How useful are meteorological indicators to assess agricultural drought across Europe?

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Motivation and aim

Drought monitoring and early warning (M&EW) is an important component of agricultural and silvicultural risk management. Meteorological indicators such as the Standardized Precipitation Index (SPI) are widely used in operational M&EW systems and for drought hazard assessment. Meteorological drought yet does not necessarily equate to agricultural drought given differences in drought susceptibility, e.g. crop-specific vulnerability, soil water holding capacity, irrigation and other management practices.

The aim of this study is to test how useful meteorological indicators are to assess agricultural drought. We therefore investigate the relation between meteorological drought indicators and remotely sensed vegetation stress for Europe at the EU NUTS3* region level. Annual crop yield statistics are usually aggregated at this spatial scale. This allows a direct comparison betwen meteorological indicators, remotely sensed vegetation stress, and crop yield in a next step.

* NUTS = Nomenclature of Units for Territorial Statistics

Data

Meteorological drought indicators

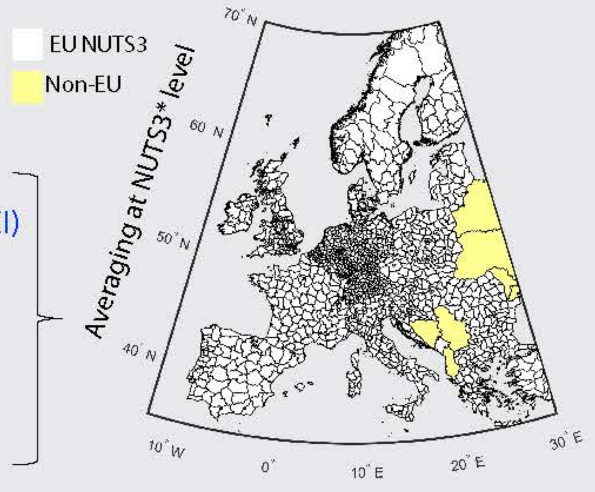
Standardized Precipitation Index (SPI)
Standardized Precipitation Evaporation Index (SPEI)

Monthly data based on E-OBS gridded rainfall and temperature

Remotely sensed vegetation stress

Vegetation Condition Index (VCI) (Kogan, 1990)
Vegetation Health Index (VHI) (Karnieli et al., 2006)

Monthly data derived from MODIS Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature



For VCI and VHI: averaging over 1) all grid cells, and 2) all grid cells of a certain land use class

Data sources

Data	Source
Rainfall	E-OBS gridded data v12.0, 0.25°
Temperature	E-OBS gridded data v12.0, 0.25°
NDVI	MOD13C2, 0.05°
Land Surface Temperature	MOD11C3, 0.05°
Land Cover Type	MCD12C1, 0.05°
FAO crop growing season	FAO GIEWS[a)]
Soil texture	European Soil Database
Irrigation map	Eurostat LUCAS
Elevation	EEA

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

$$VHI = 0.5 \cdot VCI + (1 - 0.5) \cdot TCI$$

$$TCI = \frac{LST_{max} - LST}{LST_{max} - LST_{min}}$$

NDVImax and NDVI min refers to the multi-year maximum or minimum of a specific month

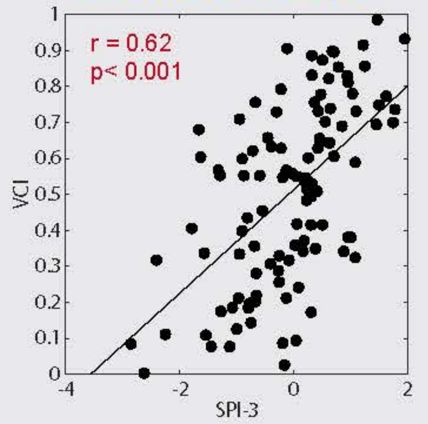
Method

Time period of analysis: 03/2000 - 12/2015

Pearson's correlation coefficient is calculated between monthly VCI or VHI and SPI or SPEI of different accumulation periods (1-6 months). Only the months of the growing season are selected for analysis.

