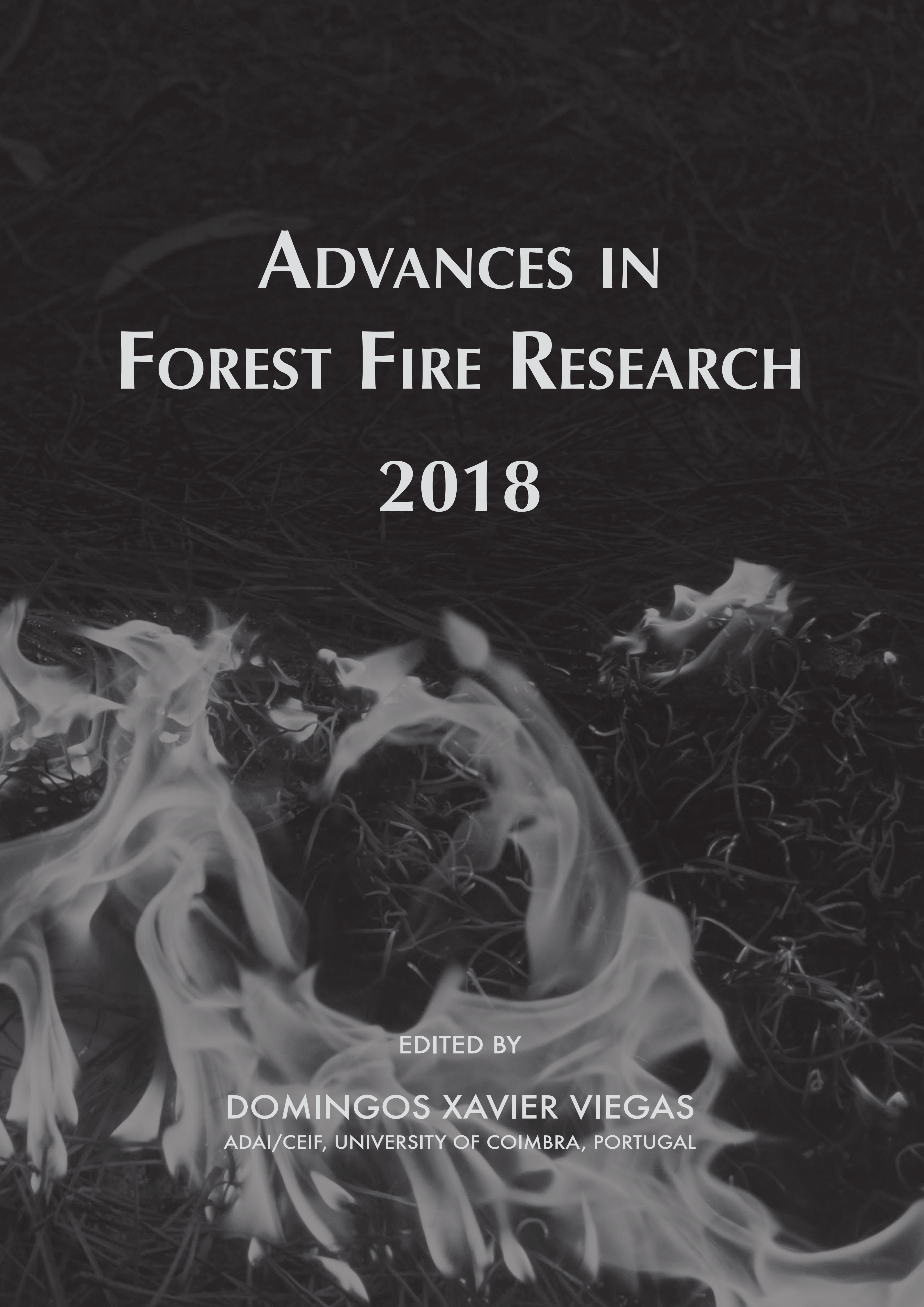

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Mean atmospheric flow pattern and forest fire risk on the Adriatic coast of Croatia

