

Local ETM+ to OLI EVI Harmonisation in Tropical Forest Environments

Methodological Research Report

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Abstract

This report evaluates ETM+ to OLI EVI harmonisation in tropical forest environments using 8,988,291 paired observations. Results show strong linear correspondence but substantial acquisition-to-acquisition variability. The empirical relationship differs markedly from the CONUS-derived framework of Roy et al. (2016), indicating that its direct application is not supported under the investigated tropical conditions. contesto, la cartografia tradizionale, caratterizzata da un'integrazione solida con altri strumenti digitali, può offrire un grandissimo contributo.

Keywords

EVI; cross-sensor harmonisation; sensor continuity; surface reflectance; vegetation indices; radiometric calibration; tropical forests; atmospheric correction; Landsat Collection 2; empirical calibration

1. Introduction

Long-term vegetation monitoring from satellite observations requires radiometric and spectral continuity across successive sensor generations. Where observations from different instruments are combined into a single temporal record, systematic differences in spectral response, radiometric calibration, atmospheric correction, and surface reflectance retrieval may propagate into derived vegetation indices and be incorrectly interpreted as changes in vegetation condition. Cross-sensor harmonisation is therefore a fundamental methodological requirement when constructing multi-decadal records from Landsat observations. The transition between the Enhanced Thematic Mapper Plus

(ETM+) and the Operational Land Imager (OLI) is of particular relevance because the two instruments employ different spectral response functions and radiometric characteristics. Although their corresponding spectral bands are sufficiently similar to permit continuity, direct comparison of surface reflectance or vegetation-index observations can retain systematic sensor-dependent differences. Empirical transformation functions have consequently been developed to minimise these differences and facilitate the integration of observations acquired by successive sensors.

A widely cited reference for ETM+ to OLI continuity is Roy et al. (2016), who characterised Landsat-7 ETM+ to Landsat-8 OLI reflective-band relationships using approximately 59 million observations distributed across the contiguous USA (CONUS). Their analysis provides an important general framework for cross-sensor transformation and demonstrated strong empirical relationships between corresponding ETM+ and OLI observations. However, the coefficients derived from that analysis are inherently conditioned by the environmental and observational characteristics represented within its calibration domain. Their transfer to substantially different environments therefore constitutes an empirical assumption rather than a demonstrated property of the sensor relationship.

This consideration is particularly relevant for tropical forest systems. Tropical seasonally dry forests exhibit combinations of canopy architecture, vegetation density, phenological variability, exposed soil background, and surface moisture conditions that differ substantially from many environments represented within the CONUS calibration domain. In addition, tropical atmospheric conditions may introduce different aerosol and water-vapour regimes and consequently affect the performance and residual behaviour of surface-reflectance retrieval algorithms. These factors may influence the relationship between corresponding ETM+ and OLI observations even where the underlying surface is nominally unchanged. EVI is especially sensitive to such considerations because it combines near-infrared, red, and blue surface reflectance through a non-linear formulation designed to reduce atmospheric and background influences while retaining sensitivity to vegetation structure and canopy density. Consequently, continuity at the individual reflectance-band level does not necessarily guarantee equivalent continuity of the derived EVI. A transformation validated for reflectance continuity in one environmental domain should therefore not automatically be assumed to provide optimal EVI continuity in another.

The present study addresses this issue through a geographically constrained empirical assessment of ETM+–OLI EVI correspondence within a defined tropical forest study domain. Near-coincident acquisitions were identified for a common WRS-2 Path/Row and subjected to explicit pixel-level quality-control criteria designed to retain observations suitable for cross-sensor comparison. EVI was calculated independently from Collection 2 Level-2 surface reflectance for each sensor, and the resulting paired observations were evaluated using regression, residual, and inter-acquisition analyses.

2. Method summary

2.1 Study-domain and scene selection

The analysis was conducted within a defined tropical forest study domain intersecting WRS-2 Path 009, Row 053. Candidate ETM+ and OLI acquisitions were identified through a SpatioTemporal Asset Catalog (STAC) query against the Landsat Collection 2 Level-2 archive. Scene discovery was constrained to the common operational period of ETM+ and OLI and to the selected WRS-2 Path/Row, with no preliminary cloud-cover

threshold imposed during the initial inventory. Near-coincident ETM+–OLI acquisition pairs were subsequently identified using a maximum temporal separation of 16 days. This interval encompasses the nominal eight-day acquisition offset between the two sensors while allowing all temporally adjacent observations within the same Landsat repeat-cycle structure to be evaluated. Candidate pairs were subsequently ranked according to acquisition-level cloud-cover metadata, while final pixel eligibility was determined independently using the explicit quality-control procedure described below.

