EARTHVOLUTION.SCIENCE

◢ TECHNICAL METHODOLOGY

DOCUMENT V1.0 · JUNE 2026 · PUBLIC RELEASE

Decadal satellite measurement of planetary surface change.

Data sources, processing pipeline, deterministic plausibility guards, and validation for the EarthVolution.Science research-grade platform.

DOCUMENT

Technical Methodology v1.0

STATUS

Public release · Peer-reviewed sources

SPATIAL SCOPE

1 km² – 100 km² AOIs · global coverage

TEMPORAL SCOPE

2015 baseline ↔ 2025 current epoch

SENSORS

Sentinel-2, Landsat-8, MODIS, VIIRS, SRTM

GEOSPATIAL LAYERS

JRC GSW / TMF / GHSL · Hansen GFC · OSM

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EarthVolution.Science · Architaly

SUGGESTED CITATION

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ABSTRACT

EarthVolution.Science is a satellite-based land-use-change analytics platform that quantifies decadal surface transformation at any user-specified location on Earth. The platform compares orbital imagery and derived geospatial products from a fixed historical epoch (2015) against the most recent available epoch (2025), producing pixel-level measurements across eight independent surface-cover parameters: water, ice/snow, vegetation, forests, sand/bare soil, built surface, roads, and human-activity infrastructure.

This document describes, in full, the data sources used, the processing pipeline applied to each parameter, the deterministic plausibility guards that prevent climatologically impossible results, the expected error margins and validation approach for each measurement, and the known limitations of the current methodology (v1.0). It is intended for institutional clients, technical reviewers, and procurement evaluators who require documentation suitable for due diligence, citation, or compliance filing, independent of the platform's user interface.

EarthVolution does not generate or estimate land-cover figures using generative AI. All quantitative measurements are derived from published, peer-reviewed remote-sensing datasets using deterministic, auditable processing steps. A constrained large language model (detailed in **Section 6**) is used solely to produce a plain-language narrative summary of pre-computed numerical results, and never to generate the underlying figures themselves.

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1 Introduction & scope

EarthVolution.Science was developed to give institutional users — researchers, public-sector bodies, educational institutions, and environmental organizations — a way to measure verifiable, decade-scale physical change at any location on Earth's surface, without requiring in-house remote-sensing expertise.

This document covers the platform's core measurement methodology as implemented in the production system at the time of publication. It does not cover business operations, pricing, or platform user-interface design, which are addressed separately on the EarthVolution.Science website.

1.1 Intended audience

- Institutional procurement and technical due-diligence reviewers
- Academic and research collaborators evaluating data provenance
- Public-sector and educational clients requiring citable methodology for compliance or grant reporting
- Internal engineering reference for current and future EarthVolution contributors

1.2 Scope of measurement

The platform measures change across eight surface-cover parameters within a user-defined Area of Interest (AOI) ranging from **1 km² to 100 km²**, comparing a fixed 2015 baseline epoch against a 2025 current epoch, at a native resolution of **10 meters per pixel** for the primary optical layers, with deterministic per-pixel fallbacks at 30 m (Landsat-8) and 250–500 m (MODIS) where higher-resolution coverage is not available for the requested epoch.

2 Data sources

Every measurement produced by EarthVolution is derived from a named, published, third-party dataset. No proprietary, simulated, or unverifiable data sources are used. **Table 1** lists each dataset, its publisher, and its role in the pipeline.

TABLE 1 · PRIMARY DATA SOURCES AND THEIR FUNCTION WITHIN THE EARTHVOLUTION PIPELINE.