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Abstract

Forest fires are the most common natural disaster during the warm part of the year on the Adriatic coast of Croatia causing extensive damage and sometimes even an ecological catastrophe. It is therefore important to understand all weather and climate conditions leading to an increased risk of forest fire ignition and spread. In this paper the relationship between mean monthly atmospheric flow pattern (monthly weather type) and mean monthly forest fire risk (monthly severity rating) has been investigated. The analysis was done for the Adriatic coastal areas in the period from 1981 to 2015 during the fire season, between May and October. The results show that in the fire seasons of the observed 35-year period the most common monthly weather types were non-gradient field, northwesterly flow and westerly flow (20%, 16% and 20% of the cases, respectively). The most frequent monthly severity rating was "high" with 44% of all cases, followed by "moderate". On the other hand, the highest monthly severity rating ("very high") was present in just 5% of cases. Dry monthly weather types (ridge and front side of the ridge, 8% and 7% of the cases, respectively) showed stronger relationship with higher monthly severity ratings, while wet types (southwesterly flow and trough) appeared very rare in case of higher monthly severity ratings. The aforementioned most common monthly weather types, denoted as mixed types, were associated with "moderate" to "high" monthly severity ratings in less than 30% of the cases, making those types difficult to connect with monthly severity ratings. The "Consecutive Month Diagrams" (CMDs) concept was introduced in order to inspect the time correlations between monthly weather types and monthly severity ratings. In general, dry weather types supported fast transition to weather conditions favoring higher severity ratings, almost regardless of the previous month conditions, with two exceptions noted. If weather type time series were expressed as "cumulative fractions in total", the trends and ratios between weather types could be easily observed in the 35-year period. Since 1990s differences between fractions of dry and wet weather types have been increasing, suggesting more months with atmospheric flow patterns connected with higher forest fire risk. The results and concepts introduced in this work, as well as further analysis of atmospheric flow patterns and forest fire risk, can help to improve the short-term and especially long-term forecasts of forest fire risk.

Keywords Adriatic, forest fire risk, severity rating, weather type

1. Introduction

On the eastern Adriatic coast under climate forcing forest fires are most frequent in warm part of the year (Republic of Croatia, 2014). Fire season and related activities are conducted from spring to autumn, usually from 1st of May until the end of October. On the national level Meteorological and Hydrological Service of Croatia (DHMZ) is acting as advisory body in fire suppression system providing specialized meteorological information to the stakeholders, Civil Protection Service and fire departments with focus on meteorological condition favoring fire ignition, rapid fire spread potential and fire severity rate (Republic of Croatia, 2015).

In last decades several high temperature and drought extremes have been recorded in Croatia, leading to higher forest fire risks (2003, 2011, 2012, 2015.) and climate analysis revealed mean temperature increase with prominent positive trend since year 2000 (Republic of Croatia, 2014). Climate is average state of the atmosphere comprised of an average from a number of weather conditions (usually 30 years), both near the surface as well as in the upper levels. In extremely dry years, in the warm part of the year, surface weather in Croatia is associated with higher temperatures and lower precipitation (Plačko Vršnak et al., 2014).

Transports of heat and moisture are influenced by surface and atmospheric flow in upper levels, especially around 5500 m that can be analyzed from geopotential height at AT500 hPa (Absolute Topography of isobaric plane at 500 hPa). Atmospheric flow at AT500 and surface weather are related. In forest fire assessments (outbreaks potential, spread, severity) daily surface weather realizations and atmospheric circulation plays as important role as the monthly means of upper level atmospheric flows.

2. Flow pattern and forest fire risk

Atmospheric flow patterns (weather types) over Southern Europe can be categorized in 8 groups (Poje, 1965). According to AT500 monthly mean fields, upper level atmospheric flow was identified as one of the following: ridge (R); front side of the ridge (R-NW); non-gradient field (NG); northwesterly flow (NWF); trough (T); westerly flow (WF); southwesterly flow (SWF) and upper level low (ULL). Each weather type is associated with prevailing surface conditions (Lončar and Bajić, 1994), monthly means of temperature and precipitation on the Adriatic (Lončar and Vučetić, 2003) and Croatia (Lončar and Bajić, 1994), so consequently monthly weather type can be associated to the mean monthly forest fire risk.

