

Large-Scale Monitoring with Landsat Time Series: Sampling, Analyses, Validation

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Talking Points

- Landsat's niche
- Role of scene-based sampling within the North American Forest Dynamics (NAFD) study
- LandTrendr: Analysis of Landsat time-series across contiguous scenes
- TimeSync: Exploring new possibilities to meet new needs for validation

Landsat: 36 years & counting

- ☑ Spatial resolution & extent
- ☑ Spectral extent & band placement
- ☑ Temporal extent (& resolution?)
- ☑ Free data! LIT format ~ new paradigm
- ☑ Bright (but distant) future: LDCM July, 2011 +6-18 months

Free Access to Landsat Imagery



Free image. This Landsat 5 image of the southeastern corner of the Black Sea is part of the general U.S. archive that will be accessible for free under the new USGS policy.

WE ARE ENTERING A NEW ERA IN THE LANDSAT Program, the oldest and most venerable of our Earth-observing satellite programs. With little fanfare, the U.S. Geological Survey (USGS) has begun providing imagery for free over the Internet. Throughout the history of the Landsat Program, the cost and access to imagery has always limited our ability to study our planet and the way it is changing. Beginning with a pilot program to provide “Web-enabled” access to Landsat 7 images of the United States that were collected between 2003 and this year, the USGS now plans to provide top-quality image products for free upon request for the entire U.S. archive, including over 2 million images back to Landsat 1 (1972) [for details and schedules, see (1)]. The release by NASA and the USGS in January 2008 of a new Landsat Data Distribution Policy (2) was a key step to this goal. Free imagery will enable reconstruction of the history of Earth’s surface back to 1972, chronicling both anthropogenic and natural changes during a time when our population doubled and the impacts of climate change became noticeable.

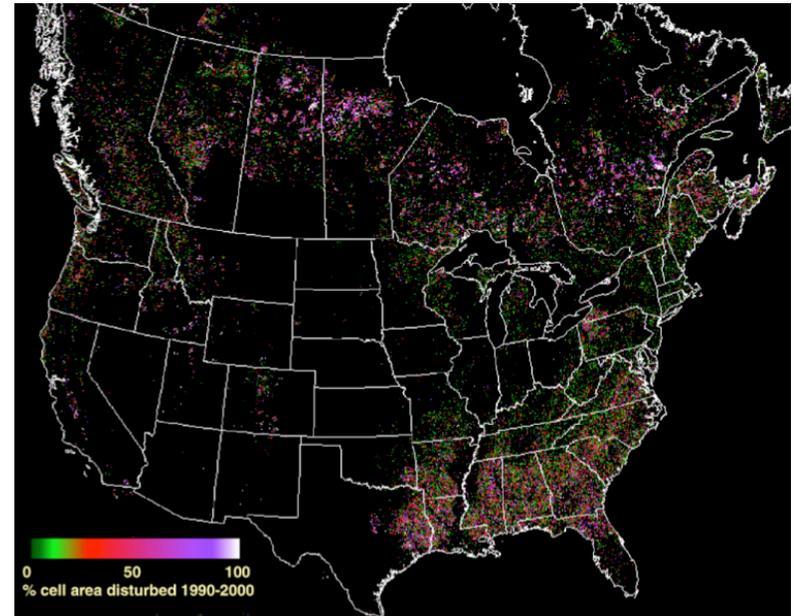
THE LANDSAT SCIENCE TEAM: CURTIS E. WOODCOCK,^{1*} RICHARD ALLEN,² MARTHA ANDERSON,³ ALAN BELWARD,⁴ ROBERT BINDSCHADLER,⁵ WARREN COHEN,⁶ FENG GAO,⁵ SAMUEL N. GOWARD,⁷ DENNIS HELDER,⁸ EILEEN HELMER,⁹ RAMA NEMANI,¹⁰ LAZAROS OREOPOULOS,⁵ JOHN SCHOTT,¹¹ PRASAD S. THENKABAIL,¹² ERIC F. VERMOTE,¹³ JAMES VOGELMANN,¹⁴ MICHAEL A. WULDER,¹⁵ RANDOLPH WYNNE¹⁶

Intro to the North American Forest Dynamics (NAFD) study

- Goward et al. 2008, Eos, Transactions, AGU
 - Six objectives (most relevant below)
 1. Estimate disturbance and regrowth metrics nationally from a sample of Landsat scenes
 2. Convert forest change to biomass change (carbon connection)
 3. Pilot similar studies with Canadian (Wulder) and Mexican (Sandoval) collaborators
- This talk: Focus on sampling aspects of NAFD*

North American Forest Dynamics (NAFD) study

Follows

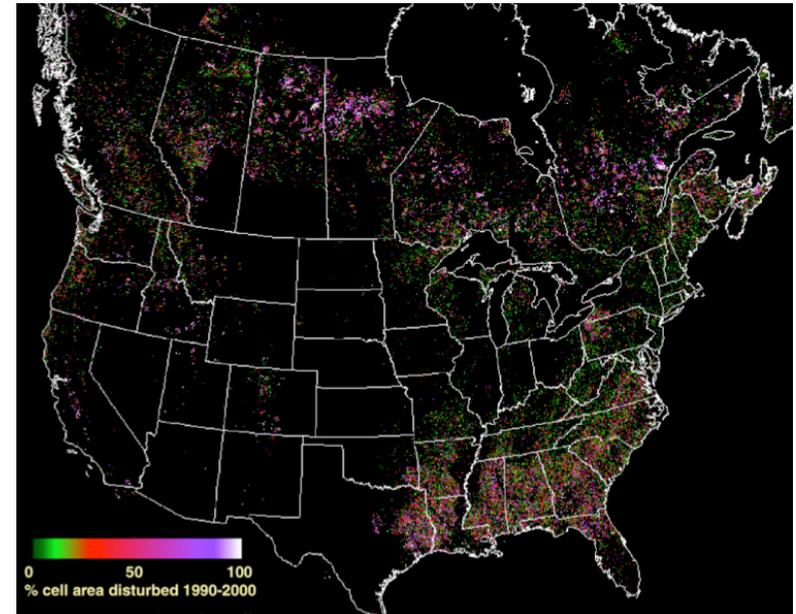
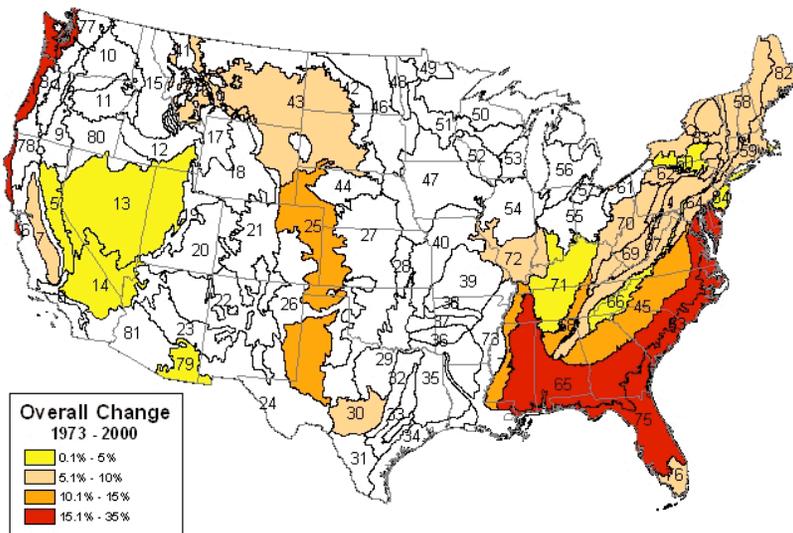


- ✓ LEDAPS (Masek et al. 2008, RSE), 10-15 year interval spatially comprehensive, US & Canada

North American Forest Dynamics (NAFD) study

Follows

- ✓ Land Cover Trends project (Loveland et al. 2002, PERS), samples for US national-level statistics, > 5-year interval



- ✓ LEDAPS (Masek et al. 2008, RSE), 10-15 year interval spatially comprehensive, US & Canada

Because not using annual data, these likely insensitive to subtle change

North American Forest Dynamics (NAFD) Study

Rationale

- Recognizing the limitations of “interval-based” datasets, we sought to compile near-annual stacks of Landsat data to address a need for a national/continental forest change statistics
- At the time of conception, processing all scenes (i.e., a national map) was not reasonable
- So we designed a scene-based sample

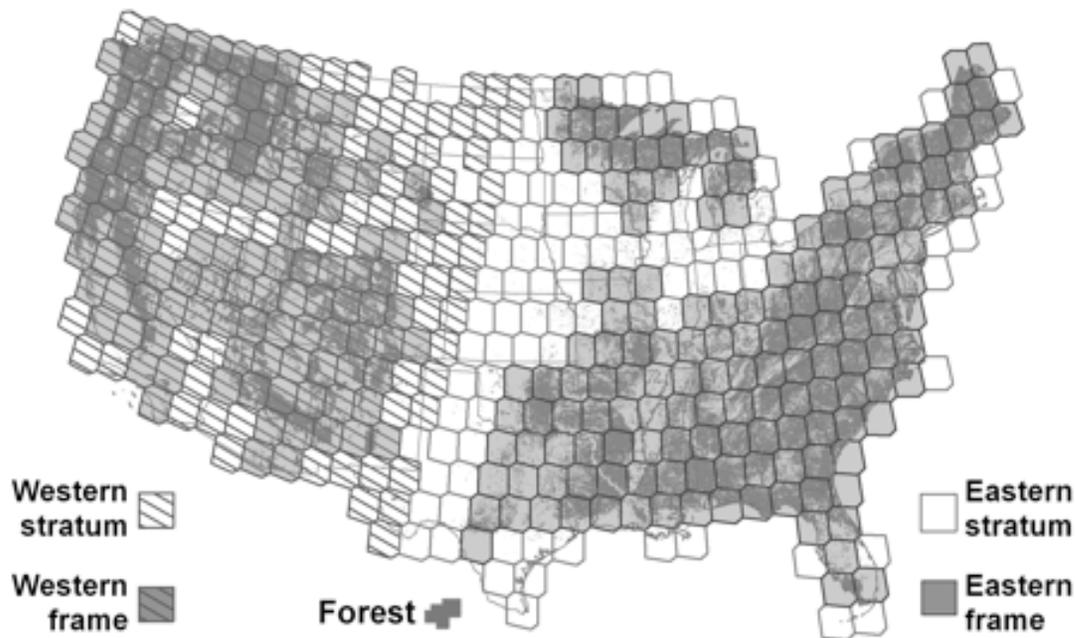
NAFD Sample Design (Kennedy et al., in prep)

- Follows Gallego (2005, JP&RS)
 - Non-overlapping WRS-2 scene areas (Thiessen Scene Areas, TSAs) as sample units
 - Unequal area sampling, so unequal probability estimator
- Appealing because probability approach allows for preferential inclusion of our specific criteria:
 1. Dispersion of scenes
 2. Exclusion of low forest area scenes
 3. Inclusion of high forest type diversity scenes
 4. Use of existing study scenes

NAFD Sample Design

Fundamental characteristics of our approach

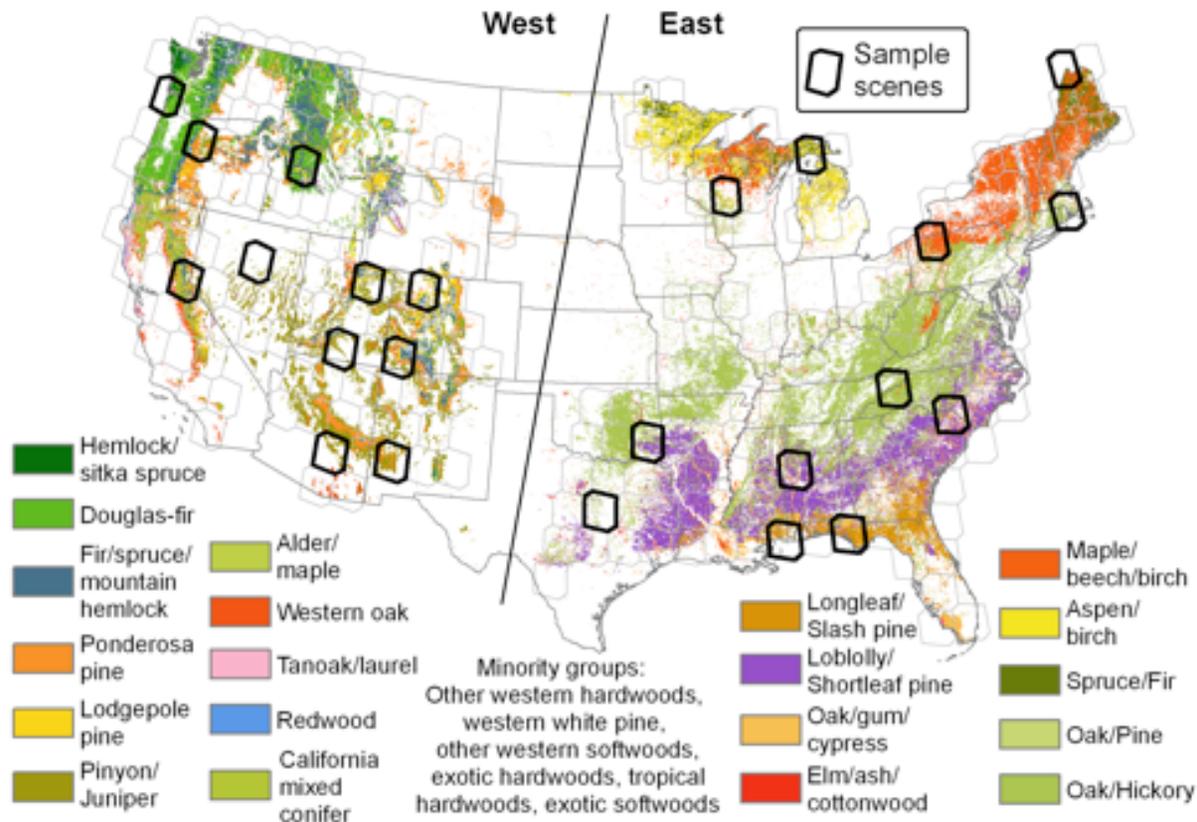
- WRS-2 TSAs are basic sample units
- Two sample strata & frames
 - scenes with $< 2\%$ cumulative forest area per stratum culled
 - east (156 TSAs), west (122 TSAs)



