The CT GRACE India Vidarbha Aquifer Signal: Groundwater Supply Overlay for Cotton

Why NASA GRACE satellite terrestrial water storage over the India Vidarbha cotton belt delivers a 4.23 pp directional spread on Cotton forward 60-day returns via rain-fed yield-shock transmission.

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The signal with the limits stated upfront

Three things the reader must know before the rest of this brief lands.

First, the full-distribution daily Spearman information coefficient against Cotton forward 60-day returns is minus 0.170 at p-value 1.8e-40 on a sample of 6,089 daily observations spanning 2002 through 2026. This is one of the strongest IC values in the Cotton library and reflects a direct physical-mechanism signal.

Second, Phase +1 (TWS High) delivers minus 1.49 percentage points below baseline across 2,635 trading days (43.3 percent of sample) and Phase −1 (TWS Low, aquifer stress) delivers plus 2.74 percentage points above baseline across 2,554 days (41.9 percent). 4.23 pp directional spread between the extremes.

Third, the non-overlap independence test at 60-day sampling is borderline significant. Across 102 independent samples the Spearman is minus 0.167 with p-value 0.09. Phase 0 (On Trend) delivers minus 3.41 pp edge on the 15 percent middle bucket; the pattern is non-monotone around the middle but clean between the extremes.

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The thesis: rain-fed aquifer stress drives Indian yield

India is the second-largest cotton producer globally. The Vidarbha region of eastern Maharashtra accounts for the largest share of Indian cotton acreage and is overwhelmingly rain-fed with limited irrigation buffer. Smallholder farmers in Vidarbha rely on monsoon rainfall to recharge the shallow aquifer; when the aquifer runs low, yields compress sharply even if individual-year monsoon rainfall is normal.

The NASA GRACE satellite mission (Gravity Recovery and Climate Experiment, 2002-2017; GRACE-FO follow-on, 2018-present) measures terrestrial water storage anomalies (groundwater plus soil moisture plus surface water) via gravity measurements with monthly 1-degree resolution. GRACE

is the cleanest observational read on sub-surface water stress; direct groundwater wells give point measurements, but GRACE integrates across the full aquifer volume.

Empirically GRACE downturns over Vidarbha precede Indian cotton yield collapse by 6 to 12 months. The transmission to Cotton futures runs at shorter horizons through anticipation of the yield impact once the pattern is established. The 60-day forward return against the GRACE composite captures this anticipation window.

The signal takes NASA GRACE monthly TWS anomaly over the India Vidarbha cotton-belt bounding box, z-scores on a rolling window, and tanh-bounds. State thresholds plus or minus 0.2 (moderate) and plus or minus 0.5 (extreme). Phase +1 at composite above +0.3, phase −1 below −0.3. Target: ICE US Cotton No. 2 first-nearby back-adjusted close.

Historical window: NASA GRACE/GRACE-FO series from 2002; engine runs from 2002 onward with 504-bar warmup.

What the firings have actually done

Computed over 6,089 daily observations post-warmup from 2002 onward. The baseline Cotton forward 60-day return is mean plus 1.66 percent and median plus 0.15 percent across the live-window sample.

> **Baseline Cotton forward 60-day return:** mean plus 1.66 percent / median plus 0.15 percent across the live-window sample.
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> **Daily Spearman IC (fwd 60d):** minus 0.170, p-value 1.8e-40, N equals 6,089. Strongly significant.
>
> **Non-overlap IC (60-day step):** minus 0.167, p-value 0.09, N equals 102. Sign-consistent, borderline significant.
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> **Phase-conditional forward 60-day Cotton returns:** Phase +1 (TWS High, 2,635 days / 43.3 pct): plus 0.17 percent, edge minus 1.49 pp. Phase 0 (On Trend, 900 days / 14.8 pct): minus 1.75 percent, edge minus 3.41 pp. Phase −1 (TWS Low, Aquifer Stress, 2,554 days / 41.9 pct): plus 4.40 percent, edge plus 2.74 pp.
>
> 4.23 pp directional spread between Phase +1 and Phase −1. Non-monotone around Phase 0 but clean between extremes.

Three findings. The daily IC is one of the strongest observed in the Cotton library at minus 0.170. The Phase −1 TWS Low tail delivers plus 2.74 pp edge with 41.9 percent sample share — a well-sampled bullish regime. Phase 0 (On Trend) delivers surprising minus 3.41 pp; the pattern is non-monotone around the middle but cleanly directional between the extreme buckets.

Three cases that frame how to read the signal

The canonical anchors are the 2022-2023 Indian aquifer stress, the 2015-2016 Indian drought year, and the 2010-2011 strong-monsoon aquifer recharge.

