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Relationship between the Standardized Precipitation Index and Global Temperature on the North American Continent

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Abstract

Dryness and droughts may be related to changes in precipitation due to climate change. If climate change continues, wildfires may worsen due to increased dryness. In this work, we investigated the relationship between the standardized precipitation index (SPI) and global temperature in North America. The following results were obtained: 1) The global temperature is closely related to the global ocean temperature; 2) When the global temperature increases, the SPI becomes slightly larger inland; and 3) there is no correlation between the global temperature and the SPI in coastal and highland areas. In conclusion, on the basis of this study and recent studies, we propose a climate process between the global temperature and the standardized index. The temperature changes approximately one year after the change in the ENSO index, and the CO_2 change rate follows the temperature change with a lag of several months. The emission and absorption of CO_2 at the Earth's surface respond to temperature changes. It is like the Earth's breathing. CO_2 emissions due to temperature increases are related to plant respiration and decomposition processes. During El Niño events, as indicated by changes in the ENSO index, temperatures increase, but the SPI is only slightly greater inland and is not related to changes in CO_2. Caution should be taken when interpreting the relationship between wildfires and climate change.

Keywords

Global Warming, Standardized Precipitation Index, Global Temperature, Correlation Coefficient, El Niño, Wildfires, Climate Change

1. Introduction

According to the U.S. Geological Survey (USGS), weather conditions have become hotter and drier, especially in the western United States, over the past few decades [1]. Dryness and drought may be related to changes in precipitation due to climate change. If climate change continues, wildfires may worsen due to an increase in dryness.

The standardized precipitation index (SPI) is a widely accepted indicator for the quantification of drought [2]. The level of precipitation should be judged relative to some climatological norm for the location. The SPI value is defined as the standardized anomaly of the precipitation as follows:

$$SPI = (P - P^*)/\sigma_P \quad (1)$$

where P = precipitation, P^* = mean precipitation, and σ_P = standard deviation of precipitation.

The SPI is an index based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount. In other words, half of the historical precipitation amounts are below the median, and half are above the median. The index is negative for drought and positive for wet conditions.

The North American continental drought indicators are available. The data for the USA and Mexico are analyzed by the NOAA/National Centers for Environmental Information (NCEI) in the USA. The data for Canada are analyzed by the Agriculture and Agri-Food Canada (AAFC) agency to maximize the number of stations available for Canada. The same methodology is used by the NCEI and AAFC to compute the SPI. The calibration period is through the end of the latest full year and is updated each year.

Next, observations of the Earth's temperature via satellites began in 1979. Two groups, the University of Alabama in Huntsville (UAH) [3] and Remote Sensing Systems (RSS) [4], have conducted observations and analyses. The temperature in the lower troposphere measured by the UAH rises very slowly, increasing and decreasing repeatedly. The average temperature increase is 0.14˚C/decade [3]. We found a good correlation between the change rates of CO_2 concentrations and satellite-based global temperature data between 1979 and 2022 [5].

The correlation between satellite-based global temperature data and the ENSO index was investigated between 1979 and 2022. El Niño events, which represent the actual phenomenon for the ENSO index and temperature changes, are clearly correlated over 40 years, except between 1991 and 1993. Mount Pinatubo in the Philippines erupted on June 15, 1991, and it was the second-largest terrestrial eruption of the 20th century. Global temperatures decreased by approximately 0.5˚C between 1991 and 1993 due to the eruption [6]. This may explain the lack of correlation between El Niño events and temperature changes between 1991 and 1993. ENSO primarily leads to temperature changes, but the changes lag behind those of ENSO by approximately one year [6].

For this reason, the relationships between the SPI and satellite-based global temperature data for North America are investigated in this paper. A temperature effect induced by El Niño events on the SPI is also considered.

2. Data Analysis

The SPI data are reported by the National Oceanic and Atmospheric Administration (NOAA), and all the original data were downloaded [7]. The 12-month average SPI values were used.

