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| **The impact of late spring frost and summer heat waves on forests of the Italian Alps analyzed through Sentinel-2 multi-temporal images** |
| **Introduction/Aim**  Extreme climate events (ECEs), such as severe droughts, heat waves, or late spring frosts, exert significant influence on forest ecosystems and their frequency is forecasted to increase thanks to climate warming, posing a threat to the sustainability of forests. Among ECEs in this study we focused on late spring frost (LSF) and summer heat waves (SHW). Projections indicate that both SHW and LSF will increase in the future in temperate and boreal forests. Time series of remote sensing data, in particular satellite multispectral images with frequent revisit time and high spatial resolution such as Sentinel-2 could be very useful to analyse both the effect of such events on forests and the recovery of forests after the events.  **Methods**  The studied area was the forested areas of the Autonomous Province of Trento (about 3000 kmq), in the Italian Alps, where a LSF event occurred in May 2019 and a SHW occurred in July 2022. 281,525 sampling points distributed on a grid of 40 by 40 m were distributed over the studies area covering 16 tree species and ranging from 100 to 2000 meters a.s.l.. Sentinel-2 satellite images spanning from April 2018 to October 2023 were used to extract NDVI (Normalised Difference Vegetation Index) values for each point. NDVI was interpolated using a GAM function to obtain a daily for each point for the interval 2018-2023. Daily average temperatures from 100 weather stations distributed over the studied area were spatialized using a kriging spatial interpolation. Phenological metrics like Greenup, Maturity and Senescence were extracted for each point using phenofit R package. Wilcoxon-Mann-Whitney test was used to determine the time periods where i) the daily temperatures of 2019 and 2022 were significantly lower or higher than the average 2018-23, and ii) the NDVI values in 2019 and 2022 were significantly different from the average 2018-23 Data were analysed by species and by elevation intervals.  **Results**  The 2019 LSF affected mainly species located between 1000 and 1300 m a.s.l., in particular European beech. The effect was different according to the elevation: i) for sampling points located below 750 m a.s.l. NDVI values were in line with the average 2018-2023; ii) for points between 1000 and 1250 m a.s.l. NDVI increased slowly compared to the average 2018-23 and reached its peak later maintaining values below the average for the entire 2019; and iii) for points above 1250 m a.s.l. there was a shift in the start of the growing season, but then the NDVI values were similar to the ones of the season 2018-2022.  The 2022 SHW affected negatively mainly species located at low elevations, while species located at high elevations experienced an increase in NDVI values compared to the period 2018-2023. Evergreen oak, was the species that suffered the most, and it recovered only the year after (2023). European beech and Norway spruce that in the study area are mainly located above 1000 m a.s.l. in 2022 showed NDVI values higher than the average, with a slight decrease in July for European beech. |