Signature of climate extremes in maize yields

Ignazio Giuntoli[1*], Francesco Laio[1], Luca Ridolfi[1]

[1] Dept of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Italy – * ignazio.giuntoli@polito.it

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RATIONALE

Crop productions face increasing pressures from a growing world population and a changing climate. Crop yield, i.e. production per unit area, can have a high variability in time as a result of different economic and environmental factors. We focus on climate and seek to quantify the influence of extremes on maize crop yield, with special emphasis on yield drops following dry spells in major producing countries.

RESEARCH QUESTIONS

- How well are drops in maize yield explained by dry spells?
- Is there a link between these drops in yield and the producer's GDP?

DATA

We carried out the analysis at the gridcell scale, globally - considering the world's top 10 maize producing countries over the period 1970-2014. We link agricultural and climate data at a common grid scale of 5 arcmin (~10 by 10 km). The analysis is limited to **rainfed crops**, as irrigated (20% of global maize areas) ones are generally less prone to yield drops from climate extremes.

Agricultural data: We use information on crop **areas**, crop **production**, and crop **yield**.

Spatial data (at 5 arcmin) – with reference to the year 2000: rainfed maize areas (ha) from the MIRCA2000 dataset (Portmann et al., 2010); maize yield (tons/ha) from the dataset proposed in Monfreda et al. (2008).
Temporal data (at the country scale) – from 1970 to 2014: maize yield (tons/ha) from the statistical database of the FAO (FAOSTAT).
Sowing and harvesting dates of crop seasons at the grid-cell scale were also retrieved from the MIRCA2000 dataset.

Maize	1	2	3	4	5	6	7	8	9	10
Top 10 producers	USA	China	Brazil	Argentina	Mexico	France	South Africa	India	Indonesia	Canada
*Production (rainfed) M tonnes / year	**184.3**	**48.8**	**32.2**	**12.9**	**11.5**	**9.1**	**8.8**	**8.0**	**7.5**	**7.1**
**Rainfed production % of total	83.5	47.7	99.0	97.1	73.8	72.1	94.7	71.8	89.4	98.2
***GDP class year 2000 GDP per capita	1	3	2	2	2	1	2	3	3	1

*Mean [1970-2014] production from FAOStat. **Year 2000 shares from the Monfreda et al. (2008) dataset.
***classes 1>12.5k$; 12.5k$<2<2.5k$; 3<2.5k$ from World Bank data.

Climate data: Global gridded Standardized Precipitation and Evaporation (SPEI) (Vicente-Serrano et al. 2010) at spatial resolution of 0.5 degree (SPEIbase v2.5) was regridded to 5 arcmin to match agricultural data. The SPEI index (SPEI>0 wet; SPEI<0 dry) summarizes climate information on the basis of historical data of precipitation and temperature at the time step of 1 or more months. We consider SPEI -1 -3 -6 -9 -12 month steps.

Portmann, F. T., Siebert, S. & Döll, P.: MIRCA2000 – Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling, Global Biogeochemical Cycles, 24, GB 1011, 2010.

Monfreda, C., N. Ramankutty, and J. A. Foley: Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000, Global Biogeochem. Cycles, 22(1): GB1022, 2008.

Vicente-Serrano, S.M., S. Beguería, J.I. López-Moreno, M. Angulo, and A. El Kenawy: A New Global 0.5° Gridded Dataset (1901–2006) of a Multiscalar Drought Index: Comparison with Current Drought Index Datasets Based on the Palmer Drought Severity Index. J. Hydrometeor., 11, 1033–1043, 2010.

Lesk, C., Rowhani, P., and Ramankutty, N.: Influence of extreme weather disasters on global crop production. Nature 529, no. 7584: 84, 2016.

