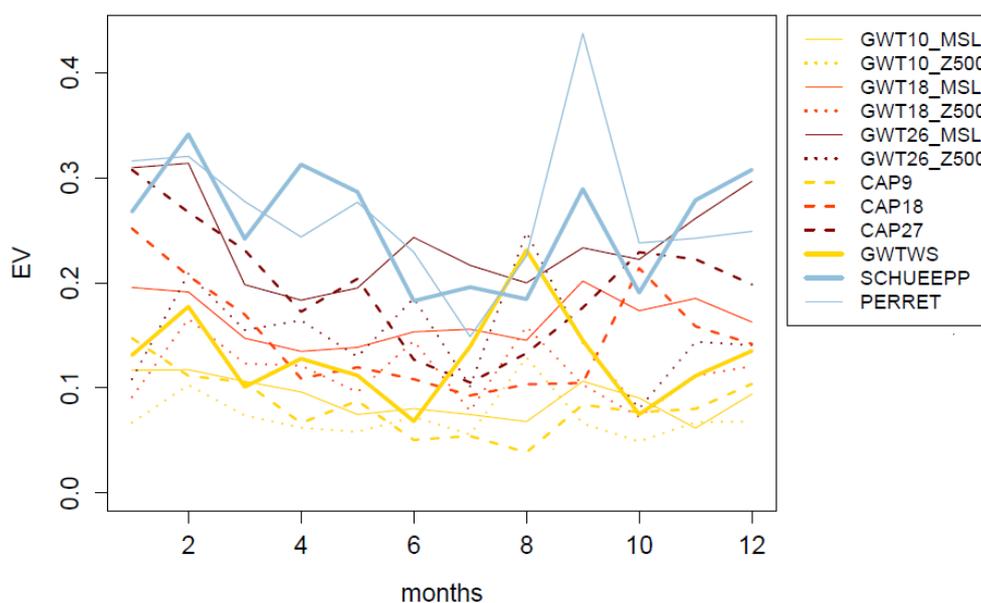
### 9.1 Evaluating the model skill using weather type classifications

While Chapters 6 and 7 evaluated the ability of the WTCs to explain surface climate variations, this chapter investigates how well the WTCs stratify the error in numeric precipitation forecast of COSMO-7 ([www.cosmo-model.org](http://www.cosmo-model.org)), which is the operational weather forecast model of MeteoSwiss. The evaluation methods are the same as in the previous analyses: explained variation (EV, see Chapter 6.1) and Brier Skill Score (BSS, see Chapter 7.1).

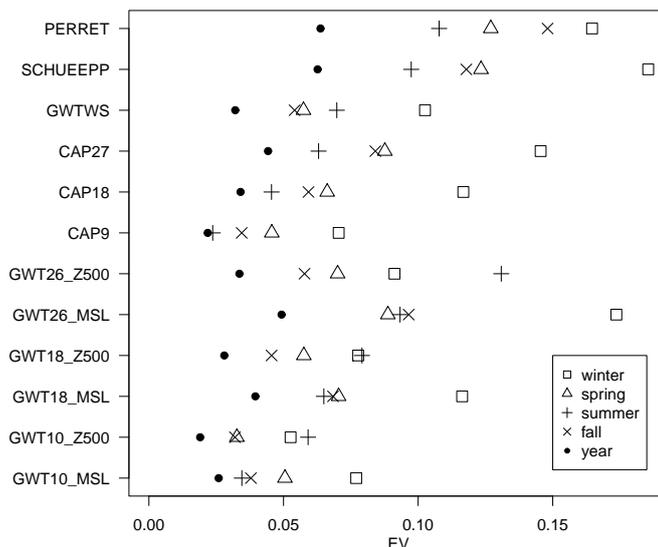
The model derived precipitation error (defined as model - observation) of COSMO-7 forecasts (00 UTC run, leadtime +6h to +30h) is hereby investigated for the period 2004 – 2009. Please note that during this time the model has been undergoing several changes. Two of the most important ones are probably the change in horizontal resolution (February 2008, old: 7 km, new: 6.6 km) and the replacement of the numerical time integration scheme (October 2007, old: Leapfrog, new: Runge-Kutta). The change in horizontal resolution is accounted for by interpolating the older COSMO-7 data to the new grid with a mesh size of 6.6 km. The two integration schemes are not differentiated to keep a relative long time series. This might affect the results, especially since numerical studies have shown that the Runge-Kutta scheme reduces the average precipitation amount by about 10% (compared to Leapfrog) for most of the test cases (Dierer et al., 2007).

The observational reference for this model evaluation is a gridded spatial analysis of daily precipitation (24h accumulation valid at 6 UTC) from approximately 440 rain-gauge station measurements. The analysis was constructed using methods described in Frei and Schär (1998) and Frei et al. (2006, Chapt. 4). For the purpose of this application, the analysis was produced directly onto the grid of the NWP model, i.e. with a nominal resolution of 6.6 km.

The values for the explained variation of precipitation error range between 0.02 and more than 0.4 and decrease with increasing time scale (*Figure 27* and *Figure 28*). This implies that precipitation error variability is apparently best explained by weather types on a monthly basis. Furthermore, large variations are observable in the different months and seasons. Some WTCs like GWTWS show a maximum of explained variation in late summer / autumn, others, like CAP, in winter. *Figure 28* indicates highest values for the two manual classifications for all time periods, followed by GWT26\_Z500, which reveals especially high values of EV in summer and CAP27 and GWT26\_MSL showing relatively large values in winter and over the whole year. From the WTCs with only few weather types, GWTWS gives best results on all time scales.