Since the 1980s DHMZ has been using a Fire Weather Index (FWI), meteorological index for forest fire risk assessment based on the methodology proposed and developed by Meteorological Service of Canada in 1960s. FWI is daily computed and contains information on vegetation, wind speed, daily precipitation, temperature and humidity. Based on the FWI as a predictor, calibrated index of daily forest fire severity rating (DSR) is calculated. Monthly severity rating (MSR) index is monthly mean of daily values (DSR). Severity rating (DSR or MSR) is numerical estimator that reflects the expected efforts required for fire suppression activities expressed in five classes: very low (1), low (2), moderate (3), high (4) and very high (5) being the most difficult. Monthly severity rating represents mean monthly forest fire risk.

In recent decades significant improvements were achieved in numerical weather prediction systems (NWP). Successful prediction of upper level atmospheric state is extended from about 3 days in 1980s to somewhere from 7 to 10 days (Haiden et al., 2015), and while seasonal forecasts in extratropics still need improvements, useful results are already achieved at least for the first month (Molteni et al., 2011). It is reasonable to assume that next progress in extended and long range NWP will first be achieved in the upper levels. To explore the possible benefits of longer lead times (up to a month), relationship between mean monthly atmospheric flow pattern (monthly weather type, MWT) and mean monthly forest fire risk (monthly severity rating; MSR) has been investigated.

3. Data analysis

In this work monthly means of the upper level atmospheric flows (AT500) in the warm part of the year (May to October) for the period of 35 years, from 1981 to 2015, were analysed for the Adriatic coast of Croatia. Relation of monthly means of the atmospheric flows (weather types) and forest fire risks (severity ratings) was investigated.

Weather type for each month was categorized based on subjective analysis of monthly mean atmospheric flows at AT500 fields that were retrieved from European Centre for Medium Range Forecast (ECMWF) reanalysis and Deutscher Wetterdienst (DWD) upper level analysis for Northern hemisphere.

Daily severity rating index was calculated for 30 stations on the Croatian coast and islands (dominant vegetation of macchia shrubland) based on the FWI methodology using measured meteorological elements. Monthly severity rating was calculated for each station to build up a contingency table of MSR and MWT.

Based on the DSR, analysis of variance was conducted for 30 stations to investigate the differences between WTs according to SRs, as a requirement for any further analysis. Analysis of variances of unequal sample sizes at the significance level of 0.05 followed by Tukey-Kramer test provided statistically significant evidences for connection between at least some MWTs and MSR index for most of the stations (<30), based on the 35 year dataset (1980-2015, summer seasons, MJJASO). Exceptions in a-posteriori analysis (2 island stations, Komiža and Goveđari) were attributed to gaps in stations time series.

Local atmospheres' potential for memory of MSR index was investigated, autocorrelation function was introduced to MSR time series.

4. Results

The most frequent MSR index in 35-year period (season MJJASO) was "high" (44%) indicating overall high forest fire risks on the Adriatic coast of Croatia (Figure 1). The most frequently observed MWTs in the same period were westerly flow (20%) and non-gradient field (20%), followed by northwesterly flow (16%) while there has been only one month in 35 years with upper level low identified as dominant monthly weather type.

