METEOROLOGY OF THE SPLIT FIRE IN CROATIA, 16 JULY 2017

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Introduction

The Split fire was the most severe fire event and the most demanding firefighting intervention in Croatia in recent years. Split is the second largest city in Croatia, situated on the mid-Adriatic coast in the region of Dalmatia, which is the most vulnerable region to wildfires (Vučetić, 2002). Narrow and urbanised coast surrounded with mountain and hills create highly complex atmospheric dynamics in that area. The aim of this research is to analyse and understand the physical-dynamical processes of the event.

Earlier studies of severe fire events in Croatia showed a characteristic vertical wind profile with a maximum wind speed at 500-700 m above ground level (agl) and abrupt speed decrease up to 3.5 km height (Vučetić and Vučetić, 1999). If the maximum wind speed in the lower troposphere exceeds 12 m s^{-1}, it is classified as a low level jet (LLJ, Bonner, 1968). LLJ usually precedes a cold front, and can have a significant effect on the beginning and spread of wildfires (Barad, 1961; Huang et al. 2009). LLJ is also related to turbulent behaviour in fire (Byram, 1954). In this research, we want to investigate whether a LLJ occurred during the Split fire in July 2017, and analyse the mesoscale atmospheric processes that were crucial to the rapid fire development and extreme behaviour. Here we present a preliminary analysis of the meteorology of the event.

Overview of the fire

The fire was reported at 2242 UTC on 16 July 2017, 15 km west from Split. Driven by the strong north-easterly *bura* wind (Adriatic local name for high wind, bora wind in English) the fire reached Splits' urban suburbs in a matter of hours (Runjić 2017). The fire developed rapidly, created multiple fronts and transitioned to a crown fire. Severe turbulence in the morning on 17 July 2017 made it impossible for firefighting aircraft to approach the site, and help the ground forces. With such intense fire activity and without aircraft help, the number of firefighting forces had to be increased fast, reaching maximum number of 168 vehicles, 796 firefighters, and more than 200 soldiers on the site. Aircraft were able to participate in the intervention from the morning on 18 July. Fire was localised on 19 July at 0900 UTC. The event lasted nine days until 25 July and burnt 4500 ha around Split.

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Materials and methods

Weather analysis was performed using meteorological data, synoptic charts and 4-km resolution mesoscale model simulations. Split-Marjan is the nearest meteorological station to the fire site. Its 10-minute automatic weather station data was used to analyse air temperature, relative humidity, precipitation, mean sea level pressure, insolation, wind speed and wind direction. The fire weather index (FWI) was calculated from meteorological elements (air temperature, relative humidity, wind speed at 1300 UTC, and 24-hour precipitation at 0600 UTC) for each day in 2017 (Van Wagner and Pickett, 1985). The Croatian Meteorological and Hydrological Service regularly analyses the monthly, seasonal and annual air temperature and precipitation, and compares it with those in the current reference climatological period 1961-1990. These maps were used for a summer season assessment. The German Meteorological Service (*Deutsche Wetterdienst*, *DWD*) synoptic charts over Europe were used for surface and upper-level analysis. Vertical atmospheric structure was analysed using the ALADIN/HR model product with 73 levels. ALADIN/HR is the operational version of the METEO-France ALADIN mesoscale model (*Aire Limiteé Adaptation Dynamique dévelopement InterNational*) in the Croatian Meteorological and Hydrological Service (e.g., Bajić et al., 2007).

Results

Overview of the antecedent meteorology

During 2017, the summer season and the preceding spring in Croatia was extremely dry and warm. Weather conditions in Split in July 2017 were very warm and dry, with an air temperature 2.1°C above average, and with only 11% of the 30-year average rainfall (Fig. 1). Conditions in the month before the fire were even more extreme, with an air temperature 3.3°C above average, and 8% of the average rainfall at the Split-Marjan meteorological station. Extremely hot and dry weather had an impact on the fire danger rating. The most endangered area in 2017 was Dalmatia where majority of the fires occurred (Ferina and Vucetic, 2018).

