

# Package ‘LandsatTS’

April 20, 2023

**Title** An R package to facilitate retrieval, cleaning, cross-calibration, and phenological modeling of Landsat time-series data

**Version** 1.1.1

**Description** This software package facilitates sample-based time series analysis of surface reflectance and spectral indices derived from sensors on the Landsat satellites. The package includes functions that enable extraction of the full Landsat record for point sample locations or small study regions using Google Earth Engine directly accessed from R. Moreover, the package includes functions for (1) data cleaning, (2) cross-sensor calibration, (3) phenological modeling, and (4) time series analysis.

**License** Modified MIT + file LICENSE

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**Depends** R (>= 3.50)

**VignetteBuilder** knitr

## R topics documented:

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lsat.example.dt	<i>Example Landsat data around Arctic research stations</i>
-----------------	---

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## Description

This dataset provides Landsat time series data for sample locations around several research stations in the Arctic. These data were extracted from Google Earth Engine using the `lsat_export_ts()` function.

## Usage

```
data("lsat.example.dt")
```

## Format

A data frame with 5296 observations on the following 23 variables.

‘system:index’ GEE index  
 CLOUD\_COVER Percent cloud cover of scene  
 COLLECTION\_NUMBER Landsat collection number  
 DATE\_ACQUIRED Acquisition date in yyyy-mm-dd format  
 GEOMETRIC\_RMSE\_MODEL RMSE of geometric residuals in meters  
 LANDSAT\_PRODUCT\_ID Landsat product identifier  
 LANDSAT\_SCENE\_ID Landsat scene identifier  
 PROCESSING\_LEVEL Processing level  
 QA\_PIXEL CFMASK pixel quality attribute bitmask  
 QA\_RADSAT Radiometric saturation bitmask  
 SPACECRAFT\_ID Name of the spacecraft  
 SR\_B1 Band 1 surface reflectance  
 SR\_B2 Band 2 surface reflectance  
 SR\_B3 Band 3 surface reflectance  
 SR\_B4 Band 4 surface reflectance  
 SR\_B5 Band 5 surface reflectance  
 SR\_B6 Band 6 surface reflectance  
 SR\_B7 Band 7 surface reflectance  
 SUN\_ELEVATION Sun elevation angle in degrees for the image center location at the image center acquisition time  
 chunk\_id Download chunk identifier  
 max\_extent JRC maximum water extent flag  
 sample\_id User specified sample location identifier  
 .geo Sample location coordinates

## Details

These data are used for the package vignette (<https://github.com/logan-berner/LandsatTS>) and function examples.

## Source

These data were extracted from Google Earth Engine using the `lsat_export_ts()` function.

## References

Landsat data are provided by the United States Geological Survey

---

```
lsat_calc_spectral_index
      Calculate spectral indices
```

---

## Description

This function computes some widely used spectral vegetation indices. Only one index can be computed at a time. Current indices include the: Normalized Difference Vegetation Index (NDVI; Rouse et al. 1974), kernel NDVI (kNDVI; Camps-Valls et al. 2020), Green NDVI (gNDVI; Gitelson and Merzlyak 1998), Soil Adjusted Vegetation Index (SAVI; Huete 1998), Wide Dynamic Range Vegetation Index (WDRVI; Gitelson 2004), Enhanced Vegetation Index (EVI; Huete et al. 2002), 2-band EVI (EVI2; Jiang et al. 2008), Near Infrared Vegetation Index (NIRv; Badgley et al. 2017), Moisture Stress Index (MSI; Rock et al. 1986), Normalized Difference Water Index (NDWI; McFeeters 1996), Normalized Difference Moisture Index (NDMI; Gao 1996), Normalized Burn Ratio (NBR, Key and Benson 1999), Normalized Difference Infrared Index (NDII; Hardisky et al. 1983), Plant Senescence Reflectance Index (PSRI; Merzlyak et al. 1999), and the Soil-Adjusted Total Vegetation Index (SATVI; Marsett et al. 2006).

## Usage

```
lsat_calc_spectral_index(dt, si)
```

## Arguments

<code>dt</code>	Data.table containing surface reflectance data.
<code>si</code>	Character string specifying abbreviation of the desired spectral index.

## Value

The input `data.table` with an appended column containing the spectral index.

