Interannual olive yield modulation forced by climate stressors in Italy: a composite index approach to support crop management

Arianna Di Poala[1], Edmondo Di Giuseppe[1], Massimiliano Pasqui[1]

1. Institute for Bioeconomy, National Research Council of Italy (IBE-CNR), Rome, Italy

Contact : arianna.dipaola@ibe.cnr.it

Consiglio Nazionale delle Ricerche

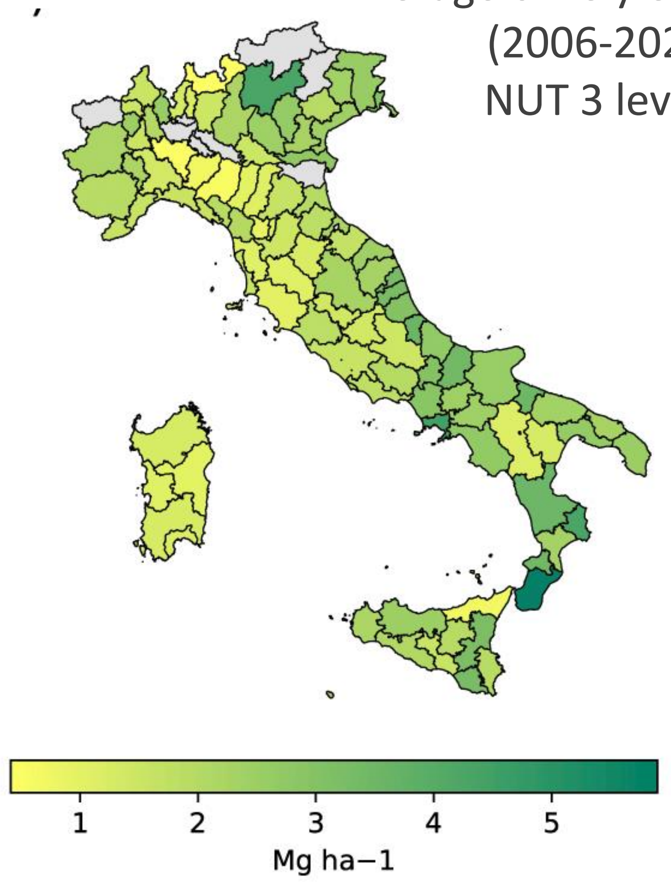
Istituto per la BioEconomia

Olive strongly depends on climate variability and change.

Problem statement:

- *Can we identify which climate-related variables mostly affect **exceptional low olive yields** on a broad spatial-temporal scale?*
- *Can we account for their possible interplays?*

Average olive yields (2006-2020) NUT 3 levels



Context:

- Olive yield variability
- Italy
- period: 2006-2020

Spatial-temporal scale:

- provincial level (i.e., NUT 3),
- **Bimonthly aggregation** of many climate-related variables (**Jan-Feb; Mar-Apr; May-Jun; Jul-Aug; Sep-Oct; Nov-Dec**)

Data:

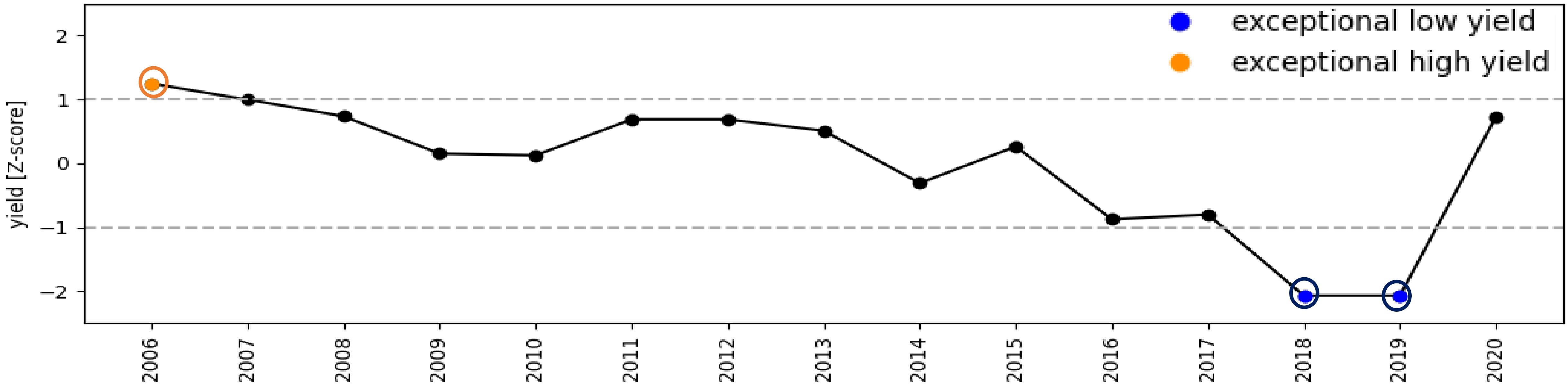
- Olive yields from National Statistic Institute of Italy (ISTAT)
- Climate-related variables from ERA5 and ERA5_land reanalysis

Exceptional high and low yields: overview.

Yield data (2006-2019, **66 provinces whit a complete time series**) standardized as Z-scores (mean = 0, 1std = 1) to aid comparison between administrative units:

Exceptional low yields: **Yields < 1std (i.e., Zscore < -1) >>** ^{L}Y

Exceptional high yields: **Yields > 1std (i.e., Zscore > 1) >>** ^{H}Y

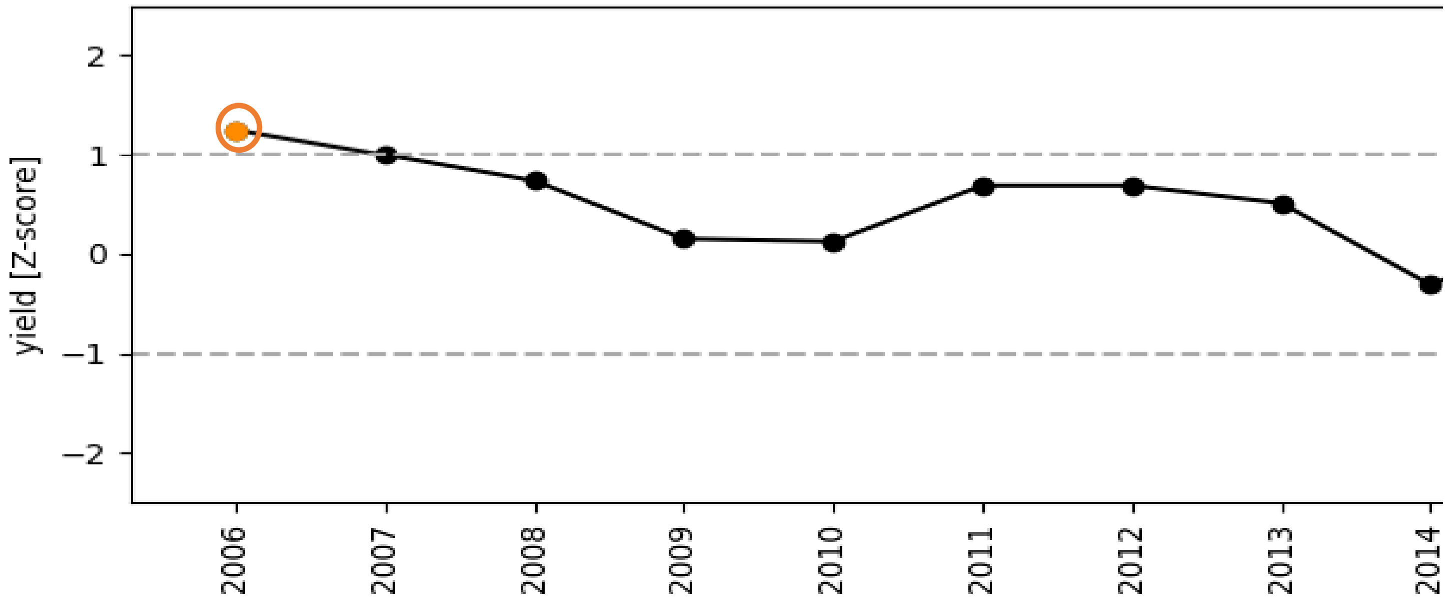


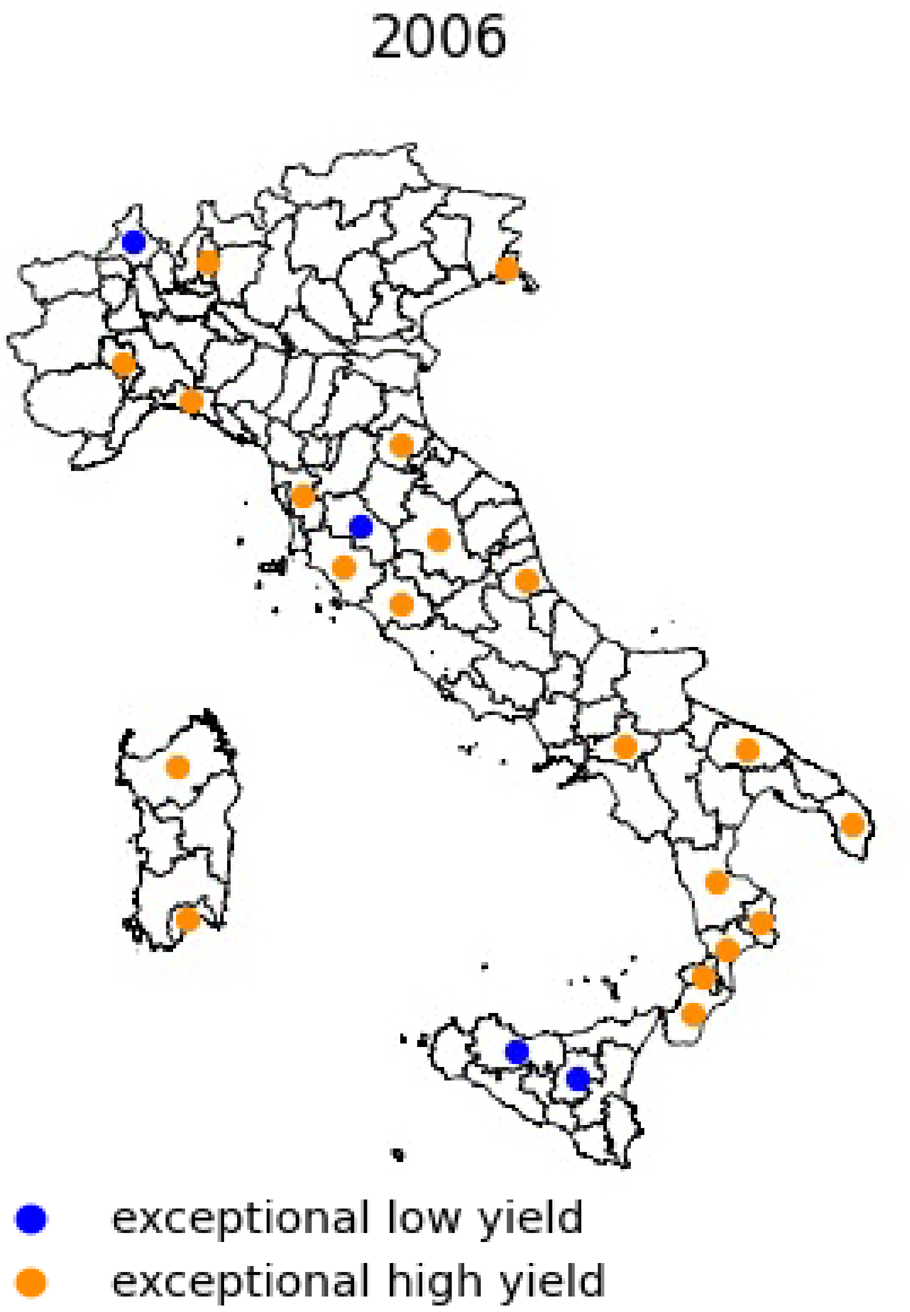
Data from provinces and years with ^{L}Y and ^{H}Y serve as Boolean to compare climate-related variables under ^{L}Y and ^{H}Y

Exceptional high and low yields: overview.

