UTILIZING PUBLIC INTERNET-CONNECTED CAMERAS FOR A CROSS-CONTINENTAL PLANT PHENOLOGY MONITORING SYSTEM

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1. INTRODUCTION

Plant phenology, the study of the periodic phases of plant development such as budburst, flowering, and leaf senescence, is one of the most sensitive and easily observed terrestrial responses to changing climate [1]. Detecting shifts in the timing of plant phenological events, however, is limited by the constraints of existing observation technologies and difficulties integrating those technologies [2,3]. Current observation methods are either manual for small-scale, high precision measurements or by satellite remote sensing for large-scale, low spatial resolution measurement. Nation-wide observation networks have been founded in attempt to document trends in plant growth dynamics at continent-wide scales and rally on-the-ground community involvement, as with the U.S. National Phenology Network, but these foundations suffer from the limitations associated with ground-based monitoring. The development of inexpensive, instrument-based field measurement is necessary to advance large scale phenology monitoring [3]. The digital images from publicly accessible, Internet-connected cameras established for non-scientific monitoring applications represent a relatively untapped, inexpensive, and easily acquired resource for augmenting large scale phenology monitoring.

We present a relatively simple and inexpensive community remote sensing approach to detect phenological events at a continental scale across North America, utilizing public, freely-available Internet-connected cameras (public cameras) associated with airports, national parks, and roadway conditions. Our methodologies for detecting changes in vegetation greenness are simple and similar to those used in previous phenology studies using digital images and the model we use to detect the timing of spring green-up and fall senescence events is a common approach used in satellite-based methods. We compare our detection with that of freely available satellite remote sensing MODIS (Moderate Resolution Imaging Spectroradiometer) products used for large-scale environmental monitoring.

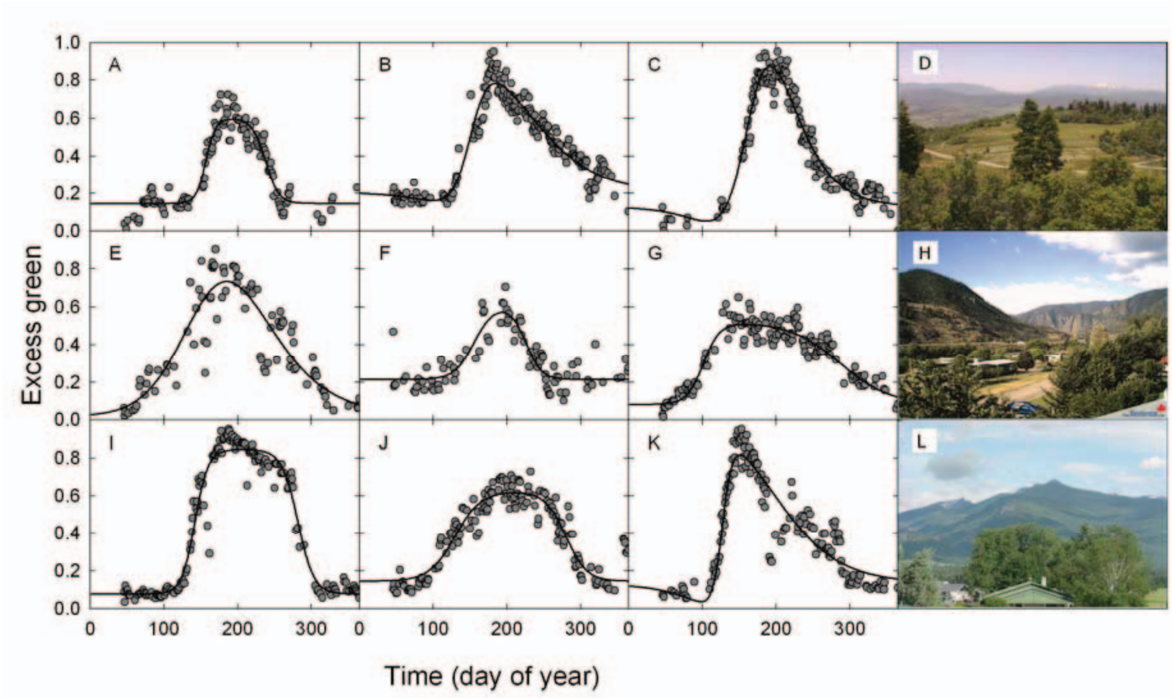

Figure 1. Camera excess green signals for hand-segmented deciduous (A, E, I), evergreen (B, F, J), and understory (C, G, K) regions within images at four test public camera containing all three vegetation types. Data plotted are daily values lying within a 5-point running mean filter. The curve is the modeled double sigmoid green signal. Example images from late June 2008 are included (D, H, L).

