STUDYING THE FOGS IN SOFIA WITH CHERNI VRAH-SOFIA STABILITY INDEX

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Abstract. A study of the fogs at Sofia, Bulgaria is carried out by the means of proposed Cherni vrah-Sofia Stability Index. By measuring the strength of static stability of the atmospheric layer over Sofia, this index depends only on the surface air temperatures at stations Sofia, Mladost and Cherni vrah and hence it is potentially useful in operational practice. By using the standard weather observations during 01/01/1992-17/12/2014 period, a simple statistical relationship between our index and horizontal visibility in Sofia is established. It is statistically correctly found that while the fogs in Sofia correspond to higher values of the index, the absence of fog favours the lower index values. This general conclusion is supported by a case study investigation of the typical for Sofia fog episode.

Keywords: fog, Sofia, Cherni vrah, index of static stability

Introduction

The considerable development of numerical models in recent decades has not yet led to significant progress in fog forecasting. The still not enough adequate model parameterisation of specific processes leading to the formation, development and dissipation of fog in the boundary layer is one of the main sources for this situation. Considered as a passive phenomenon, because the formation and the dissipation processes are usually generated by a multitude combination of general and local factors, fog is difficult to be studied in scales larger than those occurring locally (Pinheiro et al., 2006).

Holtslag et al. (2010) examine whether empirical methods like those developed in the 60s and 70s are reasonable alternative forecast tools. It appears that the so called Fog Stability Index, solely based on routine radio sounding observations, has reasonable skills. This index has been optimised for 12 stations in the Netherlands, after which it reached a high forecast skills. It appears that the Fog Stability Index scores better than direct model output, and performs reasonably once optimised for site specific conditions.

Dejmal and Novotny (2011) test the applicability of the Fog Stability Index for the prognosis of low visibility cases at 5 stations in the Czech Republic. Four different criteria are used for assessment of forecasts. Based on the large number of cases dealt with, these authors found that during the winter the accumulation of cold air near the ground happens mainly in the valleys and river basins.

Haines (1988) developed the Lower Atmosphere Stability Index to indicate the potential for wildfire growth where the ground wind is not the dominant factor. The stratification of the lower atmosphere is estimated by combining the temperature difference between two atmospheric layers, and the moisture determined by the temperature and dew point difference.

Entirely statistical methods for fog analysis and forecast are also widely used. Robasky and Wilson (2006) seek to apply statistical forecast approaches using routinely available weather observations, such as standard hourly surface observations and twice-daily upper air balloon soundings. Maier et al. (2013) divided into stages the lifecycle of three episodes with fog during autumn 2011 in central Germany with objective statistical methods. Croitoru et al. (2011) conducted a study on the spatial variability of fog in the northwestern part of Romania by various multivariate statistical techniques. The time series of the average annual, seasonal and monthly number of days with fog are used for this purpose.

In present paper we use the standard SYNOP data at meteorological stations Sofia, Mladost and Cherni vrah for studying fogs at Sofia during 01/01/1992-01/12/2014 period. The base toll, we offer is a specific index, which we name Cherni vrah-Sofia Stability Index. Based on conception of Brunt-Väisälä’s frequency, our index estimates the strength of the static stability of the atmosphere layer over Sofia. The index can simply be calculated by surface air temperature at stations Sofia and Cherni vrah. It should be noted that Godev and Takev (1968) point out the temperature difference between Sofia and the Cherni vrah as one of the factors for early spring night temperature decreases at Sofia in anticyclone weather. There is also a purely ordinary reason to offer our index. As it is well known, the fogs in Sofia generally are attended by strong temperature inversions. Zverev (1957) points out that among many others, the formation of temperature inversion layer in altitude is one of the main symptoms for predicting fog trough sounding data. Unfortunately the soundings in Sofia, Mladost are made only once in 24 hours, at 12 GMT. On the other hand, the duration of the fogs at Sofia usually continues several synoptic periods. The idea is that the regular synoptic observations at the proximity stations Sofia (595 m) and Cherni vrah (2292 m) to be considered as repeated 3 hours soundings of the atmosphere and this additional information to be used to refine the short range forecast of the fog. In this context, the proposed index realises our idea.