NAFD Sample Design

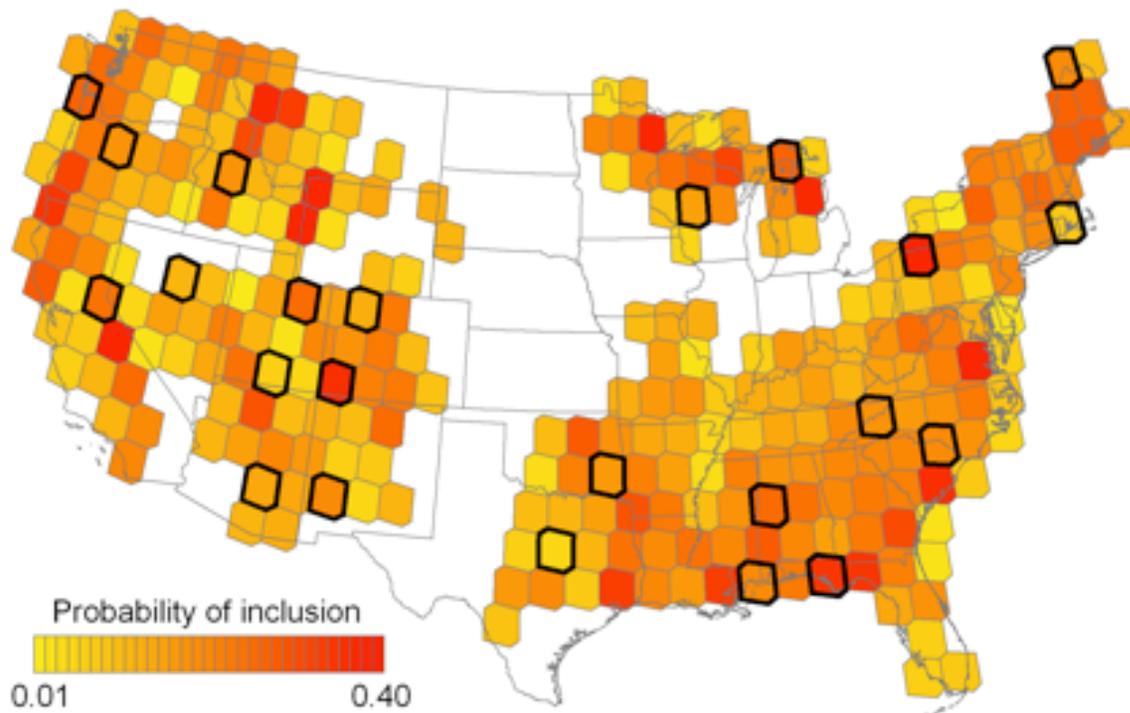
- For each frame
 - 100,000 random order TSA lists (ROTLs)
 - Each ROTL scored according to how well our four criteria were met; lists with low scores removed
 - Remaining ROTLs: 196 west, 253 east, each with known probabilities for all scenes
 - One list randomly chosen for each stratum/frame
- Analysis expandable - step through list

NAFD Sample Scenes for Phase I



- Final sample set for Phase I of project, over the FIA national forest type map
- Phase II: simply go further down the selected ROTLs and grab 25+ next scenes

NAFD Sample Design

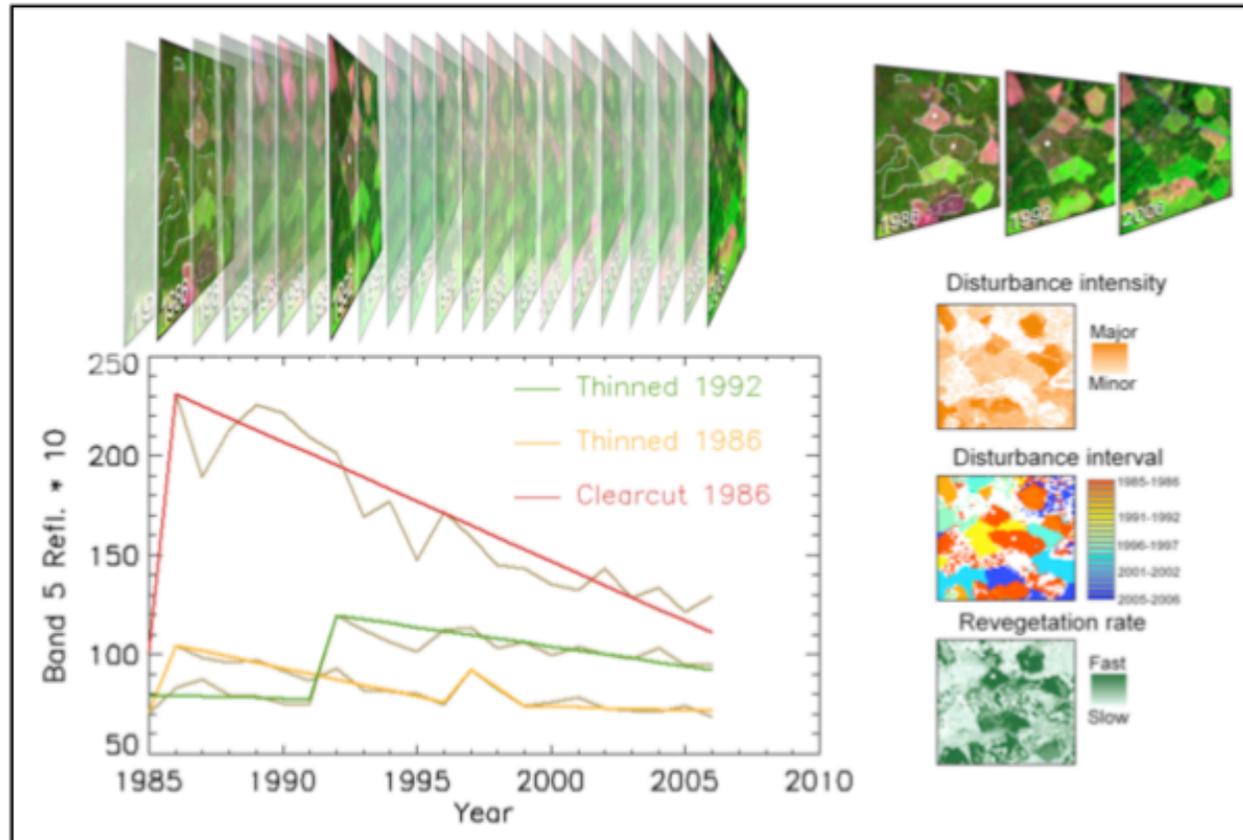


- Know probabilities of inclusion allow for statistically valid summaries by stratum at the national/continental scale
- Estimation to follow shortly:

$$\hat{\tau}_{\pi} = \sum_{i=1}^v \frac{y_i}{\pi_i}$$

Analysis of Annual Time Series

(LandTrendr, from Kennedy)



- Time series enhances signal:noise
- Segmentation of temporal signature in forests associated with disturbance and succession/regrowth

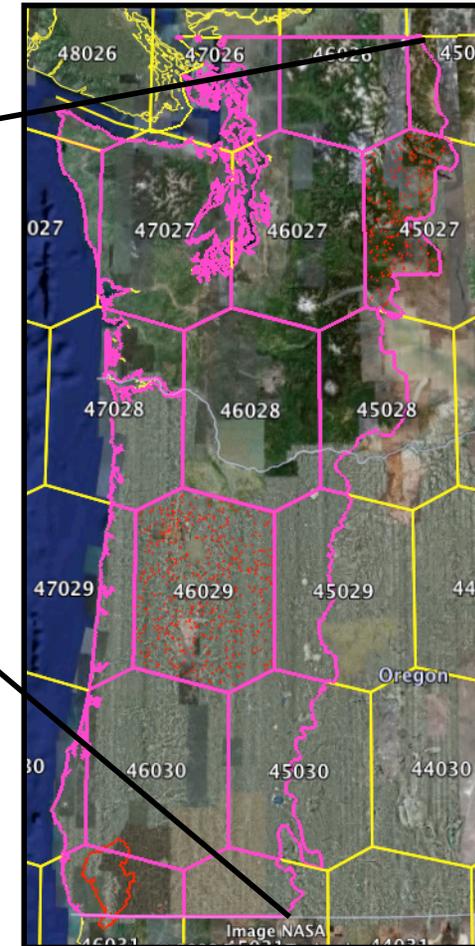
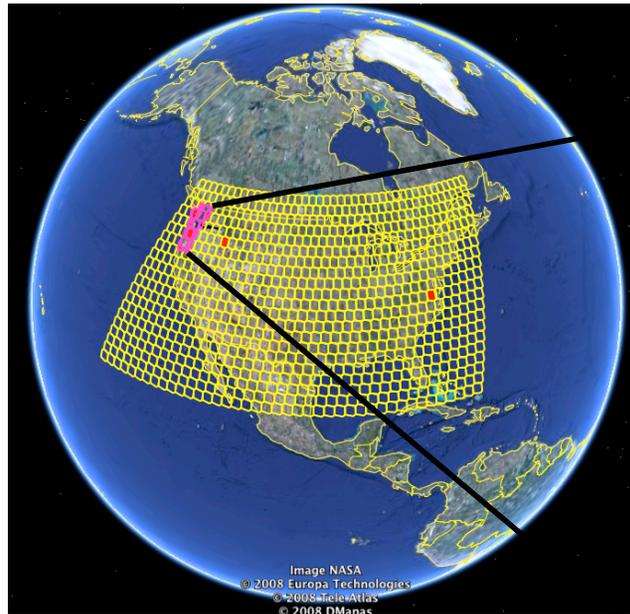
- Many possible approaches: NAFD uses Vegetation Change Tracker (VCT), Chenguan Huang

Analysis of Annual Time Series

Towards a wall-to-wall map for the US

Requirements:

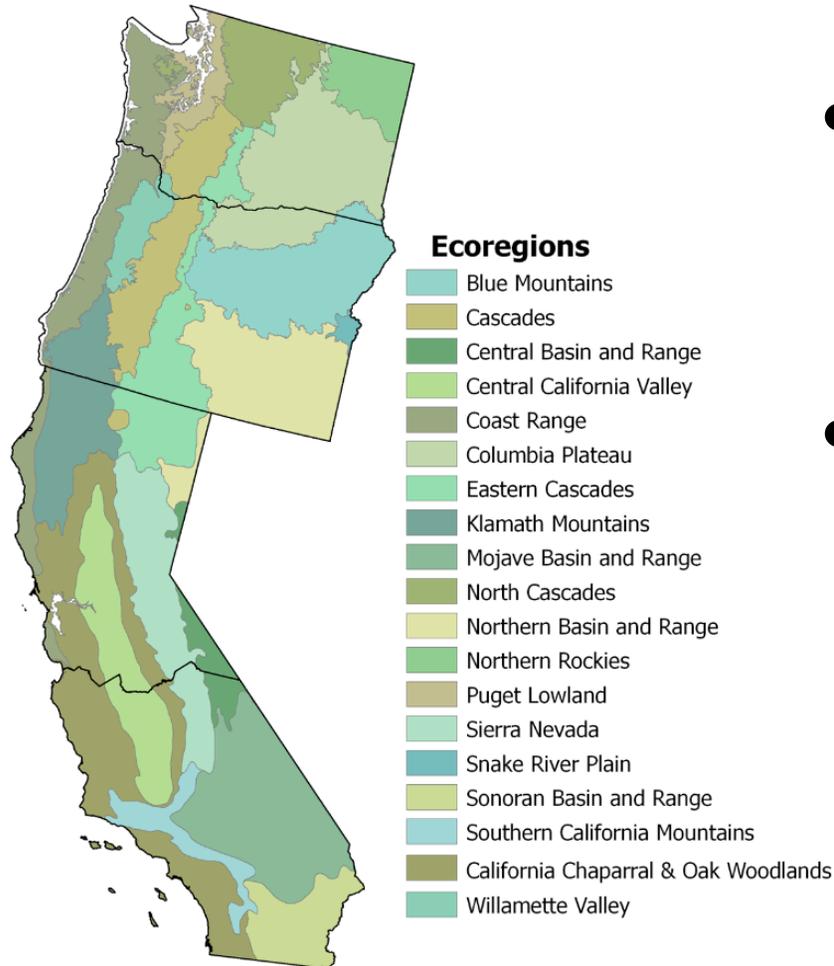
- Operationalize an algorithm
- Develop and exercise a validation protocol



