Solar Storm Effects on Local Weather

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Motivation

- Solar influence on climate have been known for more than century, but mostly on time scales of solar cycles.
- The physical causes are difficult to pinpoint. TSI alone seems to be insufficient to explain the climate signals.
- Other processes, such as cosmic ray - cloudiness connection, or a modulation of the global electrical circuit may play a role, but are difficult to study.
- Here, I look at short term solar activity, i.e., solar storms, on a time scale of hours to days.
- If correlations between weather and solar storm exist, they may help to discriminate between different hypotheses.
- Such a study is feasible and timely because of new climate data sets.

Data

- Geomagnetic storm data are simple and easy to come by. Here, I use the Dst (Disturbance Time Storm) index. Other indices could be used, such as Kp or Ap, but these indices are all highly correlated on storm time scales

- Weather data are obtained from the Historical Weather API of the Open-Meteo project (https://open-meteo.com/en/docs/historical-weather-api). That data base provides weather data on a 10x10 km re-analysis grid dating back decades.

- For this analysis, I use 53 years worth of daily data, from 1970 - 2022.

- The historical weather API provides dozens of variables. Here, I analyze temperature, pressure, windspeed, radiation, and precipitation.

- I also restrict the analysis to 19 locations across the US continent.

Methodology

- I first create a list of storm days from the Dst data, applying a threshold of either Dst = (0/18340, -50/2696, -100/454, -150/145, -200/63). The second number is the number of storm days meeting that threshold over the 53y period.

- Then for each Day of the Year (DOY) over all 53 years, and for each variable V, and a given location LOC, I calculate the mean, for example V_mean(DOY,LOC). I also calculate the variance for later use V_var(DOY,LOC).

- Next, for each DOY, variable, and location, I calculate the mean but only for storm days, say V_storm(DOY,LOC).

- The difference V_anomaly=V_storm(DOY,LOC)-V_mean(DOY,LOC) is the anomaly. However, to get numbers that are more easy to interpret those numbers, V_anomaly is normalized to the variance V_var and expressed as a percentage: V_an_percent = 100*V_anomaly/V_var.

- Lastly, the V_an_percent are averaged for a given location.

Temperature Anomaly

Variable	temperature_2m					
THRESHOLD	-0001	-0050	-0100	-0150	-0200	nT
ACTIVE DAYS	18302	2696	454	145	63	days
EAST01-N026-E279	-0.03	-1.40	-3.32	-6.88	-11.14	
EAST01-N030-E278	-0.10	-2.92	-7.00	-11.69	-16.82	
EAST01-N033-E280	-0.08	-1.61	-5.39	-1.80	-9.42	
EAST01-N035-E283	-0.10	-1.00	-3.20	-3.20	-6.59	
EAST01-N039-E285	-0.11	-4.27	-3.25	-9.43	-22.08	
EAST01-N047-E291	-0.03	-2.30	3.35	0.63	-2.19	
MID01-N030-E256	0.19	-3.32	-5.56	-10.93	9.79	
MID01-N037-E256	0.06	-5.60	-4.92	-3.96	15.29	
MID01-N049-E256	0.20	-1.41	-8.42	-11.49	-12.07	
MID02-N030-E269	0.41	-2.10	-8.09	-9.37	-11.87	
MID02-N034-E269	0.34	-2.14	-5.09	4.62	12.66	
MID02-N038-E269	0.12	-3.45	-3.85	3.22	7.20	
MID02-N042-E269	0.06	-3.82	-5.65	1.67	1.13	
MID02-N046-E269	0.02	-3.61	-6.91	0.53	-1.82	
WCOAST-N033-E243	0.21	-5.15	-6.13	-7.48	0.47	
WCOAST-N035-E240	0.22	-4.79	-5.82	-10.60	-1.52	
WCOAST-N038-E237	-0.14	-3.48	-5.46	-12.31	3.07	
WCOAST-N042-E236	-0.04	-0.97	-0.67	2.42	-7.95	
WCOAST-N047-E237	-0.15	-0.10	-5.06	-9.29	-10.90	
AVERAGE	0.06	-2.81	-4.76	-5.02	-3.41	

- The anomaly is negative
- It is consistently negative for all storm levels
- Generally a larger magnitude for stronger storm, but also poorer statistics