Yield data (2006-2019, **66 provinces whit a complete ti**
(mean = 0, 1std = 1) to aid comparison between admin

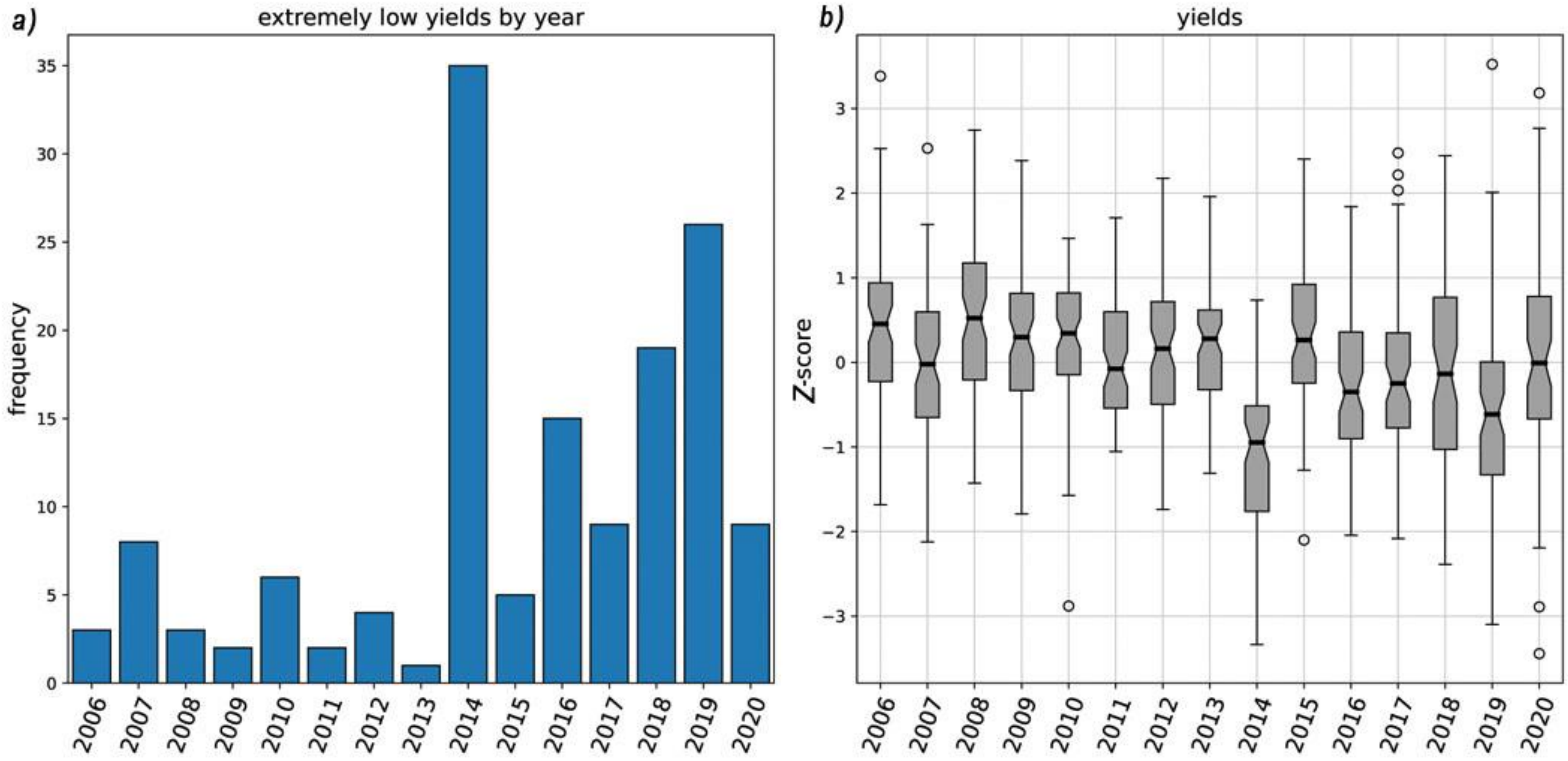
Exceptional low yields: **Yields < 1std (i.e., Zscore < -1)**
Exceptional high yields: **Yields > 1std (i.e., Zscore > 1)**





Exceptional high and low yields: overview.

Yield data (2006-2019, **66 provinces whit a complete time series**) standardized as Z-scores (mean = 0, 1std = 1) to aid comparison between administrative units:



Climate-related variables:

Weather variables and indices **aggregated at provincial level** and on a **bymonthly (*b*)** or **annual (*a*)** time frames

E.g. **Tmax**:

bimonthly aggregation ("b") at provincial level by:

1) averaging maximum daily temperatures over the province for **spatial aggregation**;
2) taking the maximum peak value over the two- months for **temporal aggregation**

January-February	>>> **Tmax_b1**
March-April	>>> **Tmax_b2**
May-June	>>> **Tmax_b3**
July-August	>>> **Tmax_b4**
September-October	>>> **Tmax_b5**
November-December	>>> **Tmax_b6**

6 seasonal variables from Tmax

- 16 climate-related variables computed for 6 bimonthly periods
- 8 annul indices

= ***104 variables*** analyzed (16x6+8=104).