Data and pre-processing

The data we use is from regular observations at the Bulgarian meteorological stations Sofia, Mladost ($42^{o}41$’N, $23^{o}19$’E; 595 m) and Cherni vrah (42° 35' N, 23° 16' E;

2292 m) during the 01/01/1992-17/12/2014 period. Actually, these are decoded SYNOP reports of National Institute of Meteorology and Hydrology, Bulgarian Academy of Science for observations in primary and intermediate synoptic hours 00, 03, 06, 09, 12, 15, 18 and 21 CMT. For station Sofia, Mladost we extract the time series of surface air temperature, horizontal visibility and the present and past weather group. For station Cherni vrah we use only time series of surface air temperature. The length of each record is 66486 points at sampling interval of 3 hour.

We define and compute our index of stability which we term Cherni vrah-Sofia Stability Index (CSSI) by the following formula:

$$\mathrm{CSSI} = \sqrt{(1+\Delta\,\mathrm{t}/17)/(1+t_{Cherni\,vrah}/273.15)}\;,$$

where Δt is the temperature difference between Cherni vrah and Sofia, Mladost and $t_{Cherni\,vrah}$ is surface air temperature at station Cherni vrah in degrees Celsius. What is the physical base of CSSI? As known the so called Brunt-Väisälä's frequency $N^2 = g\,T^{-1}(\gamma_a + d\,T/d\,z)$, where g is acceleration due to gravity, T is absolute temperature, $\gamma_a \approx 1\,\mathrm{K}/100\,\mathrm{m}$ is adiabatic lapse rate, and z is altitude, measures the local strength of the static stability of the dry atmosphere (Belinskii, 1948; Holton, 1972). The higher values of this frequency appropriate the higher degree of the layer stability. However, the extremes of Brunt-Väisälä's frequency are within the temperature inversion layers. Scaling down N by $\sqrt{g\,\gamma_a/T_0}$, where T_0 is the absolute temperature of ice melting and putting the vertical temperature gradient to be Δt divided by Cherni vrah-Sofia, altitude difference which is almost 1700 m, we get $\sqrt{(1+\Delta t/17)/(1+t/273.15)}$. Finally, we substitute t by $t_{Cherni\,vrah}$ and obtain just our CSSI.

Extracting the observations with CSSI higher than 0.5, we build a second data set. We also attach to this set a factor "*Phenomenon*" with two levels "*Fog*" and "*No fog*". While the level *Fog* corresponds to fogs and mists with horizontal visibility less or equal to 1000 m, the level *No fog* groups all other cases. We identify the cases of fogs or mists by means of the present and past weather group. The respective codes are as follows: 05.. - dry fog (haze); 10.. - mist; 11.. - patches of shallow fog; 12.. - continuous shallow fog; 28.. - fog (within past hour but not at observation time); 40.. - fog at a distance; 41.. - patches of fog; 42.. - fog, sky visible, thinning; 43.. - fog, sky not visible, thinning; 44.. - fog, sky visible, no change; 45.. - fog, sky not visible, no change; 46.. - fog, sky visible, becoming thicker; 47.. - fog, sky not visible, becoming thicker; 48.. - fog, depositing rime, sky visible; 49.. - fog, depositing rime, sky not visible.

Preliminary analysis

Figure 1 shows the parallel box plots of the CSSI for recoded into seven intervals horizontal visibility. The values of the CSSI are on vertical axis and the categorised visibility is on horizontal axis. The two bases of a box indicate the so called "hinges" (in practice first and third quartile) and thus the box height represents the interquartile range. The width of a box is proportional to the square roots of the number of observations. The medians are in the boxes. The vertical lines ("whiskers") show the largest or smallest observation that falls within a distance of 1.5 times the interquartile range from the nearest hinge.

An inspection of Figure 1 shows that the largest number of observations falls within the intervals 5-10 km horizontal visibility. The intervals 40-50 km, 1-5 km and 10-20 km are subsequent. The cases of visibilities less or equal to 1000 m are comparative not numerous but they are more than that within intervals 20-30 km and 30-40 km.

