Corrected vegetation indices from MODIS MAIAC for photosynthetic phenology assessment in the ABoVE Domain

Rong Yu[1a], Gabriel Hmimina[1a], Fred Huemmrich[2], Dave Billesbach[1], Zheng Xu[1], John Gamon[1]

[1]School of Natural Resources, University of Nebraska - Lincoln, USA
[2]NASA/Goddard Space Flight Center, USA
[a]Equally contributed to this work

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PI: Dr. John Gamon
Co-PI: Dr. Dave Billesbach
Dr. Christian Frankenberg
Dr. Fred Huemmrich

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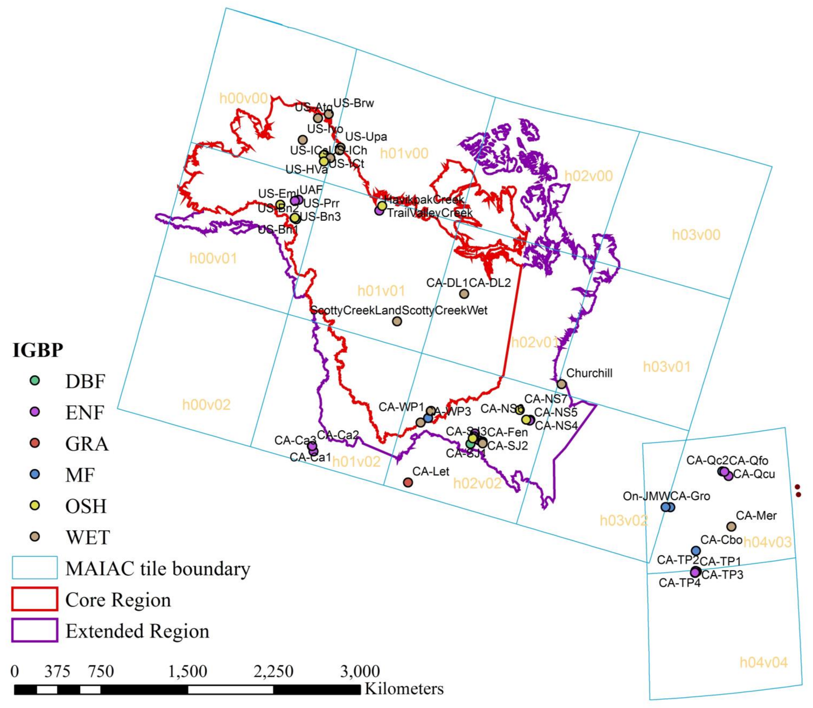

Figure 1 Map of 62 flux sites covered six IGPB cover types in Canada and Alaska, as well as MODIS MAIAC tiles for the same area.

1. Introduction

In the face of rapid climate warming and longer growing seasons, productivity of northern ecosystems could increase ("greening"). On the other hand, climate change can also lead to increased drought and disturbance, leading to reduced productivity ("browning").

High temporal and spatial resolution remote-sensing data such as the MODIS dataset are key to tracking how climate change is affecting high latitude ecosystems, but suffers from bias which may prove critical at such scales, such as the combined effects of vegetation structure, sun angle, and viewing geometry on the vegetation indices used to track phenology and productivity.

At high latitudes, multiple daily observations are made by MODIS Aqua and Terra satellites at varying sun and view zenith angles, providing a unique satellite dataset. This fine temporal and angular sampling provide an opportunity to examine how viewing geometry influences indices and impacts their interpretation. A scalable approach aimed at correcting vegetation indices for such effects has been implemented over the ABoVE domain, and its potential to better track phenology and productivity is being studied.

2. Sites, data and methods

Study sites:

In this study, we employed a total of 62 flux sites (Fig. 1). Among them, 27 sites are located within the core ABoVE domain, another 19 sites within the ABoVE extended region, and the rest are located in nearby high latitude regions for increasing the model accuracy.

These sites cover a total of six International Geosphere-Biosphere (IGBP) vegetation types, including evergreen needleleaf forests (ENF), deciduous broadleaf forests (DBF), mixed forests (MF), open shrubland (OSH), permanent wetland (WET), and grasslands (GRA). Among these, ENF, WET, and OSH are the dominant vegetation types, and 27, 14, and 12 sites are considered to be these IGBP types, respectively.

