An Universal and Index-Agnostic Bitemporal Indicator for Unsupervised Enviromental Change Detection from Multispectral Satellite Data

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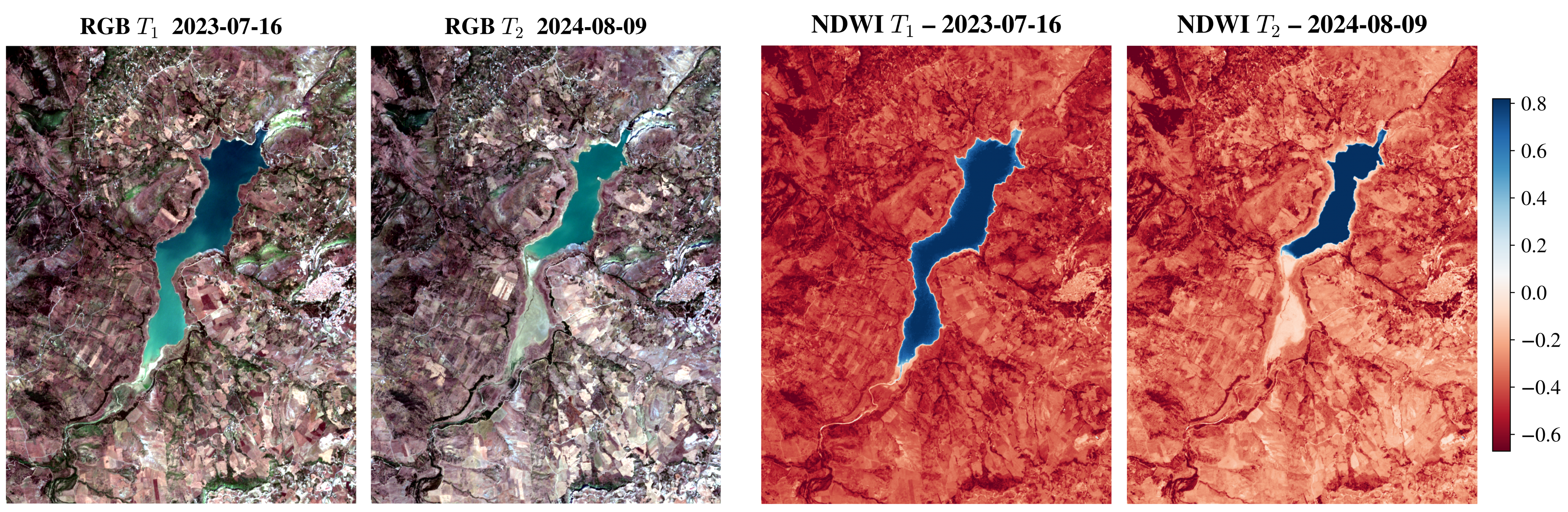
Introduction

Earth Observation monitoring is often hindered by the scarcity of ground-truth data required for Deep Learning [1], while traditional unsupervised methods struggle with radiometric and seasonal noise [2]. To bridge this gap, we introduce the **Bitemporal Spatial Autocorrelation (BSAC)** framework. Assuming stable landscapes preserve their spatial dependence [3], BSAC quantifies change through the *loss of symmetry* in the autocorrelation matrix across multiple lags.