==> significant

Pressure Anomaly

Variable	pressure_msl					
THRESHOLD	-0001	-0050	-0100	-0150	-0200	nT
ACTIVE DAYS	18302	2696	454	145	63	days
EAST01-N026-E279	-1.87	-2.76	-1.80	-8.88	-32.40	
EAST01-N030-E278	-1.35	-2.23	0.36	-6.86	-25.73	
EAST01-N033-E280	-1.13	-2.07	1.46	-8.37	-26.76	
EAST01-N035-E283	-0.97	-1.92	0.09	-11.09	-27.01	
EAST01-N039-E285	-0.81	-1.85	1.14	-7.31	-16.82	
EAST01-N047-E291	-0.81	-0.64	3.81	8.04	17.13	
MID01-N030-E256	-1.01	-2.45	3.78	0.70	-9.28	
MID01-N037-E256	-0.46	-1.55	-2.03	-8.16	-22.87	
MID01-N049-E256	-0.56	1.33	3.74	6.88	10.99	
MID02-N030-E269	-1.33	-3.00	5.58	4.59	-7.05	
MID02-N034-E269	-1.12	-2.78	9.64	4.52	-12.36	
MID02-N038-E269	-0.83	-1.42	8.87	-1.88	-21.09	
MID02-N042-E269	-0.59	0.26	6.20	-6.40	-23.68	
MID02-N046-E269	-0.37	0.58	3.45	-6.68	-18.85	
WCOAST-N033-E243	-1.99	-2.76	-6.71	-18.01	-29.87	
WCOAST-N035-E240	-1.70	-3.80	-8.48	-18.88	-32.76	
WCOAST-N038-E237	-0.98	-5.18	-11.67	-17.72	-35.90	
WCOAST-N042-E236	-0.78	-7.39	-6.65	-7.20	-6.97	
WCOAST-N047-E237	-0.45	-4.29	1.80	7.85	13.59	
AVERAGE	-1.01	-2.31	0.66	-4.99	-16.19	

- The anomaly is negative
- Considerably larger for stronger storms

==> significant

Windspeed Anomaly

Variable	windspeed_10m					
THRESHOLD	-0001	-0050	-0100	-0150	-0200	nT
ACTIVE DAYS	18302	2696	454	145	63	days
EAST01-N026-E279	0.22	2.53	9.38	25.13	27.68	
EAST01-N030-E278	-0.03	0.59	2.18	4.53	-3.75	
EAST01-N033-E280	-0.09	-0.34	-3.96	8.21	12.10	
EAST01-N035-E283	-0.22	-0.82	-3.88	3.79	10.14	
EAST01-N039-E285	-0.31	-0.22	0.44	9.69	4.34	
EAST01-N047-E291	-0.00	0.59	3.32	3.50	2.50	
MID01-N030-E256	0.14	-0.76	-6.84	-5.42	-18.10	
MID01-N037-E256	0.09	-2.41	-1.06	-4.36	0.82	
MID01-N049-E256	-0.06	-1.60	1.04	1.46	2.31	
MID02-N030-E269	0.08	-0.31	-2.96	6.02	-1.04	
MID02-N034-E269	0.16	-1.14	-1.32	6.75	10.66	
MID02-N038-E269	-0.02	-1.22	-2.07	8.39	2.97	
MID02-N042-E269	0.07	-1.85	0.13	11.31	7.74	
MID02-N046-E269	-0.09	-2.60	-4.29	5.52	11.66	
WCOAST-N033-E243	-0.22	-1.19	-2.07	4.56	-8.47	
WCOAST-N035-E240	0.38	0.60	-0.30	-2.70	-6.84	
WCOAST-N038-E237	0.11	0.11	7.13	10.55	21.71	
WCOAST-N042-E236	-0.38	-0.31	-3.10	-10.01	-15.86	
WCOAST-N047-E237	-0.47	-2.27	0.50	-9.67	-17.91	
AVERAGE	-0.03	-0.67	-0.41	4.07	2.25	

- No clear trend
- But mostly consistent for a given location over different storm levels