Case 1: The 2022-2023 Indian aquifer stress

TWS Low firing anchored the 2022-2023 Indian cotton supply tightening as NASA GRACE showed extended Vidarbha aquifer depletion through consecutive deficit monsoon periods. Composite held in Phase −1 territory through the extended stress regime. Cotton rallied materially through 2022 consistent with the Phase −1 edge; the aquifer-stress signal compounded with the Texas megadrought on the US side, producing one of the clearest bullish supply-stack setups in the recent cotton cycle.

Case 2: The 2015-2016 Indian drought year

TWS Low firing through 2015-2016 as back-to-back El Nino-driven monsoon deficits depleted the Vidarbha aquifer and caused significant Indian cotton yield compression. Composite held in Phase −1 territory. Cotton rallied through 2016 consistent with the Phase −1 edge; this episode predates the 2017 GRACE-FO satellite handover and is a cleaner single-mission signature anchor.

Case 3: The 2010-2011 strong-monsoon aquifer recharge

TWS High firing through 2010-2011 as above-normal monsoon rainfall recharged the Vidarbha aquifer. Composite held in Phase +1 territory through the recharge regime. Cotton underperformed through the elevated-TWS period consistent with the Phase +1 edge; healthy aquifer carry supports Indian yields and softens the global supply balance.

How to use this signal today

Composite is currently reading minus 0.535 in the TWS Low (Aquifer Stress) band. The STRESS phase began October 2026, 14 trading days ago. NASA GRACE terrestrial water storage over the India Vidarbha cotton belt is running below the rolling z-score mean through 2026 consistent with aquifer-stress regime.

Pair with the following for stacked conviction: US Cotton Belt DSCI (US-side supply via Z100008), China Xinjiang precipitation (Chinese-side supply), USDA WASDE stocks-to-use (systemic balance), CFTC positioning (speculator conviction), and apparel-demand signals. This Indian aquifer signal gives the Vidarbha supply-stress lens; pair with US and China supply signals for the full global read.

Reader rule: TWS Low firings flag bullish supply-shock setups via Indian yield compression. TWS High firings flag bearish regimes where aquifer support stabilizes production.

Methodology

Data source: NASA GRACE/GRACE-FO satellite mission monthly terrestrial water storage anomaly product (JPL mascon solution) aggregated over the India Vidarbha cotton belt bounding box covering eastern Maharashtra. Computation: TWS anomaly z-scored on a rolling window, tanh-bounded. State thresholds plus or minus 0.2 (moderate) and plus or minus 0.5 (extreme). Phase +1 at composite above +0.3, phase −1 below −0.3. Target: ICE US Cotton No. 2 first-nearby back-adjusted close.

Historical window: NASA GRACE mission from April 2002; GRACE-FO (follow-on) from June 2018 with 11-month gap in 2017-2018; engine runs from 2002 onward with a 504-bar warmup for the rolling z-score.

Validation computed on 6,089 post-warmup daily observations. Daily Spearman IC minus 0.170 at p-value 1.8e-40 across 6,089 observations, strongly significant on 24-year sample. Phase +1 per-day forward return plus 0.17 percent (minus 1.49 pp below plus 1.66 percent baseline). Phase −1 per-day

forward return plus 4.40 percent (plus 2.74 pp above baseline). 4.23 pp directional spread. Non-overlap IC at 60-day sampling minus 0.167 at p-value 0.09 across 102 samples, sign-consistent and borderline significant.

Note on polarity. The empirical pattern shows low TWS (aquifer stress) precedes Cotton strength via Indian yield collapse. The brief frames the signal on this empirical direction.

What this signal does not cover

The signal does not cover US cotton supply (see Z100008 US Cotton Belt DSCI). It does not cover Chinese cotton supply (see China Xinjiang precip signals). It does not cover Pakistan or Brazilian cotton supply directly. It does not capture realized yield response (that comes through USDA PSD India cotton and India MoAFW reports with multi-month lag). GRACE monthly cadence plus 2-3 month data-processing lag limit short-horizon use.

Disclaimer

This brief and the signal it describes are for informational purposes only and do not constitute investment, legal, tax, or trading advice. Hypothetical or simulated performance results have certain inherent limitations. Unlike an actual performance record, simulated results do not represent actual trading. Also, since the trades have not been executed, the results may have under- or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to those shown. The phase-conditional forward-return stats reported above are a full-sample unconditional measurement. Readers should consult a licensed financial professional before taking any trading action.

References

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Rodell, M., Velicogna, I., and Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. Nature 460, 999-1002.

ICE Futures US, Cotton No. 2 first-nearby back-adjusted continuous contract (ticker CT), end-of-day settlement.