Climate-related variables: dataframe in summary

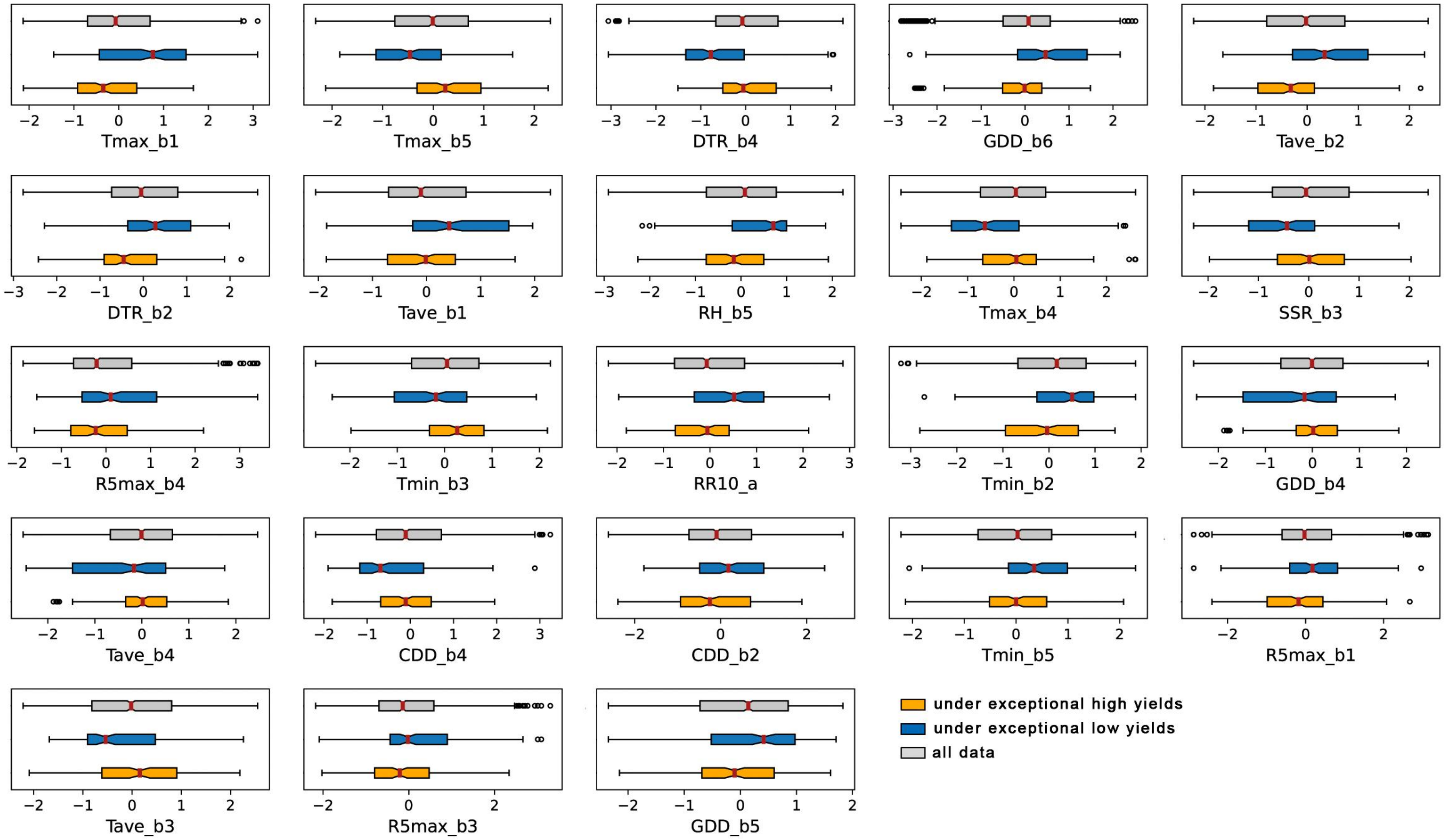
b = bimonthly aggregation
a =yearly aggregation

acronym	Long name	unit	Acronym in ERA5/ERA5_land	Temporal aggregation
Tmin	Minimum air temperature at 2 meters	°C	mn2t	b, minimum
Tmax	Maximum air temperature at 2meters	°C	mx2t	b, maximum
Tave	Average temperature at 2 meters	°C	t2m	b, average
SSR	Average daily surface net solar radiation	$J\ m^{-2}$	ssr	b, average of daily maximum
ET	Potential evapotranspiration	mm	ssr	b, cumulated
VPD	Average daily maximum Vapor Pressure Deficit	kPa	mn2t,mx2t,d2m	b, average of daily maximum
RH	Average relative humidity	0-100	t2m, d2m	b, average
SWC	Average volumetric soil water	dimensionless	swc	b, average
RR	Cumulative total Rain	mm	tp	b, cumulated
DTR	Average daily temperature range	°C	mn2t,mx2t	b, average
R1max	maximum 1 day precipitation	dimensionless	tp	b, maximum
R5max	maximum 5-consecutive-days precipitation	dimensionless	tp	b, maximum
SDII	Simple precipitation intensity index	dimensionless	tp	b
CDD	Maximum length of dry spell	dimensionless	tp	b
CWD	Maximum length of wet spell	dimensionless	tp	b
GDD	growing degree day above 0°C	°C	t2m	b
FD	Number of Frost days	dimensionless	t2m	a
ID	Number of icing days	dimensionless	tx2m	a
SD	Number of Summer days	dimensionless	tx2m	a
TN	Number of Tropical Nights	dimensionless	tn2m	a
GSL	Growing season length	dimensionless	t2m	a
RR10	annual count of days when daily precipitation is larger than 10mm	dimensionless	tp	a
RR20	annual count of days when daily precipitation is larger than 20mm	dimensionless	tp	a
RRa	Annual total Rain	mm	tp	a

Analysis Part 1: variable selection and sorting

- **Variables that segregate their distributions under ^{L}Y and ^{H}Y(Mann-Whiteny U test >>> 54 out 104**
- **Ranked by Fisher's distance between medians;**
- **Collinearity check to discard variables that carry redundant information >>> 23 remining variables**

