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Multi-scale drivers of PM2.5 and PM10 extremes in the Valley of Mexico: Synoptic regimes, boundary-layer stability, and ENSO modulation

stage 1.2

Context & Objective

Exploratory Analysis of PM Extremes

- Goal: test how "extreme PM events" change with different definitions
- Compare percentile-based (p10/p90; daily city-mean) vs operational thresholds (NOM-172; NowCast12h from RAMA)
- Produce monthly Z500′ composites + simple cycle diagnostics (hourly + seasonal harmonics)
- Output is exploratory: used to decide dataset + episode definition for Stage 2

Data & Methodology

Two event-detection branches + harmonic diagnostics

- **Reanalysis:** Z500 + winds (daily), anomalies via daily climatology (rolling smooth).
- **Branch A (daily city-mean, 2012–2024):** events = p90 (high tail) and p10 (low tail) computed within each month-year.
- **Branch B (RAMA hourly, PM10 1995–2023; PM2.5 2003–2023):** compute NowCast12h and classify events using NOM-172 (2026 thresholds).
- **Monthly composites:** event days vs rest-of-month, with basic significance markers.
- **Harmonic diagnostics (cycles):**
  - Diurnal + semidiurnal (24h + 12h) from hourly climatology (by month).
  - Annual + semiannual (365d + 182.5d) from daily climatology (day-of-year).

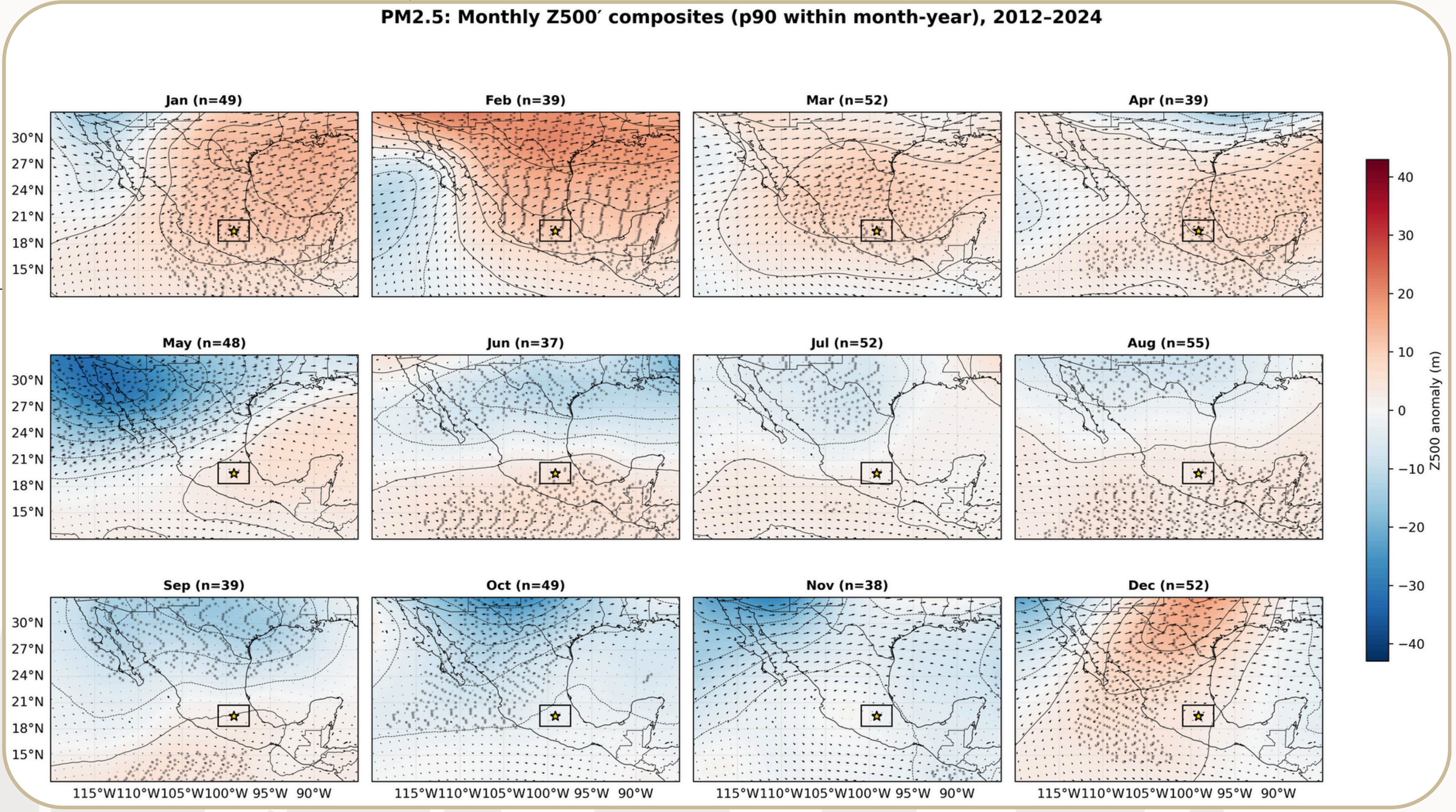
Monthly composites (recap p90 + new p10)

Exploratory synoptic patterns by month (2012–2024; within month–year)

- Goal: compare "high-pollution days" (p90) vs "low-pollution days" (p10) to see if circulation signals are consistent and season-dependent.
- Method reminder: events defined within each month-year (controls for seasonality and long-term changes), then Z500′ composites computed over those event dates.
- Interpretation scope: these are pattern-screening maps; use them to decide active months + best event definition for Stage 2.

