ALBEDO & LAND-SURFACE CHANGE

A time-series research report for the NASA Space Apps Challenge 2026
Study extent: 70°E–75.5°E, 28°N–34°N | Pakistan and neighbouring areas

Research focus

How has land-surface reflectivity varied over time, and how might those patterns relate to land cover, vegetation, surface temperature and hydrological conditions?

Period proposed for the main analysis: 2001–2025 (25 complete calendar years).
Time-series spreadsheet supplied: Giovanni / NLDAS Noah monthly albedo, 2005–2025. Its metadata identifies a North American data extent, so it is audited but not treated as Punjab evidence.

Prepared from the user's research dossier, supplied coordinate extent, supplied Giovanni spreadsheet text, the five supplied research links, NASA and NOAA documentation, and published Southern Punjab studies.

Prepared 14 November 2026

Executive summary

This report develops a research framework for investigating surface albedo across the rectangle 70°E–75.5°E and 28°N–34°N. It combines published evidence on Southern Punjab land-cover change, NASA satellite products, Giovanni and AppEEARS workflows, NOAA station observations, and a methodological example from a NASA-archived time-series paper.

Central finding at this stage: the supplied monthly albedo spreadsheet is not geographically valid for the intended Pakistan study area. Its data bounding box is –124.938° to –67.062° longitude and 25.0625° to 52.9375° latitude, which corresponds to North America. Its source product is NLDAS-2 Noah, a North American land data assimilation product. The 252 monthly values therefore cannot be used as measured albedo for Punjab.

Published studies do provide quantitative evidence that Southern Punjab experienced substantial land-cover and vegetation-index changes between 2000 and 2021. These findings support the importance of investigating albedo, but they do not themselves measure albedo. The project's original contribution should be a correctly located, quality-screened albedo time series and spatial comparison derived from a global product such as MODIS MCD43A3 V6.1.

Area of work	What is established	What remains to be calculated
Study geography	Bounding box supplied by the user: 70°E–75.5°E, 28°N–34°N.	Exact administrative mask and zone polygons.
Southern Punjab land cover	A 2023 study reports forest –31.03%, settlements +14.52%, barren land +12.87% from 2000 to 2021 in its study area.	Reproduce/compare land-cover transitions inside our exact region.
Vegetation and moisture indices	A 2024 study reports mean NDVI 0.23 to 0.14 and mean NDMI 0.28 to 0.15 between 2000 and 2021.	Our own region-specific NDVI/NDMI extraction.
Albedo	No verified albedo trend for the exact rectangle has been calculated from the supplied data.	Extract MODIS MCD43A3 and compute monthly/annual trends.
Climate context	NOAA GHCN-Daily offers global station observations, but station coverage must be checked.	Identify suitable stations and quantify completeness.

1. Study scope and research questions

The supplied bounding box is a rectangular geographic extent, not an official Punjab boundary. It includes parts of Punjab and neighbouring areas. Results for the full rectangle must therefore be labelled as results for the coordinate-defined study region. To make Punjab-specific statements, use an official Punjab administrative polygon as a second mask.

Bounding coordinates

Boundary	Coordinate
West	70°E
East	75.5°E
South	28°N
North	34°N

Primary research question

How has surface albedo changed across the coordinate-defined region between 2001 and 2025, and how do those changes vary across urban, agricultural and arid landscapes?

Secondary questions

• How do seasonal albedo patterns differ between Rabi and Kharif periods?

• Are changes in NDVI associated with changes in surface albedo?

• Do urban surfaces and surrounding agricultural areas show different albedo and land-surface-temperature patterns?

• Do arid/barren landscapes behave differently from irrigated agricultural areas?

• Are the observed long-term trends statistically significant after accounting for seasonality, missing data and temporal autocorrelation?

Proposed subregions

Zone	Illustrative focus	Research emphasis
Urban	Lahore and other built-up settlements within the box	Built-up expansion, roofs/roads, vegetation, LST and mixed pixels.
Central agricultural plains	Agricultural landscapes in the central portion of the extent	Crop cycles, green cover, harvest periods, soil exposure.
Southern agricultural plains	Multan and surrounding agricultural landscapes, where inside the mask	Vegetation/moisture indices, crop cycles, land conversion.
Arid/desert transition	Cholistan/Bahawalpur and dry landscapes where inside the mask	Bare soil, sparse vegetation and seasonal reflectivity.

These zones are analytical categories, not yet GIS-ready polygons. Their boundaries must be drawn from land-cover maps or administrative/landscape boundaries before zonal statistics are computed.

2. Scientific foundations: what albedo measures

Surface albedo is the fraction of incoming solar radiation reflected by a surface. It is dimensionless and ranges from 0 to 1, or can be expressed as a percentage. An albedo of 0.20 means that 20% of the relevant incoming radiation is reflected under the measurement conditions.

Albedo = reflected solar radiation ÷ incident solar radiation

Albedo is not identical to reflectance at one wavelength. Spectral reflectance describes the reflected fraction as a function of wavelength, while broadband albedo integrates reflectance over a spectral interval. The project's main variable should be shortwave broadband surface albedo because it is relevant to the surface shortwave energy budget.

Black-sky albedo (BSA) is directional-hemispherical reflectance under direct illumination for a specified solar angle. White-sky albedo (WSA) is bihemispherical reflectance under diffuse illumination. Actual or blue-sky albedo is a mixture of the two, depending on the diffuse fraction of incoming light. The project must state which albedo quantity it analyses.

A simplified surface energy relationship is:

Absorbed shortwave radiation = incoming shortwave radiation × (1 – albedo)

A lower albedo can increase the shortwave energy absorbed by a surface if incoming radiation and other conditions are comparable. However, surface temperature also depends on heat capacity, moisture, evapotranspiration, aerodynamic exchange, shading, longwave radiation and human heat emissions. Albedo alone does not determine temperature.

Planetary albedo and surface albedo must not be confused. Planetary albedo includes reflection by clouds, atmosphere and the surface as viewed from space. A land-surface albedo product measures the surface component. A regional MODIS land-albedo time series cannot be described as a change in Earth's planetary albedo.

Reference values compiled in the earlier research dossier are indicative only: fresh asphalt ~0.04; open ocean ~0.03–0.10; bare soil ~0.17; green grass ~0.15–0.25; desert sand ~0.20–0.40; fresh snow ~0.80–0.90. These are broad illustrative ranges, not measurements for Punjab, and actual values vary with moisture, surface condition, wavelength and sun angle.

3. Regional background: land cover and vegetation

The strongest directly relevant published evidence identified in this research is from Southern Punjab. It provides context for why land-cover and vegetation change should be investigated alongside albedo.

