The COST733 circulation type classification software: An example for surface ozone concentrations in Central Europe

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Abstract In the framework of the COST733 Action “Harmonisation and Applications of Weather Types Classifications for European Regions” a new circulation type classification software (hereafter referred to as cost733class software) is developed. The cost733class software contains a variety of (European) classification methods and is flexible towards choice of domain of interest, input variables, time step, number of circulation types, sequencing and (weighted) target variables. This work introduces the capabilities of the cost733class software in which the resulting circulation types (CTs) from various circulation type classifications (CTCs) are applied on observed summer surface ozone concentrations in Central Europe. First, the main characteristics of the CTCs in terms of circulation pattern frequencies are addressed using the baseline COST733 catalogue (cat 2.0), at present the latest product of the new cost733class software. In a second step, the probabilistic Brier skill score is used to quantify the explanatory power of all classifications in terms of the maximum 8 hourly mean ozone concentrations exceeding the 120 µg/m$^3$ threshold, this based on ozone concentrations from 130 Central European measurement stations. Evaluation results averaged over all stations indicate generally higher performance of CTCs with a higher number of types. Within the subset of methodologies with a similar number of types, the results suggest that the use of CTCs based on optimisation algorithms are performing slightly better than those based on other algorithms (prede-
fined thresholds, principal component analysis and leader algorithms). The results are further elaborated by exploring additional capabilities of the cost733class software. Sensitivity experiments are performed using different domain sizes, input variables, seasonally-based classifications and multiple-day sequencing. As an illustration, also CTCs conditioned towards temperature with various weights are derived and tested similarly. All results exploit a physical interpretation by adapting the environment-to-circulation approach, providing more detailed information on specific synoptic conditions prevailing on days with high surface ozone concentrations. This research does not intend to bring forward a favourite classification methodology or construct a statistical ozone forecasting tool but should be seen as an introduction to the possibilities of the cost733class software. It this respect, the results presented here can provide a basic user support for the cost733class software and the development of a more user- or application-specific CTC approach.

**Keywords** circulation type classifications · Brier skill score · COST733 · cost733class software · surface ozone concentration

1 Introduction

Generally, synoptic climatology is the scientific field that relates the larger-scale atmospheric conditions to a broad range of local-scale environmental elements (Barry and Perry, 1973). A first extensive description of this field of research and its developments is given by Yarnal et al (2001). Nevertheless, this paper provided only limited information on the classification of circulation types. In the framework of the COST733 action (www.cost733.org) entitled “The harmonisation and application of weather types classifications for European regions” an extensive review process is performed by Huth et al (2008), resulting in an overview of the recent tendencies and developments in both the methodology and applications of circulation pattern classifications. At present, circulation patterns are used in many different fields of atmospheric science, for a broad spectrum of purposes. Here, the possibilities of the cost733class software are shown using surface ozone concentrations over the Central European region as an example target variable; for a description of other classification applications, the reader is referred to the COST733 website (http://www.cost733.org) and to e.g. Huth et al (2008) and Philipp et al (2010).

Investigating the link between the large-scale circulation and environmental variables can in general be addressed in two fundamentally different approaches, as was suggested by Yarnal (1993) and later on adopted by Cannon et al (2002). The circulation-to-environment approach (focus of COST733 and Huth et al (2008)) arranges the circulation data of interest (e.g. sea level pressure, geopotential height...) according to a selected methodology (clustering, PCA, regression...) and than seeks relations with the local-scale
environmental variable (e.g. ozone). On the other hand, the environment-to-circulation approach structures the circulation data based on indices structuring the environmental variable, so that composite maps of the circulation variable can be derived for a specific environmental condition. Whilst the former is often used as a downscaling tool for the present-day and future climate (Kassomenos, 2003a; Hogrefe et al, 2004a; Ainslie and Steyn, 2007; Demuzere and van Lipzig, 2010a,b; Sheridan and Lee, 2010), the latter structures the circulation data based on one or more criteria defined by the environmental variable which makes its use in a predictive manner more difficult, especially with respect to achieve robustness. Nevertheless, the environment-to-circulation approach can provide some physical evidence in the driving large-scale variable conditions that form the basis of this specific environmental (in this case ozone) event. Therefore, this research paper will employ both approaches.

The usefulness of these approaches of course depends on how the surface ozone concentrations are related to a set of circulation types (CTs). In general ozone is a secondary pollutant as it has no significant direct source of emissions. An amount of ozone at a specific location depends mainly on three factors: 1) the ozone background level at that site, 2) the amount of ozone that is formed by sunlight-driven atmospheric chemical reactions and 3) the advection of ozone from polluted areas. As an example of the latter, Derwent et al (2003) used a labelling technique to characterise the contributions made by a range of sources to ozone levels at a rural location in southern England. Based on this they observed that approximately two-thirds of the ozone found at this rural site was advected by large-scale intercontinental processes and one-third arose from photochemical production on the regional scale within Europe. In this respect, the large-scale synoptic conditions not only govern the advection of ozone at a specific site or region, but can also accomodate the typical conditions favouring photochemical production of ozone.

During the last decades, several studies focused on the relationship between air pollution and synoptic circulation patterns, especially from a circulation-to-environment point of view. Hereby, circulation types are derived for a specific time and region of interest from different predictor variables (e.g. sea level pressure, wind, 850 hPa geopotential height) and are used afterwards as an indicator of high air pollution episodes. Thereby, a large number of studies relate these large-scale synoptic patterns to mean levels of surface ozone (e.g. Schjoldager (1981); Van Dop et al (1987)), whereby an attempt is done to mark these findings in relation to the associated meteorological characteristics. In general, regimes with high-pressure systems associated with high temperatures and low wind speeds are common on days with high ozone (mixing) ratios (Hogrefe et al, 2004b; Ainslie and Steyn, 2007). Comrie (1992) manually derived 9 synoptic types from daily surface weather maps to examine basic associations between surface ozone pollution and the at-
mospheric circulation. He concludes that for the Pennsylvania area (USA), high ozone concentrations occur
in summer with slow-moving anticyclones, while in winter low concentrations occur with cyclonic storms
moving in from the North and bringing cold, cloudy and windy conditions with precipitation. Differences
in winter and summer ozone conditions were further marked and described by Davies et al (1992), using a
wind speed index indicative for the sub-regional surface pressure gradients in Europe. A more recent study
of Demuzere et al (2009) provides insight in the local and regional meteorological processes that play a role
in ozone formation at four mid-latitude sites in the Netherlands. Here, the objectivised Jenkinson-Collison
method is compared with a multiple regression technique as a possible tool for downscaling climate sce-
narios for air quality purposes. It is shown that, although using a circulation type approach can provide
important physical relations between meteorology and air quality, the use of circulation types a short-term
air quality forecast tool is limited. Similarly, Carvalho et al (2010) characterize the atmospheric conditions
that lead to the ozone-rich episodes in Northern Portugal, using synoptic pattern anomalies and backward
trajectories. For the identification of the most frequent synoptic conditions related to the observed peak
ozone concentrations, several surface, low- and mid-tropospheric (1000, 500 and 850 hPa) meteorological
variables (e.g. temperature, relative humidity, zonal wind component...) were considered. The analysis of
the ozone concentrations for each selected cluster indicates that the northeast circulation pattern, together
with the southern flow, are responsible for the highest ozone peak episodes.