2.2 Spatial registration and preprocessing

The corresponding ETM+ and OLI observations were processed on their native Level-2 surface-reflectance grids. The spatial correspondence of the two grids over the selected WRS-2 Path/Row was explicitly verified prior to pixel-wise comparison. No spatial resampling, interpolation, reprojection, or sub-pixel registration adjustment was applied. Both scenes were geometrically cropped to the common study-domain boundary. Consequently, the subsequent comparison was restricted to the spatial intersection of the two acquisitions within the predefined analysis domain. The absence of resampling ensured that any observed differences in EVI were not introduced by an additional spatial transformation step.

2.3 Pixel-level quality control

Pixel eligibility was determined independently for each ETM+–OLI pair using a four-condition quality-control mask. A pixel was retained only when all specified conditions were simultaneously satisfied:

Quality-control variable	Eligibility criterion
ETM+ QA_PIXEL	Exact match to reference clear-land value 5440
OLI QA_PIXEL	Exact match to reference clear-land value 21824
ETM+ SR_ATMOS_OPACITY	< 250
OLI SR_QA_AEROSOL	Value $\in \{64, 66, 96\}$

The quality-control procedure was applied at the individual-pixel level rather than using scene-level cloud-cover metadata as a substitute for pixel screening. Thus, scene-level cloud-cover percentages were used for candidate-pair characterisation and prioritisation, whereas inclusion in the statistical analysis depended exclusively on the predefined pixel-level criteria.

The ETM+ observations considered in this analysis were acquired after the permanent failure of the Scan Line Corrector (SLC) on 31 May 2003. SLC-off data therefore contain systematic acquisition gaps. Pixels corresponding to these gaps are identified as Fill through the `QA\_PIXEL` quality information and are consequently rejected by the pixel-eligibility mask.

2.4 EVI calculation

EVI was calculated independently for the two sensors from Collection 2 Level-2 surface reflectance using the formulation:

$$EVI = 2.5 \times \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + 6\rho_{Red} - 7.5\rho_{Blue} + 1}$$

where ρ_{NIR} , ρ_{Red} and ρ_{Blue} denote atmospherically corrected surface reflectance in the corresponding spectral bands. The Collection 2 Level-2 reflectance values were converted to physical surface-reflectance units using the prescribed multiplicative scale factor and additive offset:

$$\rho = DN \times 0.0000275 - 0.2$$

EVI was calculated only for pixels satisfying the complete quality-control mask. Resulting EVI values were constrained to the interval $[-1, 1]$. No interpolation or gap filling was performed for excluded pixels.

2.5 Pairwise harmonisation analysis

For each eligible ETM+ to OLI acquisition pair, corresponding EVI observations were treated as paired measurements and evaluated using ordinary least-squares regression, with ETM+ EVI as the explanatory variable and OLI EVI as the response variable:

$$EVI_{OLI} = \alpha + \beta EVI_{ETM+} + \varepsilon$$

where α represents the fitted intercept, β the cross-sensor slope, and ε the residual component. Model performance was assessed using the coefficient of determination R^2 , root mean square error (RMSE), mean absolute error (MAE), residual distributions, and the direct paired difference:

$$\Delta EVI = EVI_{OLI} - EVI_{ETM+}$$

Residual behaviour was additionally evaluated across ETM+ EVI intervals to identify systematic departures from a single linear relationship. A quadratic model was evaluated as a diagnostic alternative:

$$EVI_{OLI} = \alpha + \beta_1 EVI_{ETM+} + \beta_2 EVI_{ETM+}^2 + \varepsilon$$

The linear formulation was retained where the additional quadratic term did not provide a substantively meaningful improvement relative to the increased model complexity.

2.6 Candidate-pair screening and final sample

An exhaustive STAC inventory identified ten temporally eligible ETM+–OLI candidate pairs within the specified Path/Row and operational overlap period. Each candidate pair was subsequently subjected to the complete pixel-level quality-control procedure. One candidate pair (ETM+ acquisition: 2016-10-04; OLI acquisition: 2016-09-26) produced no pixels satisfying all four eligibility conditions and was therefore excluded from quantitative analysis. Among the remaining eligible candidates, five pairs with the lowest combined acquisition-level cloud-cover values were selected for full harmonisation analysis.

The resulting dataset comprised 8,988,291 paired EVI observations distributed across the five selected acquisition pairs. All subsequent pooled analyses were performed on these quality-controlled paired observations, while pair-specific analyses were retained to quantify acquisition-to-acquisition variability in the estimated ETM+–OLI relationship.

3. Per-pair results

The five retained ETM+–OLI near-coincident pairs yielded consistently strong linear associations between EVI measurements, with coefficients of determination ranging from 0.875 to 0.919. However, the fitted slopes and intercepts varied between acquisition dates, indicating that the cross-sensor relationship was not invariant across the observation period.