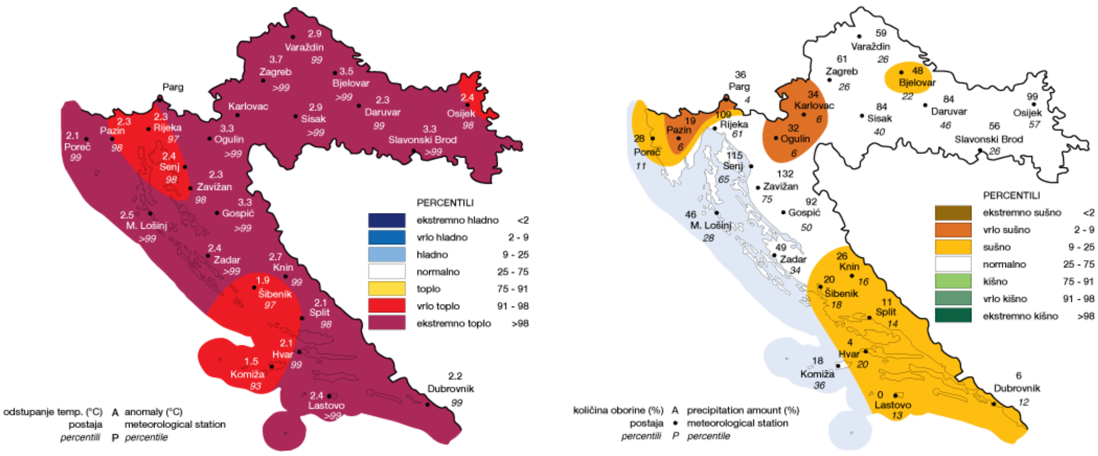

Fig 1. Climatological analysis of July 2017.
(From: http://meteo.hr/klima.php?section=klima_pracenje&param=ocjena)

Synoptic conditions

The surface synoptic charts over Europe show that weather in Croatia on 16 and 17 July 2017 were determined by the Azores high pressure to the northwest and the low pressure area to the southeast, which resulted in a high pressure gradient in the region especially along the Adriatic coast. A high pressure gradient was located within 800 km long the coastline, with isobars from approximately 1023 hPa to 1010 hPa. The Split fire started within the narrow corridor between 1020 and 1015 hPa isobars (Fig. 2a, which depicts the synoptic environment around two hours after the fire started). The upper-level chart confirms strong northerly wind at 500 hPa (Fig. 2b). Low pressure systems were situated north and southeast of Croatia, with the latter intensifying in the following hours and causing a high pressure gradient over the Adriatic coast. A pressure gradient in the area remained high in the morning on 17 July when aircraft reported a severe turbulence. Similar surface synoptic conditions continued with a slight decrease in the pressure gradient by the end of the day. On 18 July the high pressure decreased from 1200 UTC, making favourable conditions for aircraft operation.

