

Tuning into the seasons: the scientific and land-management value of intra-annual monitoring with Landsat

Now that we have annual NLCD, what is the value of satellite measurements captured throughout the year?

The USGS National Land Cover Database, newly released at yearly frequency (a.k.a., the “Annual NLCD”), is a significant achievement in remote sensing. Spanning the full (1984 – present) temporal extent of the Landsat archive, its 40-year record of land cover in the simplest, categorical level of detail allows regional quantification of trends as well as detection of major changes in each pixel across the conterminous United States. While still comparatively under-used by land managers relative to its adoption by scientists, the NLCD categories are commonly used in wildlife habitat models and other analyses in academic research. This is a major step toward consistent, robust monitoring of the US land area, but it leaves many ecological and hydrological processes unmeasured—and consequently, many scientists and land managers under-served.

Most landscape changes are small or gradual, and countless ecological, hydrological, and other processes occur within the year. While the NLCD leverages the full temporal span of the Landsat archive, the dataset does not measure or convey seasonal (e.g., phenological, hydrological) variation to scientists or managers. In order to study and manage the ecological, hydrological, and agricultural processes that occur within the year, the full *depth* and *frequency* of the Landsat archive must also be leveraged.

Landsat and other measurements captured and recorded at seasonal time scales provide scientists and land managers significant advantages. These indices represent a variety of important ecosystem characteristics, and they can be produced and delivered faster than categorical land cover datasets. Below is a list of benefits of seasonal-scale measurements from Landsat and other publicly available intra-annual imagery.

1. Capturing Phenological Dynamics

- **Vegetation Phenology:** Many ecosystems undergo rapid changes in vegetation cover and health within seasons, such as greening during spring or senescence in fall. Monitoring these transitions with indices such as the Normalized Difference Vegetation Index (NDVI) can provide crucial insights into ecosystem health.
- **Agricultural Monitoring:** Crop planting, growth, irrigation, and harvesting occur over weeks or months. Resolving these processes within the year tracks these changes, providing actionable data for precision agriculture, crop yield estimation, and cover crop verification.

2. Resolving Seasonal Habitats

- **Wildlife Management:** Many species rely on seasonally dynamic habitats, such as grasslands, wetlands, high- and low-marsh areas, or ephemeral pools. Seasonal measurements with indices such as the Normalized Difference Moisture Index (NDMI) enable the identification and tracking of critical habitats throughout breeding, migration, or overwintering periods.
- **Hydrological Variability:** Wetland inundation, snow cover, and surface water extent can change drastically within seasons. Monitoring these changes with measurements such as the Normalized Difference Water Index (NDWI) and radar backscatter coefficients supports better hydrological modeling and habitat conservation.

3. Enhancing Model Inputs

- **Watershed Hydrology:** Seasonal vegetation and land cover dynamics influence water infiltration, runoff, and evapotranspiration. Intra-annual data improve watershed and hydrological models compared to static annual inputs.
- **Carbon Flux Models:** Seasonal changes in vegetation indices (e.g., NDVI) are critical for estimating carbon fluxes and understanding terrestrial carbon dynamics.
- **Fire Behavior:** Fire behavior depends heavily on current land cover conditions, including vegetation density, moisture, and type. Seasonal updates to broad land cover categories ensure fire behavior models are fit to conditions precisely at the time of ignition and spread.

4. Detecting Subtle Trends

- **Cumulative Impacts:** Seasonal summaries of vegetation indices can reveal subtle, long-term trends in land cover, such as shifts in growing season length, wetland drying, or forest decline that may be overlooked in annual, categorical datasets until changes escalate into crises.
- **Transitional States:** Intra-annual data improve detection of transitional land cover states, such as agricultural fallow periods or regenerating forest, which are often misclassified in annual datasets.

5. Supporting Decision-Making

- **Adaptive Management:** Seasonal monitoring provides near-real-time data to inform adaptive land management, such as optimizing irrigation schedules, targeting pest and fuels control, and allocating resources for restoration and climate adaptation.
 - **Disturbances:** Events like floods, wildfires, droughts, pest outbreaks, or extreme weather can cause abrupt land cover changes. Intra-annual monitoring detects these disturbances as they occur, enabling rapid response and mitigation, whereas annual data may miss or underestimate such events.
 - **Land Management Interventions:** Restoration activities such as reforestation, wetland recovery, or riparian buffer planting can have measurable effects within months. Seasonal data allow managers to evaluate progress and adjust efforts in near-real-time.
 - **Wildfire Risk Assessments:** Vegetation canopy density and flammability change throughout the year, depending on factors like moisture content, growth stage, and senescence. Seasonal indices such as NDVI (Normalized Difference Vegetation Index) and NDMI (Normalized Difference Moisture Index) track these dynamics, enabling real-time fire risk assessments and improved long-term fire risk models.
 - **Drought Conditions:** Remote sensing indices (e.g., NDMI, radar backscatter) can detect early signs of drought stress, which increases wildfire risk. Intra-annual data allow for proactive fire mitigation planning, such as prescribed burns or mechanical fuel reductions.
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Conclusion

While annual land cover maps such as NLCD are invaluable for broad-scale, long-term monitoring, intra-annual monitoring and analysis based on spectral indices such as Normalized Difference Vegetation, Water, and moisture indices and radar backscatter provide granular, time-sensitive insights into ecological, hydrological, and anthropogenic dynamics. These capabilities are essential for effective, adaptive land management and understanding the complex interactions between ecosystems and land use.