## Examples

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
lsat.dt
```

lsat\_calc\_trend

*Calculate non-parametric vegetation greenness trends***Description**

This function evaluates and summarizes interannual trends in vegetation greenness for sample sites over a user-specified time period. Potential interannual trends in vegetation greenness are assessed using Mann-Kendall trend tests and Theil-Sen slope indicators after prewhitening each time series. This trend assessment relies on the `zyp.yuepilon()` function from the `zyp` package, which provides further details.

**Usage**

```
lsat_calc_trend(dt, si, yrs, yr.tolerance = 1, nyr.min.frac = 0.66, sig = 0.1)
```

**Arguments**

<code>dt</code>	Data.table with columns including site, year, and the vegetation index of interest.
<code>si</code>	Spectral index for which to assess trend (e.g., NDVI).
<code>yrs</code>	A sequence of years over which to assess trends (e.g., 2000:2020).
<code>yr.tolerance</code>	The number of years that a site's first/last years of observations can differ from the start/end of the user-specified time period ('yrs') for a trend to be computed.
<code>nyr.min.frac</code>	Fraction of years within the time period for which observations must be available if a trend is to be computed.
<code>sig</code>	A p-value significance cutoff used to categories trends (e.g., 0.10)

**Value**

A list that includes: (1) a summary message about the mean relative change across sample sites; (2) a data.table summarizing the number and percentage of sites that fall into each trend category; (3) a data.table with trend statistics for each sample site.

**Examples**

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
# lsat.dt <- lsat_calibrate_rf(lsat.dt, band.or.si = 'ndvi', write.output = F)
lsat.pheno.dt <- lsat_fit_phenological_curves(lsat.dt, si = 'ndvi')
lsat.gs.dt <- lsat_summarize_growing_seasons(lsat.pheno.dt, si = 'ndvi')
lsat.trend.dt <- lsat_calc_trend(lsat.gs.dt, si = 'ndvi.max', yrs = 2000:2020)
lsat.trend.dt
```

---

lsat\_calibrate\_poly      *Cross-calibrate Landsat sensors using polynomial regression*


---

## Description

There are systematic differences in spectral indices (e.g., NDVI) among Landsat 5, 7, and 8 (Landsat Collection 2). It is important to address these differences before assessing temporal trends in spectral data. Failure to address these differences can, for instance, introduce artificial positive trends into NDVI time-series that are based on measurements from multiple Landsat sensors (Ju and Masek 2016, Roy et al. 2016, Berner et al. 2020). This function cross-calibrates individual bands or spectral indices from Landsat 5/8 to match Landsat 7. Landsat 7 is used as a benchmark because it temporally overlaps with the other two sensors. Cross-calibration can only be performed on one band or spectral index at a time. The approach involves determining the typical reflectance at a sample during a portion of the growing season site using Landsat 7 and Landsat 5/8 data that were collected the same years. Polynomial regression models from first to third order are trained to predict Landsat 7 reflectance from Landsat 5/8 reflectance, the most parsimonious model is selected using BIC, and then that model is used to cross-calibrate the data. This approach is most suitable when working with data from 100s to preferably 1000s of samples.

The specific steps to cross-calibrating sensors include: (1) Identify the years when both Landsat 7 and Landsat 5/8 measured surface reflectance at a sample. (2) Pool the reflectance measurements across those years and compute 15-day moving median reflectance over the course of the growing season for each sensor and sampling sample. (3) Exclude 15-day periods with fewer than a specified number of measurements from both sets of sensors and then randomly select one remaining 15-day period from each sample. (4) Split the data into sets for model training and evaluation. (5) Train polynomial regression models that predict Landsat 7 reflectance based on Landsat 5/8 reflectance. Model order (1st to 3rd) is selected using BIC. (6) Apply the polynomial regression models to cross-calibrate measurements.

See Berner et al. (2020) for a full description of the approach.

## Usage

```
lsat_calibrate_poly(
  dt,
  band.or.si,
  doy.rng = 152:243,
  min.obs = 5,
  train.with.highlat.data = F,
  frac.train = 0.75,
  trim = T,
  overwrite.col = F,
  write.output = F,
  outfile.id = band.or.si,
  outdir = NA
)
```

## Arguments

dt	Data.table containing the band or spectral index to cross-calibrate.
band.or.si	Character string matching the column name of the band or spectral index to cross-calibrate.

