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Climate and Land Use Change
Earth Resources Observation and Science (EROS) Center

U.S. Land Surface Phenology: Methods, Data, and Applications

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23 January 2013

U.S. Department of the Interior
U.S. Geological Survey

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***

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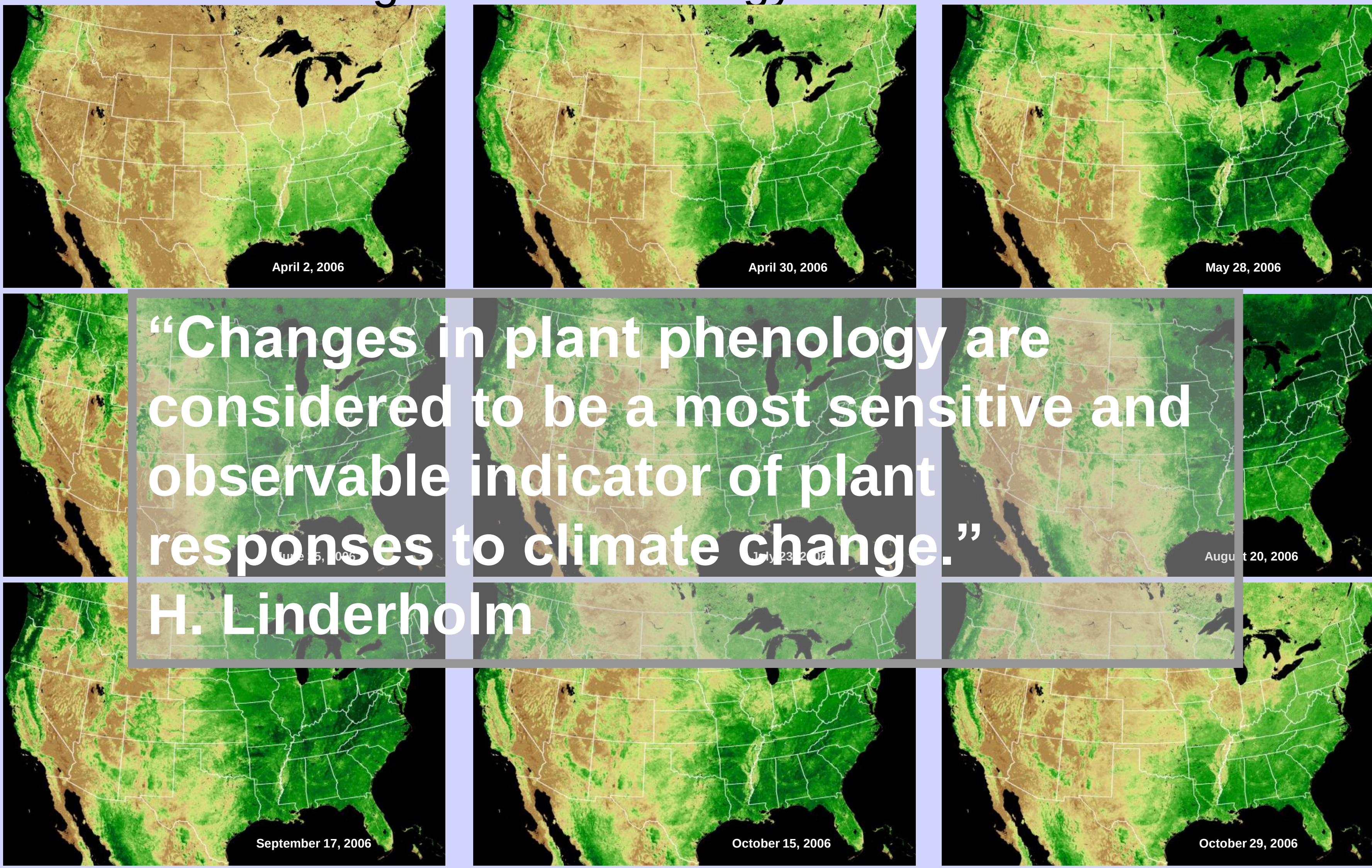
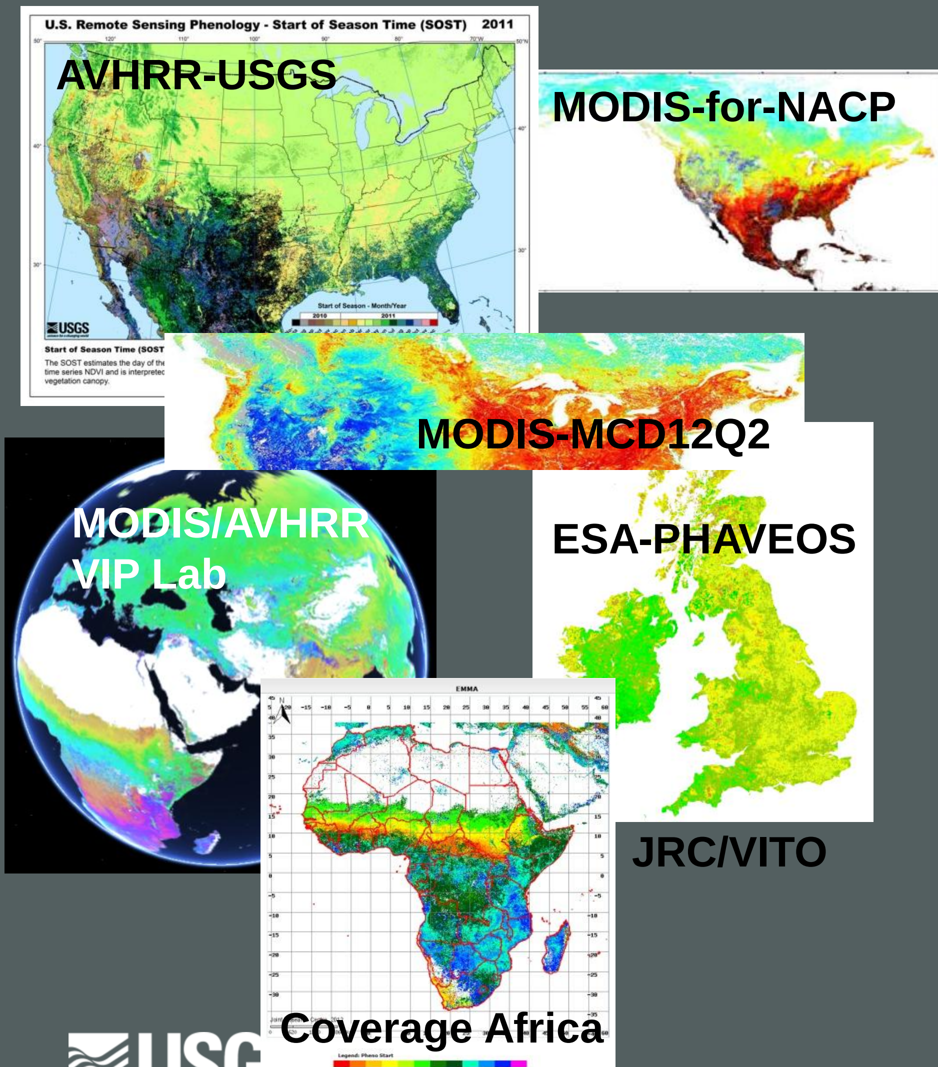
2006 Satellite Vegetation Phenology for the Conterminous U.S.



