Quantifying disturbance to forest structure with optical, LiDAR, and SAR remote sensing

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- Fused satellite imagery extracting the strengths of each individual sensor helps support operational disturbance monitoring; operational tool feasible and cost effective, especially for large area
- Tradeoffs between spatial and temporal resolution are key for assessment; cross pol L-band SAR term shown to be most useful for mapping structural attributes

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http://www.nsrcforest.org

Project Summary

Disturbance (such as wind, ice storms, disease, pollutants, climate change, and insect infestation) is a frequent occurrence in northern forest ecosystems. Timely and accurate assessment of disturbance events is critical for land managers to respond effectively and appropriately. In addition, assessing the severity of disturbance (*e.g.* magnitude of biomass and vertical structure change) is critical for broad-scale management and policy. Many of these disturbances produce partial canopy damage, so they can be challenging to detect and quantify using conventional optical remote sensing techniques.

New satellite remote sensing technologies such as synthetic aperture radar (SAR) and LiDAR, when combined with optical imagery, hold the potential to be able to identify disturbance and quantify its ecological effects more precisely than with optical imagery alone. We combined field-collected forest structural metrics with remotely sensed imagery to design and evaluate a blueprint operational image analysis system. Our specific objectives were (1) to design and evaluate a feasible approach for multi-scale, multi-sensor detection and mapping of forest disturbance, (2) to carry out a field campaign to collect calibration data from disturbance-impacted forests, (3) to assess the impact of disturbance events on forest attributes, (4) to evaluate our ability to characterize wide-ranging disturbance events using alternative remote sensing technologies, and (5) develop a blue print for an operational image processing approach that could be used in an operational context. End products include our field metric database (open access), regional maps of forest type, biomass, and canopy fractional cover, as well as higher resolution products at numerous case study areas within the study region.

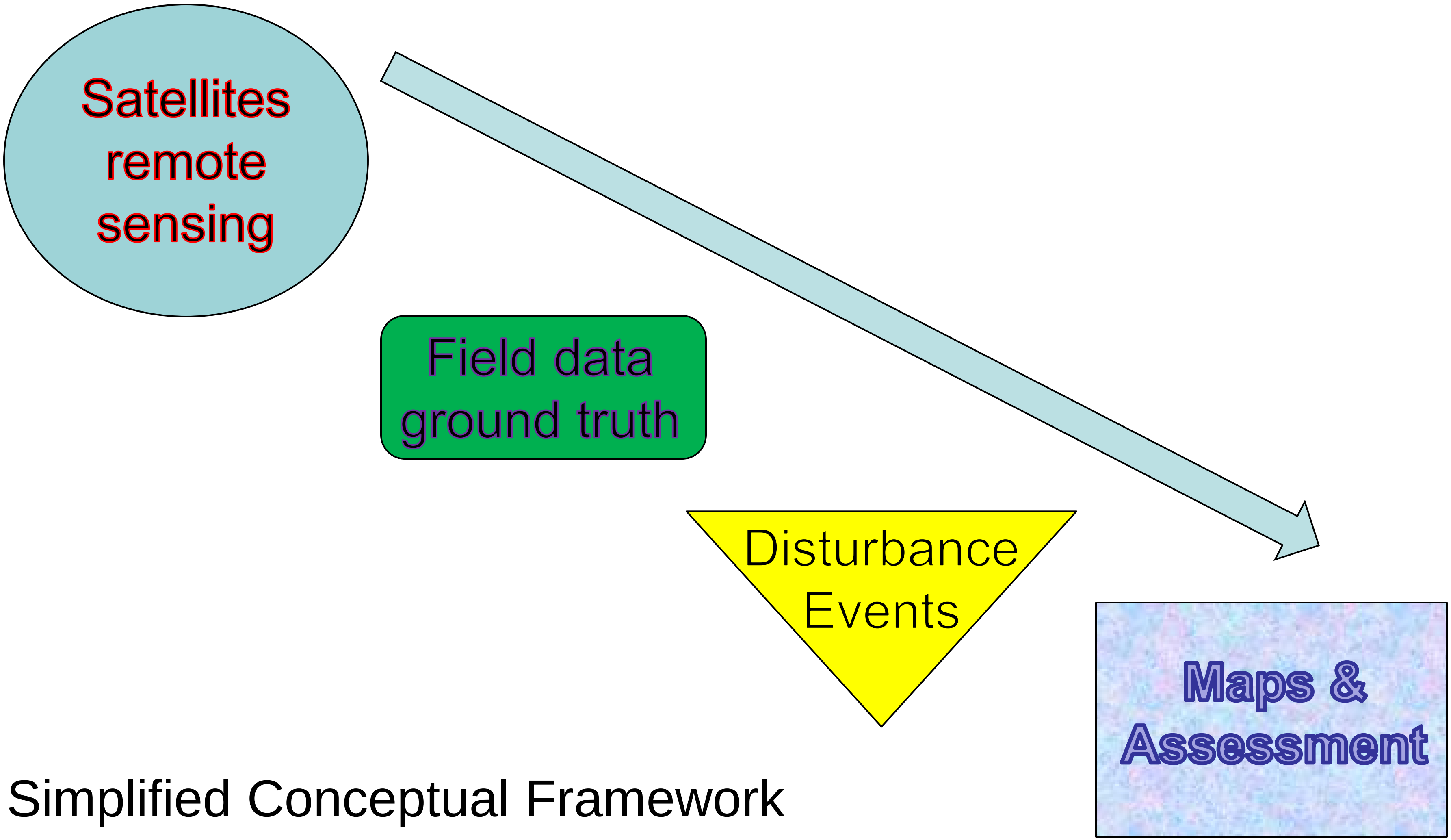
Background and Justification

- Disturbance is a frequent occurrence in forest ecosystems
- Timely and accurate assessment of disturbance events is critical for many end user groups
- Assessing the severity and understanding the scales of disturbance is critical for broad-scale management, policy, and economic decision-making
- Current mapping approaches provide limited information on forest structure
- Structural properties of forests are closely linked with ecosystem functioning

Objectives

- Evaluate and fuse multi-scale satellite remote sensing data for mapping disturbance
- Carry out a field campaign to collect calibration data from disturbance-impacted forests
- Assess the impact of disturbance events on forest attributes
- Evaluate ability to characterize ranging disturbance events with imagery
- Develop blue print for operational system and work with end users to implement monitoring