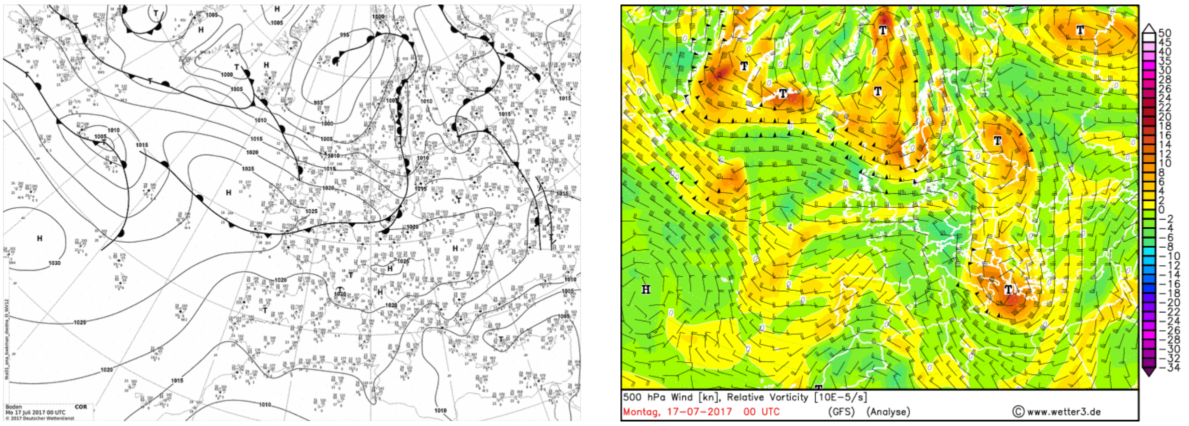

Fig 2. Surface synoptic chart at 00 UTC 17 July 2017 (a); 500 hPa wind and relative vorticity at 00 UTC 17 July 2017 (b) (From: http://www1.wetter3.de/Archiv/).

Automatic weather station

Measurements at the Split-Marjan meteorological station confirm the climatological analysis of July 2017. The whole month was very dry with only 3.5 mm of rainfall. Relative humidity from 15 to 18 July remained very low between 18% and 38%, with air temperature dropping from 33.4°C on 15 July to 26.8°C the day after (Fig. 3a). These meteorological observations highlight a cool surge in surface weather conditions that occurred on 16 July 2017, as noted from the synoptic surface and upper charts. Wind measurements indicated that the surface wind speed reached the highest gust in a month, 19.9 ms^{-1}, on the day before fire (2130 UTC on 15 July 2017 Fig. 3b). Wind gusts remained strong throughout 16 July, although decreasing to 4.5 ms^{-1} by the time fire was reported. In the early morning on 17 July wind gusts intensified again, up to 12.1 ms^{-1} (0500 UTC to 0910 UTC). This coincided with the reported turbulence.

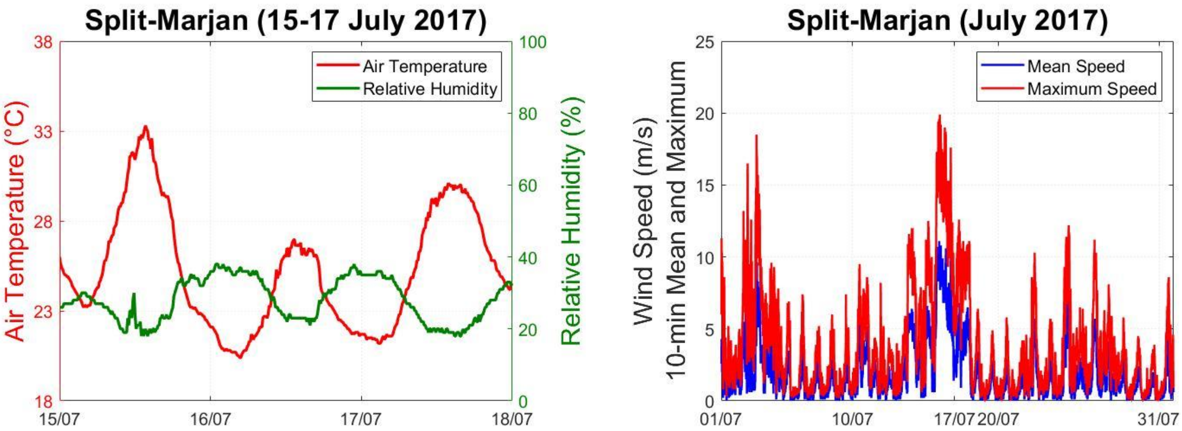

Fig 3. 10-minute air temperature (°C) and relative humidity (%) on 15-17 July 2017 (a); 10-minute mean and maximum wind speed (m s^{-1}) in July 2017 (b) at Split-Marjan meteorological station.