Looking at Figure 1 we see also that there is a stable downward tendency of the CSSI up to horizontal visibilities of 20-30 km and next the CSSI climbs.

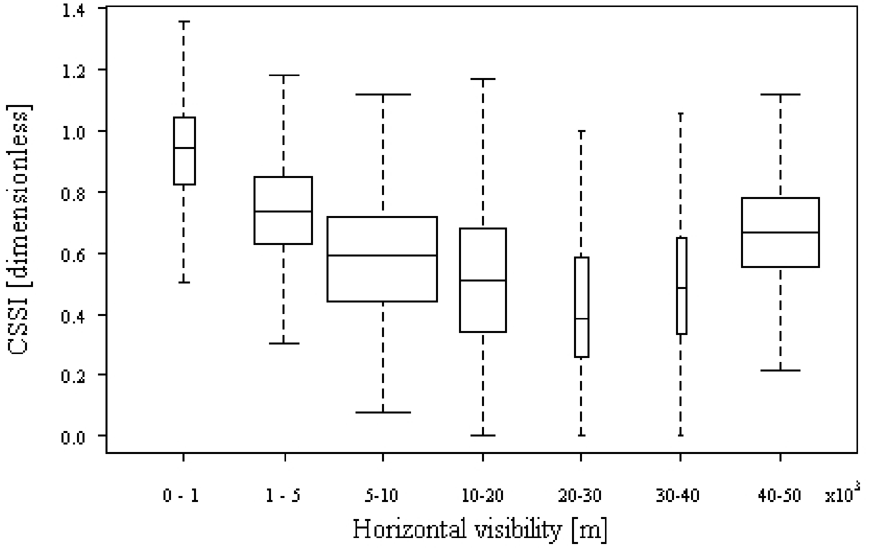

Fig. 1. Parallel box plots of the CSSI for recoded into seven intervals horizontal visibility

Testing procedures

Figure 2 shows the parallel box plots of the CSSI for two levels *Fog* and *No fog* of the factor *Phenomenon*. The figure building blocks are the same as on Figure 1 with exception of the so called "notches", the two symmetric concavities on the vertical box walls.

As seen, the cases of fogs or mists with horizontal visibility of 1000 m are considerably less that the other cases. Indeed, while the observations in category *No fog* are 44 555, the observations in category *Fog* are only 979. When the notches of two boxes on Figure 2 do not overlap this should be interpreted as a "strong evidence" that the two medians differ. As seen, this is exactly our case and we can conclude that the medians of two groups *Fog* and *No fog* differ.

So, there is a reason to assert that the fogs or mists with horizontal visibility of 1000 m take place predominantly at higher levels of the CSSI. Further we test statistically this hypothesis. The two sample t-tests are commonly performed in such cases (Wilks, 2006). It is well known this test requires the normal distributions of the samples. In our case the samples are the groups *Fog* and *No fog* and the variable under interest is CSSI. On the Figure 2 the medians seem to be in the middles of the boxes. This should be hinted as normal distributions.

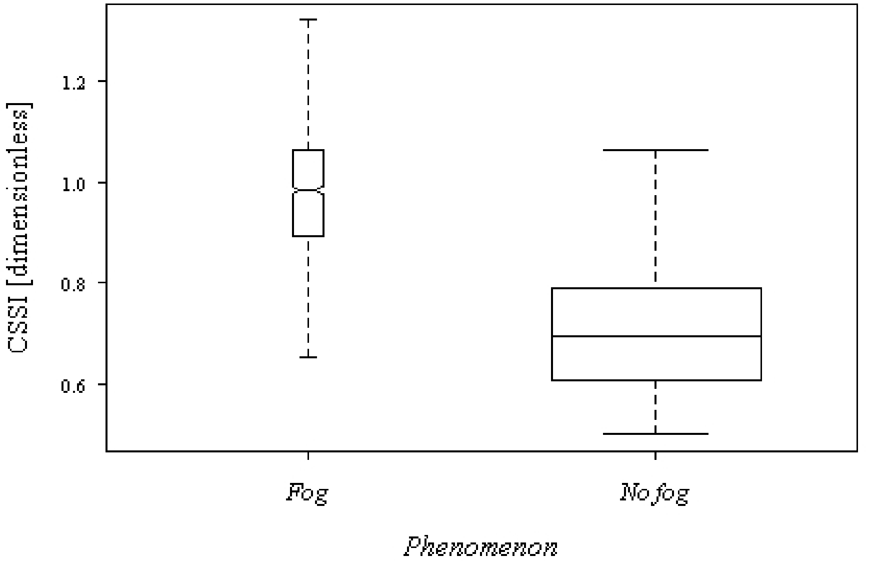

Fig. 2. Parallel box plots of the CSSI for two levels *Fog* and *No fog* of the factor *Phenomenon*