Since 1979, the University of Alabama in Huntsville (UAH) has updated global temperature datasets that represent the piecing together of temperature data from a total of fifteen instruments flying on different satellites. Further details are available [3]. Temperatures here were obtained from the datasets, and monthly data and the 13-month average of lower troposphere anomaly values were used. Notably, the 12-month SPIs were averaged over the past 12 months on the National Oceanic and Atmospheric Administration (NOAA) website, whereas the 13-month UAH temperatures were averaged over the 6 months before and after each specific month.

The multivariate ENSO index version 2 (MEI.v2) by NOAA was used as the ENSO index. Further details are available on their website [8].

The correlation coefficient r between variables x and y can be defined as follows:

$$r = \frac{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}} \tag{2}$$

For convenience, r can be easily calculated via built-in functions in Microsoft Excel®.

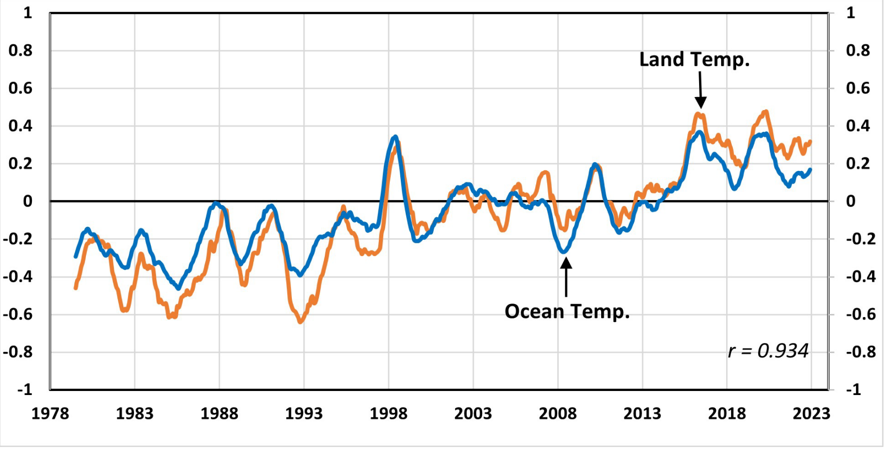
3. Results and Discussion

The 13-month average global land and ocean temperatures based on satellite observations are available from the UAH database [3]. **Figure 1(a)** compares these results between 1979 and 2022. Both results are well correlated, with a correlation coefficient of $r = 0.934$, and the changes in the global land temperature are slightly greater than those in the global ocean temperature.

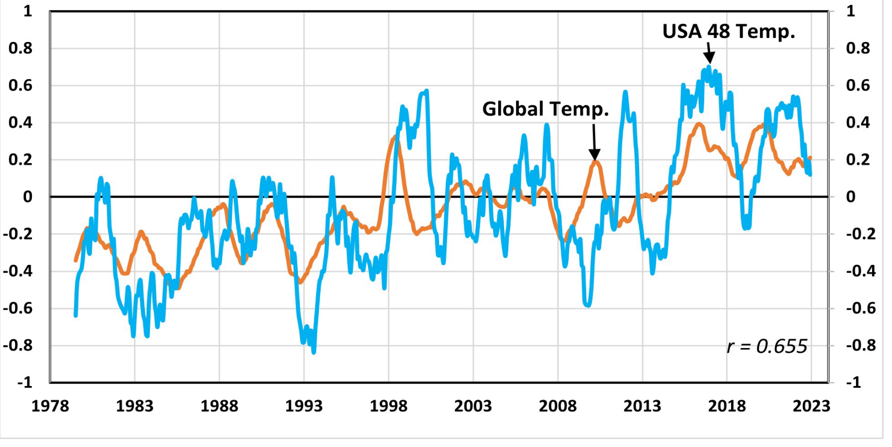
Similarly, 13-month average global and USA-48 state temperatures are available on the basis of satellite observations [3]. **Figure 1(b)** compares these results between 1979 and 2022. Both results are correlated, with a correlation coefficient of $r = 0.655$, and the temperature changes in the USA-48 state are greater than those in the global temperature.

A comparison of **Figure 1(a)** and **Figure 1(b)** clearly reveals that the global and ocean temperatures are well correlated. In fact, the correlation coefficient between the two is $r = 0.992$. This means that global temperature is almost completely controlled by ocean temperature, whereas the result shows that land temperature is slightly greater than ocean temperature, apparently because of the differences in heat capacity and areas between ocean and land.