Different approaches regarding the start and duration of the growing season are investigated:
1) uniform growing season across Europe (April-October)
2) variable crop growing season based on the FAO Global Information and Early Warning System on food and agriculture (GIEWS).

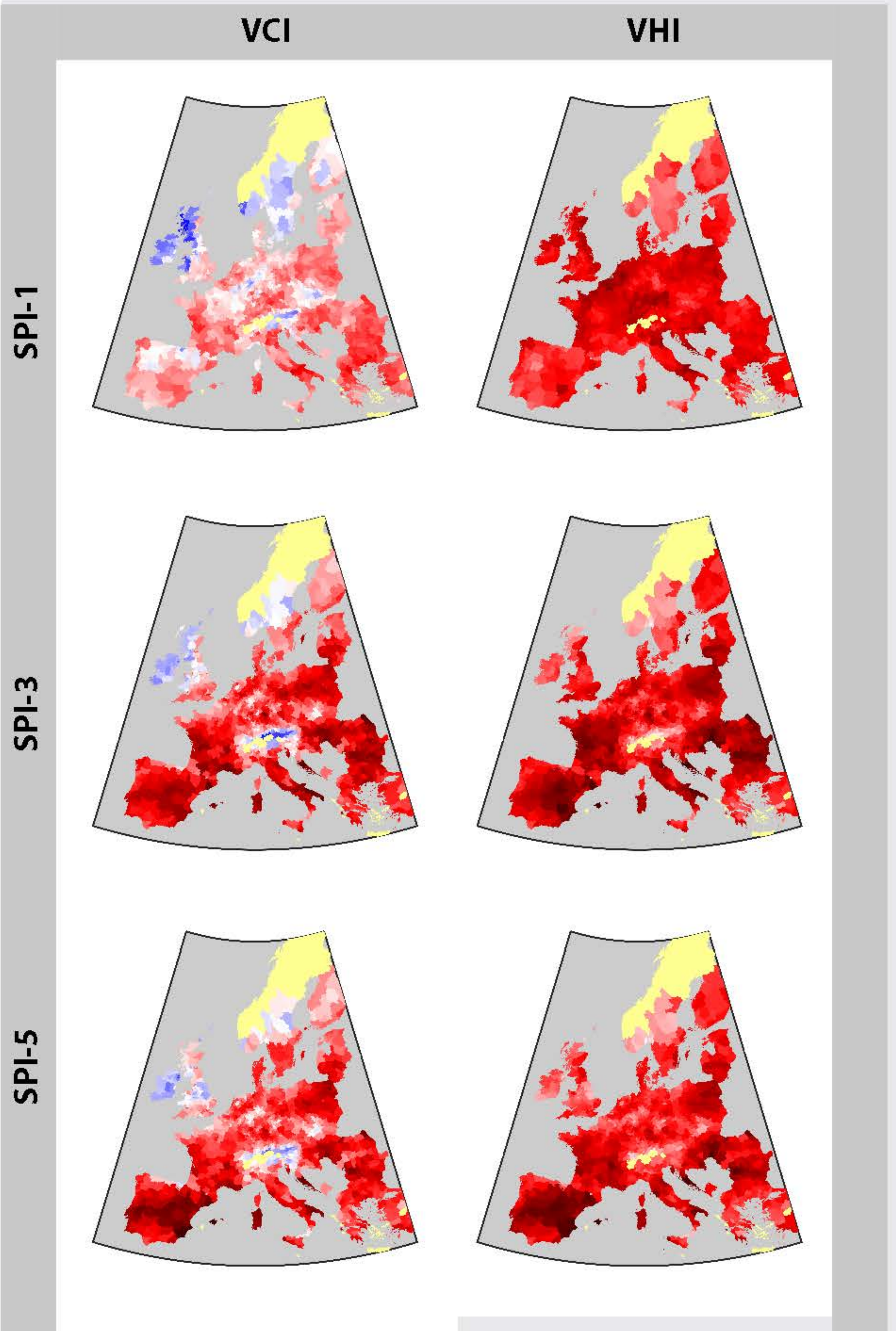
Example NUTS3 region



Correlation between meteorological indicators and vegetation stress

Different indicators

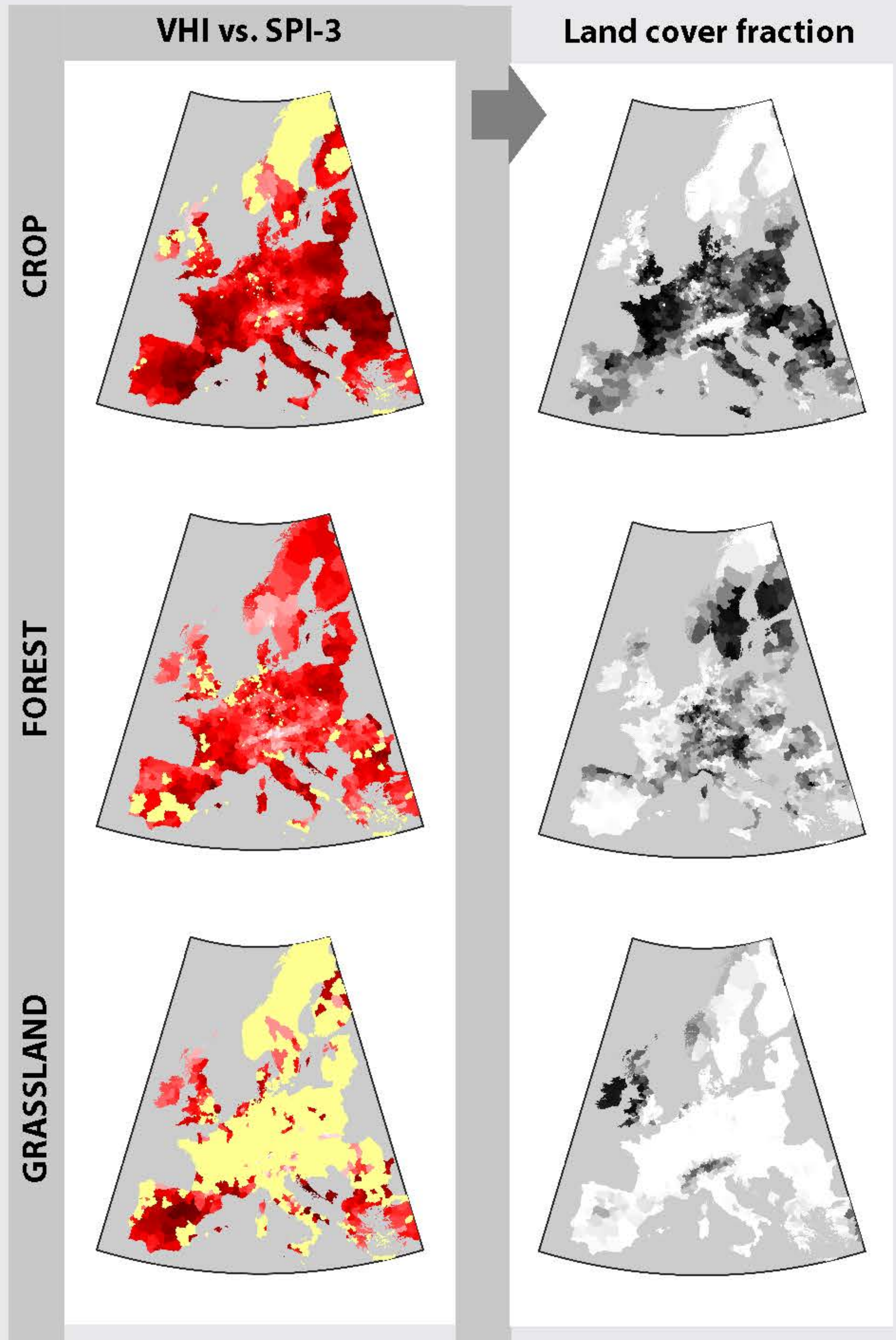
Spatial aggregation over all grid cells