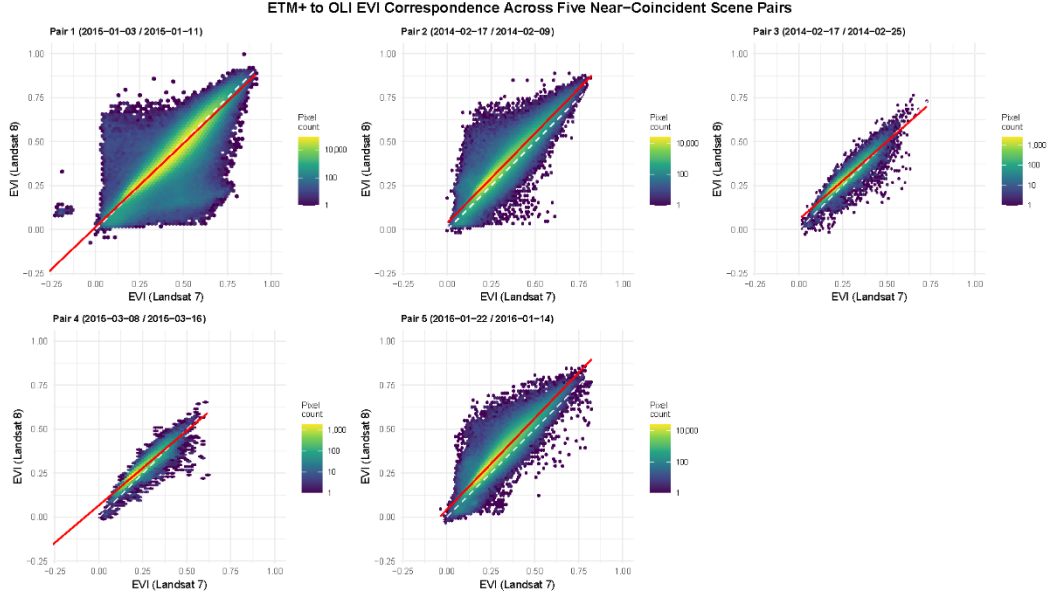


Figure 1. Pixel-density hexbin comparison of native Enhanced Vegetation Index (EVI) values between near-coincident Landsat 7 (ETM+) and Landsat 8 (OLI) scenes across five independent pairs over the Montes de María study area (Path 9, Row 53), acquired 8 days apart within the shared 16-day repeat cycle. Color indicates pixel count per hexagonal bin on a $\log_{10}$ scale (Viridis palette). The white dashed line denotes the 1:1 correspondence; the solid red line shows the ordinary least-squares fit for each pair. Sample sizes range from 38,064 (Pair 4) to 6,763,085 (Pair 1); per-pair fit statistics (slope, intercept, R^2) are reported in Table X. All pixels were restricted to those meeting the exact quality-assurance and low-aerosol/opacity criteria described in Section X (Methods), following Collection 2 Level-2 Surface Reflectance scaling.

Pair	L7 date	L8 date	Gap days	n pixels	R^2	Slope	Intercept	Mean $\Delta(L8-L7)$
pair_01	2015-01-03	2015-01-11	8	6,763,085	0.919	0.9528	0.0143	-0.0063
pair_04	2014-02-17	2014-02-09	8	1,067,302	0.894	1.0221	0.0371	+0.0432
pair_06	2014-02-17	2014-02-25	8	70,910	0.886	0.8829	0.0581	+0.0288
pair_09	2015-03-08	2015-03-16	8	38,064	0.875	0.8490	0.0668	+0.0319
pair_07	2016-01-22	2016-01-14	8	1,048,930	0.911	1.0384	0.0429	+0.0530

Pairs 04 and 06 provide an internal comparison because they use the same ETM+ acquisition (2014-02-17) but different OLI acquisitions, occurring eight days before and after the ETM+ observation, respectively. Despite the identical ETM+ reference scene, the fitted slope changes from 1.0221 to 0.8829 and the mean ΔEVI from +0.0432 to +0.0288. This demonstrates that the observed cross-sensor relationship is sensitive to acquisition-specific conditions and should not be regarded as a single invariant sensor property. Across the five pairs, the linear model provided a strong and parsimonious representation of the observed ETM+ to OLI EVI relationship. The quadratic formulation did not provide a sufficiently substantial improvement in model fit to justify the additional parameter. Consequently, the linear formulation was retained for the subsequent pooled harmonisation analysis:

$$EVI_{OLI} = \alpha + \beta EVI_{ETM+} + \epsilon$$

The observed between-pair variation in α and β was retained as an explicit component of the uncertainty assessment rather than being treated as random measurement noise.