3.1 Southern Punjab land-cover study (2000–2021)

The 2023 study “Land Use/Land Cover Change Detection and NDVI Estimation in Pakistan’s Southern Punjab Province” used Landsat imagery at 30 m for land-cover classification and MODIS MOD13Q1 at 250 m for NDVI. It analysed four reference years: 2000, 2007, 2014 and 2021. The authors used an iterative self-organising classification approach and reported accuracy assessments for the classified maps.

Class	2000 area (%)	2021 area (%)	Reported change 2000–2021
Water	2.06	3.08	+1.02 percentage points / reported +1.02%
Cropland	20.58	23.21	+2.63 percentage points / reported +2.63%
Forest	35.39	4.36	–31.03 percentage points / reported –31.03%
Settlements	8.80	23.32	+14.52 percentage points / reported +14.52%
Barren land	33.15	46.02	+12.87 percentage points / reported +12.87%

The paper's table labels the final column as percentage change, while the listed values correspond to differences between the reported percentage shares (percentage points). In this report they are reproduced as the authors' reported changes, with that interpretation caveat. The article also reports the forest share falling from 35.39% to 4.36%, and settlement share rising from 8.80% to 23.32%.

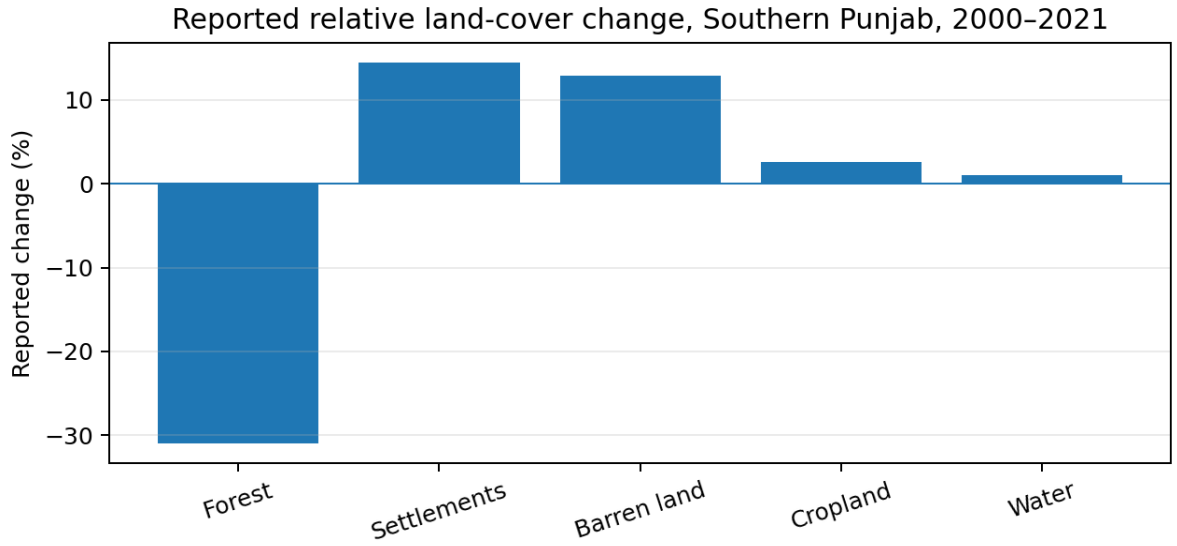


Figure 1. Replot of the study's reported class changes. The chart reproduces the reported change values; it is not a new classification of the user's coordinate rectangle.

The study reports that forest area decreased by 39,232.8 km² in its change table, while settlements increased by 18,401.5 km² and barren land by 16,157.6 km². These unusually large area totals reflect the study's own mapped study-area extent and classification; they should not be transferred to the user's bounding box.

4. Regional background: NDVI and NDMI

A 2024 study, “Assessing the impact of land use land cover changes on soil moisture and vegetation cover in Southern Punjab, Pakistan using multi-temporal satellite data,” examined land-cover, vegetation and moisture-index changes between 2000 and 2021. It reports that 7.17% of vegetation area was converted to built-up area and 1.68% of bare soil was converted to urban areas during the period.

Year	Mean NDVI	Mean NDMI
2000	0.23	0.28
2007	0.17	0.25
2014	0.19	0.20
2021	0.14	0.15

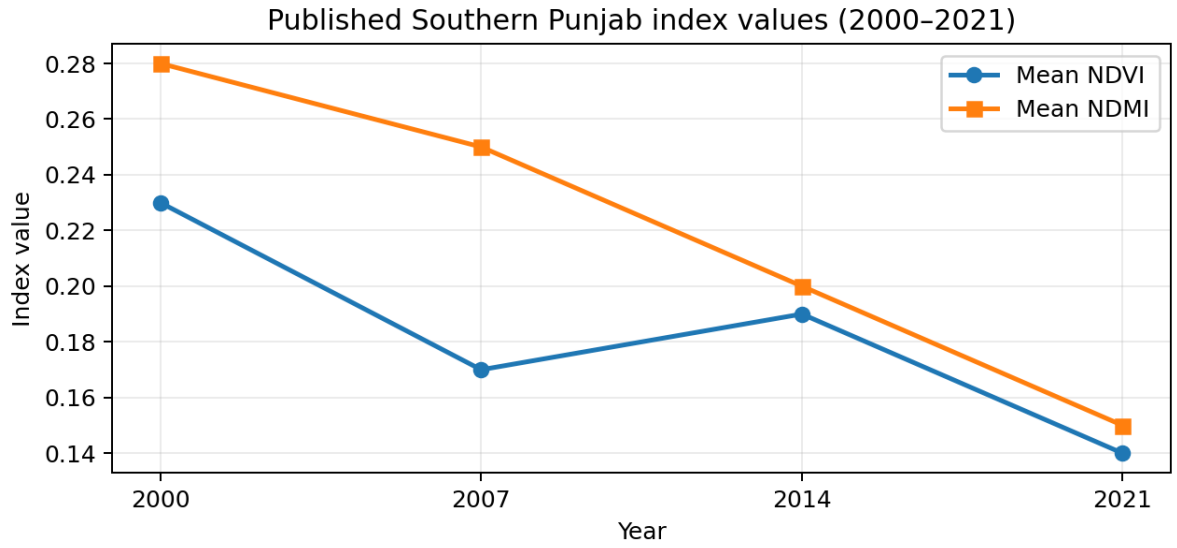


Figure 2. Published Southern Punjab mean NDVI and NDMI values. Source: 2024 study. These are not the project's own satellite extractions.

The reported NDVI decreased from 0.23 in 2000 to 0.14 in 2021. The relative decrease is approximately 39.1% (calculated from the published means: (0.14–0.23)/0.23 × 100). The reported NDMI decreased from 0.28 to 0.15, a relative decrease of approximately 46.4%. These calculations are arithmetic summaries of the paper's reported values, not independently measured trends.