Approach

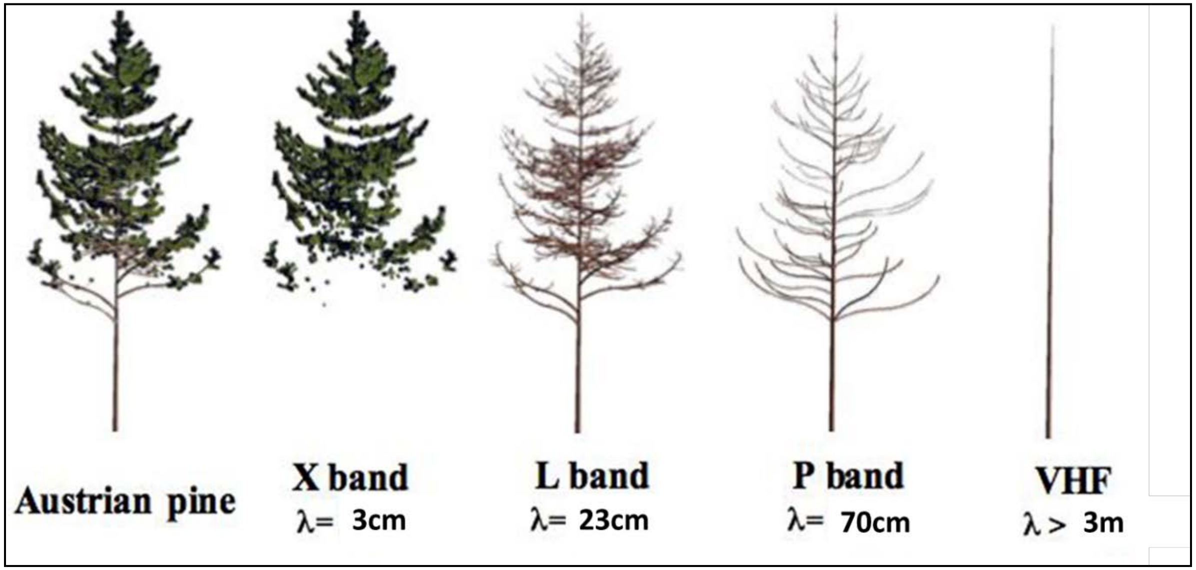


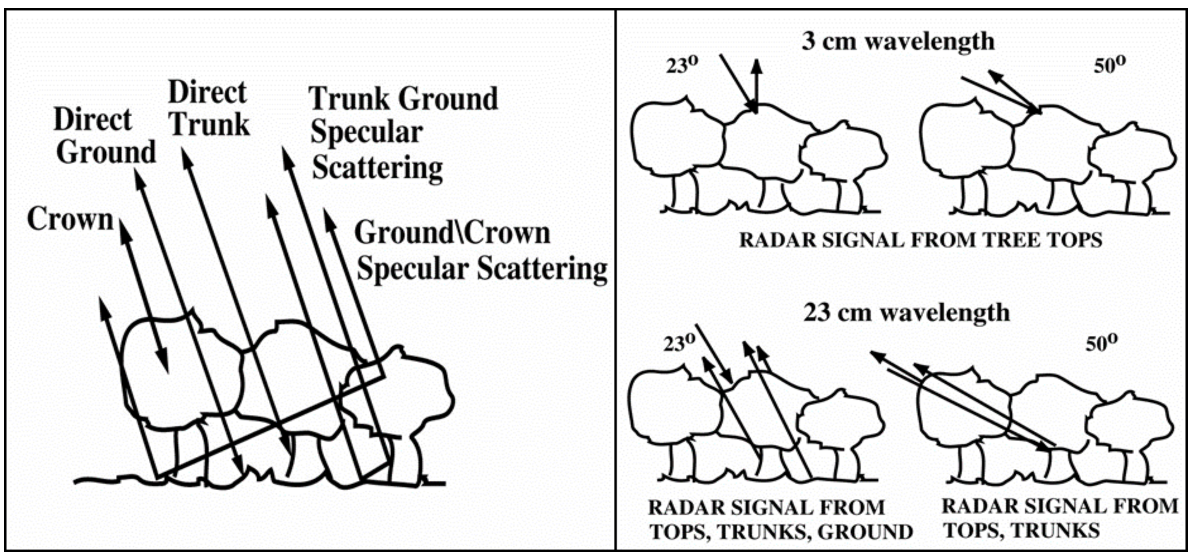
Simplified Conceptual Framework

Satellite Remote Sensing Platforms

- ❑ Obtain, process, and analyze selected remote sensing data
- ❑ Scales are key: spectral bands, spatial resolution, temporal frequency,
- ❑ We evaluated multiple satellites:
  - o Landsat 5 TM & 7ETM+
    - ❖ 8-day intervals, 30m spatial, 180km swath, broad vis-nir channels
    - ❖ 1972 – present with Landsat MSS
  - o ALOS-1 PALSAR
    - ❖ JAXA platform, L-band, fine-beam single (hh), dual (hh:hv), and quad polarimetric (hh:hv:vh:vv); FB 6.25m – 24m; WideBeam 100m
  - o MODIS
    - ❖ high temporal frequency, optical bands, 250m+ spatial, large area, 2001-present
  - o IceSAT GLAS
    - ❖ Satellite LiDAR, sporadic footprints ~75m, circa 2008

Why integrate L-band SAR for forest monitoring?





Illustrated is wavelength, penetration, and sensitivity to Austrian pine and scattering mechanisms and viewing geometry relationships.