p90 high-pollution events

p90 (PM2.5): Z500′ monthly composites

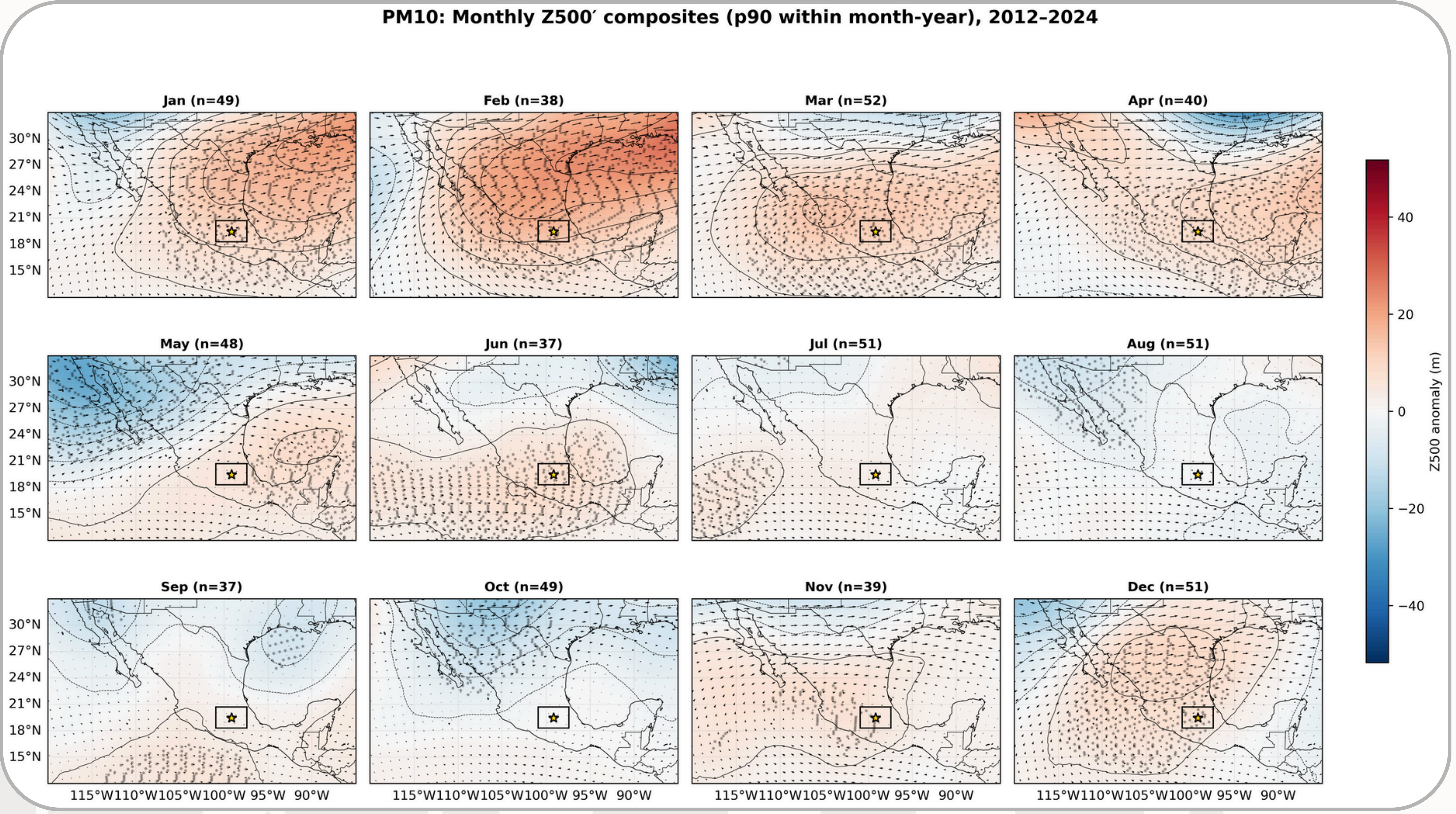


- Winter–spring (DJF–AM): persistent positive Z500′ / ridging over N-central Mexico and adjacent regions → more stable, weaker ventilation conditions.
- Flow implication: circulation favors subsidence and stagnation, consistent with accumulation rather than rapid dispersion.
- Seasonal structure: the p90 signal is strongest in dry-season months, weakening toward summer when mixing/precipitation dominate.

