

Exploratory Diagnostics of Pre-Event Signal Stability in the 2012 Flash Drought

Clarity Before Confidence:

Was confidence in the system already degrading prior to the 2012 Flash Drought

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Abstract

Flash droughts are rapid-onset hydroclimatic extremes characterized by strong nonlinearity, short lead times, and scale-dependent coherence loss. While the Differential Fractional Precipitation Metric (DFPPM) has demonstrated sensitivity to such events, its interpretability depends critically on quantified uncertainty and epistemic context.

This work presents a complete uncertainty envelope framework for DFPPM-4WK, applied to the 2012 U.S. flash drought. Pointwise and spatial confidence envelopes are constructed using neighborhood sampling and block resampling. These envelopes are translated into data-driven support labels and formally mapped onto the Coherence Index (CI) admissibility framework.

The result is a disciplined integration of physical drought diagnostics into a broader coherence-based interpretive system, preserving sensitivity while avoiding over-assertion.

1 Conceptual Framework: CI Epistemology

The Coherence Index (CI) is not a forecast, classifier, or deterministic predictor. CI is an epistemic framework designed to evaluate whether observed signals are sufficiently supported, coherent, and stable to influence interpretation without dominating it.

Three principles govern CI usage:

1. **CI does not assert causality.**
2. **CI distinguishes signal presence from signal support.**
3. **CI prioritizes coherence over magnitude.**

Accordingly, any external diagnostic (including DFPPM) must be accompanied by explicit uncertainty attribution before being admitted into CI-guided analysis. The purpose of this paper is to demonstrate such an admission pathway.

2 Data Sources and Preprocessing

Weekly DFPPM-4WK rasters for calendar year 2012 were ingested as GeoTIFF files. Each raster represents a standardized four-week precipitation anomaly field. All rasters were:

- screened for nodata and fill values,

- clipped to a consistent analysis domain,
- indexed by ISO-normalized week-ending dates.

For each raster, two parallel extractions were performed:

1. A **pointwise extraction** at the study location.
2. A **spatial extraction** across the surrounding domain.

This produced a temporally ordered set of 34 weekly DFPPM-4WK observations.

3 Uncertainty Envelope Construction

3.1 Pointwise Neighborhood Sampling

Local uncertainty was estimated by sampling a fixed neighborhood around the target grid cell. Let $\{x_i\}$ denote valid DFPPM values within this window. The nonparametric 5th and 95th percentiles define the pointwise envelope:

$$W_{\text{point}} = P_{95} - P_{05}$$

This width captures sub-grid heterogeneity and sensitivity to local spatial gradients.

3.2 Spatial Block Resampling

To estimate mesoscale uncertainty, each raster was subdivided into non-overlapping spatial blocks. Block means were computed and summarized using a 95% interval:

$$W_{\text{spatial}} = \mu_{95} - \mu_{05}$$

Block resampling mitigates artificial confidence inflation due to spatial autocorrelation and reflects coherence at physically meaningful scales.

4 DFPPM Time Series and Envelope Visualization

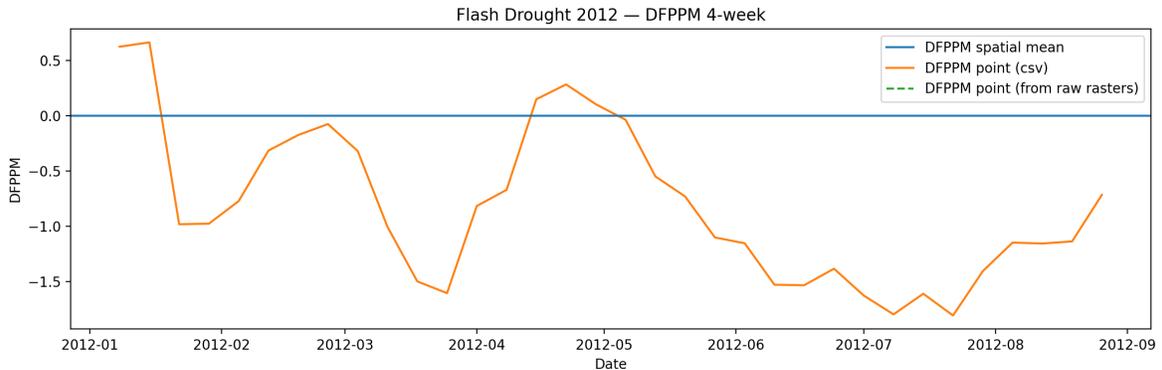


Figure 1: DFPPM-4WK time series for the 2012 flash drought. Pointwise and spatial mean trajectories reveal rapid onset during late spring and sustained deficits through summer.