The choice of an appropriate circulation classification methodology for a specific application should be
based on an objective evaluation of the explanatory power of the circulation patterns on the region they
are derived for. Distance measures are a frequently used tool to quantify the between-type variance against
the total variance (see e.g. section 6 in Huth et al (2008)). Here we follow the suggestion by Schiemann and
Frei (2010) using the Brier skill score, a skill score often used for the evaluation of probabilistic or ensemble
forecasts. This method is applied to quantify the ability of the circulation type classifications to describe
the day-to-day variations in ozone, and more specifically the ability of these classifications to represent
the observed probabilities of exceeding the 120 µg/m³ threshold for the 8-hourly mean maximum O₃
concentrations (m8hO₃) set by the European guidelines on Air quality (EU, 1999, 2008).

Although this study uses a skill score often used in the evaluation of forecasts, it is important to stress
that this paper concentrates on the evaluation of circulation type classifications and their characteristics
as available through the COST733 software, using ozone as a target variable. Hence, it is not our purpose
to build an optimal statistical model able to predict surface ozone concentrations for a specific location
or time period (e.g. Demuzere et al (2009) and references therein). Building such a statistical forecasting
framework requires substantial work with respect to local and regional surface ozone characteristics and its
drivers, which is outside the scope of the COST733 action. Therefore, we opt to present the capabilities of
the COST733 toolbox which can form a basis for a more detailed research with respect to such e.g. local
air pollutant prediction.

Section 2 of this paper describes the data, methods and most important features of the COST733class soft-
ware. Section 3 describes the results for the circulation-to-environment approach of the baseline COST733
catalogue version 2.0 (section 3.1), while the results of the environment-to-circulation approach are de-
scribed in section 3.2. The results of the sensitivity experiments using different input variables, different
domain sizes, seasonality and sequencing are presented in section 4. A conclusion of this study is presented
in section 5.

2 Data and methods

2.1 Ozone measurements

Daily m8hO3 concentrations are selected from the AIRBASE network (http://air-climate.eionet.europa.eu/)
for 130 rural background stations in Germany, Switzerland, Austria and the Czech Republic all located in
the main domain of interest (D07) (Fig. 1). As the extent of the data is on the lower time end constrained
by the continuity of the ozone series and on the higher end on the availability of ECMWF ERA40 data (see
section 2.2) and as high ozone values are most prominent in summer, only the summer months June, July
and August (JJA) for the period 1996 to 2002 are considered.

The m8hO3 concentrations are first derived as the 8 hourly averaged mean from the hourly concentra-
tions when at least 6 valid hourly values are available. Afterwards the daily 8-hourly maximum is caculated
when at least 18 valid running 8-hour averages per day are available. Unfortunately no continuous rural
background ozone time series are available for Poland and Slovakia for the period 1996-2002.

2.2 ECMWF ERA40 data

The basic input data for the classification techniques (for reasons of similarity described in section 2.3) is
the ERA40 reanalysis sea level pressure data (SLP) provided by the European Centre for Medium-Range
Weather Forecasts (Uppala et al, 2005). For the baseline cost733cat evaluation (sections 3.1.1 and 3.1.2),
12 UTC SLP for the whole period 01/09/1957 - 31/08/2002 on a 1 x 1° grid resolution is selected. The
circulation patterns are derived for the whole year, but only the types for JJA are selected for the period
Fig. 1: Location of the measurement stations (dots) and the domain sizes used to derive the circulation patterns. Domain D07 presents the original Central European domain as defined in COST733, while domains 1, 2, 3 and 4 are used for the domain size sensitivity experiments used in section 4.1.

01/06/1996 - 31/08/2002, resulting in 644 days to be analysed. As a selection of methods are also tested on their sensitivity to different input variables, the following variables are also selected from the ERA40 database and used for the experiments addressed in section 4.2: 500 hPa geopotential height (Z5), thickness between 500 hPa and 850 hPa geopotential height (K5), vorticity of the 500 hPa GPH level (Y5) and 2 meter temperature (2mT). For the domain sensitivity analysis (see section 4.1), SLP data is also selected for 4 additional domains on a 1 x 1° resolution, as displayed in Fig. 1.

2.3 The COST733 circulation classification catalogue

A first aim of the COST733 action was to compile an inventory of the existing classifications in Europe. This task is already extensively described in section 5 of Huth et al (2008). Main result here is that the
number of classifications is high (and still increasing), which makes the decision on which classification to use for a specific application hard. Hence, COST733 attempts to address this uncertainty by comparing different classification methods in order to evaluate whether one (or a few) catalogues (or more universally their algorithm of classification) are superior for a specific application. Another objective is to combine favorable properties of existing methods in order to develop a reference classification. Therefore a database of circulation type classification results under the unified input dataset and the configuration of the classification procedure is established (referred to as cost733cat) resulting in methods that are as comparable as possible. Most of the circulation type classifications from cost733cat, together with a range of other features like sequencing, multiple input and seasonality, are implemented in the cost733cat software, which forms the basis of the research described here.