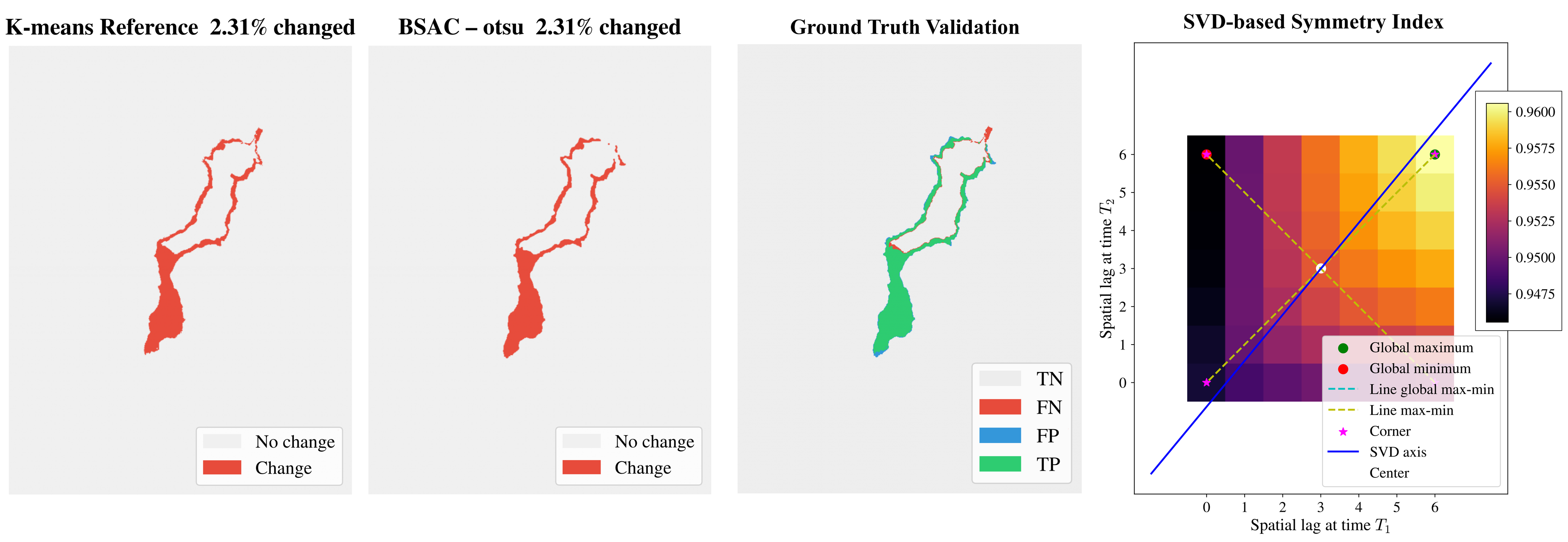
Validated across diverse environmental scenarios and showcased here on the 2024 desiccation of *Lake Rosamarina* near Caccamo (PA - Italy), this index-agnostic framework leverages sparse-matrix operations to achieve high computational scalability. By extracting three reproducible, training-free change metrics, BSAC equips National Statistical Offices with a robust, fully unsupervised tool for environmental reporting in data-scarce regions [4].

Results

A. Input Data – Lake Rosamarina, Sicily (Italy)



B. Change Maps and Change Detection via BSAC



C. Comparison and Results Metrics

Confusion Matrix – Percentages

	Predicted: No Change	Predicted: Change
Actual: No Change	97.5%	0.2%
Actual: Change	0.2%	2.1%