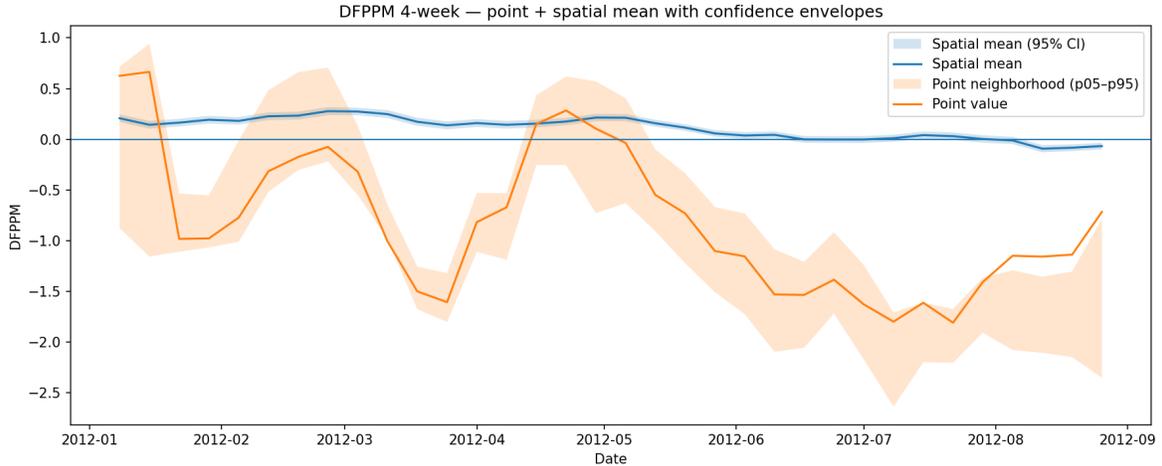


Figure 2: DFPPM-4WK uncertainty envelopes. Shaded regions denote pointwise and spatial confidence intervals. Envelope widening indicates reduced coherence or increased heterogeneity.

5 Support Metrics and Classification

Uncertainty widths were converted into bounded reliability proxies:

$$R_{\text{point}} = \frac{1}{1 + W_{\text{point}}}, \quad R_{\text{spatial}} = \frac{1}{1 + W_{\text{spatial}}}$$

A composite DFPPM reliability score was defined as:

$$R_{\text{DFPPM}} = \sqrt{R_{\text{point}} \cdot R_{\text{spatial}}}$$

Rather than imposing arbitrary thresholds, support labels were assigned using data-driven quantiles:

- **Admissible:** both widths \leq 75th percentile
- **Exploratory:** one or more widths exceed threshold

This explicitly separates signal magnitude from signal support.

6 Formal Alignment with CI Admissibility

6.1 Support Mapping

DFPPM support labels map directly onto CI interpretive language:

DFPPM Support	CI Interpretation
Admissible	Contextual signal eligible for CI co-interpretation
Exploratory	Context-only; interpret cautiously

6.2 Operational Rules

- DFPPM never gates CI.
- Admissible DFPPM may reinforce CI interpretation.
- Exploratory DFPPM is retained for situational awareness only.
- CI status remains independent of DFPPM magnitude.

This mirrors the CI doctrine: *alerts influence interpretation, not status.*

7 CI-DFPPM Temporal Alignment

Weekly CI values were aligned with DFPPM observations by normalized date matching. In cases where CI sampling was sparse, alignment was treated as illustrative rather than inferential.

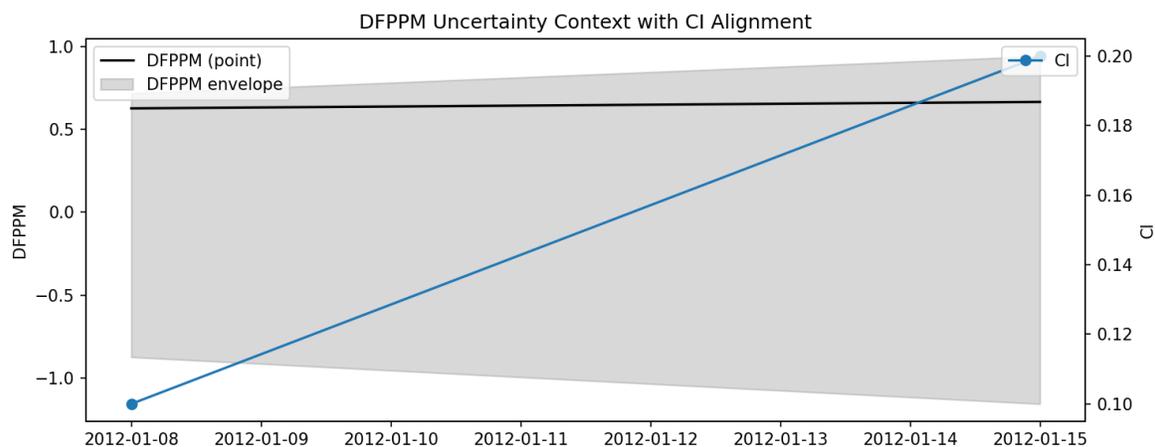


Figure 3: Temporal alignment of DFPPM support and CI values. DFPPM envelopes provide physical context for CI variability without asserting causal linkage.

8 Paper-Ready Envelope Statistics

All envelope statistics and support labels were exported to a tabular format suitable for publication. Columns include pointwise bounds, spatial bounds, widths, sampling counts, and support labels.