Dataset	Publisher	Function
Sentinel-2 L2A surface reflectance	ESA / Copernicus Programme	Primary 10 m optical imagery — NDVI, EVI, BSI, NDWI indices
Sentinel-2 Cloud Probability (s2cloudless)	ESA / Sentinel Hub	Per-pixel cloud mask for S2 composites (Skakun 2022)
Landsat-8 Collection-2 Level-2 Surface Reflectance	USGS	30 m optical fallback when S2 coverage is insufficient for the epoch (Roy 2014)
Dynamic World V1	Google Research / WRI (Brown 2022)	10 m near-real-time 9-class land-cover classification
MODIS MOD10A1	NASA / NSIDC (Hall 2002)	Daily snow / ice cover via NDSI
MODIS MOD13Q1	NASA / LP DAAC (Didan 2015)	250 m NDVI cross-validation against S2 / L8
JRC Global Surface Water (YearlyHistory)	JRC, European Commission (Pekel 2016)	Permanent surface water extent at 30 m
JRC Tropical Moist Forest v1	JRC, European Commission (Vancutsem 2021)	Undisturbed primary moist forest, catches degradation Hansen misses
Hansen Global Forest Change v1.13	University of Maryland (Hansen 2013)	Closed-canopy forest extent (≥ 30 % canopy, ≥ 5 m height) at 30 m
JRC GHSL Built-up Surface (multi-temporal)	JRC, European Commission (Pesaresi & Politis 2023)	Built-up area, 100 m, multi-epoch authoritative product
JRC GHSL Population	JRC, European Commission (Schiavina 2023)	Population density proxy at 100 m
Open Buildings v3	Google Research (Sirko 2023)	Building polygon footprints, sub-meter accuracy
NOAA VIIRS Nighttime Lights (VNL)	NOAA / Earth Observation Group (Elvidge 2017)	Human-activity radiance proxy for infrastructure-expansion delta
SRTM Digital Elevation Model v3	NASA JPL (Farr 2007)	Elevation surface for plausibility guards (glaciers, lakes, coasts)
OpenStreetMap (Overpass API snapshot)	OSM Foundation (Haklay 2010)	Vector roads, infrastructure features (current-state snapshot)

All datasets above are hosted on, or mirrored to, Google Earth Engine for deterministic server-side processing. Every numerical figure produced by the platform is traceable back to a named scene/tile of one of these collections.

3 Spatial & temporal framework

3.1 Epoch definition

The platform compares two fixed temporal epochs: a **2015 baseline** (archive) and a **2025 current epoch** (live), representing a ten-year measurement window. For each AOI, the production system builds a phenology-matched median composite within a **±1.5-month window** centred on the seasonal vegetation peak for the AOI's latitude band (e.g. June–August for Northern temperate, December–February for Southern temperate).

Where a dataset's coverage does not extend cleanly to the requested epoch:

- If the phenology window contains zero cloud-free Sentinel-2 scenes, the window widens to the full calendar year.
- If full-year Sentinel-2 coverage still yields fewer than 8 cloud-free observations, the system falls back to **Landsat-8 Collection-2 Level-2 Surface Reflectance** (operational since 2013-03-18, full pre-2015 global coverage), at 30 m, with CFmask cloud masking (Foga 2017).
- If neither S2 nor L8 yields a usable composite (e.g. open ocean), the system enters **ocean mode**: MODIS Terra/Aqua surface reflectance is used for RGB only, and all land-derived parameters return n/a with a documented reason.

Every fallback is recorded in the scan's provenance record (visible on the parameter card as "measured by") so the reader knows which sensor produced which figure.

3.2 Area of Interest (AOI)

Users define an AOI between **1 km² and 100 km²** (square, side 1 km – 10 km) by placing and resizing a reticle on the interactive map. All eight parameters are computed independently within the same AOI boundary for both epochs.

3.3 Resolution

Primary optical measurements (vegetation, sand/bare soil, built surface) are computed at **10 m**, consistent with Sentinel-2 and Dynamic World native resolution. Forests use Hansen GFC native **30 m**. Snow/ice uses MODIS native **500 m**. Population uses GHSL **100 m**. Roads are vector-based and not raster-resolution-limited; reported as total length in kilometres summed via the Haversine formula per OSM way.

4 Processing pipeline by parameter

Each of the eight surface-cover parameters is computed independently. For each, the section below states the metric, the source dataset, the detection threshold, the resolution, and any cross-validation step applied.

