Name: Land Surface Phenology

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Description:

Land surface phenology is defined as the seasonal pattern of variation in vegetated land surfaces observed from remote sensing. While the observed patterns are related to biological phenomena, land surface phenology is distinct from traditional definitions of vegetation phenology, which refer to specific life cycle events such as budbreak, flowering, or leaf senescence using in-situ observations of individual plants or species. A land surface phenology earth system data record (ESDR) would provide aggregate information at moderate (500-m) to coarse (25-km) spatial resolutions that relates to the timing of vegetation growth, senescence, and dormancy and associated surficial phenomena at seasonal and interannual time scales.

Scientific rationale, importance of measurement, and expected end uses

The rationale for this ESDR includes several dimensions. From a scientific perspective, a variety of recent evidence indicates that the effects of climate change are detectable in the phenology of ecosystems. As a result, land surface phenology has recently emerged as a key area of research in biosphere-atmosphere interactions, climate change, and global change biology. At shorter time scales and regional spatial scales, numerous studies have also demonstrated that climate processes operating at seasonal and interannual time scales (e.g., ENSO) are identifiable in the phenology of vegetation over large areas of the Earth. Studies have also shown how broad scale changes in human land use affect land surface phenology. From a modeling perspective, realistic representation of phenology is important to models of biosphere-atmosphere interactions because the phenology of vegetated land surfaces significantly affects fluxes of water, energy, carbon, and other trace gases.

Thus, land surface phenology is relevant to a suite of questions related to NASA's basic and applied science programs, and in particular to NASA's *Carbon Cycle and Ecosystems* roadmap. Specific questions identified in this roadmap for which land surface phenology has relevance include:

- How are global ecosystems changing?
- What changes are occurring in global land cover and land use, and what are their causes?
- How do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change?
- What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?
- How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?

Land surface phenology also has relevance to NASA's strategic roadmap scientific objectives relating to *Atmospheric Composition, Climate and Weather, and Water,* due to its significance in land-atmosphere interactions.

In applied sciences, land surface phenology is becoming increasingly recognized as an important source of information for numerous end-uses. Agricultural applications include the use of land surface phenology to map and monitor crop dynamics over large areas and as an input to integrative pest management. In biology, the migration patterns of birds, bats, and insect species are closely tied to land surface phenology. Similarly, land surface phenology is useful for identifying and mapping invasive plant species. Knowledge of, and the ability to predict, phenological events such as wildflower blooms, cherry blossoms, fall foliage and bird migrations can contribute significantly to the tourism industry. Finally, it is becoming increasingly evident that land surface phenology has significant relevance to human health due to its relationship to seasonal allergies and because migrating species can act as vectors for emerging diseases.

Scientific Requirements for the Measurement

The key scientific requirement for the land surface ESDR is that it provides the highest possible quality information related to seasonal and interannual scale variability in the timing and magnitude of changes in surface properties associated with biological activity. Of particular interest is the timing of processes that affect land surface fluxes of energy, carbon, and water. Specific quantities of interest include the timing and pace at which significant increases in surface green leaf area occur, the timing and duration of maximal surface green leaf area, the timing and pace of green leaf senescence, and the timing at which minimal green leaf area occurs. Specific requirements for this ESDR include:

- Accuracy: Sub-weekly, with ± 3 days ideal.
- Precision: Day of year.
- Spatial resolution: Depends on the application, but can vary from 500-m to 25-km.
- Required length of record: Beginning with the start of the AVHRR record, to 2030 and later.

Note that the prescribed requirements for both accuracy and spatial resolution exceed current capabilities. In order to meet these requirements, significant synergies with other sensors will likely be required. Also, because the quality of remote sensing products can be spatially variable, it would be useful for the land surface phenology ESDR to provide a measure of retrieval uncertainty at each pixel. For example, in areas with significant cloud cover or where the surface is spatially complex, the ESDR is likely to be less accurate.

Approach to generating the measurement

At present, there is no consensus regarding an optimal approach for producing a land surface phenology ESDR. Previous approaches have focused on estimating key dates in the phenology of the vegetated land surface and have relied on at least five strategies:

1. Prescription of thresholds in vegetation indices related to key ecosystem processes such as photosynthesis;
2. Identification of key growing season dates based on the mid-point in the annual range of vegetation index (VI) values;
3. Estimation of transition dates via spectral/harmonic analysis;
4. Identification of transition dates based on the rate of change in VI values; and
5. Derivation of transition dates from parametric models linking the temporal development in VI to a bioclimatological metric, such as accumulated growing degree-days.

Each approach has achieved some success, and all generally yield differing results. Required inputs include vegetation indices, which are by far-and-away the most commonly used data source. However, the utility of other inputs is also being increasingly explored, including retrievals from active and passive microwave measurements.

