New Developments in Satellite Observation, Interpretation and Modeling of Vegetation Phenology

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Global Phenology Assessment: Pre-EOS Era

- Limited Satellite resources for global monitoring
- Limited observation networks for validation
- Strong constraints on data processing & computational analysis

NDVI phenology from NOAA-7 AVHRR

Fig. J. Three-week composite maps of North American normalized difference vegetation index measurements for April, June, August and October, 1982. The measurements are color-coded dependent on magnitude as displayed on the color bar in the center of the figure.

Global Phenology Assessment & Monitoring Today

A golden age of resources for LSP assessment & understanding

✓ Wide diversity of accurate, overlapping satellite observations;
✓ Growing body of coordinated observation networks;
✓ Wealth of derived land products, publicly available at low or no cost to the user;
✓ Advanced computational resources for data processing & synthesis.

Courtesy R Nemani, NASA Ames
Longer Satellite Records

Satellite data continuity & investments in calibration/reprocessing enable improved accuracy for resolving seasonality & climate trends

- Legacy observations from long-lived satellite records extend over more than 3 decades (Landsat, AVHRR)
- Advanced computing resources enable frequent global reprocessing for better calibration & consistency
- Similar overlapping sensor records enable construction of continuous, long-term records (e.g. SMMR-SSM/I).

Vegetation Response to Frozen Season Changes

Correlation (r) between SMMR-SSM/I non-frozen season & MODIS summer (JJA) NDVI growth anomalies (2000-2008)

Latitudinal variations in mean r and regression slope (s) for 2000-2008

Regular Global Reprocessing for Landsat

Global monthly Landsat Processing (WELD, MEASURES)

Landsat 30 Year Change Analysis

1984-present
Landsat time series stack (LTSS)

VCT

Annual disturbance

Monthly Leaf Area at 30m resolution

Source: Ganguly et al. 2012. Rem Sens Environ 122

Courtesy David Roy (SDSU) & Rama Nemani (NASA Ames)
Exploiting a Wealth of Observations for Improved LSP Assessment

Increasing diversity of overlapping satellite observations is enabling better scaling assessments & new perspectives

✓ Overlapping sensor records enable improved accuracy, enhancements;
✓ Coordinated observations enhance science utility, e.g.:
  • Terra/Aqua MODIS
  • MODIS/AMSR-E
  • MODIS/Landsat

Comparison of overlapping GIMMS & MODIS NDVI records

AMSR-E VOD vs MODIS VI Seasonality

Vegetation canopy microwave optical depth (VOD) phenology from AMSR-E on Aqua

- VOD signal is sensitive to canopy biomass change & insensitive to atm effects
- Synergistic with canopy NDVI/EVI greenness changes from MODIS

Mean (2003-10) VOD Seasonal Range for EBLF Areas

10.7 GHz (X-band) VOD & best QC MODIS EVI & NDVI time series over Tapajos tower site

Wet/Dry Season and Drought Impacts on Amazon Canopy Phenology

- VOD is correlated with best QC MODIS LAI retrievals;
- Confirmation of large canopy seasonality & dry-season increase;
- Reduced canopy increase under large 2010 drought;
- Temporal VOD/LAI offset due to different parameter sensitivities (canopy greenness vs biomass structure);
Spatial Downscaling using MODIS & Landsat TM

Downscaling LSP dynamics through data fusion of overlapping MODIS & Landsat data

- Integration of 1-km & 250m MODIS NDVI & FPAR with 30m Landsat NDVI using an empirical model & ancillary data (DEM);
- Validation using in situ Obs networks;
- Downscaled (30m) LSP dynamics improve spatial accuracy & better resolve heterogeneity in complex terrain

Coupling Satellite Observations with In Situ Measurement Networks

Expanded measurement networks & coordination lead to better LSP calibration, validation & understanding

- Improvements in global representation, standardized methods & accuracy
- Relaxation of data use restrictions & online archives promote greater utility & science impact
- Development of new tools for LSP & site data comparisons
- Advocacy groups (e.g. NPN, CEOS LPV) promote education outreach & best practices
- Ongoing challenges: data access, funding.

MODIS Land Subsets (ORNL DAAC)

Global FLUXNET Annual Growth
Vegetation Phenology from GPS L-band Ground Reflected Multipath

✓ ~1 km² footprint approaching scale of satellite LSP signal;
✓ Large global station network available;
✓ Active research to distinguish vegetation signal from other effects.

Despite advances in observations & monitoring capabilities there are still large uncertainties in phenology observations & predictions:

- **Goal**: accurate phenology as an integral component of Biogeochem, NWP & climate models;
- Realistic model land-atm. coupling leads to better accuracy;
- Advances facilitated by community sensor/model intercomparisons (NACP) & inter-agency coordination (NOAA/NASA JCSDA, NSF NEON);
- Progress is slow due to: e.g. uncertainty in LSP metrics, model diversity, barriers between research & applications.

*Source*: A.R. Richardson et al., 2012. *Global Change Biol.* 18
Translating Observations to Better Understanding & Model Predictions

Community satellite & model data intercomparison & integration efforts are underway

NACP Multi-Scale Synthesis and Terrestrial Model Inter-comparison (MsTMIP)
New Developments: Global Reanalysis of Vegetation Phenology

50-year (1960-2009) global LAI record derived from EnKf assimilation of MODIS FPAR using a prognostic phenology model (GSI) driven by ERA-40 reanalysis meteorology

- Data assimilation provides a robust means for satellite\Observation\model data integration for production of phenology relevant datasets;
- Recent developments include a 50-yr global LAI record at 1° resolution (right);
- Strengths: Well quantified uncertainty; long, continuous record;
- Limitations: Computationally intensive; accuracy constrained by quality of satellite observations & model skill.


Figure 2. The 50 year long (1960–2009) global reanalysis data set of vegetation phenology. (a) Annual mean LAI and seasonal amplitude (contours with 1 and 2 m² m⁻²), (b) Mean spring date for grid points that have a seasonal amplitude above 1 m² m⁻².
Upcoming Missions of Opportunity

➢ New satellite missions initiated or planned & relevant to global LSP:

➢ Potential benefits include:
  ✓ Continuity of legacy observations (Landsat, MODIS);
  ✓ New measurements: vegetation canopy height & biomass change, C-fluxes & underlying environmental constraints;
  ✓ Opportunities to exploit cross-sensor synergies: biomass phenology vs CO₂ source-sink activity.

Source: Entekhabi et al. 2010. IEEE Proceedings 98(5)
Closing Thoughts...

- This is a golden age of global Earth observation & LSP assessment, supported by a growing wealth of satellite information, computational resources & coordinated measurement networks;

- Exciting opportunities are on the horizon for further exploration & discovery with new satellite missions underway or planned;

- Additional opportunities for linking satellite observations to growing diversity in measurement networks (e.g. NPN, FLUXNET, GPS, COSMOS);

- Aging Earth observing system & risks for data continuity are a major concern;

- New national/international partnerships (e.g. NASA/NOAA/DOD/ESA/JAXA, GEOSS) for joint satellite missions & data sharing should be encouraged;

- Continuing community efforts needed to break down barriers in translating new observations & understanding to better operational models & predictions.
Thank You!