4.1 Water

- **Metric**: permanent surface-water extent (m^2)
- **Source**: JRC Global Surface Water YearlyHistory (Pekel 2016, Nature) — pixel classified as permanent water where `waterClass == 3` for the requested year
- **Resolution**: 30 m (JRC native), reported at 10 m grid
- **Cross-check**: OSM water vectors used as a secondary visual reference; OSM tags do not enter the numerical figure
- **Ocean mode**: when > 95 % of the AOI is open ocean (no JRC inland-water coverage), water_m2 is set to the AOI's geometric area, as JRC GSW does not cover oceans by design

4.2 Ice / snow

- **Metric**: persistent snow / ice cover (m^2) via Normalized Difference Snow Index (NDSI)
- **Source**: MODIS MOD10A1 (Hall 2002), daily product, processed by NSIDC
- **Threshold**: `NDSI ≥ 0.40` on at least 40 % of days within the requested year ⇒ classified as persistent snow. Single-day NDSI peaks are NOT counted (this distinction prevents transient January frost in arid AOIs from being misreported as glacier)
- **Resolution**: 500 m (MODIS native)
- Returns 0 m^2 for AOIs in tropical or non-snow biomes by design, not as a data gap

4.3 Vegetation

- **Metric**: green biomass / vegetated surface (m^2) via Normalized Difference Vegetation Index (NDVI, Tucker 1979)
- **Threshold**: `NDVI ≥ 0.20`, computed at 10 m using Sentinel-2; falls back to 30 m Landsat-8 where Sentinel-2 coverage is insufficient (< 8 cloud-free observations for the epoch, or median composite degenerate with mean NDVI < 0.02 and resolved vegetation area < 0.1 km^2)
- **Equation**:

```
NDVI = (NIR - Red) / (NIR + Red)
```


Sentinel-2: NIR = B8 (842 nm), Red = B4 (665 nm) · Landsat-8: NIR = SR_B5 (865 nm), Red = SR_B4 (655 nm)

- **Cross-check**: 2025 result is compared against independent MODIS MOD13Q1 NDVI (Didan 2015) at 250 m. An absolute discrepancy > 0.05 in mean NDVI triggers a confidence flag on the parameter card
- **Secondary index**: EVI (Enhanced Vegetation Index, Huete 2002) is computed as a noise-resistant validator on densely vegetated AOIs
- **Cross-sensor caveat**: when the 2015 epoch uses Landsat-8 (30 m) and 2025 uses Sentinel-2 (10 m), the 30 m pixel cannot resolve narrow vegetation features (palm-lined medians, scattered street trees). The 2015 baseline is therefore the lower bound of true vegetated area; the percent change is reported as a directional indicator rather than a precise ratio

4.4 Forests

- **Metric**: closed-canopy forest extent (m^2)
- **Source**: Hansen Global Forest Change v1.13 (Hansen 2013, Science)
- **Threshold**: `treecover2000 ≥ 30 %` AND `lossyear > year - 2000 - 1` (i.e. canopy present at start of requested epoch, not lost before the epoch year), with implicit `≥ 5 m` canopy height per Hansen specification
- **Resolution**: 30 m (Hansen native)
- **Tropical cross-check**: JRC Tropical Moist Forest (Vancutsem 2021, Science Advances) — independent measurement of undisturbed primary moist forest, surfaced alongside Hansen for tropical AOIs. Catches selective logging and degradation that Hansen's "any closed canopy" metric does not
- Returns 0 m^2 where no closed-canopy forest is present in either epoch, consistent with the underlying biome

4.5 Sand / bare soil

- **Metric**: exposed sand and bare-soil surface (m^2)
- **Source**: Sentinel-2 Bare Soil Index (BSI, Rikimaru 2002), with Dynamic World class 7 (bare) as a secondary cross-check
- **Threshold**: `BSI ≥ 0`
- **Equation**:

```
BSI = ((SWIR + Red) - (NIR + Blue)) / ((SWIR + Red) + (NIR + Blue))
```

Sentinel-2: SWIR = B11 (1610 nm), Red = B4, NIR = B8, Blue = B2 (490 nm)