NDVI is an index of vegetation greenness derived from red and near-infrared reflectance. NDMI is a moisture-related spectral index in the cited work. Neither index is a direct albedo measurement, and neither should be described as a direct measurement of irrigation or soil water content without additional validation.

The two studies offer complementary context: one reports land-cover class changes; the other reports vegetation and moisture-index changes. They justify investigating the relationship between land cover, vegetation and albedo, but they do not establish the direction or magnitude of albedo change in the user's region.

5. Pakistan and wider regional albedo context

The earlier user-provided research dossier compiled a CERES-MODIS estimate of shortwave surface albedo over the Indo-Gangetic Plain of approximately 0.13 ± 0.02, with seasonal means around 0.13–0.14. This is a broad regional estimate and must not be presented as the measured mean for Punjab or for the coordinate rectangle.

The dossier also summarised published Himalayan–Karakoram–Hindu Kush snow and glacier albedo estimates from Ming et al. (2015): Himalaya 0.54, Hindu Kush 0.49, Karakoram 0.55 and whole HKH 0.541. These are snow/glacier-region values, not plain-region values. The mountain snow context is relevant to Pakistan's wider energy and water system, but it lies largely outside the proposed rectangle's main Punjab-plains focus.

The dossier records published observations of light-absorbing particles in northern Pakistan snow from Gul et al. (2018). Reported black-carbon concentrations in sampled snow were 2,130 ± 1,560 ng/g in summer, 2,883 ± 3,439 ng/g in autumn and 992 ± 883 ng/g in winter. These are field-sample concentrations, not satellite albedo values.

The earlier dossier also notes a conference abstract reporting a northern Pakistan snowline trend of approximately +12 m/year and a non-significant snow-cover-area trend. Because this is a conference abstract and not a fully verified peer-reviewed result in the materials reviewed, it should be labelled provisional or excluded from headline claims.

Lahore aerosol context in the dossier indicates seasonal differences in aerosol type, with dust more prominent in spring/summer and biomass-burning or urban-industrial aerosol influences more prominent in autumn/winter in the cited AERONET analysis. This can motivate a separate aerosol investigation, but aerosol optical properties are not the same as surface albedo. A causal link between Punjab emissions and snow darkening elsewhere would require transport and deposition evidence.

The central regional gap remains: a verified monthly surface-albedo climatology and trend for the exact user-defined rectangle has not yet been calculated. This is the main original analysis the project should deliver.

6. NASA datasets: recommended data architecture

Dataset / product	What it measures	Resolution / cadence	Role in this project
MODIS MCD43A3 V6.1	Black-sky and white-sky albedo; visible, NIR and shortwave broadbands.	500 m; daily product based on 16-day observations.	Primary albedo record.
MODIS MCD43A2 V6.1	BRDF/albedo quality information.	500 m; product companion.	Quality filtering; retain best retrievals.
MODIS MOD13Q1 V6.1	NDVI and EVI.	250 m; 16-day composite.	Vegetation context.
MODIS MOD11A2 V6.1	Daytime and nighttime land-surface temperature.	1 km; 8-day average.	Thermal response context.
MODIS MCD64A1	Burned-area mapping.	500 m; monthly.	Optional fire-related land-cover disturbance.
MODIS/VIIRS FIRMS	Active-fire thermal anomaly detections.	MODIS ~1 km; VIIRS ~375 m.	Optional event context; not proof of crop burning.
MERRA-2	Modelled aerosol and atmospheric composition fields.	Coarse global model grid, roughly 50 km scale.	Regional atmospheric context, not deposition measurement.
CERES	Earth radiation-budget fluxes and planetary context.	Coarse global/regional grids.	Context only; too coarse for local Lahore analysis.

MCD43A3 V6.1 is the preferred starting point because it is global, provides 500 m albedo and combines Terra and Aqua observations. Each daily product is derived from a 16-day observation window, temporally weighted towards the ninth day. Its band-specific quality information should be used, and the companion MCD43A2 quality product should be consulted.

MODIS albedo values are stored with scale factors in the product. The correct scale factor and fill values must be taken from the selected collection's product documentation and applied before analysis. Never assume the raw stored integer is already a 0–1 albedo fraction.

VIIRS VNP43 products can provide a later-period cross-check, but MODIS and VIIRS should not be concatenated as if they were a perfectly identical sensor record. A sensor-overlap comparison and harmonisation check are needed.

7. The five supplied tools and their proper roles

7.1 NASA GES DISC Hydrology Time Series

The user supplied the NASA GES DISC Hydrology Time Series tools page. GES DISC is a data archive and access environment for NASA Earth-science products. Hydrological products can add precipitation, soil-moisture, runoff or evapotranspiration context where the chosen dataset covers the study area and the period. These are explanatory variables, not albedo observations. The supplied tools page is a gateway and does not itself establish a specific Punjab time series.

Open the supplied GES DISC Hydrology Time Series page

7.2 NASA Giovanni

Giovanni provides browser-based visualisation and analysis of Earth-science data. The supplied NASA paper describes Giovanni's use for selecting a geographic area, generating area-averaged monthly time series, exporting text output, and analysing anomalies and trends. Dataset availability is product-specific. Giovanni should only be used for a variable when the selected product covers Pakistan and the requested dates.

Open NASA Giovanni

7.3 NASA AppEEARS

AppEEARS (Application for Extracting and Exploring Analysis Ready Samples) supports point samples and area samples based on vector polygons. Users can select spatial, temporal and band/layer parameters, and the service returns data values with associated quality information. This makes it suitable for extracting MODIS data over the study boundary or over separate zones.

Open NASA AppEEARS

7.4 NOAA Climate Data Online

NOAA Climate Data Online provides access to historical weather and climate observations, including daily, monthly, seasonal and annual temperature, precipitation, wind and degree-day data. NOAA's GHCN-Daily archive integrates station records from more than 100,000 stations in 180 countries and territories. However, coverage and record length vary by station, and about half of the stations report precipitation only. The team must identify actual stations within or near the rectangle, inspect their periods of record and quantify missingness before treating them as validation data.

Open NOAA Climate Data Online | GHCN-Daily documentation

7.5 NASA NTRS paper

The supplied NASA technical paper, “Time-Series Analysis of Remotely-Sensed SeaWiFS Chlorophyll in River-Influenced Coastal Regions,” is a methodological example. It is not an albedo study and its coastal chlorophyll results cannot be transferred to Punjab. Its value is the workflow: define small regions, compute monthly regional means, export time series, calculate monthly anomalies, create annual anomaly series, fit trends, and test statistical significance.