In order to create a similar platform for objective evaluation, some uniform test conditions are created. A first step contains the standardization of the source of input data and the temporal and spatial domain. The predefined input dataset is the ERA40 reanalysis dataset provided by ECMWF (the European Centre for Medium-Range Weather Forecasts) (Uppala et al, 2005) excluding discrepancies caused by different input data sources, assimilation or preprocessing schemes. Although the classification dataset is provided for 12 unified domains covering the whole of Europe (see Fig. 1 in Philipp et al (2010)), we focus here on Central Europe using domain D07 [43 - 58° N and 3 - 26° E] (Fig. 1). As originally various methods use other or more variables than SLP, they have in a second step been recalculated using solely SLP. As the objective Wetterlagenklassifikation (WLK) developed by Bissolli and Dittmann (2001) only makes physically sense with multiple input variables (U and V wind parameters at 700 hPa, geopotential height, temperature and relative humidity at 950, 850 and 700 hPa) this method is removed from the database for this study, as it limits an objective comparison with the other methods. All other CTCs, together with their respective methodology and official description are provided in Table ?? . In a third step the number of types produced by the classification methods is standardized. The original number of types are varying between 4 and 43 types. Here, it is decided to fix this number to 9, 18 and 27 with deviations by up to two from these numbers for 9 and 18 types, while for some of the 27 cluster type catalogues these deviations can be larger. Furthermore, a random cluster classification is run for 1000 iterations, from which only the best (in terms of explained variance) is used here (RAC) (Philipp, Pers. Comm.). For a detailed description of each method, the reader is referred to Philipp et al (2010). The standard version of the COST733 catalogue (hereafter referred to as cat 2.0) is based on SLP as input variable only, derived for the whole year and one-day sequence only. Unless stated otherwise, all analyses are done using cat 2.0.
Table 1: Overview of the methods produced the COST733 software. The abbreviations mentioned in the description section are used to explain the methodology described in the overview paper by Philipp et al (2010). The classifications are clustered according to their main methodology with Thres - Threshold based, PCA - Principal component analysis, LDR - leader algorithm, OPT - optimization algorithm and Random - randomly created. The methods in italic are used in the sensitivity analysis described in section 4.

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>Thres</td>
<td>GWT</td>
<td>GrossWetterTypes (GWT)</td>
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<td></td>
<td>JCT</td>
<td>Jenkinson-Collinson-Types</td>
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<td></td>
<td>LIT</td>
<td>Litynski (LITADVE/LITTC)</td>
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<tr>
<td>PCA</td>
<td>KRZ</td>
<td>Kruizinga (P27)</td>
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<td></td>
<td>PXE</td>
<td>Pca-eXtreme scores reassigned by Euclidean distance (PCAXTR)</td>
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<td></td>
<td>PCT</td>
<td>obliquely rotated PCA of subsamples in T-mode (TPCA)</td>
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<tr>
<td></td>
<td>PTT</td>
<td>orthogonally rotated PCA in T-mode</td>
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<tr>
<td>LDR</td>
<td>LND</td>
<td>LuND</td>
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<tr>
<td></td>
<td>KIR</td>
<td>KIRchhofer (KRC)</td>
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<tr>
<td></td>
<td>ERP</td>
<td>ERPicum</td>
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<tr>
<td>OPT</td>
<td>CKM</td>
<td>CKMeans</td>
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<tr>
<td></td>
<td>SOM</td>
<td>SelfOrganizing Maps (Kohonen SOM) using 1d-topology</td>
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<td></td>
<td>CAP</td>
<td>Cluster Analysis of Principal components (PCACA)</td>
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<td></td>
<td>PXK</td>
<td>Pca-eXtreme scores reassigned by K-means (PCAXTRKM)</td>
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<tr>
<td></td>
<td>SAN</td>
<td>Simulated Anealling clustering</td>
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<tr>
<td>Random</td>
<td>RAC</td>
<td>RAnBdant Centroid classification</td>
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The different variations of the classification methods are recalculated using the COST733 software tool called cost733class. While it is still under development, it is able to produce most of the automated methods shown in Table 1. Since the software allows to choose and combine input data freely (amongst other options), it is also possible to include parameters related to (high) ozone concentrations within the classification process and compare these conditioned classifications to the catalogues shown in Table 1. Therefore the 2m air temperature (2mT) field has been included as an additional parameter describing the state of the atmosphere in addition to the circulation fields (see section 4). However, since, e.g. SLP and 2mT show different units and amplitudes, each parameter is normalized as a whole in a first step. Furthermore, different weights can be applied to the various parameters, e.g. in order to make the types more depending on 2mT than on SLP.

2.4 Evaluation methodology

The approach used here follows the suggestion of Schiemann and Frei (2010), in which a method is proposed to evaluate the occurrence of continuous variables for the (non-) exceedance of a threshold dependent on the
prevailing circulation type (CT). Here, we use the probability of the m$\text{SO}_3$ concentration for a day under a certain CT to exceed the 120 µg/m$^3$ threshold. The generic Brier skill score (BSS) is derived from the Brier Score (BS) which is essentially the mean squared error of the probability forecast (Wilks, 2006):

$$BS = \frac{1}{N} \sum_{k=1}^{N} (y_k - o_k)^2,$$

(1)

where $y_k$ is the forecast probability on day $k$ and $o_k$ is the indicator for the observation, taking values 1/0 if the event occurs/does not occur on day $k$. In this context, the forecast probability is only depending on the circulation type. If CT ($i = 1, ..., I$) denotes the number of circulation types of a classification then $y_i$ is the relative frequency of the event for each CT $i$ (e.g., the number of days exceeding the 120 g/m$^3$ threshold during a specific circulation type). When a day $k$ is attributed to CT $i$, $y_i$ can be considered as a prediction of the probability of the event to occur on day $k$. Such a prediction is available for all days $k = 1, ..., N$ classified into circulation types. From Schiemann and Frei (2010) this results in a normalized resolution component of the Brier skill score used here:

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

(2)

with $N_i$ representing the frequency of each CT $i$ and $\bar{o}$ the climatological mean as a reference. BSS varies between 0 and 1, with larger values indicating more skill. The interpretation is intuitive, recognizing that the numerator of BSS is some sort of probability variance. It increases if there are large deviations of the conditional empirical event frequencies from the climatological (unconditional) frequency. In the remaining of the paper, all results of the sensitivity studies of section 4 are compared against the baseline experiment using cat 2.0 described in section 3.1.1.

