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Study of the exceptional meteorological conditions, trace gases and particulate matter measured during the 2017 forest fire in Doñana Natural Park, Spain

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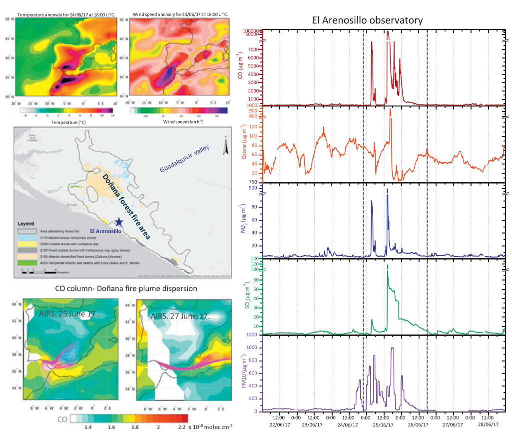
HIGHLIGHTS

- A massive forest fire occurred in Doñana Natural Park in late June 2017.
- Biodiversity in this protected area was seriously affected.
- The fire occurred under exceptional synoptic and local meteorological conditions.
- The fire reached El Arenosillo, and record-setting values of trace gases were measured.
- The Doñana plume affected the western Mediterranean basin.

GRAPHICAL ABSTRACT



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ABSTRACT

In late June 2017, a forest fire occurred in Doñana Natural Park, which is located in southwestern Europe. Many animal and plant species, some of which are threatened, suffered from the impact of this fire, and important ecosystems in the European Union were seriously affected. This forest fire occurred under exceptional weather conditions. The meteorological situation was studied at both the synoptic scale and the local scale using meteorological fields in the ERA-Interim global model from ECMWF (European Centre for Medium Range Weather Forecasts), the WRF (Weather Research and Forecasting) mesoscale model and ground observations collected at El Arenosillo observatory. Anomalies were obtained using records (observations and simulations) over the last two decades (1996–2016). An anticyclonic system dominated the synoptic meteorological conditions, but a strong pressure gradient was present; positive high pressure anomalies and negative low pressure anomalies resulted in intense NW flows. At the surface, wind gusts of 80 km h^{-1}, temperatures up to 35 °C and relative humidity values <20% were observed. In terms of anomalies, these observations corresponded to positive temperature anomalies (differences of 12 °C), positive wind speed anomalies (>29 km h^{-1}) and negative relative humidity anomalies (differences of 40%). The forest fire reached El Arenosillo observatory approximately 8 h after it began. When the fire started, record-setting maximum values were measured for all gases monitored at this site (specifically, peaks of 99,995 μg m^{-3} for CO, 951 μg m^{-3} for O_3, 478 μg m^{-3} for NO_2, 116 μg m^{-3} for SO_2

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and 1000 μg m^{-3} for PM10). According to the temporal evolution patterns of these species, the atmosphere over a burnt area can recover to initial atmospheric levels between 48 and 96 h after an event. The impact of the Doñana plume was studied using hourly forward trajectories computed with the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model to analyse the emission source for the burnt area. The Doñana fire plume affected large metropolitan areas near the Mediterranean coast. Air quality stations located in the cities of Seville and Cadiz registered the arrival of the plume based on increases in CO and PM10. Using CO as a tracer, measurements from the AIRS and MOPITT instruments allowed us to observe the transport of the Doñana plume from the Strait of Gibraltar to the Mediterranean. Finally, after two days, the Doñana forest fire plume reached the western Mediterranean basin.

1. Introduction

Climate change and air pollution will be the two greatest atmospheric challenges for societies in future decades. These environmental issues are highly connected, and there are a number of factors that link air pollution and climate change, such as emissions, atmospheric processes and chemistry (von Schneidemesser et al., 2015). Climate change has led to an increase in the frequency and intensity of extreme weather events, such as floods, droughts, heat waves and wildfires (Stott, 2016).

Wildfires occur due to dry weather and the availability of fuel and ignition sources. It is well known that temperature, relative humidity, precipitation and wind speed affect fire spread rates and intensities (Parente et al., 2018). The occurrence of weather extremes, such as hot, dry and windy conditions, leads to the most severe fires (Dupire et al., 2017). Fire season length and duration can affect large areas and have increased across all vegetated continents during the late two decades due to extreme weather events and climate change (Jolly et al., 2015).

Therefore, there is a clear feedback between climate change and forest fires. Climate change induces weather extremes, which lead to forest fires, while fire emissions contribute to climate change. These emissions increase greenhouse gas concentrations, thereby increasing atmospheric radiative forcing and aerosol concentrations and changing the Earth's albedo by depositing more light-absorbing particles onto the Earth's surface (Sommers et al., 2014).

