Sentinel-5P Emissions Over The Two Dominant US Copper Mines, Read As A Domestic Supply-Constraint Signal

Why UV Aerosol Index measurements from the Sentinel-5P satellite over Morenci and Bingham Canyon, aggregated and z-scored on a 30-over-180-day baseline, have delivered a Spearman information coefficient of plus 0.44 against copper forward 60-day returns, among the strongest in the metals signal estate.

David Stendahl · Market Lab Analytics · November 5, 2026

What this signal is

The United States produces roughly five percent of global refined copper, but concentrates that production into two operations. Freeport-McMoRan Morenci in Arizona and Rio Tinto Bingham Canyon in Utah together produce roughly two-thirds of US domestic refined copper. The remaining third is split across smaller operations: Robinson Nevada, Pinto Valley, Safford, Ray. When Morenci or Bingham Canyon slows for permit reviews, labor actions, emissions enforcement, or tariff-cycle regulatory pressure, US spot-delivery availability tightens. COMEX HG is physically-deliverable copper; the price tape responds within weeks.

This signal reads the Sentinel-5P satellite UV Aerosol Index (UVAI) over the two mine areas-of-interest. UVAI measures atmospheric aerosols in the ultraviolet band; higher UVAI over an active open-pit mine indicates ongoing haul-truck operations, flotation activity, and smelter venting. Reduced UVAI indicates reduced operations. The signal takes a 30-day UVAI mean over each mine, compares against a 180-day baseline to produce a per-mine z-score, averages the two mines, inverts the sign so operational suppression reads positive, and bounds the result through hyperbolic tangent.

On September 15, 2025 the composite reached its series maximum plus 0.4708 as US copper-tariff debate intensified and UVAI readings over both mines fell consistent with operational slowdowns. Copper rallied through the subsequent window. On May 2, 2023 the composite reached its series minimum minus 0.6198 as both sites ran at elevated UVAI indicating active production; copper forward 60-day returns were weak through the subsequent window.

Today the composite reads near plus 0.14, in Normal territory. The reading does not flag either mine stress or mine calm; US domestic supply is operating near its baseline.

Here is what the engine data says. The Spearman information coefficient of the composite against copper forward 60-day returns is plus 0.44 across 1,270 live-window trading days, among the strongest state-conditional IC values in the entire metals signal estate. State-conditional means: Phase +1 mine-stress delivered forward 60-day copper return of plus 5.45 percent; Phase −1 mine-calm delivered minus 4.97 percent. The spread is plus 10.42 percentage points. Read on for the three cases that frame the signal, the state-conditional evidence, and the four caveats that mark the limits of the lens.

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How the inputs compose

Sentinel-5P is a European Space Agency earth-observation satellite carrying the TROPOMI (Tropospheric Monitoring Instrument). TROPOMI measures the UV Aerosol Index at daily cadence across the global landmass. UVAI is a dimensionless quantity derived from the ratio of measured and modeled UV reflectances; positive UVAI indicates absorbing aerosols (dust, smoke, mining emissions), negative UVAI indicates clear-sky background.

The engine pulls daily UVAI values for two defined mine areas-of-interest: a bounding polygon around Freeport-McMoRan Morenci (Arizona) and a bounding polygon around Rio Tinto Bingham Canyon (Utah). The UVAI values are filtered through the QC flag (qc_status = OK) to retain only validated measurements.

For each mine, the engine computes a trailing 30-day mean of UVAI as the “current” reading. The 30-day window captures operational conditions over the past month while smoothing out individual-day satellite-overpass variance. A trailing 180-day mean is then computed with a 30-day lag as the “baseline”. The difference between current and baseline, scaled by the baseline standard deviation, is the per-mine z-score.

The two per-mine z-scores are averaged to produce the cluster z. The cluster z is then negated (so suppression reads positive on the composite) and passed through tanh with scale 1.5. The result is a bounded composite between minus one and plus one.

The engine also exposes the per-mine Live_Cluster_Z and Live_N_Mines diagnostic columns so users can see which specific mine is driving the composite and whether the full two-mine panel is contributing.

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What the state-conditional returns have actually done

The copper forward-60-day return baseline (unconditional) is mean plus 1.57 percent, median plus 1.32 percent. Standard deviation 8.67 percent. Percent negative 42.5 percent. State-conditional means below are expressed as edges relative to this baseline.

> **Reference baseline (1,270 copper-aligned forward-60-day windows from July 2021 through November 2026)**

> Copper forward-60-day return baseline (unconditional): mean plus 1.57 percent, median plus 1.32 percent. Standard deviation 8.67 percent. Percent negative 42.5 percent. Phase 0 source: Z102599 engine parquet joined with COMEX HG back-adjusted continuous closes.

The Mine-stress state (Market_Phase_Int = +1), 210 trading days or 15.8 percent of sample, delivered a mean forward 60-day copper return of plus 5.45 percent. That is plus 3.88 percentage points above baseline. Percent-negative only 23.4 percent; more than three-quarters of days in this state preceded positive copper fwd 60-day returns.

The Normal state (Market_Phase_Int = 0), 871 trading days or 65.5 percent of sample, delivered mean plus 2.59 percent. That is plus 1.02 percentage points above baseline. Percent-negative 39.2 percent. The modal state where US domestic supply is operating near steady-state.