Figure 2 compares the changes in the 12-month average SPI and satellite-based 13-month average temperatures at the IL Central station between 1979 and 2022. The correlation coefficient between the two is $r = 0.156$. **Figure 3** shows the



(a)



(b)

Figure 1. Changes in anomalies of satellite-based 13-month averaged temperatures (˚C) between 1979 and 2022: (a) global and ocean temperatures ($r = 0.934$) and (b) global and USA 48-state temperatures ($r = 0.655$).

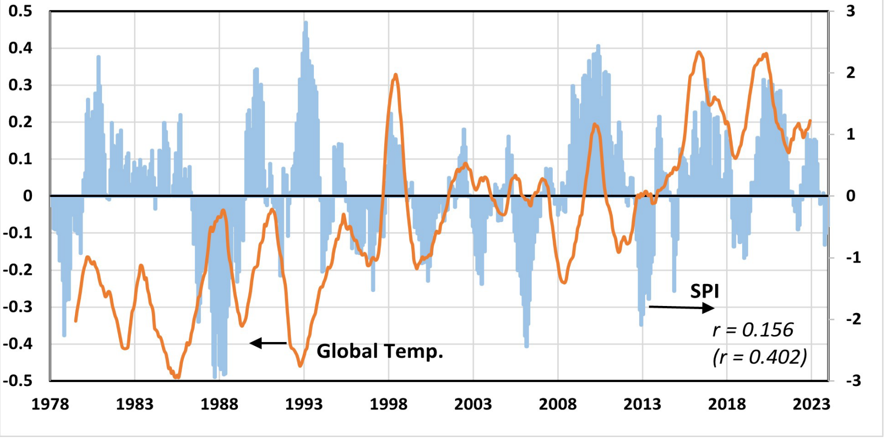


Figure 2. Changes in 12-month averaged SPI (blue bars and scales on the right) and anomalies of satellite-based 13-month averaged temperatures (˚C, red line, and scales on the left) at the IL Central station between 1979 and 2022 ($r = 0.156$ between 1979 and 2022, and $r = 0.402$ between 1995 and 2022).

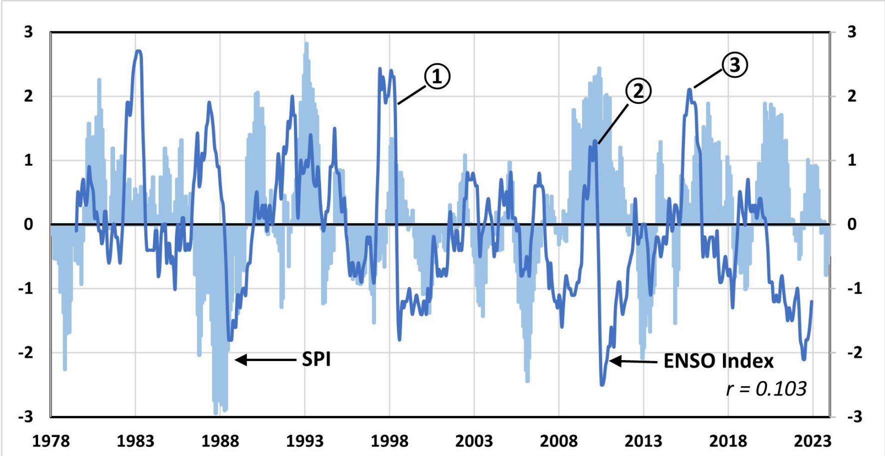
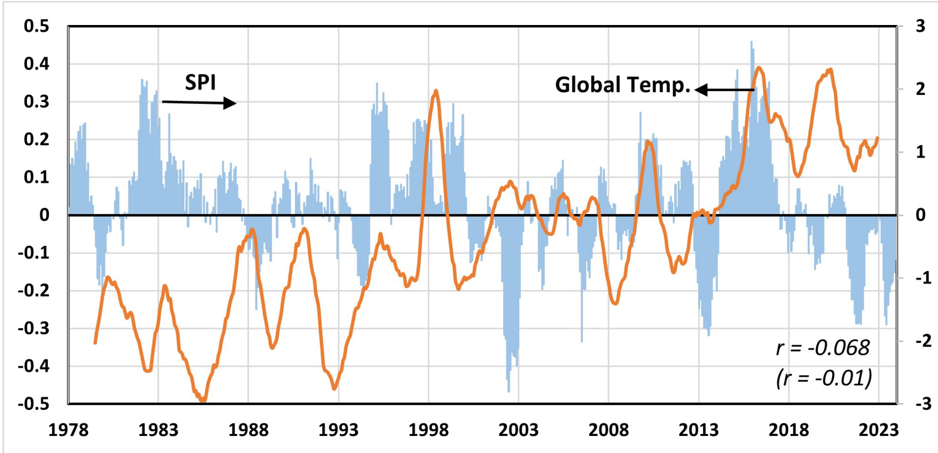


