CHIRPS Precipitation And SMAP Soil Moisture Over The Chilean Atacama, Read As A Supply-Side Stress Composite

Why combining CHIRPS 12-month precipitation and SMAP soil moisture anomalies over the Chilean copper belt, inverted and tanh-bounded, produces a 36-year supply-stress composite with Spearman IC plus 0.17 against copper forward 60-day returns; the 2009 mega-drought start and the 2015-16 El Nino wet anomaly as archetypes.

David Stendahl · Market Lab Analytics · November 5, 2026

What this signal is

Chile produces roughly twenty-eight percent of global refined copper. Almost all of it comes from the Atacama desert mining belt — Antofagasta, Atacama, and Tarapacá regions — where annual rainfall averages less than 20 millimeters per year and the mines sit at 2,000 to 4,500 meters elevation. Each mine consumes more than a cubic meter of water per tonne of ore processed, plus water for dust suppression on haul roads, tailings slurry transport, smelter cooling, and worker camps. When Chilean precipitation falls below the long-term baseline and the soil moisture that feeds aquifer recharge dries up, mine throughput follows on a multi-month lag.

This signal combines two NASA satellite products to measure Chilean copper-belt water stress. CHIRPS (Climate Hazards group Infrared Precipitation with Stations) provides a 12-month rolling precipitation z-score. SMAP (Soil Moisture Active Passive) provides a soil moisture anomaly z-score. The two z-scores are combined into a stress index, smoothed, inverted (so drought reads positive), and bounded through hyperbolic tangent. A composite near plus one is deep multi-year Chilean drought. A composite near minus one is strong wet anomaly (typical of El Nino cycles).

On September 30, 2009 the composite reached its series maximum plus 0.9813 as the 2008-2010 Chilean drought deepened; this marked the start of the “Chilean mega-drought” that dominated the decade. Copper rallied aggressively through 2010 and 2011. On December 4, 2015 the composite reached its series minimum minus 0.9961 during the strong 2015-16 El Nino wet pattern. Chilean copper production was briefly unconstrained; the signal correctly flagged water-favorable regime.

Today the composite reads near plus 0.07, in Normal territory. Chilean Atacama water availability is operating near baseline.

Here is what the engine data says. The Spearman information coefficient of the composite against copper forward 60-day returns is plus 0.17 across 8,962 live-window trading days. State-conditional means: Phase +1 water-stress state delivered forward 60-day copper return of plus 1.86 percent; Phase 0 Normal delivered plus 2.61 percent; Phase −1 water-favorable delivered minus 0.83 percent. The polarity is as-is positive. 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

CHIRPS is a 0.05-degree-resolution daily precipitation dataset produced by UC Santa Barbara's Climate Hazards Center. It integrates satellite infrared cloud-top observations with ground-station rainfall data and provides reliable 45-year reconstruction from January 1, 1981 forward across the 50-degree-south to 50-degree-north band. The Chilean Atacama falls within the coverage window.

SMAP is a NASA Earth-observation satellite launched in January 2015 that measures soil moisture at near-surface and root-zone depth. The engine uses the near-surface (top 5 cm) product because it responds fastest to precipitation input and is the strongest leading indicator of subsequent aquifer dynamics.

The engine pulls daily CHIRPS values for the Chilean copper admin1 regions (Antofagasta, Atacama, Tarapacá) and computes a 12-month rolling precipitation sum, then z-scores against a trailing baseline. The SMAP soil moisture series over the same bounding box is z-scored similarly. The two z-scores are combined (equal-weighted average), smoothed on a short window, inverted so drought reads positive, and bounded through tanh with scale 1.5.

The engine exposes diagnostic columns: the raw CHIRPS z, the raw SMAP z, and the combined pre-inversion stress index, so users can decompose the composite into its two inputs.

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What the state-conditional returns have actually done

The copper forward-60-day return baseline (unconditional) is mean plus 1.12 percent, median plus 0.74 percent. Standard deviation 8.70 percent. Percent negative 45.2 percent. State-conditional means below are expressed as edges relative to this baseline.

> **Reference baseline (8,962 copper-aligned forward-60-day windows from December 1990 through November 2026)**
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> Copper forward-60-day return baseline (unconditional): mean plus 1.12 percent, median plus 0.74 percent. Standard deviation 8.70 percent. Percent negative 45.2 percent. Phase 0 source: Z20917 engine parquet joined with COMEX HG back-adjusted continuous closes.

The Water-stress state (Market_Phase_Int = +1), 3,921 trading days or 43.5 percent of sample, delivered a mean forward 60-day copper return of plus 1.86 percent. That is plus 0.74 percentage points above baseline. The 2009-2015 Chilean mega-drought and the 2022-present continued stress contribute most of the state-day count.

The Normal state (Market_Phase_Int = 0), 2,079 trading days or 23.0 percent of sample, delivered mean plus 2.61 percent. That is plus 1.49 percentage points above baseline. Interestingly the Normal state delivers the strongest edge in this signal; moderate water availability aligns with most periods of healthy copper demand.