Open the supplied NASA NTRS paper (PDF)

8. Methodological lessons from the NASA NTRS paper

Acker, McMahon, Shen, Hearty and Casey's paper analyses SeaWiFS chlorophyll-a time series in nine river-influenced coastal regions. The authors used Giovanni to generate monthly area-averaged values, exported the time series to a spreadsheet, and applied least-squares linear regression. They calculated monthly anomalies by subtracting the long-term mean for each calendar month, then averaged monthly anomalies into annual values and regressed those annual anomalies.

Element	Approach described in the paper	Adaptation for our albedo project
Spatial sampling	Small selected regions, often 0.5° × 0.5°.	Use the full coordinate rectangle plus smaller zone polygons.
Time series	Consecutive monthly regional means.	Monthly albedo averages for each zone and the whole valid mask.
Anomalies	Subtract mean value for each calendar month.	Calculate month-of-year albedo anomalies against a fixed baseline.
Trend	Least-squares linear regression.	Use Sen's slope and Mann–Kendall as robust primary tests; linear regression as a descriptive comparison.
Significance	95% confidence, ANOVA and F-test.	Report p-values, confidence intervals and autocorrelation-aware results.
Interpretation	Discuss natural and human influences; avoid overclaiming causation.	Separate observed trend from hypothesised drivers; test competing explanations.

The paper notes that monthly area means can be useful for first-step analysis, but also warns that remote-sensing indicators may be affected by confounding factors. In its coastal chlorophyll case, suspended sediments and coloured dissolved organic matter can interfere with the signal. The equivalent lesson for albedo is that retrieval geometry, clouds, surface mixtures, snow, soil moisture and land-cover composition can affect observations.

The paper's linear-regression method is a useful transparent baseline, but the project should go further. Monthly environmental data are seasonal and often autocorrelated. A naive regression on every monthly value can overstate significance. Seasonal Mann–Kendall, Sen's slope, autocorrelation checks and confidence intervals provide a more defensible analysis.

The NASA paper itself reports that unusual flood events affected some coastal time series and that longer records can alter the apparent trend. This supports the decision to use a 25-year record where a consistent dataset is available, rather than drawing conclusions from a short interval.

9. Audit of the supplied Giovanni spreadsheet

The spreadsheet header supplied by the user reads: “Time Series, Area-Averaged of Albedo monthly 0.125 deg. [NLDAS Model (monthly)]”. It covers 2005-01-01 through 2025-12-31 and contains one value per month. That gives 21 × 12 = 252 monthly timestamps if complete.

Metadata field	Supplied value	Assessment
Product	NLDAS_NOAH0125_M_2_0_Albedo	NLDAS-2 Noah monthly model albedo.
Grid spacing	0.125°	Model grid spacing; not 500 m satellite pixels.
Start / end	2005-01 to 2025-12	21 calendar years; 252 expected months.
User bounding box	Blank	No explicit user AOI recorded in this metadata field.
Data bounding box	–124.938, 25.0625, –67.0625, 52.9375	North American domain; not Pakistan.
Fill value	–9999	Missing-value sentinel; must be excluded from calculations.
Reproduction URL	Giovanni ArAvTs URL included in spreadsheet	Useful for traceability, but does not repair the geographic mismatch.

The data bounding box is expressed as west, south, east, north. It is entirely in the western hemisphere and corresponds to the North American NLDAS domain. NLDAS-2 is the North American Land Data Assimilation System. The dataset documentation describes a 1/8-degree grid, monthly data, and Noah land-surface-model fields.

Therefore, the supplied values cannot be treated as observed or modelled albedo for Punjab. Entering a Pakistan bounding box into a different Giovanni query is not sufficient if the chosen product itself is geographically restricted. The product must be replaced with a global or Pakistan-covering dataset.

The NLDAS series can still be retained in the appendix as an example of a time-series export and metadata audit. It should be labelled “North American NLDAS sample — excluded from Punjab analysis.”

10. What can and cannot be said about the spreadsheet values

The supplied table shows monthly values for 2005–2025. The visible maximum is 49.193634 in January 2008; the visible minimum is 25.1021481 in June 2023. Values in late spring and summer are mostly clustered around approximately 25–26.7 in the displayed series, while many winter months are higher. These are observations about the North American NLDAS export only.

Observation	Value in supplied table	Permitted interpretation
Maximum monthly value	49.193634 (January 2008)	Highest listed monthly NLDAS value in the supplied series.
Minimum monthly value	25.1021481 (June 2023)	Lowest listed monthly NLDAS value in the supplied series.
Expected monthly count	252	21 years × 12 months, consistent with complete monthly coverage in the pasted table.
Fill value	–9999	Must be treated as missing, not a physical albedo value.
Seasonality	Winter months often higher; May–October lower in the listed series	Descriptive pattern for the North American domain only.

The spreadsheet values appear to be percentages in the NLDAS Noah product convention, so a value of 46.04 would correspond to 46.04% (or 0.4604 as a fraction) if the product's metadata confirms this scaling. The selected variable's units and scaling must always be checked against the product documentation before conversion.

No Punjab annual trend, percentage change, slope, anomaly, correlation or seasonal climatology can be calculated from this spreadsheet. The geographical mismatch invalidates those interpretations for the intended region. The report deliberately does not create a Punjab trend chart from these numbers.

A replacement extraction should preserve the same useful spreadsheet structure: timestamp, regional mean albedo, product identifier, spatial extent, units, scale factor, fill value, quality-filter definition and reproducibility URL.

11. Correct extraction workflow for the study region

Step 1 — Define the area

• Use west 70, south 28, east 75.5, north 34 for the bounding rectangle.

• If the intended claims are specifically about Punjab, upload or apply an official Punjab administrative polygon as a second mask.

• Create separate polygons or raster masks for urban, central agricultural, southern agricultural and arid/desert zones.

Step 2 — Select a global albedo product

• Use MODIS MCD43A3 V6.1 shortwave broadband albedo as the primary product.

• Download or extract the companion MCD43A2 quality information.

• Choose black-sky and white-sky albedo explicitly; do not label either one simply as actual albedo.

• Use the full-inversion/highest-quality retrievals for the primary analysis and document any relaxed quality mask used for sensitivity testing.

Step 3 — Set dates and frequency

• Use 2001–2025 for a 25-year main analysis if the selected collection supports the full period.

• Extract daily product observations, then aggregate to monthly means after quality filtering.

• Keep the same calendar-month definition and time zone for all products.

Step 4 — Export data and metadata

• Export the data table and quality layers.

• Save the exact AOI polygon, product collection/version, selected bands, date range, units and scale factors.

• Save the task ID or reproducibility URL and a copy of the processing notes.

Step 5 — Repeat for supporting variables

• Extract MOD13Q1 NDVI/EVI, MOD11A2 LST and suitable hydrology/precipitation products.

• Aggregate each product to monthly values and align dates.

• Do not resample products to a finer resolution and imply that new spatial detail has been created.

