**lsatTS: an R package for deriving vegetation greenness time series using Landsat satellite data**

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**Abstract**

Earth-observing satellites are crucial for assessing and monitoring global ecosystems. The Landsat satellite series provide near global surface reflectance measurements since the early 1980s and are thus a corner stone of remotely-sensed ecological assessments. Landsat surface reflectance measurements are commonly used to derive spectral indices (e.g., NDVI) that can provide insight into annual to multi-decadal changes in ecosystem biophysical properties such as vegetation greenness. Nevertheless, multiple factors impede multi-decadal assessments of spectral indices using Landsat satellite data, including ease of data access and cleaning as well as challenges with cross-sensor calibration and irregular timing of cloud-free acquisitions. The R package *lsatTS* was developed to facilitate time series analysis of spectral indices derived from Landsat surface reflectance measurements. This package includes functions that enable full data record extraction for sample sites or study regions using Google Earth Engine accessed from R. Moreover, the package includes functions for (1) rigorous data cleaning, (2) cross-sensor calibration with machine learning, (3) phenological modeling, and (4) other aspects of data analysis. Overall, this software provides a suite of functions to enable broader use of Landsat data for ecological assessments and monitoring.

**Background**

*Ecological assessment and monitoring using Earth observing satellites*

* Earth-observing are crucial for monitoring land sur
* Importance of EOS, especially Landsat
* Spectral indices are widely used as indicators of how biophysical conditions are changing.
* Arctic greening and browning

*Impediments to long-term assessments using the Landsat satellites*

* Data access and processing
  + Traditionally from USGS, but now made available through GEE
* Data cleaning
  + …It’s important but is hard
  + FMask
  + Residual water
* Cross sensor calibration
  + There are systematic differences in individual bands and spectral indices among Landsat 5’s Thematic Mapper (TM), Landsat 7’s Enhanced Thematic Mapper Plus (ETM+), and Landsat 8’s Operational Land Imager (OLI).
  + These differences can introduce spurious trends into time series generated from multiple sensors.
  + For instance, these biases can lead to spurious increases in NDVI (‘greening’) (Sulla-Menashe et al. 2017).
  + Existing approaches focus on linear corrections, but not all relationships are linear
* Irregulating timing of observations
  + Each Landsat satellite passes over a location about once every 16 days.
  + Clouds can obscure the land surface and lead to irregular acquisition surface reflectance measurements made under clear-sky conditions.
  + This makes it challenging, for instance, to assesses vegetation greenness at a desired phenological stage (e.g., maximum summer greenness).

*The lsatTS package*

**Methods and features**

Figure 1. Schematic

Table 1. Functions names and descriptions

|  |  |  |
| --- | --- | --- |
| **Step** | **Function** | **Description** |
| Data acquisition |  |  |
|  |  |  |
| Data cleaning |  |  |
|  |  |  |
|  |  |  |
| Data |  |  |
|  |  |  |

**Example application**