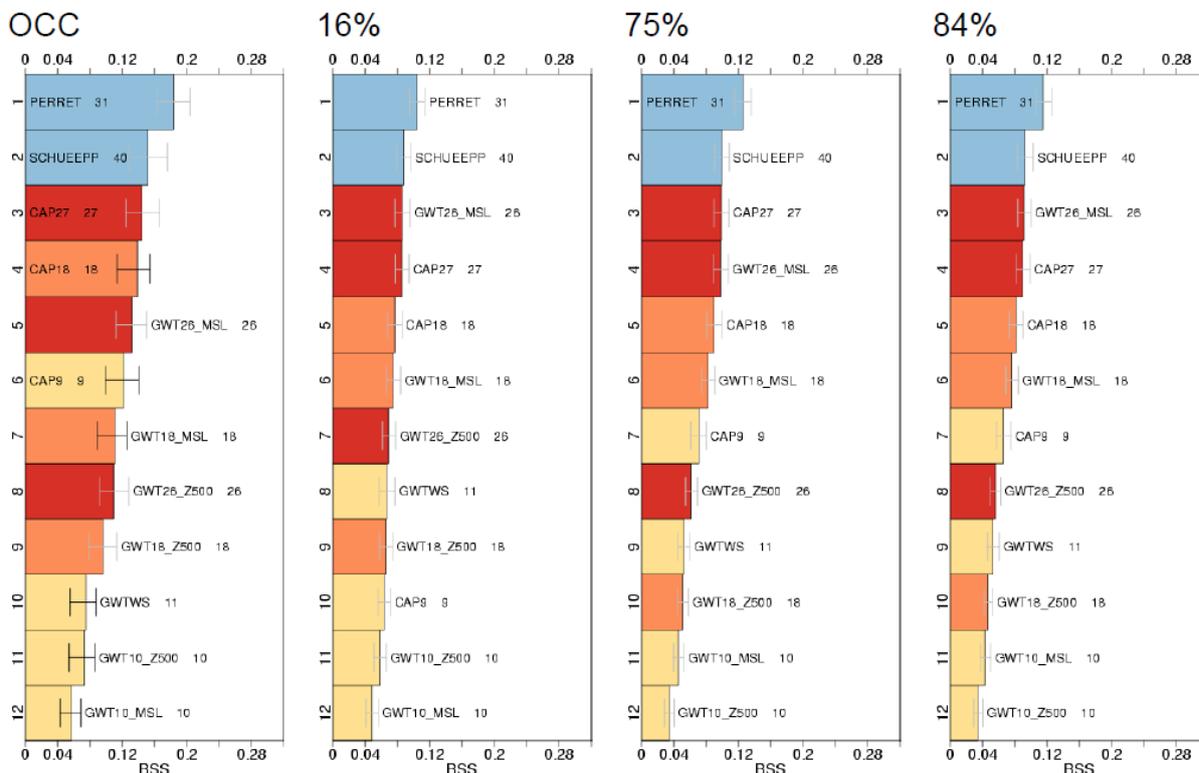


**Figure 27:** Yearly cycle of the explained variation of precipitation error (model - obs) for all weather type classifications.



**Figure 28:** Inter-seasons-variability of the explained variation of precipitation error (model - obs) for the different weather type classifications.

For the BSS evaluation of the precipitation error, the occurrence of any error (OCC, i.e. over- or underestimation) is considered as well as three quantiles of the error distribution: 16% (strong underestimation), 75% and 84% (strong overestimation). The superiority of the CAP classifications found for the plain variables is not observed for the precipitation error. Instead, GWT26\_MSL and GWT18\_MSL are comparable to CAP27 and CAP18, respectively (Figure 29). GWT performs slightly better in summer, CAP in winter (Figure 30). As for the explained variation, the manual classifications show the highest correlation with the precipitation error. Considering only WTCs with the lowest number of weather types, GWTWS and CAP9 give the best results.



