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Land Surface Phenology: Phenology metrics extraction and Phenology changes through time – Theoretical background

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Green Alternative

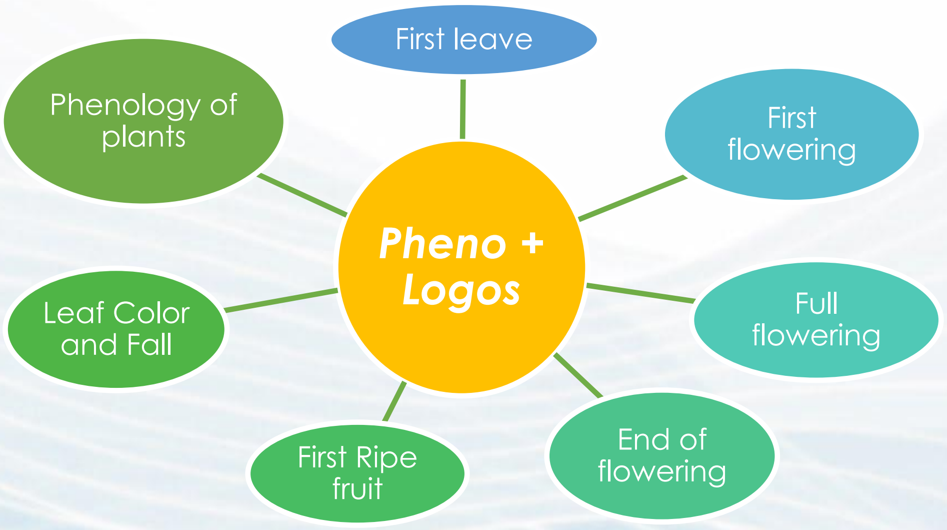
1865

Phenology

- Periodic events occurring on a seasonal basis in vegetation growth, such as germination, growing, florescence, herbage, maturation, leaf browning and withering are notable indicators for the recognition of the structure and function (i.e. the status) of terrestrial naturally vegetated ecosystems.

- Changes in seasonal patterns of natural phenomena occurring on terrestrial naturally vegetated ecosystems are influenced by fluctuations of biotic and abiotic factors taking place on a seasonal as well as annual basis.

The science of appearance



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Land Surface Phenology (LSP)

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- These changes affect the expected phenology patterns and cycles for a species and an area.

- Land surface phenology (LSP) may be utilized as a well aligned proxy to the observed phenology on the ground.

Source: operationmigration.org, 2018

- The knowledge of changes in the expected phenology patterns as well as the knowledge of LSP contribute in the improvement of measures and practices in order to enable **a viable ecosystems' preservation and ensure the sustainability of their services**.

LSP estimation with multispectral sensing

Sensors

LiDAR

SAR

Passive microwave RS systems

Optical RS

- Recent and future trend developments for LSP retrieval including sensors, data fusion, synergies, workflows, products, and networks.

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LSP estimation from satellite EO data

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Land Surface Phenology (LSP)

Regional / Global scale observations

≠ plant species specific in-situ observations

Time-series of vegetation indices

- Short / medium term trends

Phenology changes

- Detection of abrupt changes

Phenology metrics

- Start – End & length of growing season
- Peak of growing season
- End of growing season

Challenges in LSP estimation

- **Smoothing & Curve Fitting:**

In order to retrieve precise remotely sensed time series, it is crucial to perform noise smoothing for the elimination of unwanted points from the time series. One such smoothing example is the Best Index Slope Extraction (BISE).

There are several smoothing options which have been utilized in a great number of studies, such as:

- Gaussian,
- Asymmetric Gaussian,
- Double Logistic and
- adaptive Savitzky-Golay filtering

- **Gap filling:**

Gaps in time series of EO data regarding the vegetation information are present as a result of clouds, atmospheric aerosols and snow. These gaps form a difficulty in the observation of vague changes in LSP events in the start and end of the growing season. Thus, gap-filling techniques should be applied before the extraction of phenology metrics. Such techniques include:

- Estimation of a yearly curve based on neighbour pixels with identical land cover.
- Winter gaps: VI values can be set to a standard low value based on the region.
- Substitution of gaps with the seasonal average of the time series.

