MAPPING ECOSYSTEM DYNAMICS AND DISTURBANCES ACROSS US FROM 1981 TO 2012: A DATA-DRIVEN APPROACH WITH SATELLITES

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Introduction

Our landscapes are modified by natural and anthropogenic forcings constantly. The future of many terrestrial ecosystems is uncertain in face of global warming and climate changes. Sustainable management of ecosystems and natural resources depends largely on the levels of understanding in climate-vegetation interactions. Vegetation impacts climate by coupling the air and lands via biogeochemical and biophysical pathways, such as sequestrating carbon and modifying surface biophysics. Vegetation also responds to climatic variations and feeds back to affect climate. These interactions establish the importance in monitoring vegetation activities over time and space.

To date, repeatable observations of vegetated surfaces over extensive areas have been made primarily with satellites; they complements field surveys and ecosystem models for quantifying ecological responses of vegetation to the changing environment. Satellite time-series data, especially those measured at a sub-monthly scale for decades, are useful for characterizing trends and abrupt shifts in vegetation activities (Fig. 1).

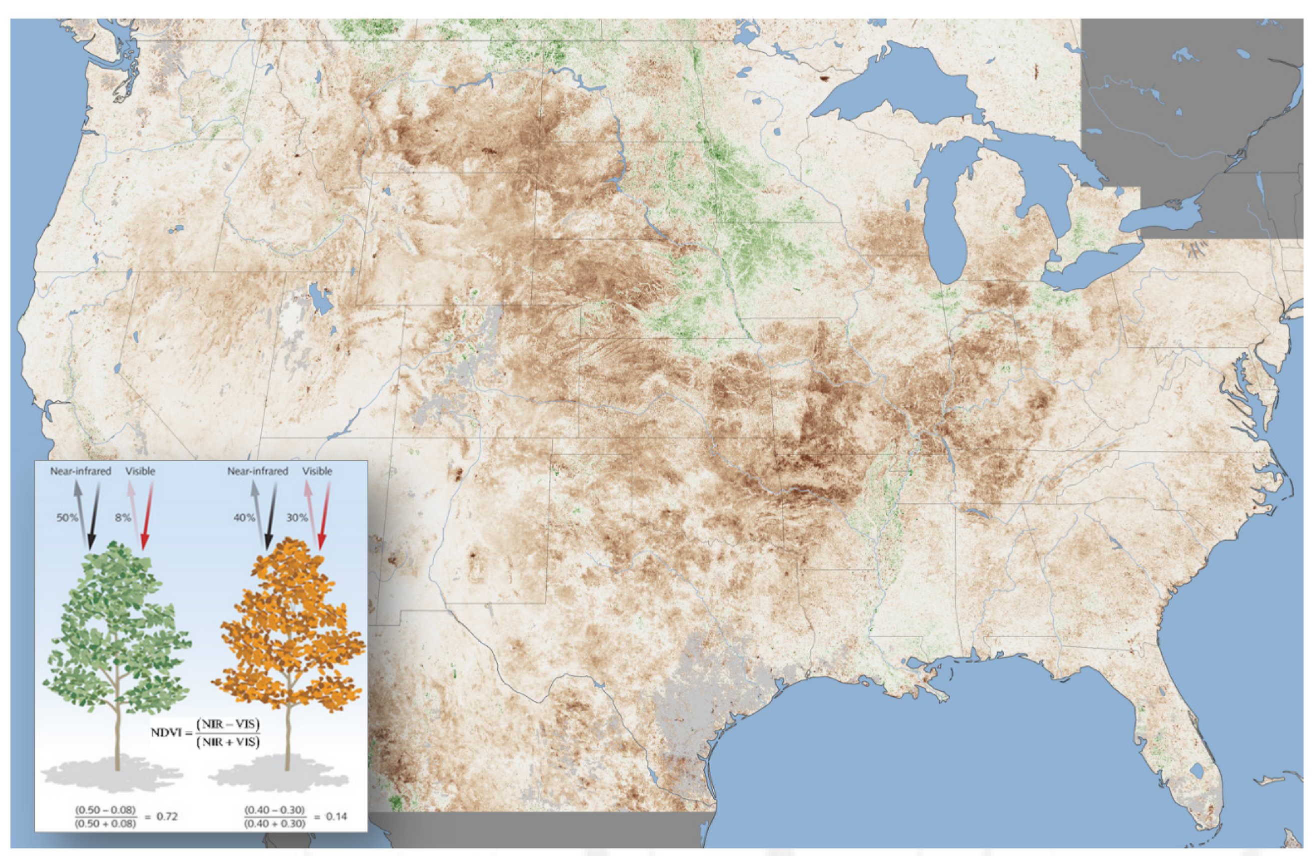

Figure 1: A nation-wide drought in July, 2012 has been observed by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS). Brown colors indicate dry conditions compared to normal., that is, low NDVI values as explained in the inset.

Aims