p90 high-pollution events

p90 (PM10): Z500′ monthly composites

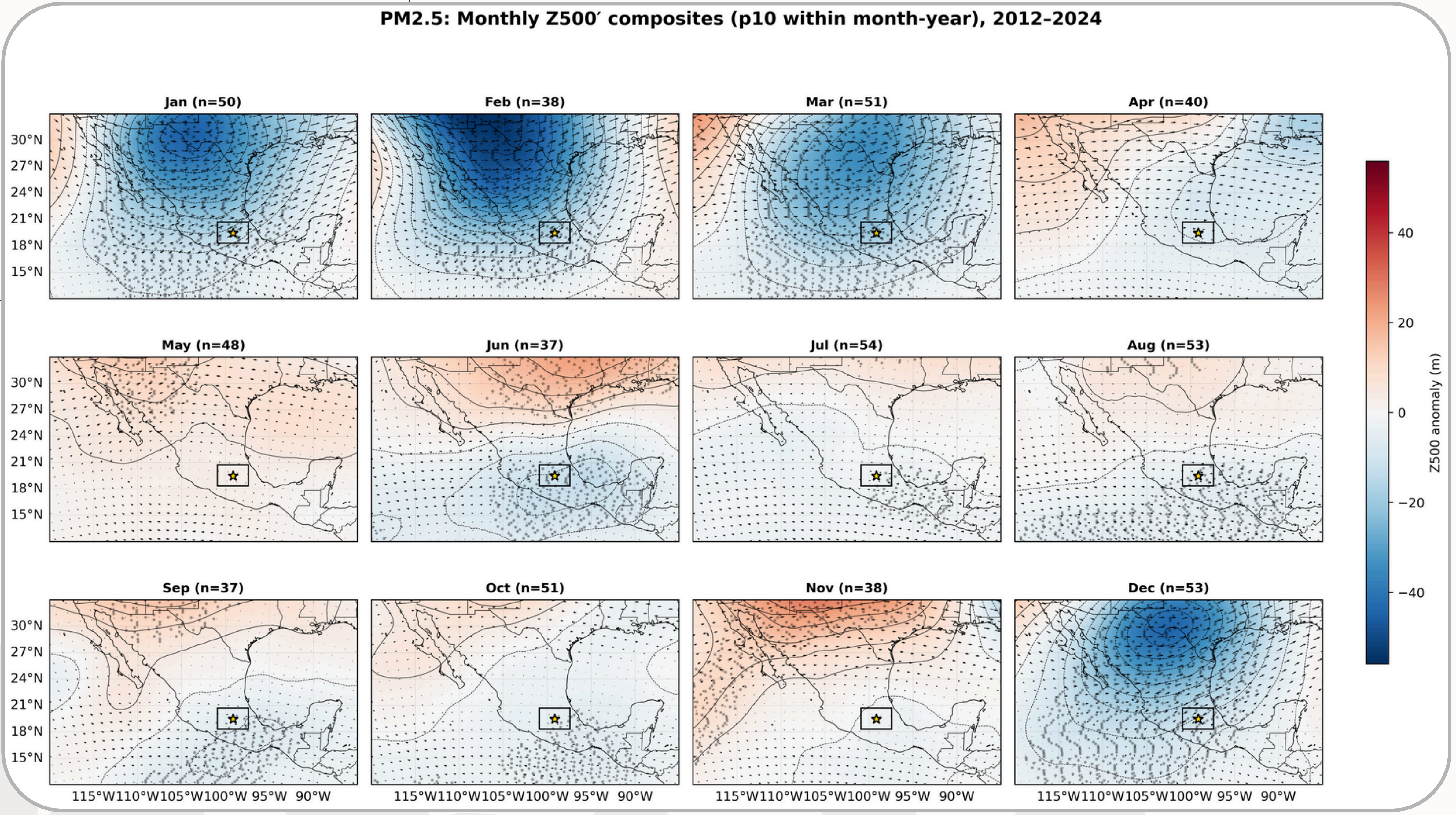
- Dry-season dominance: p90 PM10 also aligns with ridging / higher Z500′ patterns → reduced dispersion is a common ingredient.
- Compared to PM2.5: PM10 shows more month-to-month variability, suggesting stronger sensitivity to local resuspension + regional transport.
- Takeaway: high PM10 episodes still look synoptically “stagnation-like”, but with a less uniform signature than PM2.5.



p10 low-pollution events

p10 (PM2.5): Z500′ monthly composites

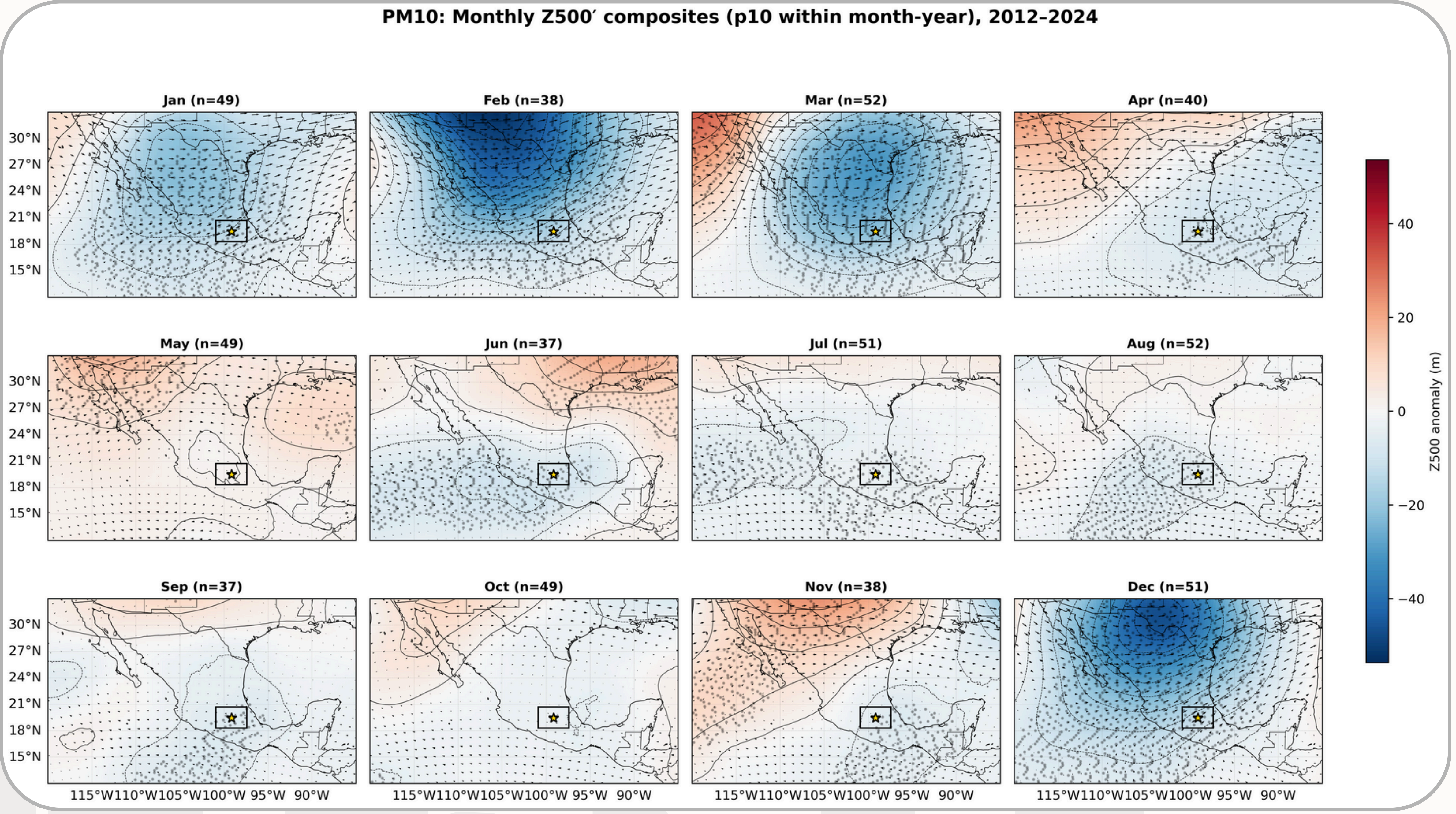
- Opposite regime to p90: many months show negative Z500′ / troughing patterns → enhanced ventilation and less stable conditions.
- Flow implication: stronger synoptic forcing tends to support mixing/advection, consistent with cleaner PM2.5 days.
- Usefulness: p10 acts as a contrast baseline, helping confirm that p90 patterns are not just "monthly climatology noise."