**Figure 29:** BSS for precipitation error covering the whole year and using different thresholds.

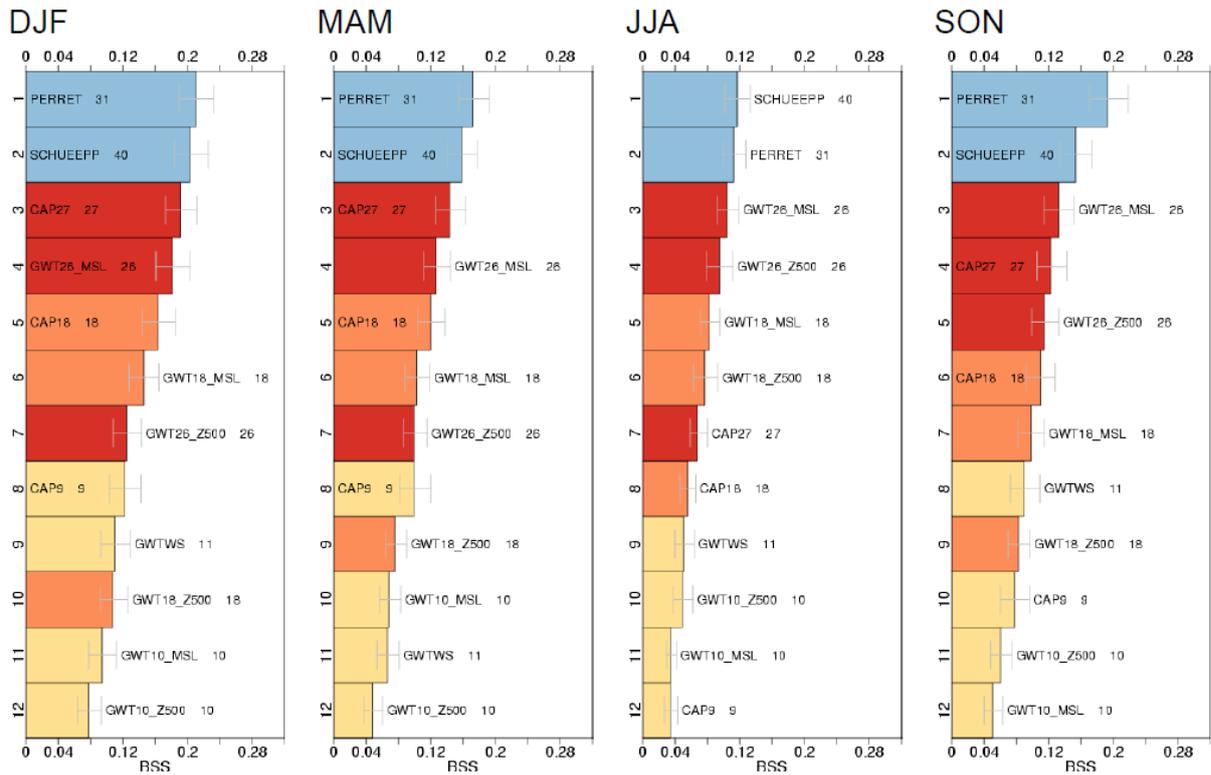


Figure 30: BSS for precipitation error for the different seasons and the 75% quantile.

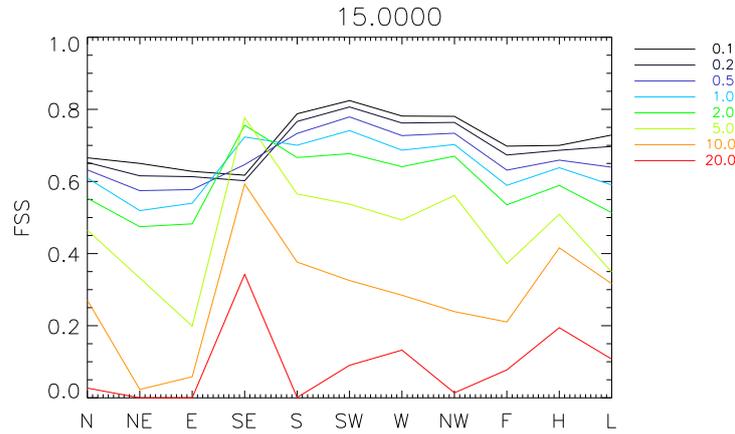
## 9.2 Weather type dependant neighbourhood verification (T. Weusthoff, MO)

In order to avoid the double penalty when verifying high resolution precipitation forecasts, new verification methods have been developed over the last years (see Ahijevych et al. (2009) for an overview). One group of methods is the so-called neighbourhood verification, which considers a region around a point of interest (= window) instead of the single point when comparing model forecasts to observations. This is done for increasing window sizes and the respective scores are calculated for the whole window. One method used for this type of verification is the Fraction skill score (Roberts and Lean, 2005). Here, the grid boxes within the windows are evaluated using different thresholds to define an event. Within the respective window, the fraction of grid points above the threshold is determined for the forecast as well as for the observation and the Fractions skill score is calculated:

$$FSS = 1 - \frac{FBS}{FBS_{ref}} = 1 - \frac{\frac{1}{N} \sum_{i=1}^N (P_{fcst} - P_{obs})^2}{\frac{1}{N} \sum_{i=1}^N P_{fcst}^2 + \frac{1}{N} \sum_{i=1}^N P_{obs}^2},$$

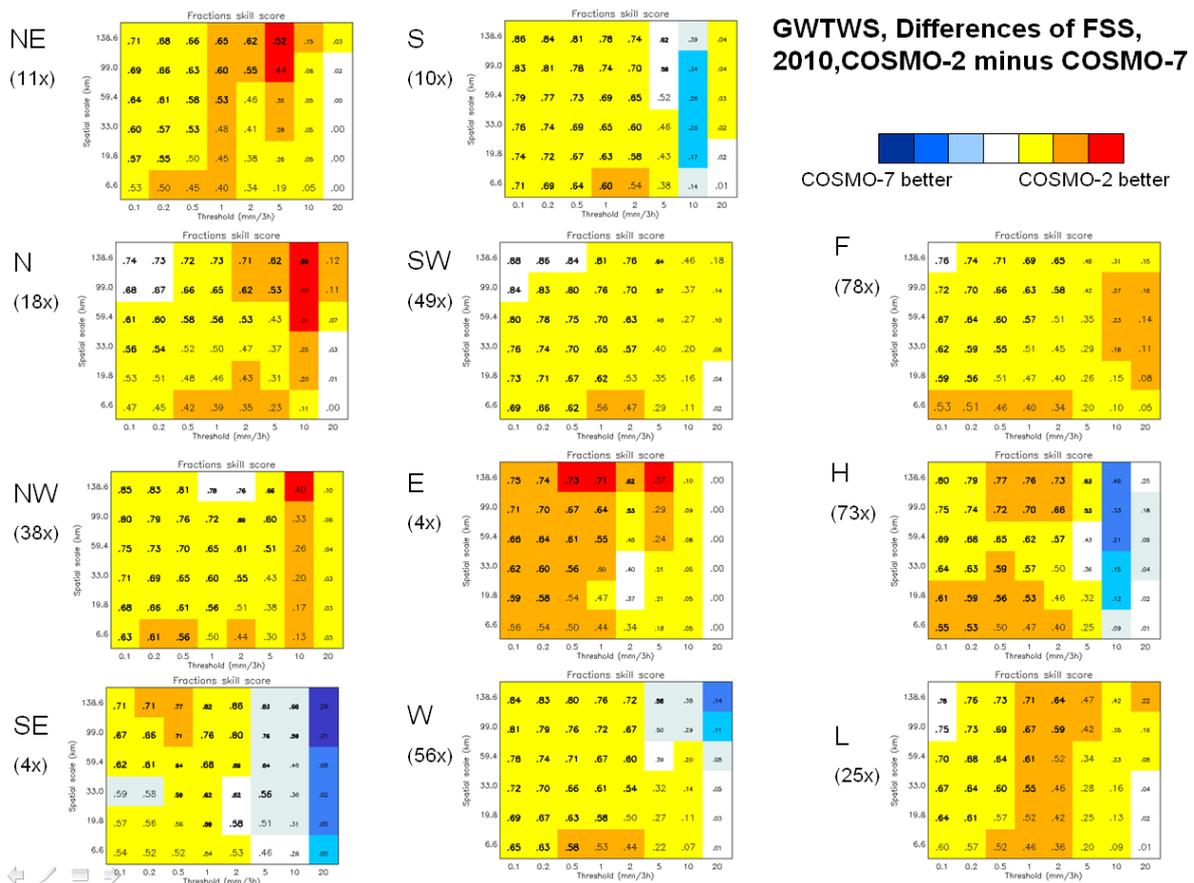
with  $N$  = number of grid points,  $P_{fcst}$  = forecast frequency and  $P_{obs}$  = observed frequency. The FSS ranges from 0 to 1 with 1 indicating perfect skill. For further information about neighbourhood verification application to COSMO forecast please refer to Weusthoff et al. (2010).