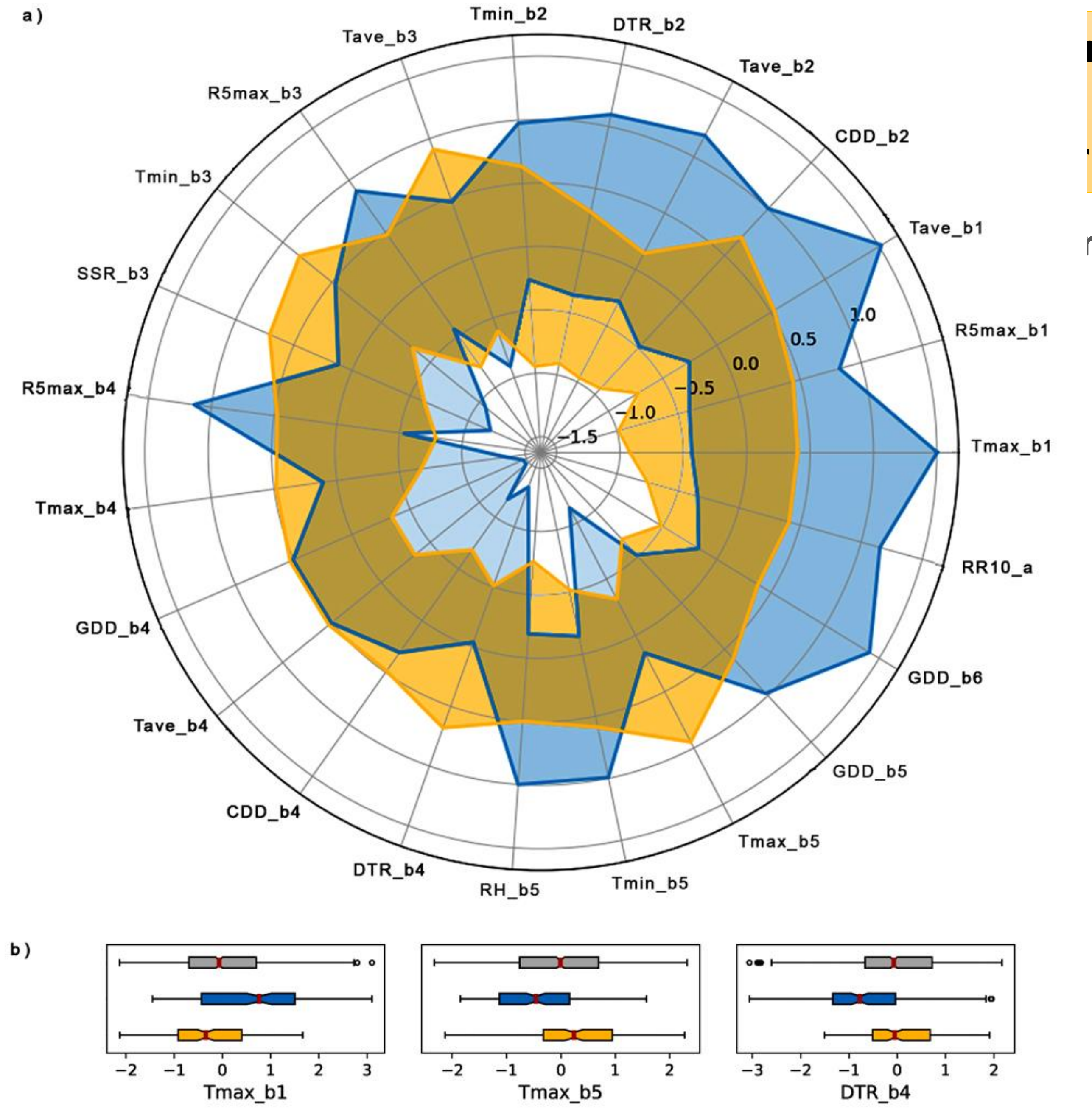
Boxplot of 23 selected ranked variables showing a significant difference for ^{H}Y (orange boxplots) and ^{L}Y (blue boxplots).



Analysis Part 1: variable selection and sorting

- Variab ... n-Whiteny U test >>> 54 out 104
- Ranke
- Collin ... rmation >>> 23 remining variables

Boxplot o ... r ^{H}Y (orange boxplots) and ^{L}Y (blue boxplots).



Variables under ^{L}Y and ^{H}Y: polar graph of interquartile ranges.

Major differences arise in bymonth 1, 2 and 4

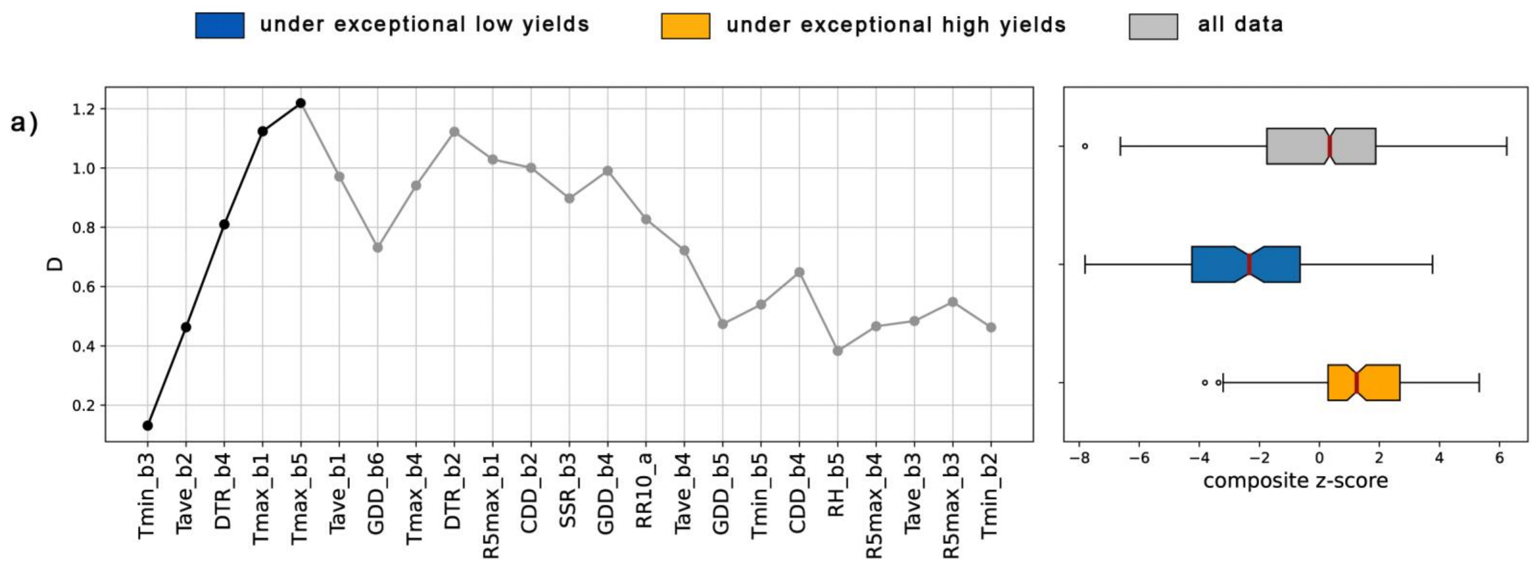
Analysis part 2:

➢ Do some variables maximize the distance under ^{L}Y and ^{H}Y when combined additively?