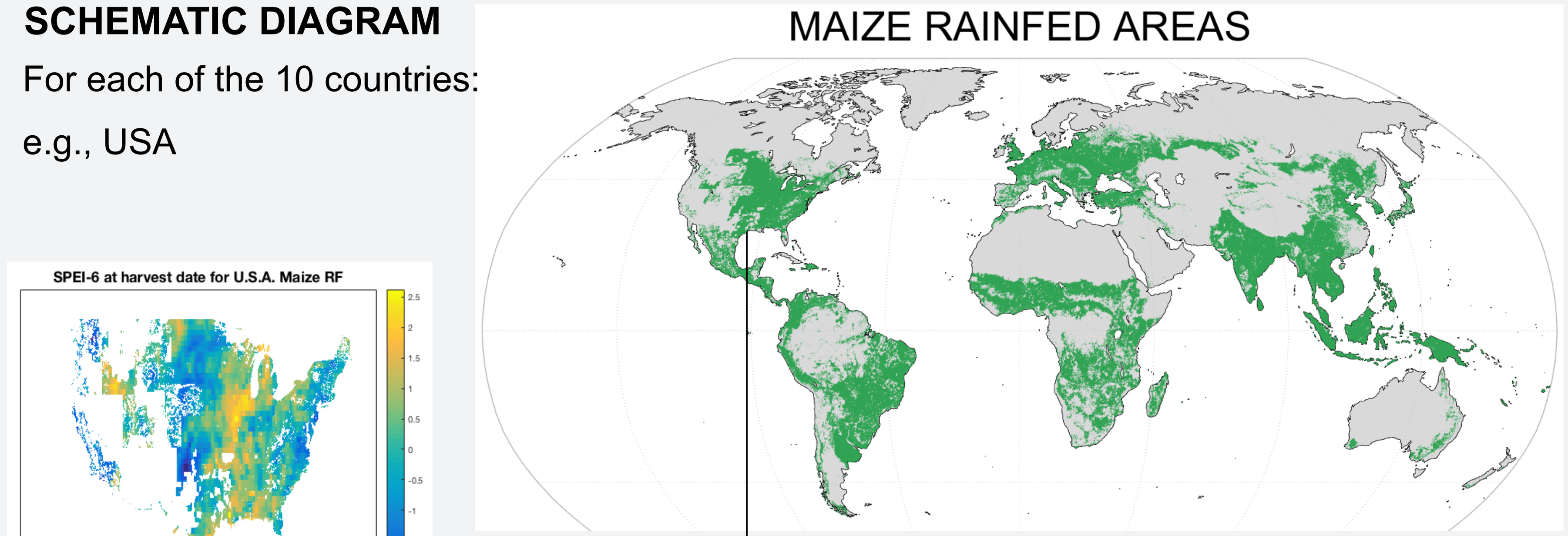
Urban, D. W., Robers, M.J., Schlenker, W., and Lobell, D.B.: The effects of extremely wet planting conditions on maize and soybean yields. Climatic Change 130, no. 2: 247-260, 2015.

METHODS – Reconciling climate data (SPEI) and crop-yield

SCHEMATIC DIAGRAM

For each of the 10 countries:

e.g., USA



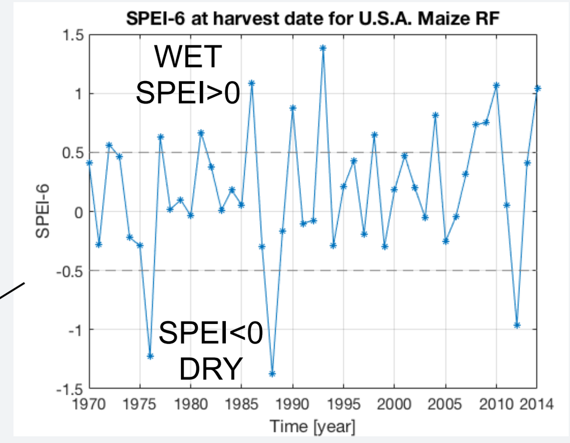
time period = 1970-2014

for the ith year and jth gridcell:

$\text{weight}_j = \text{Production}_j/\text{Production}_{tot}$

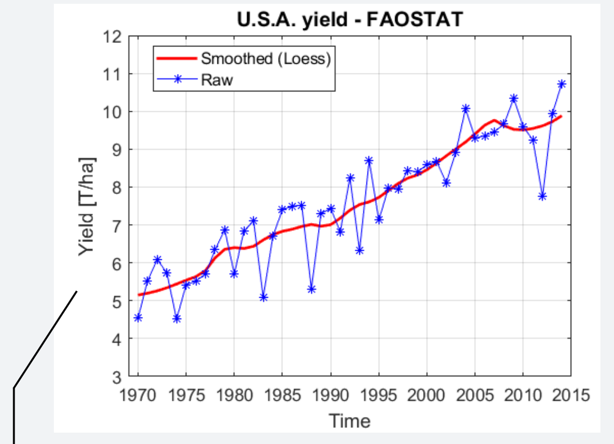
$\text{mean(SPEI6)}_i = \sum \text{SPEI}_j * \text{weight}_j$