doy.rng	Sequence of numbers specifying the Days of Year to use for model development.
min.obs	Minimum number of paired, seasonally-matched observations from Landsat 7 and Landsat 5/8 required to include a sampling sample.
train.with.highlat.data	(True/False) Should the RF models be trained using an internal high-latitude dataset that sampled the Arctic and Boreal biomes?
frac.train	Fraction of samples to use for training the random forest models. The remaining samples are used for model cross-validation.
trim	(True/False) If true, then for each sample site the percent difference in spectral indices between satellites is determined. The lowest 2.5 and highest 97.5 percentiles are then trimmed. This is meant to reduce potential differences that are not directly attributable to the sensors, but rather to exogenous factors.
overwrite.col	(True/False) Overwrite existing column or (by default) append cross-calibrated data as a new column?
write.output	(True/False) Should RF models and evaluation content be written to disk? Either way, evaluation table and figure are printed in the console.
outfile.id	Identifier used when naming output files. Defaults to the input band, but can be specified if needed such as when performing Monte Carlo simulations.
outdir	Output directory (created if necessary) to which multiple files will be written. The files include: (1) fitted random forest models as R objects, (2) evaluation data in a csv file, (3) summary of model cross-validation in a csv file, and (4) multi-panel scatter plot comparing sensors pre- and post-calibration in jpeg format. If cross-calibrating both Landsat 5 and 8, then the function returns files for both sensors.

### Value

The input data.table with an appended column titled band.xcal, where "band" is your specified band or spectral index.

### Examples

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
lsat.dt <- lsat_calibrate_poly(lsat.dt, band.or.si = 'ndvi',
                             train.with.highlat.data = TRUE,
                             write.output = FALSE)

lsat.dt
```

## Description

There are systematic differences in spectral indices (e.g., NDVI) among Landsat 5, 7, and 8 (Landsat Collection 2). It is important to address these differences before assessing temporal trends in spectral data. Failure to address these differences can, for instance, introduce artificial positive trends into NDVI time-series that are based on measurements from multiple Landsat sensors (Ju and Masek 2016, Roy et al. 2016, Berner et al. 2020). This function cross-calibrates individual bands or spectral indices from Landsat 5/8 to match Landsat 7. Landsat 7 is used as a benchmark because it temporally overlaps with the other two sensors. Cross-calibration can only be performed on one band or spectral index at a time. The approach involves determining the typical reflectance at a sample during a portion of the growing season site using Landsat 7 and Landsat 5/8 data that were collected the same years. A Random Forest model is then trained to predict Landsat 7 reflectance from Landsat 5/8 reflectance. To account for potential seasonal and regional differences between sensors, the Random Forest models also include as covariates the midpoint of each 15-day period (day of year), the spatial coordinates of each sample, and potentially other use-specified variables. This approach is most suitable when working with data from 100s to preferably 1000s of sample samples.

The specific steps to cross-calibrating sensors include: (1) Identify the years when both Landsat 7 and Landsat 5/8 measured surface reflectance at a sample. (2) Pool the reflectance measurements across those years and compute 15-day moving median reflectance over the course of the growing season for each sensor and sampling sample. (3) Exclude 15-day periods with fewer than a specified number of measurements from both sets of sensors and then randomly select one remaining 15-day period from each sample. (4) Split the data into sets for model training and evaluation. (5) Train Random Forest models that predict Landsat 7 reflectance based on Landsat 5/8 reflectance. The models also account for potential seasonal and regional differences between sensors by including as covariates the midpoint of each 15-day period (day of year) and the spatial coordinates of each sampling sample. The models are trained using the ranger function from the ranger package (Wright and Ziegler, 2017). (6) Apply the fitted Random Forest models to cross-calibrate measurements.

See Berner et al. (2020) for a full description of the approach.

## Usage

```
lsat_calibrate_rf(
  dt,
  band.or.si,
  doy.rng = 152:243,
  min.obs = 5,
  train.with.highlat.data = F,
  add.predictors = NULL,
  frac.train = 0.75,
  trim = T,
  overwrite.col = F,
  write.output = F,
  outfile.id = band.or.si,
  outdir = NA
)
```

## Arguments

<code>dt</code>	Data.table containing the band or spectral index to cross-calibrate.
<code>band.or.si</code>	Character string matching the column name of the band or spectral index to cross-calibrate.

doy.rng	Sequence of numbers specifying the Days of Year to use for model development.
min.obs	Minimum number of paired, seasonally-matched observations from Landsat 7 and Landsat 5/8 required to include a sampling sample.
train.with.highlat.data	(True/False) Should the RF models be trained using an internal high-latitude dataset that sampled the Arctic and Boreal biomes?
add.predictors	Vector of additional predictors to use in the Random Forest models. These should be time-invariant and match column names.
frac.train	Fraction of samples to use for training the random forest models. The remaining samples are used for model cross-validation.
trim	(True/False) If true, then for each sample site the percent difference in spectral indices between satellites is determined. The lowest 2.5 and highest 97.5 percentiles are then trimmed. This is meant to reduce potential differences that are not directly attributable to the sensors, but rather to exogenous factors.
overwrite.col	(True/False) Overwrite existing column or (by default) append cross-calibrated data as a new column?
write.output	(True/False) Should RF models and evaluation content be written to disk? Either way, evaluation table and figure are printed in the console.
outfile.id	Identifier used when naming output files. Defaults to the input band, but can be specified if needed such as when performing Monte Carlo simulations.
outdir	Output directory (created if necessary) to which multiple files will be written. The files include: (1) fitted random forest models as R objects, (2) evaluation data in a csv file, (3) summary of model cross-validation in a csv file, and (4) multi-panel scatter plot comparing sensors pre- and post-calibration in jpeg format. If cross-calibrating both Landsat 5 and 8, then the function returns files for both sensors.

### Value

The input data.table with an appended column titled band.xcal, where "band" is your specified band or spectral index.

### Examples

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
lsat.dt <- lsat_calibrate_rf(lsat.dt, band.or.si = 'ndvi',
                           train.with.highlat.data = TRUE,
                           write.output = FALSE)

lsat.dt
```