Presented here:

- LandTrendr (Kennedy, Yang, Cohen)
- TimeSync (Cohen, Yang, Kennedy)

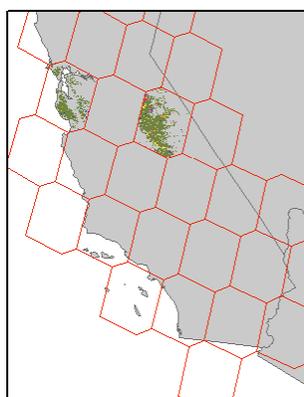
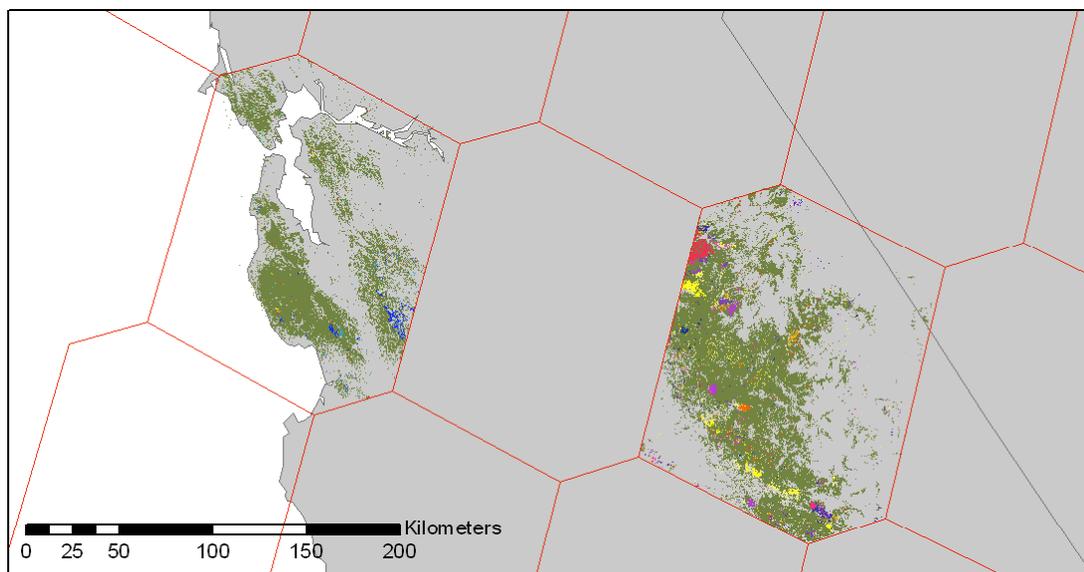
Analysis of Annual Time Series



- 54 scenes to be fully processed over three Pacific Coast states
- 2008 completion on 33 contiguous scenes
 - Develop, operationalize, and validated simultaneously

LandTrendr Disturbance Maps

- Southern California
- Annual resolution
- Forest v. non-forest mask derived by LandTrendr
- Cloud and ETM+ gaps filled as needed



First year of observed disturbance

1985	1993	2001
1986	1994	2002
1987	1995	2003
1988	1996	2004
1989	1997	2005
1990	1998	2006
1991	1999	2007
1992	2000	2008

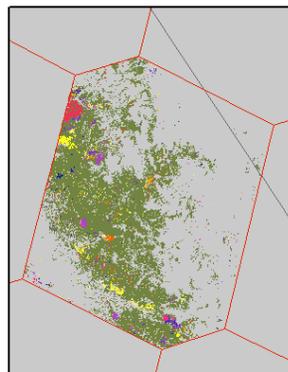
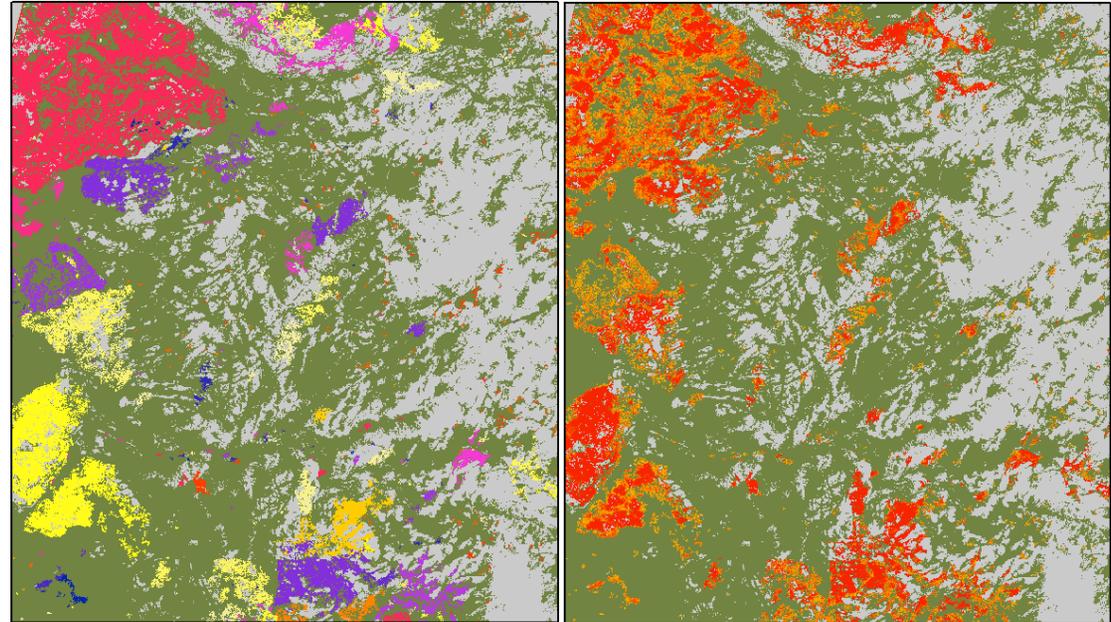


 Forest

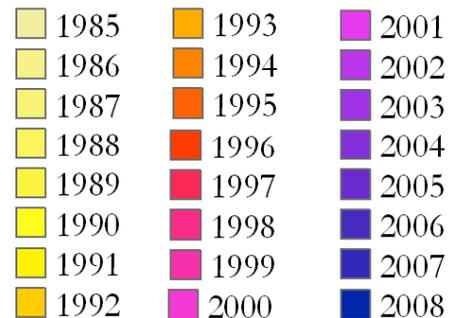
 Landsat TM
Non-overlapping
Footprints

LandTrendr: Fire in Yosemite NP

- “Abrupt” disturbances (< 3-year duration) - fire in this case
- Intensity of fire represented by percent vegetation cover loss

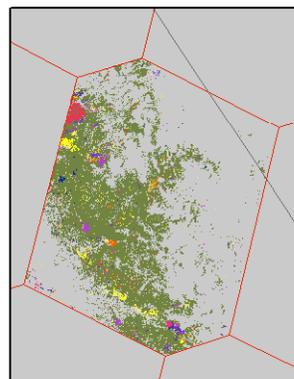
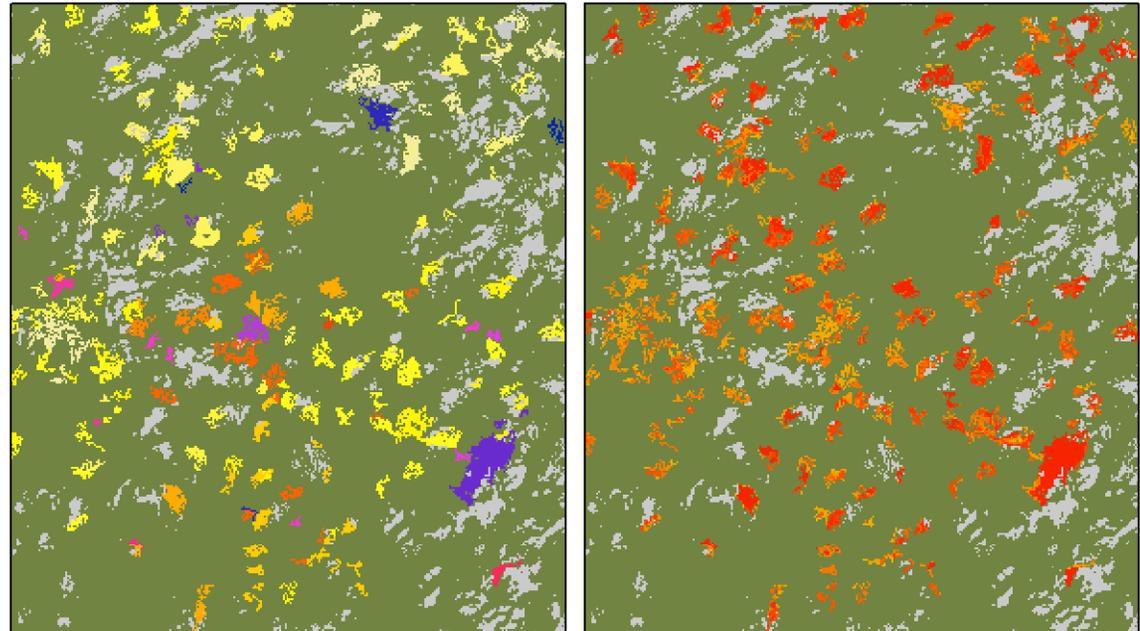


First year of observed disturbance



LandTrendr: Harvest Intensity

- “Abrupt” disturbance - harvest
- Again: Canopy cover loss as a continuous estimate
- Long-duration disturbances (e.g., insect/disease) & recovery also mapped



First year of observed disturbance

1985	1993	2001
1986	1994	2002
1987	1995	2003
1988	1996	2004
1989	1997	2005
1990	1998	2006
1991	1999	2007
1992	2000	2008



Time Series Analysis: Validation

Is it possible to find reference data to validate temporally- and spatially-rich maps?

