

Introduction

- Solar influence on climate have been known for more than century, but mostly on time scales of solar cycles. There are 100s of publications showing the 11-year solar cycle in weather time series like temperature or rainfall.
- The physical causes are difficult to pinpoint. TSI (Total Solar Irradiance) alone seems to be insufficient to explain the climate signals. TSI only varies by about 0.1% over a solar cycle and barely shows up in climate models.
- Other processes, such as cosmic ray - cloudiness connection, Solar Energetic Particles (SEPs), MeV electron bursts, or a modulation of the global electrical circuit may play a role, but are difficult to study. The possibility that the much larger variations of solar EUV/x-ray output may map somehow into the troposphere, is also considered.
- Here, I look at short term solar activity, i.e., solar (geomagnetic) storms, on a time scale of hours to days.
- If correlations between weather and solar storms exist, they may help to discriminate between different hypotheses.
- Such a study is feasible and timely because of new climate data sets.

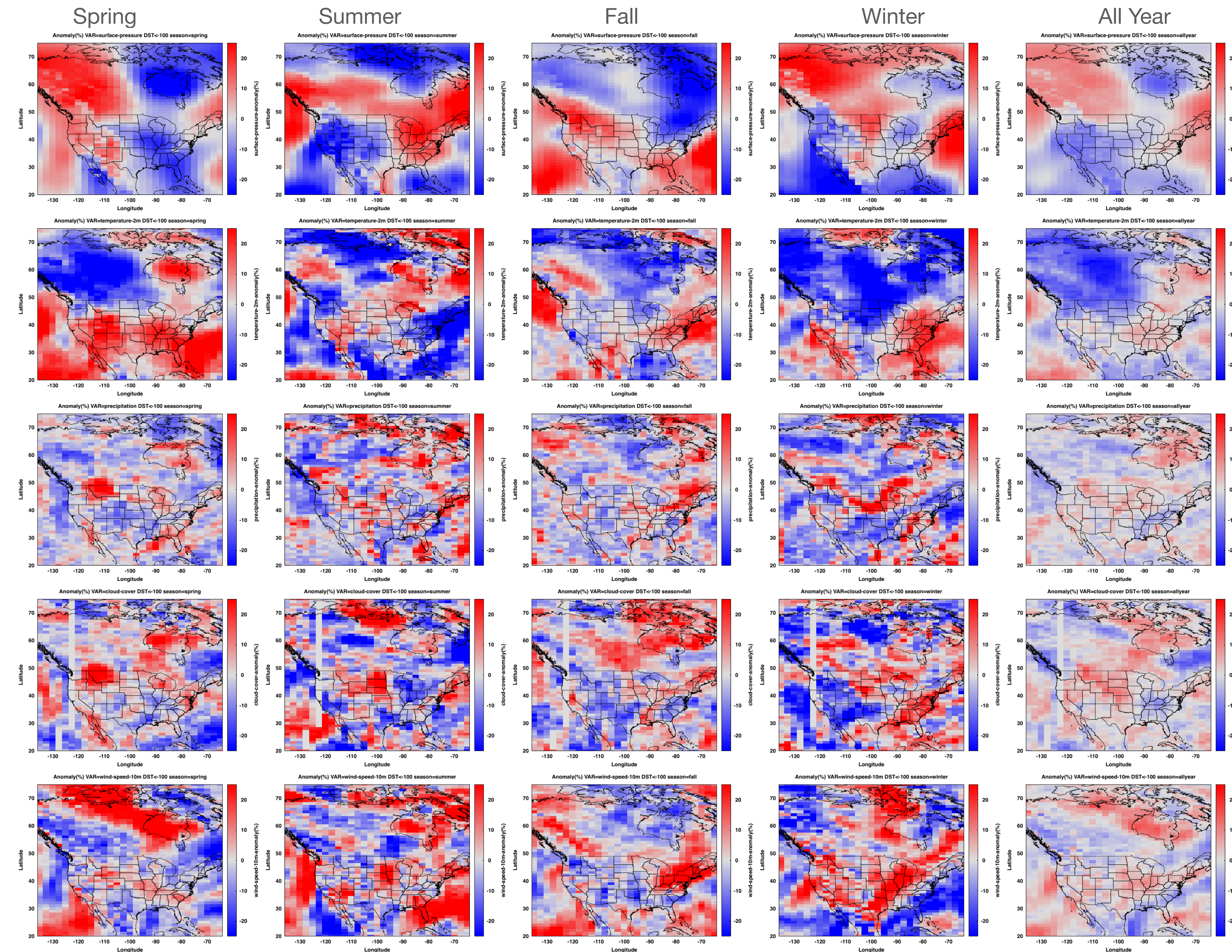
Data

- 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. A continuous 1h Dst data set is available since 1957. However, that time series is not corrected for solar wind dynamic pressure variations (Dst*), but this should only affect small Dst values.
- 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. Here, I use these data on a 1 by 2.5 degree latitude-longitude grid over North America.
- For this analysis, I use 67 years worth of hourly data, from 1957 - 2023. Because weather variable vary hourly and seasonally the use of hourly data is imperative.