## Description

This function enables users to filter out surface reflectance measurements that exhibit: (1) clouds, cloud shadows, snow, or water flagged by the CFMask algorithm; (2) surface water over the Landsat record; (3) impossibly high reflectance ( $>1.0$ ) and abnormally low reflectance ( $<0.005$ ); (4) scene cloud cover above a user-defined threshold; (5) geometric uncertainty above a user-defined threshold; (6) solar zenith angle above a user-defined threshold.

## Usage

```
lsat_clean_data(
  dt,
  cloud.max = 80,
  geom.max = 30,
  sza.max = 60,
  filter.cfmask.snow = T,
  filter.cfmask.water = T,
  filter.jrc.water = T
)
```

## Arguments

dt	Data.table generated by calling lsat_format_data().
cloud.max	Maximum allowable cloud cover in Landsat scene (percentage).
geom.max	Maximum allowable geometric uncertainty (meters).
sza.max	Maximum allowable solar zenith angle (degrees).
filter.cfmask.snow	(TRUE/FALSE) Remove measurements with CFmask flag = snow.
filter.cfmask.water	(TRUE/FALSE) Remove measurements with CFmask flag = water.
filter.jrc.water	(TRUE/FALSE) Remove sample sites that were ever inundated based on the maximum surface water extent variable from the JRC Global Surface Water Dataset.

## Value

A data.table that includes Landsat measurements that met the quality control criteria.

## Examples

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt
```

---

lsat\_evaluate\_phenological\_max

*Evaluate estimates of annual phenological maximum*


---

## Description

Assess how the number of annual Landsat measurements impacts estimates of annual maximum vegetation greenness derived from raw measurements and phenological modeling. The algorithm computes annual maximum vegetation greenness for each site using years with at least a user-specific number of measurements and then compares these with estimates derived when using progressively smaller subsets of measurements. This lets the user determine the degree to which annual estimates of maximum vegetation greenness are impacted by the number of available measurements.

## Usage

```
lsat_evaluate_phenological_max(
  dt,
  si,
  min.frac.of.max = 0.75,
  zscore.thresh = 3,
  min.obs = 6,
  reps = 10,
  outdir = NA
)
```

## Arguments

dt	Data.table output from lsat_fit_phenological_curves().
si	Character string specifying the spectral index (SI) to evaluate (e.g., NDVI).
min.frac.of.max	Numeric threshold (0-1) that defines the "growing season" as the seasonal window when the phenological curves indicate the SI is within a specified fraction of the maximum SI. In other words, an observation is considered to be from the "growing season" when the SI is within a user-specified fraction of the curve-fit growing season maximum SI.
zscore.thresh	Numeric threshold specifying the Z-score value beyond which individual measurements are filtered before computing the maximum SI.
min.obs	Minimum number of site-level measurements needed each year to be included in the evaluation (Default = 10).
reps	Number of times to bootstrap the assessment (Default = 10).
outdir	If desired, specify the output directory where evaluation data and figure should be written. If left as NA, then output is only displayed in the console and not written to disk.

## Value

A data.table and a figure summarizing how estimates of annual maximum SI vary with the number of Landsat measurements made during each growing season.

## Examples

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
# lsat.dt <- lsat_calibrate_rf(lsat.dt, band.or.si = 'ndvi', write.output = FALSE)
lsat.pheno.dt <- lsat_fit_phenological_curves(lsat.dt, si = 'ndvi')
lsat_evaluate_phenological_max(lsat.pheno.dt, si = 'ndvi')
```

---

lsat\_export\_ts

---

*Export reflectance time-series from the Landsat record using rgee*


---

## Description

This function exports surface reflectance time series for a set of point-coordinates from the whole Landsat Collection 2 record using the Google Earth Engine (GEE). The resulting time-series can then be processed using the remainder of the LandsatTS workflow.