The robustness of the BSS is shown by means of a 95 % confidence interval obtained by a nonparametric bootstrap resampling. Hence, 999 resamples of the original time series of summer days are drawn with replacement and for each of these resamples, a BSS is computed. As the dataset is pooled together from different locations, one can expect the joint distribution of the sample pairs to be dependent on the location (Bradley et al, 2008). Therefore, the bootstrap resampling is done for each station separately. As the bias (deviation of the “full” estimate from the centre of the bootstrap distribution) is negligible, the 95% percentile bootstrap confidence interval from the distribution of the Brier skill scores over all stations is determined and added as error bars in Fig. 3. These intervals are afterwards used to check whether the changes in BSS in the sensitivity studies are significant or not (see section 4). Hereby it is important to mention that these results should not be interpreted as a result of a circulation-based statistical ozone forecast model, as the capacity of only circulation types in terms of statistical forecasting models for ozone
has been shown limited by for e.g. Demuzere et al (2009). The present study therefore does not explicitly interpret the skill of the circulation types as an improvement against climatology and/or persistence (Wilks, 2006), shown in section 5 of Demuzere et al (2009). Nevertheless, the generic form of the BSS as shown by equation 4 in Schiemann and Frei (2010) shows that the actual value of the Brier Score is compared to those of a perfect prediction (=0) and a trivial reference prediction which is in this case the climatology prediction denoted by \( BS_{ref} = \bar{o}(1 - \bar{o}) \), the denominator in equation 2.

3 Results

3.1 Circulation-to-environment approach

Before the circulation types of cat 2.0 are related to daily \( m8O_3 \) concentrations, the monthly frequency characteristics of the CTs produced by the classification algorithms are addressed in section 3.1.1. Afterwards, the areal averaged and spatial BSS as well as the discriminatory power of the baseline algorithm configurations are discussed. These CTCs use only SLP as classifiable variable, with CTs derived over D07 and for the whole year (although here we use only JJA) without sequencing. Only in a later stage (section 4), the effect of other input variables, weighting, sequencing, seasons and domains will be tested. Due to the large number of CTCs available from the COST733class software, this study will mainly focus on the CTCs with approximately 18 circulation types.

3.1.1. Monthly frequencies of the CTs

The relative monthly frequencies for the algorithms with approximately 18 CTs are shown in Figure 2. Some CTCs tend to have larger differences in monthly type occurrences and can in general be characterised by the following three classes: 1) dominated to a large extent by one single circulation type, 2) intrinsic seasonal cycle and 3) uniform distribution. Most of the algorithms with 18 CTs belong to the second class, as e.g. in GWT, LND and all optimization methods. For example, the first three CTs of CKM occur for almost 50% of the days in summer, while they are almost non-existing in winter months. A probable explanation is that all these methods use distance measures that reflect pressure gradients, while the other methods use similarity metrics which do not account for this seasonal cycle. In contrast, all PCA methods (apart from PTT), KIR and LIT tend to have a more uniform distribution. Besides these two categories, the methodology PTT tends to be dominated by one type occurring for almost (or more) than 50% during the course of the whole year. For the algorithms derived for approximately 9 and 27 CTs these characteristics can generally be extrapolated (not shown). The information of the distribution of the CTs frequency occurrence can help
in the interpretation of the Brier skill score providing a quantitative estimate of the explanatory power of all classifications in reproducing the observed ozone threshold exceeding probabilities.

![Relative monthly circulation type frequencies for all algorithms with approximately 18 CTs.](image)

### 3.1.2. The Brier skill score

The Brier skill score for each circulation algorithm from cat 2.0, for the different number of classes and all stations are calculated and presented as the spatial mean over all stations in Figure 3. In general, there...
is an overall BSS increase with an increasing number of types, a feature which is strongest between the
transition from 9 to 18 types and less distinct between the 18 and 27 types. Consequently, differences in
BSS for CTCs with equal class sizes can be attributed to differences in methodologies. Also, results are
better concerning the 120 µg/m³ threshold compared to a higher threshold (e.g. 180 µg/m³) (not shown).
This is what one can intuitively expect from the BSS as higher thresholds increase the rarity of an event
which hampers the performance of the method, taking into account that the CTs are solely based on SLP.
Furthermore, most of the skill scores for the CTCs tend to have a similar tendency across the number of
circulation types as e.g. SAN09, SAN18 and SAN27 have overall a high BSS, while e.g. PTT09, PTT18
and PTT27 have an overall low score. Occasionally, some methods perform differently, as e.g. LIT09 is
ranked as one of the worst methods for the 9 types CTCs, while it is one of the best for the 18 and 27
classes CTCs. This could be explained by the fact that LIT was originally designed for 27 types, while
18 types are achieved by reducing the central index (which is relevant for central high/low pressure and
therefore for ozone production) and 9 types by completely omitting the central index (see section 2.1.2.2
in Philipp et al (2010)). In summary, the results in Figure 3 suggest that all results are robust (small
confidence intervals) and that especially the methods using optimisation algorithms tend to perform better
than others. Another worthy thing to mention is the fact that the cost733class software is able to reproduce
the original catalogues in an adequate way, as differences are overall small (not shown). One exception here
is JCT and LWTo, the latter presenting the revised automated Jenkinson-Collison scheme developed by
James (2006). This revised catalogue systematically adjusts the vorticity-flow ratio thresholds using ERA40
daily mean SLP as a basis, to force the type frequencies to be evenly-tempered between pure directional
and hybrid anticyclonic and cyclonic types. In this way, daily CTs are more homogeneously spread and less
types become classified into a small subset of the 27 available types, especially in case of the anticyclonic
and cyclonic class (not shown). These results nevertheless provide confidence that the cost733class software
is able to reproduce the original classifications.