<u>Rationale</u>: if the distance (D) under ^{L}Y and ^{H}Y computed for a composite index (C) given by the sum of two variables (e.g., C = *Tmax_b1* + *Tmax_b5*) is larger than that from each component separately, we can infer that ^{L}Y or ^{H}Y are affected by the joint effect of the two components more than by the individual components.

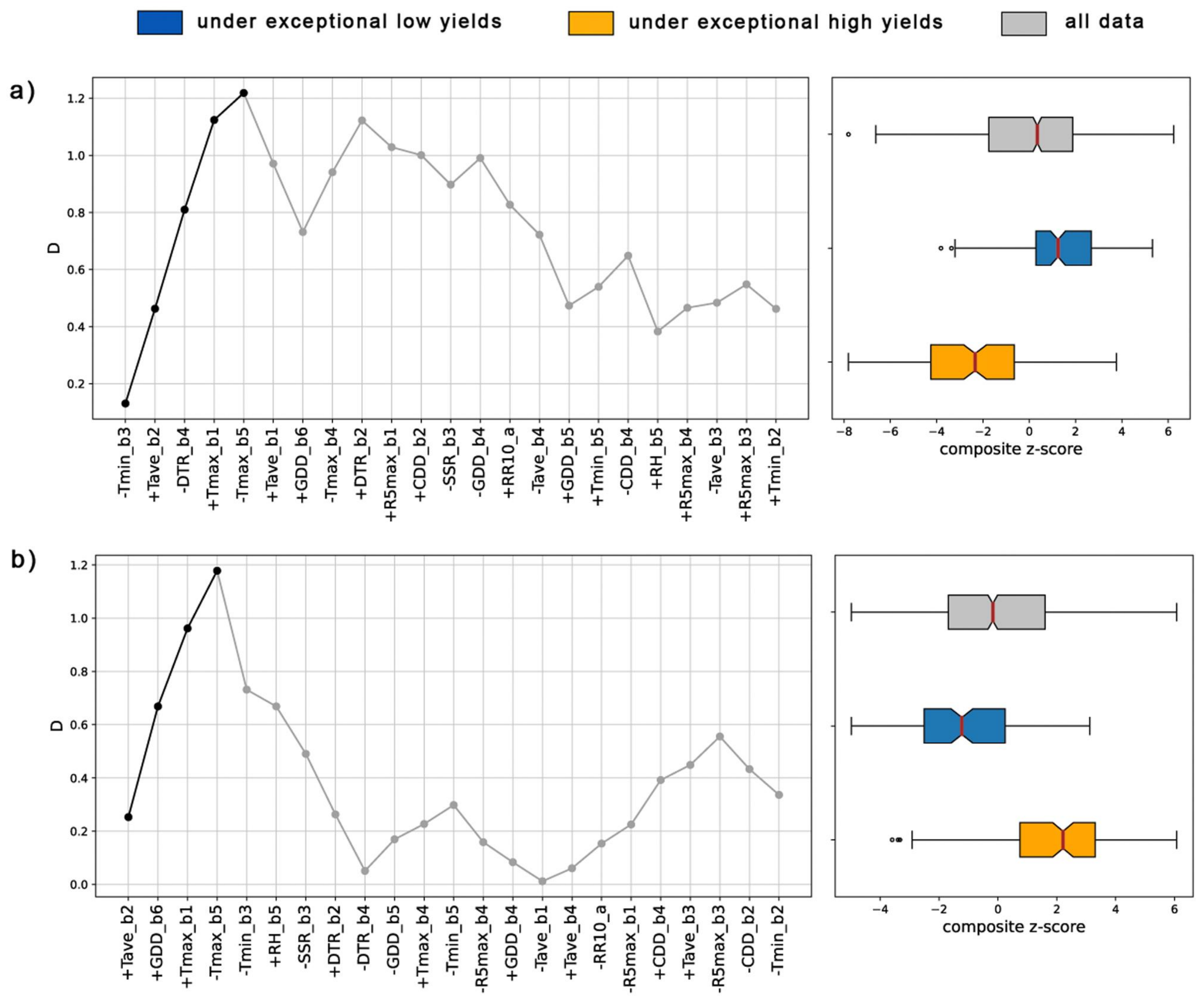
<u>Note</u>: interactions between components may reduce, increase, or have no effect on distance under LY and HY.
Hence, we designed an algorithm that iteratively explore the addition of variables and select those that gradually increase the distance of C, if possible ([Documentation and Python code on Zenodo (https://doi.org/10.5281/zenodo.5812016).](https://doi.org/10.5281/zenodo.5812016)

<u>Note</u>: results depend on the starting variable, hence the algorithm is repeated 23 times starting each time with a new initial variable



Analysis part 2:

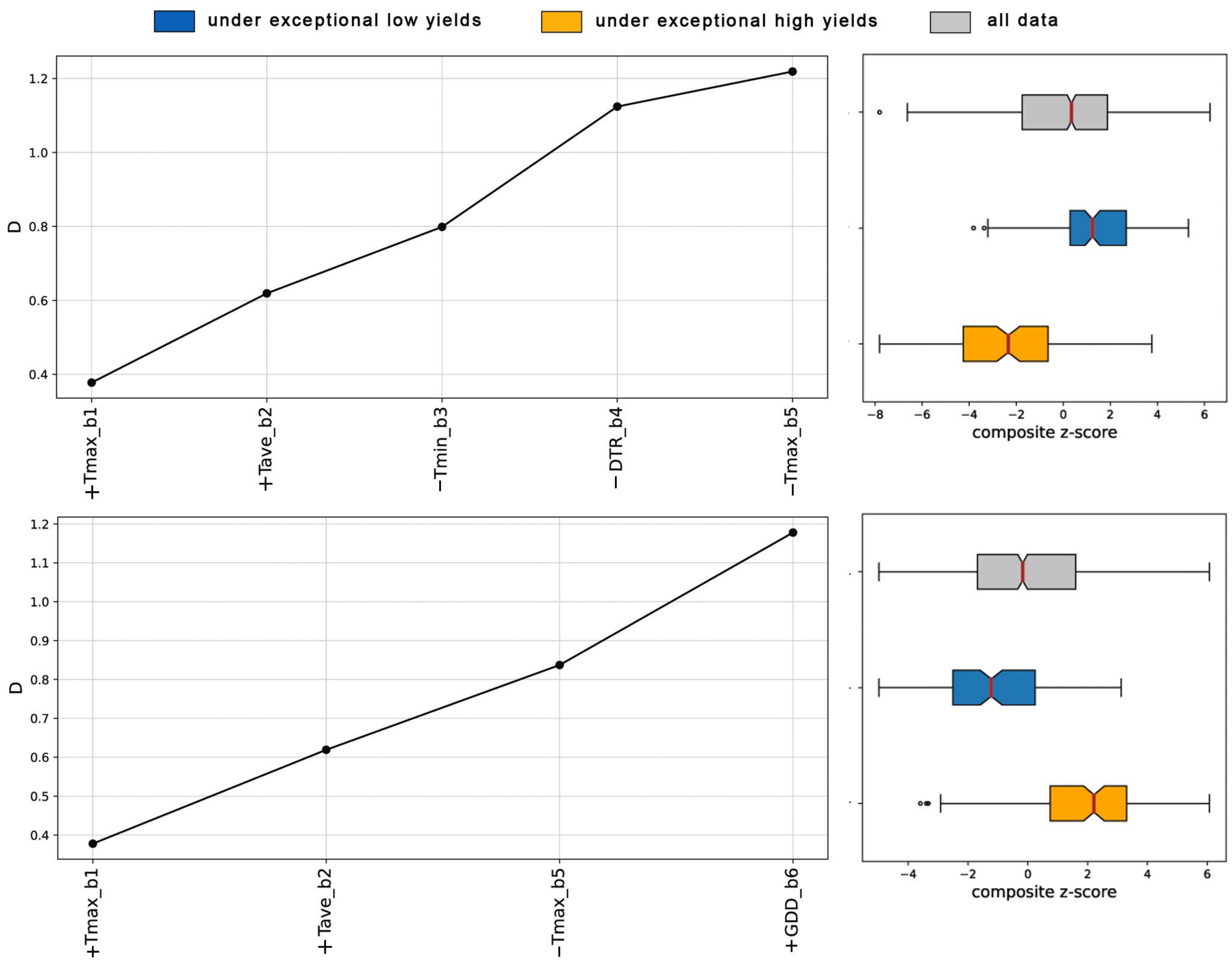
➢ **Do some variables maximize the distance under ^{L}Y and ^{H}Y when combined additively?**



Two composite indices (hereinafter **C1** and **C2**) reached almost an equal maximum score (D~1.2) and have 3-fold greater sensitivity than obtained from the top-ranked single variable (i.e., *Tmax_b1*).

Analysis part 2:

➢ Do some variables maximize the distance under ^{L}Y and ^{H}Y when combined additively?

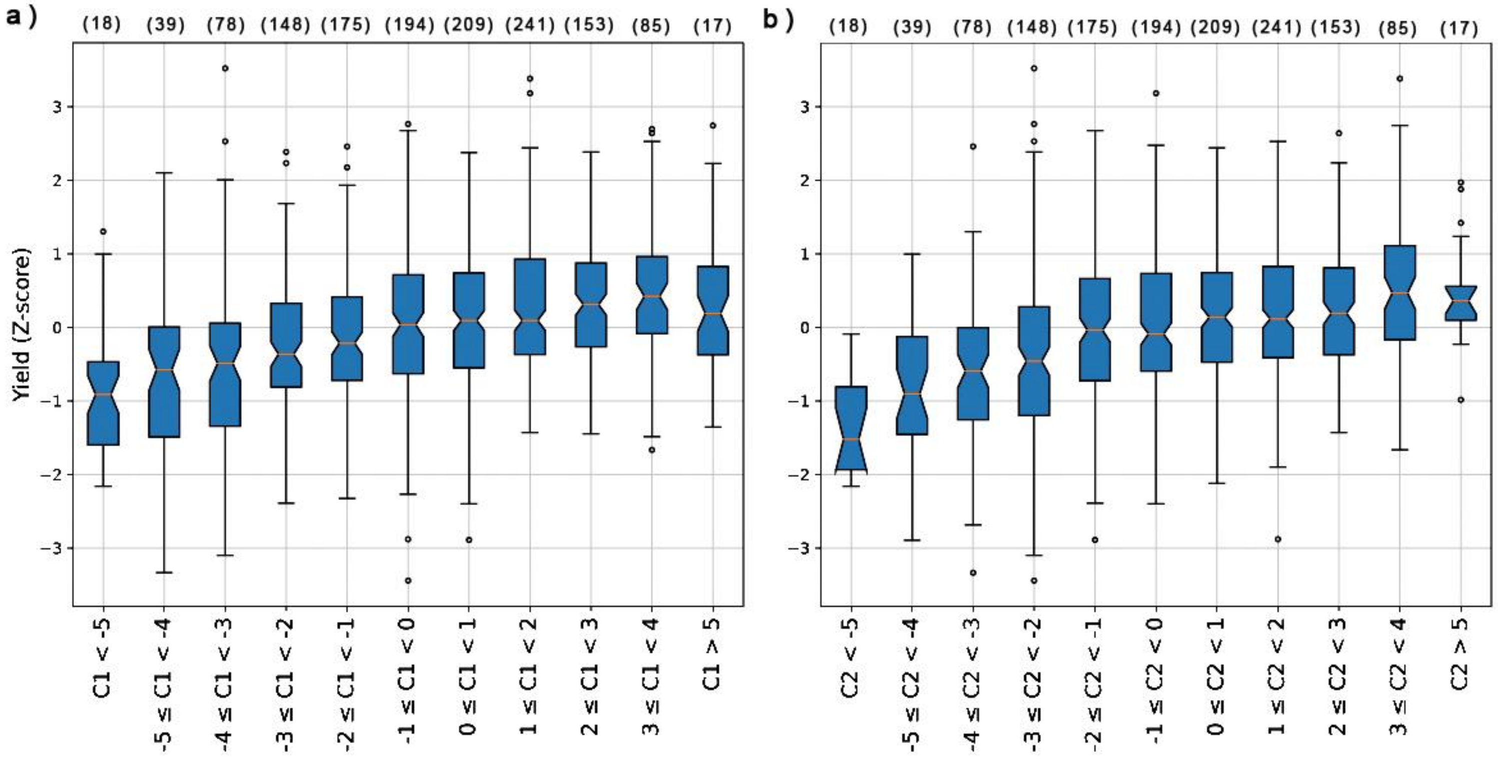


If we put the resulting components in chronological order we can have an interpretation of the composite index over the whole growing season.