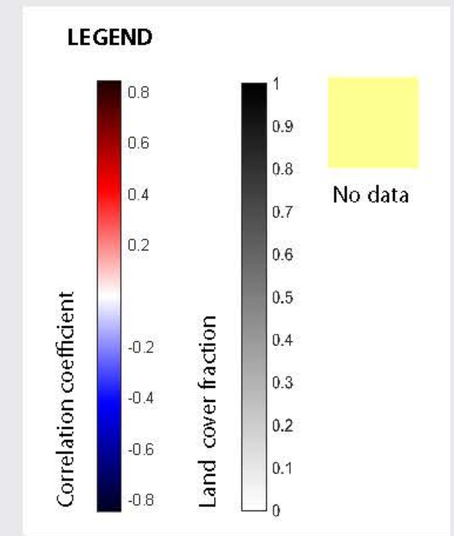
VCI and VHI versus SPI and SPEI:
There is a high correlation between VCI and SPI or SPEI for many NUTS3 regions. For some regions a negative correlation is found. SPI-3 generally shows best correlation compared to shorter or longer accumulation periods but the differences are small. Differences between SPI and SPEI are small as well. For VHI there are only positive correlations with SPI. Other results are similar as for VCI.

Different land use

Spatial aggregation over grid cells of a certain land use class