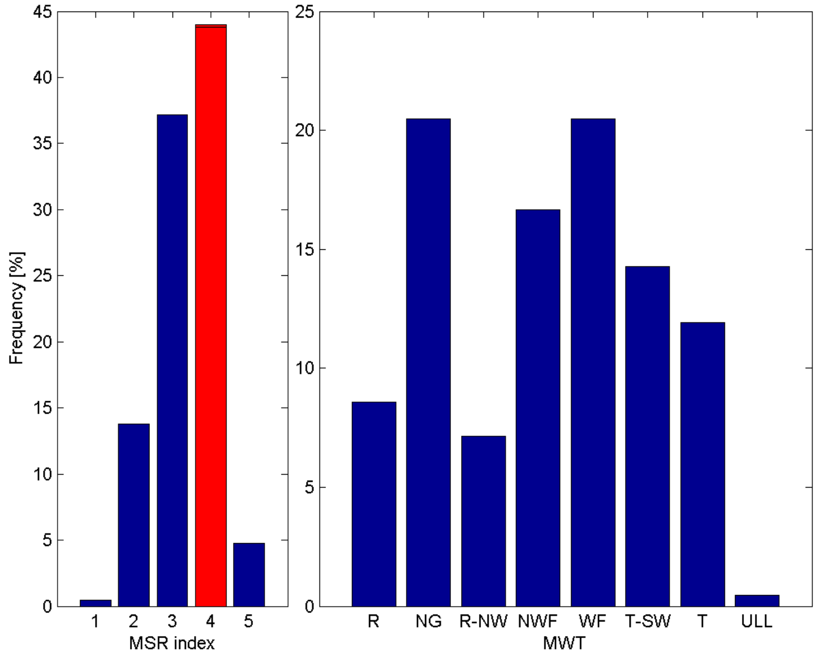

Figure 1 - Occurance of monthly severity rating (MSR index at left) and monthly weather type (MWT at right) in the warm part of the year for the Adriatic coast of Croatia from 1981 to 2015

Out of eight main atmospheric circulation patterns in upper atmosphere, two are associated with relatively dry and warm weather (R, R-NW), which could be connected with higher MSR and increased number of forest fires (Mokorić and Kalin, 2006). Northwest flow brings cold air with local showers or thunderstorms, west flow is characterized by moderate temperatures and variable precipitation amount (Mokorić and Kalin, 2006), while nongradient field also permits local convection, making those types (NWF, WF, NG) difficul to connect to MSR. Southwest flow and trough cause in average more precipitation which can be translated to lower forest fire risks and smaller MSR values. Alternative weather typing is proposed in this work, based on above mentioned discrimination, on Dry, Mixed and Wet monthly weather type. Analysis reveald only slight differences within eight weather types in respect to MSR (Figure 2, left), while larger differences between Wet and Dry weather type has been observed (Figure 2, right). Spatial differences between stations are sources of diversity for MSR and therefore higher spread of the MSRs within WT, this in turn has negative effect on basic assumption of connection between MSR and MWT. When Mixed types (NWF, WF, NG, ULL) are excluded, stronger relationship between Dry (R, R-NW) and Wet (T, T-SW) types with respect to their average severity rate is revealed and tested by t-test statistics using 95% confidence interval. Within proposed alternative weather type clasification only about 45% of the months fall into categories Dry and Wet (Figures 1 and 3).

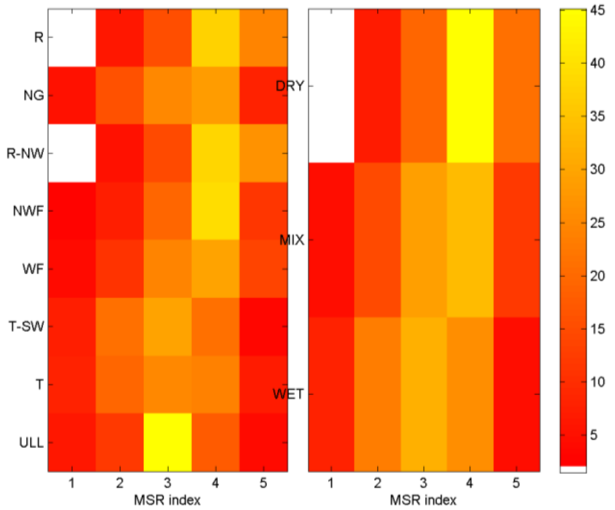

***Figure 2** - Percentage (color coded) of MSR within the MWT (left) and MSR within dry, mixed and wet MWT groups (right) in the warm part of the year for the Adriatic coast of Croatia from 1981 to 2015.*