The state of maturity of these algorithms is still low; however, it is becoming increasingly necessary to employ remote sensing proxies for key ecosystem *processes* (photosynthesis, transpiration, net primary productivity) in addition to biophysical *variables*, like LAI and fractional vegetation cover, chlorophyll content. Thus, further research is required to identify a suite of optimal methods for generating a land surface phenology ESDR. While no consensus exists on the optimal methodology for producing such an ESDR, strong consensus exists with respect to several key issues:

1. Because of constraints imposed by spatial resolution, whatever measurement strategy is used will require effective methods to cloud screen or composite data in an optimized fashion. Specifically, the presence of clouds is a key limitation for optical remote sensing that limits the consistent use of daily data. Similarly, orbital paths limit daily acquisitions of passive microwave imagery, especially at lower latitudes. These constraints are particularly important because they influence the accuracy and precision with which phenological quantities can be estimated.
2. Solar zenith angles also impart their own seasonal signals onto a phenology signature and must be removed. Several studies have shown a seasonally invariant VI signal in western conifer stands due to the canceling effects of sun angle and vegetation phenology.
3. Because of its spectral reflectance and emittance properties, the presence of snow can significantly affect the remotely sensed variables, such as VIs, that are currently used to estimate phenology. Thus, effective methods are required to screen, and perhaps adjust, for the presence of snow.
4. While the meaning of land surface phenology in deciduous forest ecosystems, temperate agro-ecosystems, and sub-humid to humid grasslands is relatively clear, there are many environments in which the precise meaning is less clear. Mixed

forests, which are geographically extensive and which contain a mix of deciduous and evergreen species is one example. Other examples include evergreen biomes, which do not manifest a seasonal amplitude of phenology that is comparable to deciduous systems, but which do nonetheless exhibit seasonal behavior in forest canopies and understories, and arid and semi-arid systems in which the phenology of vegetation can be subtle, rapid, and highly transient.

5. Because of the variability and complexity of land surface phenology at global scales, it may be necessary to develop suites of algorithms that are unique or tuned to different plant functional types or climate regimes.

The most important issue that currently constrains the development of algorithms designed to measure land surface phenology is the lack of reliable in-situ data collected for validation purposes. In the absence of high quality in-situ measurements, concrete statements regarding the feasibility and reliability of the measurement cannot be made with any degree of certitude.

In this context, the required set of in-situ measurements is presently not well-defined. Conventional field measurements consist of species-specific observations of canopy properties. The definition of land surface phenology provided in this white paper dictates that a more expansive set of measurements is necessary. Thus, in-situ measurements will need to include an integrative suite of variables that reflect temporal variations in soil properties (temperature and moisture), near surface meteorology, and aggregate measures of canopy conditions for both overstory an understory species, if present. In particular, measures of radiation interception and reflection above and below canopies would be particularly useful.

Because land surface phenology is studied over large areas using moderate to coarse resolution data, the design and implementation of field networks capable of supporting validation and calibration activities is both expensive and challenging. The National Phenology Network (NPN) may provide a significant new resource for accomplishing this challenge, in conjunction with higher spatial resolution imagery from TM/ETM+, the LDCM sensor, ASTER, and comparable platforms. However, it is important to emphasize that the NPN's scope is limited both in space and time. The expanding network of flux towers will aid in assessing landscape metabolism at the footprint size (~100 to 500-m) close to those of current high temporal satellite sensors.

Intended sources for the measurement

Current approaches to measuring land surface phenology rely almost exclusively on moderate resolution optical data sources. There does not yet exist a large body of published research on the use of other sources, such as active and passive microwave image time series. However, it is likely that future efforts will increasingly focus on products that are based on data fusion using multiple data sources. Here we distinguish between three main classes of data that are required to produce a land surface phenology ESDR:

1. Archived data sources used for retrospective processing of a land surface phenology ESDR. These sources include the AVHRR archive beginning in 1981,

SMMR data from 1978-1987, and SSM/I data from 1987 to 2005.

2. Contemporary data sources based on EOS-era sensors including MODIS (Terra and Aqua) and AMSR-E.
3. Future sensors including the VIIRS and CMIS instruments planned for deployment with NPOESS.

Necessary supporting activities, tasks

Supporting activities and tasks fall into three main groups (1) reprocessing and reanalysis of archived data; (2) provision of high quality surface climate data; and (3) validation activities. In regards to reprocessing and reanalysis of archived data, a significant need exists to support processing and reprocessing of data, including ongoing efforts to provide the best possible data set and allowance for reprocessing as new algorithms and methods are developed to produce this ESDR. Specific data sets that will require reprocessing include the AVHRR, SMMR, and SSM/I archives. In regards to surface climate data, a need exists for high quality gridded surface climate data sets available at spatial and temporal resolutions consistent with those of the land surface phenology ESDR. Critical variables include daily maximum and minimum near surface air temperatures and daily total precipitation. Ancillary remote sensing sources such as TRMM and model reanalysis products may fulfill some of this need, but more support for supplying these data sources is clearly necessary.

Finally, in regards to validation and calibration activities, significant support is required for implementation of national to global scale in-situ measurements of both phenology and surface climate variables. In the United Sates, the National Phenology Network could provide a badly needed mechanism to support this effort. The NPN is a new initiative involving several federal agencies and academic partners with the goal of creating a network for the United States to collect and coordinate phenology information from in-situ observations coincident with existing ecological networks (e.g., Ameriflux and LTER sites) and existing weather observations (e.g., NWS Cooperative Observer Program). In addition, field measurements collected through ongoing national and international initiatives including the European Phenology Network, Fluxnet, and the LTER/ILTER networks provide additional infrastructure and support for validation and calibration activities.

Key citations

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