"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.**

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

E… om
ti…

… (NDVI)

Remote Sensing Phenology - Windows Internet Explorer
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Remote Sensing Phenology
Remote Sensing Phenology uses satellites to track seasonal changes in vegetation on regional, continental, and global scales.
U.S. Remote Sensing Phenology - Time Integrated NDVI (TIN) 2005
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).
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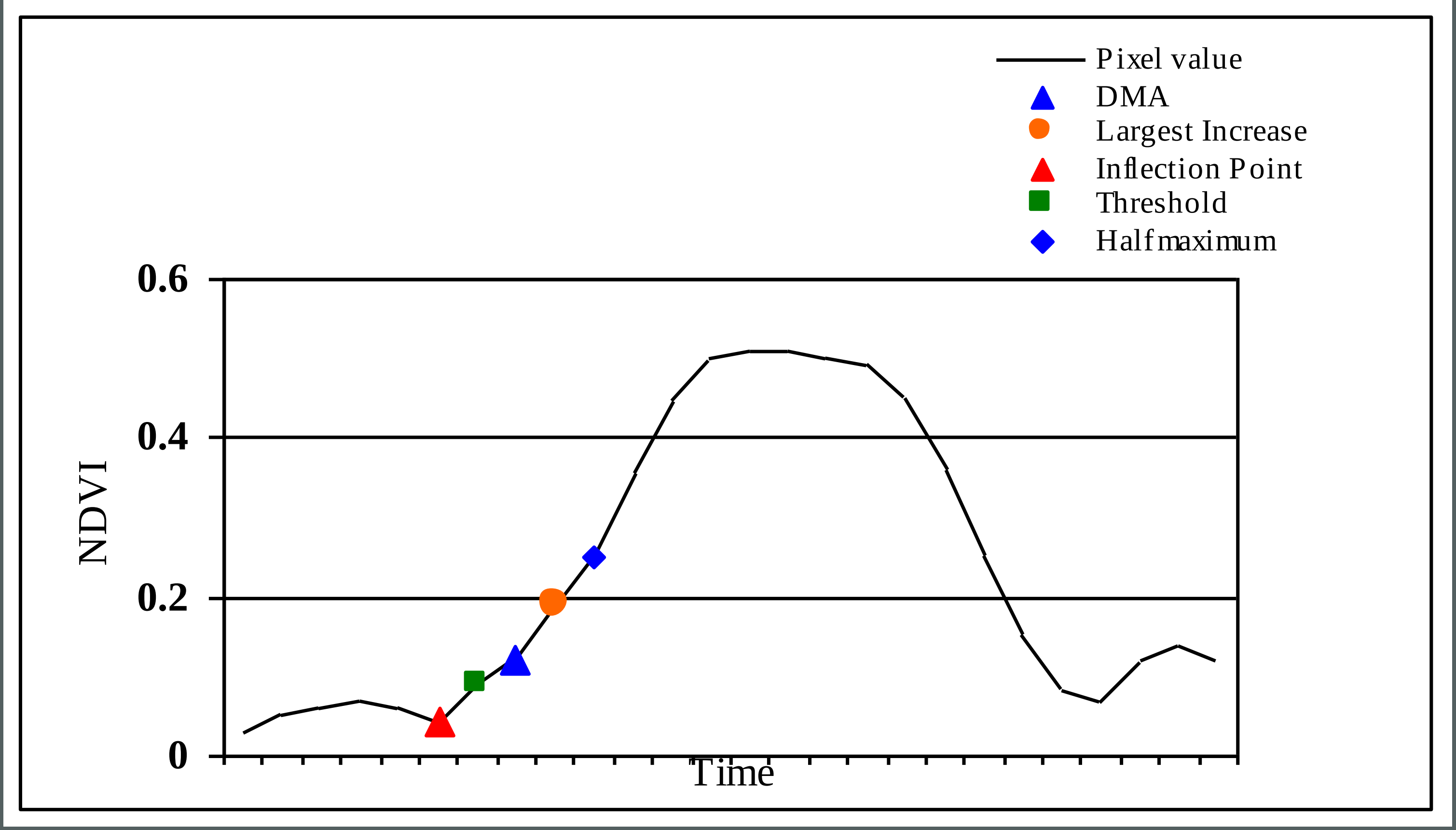
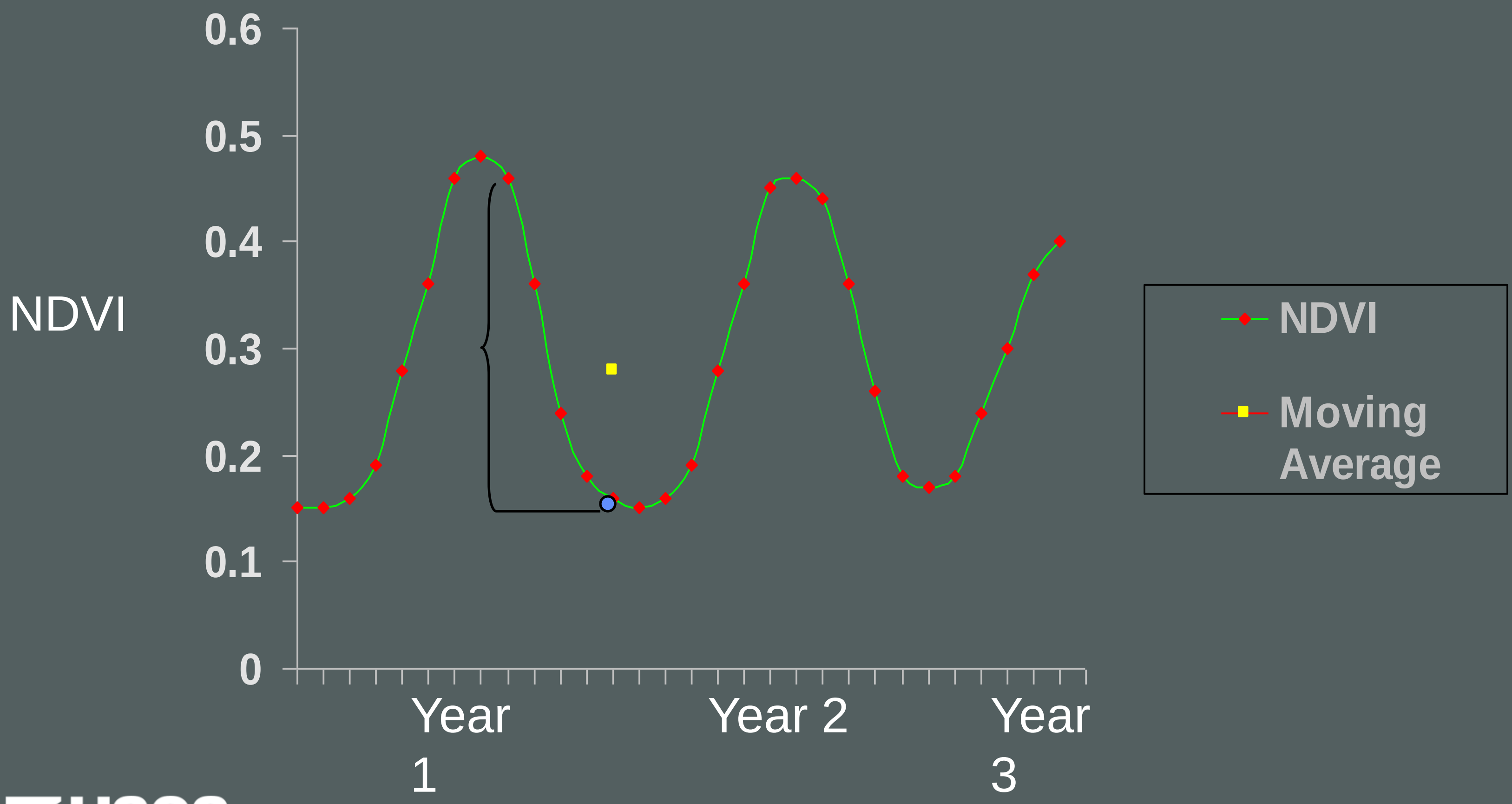
RSP Start of Season Methods