The Mine-calm state (Market_Phase_Int = −1), 249 trading days or 18.7 percent of sample, delivered mean minus 4.97 percent. That is minus 6.54 percentage points below baseline. Percent-negative 69.1 percent, well above the fifty-percent neutral line. The strongest counter-signal: when both mines are operating well above baseline emissions, copper has historically weakened.

The spread between Mine-stress and Mine-calm forward returns is plus 10.42 percentage points at 60 days, the largest state-conditional edge in the copper-signal estate. The Spearman information coefficient of the composite against copper forward-60-day returns is plus 0.44 at N 1,270.

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Three cases that frame how to read the signal

Case 1: Late 2021 Morenci operational pressure as copper rallied into 2022

The composite rose into mine-stress state in late 2021 as emissions readings over Morenci dropped alongside Freeport labor discussions and permit-cycle delays. The signal spent several weeks in Phase +1. Copper rallied aggressively through the first quarter of 2022, reaching its all-time high above 480 cents per pound in March 2022. This is the early-sample demonstration that Morenci suppression leads the US spot tape.

Case 2: April to May 2023 Bingham Canyon active operations; copper softened

On May 2, 2023 the composite reached its series minimum minus 0.6198 as UVAI over both sites was elevated and the cluster z was deeply negative. The signal flagged US domestic supply abundance. Copper forward 60-day returns were weak through the subsequent window as Fed tightening expectations rose and supply remained adequate. This is the canonical mine-calm case.

Case 3: September 2025 tariff-cycle escalation drives series maximum

On September 15, 2025 the composite reached its series maximum plus 0.4708 as US copper-tariff debate intensified. UVAI measurements over both mines dropped consistent with operational slowdowns; whether this was labor-driven, permit-driven, or market-anticipation-driven, the satellite captured the operational signature. Copper rallied through late 2025.

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How to use the signal today

This is a fast-moving domestic-supply regime identifier. Peak information coefficient horizon is approximately 60 trading days. The signal fires on daily Sentinel-5P UVAI measurements (typically available with a 2-to-3-day lag).

Three best uses.

First, as a high-conviction US domestic supply signal. The 10.42-percentage-point spread between Phase +1 and Phase −1 is the largest state-conditional edge in the copper-signal estate. Allocators adjusting copper exposure can read Mine-stress as a strongly constructive signal and Mine-calm as a strongly cautionary signal.

Second, as a filter for US copper-related news interpretation. When the signal is in Mine-stress, Freeport quarterly guidance updates, Rio Tinto Bingham operational reports, and US copper-tariff debate carry stronger directional implication for the spot tape.

Third, as the US leg of a two-sided supply framework. Pair with offshore supply signals (ACLED copper-belt events across Chile, Peru, DRC, Zambia; water-stress composites over Andean mining regions) for a global supply view. The US signal moves faster than offshore because COMEX spot delivery is US-based.

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Methodology notes

The composite is tanh of the negated cluster z-score of UVAI over Morenci and Bingham Canyon. The 30-day current window was chosen because it captures sustained operational changes while smoothing single-day satellite-overpass variance. The 180-day baseline was chosen to provide a stable reference without washing out multi-month operational cycles.

The engine also computes four confirming features: five-day composite velocity, 60-day volatility regime, 60-day correlation with copper daily returns, and 63-day lag-1 autocorrelation.

The polarity is as-is positive. Higher composite equals UVAI suppression equals operational slow-down equals US domestic supply tight equals bullish copper. Full-sample Spearman IC against copper forward 60-day returns is plus 0.44 at N 1,270.

The 2021 start reflects Sentinel-5P UVAI reliable coverage onset. Earlier data was less reliable for consistent mine-site measurement.

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What this signal does not cover

Four caveats on the signal's reach, each stated plainly.

First, the signal covers only two mines. Morenci and Bingham Canyon together produce roughly two-thirds of US refined copper. The remaining third (Robinson Nevada, Pinto Valley, Safford, Ray) is not represented. For complete US supply picture, pair with USGS monthly production reports and the individual quarterly guidance from Freeport and Rio Tinto.

Second, UVAI is a proxy for mine activity, not a direct production measurement. Cloud cover, atmospheric circulation, seasonal baseline shifts, and non-mining aerosol sources (regional wildfires, dust storms) can affect the UVAI reading independent of actual mine operations. The 180-day baseline absorbs some of this noise but extreme weather events can still contaminate the signal.

Third, the sample is only five years long. The signal has fired through one full copper cycle (2021 peak to 2023 trough to 2025 recovery) but has not been observed across multiple macro regimes. The strong IC and state-conditional edge may partly reflect favorable alignment with the single cycle in sample.

Fourth, this is a supply-side read only. Chinese demand collapse, global recession, or other macro demand shocks can and will override the domestic-supply signal. Mine stress is a necessary but not sufficient condition for copper strength; demand has to also hold up.

Not investment advice. The analysis in this brief is informational and educational. Signal readings, historical case figures, and empirical statistics are derived from publicly available data (ESA Sentinel-5P / TROPOMI UV Aerosol Index daily releases; COMEX end-of-day copper back-adjusted continuous settles) and are provided without warranty. Hypothetical performance results have inherent limitations. Readers should consult their own financial advisor before making any investment decision. (c) 2026 David Stendahl.