DRIVERS OF VEGETATION ACTIVITY DURING EUROPEAN SUMMERS: A CASUAL INFERENCE APPROACH APPLIED TO SOLAR-INDUCED FLUORESCENCE OBSERVATIONS

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Overview

Summer weather in Europe has become more **extreme** in recent years. Several studies have focused on unraveling the influence that this extreme weather may have on ecosystem dynamics.

However, as with most earth science applications, the majority of previous studies rely on correlations or linear regressions to establish cause-effect relationships, which implies that the **actual drivers of drought** and periods of vegetation stress **remain largely unresolved**.

In addition, these studies commonly use optical indices to characterize the state of vegetation in terms of greenness or structure, but fail to capture short term impacts on vegetation activity caused by water or heat stress.

Solar-induced chlorophyll fluorescence (SIF) is a byproduct of **photosynthesis**: a small fraction of light, initially absorbed by chlorophyll pigments, that is re-emitted as a subtle glow of energy (Baker, 2008).

Transpiration and **photosynthesis** are intrinsically connected via stomatal regulation.

SIF anomalies should integrate the effects of different environmental stressors on transpiration (Pagan et al., 2019).

Here we examine the underlying causality and interactions between vegetation activity (represented by changes in SIF), and potential environmental drivers of vegetation stress over European summers.