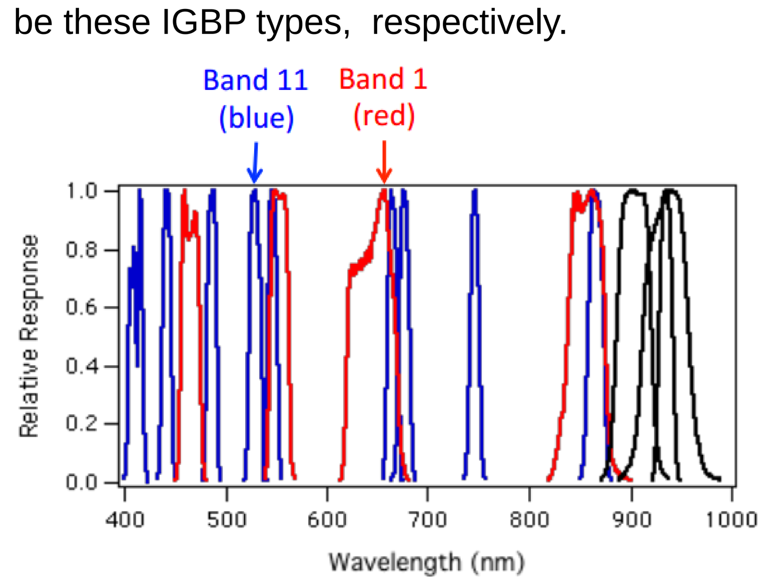

Figure 2 A profile of MODIS MAIAC bands (land bands in red and black; ocean bands in blue.

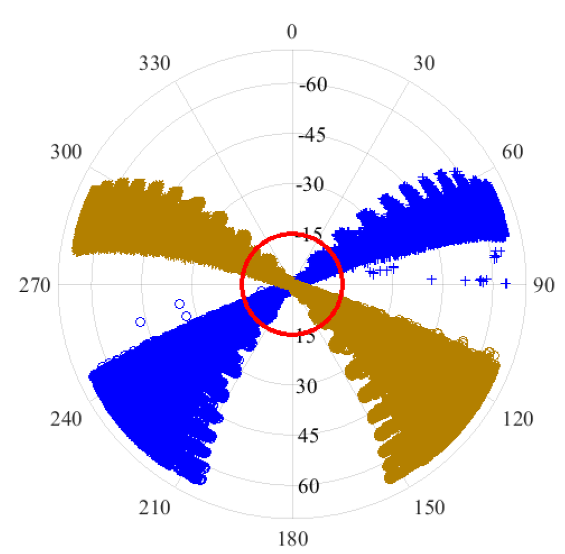

Figure 3 A polar plot for Aqua and Terra observations at backscatter, forward scatter, and nadir views.

MODIS MAIAC dataset:

In contrast to the previous MODIS datasets, this new MODIS MAIAC dataset has two advantages closely related to this study.

- It provides ocean bands (8-12) in addition to land bands (1-7), providing better spectral resolution and coverage (Fig. 2). This newly released spectral information may be helpful in tracking vegetation phenology and productivity. Notably, the ocean band 11 can serve as an important band for calculating the chlorophyll/carotenoid index (CCI) and the photochemical reflectance index (PRI), which track vegetation seasonal dynamics, and/or physiological dynamics.
- The MAIAC algorithm processes MODIS data in both temporal and spatial domains in order to reduce cloud and snow contamination while preserving the MODIS native fine temporal resolution (as opposed to MODIS products processed at 4-, 8- and 16-day scales). This dataset provides multiple observations for each day in high latitudes (Fig. 3), which makes it possible to investigate the viewing geometry effects on both bands and indices.

Random forests:

This study employed a machine learning approach - random forests (RF) - to minimize the influence of solar zenith angle (SZA) and view zenith angle (VZA) on satellite measurements. RF uses ensemble decision trees and bootstraps both observations and variables. In contrast to classic regression and other machine learning approaches, this approach has advantages of dealing with non-linear relationships, handling categorical variable, and prevailing accuracy in algorithm performance.

3. Results

Viewing geometry effect:

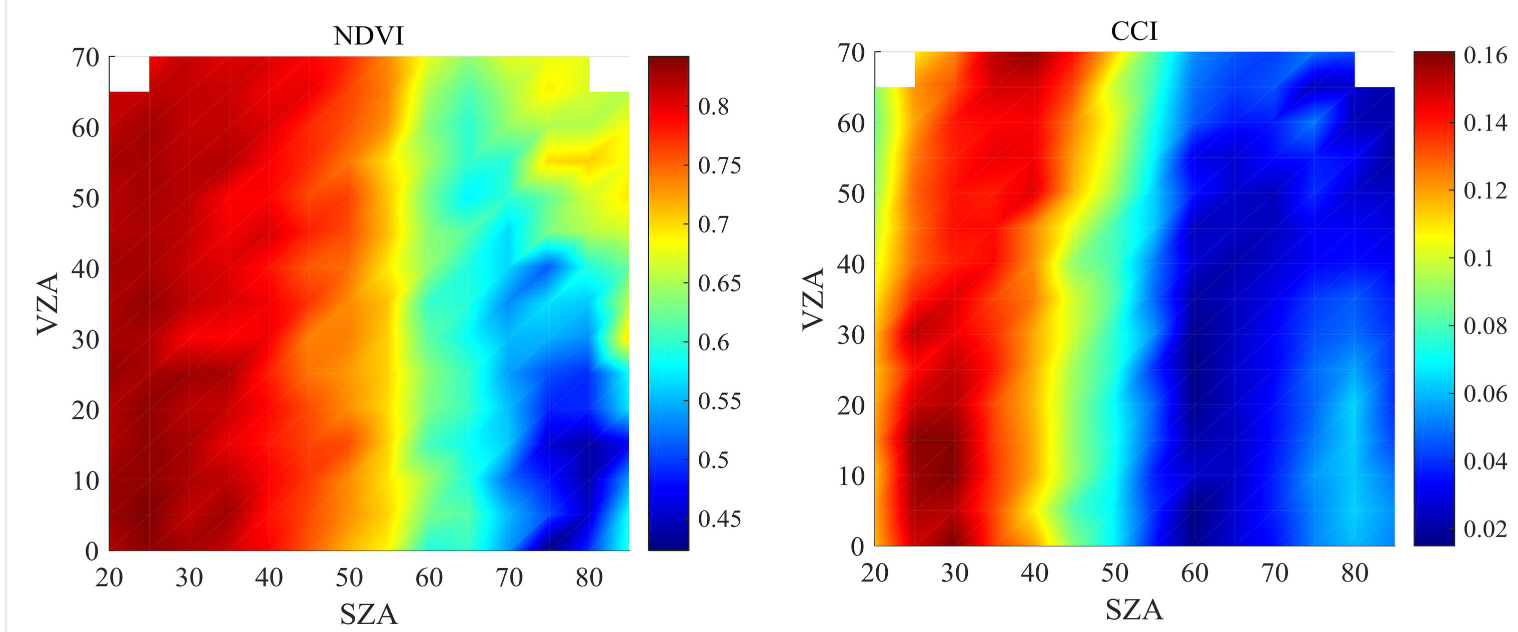

Figure 4 Magnitude of simulated effect of VZA and SZA on NDVI and CCI. This RF simulation show us that NDVI and CCI peaks at lower SZA , and CCI stays low when SZA is above 60 degree. VZA has less effect on NDVI and CCI than SZA.

Corrected vs. Uncorrected indices:

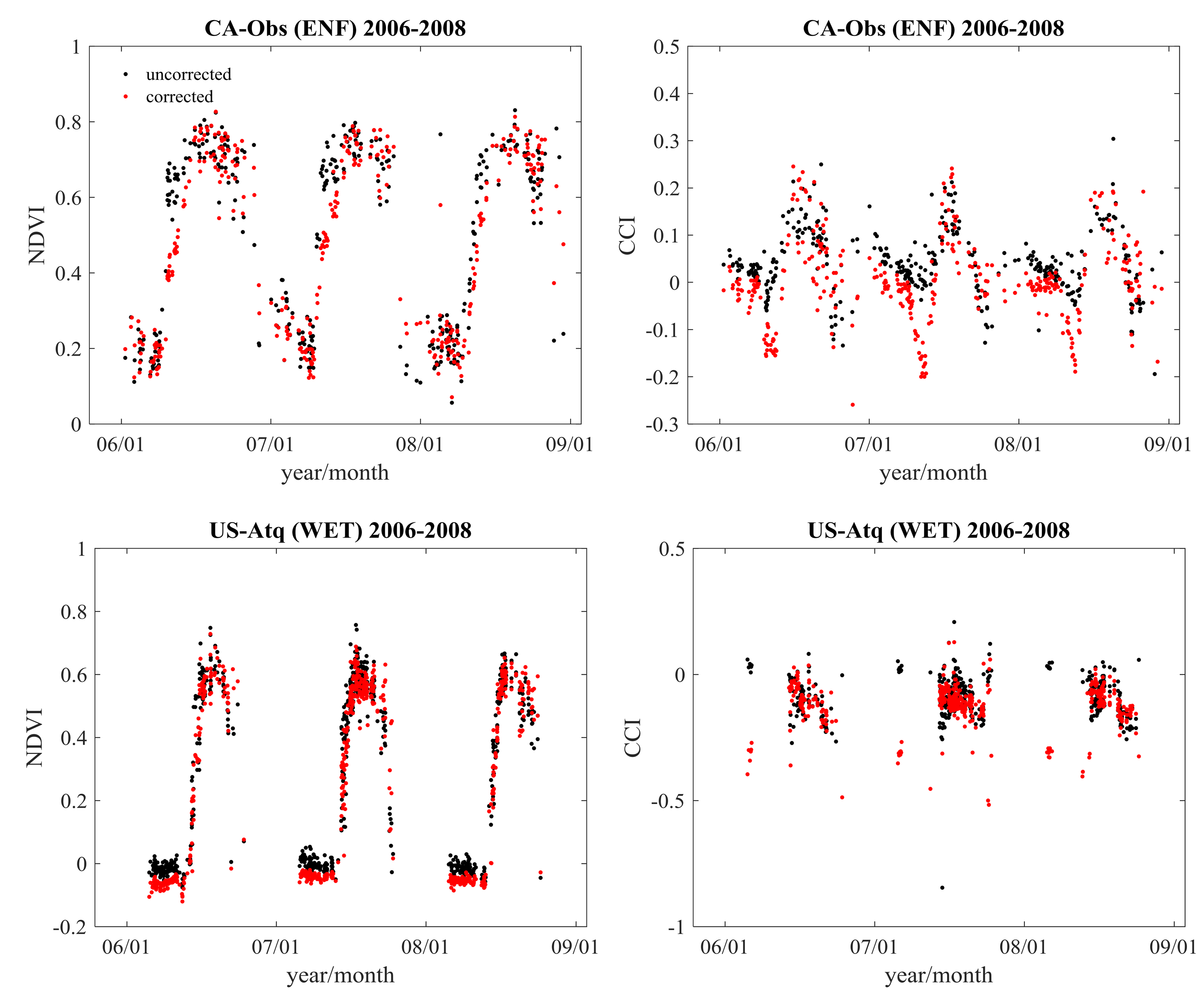

Figure 5 Sample plots of NDVI and CCI derived from corrected (red) vs uncorrected (black) band measurements for two IGBP types (ENF and WET), corresponding to boreal forest and tundra sites. In general, after the viewing geometry effects were removed, the values of indices in winter were reduced, especially for CCI, and also especially for WET (tundra) ecosystems. The spring "green-up" was delayed by correction especially in ENF (boreal forest) ecosystems. The number of outliers (unusually early green-up dates) probably caused by surface water or snow also decreased with correction. These findings illustrate the importance of angular correction of satellite data for studying changing phenology.

Differences in green-up DOY:

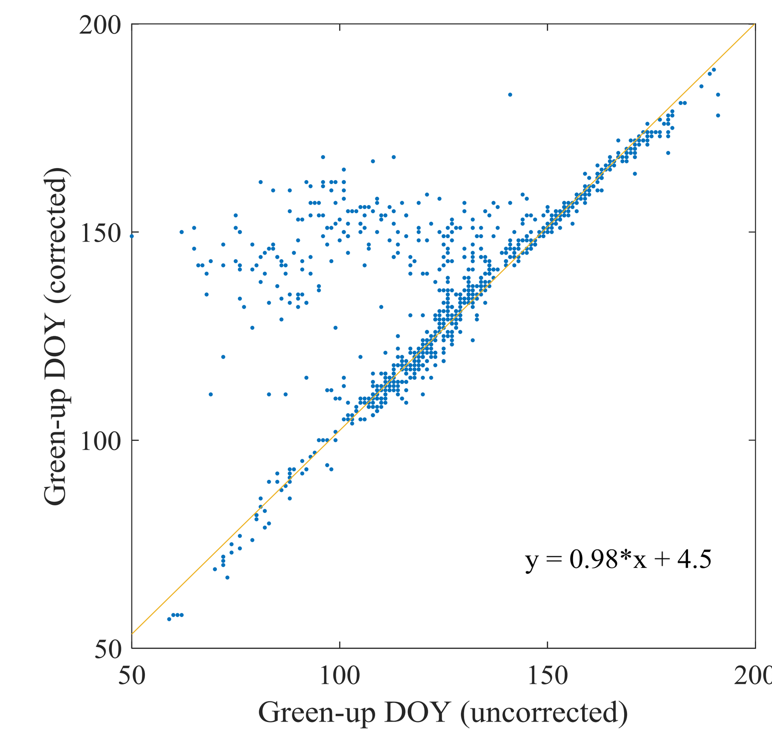

Figure 6 Differences in green-up DOY (corrected vs uncorrected). Both corrected and uncorrected NDVI values were used to estimate green-up day-of-year (DOY) for all site-years. Many site-years showed slight to great delay in "greening" when comparing green-up DOY derived from corrected vs. uncorrected data, which means that viewing geometry correction significantly affects the calculation of early spring green-up.