For polygon geometries consider using `lsat_get_pixel_centers()` to generate pixel center coordinates for all pixels within a given polygon first.

Please note: Unlike other functions in this package, this function does NOT return the time-series as an object, instead it returns a list of GEE tasks issued for the export. The actual time-series are exported as CSV objects via GEE to the user's Google Drive. This way of exporting allows for a more efficient scheduling, larger exports, and does not require the R session to continue to run in the background while the requests are processed on the GEE.

The progress of the exports can be monitored using the list of tasks returned in combination with `ee_monitoring()` from the `rgee` package, or simply by using the task overview in the GEE web code-editor (<https://code.earthengine.google.com>).

## Usage

```
lsat_export_ts(
  pixel_coords_sf,
  sample_id_from = "sample_id",
  chunks_from = NULL,
  this_chunk_only = NULL,
  max_chunk_size = 250,
  drive_export_dir = "lsatTS_export",
  file_prefix = "lsatTS_export",
  start_doy = 152,
  end_doy = 243,
  start_date = "1984-01-01",
  end_date = "today",
  buffer_dist = 0,
  scale = 30,
  mask_value = 0
)
```



```

                                st_point(c(-75.77098, 78.87256)),
                                st_point(c(-20.56182, 74.47670)),
                                st_point(c(-20.55376, 74.47749)), crs = 4326) %>%
st_sf() %>%
mutate(sample_id = c("toolik_1",
                     "toolik_2",
                     "ellesmere_1",
                     "ellesmere_1",
                     "zackenberg_1",
                     "zackenberg_2"),
       region = c("toolik", "toolik",
                  "ellesmere", "ellesmere",
                  "zackenberg", "zackenberg"))

# Export time-series using lsat_export_ts()
task_list <- lsat_export_ts(test_points_sf)

# Export time-series using with a chunk size of 2
task_list <- lsat_export_ts(test_points_sf, max_chunk_size = 2)

# Export time-series in chunks by column
task_list <- lsat_export_ts(test_points_sf, chunks_from = "region")

```

---

lsat\_fit\_phenological\_curves

*Characterize land surface phenology using spectral vegetation index time series*

---

## Description

This function characterizes seasonal land surface phenology at each sample site using flexible cubic splines that are iteratively fit to time series of spectral vegetation indices (e.g., NDVI). This function facilitates estimating annual maximum NDVI and other spectral vegetation indices with `lsat_summarize_growing_seasons()`. For each site, cubic splines are iteratively fit to measurements pooled over years within a moving window that has a user-specified width. Each cubic spline is iteratively fit, with each iteration checking if there are outliers and, if so, excluding outliers and refitting. The function returns information about typical phenology at a sample site and about the relative phenological timing of each individual measurement. This function was designed for situations where the seasonal phenology is hump-shaped. If you are using a spectral index that is typically negative (e.g., Normalized Difference Water Index) then multiply the index by -1 before running this function, then back-transform your index after running the `lsat_summarize_growing_seasons()` function.

## Usage

```

lsat_fit_phenological_curves(
  dt,
  si,
  window.yrs = 7,
  window.min.obs = 20,
  si.min = 0.15,
  spar = 0.78,
  pcnt.dif.thresh = c(-30, 30),

```

```

weight = TRUE,
spl.fit.outfile = FALSE,
progress = TRUE,
test.run = FALSE
)

```

### Arguments

<code>dt</code>	Data.table with a multi-year time series a vegetation index.
<code>si</code>	Character string specifying the spectral index (e.g., NDVI) to use for determining surface phenology. This must correspond to an existing column in the data.table.
<code>window.yrs</code>	Number specifying the focal window width in years that is used when pooling data to fit cubic splines (use odd numbers).
<code>window.min.obs</code>	Minimum number of focal window observations necessary to fit a cubic spline.
<code>si.min</code>	Minimum value of spectral index necessary for observation to be used when fitting cubic splines. Defaults to 0.15 which for NDVI is about when plants are present. Note that si.min must be $\geq 0$ because the underlying spline fitting function will error out if provided negative values.
<code>spar</code>	Smoothing parameter typically around 0.70 - 0.80 for this application. A higher value means a less flexible spline. Defaults to 0.78.
<code>pcnt.dif.thresh</code>	Vector with two numbers that specify the allowable negative and positive percent difference between individual observations and fitted cubic spline. Observations that differ by more than these thresholds are filtered out and the cubic spline is iteratively refit. Defaults to -30% and 30%.
<code>weight</code>	When fitting the cubic splines, should individual observations be weighted by their year of acquisition relative to the focal year? If so, each observation is weighted by $\exp(-0.25 * n.yrs.from.focal)$ when fitting the cubic splines.
<code>spl.fit.outfile</code>	(Optional) Name of output csv file containing the fitted cubic splines for each sample site. Useful for subsequent visualization.
<code>progress</code>	(TRUE/FALSE) Print a progress report?
<code>test.run</code>	(TRUE/FALSE) If TRUE, then algorithm is run using a small random subset of data and only a figure is output. This is used for model parameterization.