In addition, an example of the spatial distribution of the two best/worst CTCs (in terms of BSS)
with 18 circulation types is shown in Fig. 4. Obviously there are distinct spatial differences for different
Central European areas and methodologies. One can notice an overall lower Brier skill score for all CTCs
(not shown) for the Austrian stations compared to the other Central European stations used in this study.
Although some of the Asutrian measurement stations are located at a higher elevation (> 1500 m), the ozone
concentrations do not show a direct dependency on this height (not shown). Moreover, the distribution of
the ozone concentrations for the Austrian stations are well within the enveloppe of the distribution curves
of all other stations, without any significant differences in peak ozone concentrations. It could therefore be
possible that the CTCs are not able to catch synoptic situations with central anticyclonic patterns centered
Fig. 3: The Brier skill score for all classification algorithms, averaged over all measurement stations and grouped by number of CTs (C09 - upper left, C18 - upper right, C27 - lower left). 95 % bootstrap intervals are shown in black error bars.

around Austria. Hence, the patterns developed in D07 could be characterised by air mass intrusion over Austria, which does not create favourable (stagnant) conditions for high ozone concentrations in this part of the domain. This hypothesis is tested with the subjective ZAMG classification scheme, which is tailored towards and manually developed for the Eastern Alpine region (see section 2.1.1.5 in Philipp et al (2010)). The use of this subjective classification not only results in generally higher skill scores for the Austrian stations, but also for some of the other Central European stations, resulting in a spatially averaged BSS of 0.12, similar as the best performing methods shown in Fig. 3. However, as it is our aim to present the possibilities of the cost733class software, which is not able to calculate subjective classifications such as ZAMG, the use of subjective classifications selected by COST733 is not further elaborated here.
3.1.3. Discriminative power

The results of the Brier skill score as described above reflect the discriminative power of a CTC. If the method is able to group days with low/high ozone concentrations into one (or a few) distinct classes, the probability of an event under a specific CT to occur compared to the mean overall probability will increase. Hence, it is worthwhile to plot the distribution of the ozone values per circulation type for each CTC. The boxplots in Fig. 5 show the standard deviation in its width and the extreme lowest/highest values over all stations.
An introduction to the cost733class software

as the lower/upper whiskers. The range of the box and whisker values hence denote the range of values captured by the CTC, while an overlap in box/whiskers indicates that an ozone concentration value can be found in several circulation classes. This means that for a method with excellent discriminative power, the boxes should be compact with a minimum of overlap (Spekat et al, 2010). This is done for all stations and all methods with approximately 18 circulation types, using only summer (JJA) days. In general, all methods show quite some overlap between the various circulation types, exhibiting a low discriminative power. The within-class variability is large as well, what can be expected as all stations are taken into account. This means that a target ozone concentration can occur under different circulation types. Using only one station (or a cluster of stations located in a region with similar environmental characteristics) improves the results (not shown), as other (local) factors like e.g. topography, local industrial emissions etc. also favor ozone formation (Schneider, 2003; Derwent, 2008). Nevertheless, some CTCs indicate a more pronounced clustering with one (or a few) classes with high ozone concentrations and low within-type standard deviations (e.g. CKM and CAP).

In order to gain insight in the spatial sea level pressure characteristics of the circulation types, composite patterns are shown for the circulation type of each CTC that contains the largest number of stations having a maximum 8 hourly mean ozone concentration $\geq 120\mu g/m^3$ on a specific day. The frequency variability of the CTs shown in Figure 2 is taking into account by standardizing the number of stations by this value. Hence, the circulation types providing the strongest link to high ozone concentrations over the whole domain of interest is shown. If one would opt to select the circulation type related to the highest median ozone concentrations for a specific CT as is e.g. done in Demuzere et al (2009) some other CTs would be selected with rather similar SLP composite patterns (not shown). This reflects again the fact that within one CTC multiple circulation types can lead to high ozone concentrations. Here, the results are only shown for all CTCs with approximately 18 circulation types (Fig. 6), similar as for the Box-Whisker plots shown in Figure 5. In general, the majority of the circulation types show a surface high-pressure system over Central or Eastern Europe, resulting in a weak sea level pressure gradient characterised by a weak east-to southeastern surface wind in the domain of interest. Previous research has shown that this pressure configuration governs the advection of warm and dry continental air, which are in turn favourable for high ozone concentrations (e.g. Hogrefe et al (2004b); Ainslie and Steyn (2007); Demuzere et al (2009)).

It is remarkable that the composite circulation types of CKM, CAP and SAN are identical. Although all these classification methodologies belong to the optimization algorithm group using similar principles (e.g. k-means) as described in Table 1, they do have some differences in e.g. the way they handle the starting partitions and the input data that is clustered (CAP is for example using principal component time series from a S-mode principal component analysis). For a more detailed description of these methodologies the
Fig. 5: Box-Whisker plots of summer ozone concentration of all European sites grouped per circulation type for all CTCs with approximately 18 types. The bars denote the minimum and maximum value, while the box refers to the standard deviation.

reader is referred to sections 2.2.3.1, 2.2.3.2 and 2.2.3.5 in Philipp et al (2010). In spite of these differences, they all produce a class which is identical and is occurring only one day (19th of June 2000) in the summer months of the period 1996-2002. This doesn’t mean that this type has only one member overall, as the catalogues are derived for the whole year. Over Central Europe, the 19th of June 2000 is characterized by a surface high pressure system over Eastern Europe (as in Fig. 6) and an upper tropospheric ridge over
Switzerland. This results in calm weather with anomalous high temperatures, low winds and long sunshine
duration, perfect conditions for surface ozone formation over an extended area (Demuzere and van Lipzig
(2010a) and references therein).

Fig. 6: Sea level pressure composites for the circulation type of each CTCs that contains the largest number
of stations having a maximum 8 hourly mean ozone concentration exceeding the 120\(\mu g/m^3\) threshold. The
number in square brackets [ ] refers to the selected circulation type as indicated in the Box-Whisker plots
of Fig. 5
3.2 Environment-to-circulation approach

In this section, ozone features are not reconstructed based on the circulation type itself, but an inverse approach is followed. Here, mean sea level pressure, 500 hPa geopotential height (Z5), thickness between 500 and 850 GPH (K5) and 500 hPa vorticity (Y5) composite patterns are constructed based on a threshold of number of stations exceeding the 120 μg/m³ ozone concentration. Initially, four different thresholds for the number of stations are used: 65 stations (50 %), 80 stations (61 %), 95 stations (73 %) and 110 stations (85 %). The number of days from the total number of summer days between 1996 and 2002 that satisfy this conditions are 98 (15.2 %), 53 (8.2 %), 18 (2.7 %) and 2 (0.3 %) respectively. The number of days fulfilling the threshold decrease rapidly, hence a threshold of 50 % of the stations exceeding the 120 μg/m³ ozone concentration is used, resulting in a subsample of 98 JJA days. This number of stations approximately corresponds to the number of stations used in the circulation-to-environment approach of the composite patterns in section 3.1.3. Nevertheless, as the CKM, CAP and SAN composite patterns as shown in Figure 6 have exactly 110 stations exceeding the 120 μg/m³ threshold on the 19th of June 2000, the composite maps for these extreme ozone conditions occurring over a large part of Central Europe are shown as well (Fig. 8).