- The historical weather API provides dozens of variables. Here, I analyze temperature, pressure, windspeed, cloudiness, and precipitation.

Methodology

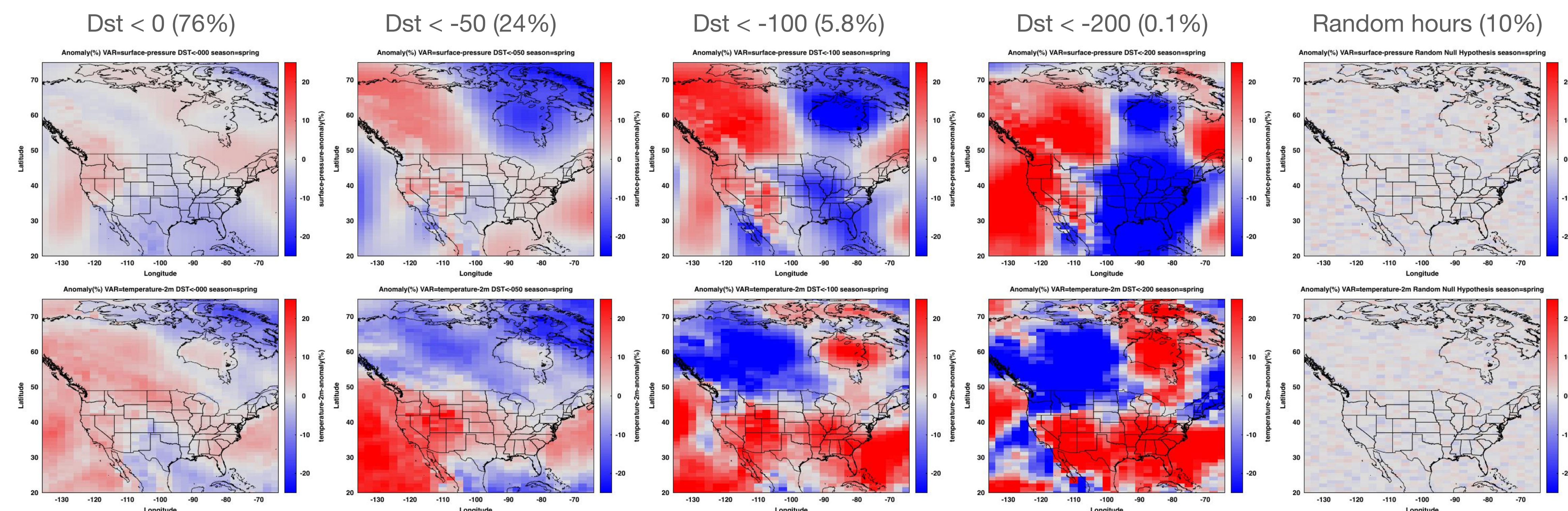
- I first create a list of storm hours of the year (hoy) from the Dst data, applying a threshold of either Dst = (0, -50, -100, -200 nT). Geomagnetic storms are characterized by a negative Dst. The strongest recorded storms typically reach -500 nT, but they are rare events. In addition to the 4 Dst values give above, I also consider the null hypothesis given by random hoy values (NULLR, 10% of all possible).
- Then, for each hoy, over all 67 years, and for each variable V, and a given location LOC, I calculate the mean, for example $V_{\text{mean}}(\text{hoy}, \text{LOC})$. I also calculate the variance for later use: $V_{\text{var}}(\text{hoy}, \text{LOC})$.
- Next, for each hoy, variable, and location, I calculate the mean but only for storm days, say: $V_{\text{storm}}(\text{hoy}, \text{LOC})$.
- The difference $V_{\text{anomaly}} = V_{\text{storm}}(\text{hoy}, \text{LOC}) - V_{\text{mean}}(\text{hoy}, \text{LOC})$ is the anomaly. However, to get numbers that are more easy to interpret, V_{anomaly} is normalized to the variance V_{var} and expressed as a percentage: $V_{\text{anomaly_per}} = 100 \cdot V_{\text{anomaly}} / V_{\text{var}}$. Lastly, for every LOC, all hoy values ($365 \cdot 24 = 8760$) of $V_{\text{anomaly_per}}$ are averaged and plotted on the lat-on grid of LOCs. These are shown in the following.
- Because geomagnetic activity has a seasonal variation (the Russell-McPherron effect) I consider each season separately. Instead of averaging over the whole year, for each of the seasons the average is taken over a +-30 day period around the solstices and equinoxes.