Figure 3. Changes in the 12-month average SPI (light blue bars) and the ENSO index (dark blue line) at the IL Central station between 1979 and 2022 (r = 0.103) (①, ②, and ③ denote three great El Niño events between 1995 and 2022).

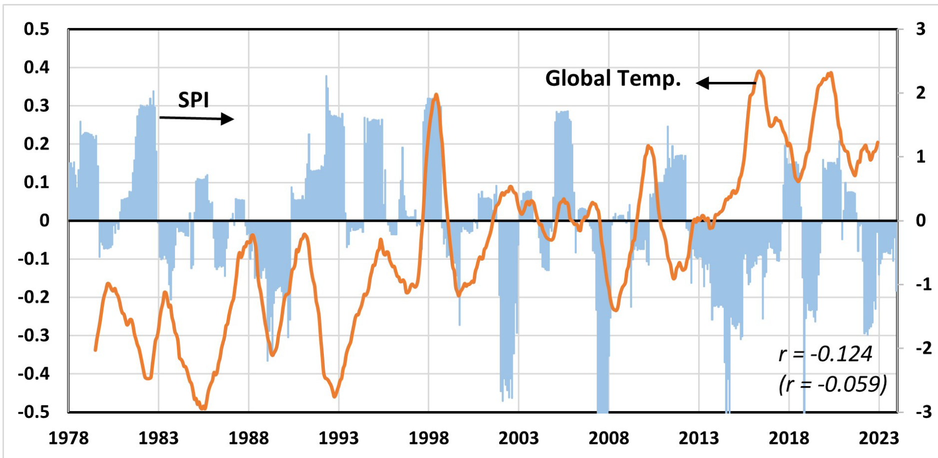
changes in the 12-month average SPI and the ENSO index at the same IL Central station between 1979 and 2022 ($r = 0.103$). Three great El Niño events were observed, as shown by ①, ②, and ③ between 1995 and 2022 in Figure 3. Since the global temperature rose due to El Niño events, the effect of temperature on the SPI was evaluated in terms of r between 1995 and 2022, when the temperature effect may be enhanced. The correlation coefficient r for the 12-month average SPI and the satellite-based 13-month average temperatures at the IL Central station (Figure 2) was 0.402 between 1995 and 2022, although r was 0156 between 1979 and 2022. This means that the SPI may be enhanced due to an increase in the global temperature.

Figure 4 shows the changes in the 12-month average SPI and anomalies of the satellite-based 13-month average temperatures in the (a) CO Platte Drainage Basin ($r = -0.068$), (b) CA South Coast Drainage Basin ($r = -0.124$), and (c) Mexico Tehuantepec Basin ($r = -0.186$) between 1979 and 2022. **Figures 4(a)-(c)** are examples of a high elevation, a coastal area, and a tropical area, respectively. No correlation between the SPI and global temperature is found for these stations, as shown by these graphs and correlation coefficients. Table 1 lists the results for other stations, including those in Canada and Mexico. The correlation coefficients between the SPI and global temperature between 1979 and 2022 and between 1995 and 2022 are calculated in Table 1. The places in blue are coastal and high elevation areas. Examples of a high elevation are the UT Uinta Basin (Station #: 4206) and the MD Appalachian Mt. (Station #: 1807). Examples of coastal areas include CA N. Coast Drainage (Station #: 401) and NC N. Coastal Plain (Station #: 3108). Examples of tropical areas include MX Valladolid (Station #: 31042) and MX Puebla (Station #: 21065). The correlation coefficients r in blue represent highly positive values, whereas those in red represent highly negative values.

