MAPPING THE SPATIAL-TEMPORAL VEGETATION RESPONSE TO DROUGHTS IN NORTHERN ITALY

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Abstract: In this study the correlation between bi-weekly drought events and vegetation greenness in northern Italy was analysed for the 2000-2020 period. To this purpose, two high-resolution datasets, based on ground data and MODIS Land Products, were collected. Bi-weekly severe and extreme droughts were investigated by mean of SPEI and SPI indices calculated at different drought timescales. Correlation maps between fields of bi-weekly vegetation (NDVI and EVI) and bi-weekly drought (SPI and SPEI) indices were computed, retaining only significant correlations. The results suggest that the vegetation types perturbed by human activities in the Po Plain, and in the Tuscan hills, are the most sensitive to drought. By contrast, all forests types, if not perturbed, apparently are quite drought-tolerant.

Keywords: MODIS Land Products, Ground Data, Drought, Vegetation Indices

Résumé : **Cartographie de la réponse de la végétation aux sécheresses dans le nord de l'Italie:** Dans cette étude, , la corrélation entre les épisodes de sècheresse et la végétation a été analysée pour la période 2000-2020 dans le nord de l'Italie. Deux jeux de données ont été collectées :des séries climatiques in situ et des produits satellitaires MODIS. Les épisodes sécheresse bihebdomadaires extrêmes ont été étudiées au moyen des indices SPEI et SPI. Des cartes de corrélation entre les indices de végétation et de sécheresse ont été calculées, et seules les corrélations significatives ont été retenues. Les résultats suggèrent que les types de végétation sensibles à la sécheresse sont ceux perturbés par les activités humaines dans la Plaine du Pô, et dans les collines Toscanes. Tous les types de forêts sont apparemment tolérants à la sécheresse.

Mots-Clés : MODIS Produits Terrestres, Séries climatiques, Sécheresse, Indices de végétation.

Introduction

Drought is a recurrent climate hazard that is generated by a natural and temporary imbalance of water availability. It develops slowly, and it includes precipitation below the normal values. Nevertheless, its severity, magnitude, and frequency can vary from region to region (Carrão et al. 2017). Several drought indices have been developed; the most important ones are the Standardized Precipitation Index (SPI, McKee et al. 1993) and the Standardized Precipitation Evapotranspiration Index (SPEI, Vicente-Serrano et al. 2010). In recent decades, drought frequency, duration, and severity have increased substantially at a global scale, especially in arid and semi-arid regions. The Mediterranean basin is an "hot spot" of climate change, and suffered the highest increase in drought magnitude. Owing to the high frequency of droughts, the Mediterranean vegetation is well adapted to drought events, adopting different morphological and phenological strategies. On the other hand, the Mediterranean landscape has been drastically modified by human activities, affecting the vegetation communities and their resistance and resilience to droughts. For these reasons, determining the impact of droughts on Mediterranean vegetation is difficult

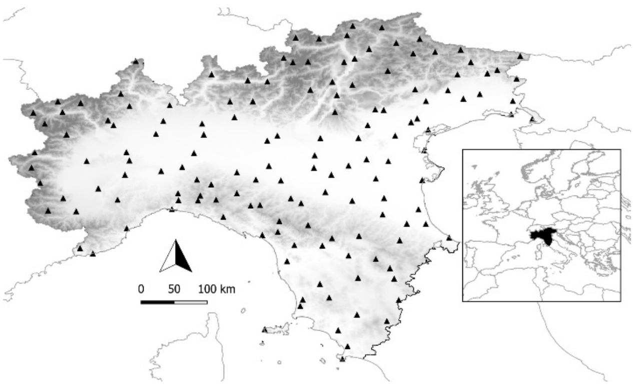

figure 1: Map of Italy, and location of the meteorological stations in Northern Italy

owing to the strong landscape diversity, with vegetation species having different resistance to drought. Northern Italy has been chosen as a case study because it is densely populated, rich in infrastructures and in varied agroecosystems, and it has a rather complex topography: it includes a low plain (Po Valley) surrounded by high mountain ranges including the Alps and Apennines (Figure 1). Northern Italy is characterised by temperate climate, where temperature is projected to rise and precipitation may significantly change by the end of the 21st century (Desiato et al. 2015). On average, in northern Italy the vegetation growing season goes form spring to summer. Increasing air temperatures are significantly affecting the duration of the growing season over Italy, and lengthening of the period between the occurrence of the last spring frost and the first autumn frost between 0.2 and 0.6 days/year was observed by the Join Research Centre of the European Union for the last decades. To the best of our knowledge, there are no studies on drought effects on the vegetation types of northern Italy covering the last 21 years. Additionally, no previous study has considered the combined effect of precipitation and atmospheric evaporative demand on drought severity, considering different drought time scales. The aim of the present work is thus to quantify the spatial distribution of drought events, and identify their effects on vegetation greenness and vegetation trends in northern Italy during the 2000-2020 period, using the combination of ground data and MODIS images at 1 km of spatial resolution. For this purpose, correlation maps between fields of bi-weekly vegetation indices (NDVI and EVI) and bi-weekly drought indices (SPI and SPEI) were computed.