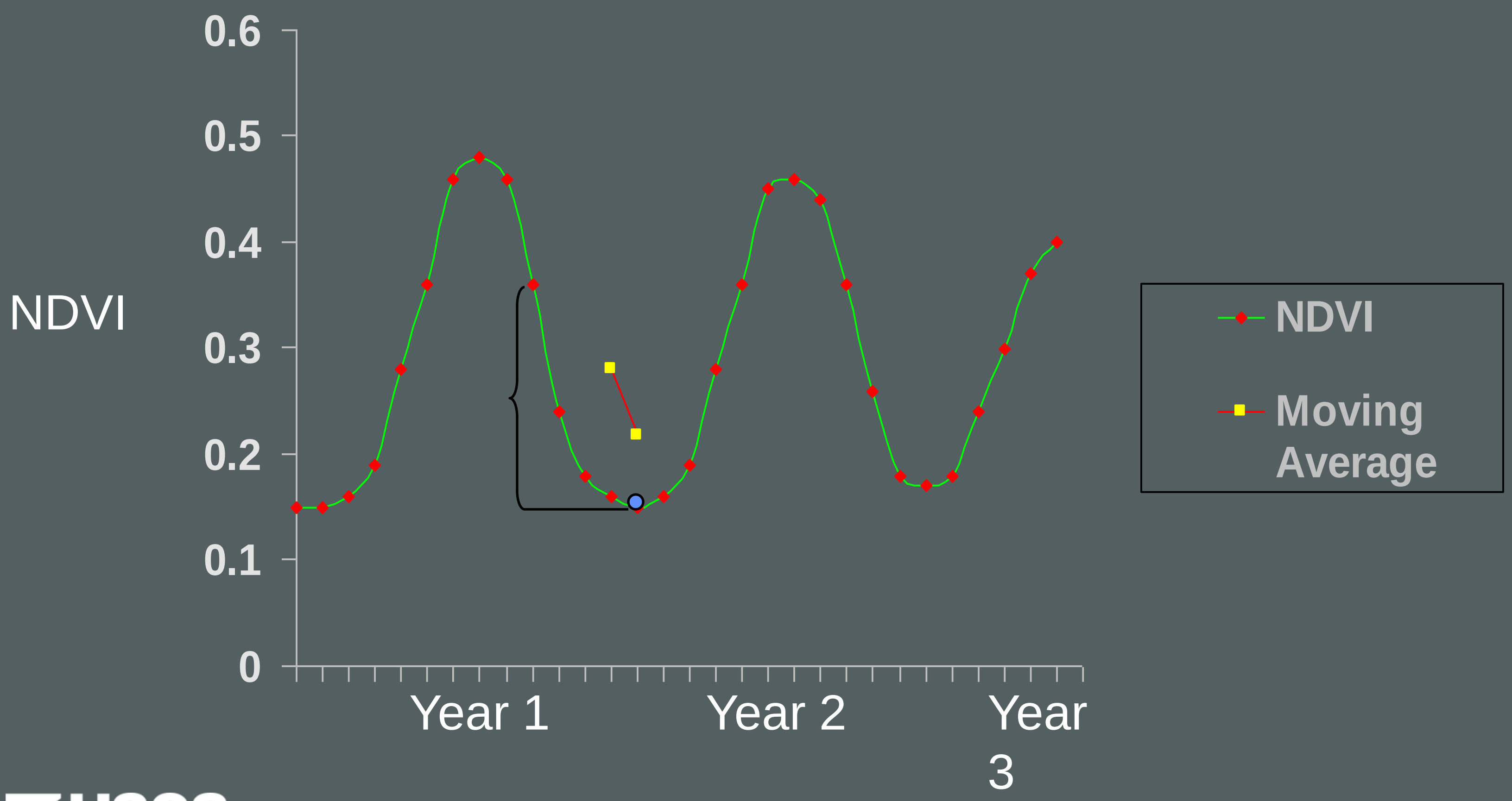
RSP Methods – Identifying Start of Season