==> insignificant, unless there is a geographical dependence

Radiation Anomaly

Variable	direct_radiation					
THRESHOLD	-0001	-0050	-0100	-0150	-0200	nT
ACTIVE DAYS	18302	2696	454	145	63	days
EAST01-N026-E279	-0.10	1.51	-1.34	-10.28	-9.58	
EAST01-N030-E278	-0.06	-2.70	-1.72	3.17	15.09	
EAST01-N033-E280	0.16	-2.14	-3.94	1.34	-4.20	
EAST01-N035-E283	0.13	-1.26	-5.30	0.12	-3.43	
EAST01-N039-E285	-0.16	-2.31	-2.18	-12.13	-22.27	
EAST01-N047-E291	-0.37	-5.68	-5.93	-9.49	-7.49	
MID01-N030-E256	0.12	-3.72	-11.27	-4.15	28.42	
MID01-N037-E256	-0.04	-7.10	-4.50	-12.87	-3.17	
MID01-N049-E256	0.46	-2.37	-6.25	-14.83	-11.23	
MID02-N030-E269	0.12	-1.39	-0.46	2.78	25.06	
MID02-N034-E269	0.04	-1.44	4.00	19.49	30.78	
MID02-N038-E269	-0.21	-2.87	8.59	13.30	26.18	
MID02-N042-E269	-0.18	-1.46	4.12	-5.39	1.39	
MID02-N046-E269	0.04	0.55	8.38	7.41	-2.04	
WCOAST-N033-E243	0.09	-6.13	-10.97	-22.91	-15.50	
WCOAST-N035-E240	0.28	-3.37	-5.27	-11.98	-7.55	
WCOAST-N038-E237	0.07	-6.64	-2.69	-2.05	9.42	
WCOAST-N042-E236	-0.17	-1.56	5.58	8.40	8.90	
WCOAST-N047-E237	0.03	-0.99	4.67	9.18	10.50	
AVERAGE	0.01	-2.69	-1.39	-2.15	3.65	

- Like windspeed, no clear trend
- But mostly consistent for a given location over different storm levels (always positive or always negative)

==> insignificant, unless there is a geographical dependence

Precipitation Anomaly

Variable	precipitation					
THRESHOLD	-0001	-0050	-0100	-0150	-0200	nT
ACTIVE DAYS	18302	2696	454	145	63	days
EAST01-N026-E279	-0.06	-1.68	-0.47	-4.32	-10.52	
EAST01-N030-E278	-0.06	-1.81	-1.35	2.87	12.40	
EAST01-N033-E280	-0.01	-1.68	-3.27	0.23	4.97	
EAST01-N035-E283	0.10	1.47	2.13	11.81	21.67	
EAST01-N039-E285	-0.21	0.51	1.83	23.34	38.71	
EAST01-N047-E291	-0.05	3.31	2.37	1.72	3.61	
MID01-N030-E256	-0.61	2.17	5.02	8.24	-12.97	
MID01-N037-E256	0.09	3.16	-0.98	2.24	-1.50	
MID01-N049-E256	-0.24	-0.66	5.27	1.99	-2.42	
MID02-N030-E269	-0.16	-0.87	-4.69	-11.92	-11.44	
MID02-N034-E269	-0.09	0.18	-12.11	-15.55	-19.56	
MID02-N038-E269	0.14	-0.45	-8.01	-10.98	-15.89	
MID02-N042-E269	-0.17	-3.20	-2.66	5.62	11.38	
MID02-N046-E269	-0.19	-0.46	-1.98	2.99	5.85	
WCOAST-N033-E243	-0.03	3.61	8.60	13.66	3.03	
WCOAST-N035-E240	0.11	-0.01	-1.00	-0.60	4.59	
WCOAST-N038-E237	0.13	5.02	7.15	1.48	7.64	
WCOAST-N042-E236	0.07	2.53	-7.48	-20.98	-27.74	
WCOAST-N047-E237	-0.14	-1.48	-6.79	-7.30	-9.08	
AVERAGE	-0.07	0.51	-0.97	0.24	0.14	

- No clear trend
- But some stations show very clear trends

==> insignificant, unless there is a geographical dependence

Takeaway

1. For many cases (storm strength, location) the signal is significantly larger than the null hypothesis. A statistical fluke is unlikely.

2. For temperature and pressure the effect seems global (over the US), but for other variables it looks like there is a regional dependence, even in the direction of the anomaly ==> need to create ‘heat maps’, but that is a computational challenge. This is similar to solar cycle scale anomalies.

3. Many effects are still unexplored: season, local time, time shifts (SEPs come before the storm, for example), type storm (CIR, CME), etc.

4. Anyone interested to collaborate?