The SLP patterns show a closed high pressure system over Central/Eastern Europe, with an increase in central pressure for an increasing number of stations that satisfy the threshold condition (compare Fig. 7 with Fig. 8). The latter has a negligible small standard deviation over D07 as this composite only represents two days. It is clear that this pattern has a close resemblance to the patterns 13, 12 and 10 from the CKM, CAP and SAN respectively (Fig. 6). These SLP patterns confirm what was shown by previous research that peak ozone episodes in Central Europe are driven by weak pressure gradients in sea surface pressure resulting in residing air masses (Baur et al, 1944; Hess and Brezowsky, 1952; Guicherit and Van Dop, 1977; Delcloo and Backer, 2008; Demuzere et al, 2009). This synoptic situation is referred to as type HM in the Grosswetterlagen by Baur et al (1944) and Hess and Brezowsky (1952), referring to a closed high over Central Europe. The other composite patterns in Figure 7 reveal a westerly geostrophic flow for the 500 geopotential height, with an increasing GPH500-GPH850 thickness towards the south of Europe and an upper air vorticity of almost zero. The standard deviations for all these variables are rather large, pointing to a large variability of the upper air conditions for the selected days. Using 110 stations as shown in Figure 8 changes the 500 hPa geopotential height field with the development of a ridge above southern Europe. In contrast to the low variability of the SLP, this fields has a large standard deviation over the center of the domain due to the fact that the mid-tropospheric flow situation of these 2 selected days
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is quite different, whereas the surface pressure conditions are almost identical. The increase in thickness between the GPH500 and GPH850 also suggests an increase in upper air temperatures compared to the thickness composite pattern as shown in Figure 7. These results indicate that high summer surface ozone concentrations are only to a limited extent influenced by upper air processes. The latter can nevertheless contribute to intercontinental transport of ozone, as suggested by Derwent et al (2004). Tracing back the remote origins of ozone sources is outside the scope of this paper, but the results here can be of interest for the sensitivity analysis addressing the surplus value of additional input variables (see section 4.2).

Fig. 7: Composite patterns for SLP (upper left), Z5 (upper right), K5 (lower left) and Y5 (lower right) for the selection of days on which 65 stations have ozone concentrations $\geq 120$ g/m$^3$ for m$m$8O$_3$. The dashed line represents the standard deviation and the black rectangle the original COST733 domain D07.
Fig. 8: Same as in Figure 7 but for 110 stations with an ozone concentration $\geq 120 \text{ g/m}^3$ for $\text{m8hO}_3$.

4 Sensitivity studies

In the following section, the role of various parameters that were set the same for all catalogues in the framework of COST 733 is addressed. As mentioned in section 2.3, three main standardization steps are followed in the development of the cost733cat software. Here, we intend to address some sensitivity studies with respect to these steps, more explicitly with respect to the domain size (section 4.1), the input variables (section 4.2), the seasonality (section 4.3), sequencing (section 4.4) and some tests with respect to the preconditioning of the circulation algorithms towards a target variable, here temperature (section 4.5). In order to keep the results surveyable we opt to provide some results only for the catalogues with approximately 18 classes.
4.1 Domain size

For the domain sensitivity study, all selected catalogues are re-run for the four increasing domain sizes shown in Fig. 1. The sensitivity is performed using ERA40 reanalysis SLP only, on a 1 x 1° grid (see section 2.2), allowing for a more straightforward comparison with the results of the standard cat 2.0. Similar as in section 3, the Brier skill score is presented averaged over all stations and for each algorithm and domain respectively (Fig. 9).

Fig. 9: The domain size dependent Brier skill score averaged over all stations for all classification algorithms included in the cost733class software. The dark grey bars represent the domain size experiment BSS and the light grey bars (with black error bars) the baseline BSS as in Figure 3 for approximately 18 types. The upper left window presents results for domain 1, upper right for domain 2, lower left for domain 3 and lower right for domain 4.

Most methods show a change which is significantly outside the 95 % confidence interval of the baseline BSS provided by the nonparametric bootstrap resampling with replacement. Some methods tend to explain the observed surface ozone probabilities better when compiled over a larger geographical area (e.g. GWT,
JCT, LIT, KRZ, LND, PXE, PXK). Others have a tendency of performing worse with increasing domain size e.g. SAN, CAP and CKM. The latter all belong to the optimization group using the same way of optimization, with only some differences in the starting partition and the data-preprocessing. All members of the threshold and PCA-based CTCs show a significant increase in BSS performance for larger domain sizes. This shows that the classification algorithms are sensitive to the choice of the domain size, whereby some CTCs clearly prefer larger (e.g. GWT, JCT and PCT) or smaller (SAN, CAP and CKM) domains.

4.2 Input variables

The sensitivity test using additional input variables is only limited to ten methods, as not all algorithms have the capacity to include more than 1 variable to be classified. For example the GWT method (Beck et al, 2007) is based on correlation coefficients between predefined prototype flow types and the pressure fields and does not provide the possibility to include e.g. thickness (see section 2.1.2.1 in Philipp et al (2010) for more information). Hence, the following methods are tested: KRZ, PXE, PCT, PTT, LND, ERP, CKM, CAP, PXK and SAN. Three variables are added (Z5 - 500 hPa geopotential height, K5 - thickness between 500 and 850 hPa and Y5 - vorticity on the 500 hPa level), each of them combined with the basic SLP variable, or all together resulting in the following set of combinations: SLP-Z5, SLP-K5, SLP-Y5, SLP-Z5-K5-Y5.

In general, the optimization methods do not profit from more input variables, and depict a strong reduction in skill for SAN and CKM (Fig. 10). For the latter, this result is striking as the methodology was originally developed in such a way that it can incorporate several types of fields by using the normalized Euclidean distance to assign a day to a specific circulation type (Enke and Spekat, 1997). In contrast, the PCA methodology group is characterised by higher BSS, with the strongest positive impact for PCT over all variable combinations. Hence, as an illustration, we opt to plot the composite patterns for this method for SLP, K5, Y5 and Z5. First the pattern for each input variable group (SLP-K5, SLP-Y5, SLP-Z5 and SLP-Z5-Y5-K5) having the highest correlation coefficient (most similar) compared to the SLP composite pattern derived in section 3.2 is selected. As the patterns are derived for domain D07 only, the correlation is only based on this domain. Than, for each of these four selected CTs, the composites of all days belonging to this type are constructed and depicted in Figures 11 and 12, showing only these variables that are used as input to the CTCs.