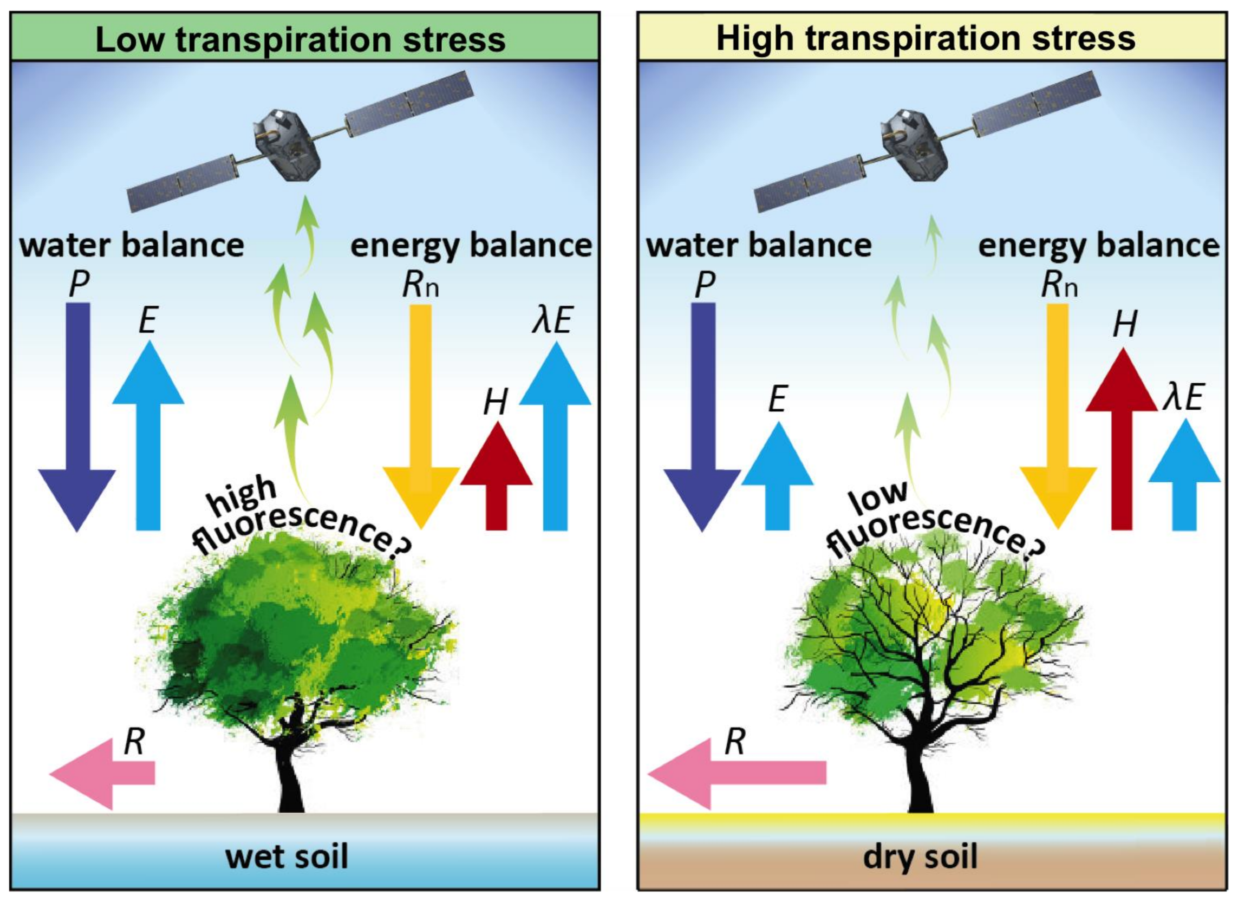


Figure 1: Relationship between various environmental stressors and SIF.

Datasets

All resulting input data is regridded a 0.5° resolution and gapfilled to obtain daily estimates where needed for the period 2008-2015.

Parameter	Source
SIF	GOME-2 MetOp-A
Absorbed Photosynthetically Active Radiation (APAR)	EUMETSAT fraction of PAR (fPAR), CERES PAR
Net Radiation (Rn)	ERA-Interim
Air Temperature (Ta)	ERA-Interim
Vapor Pressure Deficit (VPD)	AIRS air temperature and relative humidity
Precipitation (P)	MSWEP
Soil Moisture (SM)	ESA CCI