This work examines how to reliably decipher long-term satellite times-series imagery for characterizing ecosystem dynamics via advanced statistical analysis methods. Our focus is on formulating a Bayesian approach to map ecosystem dynamics and disturbances from satellite-observed NDVI data. The approach applies the concept of Bayesian model averaging to improve robustness and quantify uncertainty – an aspect essential for practical use of satellite products for decision-making.

Methods

Satellites capture reflected sunlight from the Earth at multispectral bands. The combination of reflectance at near-infrared and visible bands provides a powerful way to quantify the greenness and vitality of vegetation using a spectral index widely known as Normalized difference vegetation index (NDVI). Theories and experiments proved that NDVI is a strong indicator of chlorophyll abundance, vegetation amount, plant vigour, and plant primary production. The concept and calculation of NDVI are illustrated in Fig. 1.

To quantify ecosystem changes, we used thirty-years of NDVI dataset collected by the AVHRR satellite and a decade's worth of NDIV data from MODIS. Both the NDVI time-series data are available at a sub-monthly level, thereby allowing characterization of seasonal, abrupt, and long-term ecosystem changes. For each pixel, a NDVI time-series will be considered to be a combination of trend, seasonal, and abrupt signals plus noises (Fig.2)

NDVI(t) = Trend(t) + Seasonality (t) + Abrupt (t) + noises.

We developed a novel Bayesian inference tool to decompose NDVI time-series into individual components. Specially, the trend component generally represent the long-term changes of ecosystem, due to slow-varying forcing such as climate shift. Abrupt changes correspond to ecosystem disturbances, such as fire, clearing, logging, windthrow, and pest infestation.