p10 low-pollution events

p10 (PM10): Z500′ monthly composites

- Ventilation signature: p10 PM10 commonly aligns with lower Z500′ and more dynamic flow → conditions favoring dispersion.
- Seasonal contrast: the p10 vs p90 difference is clearest in winter–spring, when synoptic control on PM is strongest.
- Takeaway: PM10 “clean days” may reflect both meteorology and reduced resuspension/transport, so the pattern can vary by month.



p90 vs p10

summary + section conclusions

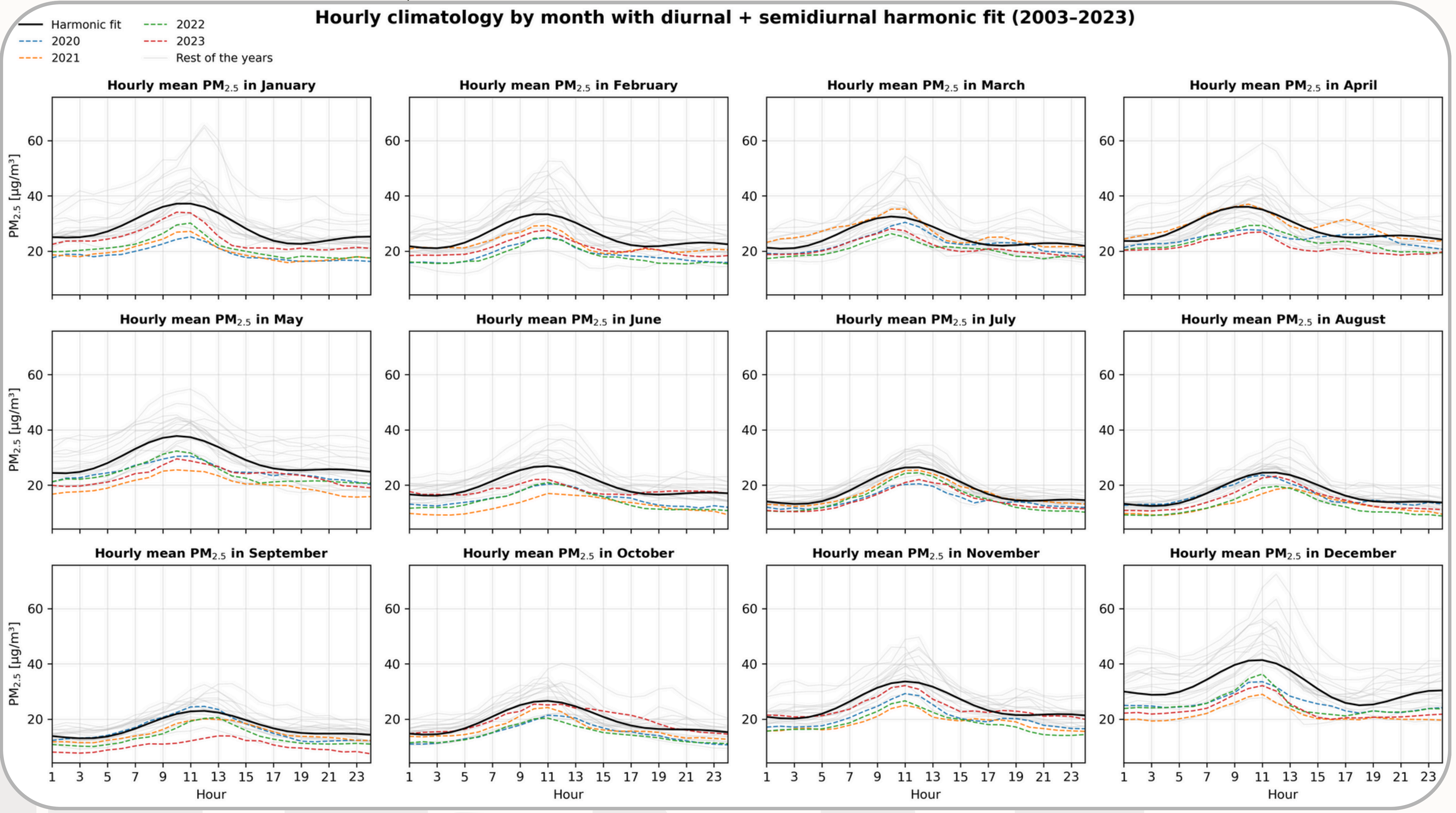
- Definition: p90 = high tail (episodes), p10 = low tail (clean baseline).
- Sample size: both give balanced counts across months (vs NOM extremes later).
- Synoptic signal: p90 ≈ ridging/stagnation; p10 ≈ troughing/ventilation.
- PM2.5 vs PM10: PM2.5 is more consistent; PM10 shows more variability (likely more local/regional influences).
- p10 provides a useful “mirror test”: patterns are broadly opposite to p90 → supports physical consistency.
- Results point to dry-season months as the main window for focused composites in Stage 2.