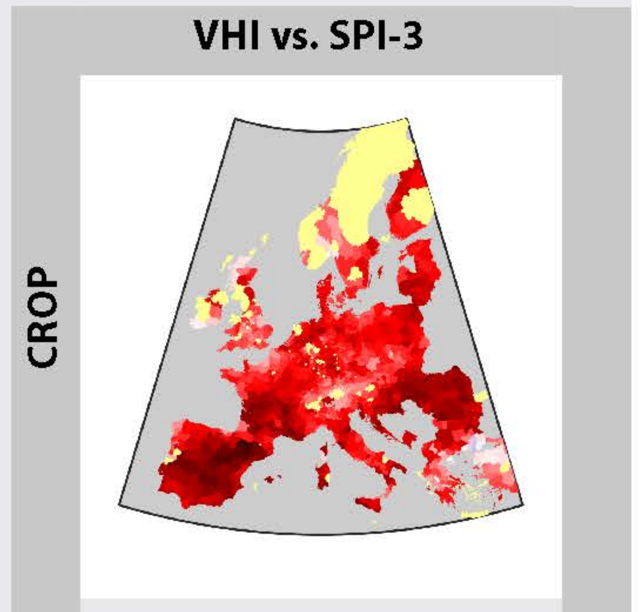


Stratification by land use:
For regions with a high fraction of crop area the correlations increase for most regions but not for all. For forest, the correlations based on VCI just representing forest cover mostly decrease. The class of forest considers many different types of forest. A lower correlation than for crops shows that shorter-term meteorological indicators (SPI and SPEI up to six months) may not be representative for lagged drought impacts on forest ecosystems.