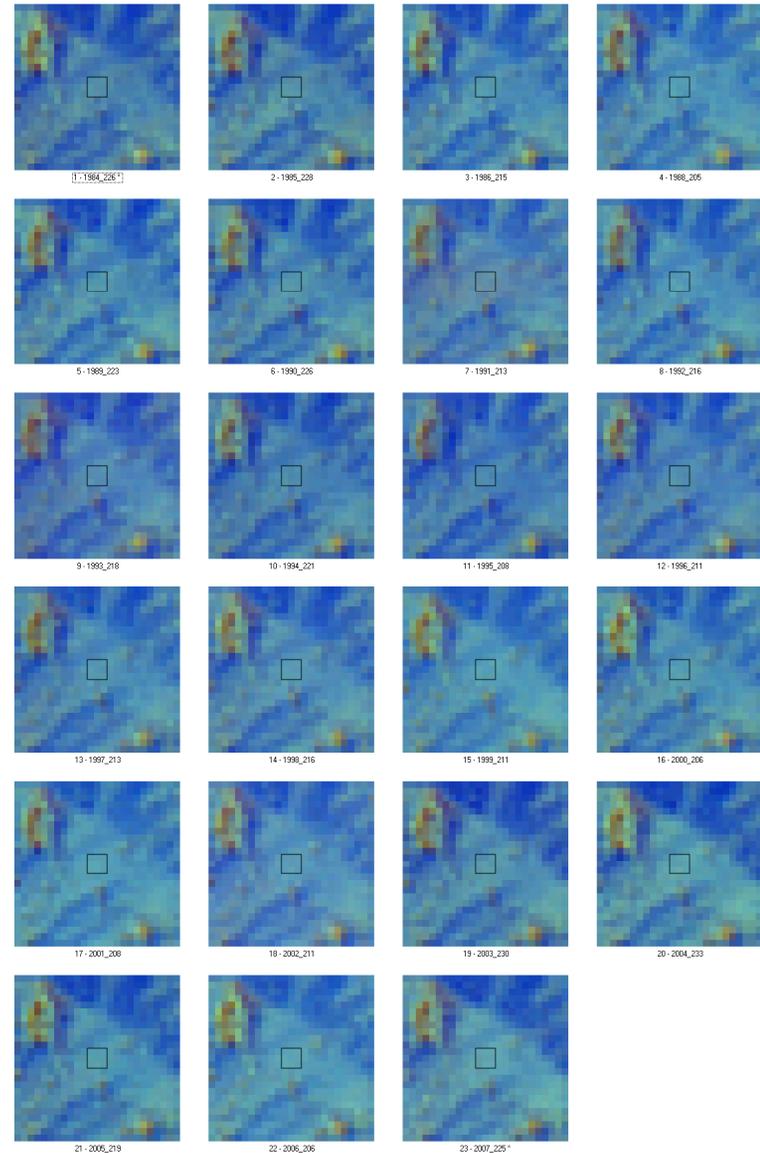
- Opportunistically, use available datasets (harvest, fire, insect outbreak records; other maps, etc) where they exist - Type 2 validation
 - But, these are limited in spatio-temporal resolution and extent, and statistical power

Time Series Analysis: Validation

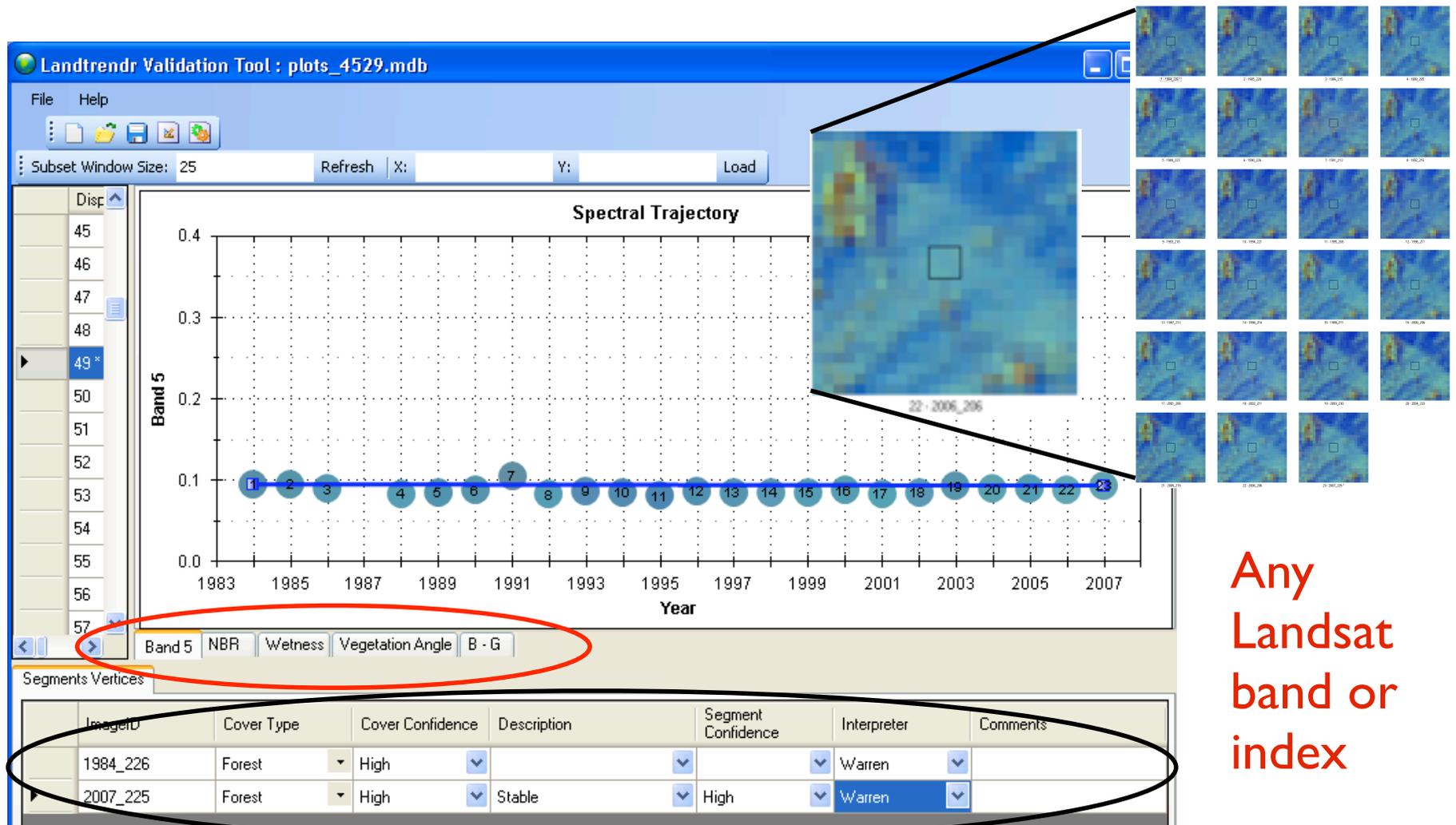
- The only dataset that captures the temporal and spatial richness of time-series maps is the times series itself - Type I validation
 - *Use of these data for validation requires novel approaches...*

TimeSync

- Syncing human and automated interpretations of Landsat time series
 - *“Enhanced” photo-interpretation of image chip series*



TimeSync: Enhancement #1

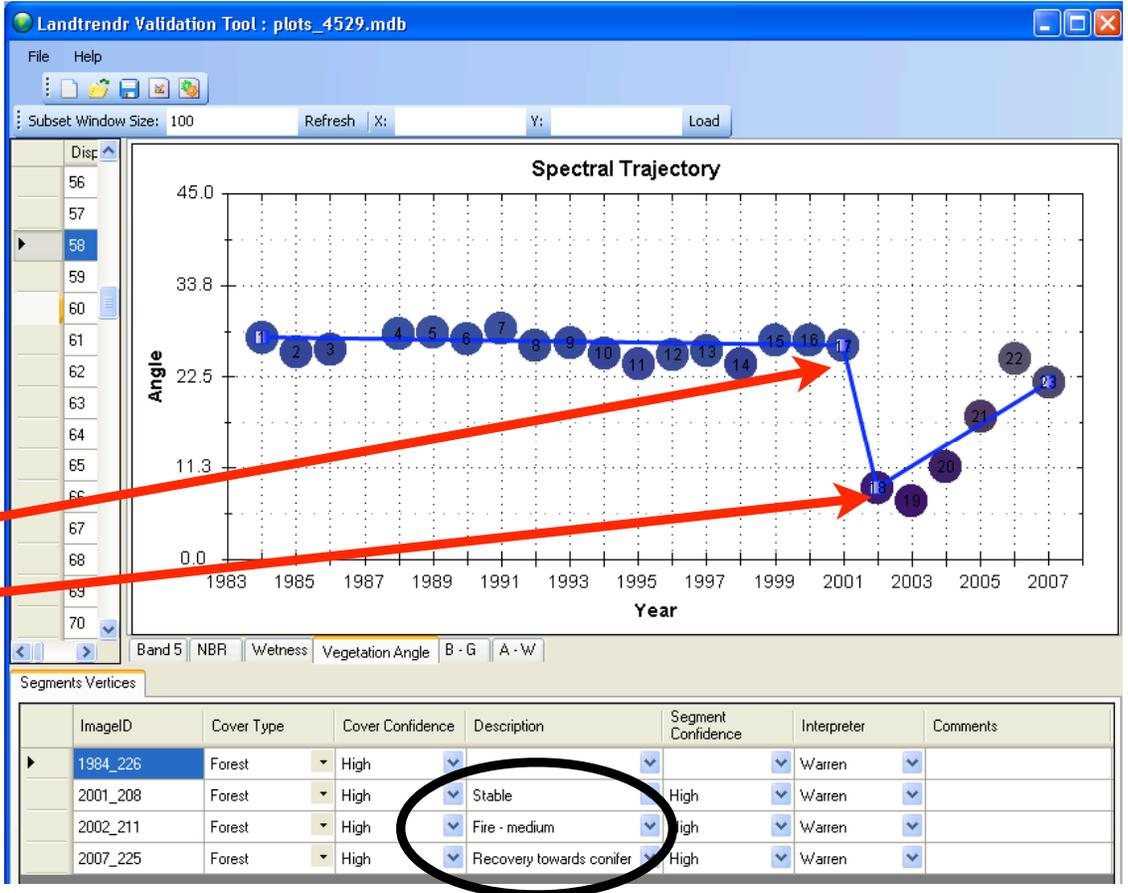
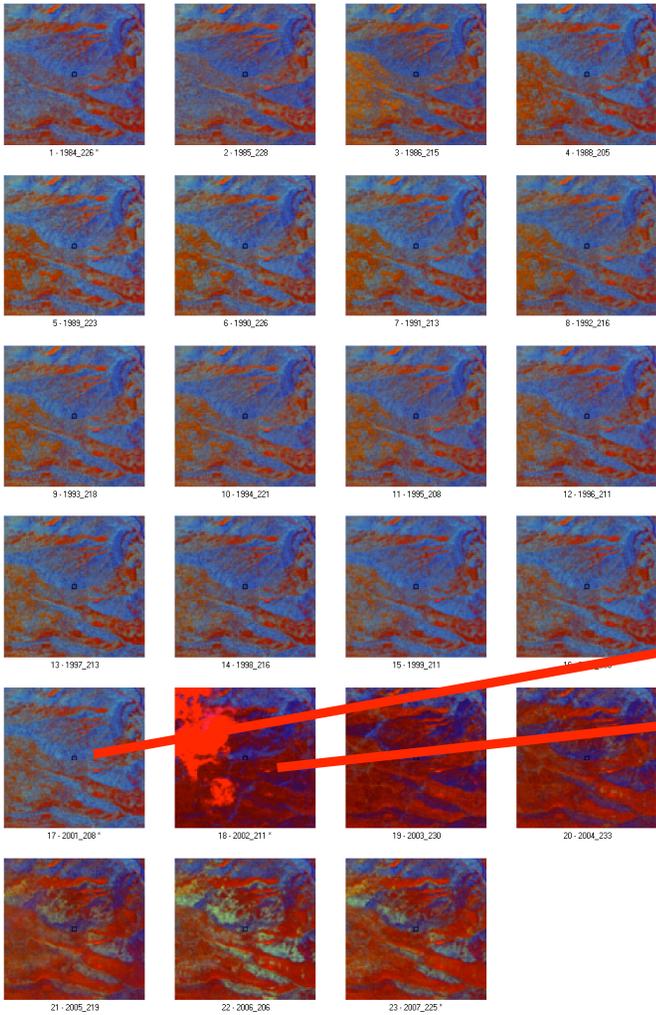