Ground truth field data

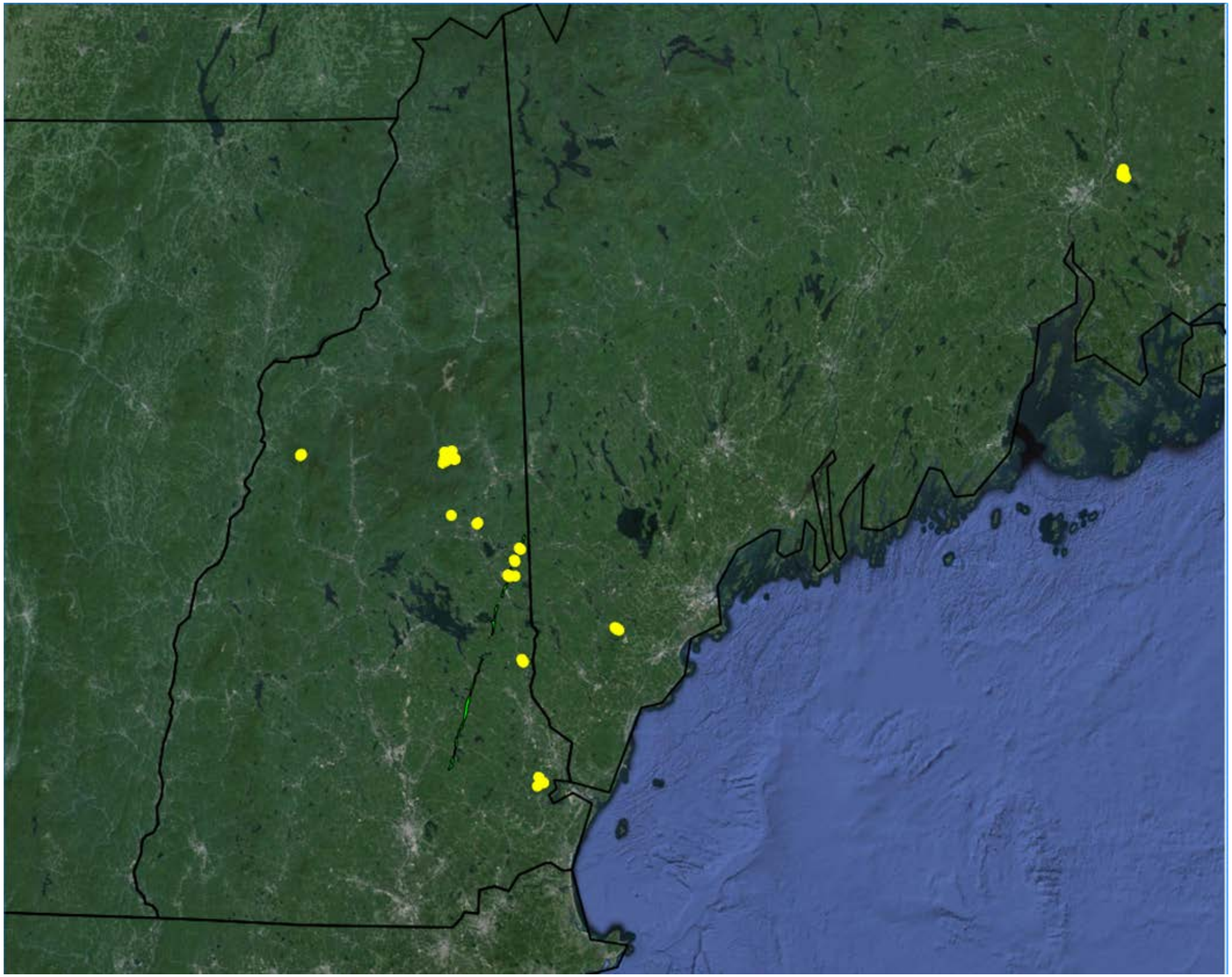
- Collect ground truth then calibrate and validate data
- Paired disturbance and adjacent reference sites across NH, ME
    - Focused on Defoliation, Windthrow, Tornado Damage, Forest Harvesting
- Additional reference sites to capture range of potential variation in canopy structure
- Georeferenced field photos and data available at open source web site

Field protocol

- Systematic, georeferenced cluster of sample points matched to moderate-resolution pixel spacing
- Overstory characteristics (species composition, basal area, biomass, height, crown structure)
- Understory and downed necromass
- Quantify recent mortality/harvest
- Photogrammetry and laser quadrat sampling for horizontal and vertical canopy structure and density

NSRC Field Sites 2011

- Field data available on web-GIS and with request to PI



Landsat and PALSAR approach

- Built scripts to automatically pre-process Landsat
  - Surface reflectance using 6S with MODIS AOD
  - Cloud masks with FMASK
  - Thermal with MODTRAN 5.2

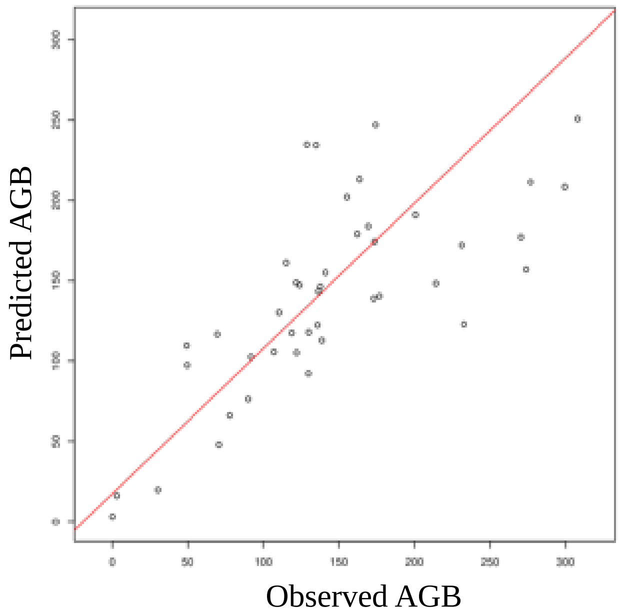
- Pre-process PALSAR with operational technique
  - Fine-beam single, dual, and quad polarization
  - SLC – sigma nought ($\sigma°$ dB)
  - Terrain geocode with DEM following range-Doppler

- Execute data mining routines
  - Identify optimal bands
  - Evaluate accuracy and performance
  - Build empirical regression models for attributes to map