Multispectral satellite sensor characteristics for LSP studies

Satellite Sensor	Orbit Type	Operation Timespan	Spatial Resolution	Temporal Resolution	Data Access
AVHRR	Sun-synchronous	1978 - Present	1.1 km at nadir	Daily	Non-commercial
MODIS	Sun-synchronous	1999 - Present	250 m, 500 m, 1 km	16 days	Non-commercial
VIIRS	Sun-synchronous	2011 - Present	375 m, 250 m, 750 m	Daily	Non-commercial
PROBA - V	Sun-synchronous	2013 - 2020	100 m, 300 m, 1 km	Daily	Non-commercial
AHI	Geostationary	2014 - Present	500 m, 1 km, 2 km	10 min	Commercial
Landsat	Sun-synchronous	1972 - Present	30m, 80m	16-days	Non-commercial
Sentinel-2	Sun-synchronous	2015 - Present	10 m, 20 m, 60 m	5-days	Non-commercial
PlanetScope	Sun-synchronous	2019 - Present	3.7 m at nadir	Daily	Commercial

Source: I. Soubry, I. Manakos, C. Kalaitzidis, Recent Advances in Land Surface Phenology Estimation with Multispectral Sensing, 7th International Conference on Geographical Information Systems Theory, Applications and Management, April 23-25 2021, Prague, Czech Republic, doi: 10.5220/0010555801340145

Global LSP products

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Global LSP products	Duration	Source	Spatial Resolution	LSP Metrics
MCD12Q2*	2001-2017	EVI2 from MODIS BRDF Adjusted Reflectance (NBAR)	500 m	The total number of vegetation cycles detected for the product year, the onset of greenness, greenup midpoint, maturity, peak greenness, senescence, greendown midpoint, dormancy, overall and phenology metric-specific quality information
VIIRS GLSP*	2012-Present	EVI2 from daily VIIRS BRDF NBAR	500 m	This product provides consistent spatial and temporal estimates of the timing and magnitude of phenological development of the vegetated land surface across the globe. Global LSP metrics on an annual basis (greenup onset, date at mid greenup phase, maturity onset, senescence onest, date at mid senescence phase, dormancy onset).
MEaSUREs VIP*	1981-2014	NDVI and EVI2 from AVHRR 1981-1999; MODIS MOD09 2000-2014	5600 m	The VIP15 VI product contains 12 Science Datasets (SDS) which include the calculated VIs (NDVI and EVI2) as well as quality assurance/pixel reliability, the input Visible/Near Infrared (VNIR) surface reflectance data, and viewing geometry. Gaps in the daily product are filled using long term mean VI records derived from the more than 30 year time series of data. A low resolution browse image showing NDVI as a color map is also available.

*MCD12Q2: MODIS Land Cover Dynamics product; VIIRS GLSP: Global Land Surface Phenology product; MEaSUREs VIP: Making Earth System Data Records for Use in Research Environments Vegetation Index and Phenology global dataset.

Multi-source EO data for LSP estimation

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- Data fusion & Synergies

Method	Sensor combination	Details	Source
FORCE ImproPhe	MODIS, Landsat, Sentinel	Uses local pixel neighborhood, denoises LSP, preserves sharp edges	(Frantz, 2019)
Automatic co-registration	Landsat, Sentinel	Co-registration of Landsat-8 to Sentinel-2A & Sentinel-2A to Sentinel-2B	(Skakun et al., 2017)
Assisted downscaling	Landsat, Sentinel	Downscales Landsat-8 to Sentinel-2 resolution	(Li & Roy, 2017)
Super-resolution enhancement	Landsat, Sentinel	Uses convolution neural networks trained with Sentinel-2 data	(Pouliot et al., 2018)
HLS	Landsat, Sentinel	A combined Landsat/Sentinel product	(Claverie et al., 2018)

Source: I. Soubry, I. Manakos, C. Kalaitzidis, Recent Advances in Land Surface Phenology Estimation with Multispectral Sensing, 7th International Conference on Geographical Information Systems Theory, Applications and Management, April 23-25 2021, Prague, Czech Republic, doi: 10.5220/0010555801340145

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Ground phenology networks for LSP validation

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Phenology Networks	Purpose	Users	Collaborations	Extra information
USA-NPN	Collect, store, distribute phenology data	Researchers, natural resource managers, policy-makers, educators, citizen scientists, NGO’s	-NEON; -Nature’s Notebook	Standardized plant & animal observation protocols
NEON	Collect ecological data: in situ measurements/ observations & airborne remote sensing surveys	Researchers	-81 field sites in US	175 open access products
PEP725	Open access database to facilitate phenological research, education, environmental monitoring	Researchers, educators	-7 phenology network partners; -32 European meteorological services	-Volunteer data collected from 1868 to present; -12 million records
GLOBE	International science and education program to promote teaching and learning of science	Students, educators	-NASA, NSF, NOAA; -121 countries	Over 150 million ground biophysical measurements
PhenoCam	For phenological model validation, evaluation of satellite RS products, studies of climate change impacts on terrestial ecosystems	Researchers, remote sensing specialists	-750 sites across North America	Data derived from visible-wavelength digital camera imagery

