

Potential of VIIRS data for regional monitoring of gypsy moth defoliation: Implications for forest threat early warning system

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A NASA RPC (Rapid Prototyping Capability) experiment was conducted to assess the potential of VIIRS (Visible/Infrared Imager/Radiometer Suite) data for monitoring non-native gypsy moth (*Lymantria dispar*) defoliation of forests. This experiment compares defoliation detection products computed from simulated VIIRS and from MODIS (Moderate Resolution Imaging Spectroradiometer) time series products as potential inputs to a forest threat EWS (Early Warning System) being developed for the USFS (USDA Forest Service). Gypsy moth causes extensive defoliation of broadleaved forests in the United States and is specifically identified in the Healthy Forest Restoration Act (HFRA) of 2003.

The HFRA mandates development of a national forest threat EWS. This system is being built by the USFS and NASA is aiding integration of needed satellite data products into this system, including MODIS products. This RPC experiment enabled the MODIS follow-on, VIIRS, to be evaluated as a data source for EWS forest monitoring products.

The experiment included 1) assessment of MODIS-simulated VIIRS NDVI products, and 2) evaluation of gypsy moth defoliation mapping products from MODIS-simulated VIIRS and from MODIS NDVI time series data. This experiment employed MODIS data collected over the ~15 million acre mid-Appalachian Highlands during the annual peak defoliation time frame (~June 10 through July 27) during 2000–2006.

NASA Stennis Application Research Toolbox software was used to produce MODIS-simulated VIIRS data and NASA Stennis Time Series Product Tool software was employed to process MODIS and MODIS-simulated VIIRS time series data scaled to planetary reflectance. MODIS-simulated VIIRS data was assessed through comparison to Hyperion-simulated VIIRS data using data collected during gypsy moth defoliation. Hyperion-simulated MODIS data showed a high correlation with actual MODIS data (NDVI R^2 of 0.877 and RMSE of 0.023). MODIS-simulated VIIRS data for the same date showed moderately high correlation with Hyperion-simulated VIIRS data (NDVI R^2 of 0.62 and RMSE of 0.035), even though the datasets were collected about a half an hour apart during changing weather conditions.

MODIS products (MOD02, MOD09, and MOD13) and MOD02-simulated VIIRS time series data were used to generate defoliation mapping products based on image classification and image

differencing change detection techniques. Accuracy of final defoliation mapping products was assessed by image interpreting over 170 randomly sampled locations found on Landsat and ASTER data in conjunction with defoliation map data from the USFS.

The MOD02-simulated VIIRS 400-meter NDVI classification produced a similar overall accuracy (87.28 percent with 0.72 Kappa) to the MOD02 250-meter NDVI classification (86.71 percent with 0.71 Kappa). In addition, the VIIRS 400-meter NDVI, MOD02 250-meter NDVI, and MOD02 500-meter NDVI showed good user and producer accuracies for the defoliated forest class (≥ 70 percent) and acceptable Kappa values (≥ 0.66). MOD02 and MOD02-simulated VIIRS data both showed promise as data sources for regional monitoring of forest disturbance due to insect defoliation.

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Presentation Outline



- Project Background
 - Project Partners
 - Rationale for Work
- Simulation of VIIRS Data from MODIS Imagery
- Mapping of Gypsy Moth Defoliation from Simulated VIIRS and MODIS Time Series Data
- Relevance of Results

