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Commentary

Spatial sampling inconsistency leads to differences in phenological sensitivity to warming between natural and experiment sites

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Plant spring phenology is receiving increasing attention owing to the recognition of its high sensitivity to ongoing climatic warming [1]. Changes in plant spring phenology can substantially influence a wide range of ecosystem structure and functions, which can not only affect human-beings but also in turn affect climate [2]. Warming experiments have been widely conducted to help understand, and thus predict plant phenological response to climate. Most of these experiment-based studies have focused on reporting the signs and magnitudes of phenological responses, and a few have included temperature sensitivity (phenological shifts per unit temperature change). However, applying the outputs of these experiments to predict future phenological response to climate change remains challenging.

Wolkovich et al. [1] compiled phenological data on 1,634 plant species across 51 sites and found that the temperature sensitivity (in d/°C) of flowering and leafing dates, based on long-term observations, was 8.5-fold and 4.0-fold of that for warming experiments. The authors then concluded that warming experiments significantly underestimate the plant phenological responses to warming. Their results are timely in highlighting the need for careful assessment of the warming experiments which are widely used in climate change research.

We note that Wolkovich et al. [1] did not consider spatial sampling differences between the observation and experiment sites. As widely reported [3,4], phenological responses to temperature vary dramatically among locations, species and vegetation types. This spatial variability may contribute to the sensitivity difference calculated by Wolkovich et al. [1]. To address this, we used spring phenology from satellite-derived measurements of vegetation greenness (Normalized Difference Vegetation Index, NDVI) [5] to compare the temperature sensitivity of spring phenology between the corresponding experiment and observation sites in the study of Wolkovich.

As shown in Fig. 1, the temperature sensitivity was 1.6–3.3 fold higher at the observation sites than at the experiment sites. This difference due to the different location accounted for 103% (51%–166%) of the difference in flowering date and 86% (43%–138%) of the difference in leafing date reported by Wolkovich et al. [1]. Although there are differences in satellite-retrievals of spring phenology among the five methods used, the methods demonstrated consistently higher sensitivities at the observation site than those at the experiment sites. This magnitude of spatially-induced sensitivity difference is close to that estimated by Wolkovich et al. [1]. Therefore, one cannot rule out the possibility that the location sampling of experiment and observations sites may have contributed to the sensitivity difference reported in their study.

Meta-analysis is collecting published data over number of sites, such as Wolkovich et al. [1], provides good resources to explore in global change studies. Such meta-analyses commonly perform null-hypothesis statistical testing (e.g., *t*-test) based on the assumption that spatial samplings of the collected sites are evenly/randomly distributed and do not confound with the null-hypothesis to be tested. Such assumption is unwarranted at least for the impacts of climate change on phenology and can lead to exaggeration on the confidence of the conclusion. Our results showed that the reported difference in temperature sensitivity of phenology between experiment sites and observation sites may largely result from the non-pair and uneven spatial sampling of them. This sensitivity difference induced by spatial sampling is not surprising considering large site-to-site variations in the background climate [9,10], vegetation types, soil properties and altitude [11], further highlighting the necessity to carefully examine the statistical deduction in meta-analyses that neglects spatial variations in the collected sites. Satellite dataset has become a useful source for large-scale phenology studies. We took use of multi-model to estimate the spring phenology and confirmed the spatial differential sensitivity in response to warming [5]. At the same time, multi-source of satellite data could also be considered in order to verify the consistency of satellite products and further confirm the aim of our study [12].

Besides uncertainties related to site locations, recent studies have also revealed several possible sources of uncertainties in estimating temperature sensitivity of phenology. For example, Clark et al. [13] found that spring phenology was more sensitive to temperature change in late winter and weeks before onset than to the