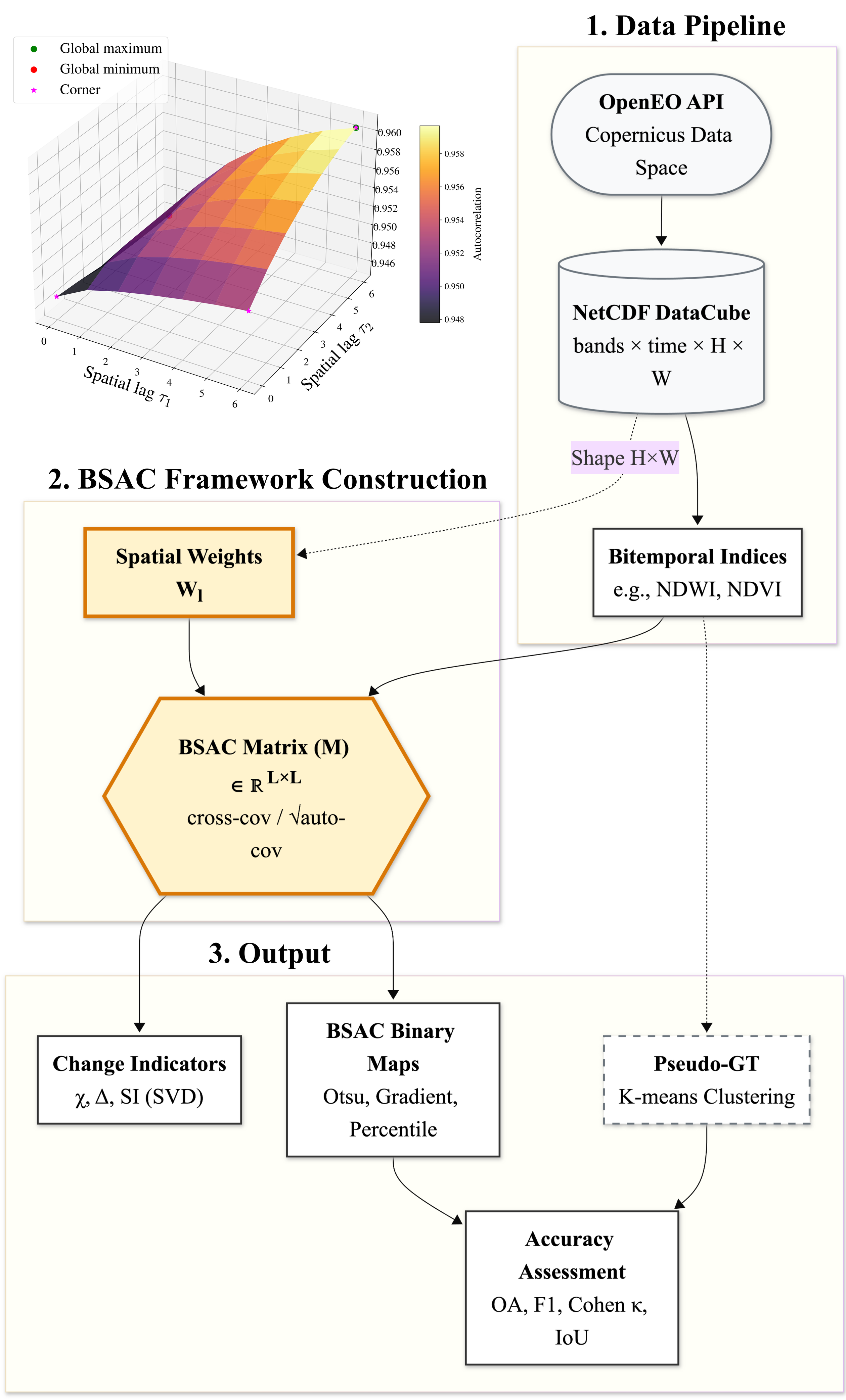
Metrics Heatmap

	OA	Precision	F1	Kappa	IoU	MCC
BSAC otsu	0.996	0.920	0.918	0.916	0.849	0.916
CVA	0.726	0.072	0.134	0.095	0.072	0.209
IR-MAD	0.951	0.306	0.452	0.432	0.292	0.497
ISFA	0.866	0.147	0.256	0.225	0.147	0.356
PCA-KMeans	0.734	0.074	0.136	0.098	0.073	0.212

Conclusions & Future Work

- **Unsupervised & Index-Agnostic**: Quantifies structural shifts without training data, operating on any pre-computed multispectral index.
- **Robustness**: Outperforms classical statistical methods by intrinsically filtering radiometric noise and artifacts.
- ***Future Work* - SAR Fusion**: Extending to multi-modal tensor fusion with Sentinel-1 SAR

BSAC Matrix Pipeline



Methodological Core

1. Topological Projection

Maps spectral index $\boldsymbol{z_t}$ into L spatial scales via sparse Moore adjacency matrix $\boldsymbol{W}$ as $\tilde{\boldsymbol{z}}_t^{(l)} = \boldsymbol{W}_l \boldsymbol{z_t}$ [5]

2. Bitemporal Spatial Autocorrelation Matrix

Encodes cross-scale structural predictions, capturing macroscopic landscape shifts and isolating local pixel-level fluctuations:

$$M[l,k] = \frac{Cov(\tilde{\boldsymbol{z}}_{t_1}^{(l)}, \tilde{\boldsymbol{z}}_{t_2}^{(k)})}{\sigma\left(\tilde{\boldsymbol{z}}_{t_1}^{(l)}\right)\sigma\left(\tilde{\boldsymbol{z}}_{t_2}^{(k)}\right)}$$

3. Symmetry Breaking Indicators

Quantifies topological disruption via three metrics

a. **Stability Trigger ($\chi \in \{0,1\}$):** Flags non-stationary events (diagonal dominance violation).

b. **Asymmetry Magnitude Δ:** Measures change severity: $\Delta = \frac{1}{L}\,||\mathcal{M} - \mathcal{M}^T||_F$

c. **Symmetry Index ($\boldsymbol{SI} \in [0,1]$):** Evaluates structural self-similarity via SVD, measuring the angular deviation of the principal axis from the diagonal.

References

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