1. Data and Method

1.1 Data

Two new high-resolution datasets for the 2000-2020 period were prepared for northern Italy:

- Remote sensing: MODIS "Land Product" were extracted from the NASA/USGS Land Resources Distributed Active Archive Center (LP DAAC) and cropped on the study area. To investigate on drought events the 8-Day Land Surface Temperature (LST, MOD11) and Evapotranspiration (MOD16) products were collected. Moreover the 16-Day Vegetation Index (MOD13) as Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) were selected. The data were downloaded at a spatial resolution of 1km and for the months between March and August included. This allows examination of vegetation growing season to avoid winter snow cover. The LST values were aggregated at bi-weekly scale (16 days) and converted from Kelvin to Celsius. For the selected products, all pixels that included no data, or were covered with clouds were removed. Urban areas and waterbodies were masked according to the CORINE Land Cover product (MCD12).
- Ground data: 150 daily precipitation series were obtained from the National System for the Collection, Processing and Dissemination of Climatic Data of Environmental Interest (SCIA, Figure 1). Daily precipitation series were quality controlled and, to facilitate the comparison with remote sensing products, data were aggregate at bi-weekly scale. Non-complete series were reconstructed by means of a gap-filling procedure based on the average of measurements at nearby stations (Vicente-Serrano et al. 2017). Homogeneity analysis was performed, and the Standard Normal Homogeneity Test (SNHT) was applied. Bi-weekly precipitation series were interpolated on a cell grid at 1x1 km by Universal Kriging. Because stations are located at a different altitudinal range and distance, for each cell grid, the latitude, longitude, elevation, aspect and distance to shoreline were taken into account as auxiliary variables (Baronetti et al. 2020).

1.1 Method

First, the main bi-weekly spring and summer drought events for the 2000-2020 period were identified. On the basis of the gridded precipitation dataset, the LST and the Evapotranspiration products, the combination of two drought indices, SPI and SPEI calculated at medium (12 months) and long-time scales (24 and 36 months), was adopted. The Standardized Precipitation Index (SPI) is based only on precipitation data, it is calculated on the total cumulative weekly (or monthly) precipitation. SPI values usually span the range ± 3, where negative values indicate dry periods and positive values stand for wet periods. By contrast, the SPEI, based upon the same calculation procedure used for the SPI, considers both precipitation and temperature. It assumes that water balance, expressed as the difference between precipitation and evapotranspiration, is the best drought identifier. In the following, the bi-weekly SPEI and SPI values were estimated at 12-, 24-, and 36- month timescales and the drought events were identified using three parameters: i) classification in severe (SPI or SPEI<-1.28) and extreme (SPI or SPEI<-1.65) episodes; ii) minimum duration of 3 consecutive weeks; iii) drought conditions that affect at least the 25% of study area (González-Hidalgo et al. 2018). Later, the events were characterised by the starting and ending week, magnitude, duration and percentage of affected area.

Drought (SPEI and SPI) and vegetation (NDVI and EVI) trends were analysed by mean of the Mann Kendall test (Mann, 1945), and the most sensitive areas in Northern Italy were detected. Finally, with the aim of identifying the vegetation areas mostly interested by droughts, the Pearson’s correlation coefficients between bi-weekly vegetation (NDVI and EVI) and bi-weekly drought (SPEI and SPI) indices were computed considering medium (12 months) and long drought (24 and 36 months) timescales. Correlation maps with 1 km of spatial resolution were obtained, and only the significant (p-value <0.05) and the highest correlation (above >0.6) were retained (Gouveia et al., 2016). On the basis of the correlation maps, drought impacts over the timescales were investigated as the percentage of the vegetation area with strong correlation at 12-, 24- and 36- months.