CLIMATE



Yearly mean SPEI6 @ harvest date

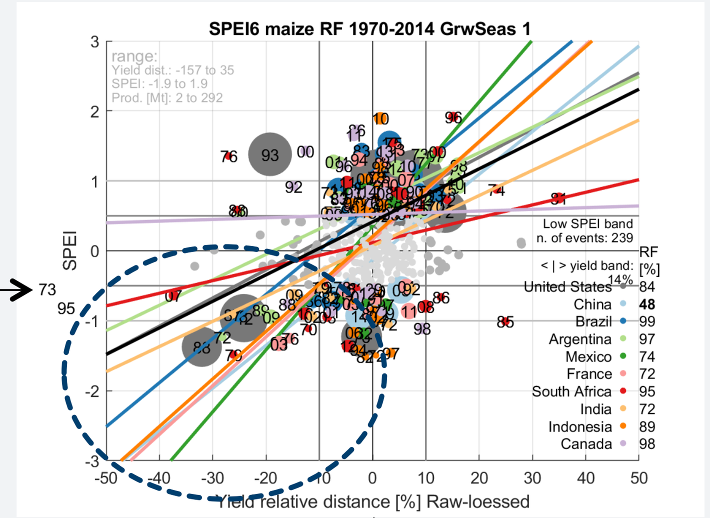
CROP YIELD



Yearly distance from Loess fit [%]

y-axis

x-axis

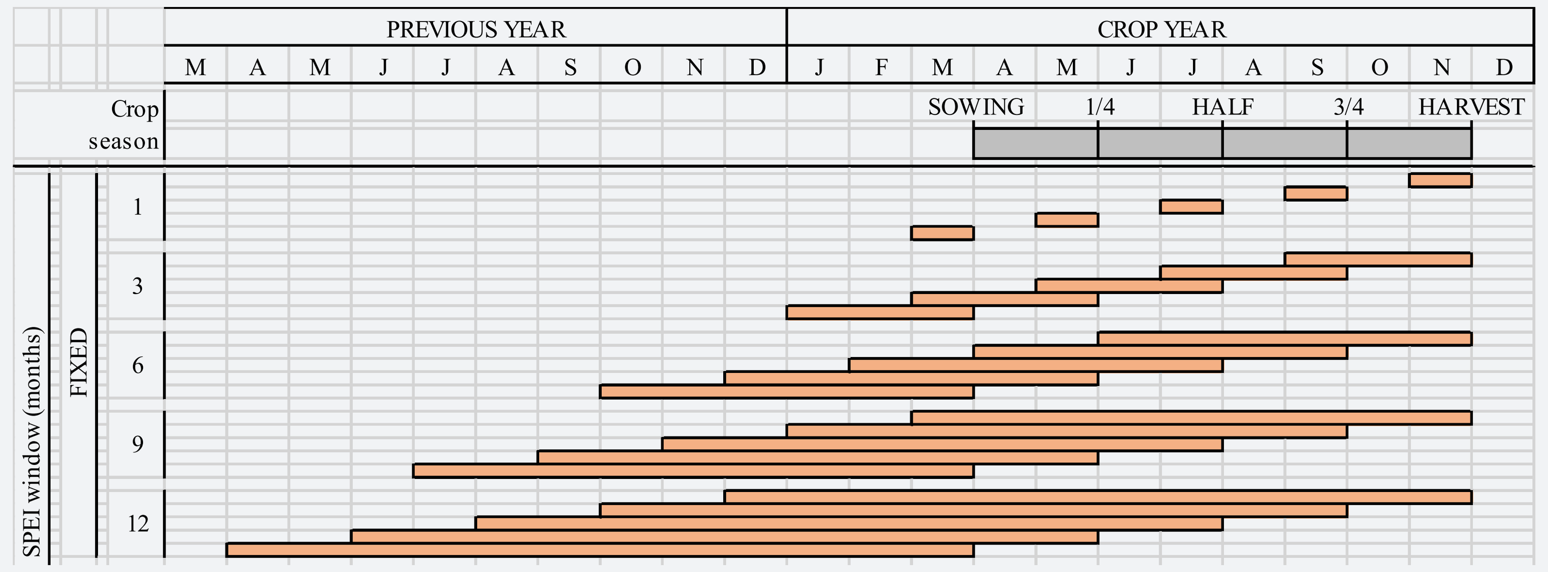


- Events in this area: a decrease in yield occurs (Yield-distance<0) during a dry spell (SPEI<0)

- Regression lines are plotted per country weighted on year production.