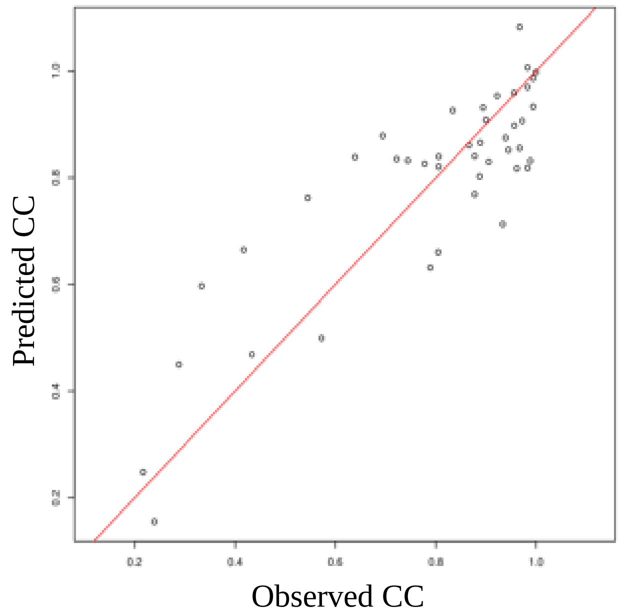
Landsat and PALSAR approach

- Mapping attributes calibrated with field ground truth

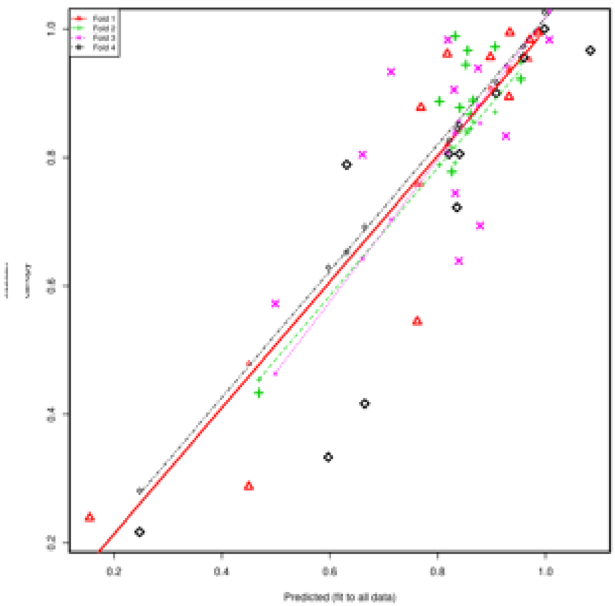
Biomass



Canopy Cover



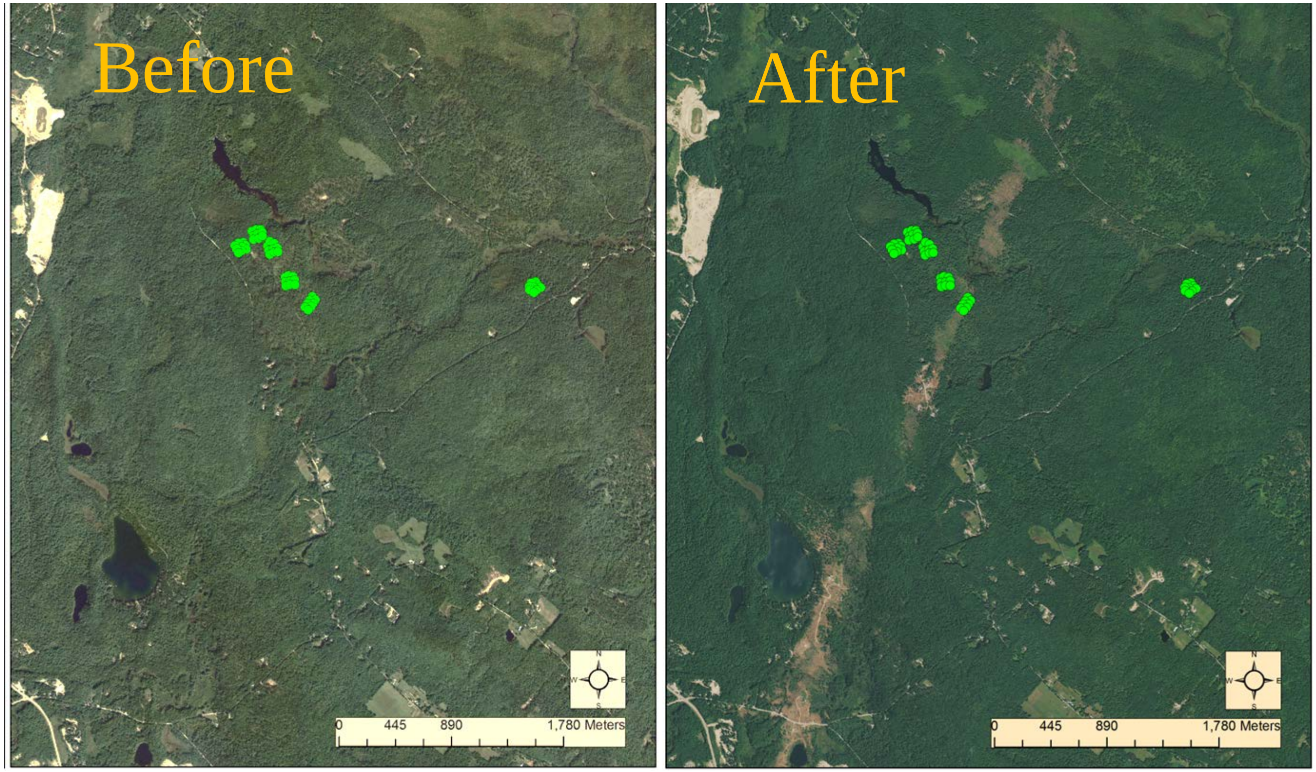
Canopy Cross Validation Illustration



- Scatterplots of observed vs predicted values of AGB (left) and CC (middle)
- Fused PALSAR HV data combined with Landsat SWIR was advantageous
- Cross validated out of sample n-folds highlighting rigorous results across diverse sites (right).

Tornado Case Study (July 2008)

Before and after true-color NAIP highlights tornado path across portion of Carroll County, NH; green dots show field data sites