- **Resolution**: 10 m
- **Exclusion masks**: GHSL Built-up Surface and MODIS persistent-ice masks are subtracted before reporting, to prevent double-counting built surfaces or glacier surfaces as bare soil

4.6 Built surface

- **Metric**: built / impervious surface footprint (m^2)
- **Primary source**: JRC GHSL Built-up Surface multi-temporal product (Pesaresi & Politis 2023) — 100 m, multi-epoch authoritative product; provides directly comparable 2015 and 2025 figures
- **Cross-validation**: (i) Dynamic World class 6 (built) at 10 m, and (ii) Open Buildings v3 polygons (Sirko 2023) for sub-meter footprint accuracy on the 2025 epoch. Divergence beyond ± 15 % between sources triggers a confidence flag
- **Resolution**: 100 m (GHSL primary), 10 m (DW secondary)

4.7 Roads

- **Metric**: total road-network length within the AOI, in kilometres
- **Source**: OpenStreetMap via Overpass API, current-state snapshot
- **Computation**: each OSM way with `highway=*` tag is broken into consecutive node pairs; per-pair geodesic distance is computed via the Haversine formula; total summed
- **Resolution**: vector-based, not raster-limited
- **Temporal handling**: OSM does not expose a historical API for arbitrary AOIs. The roads figure is therefore a current-state snapshot, not a 2015 baseline. The decadal change signal for road infrastructure is supplied separately via the VIIRS Nighttime Lights temporal proxy (see §4.8), which is the peer-reviewed development-economics standard (Elvidge 2017, used by the World Bank)
- **Roadmap note (v2)**: a self-hosted OSHDB historical OSM snapshot is on the platform roadmap to provide a true 2015 OSM baseline

4.8 Human-activity infrastructure

Unlike the seven parameters above, "human-activity infrastructure" is **not** a single composite indicator. The platform deliberately surfaces three independent measurements rather than a single fused score, so the reader can audit each on its own peer-reviewed basis:

1. **OSM tag counts** — number of bridges, piers, industrial parcels, factories, railways and similar infrastructure features within the AOI (current-state snapshot)
2. **Built-surface delta** — multi-temporal GHSL change measured in m^2 (see §4.6)
3. **VIIRS Nighttime Lights radiance Δ** — mean $nW/cm^2/sr$ in 2015 vs 2025, the peer-reviewed proxy for socio-economic / infrastructure development used by the World Bank Economic Reviews

Aggregating these three into a single composite score would obscure the provenance of each measurement; the platform's research-grade discipline requires that each component remains independently traceable.

5 Deterministic plausibility guards

The platform applies several deterministic, peer-reviewed plausibility guards before any figure is reported. These guards prevent the system from producing climatologically or geographically impossible results (snow in the Sahara, vegetation under glaciers, ocean water counted as flooding, etc.). All guards are applied server-side and are visible in the per-parameter provenance record.

5.1 Köppen climate-zone consistency

Every AOI is tagged with its Köppen–Geiger climate classification (Beck 2018). Parameters incompatible with the local climate are flagged as not scientifically detectable rather than silently reported as zero. Example: an NDSI ≥ 0.40 reading in a BWh (hot desert) zone triggers a guard, because persistent snow there is climatologically impossible and any such reading is by definition a sensor artefact.

5.2 MODIS persistent-snow guard

Snow/ice is counted only where MODIS NDSI ≥ 0.40 holds for at least **40 % of the days** within the requested year (≈ 146 days). Single-day or short-window NDSI peaks (e.g. a January frost in an arid AOI) are explicitly excluded. This distinction between transient and persistent snow is essential to prevent false-positive glacier classifications.

5.3 Coastal tidal-water guard

For AOIs that overlap a coastline, the water mask is intersected with the SRTM-derived 5 m above-mean-sea-level elevation contour. Pixels below that contour are flagged as tidal margin, and inter-epoch water-extent differences inside that margin are reported with an explicit caveat. This prevents tidal cycle phase differences between 2015 and 2025 acquisition dates from being misread as decadal sea-level change.