### Value

Data.table that provides, for each observation, information on the phenological conditions for that specific day of year during the focal period. These data can then be used to estimate annual maximum spectral index and other growing season metrics using `lsat_summarize_growing_season()`. A figure is also generated that shows observation points and phenological curves for nine random sample locations.

### Examples

```

data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
lsat.dt <- lsat_calibrate_rf(lsat.dt, band.or.si = 'ndvi',

```

```
write.output = FALSE, train.with.highlat.data = TRUE)
lsat.pheno.dt <- lsat_fit_phenological_curves(lsat.dt, si = 'ndvi')
lsat.pheno.dt
```

---

lsat_format_data	<i>Formats Landsat data for analysis</i>
------------------	--

---

## Description

This function takes Landsat data exported from GEE and formats it for subsequent use. The function parses sample site coordinates and time period of each measurement, scales band values, and formats column names as needed for subsequent analysis using the LandsatTS package.

## Usage

```
lsat_format_data(dt)
```

## Arguments

**dt** Data.table with Landsat data exported from Google Earth Engine using `lsat_export_ts()`.

## Value

Data.table with formatted and scaled values.

## Examples

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt
```

---

lsat_get_pixel_centers	<i>Get Landsat 8 pixel centers for a polygon or a buffered point</i>
------------------------	--

---

## Description

A convenience helper function that determines the Landsat 8 grid (pixel) centers within a polygon plus an optional buffer. It can also be applied to a single point to retrieve all pixels within a buffer.

Does not work for large polygons. The default maximum number of pixels set by EE is 10000000 this should not be exceeded. Consider whether extraction for a large polygon is a good idea, if yes split the polygon into manageable chunks.

For the unlikely case that a polygon exceeds the boundaries of the Landsat tile closest to the polygon's center, the polygon is clipped at the boundaries of the Landsat tile and a warning is issued. Again, if this is the case, consider processing smaller polygons instead.

Please note: The approximation of the tile overlap with the polygon generates a warning by the `sf` package that the coordinates are assumed to be planar. This can be ignored.

**Usage**

```
lsat_get_pixel_centers(
  polygon_sf,
  pixel_prefix = "pixel",
  pixel_prefix_from = NULL,
  buffer = 15,
  plot_map = F,
  lsat_WRS2_scene_bounds = NULL
)
```

**Arguments**

<code>polygon_sf</code>	Simple feature with a simple feature collection of type "sfc_POLYGON" containing a single polygon geometry. Alternatively, a simple feature containing a simple feature collection of type 'sfc_POINT' with a single point.
<code>pixel_prefix</code>	Prefix for the generated pixel identifiers (output column "sample_id"). Defaults to "pixel".
<code>pixel_prefix_from</code>	Optional, a column name in the simple feature to specify the pixel_prefix. Overrides the "pixel_prefix" argument.
<code>buffer</code>	Buffer surrounding the geometry to be included. Specified in m. Defaults to 15 m - the nominal half-width of a Landsat pixel.
<code>plot_map</code>	Optional, default is FALSE. If TRUE the retrieved pixel centers and the polygon are plotted on a summer Landsat 8 image (grey-scale red band) using mapview. If a character is supplied an additional output to a file is generated (png, pdf, and jpg supported, see mapview::mapshot). Note: Both slow down the execution of this function notably, especially for large polygons! Only use in interactive R sessions.
<code>lsat_WRS2_scene_bounds</code>	File path to the Landsat WRS2 path row scene boundaries. If not specified the boundaries are downloaded to a temporary file when the function is executed for the first time during a session. To avoid future downloads, the file may be downloaded manually and it's file path specified using this argument. The file can be found here: <a href="https://prd-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/atoms/files/WRS-2_bound_world_0.kml">https://prd-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/atoms/files/WRS-2_bound_world_0.kml</a> See also: <a href="https://www.usgs.gov/core-science-systems/nli/landsat/landsat-shapefiles-and-kml-files">https://www.usgs.gov/core-science-systems/nli/landsat/landsat-shapefiles-and-kml-files</a>

**Value**

sf object of point geometries for Landsat 8 pixel centers within the polygon or the buffer around the point coordinate specified. For use in `lsat_export_ts()`.

**Author(s)**

Jakob J. Assmann

**Examples**