Any
Landsat
band or
index

Connected to Access database; picklists, comments

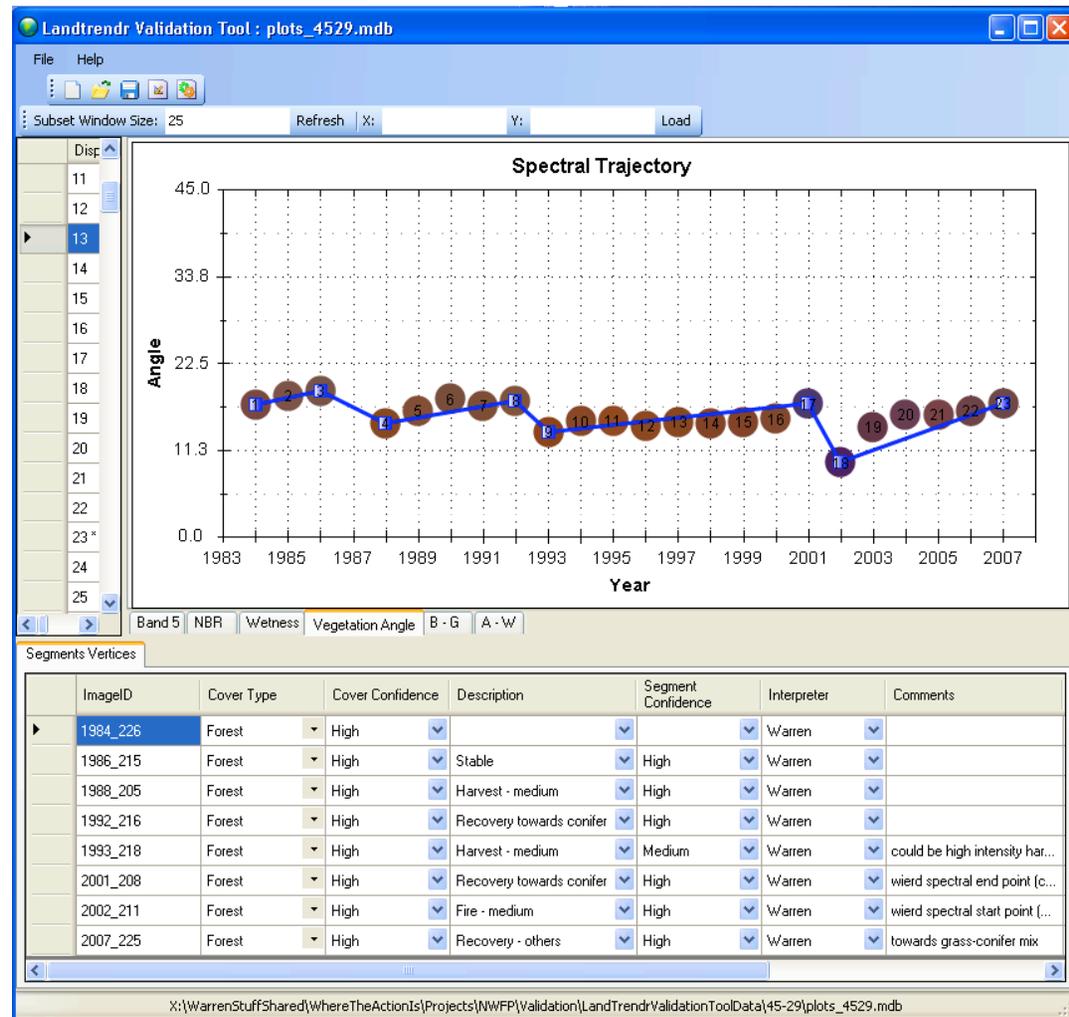
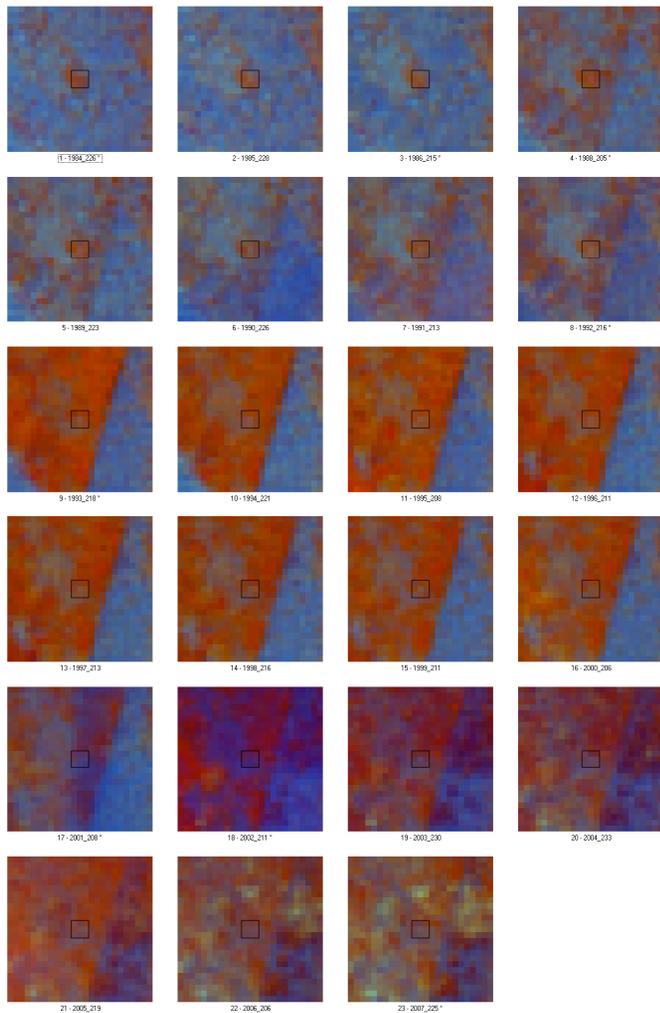
TimeSync

Stable-fire-recovery

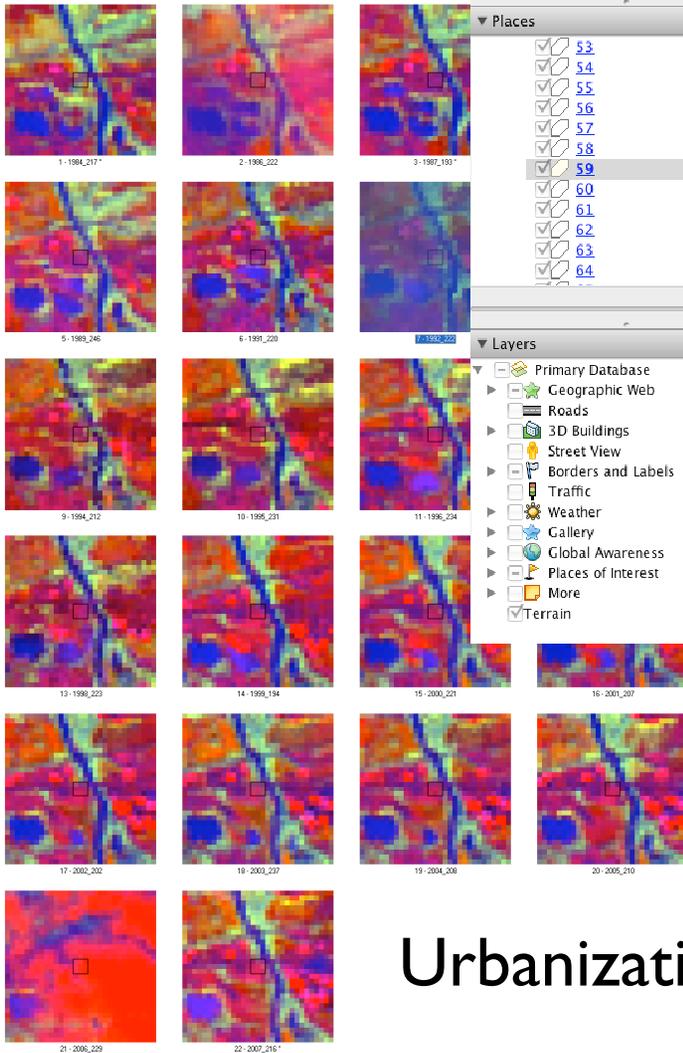


TimeSync

Partial harvest, nearly complete harvest, wildfire



Enhancement #2: Google Earth interface

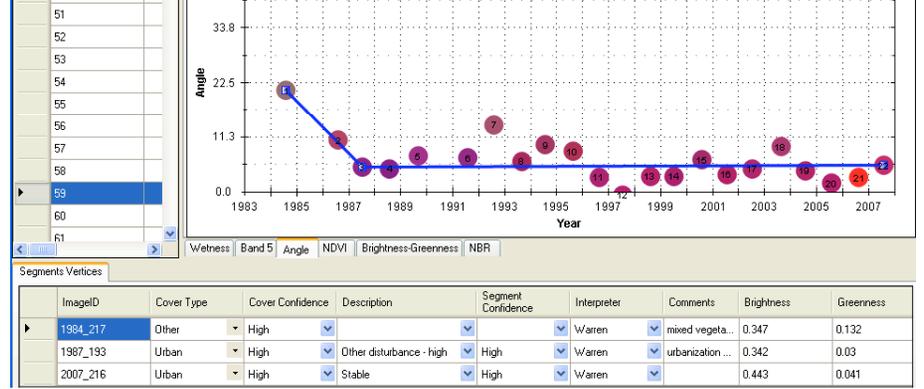


Google Earth interface components:

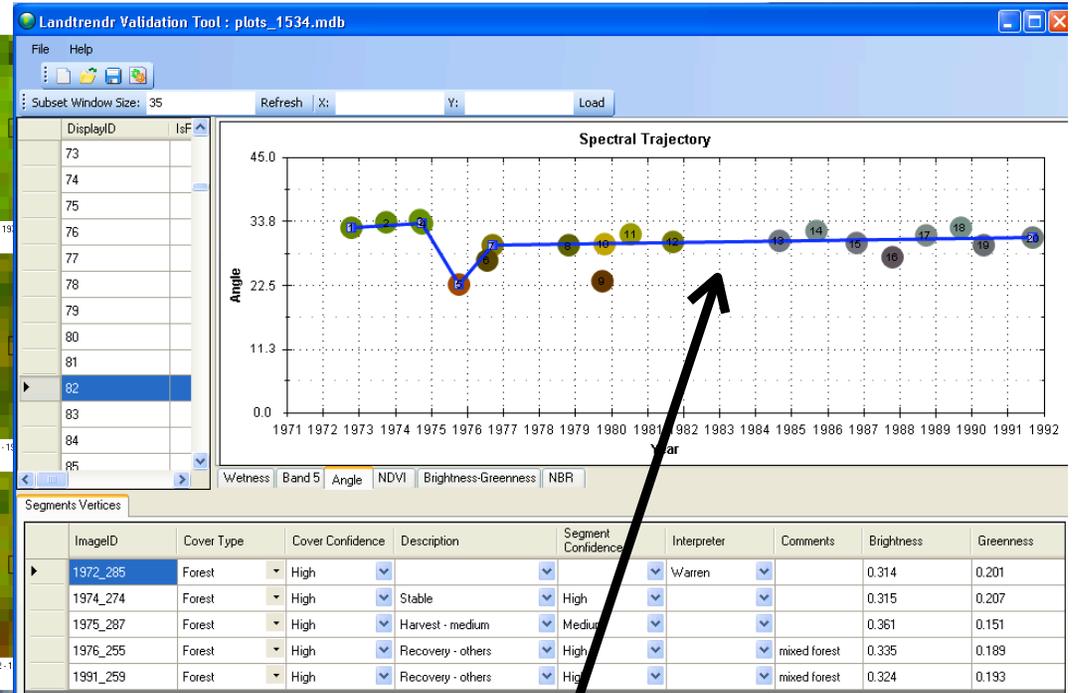
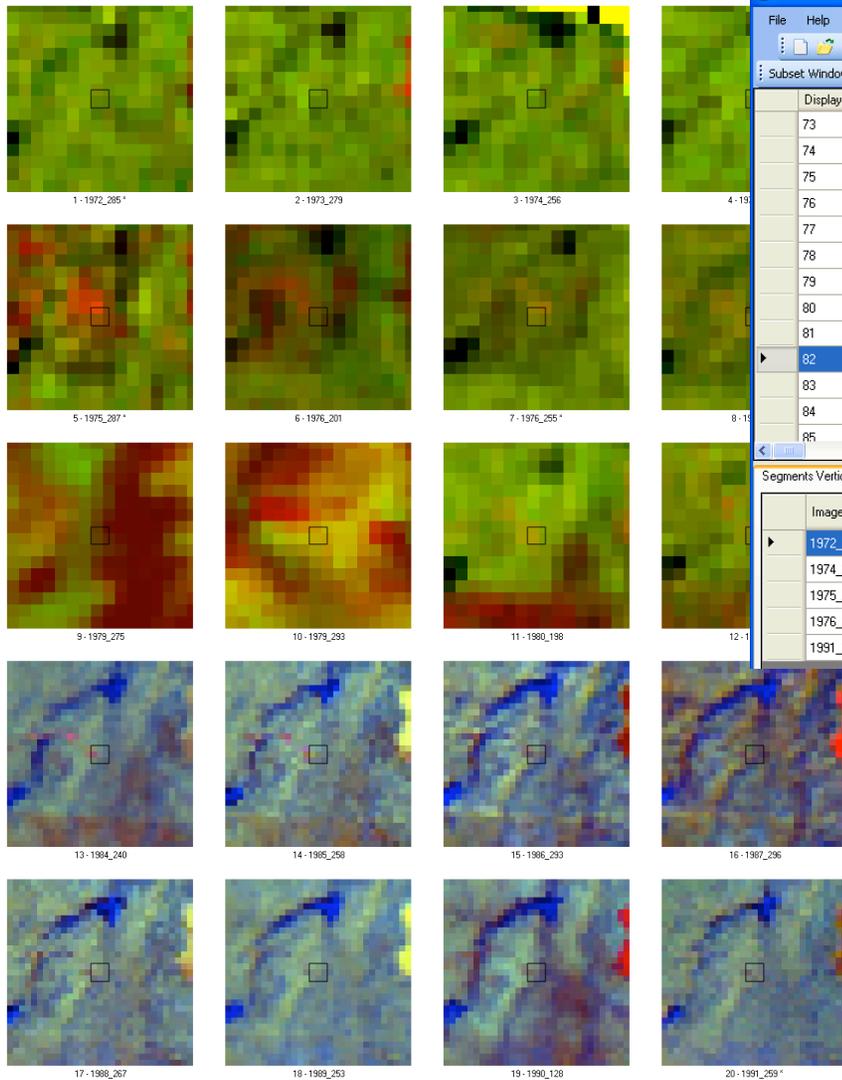
- Search:** Fly To, Find Businesses, Directions. Fly to e.g., San Francisco.
- Places:** List of places 53 through 64, with 59 selected.
- Layers:**
 - Primary Database
 - Geographic Web
 - Roads
 - 3D Buildings
 - Street View
 - Borders and Labels
 - Traffic
 - Weather
 - Gallery
 - Global Awareness
 - Places of Interest
 - More
 - Terrain