5.4 Ocean-mode fallback

When > 95 % of the AOI is open ocean (detected via JRC GSW absence and S2 imagery scarcity), the platform enters ocean mode: MODIS Terra surface reflectance is used to produce the RGB, water_m2 is set to the AOI geometric area, and all land-derived parameters (NDVI, EVI, BSI, DW classification, GHSL, Hansen) return `0` with an explicit ocean_mode = true flag in the provenance record.

5.5 Built-surface / sand exclusion

GHSL built-up pixels are subtracted from the sand/bare mask before reporting, to prevent double-counting an impervious built surface as bare soil. Similarly, MODIS persistent-ice pixels are excluded from both the sand and vegetation masks.

6 Error margins & confidence classification

Each parameter card displayed on the platform includes a stated error margin reflecting the documented accuracy of its underlying source dataset, not an internally estimated figure. **Table 2** summarises the margins by parameter.

TABLE 2 · ERROR MARGINS AS DISPLAYED ON PRODUCTION PARAMETER CARDS.

Parameter	Stated error margin	Basis
Water	± 5 – 15 %	JRC GSW documented classification accuracy (Pekel 2016)
Ice / Snow	NDSI ≥ 0.40 threshold sensitivity	MODIS MOD10A1 NSIDC product accuracy (Hall 2002)
Vegetation	NDVI ± 0.05 cross-sensor tolerance	S2 vs MOD13Q1 published agreement bands (Skakun 2022)
Forests	≥ 30 % canopy threshold sensitivity	Hansen GFC v1.13 documented accuracy (Hansen 2013)
Sand / Bare Soil	BSI ≥ 0 threshold sensitivity	Sentinel-2 SR + BSI (Rikimaru 2002) accuracy
Built Surface	± 15 % cross-source tolerance	GHSL ↔ DW ↔ Open Buildings v3 published agreement
Roads	± 5 % length	OSM positional/completeness accuracy (varies by region; Haklay 2010)
Human-Activity Infrastructure	VIIRS Δ ± 10 %	VIIRS Nighttime Lights inter-annual accuracy (Elvidge 2017)

6.1 Confidence classification

Each scan is assigned an overall confidence rating — **HIGH**, **MEDIUM**, or **LOW** — derived deterministically from the following rule set:

- **HIGH** — MODIS NDVI cross-check absolute Δ < 0.05 AND Sentinel-2 cloud-free observation count ≥ 8 in both epochs AND no plausibility guard triggered
- **MEDIUM** — Sentinel-2 observation count ≥ 4 in both epochs OR cross-check Δ between 0.05 and 0.10 OR exactly one plausibility guard triggered
- **LOW** — Sentinel-2 observation count < 4 in either epoch OR cross-check Δ > 0.10 OR multiple plausibility guards triggered OR a Landsat-8 fallback was used for both epochs

7 AI narrative layer

Following computation of all eight parameters, a constrained large language model generates a plain-language narrative summarising the pre-computed, deterministic results for the selected AOI. **This narrative layer does not calculate, estimate, or alter any numerical value**; it interprets and contextualises figures that have already been finalised by the geospatial processing pipeline described in §4.

7.1 Model and configuration

The narrative layer is currently served by **Anthropic Claude Haiku 4.5**, accessed via the Emergent LLM integration layer. This smaller-footprint model was selected after internal comparative testing against larger Claude Sonnet and GPT-class models, which showed the constrained Haiku model produced narrative output of equal or greater specificity and length at substantially lower operating cost — and crucially, with stricter adherence to the "no number invention" constraint.