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Current and future LSP estimation era

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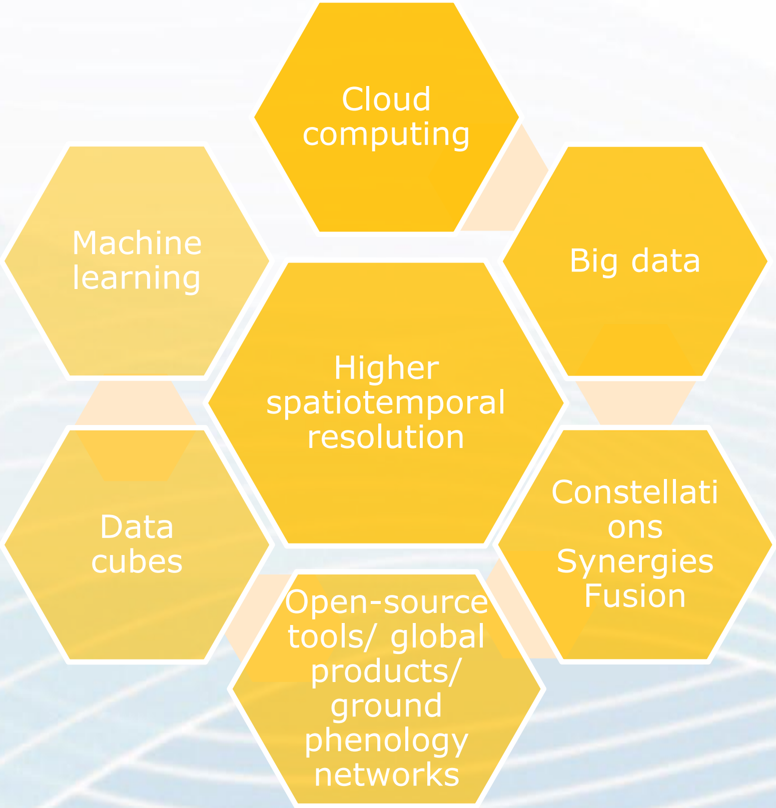

- Big data
- Transfer of processing burden from personal computers to external server accessed through the cloud
- Data cubes: Time-series multi-dimensional (space and time) stack of spatially aligned pixels.
- Machine learning: To fill spatiotemporal ground-based LSP in order to forecast phenophases with the use of RS and meteorological data; Fitting algorithms for LSP time series analysis

Open-source software tools for LSP estimation

Tool	LSP Metrics
SPIRITS	Start of Season (SOS), End of Season (EOS)
TIMESAT	SOS, EOS, Length of Season (LOS), time for the mid of season, rate of increase at the beginning of the season, rate of decrease at the end of the season, value for the start of the season, value for the end of the season
PhenoSat	SOS, green-up, maximum vegetation development, maturity, senencence, dormancy
'greenbrown' R package	SOS, EOS, LOS, peak of season
'phenex' R package	Greenup, senescence, day of max/min NDVI
'BFAST' R package	Abrupt changes detection of a time series
DATimeS	SOS, EOS, LOS, maximum value, day of maximum value, amplitude
PhenologyMetrics by CERTH (based on 'phenex' package)	Greenup, senescence, day of max/min NDVI
PhenologyChanges by CERTH (based on 'BFAST' package)	Abrupt changes detection of a time series

PhenologyMetrics by CERTH

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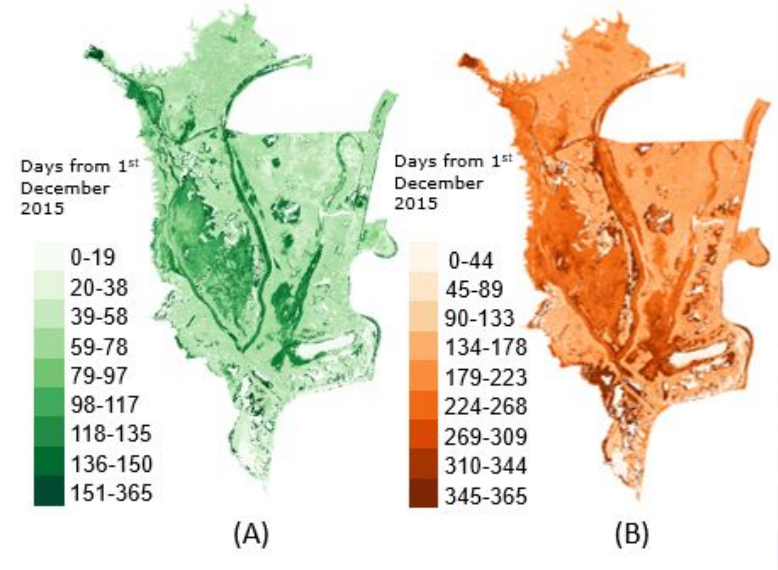
- **Objective:** Estimation of phenology metrics
- **Brief description:** Generation of phenology related layers of information relying on NDVI time series covering a vegetation growth period, which commonly corresponds to a one-year period. PhenologyMetrics module was developed during European Union’s Horizon 2020 “ECOPOTENTIAL” programme.
- **Input:** NDVI time series
- **Output:** The phenology metrics are estimated per pixel with the exploitation of R phenex package and they encompass
  - (a) the day of the growth period, at which the greenup takes place,
  - (b) the day of the growth period with the highest NDVI value and
  - (c) the day of the growth period, at which senescence takes place.