AppEEARS supports spatial and temporal subsetting and returns associated quality data. Giovanni can be used for exploratory area-averaged time series when the selected product is available for the region. For high-resolution zonal comparisons, a polygon-based extraction or a GIS workflow may be more appropriate.

12. Statistical analysis plan

12.1 Monthly climatology

For each calendar month, calculate the mean across the selected baseline years. For example, the January climatology is the average of all valid January observations in the baseline period. This gives a 12-month seasonal cycle.

12.2 Monthly anomaly

Anomaly(t) = observed monthly albedo(t) – long-term mean for that calendar month

Using a month-specific baseline avoids confusing normal seasonal changes with long-term anomalies. The baseline period must be stated and held consistent across comparisons.

12.3 Annual and seasonal means

Calculate annual means only when a year meets a pre-defined completeness threshold. Calculate Rabi and Kharif means using explicit date definitions and note that local crop calendars differ by crop and district. A simple calendar-month grouping is a proxy for agricultural seasons, not a crop-specific phenology model.

12.4 Trend estimation

• Sen's slope: estimates the median rate of change per unit time and is less sensitive to outliers than ordinary least squares.

• Mann–Kendall: tests for a monotonic trend without assuming a normally distributed variable.

• Seasonal Mann–Kendall: compares like seasons/months to reduce seasonal confounding.

• Autocorrelation: test residuals or use an appropriate correction/pre-whitening approach.

• Confidence intervals and p-values: report uncertainty, not just the slope.

• Multiple comparisons: if many zones or months are tested, control false discoveries or clearly label exploratory results.

12.5 Correlations and attribution

Correlations between albedo, NDVI, LST, rainfall and soil-moisture indicators can identify co-variation. They do not prove that one variable caused another. Consider lagged relationships, seasonality and land-cover composition. If a claim is about urbanisation causing an albedo shift, the analysis needs land-cover transition evidence and comparison with stable control areas.

13. Processes and hypotheses to investigate

Agricultural cycles

Vegetation growth, crop maturity, harvesting, crop residue and exposed soil can all alter surface reflectance. A seasonal albedo cycle may be strong even when the long-term trend is weak. Compare like months across years and calculate separate Rabi/Kharif summaries. Do not assume that every low-NDVI month corresponds to a particular crop stage without crop-calendar or field evidence.

Urbanisation

Urban surfaces are mixtures of roofs, roads, concrete, asphalt, trees, bare ground and shadows. A 500 m pixel may contain several of these. Urban albedo can rise or fall depending on materials and land-cover mix; it is not scientifically safe to assume that every built-up expansion makes albedo lower. Compare urban cores, peri-urban zones and stable rural controls.

Arid and desert surfaces

Bare soil and sand have reflectance characteristics that differ from green vegetation and water, but soil colour, grain size, mineralogy, crusting and moisture all matter. A desert pixel can show seasonal changes in vegetation or moisture. Use a land-cover mask to avoid interpreting a change in pixel composition as a material-property change.

Hydrology and soil moisture

Wet soil often has different reflectance from dry soil. Rainfall, irrigation and evapotranspiration can influence vegetation and surface moisture. GLDAS or other suitable global products can provide context, but coarse model grids should not be interpreted as field-scale measurements.

Aerosols and snow

Aerosols affect atmospheric radiation and may darken snow if light-absorbing particles are deposited on it. That mechanism is particularly relevant to northern Pakistan's snow and glacier environments. It is not a direct explanation for plains albedo without evidence of deposition, transport and surface change.

Hypotheses

Code	Hypothesis to test
H1	Urban and surrounding rural areas exhibit different albedo patterns and trends.
H2	Agricultural areas show seasonal albedo differences between Rabi and Kharif periods.
H3	Changes in vegetation index are associated with changes in surface albedo.
H4	Urban, agricultural and arid zones show different land-surface-temperature patterns.
H5	Long-term albedo trends vary across the four landscape zones.
H6	Areas with substantial land-cover conversion show different albedo trajectories from relatively stable areas.

14. Research timeline and deliverables

Phase	Work	Deliverable
A. Scope and boundary	Confirm bounding box; obtain official Punjab polygon; define zone masks.	AOI GeoJSON/shapefile and coordinate metadata.
B. Product selection	Check global coverage, dates, units, scaling, QA and product versions.	Dataset register and extraction plan.
C. Extraction	Obtain MCD43A3/MCD43A2; then NDVI, LST and hydrology context.	Raw data exports and reproducibility notes.
D. Quality control	Mask fill values and low-quality retrievals; calculate valid-pixel coverage.	QC report and valid-observation counts.
E. Time-series construction	Create monthly, annual and seasonal means for each zone and the full region.	252-month tables per variable for 2005–2025, or full available range.
F. Statistical testing	Climatologies, anomalies, Sen's slope, Mann–Kendall, confidence intervals.	Trend summary tables and statistical plots.
G. Interpretation	Compare zones, published Southern Punjab studies and climate context.	Evidence-based discussion and limitations.
H. Final presentation	Maps, time-series charts, workflow, findings and reproducible sources.	Space Apps report/demo/presentation.

Recommended analysis windows: 2001–2005 baseline context; 2006–2010; 2011–2015; 2016–2020; and 2021–2025. These windows can help structure interpretation, but the main statistical test should use the complete monthly record rather than only five-year averages.

A separate 2026 update can be included only as a partial-year observation. Do not compare January–November 2026 directly with complete calendar-year means without a matched-month comparison.

15. Data quality, limitations and interpretation safeguards

Issue	Why it matters	Safeguard
Geographic mismatch	Wrong AOI means wrong region, regardless of data length.	Check the data bounding box and map footprint before analysis.
BSA vs WSA	They represent different illumination conditions.	Name the exact albedo variable; estimate blue-sky only with diffuse/direct inputs.
Quality flags	Poor BRDF inversions can bias averages.	Use companion quality product and report accepted-pixel fraction.
16-day window	Daily MCD43 values are temporally smoothed, not independent single-day snapshots.	Aggregate appropriately; avoid event-scale claims.
Mixed pixels	500 m pixels can contain multiple land-cover types.	Use land-cover masks and interpret urban edges carefully.
Seasonality	Crop cycles can mimic long-term change.	Use month-specific anomalies and seasonal tests.
Clouds and gaps	Missing retrievals can change sample composition.	Report valid-pixel counts and missingness by month/year.
Model vs satellite	NLDAS is model output, MCD43 is satellite-derived retrieval.	Keep provenance distinct; do not call model output a direct satellite measurement.
Station coverage	Ground stations may be sparse or incomplete.	Check station coordinates, record length and completeness.
Causation	Correlation does not establish a physical cause.	Use cautious language and additional evidence.

The most important safeguard is provenance: every chart should identify the dataset, version, variable, units, spatial extent, date range, quality filter and aggregation method. A chart without these details is difficult to reproduce and easy to misinterpret.