Fire weather conditions

Fig. 4 shows daily values of the Fire Weather Index (FWI), Initial Spread Index (ISI) and Fine Fuel Moisture Code (FFMC) in 2017 based on data from the Split-Marjan meteorological station. The FWI reached an annual maximum at 1300 UTC on 16 July 2017, and reached the peak value of 74.0 at midday. The fire started later that evening. The FWI indicates that the fire danger was extreme and that the most severe fire weather conditions in the whole year occurred exactly on 16 July 2017. On the same day, ISI had its seasonal peak with a maximum value of 27.4. According to definition of ISI (which is a function of wind speed and fine fuel moisture, Van Wagner and Pickett, 1985), if it is greater than 18, then the estimated speed of a fire front is 18.3 m min^{-1}. Along with rapid spreading, fire may create multiple fronts and develop to a crown fire, all of which happened in the first few hours of the Split fire during the night between 16 and 17 July 2017.

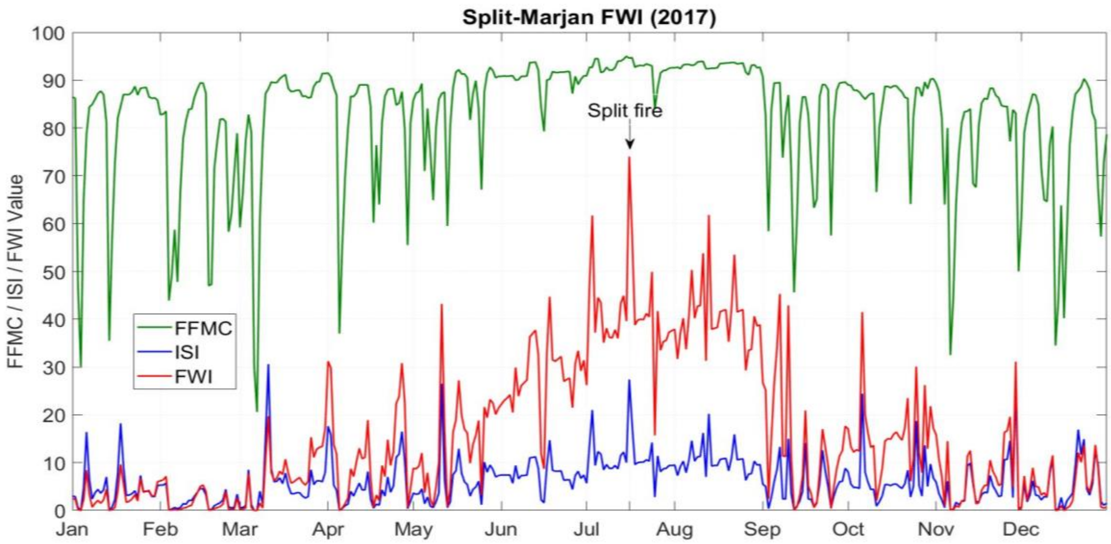

Fig 4. The daily course of indices: Fire Weather Index (FWI), Initial Spread Index (ISI) and Fine Fuel Moisture Code (FFMC) for the Split-Marjan meteorological station at 12 UTC 1 January 2017 to 31 December 2017.

ALADIN vertical profiles and cross section

Simulated vertical cross section (from Split to 300 km inland) shows the subsidence of north-easterly *bura* wind up to 5 km height (Fig. 5a). This subsidence is related to the high pressure gradient from synoptic analysis. Cold air accelerated down to the Adriatic coast at maximum speed between 27 and 30 m s^{-1}. Also, model simulated a hydraulic jump structure above the mountains in the outback of Split. Previous studies showed that the Adriatic severe bora can be partly explained by the hydraulic theory, as one as the possible mechanisms of a strong surface downslope wind (e.g. Vučetić, 1993). The vertical wind speed profile indicated strong vertical gradient in the grid point next to fire site, at location of village Donje Sitno close to Split (Fig. 5b). Model simulated LLJ from the midnight on 16 July 2017 until 0900 UTC, and then again from 1500 UTC. LLJ strengthened towards the end of a day, with a maximum of 19.3 m s^{-1} at 2000 UTC. At 2200 UTC, around the time the fire started, LLJ had a speed of 17 m s^{-1} at 1005 m agl. Although its' speed slightly decreased during the night on 17 July, LLJ remained persistent until the next morning, right at the time when aircraft reported a strong turbulence.