The Water-favorable state (Market_Phase_Int = −1), 3,022 trading days or 33.5 percent of sample, delivered mean minus 0.83 percent. That is minus 1.95 percentage points below baseline. The 2015-16 El Nino window and other wet-anomaly periods live here.

The spread between Water-stress and Water-favorable forward returns is plus 2.69 percentage points at 60 days. The Spearman information coefficient of the composite against copper forward-60-day returns is plus 0.17 at N 8,962.

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Three cases that frame how to read the signal

Case 1: September 2009 Chilean mega-drought starts

The composite reached its series maximum plus 0.9813 on September 30, 2009 as the 2008-2010 Chilean drought deepened and the water table declined across the Atacama. Multiple mines reported early signs of water-driven operational stress. Copper rallied aggressively through 2010 and 2011 as supply concerns combined with China stimulus. This marked the start of the Chilean “mega-drought” that dominated the 2010s decade.

Case 2: December 2015 strong El Nino wet anomaly

On December 4, 2015 the composite reached its series minimum minus 0.9961 as the strong 2015-16 El Nino produced sustained above-normal rainfall across Chile. CHIRPS showed precipitation well above baseline and SMAP showed soil moisture well above the 2015 baseline. Chilean copper production was briefly unconstrained. Copper was already weak on the China-slowdown cycle; the water-favorable reading was consistent with the demand-driven decline.

Case 3: 2022 through 2025 continued mega-drought with intermittent relief

The composite oscillated between stress and neutral across 2022 through 2025 as the Chilean mega-drought continued but with intermittent La Nina wet pulses providing temporary relief. Copper traded a wide range across the window as supply-side water stress combined with demand-side uncertainty. The signal spent more than half of this window in Phase +1 water-stress; this is the modern working case of persistent elevated readings.

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How to use the signal today

This is a slow-moving leading indicator for Chilean copper supply constraint. Peak information coefficient horizon is approximately 60 trading days. The signal moves on CHIRPS daily updates (2-to-3-day lag) and SMAP roughly-daily updates.

Three best uses.

First, as a Chilean supply-regime identifier. Water-stress state has historically preceded moderately above-baseline copper fwd-60-day returns. Pair with physical-market indicators (LME copper stocks, TC/RC concentrate charges) to confirm supply tightness is landing.

Second, as a filter for Chilean copper-production news interpretation. When the signal is in Water-stress, BHP Escondida production guidance, Codelco Chuquicamata water-permit renewals, and Antofagasta water-use regulations carry stronger directional implication for copper.

Third, as part of a multi-mechanism Chilean supply read. Pair with Z32328 (GRACE aquifer gravimetry) for a surface-water plus deep-aquifer dual-read. The two signals can disagree during periods where precipitation is replenishing but aquifers remain depleted (or vice versa) — those disagreements contain useful information.

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Methodology notes

The composite is tanh of the negated combined-stress index of CHIRPS 12-month precipitation z plus SMAP soil moisture anomaly z. The two inputs are equal-weighted. The 12-month window on CHIRPS was chosen because it captures full annual precipitation cycles plus one lag. The SMAP soil moisture is read at near-surface (top 5 cm) because that responds fastest to precipitation input.

The engine 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 drought equals supply constraint equals constructive copper. Full-sample Spearman IC against copper forward 60-day returns is plus 0.17 at N 8,962.

The 1990 start reflects reliable Chilean station data for the CHIRPS retrospective; the SMAP soil-moisture component began January 2015. Before 2015 the composite relies on CHIRPS alone with SMAP neutral-zero; after 2015 it uses both inputs equal-weighted.

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What this signal does not cover

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

First, this is a Chile-only signal. Peru, DRC, and Zambia copper supply (collectively another 30 percent of global production) are not represented. For a complete supply picture, pair with Z32329 (Peru aquifer), Z11471 (Chile plus Peru drought composite), or Z85614 (ACLED copper-belt events across all four countries).

Second, the signal uses surface precipitation and near-surface soil moisture. Deep aquifer dynamics (which move on multi-year timescales) are captured by GRACE gravimetry, not by CHIRPS or SMAP. Z32328 reads GRACE directly; the two signals can disagree during periods where surface water is replenishing but deep aquifers remain depleted.

Third, Chilean copper companies have invested heavily in seawater desalination since 2015. Escondida's desal plant commissioned in 2017; Codelco Chuquicamata has phased in desalination

capacity since 2019. These capital investments have partially decoupled some operations from aquifer constraint, which can weaken the signal's impact on current output even with a strong water-stress reading.

Fourth, this is a supply-side read only. Chinese demand collapse, global recession, or other macro demand shocks can and will override the supply signal. The 2015-16 case is the demonstration: wet anomaly flagged water-favorable but copper was already weak on the China slowdown.

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 (CHIRPS daily precipitation; NASA SMAP soil moisture; 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.