- **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

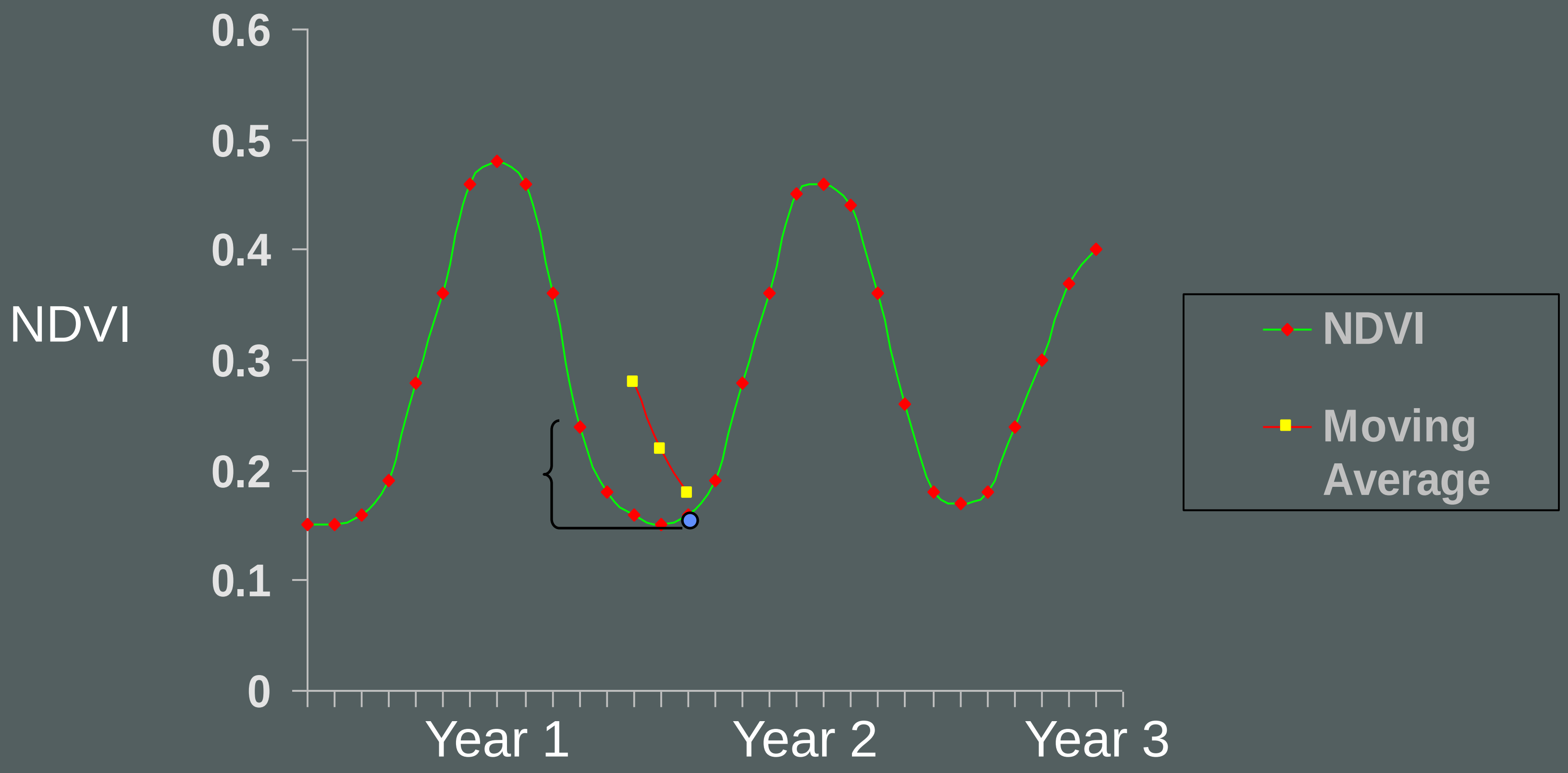
DMA Start of Season Calculation



DMA of Season Calculation



DMA Start of Season Calculation



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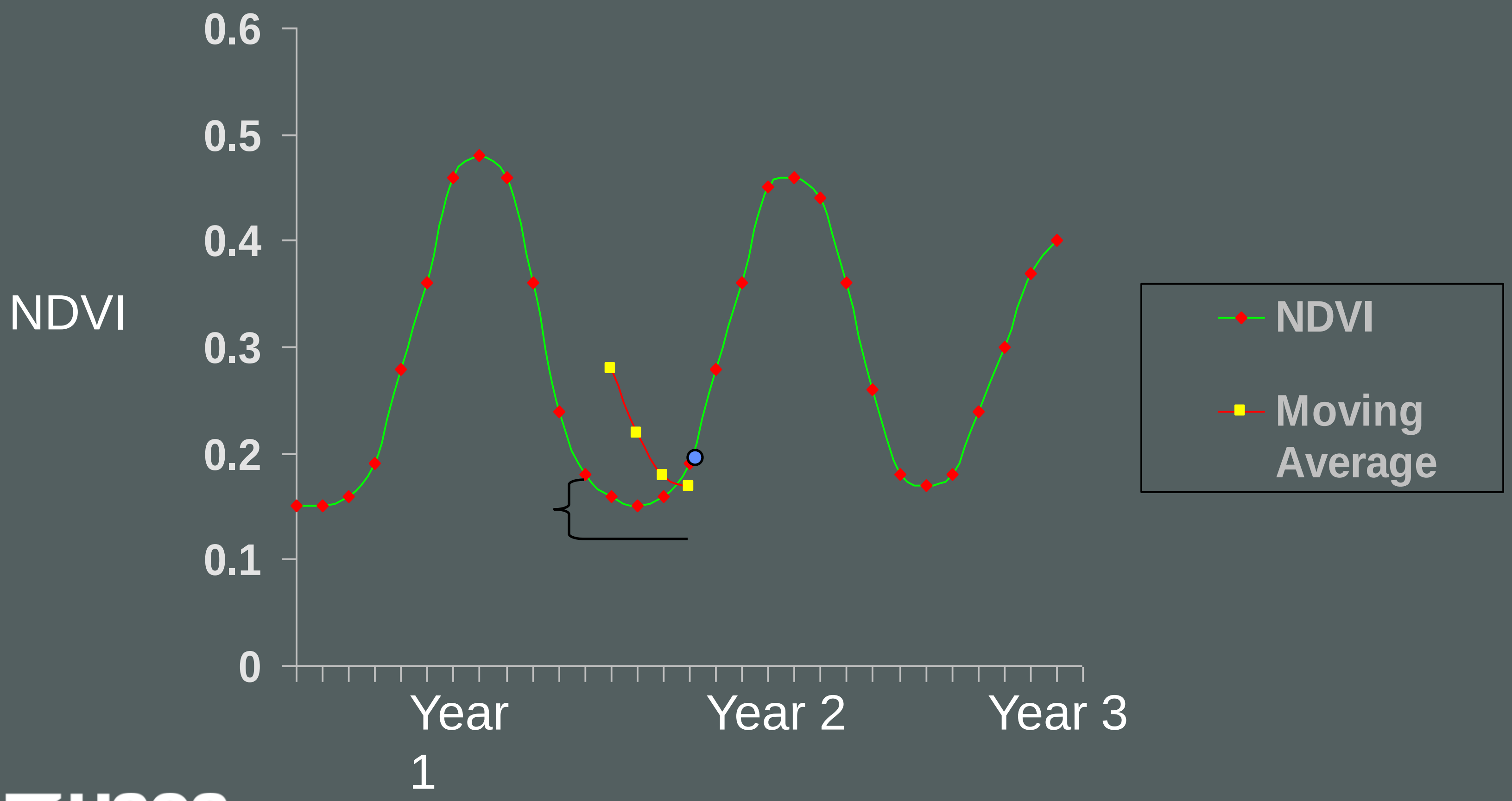
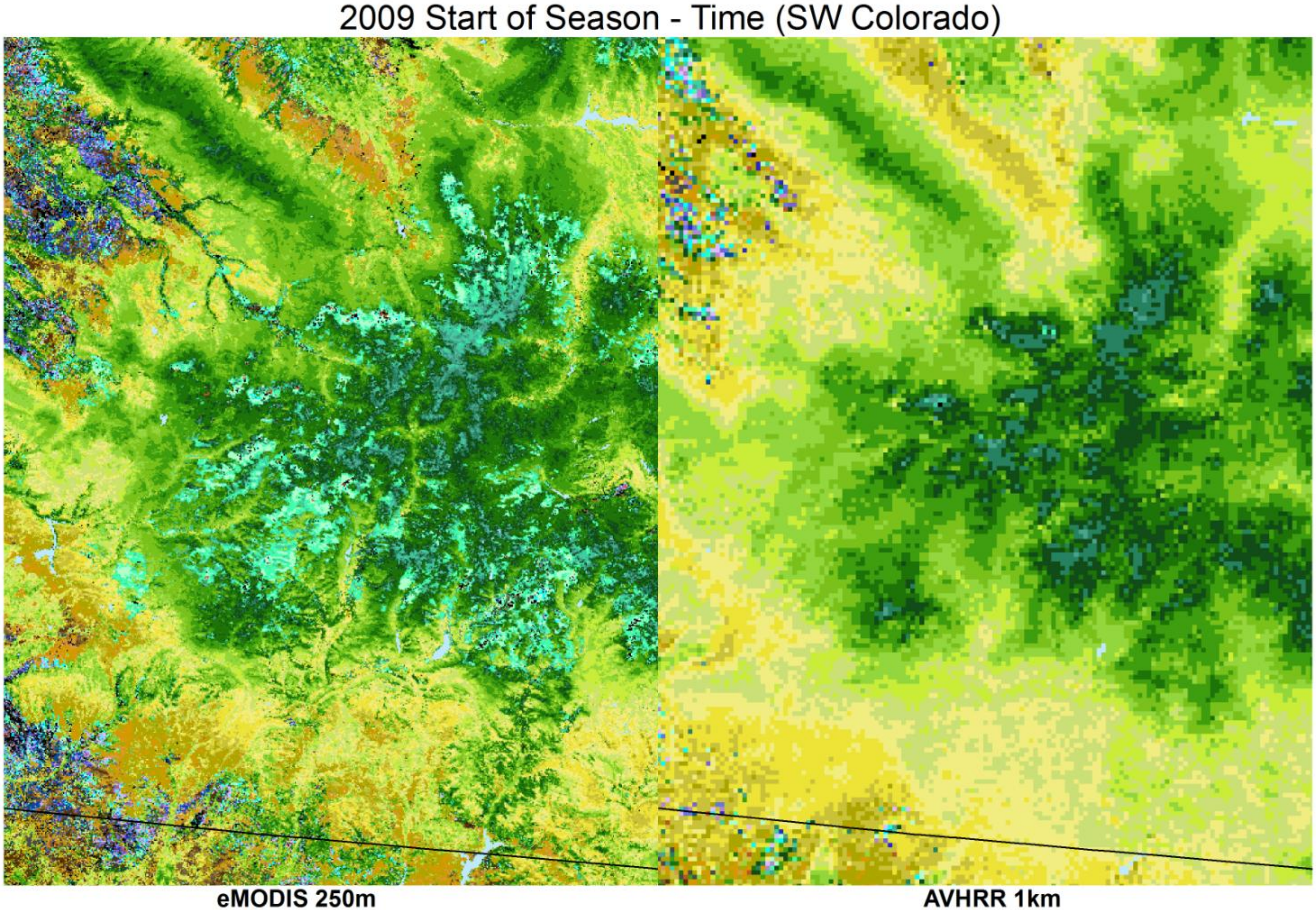
DMA Start of Season Calculation