Figure 3 represents the normal quantile-quantile plots for the groups *Fog* and *No fog* of the factor *Phenomenon*. The theoretical quantiles are on the horizontal axes and sample quantiles are on vertical axes. The group *Fog* is on the left and on the right is the group *No fog*. The first and third quartiles define the straight line drawn.

As seen the left plot produces points close to the straight line and there is not a cause for concern about departures from normality for the group *Fog*. We also see that the outer parts of the experimental curve for group *No fog* are steeper that the middle part which indicates that by having heavy tails the distribution deviates from normality.

We test statistically these observations. One sample Jarque-Bera test for normality is used for this purpose. For the sample *Fog* the test statistic is 5.7087 and the p-value 0.05759. For sample *No fog* the test statistic is 3616.6571 and the corresponding p-value

2.2×10^{-16}. We are able to reject the null hypothesis of normality for the group *No fog*.
So, there is not normal distribution. It is advisable in this case to use the non-parametric analogues of the t-tests. We perform the two-sample Wilcoxon Man-Whitney rang sum test. The null hypothesis is that the two populations being compared have identical distributions. The alternative hypothesis is that the population distributions differ in location, i.e. the median. In our case the W test statistic has a value of 40355923 and corresponding p-value is 2.2×10^{-16}. We are able to reject the null hypothesis of identical distributions. Sample medians are 0.9834 and 0.6943 for groups *Fog* and *No fog* respectively. Summing up, the performed statistical analysis gives strong evidence that the fogs or mists with horizontal visibility of 1000 m correspond to higher values of CSSI in comparison with cases without fog.

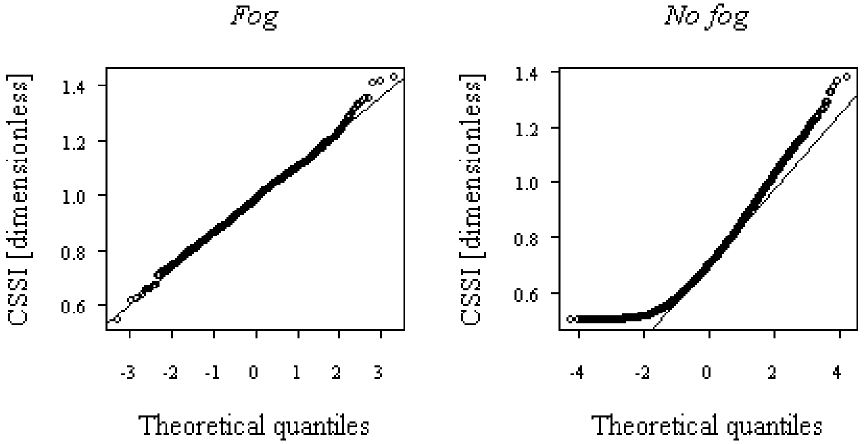

Fig. 3. Normal probability plots of CSSI for two groups *Fog* and *No fog*

A typical example

Here, we illustrate our main results by a detailed analysis of a particular situation with fog in Sofia. The analysed period is 12 00-16 12/21/2014. Figure 4 represents absolute topography maps of the 500 hPa level and the sea level pressure on 15 12/12/2014 GMT. During this period under consideration the visibility in Sofia is at its lowest on 15/12/2014, when the Balkan Peninsula is influenced by the upper ridge at the 500 hPa (Figure 4, left). During the period 13-15/12 in Sofia a high sea level pressure of 1027-1030 hPa dominates. On 15 12/12/2014 the anticyclone extends all over South-East Europe and a very deep and quite large cyclone determines the dynamic weather over North-West Europe (Figure 4, right). At this time over Balkan Peninsula the warm air mass transfers and observed temperatures at 850 hPa over Bulgaria are 6-8^{o}C (Figure 5).