Urbanization

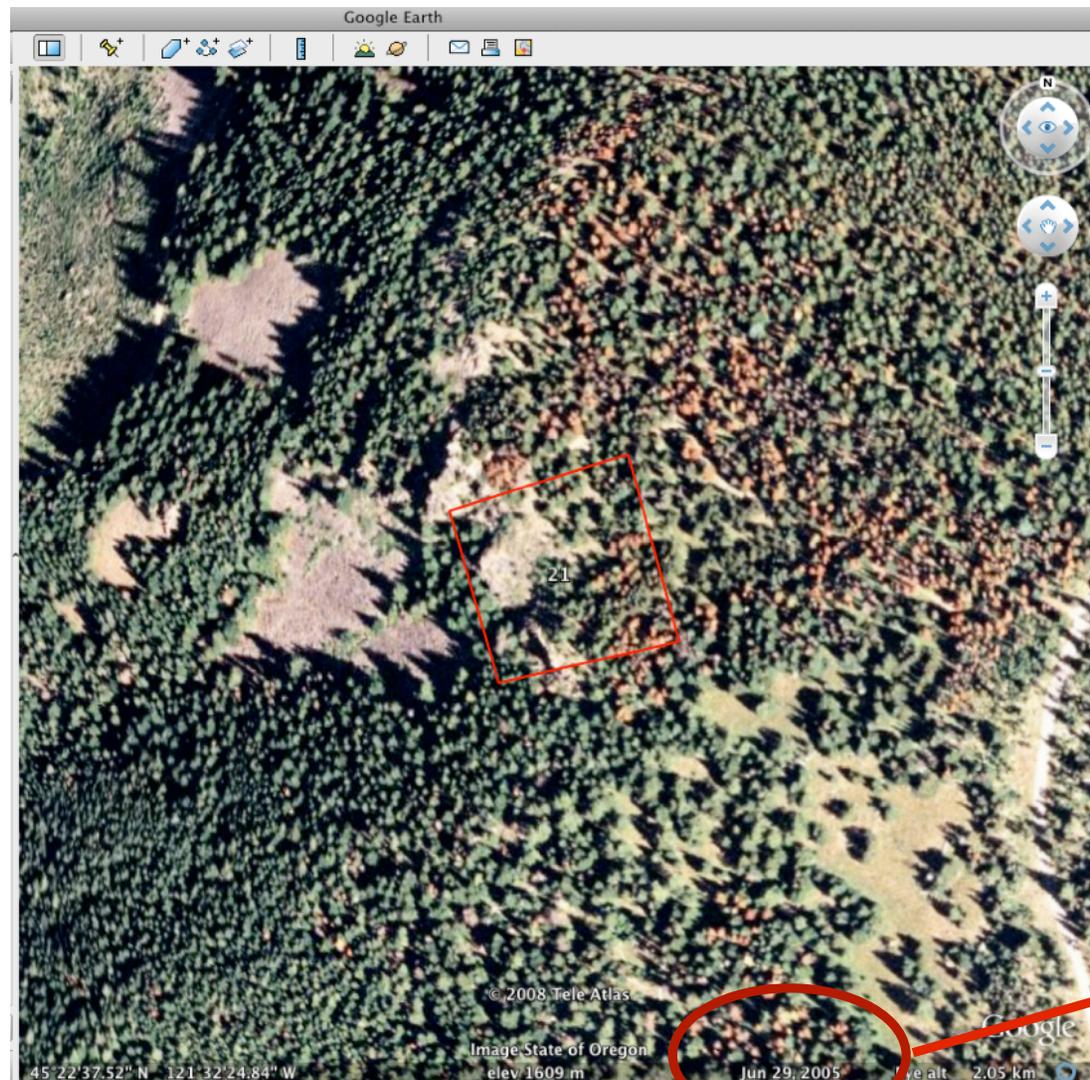


TimeSync

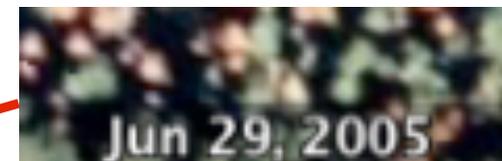


Across the MSS - TM/
ETM+ divide (TasCap
Angle)

TimeSync

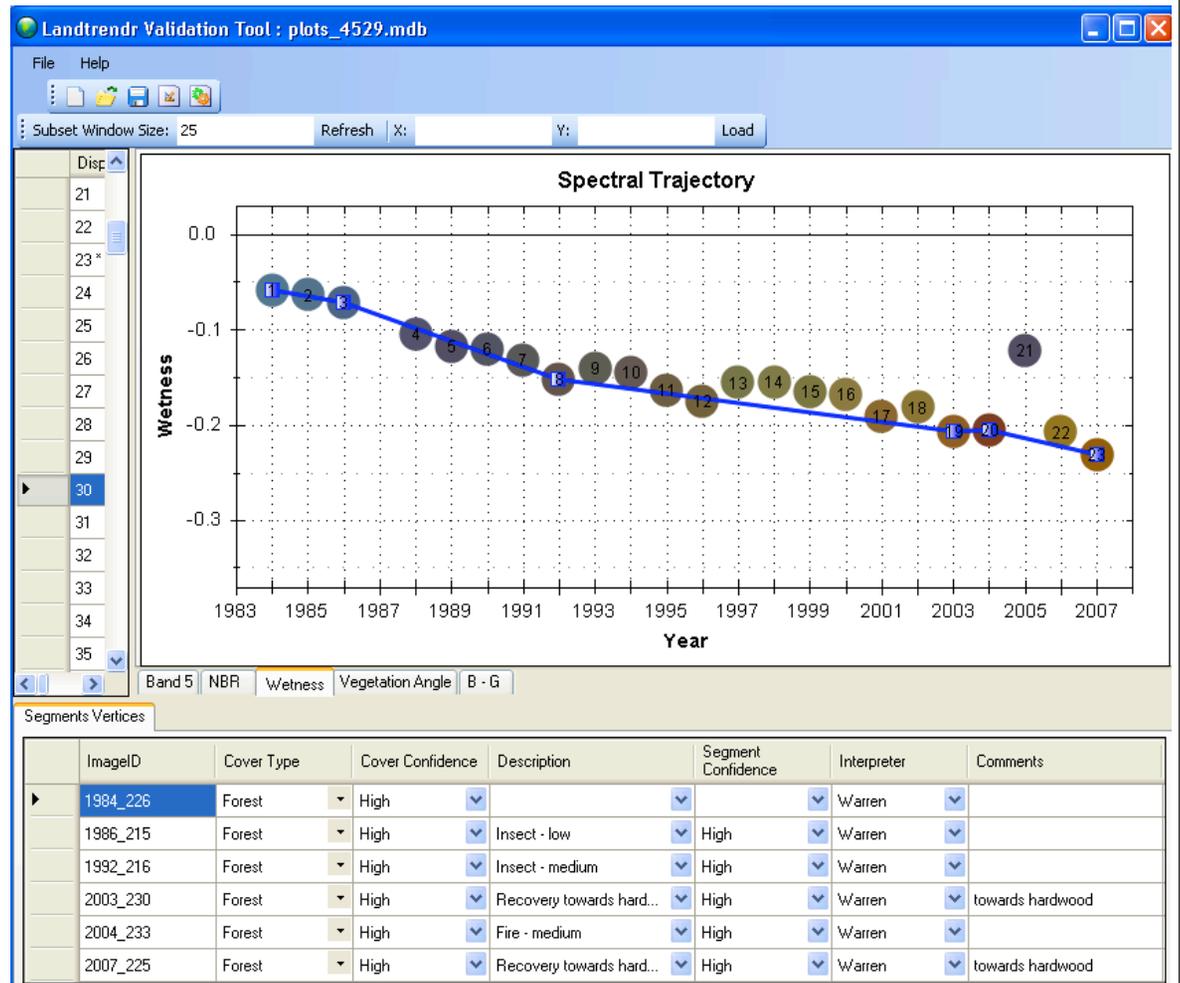
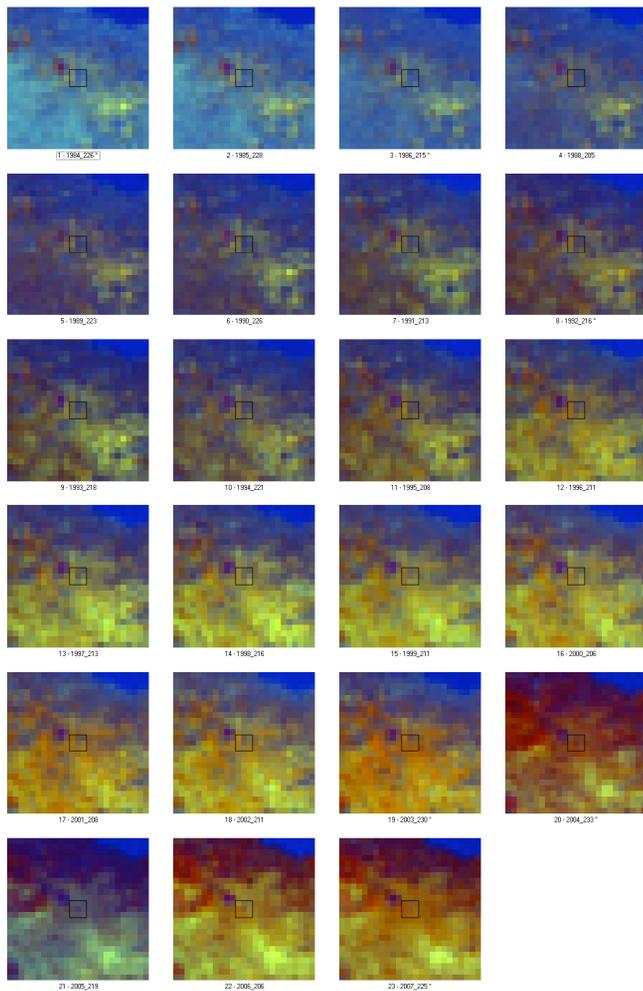


If lucky, with GE you can catch insect-related disturbance and relate that to observed long duration-subtle spectral change