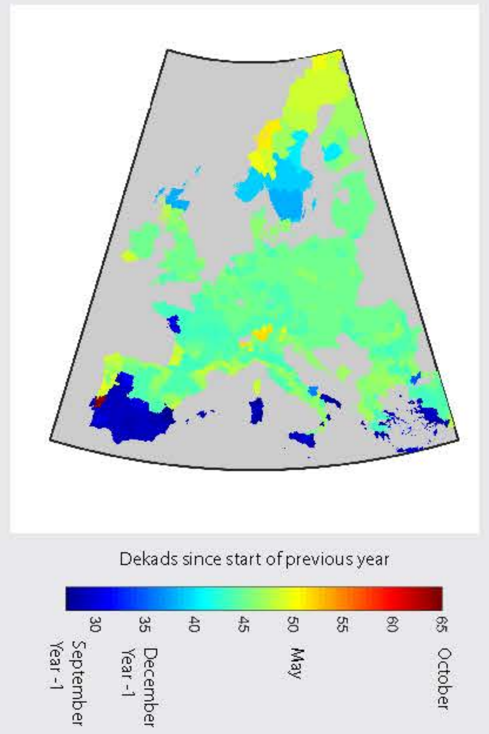
Growing season timing

Variable length of crop growing season



Surprisingly, the correlations based on a spatially variable crop growing season are slightly lower than for the uniform growing season. For some NUTS3 regions in southern Spain the correlation increases. A lower correlation may also result from the spatial and temporal aggregation of the information on the start and duration of the growing season.

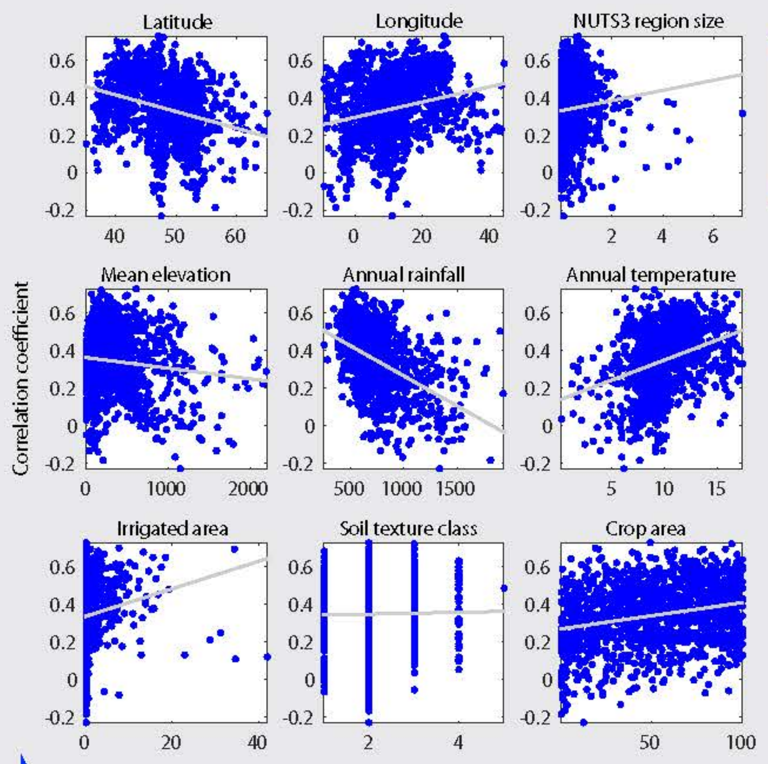
Start of growing season



The map displays the start of the first crop growing season according to FAO GIEWS [a)]. For aggregation at the NUTS3 level the majority value was selected.

Explanatory factors of spatial patterns

Geographic variables versus strength of correlation: example based on correlation between VCI and SPI-3 for cropland (n = number of NUTS3 regions)

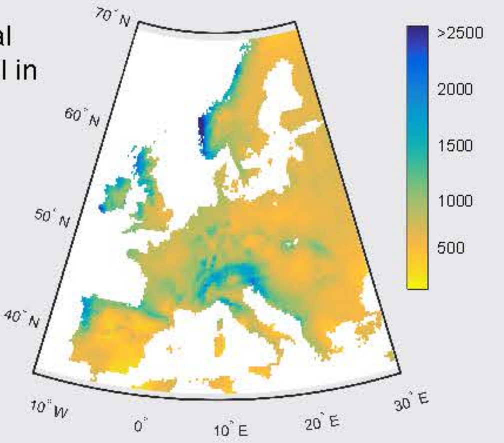


A linear model based on all left shown predictors explains 42% of the variability in spatial patterns of correlation.