Project Background

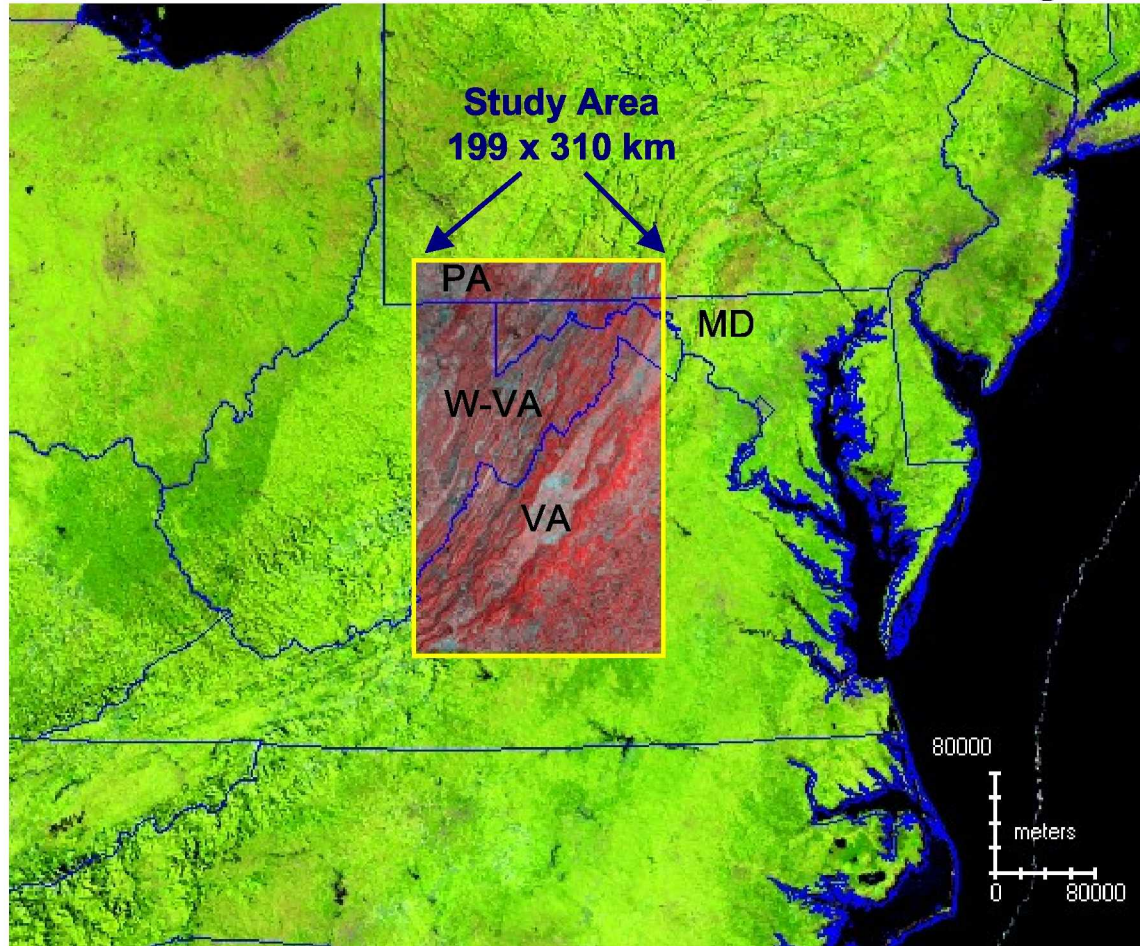


- Work regards a NASA/USDA Forest Service partnership
 - NASA is helping USDA Forest Service to implement satellite remote sensing data into its emerging Forest Threat Early Warning System
 - The USDA Forest Service intends to use MODIS and follow-on VIIRS imagery for regional monitoring of forest damage (e.g., defoliation) from biotic threats (e.g., Gypsy Moth)
- The RPC experiment addresses: How does VIIRS time series data compare to MODIS data for monitoring gypsy moth defoliation?
- Project regards many national applications (e.g., agricultural efficiency, coastal management, ecological forecasting, disaster management, and carbon management)

Study Area Location



Study Area Outlined in Yellow Below (Total ~15.5 Million Acres)
Gypsy Moth Defoliation Occurred on Multiple Years During MODIS Era



Note: This Area Encompasses Several Landsat Scenes

An Aerial View of Gypsy Moth Defoliation

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Denuded, Partially Denuded, Chlorotic, and Green Forest Vegetation



Project Objectives



1. Assess 250-meter MODIS data for simulating 400-meter VIIRS data
2. Compare VIIRS and MODIS data for mapping historic gypsy moth defoliation
 - Assess accuracy of detection products compared to reference data
 - Higher spatial resolution NASA satellite data (primarily Landsat and ASTER imagery)
 - USDA Forest Service geospatial data (defoliation sketch maps and other data)
 - Focus on 2001 because of known extensive defoliation and available reference data