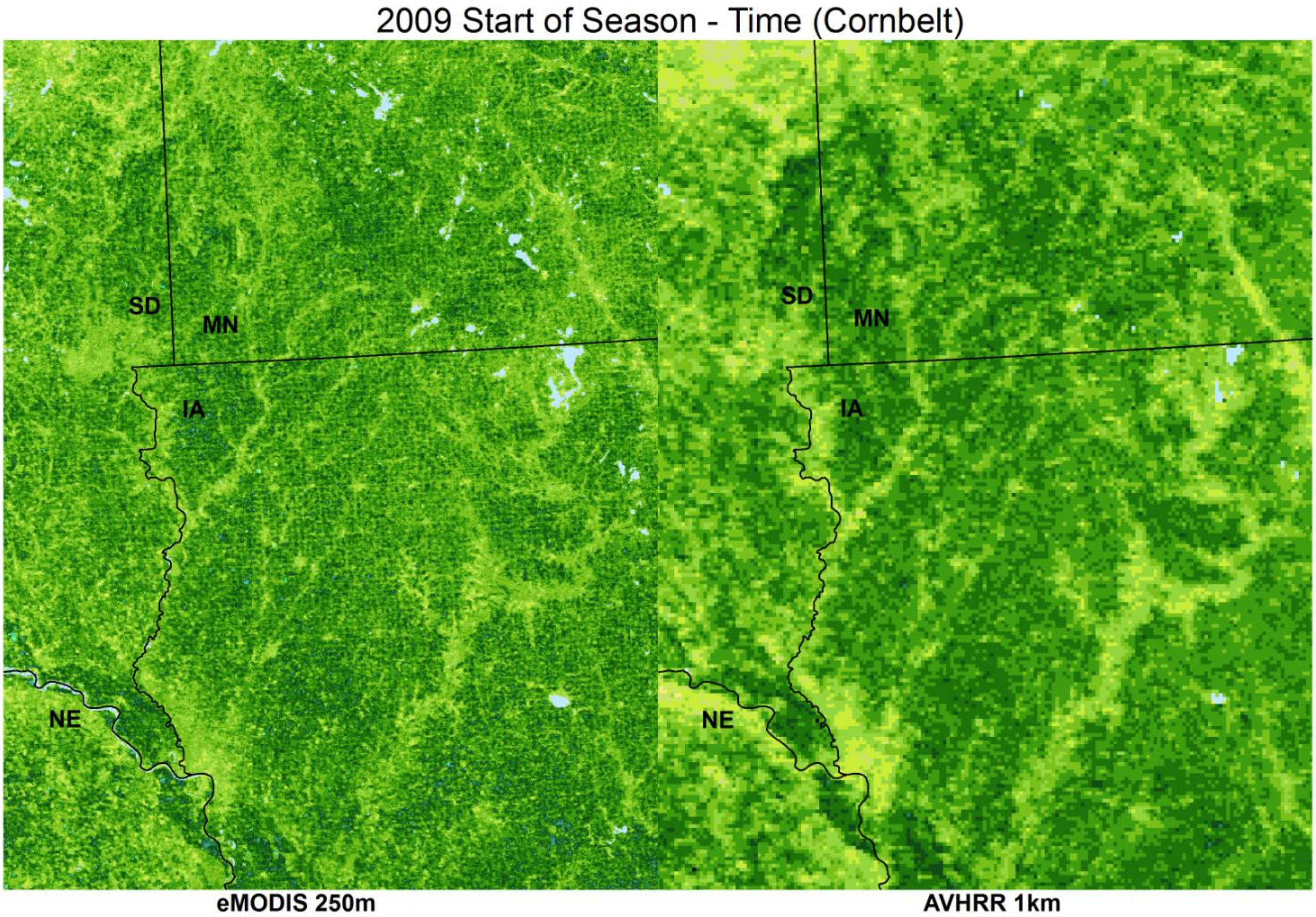




2001-2011

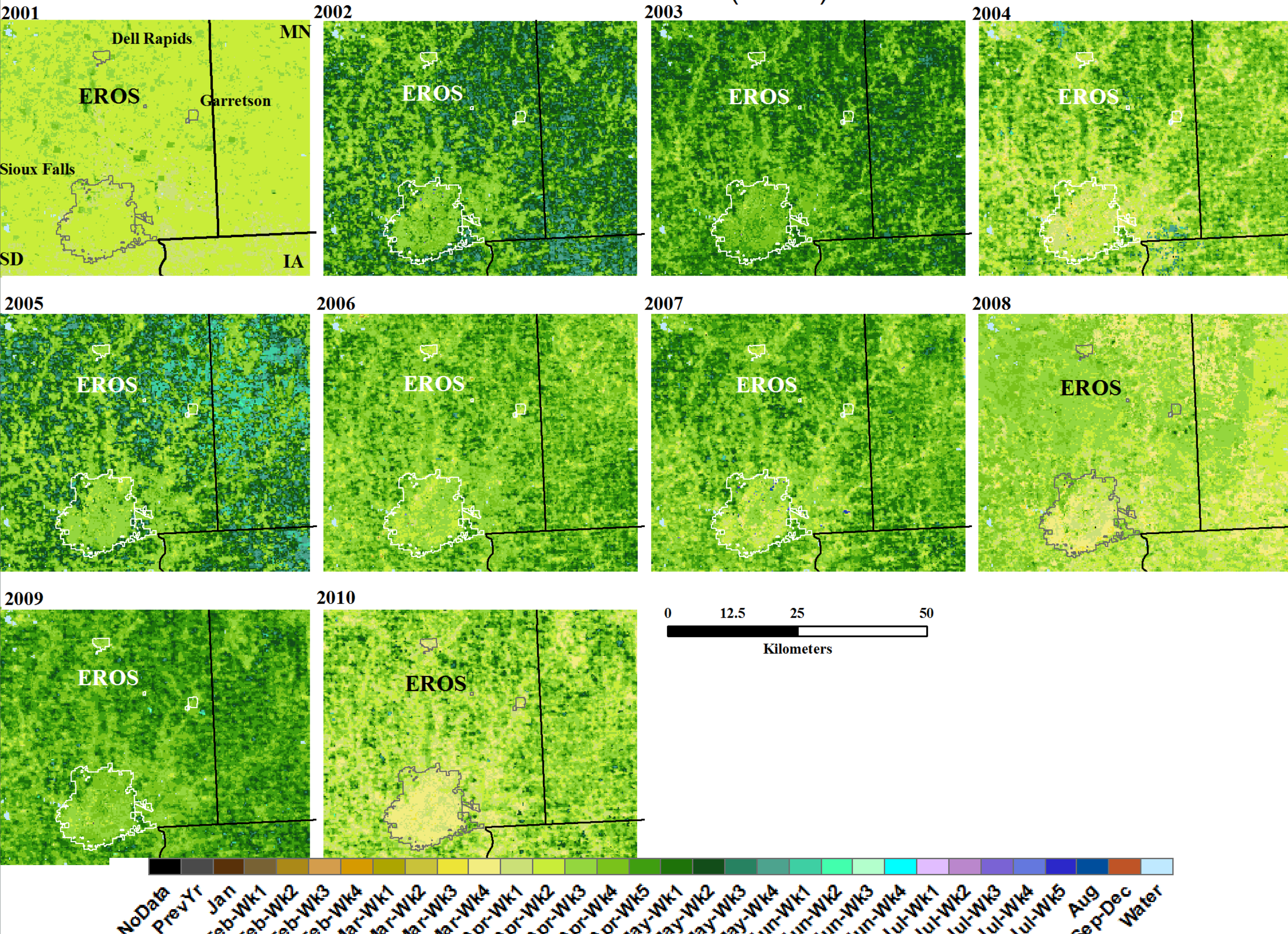
1989-2011

Phenological metrics available at multiple resolutions



Phenological metrics available at multiple resolutions

Start of Season-Time (SOST)