Diurnal + semidiurnal harmonics from RAMA hourly data

Diurnal structure (24 h + 12 h harmonics)

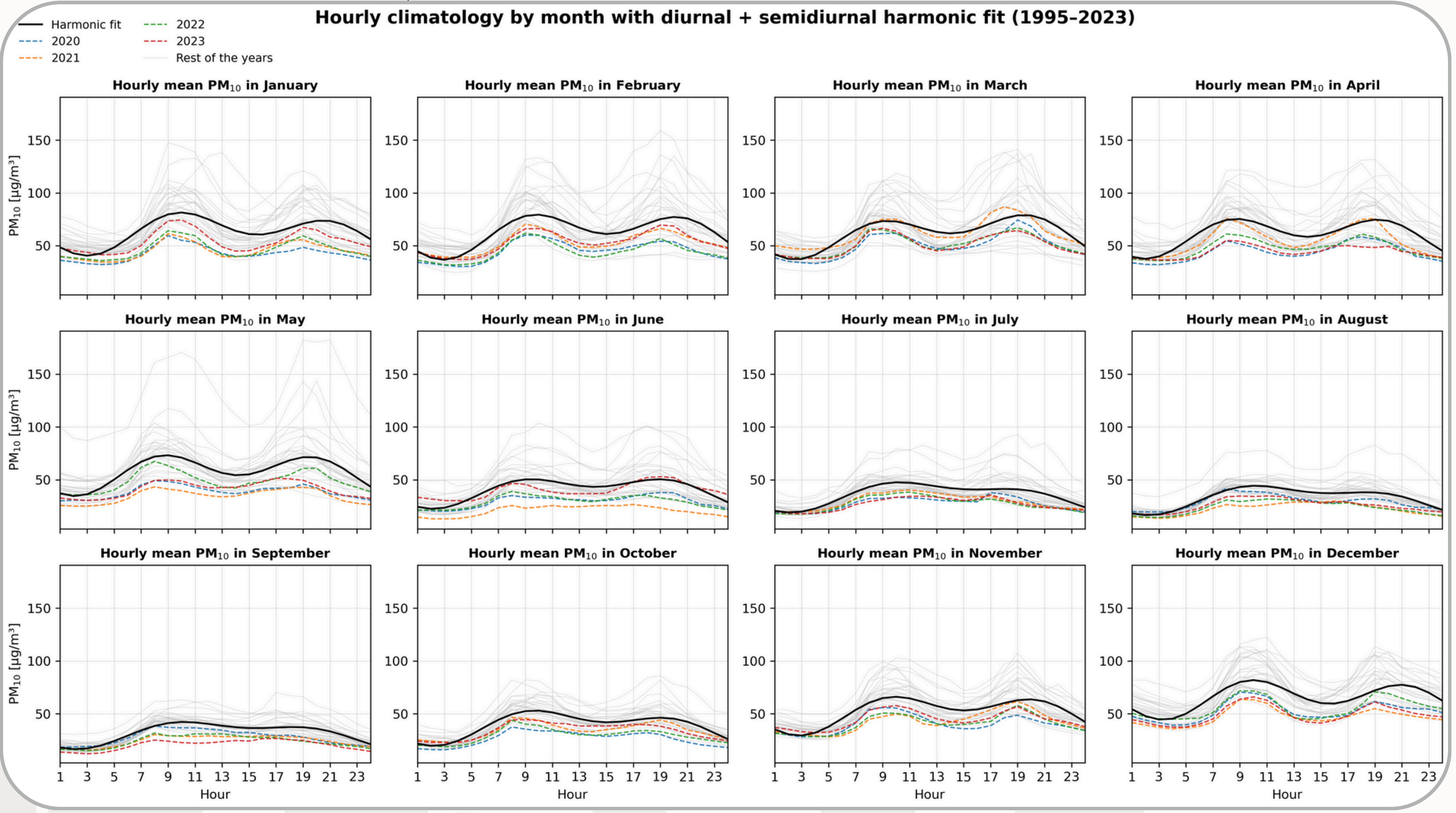
- Goal: characterize the typical within-day cycle to identify peak hours relevant for hourly-based event definitions.
- Approach: build hourly climatology by month, then fit diurnal (24 h) + semidiurnal (12 h) harmonics.
- Why it matters: extreme PM can be sensitive to rush-hour peaks and boundary-layer evolution, which daily averages can hide.

PM2.5 hourly climatology + harmonics



- Clear diurnal cycle: main peak occurs in the morning-midday window, with month-to-month amplitude changes.
- Dry-season amplification: higher levels and stronger structure in winter months, consistent with shallower mixing + weaker dispersion.
- Fit quality: the harmonic curve captures the dominant daily shape, supporting its use for timing diagnostics.

PM10 hourly climatology + harmonics



- More pronounced structure: PM10 shows a stronger diurnal amplitude, often with two-peak behavior (traffic + evening stabilization).
- Seasonality: the largest amplitudes appear in dry-season months, matching known ventilation/resuspension sensitivity.
- Interpretation: suggests PM10 extremes may be especially tied to hour-of-day processes plus synoptic background.