Simulating VIIRS Data from MODIS Data



- Hyperion data was used to simulate MODIS from same date (7/24/2001)
- Hyperion and MODIS imagery from 7/24/2001 were used to simulate VIIRS
- Application Research Toolbox (ART) software was used for the simulations
- Simulation data was validated via reflectance band and NDVI correlation analysis (results given below)

Comparison	RED	Red	NIR	NIR	NDVI	NDVI
	r^2	RMSE	r^2	RMSE	r^2	RMSE
Hyperion-simulated MODIS versus MODIS	0.83	0.005	0.88	0.015	0.88	0.023
MODIS-simulated VIIRS versus Hyperion-simulated VIIRS	0.56	0.007	0.63	0.024	0.62	0.035



Mapping Gypsy Moth Defoliation from Simulated VIIRS and MODIS Data

- Highlights on Product Development
- Example Products
- Product Validation

Reducing Noise in the MODIS Time Series Data

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- Data from each MODIS product was independently preprocessed to reduce inclusion of clouds and other low-quality data
 - MODIS MOD02 (planetary reflectance data) and MOD13 (atmospherically corrected NDVI)
- The Time Series Product Tool (TSPT) was used to derive “cleaned” time series data products from MODIS data
 - TSPT was developed at NASA Stennis Space Center
 - TSPT outputs vegetation index products (e.g., NDVI)
 - TSPT temporally filters out noise and interpolates data voids to produce daily cloud-free NDVI products

Computing Maximum NDVI Composites Over Peak Defoliation Time Frame

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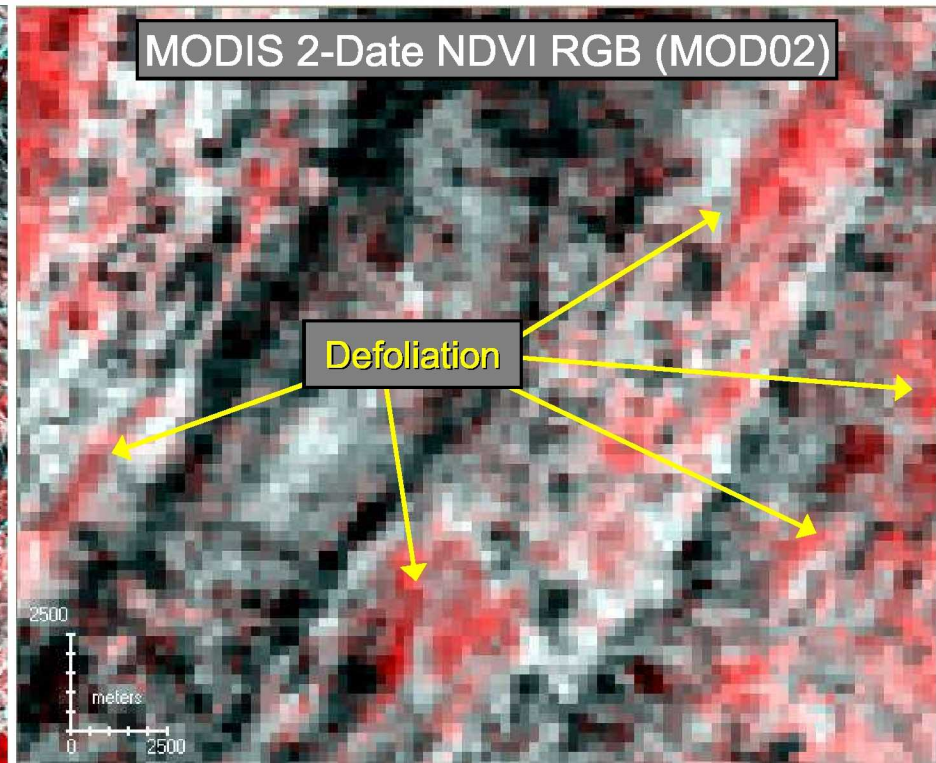
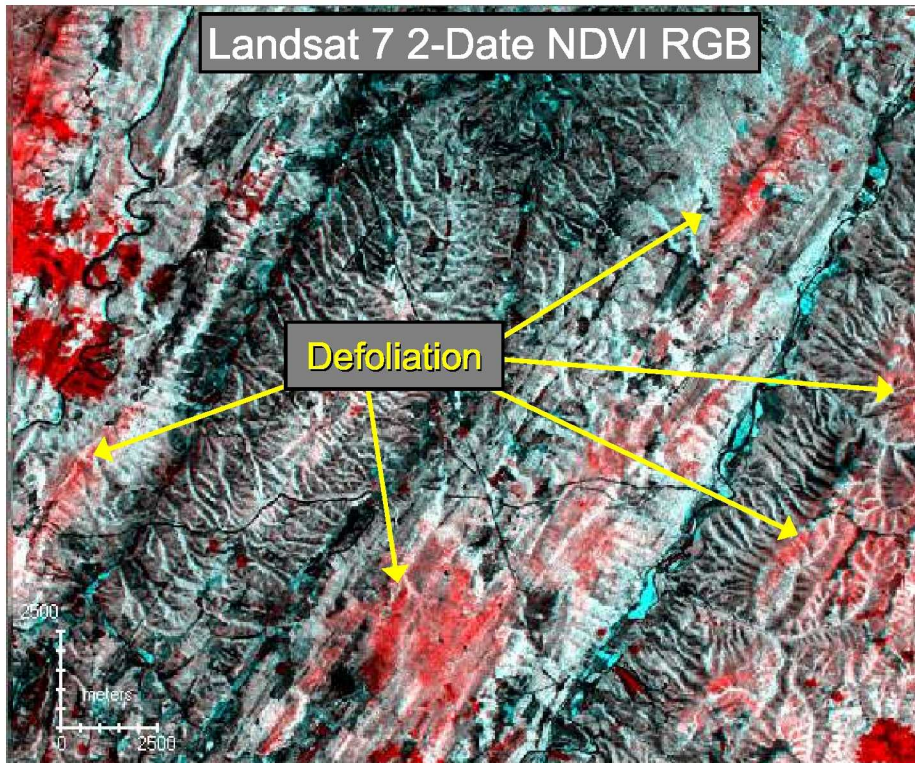
- Using simulated VIIRS and MODIS data, we computed a maximum NDVI composite for the gypsy moth defoliation period of each year (~ June 10–July 27)
 - Time series includes defoliated and non-defoliated years
- Also computed maximum NDVI during peak defoliation period for the entire 7-year time series (2000–2006)
- Stacked 2001 maximum NDVI peak defoliation image, along with maximum NDVI peak defoliation over the whole 2000–2006 time series
- Applied data stack to compute defoliation detection products
 - Used 2001 Landsat and ASTER data for product validation