Carroll County (NH) Tornado Analysis

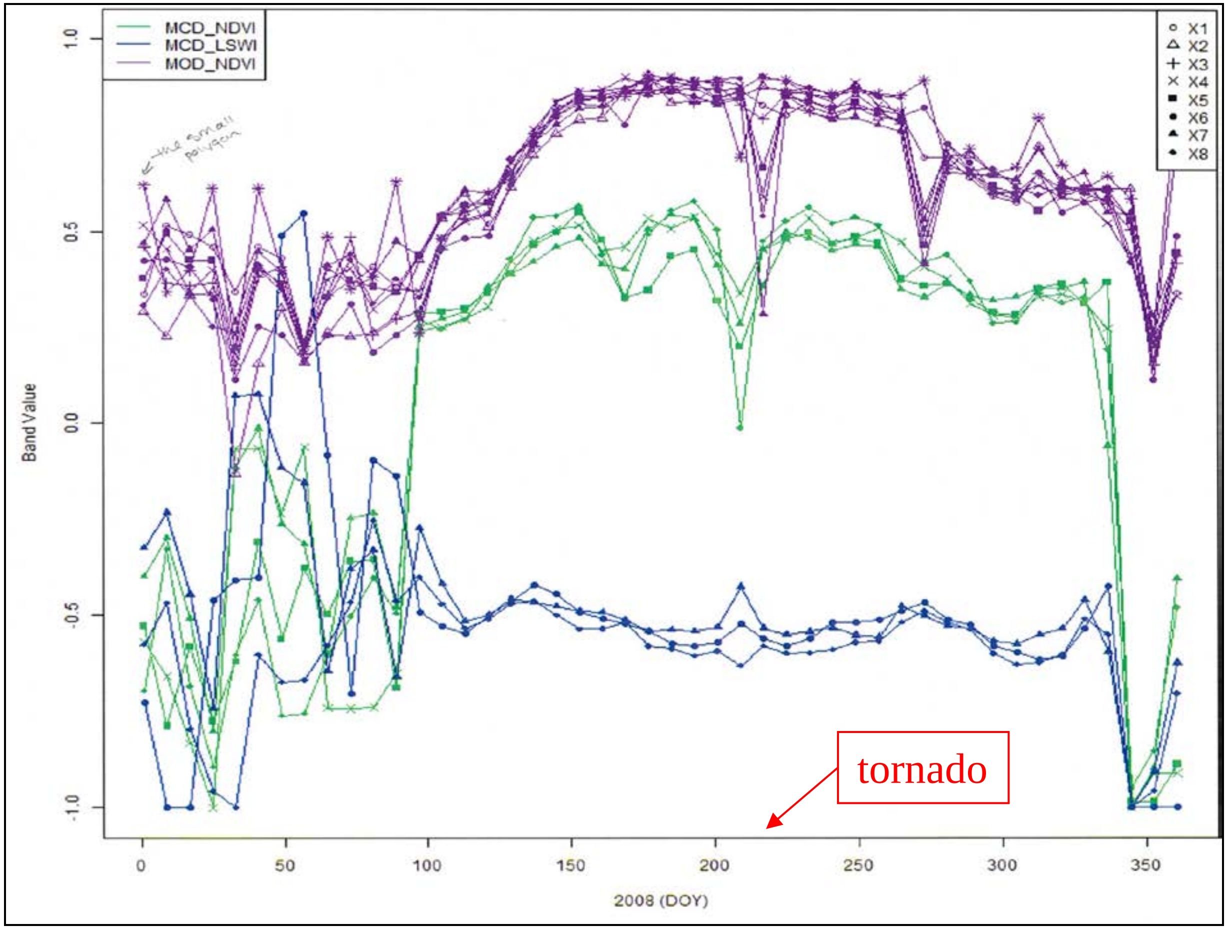
- 2500+ hectares modest canopy damage
- 1410 hectares severe (>50%) damage
  - mean AGB loss ~114 Mg / ha in path
- Total AGB loss in Carroll County from July 2008 tornado ~298,250 Mg

MODIS Disturbance Index

- Data sources:
  - MOD09Q1 8-day 250-m red & NIR reflectance
  - MCD43A4 8-day 500-m nadir-adjusted visible & NIR reflectance
- In simple terms, automatically look for phenological events" or shifts in indices
- Algorithm:
  - Focused on NDVI from MOD09; and NDVI, LSWI, and EVI from MCD43
  - Calculate annual integrated vegetation index anomaly accumulated below cutoff threshold (disturbance index) for each VI
  - Map gridded disturbance indices over area of interest
- Computational considerations:
  - Multithreading allowed for fast extraction and analysis of 10 year time series

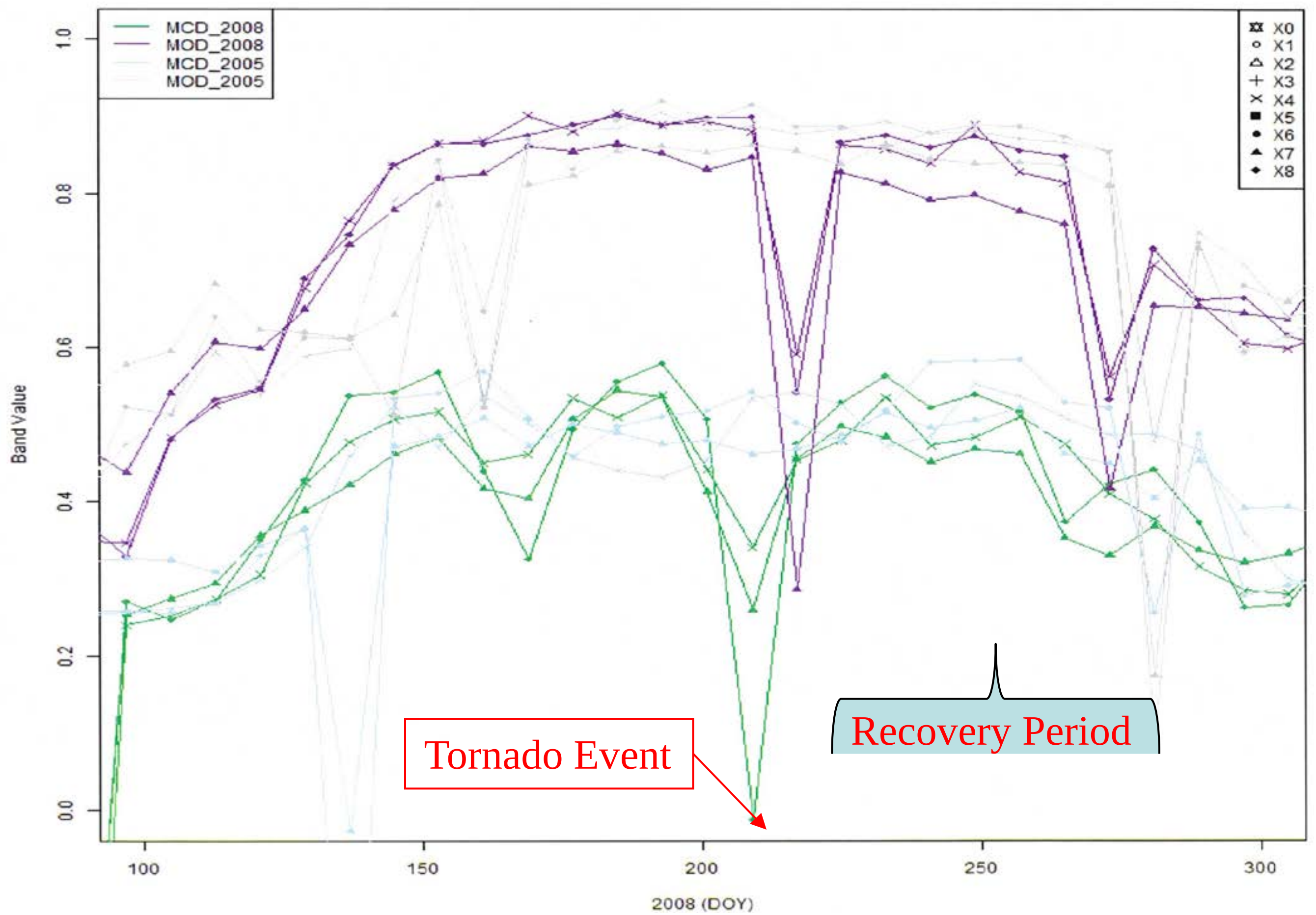
MODIS Disturbance Index

- MCD43A4 (500m) v MOD09Q1 (250m)
- NDVI & LSWI
- Different indices investigated (NDSVI, SATVI, NDTI, Albedo)
- Use MODIS to identify "timing" of an event or automatic detection