2. Results

Table 1 shows the main bi-weekly summer and spring drought events detected by SPEI and SPI indices in northern Italy at 12-month time scale. The analysis identified nine main events with the longest ones during summer. Some events are especially relevant: July 7, 2003- August 08, 2003 with 8 consecutive weeks and 30% of area under drought; May 9, 2005 – August 18, 2005 with 14 weeks of duration and 25% of area interested; June 26, 2017-August 29, 2017 lasting 10 week and 35% of area under drought. There is clear agreement between the episodes recorded by the different indices, except for two events. One was in 2007, lasting 4 weeks and 30% of area under drought according to SPEI (April 7, 2007 – April 27, 2007), whereas for SPI the event interested 40% of northern Italy area and had a length of 10 consecutive weeks (March 6, 2007 – May 5, 2007). The second event was recorded in 2017, specifically June 26, 2017 ⁻ August 29, 2017 for SPEI, lasting 10 weeks and 35% of area under drought. Similarly to the previous event, the two indices recorded a close ending date (August 29, 2017) but SPI used to detect an earlier stating data (May 25, 2017) and 5% more of area interested by drought.

Table 1: Main summer and spring drought episodes observed in the 2000-2020 period by SPEI and SPI, calculated at 12 months. For each event are reported the starting week and the ending week and the percentage of area under drought.

SPEI				SPI			
Start	**End**	**Week**	**%Area**	**Start**	**End**	**Week**	**%Area**
12/07/2003	29/08/2003	8	30	12/07/2003	29/08/2003	8	45
05/03/2004	06/04/2004	8	30	05/03/2004	12/04/2004	8	40
09/05/2005	18/08/2005	14	25	09/05/2005	28/08/2005	13	32
10/06/2006	26/06/2006	4	25	10/06/2006	26/06/2006	6	28
07/04/2007	23/04/2007	4	30	06/03/2007	09/05/2007	10	40
21/03/2012	06/04/2012	4	25	21/03/2012	06/04/2012	4	30
25/05/2014	10/06/2014	4	32	25/05/2014	10/06/2014	4	25
26/06/2017	29/08/2017	10	35	25/05/2017	29/08/2017	14	40
25/06/2020	28/08/2020	8	25	24/05/2020	11/07/2020	8	30

Figure 2 shows the spatial distributions of drought trends calculated with the SPEI at 12 months and of vegetation trends according to the NDVI index for the 2000-2020 period. The results indicated that in the Po Plain and in the Tuscan hills drought increased, but significant and negative trends (-3 and -1 ΔSPEI/21year) were recorded only in the Po Valley. The spatial distribution map of vegetation trends for the 2000-2020 period showed negative NDVI trends in the Po Valley and in few sectors of the Tuscan hills. In those areas an intensification of vegetation stress was observed with negative and not significant NDVI trends between -0.10 and -0.05 ΔNDVI/21year. This suggested that the Po Valley, and the Tuscan hills in part, are very sensitive areas to droughts with significant and negative impacts on vegetation.

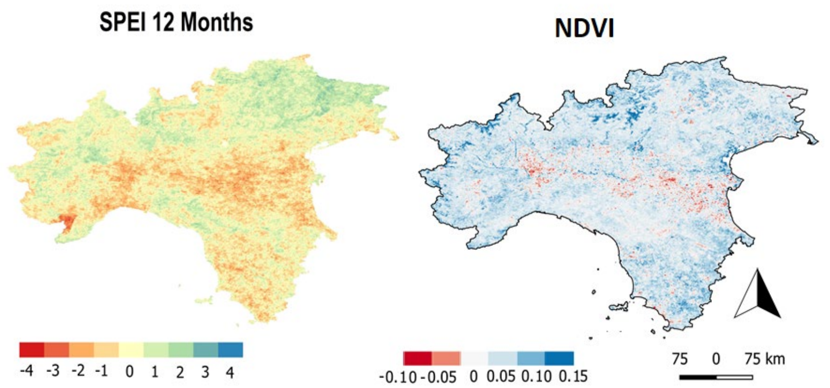

figure 2: Trends investigation for SPEI 12 months (left panel) and for NDVI (right panel) observed for the 2000-2020 period.

The correlation maps between drought and vegetation were produced at 12-, 24-, and 36-months in order to study plants response at medium and long drought timescales. In figure 3 the correlation map between SPEI and NDVI index at 12-, 24- and 36-months is shown. Figure 3 indicates that, in keeping with the spatial distribution of the negative and significant SPEI and NDVI trends recorded for the 2000-2020 period, the strongest correlations were found in the Po Valley and the Tuscan hills. Apparently, differences were not observed through the timescales. Table 2 shows the percentage of the vegetation with strong correlations between the SPEI index and the two vegetation indices (NDVI and EVI). Similar results were observed for the two vegetation indices and looking at the correlation between SPEI and NDVI, 5% of the study area shows a strong vegetation response to drought at 12 months, 7% at 24 months and 10% at 36 months. This means that at long drought timescales, the percentage of involved vegetation is double than at short timescales.