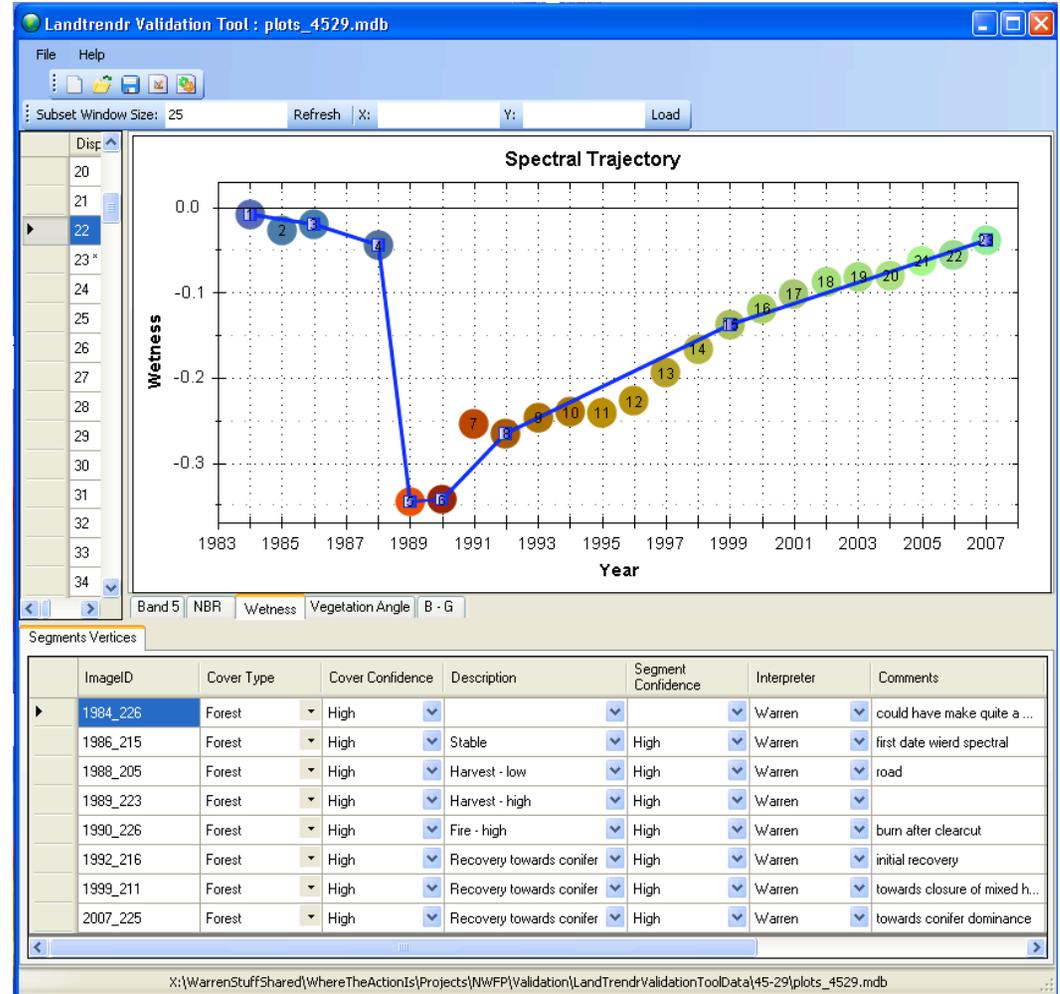
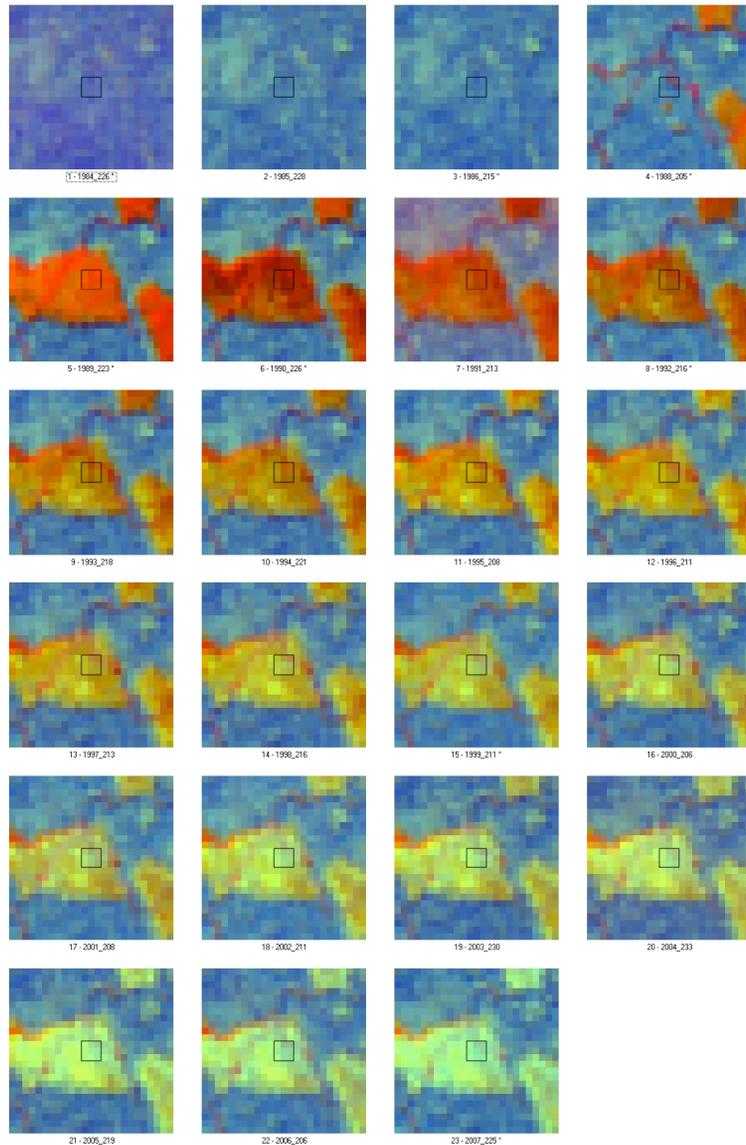


TimeSync

Insects/disease, followed by fire

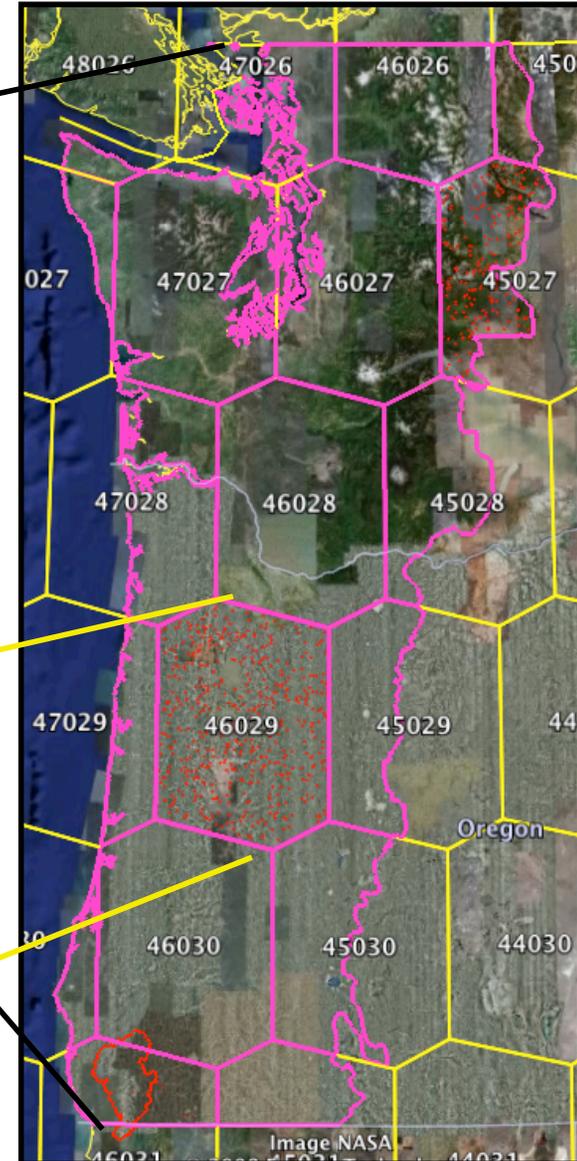
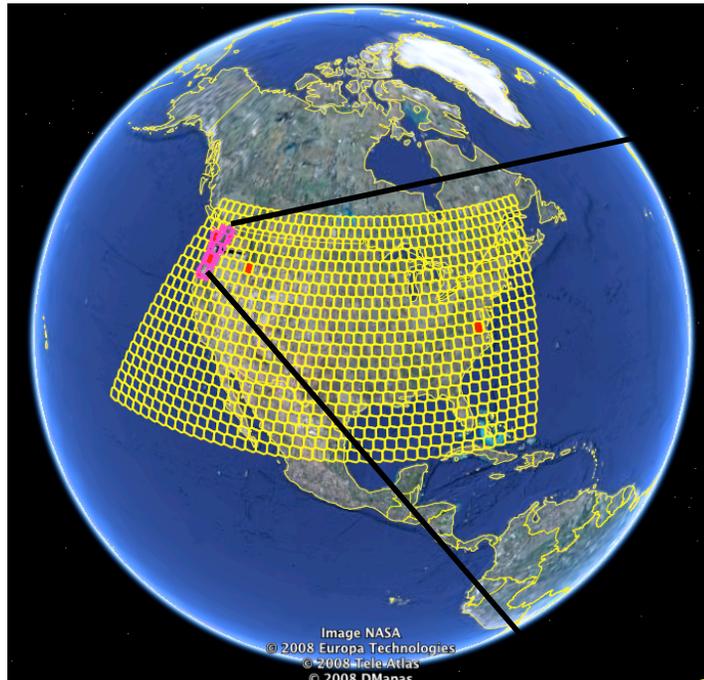


TimeSync - Recovery After Disturbance



Validation (Type I): Sampling Design.....

Google Earth interface



- Stratification by TSA
- Randomly located plot list
- Interpret ~ 200 per full TSA



Validation: TimeSync v. LandTrendr

- What is compared/summarized?
 - Disturbance & regrowth
 - Segment start date, duration
 - Summarize agreement and disagreement by TimeSync observed agent (e.g., fire, harvest, etc.) and relative intensity (L,M,H)

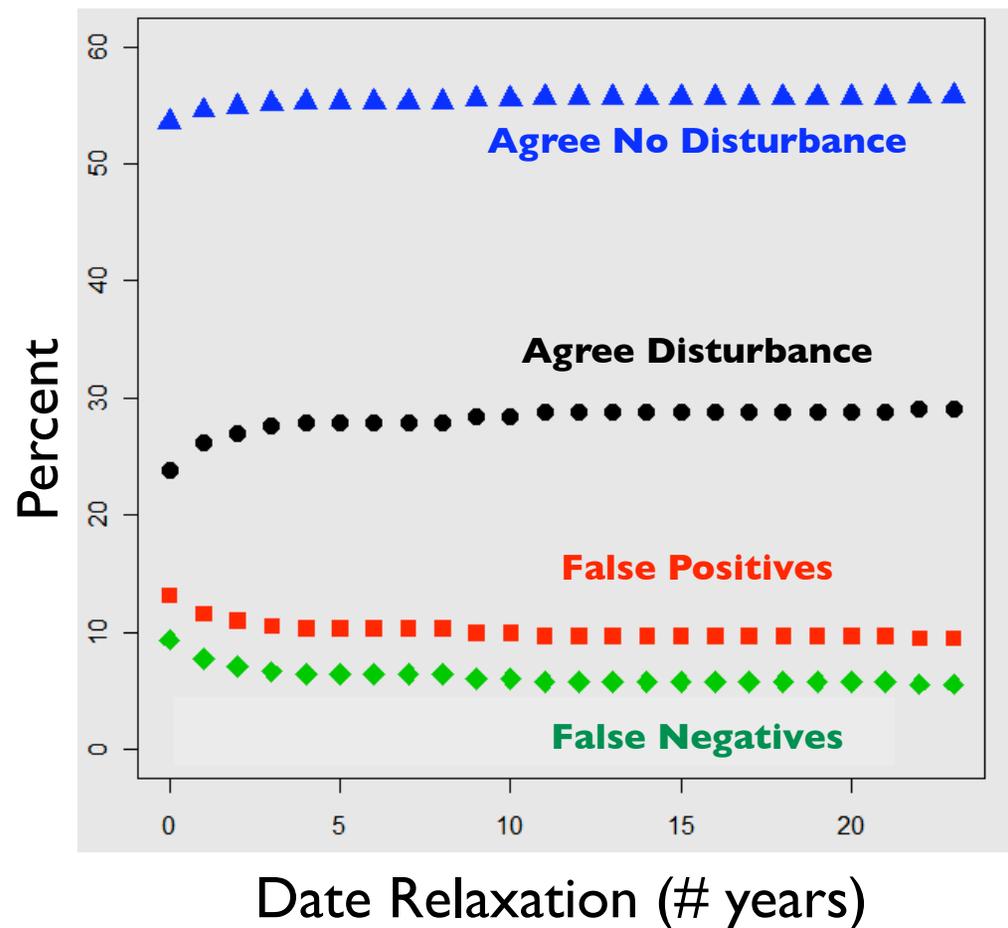
TimeSync v. LandTrendr

Fully Restricted	TimeSync	
LandTrendr	Disturbance	No Disturbance
Disturbance	107	59
No Disturbance	42	240

2-year Relaxation	TimeSync	
LandTrendr	Disturbance	No Disturbance
Disturbance	118	48
No Disturbance	31	240