Neighbourhood verification is usually done for individual cases and the results are then aggregated for the period of several months or a year. The aggregation can also be done for individual weather types resulting in weather type dependant verification. An example using the GWTWS classification is given in Figure 31. Displayed are the results of the Fractions skill score for COSMO-7 evaluated for the year 2010. The window size used for this example is 15 grid points. The different colours represent different thresholds for the identification of an event. In this example, the western situations reveal higher FSS values, i.e. a better precipitation forecast than for example the North and NorthEast situations.



**Figure 31:** Weather type dependant verification using the neighbourhood method. Results of Fractions skill score for a window size of 15 grid points.

The neighbourhood method not only allows the evaluation of a forecast on different spatial scales but as a consequence also gives the possibility to directly compare the forecast quality of two models with different resolution. This is exemplarily shown in Figure 32. For the interpretation of the results, the number of cases for each weather types has to be kept in mind. The larger the statistics are, the more robust the results. Therefore, the WTCs with more than 11 classes are not suitable for this application.



**Figure 32:** Weather type dependant verification using the neighbourhood method. Each box represents a weather type displaying the FSS results for different window sizes (vertical axis) and thresholds (horizontal axis). While the absolute values give the results of COSMO-2, the colours represent the difference in skill between COSMO-2 and COSMO-7. Warm colours indicate better skill for COSMO-2, cold colours better skill for COSMO-7.

### 9.3 COSMO-MOS (V. Stauch, MO)

Provided the weather types are able to stratify the numerical weather prediction model error, they are an ideal candidate to help statistically correct the forecasts. For this, the weather types are derived from the current forecast in order to serve as a predictor in, for example, a regression model for the forecast error.

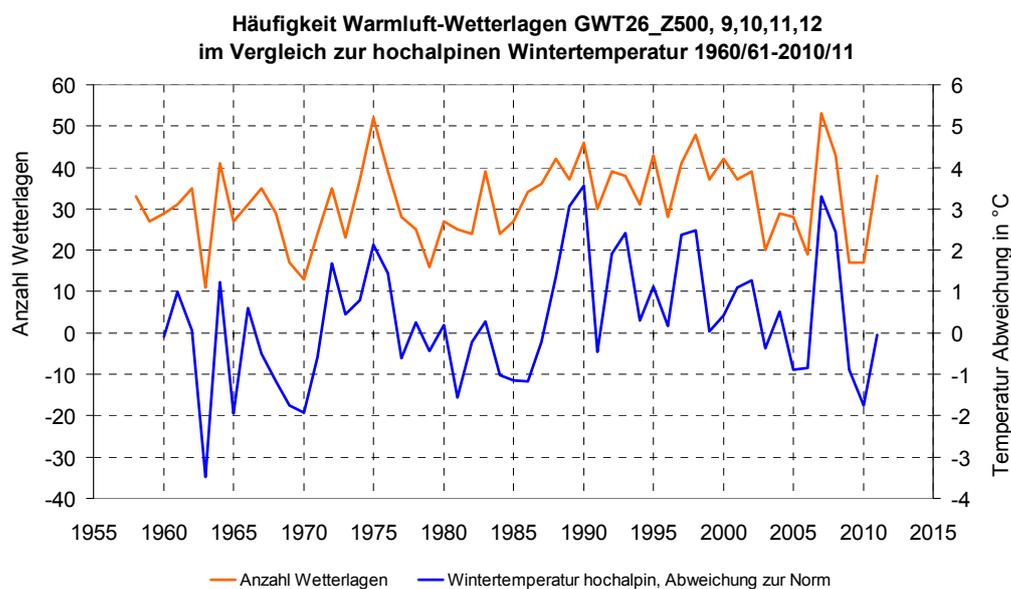
The main advantage is the aggregated nature of the weather types presumably resulting in compact regression equations and hence robust regression parameters.

The value of weather types as predictors will be investigated in the MeteoSwiss project "COSMO-MOS" that aims at the development of a flexible correction algorithm for COSMO forecasts based on multiple regression models. Model selection approaches will be applied for the choice of the most important predictors based on long time series of COSMO forecasts and point observations of surface parameters (e.g. wind, global radiation) that will reveal the predictive power of weather types to explain COSMO forecast errors for these variables.

#### 9.4 Climatological analyses (S. Bader et al., 2011, KD)

Bader et al. (2011) analyzed correlations between high alpine warm and cold winters and weather types using the GWT26\_Z500 classification. Out of the 26 weather types of this classification, four warm advection types and four cold advection types have been compared to high alpine winter temperatures (see caption of *Figure 33*). The time series of the frequency of warm advection weather types (red) and the winter temperature in the Alps (blue) are displayed *Figure 33*. The warm weather types are more frequent in the warm winters; this becomes especially apparent in the warm winters 2006/2007 and 2007/2008. For the whole time period from 1958 to 2011, a significant correlation ( $r = 0.82$ ) has been found.