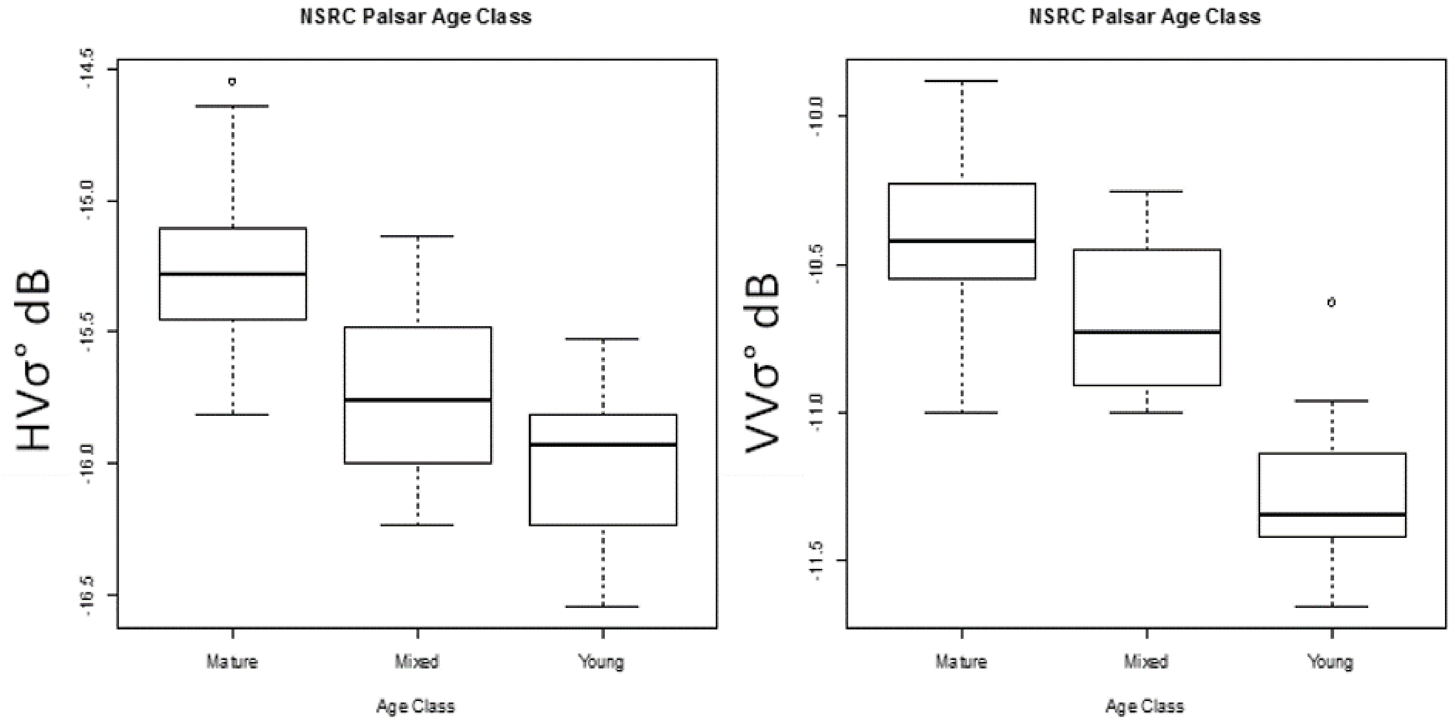


MODIS Disturbance Index

- NDVI comparisons; 2008 v. 2005
- MCD43A4 v MOD09Q1
- Temporal composting windows vary by product
- Lower magnitude / amplitude in indices during “recovery”



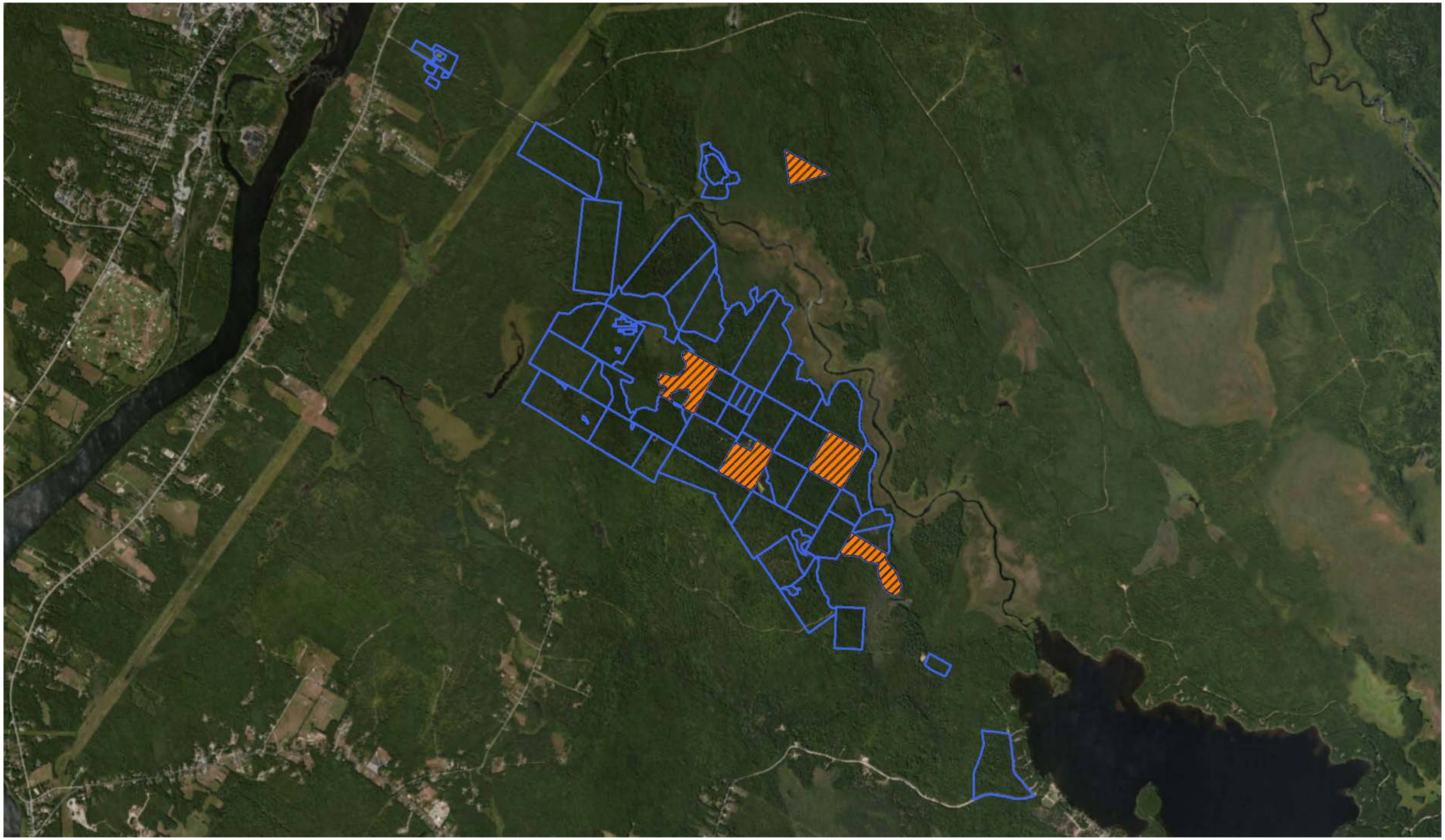
Maine Penobscot Experimental Forest case study