Annual + semiannual harmonics on daily series

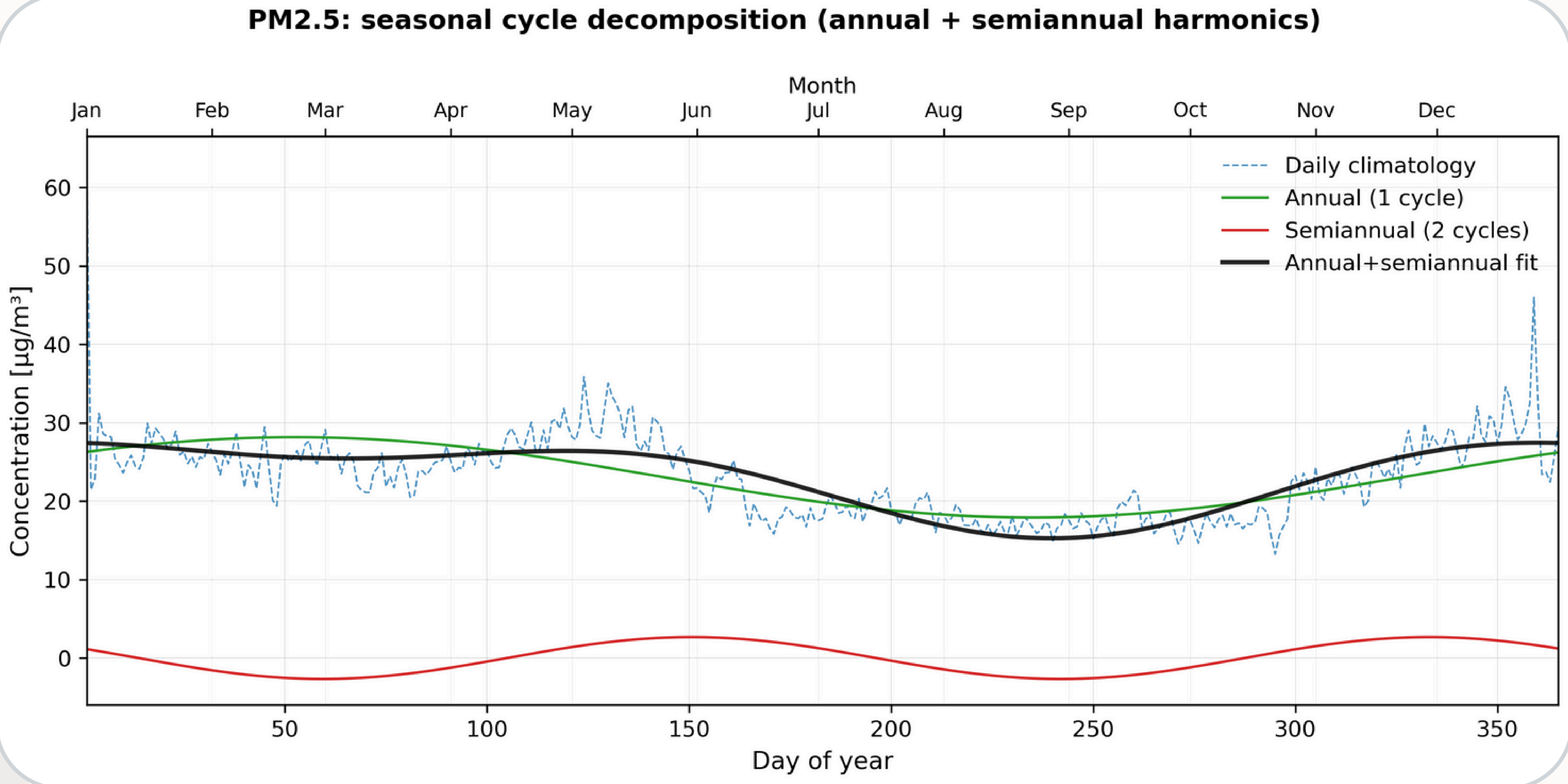
Seasonal cycle (365 d + 182.5 d harmonics)

- Goal: quantify the seasonal baseline to support month/season targeting and interpret when extremes are most plausible.
- Approach: compute daily climatology (day-of-year) and fit annual + semiannual harmonics.
- Use: provides a compact summary of seasonality strength (and whether a single annual wave is enough).

PM2.5 seasonal harmonics

(annual + semiannual)

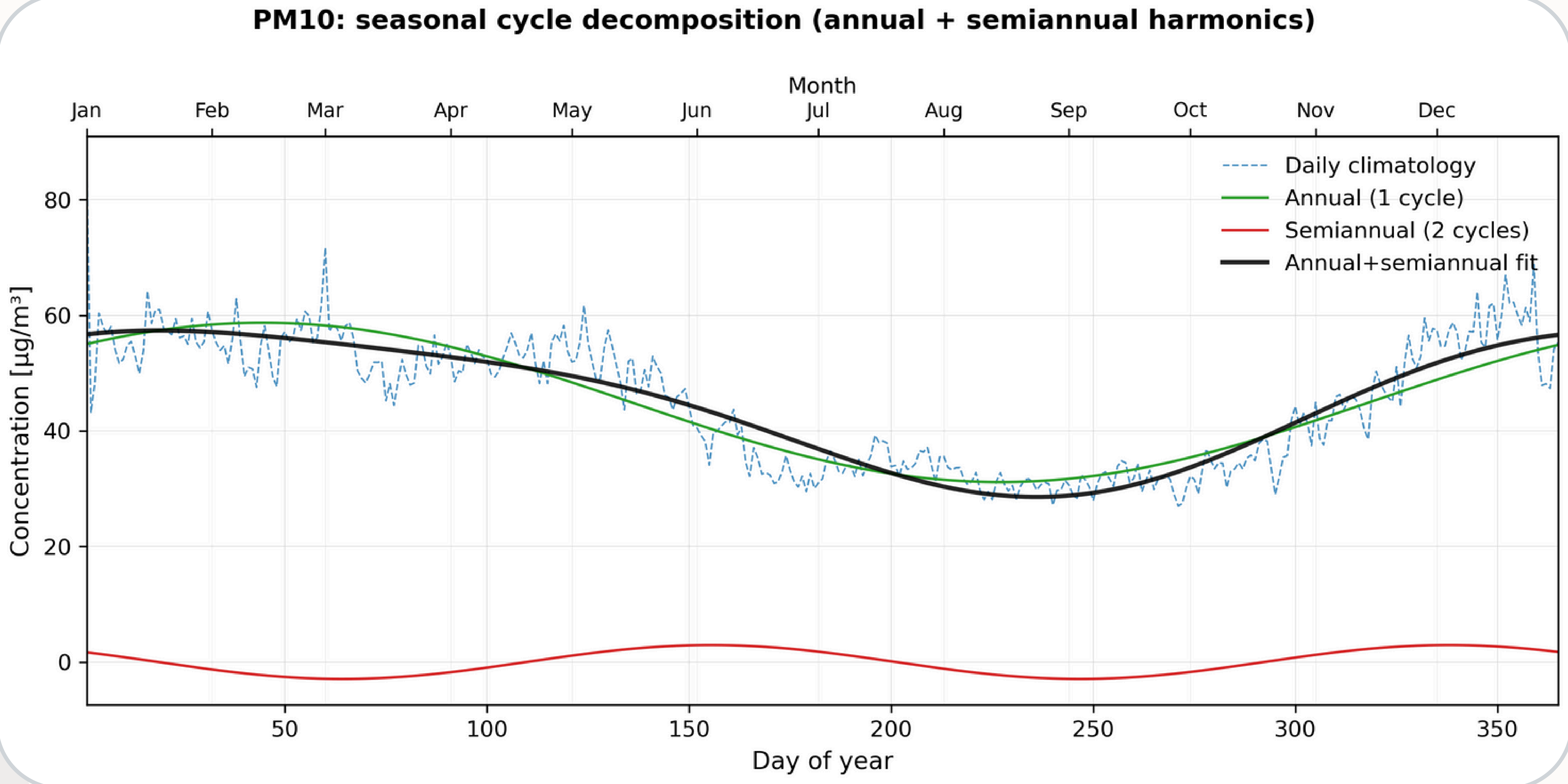
- Strong annual cycle: clear dry-season high / wet-season low behavior dominates the baseline.
- Semiannual is minor: the semiannual component is small, implying one main seasonal peak explains most variability.
- Implication: supports focusing Stage 2 on DJF–AM for PM2.5 synoptic composites.