The SLP composite for the baseline CTs shows a similar spatial pattern within the D07 domain, although the location of its central pressure center is more to the South and its spatial extent more towards the West (Fig. 11). The SLP composites from the sensitivity experiments alter both in spatial extent and SLP strength. Except for experiment SLP-K5, they all show stronger maximum pressure values, which is similar
to the SLP composite pattern that produced by taking into account a larger number of stations exceeding the threshold of 120 $\mu g/m^3$ (see Fig. 8). The fact that the introduction of thickness between 500 and 850 hPa doesn't introduce some additional information or improvement in explanatory power is probably due to its autocorrelation with the reference SLP field. The spatial SLP extent changes throughout the experiments, with a delocation of the anticyclonic system towards the east, middle and west of D07 for experiments SLP-Y5, SLP-Z5-Y5-K5 and SLP-Z5 respectively. The atmospheric tickness composites for the experiments SLP-K5 and SLP-Z5-Y5-K5 (Fig. 12) have a similar structure with slightly lower thicknesses, and hence upper air temperatures, for the the SLP-Z5-Y5-K5 configuration. The 500 hPa geopotential height composite patterns more reflect the stronger residing high pressure area over Central Europe, especially for the CTCs that use the SLP, Z5, Y5 and K5 as input variables, resulting in a weakening of the meridional flow (Fig. 12). This analysis supports the idea that high ozone concentrations are to a large extend moderated through

**Fig. 10:** As in Figure 9 but for different input variables: SLP-K5 (*upper left*), SLP-Y5 (*upper right*), SLP-Z5 (*lower left*) and SLP-Z5-Y5-K5 (*lower right*).
Fig. 11: Overview of the CTs with the largest similarity in SLP compared to the SLP composite pattern as shown in Figure 7 for the following configurations: the baseline cat 2.0 (upper left), SLP-K5 (lower left), SLP-Y5 (middle right), SLP-Z5 (lower left) and SLP-Z5-Y5-K5 (lower right).
Fig. 12: Same as Fig. 11 but for the other input variables used in the CTCs.
surface conditions, but including upper air variables can increase the explanatory power of the CTCs, by creating conditions with even stronger residing air masses.

4.3 Seasonality

Whereas the baseline cat 2.0 is developed taking into account all months for the period September 1957 to August 2002 (yearly catalogue), the CTs derived for this section are based on the summer months June-July-August only. This way, one can address the question whether for this specific application of summer ozone, “summer” types are preferred compared to “yearly-developed” circulation types. The threshold methods GWT, JCT and LIT use fixed thresholds throughout the year to derive the circulation patterns. In other words, the circulation pattern from e.g. JCT for the 1st of June 2000 based on the whole year will be the same as the circulation type based on the summer months only. Hence, they do not show a change in terms of BSS. In general, all other methods give a significant higher skill score, except for PCT, PTT and KIR (Fig. 13). The largest increase in BSS is seen LND and PXK. No separation in results can be made here between methods having a seasonal cycle inherent to its methodology (OPT methods, see section 3.1.1) and those lacking these seasonal properties. Those algorithms have mostly one or a few big summer-classes of persistent high-pressure patterns. This is especially true for the OPT methods because they reduce the within-type variance which is naturally smaller between high-pressure situations than in low-pressure situations with eddies. In fact, the methods showing this clear seasonality in the yearly-developed catalogue are characterised by an increase in BSS that is often stronger compared to some methods without seasonal properties, e.g. PCT.

4.4 Sequencing

Here we select the classification algorithms as they are used in section 4.2. Again, the number of types is 18 and only SLP is used as an input variable. The classifications are done using a 4 and 10-day sequencing. This means that one does not only classifies single daily fields, but a whole sequence of successive daily fields. This concept is described in more detail in Philipp (2009).

For the majority of the classifications, a 4-day sequencing has a negligible effect on the Brier skill score (Fig. 14) with a change in skill within the 95 % confidence intervals. The sensitivity increases using 10-day sequences, with a large increase in skill for KRZ and PTT. For the latter, this is in line with (Philipp, 2009) who tested various sequencing lengths with respect to surface air temperatures in Europe using PTT and SANDRA. All other methodologies show a variable behaviour with respect to the 10-day sequence experiment, some having small but significant BSS increase (PXK) and others showing a
significant deterioration (PXE, PCT, ERP, CKM and SAN). This is not what one intuitively would expect, as high ozone concentrations often occur under persistent high pressure conditions, a characteristic that might be addressed by extending the sequence length.

4.5 CTs conditioned towards temperature

In Demuzere et al (2009) it is shown that the Jenkinson-Collison classification performs poor as an air quality forecast model on a daily scale, but still captures some physical linkages between the large-scale circulation types and related surface weather elements. Other studies have also shown that the integration of the target variable could be beneficial as a downscaling procedure (Huth et al, 2008; Spekat et al, 2010). Moreover, also the composite plots in section 3.2 suggested that the use of surface input variables could be more relevant for ozone applications compared to the use of upper atmosphere parameters. The cost733class
software is constructed in such a way that the user can condition SLP-based circulation types towards a target variable. As daily surface ozone data is at present not available as a gridded dataset, we opt to use 2 meter temperature (2mT) from the ERA40 reanalysis dataset on a 1x1° resolution, a variable shown to be strongly related to ozone at the surface (Camalier et al, 2007). The exercise is done for the 10 classifications used to test the effect of different input variables and the CTs are derived for D07. An additional feature of the cost733Class software is the introduction of a weighting property, based on which you can increase the importance of a specific field during the classification algorithm (see description in section 2.3). A weight of one means that 2mT has equal importance as SLP, while a weight of 3 triples the importance of 2mT in comparison with SLP. In this case, we opt to test weighting factors 1, 3 and 10 on 2mT, for which the results are depicted in Fig. 15.