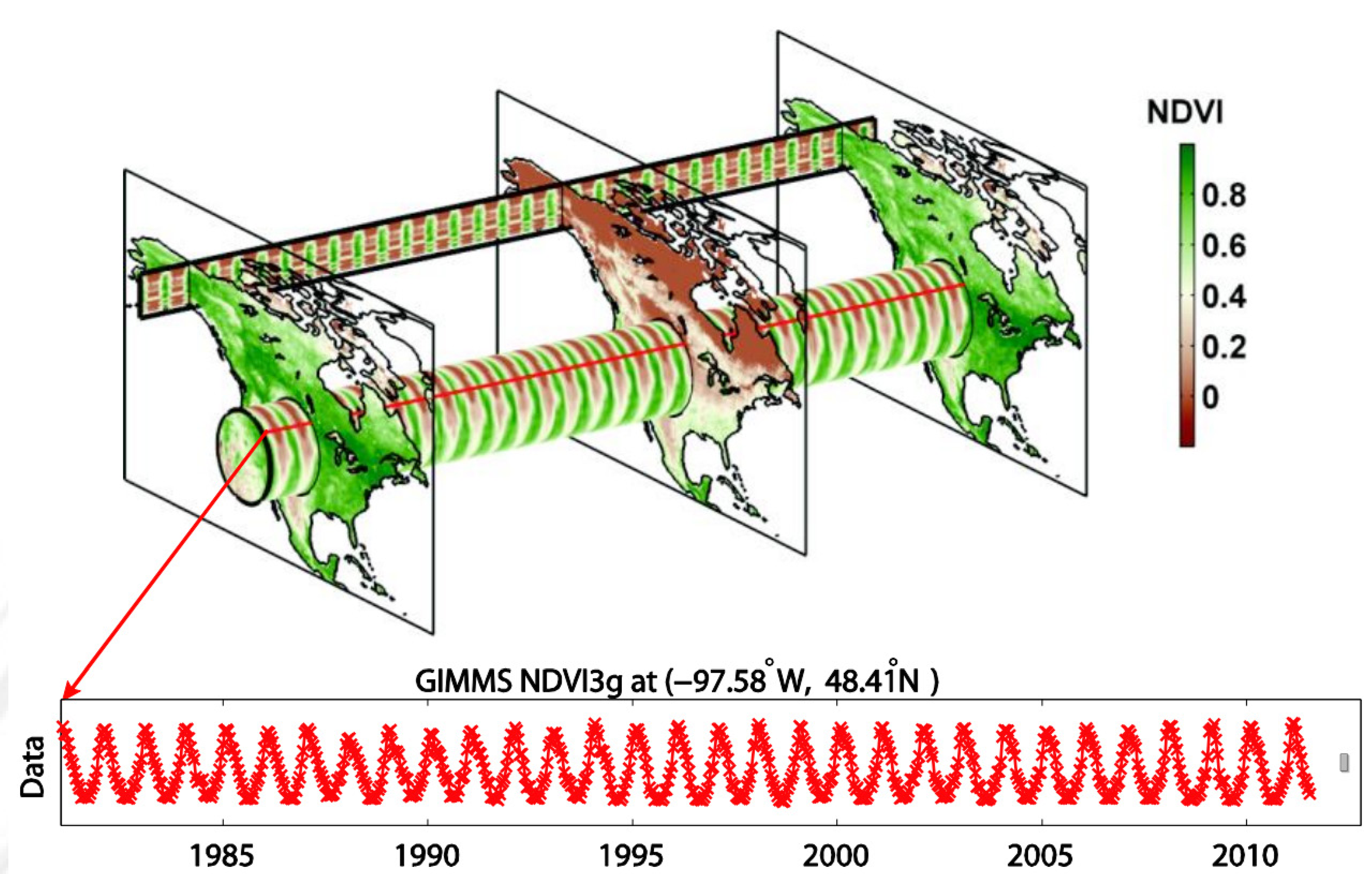

Figure 2: Spatial-temporal NDVI data acquired by NOAA's Advanced Very High Resolution Radiometer over the past thirty years. The red curve gives a sample NDVI time-series for a pixel.

Results

The combined use of satellite NDVI and Bayesian inference generates information on how vegetation—forests, grassland, and agro-ecosystems—has been changing across large geographic areas. The level of details of the information is unprecedented, compared to conventional solutions. Using MODIS satellite data over the Shawnee state forest in Ohio as an example, a 3D volumetric view of the spatial temporal patterns of forest dynamics was derived with our Bayesian method (Fig. 3). Brown areas indicate spatial and temporal locations where the forest ecosystem is of low vitality. The probability of observing abrupt changes in Feb 2003 has been depicted for all the pixels of the study area (top left); the subregions with high probabilities delineate the disturbed forests, a pattern consistent with that of the high-resolution Landsat image where the regions struck by the 2003 icestorm was easily visible.