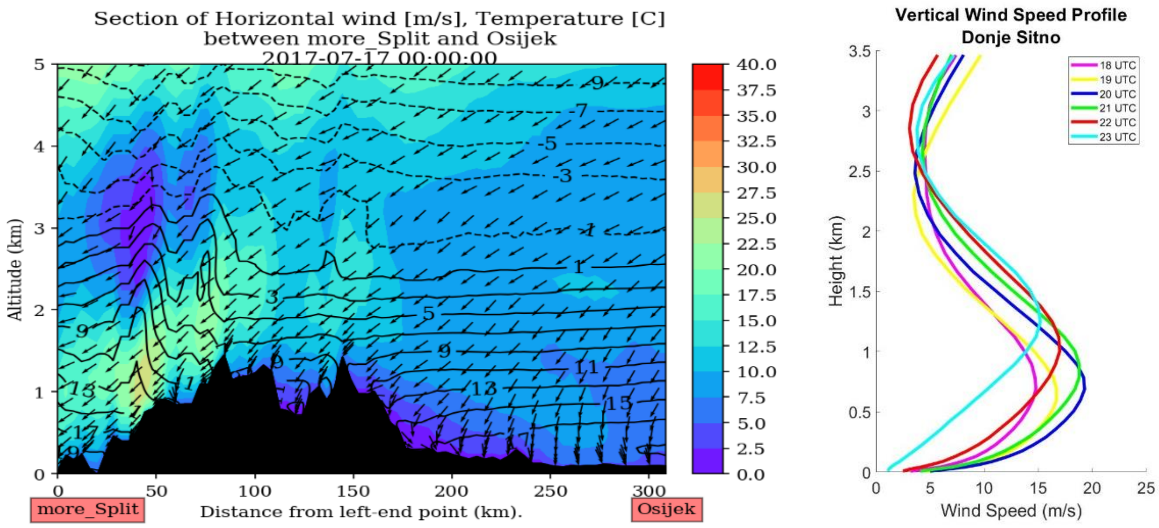

Fig. 5. Cross section with horizontal wind speed (m s^{-1}) and direction, and air temperature (°C) between Split and Osijek at 00 UTC 17 July 2017 (a), vertical profile of wind speed (m s^{-1}) at Donje Sitno at 18-23 UTC 16 July 2017 (b) from the ALADIN/HR model.

Discussion

Preliminary meteorological analysis of the Split fire event gave us an insight of factors that likely contributed to this severe and dangerous fire event. Those are:

- Extremely dry and warm weather conditions during the summer season and the proceeding spring in Croatia in 2017.
- Synoptic environment that resulted in the high pressure gradient in the region, causing a strong downslope north-easterly *bura* wind before and during the first day of the fire.
- Observational records confirm that north-easterly flow brought cool and dry air that resulted in a drop in air temperature and the lowest relative humidity for July 2017.
- Model simulated development of a low-level jet stream, which strengthened right before the fire started and persisted through the night and the following morning. Turbulence associated with LLJ caused the crown fire behaviour and rapid fire growth.

Although the FWI has indicated the timing of the Split Fire quite well, the fire's severity was much determined by the high wind and jet environment on that day. The ISI does consider wind speed, however, its application focuses on fire spread after ignition. Future work will thus focus on whether it is appropriate to incorporate LLJ information in a new potential fire index. In terms of dynamics, LLJ development under the synoptic background of the *bura* wind should be investigated because the jet level is critical to fire development. To what degree a LLJ contributes to the dryness and temperature in a region with topographic effect also needs to be clarified.

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