16. Results template: what the final analysis should report

The following table is intentionally left as a reporting template. It must be populated only after the correct Pakistan-region extraction has been completed.

Metric	Whole rectangle	Urban	Central agriculture	Southern agriculture	Arid/desert
Mean shortwave albedo					
Albedo trend (per year)					
Mann–Kendall p-value					
Sen's slope confidence interval					
Mean NDVI					
NDVI trend					
Mean daytime LST					
Rabi–Kharif albedo difference					
Valid data coverage (%)					

Recommended figures

- Map of the study boundary, administrative mask and four zone polygons.
- Annual mean shortwave albedo map for selected comparison years.
- Monthly albedo climatology for each zone.
- Monthly and annual albedo anomaly time series.
- Trend map showing Sen's slope and significance mask.
- NDVI and LST time series alongside albedo, with separate axes and clear units.
- Land-cover transition map and urban/rural comparison.

Do not fill this table with the NLDAS values supplied in the spreadsheet. Those values belong to the North American NLDAS extent and are excluded from the Punjab analysis.

17. Conclusions and project positioning

The research establishes a credible scientific basis for a regional albedo investigation, but it does not yet establish an albedo trend for the user's coordinate-defined area. The strongest verified regional evidence concerns land-cover and vegetation changes in Southern Punjab, including reported declines in forest share and mean vegetation/moisture indices between 2000 and 2021.

The supplied Giovanni spreadsheet is valuable as a worked example of an area-averaged monthly time-series export and as a lesson in metadata validation. Its data bounding box and NLDAS-2 product identity show that it is North American, so it cannot be used to infer Punjab albedo. This audit is a substantive part of the project's data-quality process.

The recommended next step is to extract MODIS MCD43A3 V6.1 shortwave albedo for the correct coordinate rectangle, apply quality filtering using MCD43A2, and calculate monthly/annual statistics for the whole region and the four zones. NDVI, LST, precipitation and soil-moisture data can then be aligned to examine associations and competing explanations.

Suggested project framing: “A 25-year satellite time-series investigation of changing surface reflectivity across a diverse South Asian landscape, comparing urban, agricultural and arid environments.”

The strongest final claim will not be that albedo changed by a particular amount before the data have been analysed. It will be a reproducible, spatially explicit result with a transparent method, uncertainty estimates and a clear distinction between observed patterns and proposed explanations.

Appendix A. Glossary

Term	Meaning
Albedo	Fraction of incoming solar radiation reflected by a surface.
BSA	Black-sky albedo; directional-hemispherical reflectance under direct illumination.
WSA	White-sky albedo; bihemispherical reflectance under diffuse illumination.
Blue-sky albedo	Actual albedo under a mixture of direct and diffuse illumination.
BRDF	Bidirectional reflectance distribution function; describes directional reflection.
NDVI	Normalized Difference Vegetation Index, a vegetation-greenness indicator.
NDMI	Normalized Difference Moisture Index; moisture-related spectral index.
LST	Land-surface temperature; not the same as near-surface air temperature.
Anomaly	Difference between an observation and an appropriate climatological reference.
Sen's slope	Robust estimate of the median rate of trend.
Mann–Kendall	Non-parametric test for a monotonic trend.
GHCN-Daily	NOAA's Global Historical Climatology Network daily station dataset.
NLDAS	North American Land Data Assimilation System.
QA	Quality assurance / quality information used to screen observations.

Appendix B. References and source register

The following references distinguish user-supplied sources, NASA/NOAA product documentation, and peer-reviewed regional research. Links are included for reproducibility. Dataset documentation should be consulted again when the final extraction is performed because product versions and availability can change.

1. User-supplied platforms and technical paper

NASA Goddard Earth Sciences Data and Information Services Center (GES DISC). Hydrology Time Series tools page. Link

NASA GES DISC. Giovanni, browser-based Earth-science data visualisation and analysis environment. Link

NASA. AppEEARS (Application for Extracting and Exploring Analysis Ready Samples). Link

NOAA National Centers for Environmental Information. Climate Data Online. Link

Acker, J. G., McMahon, E., Shen, S., Hearty, T., & Casey, N. “Time-Series Analysis of Remotely-Sensed SeaWiFS Chlorophyll in River-Influenced Coastal Regions.” NASA Technical Reports Server, accession 20090042747. PDF

2. NASA and NOAA dataset documentation

NASA / USGS LP DAAC. MODIS/Terra+Aqua BRDF/Albedo Albedo Daily L3 Global 500 m, Version 6.1 (MCD43A3). Dataset record | Earth Engine catalogue

NASA MODIS. BRDF/Albedo product information. Product page

NASA AppEEARS. Application overview and documentation. Application

NOAA NCEI. Global Historical Climatology Network Daily (GHCN-Daily). Dataset documentation

NASA Open Data. NLDAS Noah Land Surface Model L4 Monthly 0.125° × 0.125° Version 2.0. Dataset record

3. Published Southern Punjab studies

“Land Use/Land Cover Change Detection and NDVI Estimation in Pakistan’s Southern Punjab Province.” Sustainability, 15(4), 3572 (2023). DOI / article

“Assessing the impact of land use land cover changes on soil moisture and vegetation cover in Southern Punjab, Pakistan using multi-temporal satellite data.” (2024). DOI / article

4. Additional references from the user's earlier research dossier

Ming, J. et al. (2015). “Widespread albedo decreasing and induced melting of Himalayan snow and ice.” PLOS ONE, 10(6).

Gul, C. et al. (2018). “Light-absorbing particles in snow/ice in northern Pakistan.” Atmospheric Chemistry and Physics, 18, 4981 ff. The user's dossier summarises seasonal black-carbon and insoluble organic-carbon sample concentrations.

Goessling, H. F., Rackow, T., & Jung, T. (2024). “Recent global temperature surge intensified by record-low planetary albedo.” Science. The user's dossier summarises the global planetary-albedo result; it is context only, not a Punjab surface-albedo measurement.

5. User-provided research material

Albedo: Research Dossier (Global and Pakistan), compiled 14 November 2026, supplied in this conversation. The report uses it as a background compilation and preserves its own cautions about unverified conference-abstract findings and the absence of a Pakistan-specific monthly albedo series.

Giovanni spreadsheet text supplied in the conversation: “Time Series, Area-Averaged of Albedo monthly 0.125 deg. [NLDAS Model (monthly)]”, January 2005–December 2025, including metadata, bounding box, fill value and monthly values. The supplied export is audited in Sections 9–10 and excluded from Punjab results because its data bounding box is North American.

Appendix C. Reproducibility checklist

Before publishing any map, graph or numerical result, confirm each item below.