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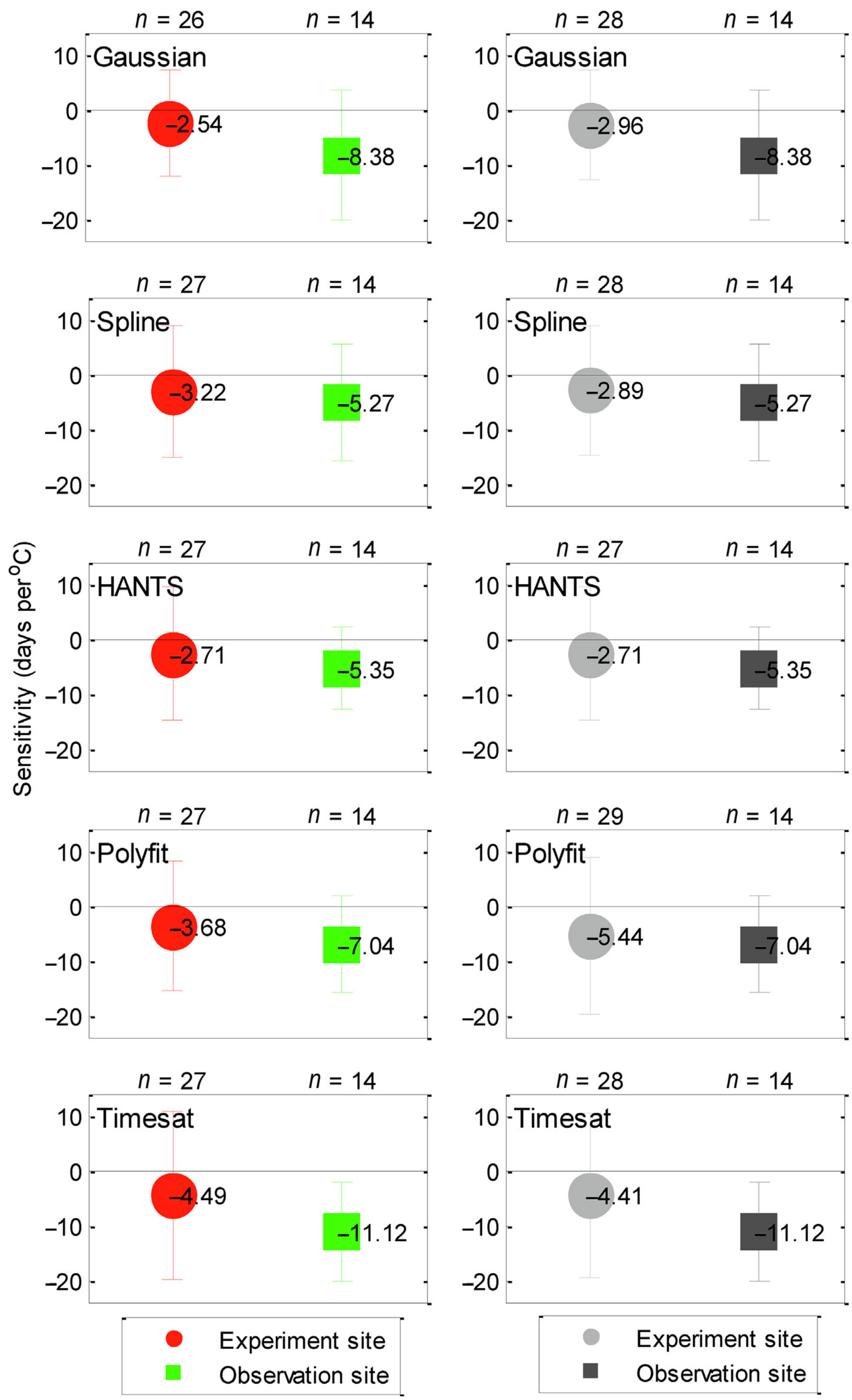

Fig. 1. Temperature sensitivity of the spring phenology (mean, S.D. presented by bar). These colored are averaged for sites of non-evergreen [6] vegetation only, and those in gray are for all sites with phenology retrievals. Considering difference among methods in determining spring phenology, we retrieved spring phenology using five different approaches [5], including Gauss, Spline, HANTS, Polyfit, and Timesat (see Ref. [5] for details). The NDVI was observed by the sensor VGT-S onboard the satellite SPOT [7] from 1999 to 2009. Temperature sensitivity was first calculated for each site and then was averaged for the observation and experiment site, respectively. We used mean annual temperature provided by the Climatic Research Unit TS3.0 (CRU) [8]. The top horizontal axis labels correspond to the number of sites whose spring phenology was retrieved by the corresponding approach. NDVI time-series is extracted from 3×3 pixels with the experiment or observation site in center. The spatial resolution of the pixel is about 0.0089°. According to the longitude and latitude in [1], sites #24, #32, #34, and #36 have no phenology data for lack of NDVI values. Site #0 in Australia was not included. Sites #11–13, #16, and #30 are evergreen vegetation and non-vegetation. There are 37 experimental (#0–36) and 14 observation sties in Ref. [1].

mean temperature of the whole year. Piao et al. [14] found that spring phenology was triggered more by daytime temperature than by nighttime or daily average temperature, but the spring carbon uptake was weakened with the increase of temperature [15]. The temperature sensitivity of plant phenology thus could be defined more exactly in terms of these items. Given the importance to estimate accurately the response of plant phenology to temperature change, these sources of uncertainties and the definition of temperature sensitivity should be carefully considered in future studies in order to better predict how future warming will impact the phenology of plants.

Conflict of interest

The authors declare that they have no conflict of interest.

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