Views of Gypsy Moth Defoliation on Landsat 7 versus MODIS NDVI RGBs

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Landsat – 6/10/2000 NDVI Loaded in Red; 7/15/2001 NDVI Loaded into Blue and Green
MODIS – Maximum NDVI Peak Defoliation All Years in Red; Same for 2001 in Blue in Green



- Red tones – defoliation in 2001, except some deep red is clouds on the Landsat data
- Both Landsat and MODIS show defoliation, though the MODIS composite is cloud free

Method for MODIS Image Classification of Gypsy Moth Defoliation

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- Produced ISODATA unsupervised classifications based on 2-date NDVI, including peak defoliation maximum NDVI for 2001 and peak defoliation maximum NDVI for whole time series (2000–2006)
 - Example classifications included those from MOD13 250 m, MOD02 250 m, and simulated VIIRS 400 m data
 - Each classification used same settings: 20 cluster classes, 100 iterations, and 99.5% convergence for output
- Each case – regrouped initially into 3 classes (non-forest, green forest, and defoliated forest)
- Applied post-classification “filtering” technique to reduce classification errors from patches smaller than 1x1 km
- Regrouped result into final classification of defoliated forest versus “other”

2001 Defoliation Classifications from MOD13, MOD02, and Simulated VIIRS NDVI Products

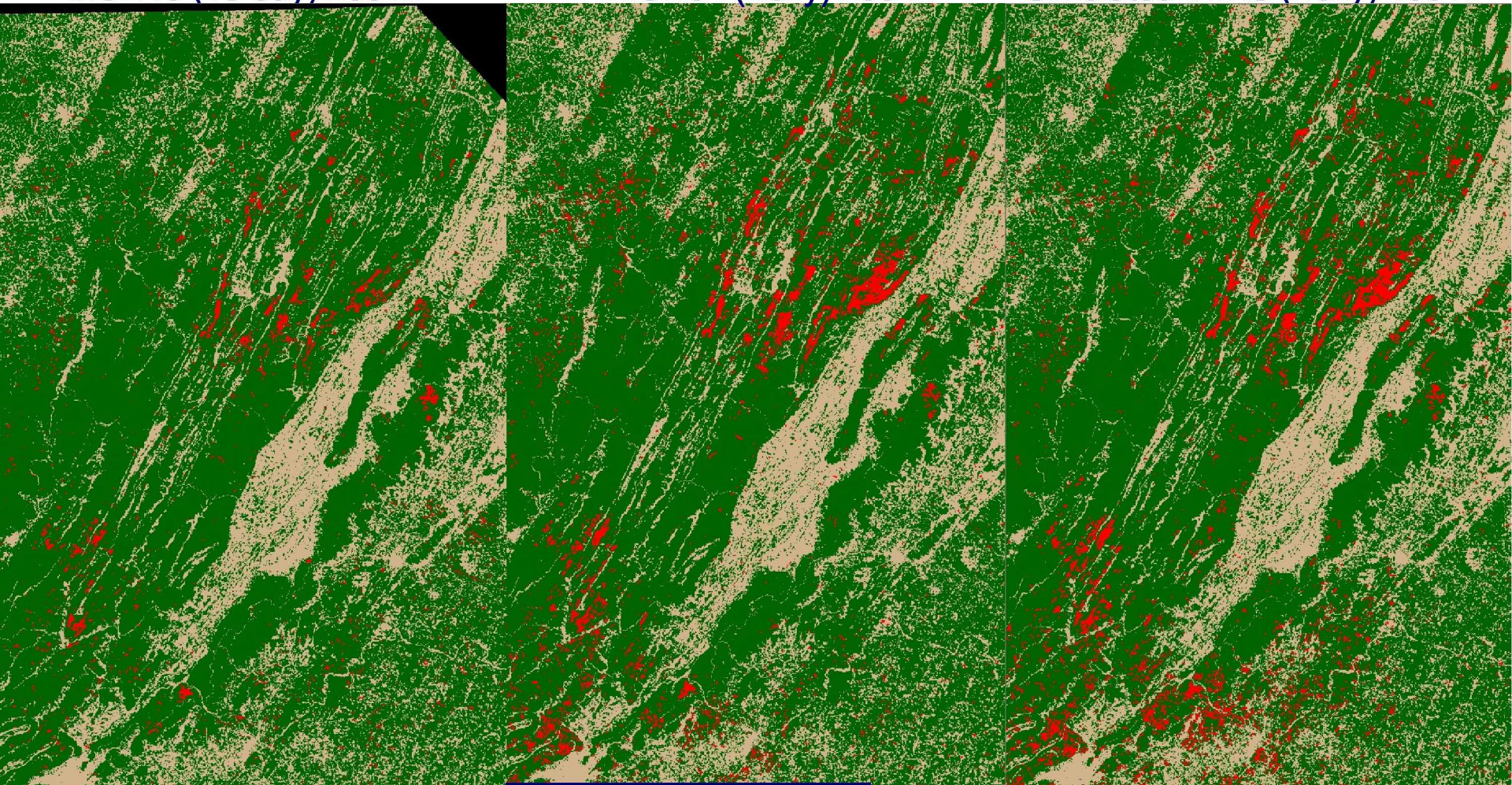
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MOD13 (16-day) 250 m

MOD02 (Daily) 250 m

Simulated VIIRS (Daily) 400 m



NON-FOREST – TAN
HEALTHY FOREST – GREEN
DEFOLIATED FOREST – RED
FOREST MASK – NLCD 2001

Views of Defoliation from Maximum NDVI RGBs (MOD13, MOD02, and MOD02-based VIIRS)