- Lines from 1[st] to 3[rd] quadrant: yield losses correspond to negative SPEI (dry spells).

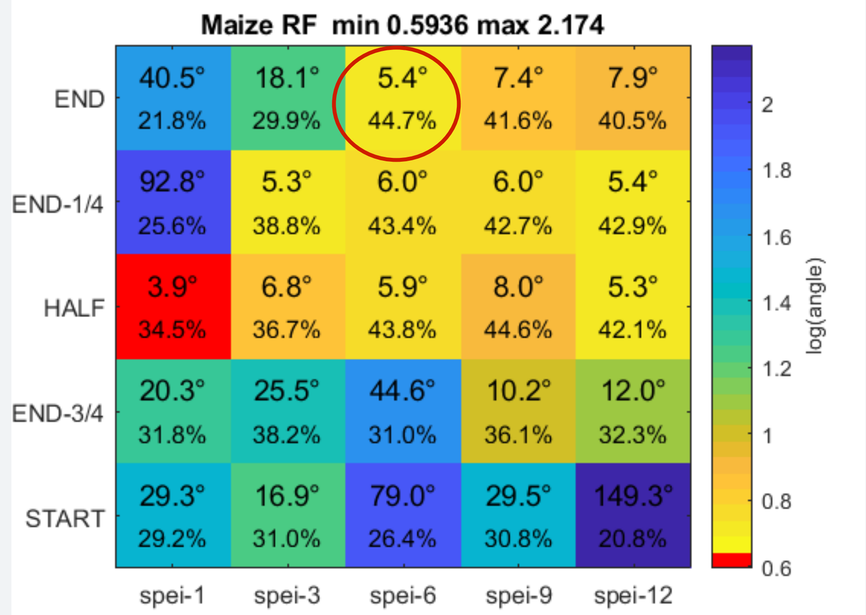
SPEI-MONTH WINDOW SENSITIVITY ANALYSIS



Set up for the sensitivity analysis of the SPEI month windows with respect to the crop length. The above example refers to an 8-month growing season (early April through late November).

RESULTS

SENSITIVITY ANALYSIS

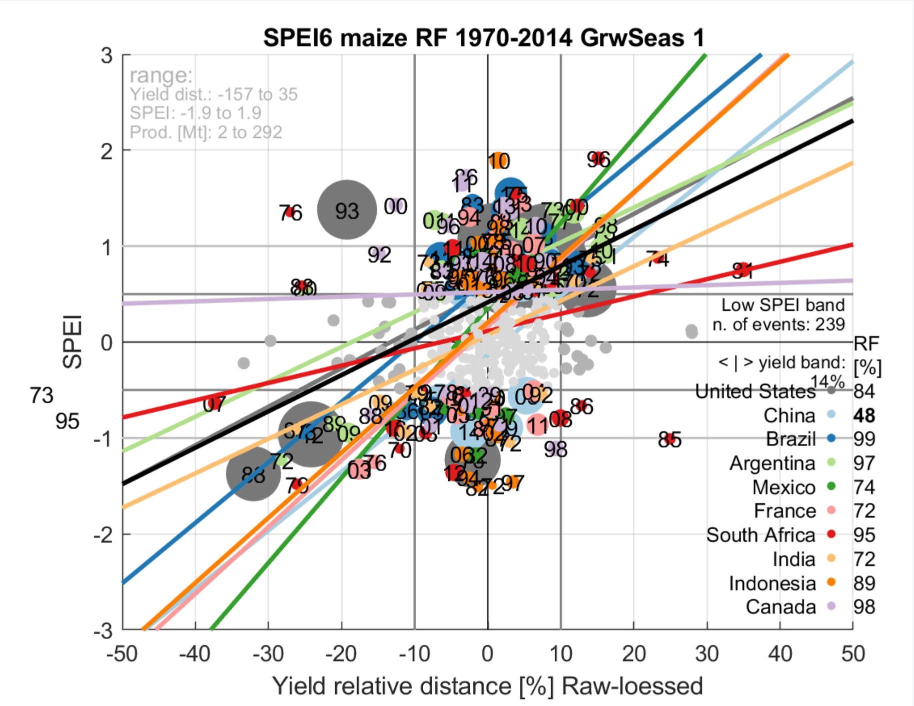


Finding the SPEI-month window and the crop season period that maximizes the concurrence of yield drops and SPEI<0:

- For each combination we express the angle between the centre of mass (of events with SPEI<-0.5) and the negative x-axis (SPEI=0).
- and the percentage of events falling in the 3[rd] quadrant (SPEI<-0.5, Yld-dist<0).

