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Long-term Measurements of SO_2 Concentrations Within the Atmospheric Column on Gozo (Maltese Islands)

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Abstract Sulphur dioxide (SO_2) concentrations were measured over a twelve-year period (2011 - 2023) at the Giordan Lighthouse Atmospheric Observatory, located on the Island of Gozo (forming part of the Maltese Archipelago), in the Central Mediterranean. Trend analysis reveals that SO_2 concentrations are decreasing at an annual average rate of 0.03 ppbv per year. This is in keeping with what has been recorded throughout Europe following the introduction of several sulphur directives by the European Union and stringent regulations on marine fuels by the International Maritime Organisation. SO_2 concentrations exhibit a strong seasonal variability of 55.9% with a maximum in July and a minimum in March, which contrasts with what is observed in Northern Europe. The diurnal amplitude of SO_2 is 29.7% with a maximum at 10:00 and a minimum at 19:00. With respect to wind direction, SO_2 concentrations exhibit a maximum when the prevailing wind in from the 0° - 60° sector due to emissions originating mainly from two sources, the active Etna volcano and ships traversing the Straits of Sicily. A broad minimum of circa 0.32 ppbv is observed when the wind is blowing from the 160° - 300° sector.

Keywords: sulphur dioxide, Giordan Lighthouse, Central Mediterranean, shipping emissions, Etna volcano

1. Introduction

Sulphur is introduced in the atmosphere mainly in the form of gaseous sulfur dioxide (SO_2) as it is emitted from various natural and anthropogenic sources. Volcanic activities are one of the most significant natural sources of SO_2 in the Mediterranean. In fact, the three major volcanos in the Mediterranean namely, Etna, Stromboli and Vulcano (Ferrara et al., 2000) regularly emit sulphur compounds. During periods of intense volcanic eruptions, large quantities of sulphur-containing gases are released, which contribute to higher SO_2 concentrations in the lower atmosphere. SO_2 is also emitted from geothermal areas located in Italy and Greece (D'Alessandro et al., 2013). These two natural emission sources contribute to an elevated atmospheric SO_2 concentrations on a local and regional scale.

SO_2 is also a predominant anthropogenic source mainly originating from the burning of fossil fuels (coal, oil and natural gas) by power plants (Vairo et al., 2014), road transport (Takeshita, 2011) and international shipping (Berg et al., 2012). Industrial activities such as oil refining and metal smelting emit SO_2 in the atmosphere (Serbula et al., 2015). Residential heating and biomass burning also contribute to atmospheric SO_2, particularly in rural areas.

During the last decades, the European Union (EU) has implemented a number of legislations to regulate the different aspects of air pollution particularly those related to SO_2. Such directives and stringent regulations contributed to the mitigation of SO_2 emissions across Europe and helped improve air quality on a regional scale. In fact, scientific evidence shows that between 1980 and 2004, SO_2 emissions amongst the European countries have dropped by 73% (Vestreng et al., 2007).

The concentration of SO_2 in continental background air ranges from 20 pptv to over 1 ppbv (Seinfeld, 2016). Despite the current low levels of atmospheric SO_2 concentrations in Europe, little is known about the variability of this air pollutant in the Central Mediterranean, during the last decade. The objective of this paper is to analyse the annual trends, together with the seasonal, diurnal and wind variabilities of SO_2 concentrations measured at the Giordan Lighthouse Observatory on the Island of Gozo, in the Central Mediterranean.

2. Monitoring Site and Instrumentation

The Giordan Lighthouse Observatory is located on the Island of Gozo, forming part of the Maltese Archipelago, in the Central Mediterranean. A detailed description of the Observatory and a list of the air quality and meteorological parameters being recorded is provided in (D'Amico et al., 2024). A summary of the meteorological characteristics of the location is reported in (Ciarlo` et al., 2025).

The SO_2 concentration measurements being considered in this study commenced on 20 January 2011 and lasted until 31 July 2023. The SO_2 concentrations were

recorded with a Thermo Scientific Model 43i SO_2 analyser. Most likely, the data set that is analysed here, is the longest data collection of SO_2 concentration measurements collected in the Central Mediterranean. However, a minor data gap exists from 17 August 2020 to 30 October 2020. During this time, the SO_2 analyser was sent for servicing.

3. Results and Discussion

Data processing was followed by data analysis, leading to the results that are explained in what follows.

The annual average varied from 0.23 ppbv to 0.82 ppbv, which is similar to what was observed on mainland Europe (Seinfeld, 2016). Trend analysis shows that the SO_2 concentration is decreasing at an annual rate of approximately 0.03 ppbv per year (refer to Figure 1).

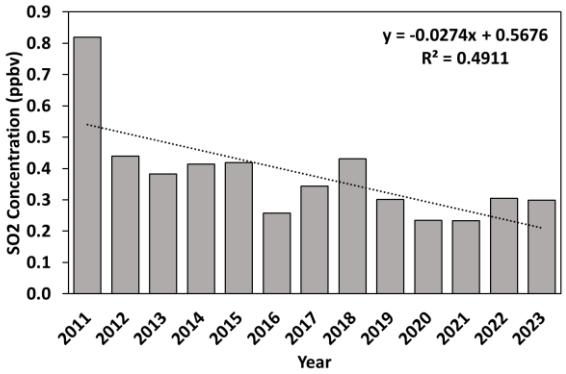

Figure 1. Time series of the average annual sulphur dioxide concentration.

The monthly average concentration varied from 0.28 ppbv in March to 0.50 ppbv in July (refer to Figure 2). Indeed, the SO_2 concentration exhibits a seasonal cycle in the Central Mediterranean, which is in contrast to what is observed in Northern European countries due to the increase in the use of fossil fuels for domestics heating in winter, while in summer the Mediterranean is dominated by high influx of tourists (higher anthropogenic activity).

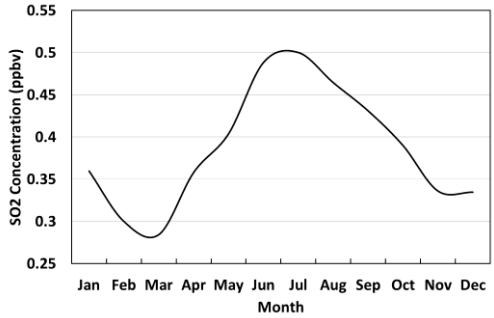

Figure 2. Average monthly variability in sulphur dioxide concentration.

The average diurnal cycle for the SO_2 concentration experiences a minimum of 0.34 ppbv at 19:00 and a maximum of 0.45 ppbv at 10:00. SO_2 maximum concentration is attained when the prevailing wind is blowing from the 30° - 50° sector due to the influence of the Etna emissions given that the distance between the Giordan Lighthouse Atmospheric Observatory and Mount Etna is approximately 200 km. Air parcels arriving from the 160° - 310° sector are not influenced by distant anthropogenic and natural SO_2 emissions, implying that the wind sector represents the background SO_2 concentration level for the Maltese Islands, which is approximately 0.32 ppbv.

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