Forest fires have impacts on the biosphere-atmosphere interface, atmospheric chemistry, atmospheric circulation, the composition of the ecosystem and its distribution, environmental degradation and air quality (Chen et al., 2017). Chemical species released by wildfires include gases such as CO_2, carbon monoxide (CO), methane (CH_4), non-methane organic compounds, nitrogen oxides (NO_x), nitrous oxide (N_2O) and sulphur dioxide (SO_2). The controlled combustion of various biomass fuels under laboratory conditions has revealed the presence of >500 different volatile organic compounds (VOCs), which differ in terms of reactivity, health effects and the ability to form active climate constituents (Gilman et al., 2015). Moreover, the simultaneous emission of nitrogen oxides and reactive VOCs from the combustion of biomass leads to the photochemical formation of tropospheric ozone (O_3) and secondary organic aerosols (Alvarado and Prinn, 2009).

On the other hand, smoke is the main forest fire-produced atmospheric constituent that affects air quality and climate because the massive plumes can travel thousands of kilometres downwind. The monitoring of these plumes is only possible through satellite measurements, such as AIRS or MOPITT CO measurements, because CO is emitted by forest fires (Ding et al., 2015).

This work analyses the case of a large forest fire that occurred in June 2017 in an important ecological area (Doñana Natural Park, located in southwestern Europe) under exceptional meteorological conditions because it is a clear example of the connection between extreme weather events, forest fires, air quality degradation and climate change. The meteorological context, impact on biodiversity and CO, O_3, NO_2, SO_2 and PM10 levels are analysed. The regional impact of the fire plume is studied by means of space observations and transport models.

2. Area description, instrumentation, atmospheric models and satellite observations

2.1. Area description

The area of Doñana (116,487 ha of a protected park) is considered to be a major hot spot of biodiversity (López-López et al., 2011) and one of the most important wetlands in Europe. It is part of the Guadalquivir River basin and is composed of highly diverse ecosystems: forests, ponds, fossil and mobile dunes, riverbanks and beaches. The Doñana area features rich flora and fauna with many endemic, threatened, and endangered species. Despite this high biodiversity, there are many threats to its conservation, such as summer tourism, the pilgrimage of El Rocio, contamination due to heavy metals and pesticides, intensive agriculture in its surroundings, aquiculture and frequent forest fires (Groom et al., 2006). At least 80% of the forest fires detected in the area are anthropogenically induced, 50% of which are directly provoked, and only 4% are naturally induced (WWF/Adena, 2008). The vegetation in the area, which was intensively reforested with pines (*Pinus pinea*) and wide areas of shrublands, makes this territory highly sensitive to forest fires. These pyrophytic species facilitate the fast expansion of fires, especially in summer, when high temperatures and drought conditions predominate. Fires are natural disturbances in Mediterranean ecosystems and have contributed to landscape dynamics for thousands of years (Trabaud, 1993). A large number of flora and fauna species have adapted to periodic fires by developing strategies that allow them to germinate, resprouting or recolonizing their habitat after fire. However, the delicate structure of the Mediterranean ecosystem is altered when forest fires of anthropogenic origin reoccur frequently.

El Arenosillo observatory is located in the SW Iberian Peninsula in Doñana National Park, 1 km from the Atlantic Ocean coastline (Fig. 1). Surface meteorological conditions, solar radiation, surface chemistry species (CO, O_3, NO_2 and SO_2), and optical, chemical and microphysical aerosol properties are routinely monitored. The urban area of Huelva is located 35 km away from El Arenosillo in the NW direction. The Seville metropolitan area is the largest urban area in SW Europe, with >1.5 million inhabitants, while the Cadiz urban area has a population >0.5 million inhabitants. These urban areas are near Doñana Natural and National Park (approximately 60–70 km away). The transport of Doñana forest fire plumes to these areas could have potentially impact ~2 million inhabitants.

2.2. Trace gases and meteorological instrumentation

Trace gases were measured at El Arenosillo observatory. O_3 was collected with an analyser (Dasibi 1008 RS) based on the absorption of ultraviolet radiation at 254 nm using a flow rate of 2 l min^{-1}. NO_2 was recorded with an analyser (TAPI 200E) based on the chemiluminescence method using a flow rate of 0.5 l min^{-1}. SO_2 was measured using an analyser (TAPI T100) based on the ultraviolet fluorescence technique using a flow rate of 0.65 l min^{-1}. CO measurements were obtained using an analyser (TAPI T300) based on non-dispersive infrared spectroscopy using a flow rate of 0.8 l min^{-1}. PM10 was measured at