What and why

- Identify, track, and understand climate-related events (i.e., phenological phenomena and drought)
  - Provide early warning of anomalous events/adverse impacts
  - Track variability and identify trends
  - Assess and understand causes and consequences
  - Research techniques and implement operational production

- Vegetation Dynamics Project at EROS
- Reed et al., (1994) *JVegSci*
“Changes in plant phenology are considered to be a most sensitive and observable indicator of plant responses to climate change.”

H. Linderholm
Satellite Derived Land Surface Phenology Products

LAND SURFACE PHENOLOGY: the seasonal pattern of variation in vegetated land surfaces as characterized by remote sensing.

- While the observed patterns are related to biological phenomena, land surface phenology is distinct from traditional definitions of vegetation phenology.
- Traditional definitions refer to specific life cycle events such as budbreak, flowering, or leaf senescence using in-situ observations of individual plants or species.

Slide courtesy of Matt Jones, CEOS Phenology LPV Co-chair
Remote Sensing Phenology

Remote Sensing Phenology uses satellites to track seasonal changes in vegetation on regional, continental, and global scales.

USGS' Remote Sensing Phenology effort is supported by the Geographic Analysis and Monitoring Program (http://gam.usgs.gov) and the Land Remote Sensing Program (http://remotesensing.usgs.gov).

Normalized Difference Vegetation Index (NDVI)
RSP Start of Season Methods

![Graph showing NDVI over time with various markers indicating DMA, Largest Increase, Inflection Point, Threshold, and Half maximum.](image)

- **Pixel value**
- **DMA**
- **Largest Increase**
- **Inflection Point**
- **Threshold**
- **Half maximum**
RSP Methods – Identifying Start of Season

- **Comparison to a moving average; borrowed from stock market trend analysis**
  - calculate the average of previous $n$ time periods (e.g., the previous 5 biweekly observations)
  - plot both current time series and moving average
  - when current data become higher than moving average, a trend change (start of season) is occurring
  - can be applied operationally for rapid identification of SOS
DMA Start of Season Calculation

- Year 1
- Year 2
- Year 3

- NDVI
- Moving Average

USGS
DMA of Season Calculation

NDVI

Year 1
Year 2
Year 3

NDVI

Moving Average
DMA Start of Season Calculation

NDVI

Year 1  Year 2  Year 3

NDVI
Moving Average

USGS
DMA Start of Season Calculation

![Graph showing NDVI values and moving average over years 1, 2, and 3](image)
Phenological metrics available at multiple resolutions
Phenological metrics available at multiple resolutions
Evaluation

- Validation of remote sensing phenology remains a large challenge (Ground “truth” phenology disconnect)
- Considerable QA checking done on USGS phenological data
  - Known issues posted on website
- Poster presented at Phenology 2012 Conference compared carbon flux phenology (start of season) with several remote sensing methods (DMA and Timesat) and multiple satellite RS input data sets (AVHRR and MODIS)
Comparison with Carbon Flux Tower “start of season” (CFP)

- Northern mixed prairie flux towers (Lethbridge, Ft. Peck, Cottonwood)
- 16 flux tower/years of data (18 for AVHRR)
- Compared CFP SOS with 2 sensors and 2 LSP phenology extraction methods
# SOS Results: CFP comparison

<table>
<thead>
<tr>
<th></th>
<th>DMA36</th>
<th>DMA30</th>
<th>TIMESAT 10%</th>
<th>TIMESAT 20%</th>
<th>TIMESAT 30%</th>
<th>TIMESAT 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR 1000m</td>
<td>0.57***</td>
<td>0.40**</td>
<td>0.24*</td>
<td>0.24*</td>
<td>0.50***</td>
<td>0.44**</td>
</tr>
<tr>
<td>TERRA MODIS 1000m</td>
<td>0.21</td>
<td>0.15</td>
<td>0.14</td>
<td>0.19</td>
<td>0.41**</td>
<td>0.43**</td>
</tr>
<tr>
<td>AQUA MODIS 1000m</td>
<td>0.33*</td>
<td>0.13</td>
<td>0.14</td>
<td>0.15</td>
<td>0.15</td>
<td>0.32</td>
</tr>
<tr>
<td>TERRA MODIS 250m</td>
<td>0.10</td>
<td>0.08</td>
<td>0.09</td>
<td>0.24</td>
<td>0.22</td>
<td>0.52**</td>
</tr>
</tbody>
</table>