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 compareed carbon flux phenology (start of season) with several remote sensing methods (DMA and Timesat) and multiple satellite RS input data sets (AVHRR and MODIS)**

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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**

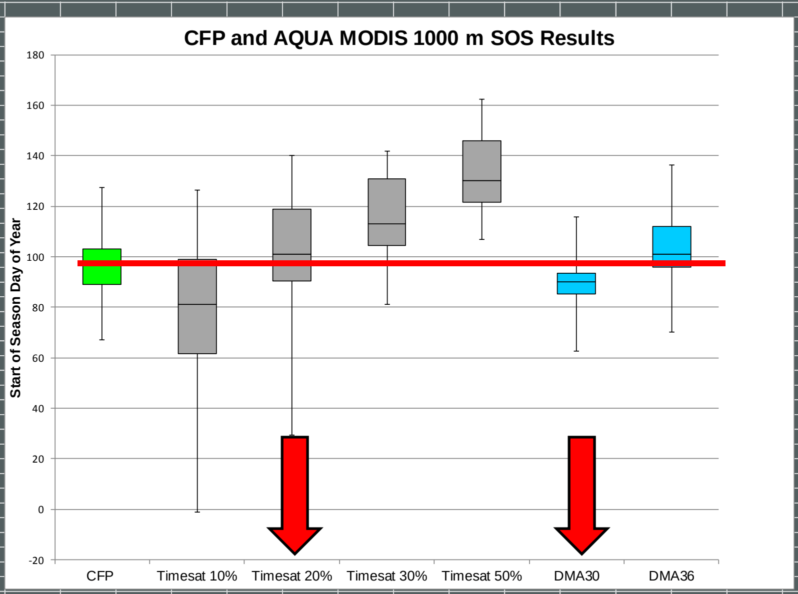
SOS Results: CFP comparison

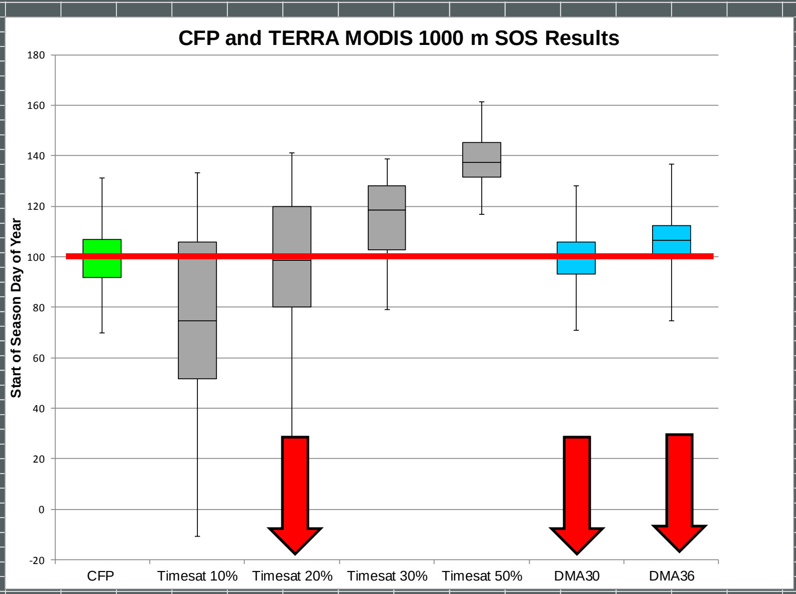
	DMA36	DMA30	TIMESAT 10%	TIMESAT 20%	TIMESAT 30%	TIMESAT 50%
AVHRR 1000m	0.57***	0.40**	0.24*	0.24*	0.50***	0.44**
TERRA MODIS 1000m	0.21	0.15	0.14	0.19	0.41**	0.43**
AQUA MODIS 1000m	0.33*	0.13	0.14	0.15	0.15	0.32
TERRA MODIS 250m	0.10	0.08	0.09	0.24	0.22	0.52**

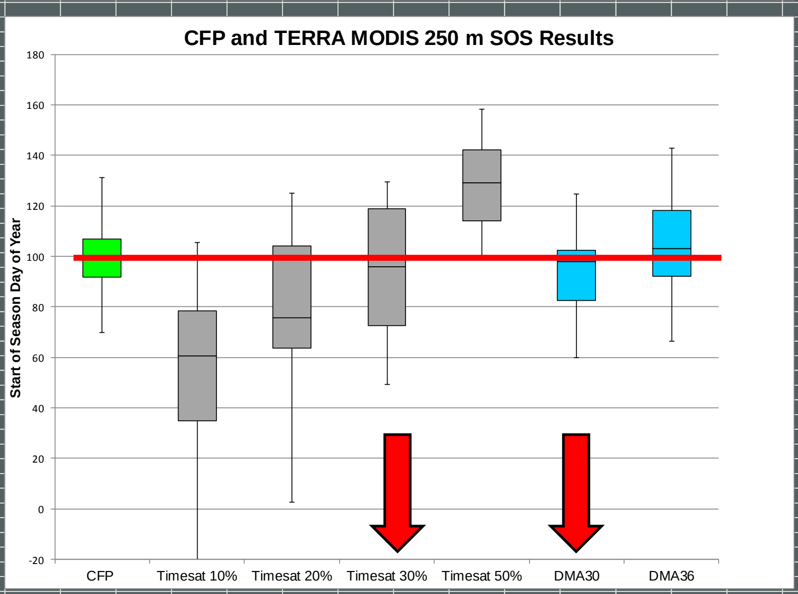
***P<0.001

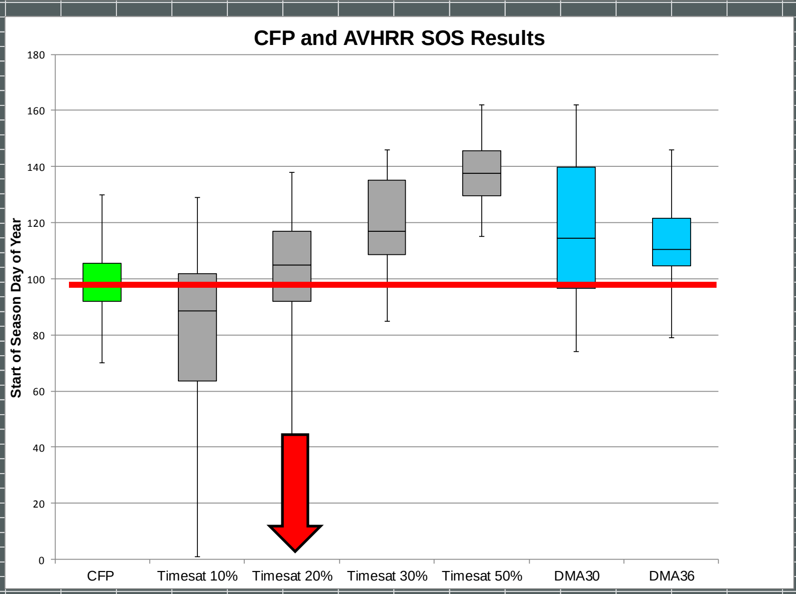
**P<0.01

*P<0.05









Arrows indicate mean SOS within +/- 7 days

Users and Applications

Organization	Type of stakeholder	URL/publication	Purpose of using Phenology Metrics
USGS/CLU, University of Nebraska	Provides funds (FY2006-FY2010), receives products, provides direction	Brown et al., 2008, GIScience and Remote Sensing	Season start and end data ingested in VegDRI models
USGS/CLU	Receives products	N/A	Season start data ingested in models of invasive species and ecosystem performance
USGS/Native American Activities	Receives products	N/A	For natural resources and climate change research
USGS/National Phenology Network	Receives products, provides direction	http://www.usanpn.org/	For visualization of phenology across CONUS
US Fish and Wildlife Service	Receives products	N/A	For research into invasive species spread in arid SW

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).

