Long-horizon empirical research finds that the relationship between solar activity (typically proxied by sunspot counts or geomagnetic indices) and S&P 500 returns is extremely weak. CXO Advisory, using monthly sunspot numbers and Shiller's S&P Composite data from 1871 to 2018, reports a Pearson correlation of $r = -0.02$ with $R^2 = 0.00$ for monthly returns, and $r = -0.07$, $R^2 = 0.01$ for annual returns, meaning sunspots explain essentially none of the variation in equity returns. A recent dissertation on "Solar Influences on Financial Markets" finds stronger negative correlations only for technology-heavy indices like NASDAQ in 2015–2024, while broad indices such as SPY (S&P 500 ETF) show much weaker effects. Taken together, the evidence strongly suggests solar activity is **not** a robust or sufficient basis for S&P 500 investment decisions.[1][2]

Below, the statistical tools, data sources, core formulas, and risk/legal considerations are laid out in a structured way.

1. Data and notation

1.1 Core time series

Let:

- t index time in years (or months, depending on frequency).
- S_t: annual (or monthly) average **sunspot number**, typically taken from the SILSO International Sunspot Number v2.0 series produced by the Royal Observatory of Belgium.[3][4]
- R_t^{SP}: **S&P 500 total return** over period t (including dividends), derived from:
  - Shiller's S&P Composite data (1871–1926).[1]
  - Modern S&P 500 levels and total return data from FRED, SlickCharts, or equivalent sources for 1926 onward.[5][6]

A standard definition of a simple return for period t is:

$$R_t^{\text{SP}} = \frac{P_t + D_t - P_{t-1}}{P_{t-1}},$$

where P_t is the index level at the end of period t and D_t is the dividend paid during period t.[6][5] Log-returns are often used in research:

$$r_t^{\mathrm{SP}} = \ln\left(\frac{P_t + D_t}{P_{t-1}}\right),$$

because they are additive over time and better behaved statistically.[1]

1.2 Geomagnetic indices as refined proxies

Some studies focus on **geomagnetic activity** rather than raw sunspot counts, arguing that it is more closely linked to human health, mood and technological disruption. A commonly used daily or monthly proxy is the **Ap-index**:[7]

- A_t^{p}: mean Ap-index over period t, summarising geomagnetic disturbance levels.[8][7]

In that case, the solar-related regressor is A_t^{p} instead of (or in addition to) S_t.

2. Correlation and basic dependence tests

2.1 Pearson correlation

The Pearson correlation between sunspot activity and S&P 500 returns is:

$$\rho_{S,R} = \frac{\mathrm{Cov}(S_t, R_t^{\mathrm{SP}})}{\sigma_S \sigma_R} = \frac{\sum_{t=1}^{T} (S_t - \acute{S})(R_t^{\mathrm{SP}} - \overline{R^{\mathrm{SP}}})}{\sqrt{\sum_{t=1}^{T} ¿¿¿}}$$

where $\acute{S}$ and $\overline{R^{\mathrm{SP}}}$ are sample means and T is the number of observations.[1]

Key findings:

- CXO (1871–2018, monthly data): $\rho_{S,R} \approx -0.02$, $R^2 \approx 0.00$ for monthly returns; $\rho_{S,R} \approx -0.07$, $R^2 \approx 0.01$ for annual returns.[1]

- Long-sample reconstructions over 1871–2020+ give very similar magnitudes: correlations near zero and R^2 well below 1 % when regressing annual S&P returns on annual sunspot numbers.[1]

The coefficient of determination

$$R^2 = \rho_{S,R}^2$$

measures the fraction of variance in S&P returns statistically "explained" by variation in solar activity. Values $R^2 \le 0.01$ mean **less than 1 %** of return variation is associated with sunspot fluctuations, which is economically negligible.[1]

2.2 Spearman rank correlation

To capture monotonic but non-linear dependence, many studies report **Spearman rank correlations**:

$$\rho_{S,R}^{\mathrm{Sp}} = \rho\left(\mathrm{Rank}\left(S_t\right), \mathrm{Rank}\left(R_t^{\mathrm{SP}}\right)\right).$$

- CXO's annual sunspot vs. return ranks also yield very small ¿ $\rho^{\mathrm{Sp}} \vee$ ¿, confirming the lack of a stable monotonic relationship across 1871–2018.[1]
- The 2015–2024 study "Solar Influences on Financial Markets" reports much stronger **negative** Spearman correlations for the NASDAQ Composite (IXIC), with yearly ρ between about -0.65 and -0.69, and significant p-values, especially when sunspot activity **leads** returns by 1–3 years. For SPY (S&P 500 ETF), however, the reported correlations are meaningfully weaker and less consistent.[2]

Thus, even where non-linear dependence exists, it appears **index-specific** (technology-biased indices) and sample-sensitive, not a robust property of S&P 500 over a century-plus.

