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      created for two-to-three-year intervals between 2001 and the most recent year. These products
      provide spatially explicit and reliable information on the Nation’s land cover and land cover
      change. NLCD continues to provide innovative, consistent, and robust methodologies for
      production of a multi-temporal land cover and land cover change database. NLCD 2021 adds an
      additional year to the map products produced for NLCD 2019, with a streamlined compositing
      process for assembling and preprocessing Landsat imagery and geospatial ancillary datasets; a
      temporally, spectrally, and spatially integrated land cover change analysis strategy; a theme-
      based post-classification protocol for generating land cover and change products; a continuous
      fields biophysical parameters modeling method; and a scripted operational system. The overall
      accuracy of the 2019 Level I land cover was 91%. Results from this study confirm the robustness
      of this comprehensive and highly automated procedure for NLCD 2021 operational mapping (see
      https://doi.org/10.1080/15481603.2023.2181143 for the latest accuracy assessment publication).
      Questions about the NLCD 2021 land cover product can be directed to the NLCD 2021 land cover
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    at each pixel location from valid (no cloud/shadow/snow/fill data in the pixel QA) pixels in
    an image stack. The observation with the shortest Euclidean distance to this median-value
    point in six-dimensional (six-band) space provides the values for each band for that pixel.
    For “leaf-on” (growing season) composite images, the range of dates used to query for
    eligible Landsat observations is May 1 to September 30, and for “leaf-off”, November 1
    through April 1. These composites are generated across all Landsat optical bands (informally,
    the wavelength bands blue, green, red, NIR, SWIR1, and SWIR2; equivalently, the wavelength
    ranges for Landsat TM/ETM+ bands 1, 2, 3, 4, 5, and 7). We generated annual leaf-on
    composites from 2000 to 2021, and annual leaf-off composites from 2018 to 2021.</procdesc>
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    <procdesc>Landsat synthetic imagery - Synthetic images are generated from a model of Landsat
    surface reflectance (or brightness temperature, etc.), analogous to the approach by Zhu et
    al. (2015) (https://doi.org/10.1016/j.rse.2015.02.009). Synthetic images in this case are
    derived from the LCMAP CCDC CONUS 1.3 harmonic models
    (https://www.usgs.gov/media/files/lcmap-collection-13-ccdc-add). Data is produced for the
    same six bands considered in composite generation—the thermal band harmonic model is not
    used. For NLCD 2021 we produced CONUS leaf-on synthetic imagery for 2000-2020 based on the
    July 1 date. In addition, we generated CONUS leaf-off synthetic imagery for 2018-2020 based
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    <procdesc>Land cover classification (imagery) - In addition to Landsat imagery (leaf-on
    composite and leaf-off CCDC-synthetic), other datasets used as input into the land cover
    classification were: segmented-polygon-based mean of Landsat imagery, digital elevation data
    and derivatives (aspect, slope, and position index); forest disturbance year 1984-2021, 90th
    percentile and 20th percentile Normalized Difference Vegetation Index (NDVI), and 20th
    percentile Normalized Difference Water Index (NDWI). Landsat composites, synthetic images,
    and annual percentile spectral indices were created for leaf on and leaf off in 2019 and 2021
    based on NLCD block mapping units (generally 9 Landsat path/rows per block). The use of the
    same style change pairs ensures proper phenological matches and similar spectral properties.
```

It also reduces the overlap area between this type of imagery compared to individual Landsat path/row images. </procdesc>
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<procdesc>Land cover classification (modeling change) - NLCD 2021 was produced by modeling land cover change over the time interval between 2019 and 2021. Models used included; the Multi-Index Integrated Change Analysis (MIICA) model (https://doi.org/10.1016/j.rse.2013.01.012), which captures change between two dates of imagery; the Time-Series method Using Normalized Spectral Distance (NSD) index (TSUN), which produces a forest land cover change disturbance year map; a water detection model, which captures water for each date of Landsat imagery; models that detect cultivated crop for each date Landsat imagery; and a time series model to detect cultivated crop change. Landsat imagery, ancillary data (see datasets listed under Source Information), the MIICA outputs, other change detection outputs, and the 1986 to 2021 disturbance year map (derived from our change detection procedures) comprise the training data. </procdesc>
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<procdesc>Land cover classification (training data and image segmentation) - The training dataset models were built with Landsat images and derived indices, spectral change products, trajectory analysis, and ancillary data, including previous years’ NLCD land cover; LANDFIRE-EVH; CDL; NWI; cultivated cropland 2008 to 2021; MTBS fire year, NLCD tree canopy and RCMAP land cover. Image segmentation, using Ecognition, was performed on the synthetic and composite imagery, and the resulting image objects were used to mitigate noise in the training data. The final output of this stage is training data for each of the target years, used as input into the initial land cover classification stage. </procdesc>
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<procdesc>Land cover classification (decision tree) - For each year of Landsat data, two percent of all available training data per NLCD block was drawn from the data as training samples with 5000 minimum samples and 1000000 maximum samples for each land cover class, and one percent was drawn as validation samples. The See5 decision tree classification software was run on the training samples to generate a set of rules, and the decision rules were applied to generate a land cover classification for each target year. The See5 classifier was run with five sets of independent variables: the 1986 to 2021 disturbance year map derived from our change detection procedures; the set of Landsat images; polygon-based (from image segmentation) mean of Landsat images; annual percentile spectral indices; and a DEM and derivatives. The See5 classification was run three times on each NLCD block: 1) with all land cover classes plus the 1986 to 2021 disturbance year data; 2) with urban and wetland classes omitted; and 3) with urban and wetland classes omitted, and without the disturbance year data, since these classes have separate process steps. Urban is directly derived from percent impervious, and wetland is derived from the postprocessing of integrating first classification, wetland potential index, change detection, and NLCD wetland base. Wetland potential index is derived from the NWI, hydric soil, and NLCD wetland classes. </procdesc>
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<procdesc>Land cover classification (U-net machine learning) - We also produced a Unet classification for the entire CONUS: inputs included NLCD2019 as training data, leaf-on composite and leaf-off synthetic Landsat imagery, and digital elevation data. </procdesc>
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<procdesc>Land cover change refinement - A post-classification refinement process was used to refine the land cover change between NLCD 2019 and NLCD 2021. We checked for consistency of land cover labels between 2019 and 2021; and compared the classification change with imagery-based change detection, ancillary data, and NLCD 2019. Additional refinement was conducted class-by-class in hierarchical order: 1) water; 2) wetlands; 3) forest and forest transition; 4) rangeland shrubland, herbaceous, and barren, and 5) agriculture. Models were developed for refinement of each class and each type of confusion. </procdesc>
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<procdesc>Land cover classification integration - The final integration step resolved class label issues pertinent to local environments and boundary pixels, and ensured that all pixels in a segmentation object were in the same class. Developed classes were derived from percent developed impervious surface. Pixel-based and object-based land cover labels were checked for differences, and were reconciled by a rule-based model. Water and developed classes were left intact in areas that were smaller than segmentation objects. Change trajectories for each class were checked for consistency through all years. </procdesc>
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