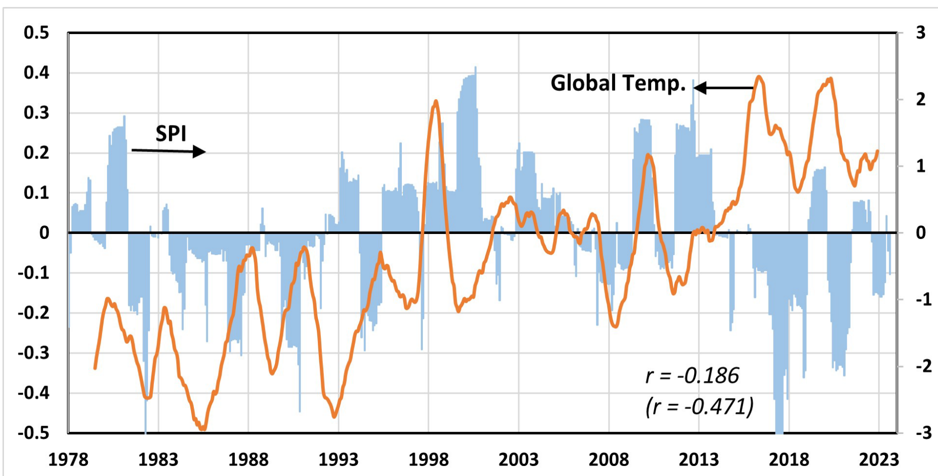
Figure 5 shows the 12-month SPI for North America in 2024 by NOAA [7]. The SPI values in ocean coastal areas are different from those in inland areas and



(a)



(b)



(c)

Figure 4. Changes in the 12-month average SPI and anomalies of satellite-based 13-month average temperatures (˚C) in the (a) CO Platte Drainage Basin ($r = -0.068$ between 1979 and 2022 and $r = -0.01$ between 1995 and 2022), (b) CA South Coast Drainage Basin ($r = -0.124$ between 1979 and 2022 and $r = -0.059$ between 1995 and 2022), and (c) Mexico Tehuantepec Basin ($r = -0.186$ between 1979 and 2022 and $r = -0.471$ between 1995 and 2022) between 1979 and 2022.

Table 1. Stations analyzed for changes in the 12-month average SPI and the anomaly of satellite-based 13-month average temperatures, and these correlation coefficients r (see [2] for details such as station #. The places in blue are coastal and high elevation areas).

Place	Station	Location		r	
	#	Latitude	Longitude	1979-2022	1995-2022
AK Fairbanks	26411	64.8	−147.88	0.249	0.356
AK ANCHORAGE Intl Ap	26451	61.17	−150.03	0.065	0.251
AK Juneau AP	25309	58.36	−134.56	0.282	0.164
CA N. COAST DRNG.	401	47.4	−114.3	−0.054	−0.055
IL Central	1104	40.5	−89.3	0.156	0.402
CO PLATTE DRAINAGE BASIN	504	40.2	−104.3	−0.068	−0.01
UT UINTA BASIN	4206	40	−109.5	0.134	0.033
MD Appalachian Mt.	1807	39.4	−77.8	0.139	0.074
CA SAN JOAQUIN DRNG.	405	38.7	−98.2	−0.098	−0.006
CA S. COAST DRNG.	406	38.6	−95.9	−0.124	0.059
NC N. Coastal Plain	3108	36.1	−77.2	0.279	0.102
OK Central	3405	35.5	−97.2	0.024	0.24
CA S.E. Desert BASINS	407	35.1	−116.4	−0.168	0.142
AZ N. Central	203	34.6	−112.5	−0.241	0.187
AZ S. Central	206	33.3	−112.1	−0.289	0.213
TX S. Central	4107	29.3	−97.6	0.089	0.294
FL Keys	807	24.8	−81.1	−0.051	−0.159
NT	2353	68.78	−81.24	0.008	−0.16
NT DELINE	1022	65.22	−123.43	−0.025	−0.262
BC VANCOUVER SEA IS.	8380	49.18	−123.18	0.205	0.009
ON TORONTO	8731	43.68	−79.63	−0.058	−0.07
MX VALLADOLID	31042	20.7	−88.22	0.192	0.115
MX PUEBLA	21065	19.03	−98.2	0.09	−0.057
MX TEHUANTEPEC	20149	16.33	−95.23	−0.186	−0.471