→ SPEI-6 at the crop-harvest

CLIMATE-YIELD LINK



There is a clear pattern 1[st]-3[rd] quadrant, suggesting that in general:
Years with negative yield correspond to seasons in which the SPEI was negative. Conversely, to positive yield one could expect that wetter than normal conditions would bring about increases in yield.

Exceptions exist, e.g. in 1993 in the US Midwest the yield decreased substantially as a result of floodings in the area throughout the summer.

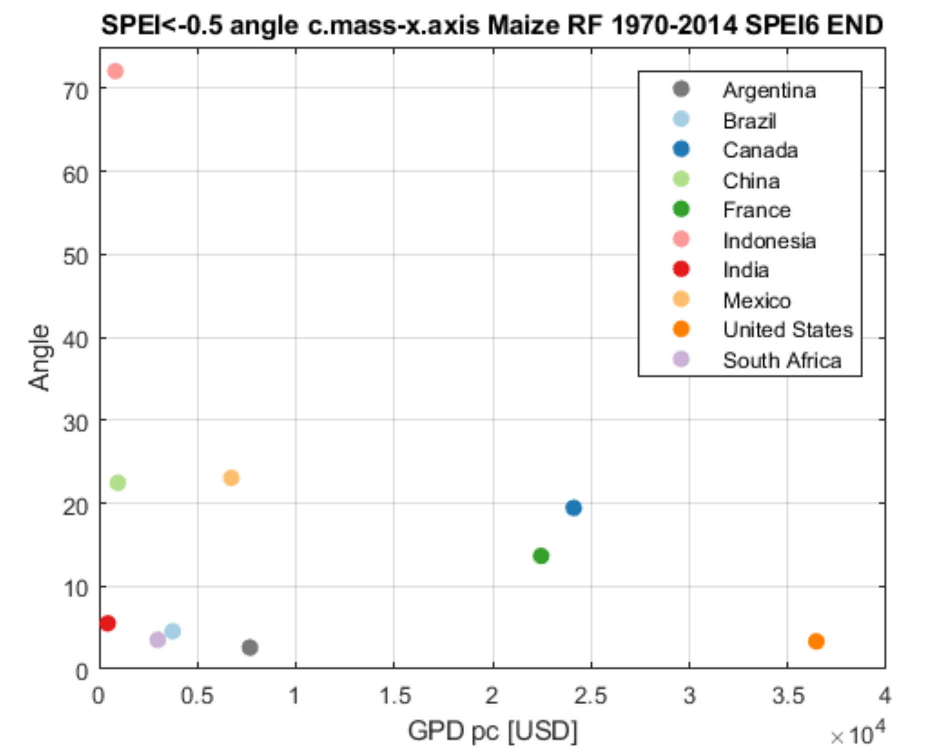
Other events in the 2[nd] or 4[th] quadrant may result from policy trades, variations in demand and stock, or other political or economical causes.

GDP ROLE IN VULNERABILITY TO YIELD LOSS

The lower the angle center of mass to negative x-axis, the higher the vulnerability to negative speis (dry spells).

Angles within 10°include both emerging economies like India, South Africa, Brazil, but also the USA with the highest GDP pc.
Other high GDP countries like France and Canada seem to be less sensitive than the USA to yield losses from dry spells.

There may be a bias because the results are weighted with the production, so countries that produce more drive the choice of SPEI-month window and period of crop-season.



CONCLUSIONS

The occurrence of dry spells can cause substantial drops in maize yields, especially during the second half of the crop season. Generally, major climate-driven drops are observed in countries with higher GDP pc (and generally higher yields). This echoes the findings by Lesk et al. (2016) using events from the EMDAT database: technically developed agricultural systems experience the largest reductions in yield from climate extremes, possibly because yield maximizing strategies are favored in higher income countries.

FUTURE WORK

Analysis of other crops (soybeans, wheat) will provide further understanding on the signature of climate extremes on yields considering also the wet spells (SPEI>0), whose occurrence may damage the crop, especially during the sowing/growth stage (Urban et al., 2015).

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