The supply of warm and cold air apparently influences the high alpine temperature regime to a high degree. 60 % of the long term variability can be explained by the variability of frequencies of warm and cold advection weather types. The influence of the warm advection is hereby stronger than that of the cold advection. This result implies that the variability of the high alpine winter temperatures is mainly caused by changes in the atmospheric circulation pattern.



**Figure 33:** Frequency of winterly warm advection weather types of GWT26\_Z500 (Weather types 9, 10, 11, 12) in comparison to the high alpine winter temperatures (averaged over homogeneous measured time series of Jungfrau-joch (3580 m a.s.l.), Güttsch (2282 m a.s.l.), Weissfluhjoch (2690 m a.s.l.), Säntis (2490 m a.s.l.) und Gd. St. Bernard (2472 m a.s.l.)).

## 10 Conclusions

This report serves as an overview document for the new weather type classifications (WTCs) introduced at MeteoSwiss. Altogether 10 different WTCs based on two different methods are calculated on a daily basis. The reason for this large number of weather types lies in the different user requirements of the users. It is not possible to identify one best WTC that is usable for all applications. Instead, for each application the most adequate WTC has to be chosen. The results of this report show that the manual classifications and CAP27 are doing the best job in explaining the long-term variability of the investigated parameters. However, for an application in conditional verification of numerical weather prediction models, which is usually done on a yearly basis, the statistics would be too small to get robust results if a WTC with many types is used. In this framework, one would prefer the WTCs with only few types like CAP9 or GWTWS. The WTCs with many types may be preferred for climatological applications.

Most of the evaluations presented in this report have been conducted for all 10 new automatic weather type classifications as well as for the two former manual ones. The trend analysis has been restricted to one WTC, namely CAP9. Only one of the nine weather types in this WTC shows a significant trend over the considered 50 years period: the high pressure situations over the Alps (WT5) increased from 1960 to 2009 by 0.2 occurrences per year. This trend has its origin mainly in the winter season, where WT5 also shows a significant increase. In spring, a significant decrease has been detected for WT1 (NorthEast, indifferent), but none for the two other seasons.

Using the AWS, Wanner et al. (2000) found an increase of convective weather types going along with a decrease of advective types in the early 1970s. These significant trends do not occur in any of the other investigated WTCs. They may partly be attributed to inhomogeneities in the manual classification procedure, which can be avoided by the use of automatic classifications.

The main part of the report dealt with the ability of the WTCs to explain the variability of different meteorological parameters: precipitation, temperature, and sea level pressure. The evaluation has been done using the two concepts of explained variance (EV) and Brier Skill Score (BSS). The latter has been calculated both for the whole investigation area and pixel-wise allowing a spatial evaluation. For most of the parameters, CAP27 and the manual classifications reveal the best scores. Generally, the skill increases for increasing type number. Therefore, WTCs with different type numbers should not be compared. In the following, a short summary on the findings is provided, ordered by the different parameters considered.

The variability of **precipitation** over the whole year is best explained by CAP27, while with respect to the individual seasons GWT has better skill in spring and summer. The best WTC with only few types is CAP9. Most WTCs show best skill in the north western part of the domain, the GWT classifications based on Z500 in the southern part. A more detailed analysis of the spatial precipitation structures for the individual WTCs could help to explain this result.

**Temperature** (in contrast to precipitation) is best explained in winter and in summer – the latter is especially true for Schüepp. This can also clearly be seen in the spatial analysis, where Schüepp reveals high values in summer over the whole domain. This is probably due to the use of multi level input parameters for the classification. The GWT classifications based on Z500 show the best skill on the Alpine ridge, while the others give higher score north of the Alps. On a yearly basis, the CAP classifications give the best results, followed by the two manual classifications. This is different for the individual seasons: in winter, Perret and GWT based on MSL perform best, in spring the manual classifications, in summer Schüepp, followed by GWT based on Z500 and in fall CAP27 followed by the manual classifications. The observation that Schüepp performs best in almost every single month, but worse for the whole year cannot be explained at the moment and needs further investigation.

The results for the **sea level pressure** reveal the differences in the classification procedures. CAP, which is derived by an optimization procedure based on sea level pressure, performs clearly better than all other WTCs. From the other WTCs, the manual Schüepp and Perret classifications are best and generally, the values increase with increasing type number. There is rarely a variation in skill observable for the different seasons and on the spatial scale.

The WTCs of the new catalogue provided by COST 733 (cost733cat-2.0) are used to investigate the impact of additional parameters included in the classification process. In contrast to the first catalogue (cost733cat-1) where only sea level pressure was used as base field, the WTCs in the second catalogue also include other input parameters, e.g. 500 hPa geopotential heights, vorticity or a combination of parameters. The BSS analysis for precipitation did not show a significant impact of the additional variables. Therefore, the implementation of the simple classification procedure based on just sea level pressure for CAP and based on sea level pressure and 500 hPa geopotential heights, respectively for the GWT methods seems to be a good choice for precipitation. This is completely different for temperature. Here, the use of multi-level information has a very high impact on the BSS results and with respect to temperature it would be advisable to use classifications based on multiple input data like, for example, sea level pressure and 500 hPa geopotential height.

Finally, some applications of WTCs have been presented. One example was the evaluation of the model derived **precipitation error** (COSMO-7 minus gridded precipitation analysis) using explained variation and Brier skill score. The results show not only how well the WTCs stratify the error, but also how well the models quality is related to the weather types, i.e. which WTC is most appropriate to investigate deficiencies of the model occurring in specific weather types. The manual classifications show the best skill in explaining the variability of the precipitation error. CAP and GWT classifications generally reveal similar skill. GWT is slightly better in summer, CAP in winter. Considering only WTCs with the lowest number of types, GWTWS and CAP9 give the best results.