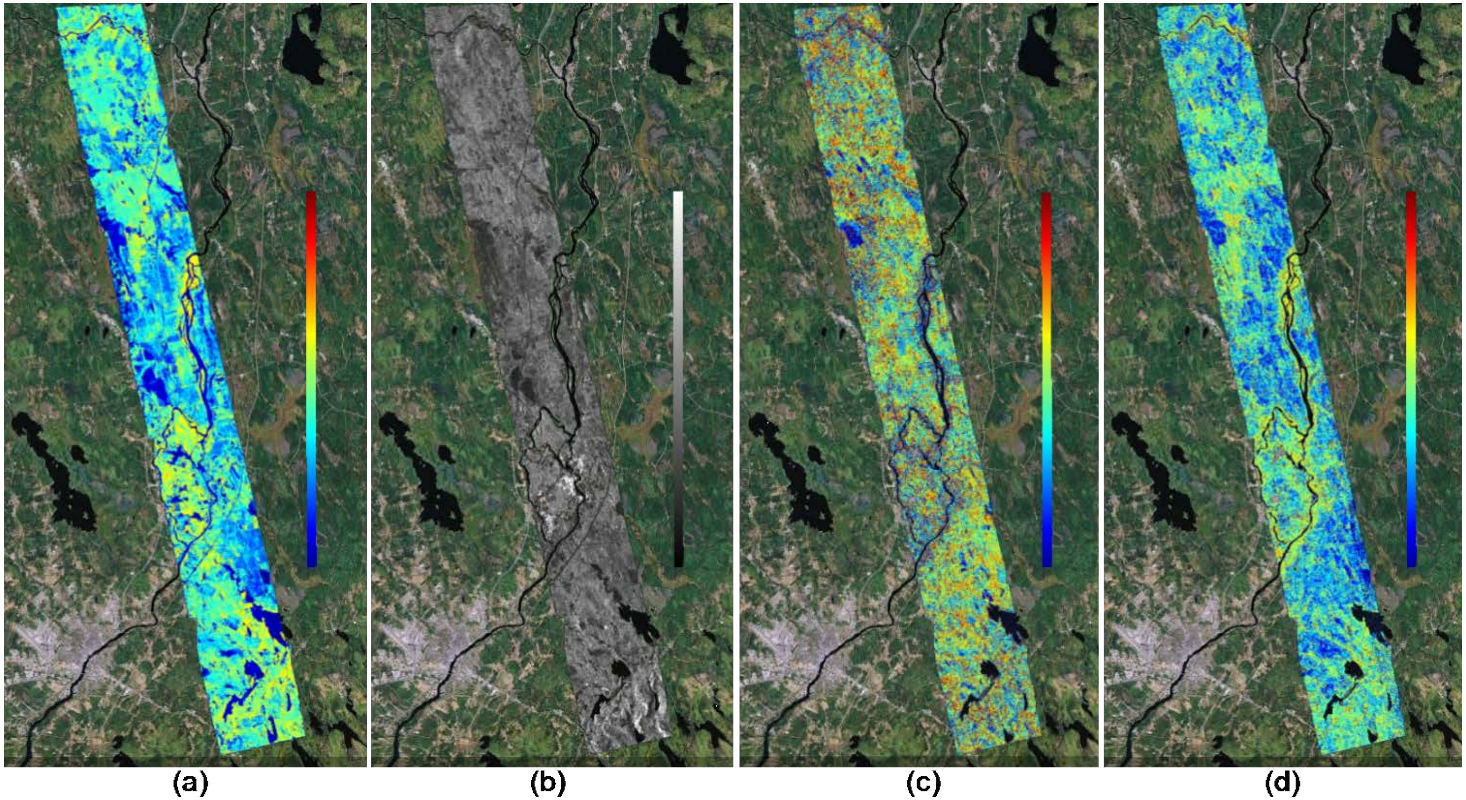
- Mapping harvest managements via stand age
- Box and whisker plots for age class and polarization
- Additional PLR bands are advantageous for distinguishing age classes; thus quad pol terms useful for determining impacts of disturbance on stand age, and help describe impacts to biomass, productivity, and carbon.

Maine Penobscot Experimental Forest case study

- Mapping stand age, height, and harvest managements
- Fused PALSAR quad pol with hv & Landsat with SWIR performed best
- 88% accuracy for stage age using ordinal logistic regression
- “Mixed” class had 5 misclassifications (orange strips)
- Applying model to additional managements / case study areas in 2014