are generally lower. The SPI values in inland areas are greater than those in ocean coastal areas, and the SPI values in mountain areas are between those in coastal and inland areas. The SPI values in Figure 5 are consistent with our results of the relationship between the SPI and the global temperature. The trend of the SPI in North America is clearly complicated and cannot be explained by a single factor, such as climate change. Therefore, caution should be taken when interpreting the relationship between wildfires and climate change.

The following results are summarized.

1) The global temperature is closely related to the global ocean temperature.

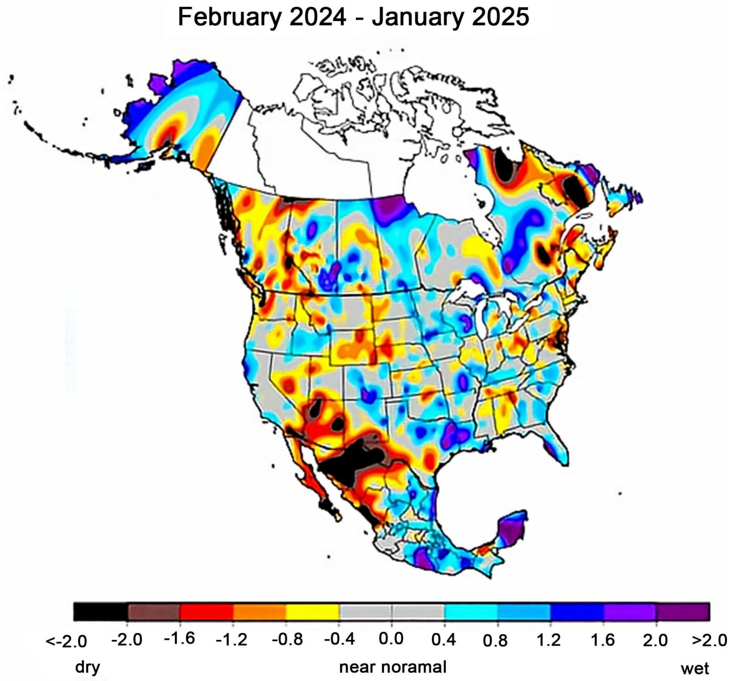


Figure 5. 12-month SPI for North America in 2024 by NOAA [7].

2) When the global temperature increases, the SPI is also slightly greater inland.

3) There is no correlation between global temperature and the SPI on the coast or in highlands.

4) This is because, in addition to the influence of global temperature, the specific characteristics of the coast and the lower temperatures at higher altitudes can affect precipitation.

5) Precipitation in coastal California may not be related to temperature.

4. Conclusions

In conclusion, the relationship between the global temperature and the standardized index can be summarized on the basis of the present work and our recent works [9]-[11]. The temperature changes approximately one year after the ENSO index changes, and the CO_2 change rate follows the temperature change rate with a lag of several months. CO_2 emission and absorption at the Earth's surface respond to temperature changes. It was like Earth's breathing. CO_2 emissions due to relatively high temperatures are related to plant respiration or decomposition processes. During El Niño events or greater changes in the ENSO index, temperatures increase, but the SPI is only slightly greater inland but is not related to changes in CO_2. The trend of the SPI in North America is clearly complicated and cannot be explained by a single factor, such as climate change. Caution should be taken when interpreting the relationship between wildfires and climate change.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Abbreviations

USGS: U.S. Geological Survey

NOAA: National Oceanic and Atmospheric Administration

UAH: University of Alabama in Huntsville

SPI: Standardized Precipitation Index

ENSO Index: El Niño-Southern Oscillation Index

r: correlation coefficient