Comparing the results for the catalogues developed with different weights show significant differences for some CTCs. In general, the methods that have a better BSS in one weight category show a similar feature over other weight categories, apart from SAN, CAP and PCT who deviate from this general feature. PXE and PXK show a similar strong increase of BSS over all weighting categories, suggesting again that optimisation feature of the k-means clustering has no clear effect on the final CTs. Although the CKM method shows a decrease in skill when using a weight of 1 for 2mT, it shows a large increase in skill by increasing the weight with a factor 10. In contrast, while PTT shows a minor increase for the first case, its skill disappears completely for larger weighting factors. Hence, this analysis shows that not all methods show a significant improvement in their BSS although 2mT has been frequently mentioned to play a major role in ozone formation (e.g. (Camalier et al, 2007)). For the optimisation methods the effect is large when

Fig. 14: Similar as in Figure 9 but with the dark grey bars referring to the BSS for the sequencing experiment: (a) 4-day and (b) 10-day sequencing.
Fig. 15: Similar as in Figure 9 but with the dark grey bars referring to the BSS for the conditioning experiment towards 2 meter temperature weighted with a factor 1 (left), 3 (middle) and 10 (right).

using a large weight, while for other methods the effect is small or even negative, as for PCT, PTT and LND. In this sense, one could opt to classify 2mT directly (in combination with other surface elements like e.g. cloud cover, shortwave downward radiation, ...) often referred to as “weather” type classifications (Huth et al, 2008). Although this approach has already been used in several climate change and bioclimatological studies (Kalkstein and Giannini, 1991; Smoyer et al, 2000; Kysely and Huth, 2004), this paper concentrates on the larger-scale synoptic patterns. Therefore, this feature is not tested here, although the cost733class software has the potential to be used as a “weather” type classification.

5 Summary and conclusions

In this study, the circulation type classification software cost733class developed within the COST733 Action Harmonisation and Applications of Weather Types Classifications for European Regions is presented using surface ozone concentrations in Central Europe as an example target variable. The stations are selected based on the availability of continuous time series and ERA40 data, resulting in a selection of 130 background rural stations spread over Germany, Austria, Switzerland and the Czech Republic. The two main approaches in synoptic climatology are used to elaborate the results: (1) the circulation-to-environment approach using
the probabilistic skill score as a quantitative measure for the explanatory power of the CTCs and (2) the environment-to-circulation approach, used to get more physical insight in the large-scale synoptic conditions favouring high ozone concentrations. Hence, this paper not only describes the technical capabilities of the cost733class software by using the software for a variety of sensitivity experiments with respect to domain size, input variables, seasonality, sequencing and conditioned circulation types; it also provides some insight in the use of circulation types for surface ozone applications. For all experiments, the explanatory power of the classifications is quantified using the normalized resolution component of the Brier skill score as suggested by Schiemann and Frei (2010). This score measures the probability of the m8hO3 concentration to exceed the 120 \( \mu g/m^3 \) threshold depending on the prevailing circulation type.

First, the main properties of the baseline CTCs using SLP as input variable for the Central European domain D07 with 1-day sequencing are described through the monthly circulation type frequencies of each methodology. Over all number of circulation types, most methods reflect a uniform distribution of the types over the whole year. In contrast, the optimization methods tend to produce CTs that are seasonally varying in their frequency of occurrence. Furthermore, PTT has the tendency to produce one class occurring for more than 50 % of the time. Although the differences in frequencies are substantial for some methods, no clear link is found with the Brier skill score results. The methods do have an increasing BSS with higher number of circulation classes. Furthermore, the scores tend to be similar for each method over all class size groups, with some exceptions like e.g. LIT.

In a second step, the functionalities of the cost733class software are fully explored by a set of sensitivity experiments for different domain sizes, input variables, seasonality, sequencing and the conditioning of the circulation types towards a 2 meter temperature with different weighting factors. For all experiments, no overall valid conclusions can be drawn. Depending on the number of classes and the methodology, some methods improve their skills with respect to surface ozone properties for the different experiments while others deteriorate. The optimization methods show a variable skill sensitivity with respect to the domain size experiments. With respect to the classification of upper atmospheric variables, the results overall worsen. For this subset of classifications, this result confirms what was suggested previously by other authors, viz. the inclusion of additional levels yields only little extra information over using a single level owing to a high degree of dependance among individual levels (Kidson, 1997; Romero et al, 1999). On the other hand, a gain in score is obtained when the cost733class software is only applied for the summer months June, July and August, which effectively increases the number of summer CTs.

The BSS for the PCA and leader-based methodologies are positively related to an increase in domain size. The same is also true with respect to the application of different input variables. As an illustration, the patterns having the strongest correlation with the SLP composite pattern derived from an environment-
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to-circulation approach point of view are shown for PCT. For each of the input sensitivity experiments, the SLP composite shows a tendency towards re-location of its high-pressure center depending on the experiment, and a strengthening of the pressure values. The composite patterns for vorticity, 500-850 hPa thickness and 500 hPa geopotential height show a tendency towards more persistent upper atmosphere conditions, compared to the more zonal-flow oriented circulation type derived from the environmental-to-circulation approach. With respect to a 4- or 10-days sequencing, the methodologies show a variable behaviour, some having a small but significant BSS increase and others showing a significant decrease in skill. A last sensitivity experiment tests the conditioning of the circulation types with respect to 2 meter temperature, often shown to be strongly related to ozone. Better results are obtained for the optimization methods, while the PCA and leader algorithm based methods have decreased skill scores. Overall, imposing different weighting factors on the temperature field, the latter up to three times more important than the SLP input, does not alter these findings.

Based on these results it is clear that circulation types based on sea level pressure and (or) variables from the upper atmosphere have limited explanatory power with respect to peak surface ozone concentrations. The CTCs are able to produce large-scale structures which produce some meteorological characteristics governing high ozone concentrations but they are not able to capture local or regional elements that also play a role in the formation of ozone, such as emission sources, topography etc. The baseline analysis and sensitivity experiments pointed out that, if one is interested in explaining local or regional ozone variability, attention should be paid to the choice of the domain location and size, the input parameters (e.g. by taking into account more surface variables such as incoming solar radiation, humidity or cloud properties) and the choice of classification algorithm.

Nevertheless, this paper gives a nice overview of the capabilities of the cost733class software. Comparing the original catalogues developed by their respective authors and the ones reproduced by the software demonstrates that the software is able to retain the main properties from the original circulation classification schemes. Moreover, the software has interesting additional features like the possibility to classify multiple variables, in order to derive more complex air mass or pure weather type classifications, extended with a possibility to weight some or all input fields. Furtermore, the cost733class software can be compiled on any possible time step (hourly, daily, monthly, …) and an user-defined time frame. Finally, the software is user-friendly and delivered with an extensive user guide and can be compiled under various operating systems.

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