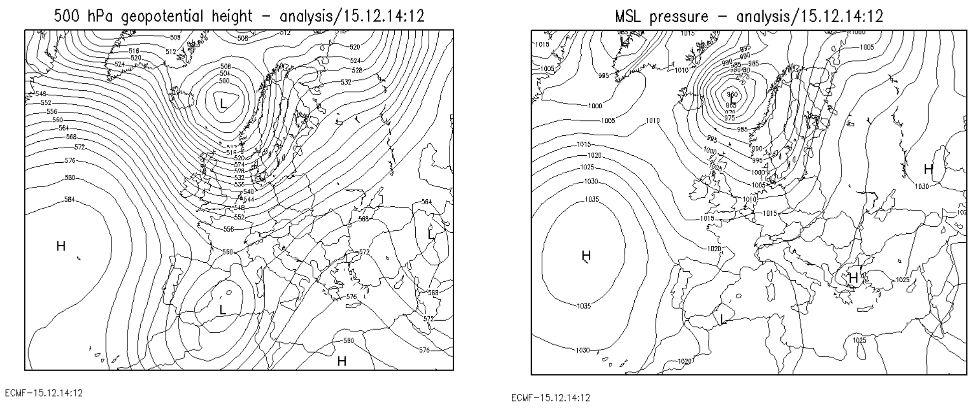

Fig. 4. Geopotential at 500 hPa (left) and sea level pressure (right); ECMWF analysis 15 12/12/2014 GMT

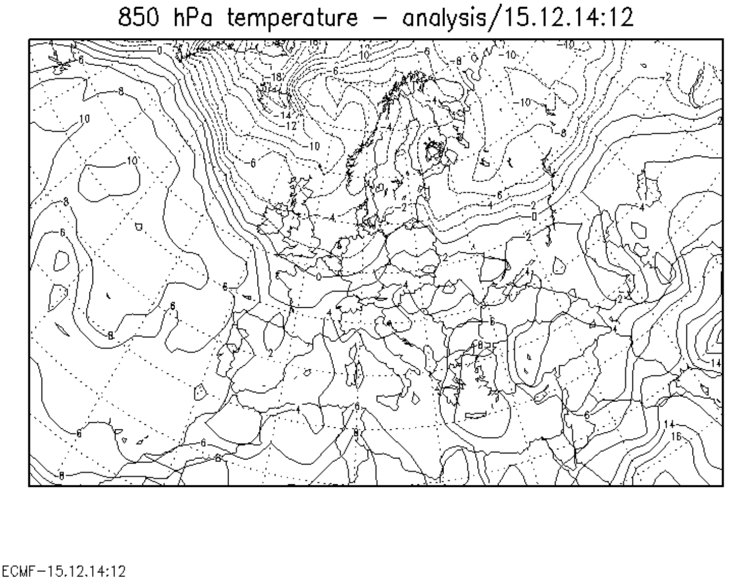

Fig. 5. Temperature at 850 hPa, ECMWF analysis on 15 12/12/2014, GMT

During the cold season, both a clear sky and a light wind in anticyclonic conditions lead to strong night radiation cooling of the earth's surface, which creates ground inversions. This is a typical scenario that produces fog. The combination between a warm spell on 850 hPa and the ground inversion leads to intensification of fog, especially in high valley field.