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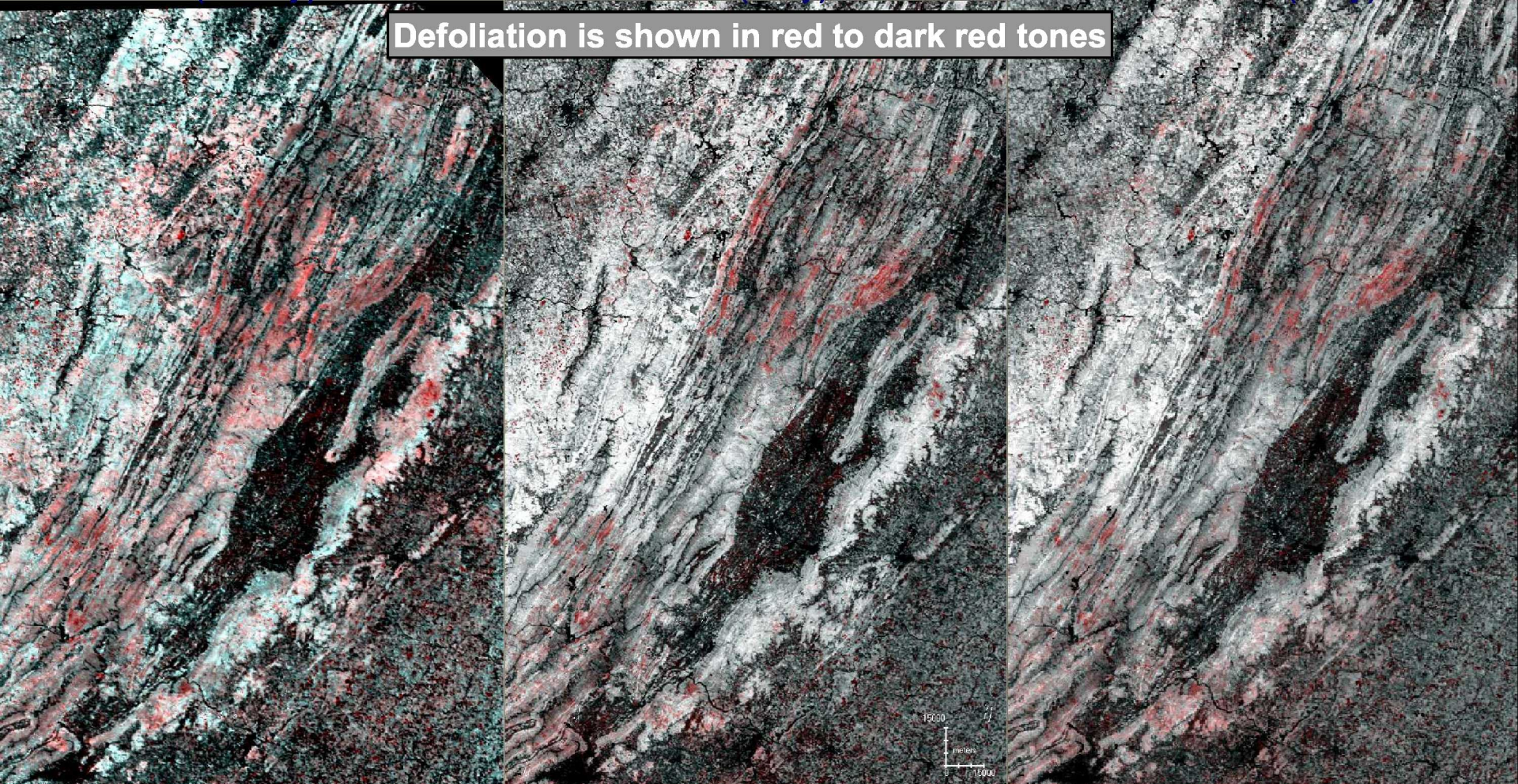


MOD13 (16 day) 250 m

MOD02 (daily) 250 m

Simulated VIIRS (daily) 400 m

Defoliation is shown in red to dark red tones



Above RGBs – Maximum NDVI Peak Defoliation All Years in Red; Same for 2001 in Blue and Green
Peak Defoliation Time Frame – Set to June 10 through July 27