Methodology

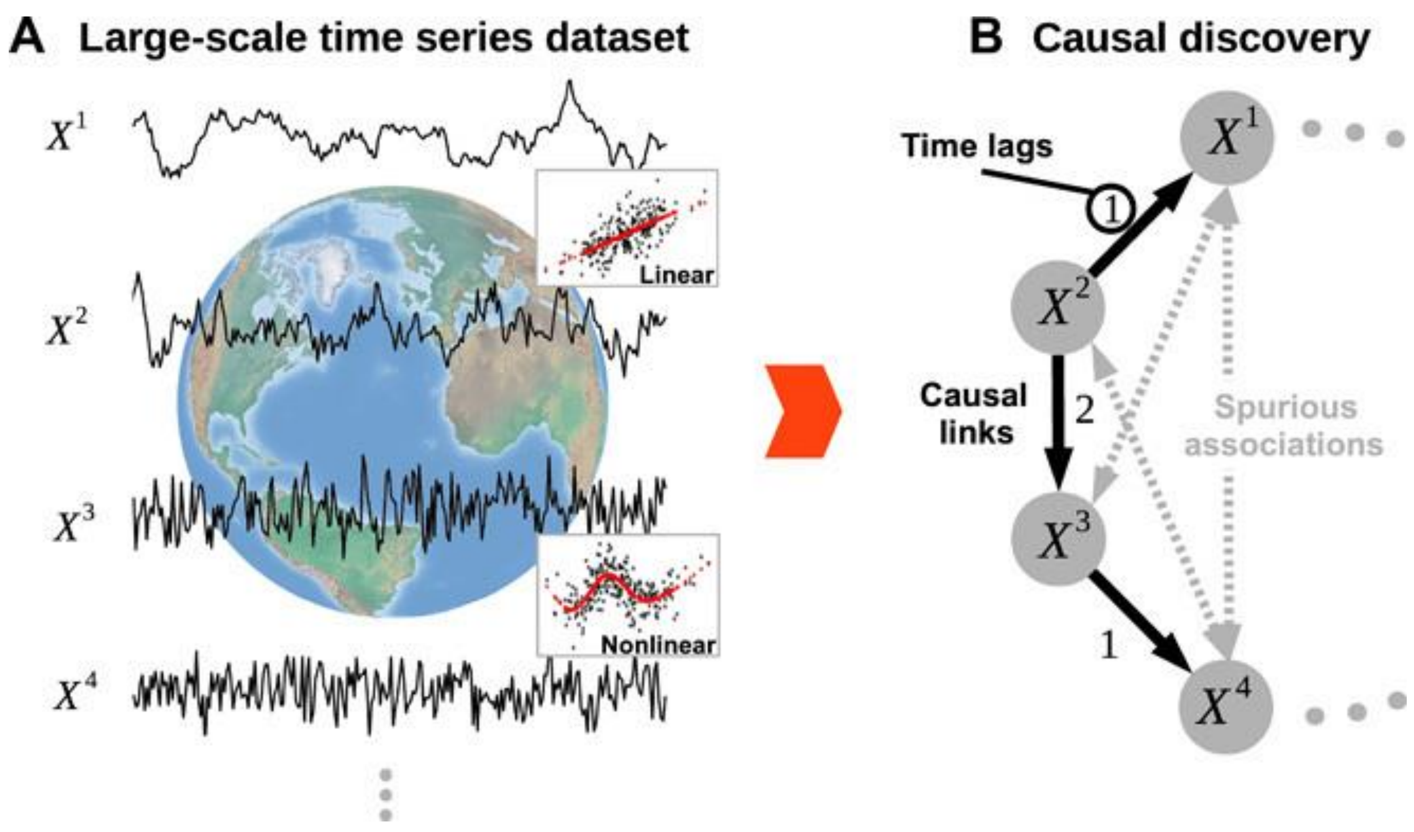
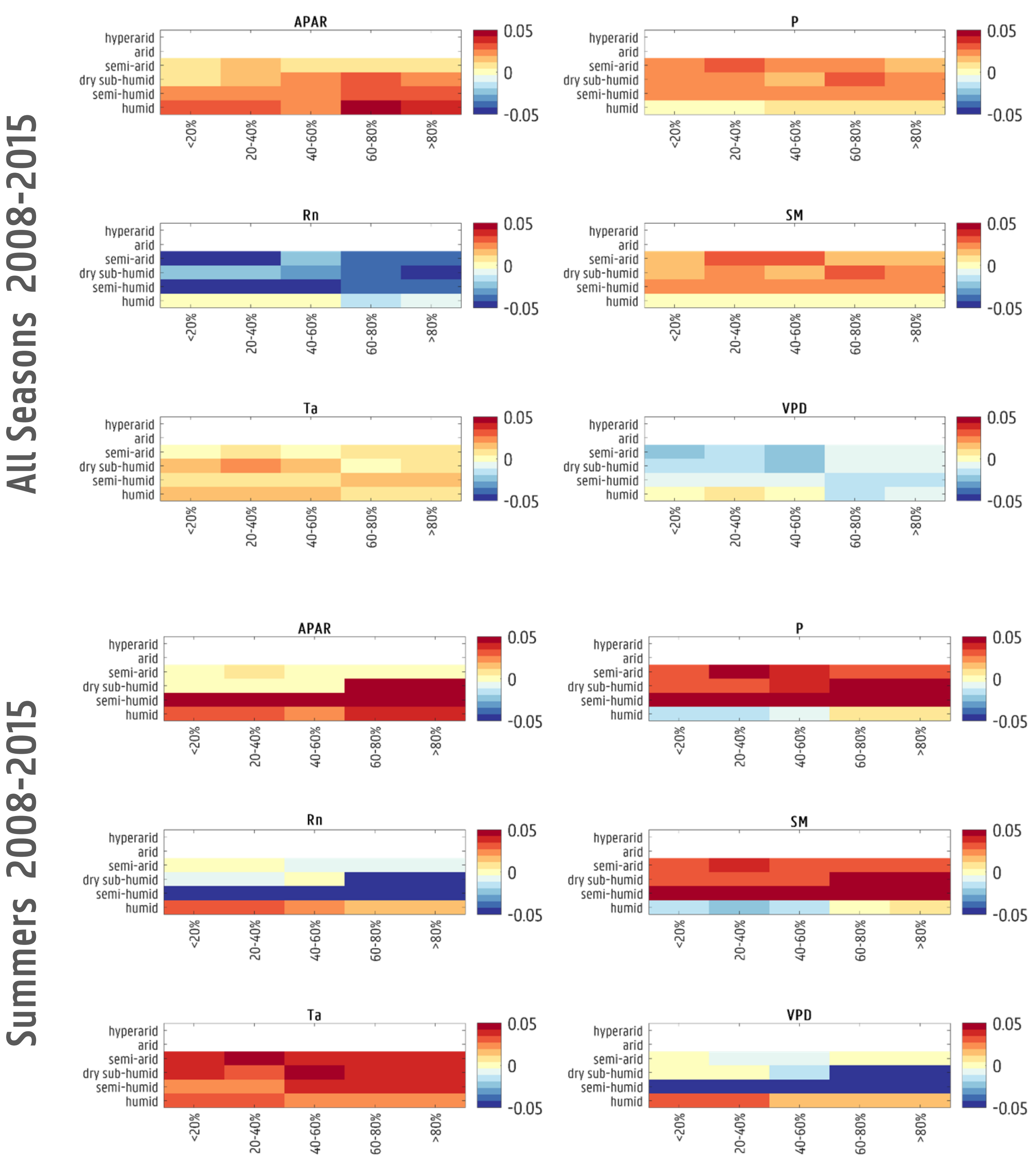