PM10 seasonal harmonics

(annual + semiannual)

- Annual dominates, but noisier: PM10 follows the same dry-season enhancement, with larger day-to-day spread.
- Semiannual still small: secondary cycle exists but remains weak compared to the annual component.
- Implication: PM10 seasonality is strong, but extremes may reflect added local/regional processes beyond seasonal forcing.



NOM-172 NowCast12h thresholds (event definition from RAMA hourly)

Event definition

- Why NowCast: 24 h averages are “late”; NowCast provides a preventive, near-real-time approximation using the last 12 hours.
- Core math (Anexo A idea): compute a weighted 12 h moving average where weights depend on recent variability (stable → weights similar; rapidly changing → recent hours get more weight).
- Workflow here: compute NowCast12h → assign 2026 categories → export event-day CSVs → feed directly into monthly composites + event counts.

NOM event counts

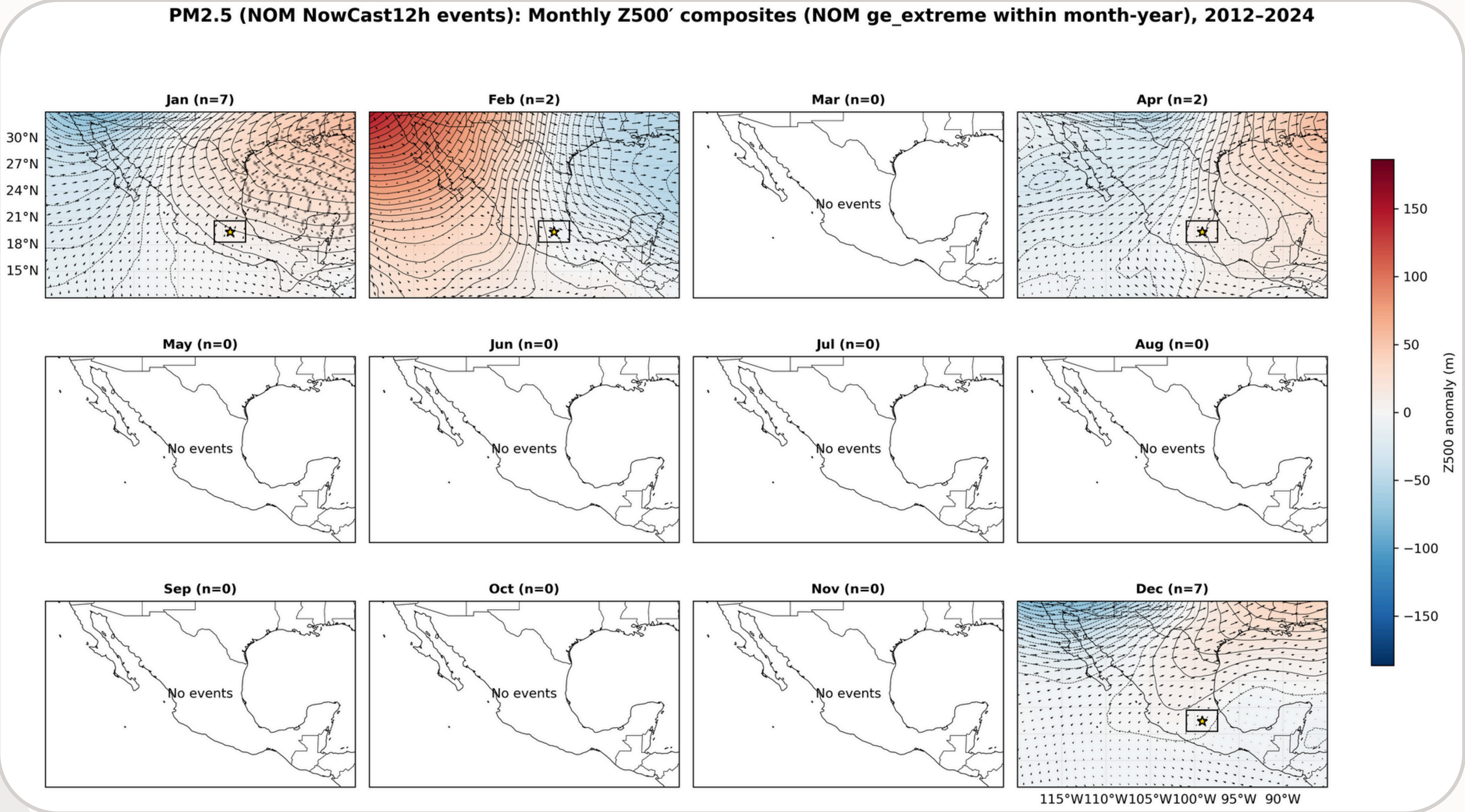
(≥ Extremely Poor, 2012–2023)

- PM10 is much more frequent than PM2.5 at the "Extremely Poor" level (PM10: 70 vs PM2.5: 18).
- Strong seasonality: events concentrate in DJF + early spring; many months are zero-event months.
- Interpretation: NOM extremes are rare by design, so composites will be sparse but policy-relevant.