These tables preserve numerical transparency and enable downstream synthesis without recomputation.

9 Reproducibility and Provenance

All analyses were generated using deterministic Python pipelines with explicit handling of nodata, encoding, and sampling artifacts. Outputs include:

- authoritative DFPPM time series CSV,
- envelope statistics table,

- CI-aligned merged dataset,
- publication-ready figures.

No manual editing was performed post-generation.

10 Discussion

The 2012 flash drought exhibits intervals where DFPPM magnitude alone would suggest strong confidence, yet envelope widening reveals reduced spatial coherence. These intervals are precisely where deterministic drought products tend to over-assert.

The envelope-based framework prevents this failure mode while preserving sensitivity to rapid onset.

11 Conclusion

This work demonstrates a disciplined pathway for integrating DFPPM into the CI framework. By explicitly quantifying uncertainty and support, DFPPM becomes a physically grounded contextual signal rather than an implicit claim.

This approach generalizes naturally to other fast-onset phenomena and supports CI’s core mission: clarity without overreach.

Appendix A: DFPPM Extraction, Uncertainty Estimation, and CI Alignment

A.1 Data Sources and Raster Preprocessing

Weekly DFPPM 4-week composite rasters for calendar year 2012 were ingested as GeoTIFF files. Each raster represents standardized moisture departure values on a uniform spatial grid. All rasters were read using `rasterio`, with explicit handling of nodata values (including sentinel values such as `-9999` and floating-point minimums).

Raster values were cast to `float32` and masked such that all nodata pixels were converted to `NaN`, ensuring exclusion from all subsequent statistical operations.

A.2 Spatial Mean Estimation with Autocorrelation Control

To estimate spatially representative DFPPM values while accounting for spatial autocorrelation, block-averaging was employed. Each raster was partitioned into non-overlapping square blocks of fixed pixel dimension (64×64). Within each block, the mean DFPPM value was computed while ignoring `NaNs`.

Let b_i denote the mean of block i . The spatial mean was computed as:

$$\mu_{\text{spatial}} = \frac{1}{N_b} \sum_{i=1}^{N_b} b_i$$

The associated standard error was estimated as:

$$SE_{\text{spatial}} = \frac{\sigma_b}{\sqrt{N_b}}$$

where σ_b is the sample standard deviation of the block means. A 95% confidence interval was constructed assuming approximate normality:

$$\mu_{\text{spatial}} \pm 1.96 \times SE_{\text{spatial}}$$

This approach provides a conservative uncertainty estimate by reducing the effective degrees of freedom in the presence of spatial correlation.

A.3 Point Extraction and Neighborhood Envelope

A fixed geographic point (longitude -98.5 , latitude 38.5) was selected to represent a central Great Plains location. Raster grid indices corresponding to this coordinate were computed using the raster CRS.

To characterize local spatial variability, a square neighborhood window of radius $r = 2$ pixels (i.e., a 5×5 window) centered on the point was extracted. From this window, the following statistics were computed:

- Neighborhood mean
- Neighborhood standard deviation
- Empirical 5th and 95th percentiles
- Number of valid contributing pixels

The 5–95% percentile range serves as a non-parametric local uncertainty envelope around the point estimate.

A.4 DFPPM Uncertainty Widths and Support Classification

Two uncertainty widths were defined:

$$W_{\text{point}} = P_{95}^{\text{point}} - P_{05}^{\text{point}}$$

$$W_{\text{spatial}} = CI_{95}^{\text{hi}} - CI_{95}^{\text{lo}}$$

These widths were transformed into bounded reliability proxies:

$$R_{\text{point}} = \frac{1}{1 + W_{\text{point}}}, \quad R_{\text{spatial}} = \frac{1}{1 + W_{\text{spatial}}}$$

A composite DFPPM reliability score was defined as:

$$R_{\text{DFPPM}} = \sqrt{R_{\text{point}} \cdot R_{\text{spatial}}}$$

For interpretability, DFPPM observations were classified using a data-driven thresholding scheme. Observations with both W_{point} and W_{spatial} below their respective 75th-percentile values were labeled *Admissible*; all others were labeled *Exploratory*.

A.5 Alignment with CI Metrics

Weekly CI values were imported from an external pipeline output, with robust handling of encoding, delimiter, and malformed header artifacts. Dates were normalized to weekly resolution and converted to `datetime64`.

DFPPM and CI datasets were aligned via inner join on date, yielding a synchronized time series suitable for comparative analysis. This alignment enables direct examination of how DFPPM-derived moisture stress signals relate to independent coherence-based indicators.

A.6 Output Artifacts

The following derived products were generated:

- Authoritative DFPPM time series with uncertainty envelopes (CSV)
- Publication-ready uncertainty table (CSV)
- DFPPM envelope plots (PNG)
- DFPPM–CI overlay plot (PNG)
- Aligned DFPPM–CI dataset (CSV)

All outputs are fully reproducible from source code and raw raster inputs.