Analysis part 2:

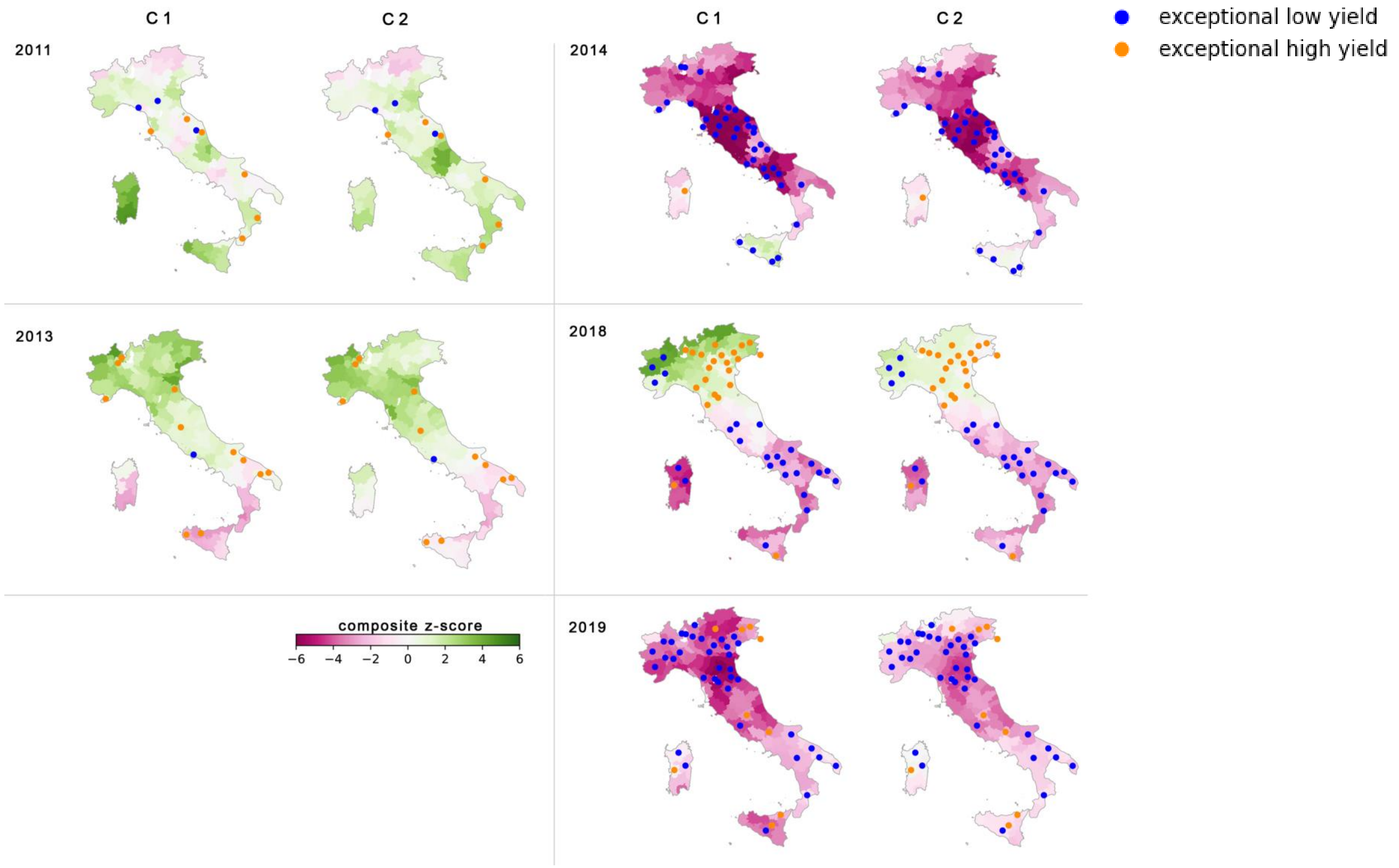
➢ **Do some variables maximize the distance under ^{L}Y and ^{H}Y when combined additively?**

Likelihood estimates of exceptional low yields (^{L}Y) given different critical thresholds (S) of C1 and C2.



	C1	C2
$S < -5$	0.45	0.61
$S < -4$	0.40	0.46
$S < -3$	0.37	0.39
$S < -2$	0.32	0.35
$S < -1$	0.28	0.28

Let we map the observed ^{L}Y and ^{H}Y against the C1 and C2 in favorable production years 2011 and 2013, and unfavorable years 2014, 2018, and 2019



Conclusion and future implications

- The number of provinces with low yields has been increasing since 2014
- Both C1 and C2 include *Tmax_b1*, *Tave_b2*, and *Tmax_b5,* thus:

  i) winter-to-early spring and late autumn temperatures are important drivers of the whole productive year;

  ii) temperature has the highest impact at a broad spatio-temporal scale
- These outcomes seems to suggest that unfavorable weather conditions enhance major insect pests which in turns damage olive production,
- if the composite risk indices fall below a critical threshold of -5, the probability of attaining an extremely low yield ^{L}Y is approximately 45% according to C1, and 61% according to C2.
- We suggest the composite index as a potentially useful climate risk indices for developing seasonal climate services

Thank you for your attention

For contacts and further information: arianna.dipaola@ibe.cnr.it