7.2 Constraints

- The model is provided only the pre-computed numerical deltas, source dataset names, and AOI metadata as input. It has no independent access to raw imagery beyond the RGB and class-map composites generated by the pipeline
- The model is instructed to flag, not silently reconcile, any cross-check divergence exceeding the stated tolerance (see §4.3)
- The model output is descriptive and explanatory only; it carries no independent evidentiary weight beyond the numerical results it describes
- System prompt explicitly forbids: invention of unreported figures, claims about causation, predictions about future state, and any framing that contradicts a plausibility guard verdict

8 Validation approach

Validation of the EarthVolution pipeline currently rests on three mechanisms:

1. **Source-level accuracy** — each underlying dataset (Sentinel-2, MODIS, Hansen GFC, JRC GSW/TMF/GHSL, OSM, VIIRS, SRTM, Landsat-8) carries its own published, peer-reviewed accuracy assessment, inherited directly by EarthVolution's output rather than independently re-derived
2. **Cross-source agreement checks** — select parameters (currently vegetation, forests, built surface) are computed via two or more independent source datasets and compared; divergence beyond a stated tolerance is surfaced to the user as a confidence flag rather than reconciled silently
3. **Case-study validation** — a fixed set of reference sites with well-documented, independently verifiable decadal change is used as internal regression tests (Table 3)

8.1 Reference case studies

TABLE 3 · STANDING VALIDATION REFERENCE SITES.

Site	Location	Validation rationale
Aletsch Glacier	Valais, Switzerland	Independently documented, well-published decadal glacial retreat
Lake Chad	Central Africa	Independently documented, well-published decadal surface-water contraction
Santarém Soy Frontier	Pará, Brazilian Amazon	Independently documented, well-published deforestation / agricultural conversion
Dubai Marina & Palm Jumeirah	UAE	Independently documented, well-published coastal infill and urban expansion

9 Known limitations

EarthVolution is built on real, peer-reviewed remote-sensing data, but no remote-sensing measurement is without limitation. The following are acknowledged constraints of the current methodology (v1.0):

- **Resolution ceiling** — the finest native resolution across the optical layers is 10 m. Sub-10 m surface changes (individual buildings < 100 m², single trees) are not individually resolved
- **Cloud and atmospheric interference** — optical layers are subject to residual cloud contamination in the source composite, which can affect classification at AOI margins. The s2cloudless cloud probability mask (Skakun 2022) is applied at 40 % threshold to minimise this
- **Epoch composite variability** — "2015" and "2025" values represent the best available composite within their respective windows, not a single fixed acquisition date. This can introduce seasonal/tidal variability for parameters sensitive to short-term variability (e.g. water extent at coastal margins, snow line on Alpine glaciers)
- **OSM data currency** — OpenStreetMap is a continuously updated, crowd-sourced dataset; its completeness and currency vary materially by region, particularly outside well-mapped urban areas. The roads figure is a current-state snapshot
- **Cross-sensor 2015 baseline** — for AOIs where Sentinel-2 had insufficient coverage in 2015 (typical for any AOI requested for early-2015 phenology), the platform falls back to Landsat-8 at 30 m. The resolution differential between L8 (30 m) 2015 and S2 (10 m) 2025 means the 2015 baseline structurally undercounts narrow vegetation features. This is reported on the parameter card as a cross-sensor caveat
- **Population and built-surface lag** — GHSL multi-temporal products are released on a multi-year cycle; the 2025 figure may rest on 2022–2023 satellite acquisitions extrapolated forward
- **Roads historical baseline absence** — OpenStreetMap exposes no historical query API for arbitrary AOIs, so a true 2015 OSM road baseline is not currently available. VIIRS Nighttime Lights is the peer-reviewed temporal proxy used in its place

10 Version history

TABLE 4 · VERSION HISTORY. INSTITUTIONAL USERS SHOULD CITE THE VERSION NUMBER ALONGSIDE THE PUBLICATION DATE.

Version	Date	Summary of changes
1.0	June 2026	Initial public release of methodology documentation. Vegetation pipeline upgraded to Sentinel-2 NDVI with Landsat-8 fallback. Deterministic plausibility guards (§5) documented. JRC TMF, Open Buildings v3, GHSL Population, SRTM and s2cloudless added to dataset inventory.

11 References & citation format

11.1 Peer-reviewed primary sources

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11.2 Citing this document

Institutional users referencing this methodology in compliance filings, academic work, or procurement documentation should cite as follows:

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11.3 Contact

For technical questions regarding this methodology, institutional clients may contact EarthVolution.Science directly at **info@architaly.green**, or via the contact details published at earthvolution.science.

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