```
# Using sf, dplyr, rgee and purr
library(sf)
library(dplyr)
```



```

library(rgee)
library(purrr)

# Initialize EE
ee_initialize()

# Specify a region to retrieve pixel centers for
test_poly_sf <- list(matrix(c(-138.90125, 69.58413,
                             -138.88988, 69.58358,
                             -138.89147, 69.58095,
                             -138.90298, 69.57986,
                             -138.90125, 69.58413),
                             ncol = 2, byrow = TRUE)) %>%
  st_polygon() %>%
  st_sfc(crs = 4326) %>%
  st_sf()

# Retrieve pixel centers and plot to mapview
pixels <- lsat_get_pixel_centers(test_poly_sf, plot_map = TRUE)

## Ge pixel centers for multiple regions
# Create multi-polygon sf
ellesmere <- st_polygon(list(matrix(c(-75.78526, 78.86973,
                                     -75.78526, 78.87246,
                                     -75.77116, 78.87246,
                                     -75.77116, 78.86973,
                                     -75.78526, 78.86973),
                                     ncol = 2, byrow = TRUE)))
zackenberg <- st_polygon(list(matrix(c(-20.56254, 74.47469,
                                       -20.56254, 74.47740,
                                       -20.55242, 74.47740,
                                       -20.55242, 74.47469,
                                       -20.56254, 74.47469),
                                       ncol = 2, byrow = TRUE)))
toolik <- st_polygon(list(matrix(c(-149.60686, 68.62364,
                                   -149.60686, 68.62644,
                                   -149.59918, 68.62644,
                                   -149.59918, 68.62364,
                                   -149.60686, 68.62364),
                                   ncol = 2, byrow = TRUE)))
test_regions_sf <- st_sfc(ellesmere, zackenberg, toolik, crs = 4326) %>%
  st_sf() %>%
  mutate(region = c("ellesmere", "zackenberg", "toolik"))

# Split and map lsat_get_pixel_centers using dplyr and purrr
pixel_list <- test_regions_sf %>%
  split(.$region) %>%
  map(lsat_get_pixel_centers,
       pixel_prefix_from = "region") %>%
  bind_rows()

```

---

lsat\_neighborhood\_mean

---

*Compute Neighborhood Average Landsat Surface Reflectance*


---

**Description**

For each band, this function computes average surface reflectance across neighboring voxels at a sample site. Use this function when working with Landsat data extracted for buffered points. Also, make sure to have previously cleaning the individual observations using `lsat_clean_data()`.

**Usage**

```
lsat_neighborhood_mean(dt)
```

**Arguments**

`dt` A data.table containing coincident surface reflectance measurements for multiple Landsat pixels at each sample site.

**Value**

A data.table with average surface reflectance

---

<code>lsat_plot_trend_hist</code>	<i>Create a histogram summarizing relative temporal changes in a spectral index across all sample sites.</i>
-----------------------------------	--

---

**Description**

Create a histogram summarizing relative temporal changes in a spectral index across all sample sites.

**Usage**

```
lsat_plot_trend_hist(dt, xlim = c(-30, 30))
```

**Arguments**

`dt` A data.table output from `lsat_calc_trend()`

`xlim` Numeric vector specifying the minimum and maximum values for the histogram x-axis.

**Value**

A histogram generated by `ggplot2`

**Examples**

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
# lsat.dt <- lsat_calibrate_rf(lsat.dt, band.or.si = 'ndvi', write.output = F)
lsat.pheno.dt <- lsat_fit_phenological_curves(lsat.dt, si = 'ndvi')
lsat.gs.dt <- lsat_summarize_growing_seasons(lsat.pheno.dt, si = 'ndvi')
lsat.trend.dt <- lsat_calc_trend(lsat.gs.dt, si = 'ndvi.max', yrs = 2000:2020)
lsat_plot_trend_hist(lsat.trend.dt)
```

---

lsat_summarize_data	<i>Summarize availability of Landsat data for each sample site</i>
---------------------	--

---

### Description

This little function summarizes the temporal period and availability of observations at each sample site.

### Usage

```
lsat_summarize_data(dt)
```

### Arguments

dt                      Data.table with columns named "sample.id" and "year".

### Value

Data.table summarizing for each sample site the first, last, and number of years with observations, the minimum and maximum number of observations in a year, and the total number of observations across years. Also returns a figure showing the median (2.5 and 97.5 percentiles) number of observations per sample site across years for each Landsat satellite.