Method for Accuracy Assessment of Defoliation Detection Products

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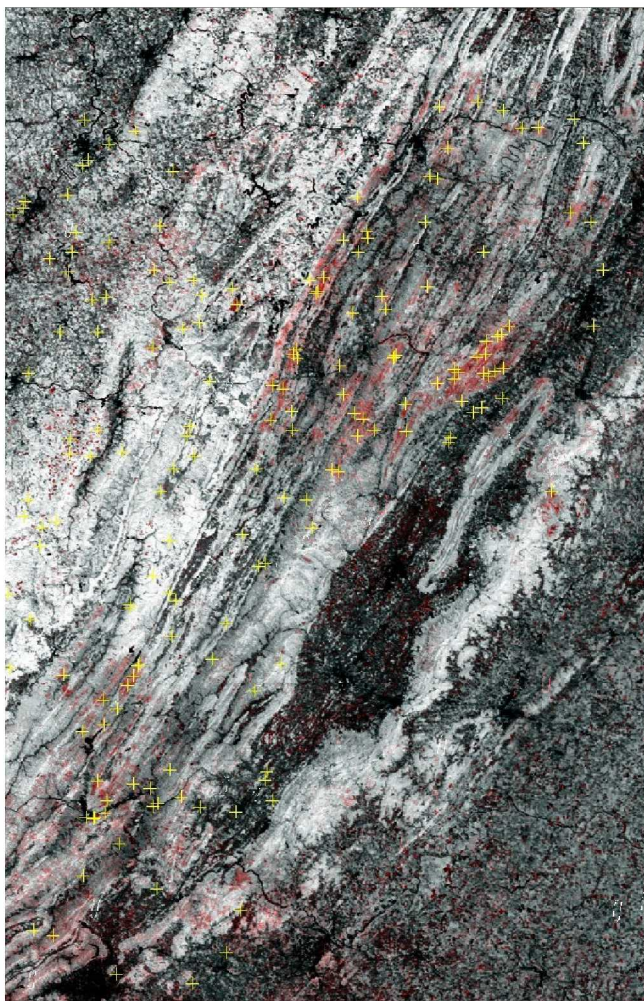
- Drew stratified random sample locations from best apparent 3-class classification (MOD02 250-meter result)
 - 50 samples or more selected per class
 - Defoliated forest, non-defoliated forest, and non-forest classes
- An experienced image analyst interpreted apparent class value of each random sample location on Landsat or ASTER RGB displays – this constituted the reference data
- Interpretation results were compared to each test classification (MOD02, simulated VIIRS, and MOD13 products)
- Final results were summarized for 2 basic classes (defoliated forest versus “other”)

Location of Sample Points Used in Accuracy Assessment

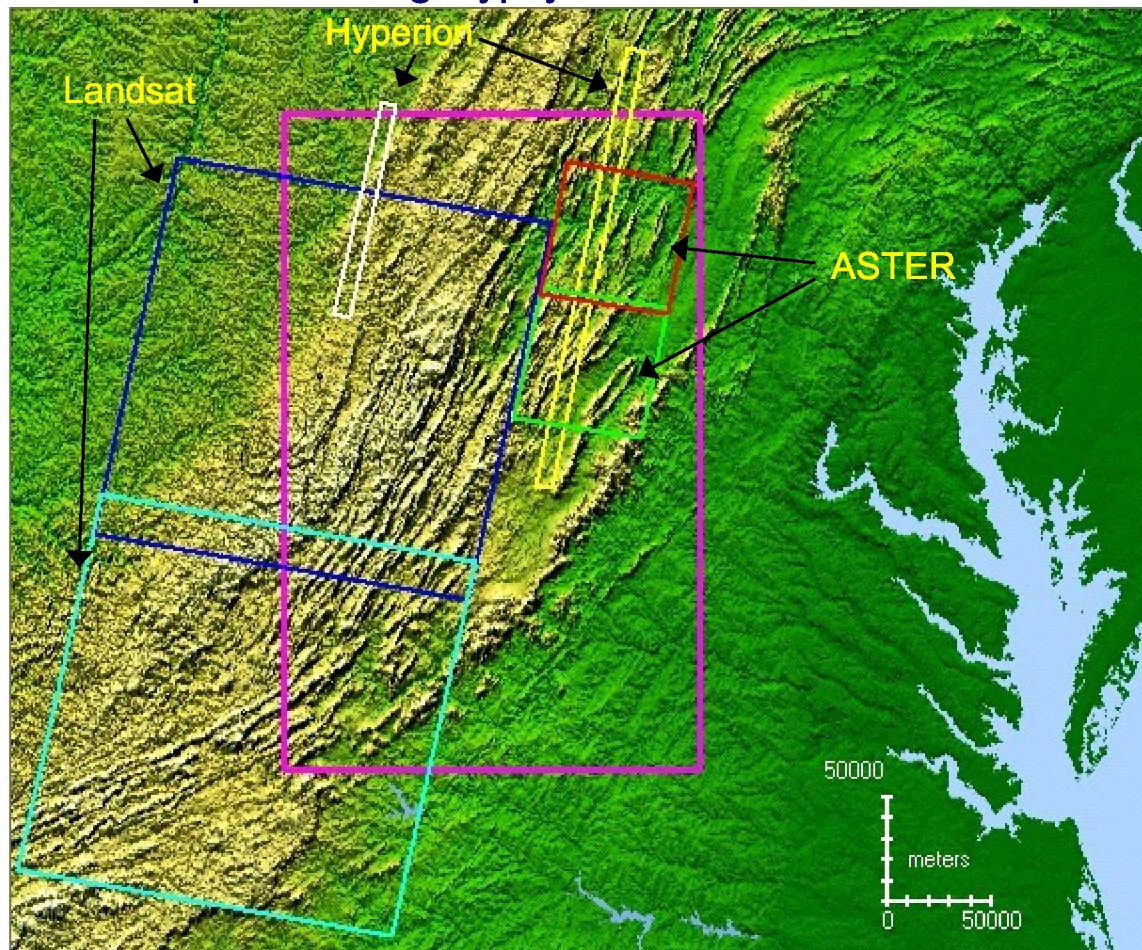
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Sample Points (Yellow) Overlaid
onto MOD02 250 m NDVI RGB