Anomalies of pressure, temperature, etc.



Anomalies for different seasons and different variables. From top to bottom: pressure, temperature, precipitation, cloud cover, and wind speed. These anomalies are for geomagnetic storm hours with a Dst < 100 nT. For each season we average the hourly anomalies between +-30 days around the equinoxes and solstices. Significant anomalies exist for all seasons. They show distinct patterns which sometimes align with geographical features like coast lines or mountain ranges. The patterns differ to some extent from season to season. Because of that the all year patterns are weaker. Pressure and temperature anomalies show more spatial coherence than the other variables and are less noisy. There is no discernible north-south gradient, indicating that particle precipitation is an unlikely cause for the anomalies.

Anomalies at different Dst



Shown for pressure and temperature only: As storms get stronger, the anomalies get larger. Also, the patterns change somewhat, and, because of the poorer statistics, get somewhat noisier. At the lowest activity (Dst < 0) the patterns can be more different. This category is dominated by substorms, which are different from storms. The rightmost figures show the null hypothesis, i.e., random hours of the year instead of the storm hours. As expected, there is no signal except for some noise. This proves that the anomalies are real.

Summary and Conclusions

- For all variables, and for all activity levels, the weather anomalies are significantly larger than the null hypothesis. The anomalies get larger as at the storms get stronger. A statistical fluke is highly unlikely.
- The results show seasonal dependence. A seasonal dependence is expected because geomagnetic activity is seasonally modulated (Russell-McPherron effect.) However, the magnitude of the anomalies do not show a significant seasonal variation; rather, the patterns change. Thus, either the underlying seasonal weather pattern matter, or the driving mechanism changes due to season. The latter may hint at an electrical coupling with the ionosphere, or a non-geomagnetic cause (EUV/x-ray variations?)
- The results do not show any significant latitude dependence, which one would expect if the underlying causes were related to precipitating particles, like SEPs, CRs, or MeV electron bursts. Thus, cloudiness modulation through particles seems unlikely.
- However, orographic features show up in the patterns, such as the Rocky Mountains, and coastlines. This may indicate a modulation of the atmospheric circulation patterns, possibly by ionosphere convection changes and an electrical coupling. Ionospheric convection increases by an order of magnitude during storms, and also differs by season.
- Many effects still need to be explored, for example, local time dependence, time lags, or possible differences by storm types (CIR, CME), etc..