PhenologyMetrics by CERTH

- PhenologyMetrics is relying on the application of the “phenoPhase” function to NDVI time series layers to estimate per area, **NDVI peak**, **greenup date** and **senescence date**, within the detected values' fluctuation (possible phenological cycles).
- If values are assigned to objects representing vegetation communities (patches/ objects), then the number of peaks per area is provided, as a proxy for the object's encapsulated biodiversity.



Day of year for which (A) greenup and (B) senescence are detected for Doñana marshlands between December 2015 and November 2016.

Credit: Horizon 2020 “ECOPOTENTIAL” programme, Deliverable D6.3

PhenologyChanges by CERTH

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- **Objective:** Detection of changes in phenological cycle series according to the BFAST method.

- **Brief description:** The PhenologyChanges module facilitates the monitoring of abrupt changes along the vegetation phenology cycles of sequential years through numerous annual NDVI series. This is based on the iterative decomposition of the time series into trend, seasonal and remainder components, which is performed using the BFAST R package. PhenologyChanges module was developed during European Union’s Horizon 2020 “ECOPOTENTIAL” programme.
- **Input:** NDVI time series

- **Output:** The estimation of phenology changes is performed at pixel basis by utilizing the R BFAST (Breaks For Additive Seasonal and Trend) package and it includes
  (a) the calculation of the dates when abrupt changes took place,
  (b) the total number of the observed abrupt changes and
  (c) the date of the maximum abrupt change detected.

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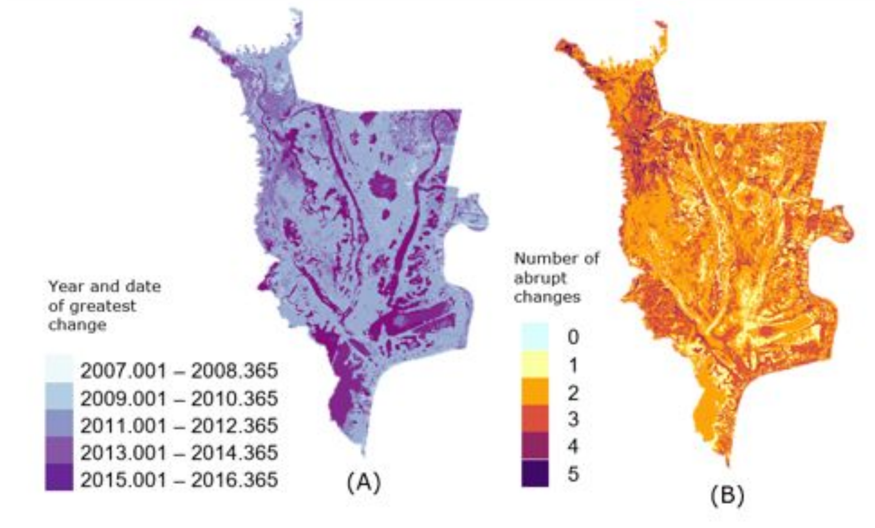
- Abrupt trend changes/ breaks in the vegetation phenology cycles throughout numerous annual data series, based on the iterative decomposition of the NDVI time series into trend, seasonal and remainder components.
- The total number and occurrence dates of abrupt changes, and the date of the maximum abrupt change, are calculated for each area at pixel basis.



(A) Time period for which the greatest abrupt change occurred {year.day-of-year} in Doñana marshlands, and (B) total number of abrupt changes that occurred between 2007 and 2016.

Credit: Horizon 2020 “ECOPOTENTIAL” programme, Deliverable D6.3

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Thank you for your attention

It’s time to practice!

On behalf of CERTH’s team

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