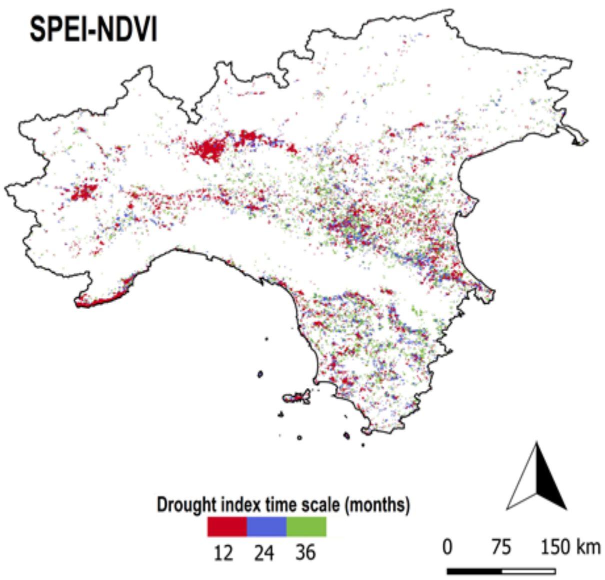

figure 3: Time-scales of the SPEI showing the correlations with the NDVI. Non-significant correlations were removed

In detail, according with the CORINE Land Cover, forests and herbaceous mixed with croplands are the mostly sensitive vegetation types to droughts with 7% of area under drought at 12 months in the first and 5% in the second. While for natural forests the percentages are lower and reached the 5% only at 36 months.

Table 2: Percentage of the vegetation with significant correlations at short, medium and long drought time-scales.

Timescale	**Percentage of vegetation (%)**	
	SPEI-NDVI	**SPEI-EVI**
12 Months	5%	3%
24 Months	7%	4%
36 Months	10%	7%

Discussion and Conclusion

Adding to the literature devoted to the Mediterranean area (e.g., Longobardi et al. 2016), this work contributes to characterise droughts and vegetation stress in northern Italy, an area that is rich in water resources. Two new high-resolution datasets based on meteorological stations and MODIS images were generated, and the applied methodology was useful to best characterise vegetation response at short, medium and long drought timescales. Our study indicated that the application of a single index is not enough in the detection of drought events. Even if SPEI and SPI agree in the detection of nine drought episodes, in 2007 and in 2017 SPI used to detect events that are more spatially and temporally extended. This has suggested that in the 2000-2020 period the dominant drought triggering factor seems to be absence of precipitation. In fact, in the last 20 years, longer dry periods and more frequent extreme precipitation events were observed (Acquaotta et al. 2019).

The investigation of vegetation responses in the main drought events shows that the effects are not exclusively correlated with temperature trends in Northern Italy. In fact, Ceppi et al (2012) reported that the largest temperature increase is experienced by the Alps, with marked impacts for example on glacier volume. Here, however, the most sensitive areas to droughts are the Po Plain and the Tuscan hills. This suggests the importance of always taking into account the variability of precipitation in the study of droughts, and the large heterogeneity of drought events and vegetation response in Northern Italy.

The outcomes of this research indicated that the impact of droughts on vegetation depends on vegetation communities. The vegetation types with the highest response to droughts seem to be those perturbed by human activities. In fact, high sensitivity to droughts was observed for all vegetation types mixed with croplands. In Italy, especially in the Po Plain, the extent of monoculture (rice and maize) has increased in the last sixty years; habitat biodiversity has decreased, and natural areas have become ever more fragmented (Cardarelli et al. 2011). Recently, findings in community ecology have led to the hypothesis that species diversity should play a critical role in drought avoidance, in fact species sharing the same ecological niches strongly compete for the same resources, leading to a reduction of resistance or resilience to drought (Grossiord, 2020).

To conclude, the outcomes of this research showed that even if, in the recent years, drought events become more frequent in northern Italy, and the episodes of 2012 and of 2017 costed the agricultural industry losses for over 500 million euro (e.g., crop production, livestock and water resources, Magno et al. 2019), minimal drought impacts were observed for most forest types. In fact, Mediterranean forests, if not perturbed, are characterized by tolerance to and recovery from drought events. However, the increase of dry periods during the wet season could increase the potential risk for forest fires, and set northern Italy forests at risk.

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