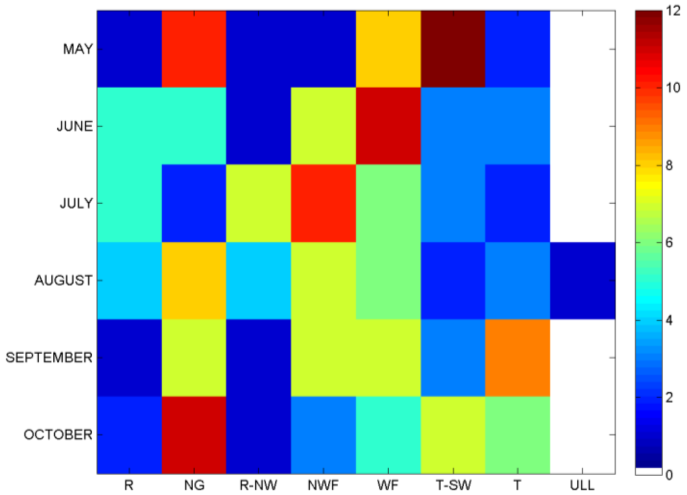

***Figure 3** - Occurrence in number of weather type per month in warm part of the year from 1981 to 2015. Upper level low was observed once.*

Consecutive months diagrams" (CMDs) were constructed from 35 years of monthly data for MSR (average value) and MWT (number of months). Previous month is on X-axis and current month is on Y-axis. In the diagrams average value of all recorded pairs is plotted for MSR (Figure 4) and total number of months for MWT (Figure 5).

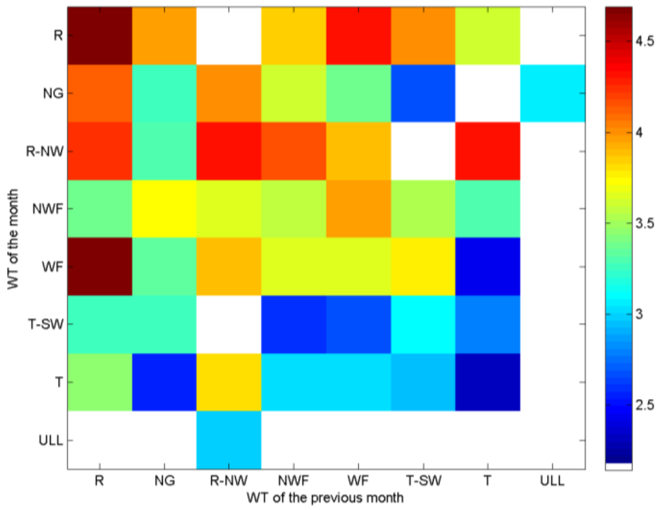

Figure 4 - "Consecutive Month Diagram" for MSR (color coded is MSR of MWT transition pair) for the Adriatic coast of Croatia based on the 35 years of data (1981-2015) for warm part of the year.

From Figure 4 can be seen that very high monthly severity rating (MSR) was recorded in months with main atmospheric circulation patterns in upper atmosphere identified as ridge (R) or westerly flow (WF) if in a preceding month MWT was ridge (R). This combinations however are not often recorded, as it can be seen from low values in CMD on Figure 5. The most frequent pairs are west flow followed by westerly flow (WF→WF), and northwesterly flow followed by northwesterly flow (NWF→NWF), both combination yielding on average moderate to high values of monthly severity rating.

When southwesterly flow associated with the trough (T-SW) was followd by nongradient field (NG) low and very low average MSR index was observed. Transition pair (T-SW→NG) is quite frequent on the Adriatic coast of Croatia. In general, T-SW in a previous month is a good indicator of low and medium MSR with an exception of month when ridge (R) was observed. Another Wet class member, trough (T), in the previous month can also be considered as good indicator for low and medium classes with noticable exception in month when northwesterly flow associated with the ridge (R-NW) was observed. It should be noted (Figure 4) that R-NW and R types are supporting fast transitions to weather conditions favorable to higher severity rating, almost regardless of the previous month conditions. Exceptions are NG in previous month for R-NW (NG→R-NW) and trough preceding ridge (T→R), which was quite common transition pair.