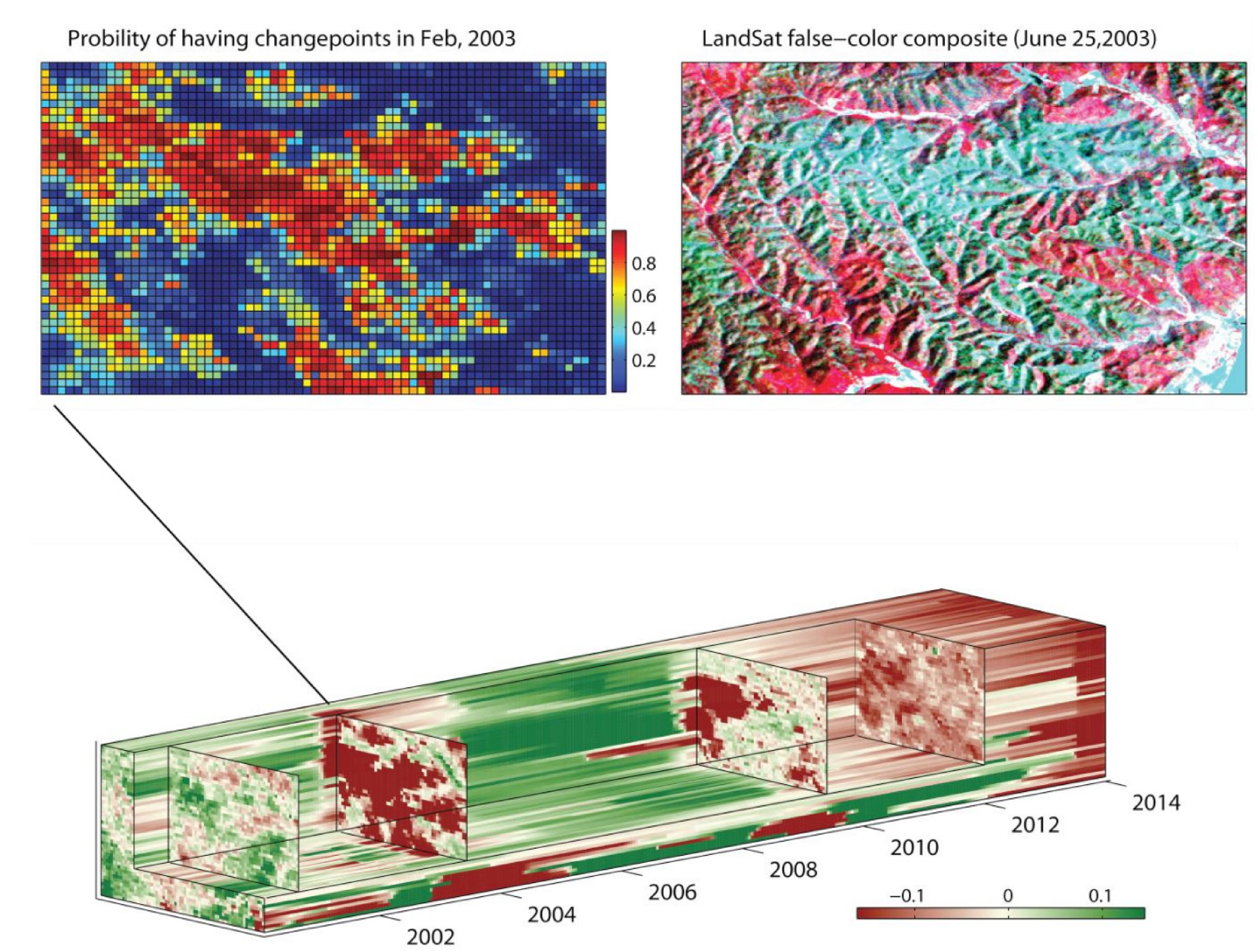

Figure 3: The decomposition of NDVI data to derive forest dynamics and disturbance information over the Shawnee state forest, Ohio. As an example, the region struck by icestorm in Feb. 2003 has been successfully identified (top left), matching the pattern from the high-resolution image (top right).

Conclusion

We developed a robust data-intensive approach to mapping vegetation dynamics and detecting ecosystem disturbance using satellite observations. This methodological framework represents a paradigm shift in analyzing remote sensing data, especially due to the reliability of information derived and their direct relevance to practical applications. Further, the vegetation information derived provides a benchmark product to verify and validate ecological forecasting models.

Bibliography

Zhao, K., & Jackson, R. 2014. Biophysical forcings of land-use changes from potential forestry activities in North America. Ecological Monographs, 84 (2), 329-353.

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