2. METHODS

We manually identified over 1400 publicly available cameras with vegetation across North America and collected twice-daily images from February 2008–2009. For a subset of 30 test locations, we masked image vegetation type (understory, deciduous, evergreen) and calculated per pixel "greenness" as excess green (2 × value of the green pixel – value of the red pixel – value of the blue pixel. We obtained daily MODIS satellite surface reflectance data products for the 30 test from January 1 - December 31, 2008. Per pixel satellite greenness was calculated as the normalized difference vegetation index (NDVI). We modeled spring green-up and fall senescence in public camera images and MODIS daily surface reflectance satellite products using a double sigmoid function [4]. We compared both method's detection of spring green up and fall senescence.

3. RESULTS

Of our initial 1495 public cameras, we were able to georeference 1141 public cameras. Both public camera and satellite pixel green-up signals had high day to day and between location variability. Image

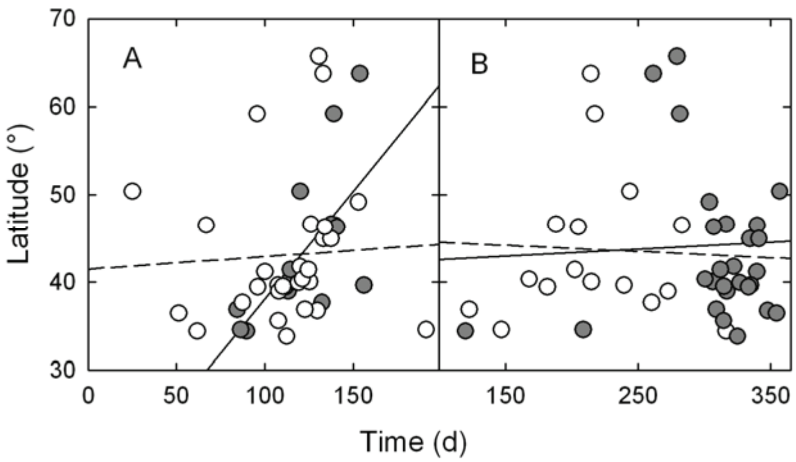

Figure 2. Latitudinal trends in the estimated dates of spring (A) and fall (B) from deciduous vegetation of public cameras (filled circles, solid line) and corresponding satellite pixels (open circles, dashed line).

over- and under-exposure and automatic white balance introduced noise to public camera excess green measurements of vegetation, while cloud cover and varying atmospheric conditions introduced noise to satellite NDVI time series. Public cameras had an equivalent or higher ability to detect spring compared to satellite-based data for corresponding locations, with fewer poor quality days, shorter continuous days of bad data, and significantly lower errors of spring estimates. Manual camera image segmentation into deciduous, evergreen, and understory vegetation allowed detection of spring and fall onset for multiple vegetation types (Fig.1). Although varying image exposure and color correction introduced noise to public camera measurements, we were able to correlate spring green-up across North America with visual validation from images and detect a latitudinal trend which was not evident from satellite signals (Fig.2).

Advantages of a public camera-based monitoring system include frequent image capture (sub-daily) and the potential to detect quantitative responses to environmental changes in organisms, species and communities. Public cameras represent a relatively untapped and freely available resource for supporting large-scale ecological and environmental monitoring. Problems specific to public camera-based phenological monitoring include widely varying image resolution among the public cameras, lack of control over public camera operation resulting in changed Internet addresses, removed cameras, and changes in view angle without warning; and automatic white/color balance that add variability to greenness time series unrelated to changes in vegetation. Despite these challenges, Internet-connected public cameras can contribute greatly to phenological monitoring and our ability to detect changes in our environment. They can provide useful information about phenological events at locations spanning regional to global scales and can augment ground-based phenological monitoring which provides the exact timing of budburst for individual plants, but at considerable labor cost and often limitation to small areas. Public cameras provide inexpensive, easily accessible, and high frequency monitoring (minute to daily image capture) at a wide number of locations, covering a much larger area than possible with traditional ground monitoring. Furthermore, active research in color detection, computer vision and cyber infrastructure promises to streamline and automate digital camera-based monitoring in the future, further reducing human costs of field detection.

4. REFERENCES

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