4. Pixel-weighted pooled estimate

A total of 8,988,291 paired pixels from the five retained acquisition pairs were included in the pooled analysis. The observations were weighted according to the number of eligible paired pixels contributed by each acquisition pair, thereby retaining the relative

contribution of each dataset to the combined estimate. The resulting pooled linear harmonisation function was:

$$EVI_{OLI} = 0.0209 + 0.9700, EVI_{ETM+} + \epsilon$$

with a pooled coefficient of determination of ($R^2 = 0.9145$) based on ($n = 8,988,291$) paired pixels. The slope of 0.9700 indicates a near-unity relationship between ETM+ and OLI EVI across the pooled observations, while the positive intercept indicates a small systematic offset between the two sensor-derived EVI measurements. These coefficients represent the empirical pooled relationship for the investigated tropical forest study domain and acquisition set; they are therefore treated as locally derived harmonisation parameters rather than as sensor-invariant calibration coefficients.

5. Data and code availability

Raw diagnostic outputs for each of the five pairs (per-pixel EVI rasters, harmonization masks, and full residual diagnostics) are archived alongside this report. The processing pipeline is implemented as a single, self-contained R script (dependencies: `rstac`, `terra`, `sf`) organized into five sequential steps: (1) STAC-based discovery and download of the required Landsat Collection 2 Level-2 bands (Blue, Red, NIR, QA_PIXEL, and ATMOS_OPACITY for Landsat 7 / AEROSOL_QA for Landsat 8) via the Microsoft Planetary Computer catalogue; (2) cropping of all bands to the study-area boundary; (3) construction of the per-pixel harmonization mask (exact QA_PIXEL match plus atmospheric-opacity/aerosol thresholds), Surface Reflectance scaling, and native EVI computation for both sensors; (4) per-pair ordinary least-squares regression, pixel-weighted pooling across pairs, and comparison against the Roy et al. (2016) coefficients; and (5) automated generation of the synthesis report and comparative tables (CSV) reproduced above. The script expects a single input — the study-area boundary shapefile, placed at `./harmonization/0_study_area/study_area.shp` — and creates all intermediate and output directories (`01_raw/`, `02_crop/`, `03_evi/`, `04_synthesis/`) programmatically using relative paths, so that the full pipeline can be re-run end-to-end on any machine without modification. Code is available at [repository link to be added].

Appendix: Per-pair scene identifiers

Pair	Landsat 7 scene ID	Landsat 8 scene ID
pair_01	LE07_L2SP_009053_20150103_02_T1	LC08_L2SP_009053_20150111_02_T1
pair_04	LE07_L2SP_009053_20140217_02_T1	LC08_L2SP_009053_20140209_02_T1
pair_06	LE07_L2SP_009053_20140217_02_T1	LC08_L2SP_009053_20140225_02_T1
pair_09	LE07_L2SP_009053_20150308_02_T1	LC08_L2SP_009053_20150316_02_T1
pair_07	LE07_L2SP_009053_20160122_02_T1	LC08_L2SP_009053_20160114_02_T1

Data Availability

All observational data used in this study are publicly available Landsat Collection 2 Level-2 surface reflectance data. Landsat 7 ETM+ and Landsat 8 OLI observations were accessed from the publicly available Landsat archive through a SpatioTemporal Asset Catalog (STAC) interface, as described in the Methods section and cited explicitly in the text.

The analysis was conducted using scenes acquired over WRS-2 Path 009, Row 053. The original satellite observations are publicly accessible from the corresponding data providers and are not subject to any data-access restriction imposed by the authors.

All scene-selection criteria, temporal pairing procedures, pixel-level quality-control criteria, EVI calculations, and statistical analyses used to derive the results reported here are described in the Methods section. The paired observations and summary statistics reported in the manuscript were derived directly from the publicly available source data following this documented procedure.

No proprietary or restricted-access datasets were used in this study.

Code Availability

The R code used for the ETM+–OLI EVI harmonisation analysis is publicly available in the GitHub repository associated with this study. The script `01_harmonization.R` implements the principal data-acquisition, preprocessing, EVI calculation, pixel-level quality-control, cross-sensor pairing, and statistical analysis procedures described in this report.

The code is available at:

https://github.com/gcmacchi/MontesMaria_SocioEcological_GWR/blob/main/01_harmonization.R

The script uses publicly available Landsat Collection 2 Level-2 data accessed through the Microsoft Planetary Computer STAC catalogue and requires the R packages `rstac`, `terra`, and `sf`. The repository also contains the configuration and supporting files required by the harmonisation workflow.

Author Contributions

Conceptualization: G.M.J.; Methodology: G.M.J., A.P.C., E.M.; Software: G.M.J.; Formal analysis: G.M.J., A.P.C.; Investigation: G.M.J., A.P.C.; Resources: G.M.J., E.M.; Data curation: E.M.; Writing—original draft: G.M.J., A.P.C.; Writing, review and editing: G.M.J., A.P.C., E.M.; Visualization: G.M.J., E.M.; Supervision: A.P.C. All authors contributed to the development of the work and approved the final version of the manuscript.

Reference

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