## References

- Ahijevych, D., E. Gilleland, and B. Brown, 2009: Application of Spatial Verification Methods to Idealized and NWP-Gridded Precipitation Forecasts. *Wea. and Forecasting*, 24, 1485–1497.
- Bader, S., T. Schlegel, and S. Fukutome, 2011: „Milde und kalte Bergwinter“, Interner Bericht, MeteoSchweiz
- Beck C., 2000: Zirkulationsdynamische Variabilität im Bereich Nordatlantik-Europa seit 1780 (Variability of circulation dynamics in the North-Atlantic-European region). *Würzburger Geographische Arbeiten* 95 (in German).
- Beck, C., J. Jacobbeit, and P.D. Jones, 2007: Frequency and within-type variations of large scale circulation types and their effects on low-frequency climate variability in Central Europe since 1780. *Int. J. Climatology*, 27, 473–491
- Beck C. and A. Philipp, 2010: Evaluation and comparison of circulation type classifications for the European domain. *Physics and Chemistry of the Earth*, 35(9-12), 374–387, doi:10.1016/j.pce.2010.01.001
- Comrie, A.C., 1996: An all-season synoptic climatology of air pollution in the U.S.-Mexico border region. *Professional Geographer*, 48, 237–251, doi:10.1111/j.0033-0124.1996.00237.x
- Dierer, S., 2009: Final report of the COSMO priority project “Tackle deficiencies in quantitative precipitation forecasts”, COSMO Technical Report, No. 15, available at [www.cosmo-model.org](http://www.cosmo-model.org).
- Ekstroem, M., P. Jonsson, and L. Baerring, 2002: Synoptic pressure patterns associated with major wind erosion events in southern Sweden (1973–1991). *Climate Research*, 23, 51–66
- Frei, C., and C. Schär, 1998: A precipitation climatology of the Alps from high-resolution rain-gauge observations, *Int. J. Climatol.*, 18, 873– 900.
- Frei C., R. Schöll, J. Schmidli, S. Fukutome, and P.L. Vidale, 2006: Future change of precipitation extremes in Europe: An intercomparison of scenarios from regional climate models, *J. Geophys. Res.*, 111, D06105, doi:10.1029/2005JD005965
- Haylock, M.R., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones, and M. New. 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation for 1950–2008. *J. Geophys. Res. (Atmospheres)*, 113, D20119, 12 pp., doi:10.1029/2008JD10201
- Hewitson, B. and R. Crane, 1992: Regional climates in the GISS global circulation model and synoptic-scale circulation. *Journal of Climate*, 5, 1002–1011
- Jetel, M., 2009: Langfristige Trendanalyse von Wetterlagen im Alpenraum. Diplomarbeit, Universität Bern, 172 pp.
- Murphy, A.H., 1973: A new vector partition of the probability score. *J. Appl. Meteor.*, 12, 595–600.
- Philipp A. and 18 co-authors, 2010: Cost733cat - A database of weather and circulation type classifications. *Phys. Chem. Earth (B)*, 35, 360–373
- Roberts, N., and H. Lean, 2008: Scale-selective verification of rainfall accumulations from high-resolution forecasts of convective events. *Mon. Wea. Rev.*, 136, 78–97
- Salvisberg, E., 1996: Wetterlagenklimatologie – Möglichkeiten und Grenzen ihres Beitrages zur Klimawirkungsforschung im Alpenraum. Dissertation, Geographisches Institut der Universität Bern, Bern, 187 pp.

Schiemann, R., and C. Frei, 2010: Wetterlagen und Niederschlagsverteilung im europäischen Alpenraum. Tafel 2.8, Hydrologischer Atlas der Schweiz. Available from University of Berne.

Schiemann, R. and C. Frei, 2010: How to quantify the resolution of surface climate by circulation types: An example for Alpine precipitation, *Physics and Chemistry of the Earth*, 35, 403-410, doi:10.1016/j.pce.2009.09.005

Schüepp, M., 1979: Witterungsklimatologie (Klimatologie der Schweiz, Band III). Beihefte zu den Annalen der Schweizerischen Meteorologischen Anstalt 1978, 89 S.

SMA, 1985: Alpenwetterstatistik / Witterungskalender. Schweizerische Meteorologische Anstalt. 63 pp.

Uppala, S. M. and 45 co-authors, 2005: The ERA-40 re-analysis. *Quart. J. Roy. Meteor. Soc.*, 131, 2961-3012

Wanner, H., D. Gyalistras, J. Luterbacher, R. Rickli, E. Salvisberg, and C. Schmutz, 2000: Klimawandel im Schweizer Alpenraum. vdf Hochschulverlag AG an der ETH Zürich, 285 pp.

Weusthoff, T., F. Ament, M. Arpagaus, and M. W. Rotach, 2010: Assessing the Benefits of Convection-Permitting Models by Neighborhood Verification: Examples from MAP D-PHASE. *Mon. Wea. Rev.*, **138**, 3418–3433. doi: 10.1175/2010MWR3380.1

## Acknowledgement

The author acknowledges the E-OBS dataset from the EU-FP6 project ENSEMBLES (<http://ensembles-eu.metoffice.com>) and the data providers in the ECA&D project (<http://eca.knmi.nl>). The author also wishes to acknowledge use of the Ferret program for analysis and graphics in this paper. Ferret is a product of NOAA's Pacific Marine Environmental Laboratory. (Information is available at <http://ferret.pmel.noaa.gov/Ferret/>). The experiments were partly done at the Swiss National Supercomputing Centre (CSCS) in Manno, Switzerland. Many thanks for the reviews go to Christoph Frei, Philippe Steiner and Simon Scherrer.

## APPENDIX A **MeteoSwiss weather type classifications**

The two tables presented here list the individual weather types of the 10 automatic weather type classifications. The grey shaded types are attributed to the group of advective weather types while the unfilled cells represent the convective weather types.