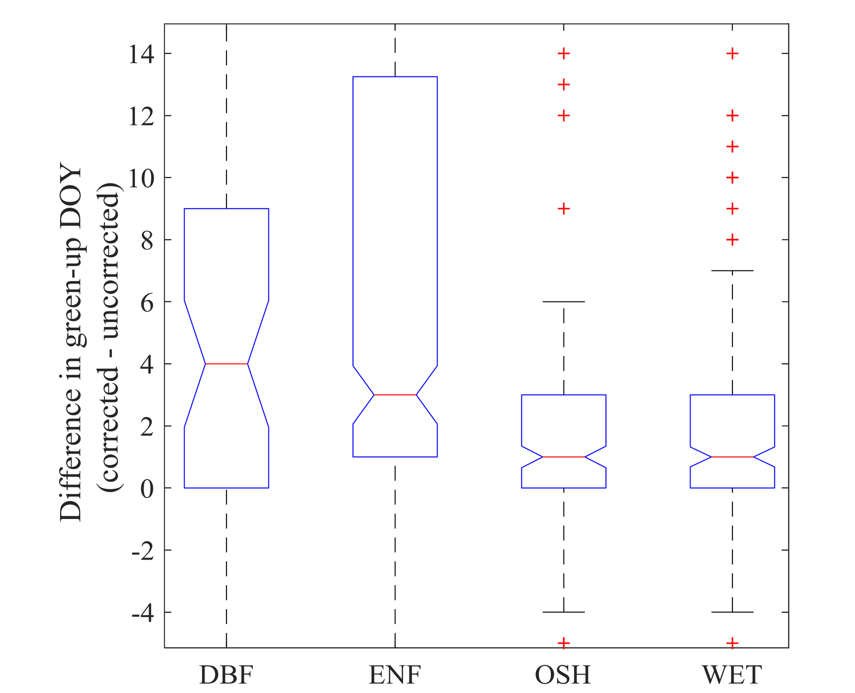

Figure 7 Boxplot of the differences in green-up DOY (corrected minus uncorrected). Differences in green-up DOY were larger at boreal forest sites (ENF & DBF) than shrubland and wetland tundra sites (OSH & WET), which means viewing geometry has larger effects on advancing green-up DOY in forest ecosystems than shrubland and wetland ecosystems. This illustrates the importance of canopy structure influences on the angular responses.

In summary:

- Solar zenith angle showed a strong effect on the vegetation indices, which illustrates the need to remove or reduce viewing geometry effects before using vegetation indices to detect changes in terrestrial vegetation in high latitudes.
- Corrected indices showed better ability to remove snow/water contamination in winter.
- Corrected NDVI delayed apparent "greening" for many site-years. This raises a caution when we use vegetation indices to interpret phenology and productivity in high latitudes.
- When a boreal ecosystem changes from a forest ecosystem to a shrubland or wetland ecosystem, or vice versa, the green-up DOY derived from uncorrected indices would probably introduce a large bias.

4. Discussion

The novel MODIS MAIAC dataset brings both new challenges and new opportunities. In this study, we utilized the new MODIS MAIAC dataset with ocean bands and multiple daily observations, and explored ways to remove the viewing geometry influences on vegetation indices. We believe the corrected indices based on this dataset using the RF approach can better reflect seasonal vegetation dynamics, and could be used for estimating vegetation phenology and productivity, as well as for analyzing the relationship between phenology, productivity, and climate change in high latitudes.

The comparison of phenological metrics obtained using the uncorrected and corrected NDVI reveals a significant difference in the timing of apparent vegetation green-up, which varies between vegetation types. There is a more consistent distribution of green-up day-of-year after correction due to a decrease in unusually early estimated green-up dates. More study is needed to see if this artifact may be relevant to the previously reported greening trend in boreal ecosystems.

Based on this site-level analysis, our next steps will be to use these methods to evaluate phenology and productivity relationships across the ABoVE domain. Future work is also needed to further verify corrected indices with independent data (e.g. ground optical measurements truth and solar-induced fluorescence). A particular focus will be on assessing the importance of this correction for previously reported trends in boreal ecosystem phenology and productivity in response to climate change.