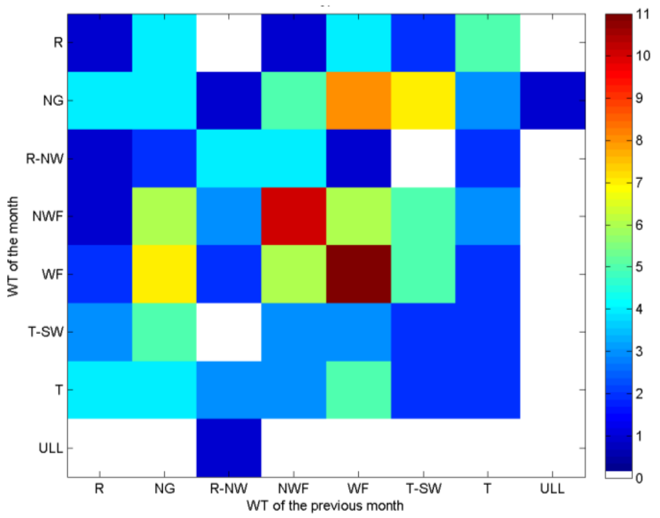

Figure 5 - "Consecutive Month Diagram" for MWT occurance (color coded is number of cases of the MWT transition pair) for the Adriatic coast of Croatia based on the 35 years of data (1981-2015) for warm part of the year.

Time series of weather types and alternative weather types were constructed. Due to low number of samples within each weather type Mann-Kendall test was not applicable to test for the trends in weather types. In order to assess, at least to some degree, the temporal changes in weather types, cumulative fraction functions were introduced to the data. At each time step (month) cumulative number of occurrence of each weather type from the start of the period (May, 1981) was normalized by a total number of months within the whole period. In the end, sum of the weather type's cumulative fractions on the right-hand side equals 1 on Figures 6 and 7.

Jumps in the weather type's and alternative weather type's cumulative fraction functions are indicators of higher than normal number of particular weather type, while flat intervals indicate lack of particular weather type in some period.

Since 1995 Mixed weather types are dominant in the Adriatic coast of Croatia. Mixed weather types can be associated both with low and high MSR. Forecasting difficulty of MSR is increasing with the increase of Mixed Types.

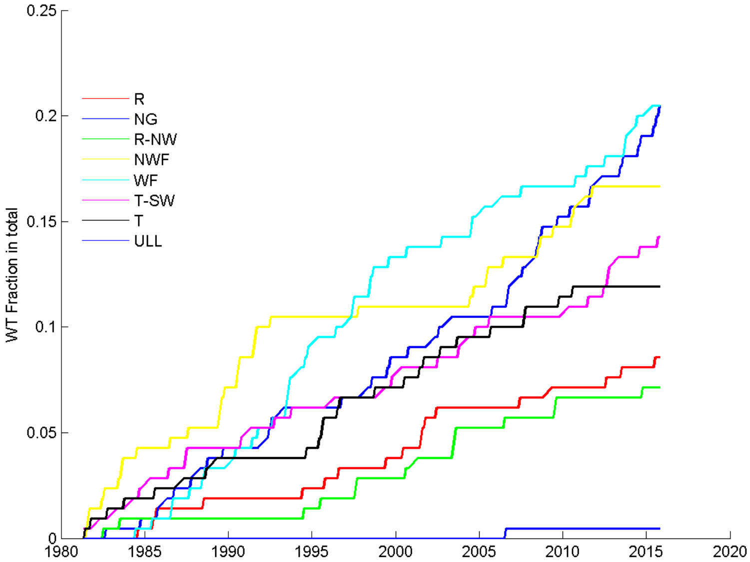

Figure 6 - Weather type (WT) cumulative fraction in total of 35 (1981-2015) warm seasons (MJJASO) in the Adriaitic coast of Croatia.