Check	Required record
Geography	Exact bounding box and/or polygon; CRS; administrative mask; zone definitions.
Dataset identity	Provider, product name, collection/version, DOI or catalogue link.
Variable	Exact layer/band name; BSA/WSA/shortwave designation.
Units	Raw units, scale factor, offset and final unit.
Time	Start/end dates; timestamp convention; aggregation interval.
Quality control	QA rule, fill values, valid-pixel threshold, missingness.
Spatial averaging	Pixel weighting method; land/water mask; treatment of partial pixels.
Statistics	Climatology baseline, anomaly definition, trend method, autocorrelation treatment, confidence intervals.
Validation	Available station data, comparison method, station completeness.
Reproducibility	Download task ID, query URL, code version, export date and processing notes.

Final status: literature review and methodology are assembled; the provided North American NLDAS export has been audited and excluded; the correct Pakistan-region MODIS albedo extraction and original statistical analysis remain to be completed.

Appendix D. Supplied Giovanni / NLDAS spreadsheet text

The export below is reproduced exactly as supplied by the user: metadata block first, then the 252 monthly values (January 2005 to December 2025). It is retained as a worked example of a Giovanni area-averaged time-series export and is **excluded from Punjab analysis** (North American NLDAS domain; see Sections 9 and 10).

D.1 Export metadata

Title	Time Series, Area-Averaged of Albedo monthly 0.125 deg. [NLDAS Model (monthly)
User Start Date	2005-01-01T00:00:00Z
User End Date	2025-12-31T23:59:59Z
User Bounding Box	(blank)
Data Bounding Box	-124.938, 25.0625, -67.0625, 52.9375
URL to Reproduce Results	https://giovanni.gsfc.nasa.gov/#service=ArAvTs&starttime=2005-01-01T00:00:00Z&endtime=2025-12-31T23:59:59Z&data=NLDAS_NOAH0125_M_2_0_Albedo&dataKeyword=Albedo&portal=GIOVANNI&format=json
Fill Value (mean_NLDAS_NOAH0125_M_2_0_Albedo)	-9999

D.2 Verification of the pasted series

Records: 252 (21 years × 12 months); fill values (-9999) present: 0. Maximum: 49.193634 (2008-01). Minimum: 24.9468575 (2015-05). Values are NLDAS-2 Noah model albedo in percent and are not Punjab observations.

D.3 Year-by-month overview (values rounded to 2 decimals for display)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	46.04	41.21	38.17	28.72	25.03	25.12	25.93	26.23	25.91	25.78	32.63	44.04
2006	42.19	41.51	39.62	30.24	25.20	25.12	25.93	26.23	25.94	26.47	31.46	40.59
2007	45.56	45.68	39.11	31.06	25.28	25.15	25.93	26.23	25.92	25.90	30.81	47.61
2008	49.19	48.06	40.92	32.36	25.55	25.18	25.95	26.23	25.89	26.01	30.58	44.69
2009	48.19	44.41	39.35	31.75	25.44	25.12	25.93	26.23	25.91	26.74	28.21	42.16
2010	46.81	46.50	34.79	26.61	25.22	25.14	25.93	26.23	25.91	25.90	31.95	44.45
2011	48.26	47.51	41.26	32.93	26.04	25.29	25.93	26.23	25.90	25.86	31.05	38.78
2012	41.90	40.81	35.65	27.71	25.12	25.18	25.95	26.23	25.89	26.37	31.35	40.83
2013	44.30	43.85	39.82	34.39	25.42	25.11	25.92	26.23	25.92	26.02	32.21	44.63
2014	45.22	46.83	40.98	34.13	25.73	25.11	25.93	26.23	25.92	25.69	33.84	40.37
2015	44.12	42.78	37.47	30.19	24.95	25.10	25.92	26.23	25.90	25.95	30.02	40.11
2016	45.95	42.00	35.71	30.71	25.14	25.13	25.95	26.23	25.89	26.00	29.01	43.58
2017	47.25	43.02	38.37	30.99	25.91	25.15	25.93	26.23	25.93	26.02	33.92	40.22
2018	43.38	43.33	39.47	34.81	25.28	25.10	25.92	26.23	25.92	26.64	33.90	40.70
2019	45.02	47.16	42.02	31.53	25.36	25.11	25.92	26.23	25.98	26.68	34.24	43.54
2020	45.82	44.68	39.00	33.36	25.95	25.17	25.95	26.23	25.92	27.70	32.90	39.39
2021	44.34	46.75	36.62	28.34	25.15	25.13	25.92	26.23	25.91	25.91	30.35	41.14
2022	45.15	43.81	38.47	33.50	26.15	25.21	25.93	26.23	25.90	25.86	35.29	44.23
2023	45.73	45.07	43.06	34.93	25.52	25.10	25.92	26.23	25.90	26.56	32.12	37.53
2024	44.14	39.25	36.90	29.71	25.25	25.15	25.95	26.23	25.89	25.77	30.11	39.98
2025	44.20	44.37	37.38	32.06	25.28	25.11	25.92	26.23	25.90	25.85	30.43	42.55

The unrounded values for every month are listed in D.4 on the following pages.

D.4 Full monthly data (as supplied)