### Examples

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat_summarize_data(lsat.dt)
```

---

lsat_summarize_growing_seasons	<i>Summarize growing season characteristics using spectral vegetation indices</i>
--------------------------------	---

---

### Description

This function not only computes mean, median, and 90th percentile of a spectral index (SI) using observations for a user-specified "growing season," but also estimates the annual maximum SI and associated day of year using phenology modeling and growing season observations.

### Usage

```
lsat_summarize_growing_seasons(
  dt,
  si,
  min.frac.of.max = 0.75,
  zscore.thresh = 3
)
```

**Arguments**

<code>dt</code>	Data.table generated by the function <code>lsat_fit_phenological_curves()</code> .
<code>si</code>	Character string specifying the spectral vegetation index to summarize (e.g., NDVI).
<code>min.frac.of.max</code>	Numeric threshold (0-1) that defines the "growing season" as the seasonal window when the phenological curves indicate the SI is within a specified fraction of the maximum SI. In other words, an observation is considered to be from the "growing season" when the SI is within a user-specified fraction of the curve-fit growing season maximum SI.
<code>zscore.thresh</code>	Numeric threshold specifying the Z-score value beyond which individual observations are filtered before summarizing growing season SI.

**Value**

Data.table summarizing annual growing season conditions based on a spectral index.

**Examples**

```
data(lsat.example.dt)
lsat.dt <- lsat_format_data(lsat.example.dt)
lsat.dt <- lsat_clean_data(lsat.dt)
lsat.dt <- lsat_calc_spectral_index(lsat.dt, 'ndvi')
# lsat.dt <- lsat_calibrate_rf(lsat.dt, band.or.si = 'ndvi', write.output = F)
lsat.pheno.dt <- lsat_fit_phenological_curves(lsat.dt, si = 'ndvi')
lsat.gs.dt <- lsat_summarize_growing_seasons(lsat.pheno.dt, si = 'ndvi')
lsat.gs.dt
```

---

noatak.dt

---

*Example Landsat data for the Noatak National Preserve*


---

**Description**

This dataset provides Landsat time series data for 100 random sample locations within the Noatak National Preserve, USA. These data were extracted from Google Earth Engine using the `lsat_export_ts()` function.

**Usage**

```
data("noatak.dt")
```

**Format**

A data frame with 99600 observations on the following 23 variables.

‘system:index’ GEE index  
 CLOUD\_COVER Percent cloud cover of scene  
 COLLECTION\_NUMBER Landsat collection number  
 DATE\_ACQUIRED Acquisition date in yyyy-mm-dd format  
 GEOMETRIC\_RMSE\_MODEL RMSE of geometric residuals in meters

LANDSAT\_PRODUCT\_ID Landsat product identifier  
 LANDSAT\_SCENE\_ID Landsat scene identifier  
 PROCESSING\_LEVEL Landsat processing level  
 QA\_PIXEL CFMASK pixel quality attribute bitmask  
 QA\_RADSAT Radiometric saturation bitmask  
 SPACECRAFT\_ID Name of the spacecraft  
 SR\_B1 Band 1 surface reflectance  
 SR\_B2 Band 2 surface reflectance  
 SR\_B3 Band 3 surface reflectance  
 SR\_B4 Band 4 surface reflectance  
 SR\_B5 Band 5 surface reflectance  
 SR\_B6 Band 6 surface reflectance  
 SR\_B7 Band 7 surface reflectance  
 SUN\_ELEVATION Sun elevation angle in degrees for the image center location at the image center acquisition time  
 chunk\_id Download chunk identifier  
 max\_extent JRC maximum water extent flag  
 sample\_id User specified sample location identifier  
 .geo Sample location coordinates

### Source

Generated as example data for Berner et al. (2023)

### References

Landsat data are provided by the United States Geological Survey

---

noatak.sf

*Noatak National Preserve Simple Feature*

---

### Description

This dataset provides the spatial boundary of the Noatak National Preserve, USA, as a multipolygon simple feature.

### Usage

```
data("noatak.sf")
```

### Format

A simple feature data frame with 1 observations on the following 1 variable.

```
geometry a sfc_MULTIPOLYGON
```

**Source**

Downloaded from <https://irma.nps.gov/DataStore/Reference/Profile/2296705>

**References**

US National Park Service. 2022. Administrative Boundaries of National Park System Units - National Geospatial Data Asset (NGDA) NPS National Parks Dataset. NPS - Land Resources Division. <https://irma.nps.gov/DataStore/Reference/Profile/2296705>

**Examples**

```
data(noatak.sf)
plot(noatak.sf)
```

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