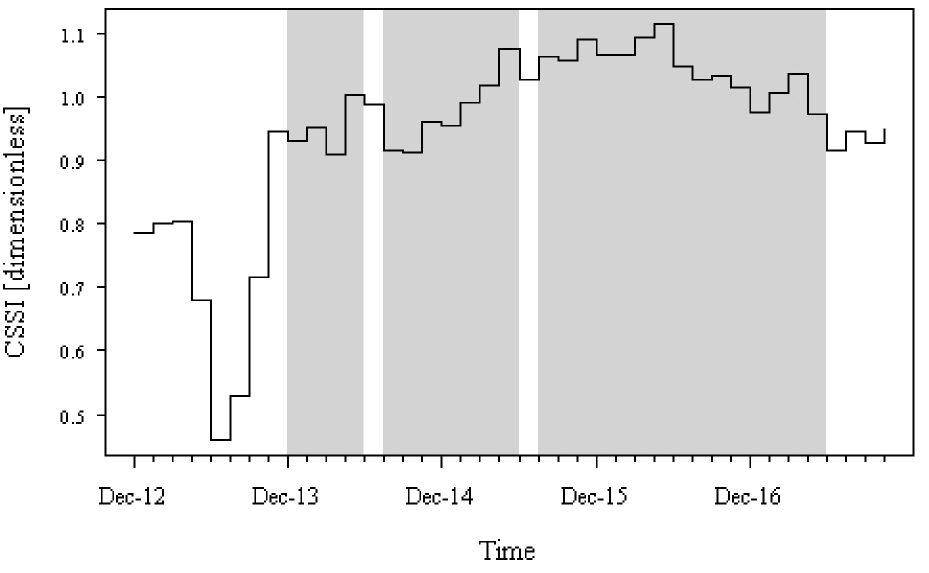

Fig. 6. Time series of CSSI in Sofia for period 12 00-16 21/12/2014 GMT

Figure 6 presents the time series of CSSI for the period 12 00-16 12/12/2014. Foggy periods are in grey. As seen, the episode with fog starts on 13 00/12/1014 and ends on 16 21/12/2014. During this episode horizontal visibility ranges from 100 m to 900 m. The two 3-hour interruptions are at 13 12/12/2014 and at 14 12/12/2014 when the visibility raises to 2000 m and 1500 m respectively.

Figure 6 clearly shows that CSSI sharply increases with the beginning of the fog and it keeps up these high values during the entire episode. As seen, in both interruptions the CSSI decreases but only locally. When the foggy episode ends our index drops. The observed course of CSSI is completely in accordance with our finding that fogs require as whole higher values of our stability index.

Summary

The objective of our paper was to study the fogs in Sofia, Bulgaria by means of a specific index of stability which we offer. The standard synoptic observations from meteorological stations Sofia, Mladost and Cherni vrah for the period 01/01/1992-01/12/2014 are used for this purpose. Based on the conception of Brunt-Väisälä's frequency, our stability index CSSI measures the strength of the static stability of the atmosphere layer over Sofia. The index depends only on the surface air temperatures in Sofia and Cherni vrah.

We establish a downward trend of CSSI up to 20-30 km horizontal visibilities. The statistical tests we perform clearly show that the fogs and mists with visibility up to 1000 m require as a whole higher values of CSSI compared to cases without fog. Sample medians for the groups of fogs or mists with visibility up to 1000 m and all other cases without fog are 0.9834 and 0.6943 respectively. Additionally, we verify our general conclusion by analysing a typical for Sofia fog episode in more detail.

What is the potential prognostic significance of CSSI? If the forecast presumes an occurrence or retention of already formed fog one can calculated CSSI by means of forecasted temperature at Sofia and Cherni vrah. A trend to higher values of CSSI additionally favours the fog occurrence or continuation. In contrast, a trend towards to lower CSSI reduces the chance of the fog.

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Изучаване на мъглата в София чрез индекс на устойчивост Черни връх-София

А. Стойчева, С. Евтимов

Резюме: В настоящата работа е проведено изучаване на мъглата в София чрез предложен от авторите индекс на устойчивост Черни връх-София. Отчитайки степента на статична устойчивост на атмосферния слой над София, този индекс зависи само от две температури – приземната температура в синоптична станция София, Младост и температурата във високопланинската обсерватория Черни връх, което го прави полезен за оперативната практика. Чрез използване на данните от стандартните синоптични наблюдения в посочените метеорологични станции за периода 01/01/1992-01/12/2014, е установена статистическа връзка между стойностите на индекса и хоризонталната видимост в София. Статистически достоверно е намерено, че мъглите в София се реализират при по-високите стойности на Индекса, докато добрата видимост съответства на по-ниските такива. Тази връзка е проверена и при една типична за възникване на мъгла в София синоптична обстановка.