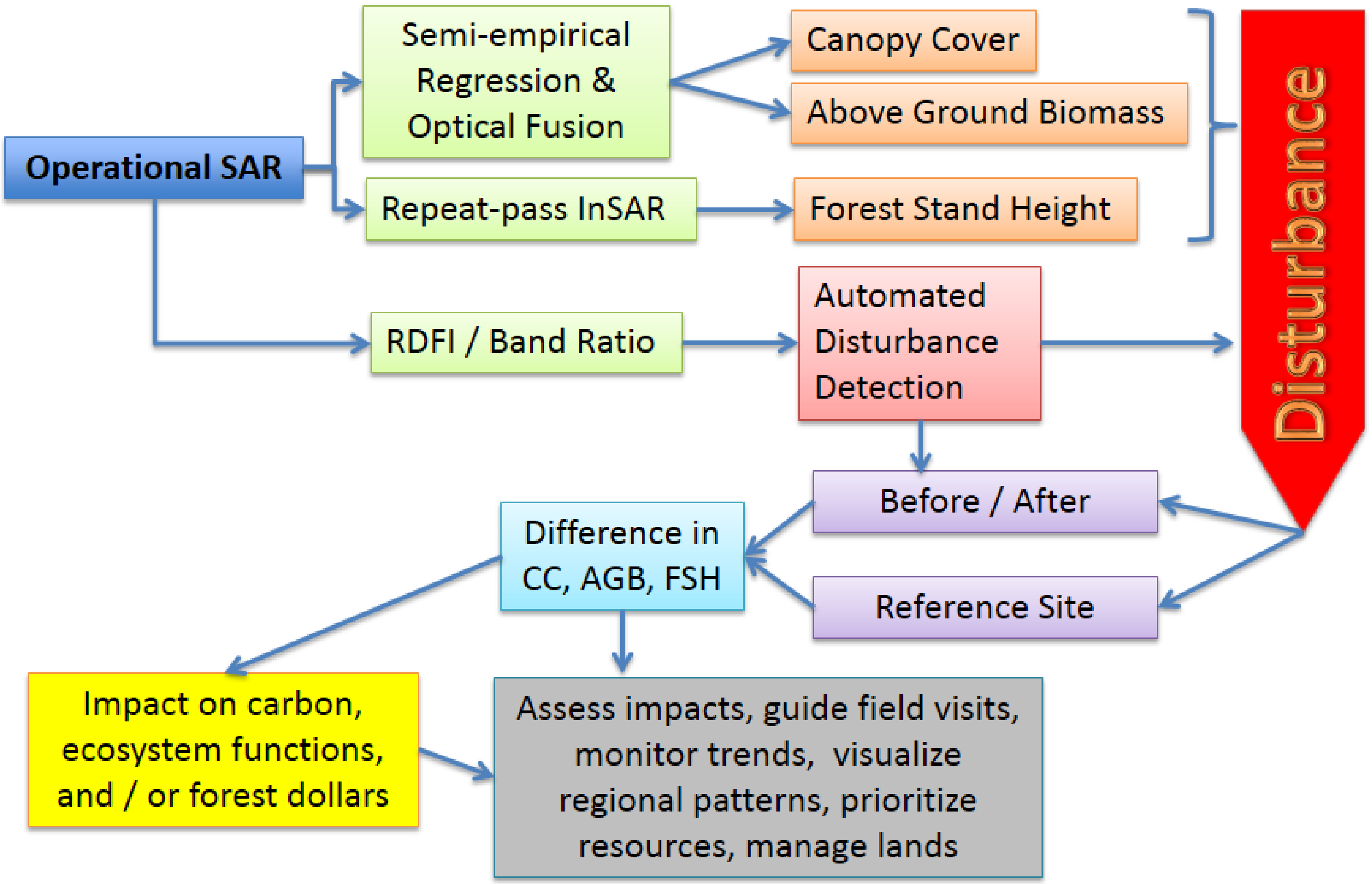


Routines for Forest Stand Height (FSH) Maps



- Comparison between different methods for estimating vegetation height over large spatial scales (the width of the strip above is 4 km): a.) LVIS lidar, b.) radar cross section (backscatter), c.) differential height and d.) interferometric correlation magnitude. Data from P Siqueira.
- Technical obstacle (ALOS-1 orbital shift) made tornado FSH maps inaccurate

NF blue print for monitoring platform that integrates SAR for improved mapping of disturbance and forest structure



Implications and applications in the Northern Forest region

- Operational “disturbance monitoring” that integrates remote sensing (eg, Landsat, PALSAR, & MODIS) is feasible and cost-effective

- Cost effective, operational Lidar is most likely more than a decade away; until then it’s a research tool

- New SAR missions (eg, Sentinel-1 and ALOS-2) can make noteworthy contributions towards monitoring disturbance at moderate scales (few hectares) for the next decade

Implications and applications in the Northern Forest region (continued)

- Relatively rapid, automated, and multi-scale
- Linked to valued ecosystem attributes (biomass, canopy cover, basal area, crown density, stand height); goes beyond categorical labels
- Complements existing efforts and help fill information gaps; working with end user groups for disturbance assessments and decision making; growing our open source web-GIS with end user partners
- Help decision makers assess impacts on productivity, carbon, and sustainability

Future directions

- Implement operational disturbance metrics that integrate SAR with Federal agencies and local assessment teams
- Integrate ground based 3-D, Lidar metrics of structure
- Evaluate across more applications / case studies
- Develop tool geared at carbon markets and MRV protocol

List of products

- Key maps and assessment products available at project website with more to come soon
  - Stand age maps of PEF and surrounding area
  - Regional biomass and canopy cover maps
  - MODIS time series anomalies / hot spot maps
  - Case study maps (eg, loss in above ground biomass from 2008 tornado)
  - Summary statistical outcomes and model results (pdf, ppt)
  - Algorithms, Python code, field data, and more available with request to PI

- Poster presentations
  - Torbick, Ducey. 2012. Mapping forest disturbance. Eastern CANUSA Forest Science Conference, Durham, NH.
  - Torbick, Salas. 2013. Monitoring forest disturbance and update on Phase 3 activities. JAXA Kyoto and Carbon Initiative, Tokyo, Japan. December 2-6th.

- Technical manuscripts:
  - Mapping tornado damage with multi-scale remote sensing (in prep).

- Project website
  - nsrc.appliedgeosolutions.com
  - Will continue to grow and be updated; operationalizing algorithms

- Additional information available from PI
  - Code, algorithms, field data metrics, statistics, image data, etc…

- Follow on proposal
  - USDA SBIR. Operationalizing SAR metrics for disturbance monitoring (in review)
  - Discussions with end user groups (eg, USFS ForWarn) about integrating operational map products into existing decision support tools

Thanks

- Thanks to the generous financial support and project management from NSRC USFS and Theme 2 staff
- We are continuing to work with USFS Eastern Forest Environmental Threat Assessment Center, NH Forest Health Program, Forest Inventory & Analysis, National Inventory & Monitoring Applications Center, & USFS Northern Research Station to implement the tools, enhance metrics, and gap fill assessment.
- The project website will remain active and grow as these projects develop (www.nsrc.appliedgeosolutions.com will migrate in 2014 to dedicated site)