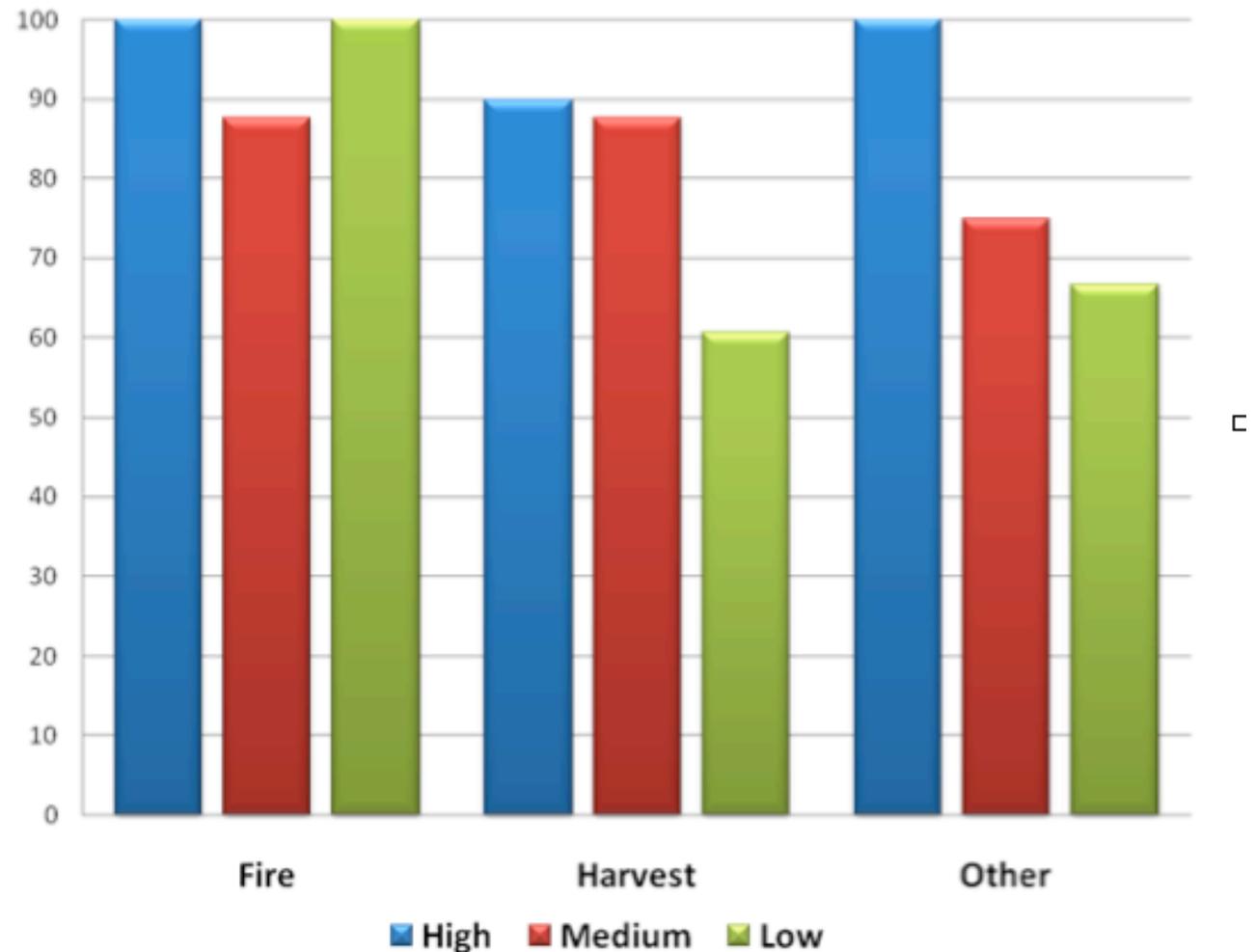
Fully Relaxed	TimeSync	
LandTrendr	Disturbance	No Disturbance
Disturbance	125	41
No Disturbance	24	240

Disturbance Only



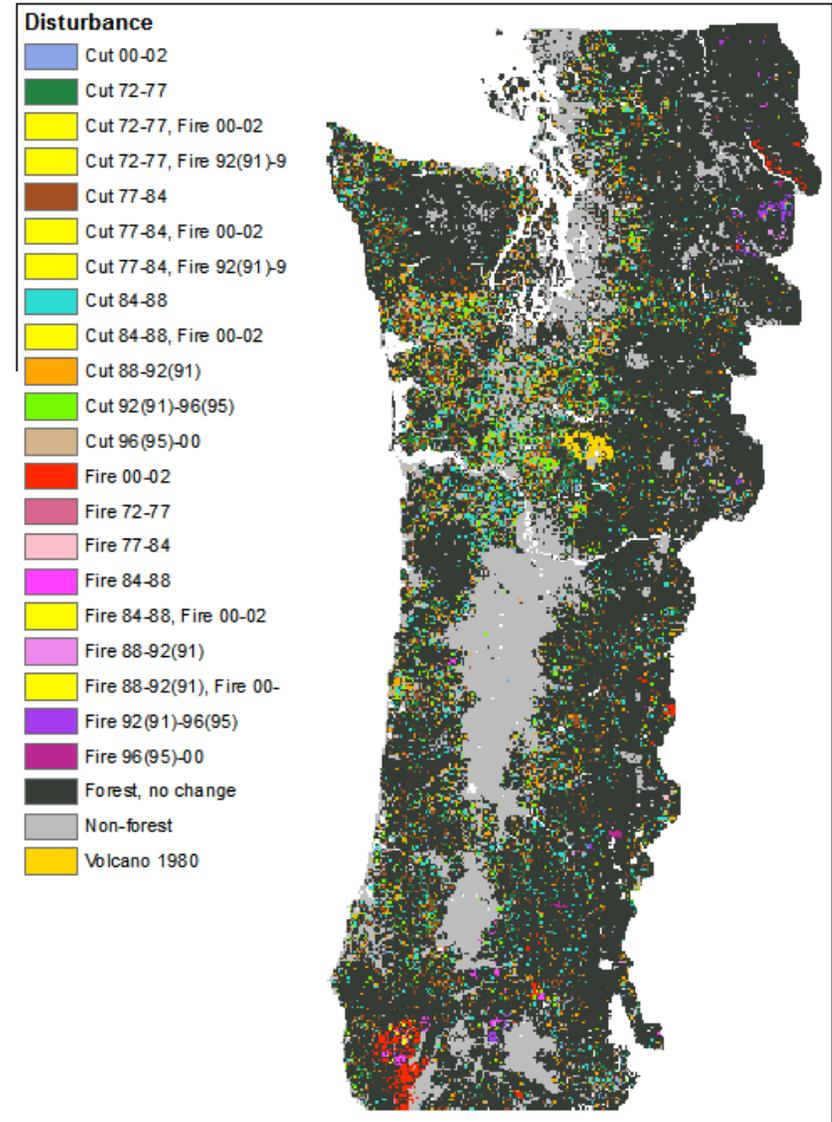
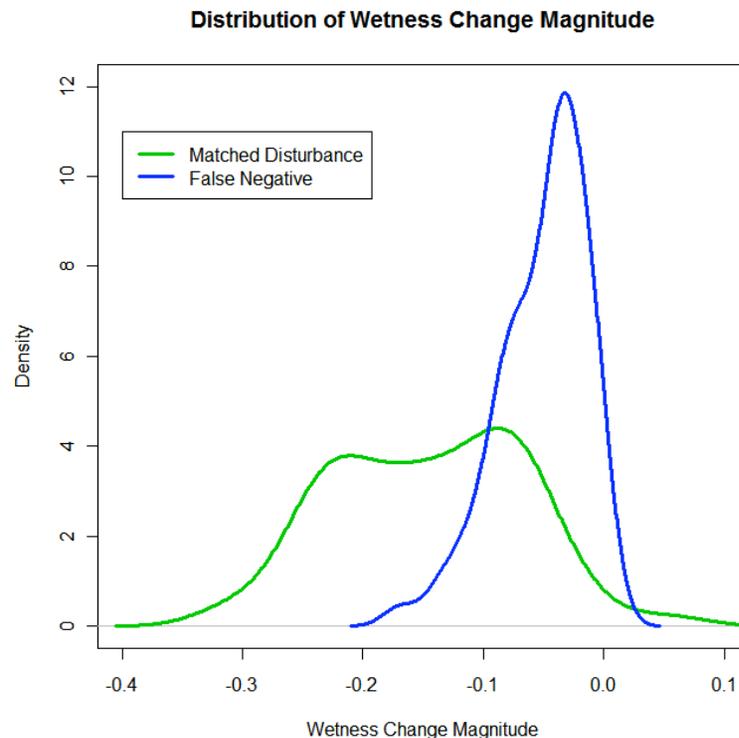
TimeSync v. LandTrendr

Percent agreement: *disturbance agent and relative intensity* (from TimeSync)



TimeSync v. Previous Map

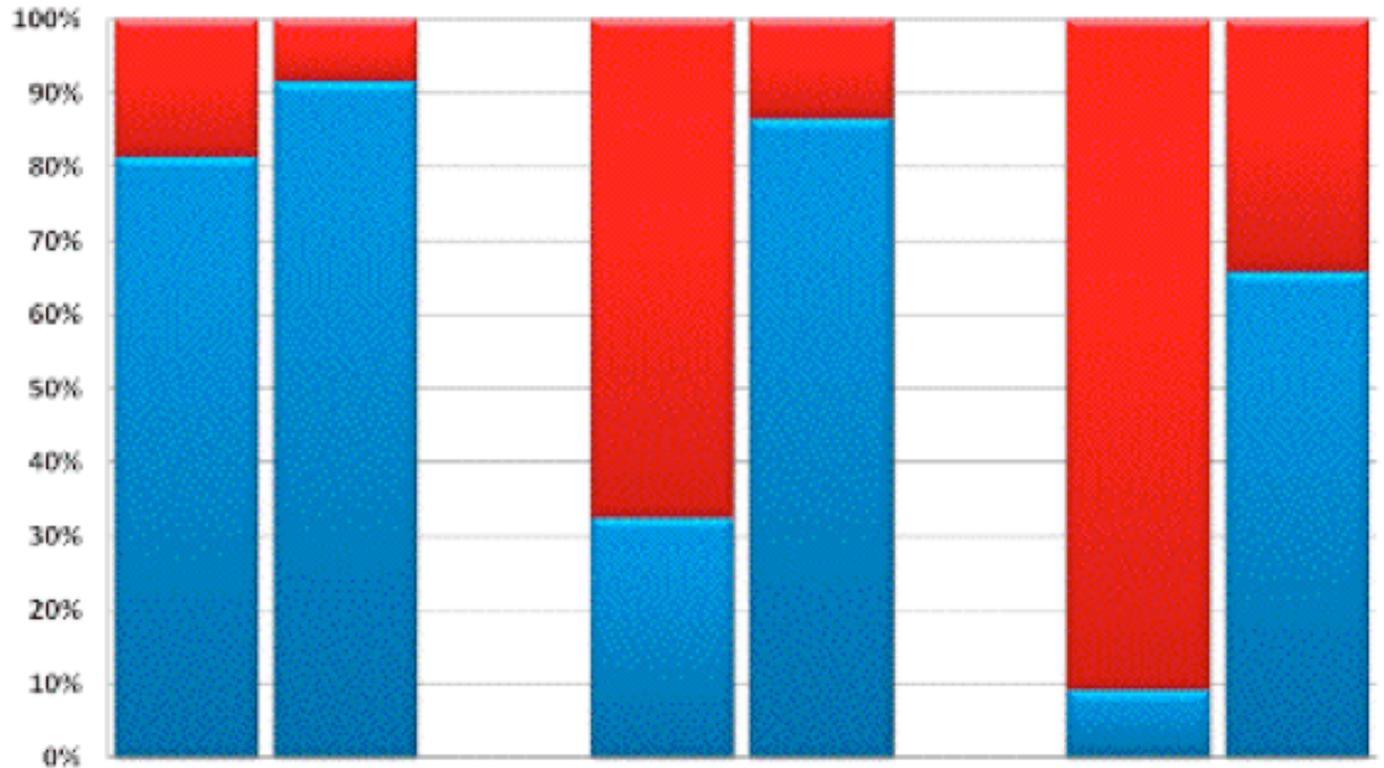
- 2–7 year interval NWFP disturbance map compared with TimeSync (1984–2002)
- Targeted only high intensity disturbance



Previous Map (PM) v. LandTrendr (LT)

■ Percent agreement with TimeSync

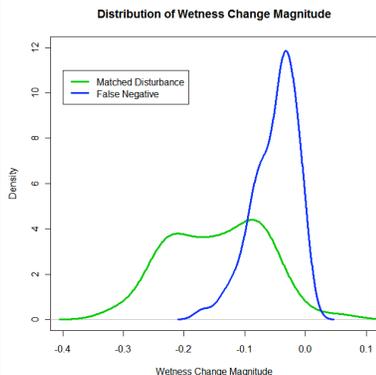
■ False negative



PM LT
High intensity disturbance

PM LT
Medium intensity disturbance

PM LT
Low intensity disturbance



Summary

- For mapping of spatially-detailed, long-term trends in forest dynamics Landsat is the sensor of choice
- Routine processing of large amounts of Landsat time series is becoming the order of the day
- This is being facilitated the opening of the US archive - international station data to follow

Summary

- Algorithms to process the data are being developed and operationalized; e.g., VCT (NAFD), LandTrendr (presented here)
- Appropriate reference data for change detection is a rare commodity
 - We can take advantages of existing, independently derived data opportunistically (Type 2 validation)
 - *And* we can use the Landsat times series itself (Type 1 validation)

Summary

- TimeSync was developed to meet the needs for Landsat time series analysis in the modern era
 - ✓ *Exploration*
 - TimeSync can be used to quickly and simply visualize what Landsat time series are capable of detecting
 - ✓ *Calibration*
 - TimeSync can help determine how well an algorithm is working

Summary

✓ *Validation*

- TimeSync can provide a statistically valid and inexpensive means for validating maps derived from Landsat time series
- Opportunistic use of independent datasets supports the validation as always; i.e., nothing is lost

Thank you!
Questions?