2.3 Lead–lag (cross-correlation) analysis

To test whether solar activity **leads** the market, one computes cross-correlations:

$$\rho(\ell) = \mathrm{Corr}\left(S_{t-\ell}, R_t^{\mathrm{SP}}\right), \ell \in \{-L, \ldots, 0, \ldots, L\},$$

where $\ell > 0$ means solar activity leads returns by ℓ periods, and $\ell < 0$ means the market leads solar activity.[1]

- CXO finds weak peaks in $¿\rho(\ell)\vee¿$ at $\ell \approx +5$ to $+8$ years and $\ell \approx -2$ to -5 years, suggesting some long-cycle co-movement, but the authors stress these may be *noise* given the small number of solar and bull–bear cycles in the sample.[1]
- The 2015–2024 study finds the strongest negative correlations for NASDAQ when sunspots **lead** by 1–3 years or 1–12 months, but these results are limited to a short window and do not directly generalise to S&P 500.[2]

From an investment perspective, lead–lag patterns are only useful if they are **stable over long periods** and economically large; current evidence fails that test for S&P 500.

3. Regression models and explanatory power

3.1 Simple linear regression

A baseline model regresses returns on sunspot activity:

$$R_t^{\mathrm{SP}} = \alpha + \beta S_t + \varepsilon_t ,$$

where:

- α is the intercept (average return when $S_t = 0$),
- β measures the marginal change in expected return per unit change in sunspots,
- ε_t is the residual (unexplained part) with $E[\varepsilon_t] = 0$.[1]

Estimating via ordinary least squares (OLS):

$$\acute{\beta} = \frac{\sum_t (S_t - \acute{S})(R_t^{\mathrm{SP}} - \overline{R^{\mathrm{SP}}})}{\sum_t ¿¿}$$

On long-horizon annual data (1871–2018):

- $¿\acute{\beta}\vee¿$ is close to zero,

- the t-statistic for $\hat{\beta}$ is small in absolute value, and
- the p-value typically exceeds 0.05, implying β is statistically indistinguishable from 0.[1]

The fitted R^2 matches ρ^2 and is practically zero, again confirming that the **linear predictive content of sunspots for S&P 500 is negligible**.

3.2 Non-linear and phase-based models

Some authors attempt to capture non-linearities by using polynomial or cyclical transformations, e.g.:

$$R_t^{\mathrm{SP}} = \alpha + \beta_1 S_t + \beta_2 S_t^2 + \varepsilon_t,$$

or coding **solar cycle phase**:

$$\phi_t = \sin\left(2\pi \frac{S_t}{S_{max}}\right), R_t^{\mathrm{SP}} = \alpha + \beta_1 S_t + \beta_2 \phi_t + \varepsilon_t.$$

In long-sample studies, adding S_t^2 or ϕ_t typically improves R^2 by **fractions of a percentage point**, leaving the explanatory power still well below any economically meaningful threshold. In other words, even more flexible functional forms do not turn solar activity into a useful predictor of S&P 500 returns.[1]

3.3 Models with geomagnetic indices (Ap-index)

The 2019 Hindawi paper “Effect of Ap-Index of Geomagnetic Activity on S&P 500 Stock Market Return” replaces S_t with geomagnetic activity A_t^{p}:[7][8]

$$R_t^{\mathrm{SP}} = \alpha + \gamma A_t^{\mathrm{p}} + \delta^{\top} X_t + \varepsilon_t,$$

where X_t is a vector of control variables (e.g. liquidity measures, seasonality proxies).

The authors find:

- $\gamma < 0$: higher geomagnetic activity is associated with lower S&P 500 returns.

- The effect is statistically significant; markets with higher liquidity amplify the negative influence.
- However, even in their specification the incremental explanatory power of A_t^{p} is modest, and the mechanism is hypothesised (health, mood, behaviour), not proven causally.[8][7]

For asset allocation in a broad S&P 500 portfolio, such a small additional factor is unlikely to materially improve risk–return trade-offs relative to standard macro and valuation variables.

4. Why solar activity is a poor standalone investment signal

4.1 Economic magnitude vs. statistical significance

Even when a coefficient is statistically significant, investors must ask whether the **economic effect size** is material. Suppose a long-run regression yields:

$$R_t^{\mathrm{SP}} \approx 0.10 - 0.00004\, S_t,$$

where returns are in decimal form (10 % average annual return, -0.00004 per unit sunspot).[1]

If sunspots move from a low of 10 to a high of 200 (typical cycle range):[4][3]

- Change in expected return due to sunspots:

$$\Delta E\left[R^{\mathrm{SP}}\right] \approx -0.00004 \times (200 - 10) \approx -0.0076,$$

i.e. **less than 1 percentage point** in expected annual return across the entire cycle.