Type	GWTWS	GWT10 (GWT10_MSL and GWT10_Z500)	GWT18 (GWT18_MSL and GWT18_Z500)	GWT26 (GWT26_MSL and GWT26_Z500)
1	West	West	West, cyclonic	West, cyclonic
2	SouthWest	SouthWest	SouthWest, cyclonic	SouthWest, cyclonic
3	NorthWest	NorthWest	NorthWest, cyclonic	NorthWest, cyclonic
4	North	North	North, cyclonic	North, cyclonic
5	NorthEast	NorthEast	NorthEast, cyclonic	NorthEast, cyclonic
6	East	East	East, cyclonic	East, cyclonic
7	SouthEast	SouthEast	SouthEast, cyclonic	SouthEast, cyclonic
8	South	South	South, cyclonic	South, cyclonic
9	Low Pressure	Low Pressure	West, anticyclonic	West, anticyclonic
10	High Pressure	High Pressure	SouthWest, anticyclonic	SouthWest, anticyclonic
11	Flat Pressure		NorthWest, anticyclonic	NorthWest, anticyclonic
12			North, anticyclonic	North, anticyclonic
13			NorthEast, anticyclonic	NorthEast, anticyclonic
14			East, anticyclonic	East, anticyclonic
15			SouthEast, anticyclonic	SouthEast, anticyclonic
16			South, anticyclonic	South, anticyclonic
17			Low Pressure	West, indifferent
18			High Pressure	SouthWest, indifferent
19				NorthWest, indifferent
20				North, indifferent
21				NorthEast, indifferent
22				East, indifferent
23				SouthEast, indifferent
24				South, indifferent
25				Low Pressure
26				High Pressure

Type	CAP9	CAP18	CAP27
1	NorthEast, indifferent	West-NorthWest, indifferent, flat pressure	West, indifferent, flat pressure
2	West-SouthWest, cyclonic, flat pressure	West-NorthWest, anti-cyclonic, flat pressure	High pressure over Eastern Europe
3	Westerly flow over Northern Europe	East, indifferent	NorthWest, anticyclonic, flat pressure
4	East, indifferent	West-SouthWest, cyclonic, flat pressure	West-SouthWest, cyclonic, flat pressure
5	High Pressure over the Alps	South, anticyclonic	NorthWest, indifferent
6	North, cyclonic	SouthEast, indifferent	Trough over Central Europe
7	West-SouthWest, cyclonic	South, cyclonic, flat pressure	East-SouthEast, indifferent
8	High Pressure over Central Europe	NorthWest, cyclonic	South-SouthEast, anti-cyclonic
9	Westerly flow over Southern Europe, cyclonic	NorthEast, cyclonic	East, indifferent
10		High pressure over the Alps	NorthWest, cyclonic
11		West, cyclonic	West-NorthWest, anti-cyclonic
12		East-SouthEast, anticyclonic	High pressure over the Alps
13		East, cyclonic	Westerly Flow over Northern Europe
14		West-SouthWest, cyclonic	South-SouthEast, cyclonic
15		Westerly flow over northern Europe	West-NorthWest, cyclonic
16		Low pressure over the Alps	East, anticyclonic / indifferent
17		High pressure over Eastern Europe	South-SouthWest, cyclonic
18		Westerly Flow over Southern Europe, cyclonic	East-SouthEast, anticyclonic
19			SouthWest, cyclonic
20			West, indifferent
21			West, cyclonic
22			NorthEast, cyclonic
23			East, cyclonic
24			West-SouthWest, cyclonic
25			Low pressure over the Alps
26			High pressure over Central Europe
27			Westerly Flow over Southern Europe, cyclonic

### Arbeitsberichte der MeteoSchweiz

- 234** Hächler P, Burri K, Dürr B, Gutermann T, Neururer A, Richner H, Werner R: 2011, Der Föhnfall vom 8. Dezember 2006 – Eine Fallstudie, 47pp, CHF 68.-
- 233** Wüthrich C, Scherrer S, Begert M, Croci-Maspoli M, Marty C, Seiz G, Foppa N, Konzelmann T, Appenzeller C: 2010, Die langen Schneemessreihen der Schweiz - Eine basisklimatologische Netzanalyse und Bestimmung besonders wertvoller Stationen mit Messbeginn vor 1961, 33pp, CHF 64.-
- 232** Willi, M: 2010, Gridding of Daily Sunshine Duration by Combination of Station and Satellite Data, 92pp, CHF 78.-
- 231** Scherrer, S: 2010, Die Niederschlagstotalisatoren der Schweiz –Eine basisklimatologische Netzanalyse und Bestimmung besonders wertvoller Stationen, 32pp, CHF 64.-
- 230** Michel, D, MW Rotach, R Gehrig, R Vogt: 2010, Experimental investigation of micrometeorological influences on birch pollen emission, 37 pp, CHF 56.-
- 229** Philipona R, Levrat G, Romanens G, Jeannet P, Ruffieux D and Calpini B: 2009, Transition from VIZ / Sippicanto ROTRONIC - A new humidity sensor for the SWISS SRS 400 Radiosonde, 37pp, CHF 66.-
- 228** MeteoSchweiz: 2009, Klimabericht Kanton Graubünden, 40pp, nur als .pdf erhältlich
- 227** MeteoSchweiz, 2009, Basisanalysen ausgewählter klimatologischer Parameter am Standort KKWLeibstadt, 135pp, CHF 88.-
- 226** MeteoSchweiz: 2009, Basisanalysen ausgewählter klimatologischer Parameter am Standort KKW-Mühleberg, 135pp, CHF 88.-
- 225** MeteoSchweiz: 2009, Basisanalysen ausgewählter klimatologischer Parameter am Standort KKW-Gösgen, 135pp, CHF 88.-
- 224** MeteoSchweiz: 2009, Basisanalysen ausgewählter klimatologischer Parameter am Standort KKW-Beznau, 135pp, CHF 88.-
- 223** Dürr B: 2008, Automatisiertes Verfahren zur Bestimmung von Föhn in den Alpentälern, 22pp, CHF 62.-
- 222** Schmutz C, Arpagaus M, Clementi L, Frei C, Fukutome S, Germann U, Liniger M und Schacher F: 2008, Meteorologische Ereignisanalyse des Hochwassers 8. bis 9. August 2007, 29pp, CHF 64.-
- 221** Frei C, Germann U, Fukutome S und Liniger M: 2008, Möglichkeiten und Grenzen der Niederschlagsanalysen zum Hochwasser 2005, 19pp, CHF 62.-
- 220** Ambühl J: 2008, Optimization of Warning Systems based on Economic Criteria, 79pp, CHF 75.-
- 219** Ceppi P, Della-Marta PM and Appenzeller C: 2008, Extreme Value Analysis of Wind Observations over Switzerland, 43pp, CHF 67.-
- 218** MeteoSchweiz (Hrsg): 2008, Klimaszenarien für die Schweiz – Ein Statusbericht, 50pp, CHF 69.-
- 217** Begert M: 2008, Die Repräsentativität der Stationen im Swiss National Basic Climatological Network (Swiss NBCN), 40pp, CHF 66.-
- 216** Della-Marta PM, Mathis H, Frei C, Liniger MA and Appenzeller C: 2007, Extreme wind storms over Europe: Statistical Analyses of ERA-40, 80pp, CHF 75.-
- 215** Begert M, Seiz G, Foppa N, Schlegel T, Appenzeller C und Müller G: 2007, Die Überführung der klimatologischen Referenzstationen der Schweiz in das Swiss National Climatological Network (Swiss NBCN), 47pp, CHF 68.-