Figure 2: From Runge et al., 2019, a representation of a casual discovery problem for an Earth systems dataset. Nodes depicted in (B) represent each variable.

The tigramite casual time series analysis python package is used to examine casual dependencies between SIF and each potential environmental driver (APAR, Rn, Ta, VPD, P, SM). As we are interested in more immediate influences on vegetation activity, results are shown for a lag of zero. While directionality cannot be determined using a tau of zero, the condition-selection (PC) momentary conditional independence test (MCI) is used to evaluate the differences in strength of causality between the drivers and SIF. A partial correlation test is used to test for independencies.

Results



European regions are grouped by their fraction of vegetative cover (derived from MODIS) and aridity index (from CGIAR, derived from the relationship of annual average precipitation and potential evapotranspiration).

Common casual relationships and dynamics are observed from these groupings across the entire time series (upper panels). In more arid regions of Europe, P and SM show stronger positive relationships with SIF (therefore, increasing P and SM result in increasing vegetation productivity). In contrast, VPD exhibits stronger negative relationships with SIF as aridity increases. The higher the atmospheric demand for water, the lower vegetation productivity. APAR, which is inherently a function of vegetative growth and expanse, exhibits stronger positive relationships as vegetative fraction increases.

Similar but much stronger patterns are observed for nearly all environmental drivers during the summer months (lower panels). In more humid regions, P and SM have much weaker influences on SIF, even resulting in negative relationships for less vegetated areas. However, in more arid regions, P and SM are most strongly positively related to SIF across all vegetation fractions.

Figure 3: Results of MCI strength (color scale) for each environmental driver in relation to SIF over Europe during the full time series (2008-2015, top panels) and restricted to summers (lower panels). Regions are grouped by aridity index (y-axis) and fraction of vegetative color (x-axis).

Next Steps

GOME-2 MetOp-A SIF is used in this analysis due to its extended time length availability. As prior studies have highlighted, GOME-2 SIF can exhibit high amounts of noise, making it difficult to rely on for sub-weekly analysis. The Sentinel 5P (launched in late 2017) TROPOMI sensor is expected to improve the insufficiencies of prior SIF products, and data is available at a much higher spatial resolution. As nearly two years of data are now available, further research has started to experiment swapping in this newer product and focus on more recent and extreme European summer conditions.

With higher spatial and temporal data, the SIF signal will also be decomposed into the component that relates to fluorescence yield, which represents the faster biochemical responses that are expected to occur on daily time scales.

References:

Baker, N.R., *Annual Review of Plant Biology*, 59(1), 89-113 (2008)

Pagán et. al., *Remote Sensing*, 11(4), 413 (2019)

Runge et. al, *Science Advances*, 5(11), eaau4996 (2019)

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