Given that annual S&P 500 return volatility is on the order of 15–20 %, this predicted shift is tiny relative to noise. It is very unlikely that an investor can exploit such a weak edge after transaction costs, taxes, and model uncertainty.[5]

4.2 Non-stationarity of markets, limited number of cycles

The solar cycle is about 11 years on average. Over 150 years, the number of full solar cycles is roughly 14, which is a **small sample** for detecting subtle cyclical relationships, especially when overlaid with regime changes in:[9]

- monetary policy (gold standard, Bretton Woods, modern fiat with QE),
- market structure and regulation,
- sector composition of S&P 500 (from railroads and heavy industry to tech/platforms),
- inflation environments and globalisation shocks.[10][1]

Because both economic regimes and the composition of the index drift over time, any small correlation found in one sub-period may not hold in another. This non-stationarity severely limits the reliability of solar-based “rules”.

4.3 Causality vs. correlation

Even where correlations are stronger (e.g. NASDAQ and sunspots in 2015–2024), the core statistical limitation remains: **correlation is not causation**.[7][2]

Establishing causality would require, for example:

- robust results across multiple disjoint samples,
- clear mechanisms (e.g. geomagnetic disruption of specific technologies) with measurable channels,
- identification strategies (natural experiments, instrumental variables) that separate solar effects from confounders like monetary conditions or sector booms.

Current literature offers interesting hypotheses and suggestive evidence, particularly around geomagnetic activity, but **falls short of a trading-grade causal model** for S&P 500.

5. Conditional and niche uses of solar information

Despite these limitations, solar and geomagnetic data can still matter in narrower contexts:

- **Sector-specific risk management.** Operators and investors in communications, satellite, aerospace, and power-grid infrastructure may legitimately incorporate forecasts of solar maxima and geomagnetic storms into operational risk and contingency planning.[11][12]
- **Tech-heavy indices.** The 2015–2024 period suggests that NASDAQ and some foreign indices show stronger negative rank correlations with sunspots, especially around solar

maxima. For specialised, highly technical quantitative funds, solar data might be one small feature in a larger multi-factor model—not a standalone timing rule.[2]

For broad, long-term S&P 500 investing, however, these are peripheral considerations.

6. Risk disclosures and legal disclaimers

Given the nature of this topic, it is essential to articulate risks and legal caveats explicitly.

6.1 No investment advice

- This article is provided **for informational and educational purposes only**.
- Nothing herein constitutes, or should be construed as, **investment advice, financial advice, trading advice, legal advice, tax advice, or any other form of professional advice**.
- The discussion of historical relationships between solar activity and financial markets is **descriptive and analytical**, not prescriptive. It is not a recommendation to buy, sell, or hold any security, index, derivative, or other financial instrument.

6.2 No solicitation or offer

- This text does **not** constitute an offer to sell or a solicitation of an offer to buy any financial product or service in any jurisdiction.
- Any references to specific indices (e.g. S&P 500, NASDAQ, SPY) are for illustrative purposes only and do not imply endorsement or recommendation.[2][1]

6.3 Past performance and model limitations

- **Past performance is not indicative of future results.** Historical correlations—whether weak or strong—may not persist, and future market behaviour may differ materially from the past.
- All models discussed (correlation, regression, lead–lag, spectral analysis) rely on assumptions that may be violated in practice (e.g. stationarity, linearity, homoscedasticity). Results are subject to **model risk** and **estimation error**.[7][1]

- Small effects that appear statistically significant in some samples (e.g. geomagnetic Ap-index on S&P 500 returns) may be due to data-mining, look-ahead bias, or omitted variables, and may **disappear out-of-sample**.[13][7]

6.4 Market risks

Investing in equities, including through broad indices such as the S&P 500, involves substantial risks, including but not limited to:

- market risk (price volatility, drawdowns),
- sector and concentration risk,
- interest-rate and inflation risk,
- liquidity risk,
- geopolitical and regulatory risk.

These risks are generally far larger than any hypothesised effect of solar activity. Investors can lose part or all of their invested capital.

6.5 Responsibility and due diligence

- Any investment decision should be based on the investor's **individual objectives, risk tolerance, financial situation, and time horizon**, and ideally made in consultation with a qualified, licensed financial adviser or other professional.
- Before acting on any information related to solar or geomagnetic cycles, investors should perform **independent research**, critically evaluate the robustness of the evidence, and consider mainstream risk–return factors (earnings, valuations, macroeconomics, diversification).

7. Overall conclusion

Long-run statistical evidence shows that sunspot counts and simple solar-cycle metrics have **near-zero explanatory power** for S&P 500 returns, with ¿ $\rho \vee$ ¿ close to 0 and R^2 close to 0 over more than a century of data.[1] More refined measures such as the geomagnetic Ap-index exhibit a statistically detectable *negative* impact on U.S. stock returns, but the economic effect is small and best interpreted as one of many behavioural or operational risk factors rather than a primary driver of equity performance.[7][8]

For mainstream investors in broad indices like the S&P 500, basing allocation or timing decisions on solar activity is **not advisable**. Solar and geomagnetic data may be of niche relevance for certain sectors and specialised quantitative strategies, but they are vastly overshadowed by fundamental and macroeconomic variables in determining long-term portfolio outcomes.

In short: the sun undoubtedly powers life and shapes the space environment, but as a standalone signal for S&P 500 investment timing, it is—at least with current evidence—mostly darkness.

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