Location of 2001 Landsat, ASTER, and EO-1 Data
Acquired During Gypsy Moth Defoliation of 2001



Relative Accuracy of Example 2001 Defoliation Classification Products

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2001 Classification Product	Defoliated Forest			Other			Overall	
	PA	UA	Kappa	PA	UA	Kappa	OA	OK
MOD02 NDVI 250 m	91% (52/57)	78% (52/67)	0.67	87% (101/116)	95% (101/106)	0.86	88% (153/173)	0.75
VIIRS NDVI 400 m (Simulated from MOD02)	86% (49/57)	78% (49/63)	0.67	88% (102/116)	93% (102/110)	0.78	87% (151/173)	0.72
MOD13 NDVI 250 m	44% (25/57)	86% (25/29)	0.79	97% (112/116)	78% (112/144)	0.33	79% (137/173)	0.46

Note: PA = % Producer's Agreement (# correct/total), UA = % User's Agreement (# correct/total), Kappa = Kappa Statistic, OA = % Overall Agreement (# correct/total), and OK = Overall Kappa.

Conclusions for Example 2001 Defoliation Mapping Products

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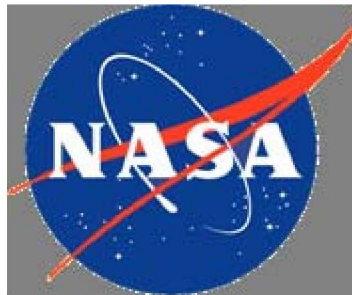


- Simulated VIIRS and MODIS time series data was processed into effective defoliation maps for 2001
 - Such products were aided by temporal processing techniques that considered pest phenology
 - Such products appear to work well for monitoring extensive patches of defoliation
- Temporal composites of daily MOD02 data produced the best results
 - MOD02 250 m and simulated 400 m VIIRS NDVI products yielded the best results
 - MOD13 NDVI products showed the lowest overall accuracy, in part from omission of defoliation areas

Relevance of RPC Experiment



- The RPC project enabled the USDA Forest Service to assess potential of simulated VIIRS and MODIS data for monitoring gypsy moth defoliation and for contributing to their forest threat early warning system
- This experiment yielded the first cloud-free satellite views and wall-to-wall maps of the 2001 gypsy moth defoliation over the entire 15.5 million acre study area
- Since the case study focused on 1 region and 1 year, the USDA Forest Service has requested that extra analysis be done for other years and regions
- More work also needs to be done to assess potential of technology for nowcasts as well as more automated hindcasts of forest defoliation



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