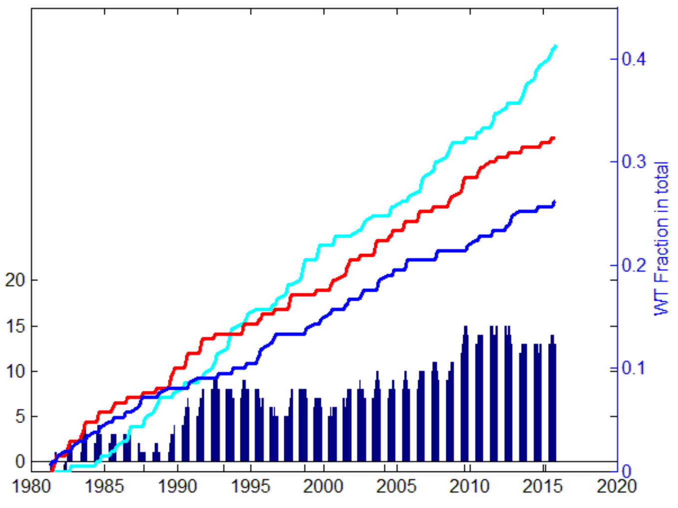

Figure 7 - Alternative weather type (WT) cumulative fraction in total. Mixed (cyan), Dry (red) and Wet (blue) as lines (right), with Dry-Wet differences in bars (left).

5. Discussion and conclusions

Manual typing of monthly means of upper level atmospheric flow provided the basis for weather type analysis in warm part of the years between 1981 and 2015 with total of 210 month analyzed. Weather type analysis results were in line with expectations and work by other authors (Mokorić and Kalin, 2010).

Analysis of variances provided statistical confidence in at least some relation between MWT and MSR index, and although the nature of their interconnection was not in the focus of the work presented in this paper, it provided the basis for the inspection of time correlations. Autocorrelation of MSR time series was found to be above 95% confidence interval for time lag of 1 month indicating atmospheric potential for 1 month "memory" and providing grounds for construction of 2 consecutive months MSR and MWT histograms, "Consecutive Month Diagrams" or CMDs.

Shortcoming of the methodology is subjective weather typing sensitive to individual experience. There is a potential to overcome it using Principle Component Analysis of mean upper level atmospheric circulation fields and Clustering, however it is beyond the scope of this work. Although PCA would yield higher degree of generalization, original weather typing with 8 classes is widely used in synoptic practice in Croatia and justification of this methodology could be seen on national level where experts can easily attribute weather conditions to familiar upper level atmospheric flow patterns. Proposed alternative weather typing provided stronger statistical discrimination between mean Severity Rating but is should be noted that less than a half of all months in 35 year period (MJJASO) fall in Wet or Dry category which is limiting factor for this approach.

Severity rating based on the FWI seems to produce good results for Adriatic coast of Croatia (Vučetić and Vučetić, 2011), however, from Figure 1 with average MSR class "high" it is clear that calibration of classes needs to be updated in order to accommodate for the warming trend and its effects, observed in Mediterranean region (and Croatia) in last decades (Republic of Croatia, 2014).

Weather types and alternative weather types time series, expressed as cumulative fractions in total, revealed relatively stable ratios of upper level atmospheric flows with increase of the NG type and decrease in NWF in recent years. Interestingly, WF had noticeable increase in 1990s and especially in 2000s, but although still dominant in warm part of the year, in recent years there was a decrease of WF. Westerly flow cannot be connected to MSR due to high spatial variability of precipitation across the Eastern Adriatic Coast associated with this weather type. Decrease in WF fraction is not followed by increased confidence in alternative weather type association to MSR, since in the whole period steady increase of Mixed weather types was observed (Figure 7). However, differences between fractions of Dry and Wet weather types have been increasing since 1990 suggesting more months with Dry weather types that can be connected to higher classes of MSR.

Constructed CMDs contain enough data for justification of the conclusions drawn from it. MSR and MWT CMDs are coupled and should be interpreted in parallel. Higher numbers in MWT CMD per transition pair (WT0→WT1) imply more significant value of MSR for that pair. MWT and MSR CMDs may have a potential in forecasting environment on extended time scales where present day NWP systems are managing to reproduce upper level fields but struggle to adequately reproduce surface weather. In such circumstances, for the Adriatic coast of Croatia, CMDs statistically constructed in this work could serve as mapping functions between forecasted upper level atmospheric conditions and possible monthly severity rating. This concept however, needs to be developed further and tested.

6. Acknowledgement

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