NOM composites

(PM2.5, ≥ Extremely Poor)

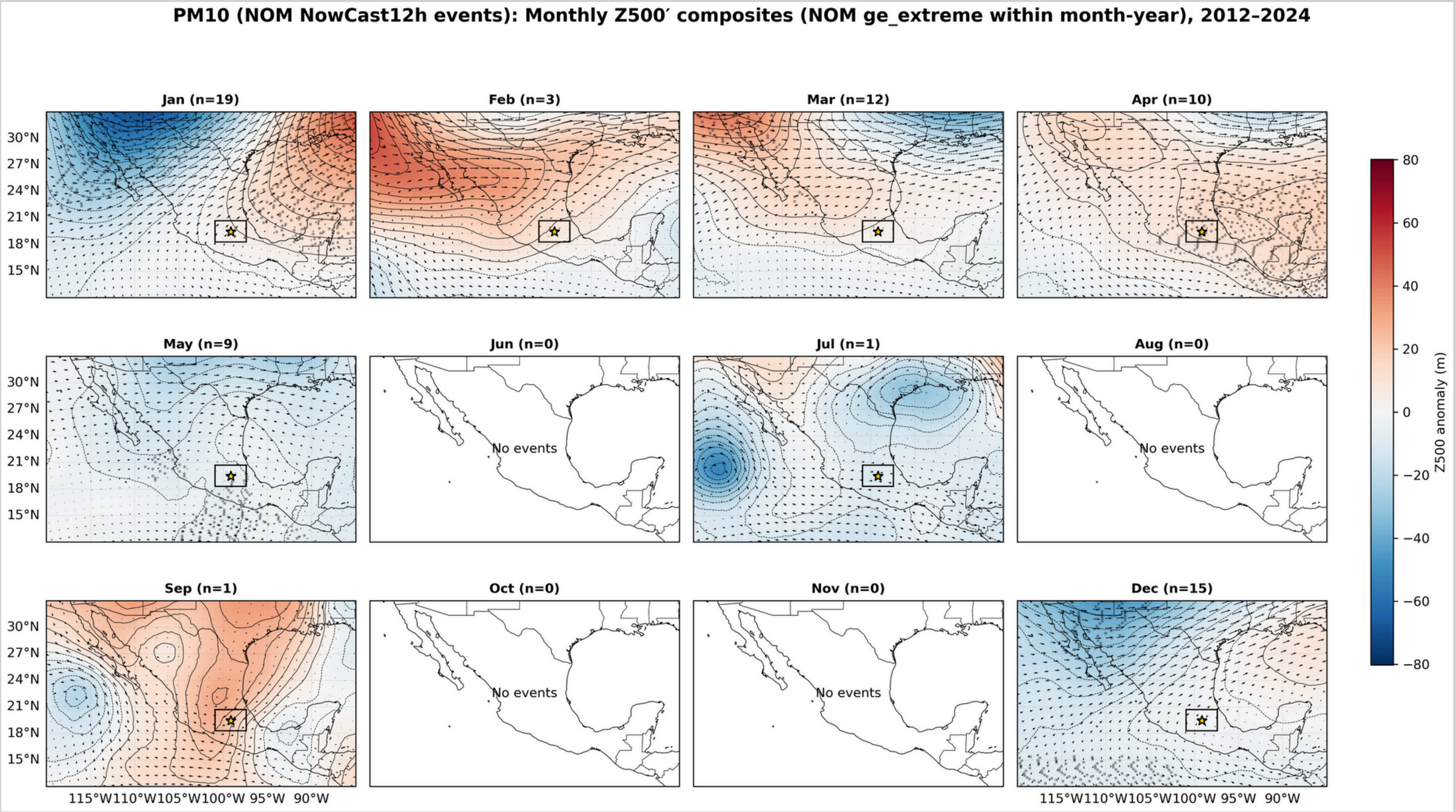
- Very sparse sampling: signal is concentrated in Jan/Feb/Apr/Dec → interpretation should be month-specific (n is small).
- Winter patterns dominate: composites suggest extremes occur under dry-season synoptic backgrounds that limit dispersion.
- Usefulness: helps identify which months are even feasible for threshold-based synoptic analysis.



NOM composites

(PM10, ≥ Extremely Poor)

- More events than PM2.5: still seasonal, but PM10 provides enough winter cases to see structured patterns.
- Mixed synoptic flavors: some months look ridge/stagnation-like, others reflect regional flow anomalies, consistent with PM10's broader sensitivity.
- Note: months with n≈0–1 are illustrative only, not stable composites.



Percentiles vs NOM thresholds (conceptual comparison)

- Percentiles (p90/p10): relative extremes → balanced sample sizes across months; good for exploring consistent synoptic fingerprints.
- NOM NowCast thresholds: absolute health-based extremes → rare + highly seasonal, but directly linked to policy/alerts.
- Stage 2 decision point: choose definition based on the trade-off between physical interpretability + sample size (percentiles) vs regulatory relevance (NOM).

Next Steps

(Stage 1.2 → Stage 2.1)

- Finalize dataset choice (daily city-mean vs RAMA-based; temporal coverage vs representativeness)
- Finalize event definition (percentile vs NOM threshold; daily vs hourly applicability)
- Seasonal/monthly stratification + baseline episode climatology (counts, frequency, basic severity)
- Re-run composites only for episode-active months, then start preliminary interpretation

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thank you!