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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.

Dataset	Utilization stratification	Multiple-regression prediction
Latitude proxy	80%	24%
SOST	44%	92%
Elevation	24%	32%

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.

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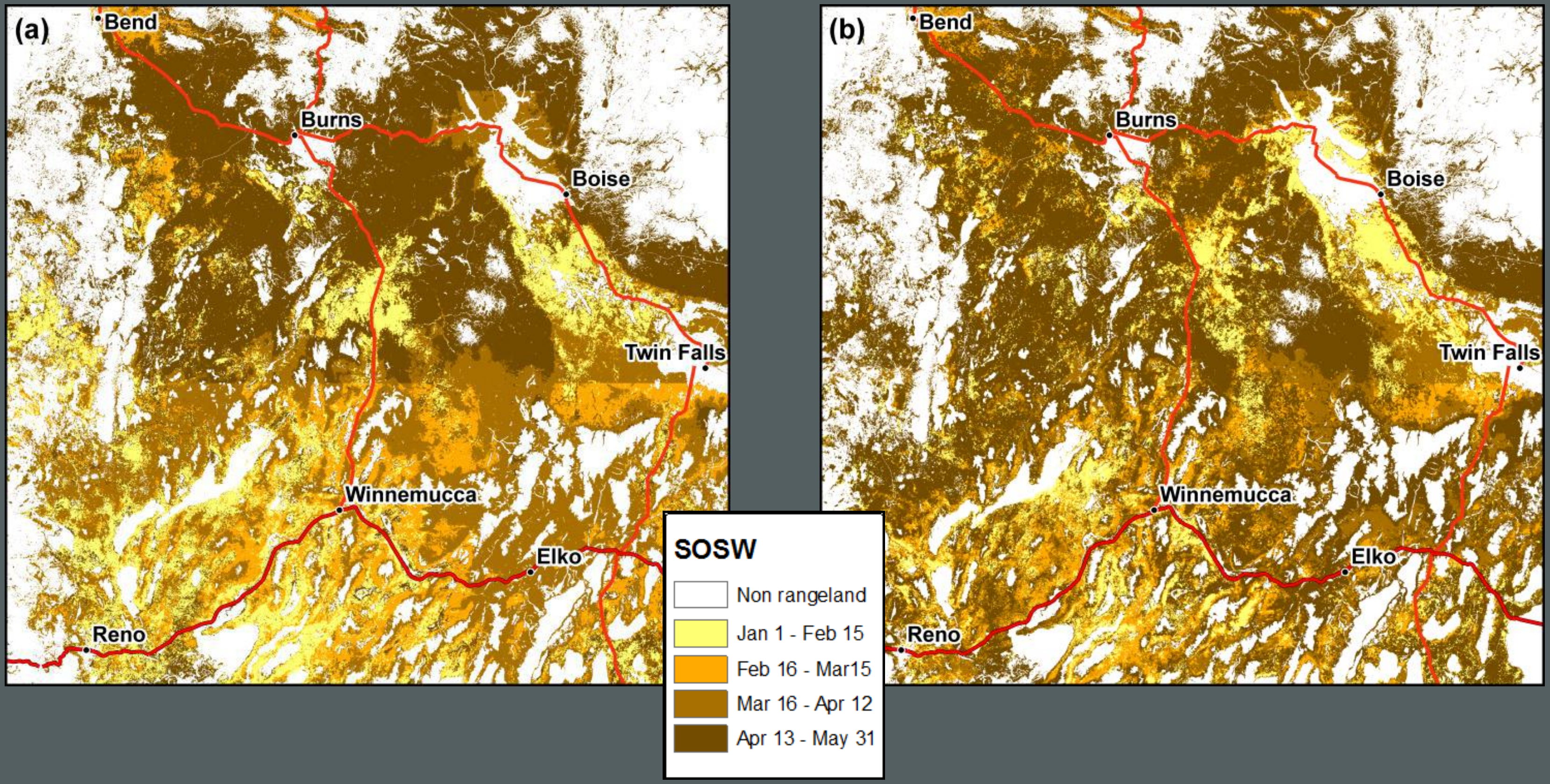
2001(a) & 2006 (b) Cheatgrass Start of Sustained Growth Week (SOSW) Maps



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.

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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?

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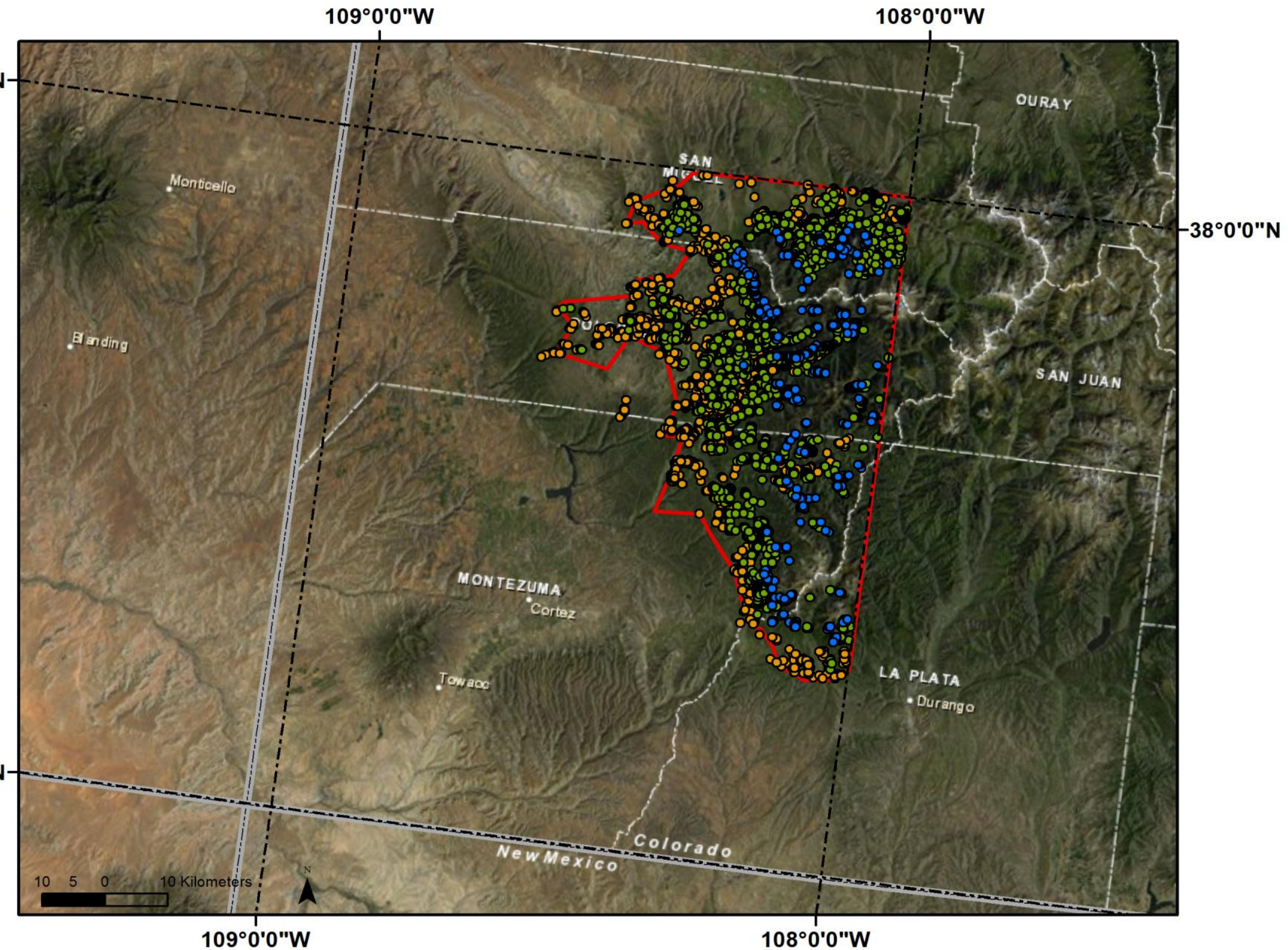
Aspen Samples