Columns: time, mean_NLDAS_NOAH0125_M_2_0_Albedo

time	albedo (%)	time	albedo (%)	time	albedo (%)	time	albedo (%)
2005-01-01	46.0376167	2010-04-01	26.6136341	2015-07-01	25.9248714	2020-10-01	27.7017422
2005-02-01	41.2142715	2010-05-01	25.2202644	2015-08-01	26.2304115	2020-11-01	32.9023705
2005-03-01	38.1714249	2010-06-01	25.142477	2015-09-01	25.9031944	2020-12-01	39.3938637
2005-04-01	28.7173519	2010-07-01	25.9274902	2015-10-01	25.9490929	2021-01-01	44.3373108
2005-05-01	25.0284309	2010-08-01	26.2312279	2015-11-01	30.0161552	2021-02-01	46.7458076
2005-06-01	25.1177692	2010-09-01	25.9073124	2015-12-01	40.1092606	2021-03-01	36.6164436
2005-07-01	25.9252396	2010-10-01	25.8999577	2016-01-01	45.9514885	2021-04-01	28.3413677
2005-08-01	26.231142	2010-11-01	31.9547443	2016-02-01	42.0014305	2021-05-01	25.1453037
2005-09-01	25.9070396	2010-12-01	44.4519806	2016-03-01	35.7082825	2021-06-01	25.1278591
2005-10-01	25.7813835	2011-01-01	48.2555809	2016-04-01	30.7061119	2021-07-01	25.9246559
2005-11-01	32.6310654	2011-02-01	47.505146	2016-05-01	25.1382618	2021-08-01	26.2306061
2005-12-01	44.0439758	2011-03-01	41.2556686	2016-06-01	25.1302395	2021-09-01	25.9050083
2006-01-01	42.1888847	2011-04-01	32.9254417	2016-07-01	25.9474106	2021-10-01	25.9105015
2006-02-01	41.5084991	2011-05-01	26.0368156	2016-08-01	26.2279282	2021-11-01	30.3470974
2006-03-01	39.6176796	2011-06-01	25.2909966	2016-09-01	25.8903694	2021-12-01	41.1412926
2006-04-01	30.237545	2011-07-01	25.9347649	2016-10-01	26.00317	2022-01-01	45.1506958
2006-05-01	25.2030602	2011-08-01	26.2308617	2016-11-01	29.0086174	2022-02-01	43.8121834
2006-06-01	25.1188316	2011-09-01	25.9038773	2016-12-01	43.5758476	2022-03-01	38.4669495
2006-07-01	25.9253445	2011-10-01	25.8616066	2017-01-01	47.2542419	2022-04-01	33.4968681
2006-08-01	26.2310295	2011-11-01	31.0549507	2017-02-01	43.0243645	2022-05-01	26.1534634
2006-09-01	25.9423943	2011-12-01	38.7845154	2017-03-01	38.3699684	2022-06-01	25.2105637
2006-10-01	26.4666786	2012-01-01	41.8982811	2017-04-01	30.9913464	2022-07-01	25.9283161
2006-11-01	31.4574356	2012-02-01	40.812809	2017-05-01	25.909853	2022-08-01	26.230135
2006-12-01	40.593483	2012-03-01	35.6454163	2017-06-01	25.1498718	2022-09-01	25.8968945
2007-01-01	45.5648155	2012-04-01	27.7143974	2017-07-01	25.9255505	2022-10-01	25.8579865
2007-02-01	45.6806526	2012-05-01	25.1203136	2017-08-01	26.2303772	2022-11-01	35.2911377
2007-03-01	39.1132126	2012-06-01	25.1808281	2017-09-01	25.934618	2022-12-01	44.2279663
2007-04-01	31.0626526	2012-07-01	25.9491386	2017-10-01	26.0157738	2023-01-01	45.7310562
2007-05-01	25.281002	2012-08-01	26.2280998	2017-11-01	33.9208145	2023-02-01	45.0667267
2007-06-01	25.1479473	2012-09-01	25.8867912	2017-12-01	40.2199097	2023-03-01	43.0563011
2007-07-01	25.9281273	2012-10-01	26.3719845	2018-01-01	43.3767929	2023-04-01	34.9340096
2007-08-01	26.2308998	2012-11-01	31.3503227	2018-02-01	43.3302307	2023-05-01	25.5224762
2007-09-01	25.9158134	2012-12-01	40.8266296	2018-03-01	39.4706497	2023-06-01	25.1021481
2007-10-01	25.9028606	2013-01-01	44.2952423	2018-04-01	34.812561	2023-07-01	25.924324
2007-11-01	30.8074894	2013-02-01	43.8517761	2018-05-01	25.2784767	2023-08-01	26.2300129
2007-12-01	47.609539	2013-03-01	39.8183136	2018-06-01	25.1030369	2023-09-01	25.8994598
2008-01-01	49.193634	2013-04-01	34.3916168	2018-07-01	25.9248886	2023-10-01	26.5591202
2008-02-01	48.0598602	2013-05-01	25.4239731	2018-08-01	26.2304211	2023-11-01	32.1191826
2008-03-01	40.915657	2013-06-01	25.1073284	2018-09-01	25.9193344	2023-12-01	37.5320969
2008-04-01	32.3576241	2013-07-01	25.9248486	2018-10-01	26.6391029	2024-01-01	44.1379166
2008-05-01	25.5465031	2013-08-01	26.2301273	2018-11-01	33.9004059	2024-02-01	39.2455864
2008-06-01	25.1848602	2013-09-01	25.9230328	2018-12-01	40.6978264	2024-03-01	36.8963356
2008-07-01	25.9478474	2013-10-01	26.0244579	2019-01-01	45.0206184	2024-04-01	29.7055111
2008-08-01	26.2293835	2013-11-01	32.2099266	2019-02-01	47.1606331	2024-05-01	25.2452202

time	albedo (%)	time	albedo (%)	time	albedo (%)	time	albedo (%)
2008-09-01	25.8900948	2013-12-01	44.6294746	2019-03-01	42.0224876	2024-06-01	25.1540928
2008-10-01	26.0107059	2014-01-01	45.2217216	2019-04-01	31.5252399	2024-07-01	25.9468498
2008-11-01	30.5849495	2014-02-01	46.8315735	2019-05-01	25.3552589	2024-08-01	26.2278519
2008-12-01	44.6949654	2014-03-01	40.9828758	2019-06-01	25.1084194	2024-09-01	25.8859863
2009-01-01	48.1900978	2014-04-01	34.125946	2019-07-01	25.9248028	2024-10-01	25.7694168
2009-02-01	44.4050674	2014-05-01	25.7267189	2019-08-01	26.230299	2024-11-01	30.1055336
2009-03-01	39.3512993	2014-06-01	25.1129131	2019-09-01	25.9756794	2024-12-01	39.9823799
2009-04-01	31.7517529	2014-07-01	25.9252415	2019-10-01	26.6764908	2025-01-01	44.1991844
2009-05-01	25.4381676	2014-08-01	26.2306156	2019-11-01	34.2433739	2025-02-01	44.3708
2009-06-01	25.1213551	2014-09-01	25.9185715	2019-12-01	43.5436058	2025-03-01	37.3837547
2009-07-01	25.9255009	2014-10-01	25.6893921	2020-01-01	45.816021	2025-04-01	32.0583763
2009-08-01	26.2310886	2014-11-01	33.8360672	2020-02-01	44.6821251	2025-05-01	25.2770653
2009-09-01	25.9050426	2014-12-01	40.3655663	2020-03-01	39.0034599	2025-06-01	25.105751
2009-10-01	26.739851	2015-01-01	44.1186829	2020-04-01	33.3589287	2025-07-01	25.9246311
2009-11-01	28.2124767	2015-02-01	42.7837868	2020-05-01	25.9464073	2025-08-01	26.2301769
2009-12-01	42.1646614	2015-03-01	37.4682808	2020-06-01	25.1658669	2025-09-01	25.8969784
2010-01-01	46.8111534	2015-04-01	30.1874065	2020-07-01	25.9485588	2025-10-01	25.8524132
2010-02-01	46.5033913	2015-05-01	24.9468575	2020-08-01	26.227951	2025-11-01	30.432003
2010-03-01	34.7933731	2015-06-01	25.0966797	2020-09-01	25.9205284	2025-12-01	42.5526924

Timestamps are 00:00:00 UTC on the first day of each month, as in the export. Source: NASA Giovanni, NLDAS_NOAH0125_M_2_0_Albedo.