***P<0.001

**P<0.01

*P<0.05
Arrows indicate mean SOS within +/- 7 days
## Users and Applications

<table>
<thead>
<tr>
<th>Organization</th>
<th>Type of stakeholder</th>
<th>URL/publication</th>
<th>Purpose of using Phenology Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGS/CLU, University of Nebraska</td>
<td>Provides funds (FY2006-FY2010), receives products, provides direction</td>
<td>Brown et al., 2008, GIScience and Remote Sensing</td>
<td>Season start and end data ingested in VegDRI models</td>
</tr>
<tr>
<td>USGS/CLU</td>
<td>Receives products</td>
<td>N/A</td>
<td>Season start data ingested in models of invasive species and ecosystem performance</td>
</tr>
<tr>
<td>USGS/Native American Activities</td>
<td>Receives products</td>
<td>N/A</td>
<td>For natural resources and climate change research</td>
</tr>
<tr>
<td>US Fish and Wildlife Service</td>
<td>Receives products</td>
<td>N/A</td>
<td>For research into invasive species spread in arid SW</td>
</tr>
</tbody>
</table>
Phenological Metrics in Modeling Cheatgrass

The premise of developing a start of sustained-growth week dataset to use in the cheatgrass percent cover modeling process is that identifying cheatgrass phenology, and distinguishing it from phenologies of other vegetation, is critical to our ability to use remote sensing technologies to map the spatial and temporal dynamics of the cheatgrass invasion. Contributes to modeling cheatgrass using growing season NDVI (GSN).
Model Use of SOST variable

The SOST variable overwhelmingly dominated the development of the regression equation; this indicates the importance of each spatial variable in predicting SOSW.

Table 1. Spatial variables used to develop the model to estimate cheatgrass start of sustained-growth week (SOSW). Frequency of variable usage for stratification and development of regression algorithms is displayed.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Utilization stratification</th>
<th>Multiple-regression prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude proxy</td>
<td>80% 44% 24%</td>
<td>24% 92% 32%</td>
</tr>
<tr>
<td>SOST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2001(a) & 2006 (b) Cheatgrass Start of Sustained Growth Week (SOSW) Maps

Training data $R^2 = 0.85$, average error = 0.9; relative error = 0.33.
Test data $R^2 = 0.88$, average error = 1.2; relative error = 0.24.
Aspen Phenology Study

- Investigate phenological patterns and trends for trembling aspen across elevational gradients
- Investigate phenology/climate relationships in healthy and disturbed aspen
- How is the phenology of aspen changing related to climate?
- Does disturbance change the phenology?
- Does disturbance change the phenology/climate relationships?
Aspen Samples

- <2700m  
  n = 1161

- 2700m – 2699m  
  n = 2454

- >2999m  
  n = 410
Aspen Phenology Study

Table 1. Correlation between EOST and temperature

<table>
<thead>
<tr>
<th></th>
<th>T min</th>
<th>T mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Elev EOST</td>
<td>0.68**</td>
<td>0.50*</td>
</tr>
<tr>
<td>Med Elev EOST</td>
<td>0.71**</td>
<td>0.56**</td>
</tr>
<tr>
<td>High Elev EOST</td>
<td>0.64**</td>
<td>0.47*</td>
</tr>
</tbody>
</table>
Challenges and opportunities

- **Challenges**
  - Length of record
  - Providing continuity at the end of AVHRR and MODIS records >> transition activities to VIIRS
  - Improving validation and historical assessment
  - Modernize methods

- **Opportunities**
  - VIIRS transition
  - Multiscale analysis of phenology and drought (augment with Landsat-resolution, data fusion)
  - Historical assessment (e.g. utilization of VIP data record)
Thank you

jfbrown@usgs.gov
http://phenology.cr.usgs.gov
http://earlywarning.cr.usgs.gov/usewem

Contributions by S. Boyte, G. Meier, R. Euelsizer
Additional Materials
Recent project publications