- <2700m
  n = 1161
- 2700m – 2699m
  n = 2454
- >2999m
  n = 410



Aspen Phenology Study

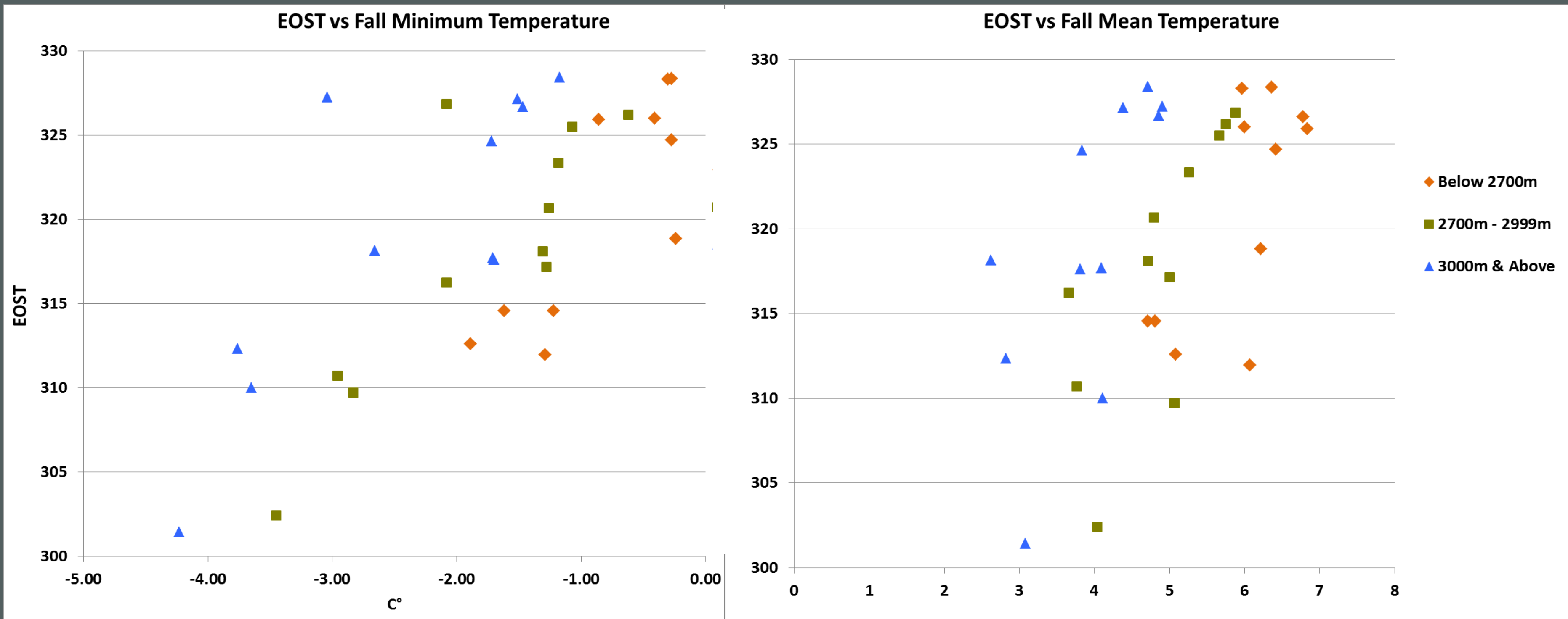


Table 1. Correlation between EOST and temperature

	T min	T mean
Low Elev EOST	0.68**	0.50*
Med Elev EOST	0.71**	0.56**
High Elev EOST	0.64**	0.47*

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

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http://phenology.cr.usgs.gov

http://earlywarning.cr.usgs.gov/usewem

Contributions by S. Boyte, G. Meier, R. Evelsizer

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Additional Materials

Recent project publications

Brown, J.F., and Pervez, M.S., 2013, Recent expansion in irrigated cropland in the U.S. and across the High Plains Aquifer, *Agricultural Systems* (in review).

Meier, G. , Brown, J.F., Evelsizer, R. and Vogelmann, J., 2013, Characterizing recent phenological and climate relationships in trembling aspen (Populus temuloides), (in preparation).

Wardlow, B.D., Tadesse, T., Brown, J.F., Callahan, C., Swain, S., and Hunt, E., 2012, The Vegetation Drought Response Index (VegDRI): An integration of satellite, climate, and biophysical data, *in* Wardlow, B.D. and others, eds., Remote sensing for drought: Innovative monitoring approaches: CRC Press/Taylor & Francis,Boca Raton, FL, p. 51-74.

Pervez, M.S. and Brown, J.F., 2010, Mapping irrigated lands at 250-m scale by merging MODIS data and national agricultural statistics, *Remote Sensing*, 2(10), 2388-2412; doi:10.3390/rs2102388.

Tadesse, T., Wardlow, B.D., Hayes, M.J., Svoboda, M.D., and Brown, J.F., 2010, The Vegetation Outlook (VegOut): a new method for predicting vegetation seasonal greenness, *GIScience & Remote Sensing*, 47 (1), p. 25-52.

Gu, Y., Brown, J.F., Miura, T., van Leeuwen, W., and Reed, B.C., 2010, Phenological classification of the United States: A geographic framework for extending multi-sensor time-series data, *Remote Sensing*, 2(2), 526-544; doi: 10.3390/rs2020526.

White, M.A., de Beurs, K.M., Didan, K., Inouye, D.W., Richardson, A.D., Jensen, O.P., O'Keefe, J., Zhang, G., Nemani, R.R., van Leeuwen, W.J.D., Brown, J.F., de Wit, A., Schaepman, M., Lin, X., Dettinger, M., Bailey, A.S., Kimball, J., Schwartz, M.D., Baldocchi, D.D., Lee, J.T., and Lauenroth, W.K., 2009, Intercomparison, interpretation, and assessment of spring phenology in North America estimated from remote sensing for 1982 to 2006, *Global Change Biology*, doi: 10.1111/j.1356-2486.2009.01910.x.

Gu, Y., Hunt E., Wardlow, B., Basara, J., Brown, J.F., and Verdin, J.P., 2008, Evaluation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data, *Geophysical Research Letters,* 35 (22), L22401.

Brown, J.F., Wardlow, B.D., Tadesse, T., Hayes, M.J., and Reed, B.C., 2008, The Vegetation Drought Response Index (VegDRI): a new integrated approach for monitoring drought stress in vegetation: *GIScience & Remote Sensing*, 45 (1), p. 16-46.

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