### Veröffentlichungen der MeteoSchweiz

- 86** Walker, D: 2010, 2010, Cloud effects on erythemal UV radiation in a complex topography, 106 pp, CHF 81.-
- 85** Ambühl, J: 2010, Neural interpretation of ECMWF ensemble predictions, 48pp, CHF 68.-
- 84** Ambühl, J: 2010, Customer oriented warning systems, 91pp, CHF 78.-
- 83** Ceppi, P: 2010, Spatial characteristics of gridded Swiss temperature trends: local and large-scale influences, 82pp, CHF 76.-
- 82** Blanc, P: 2009, Ensemble-based uncertainty prediction for deterministic 2 m temperature forecasts, 90pp, CHF 78.-
- 81** Erdin R: 2009, Combining rain gauge and radar measurements of a heavy precipitation event over Switzerland: Comparison of geostatistical methods and investigation of important influencing factors, 109pp, CHF 81.-
- 80** Buzzi M: 2008, Challenges in Operational Numerical Weather Prediction at High Resolution in Complex Terrain, 186pp, CHF 103.-
- 79** Nowak D: 2008, Radiation and clouds: observations and model calculations for Payerne BSRN site, 101 pp, CHF 80.-
- 78** Arpagaus M, Rotach M, Ambrosetti P, Ament F, Appenzeller C, Bauer H-S, Bouttier F, Buzzi A, Corazza M, Davolio S, Denhard M, Doringner M, Fontannaz L, Frick J, Fundel F, Germann U, Gorgas T, Grossi G, Hegg C, Hering A, Jaun S, Keil C, Liniger M, Marsigli C, McTaggart-Cowan R, Montani A, Mylne K, Ranzi R, Richard E, Rossa A, Santos-Muñoz D, Schär C, Seity Y, Staudinger M, Stoll M, Vogt S, Volkert H, Walser A, Wang Y, Werhahn J, Wulfmeyer V, Wunram C and Zappa M: 2009, MAP D-PHASE: Demonstrating forecast capabilities for flood events in the Alpine region. Report of the WWRP Forecast Demonstration Project D-PHASE submitted to the WWRP Scientific Steering Committee, 65pp, CHF 73.-
- 77** Rossa AM: 2007, MAP-NWS – an Optional EUMETNET Programme in Support of an Optimal Research Programme, 67pp, CHF 73.-
- 76** Baggenstos D: 2007, Probabilistic verification of operational monthly temperature forecasts, 52pp, CHF 69.-
- 75** Fikke S, Ronsten G, Heimo A, Kunz S, Ostrozlik M, Persson PE, Sabata J, Wareing B, Wichura B, Chum J, Laakso T, Sääntti K and Makkonen L: 2007, COST 727: Atmospheric Icing on Structures Measurements and data collection on icing: State of the Art, 110pp, CHF 83.-
- 74** Schmutz C, Müller P und Barodte B: 2006, Potenzialabklärung für Public Private Partnership (PPP) bei MeteoSchweiz und armasuisse Immobilien, 82pp, CHF 76.-
- 73** Scherrer SC: 2006, Interannual climate variability in the European and Alpine region, 132pp, CHF 86.-
- 72** Mathis H: 2005, Impact of Realistic Greenhouse Gas Forcing on Seasonal Forecast Performance, 80pp, CHF 75.-
- 71** Leuenberger D: 2005, High-Resolution Radar Rainfall Assimilation: Exploratory Studies with Latent Heat Nudging, 103pp, CHF 81.-
- 70** Müller G und Viatte P: 2005, The Swiss Contribution to the Global Atmosphere Watch Programme – Achievements of the First Decade and Future Prospects, 112pp, CHF 83.-
- 69** Müller WA: 2004, Analysis and Prediction of the European Winter Climate, 115pp, CHF 34.
- 68** Bader S: 2004, Das Schweizer Klima im Trend: Temperatur- und Niederschlagsentwicklung seit 1864, 48pp, CHF 18.-