Predictor	Unit	Model coefficient	Significance
Latitude	Degree	-0.33	***
Longitude	Degree	0.31	***
NUTS3 region size	-	1.01	***
Mean elevation	m	-0.10	*
Annual rainfall	mm	-0.32	***
Annual temperature	°C	0.30	***
Irrigated area	%	-0.20	***
Soil texture	Class*	-0.06	**
Crop area	%	0.04	**

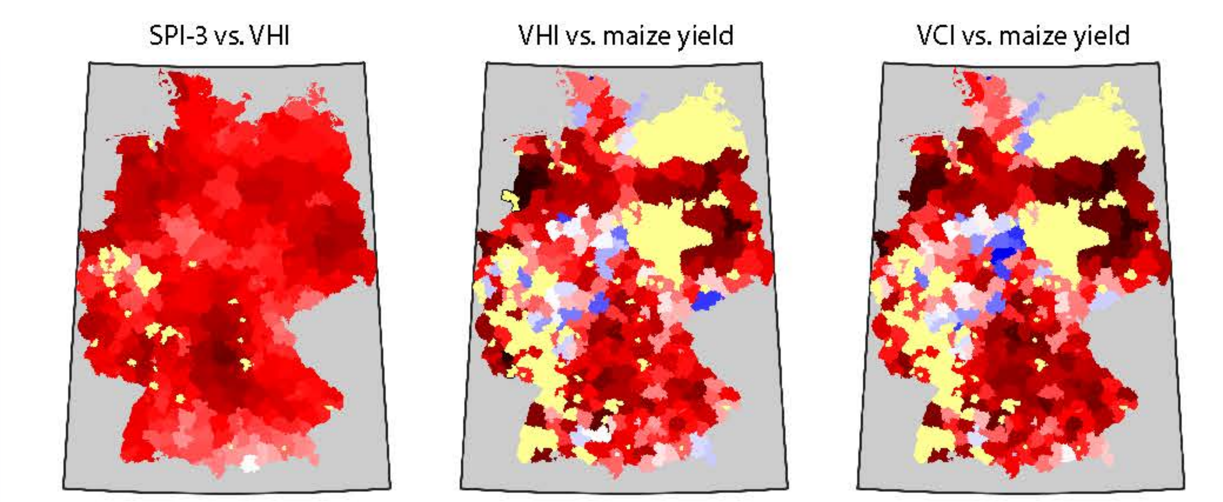
* from coarse (1) to fine texture (5) *** <0.001 ** <0.01 * <0.05

Annual rainfall in mm



Climatically dryer areas show high correlations between SPI or SPEI and vegetation stress, whereas the wettest parts of Europe (radiation limited regions) show lower (for VHI) or negative correlations (for VCI).

Outlook: link to crop yield



Legend: see European-scale correlation maps (same color coding)

Example: Germany

Time period of analysis: 2000-2014

VCI and VHI represent the mean over the growing season

Annual maize yield was detrended prior to analysis

Overall similar spatial patterns are found for meteorological indicators vs. VCI or VHI (monthly data) and VCI or VHI vs. detrended maize yield (annually aggregated data); but there is higher spatial variability of the correlation with maize yield and missing data for many regions do not allow for a complete comparison. A crop-specific cultivation area mask could potentially increase the link between remotely sensed vegtation stress and crop yield.

Conclusion

The moderate to high correlations between SPI or SPEI and remotely sensed vegetation stress reveal that meteorological drought indicators are in most cases useful to assess agricultural drought. However, there is spatial variability in the strength of correlation, which can be partly explained by geographic variables. For the wettest parts of Europe negative correlations with VCI especially for short accumulation periods suggest that short droughts could be beneficial for vegetation growth. A further link to crop yield, shown for one example country, highlights that the relation between drought indicators and crop yield is more complex. Overall, our analysis identifies regions where meteorological indicators are closely linked to vegetation stress and areas where further indicators need to be considered. Such information may help to tailor drought M&EW systems to specific regions.

Acknowledgments

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a) http://www.fao.org/giews/english/index.htm
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